The Tesla Archives

BY DEREK WORTHINGTON



ÆTHERFORCE

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[ILLUSTRATED.]

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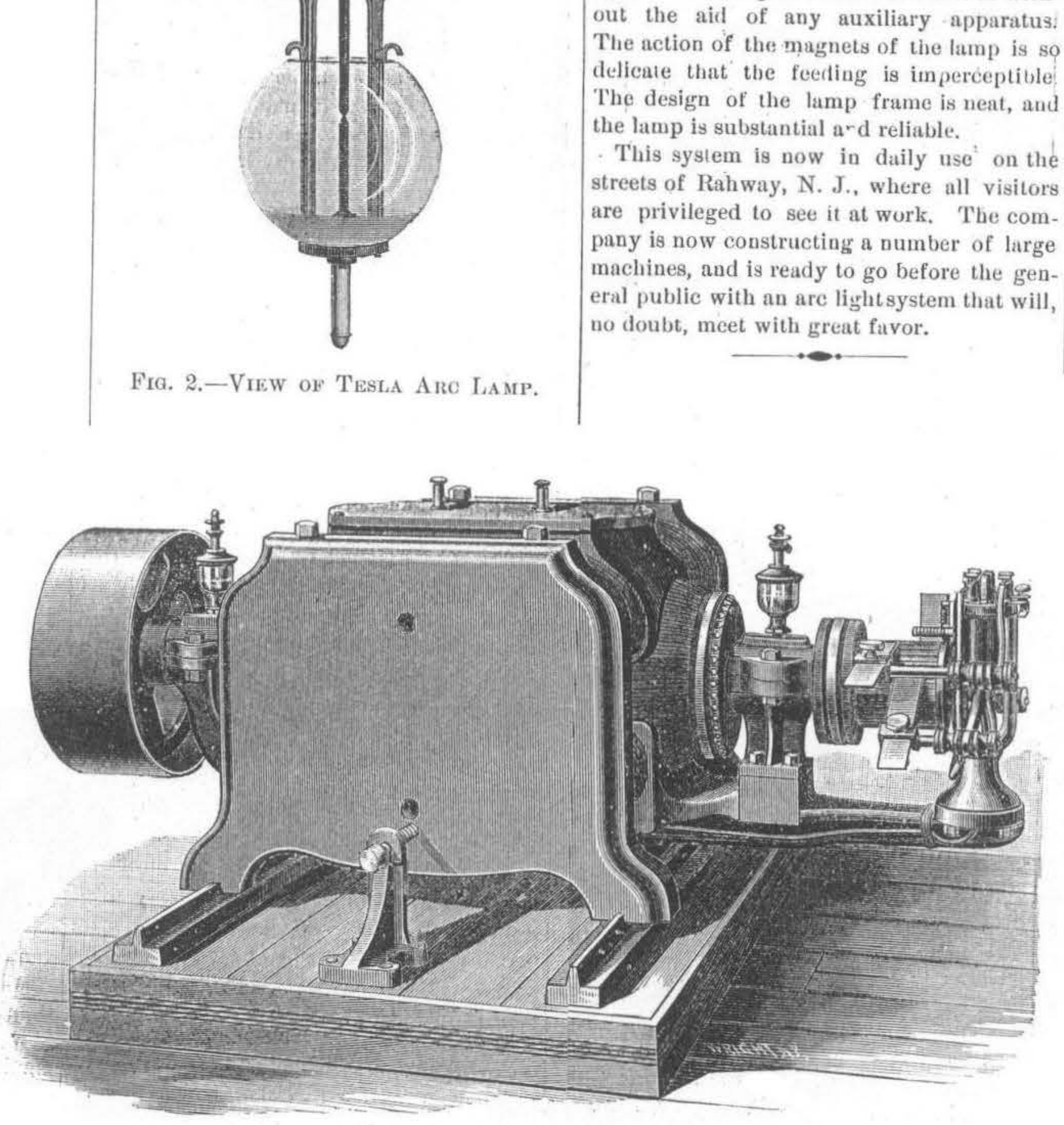


FIG. 1.—VIEW OF DYNAMO OF TESLA ELECTRIC LIGHT COMPANY.

The Tesla Electric Light Company.

This company has been organized nearly two years, and has devoted that time to perfecting a complete arc-light system, which we take pleasure in presenting to the readers of the REVIEW in this issue. The headquarters of the company are in Rahway, N. J., and a branch office in New York. The president of the company is Mr. B. A. Vail, of Rahway; vice-president and treasurer, Robert Lane, of East Orange; secretary, H. C. Carmen; electrician, N. Tesla. The particular improvements that are claimed for this system relate to the efficiency, the regulation and the safety. There are a number of novel features, particularly in the construction of the machine and its regulation.

In the illustration, Fig. 1, is given a side view of the Tesla dynamo. The magnetic frame of the machine is so constructed as to concentrate the greatest amount of developed magnetism upon the armature. To this end the cores of the field magnets are made tapering, and the magnetic frame is the smallest in section at the middle. The magnetism is in this way, the inventor states, concentrated upon the middle; the central line is sharply defined, and a better working of the armature is obtained. The main improvements claimed are, however, embodied in the construction and winding of the armature, which is supported upon a separately cast-base piece, fastened to the lower core by means of fusible dia-magnetic material. The object of the construction is to reduce to the minimum the development of Foucault's currents in the armature core; and also to reduce to a minimum the resistance of the inactive wire on the sides of the armature, and to balance both parts of the armature. The shape of the amature is so calculated that these objects are obtained.

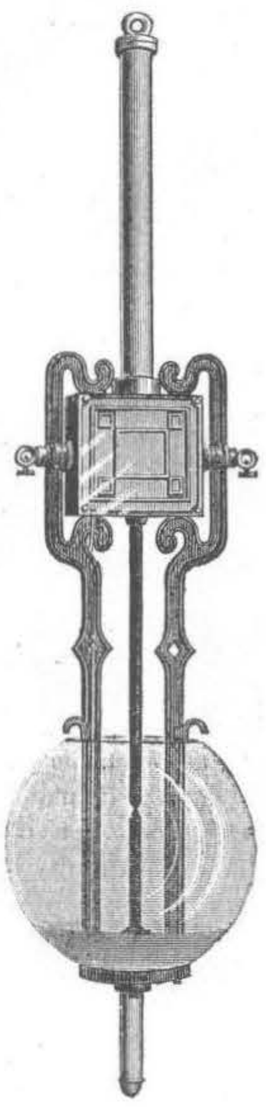


FIG. 2.—VIEW OF TESLA ARC LAMP.

Mr. Tesla, the inventor, has obtained broad patents on the regulation of a dynamo machine on entirely novel principles. This method of regulation secures advantages in the way of economy and safety that he is confident are peculiar to this system alone. No auxiliary resistances, or opposing coils, are used, and the regulation is effected without waste of power.

In Fig. 2 is shown a view of the Tesla arc lamp. The main objects desired to be secured by the inventor, were first of all, simple and reliable apparatus; preventing the vibrations of the movable carbon in consequence of the fluctuations of the current; then to obtain a perfect feed and a steady light. The lamp cuts itself out and in without the aid of any auxiliary apparatus. The action of the magnets of the lamp is so delicate that the feeding is imperceptible. The design of the lamp frame is neat, and the lamp is substantial and reliable.

This system is now in daily use on the streets of Rahway, N. J., where all visitors are privileged to see it at work. The company is now constructing a number of large machines, and is ready to go before the general public with an arc light system that will, no doubt, meet with great favor.

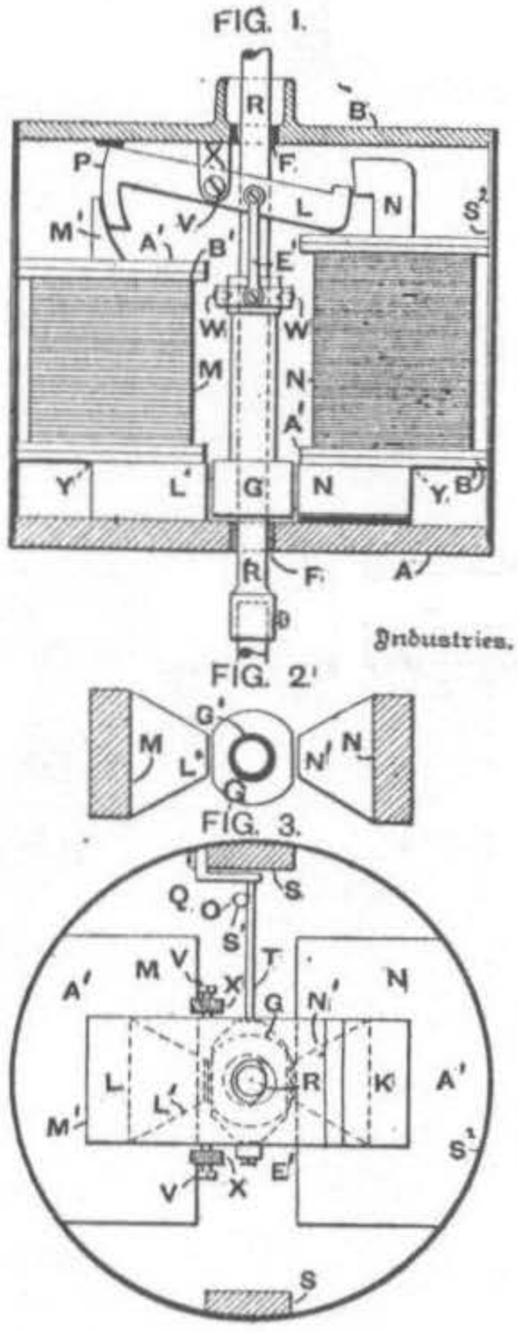
ABSTRACTS OF PUBLISHED SPECIFICATIONS, 1886.

1877. "Improvements in electric lamps." N. TESLA. Dated February 9. 8d. An armature lever swings between the upper ends of the cores of these helices, and at the other ends of the cores are pole pieces between which is an armature that is connected to a tubular clamp around the upper carbon holder, and this tubular clamp is suspended from the aforesaid armature lever. The cores and pole pieces of said helices, the swinging armature lever and the armature of the clamp form a compound magnet. The electric current passes from the + binding post through the shunt helix of high resistance to the – binding post, also from the + binding post the current passes through the carbon holders and carbons to the main line helix, and a branch from this helix goes to the – binding post, and the end of said helix is connected to one of the pole pieces of the shunt magnet and is insulated. When the energy of the shunt core is increased by the increased resistance of the arc, the clamp is moved to allow the carbons to feed, and when the current through the shunt is abnormally strong, the armature of the clamp coming into contact with the pole of the shunt magnet closes a branch circuit, that allows the electric current to pass through the clamp and the branch and a part of the main helix to the negative binding post, so that the continuity of the circuit is preserved and the shunt magnet is not injured, and as soon as the carbons come into contact and a path for the current is re-established through them, the carbons are separated to form the arc. The ends of the swinging armature lever are curved, so also are the adjacent pole pieces of the respective cores, and the poles at the other ends of the cores converge to the faces that act upon the armature at the bottom of the tubular clamp, and there is a spring that tends to swing the armature clamp away from the aforesaid insulated pole pieces. The claims are 12 in number.

ELECTRICITY.

ARC LAMPS.—*N. Tesla, Rahway, New Jersey, U.S.A.*—M represents the main and N the shunt magnet, both securely fastened to the base A. To the magnets are fastened the brass washers A^1. Similar washers B^1 of insulating material serve to insulate the wires from the brass washers. The magnets M and N are made very flat, so that a comparatively small number of convolutions is sufficient to produce the required magnetism; besides, a greater surface is offered for cooling off the wires. The upper pole pieces M^1 N are curved, and the lower pole pieces L^1 N^1 are brought near together, tapering towards the armature G to concentrate the magnetism upon the armature. The armature G is fastened to the clamp G^1, formed of a brass tube provided with gripping jaws. The clamp G^1 is supported on bearings W carried by a lever T, one end of which rests upon an

FIG. 1.



Industries.

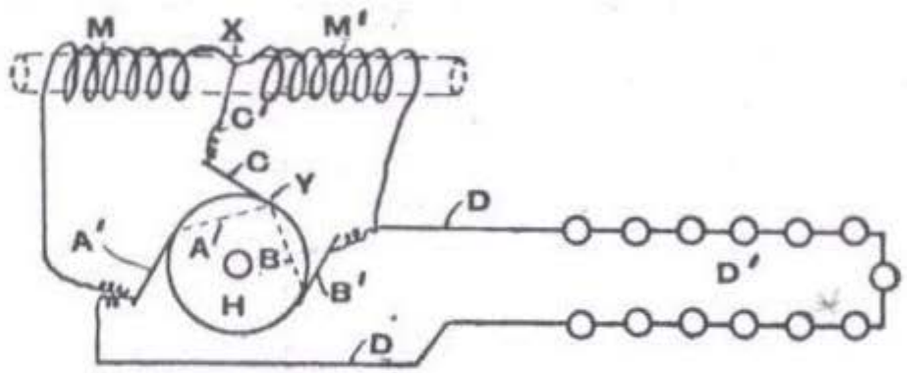
FIG. 2.

FIG. 3.

adjustable support Q of the side columns S, the other end being connected by means of the link E^1 to the armature lever L, which has its ends curved so as to correspond to the form of the upper pole pieces of the magnets M and N. It is hung upon the pivots V, which are in the jaw X of the top plate B. At the start the carbons are in contact, and upon the passage of the current the main magnet is caused to attract the clamping armature G with sufficient force to clamp firmly the rod by means of the gripping jaws. At the same time the armature lever L is pulled down and the carbons separated. The whole of the soft iron parts M^1, L^1, G, N^1, N, and L form a compound magnet, and the shunt magnet is magnetised by magnetic induction from the magnet M. The carbons being separated, the fine wire receives a portion of the current, and consequently the magnetism of the whole compound magnet is diminished. As the carbons burn away, the fine wire receives more current, and the magnetism diminishes in proportion. This causes the armature lever L to swing, and the armature G to descend gradually under the weight of the moving parts, until the end P strikes a stop on the top plate B. The further downward movement of the armature lever being prevented, the arc becomes longer as the carbons are consumed, and the compound magnet is weakened more and more until the clamping armature G releases the hold of the gripping jaws upon the rod R, and the latter is allowed to drop a little, thus shortening the arc. The fine wire now receiving less current, the magnetism increases, and the rod is clamped again and slightly raised if necessary. The lamp cuts itself out automatically when the arc gets too long, and re-inserts itself automatically in the circuit if the carbons drop together. Twelve claims are made for combinations of parts described.—No. 1877. February 9th, 1886. 8*d*.

ELECTRICITY.

DYNAMO ELECTRIC MACHINES.—*N. Tesla, Rahway, New Jersey, U.S.A.*—The object of this invention is to provide an improved method for regulating the current of dynamo electric machines. A^1 and B^1 are the brushes of the main circuit, and C an auxiliary brush. The working circuit D extends from the brushes A^1 and B^1, and contains electric lamps in series or in multiple arc. M M^1 represent the field helices, the ends of which are connected to the main brushes. The shunt wire C^1 extends from the auxiliary brush C to the intermediate point X in the circuit of the field helices. H represents the commutator with the plates of ordinary construction. A current will flow over the auxiliary brush, to or from the commutator, according to the relative position of the brushes. If, for instance, the commutator space between the brushes A^1 and C, when the latter is at the neutral point, is diminished, a current will flow from the point Y over the shunt C^1 to the brush B^1, thus strengthening the current in the part M^1, and partly neutralising the current in the part M; but if the space between the brushes A^1 and C is increased, the current will flow over the auxiliary brush in an opposite direction, and the current in M will be strengthened, and in M^1 partly neutralised. By combining with the brushes A^1 B^1 and C any known automatic regulating mechanism, the current developed can be regulated in pro-



portion to the demands in the working circuit. The respective cores of the field magnet are subjected to the neutralising or intensifying effects of the current in the shunt through C^1, and the magnetism of the cores will be partially neutralised or the point of greatest magnetism shifted, so that it will be more or less remote from, or approaching to, the armature, and hence the action of the field magnets on the armature will be correspondingly varied. Claims: (1) The combination with the commutator, having two or more main brushes and an auxiliary brush, of the field helices, having their ends connected to the main brushes, and a branch or shunt connection from an intermediate point of the field helices to the auxiliary brush, and means for varying the relative position upon the commutator of the respective brushes, as set forth; (2) the combination with the commutator and the main brushes, and one or more auxiliary brushes, of the field helices in the main circuits, and one or more shunt connections from the field helices to the auxiliary brushes, the relative positions upon the commutator of the respective brushes being adjustable for the purpose set forth.—No. 2975. March 2nd, 1886. 8*d*.

ABSTRACTS OF PUBLISHED SPECIFICATIONS, 1886.

2975. "Improvements in dynamo-electric machines." N. TESLA. Dated March 2. 8d. Claims:—First. The combination with the commutator having two or more main brushes, and an auxiliary brush, of the field helices having their ends connected to the main brushes and a branch or shunt connection from an intermediate point of the field helices to the auxiliary brush, and means for varying the relative position upon the commutator of the respective brushes, substantially as set forth. Second. The combination with the commutator and main brushes and one or more shunt connections of the field helices in the main circuits and one or more shunt connections from the field helices to the auxiliary brushes, the relative positions upon the commutator of the respective brushes being adjustable, for the purposes set forth.

PHENOMENA OF ALTERNATING CURRENTS.*

By Prof. ELIHU THOMSON.

THE actions produced and producible by the agency of alternating currents of considerable energy are assuming greater importance in the electric arts. I mean, of course, by the term alternating currents, currents of electricity reversed at frequent intervals, so that a positive flow is succeeded by a negative flow, and that again by a positive flow, such reversals occurring many times in a second, so that the curve of current of electromotive force will, if plotted, be a wave line, the amplitude of which is the arithmetical sum of

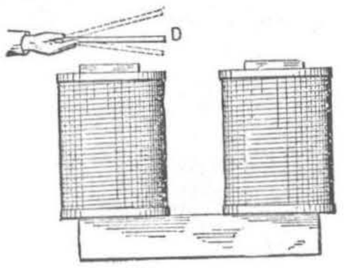


FIG. 1.

the positive and negative maxima of current or electromotive force, as the case may be, while a horizontal middle line joins the zero points of current or electromotive force.

It is well known that such a current passing in a coil or conductor laid parallel with or in inductive relation to a second coil or conductor, will induce in the second conductor, if on open circuit, alternating electromotive forces, and that if its terminals be closed or joined, alternating currents of the same rhythm, period, or pitch, will circulate in the second conductor This is the action occurring in any induction coil whose primary wire is traversed by alternating currents, and whose secondary wire is closed either upon itself directly or through a resistance. What I desire to draw attention to in the present paper are the mechanical actions of attraction and repulsion which will be exhibited between the two conductors, and the novel results which may

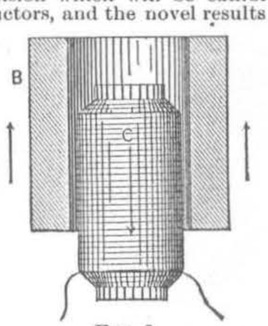


FIG. 2.

be obtained by modifications in the relative dispositions of the two conductors.

In 1884, while preparing for the International Electrical Exhibition at Philadelphia, we had occasion to construct a large electro-magnet, the cores of which were about six inches in diameter and about twenty inches long. They were made of bundles of iron rod of about $\frac{5}{16}$ inch diameter. When complete, the magnet was energized by the current of a dynamo giving continuous currents, and it exhibited the usual powerful magnetic effects. It was found also that a disk of sheet copper, of about $\frac{1}{16}$ inch thickness and 10 inches

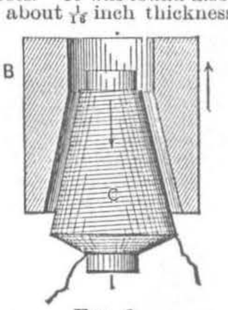


FIG. 3.

in diameter, if dropped flat against a pole of the magnet, would settle down softly upon it, being retarded by the development of currents in the disk due to its movement in a strong magnetic field, and which currents were of opposite direction to those in the coils of the magnet. In fact, it was impossible to strike the magnet pole a sharp blow with the disk, even when the attempt was made by holding one edge of the disk in the hand and bringing it down forcibly toward the magnet. In attempting to raise the disk quickly off the pole, a similar but opposite action of resistance to

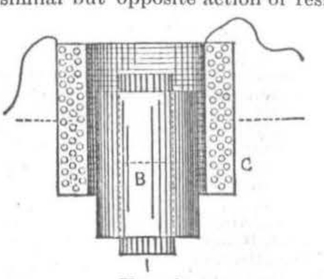


FIG. 4.

movement took place, showing the development of currents in the same direction to those in the coils of the magnet, and which currents, of course, would cause attraction as a result.

* From a paper read before the recent meeting of the American Institute of Electrical Engineers, New York, and reported in the *Electrical World*.

The experiment was, however, varied, as in Fig. 1. The disk, D, was held over the magnet pole, as shown, and the current in the magnet coils cut off by shunting them. There was felt an attraction of the disk or a dip toward the pole. The current was then put on by opening the shunting switch, and a repulsive action or lift of the disk was felt. The actions just described are what would be expected in such a case, for when attraction took place, currents had been induced in the disk, D, in the same direction as those in the magnet coils beneath it, and when repulsion took place the induced current in the disk was of opposite character or direction to that in the coils.

Now let us imagine the current in the magnet coils to be not only cut off, but reversed back and forth.

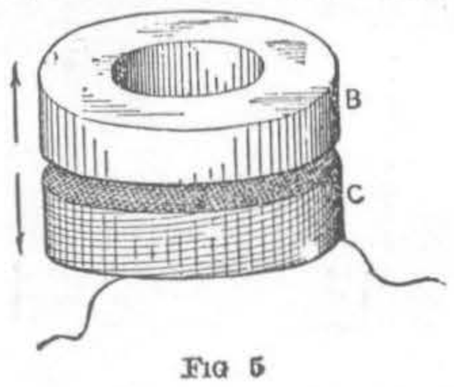


FIG 5

For the reasons just given, we will find that the disk, D, is attracted and repelled alternately; for, whenever the currents induced in it are of the same direction with those in the inducing or magnet coil, attraction will ensue, and when they are opposite in direction, repulsion will be produced. Moreover, the repulsion will be produced when the current in the magnet coil is rising to a maximum in either direction, and attraction will be the result when the current of either direction is falling to zero, since in the former case opposite currents are induced in the disk, D, in accordance with well known laws, and in the latter case currents of the same direction will exist in the disk, D, and the magnet coil. The disk might, of course, be replaced by a ring of copper or other good conductor, or by a closed coil of bare or insulated wire, or by a series of disks, rings or coils superposed, and the results would be the same. Thus far, indeed, we have nothing of a particularly novel character, and, doubtless, other

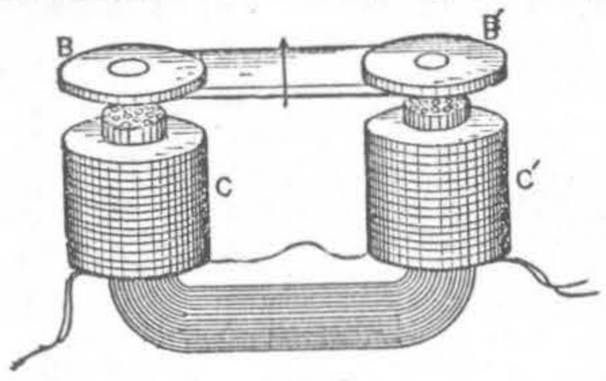


FIG 6.

experimenters have made very similar experiments and noted similar results to those described.

The account just given of the effects produced by alternating currents, while true, is not the whole truth, and just here we may supplement it by the following statements:

An alternating current circuit or coil repels and attracts a closed circuit or coil placed in direct or magnetic inductive relation therewith; but the repulsive effect is in excess of the attractive effect.

When the closed circuit or coil is so placed, and is of such low resistance metal that a comparatively large current can circulate as an induced current, so as to be subject to a large self-induction, the repulsive far exceeds the attractive effort.

For want of a better name, I shall call this excess of repulsive effect the "electro-inductive repulsion" of the coils or circuits.

This preponderating repulsive effect may be utilized or may show its presence by producing movement or pressure in a given direction, by producing angular

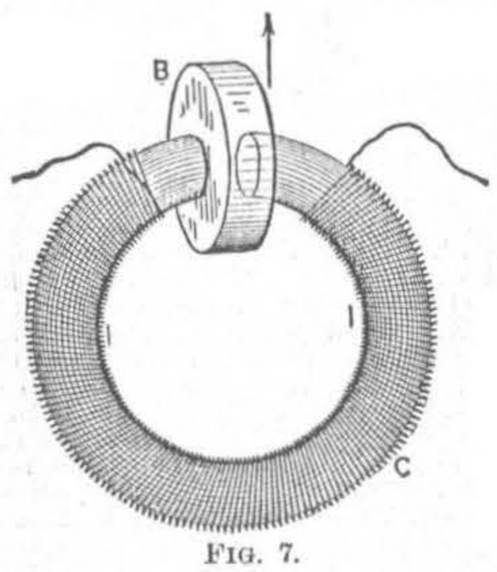


FIG. 7.

deflection as of a pivoted body, or by producing continuous rotation with a properly organized structure. Some of the simple devices realizing the conditions I will now describe.

In Fig. 2, C is a coil traversed by alternating currents, B is a copper case or tube surrounding it, but not exactly over its center. The copper tube, B, is fairly massive and is the seat of heavy induced currents. There is a preponderance of repulsive action, tending to force the two conductors apart in an axial line. The part, B, may be replaced by concentric tubes slid one in the other, or by a pile of flat rings, or by a closed coil of coarse or fine wire insulated, or not. If the coil, C, or primary coil, is provided with an iron core such as a bundle of fine iron wires, the effects are greatly increased in intensity, and the repulsion with a strong primary current may become quite vigorous, many pounds of thrust being producible by apparatus of quite moderate size.

The forms and relations of the two parts, C and B, may be greatly modified, with the general result of a preponderance of repulsive action when the alternating currents circulate.

Fig. 3 shows the part, B, of an internally tapered or coned form, and C of an externally coned form, wound on an iron wire bundle, I. The action in Fig. 2 may be said to be analogous to that of a plain solenoid

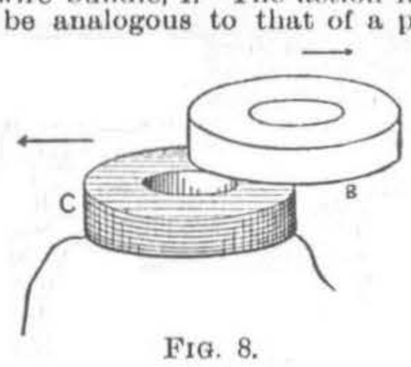


FIG. 8.

with its core, except that repulsion, and not attraction, is produced, while that of Fig. 3 is more like the action of tapered or conically wound solenoids and taper cores. Of course, it is unnecessary that both be tapered. The effect of such shaping is simply to modify the range of action and the amount of repulsive effort existing at different parts of the range.

In Fig. 4 the arrangement is modified so that the coil, C, is outside, and the closed band or circuit, B, inside and around the core, I. Electro-inductive repulsion is produced as before.

It will be evident that the repulsive actions will not be mechanically manifested by axial movement or effort when the electrical middles of the coils or circuits are coincident. In cylindrical coils in which the current is uniformly distributed through all the

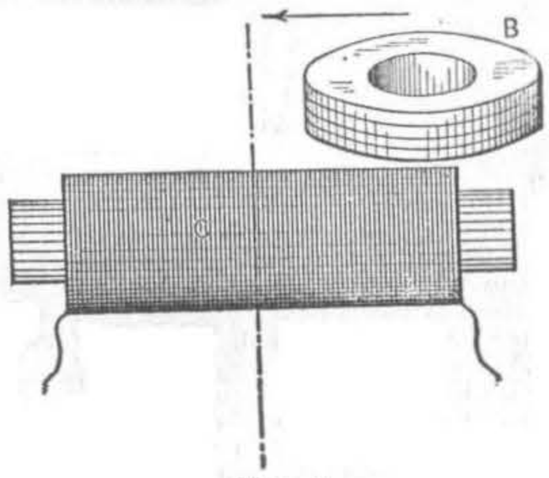


FIG. 9.

parts of the conductor section, what I here term the electrical middle, or the center of gravity of the ampere turns of the coils, will be the plane at right angles to its axis at its middle, that of B and C, in Fig. 4, being indicated by a dotted line. To repeat, then, when the centers or center planes of the conductors, Fig. 4, coincide, no indication of electro-inductive repulsion is given, because it is mutually balanced in all directions; but when the coils are displaced, a repulsion is manifested, which reaches a maximum at a position depending on the peculiarities of proportion and distribution of current at any time in the two circuits or conductors.

It is not my purpose now to discuss the ways of determining the distribution of currents and mechanical effects, as that would extend the present paper much beyond its intended limit. The forms and relative arrangement of the two conductors may be greatly varied. In Fig. 5 the parts are of equal diameter, one,

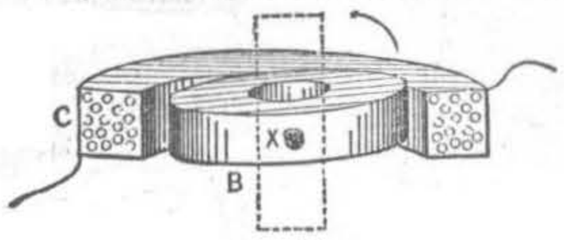


FIG 10.

B, being a closed ring, and the other, C, being an annular coil placed parallel thereto; and an iron core or wire bundle placed in the common axis of the two coils increases the repulsive action. B may be simply a disk or plate of any form, without greatly affecting the nature of the action produced. It may also be composed of a pile of copper washers or a coil of wire, as before indicated.

An arrangement of parts somewhat analogous to that of a horseshoe electro magnet and armature is shown in Fig. 6. The alternating current coils, C C', are wound upon an iron wire bundle bent into U form, and opposite its poles is placed a pair of thick copper disks, B B', which are attracted and repelled, but with

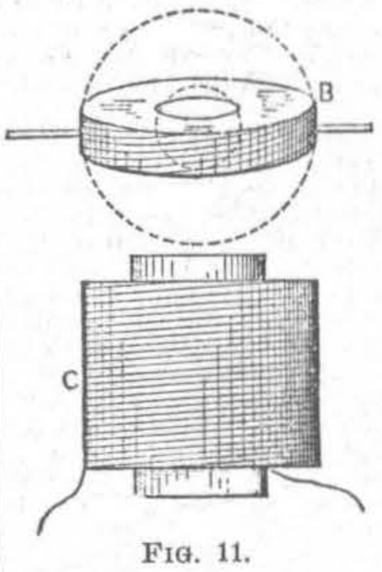


FIG. 11.

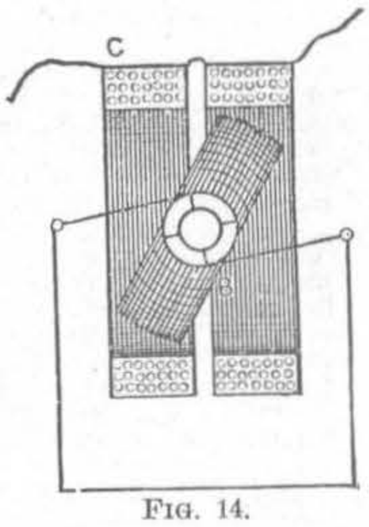


FIG. 14.

an excess of repulsion depending on their form, thickness, etc.

If the iron core takes the form of that shown by I I, Fig. 7, such as a cut ring with the coil, C, wound thereon, the insertion of a heavy copper plate, B, into the slot or divided portion of the ring will be opposed by a repulsive effort when alternating currents pass in C. This was the first form of device in which I noticed the phenomenon of repulsive preponderance in question. The tendency is to thrust the plate, B, out of the slot in the ring excepting only when its center is coincident with the magnetic axis joining the poles of the ring between which B is placed.

If the axes of the conductors, Fig. 5, are not coincident, but displaced, as in Fig. 8, then, besides a simple repulsion apart, there is a lateral component or tendency, as indicated by the arrows. Akin to this is the experiment illustrated in Fig. 9. Here the closed con-

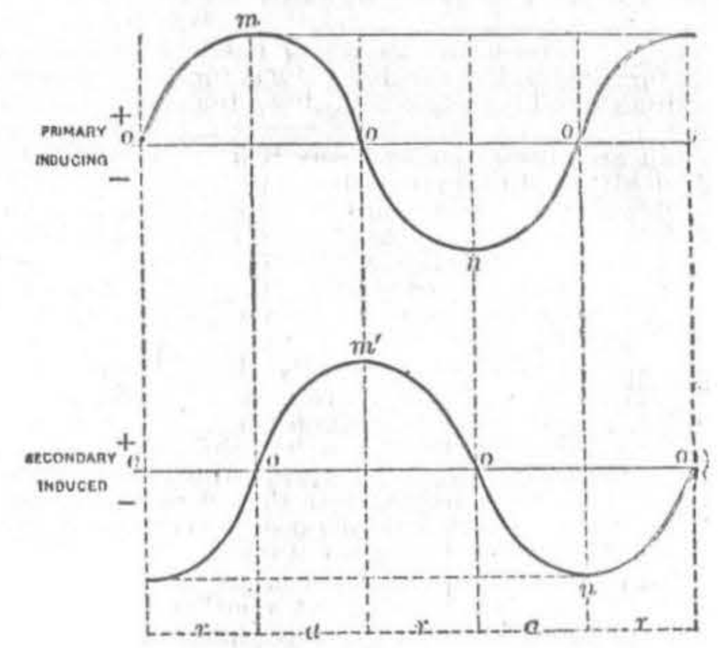


FIG. 12.

ductor, B, is placed with its plane at right angles to that of C, wound on a wire bundle. The part, B, tends to move toward the center of the coil, C, so that its axis will be in the middle plane of C, transverse to the core, as indicated by the dotted line. This leads us at once to another class of actions, *i. e.*, deflective actions.

When one of the conductors, as B, Fig. 10, composed of a disk, or, better, of a pile of thin copper disks, or of a closed coil of wire, is mounted on an axis, X, transverse to the axis of coil, C, through which coil the alternating current passes, a deflection of B to the position indicated by dotted lines will take place, unless the plane of B is at the start exactly coincident with that of C. If slightly inclined at the start, deflection will be caused as stated. It matters not whether the coil, C, incloses the part, B, or be inclosed by it, or whether the coil, C, be pivoted and B fixed, or both be

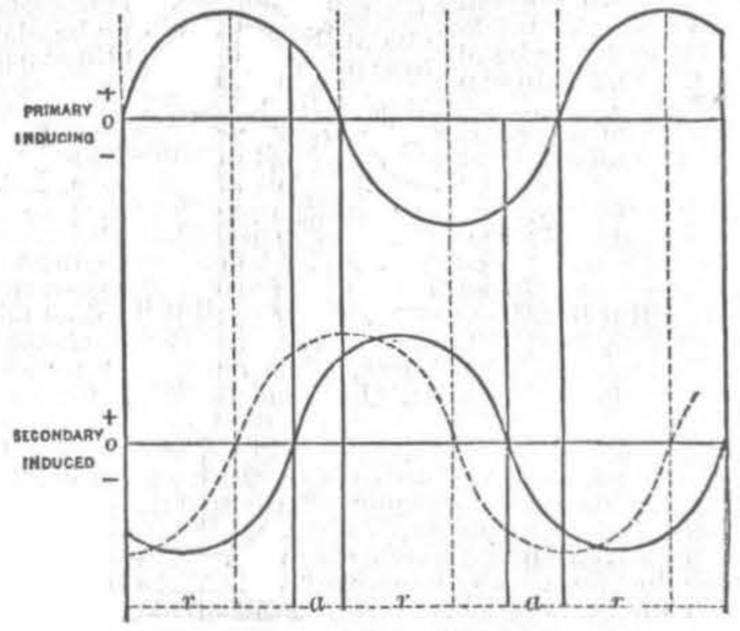


FIG. 13.

pivoted. In Fig. 11 the coil, C, surrounds an iron wire core, and B is pivoted above it, as shown. It is deflected, as before, to the position indicated in dotted lines.

It is important to remark here that in cases where deflection is to be obtained, as in Figs. 10 and 11, B had best be made of a pile of thin washers or a closed coil of insulated wire instead of a solid ring. This avoids the lessening of effect which would come from the induction of currents in the ring, B, in other directions than parallel to its circumference.

We will now turn our attention to the explanation of the actions exhibited, and afterward refer to their

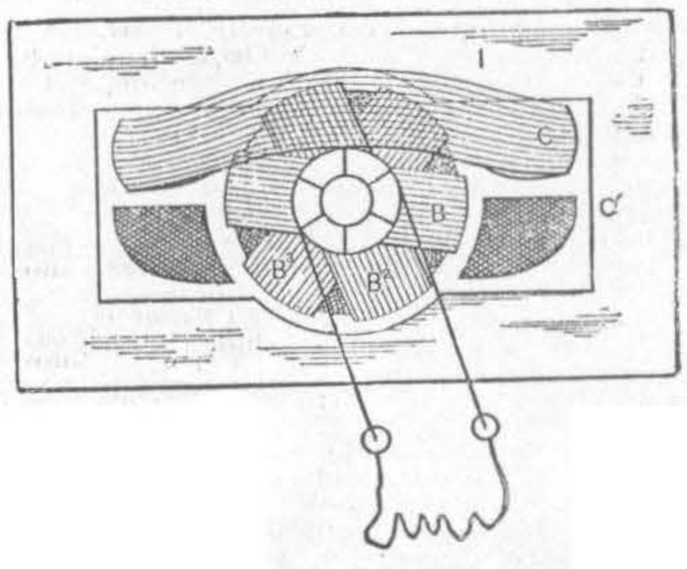


FIG. 15.

possible applications. It may be stated as certainly true that were the induced currents in the closed conductor unaffected by any self-induction, the only phenomena exhibited would be alternate equal attractions and repulsions, because currents would be induced in opposite directions to that of the primary current when the latter current was changing from zero to maximum positive or negative current, so producing

repulsion; and would be induced in the same direction when changing from maximum positive or negative value to zero, so producing attraction.

This condition can be illustrated by a diagram, Fig. 12. Here the lines of zero current are the horizontal straight lines. The wavy lines represent the variations of current strength in each conductor, the current in one direction being indicated by that portion of the curve above the zero line, and in the other direction by that portion below it. The vertical dotted lines simply mark off corresponding portions of phase or succession of times.

Here it will be seen that in the positive primary current descending from m, its maximum, to the zero line, the secondary current has risen from its zero to m^1, its maximum. Attraction will therefore ensue, for the currents are in the same direction in the two conductors. When the primary current increases from zero to its negative maximum, n, the positive current in the secondary closed circuit will be decreasing from m^1, its positive maximum, to zero; but, as the currents are in opposite directions, repulsion will occur. These actions of attraction and repulsion will be reproduced continually, there being a repulsion, then an attraction, then a repulsion, and again an attraction, during one complete wave of the primary current. The letters, r, a, at the foot of the diagram, Fig. 12, indicate this succession.

In reality, however, the effects of self-induction in causing a lag, shift, or retardation of phase in the secondary current will considerably modify the results, and especially so when the secondary conductor is constructed so as to give to such self-induction a large value In other words, the maxima of the primary or inducing current will no longer be found coincident with the zero points of the secondary currents. The effect will be the same as if the line representing the wave of the secondary current in Fig. 12 had been shifted forward to a greater or less extent. This is indicated in diagram, Fig. 13. It gives doubtless an exaggerated view of the action, though from the effects of repulsion which I have produced, I should say it is by no means an unrealizable condition.

It will be noticed that the period during which the currents are opposite, and during which repulsion can take place, is lengthened at the expense of the period

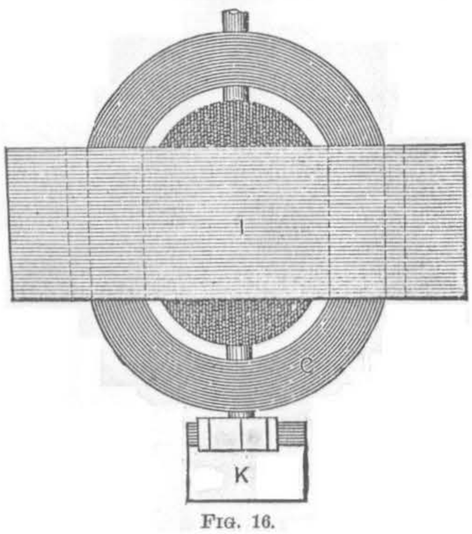


FIG. 16.

during which the currents are in the same direction for attractive action. These differing periods are marked r, a, etc., or the period during which *repulsion* exists is from the zero of the primary or inducing current to the succeeding zero of the secondary or induced current; and the period during which *attraction* exists is from the zero of the induced current to the zero of inducing current.

But far more important still in giving prominence to the repulsive effect than this difference of effective period is the fact that during the period of repulsion both the inducing and induced currents have their greatest values, while during the period of attraction the currents are of small amounts comparatively. This condition may be otherwise expressed by saying that the period during which repulsion occurs includes all the maxima of current, while the period of attraction includes no maxima. There is then a *repulsion due to the summative effects of strong opposite currents* for a *lengthened period*, against an *attraction* due to the summative effects of *weak currents* of the *same direction* during a *shortened period*, the resultant effect being a greatly *preponderating* repulsion.

It is now not difficult to understand all the actions before described as obtained with the varied relations of coils, magnetic fields, and closed circuits. It will be easily understood, also, that an alternating magnetic field is in all respects the same as an alternating current coil in producing repulsion on the closed conductor, because the repulsions between the two conductors are the result of magnetic repulsions arising from opposing fields produced by the coils when the currents are of opposite directions in them.

Thus far I have applied the repulsive action described in the construction of alternating current indicators, alternating current arc lamps, regulating devices for alternating currents, and to rotary motors for such currents. For current indicators, a pivoted or suspended copper band or ring composed of thin washers piled together and insulated from one another, and made to carry a pointer or index has been placed in the axis of a coil conveying alternating currents whose amount or potential is to be indicated. Gravity or a spring is used to bring the index to the zero of a divided scale, at which time the plane of the copper ring or band makes an angle of, say, 15 degrees to 20 degrees with the plane of the coil. This angle is increased by deflection more or less great, according to the current traversing the coil. The instrument can be calibrated for set conditions of use. Time would not permit of a full description of these arrangements as made up to the present.

In arc lamps the magnet for forming the arc can be composed of a closed conductor, a coil for the passage of current, and an iron wire core. The repulsive action upon the closed conductor lifts and regulates the carbons in much the same manner that electro magnets do when continuous currents are used. The electro-inductive repulsive action has also been applied to regulating devices for alternating currents, with the details of which I cannot now deal.

For the construction of an alternating current motor which can be started from a state of rest the principle has also been applied, and it may here be remarked that a number of designs of such motors is practicable.

One of the simplest is as follows: The coils, C, Fig. 14, are traversed by an alternating current and are placed over a coil, B, mounted upon a horizontal axis, transverse to the axis of the coil, C. The terminals of the coil, B, which is wound with insulated wire, are carried to a commutator, the brushes being connected by a wire, as indicated. The commutator is so constructed as to keep the coil, B, on short circuit from the position of coincidence with the plane of C to the position where the plane of B is at right angles to that of C; and to keep the coil, B, open-circuited from the right-angled position, or thereabouts, to the position of parallel or coincident planes. The deflective repulsion exhibited by B will, when its circuit is completed by the commutator and brushes, as described, act to place its plane at right angles to that of C; but being then open-circuited, its momentum carries it to the position just past parallelism, at which moment it is again short-circuited, and so on. It is capable of very rapid rotation, but its energy is small. I have, however, extended the principle to the construction of more complete apparatus. One form has its revolving portion or armature composed of a number of sheet iron disks wound as usual with three coils crossing near the shaft. The commutator is arranged to short-circuit each of these coils in succession, and twice in a revolution, and for a period of 90 degrees of rotation each. The field coils surround the armature, and there is a laminated iron field structure completing the magnetic circuit. I may say here that surrounding the armature of a dynamo by the field coils, though very recently put forth as a new departure, was described in various Thomson-Houston patents, and to a certain extent all Thomson-Houston machines embody this feature.

Figs. 15 and 16 will give an idea of the construction of the motor referred to. C C^1 are the field coils or inducing coils, which alone are put into the alternating current circuit. I I is a mass of laminated iron, in the interior of which the armature revolves, with its three coils, B, B^2, B^3, wound on a core of sheet iron disks. The commutator short-circuits the armature coils in succession in the proper positions to utilize the repulsive effect set up by the currents which are induced in them by the alternations in the field coils. The motor has no dead point, and will start from a state of rest and give out considerable power, but with what economy is not yet known.

A curious property of the machine is that at a certain speed, depending on the rapidity of the alternations in the coil, C, a continuous current passes from one commutator brush to the other, and it will energize electro magnets and perform other actions of direct currents. Here we have, then, a means of inducing direct currents from alternating currents. To control the speed and keep it at that required for the purpose, we have only to properly gear the motor to another of the ordinary type for alternating currents, namely, an alternating-current dynamo used as a motor. The charging of storage batteries would not be difficult with such a machine, even from an alternating-current line, though the losses might be considerable.

ELECTRICAL REVIEW

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The Tesla System of Distribution and Electric Motors for Alternating Currents..

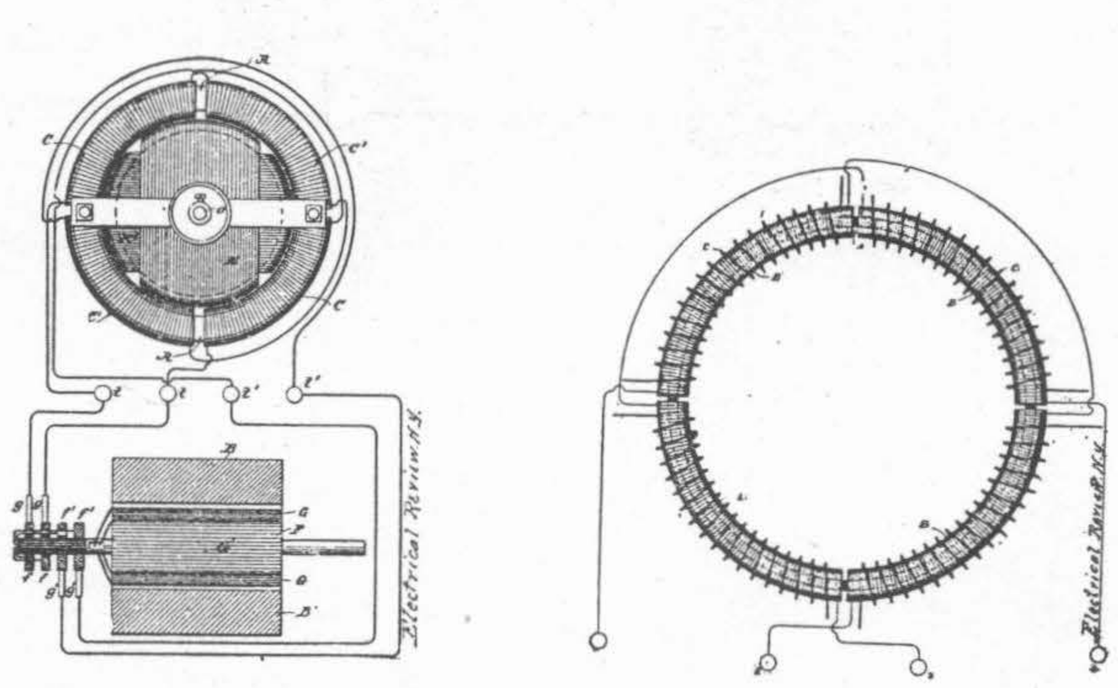
Six patents were issued last week under date of May 1st to Nickola Tesla, involving the various features of his very remarkable system of distribution and transmission of power by alternating currents, which are at the same time adapted for the production of light. The system is based upon a novel principle, which is very clearly set forth in the claim of one of the patents, namely, producing a continuously progressive rotation of the polarities of either or both elements (the armature or field magnet or magnets) of a motor, by developing alternating currents in independent circuits, including the magnetizing coils of either or both elements; and as a modification of this, shifting the poles of one element by alternating currents while magnetizing the other element by direct or continuous current.

One of the most interesting forms shows a generator of alternating currents whose armature contains two independent circuits of varying phase, and these two circuits are connected with the field-magnet coils of the motor in such manner that the alternating impulses in these two circuits will produce a continuous rotary shifting of the poles of the field-magnet and communicate a rotary effort to the armature, which in itself is a body of iron with coils of wire, whose circuit is entirely closed. That is, there is no communication whatever of the armature circuit with any other circuit, and consequently there is no commutator, collector or brushes of any kind carried by the armature. It will thus be seen that there is here developed a curious and interesting phase in the construction and operation of electric motors, and one which is entirely novel, in that there is no portion of the entire motor subject to wear and tear in even the slightest degree, except the shaft and its bearings. The direct consequence of this in the commercial use of motors is of great importance, as the attendant having charge of an electric motor of this character would have no more responsibility than he would have in looking after the lubrication of a counter-shaft.

Another interesting feature is the result of perfect synchronism between the motor and generator which arises from the peculiar principle of operation of the motor, and the latter can be constructed to run at a predetermined speed provided the speed of the generator and that of the motor have a common divisor. The practical result of this is perfectly constant speed in the motor with constant potential supply, no matter how much the load may vary on the motor. The motor when running at its highest attainable speed reverses almost instantaneously, on a reversal of the line connections, so that the simple motion of the switch effects the instantaneous reversal of the direction, and the time occupied in changing from highest speed in one direction to highest speed in the opposite direction is but a fraction of a second. The rotary effort of the armature is very great, and there is no difficulty whatever attendant upon the starting of the motor under load. The efficiency is extremely high, and can be increased to the highest possible extent attainable by continuous current motors.

The system also takes with it the novel construction and operation of transformers, a simple form of which is illustrated by Fig. 2, which shows a closed magnetic circuit wound with four primary coils which are connected into two high tension circuits in such manner as to produce two consequent poles at opposite ends of a diameter and these by the action of the generated current in the high tension circuits progressively shifting around the magnetic circuit, carrying the consequent poles continuously around; in other words, the two consequent poles rotate continuously, the winding of course remaining stationary. The secondary coils are wound on the primaries and can be connected among themselves in any desired manner according to the work to be performed.

It will be observed, therefore, that the action of the alternating currents is not to reverse polarities of the core, but to simply rotate them by the peculiar action of the current impulses in the two primary circuits, and it seems to follow as a matter of course



FIGS. 1 AND 2.—THE TESLA SYSTEM OF TRANSMISSION OF POWER AND THE DISTRIBUTION OF ELECTRICAL ENERGY.

that there is less energy wasted in the conversion than occurs in the ordinary converter where the magnetic poles are alternately reversed. Instead of using four wires from the generator three can be used and one of the three forming a common return for the other two.

Altogether, Mr. Tesla is to be congratulated, not alone on having produced something entirely novel in the electrical world, but also for having made thoroughly practicable the utilization of alternate currents for the transmission of power. The motors for a given out-put of mechanical energy are extremely small and are, as stated, absolutely self-regulating and there is no electrical element of wear and tear connected with them in any manner whatever, and this feature alone of the closed circuit armature without external connections stamps the series of inventions as being something entirely new and original, and it looks as though the new principle would have great influence on the application of alternating currents to practical forms of electric motors, and we congratulate Mr. Tesla upon his success in this direction,

GENERAL MEETING.

AFTERNOON SESSION, MAY 16th, 1888.

THE CHAIRMAN:—At the opening of our morning session, I had to announce that through serious sickness, our President, Mr. Edward Weston, who was unanimously elected last night was unable to be present. Mr. Weston has, however, made considerable effort to be with us to-day and he comes here from a sick bed. I think in securing the services of Mr. Weston in the presidency the Institute has secured one whose international reputation will be of benefit to it through the coming year. The Institute, as you are well aware, is a society whose membership is not merely confined to New York, but extends throughout every state and territory of the union, and includes to-day almost ever country on the civilized globe. Mr. Weston's reputation as an electrical engineer is co-extensive with the membership of the Institute, and I am therefore very glad to salute him as my successor, and now to introduce him to you.

Mr. Weston took the chair, and addressed the meeting as follows:

Gentlemen and Members of the Institute: I am not quite so sick as our former president, Mr. Martin, would lead you to believe; but since yesterday I have made a few trips between the equator and the north pole. I have been jumping as you will see between pretty wide extremes. To stop the too rapid motion I have taken considerable quinine and it leaves me in a somewhat befogged condition of mind. I am therefore not feeling well enough to address the Institute in the way that I should do in accepting the presidency. I feel extremely honored by the kindness of your selection. I accept the office with grave doubts, because I fear I cannot give as much time to it as our past worthy president has done, and show in the same time such remarkable growth of the Institute. I am informed that in the year of his presidency the actual membership of the Institute has about doubled itself, an indication of excellent work The papers that I have read, from what I have seen of the proceedings, have been worthy of the society. The character of the papers shows a con-

stant upward tendency. I hope it will continue so. We have nothing to be ashamed of in the past, and I hope we shall find nothing to be ashamed of in the future. I had intended te speak in full of the present state and future progress of electricity. I am unble to do that to-day. I really cannot stand it. Therefore I beg to apologize for disappointing you. I am not in fit condition even to occupy the President's chair, and as Mr. Martin has suggested that he would rather withdraw to-day, I would like Mr. Upton, if he would kindly do so, to accept the position this afternoon. (Applause.)

Mr. Francis R. Upton took the chair.

THE CHAIRMAN:—The first paper this afternoon is on "A New System of Alternate Current Motors and Transformers" by Mr. Tesla.

MR. GEO. M. PHELPS, JR.:—I would like about two minutes before the paper is read. I do not rise to propose a vote of thanks to our retiring President, because I think votes of thanks, like the resolutions in political conventions, "pointing with pride, &c.," have become a custom "more honored in the breach than in the observance." But I do feel that a word ought to be said, and I feel very confident that I express the general opinion in saying a word recognizing the zeal, the activity and the intelligence which have charactarized the administration of the office of President during the past year. The growth in membership, the character of the work accomplished, and, in general, all the activities of the Institute during the past year constitute a record to which I think we shall always look back with satisfaction, and with reasonable and just pride. It has been a matter of astonishment to me to observe the amount of time and the intelligent effort which so busy a man as our ex-President has found it possible to give to the interests of this Institute. He has not spared himself in any particular; there is no work that he could do that has been left undone, and our condition at the present time is a sufficient evidence of the truth of what I say, and I have not the slightest doubt that all here present join with me, and feel that it is no more than a meagre statement of the facts. (Applause.)

THE CHAIRMAN:—Is any formal motion to be made and entered in the minutes?

MR. PHELPS:— I think not, sir. As I expressly stated, I would prefer, as far as I am concerned, to avoid a formal motion. But

the way in which my remarks were received sufficiently justified my assumption that they expressed the general opinion of the members present.

MR. MAILLOUX:—I would move that the remarks made by Mr. Phelps be heartily accepted and approved and endorsed by the society. The motion was seconded by Mr. Wheeler.

CAPT. O. E. MICHAELIS:—I would merely like to add one word to the enconium pronounced on Mr. Phelps. I have been fortunate enough to be associated with our past President in the Council during the past year and I can heartily endorse everything Mr. Phelps said; I would like, however to call the attention of the Institute to one fact to which they are indebted to our past President alone, and that is the valuable addition to our transactions in the shape of the bibliography that now appears with them regularly. That was Mr. Martin's idea, and it has been carried out by him. You all must know how much time such a thing has taken, and he has done that entirely of his own motion and for the good of the Institute. (Applause.)

THE CHAIRMAN:—I understand the motion to be that the remarks of Mr. Phelps be added in full in our minutes and with the cordial approval of the members. All those approving will signify by rising. The resolution was unanimously carried.

MR. NIKOLA TESLA:—I desire to express my thanks to Prof. Anthony for the help he has given me in this matter. I would also like to express my thanks to Mr. Pope and Mr. Martin for their aid. The notice was rather short, and I have not been able to treat the subject as extensively as I could have desired, my health not being in the best condition at present. I ask your kind indulgence, and I shall be very much gratified if the little I have done meets your approval.

Mr. Tesla read the following paper.

American Institute Of Electrical Engineers-Transactions
May 16, 1888

A NEW SYSTEM OF ALTERNATE CURRENT MOTORS AND TRANSFORMERS.

BY NIKOLA TESLA.

In the presence of the existing diversity of opinion regarding the relative merits of the alternate and continuous current systems great importance is attached to the question whether alternate currents can be successfully utilized in the operation of motors. The transformers with their numerous advantages, have afforded us a relatively perfect system of distribution; and although, as in all branches of the art, many improvements are desirable, comparatively little remains to be done in this direction The transmission of power on the contrary, has been almost entirely confined to the use of continuous currents, and notwithstanding that many efforts have been made to utilize alternate currents for this purpose, they have, up to the present, at least as far as known, failed to give the result desired. Of the various motors adapted to be used on alternate current circuits the following have been mentioned: 1. A series motor with subdivided field. 2. An alternate current generator having its field excited by continuous currents. 3. Elihu Thomson's motor. 4. A combined alternate and continuous current motor. Two more motors of this kind have suggested themselves to me. 1. A motor with one of its circuits in series with a transformer and the other in the secondary of the transformer. 2. A motor having its armature circuit connected to the generator and the field coils closed upon themselves. These, however,I mention only incidentally.

The subject which I now have the pleasure of bringing to your notice is a novel system of electric distribution, and transmission of power by means of alternate currents, affording peculiar advantages, particularly in the way of motors, which I am confident will at once establish the superior adaptability of these currents to the transmission of power and will show that many results heretofore unattainable can be reached by their use;

results which are very much desired in the practical operation of such systems and which cannot be accomplished by means of continuous currents.

Before going into a detailed description of this system, I think it necessary to make a few remarks with reference to certain conditions existing in continuous current generators and motors, which, although generally known, are frequently disregarded.

In our dynamo machines, it is well known, we generate alternate currents which we direct by means of a commutator, a complicated device and, it may be justly said, the source of most of the troubles experienced in the operation of the machines. Now, the currents so directed cannot be utilized in the motor, but they must—again by means of a similar unreliable device—be reconverted into their original state of alternate currents. The function of the commutator is entirely external, and in no way does it affect the internal working of the machines. In reality, therefore, all machines are alternate current machines, the currents appearing as continuous only in the external circuit during their transit from generator to motor. In view simply of this fact, alternate currents would commend themselves as a more direct application of electrical energy, and the employment of continuous currents would only be justified if we had dynamos which would primarily generate, and motors which would be directly actuated by such currents.

But the operation of the commutator on a motor is two-fold; firstly, it reverses the currents through the motor, and secondly, it effects automatically, a progressive shifting of the poles of one of its magnetic constituents. Assuming, therefore, that both of the useless operations in the system, that is to say, the directing of the alternate currents on the generator and reversing the direct currents on the motor, be eliminated, it would still be necesssary in order to cause a rotation of the motor, to produce a progressive shifting of the poles of one of its elements, and the question presented itself.—How to perform this operation by the direct action of alternate currents? I will now proceed to show how this result was accomplished.

In the first experiment a drum-armature was provided with two coils at right angles to each other, and the ends of these coils were connected to two pairs of insulated contact-rings as usual. A ring was then made of thin insulated plates of sheet-iron and wound with four coils, each two opposite coils being connected

together so as to produce free poles on diametrically opposite sides of the ring. The remaining free ends of the coils were then connected to the contact-rings of the generator armature so as to form two independent circuits, as indicated in figure 9. It

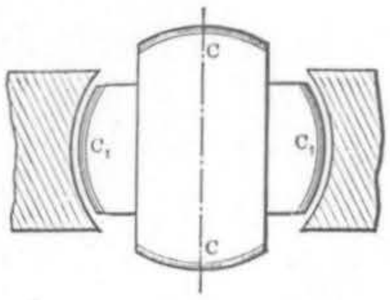


Fig. 1.

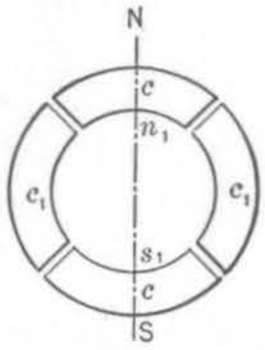


Fig. 1a.

may now be seen what results were secured in this combination, and with this view I would refer to the diagrams, figures 1 to 8*a*. The field of the generator being independently excited, the rotation of the armature sets up currents in the coils c c, varying in strength and direction in the well-known manner. In the position shown in figure 1, the current in coil c is nil while coil c_1 is traversed by its maximum current, and the connections may be such that the ring is magnetized by the coils c_1 c_1 as indicated by the letters N S in figure 1*a*, the magnetizing effect of the coils *c c* being nil, since these coils are included in the circuit of coil c.

In figure 2, the armature coils are shown in a more advanced position, one-eighth of one revolution being completed. Figure

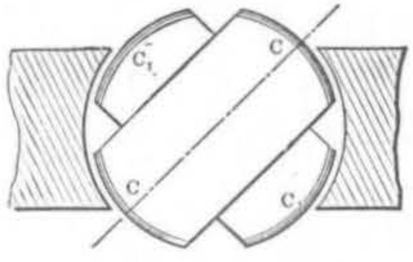


Fig. 2.

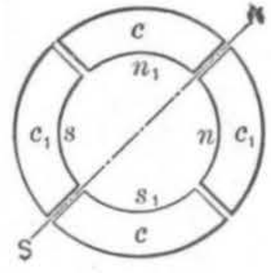


Fig. 2a.

2*a* illustrates the corresponding magnetic condition of the ring. At this moment the coil c_1 generates a current of the same direction as previously, but weaker, producing the poles n_1 s_1 upon the ring; the coil c also generates a current of the same direction, and the connections may be such that the coils *c c* produce

the poles *n s*, as shown in figure 2*a*. The resulting polarity is indicated by the letters N S, and it will be observed that the poles of the ring have been shifted one-eighth of the periphery of the same.

In figure 3 the armature has completed one-quarter of one rev-

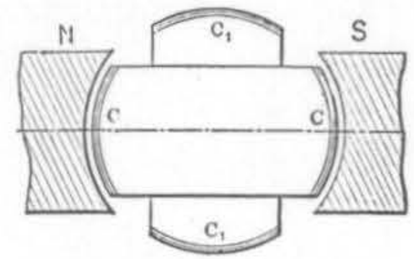


Fig. 3.

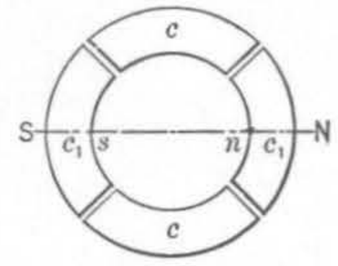


Fig. 3 a.

olution. In this phase the current in coil c is maximum, and of such direction as to produce the poles N S in figure 3*a*, whereas the current in coil c_1 is nil, this coil being at its neutral position. The poles N S in figure 3*a* are thus shifted one quarter of the circumference of the ring.

Figure 4 shows the coils c c in a still more advanced position, the armature having completed three-eighths of one revolution. At that moment the coil c still generates a current of the same direction as before, but of less strength, producing the comparatively weaker poles *n s* in figure 4*a*. The current in the coil c_1 is of the same strength, but opposite direction. Its effect is therefore, to produce upon the ring the poles n_1 s_1 as indicated

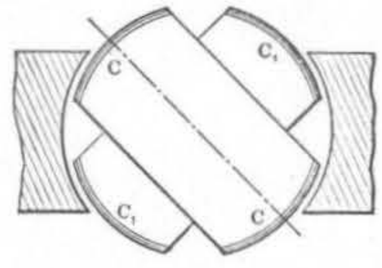


Fig. 4.

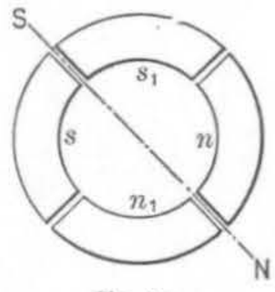


Fig. 4 a.

and a polarity, N S, results, the poles now being shifted three-eighths of the periphery of the ring.

In figure 5 one-half of one revolution of the armature is completed, and the resulting magnetic condition of the ring is indicated in figure 5*a*. Now the current in coil c is nil, while the coil c_1 yields its maximum current, which is of the same direction as previously; the magnetizing effect is, therefore, due to the coils,

c_1 c_1 alone, and, referring to figure 5*a*, it will be observed that the poles N S are shifted one half of the circumference of the ring. During the next half revolution the operations are repeated, as represented in the figures 6 to 8*a*.

A reference to the diagrams will make it clear that during one revolution of the armature the poles of the ring are shifted once around its periphery, and each revolution producing like effects, a rapid whirling of the poles in harmony with the rotation of the armature is the result. If the connections of either one of the circuits in the ring are reversed, the shifting of the poles is made to progress in the opposite direction, but the operation is identi-

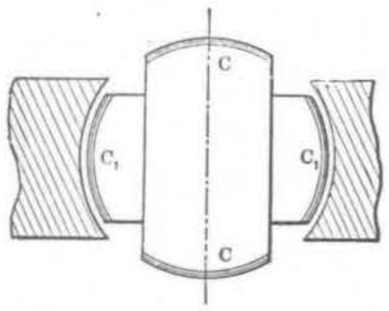


Fig. 5.

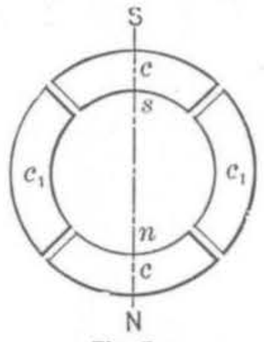


Fig. 5 a.

cally the same. Instead of using four wires, with like result, three wires may be used, one forming a common return for both circuits.

This rotation or whirling of the poles manifests itself in a series of curious phenomena. If a delicately pivoted disc of steel or other magnetic metal is approached to the ring it is set in rapid rotation, the direction of rotation varying with the position of the disc. For instance, noting the direction outside of the ring it will be found that inside the ring it turns in an opposite direction, while it is unaffected if placed in a position symmetrical to the ring. This is easily explained. Each time that a pole approaches, it induces an opposite pole in the nearest point on the disc, and an attraction is produced upon that point; owing to this, as the pole is shifted further away from the disc a tangential pull is exerted upon the same, and the action being constantly repeated, a more or less rapid rotation of the disc is the result. As the pull is exerted mainly upon that part which is nearest to the ring, the rotation outside and inside, or right and left, respectively, is in opposite directions, figure 9. When placed symmetrically to the ring, the pull on the opposite sides of the disc being equal

no rotation results. The action is based on the magnetic inertia of the iron; for this reason a disc of hard steel is much more affected than a disc of soft iron, the latter being capable of very rapid variations of magnetism. Such a disc has proved to be a

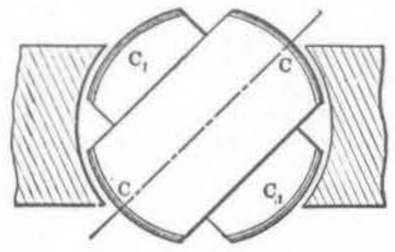


Fig. 6.

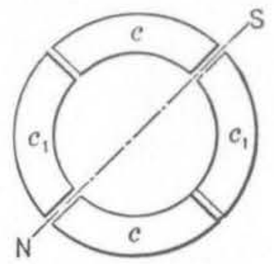


Fig. 6 a.

very useful instrument in all these investigations, as it has enabled me to detect any irregularity in the action. A curious effect is also produced upon iron filings. By placing some upon a paper and holding them externally quite close to the ring they are set in a vibrating motion, remaining in the same place, although the paper may be moved back and forth; but in lifting the paper to a certain height which seems to be dependent on the intensity of the poles and the speed of rotation, they are thrown away in a direction always opposite to the supposed movement of the poles. If a paper with filings is put flat upon the ring and the current turned on suddenly, the existence of a magnetic whirl may easily be observed.

To demonstrate the complete analogy between the ring and a revolving magnet, a strongly energized electro-magnet was rotated by mechanical power, and phenomena identical in every particular to these mentioned above were observed.

Obviously, the rotation of the poles produces corresponding inductive effects and may be utilized to generate currents in a

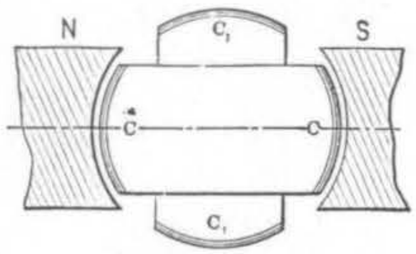


Fig. 7.

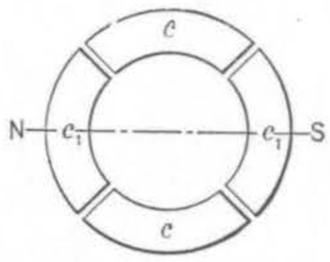


Fig. 7 a.

closed conductor placed within the influence of the poles. For this purpose it is convenient to wind a ring with two sets of

superimposed coils forming respectively the primary and secondary circuits, as shown in figure 10. In order to secure the most economical results the magnetic circuit should be completely closed, and with this object in view the construction may be modified at will.

The inductive effect exerted upon the secondary coils will be

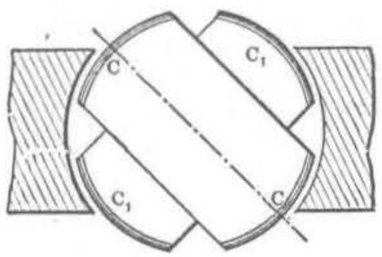


Fig. 8.

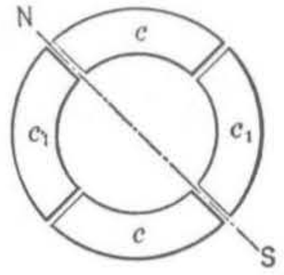


Fig. 8 a.

mainly due to the shifting or movement of the magnetic action; but there may also be currents set up in the circuits in consequence of the variations in the intensity of the poles. However, by properly designing the generator and determining the magnetizing effect of the primary coils, the latter element may be made to disappear. The intensity of the poles being maintained constant, the action of the apparatus will be perfect, and the same result will be secured as though the shifting were effected by means of a commutator with an infinite number of bars. In such case the theoretical relation between the energizing effect of each set of primary coils and their resultant magnetizing effect may be expressed by the equation of a circle having its centre coinciding with that of an orthogonal system of axes, and in which the radius represents the resultant and the co-ordinates both of its components. These are then respectively the sine and cosine of the angle a between the radius and one of the axes ($O\ X$). Referring to figure 11, we have $r = x_2 + y_2$; where $x = r \cos a$, and $y = r \sin a$.

Assuming the magnetizing effect of each set of coils in the transformer to be proportional to the current—which may be admitted for weak degrees of magnetization—then $x = K c$ and $y = K c^1$, where K is a constant and c and c^1 the current in both sets of coils respectively. Supposing, further, the field of the generator to be uniform, we have for constant speed $c^1 = K^1 \sin a$ and $c = K^1 \sin (90° + a) = K^1 \cos a$, where K^1 is a constant. See figure 12.

Therefore, $x = K c = K K^1 \cos a$;
$y = K c^1 = K K^1 \sin a$, and
$K K^1 = r$.

That is, for a uniform field the disposition of the two coils at right angles will secure the theoretical result, and the intensity of the shifting poles will be constant. But from $r^2 = x^2 + y^2$ it follows that for $y = 0$, $r = x$; it follows that the joint magnetizing effect of both sets of coils should be equal to the effect of one set when at its maximum action. In transformers and in a certain class of motors the fluctuation of the poles is not of great importance, but in another class of these motors it is desirable to obtain the theoretical result.

In applying this principle to the construction of motors, two typical forms of motor have been developed. First, a form having a comparatively small rotary effort at the start but maintaining a perfectly uniform speed at all loads, which motor has been termed synchronous. Second, a form possessing a great rotary effort at the start, the speed being dependent on the load.

These motors may be operated in three different ways: 1. By the alternate currents of the source only. 2. By a combined action of these and of induced currents. 3. By the joint action of alternate and continuous currents.

The simplest form of a synchronous motor is obtained by winding a laminated ring provided with pole projections with four

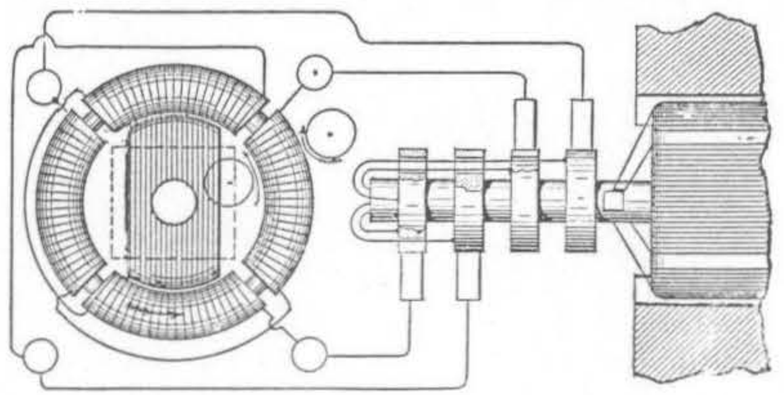


Fig. 9.

coils, and connecting the same in the manner before indicated. An iron disc having a segment cut away on each side may be used as an armature. Such a motor is shown in figure 9. The disc being arranged to rotate freely within the ring in close proximity to the projections, it is evident that as the poles are shifted it will, owing to its tendency to place itself in such a position as to

embrace the greatest number of the lines of force, closely follow the movement of the poles, and its motion will be synchronous with that of the armature of the generator; that is, in the peculiar disposition shown in figure 9, in which the armature produces by one revolution two current repulses in each of the circuits. It is evident that if, by one revolution of the armature, a greater

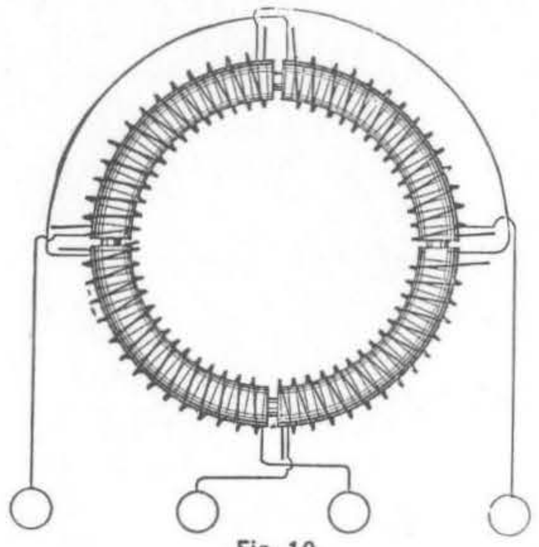


Fig. 10.

number of impulses is produced, the speed of the motor will be correspondingly increased. Considering that the attraction exerted upon the disc is greatest when the same is in close proximity to the poles, it follows that such a motor will maintain exactly the same speed at all loads within the limits of its capacity.

To facilitate the starting, the disc may be provided with a coil closed upon itself. The advantage secured by such a coil is evident. On the start the currents set up in the coil strongly energize the disc and increase the attraction exerted upon the same by the ring, and currents being generated in the coil as long as the speed of the armature is inferior to that of the poles, considerable work may be performed by such a motor even if the speed be below normal. The intensity of the poles being constant, no currents will be generated in the coil when the motor is turning at its normal speed.

Instead of closing the coil upon itself, its ends may be connected to two insulated sliding rings, and a continuous current supplied to these from a suitable generator. The proper way to start such a motor is to close the coil upon itself until the normal speed is reached, or nearly so, and then turn on the continuous current. If the disc be very strongly energized by a continuous

current the motor may not be able to start, but if it be weakly energized, or generally so that the magnetizing effect of the ring is preponderating it will start and reach the normal speed. Such a motor will maintain absolutely the same speed at all loads. It has also been found that if the motive power of the generator is not excessive, by checking the motor the speed of the generator is diminished in synchronism with that of the motor. It is characteristic of this form of motor that it cannot be reversed by reversing the continuous current through the coil.

The synchronism of these motors may be demonstrated experimentally in a variety of ways. For this purpose it is best to employ a motor consisting of a stationary field magnet and an armature arranged to rotate within the same, as indicated in figure 13. In this case the shifting of the poles of the armature produces a rotation of the latter in the opposite direction. It results therefrom that when the normal speed is reached, the poles of the armature assume fixed positions relatively to the field magnet and the same is magnetized by induction, exhibiting a distinct pole on each of the pole-pieces. If a piece of soft iron is approached to the field magnet it will at the start be attracted with a rapid vibrating motion produced by the reversals of polarity of the magnet, but as the speed of the armature increases the vibrations become less and less frequent and finally entirely cease. Then the iron is weakly but permanently attracted, showing that

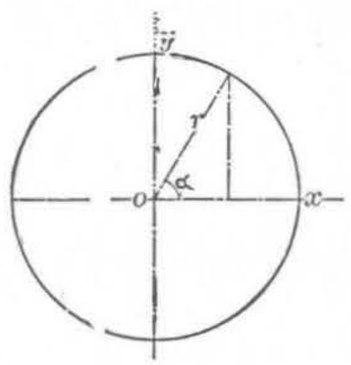


Fig. 11.

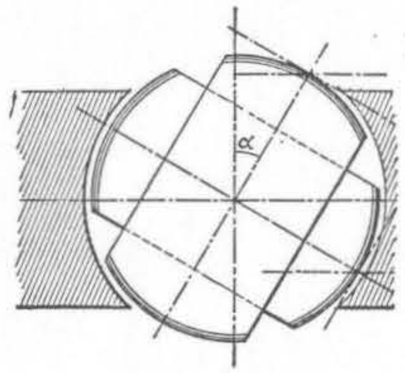


Fig. 12.

the synchronism is reached and the field magnet energized by induction.

The disc may also be used for the experiment. If held quite close to the armature it will turn as long as the speed of rotation of the poles exceeds that of the armature; but when the normal speed is reached or very nearly so, it ceases to rotate and is permanently attracted.

A crude but illustrative experiment is made with an incandescent lamp. Placing the lamp in circuit with the continuous current generator and in series with the magnet coil, rapid fluctuations are observed in the light in consequence of the induced currents set up in the coil at the start; the speed increasing, the fluctuations occur at longer intervals, until they entirely disappear, showing

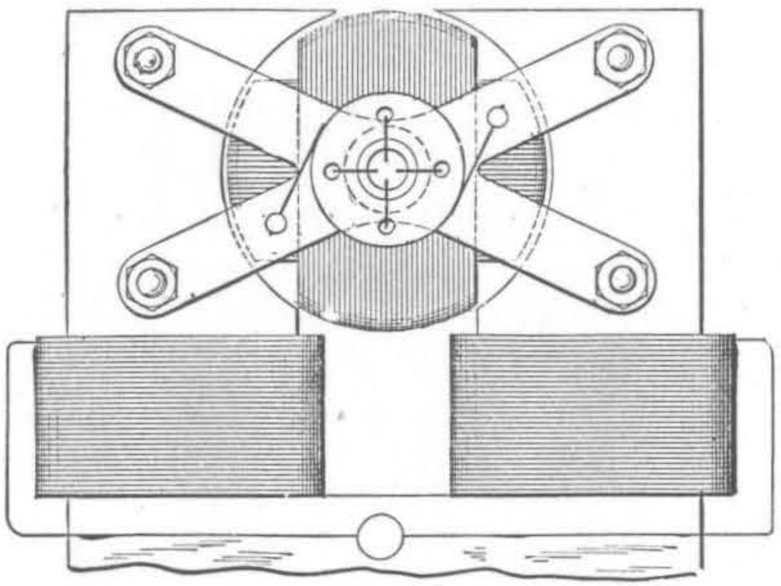


Fig. 13.

that the motor has attained its normal speed.

A telephone receiver affords a most sensitive instrument; when connected to any circuit in the motor the synchronism may be easily detected on the disappearance of the induced currents.

In motors of the synchronous type it is desirable to maintain the quantity of the shifting magnetism constant, especially if the magnets are not properly subdivided.

To obtain a rotary effort in these motors was the subject of long thought. In order to secure this result it was necessary to make such a disposition that while the poles of one element of the motor are shifted by the alternate currents of the source, the poles produced upon the other elements should always be maintained in the proper relation to the former, irrespective of the speed of the motor. Such a condition exists in a continuous current motor; but in a synchronous motor, such as described, this condition is fulfilled only when the speed is normal.

The object has been attained by placing within the ring a properly subdivided cylindrical iron core wound with several independent coils closed upon themselves. Two coils at right angles as

in figure 14, are sufficient, but a greater number may be advantageously employed. It results from this disposition that when the poles of the ring are shifted, currents are generated in the closed armature coils. These currents are the most intense at or near the points of the greatest density of the lines of force, and their effect is to produce poles upon the armature at right angles to those of the ring, at least theoretically so; and since this action is entirely independent of the speed—that is, as far as the location of the poles is concerned— a continuous pull is exerted upon the periphery of the armature. In many respects these motors are similar to the continuous current motors. If load is put on, the speed, and also the resistance of the motor, is diminished and more current is made to pass through the energizing coils, thus increasing the effort. Upon the load being taken off, the counter-electromotive force increases and less current passes through the primary or energizing coils. Without any load the speed is very nearly equal to that of the shifting poles of the field magnet.

It will be found that the rotary effort in these motors fully equals that of the continuous current motors. The effort seems to be greatest when both armature and field magnet are without any projections; but as in such dispositions the field cannot be concentrated, probably the best results will be obtained by leaving pole projections on one of the elements only. Generally, it

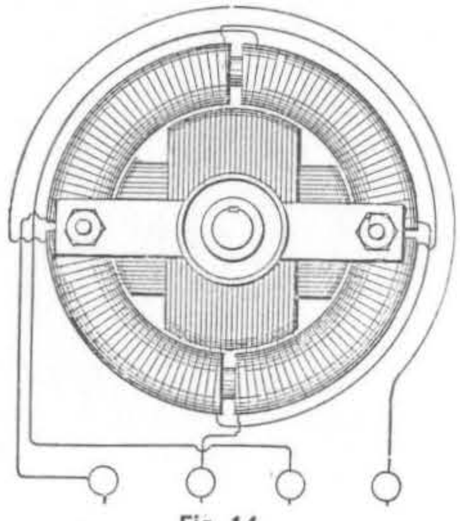


Fig. 14.

may be stated that the projections diminish the torque and produce a tendency to synchronism.

A characteristic feature of motors of this kind is their capacity of being very rapidly reversed. This follows from the peculiar

action of the motor. Suppose the armature to be rotating and the direction of rotation of the poles to be reversed. The apparatus then represents a dynamo machine, the power to drive this machine being the momentum stored up in the armature and its speed being the sum of the speeds of the armature and the poles.

If we now consider that the power to drive such a dynamo would be very nearly proportional to the third power of the speed, for that reason alone the armature should be quickly reversed. But simultaneously with the reversal another element is brought into action, namely, as the movement of the poles with respect to the armature is reversed, the motor acts like a transformer in which the resistance of the secondary circuit would be abnormally diminished by producing in this circuit an additional electro-motive force. Owing to these causes the reversal is instantaneous.

If it is desirable to secure a constant speed, and at the same time a certain effort at the start, this result may be easily attained in a variety of ways. For instance, two armatures, one for torque and the other for synchronism, may be fastened on the same shaft and any desired preponderance may be given to either one, or an armature may be wound for rotary effort, but a more or less pronounced tendency to synchronism may be given to it by properly constructing the iron core; and in many other ways.

As a means of obtaining the required phase of the currents in both the circuits, the disposition of the two coils at right angles is the simplest, securing the most uniform action; but the phase may be obtained in many other ways, varying with the machine employed. Any of the dynamos at present in use may be easily

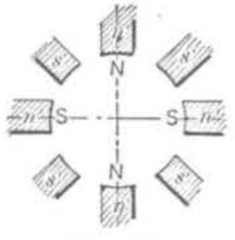


Fig. 15.

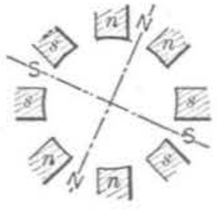


Fig. 16.

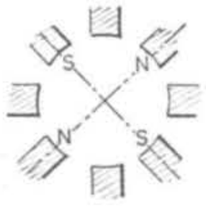


Fig. 17.

adapted for this purpose by making connections to proper points of the generating coils. In closed circuit armatures, such as used in the continuous current systems, it is best to make four derivations from equi-distant points or bars of the commutator, and to connect the same to four insulated sliding rings on the shaft. In

this case each of the motor circuits is connected to two diametrically opposite bars of the commutator. In such a disposition the motor may also be operated at half the potential and on the three-wire plan, by connecting the motor circuits in the proper order to three of the contact rings.

In multipolar dynamo machines, such as used in the converter systems, the phase is conveniently obtained by winding upon the armature two series of coils in such a manner that while the coils of one set or series are at their maximum production of current, the coils of the other will be at their neutral position, or nearly so, whereby both sets of coils may be subjected simultaneously or successively to the inducing action of the field magnets.

Generally the circuits in the motor will be similarly disposed, and various arrangements may be made to fulfill the requirements; but the simplest and most practicable is to arrange primary circuits on stationary parts of the motor, thereby obviating, at least in certain forms, the employment of sliding contacts. In such a case the magnet coils are connected alternately in both the circuits; that is, 1, 3, 5.....in one, and 2, 4, 6.....in the other, and the coils of each set of series may be connected all in the same manner, or alternately in opposition; in the latter case a motor



Fig. 18.

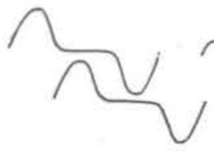


Fig. 19.

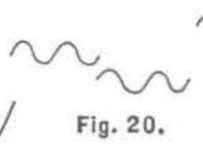


Fig. 20.

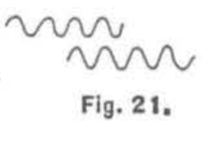


Fig. 21.

with half the number of poles will result, and its action will be correspondingly modified. The figures 15, 16, and 17, show three different phases, the magnet coils in each circuit being connected alternately in opposition. In this case there will be always four poles, as in figures 15 and 17, four pole projections will be neutral, and in figure 16 two adjacent pole projections will have the same polarity. If the coils are connected in the same manner there will be eight alternating poles, as indicated by the letters n' s' in figure 15.

The employment of multipolar motors secures in this system an advantage much desired and unattainable in the continuous current system, and that is, that a motor may be made to run exactly at a predetermined speed irrespective of imperfections in construction, of the load, and, within certain limits, of electromotive force and current strength.

In a general distribution system of this kind the following plan should be adopted. At the central station of supply a generator should be provided having a considerable number of poles. The motors operated from this generator should be of the synchronous type, but possessing sufficient rotary effort to insure their starting. With the observance of proper rules of construction it may be admitted that the speed of each motor will be in some inverse proportion to its size, and the number of poles should be chosen accordingly. Still exceptional demands may modify this rule. In view of this, it will be advantageous to provide each motor with a greater number of pole projections or coils, the number being preferably a multiple of two and three. By this means, by simply changing the connections of the coils, the motor may be adapted to any probable demands.

If the number of the poles in the motor is even, the action will be harmonious and the proper result will be obtained; if this is not the case, the best plan to be followed is to make a motor with a double number of poles and connect the same in the manner before indicated, so that half the number of poles result. Suppose, for instance, that the generator has twelve poles, and it would be desired to obtain a speed equal to $\frac{12}{7}$ of the speed of the generator. This would require a motor with seven pole projections or magnets, and such a motor could not be properly connected in the circuits unless fourteen armature coils would be provided, which would necessitate the employment of sliding contacts. To avoid this, the motor should be provided with fourteen magnets and seven connected in each circuit, the magnets in each circuit alternating among themselves. The armature should have fourteen closed coils. The action of the motor will not be quite as perfect as in the case of an even number of poles, but the drawback will not be of a serious nature.

However, the disadvantages resulting from this unsymmetrical form will be reduced in the same proportion as the number of the poles is augmented.

If the generator has, say, n, and the motor n_1 poles, the speed of the motor will be equal to that of the generator multiplied by $\frac{n}{n_1}$.

The speed of the motor will generally be dependent on the number of the poles, but there may be exceptions to this rule. The speed may be modified by the phase of the currents in the

circuits or by the character of the current impulses or by intervals between each or between groups of impulses. Some of the possible cases are indicated in the diagrams, figures 18, 19, 20 and 21, which are self-explanatory. Figure 18 represents the condition generally existing, and which secures the best result. In such a case, if the typical form of motor illustrated in figure 9 is employed, one complete wave in each circuit will produce one revolution of the motor. In figure 19 the same result will be effected by one wave in each circuit, the impulses being successive; in figure 20 by four, and in figure 21 by eight waves.

By such means any desired speed may be attained; that is, at least within the limits of practical demands. This system possesses this advantage besides others, resulting from simplicity. At full loads the motors show an efficiency fully equal to that of the continuous current motors. The transformers present an additional advantage in their capability of operating motors. They are capable of similar modifications in construction, and will facilitate the introduction of motors and their adaptation to practical demands. Their efficiency should be higher than that of the present transformers, and I base my assertion on the following:—

In a transformer as constructed at present we produce the currents in the secondary circuit by varying the strength of the primary or exciting currents. If we admit proportionality with respect to the iron core the inductive effect exerted upon the secondary coil will be proportional to the numerical sum of the variations in the strength of the exciting current per unit of time; whence it follows that for a given variation any prolongation of the primary current will result in a proportional loss. In order to obtain rapid variations in the strength of the current, essential to efficient induction, a great number of undulations are employed, from this practice various disadvantages result. These are increased cost and diminished efficiency of the generator, more waste of energy in heating the cores, and also diminished output of the transformer, since the core is not properly utilized, the reversals being too rapid. The inductive effect is also very small in certain phases, as will be apparent from a graphic representation, and there may be periods of inaction, if there are intervals between the succeeding current impulses or waves. In producing a shifting of the poles in a transformer, and thereby inducing currents, the induction is of the ideal character, being always

maintained at its maximum action. It is also reasonable to assume that by a shifting of the poles less energy will be wasted than by reversals.

DISCUSSION.

MR. T. C. MARTIN :—Prof. Anthony I believe, is here, and as he has given this subject some attention I think he might very properly supplement Mr. Tesla's paper with some remarks.

MR. TESLA :—I want to express once more my best thanks to Prof. Anthony for aiding me in many respects, and I hope he will be able to enlighten you upon many of the features in this system that I was unable to explain at present.

PROF. W. A. ANTHONY:—Mr. President and Gentlemen: I have been referred to as having had something to do with these forms of motor. I am very glad to be able to add my testimony to what Mr. Tesla has already given you in regard to their action, and I confess that on first seeing the motors the action seemed to me an exceedingly remarkable one. After my first visit to Mr. Tesla's works some of the motors, I think these very two that you see here on the table, were brought to me to make some tests of their efficiency, and probably you will be more interested in that than anything else that I might say. I am sorry to have not brought with me the exact figures we obtained, but I can give you from memory something of the result. This little motor that you see here gave us about half a horse power, and had an efficiency of something above fifty per cent., which I considered a very fair efficiency for a motor of this size, as we cannot expect with such small motors to get as high efficiency as we can with larger ones. This I believe is the armature that Mr. Tesla calls the armature for high rotary effort. This little pulley which is only about three inches in diameter gave a pull of something like fifty pounds, as I remember it, on turning on the current, so that you see the rotary effort is very considerable and that is also shown in the quickness with which the armature willreverse its motion on reversing the relation of the two currents which pass through the two opposite coils. That could be done by shifting two of the wires or simply shifting a reversing key in one of the circuits, and the armature would stop and reverse its motion so quickly that it was almost impossible to tell when the change took place. That shows, as I have said, the very considerable rotary effort that the armature presents.

This motor (referring to the second specimen) gave us, I think, about one and one-quarter horse power and showed a somewhat higher efficiency than the other, a little over sixty per cent. This would run, with the armature as here constructed, almost at the speed of the generator even under a very heavy load. When the load was brought up to the maximum load, where the efficiency began to fall off somewhat, the speed of rotation was reduced. As I remember now, it was reduced to about twenty-eight hundred, and the speed, you see, kept up very nearly to that of the generator under heavy load.

I can add very little to what Mr. Tesla has already given you in regard to these motors. I have no question but that all of you would be as much interested as I was in seeing them work. That is really the best way in which to deter mine what the motors will do. (Applause.)

MR. TESLA :—Mr. President and Gentlemen: Prof. Anthony just made the remark that the speed of this motor fell off when the load was increased. That was due to the fact that this armature was designed to secure a considerable effort from the start. But if we make an armature which is only designed for synchronism, the speed will always be the same no matter what the load; only there is a disadvantage that at the outset the rotary effort is so small that it is apt not to start. It would generally start if put in a proper position, but if not put in a proper position it might not start. If we employ an armature consisting of a cutaway block of steel with a coil, it will maintain speed at all loads. The importance of maintaining the intensity of the pole constant is that, if this can be produced, we can utilize, instead of the subdivided armature, an ordinary steel block with the same result. It is only desired to close the magnetic field. You can readily see, if the poles are fixed, that it is not necessary to sub-divide the armature, if the intensity of the force is constantly maintained the same. But, if the intensity is not maintained the same, then it is necessary to subdivide, and generally in the results that I have obtained I have found that it is necessary to subdivide. I attribute the good results obtained by the tests of Professor Anthony to the fact that the dynamo used by him has a powerful field and a small armature, and the field is very concentrated, and for that reason, probably, the result is nearer the theoretical.

PROF. THOMSON :—I have certainly been very much interested

in the description given by Mr. Tesla of his new and admirable little motor. I have, as probably you may be aware, worked in somewhat similar directions and towards the attainment of similar ends. The trials which I have made have been by the use of a single alternating current circuit, not a double alternating circuit; a single circuit supplying a motor constructed to utilize the alternation and produce rotation. I have carried on since the last annual meeting of the Institute the development and perfecting, as far as my time allowed, of a closed circuit armature, if we may so term it, related to the alternating field. That is the plan which I used and which I brought to the notice of the Institute last year; it was to make a laminated field and in that field to place an armature, also laminated, winding upon the armature a coil, which periodically is close-circuited during the revolution by a suitable commutator or circuit-closing device. I have made several such motors on different designs and they uniformly start from a state of rest and develop power, and some of them show, at speeds close to the rate of alternations of the dynamo, a tendency to synchronize. Their rotary effort in most cases is a little greater, near that point than at other points. I hope before a long while to bring most of these results before the notice of the Institute, and I would therefore prefer delaying further remarks on motors of this description. I certainly think there is a field for alternating motors, and there is undoubtedly an opportunity for obtaining motors which possess even some advantages over the continuous current motors. (Applause.)

Mr. Tesla:—Gentlemen, I wish to say that the testimony of such a man as Prof. Thomson, as being foremost in his profession, flatters me very much. I might say that I have worked in the same line with Prof. Thomson at a period when the invention of Prof. Thomson was not known to me. I had a motor identically the same as that of Prof. Thomson, but I was anticipated by him. I believe that although that particular form of motor has the disadvantage that a pair of brushes must be employed to short-circuit the armature coil, that such a form of motor may be made practicable, for the simple reason that a motor resembles a transformer, and such a transformer, we well know, can be brought to a very high efficiency. On the other hand, the armature may be provided with conductors that are of comparatively low resistance, and it is a mere matter of making a perfect arrangement for short circuiting. You will see the

advantage of this disposition of the closed circuit coil—that this action is maintained always at the maximum, and it is indeed more perfect than if the polarities were shifted by means of a commutator.

The Chairman:—Unless there are some other remarks on this subject we shall have to pass to the consideration of the next paper. I think thanks are due to Mr. Tesla for his paper. The next paper in order is "Underground Electrical Systems in Europe and America," by Prof. G. W. Plympton, of the Brooklyn Subway Board.

Prof. Plympton:—Mr. President and Gentlemen of the Institute. This is a place in which I should seek to stand for instruction rather than to impart any information. I have looked for a long time to gentlemen of this organization for such information as should guide me in the work I am doing. I shall be very brief with the so-called paper, and will give a little of what I have to communicate, orally in the way of a description of some plates and a narrative of my journey.

Prof. Plympton then read the following paper:

From this curve the currents for intermediate positions of the coil may be determined and the degree of accuracy of which the instrument is capable may be estimated.

The Chairman read the communication from the Secretary of the Electric Club, which had been presented at the annual meeting on the previous day, inviting members of the Institute to visit the house of the Electric Club.

THE CHAIRMAN:—I have another announcement to make in regard to Mr. Tesla's motor. I believe that this motor—Mr. Tesla can correct me if I am not right—is the first good alternating current motor that has been put before the public anywhere—is that not so, Mr. Tesla? And he says that the system can be seen in practical operation at 89 Liberty street, second floor, and he invites you all to come and see it. (Applause.)

The next meeting of the Institute will take place on June 12th, and Mr. F. J. Sprague will read a paper on "The Engineering Problems of Electric Railway Work," and I hope that all will be present so as to lend the scientific atmosphere that is needed for papers of this class, to the occasion. (This meeting was subsequently postponed to June 19th.)

The general meeting then adjourned.

ELECTRO-DYNAMIC ROTATION BY MEANS OF ALTERNATING CURRENTS.

Professor Galileo Ferraris, of Turin, who, as will be remembered, was one of the first to make a strictly scientific investigation of transformers, and who has since then continued to devote attention to alternating currents, has just published the results of some experiments made with a view to produce continuous rotation by their means. The experiments are interesting, because the apparatus used was based upon an entirely new principle, which may be capable of further development. The question how to produce continuous rotation by means of alternating currents is just now occupying the minds of many electricians, because the production of an alternating current motor would greatly increase the earning capacity of central electric light stations supplying alternating currents. Whether the apparatus devised by Professor Ferraris, and which we are about to describe, will lead to the discovery of an alternating current motor, is a question on which we do not pretend to prophesy; but as the principle involved may also have other applications, notably in the construction of meters for measuring the supply of electricity, we think it of sufficient importance to lay a short abstract of the investigation before our readers. The principle on which the apparatus is based is exceedingly simple, and will be understood by reference to the accompanying sketches. Let in Fig. 1 the lines O A and O B represent in direction and magnitude the strength of two magnetic fields. The combined action of these fields on a unit pole, placed in the point O, would then be represented by the resultant O R. Instead of having two distinct fields, we have one resultant field, represented in direction and magnitude by this line. If both fields undergo periodic variations of the same period, the resultant field O R will also undergo a periodic variation, and the point R will traverse a curve, the form of which depends upon the precise manner in which the lines O A and O B change with the time. The fields O A and O B can be produced by two coils, having the lines O X and O Y respectively for their axes, and which coils are traversed by alternating currents of the same period. If the alternating currents may be expressed as sine functions of the time, and if there is an appreciable lag between the currents in the two coils, the point R describes an ellipse round O as centre. In

this case the line O R representing the resultant field revolves round the centre O, the direction and magnitude of the resultant field changing at every instant. If, however, there is no lag between the two currents, that is to say, if they pass through zero simultaneously, the direction of the resultant field O R remains stationary, and the point R performs harmonic oscillation over the line R O and its prolongation with O as centre. This may be considered as a special case of the ellipse where the latter has been flattened down to a mathematical line. Another special case occurs when the ellipse becomes a circle, and this must evidently take place when the lag between the two currents is 90°, when the coils are at right angles to each other, and when the component fields are equally strong. A metallic body suspended in the centre of the two fields, and free to revolve, must evidently have a tendency to participate in the rotation of the resultant field.

The application of this very simple principle will be clear from Fig. 2, in which the two coils are indicated by the rectangles A and B, the connections being made by the wires $1\,1^1$ and $2\,2^1$ respectively. When alternating currents are sent through these coils a resultant field is produced, which revolves round the line O O. In the centre between the coils is suspended a small hollow cylinder of copper, and as the lines of the resultant field cut the metal Foucault currents are induced, and by the interaction of these induced currents and the revolving field the cylinder is set in rotation. The action is exactly the reverse of that occurring in the well known experiment in which a copper disc is rapidly revolved below a compass needle, with the result that the compass needle is deflected on account of the induced currents in the copper disc, and ultimately caused to rotate with the copper disc.

Up to the present we have spoken of two distinct currents being required in the coils A and B, one lagging behind the other by a quarter period; and to perform the experiment we might employ an alternating current dynamo with two circuits in the armature, so arranged with regard to each other as to produce the desired lag. It is, however, possible to perform the experiment by using an ordinary alternating current machine with only one circuit on the armature, and to produce the second current by means of a transformer. The current from the machine is sent through the primary of the transformer and then through the coil A, whilst the secondary current obtained from the transformer is sent through the coil B. It is then possible, by the interposition of a suitable inert resistance into the secondary circuit, to obtain very nearly the desired lag of 90° between the currents in the two coils. As the strength of the secondary current will, by the insertion of the resistance, be considerably reduced, it is necessary, in order to obtain approximately equal fields from the two coils, to employ a larger number of turns in the coil B than in A. Another method of producing the desired result consists in using a transformer with one primary and two secondary coils, and to insert into the circuit of one of the secondary coils a large self induction, and into that of the other a large inert resistance, by which means the desired lag between the two secondary currents can also be obtained. It will be seen that in either of these ways it is possible, by means of a simple alternating current and a transformer, the coils of which are abreast, to obtain a revolving magnetic field of approximately uniform intensity, by which phenomena can be produced in every respect similar to those obtainable from a revolving permanent steel magnet.

In the first experiment made by Professor Ferraris, a Gaulard & Gibbs transformer, with an equal number of turns in the primary and secondary coils, was used. In the primary circuit was included the coil A, consisting of a few turns of stout wire, whilst in the secondary circuit were included an adjustable and non-inductive resistance and the coil B, the latter consisting of many turns of fine wire. A small hollow copper cylinder was suspended on a thread in the centre of the two coils, as shown in Fig. 2. If the current was sent through only one of the coils, the cylinder remained at rest; but if currents were sent through both coils, the cylinder immediately started to revolve, twisting the thread on which it was suspended. A reversing switch was inserted in the secondary circuit, and if the current through this circuit was inverted, the cylinder was immediately brought to rest, and started in the opposite direction. Professor Ferraris next substituted a small iron cylinder for the copper one, and found equal results; but when using an iron cylinder sufficiently large to nearly fill the place within the coils, the experiment did not succeed so well. He attributes this to the greater self induction which the presence of iron in a large mass necessarily introduces into both circuits. Another experiment was made with a small iron cylinder, composed of a number of thin discs insulated from each other, and this experiment also succeeded. Foucault currents could not in this case be the cause of rotation, and Professor Ferraris thinks that the rotation is due to hysteresis. A larger apparatus was then constructed, which is indicated in our sketch Fig. 3. In this case the copper cylinder, which was mounted upon a horizontal axis in bearings, had a diameter of 3½in., and was 7in. long, its weight being 11lb. This cylinder was closely surrounded by the primary and secondary coils wound upon wooden bobbins. To make room for the shaft each coil was in halves, the primary consisting of ninety-six turns of seventy-seven mils. wire, both coupled in series, so as to produce the effect of a coil of 192 turns; the secondary consisting of 504 turns of thirty-eight mils. wire, both being coupled in parallel, so as to produce the effect of 504 turns. The resistance of the primary coils was 7·12 and 6·63 ohms respectively, and that of the two secondary coils coupled in parallel was 3·43 ohms. In the secondary circuit was also inserted a rheostat without self induction, and the best results were obtained when the rheostat was set to between 15 and 18 ohms. A Gaulard & Gibbs transformer was used, giving eighty reversals per second. The copper cylinder began to revolve when the primary current was 5 ampères, and with higher currents the velocity could be increased to nine hundred revolutions per minute, and might have been still further increased but for the somewhat imperfect mechanical arrangements, which occasioned considerable vibrations. To the shaft was applied a small friction dynamometer, and the following table gives the work obtained on the brake by a primary current of 9 ampères at different speeds:—

Revolutions per minute....	262	400	546	653	722	770	772	900
Watts obtained on brake...	1·32	2·12	2·65	2·77	2·55	2·40	2·04	0

The maximum energy was obtained at 650 revolutions. Beyond that speed the energy decreased, which is attributed by Professor Ferraris to the imperfect mechanical arrangement of the apparatus, causing a considerable waste of power in vibrations. If it were not for this, the maximum energy would have been obtained at about 1200 revolutions, whilst at 2400 revolutions, which is the speed of the revolving resultant field, no energy at all could be obtained. Professor Ferraris suggests that this apparatus may be used for lecture purposes, and as a motor when the power required is small, and it may also be used as an electricity meter. The torque exerted by the revolving field upon the copper cylinder is proportional to the square of the current, and in order that the total number of revolutions performed in a given time may be an indication of the number of coulombs supplied, it is necessary to introduce some opposing force which varies with the square of the velocity. If this can be done, and if the friction of the journals can be sufficiently reduced, an ordinary counter attached to the axis would indicate the quantity of electricity supplied.

THE TESLA SYSTEM OF DISTRIBUTION AND ELECTRIC MOTORS FOR ALTERNATING CURRENTS.

Six patents, says the *Electrical Review* of New York, were issued last week under date of May 1st to Nickola Tesla, involving the various features of his very remarkable system of distribution and transmission of power by alternating currents, which are at the same time adapted for the production of light. The system is based upon a novel principle, which is very clearly set forth in the claim of one of the patents—namely, producing a continuously progressive rotation of the polarities of either or both elements (the

armature or field magnet or magnet) of a motor, by developing alternating currents in independent circuits, including the magnetising coils of either or both elements; and as a modification of this, shifting the poles of one element by alternating currents while magnetising the other element by direct or continuous current.

One of the most interesting forms shows a generator of alternating currents whose armature contains two independent circuits of varying phase, and these two circuits are connected with the field-magnet coils of the motor in such manner that the alternating impulses in these two circuits will produce a continuous rotary shifting of the poles of the field-magnet and communicate a rotary effort to the armature, which in itself is a body of iron with coils of wire, whose circuit is entirely closed. That is, there is no communication whatever of the armature circuit with any other

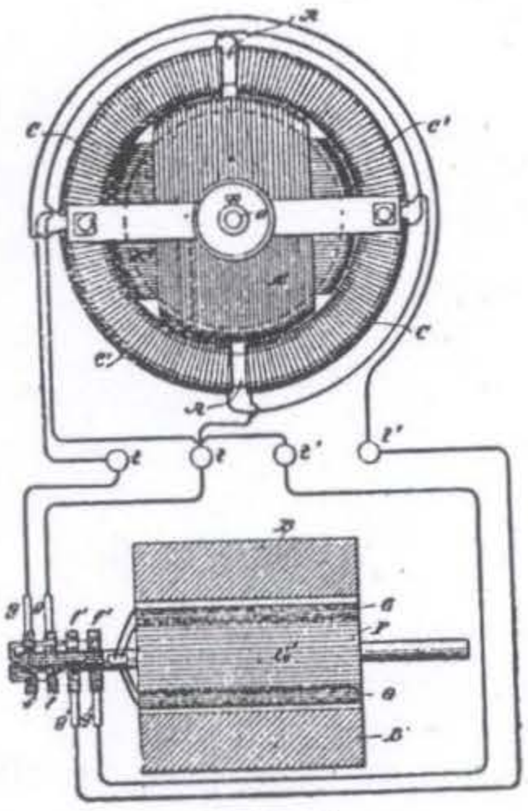


FIG. 1.

circuit, and consequently there is no commutator, collector, or brushes of any kind carried by the armature. It will thus be seen that there is here developed a curious and interesting phase in the construction and operation of electric motors, and one which is entirely novel, in that there is no portion of the entire motor subject to wear and tear in even the slightest degree, except the shaft and its bearings. The direct consequence of this in the commercial use of motors is of great importance, as the attendant having charge of an electric motor of this character would have no more responsibility than he would have in looking after the lubrication of a counter-shaft.

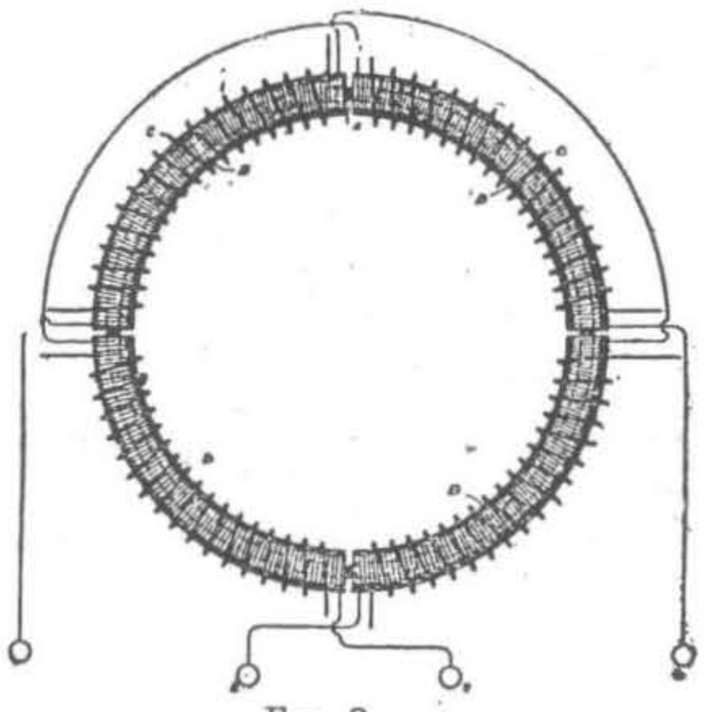


FIG. 2.

Another interesting feature is the result of perfect synchronism between the motor and generator which arises from the peculiar principle of operation of the motor, and the latter can be constructed to run at a predetermined speed provided the speed of the generator and that of the motor have a common divisor. The practical result of this is perfectly constant speed in the motor with constant potential supply, no matter how much the load may vary on the motor. The motor when running at its highest attainable speed reverses almost instantaneously, on a reversal of the line connections, so that the simple motion of the switch effects the instantaneous reversal of the direction, and the time occupied in changing from highest speed in one direction to highest speed in the opposite direction is but a fraction of a second. The rotary effort of the armature is very great, and there is no difficulty whatever attendant upon the starting of the motor under load. The efficiency is extremely high, and can be increased to the highest possible extent attainable by continuous current motors.

The system also takes with it the novel construction and operation of transformers, a simple form of which is illustrated by Fig. 2, which shows a closed magnetic circuit wound with four primary coils which are connected into two high-tension circuits in such manner as to produce two consequent poles at opposite ends of a diameter, and these by the action of the generated current in the high-tension circuits progressively shifting around the magnetic circuit, carrying the consequent poles continuously around; in other words, the two consequent poles rotate continuously, the winding, of course, remaining stationary. The secondary coils are wound on the primaries, and can be connected among themselves in any desired manner, according to the work to be performed.

It will be observed, therefore, that the action of the alternating currents is not to reverse polarities of the core, but to simply rotate them by the peculiar action of the current impulses in the two primary circuits, and it seems to follow, as a matter of course, that there is less energy wasted in the conversion than occurs in the ordinary converter, where the magnetic poles are alternately reversed. Instead of using four wires from the generator three can be used, and one of the three forming a common return for the other two.

Altogether, Mr. Tesla is to be congratulated, not alone on having produced something entirely novel in the electrical world, but also for having made thoroughly practicable the utilisation of alternate currents for the transmission of power. The motors for a given output of mechanical energy are extremely small, and are, as stated, absolutely self-regulating, and there is no electrical element of wear and tear connected with them in any manner whatever, and this feature alone of the closed circuit armature without external connections stamps the series of inventions as being something entirely new and original, and it looks as though the new principle would have great influence on the application of alternating currents to practical forms of electric motors, and we congratulate Mr. Tesla upon his success in this direction.

ELECTRO-DYNAMIC ROTATION BY MEANS OF ALTERNATING CURRENTS.*

Prof. Galileo Ferraris, of Turin, who, as will be remembered, was one of the first to make a strictly scientific investigation of transformers, and who has since then continued to devote attention to alternating currents, has just published the results of some experiments made with a view to produce continuous rotation by their means. The experiments are interesting, because the apparatus used was based upon an entirely new principle, which may be capable of further development. The question how to produce continuous rotation by means of alternating currents is just now occupying the minds of many electricians, because the production of an alternating-current motor would greatly increase the earning capacity of central electric light stations supplying alternating currents. Whether the apparatus devised by Prof. Ferraris, and which we are about to describe, will lead to the discovery of an alternating-current motor, is a question on which we do not pretend to prophesy; but as the principle involved may also have other applications, notably in the construction of meters for measuring the supply of electricity, we think it of sufficient importance to lay a short abstract of the investigation before our readers. The principle on which the apparatus is based is exceedingly simple, and will be understood by reference to the accompanying sketches. Let in Fig. 1 the lines O A and O B represent in direction and magnitude the strength of two magnetic-fields. The combined action of these fields on a unit pole, placed in the point O, would then be represented by the resultant O R. Instead of having two distinct fields, we have one resultant field, represented in direction and magnitude by this line. If both fields undergo periodic variations of the same period, the resultant field O R will also undergo a periodic variation, and the point R will traverse a curve, the form of which depends upon the precise manner in which the lines O A and O B change with the time.

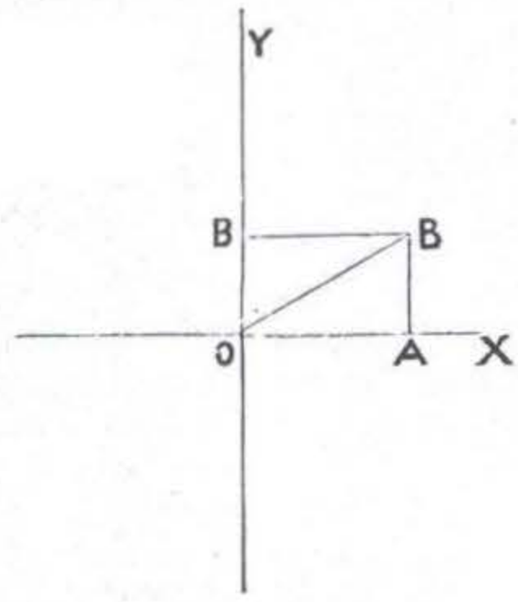


FIG. 1.

The fields O A and O B can be produced by two coils, having the lines O X and O Y respectively for their axes, and which coils are traversed by alternating currents of the same period. If the alternating currents may be expressed as sine functions of the time, and if there is an appreciable lag between the currents in the two coils, the point R describes an ellipse round O as centre. In this case the line O R representing the resultant field revolves round the centre O, the direction and magnitude of the resultant field changing at every instant. If, however, there is no lag between the two currents—that is to say, if they pass through zero simultaneously—the direction of the resultant field O R remains stationary, and the point R performs harmonic oscillation over the line R O and its prolongation with O as centre. This may be considered as a special case of the ellipse where the latter has been flattened down to a mathematical line. Another special case occurs when the ellipse becomes a circle, and this must evidently take place when the lag between the two currents is 90°, when the coils are at right angles to each other, and when the component fields are equally strong. A metallic body suspended in the centre of the two fields, and free to revolve, must evidently have a tendency to participate in the rotation of the resultant field.

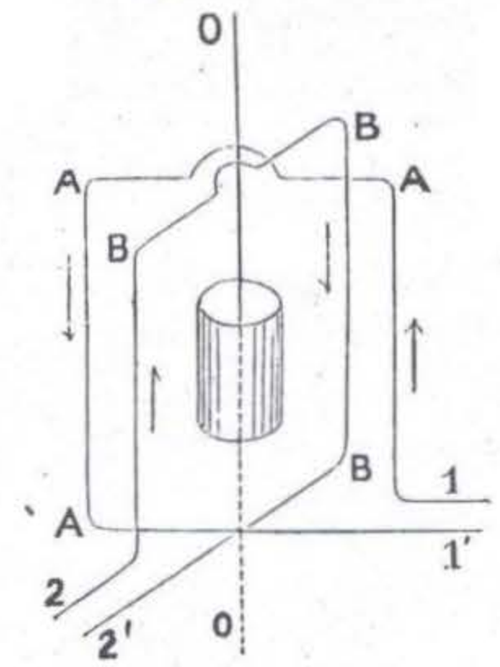


FIG. 2.

The application of this very simple principle will be clear from Fig. 2, in which the two coils are indicated by the rectangles A and B, the connections being made by the wires 1 1^1 and 2 2^1 respectively. When alternating currents are

* Abstracted from a pamphlet recently issued by Signor Ferraris. We have also availed ourselves of an excellent abstract which appeared in *Industries* of May 18th.

sent through these coils a resultant field is produced, which revolves round the line O O. In the centre between the coils is suspended a small hollow cylinder of copper, and as the lines of the resultant field cut the metal Foucault currents are induced, and by the interaction of these induced currents and the revolving field the cylinder is set in rotation. The action is exactly the reverse of that occurring in the well-known experiment in which a copper disc is rapidly revolved below a compass needle, with the result that the compass needle is deflected on account of the induced currents in the copper disc, and ultimately caused to rotate with the copper disc.

Up to the present we have spoken of two distinct currents being required in the coils A and B, one lagging behind the other by a quarter period; and to perform the experiment we might employ an alternating-current dynamo with two circuits in the armature, so arranged with regard to each other as to produce the desired lag. It is, however, possible to perform the experiment by using an ordinary alternating-current machine with only one circuit on the armature, and to produce the second current by means of a transformer. The current from the machine is sent through the primary of the transformer and then through the coil A, whilst the secondary current obtained from the transformer is sent through the coil B. It is then possible, by the interposition of a suitable inert resistance into the secondary circuit, to obtain very nearly the desired lag of 90° between the currents in the two coils. As the strength of the secondary current will, by the insertion of the resistance, be considerably reduced, it is necessary in order to obtain approximately equal fields from the two coils to employ a larger number of turns in the coil B than in A. Another method of producing the desired result consists in using a transformer with one primary and two secondary coils, and to insert into the circuit of one of the secondary coils a large self-induction, and into that of the other a large inert resistance, by which means the desired lag between the two secondary currents can also be obtained. It will be seen that in either of these ways it is possible, by means of a simple alternating current and a transformer, the coils of which are abreast, to obtain a revolving magnetic-field of approximately uniform intensity, by which phenomena can be produced in every respect similar to those obtainable from a revolving permanent steel magnet.

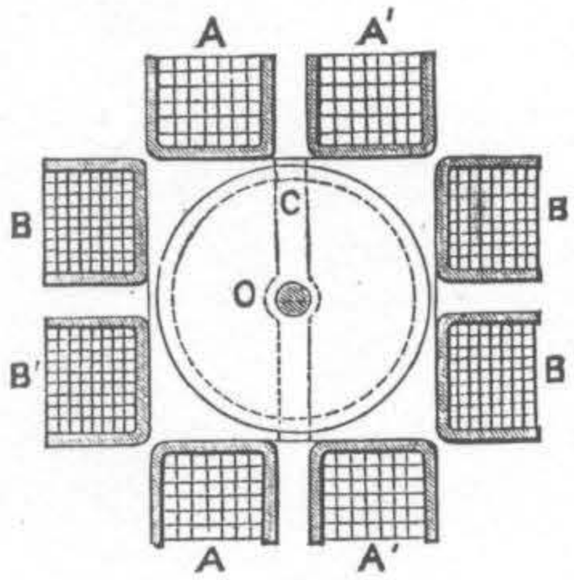


FIG. 3.

In the first experiment made by Prof. Ferraris, a Gaulard and Gibbs transformer, with an equal number of turns in the primary and secondary coils, was used. In the primary circuit was included the coil A, consisting of a few turns of stout wire, whilst in the secondary circuit were included an adjustable and non-inductive resistance and the coil B, the latter consisting of many turns of fine wire. A small hollow copper cylinder was suspended on a thread in the centre of the two coils, as shown in Fig. 2. If the current was sent through only one of the coils, the cylinder remained at rest; but if currents were sent through both coils, the cylinder immediately started to revolve, twisting the thread on which it was suspended. A reversing switch was inserted in the secondary circuit, and if the current through this circuit was inverted, the cylinder was immediately brought to rest, and started in the opposite direction. Prof. Ferraris next substituted a small iron cylinder for the copper one, and found equal results; but when using an iron cylinder sufficiently large to nearly fill the place within the coils, the experiment did not succeed so well. He attributes this to the greater self-induction which the presence of iron in a large mass necessarily introduces into both circuits. Another experiment was made with a small iron cylinder, composed of a number of thin discs insulated from each other, and this experiment also succeeded. Foucault currents could not in this case be the cause of rotation, and Prof. Ferraris thinks that the rotation is due to hysteresis. A larger apparatus was then constructed, which is indicated in our sketch (Fig. 3). In this case the copper cylinder, which was mounted upon a horizontal axis in bearings, had a diameter of 3½in., and was 7in. long, its weight being 11lb. This cylinder was closely surrounded by the primary and secondary coils wound upon wooden bobbins. To make room for the shaft each coil was in halves, the primary consisting of ninety-six turns of seventy-seven mils. wire, both coupled in series, so as to produce the effect of a coil of 192 turns; the secondary consisting of 504 turns of thirty-eight mils. wire, both being coupled in parallel, so as to produce the effect of 504 turns. The resistance of the primary coils was 7·12 and 6·63 ohms respectively, and that of the two secondary coils coupled in parallel was 3·43 ohms. In the secondary circuit was also inserted a rheostat without self-induction, and the best results were obtained when the rheostat was set to between 15 and 18 ohms. A Gaulard and Gibbs transformer was used, giving eighty reversals per second. The copper cylinder began to revolve when the primary current was 5 amperes, and with higher currents the velocity could be increased to 900 revolutions per minute, and might have been still further increased but for the somewhat imperfect mechanical arrangements, which occasioned considerable vibrations. To the shaft was applied a small friction dynamometer, and the following table gives the work obtained on the brake by a primary current of nine amperes at different speeds:—

Revolutions per minute.....	262	430	516	653	722	770	900
Watts obtained on brake ...	1·32	2·12	2·65	2·77	2·55	2·40	0

The maximum energy was obtained at 650 revolutions. Beyond that speed the energy decreased, which is attributed by Prof. Ferraris to the imperfect mechanical arrangement of the apparatus, causing a considerable waste of power in vibrations. If it were not for this, the maximum energy would have been obtained at about 1,200 revolutions, whilst at 2,400 revolutions, which is the speed of the revolving resultant field, no energy at all could be obtained. Prof. Ferraris suggests that this apparatus may be used for lecture purposes, and as a motor when the power required is small, and it may also be used as an electricity meter. The torque exerted by the revolving field upon the copper cylinder is proportional to the square of the current, and in order that the total number of revolutions performed in a given time may be an indication of the number of coulombs supplied, it is necessary to introduce some opposing force which varies with the square of the velocity. If this can be done, and if the friction of the journals can be sufficiently reduced, an ordinary counter attached to the axis would indicate the quantity of electricity supplied.

NOTE ON THE TESLA ALTERNATING CURRENT MOTOR.

BY DR. LOUIS DUNCAN, JOHNS HOPKINS UNIVERSITY.

To the Editor of Electrical Review:

The Tesla alternating current electro-motor has attracted so much notice in the last week or so—a paper describing it having been read before the Boston Society of Arts, another before the American Institute of Electrical Engineers, and a description in the Electrical Review—that one is naturally led to inquire as to its possible advantages. The description published in this journal is the only one I have seen, and if one is to accept literally the statement contained in it, the Tesla motor has an unprecedented field of usefulness.

We may, for our present purposes, divide motors into two classes: Continuous, in which the armature coils are unsymmetrical with respect to the poles, and which, therefore, give a practically constant torque, and alternating motors, in which the armature coils are symmetrical with respect to the poles, and which, therefore, give a torque varying both in magnitude and sign during a period of the counter E. M. F. The Tesla motor belongs to this latter class.

In every motor the torque is equal to the rate of change of lines of induction through the armature circuit for a small angular displacement, multiplied by the armature current, or

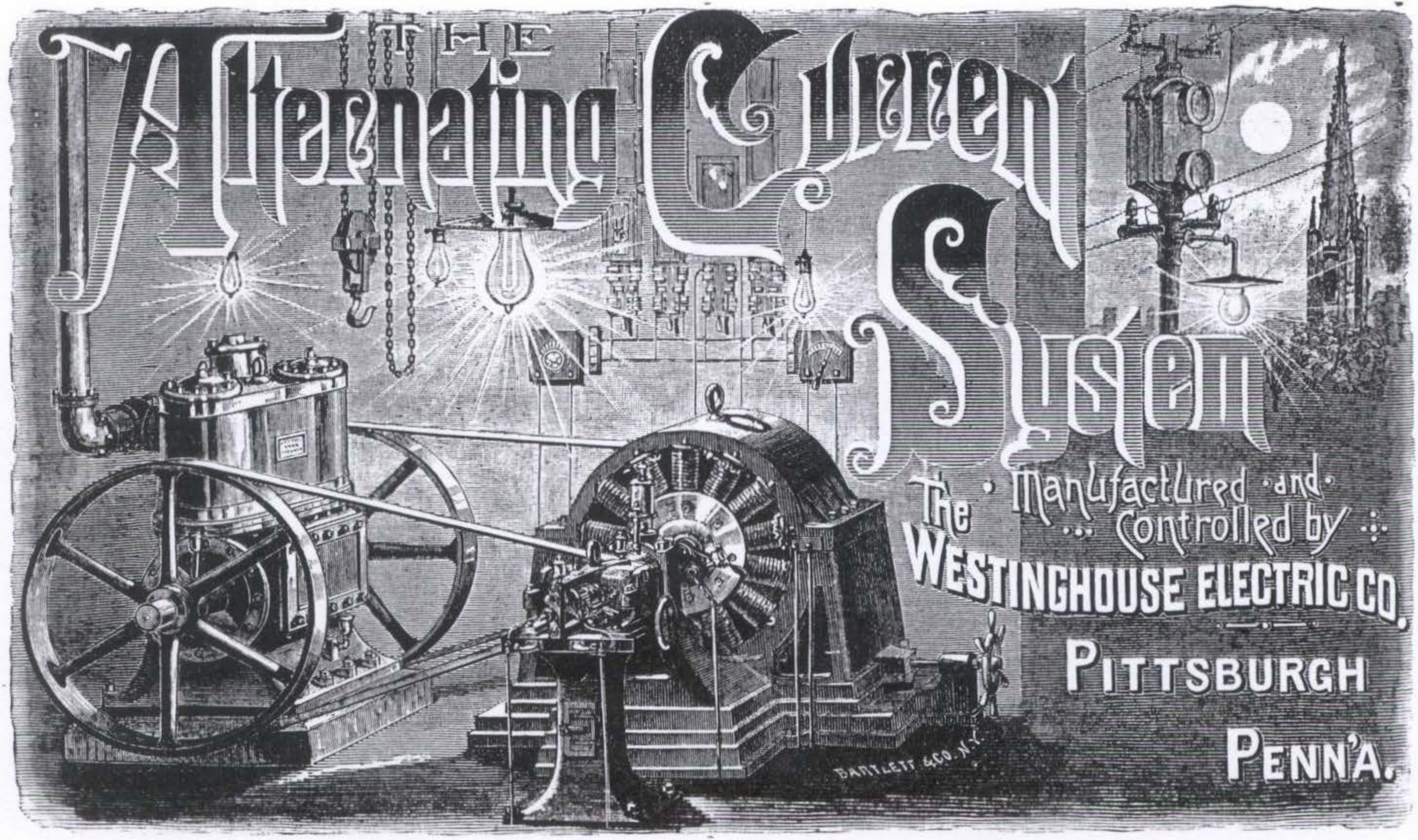
$$\frac{dm}{dt} \, I$$

In the Tesla motor the first of these terms is greatest when the coil is opposite a pole and the field currents have their greatest amplitude; it is zero at a point about 45° from this, supposing we neglect armature reactions. It depends on several things; the E.M.F. which determines it is due to changes in the number of lines of force passing through the armature circuit caused by (1) changes in the field currents; (2) the motion of the armature. The current depends on these E. M. Fs., and on the reduced self-induction and resistance of its circuit. The motor can only do work when the first cause of E. M. F. is the greater, for a current in the direction of the ordinary counter E. M. F. would stop the motion. In some parts of a revolution the two E. M. Fs. work together, retarding the motion; in others, the induced E. M. F. produces a current causing the motor to revolve. It is impossible for me, with only a meagre description of the principles of the machine to give an idea of the relative magnitudes of these effects. Some of the results however are the following: Having given a definite number of reversals of the dynamo, there are a number of speeds, multiples of these reversals, at which the motor will govern itself when it is doing a certain amount of work. At one of these speeds, depending on the construction of the motor, the output will be a maximum. Now I see the statement that "there is no difficulty whatever attendant upon starting the motor under load." I cannot reconcile this with above facts. That the torque for a smaller number of revolutions than ordinarily used, might be greater, one can readily see, since the counter E. M. F. is less in proportion to the induced E. M. F., but it must be remembered that for certain speeds, even the induced current, would tend to stop the motion; how the motor is to pass these critical speeds I do not see. Again, if the maximum load is suddenly thrown on while the motor is running at its proper speed. Then, if the inertia be great the motor will fall behind its point of maximum work and either stop or take up some slower speed.

What the possible efficiency and output of the motor may be only experiment can tell. I have shown* that the output of an ordinary alternating motor is equal to that of a continuous current motor, supplied with a corresponding E. M. F. The efficiency might be great, but it has the disadvantage that about the same current flows for no work and maximum work, so for light loads the efficiency can hardly be very high.

With our present knowledge of alternating currents, it is useless to attempt to calculate from the simple though misleading assumptions ordinarily made, the output, conditions of maximum work, etc., of this machine. Experiment alone can determine its value, and one properly conducted and interpreted set of experiments should enable us to judge both the merit of the invention and its best possible form. I cannot see, however, how, in the form described in the last issue of this journal, the motor can work under conditions of a suddenly varying load as satisfactorily as continuous current motors.

* Inst. Elec. Eng'rs, February, 1888.


THE
Alternating Current
System
Manufactured and Controlled by
The WESTINGHOUSE ELECTRIC CO.
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A NEW SYSTEM OF ALTERNATE CURRENT MOTORS AND TRANSFORMERS.[1]

BY NIKOLA TESLA.

In the presence of the existing diversity of opinion regarding the relative merits of the alternate and continuous current systems, great importance is attached to the question whether alternate currents can be successfully utilized in the operation of motors. The transformers, with their numerous advantages, have afforded us a relatively perfect system of distribution, and although, as in all branches of the art, many improvements are desirable, comparatively little remains to be done in this direction. The transmission of power, on the contrary, has been almost entirely confined to the use of continuous currents, and notwithstanding that many efforts have been made to utilize alternate currents for this purpose, they have, up to the present, at least as far as known, failed to give the result desired. Of the various motors adapted to be used on alternate current circuits the following have been mentioned: 1. A series motor with subdivided field. 2. An alternate current generator having its field excited by continuous currents. 3. Elihu Thomson's motor. 4. A combined alternate and continuous current motor. Two more motors of this kind have suggested themselves to me. 1. A motor with one of its circuits in series with a transformer and the other in the secondary of the transformer. 2. A motor having its armature circuit connected to the generator and the field coils closed upon themselves. These, however, I mention only incidentally.

The subject which I now have the pleasure of bringing to your notice is a novel system of electric distribution and transmission of power by means of alternate currents, affording peculiar advantages, particularly in the way of motors, which I am confident will at once establish the superior adaptability of these currents to the transmission of power and will show that many results heretofore unattainable can be reached by their use; results which are very much desired in the practical operation of such systems and which cannot be accomplished by means of continuous currents.

Before going into a detailed description of this system, I think it necessary to make a few remarks with reference to certain conditions existing in continuous current generators and motors, which, although generally known, are frequently disregarded.

In our dynamo machines, it is well known, we generate alternate currents which we direct by means of a commutator, a complicated device and, it may be justly said, the source of most of the troubles experienced in the operation of the machines. Now, the currents so directed cannot be utilized in the motor, but they must—again by means of a similar unreliable device—be reconverted into their original state of alternate currents. The function of the commutator is entirely external, and in no way does it affect the internal working of the machines. In reality, therefore, all machines are alternate current machines, the

1. Read before the American Institute of Electrical Engineers, May 16, 1888.

currents appearing as continuous only in the external circuit during their transit from generator to motor. In view simply of this fact, alternate currents would commend themselves as a more direct application of electrical energy, and the employment of continuous currents would only be justified if we had dynamos which would primarily generate, and motors which would be directly actuated by such currents.

But the operation of the commutator on a motor is twofold; firstly, it reverses the currents through the motor, and secondly, it effects, automatically, a progressive shifting of the poles of one of its magnetic constituents. Assuming, therefore, that both of the useless operations in the system, that is to say, the directing of the alternate currents on the generator and reversing the direct currents on the motor, be eliminated, it would still be necessary, in order to cause a rotation of the motor, to produce a progressive shifting of the poles of one of its elements, and

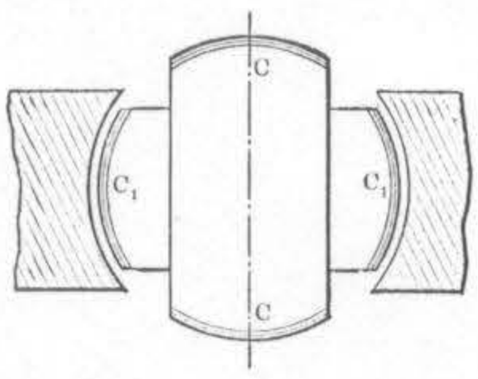

Fig. 1.

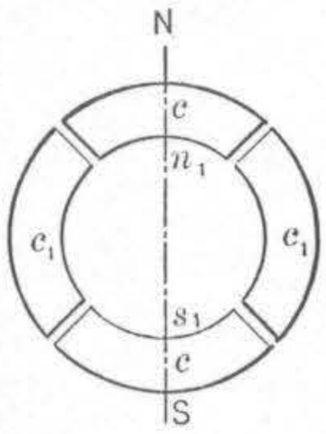

Fig. 1a.

the question presented itself,—How to perform this operation by the direct action of alternate currents? I will now proceed to show how this result was accomplished.

In the first experiment a drum-armature was provided with two coils at right angles to each other, and the ends of these coils were connected to two pairs of insulated contact-rings as usual. A ring was then made of thin insulated plates of sheet-iron and wound with four coils, each two opposite coils being connected together so as to produce free poles on diametrically opposite sides of the ring. The remaining free ends of the coils were then connected to the contact-rings of the generator armature so as to form two independent circuits, as indicated in figure 9.

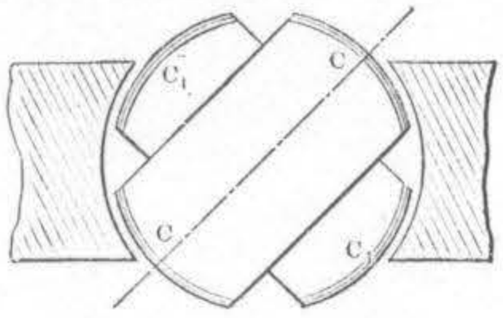

Fig. 2.

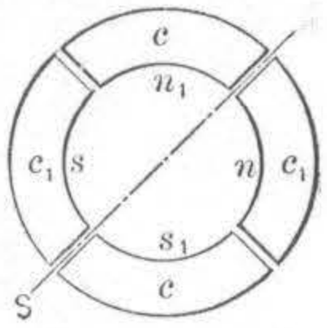

Fig. 2 a.

It may now be seen what results were secured in this combination, and with this view I would refer to the diagrams, figures 1 to 8*a*. The field of the generator being independently excited, the rotation of the armature sets up currents in the coils c c, varying in strength and direction in the well-known manner. In the position shown in figure 1 the current in coil c is nil while coil C_1 is traversed by its maximum current, and the connections may be such that the ring is magnetized by the coils c_1 c_1 as indicated by the letters N S in figure 1*a*, the magnetizing effect of the coils *c c* being nil, since these coils are included in the circuit of coil c.

In figure 2 the armature coils are shown in a more advanced position, one-eighth of one revolution being completed. Figure 2*a* illustrates the corresponding magnetic condition of the ring. At this moment the coil C_1 generates a current of the same direction as previously, but weaker, producing the poles n_1 s_1 upon the ring; the coil c also generates a current of the same direction, and the connections may be such that the coils *c c* produce the poles *n s*, as shown in figure 2*a*. The resulting polarity is indicated by the letters N S, and it will be observed that the poles of the ring have been shifted one-eighth of the periphery of the same.

In figure 3 the armature has completed one-quarter of

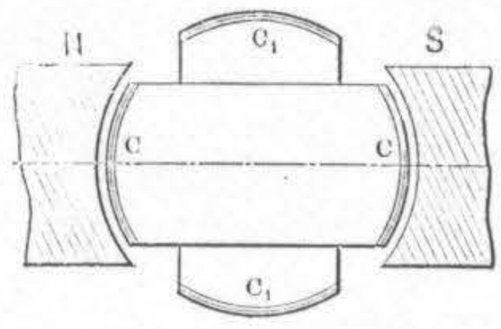

Fig. 3.

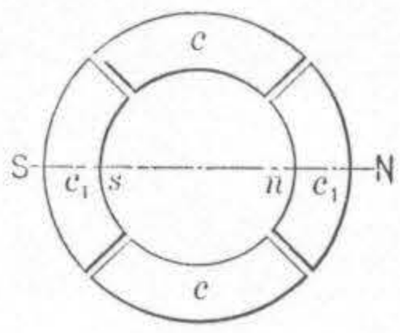

Fig. 3 a.

one revolution. In this phase the current in coil c is maximum, and of such direction as to produce the poles N S in figure 3*a*, whereas the current in coil C_1 is nil, this coil being at its neutral position. The poles N S in figure 3*a* are thus shifted one-quarter of the circumference of the ring.

Figure 4 shows the coils c c in a still more advanced position, the armature having completed three-eighths of one revolution. At that moment the coil c still generates a current of the same direction as before, but of less strength, producing the comparatively weaker poles *n s* in figure 4*a*. The current in the coil C_1 is of the same strength, but of opposite direction. Its effect is, therefore, to produce upon the ring the poles n_1 and s_1 as indicated, and a polarity, N

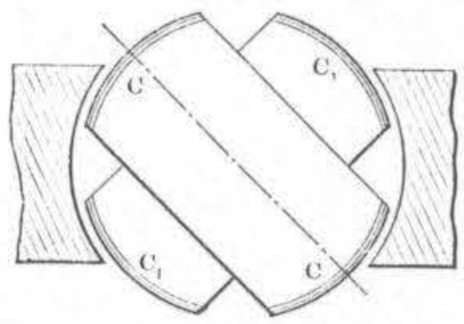

Fig. 4.

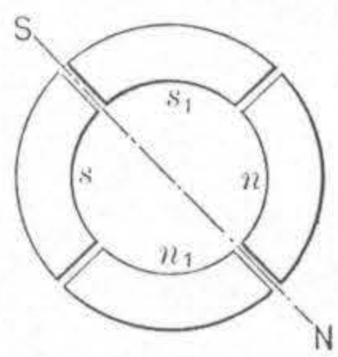

Fig. 4 a.

s, results, the poles now being shifted three-eighths of the periphery of the ring.

In figure 5 one-half of one revolution of the armature is completed, and the resulting magnetic condition of the ring is indicated in figure 5*a*. Now, the current in coil c is nil, while the coil C_1 yields its maximum current, which is of the same direction as previously; the magnetizing effect is, therefore, due to the coils c_1 c_1 alone, and, referring to figure 5*a*, it will be observed that the poles N S are shifted one-half of the circumference of the ring. During the next half revolution the operations are repeated, as represented in the figures 6 to 8*a*.

A reference to the diagrams will make it clear that during one revolution of the armature the poles of the ring

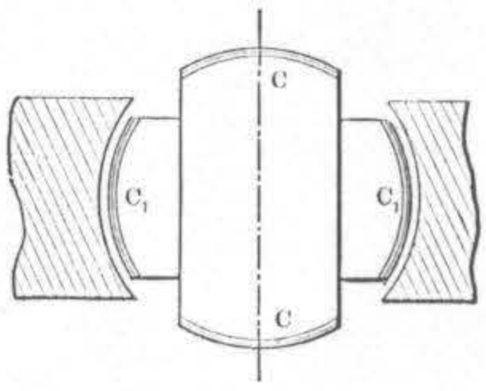

Fig. 5.

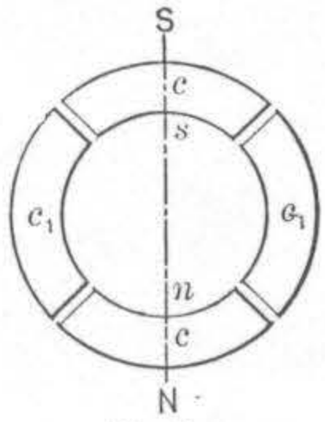

Fig. 5 a.

are shifted once around its periphery, and each revolution producing like effects, a rapid whirling of the poles in harmony with the rotation of the armature is the result. If the connections of either one of the circuits in the ring are reversed, the shifting of the poles is made to progress in the opposite direction, but the operation is identically

the same. Instead of using four wires, with like result, three wires may be used, one forming a common return for both circuits.

This rotation or whirling of the poles manifests itself in a series of curious phenomena. If a delicately pivoted disc of steel or other magnetic metal is approached to the ring it is set in rapid rotation, the direction of rotation varying with the position of the disc. For instance, noting the direction outside of the ring it will be found that inside the ring it turns in an opposite direction, while it is unaffected if placed in a position symmetrical to the ring. This is easily explained. Each time that a pole approaches it induces an opposite pole in the nearest point on the disc, and an attraction is produced upon that point; owing to this, as the pole is shifted further away from the disc a tangential pull is exerted upon the same, and the action being constantly repeated, a more or less rapid rotation of the disc is the result. As the pull is exerted mainly upon

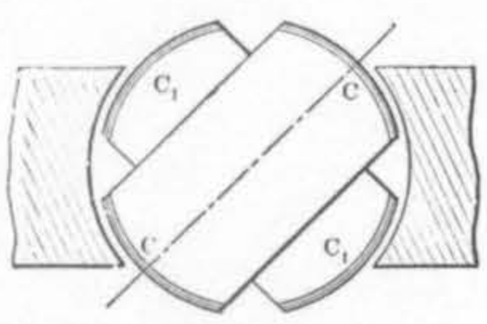

Fig. 6.

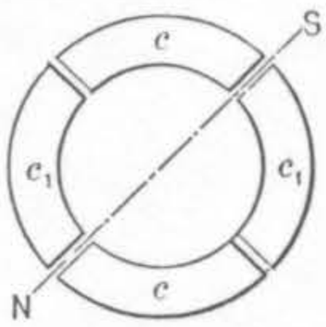

Fig. 6 a.

that part which is nearest to the ring, the rotation outside and inside, or right and left, respectively, is in opposite directions, figure 9. When placed symmetrically to the ring, the pull on opposite sides of the disc being equal, no rotation results. The action is based on the magnetic inertia of the iron; for this reason a disc of hard steel is much more affected than a disc of soft iron, the latter being capable of very rapid variations of magnetism. Such a disc has proved to be a very useful instrument in all these investigations, as it has enabled me to detect any irregularity in the action. A curious effect is also produced upon iron filings. By placing some upon a paper and holding them externally quite close to the ring they are set in a vibrating motion, remaining in the same place, although the paper may be moved back and forth; but in lifting the paper to a certain height which seems to be dependent on the intensity of the poles and the speed of rotation, they are thrown away in a direction always opposite to the supposed movement of the poles. If a paper with filings is put flat upon the ring and the current turned on suddenly, the existence of a magnetic whirl may be easily observed.

To demonstrate the complete analogy between the ring and a revolving magnet, a strongly energized electro-magnet was rotated by mechanical power, and phenomena identical in every particular to those mentioned above were observed.

Obviously, the rotation of the poles produces corresponding inductive effects and may be utilized to generate cur-

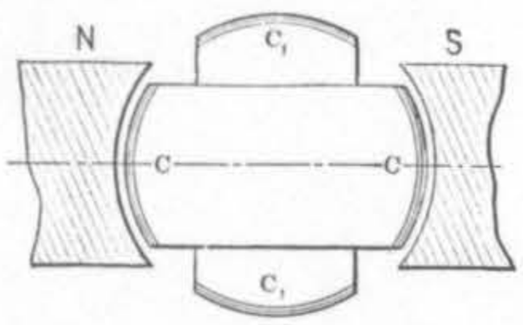

Fig. 7.

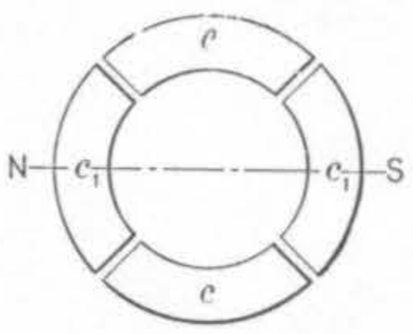

Fig. 7 a.

rents in a closed conductor placed within the influence of the poles. For this purpose it is convenient to wind a ring with two sets of superimposed coils forming respectively the primary and secondary circuits, as shown in figure 10. In order to secure the most economical results the magnetic circuit should be completely closed, and with this object in view the construction may be modified at will.

The inductive effect exerted upon the secondary coils will be mainly due to the shifting or movement of the magnetic action; but there may also be currents set up in

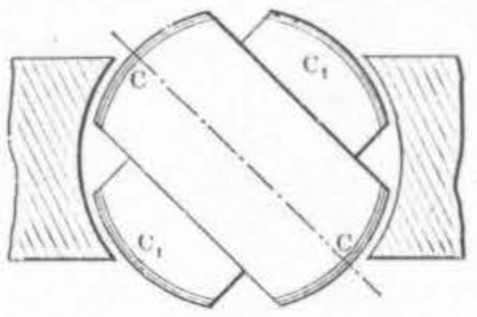

Fig. 8.

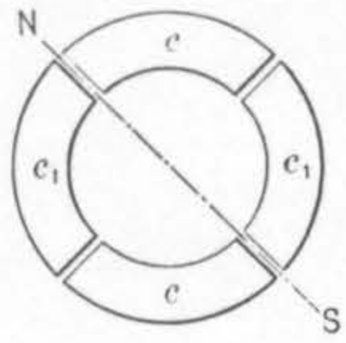

Fig. 8 a.

the circuits in consequence of the variations in the intensity of the poles. However, by properly designing the generator and determining the magnetizing effect of the primary coils, the latter element may be made to disappear. The intensity of the poles being maintained constant, the action of the apparatus will be perfect, and the same result will be secured as though the shifting were effected by means of a commutator with an infinite number of bars. In such case the theoretical relation between the energizing effect of each set of primary coils and their resultant magnetizing effect may be expressed by the equation of a circle having its centre coinciding with that of an orthogonal system of axes, and in which the radius represents the resultant and the co-ordinates both of its components. These are then respectively the sine and cosine of the angle a between the radius and one of the axes (OX). Referring to figure 11, we have $r^2 = x^2 + y^2$; where $x = r \cos \alpha$, and $y = r \sin \alpha$.

Assuming the magnetizing effect of each set of coils in the transformer to be proportional to the current—which

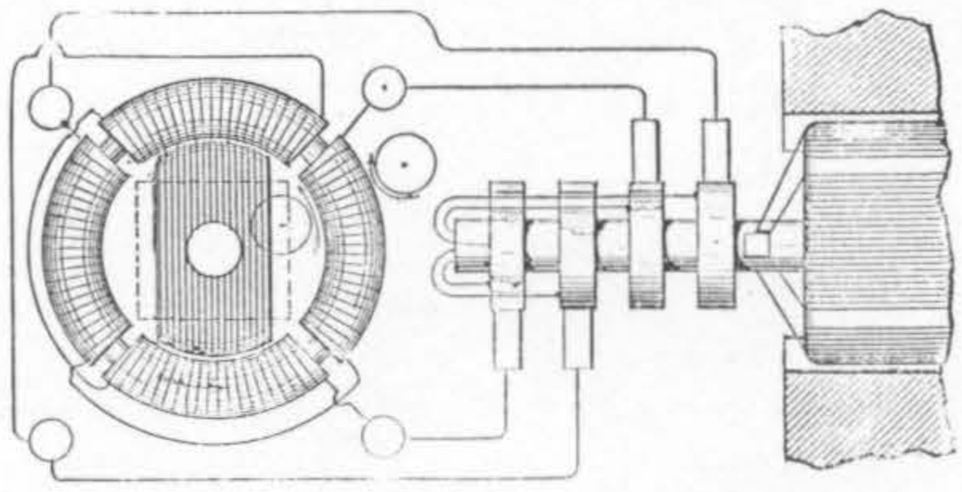

Fig. 9.

may be admitted for weak degrees of magnetization—then $x = Kc$ and $y = Kc^1$, where K is a constant and c and c^1 the current in both sets of coils respectively. Supposing, further, the field of the generator to be uniform, we have for constant speed $c^1 = K^1 \sin \alpha$ and $c = K^1 \sin (90° + \alpha)$ $= K^1 \cos \alpha$, where K^1 is a constant. See figure 12.

Therefore, $x = Kc = KK^1 \cos \alpha$;
$y = Kc^1 = KK^1 \sin \alpha$, and
$KK^1 = r$.

That is, for a uniform field the disposition of the two coils at right angles will secure the theoretical result, and the intensity of the shifting poles will be constant. But from $r^2 = x^2 + y^2$ it follows that for $y = 0$, $r = x$; it follows that the joint magnetizing effect of both sets of coils should be equal to the effect of one set when at its maximum action. In transformers and in a certain class of motors the fluctuation of the poles is not of great importance, but in another class of these motors it is desirable to obtain the theoretical result.

In applying this principle to the construction of motors, two typical forms of motor have been developed. First, a form having a comparatively small rotary effort at the start, but maintaining a perfectly uniform speed at all

loads, which motor has been termed synchronous. Second, a form possessing a great rotary effort at the start, the speed being dependent on the load.

These motors may be operated in three different ways: 1. By the alternate currents of the source only. 2. By a combined action of these and of induced currents. 3. By the joint action of alternate and continuous currents.

The simplest form of a synchronous motor is obtained by winding a laminated ring provided with pole projections with four coils, and connecting the same in the manner before indicated. An iron disc having a segment cut away on each side may be used as an armature. Such a motor is shown in figure 9. The disc being arranged to rotate freely within the ring in close proximity to the projections, it is evident that as the poles are shifted it will, owing to its tendency to place itself in such a position as to embrace the greatest number of the lines of force, closely follow the movement of the poles, and its motion will be synchronous with that of the armature of the generator; that is, in the peculiar disposition shown in figure 9, in which the armature produces by one revolution two current impulses in each of the circuits. It is evident that if, by one revolution of the armature, a greater number of impulses is produced, the speed of the motor will be correspondingly increased. Considering that the attraction exerted upon the disc is greatest when the same is in close proximity to the

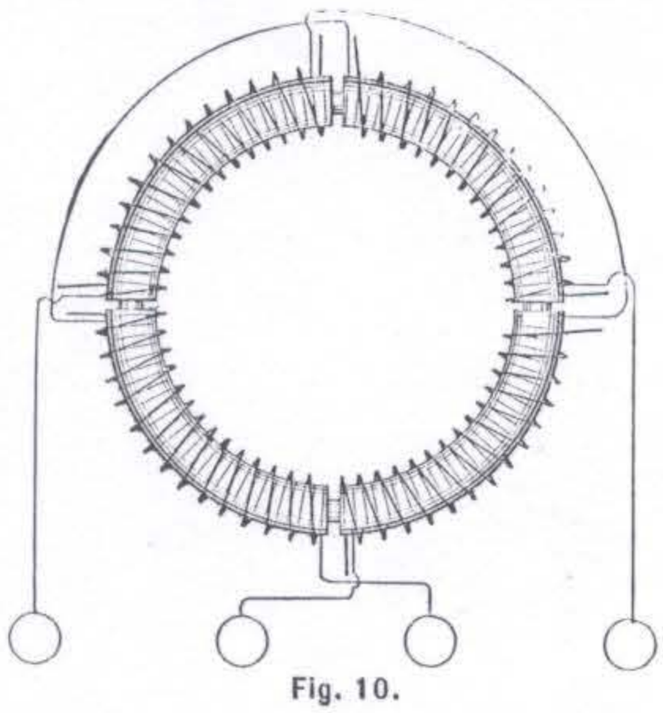

Fig. 10.

poles, it follows that such a motor will maintain exactly the same speed at all loads within the limits of its capacity.

To facilitate the starting, the disc may be provided with a coil closed upon itself. The advantage secured by such a coil is evident. On the start the currents set up in the coil strongly energize the disc and increase the attraction exerted upon the same by the ring, and currents being generated in the coil as long as the speed of the armature is inferior to that of the poles, considerable work may be performed by such a motor even if the speed be below normal. The intensity of the poles being constant, no currents will be generated in the coil when the motor is turning at its normal speed.

Instead of closing the coil upon itself, its ends may be connected to two insulated sliding rings, and a continuous current supplied to these from a suitable generator. The proper way to start such a motor is to close the coil upon itself until the normal speed is reached, or nearly so, and then turn on the continuous current. If the disc be very strongly energized by a continuous current the motor may not be able to start, but if it be weakly energized, or generally so that the magnetizing effect of the ring is preponderating it will start and reach the normal speed. Such a motor will maintain absolutely the same speed at all loads. It has also been found that if the motive power of the generator is not excessive, by checking the motor the speed of the generator is diminished in synchronism with that of the motor. It is characteristic of this form of motor that it cannot be reversed by reversing the continuous current through the coil.

The synchronism of these motors may be demonstrated experimentally in a variety of ways. For this purpose it is best to employ a motor consisting of a stationary field magnet and an armature arranged to rotate within the same, as indicated in figure 13. In this case the shifting of the poles of the armature produces a rotation of the latter in the opposite direction. It results therefrom that when the normal speed is reached, the poles of the armature assume fixed positions relatively to the field magnet and the same

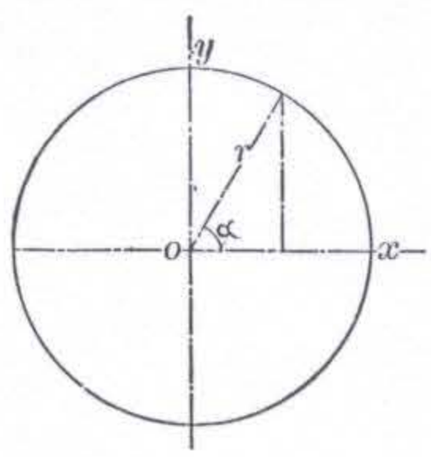

Fig. 11.

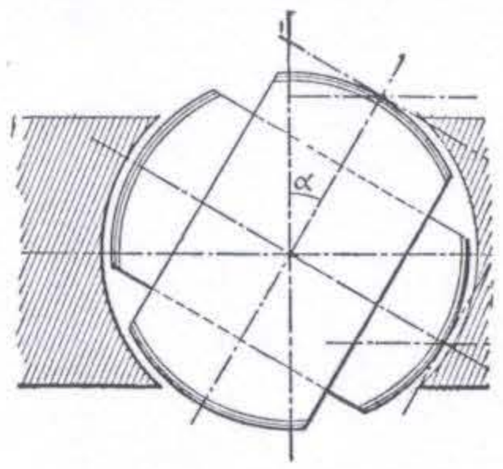

Fig. 12.

is magnetized by induction, exhibiting a distinct pole on each of the pole-pieces. If a piece of soft iron is approached to the field magnet it will at the start be attracted with a rapid vibrating motion produced by the reversals of polarity of the magnet, but as the speed of the armature increases the vibrations become less and less frequent and finally entirely cease. Then the iron is weakly but permanently attracted, showing that the synchronism is reached and the field magnet energized by induction.

The disc may also be used for the experiment. If held quite close to the armature it will turn as long as the speed of rotation of the poles exceeds that of the armature; but when the normal speed is reached, or very nearly so, it ceases to rotate and is permanently attracted.

A crude but illustrative experiment is made with an incandescent lamp. Placing the lamp in circuit with the continuous current generator, and in series with the magnet coil, rapid fluctuations are observed in the light in consequence of the induced currents set up in the coil at the start; the speed increasing, the fluctuations occur at longer intervals, until they entirely disappear, showing that the motor has attained its normal speed.

A telephone receiver affords a most sensitive instrument; when connected to any circuit in the motor the synchronism may be easily detected on the disappearance of the induced currents.

In motors of the synchronous type it is desirable to

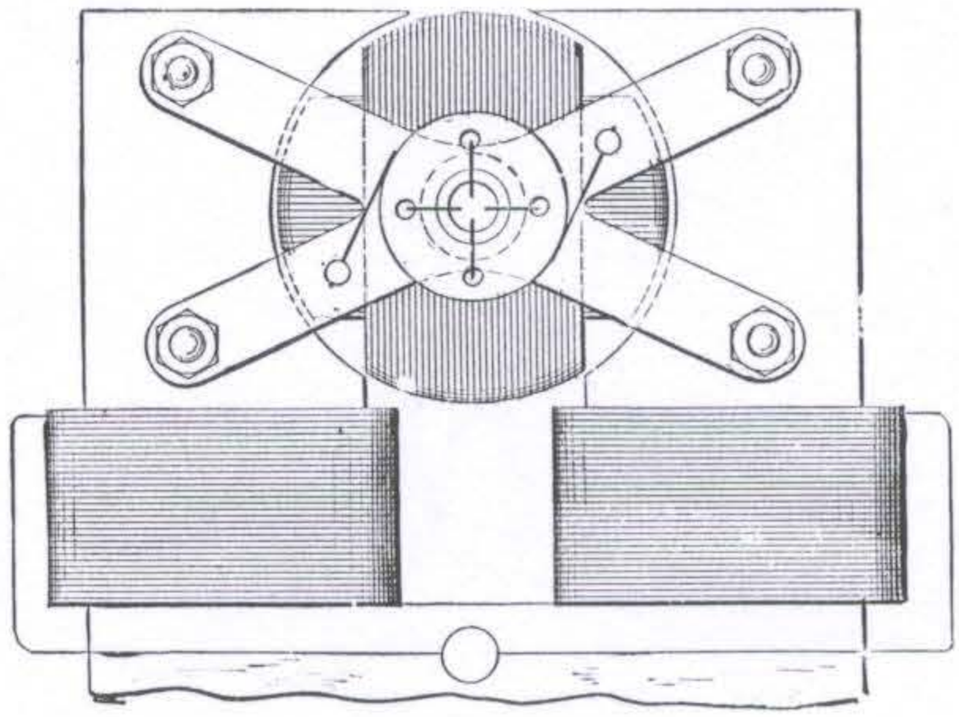

Fig. 13.

maintain the quantity of the shifting magnetism constant, especially if the magnets are not properly subdivided.

To obtain a rotary effort in these motors was the subject of long thought. In order to secure this result it was necessary to make such a disposition that while the poles of one element of the motor are shifted by the alternate

currents of the source, the poles produced upon the other element should always be maintained in the proper relation to the former, irrespective of the speed of the motor. Such a condition exists in a continuous current motor; but in a synchronous motor, such as described, this condition is fulfilled only when the speed is normal.

The object has been attained by placing within the ring a properly subdivided cylindrical iron core wound with several independent coils closed upon themselves. Two coils at right angles as in figure 14, are sufficient, but a greater number may be advantageously employed. It results from this disposition that when the poles of the ring are shifted, currents are generated in the closed armature coils. These currents are the most intense at or near the points of the greatest density of the lines of force, and their effect is to produce poles upon the armature at right angles to those of the ring, at least theoretically so; and since this action is entirely independent of the speed—that is, as far as the location of the poles is concerned—a continuous pull is exerted upon the periphery of the armature. In many respects these motors are similar to the continuous current motors. If load is put on, the speed, and also the resistance of the motor, is diminished and more current is made to pass through the energizing coils, thus increasing the effort. Upon the load being taken off, the counter-electromotive force increases and less current passes through the primary or energizing coils. Without any load the speed is very nearly equal to that of the shifting poles of the field magnet.

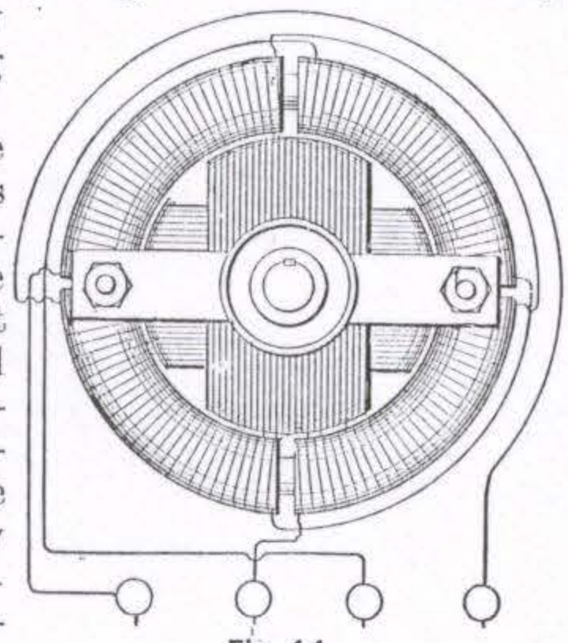

Fig. 14.

It will be found that the rotary effort in these motors fully equals that of the continuous current motors. The effort seems to be greatest when both armature and field magnet are without any projections; but as in such dispositions the field cannot be very concentrated, probably the best results will be obtained by leaving pole projections on one of the elements only. Generally, it may be stated that the projections diminish the torque and produce a tendency to synchronism.

A characteristic feature of motors of this kind is their capacity of being very rapidly reversed. This follows from the peculiar action of the motor. Suppose the armature to be rotating and the direction of rotation of the poles to be reversed. The apparatus then represents a dynamo machine, the power to drive this machine being the momentum stored up in the armature and its speed being the sum of the speeds of the armature and the poles. If we now consider that the power to drive such a dynamo would be very nearly proportional to the third power of the speed, for this reason alone the armature should be quickly reversed. But simultaneously with the reversal another element is brought into action, namely, as the movement of the poles with respect to the armature is reversed, the motor acts like a transformer in which the resistance of the secondary circuit would be abnormally diminished by producing in this circuit an additional electromotive force. Owing to these causes the reversal is instantaneous.

If it is desirable to secure a constant speed, and at the same time a certain effort at the start, this result may be easily attained in a variety of ways. For instance, two armatures, one for torque and the other for synchronism, may be fastened on the same shaft, and any desired preponderance may be given to either one, or an armature may be wound for rotary effort, but a more or less pronounced tendency to synchronism may be given to it by properly constructing the iron core; and in many other ways.

As a means of obtaining the required phase of the currents in both the circuits, the disposition of the two coils at right angles is the simplest, securing the most uniform action; but the phase may be obtained in many other ways, varying with the machine employed. Any of the dynamos at present in use may be easily adapted for this

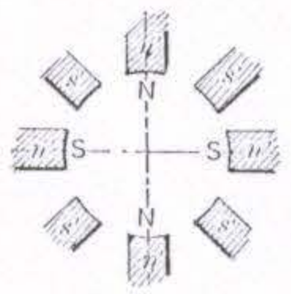

Fig. 15.

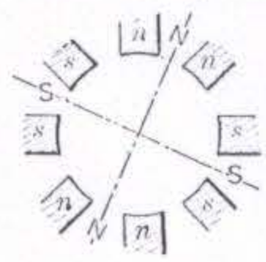

Fig. 16.

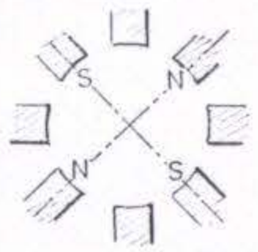

Fig. 17.

purpose by making connections to proper points of the generating coils. In closed circuit armatures, such as used in the continuous current systems, it is best to make four derivations from equi-distant points or bars of the commutator, and to connect the same to four insulated sliding rings on the shaft. In this case each of the motor circuits is connected to two diametrically opposite bars of the commutator. In such a disposition the motor may also be operated at half the potential and on the three-wire plan, by connecting the motor circuits in the proper order to three of the contact rings.

In multipolar dynamo machines, such as used in the converter systems, the phase is conveniently obtained by winding upon the armature two series of coils in such a manner that while the coils of one set or series are at their maximum production of current, the coils of the other will be at their neutral position, or nearly so, whereby both sets of coils may be subjected simultaneously or successively to the inducing action of the field magnets.

Generally the circuits in the motor will be similarly disposed, and various arrangements may be made to fulfill the requirements; but the simplest and most practicable is to arrange primary circuits on stationary parts of the motor, thereby obviating, at least in certain forms, the employment of sliding contacts. In such a case the magnet coils are connected alternately in both the circuits; that is, 1, 3, 5.....in one, and 2, 4, 6.....in the other, and the coils of each set of series may be connected all in the same manner, or alternately in opposition; in the latter case a motor



Fig. 18.

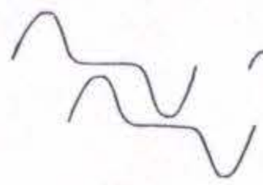

Fig. 19.

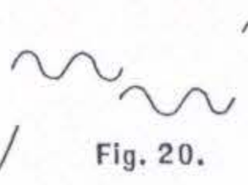

Fig. 20.

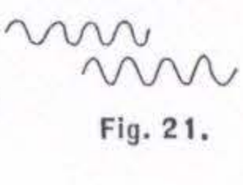

Fig. 21.

with half the number of poles will result, and its action will be correspondingly modified. The figures 15, 16 and 17, show three different phases, the magnet coils in each circuit being connected alternately in opposition. In this case there will be always four poles, as in figures 15 and 17, four pole projections will be neutral, and in figure 16 two adjacent pole projections will have the same polarity. If the coils are connected in the same manner there will be eight alternating poles, as indicated by the letters n' s' in figure 15.

The employment of multipolar motors secures in this system an advantage much desired and unattainable in the continuous current system, and that is, that a motor may be made to run exactly at a predetermined speed irrespective of imperfections in construction, of the load, and, within certain limits, of electromotive force and current strength.

In a general distribution system of this kind the following plan should be adopted. At the central station of supply a generator should be provided having a consider-

able number of poles. The motors operated from this generator should be of the synchronous type, but possessing sufficient rotary effort to insure their starting. With the observance of proper rules of construction it may be admitted that the speed of each motor will be in some inverse proportion to its size, and the number of poles should be chosen accordingly. Still exceptional demands may modify this rule. In view of this, it will be advantageous to provide each motor with a greater number of pole projections or coils, the number being preferably a multiple of two and three. By this means, by simply changing the connections of the coils, the motor may be adapted to any probable demands.

If the number of the poles in the motor is even, the action will be harmonious and the proper result will be obtained; if this is not the case the best plan to be followed is to make a motor with a double number of poles and connect the same in the manner before indicated, so that half the number of poles result. Suppose, for instance, that the generator has twelve poles, and it would be desired to obtain a speed equal to $\frac{12}{7}$ of the speed of the generator. This would require a motor with seven pole projections or magnets, and such a motor could not be properly connected in the circuits unless fourteen armature coils would be provided, which would necessitate the employment of sliding contacts. To avoid this the motor should be provided with fourteen magnets and seven connected in each circuit, the magnets in each circuit alternating among themselves. The armature should have fourteen closed coils. The action of the motor will not be quite as perfect as in the case of an even number of poles, but the drawback will not be of a serious nature.

However, the disadvantages resulting from this unsymmetrical form will be reduced in the same proportion as the number of the poles is augmented.

If the generator has, say, n, and the motor n_1 poles, the speed of the motor will be equal to that of the generator multiplied by $\frac{n}{n_1}$.

The speed of the motor will generally be dependent on the number of the poles, but there may be exceptions to this rule. The speed may be modified by the phase of the currents in the circuits or by the character of the current impulses or by intervals between each or between groups of impulses. Some of the possible cases are indicated in the diagrams, figures 18, 19, 20 and 21, which are self-explanatory. Figure 18 represents the condition generally existing, and which secures the best result. In such a case, if the typical form of motor illustrated in figure 9 is employed, one complete wave in each circuit will produce one revolution of the motor. In figure 19 the same result will be effected by one wave in each circuit, the impulses being successive; in figure 20 by four, and in figure 21 by eight waves.

By such means any desired speed may be attained; that is, at least within the limits of practical demands. This system possesses this advantage besides others, resulting from simplicity. At full loads the motors show an efficiency fully equal to that of the continuous current motors. The transformers present an additional advantage in their capability of operating motors. They are capable of similar modifications in construction, and will facilitate the introduction of motors and their adaptation to practical demands. Their efficiency should be higher than that of the present transformers, and I base my assertion on the following:—

In a transformer as constructed at present we produce the currents in the secondary circuit by varying the strength of the primary or exciting currents. If we admit proportionality with respect to the iron core the inductive effect exerted upon the secondary coil will be proportional to the numerical sum of the variations in the strength of the exciting current per unit of time; whence it follows that for a given variation any prolongation of the primary current will result in a proportional loss. In order to obtain rapid variations in the strength of the current, essential to efficient induction, a great number of undulations are employed. From this practice various disadvantages result. These are, increased cost and diminished efficiency of the generator, more waste of energy in heating the cores, and also diminished output of the transformer, since the core is not properly utilized, the reversals being too rapid. The inductive effect is also very small in certain phases, as will be apparent from a graphic representation, and there may be periods of inaction, if there are intervals between the succeeding current impulses or waves. In producing a shifting of the poles in the transformer, and thereby inducing currents, the induction is of the ideal character, being always maintained at its maximum action. It is also reasonable to assume that by a shifting of the poles less energy will be wasted than by reversals.

A New System of Alternate Current Motors and Transformers.

BY NIKOLA TESLA.—READ BEFORE THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, MAY 16, 1888.

In the presence of the existing diversity of opinion regarding the relative merits of the alternating and continuous current systems, great importance is attached to the question whether alternate currents can be successfully utilized in the operation of motors. The transformers, with their numerous advantages, have afforded us a relatively perfect system of distribution, and although, as in all branches of the art, many improvements are desirable, comparatively little remains to be done in this direction. The transmission of power, on the contrary, has been almost entirely confined to the use of continuous currents, and notwithstanding that many efforts have been made to utilize alternate currents for this purpose; they have, up to the present, at least as far as known, failed to give the result desired. Of the various motors adapted to be used on alternate current circuits the following have been

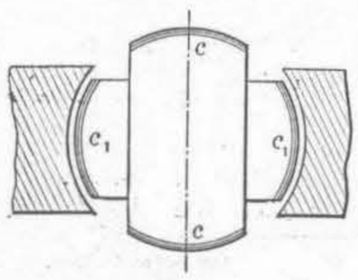

Fig. 1.

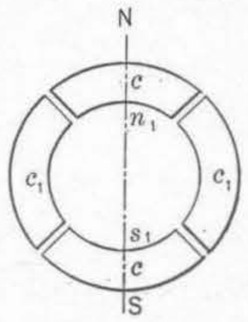

Fig. 1a.

mentioned: 1. A series motor with subdivided field. 2. An alternate current generator having its field excited by continuous currents. 3. Elihu Thomson's motor. 4. A combined alternate and continuous current motor. Two more motors of this kind have suggested themselves to me. 1. A motor with one of its circuits in series with a transformer and the other in the secondary of the transformer. 2. A motor having its armature circuit connected to the generator and the field coils closed upon themselves. These, however, I mention only incidentally.

The subject which I now have the pleasure of bringing to your notice is a novel system of electric distribution and transmission of power by means of alternate currents, affording peculiar advantages, particularly in the way of motors, which I am confident will at once establish the superior adaptability of these currents to the transmission of power, and will show that many results heretofore unattainable can be reached by their use; results which are very much desired in the practical operation of such systems, and which cannot be accomplished by means of continuous currents.

Before going into a detailed description of this system, I think it necessary to make a few remarks with reference to certain conditions existing in continuous current generators and motors, which, although generally known, are frequently disregarded.

In our dynamo machines, it is well known, we generate alternate currents, which we direct by means of a commutator, a complicated device, and, it may be justly said, the source of most of the troubles experienced in the operation of the machines. Now, the currents so directed cannot be utilized in the motor, but they must—again by means of a similar unreliable device—be reconverted into their original state of alternate currents. The function of the commutator is entirely external, and in no way does it affect the internal working of the machines. In reality, therefore, all machines are alternate current machines, the currents appearing as continuous only in the external circuit during their transit from generator to motor.

In view simply of this fact, alternate currents would commend themselves as a more direct application of electrical energy, and the employment of continuous currents would only be justified if we had dynamos which would primarily generate, and motors which would be directly actuated by such currents.

But the operation of the commutator on a motor is two-fold; firstly, it reverses the currents through the motor, and secondly, it effects, automatically, a progressive shifting of the poles of one of its magnetic constituents. Assuming, therefore, that both of the useless operations in the system, that is to say the directing of the alternate currents on the generator and reversing the direct currents on the motor, be eliminated, it would still be necessary, in order to cause a rotation of the motor, to produce a progressive shifting of the poles of one of its elements, and the question presented itself, How to perform this operation by the direct action of alternate currents? I will now proceed to show how this result was accomplished.

In the first experiment a drum-armature was provided with two coils at right angles to each other, and the ends of these coils were connected to two pairs of insulated contact-rings as usual. A ring was then made of thin insulated plates of sheet iron and wound with four coils, each two opposite coils being connected together so as to produce free poles on diametrically opposite sides of the ring. The remaining free ends of the coils were then connected to the contact-rings of the generator armature so as to form two independent circuits, as indicated in Fig. 9. It may now be seen what results were secured in this combination, and with this view I would refer to the diagrams, Figs. 1 to 8*a*. The field of the generator being independently excited, the rotation of the armature sets up currents in the coils *c c*, varying in strength and direction in the well-known manner. In the position shown in Fig. 1 the current in coil *c* is nil while coil c^1 is traversed by its maximum current, and the connections may be such that the ring is magnetized by the coils *c c*, as indicated by the letters *N S* in Fig. 1*a*, the magnetizing effect of the coils *c c* being nil, since these coils are included in the circuit of coil *c*.

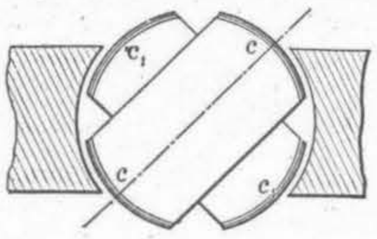

Fig. 2.

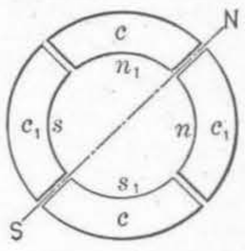

Fig. 2 a.

In Fig. 2 the armature coils are shown in a more advanced position, one-eighth of one revolution being completed. Fig. 2*a* illustrates the corresponding magnetic condition of the ring. At this moment the coil *c* generates a current of the same direction as previously, but weaker, producing the poles n_1 s_1 upon the ring; the coil *c* also generates a current of the same direction, and the connections may be such that the coils *c c* produce the poles *n s*, as shown in Fig. 2*a*. The resulting polarity is indicated by the letters *N S*, and it will be observed that the poles of the ring have been shifted one-eighth of the periphery of the same.

In Fig. 3 the armature has completed one-quarter of one revolution. In this p current in coil *C* is a maximum, and of such direction as to produce the poles *N S* in Fig. 3*a*, whereas the current in coil c_1 is nil, this coil being at its neutral position. The poles *N S* in Fig. 3*a* are thus shifted one-quarter of the circumference of the ring.

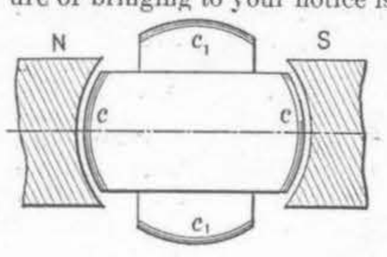

Fig. 3.

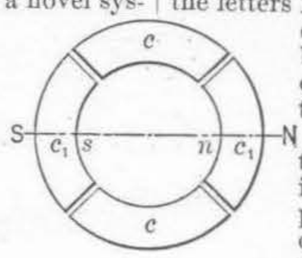

Fig. 3 a.

Fig. 4 shows the coils *c c* in a still more advanced position, the armature having completed three-eighths of one revolution. At that moment the coil *c* still generates a current of the same direction as before, but of less strength, producing the comparatively weaker poles *n s* in Fig. 4*a*. The current in the coil *c* is of the same strength, but of opposite direction. Its effect is, therefore, to produce upon the ring the poles n_1 and s_1 as indicated, and a polarity *N S* results, the poles now being shifted three-eighths of the periphery of the ring.

In Fig. 5 one-half of one revolution of the armature is completed, and the resulting magnetic condition of the ring is indicated in Fig. 5*a*. Now, the current in coil *c* is nil, while the coil *c* yields its maximum current, which is of the same direction as previously; the magnetizing effect is therefore due to the coils *c c* alone, and, referring to Fig. 5*a*, it will be observed that the poles *N S* are shifted one-half of the circumference of the ring. During the next half-revolution the operations are repeated, as represented in the Figs. 6 to 8*a*.

A reference to the diagrams will make it clear that during one revolution of the armature the poles of the ring are shifted once around its periphery, and each revolution producing like effects, a rapid whirling of the poles in harmony with the rotation of the armature is the result. If the connections of either one of the circuits in the ring are reversed, the shifting of the poles is made to progress in the opposite direction, but the operation is identically the same. Instead of using four wires, with like result, three wires may be used, one forming a common return for both circuits.

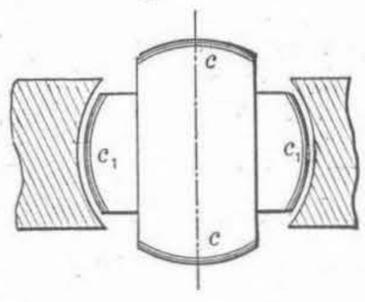

Fig. 5.

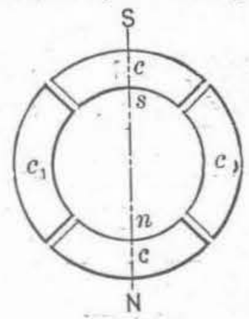

Fig. 5 a.

This rotation or whirling of the poles manifests itself in a series of curious phenomena. If a delicately pivoted disc of steel or other magnetic metal is approached to the ring it is set in rapid rotation, the direction of rotation varying with the position of the disc. For instance, noting the direction outside of the ring it will be found that inside the ring it turns in an opposite direction, while it is unaffected if placed in a position symmetrical to the ring. This is easily explained. Each time that a pole approaches it induces an opposite pole in the nearest point on the disc and an attraction is produced upon that point; owing to this, as the pole is shifted further away from the disc a tangential pull is exerted upon the same, and the action being constantly repeated, a more or less rapid rotation of the disc is the result. As the pull is exerted mainly upon that part which is nearest to the ring, the rotation outside and inside, or right and left, respectively, is in opposite directions. When placed symmetrically to the ring, the pull on opposite sides of the disc being equal, no rotation results. The action is based on the magnetic inertia of the iron; for this reason a disc of hard steel is much more affected than a disc of soft iron, the latter being capable of very rapid variations of magnetism. Such a disc has proved to be a very useful instrument in all these investigations, as it has enabled me to detect any irregularity in the action. A curious effect is also produced upon iron filings. By placing some upon a paper and holding them externally quite close to the ring they are set in a vibrating motion, remaining in the same place, although the paper may be moved back and forth; but in lifting the paper to a certain height which seems to be dependent on the intensity of the poles and the speed of rotation, they are thrown away in a direction always opposite to the supposed movement of the poles. If a paper with filings is put flat upon the ring and the current turned on suddenly, the existence of a magnetic whirl may be easily observed.

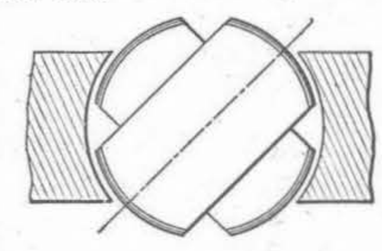

Fig. 6.

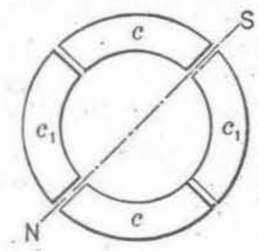

Fig. 6 a.

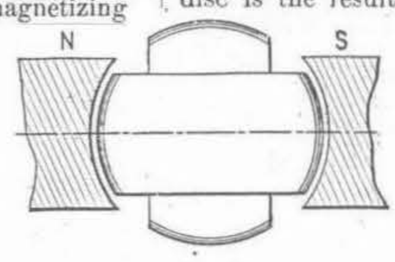

Fig. 7.

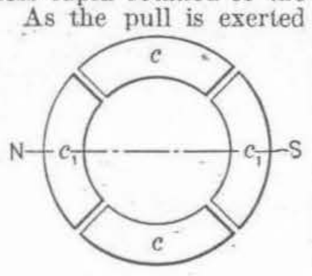

Fig. 7 a.

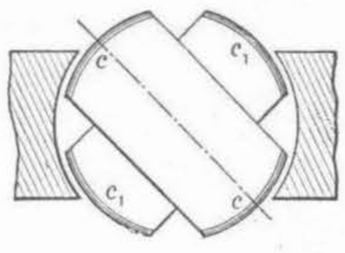

Fig. 4.

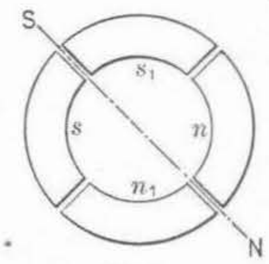

Fig. 4 a.

To demonstrate the complete analogy between the ring and a revolving magnet, a strongly energized electro-magnet was rotated by mechanical power, and phenomena identical in every particular to those mentioned above were observed.

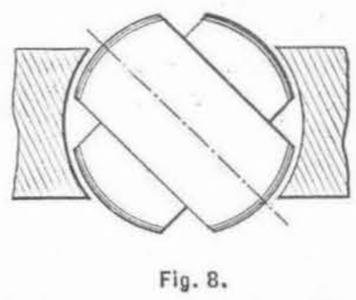
Fig. 8.

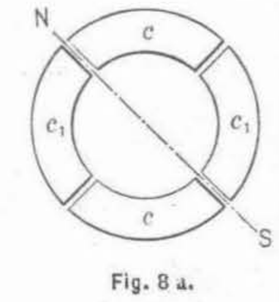

Fig. 8 a.

Obviously the rotation of the poles produces corresponding inductive effects, and may be utilized to generate currents in a closed conductor placed within the influence of the poles. For this purpose it is convenient to wind a ring with two sets of superimposed coils, forming respectively the primary and secondary circuits. In order to secure the most economical results, the magnetic circuit should be completely closed, as shown in Fig. 10, and with this object in view the construction may be modified at will.

The inductive effect exerted upon the secondary coils will be mainly due to the shifting or movement of the magnetic action; but there may also be currents set up in the circuits in consequence of the variations in the intensity of the poles. However, by properly designing the generator and determining the magnetizing effect of the primary coils, the latter element may be made to disappear. The intensity of the poles being maintained constant, the action of the apparatus will be perfect, and the same result will be secured as though the shifting were effected by means of a commutator with an infinite number of bars. In such case the theoretical relation between the energizing effect of each set of primary coils and their resultant magnetizing effect may be expressed by the equation of a circle having its center coinciding with that of an orthogonal system of axes, and in which the radius represents the resultant, and the co-ordinates both of its components. These are then respectively the sine and cosine of the angle *a* between the radius and one of the axis (*O X*). Referring to Fig. 11 we have $r^2 = x^2 + y^2$; where $x = r \cos a$, and $y = r \sin a$.

Assuming the magnetizing effect of each set of coils in the transformer to be proportional to the current—which may be admitted for weak degrees of magnetization—then $x = K c$ and $y = K c^1$, where *K* is a constant and *c* and c^1 the current in both sets of coils respectively. Supposing further, the field of the generator to be uniform, we have for constant speed $c^1 = K^1 \sin a$ and $c = K^1 \sin (90° + a) = K^1 \cos a$, where K^1 is a constant. See Fig 12.

Therefore $x = K c = K K^1 \cos a$,

$y = K c^1 = K K^1 \sin a$, and

$K K^1 = r$.

That is, for a uniform field the disposition of the two coils at right angles will secure the theoretical result, and the intensity of the shifting poles will be constant. But from $r^2 = x^2 + y^2$ it follows that for $y=0$, $r = x$; it follows that the joint magnetizing effect of both sets of coils should be equal to the effect of one set when at its maximum action. In transformers and in a certain class of motors the fluctuation of the poles is not of great importance, but in another class of these motors it is desirable to obtain the theoretical result.

In applying this principle to the construction of motors, two typical forms of motor have been developed. First, a form having a comparatively small rotary effort at the start, but maintaining a perfectly uniform speed at all loads, which motor has been termed synchronous. Second, a form possessing a great rotary effort at the start, the speed being dependent on the load.

These motors may be operated in three different ways: 1. By the alternate currents of the source only; 2. By a combined action of these and of induced currents. 3. By the joint action of alternate and continuous currents.

The simplest form of a synchronous motor is obtained by winding a laminated ring provided with pole projections with four coils, and connecting the same in the manner before indicated. An iron disc having a segment cut away on each side may be used as an armature. Such a motor is shown in Fig. 9. The disc being arranged to rotate freely within the ring in close proximity to the projections, it is evident that as the poles are shifted it will, owing to its tendency to place itself in such a position as to embrace the greatest number of the lines of force, closely follow the movement of the poles, and its motion will be synchronous with that of the armature of the generator; that is, in the peculiar disposition shown in Fig. 9, in which the armature produces by one revolution two current impulses in each of the circuits. It is evident that if, by one revolution of the armature, a greater number of impulses is produced, the speed of the motor will be correspondingly increased. Considering that the attraction exerted upon the disc is greatest when the same is in close proximity to the poles, it follows that such a motor will maintain exactly the same speed at all loads within the limits of its capacity.

To facilitate the starting, the disc may be provided with a coil closed upon itself. The advantage secured by such a coil is evident. On the start the currents set up in the coil strongly energize the disc and increase the attraction exerted upon the same by the ring, and the currents are generated in the coil as long as the speed of the armature is inferior to that of the poles. Considerable

work may be performed by such a motor even if the speed be below normal. The intensity of the poles being constant, no currents will be generated in the coil when the motor is turning at its normal speed.

Instead of closing the coil upon itself, its ends may be connected to two insulated sliding rings, and a continuous current supplied to these from a suitable generator. The proper way to start such a motor is to close the coil upon itself until the normal speed is reached, or nearly so, and then turn on the continuous current. If the disc be very strongly energized by a continuous current the motor may not be able to start,

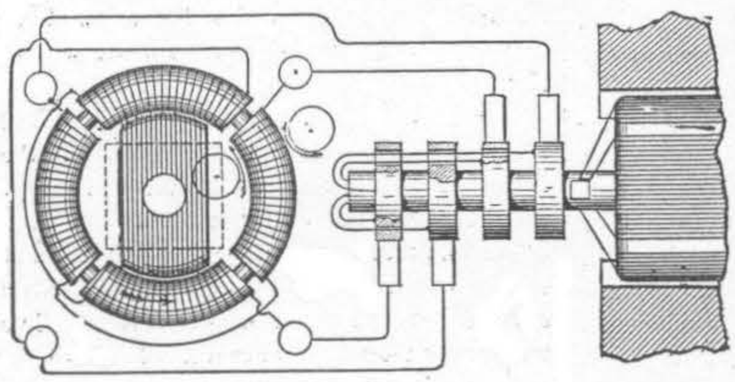

Fig. 9.

but if it be weakly energized, or generally so that the magnetizing effect of the ring is preponderating it will start and reach the normal speed. Such a motor will maintain absolutely the same speed at all loads. It has also been found that if the motive power of the generator is not excessive, by checking the motor the speed of the generator is diminished in synchronism with that of the motor. It is characteristic of this form of motor that it cannot be reversed by reversing the continuous current through the coil.

The synchronism of these motors may be demonstrated experimentally in a variety of ways. For this purpose it is best to employ a motor consisting of a stationary field magnet and an armature arranged to rotate within the same, as indicated in Fig. 13. In this case the shifting of the poles of the armature

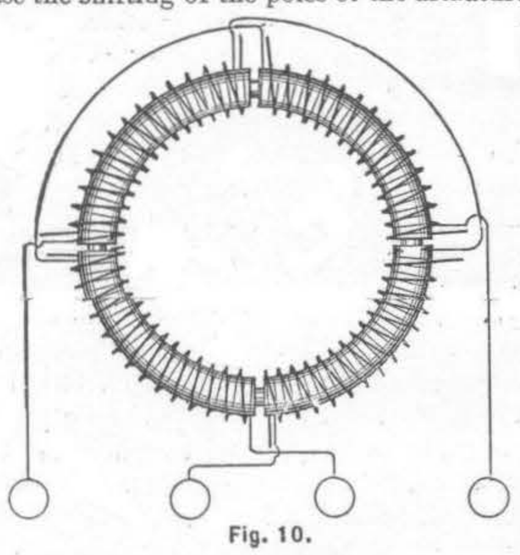

Fig. 10.

produces a rotation of the latter in the opposite direction. It results therefrom that when the normal speed is reached the poles of the armature assume fixed positions relatively to the field magnet and the same is magnetized by induction, exhibiting a distinct pole on each of the pole pieces. If a piece of soft iron is approached to the field magnet it will at the start be attracted with a rapid vibrating motion produced by the reversals of polarity of the magnet, but as the speed of the armature increases the vibrations become less and less frequent and finally entirely cease. Then the iron is weakly but permanently attracted, showing that the synchronism is reached and the field magnet energized by induction.

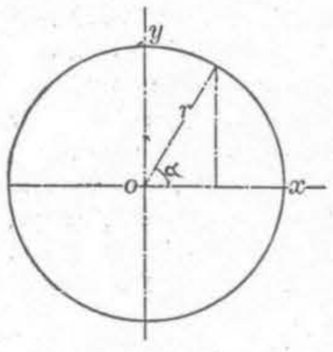

Fig. 11.

The disc may also be used for the experiment. If held quite close to the armature it will turn as long as the speed of rotation of the poles exceeds that of the armature; but when the normal speed is reached, or very nearly so, it ceases to rotate and is permanently attracted.

A crude but illustrative experiment is made with an incandescent lamp. Placing the lamp in circuit with the continuous current generator, and in series with the magnet coil, rapid fluctuations are observed in the light in consequence of the induced currents set up in the coil at the start; the speed increasing, the fluctuations occur at longer intervals, until they entirely disappear, showing that the motor has attained its normal speed.

A telephone receiver affords a most sensitive instrument; when connected to any circuit in the motor the synchronism may be easily detected on the disappearance of the induced currents.

In motors of the synchronous type it is desirable to maintain the quantity of the shifting magnetism constant, especially if the magnets are not properly subdivided.

To obtain a rotary effort in these motors was the subject of long thought. In order to secure this result it was necessary to make such a disposition that while the poles of one element of the motor are shifted by the alternate currents of the source, the poles produced upon the other element should always be maintained in the proper relation to the former, irrespective of the speed of the motor. Such a condition exists in a continuous current motor; but in a synchronous motor, such as described, this condition is fulfilled only when the speed is normal.

The object has been attained by placing within the ring a properly subdivided cylindrical iron core, wound with several independent coils closed upon themselves. Two coils at right angles are sufficient, but a greater number may be advantageously employed, as in Fig. 14. It results from this disposition that when the poles of the ring are shifted, currents are generated in the closed armature coils. These currents are the most intense at or near the points of the greatest density of the lines of force, and their effect is to produce poles upon the armature at right angles to those of the ring, at least, theoretically so; and since this action is entirely independent of the speed—that is, as far as the location of the poles are concerned—a continuous pull is exerted upon the periphery of the armature. In many respects these motors are similar to the continuous current motors. If load is put on, the speed, and also the resistance of the motor, is diminished, and more current is made to pass through the energizing coils, thus increasing the effect. Upon the load being taken off, the counter electro-motive force increases, and less current passes through the primary or energizing coils. Without any load, the speed is very nearly equal to that of the shifting poles of the field magnet.

It will be found that the rotary effort in these motors fully equals that of the continuous current motors. The effort seems to be greatest when both armature and field magnet are without any projections; but as in such dispositions the field cannot be very concentrated, probably the best results will be obtained by leaving pole projections on one of the elements only. Generally it may be stated that the projections diminish the torque and produce a tendency to synchronism.

A characteristic feature of motors of this kind is their capacity of being very rapidly reversed. This follows from the peculiar action of the motor. Suppose the armature to be rotating and the direction of rotation of the poles to be reversed. The apparatus then represents a dynamo machine, the power to drive this machine being the momentum stored up in the armature and its speed being the sum of the speeds of the armature and the poles. If we now consider that the power to drive such a dynamo would be very nearly proportional to the third power of the speed, for this reason alone the armature should be quickly reversed. But simultaneously with the reversal another element is brought into action; namely, as the movement of the poles with respect to the armature is reversed, the motor acts like a transformer in which the resistance of the secondary circuit would be abnomalrly diminished by producing in this circuit an additional electro-motive force. Owing to these causes the reversal is instantaneous.

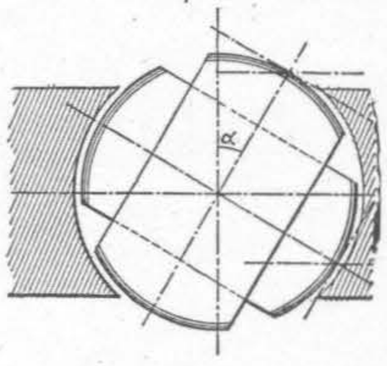

Fig. 12.

If it is desirable to secure a constant speed, and at the same time a certain effort at the start, this result may be easily attained in a variety of ways. For instance, two armatures, one for torque and the other for synchronism, may be fastened on the same shaft, and any desired preponderance may be given to either one, or an armature may be wound for rotary effort, but a more or less pronounced tendency to synchronism may be given to it by properly constructing the iron core; and in many other ways.

As a means of obtaining the required phase of the currents in both the circuits, the disposition of the two coils at right angles is the simplest, securing the most uniform action; but the phase may be obtained in many other ways, varying with the machine employed. Any of the dynamos at present in use may be easily adapted for this purpose by making connections to proper points of the generating coils. In closed circuit armatures, such as used in the continuous current systems, it is best to make four derivations from equi-distant points or bars of the commutator, and to connect the same to four insulated sliding rings on the shaft. In this case each of the motor circuits is connected to two diametrically opposite bars of the commutator. In such a disposition the motor may also be operated at half the potential and on the three-wire plan, by connecting the motor circuits in the proper order to three of the contact rings.

In multipolar dynamo machines, such as use the converter systems, the phase is conveniently obtained by winding upon the armature two series of coils in such a manner that while the coils of one set or series are at their maximum production of current, the coils of the other will be at their neutral position, or nearly so, whereby both sets of coils may be subjected simultaneously or successively to the inducing action of the field magnets.

Generally the circuits in the motor will be similarly disposed, and various arrangements may be made to fulfill the requirements; but the simplest and most practicable is to arrange primary circuits on stationary parts of the motor, thereby obviating, at least in certain forms, the employment of sliding contacts. In such a case the magnet coils are connected alternately in both the circuits; that is, 1, 3, 5 in one, and 2, 4, 6 in the other, and the coils of each set of series may be connected, all in the same manner, or alternately in opposition; in the latter case a motor with half the number of poles will result and its action will correspondingly modified.

The employment of multipolar motors secures in this system an advantage much desired and unattainable in the continuous current system, and that is, that a motor may be made to run exactly at a predetermined speed irrespective of imperfections in construction, of the load, and, within certain limits, of electromotive force and current strength.

In a general distribution system of this

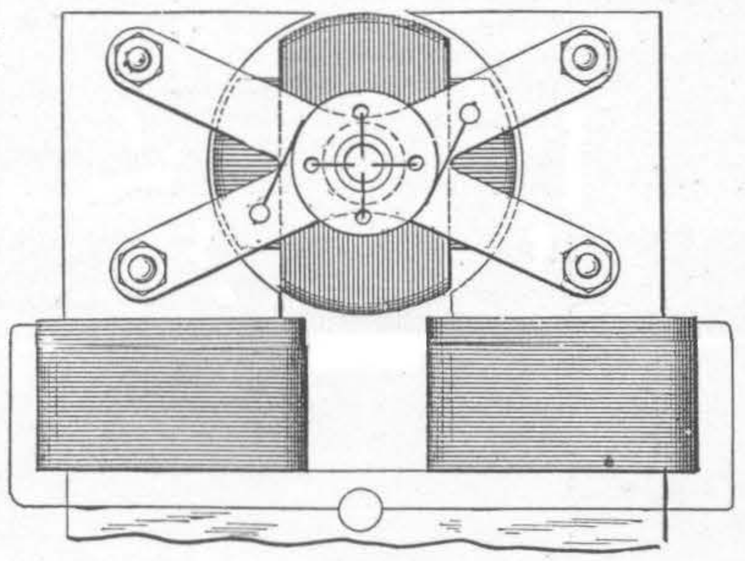

Fig. 13.

kind the following plan should be adopted. At the central station of supply, a generator should be provided having a considerable number of poles. The motors operated from this generator should be of the synchronous type, but possessing sufficient rotary effort to insure their starting. With the observance of proper rules of construction it may be admitted that the speed of each motor will be in some inverse proportion to its size, and the number of poles should be chosen accordingly. Still, exceptional demands may modify this rule. In view of this, it will be advantageous to provide each motor with a greater number of pole projections or coils, the number being preferably a multiple of two and three. By this means, by simply changing the connections of the coils, the motor may be adapted to any probable demands.

If the number of the poles in the motor is even, the action will be harmonious and the proper result will be obtained; if this is not the case, the best plan to be followed is to make a motor with a double number of poles and connect the same in the manner before indicated, so that half the number of poles result. Suppose, for instance, that the generator has twelve poles and it would be desired to obtain a speed equal to $\frac{1}{7}^{2}$ of the speed of the generator. This would require a motor with seven pole projections or magnets, and such a motor could not be properly connected in the circuits, unless fourteen armature coils would be provided, which would necessitate the employment of sliding contacts. To avoid this the motor should be provided with fourteen magnets and seven connected in each circuit, the magnets in each circuit alternating among themselves. The armature should have fourteen closed coils. The action of the motor will not be quite as perfect as in the case of an even number of poles, but the drawback will not be of a serious nature.

However, the disadvantages resulting from this unsymmetrical form will be reduced in the same proportion as the number of the poles is augmented.

If the generator has, say, n, and the motor n_1 poles, the speed of the motor will be equal to that of the generator multiplied by $\frac{n}{n_1}$.

The speed of the motor will generally be dependent on the number of the poles, but

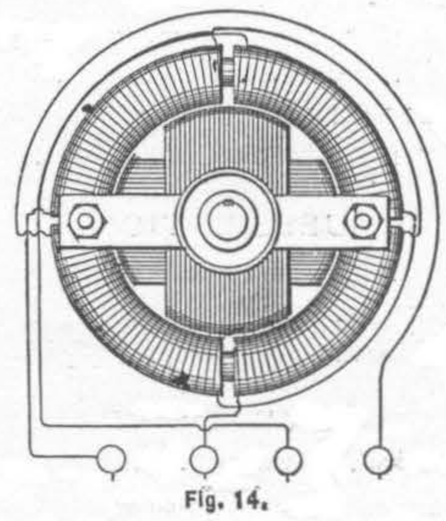

Fig. 14.

there may be exceptions to this rule. The speed may be modified by the phase of the currents in the circuits or by the character of the current impulses or by intervals between each or between groups of impulses. Some of the possible cases are indicated in the diagrams, Figs. 18, 19, 20 and 21, which are self-explanatory. Fig. 18 represents the condition generally existing, and which secures the best result. In such a case, if the typical form of motor illustrated in Fig. 14 is employed, one complete wave in each circuit will produce one revolution of the motor. In Fig. 19 the same result will be effected by one wave in each circuit; in Fig. 20 by two, and in Fig. 21 by four waves.

By such means any desired speed may be attained; that is, at least within the limits of practical demands. This system possesses this advantage besides others, resulting from simplicity. At full loads, the motors show an efficiency fully equal to that of the continuous current motors. The transformers present an additional advantage in their capability of operating motors. They are capable of similar modifications in construction, and will facilitate the introduction of motors and their adaptation to practical demands. Their efficiency should be higher than that of the present transformers, and I base my assertion on the following:

In a transformer as constructed at present, we produce the currents in the secondary circuit by varying the strength of the primary or exciting currents. If we admit proportionality with respect to the iron core, the inductive effect exerted upon the secondary coil will be proportional to the numerical sum of the variations in the strength of the exciting current per unit of time; whence it follows that for a given variation any prolongation of the primary current will result in a proportional loss. In order to obtain rapid variations in the strength of the current, essential to efficient induction, a great number of undulations are required and employed. From this various disad-

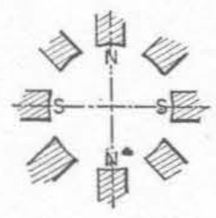

Fig. 15.



Fig. 16.

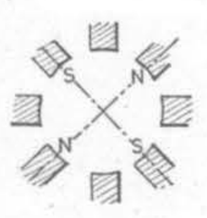

Fig. 17.

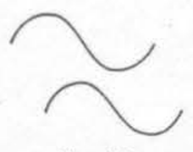

Fig. 18.

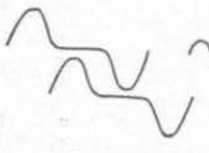

Fig. 19.

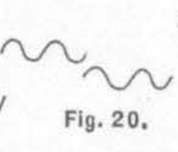

Fig. 20.

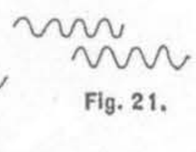

Fig. 21.

vantages result. These are, increased cost and diminished efficiency of the generator, more waste of energy in heating the cores, and also diminished output of the transformer, since the core is not properly utilized, the reversals being too rapid. The inductive effect is also very small in certain phases, and there may be periods of inaction, if there are intervals between the succeeding current impulses or waves. In producing a shifting of the poles in the transformer, and thereby inducing currents, the induction is of the ideal character, being always maintained at its maximum action.

A New System of Alternate Current Motors and Transformers.*

BY NIKOLA TESLA.

In the presence of the existing diversity of opinion regarding the relative merits of the alternate and continuous current systems, great importance is attached to the question whether alternate currents can be successfully utilized in the operation of motors. The transformers, with their numerous advantages, have afforded us a relatively perfect system of distribution, and although, as in all branches of the art, many improvements are desirable, comparatively little remains to be done in this direction. The transmission of power, on the contrary, has been almost entirely confined to the use of continuous currents, and notwithstanding that many efforts have been made to utilize alternate currents for this purpose, they have, up to the present, at least as far as known, failed to give the result desired. Of the various motors adapted to be used on alternate current circuits the following have been mentioned: 1. A series motor with subdivided field. 2. An alternate current generator having its field excited by continuous currents. 3. Elihu Thomson's motor. 4. A combined alternate and continuous current motor. Two more motors of this kind have suggested themselves to me. 1. A motor with one of its circuits in series with a transformer and the other in the secondary of the transformer. 2. A motor having its armature circuit connected to the generator and the field coils closed upon themselves. These, however, I mention only incidentally.

The subject which I now have the pleasure of bringing to your notice is a novel system of electric distribution and transmission of power by means of alternate currents, affording peculiar advantages, particularly in the way of motors, which I am confident will at once establish the superior adaptability of these currents to the transmission of power and will show that many results heretofore unattainable can be reached by their use: results which are very much desired in the practical operation of such systems and which cannot be accomplished by means of continuous currents.

Before going into a detailed description of this system, I think it necessary to make a few remarks with reference to certain conditions existing in continuous current generators and motors, which, although generally known, are frequently disregarded.

In our dynamo machines, it is well known, we generate alternate currents which we direct by means of a commutator, a complicated device and, it may be justly said, the source of most of the troubles experienced in the operation of the machines. Now, the currents so directed cannot be utilized in the motor, but they must—again by means of a similar unreliable device—be re-converted into their original state of alternate currents. The function of the commutator is entirely external, and in no way does it affect the internal working of the machines. In reality, therefore, all machines are alternate current machines, the currents appearing as continuous only in the external circuit during their transit from generator to motor. In view simply of this fact, alternate currents would commend themselves as a more direct application of electrical energy, and the employment of continuous currents would only be justified if we had dynamos which would primarily generate, and motors which would be directly actuated by such currents.

But the operation of the commutator on a motor is twofold; firstly, it reverses the currents through the motor, and secondly, it effects, automatically, a progressive shifting of the poles of one of its magnetic constituents. Assuming, therefore, that both of the useless operations in the system, that is to say, the directing of the alternate currents on the generator and reversing the direct currents on the motor, be eliminated, it would still be necessary, in order to cause a rotation of the motor, to produce a progressive shifting of the poles of one of its elements, and the question presented itself, How to perform this operation by the direct action of alternate currents? I will now proceed to show how this result was accomplished.

In the first experiment a drum-armature was provided with two coils at right angles to each other, and the ends of these coils were connected to two pairs of insulated contact-rings as usual. A ring was then made of thin insulated plates of sheet iron and wound with four coils, each two opposite coils being connected together so as to produce free poles on diametrically opposite sides of the ring. The remaining free ends of the coils were then connected to the contact-rings of the generator armature so as to form two independent circuits, as indicated in Fig. 9. It may now be seen what results were secured in this combination, and with this view I would refer to the diagrams, Figs. 1 to 8*a*. The field of the generator being independently excited, the rotation of the armature sets up currents in the coils *c c*, varying in strength and direction in the well known manner. In the position shown in Fig. 1 the current in coil *c* is nil while coil c_1 is traversed by its maximum current, and the connections may be such that the ring is magnetized by the coils *c c*, as indicated by the letters *N S* in Fig. 1*a*, the magnetizing effect of the coils *c c* being nil, since these coils are included in the circuit of coil *c*.

In Fig. 2 the armature coils are shown in a more advanced position, one-eighth of one revolution being completed. Fig. 2*a* illustrates the corresponding magnetic condition of the ring. At this moment the coil *c* generates a current of the same direction as previously, but weaker, producing the poles n_1 s_1 upon the ring; the coil *c* also generates a current of the same direction, and the connections may be such that the coils *c c* produce the poles *n s*, as shown in Fig 2*a*. The resulting polarity is indicated by the letters *N S*, and it will be observed that the poles of the ring have been shifted one-eighth of the periphery of the same.

In Fig. 3 the armature has completed one-quarter of one revolution. In this phase the current in coil *c* is a maximum, and of such direction as to produce the poles *N S* in Fig. 3*a*, whereas the current in coil c_1 is nil, this coil being at its neutral position. The poles *N S* in Fig. 3*a* are thus shifted one-quarter of the circumference of the ring.

Fig. 4 shows the coils *c c* in a still more advanced position, the armature having completed three-eighths of one revolution. At that moment the coil *c* still generates a current of the same direction as before, but of less strength, producing the comparatively weaker poles *n s* in Fig. 4*a*. The current in the coil *c* is of the same strength, but of opposite direction. Its effect is, therefore, to produce upon the ring the poles n_1 and s_1 as indicated, and a polarity *N S* results, the poles now being shifted three-eighths of the periphery of the ring.

In Fig. 5 one-half of one revolution of the armature is completed, and the resulting magnetic condition of the ring is indicated in Fig. 5*a*. Now, the current in coil *c* is nil, while the coil c_1 yields its maximum current, which is of the same direction as previously; the magnetizing effect is therefore due to the coils c_1 c_1 alone, and, referring to Fig. 5*a*, it will be observed that the poles *N S* are shifted one-half of the circumference of the ring. During the next half-revolution the operations are repeated, as represented in the Figs. 6 to 8*a*.

A reference to the diagrams will make it clear that during one revolution of the armature the poles of the ring are shifted once around its periphery, and each revolution producing like effects, a rapid whirling of the poles in harmony with the rotation of the armature is the result. If the connections of either one of the circuits in the ring are reversed, the shifting of the poles is made to progress in the opposite direction, but the operation is indentically the same. Instead of using four wires, with like result, three wires may be used, one forming a common return for both circuits.

This rotation or whirling of the poles manifests itself in a series of curious phenomena. If a delicately pivoted disc of steel or other magnetic metal, Fig. 9, is approached to the ring it is set in rapid rotation, the direction of rotation varying with the position of the disc. For instance, noting the direction outside of the ring it will be found that inside the ring it turns in an opposite direction, while it is unaffected if placed in a position symmetrical to the ring. This is easily explained. Each time that a pole approaches, it induces an opposite pole in the nearest point on the disc and an attraction is produced upon that point; owing to this, as the pole is shifted further away from the disc a tangential pull is exerted upon the same, and the action being constantly repeated, a more or less rapid rotation of the disc is the result. As the pull is exerted mainly upon that part which is nearest to the ring, the rotation outside and inside, or right and left, respectively, is in opposite directions. When placed symmetrically to the ring, the pull on opposite sides of the disc being equal, no rotation results. The action is based on the magnetic inertia of the iron; for this reason a disc of hard steel is much more affected than a disc of soft iron, the latter being capable of very rapid variations of magnetism. Such a disc has proved to be a very useful instrument in all these investigations, as it has enabled me to detect any irregularity in the action. A curious effect is also produced upon iron filings. By placing some upon a paper and holding them externally quite close to the ring they are set in a vibrating motion, remaining in the same place, although the paper may be moved back and forth; but in lifting the paper to a certain height which seems to be dependent on the intensity of the poles and the speed of rotation, they are thrown away in a direction always opposite to the supposed movement of the poles. If a paper with filings is put flat upon the ring and the current turned on suddenly, the existence of a magnetic whirl may be easily observed.

To demonstrate the complete analogy between the ring and a revolving magnet, a strongly energized electro-magnet was rotated by mechanical power, and phenomena identical in every particular to those mentioned above were observed.

Obviously, the rotation of the poles produces corresponding inductive effects and may be utilized to generate currents in a closed conductor placed within the influence of the poles. For this purpose it is convenient to wind a ring with two sets of superimposed coils forming respectively the primary and secondary circuits. In order to secure the most economical results the magnetic circuit should be completely closed, as shown in Fig. 10, and with this object in view the construction may be modified at will.

The inductive effect exerted upon the secondary coils will be mainly due to the shifting or movement of the magnetic action; but there may also be currents set up in the circuits in consequence of the variations in the intensity of the poles. However, by properly designing the generator and determining the magnetizing effect of the primary coils, the latter element may be made to disappear. The intensity of the poles being maintained constant, the action of the apparatus will be perfect and the same result will be secured as though the shifting were effected by means of a commutator with an infinite number of bars. In such case the theoretical relation between the energizing effect of each set of primary coils and their resultant magnetizing effect may be expressed by the equation of a circle having its centre coinciding with that of an orthogonal system of axes, and in which the radius represents the resultant and the co-ordinates both of its components. These are then respectively the sine and cosine of the angle α between the radius and one of the axes (*o x*). Referring to Fig. 11 we have $r^2 = x^2 + y^2$; where $x = r \cos \alpha$, and $y = r \sin \alpha$.

Assuming the magnetizing effect of each set of coils in the transformer to be proportional to the current—which may be admitted for weak degrees of magnetization—then $x = K c$ and $y = K c^1$, where *K* is a constant and *c* and c^1 the current in both sets of coils respectively. Supposing further, the field of the generator to be uniform, we have for constant speed $c^1 = K^1 \sin \alpha$ and $c = K^1 \sin (90° + \alpha) = K^1 \cos \alpha$, where K^1 is a constant. See Fig. 12.

Therefore
$$x = K c = K K^1 \cos \alpha;$$
$$y = K c^1 = K K^1 \sin \alpha, \text{ and}$$
$$K K^1 = r.$$

That is, for a uniform field the disposition of the two coils at right angles will secure the theoretical result, and the intensity of the shifting poles will be constant. But from $r^2 = x^2 + y^2$ it follows that for $y = 0$; $r = x$; it follows that the joint magnetizing effect of both sets of coils should be equal to the effect of one set when at its maximum action. In transformers and in a certain class of motors the fluctuation of the poles is not of great importance, but in another class of these motors it is desirable to obtain the theoretical result.

In applying this principle to the construction of motors, two typical forms of motor have been developed. First, a form having a comparatively small rotary effort at the start, but maintaining a perfectly uniform speed at all loads, which motor has been termed synchronous. Second, a form possessing a great rotary effort at the start, the speed being dependent on the load.

These motors may be operated in three different ways:

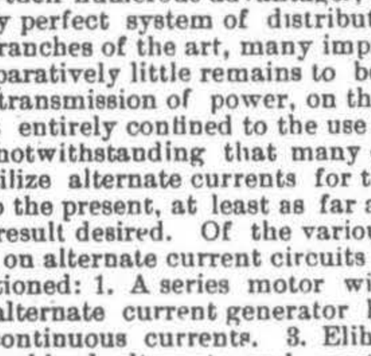

Fig. 1.

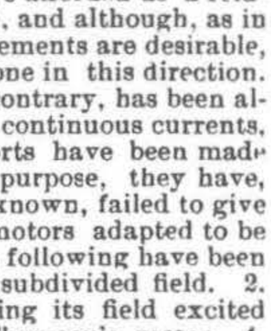

Fig. 1a.

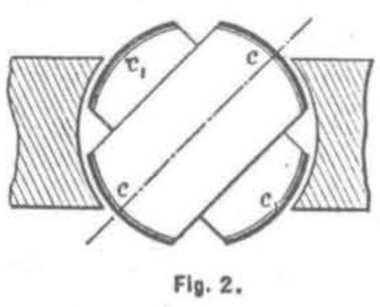

Fig. 2.

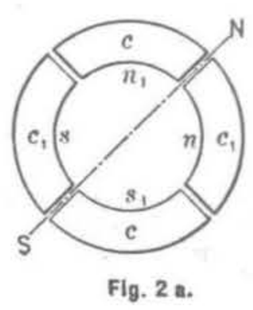

Fig. 2a.

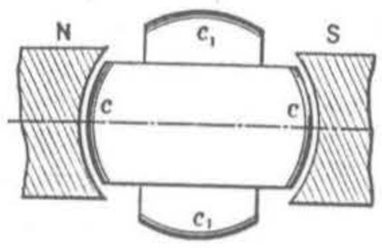

Fig. 3.

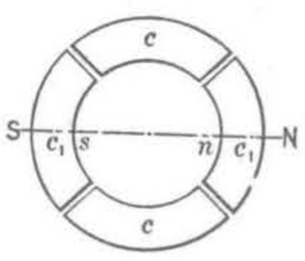

Fig. 3a.

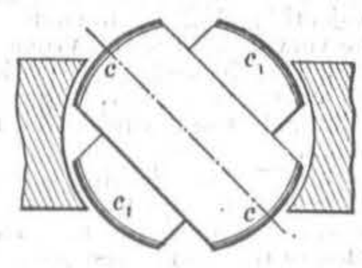

Fig. 4.

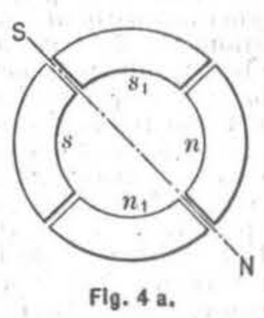

Fig. 4 a.

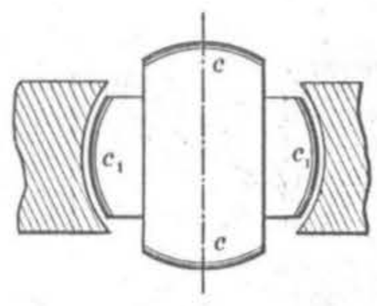

Fig. 5.

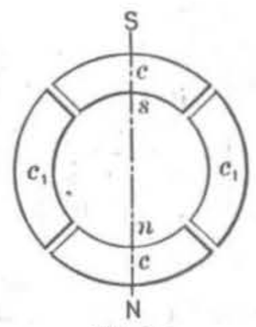

Fig. 5 a.

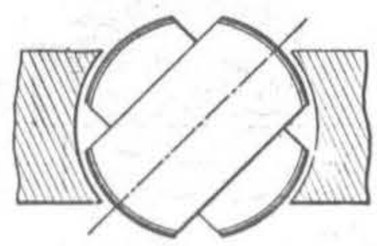

Fig. 6.

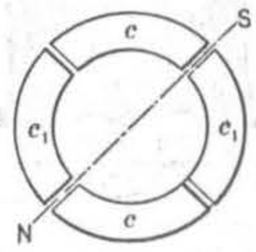

Fig. 6 a.

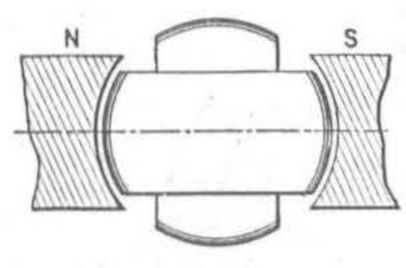

Fig. 7.

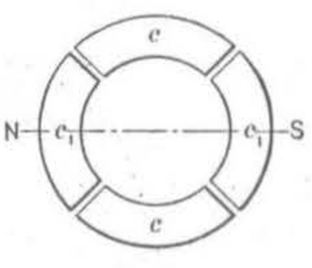

Fig. 7 a.

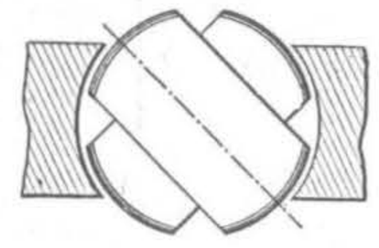
Fig. 8.

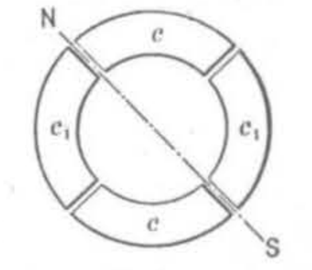

Fig. 8 a.

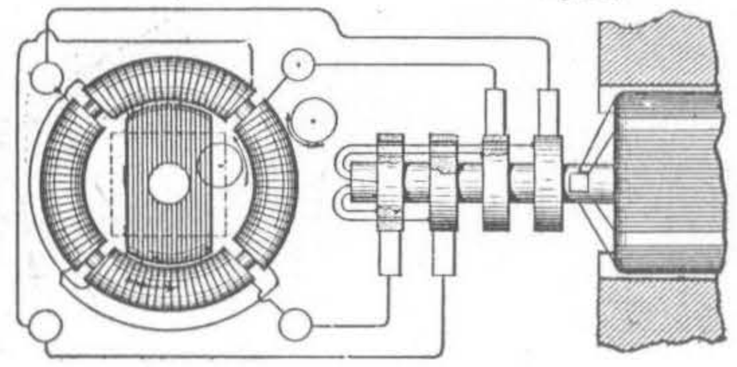
Fig. 9.

A NEW SYSTEM OF ALTERNATE CURRENT MOTORS AND TRANSFORMERS.

* Read before the American Institute of Electrical Engineers, May 16.

1. By the alternate currents of the source only. 2. By a combined action of these and of induced currents. 3. By the joint action of alternate and continuous currents.

The simplest form of a synchonous motor is obtained by winding a laminated ring provided with pole projections with four coils, and connecting the same in the manner before indicated. An iron disc having a segment cut away on each side may be used as an armature. Such a motor is shown in Fig. 9. The disc being arranged to rotate freely within the ring in close proximity to the projections, it is evident that as the poles are shifted it will, owing to its tendency to place itself in such a position as to embrace the greatest number of the lines of force, closely follow the movement of the poles, and its motion will be synchronous with that of the armature of the generator; that is, in the peculiar disposition shown in Fig. 9, in which the armature produces by one revolution two current impulses in each of the circuits. It is evident that if, by one revolution of the armature, a greater number of impulses is produced, the speed of the motor will be correspondingly increased. Considering that the attraction exerted upon the disc is greatest when the same is in close proximity to the poles, it follows that such a motor will maintain exactly the same speed at all loads within the limits of its capacity.

To facilitate the starting the disc may be provided with a coil closed upon itself. The advantage secured by such a coil is evident. On the start the currents set up in the coil strongly energize the disc and increase the attraction exerted upon the same by the ring, and currents are generated in the coil as long as the speed of the armature is inferior to that of the poles. Considerable work may be performed by such a motor even if the speed be below normal. The intensity of the poles being constant, no currents will be generated in the coil when the motor is turning at its normal speed.

Instead of closing the coil upon itself, its ends may be connected to two insulated sliding rings, and a continuous current supplied to these from a suitable generator. The proper way to start such a motor is to close the coil upon itself until the normal speed is reached, or nearly so, and then turn on the continuous current. If the disc be very strongly energized by a continuous current the motor may not be able to start, but if it be weakly energized, or generally so that the magnetizing effect of the ring is preponderating it will start and reach the normal speed. Such a motor will maintain absolutely the same speed at all loads. It has also been found that if the motive power of the generator is not excessive, by checking the motor the speed of the generator is diminished in synchronism with that of the motor. It is characteristic of this form of motor that it cannot be reversed by reversing the continuous current through the coil.

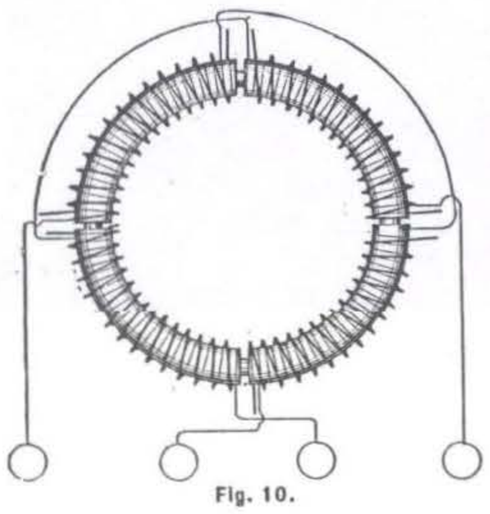

Fig. 10.

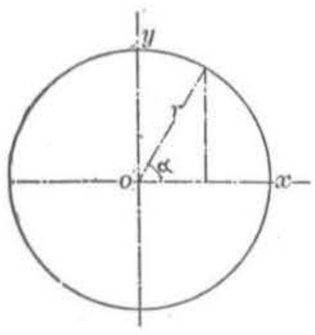

Fig. 11.

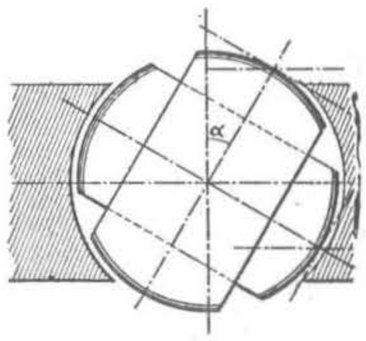

Fig. 12.

The synchronism of these motors may be demonstrated experimentally in a variety of ways. For this purpose it is best to employ a motor consiting of a stationary field magnet and an armature arranged to rotate within the same, as indicated in Fig. 13. In this case the shifting of the poles of the armature produces a rotation of the latter in the opposite direction. It results therefrom that when the normal speed is reached the poles of the armature assume fixed positions relatively to the field magnet and the same is magnetized by induction, exhibiting a distinct pole on each of the pole pieces. If a piece of soft iron is approached to the field magnet it will at the start be attracted with a rapid vibrating motion produced by the reversals of polarity of the magnet, but as the speed of the armature increases the vibrations become less and less frequent and finally entirely cease. Then the iron is weakly but permanently attracted, showing that the synchronism is reached and the field magnet energized by induction.

The disc may also be used for the experiment. If held quite close to the armature it will turn as long as the speed of rotation of the poles exceeds that of the armature; but when the normal speed is reached, or very nearly so, it ceases to rotate and is permanently attracted.

A crude but illustrative experiment is made with an incandescent lamp. Placing the lamp in circuit with the continuous current generator, and in series with the magnet coil, rapid fluctuations are observed in the light in consequence of the induced currents set up in the coil at the start; the speed increasing, the fluctuations occur at longer intervals, until they entirely disappear, showing that the motor has attained its normal speed.

A telephone receiver affords a most sensitive instrument; when connected to any circuit in the motor the synchronism may be easily detected on the disappearance of the induced currents.

In motors of the synchronous type it is desirable to maintain the quantity of the shifting magnetism constant, especially if the magnets are not properly subdivided.

To obtain a rotary effort in these motors was the subject of long thought. In order to secure this result it was necessary to make such a disposition that while the poles of one element of the motor are shifted by the alternate currents of the source, the poles produced upon the other element should always be maintained in the proper relation to the former, irrespective of the speed of the motor. Such a condition exists in a continuous current motor; but in a synchronous motor, such as described, this condition is fulfilled only when the speed is normal.

The object has been attained by placing within the ring a properly subdivided cylindrical iron core wound with several independent coils closed upon themselves. Two coils at right angles are sufficient, as in Fig. 14, but a greater number may be advantageously employed. It results from this disposition that when the poles of the ring are shifted, currents are generated in the closed armature coils. These currents are the most intense at or near the points of the greatest density of the lines of force, and their effect is to produce poles upon the armature at right angles to those of the ring, at least theoretically so; and since this action is entirely independent of the speed—that is, as far as the location of the poles is concerned—a continuous pull is exerted upon the periphery of the armature. In many respects these motors are similar to the continuous current motors. If load is put on, the speed, and also the resistance of the motor, is diminished and more current is made to pass through the energizing coils, thus increasing the effect. Upon the load being taken off, the counter-electromotive force increases and less current passes through the primary or energizing coils. Without any load the speed is very nearly equal to that of the shifting poles of the field magnet.

It will be found that the rotary effort in these motors fully equals that of the continuous current motors. The effort seems to be greatest when both armature and field magnet are without any projections; but as in such dispositions the field cannot be very concentrated, probably the best results will be obtained by leaving pole projections on one of the elements only. Generally, it may be stated that the projections diminish the torque and produce a tendency to synchronism.

A characteristic feature of motors of this kind is their capacity of being very rapidly reversed. This follows from the peculiar action of the motor. Suppose the armature to be rotating and the direction of rotation of the poles to be reversed. The apparatus then represents a dynamo machine, the power to drive this machine being the momentum stored up in the armature and its speed being the sum of the speeds of the armature and the poles. If we now consider that the power to drive such a dynamo would be very nearly proportional to the third power of the speed, for this reason alone the armature should be quickly reversed. But simultaneously with the reversal another element is brought into action; namely, as the movement of the poles with respect to the armature is reversed, the motor acts like a transformer in which the resistance of the secondary circuit would be abnormally diminished by producing in this circuit an additional electromotive force. Owing to these causes the reversal is instantaneous.

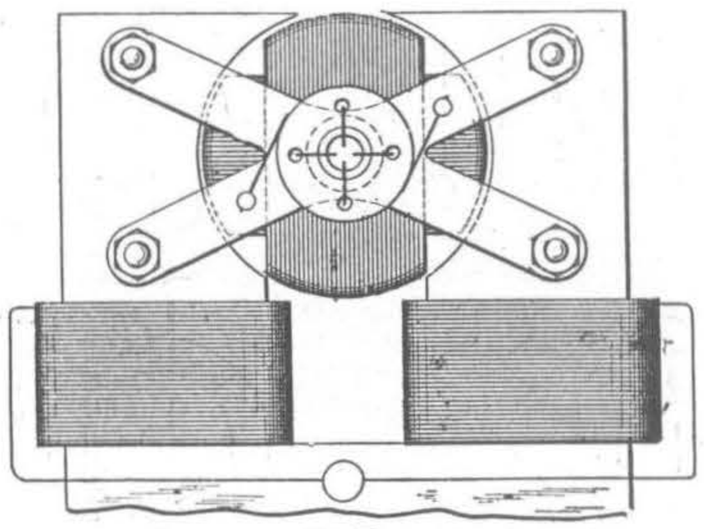

Fig. 13.

If it is desirable to secure a constant speed, and at the same time a certain effort at the start, this result may be easily attained in a variety of ways. For instance, two armatures, one for torque and the other for synchronism, may be fastened on the same shaft, and any desired preponderance may be given to either one; or an armature may be wound for rotary effort, but a more or less pronounced tendency to synchronism may be given to it by properly constructing the iron core; and in many other ways.

As a means of obtaining the required phase of the currents in both the circuits, the disposition of the two coils at right angles is the simplest, securing the most uniform action; but the phase may be obtained in many other ways, varying with the machine employed. Any of the dynamos at present in use may be easily adapted for this purpose by making connections to proper points of the generating coils. In closed circuit armatures, such as used in the continuous current systems, it is best to make four derivations from equi-distant points or bars of the commutator, and to connect the same to four insulated sliding rings on the shaft. In this case each of the motor circuits is connected to two diametrically opposite bars of the commutator. In such a disposition the motor may also be operated at half the potential and on the three-wire plan, by connecting the motor circuits in the proper order to three of the contact rings.

In multipolar dynamo machines, such as use the converter systems, the phase is conveniently obtained by winding upon the armature two series of coils in such a manner that while the coils of one set or series are at their maximum production of current, the coils of the other will be at their neutral position, or nearly so, whereby both sets of coils may be subjected simultaneously or successively to the inducing action of the field magnets.

Generally the circuits in the motor will be similarly disposed and various arrangements may be made to fulfill the requirements; but the simplest and most practicable is to arrange primary circuits on stationary parts of the motor, thereby obviating, at least in certain forms, the employment of sliding contacts. In such a case the magnet coils are connected alternately in both the circuits: that is, 1, 3, 5 in one, and 2, 4, 6 in the other, Fig. 15, and the coils of each set of series may be connected, all in the same manner, or alternately in opposition, Fig. 16; in the latter case a motor with half the number of poles will result and its action will be correspondingly modified, Fig. 17.

The employment of multipolar motors secures in this system an advantage much desired and unattainable in the continuous current system, and that is, that a motor may be made to run exactly at a predetermined speed irrespective of imperfections in construction, of the load, and, within certain limits, of electromotive force and current strength.

In a general distribution system of this kind the following plan should be adopted. At the central station of supply, a generator should be provided having a considerable number of poles. The motors operated from this generator should be of the synchronous type, but possessing sufficient rotary effort to insure their starting. With the observance of proper rules of construction it may be admitted that the speed of each motor will be in some inverse proportion to its size, and the number of poles should be chosen accordingly. Still, exceptional demands may modify this rule. In view of this, it will be advantageous to provide each motor with a greater number of pole projections or coils, the number being preferably a multiple of two and three. By this means, by simply changing the connections of the coils, the motor may be adapted to any probable demands.

If the number of the poles in the motor is even the action will be harmonious and the proper result will be obtained; if this is not the case the best plan to be followed is to make a motor with a double number of poles and connect the same in the manner before indicated, so that half the number of poles result. Suppose, for instance, that the generator has twelve poles and it would be desired to obtain a speed equal to $\frac{1}{7}$ of the speed of the generator. This would require a motor with seven pole projections or magnets, and such a motor could not be properly connected in the circuits unless fourteen armature coils would be provided, which would necessitate the employment of sliding contacts. To avoid this the motor should be provided with fourteen magnets and seven connected in each circuit, the magnets in each circuit alternating among themselves. The armature should have fourteen closed coils. The action of the motor will not be quite as perfect as in the case of an even number of poles, but the drawback will not be of a serious nature.

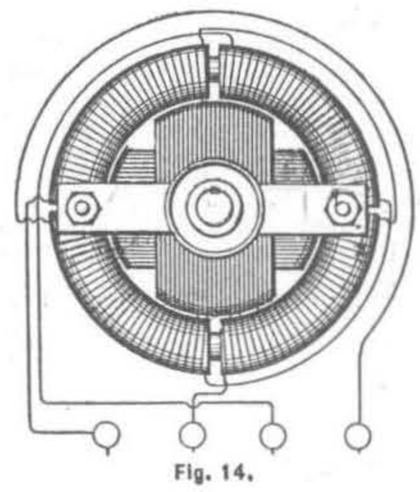

Fig. 14.

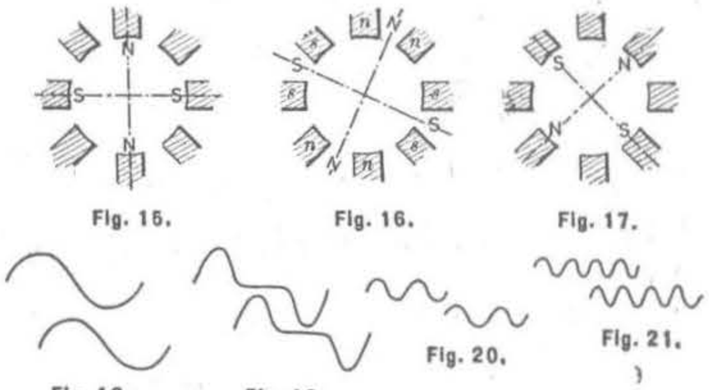

Fig. 15. Fig. 16. Fig. 17.

Fig. 18. Fig. 19. Fig. 20. Fig. 21.

A NEW SYSTEM OF ALTERNATE CURRENT MOTORS AND TRANSFORMERS.

However, the disadvantages resulting from this unsymmetrical form will be reduced in the same proportion as the number of the poles is augmented.

If the generator has, say, n, and the motor n_1 poles, the speed of the motor will be equal to that of the generator multiplied by $\frac{n}{n_1}$.

The speed of the motor will generally be dependent on the number of the poles, but there may be exceptions to this rule. The speed may be modified by the phase of the currents in the circuits or by the character of the current impulses or by intervals between each or between groups of impulses. Some of the possible cases are indicated in the diagrams, Figs. 18, 19, 20 and 21, which are self-explanatory. Fig. 18 represents the condition generally existing, and which secures the best result. In such a case, if the typical form of motor illustrated in Fig. 14 is employed, one complete wave in each circuit will produce one revolution of the motor. In Fig. 19 the same result will be effected by one wave in each circuit; in Fig. 20 by two, and in Fig. 21 by four waves.

By such means any desired speed may be attained; that is, at least within the limits of practical demands. This system possesses this advantage besides others, resulting from simplicity. At full loads the motors show an efficiency fully equal to that of the continuous current motors. The transformers present an additional advantage in their capability of operating motors. They are capable of similar modifications in construction, and will facilitate the introduction of motors and their adaptation to practical demands. Their efficiency should

be higher than that of the present transformers, and I base my assertion on the following:

In a transformer as constructed at present we produce the currents in the secondary circuit by varying the strength of the primary or exciting currents. If we admit proportionality with respect to the iron core the inductive effect exerted upon the secondary coil will be proportional to the numerical sum of the variations in the strength of the exciting current per unit of time; whence it follows that for a given variation any prolongation of the primary current will result in a proportional loss. In order to obtain rapid variations in the strength of the current, essential to efficient induction, a great number of undulations are required and employed. From this various disadvantages result. These are, increased cost and diminished efficiency of the generator, more waste of energy in heating the cores and also diminished output of the transformer, since the core is not properly utilized, the reversals being too rapid. The inductive effect is also very small in certain phases, as will be apparent from a graphic representation, and there may be periods of inaction, if there are intervals between the succeeding current impulses or waves. In producing a shifting of the poles in the transformer, and thereby inducing currents, the induction is of the ideal character, being always maintained at its maximum action. It is also reasonable to assume that by a shifting of the poles less energy will be wasted than by reversals.

The Continuous Current, Limited, versus The Alternating Current, Unlimited.*

BY G. CUTTER.

You will see by the title of my paper that I declare my position more positively than my predecessors, and I do not claim to be impartial and then offer arguments all tending from one side of the question.

The tendency has been among the originators of central station systems towards high potential, not only in distributing electrical energy but in other departments of engineering; one of the most striking instances outside of our own special department being the high pressure hot water for distributing heat in Boston.

Mr. Abbott, chief engineer of this company, considers his problem simply one of distribution. This is the case with electrical distribution. It is simply the distribution problem, and the question is, the cheapest method of distributing the energy we sell.

That the continuous current has done a great work in the distribution of lights from central stations, none of us will deny, and that in certain cases it has been successful in spite of the limitations of such a method of distribution, we are also pleased to admit. The effort among the originators of central station systems has been in the direction of high potential. We are all more or less familiar with the many and various devices and methods that have been adopted to enable us to use high potentials in distributing our energy. This is not only the case in electrical work, but it is also the tendency in other classes of central station distribution. Outside of our own special department, one of the most striking instances is the system of distributing heat in Boston.

I do not wish to close the door on the continuous current nor on any department of electrical work whatsoever, as I wish for the greatest work possible with electricity, and stand ready to rejoice at the success of any method, be it with continuous current or without. I wish merely to show that in the present stage of our industry, the alternating current has decidedly the best outlook.

Mr. Leonard figures the cost of copper for the feeders of the three-wire system, and the copper and the converters in the converter system, and draws a very pretty diagram to show how far he can go with the continuous current three-wire system for the same money as with the converter system. The very best answer, to my mind, to these figures, is to have Mr. Leonard's customers ask him to put in the installation at the prices he gives. We will, in such a case, give him the advantage of the difference in price of copper.

One feature of this figuring is something I do not quite understand; for instance, in Table No. 3 of the Ward Leonard paper, it is stated, "that with 30 volts maximum loss, the cost of copper per lamp for the three-wire system at 6,000 feet would be $3.87." Then in his analysis of this table he calls this 6,000 feet ".the average feeder length," and says this is equal to a circular area of 18,000 feet, or 3½ miles. How many times have I wished that the cost of copper for distributing on lamps was as elastic as this implies. Now, a radius of 18,000 feet circle is 9,000 feet. Mr. Leonard figures 800 feet between feeder terminals for his mains, and 100 feet from the mains to the lamps. We will suppose that half this distance between feeder terminals, 400 feet, and the 100 feet for the service wires are in a direct line with the feeder itself, thus making the feeder 6,500 feet long. I would like to understand how the cost of wires for a lamp 6,500 feet away can be the same with the same system as for 9,000 feet away. The relative cost of the wire under such circumstances being as the squares of the distances, I make it cut that the wire work for 9,000 feet costs about double that for 6,500 feet.

The continuous current advocates try to scare away the alternating current with the cry of "danger." To attempt this at the present day, in the face of the large amount of good work that has been done with high tension currents, is about like trying to mop out the ocean with a kitchen mop. The people who raise the cry, with few exceptions, do it for a check on the alternating current, not because they fear the danger they portray. If the danger is such as to preclude the high tension system, we might as well stop at that point and not bother to figure on the cost, depreciation, etc., of high tension plants. Their remarks, and the practices of the companies some of them represent, show that neither of them fear this danger. They are kind enough to say they think the converter system might be used as an adjunct to the continuous current plant to reach outlying districts beyond the limits of their favorite, but limited, system. If the alternating current is such a dangerous fellow as they try to prove, why should they advocate its use for outlying points, especially when such points would consist largely of residences? I must ask them if they would distribute lamps around the family hearth for servants and children to handle, with a system that is too dangerous to use in stores and offices? The converter was developed on purpose to enable us to reach customers at a distance, and still have the E. M. F. at the lamps reduced to a harmless quantity. By systems of installation already in use, the secondaries can all be made absolutely safe. The danger then is reduced to the primary wires.

Dynamos of 1,200 volts are run on three-wire sytem. I must therefore ask a direct question. Is a 2,400 volt system of distribution continuous current less dangerous than 1,000 volts alternating? If the tension of 1,000 volts is dangerous, why install and advocate systems of 2,400 volts?

I feel that I must raise another point to show that fear of high tension is assumed for city policy, and not philanthropy. Suppose we do not adopt the policy of grounding the secondary, and some transformer leaks. The individual secondary is thereby subjected to the same tension to ground as the primary; provided, of course, that the other ground comes on the opposite primary wire. On this secondary circuit may be put few lamps that people could handle. This is probable. Therefore the danger of such a leak only exists in a few lamps.

Mr. Leonard says, the best method of distributing the electric energy from a distant point is with the motor generator. Two 1,200 volt dynamos to be connected in multiple and the circuit carried to the upper story of some building where the motor generators are placed. From this upper story the regular three-wire low tension system is distributed Leave out the item of cost of the secondary system, and its limitations, but consider how the danger. If any one motor generator of the whole lot should leak, there would then be the danger of the 2,400 volt tension throughout the whole network. I quote Mr. Leonard: "The motor-generator for this work is ready for market, but it has been learned that the cost per lamp can be very materially reduced by increasing the speed."

The alternating current converter is, as Mr. Kennedy well said, "the simplest piece of apparatus imaginable;" and it has no moving parts whatever; no increase of speed; therefore, the relative danger of leakage between the two converters is almost as one to infinity, in favor of the alternator. And still, the leak in the alternate converter endangers a few lamps only, whereas the leak in the motor generator endangers the whole network. Here is a company with able representatives facing their almighty dollar, and advocating a system in which a leak would give 2,400 volts throughout a network of wires, and then facing somebody else's dollar, and crying "danger" against a system in which a leak gives 1,000 volts to a few lamps, and even that danger can be eliminated.

When Faraday was showing some experiments illustrating his great discoveries, and showed how simple it was to produce the electric spark with his apparatus, the Dean said "he was sorry for it, as it put new power into the hands of the incendiary."

Gentlemen, when any new devices are put forth to the world there are always people who cry them down for one reason or another and generally the cry of danger is raised; but our progress is not checked in any such manner. These considerations lead me to believe that our continuous current friends do not fear the danger or consider it should hinder our progress beyond the limited field of the continuous current.

The alternating current requires no pressure wires, because of the facility of making a voltmeter which compensates for the variation in loads. As the alternator plant is operated with a very low percentage of drop, in this case I have figured on 2½ per cent. The difficulties of regulating for change of load are very slight, and the apparatus for accomplishing this is very cheap. Moreover, wherever regulators are used for alternating currents, they consume little or no power in doing their work—just the reverse of the continuous current regulators.

Whatever improvement is made in the 110 or higher voltage lamp, will also give a proportional benefit in the 50-volt lamp; briefly then, the 50-volt lamp will probably always be 25 per cent. better than the 110-volt lamp.

In distributing our energy we wish that system which will enable us to accomplish the most, and which will be readily adaptable to the various demands.

As Mr. Bliss has promised a paper on the continuous side of this question, I certainly hope he will give us figures that will enable us to understand how the dividends can be paid by the actual earning capacity of large central stations of the continuous system, not only because I wish to know positively that these enterprises are a sure success, but also for the benefit that such demonstrations will be to the alternating side of the question, because if that will pay which is so limited in its capabilities, we can certainly feel sure that another installation furnishing the same class of energy can pay still better by virtue of its greater flexibility and almost limitless possibilities.

Mr. Leonard says: "Cost of operating and maintenance of any system is certainly reduced if they can operate from one source of supply." The remark was made as applying to central stations, but it appears to me to apply also to accumulator stations, because they must be operated at low potential; therefore they must have many of these accumulutor stations, each one of which is of necessity equipped with many and various devices for regulating the feeders, etc. That attempts are being made to run lights from accumulator stations, we are all well aware, and hope, of course, that they will prove a success, but that remains yet to be proven. When they are perfectly developed, and supplied with all the regulating devices above mentioned which appear to be necessary, the possibilities of profit may disappear, and I am free to admit I am afraid they will.

The idea of converting our energy seems to be the prevailing idea to-day, and our electric journals are filled with illustrations, paragraphs, figures, etc., about some sort of a converter system, alternating converter, continuous current converter, accumulator converter, and advocating it, or trying to prove that their special system of conversion is the best. This is interesting, as it shows pretty conclusively the general feeling that the continuous current of itself is altogether too limited in its possibilities for the work that we have in hand all over the world to-day. Our industry is growing, and the people are not satisfied with working within just such prescribed limits. Hence the various devices that enable us to go beyond those limits, and the alternating current seems to be just the thing wanted for the purpose, as it does its work in a manner not accomplished by any other converter system.

Admitting that the continuous current may be made quite a success, it still can never be placed about town in all sorts of situations, and of all sizes, as can the alternating current converter. It is a machine more or less difficult to keep in order, being, as Mr. Leonard says, "run at a high speed," that necessarily means constant watching. Therefore, these converters must be used in secondary stations with low tension system distributed from them. This is also the case with the accumulator. It also requires a great deal of attention, and if used for central station distribution must be placed about town in secondary stations. As the network from each secondary station is low tension, we must still work on high percentage of loss, in order not to have too many stations, and this combination of low potential and high percentage of loss, means constant attention to the regulating devices; that is to say, every one of these secondary stations embraces more or less the difficulties of the present continuous current station. And, further still, the secondary network can give but a uniform electrical condition theoretically; therefore your continuous current, whether it is of the three-wire system, multiple series system, continuous current converter system, or accumulator system, is limited, and very much so, in its possibilities. Any use of them at all requires high engineering ability, and the very best of engineering ability can only accomplish a limited amount of work.

The alternating current is entirely a different sort of a fellow; extremely flexible and unlimited. It enables us to start small and grow with the demands, with but very little trouble in the calculations. The cost of the conductors being a very small part of the whole installation, it is easily determined what the installation will cost. Those of you who have made calculations for the continuous current plant, or have been called upon to furnish the necessary data for such a calculation, appreciate readily the difficulties involved; nearly all of which difficulties disappear the minute you begin to work with the alternating current. The change in the load of a considerable amount in one part or the other is readily taken care of by an ordinary man, and at no very great expense; possibly a little work for the expressman to carry a few converter boxes from one customer who has given up lights to another who has taken some on. There is no great bother about maintaining proper potential. The current will also furnish almost any phases of electricity desired. Instead of having a couple of wires in our rooms which will furnish 110 volts, and no more or no less, we have a couple of wires which will furnish any voltage, or most any quantity desired, so that if a new industry should arise where 8,000 or 10,000 volts are required, two little wires carrying the alternating current will furnish the energy which can be converted to this potential. Or, if a very large quantity is desired of low potential, these same two wires will furnish it.

For the rental of lights alone, the general impression has been that the alternating current can do it satisfactorily.

The work of motors on the alternating current has been discussed sufficiently before the Club, therefore we will await further developments in this direction. The alternating current motor is certainly further advanced to-day than was the continuous current motor when the work commenced with the continuous current distribution, so we will soon be able to rent power from our alternating network, provided it is found policy to do so from the electric lighting circuits.

There are other industries not before the world which certainly bid fair to become of great importance, and as one department has been pretty well developed, I will allude to that more particularly, and that is the welding and manipulating of metals by electricity. I have been fortunate enough to secure a number of samples of metals welded in this way, showing that I am not dealing in "futures" when talking of this industry. I believe that a large source of revenue to central stations that are providing alternating currents will be in furnishing the energy for this class of work. As it may be said that the continuous current is also being used for the welding of metals, I must say that this method has not proven a success, having seen the operation in a large work-shop in Paris, where they tried to make oil tanks by welding metals together with a voltaic arc. I know that the method is not at all a partial success as yet, as metal is oxidized and destroyed, burnt up, so to speak, by the intense heat.

The continuous current can be used for electric welding, but as enormous quantities of current are required the dynamo supplying the same must be near the work. This limits the continuous current very much for this class of work. Not so with the alternating current converter. We can attach on to our two little wires a very small converter for jewelry work, or a very large converter for heavy welding.

Another feature of the question is this, it is easier to work the registering meter on the alternating current than on the continuous current. The difficulty in this class of meter lies in the fact that they must record in proportion to the number of lamps burning, or the ampères used, whereas the work done is, by itself, in proportion to the square of the ampères. This difficulty is quite easily met in the alternating current by the use of a simple kicking coil, but it is not one easily met in the continuous current.

* Abstract of paper read before the Chicago Electric Club.

A Singular Confirmation of the Tesla Theory of Alternating Current Motors.

Nothing is so strongly suggestive of the mysterious workings of the human intellect as the oft recurring fact of the independent discovery of a new scientific principle by two men in different parts of the world, and generally unknown to each other. And in no field has this fact of independent discovery been as apparent as in that of electrical science. We have now another instance to record. Right on the heels of the recent publication of Tesla's very interesting alternating current motor, comes the announcement, in London *Industries*, of a similar discovery by Prof. Galileo Ferraris, of Turin, of which we append a brief abstract:

The principle on which the apparatus is based is exceedingly simple, and will be understood by reference to the accompanying

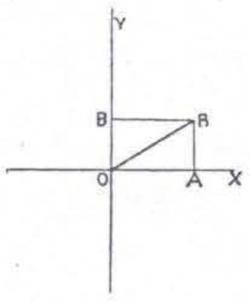

FIG. 1.

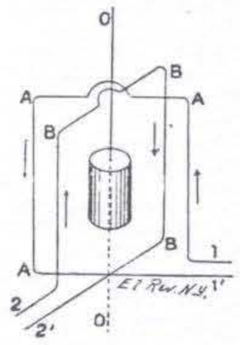

FIG. 2.

sketches. Let in Fig. 1 the lines *O A* and *O B* represent in direction and magnitude the strength of two magnetic fields. The combined action of these fields on a unit pole, placed in the point *O*, would then be represented by the resultant *O R*. Instead of having two distinct fields, we have one resultant field, represented in direction and magnitude by this line. If both fields undergo periodic variations of the same period, the resultant field *O R* will also undergo a periodic variation, and the point *R* will traverse a curve, the form of which depends upon the precise manner in which the lines *O A* and *O B* change with the time. The fields *O A* and *O B* can be produced by two coils, having the lines *O X* and *O Y* respectively for their axes, and which coils are traversed by alternating currents of the same period. If the alternating currents may be expressed as sine functions of the time, and if there is an appreciable lag between the currents in the two coils, the point *R* describes an ellipse round *O* as center. In this case line *O R*, representing the resultant field, revolves round the center, *O*, the direction and magnitude of the resultant field changing at every instant. If, however, there is no lag between the two currents, that is to say, if they pass through zero simultaneously, the direction of the resultant field, *O R*, remains stationary, and the point *R* performs harmonic oscillation over the line *R O* and its prolongation with *O* as center. This may be considered as a special case of the ellipse where the latter has been flattened down to a mathematical line. Another special case occurs when the ellipse becomes a circle, and this must evidently take place when the lag between the two currents is 90°, when the coils are at right angles to each other, and when the component fields are equally strong. A metallic body suspended in the center of the two fields, and free to revolve, must evidently have a tendency to participate in the rotation of the resultant field.

The application of this very simple principle will be clear from Fig. 2, in which the two coils are indicated by the rectectangles *A* and *B*, the connections being made by the the wires 1' and 2' respectively. When alternating currents are sent through these coils a resultant field is produced, which revolves round the line *OO*. In the center, between the coils, is suspended a small hollow cylinder of copper, and as the lines of the resultant field cut the metal Foucault currents are induced, and by the interaction of these induced currents and the revolving field the cylinder is set in rotation. The action is exactly the reverse of that occurring in the well-known experiment in which a copper disc is rapidly revolved below a compass needle, with the result that the compass needle is deflected on account of the induced currents in the copper disc, and ultimately caused to rotate with the copper disc.

Up to the present we have spoken of two distinct currents being required in the coils *A* and *B*, one lagging behind the other by a quarter period; and to perform the experiment we might employ an alternating current dynamo with two circuits in the armature, so arranged with regard to each other as to produce the desired lag. It is, however, possible to perform the experiment by using an ordinary alternating current machine with only one circuit on the armature, and to produce the second current by means of a transformer.

In the first experiment made by Professor Ferraris, a Gaulard & Gibbs transformer, with an equal number of turns in the primary and secondary coils, was used. In the primary circuit was included the coil *A*, consisting of a few turns of stout wire, whilst in the secondary circuit were included an adjustable and non-inductive resistance and the coil *B*, the latter consisting of many turns of fine wire. A small hollow copper cylinder was suspended on a thread in the center of the two coils, as shown in Fig. 2. If the current was sent through only one of the coils, the cylinder remained at rest; but if currents were sent through both coils, the cylinder immediately started to revolve, twisting the thread on which it was suspended. A reversing switch was inserted in the secondary circuit, and if the current through this circuit was inverted, the cylinder was immediately brought to rest, and started in the opposite direction. Professor Ferraris next substituted a small iron cylinder for the copper one, and found equal results; but when using an iron cylinder sufficiently large to nearly fill the place within the coils, the experiment did not succeed so well. He attributes this to the greater self-induction which the presence of iron in a large mass necessarily introduces into both circuits. Another experiment was made with a small iron cylinder, composed of a number of thin discs insulated from each other, and this experiment also succeeded. Foucault currents could not in this case be the cause of rotation, and Professor Ferraris thinks that the rotation is due to hysteresis. A large apparatus was then constructed which is indicated in our sketch, Fig. 3. In this case, the copper cylinder, which was mounted upon a horizontal axis in bearing, had a diameter of 3½ inches, and was 7 inches long, its weight being 11 pounds. This cylinder was closely surrounded by the primary and secondary coils wound upon wooden bobbins. To make room for the

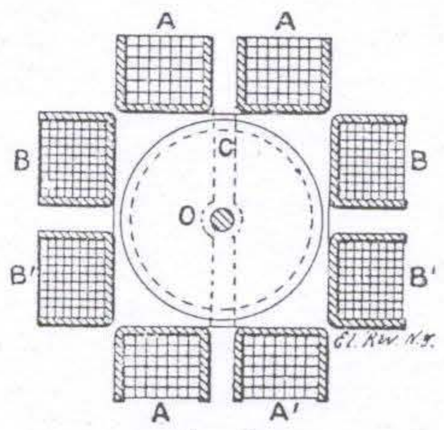

FIG. 3.

shaft each coil was in halves, the primary consisting of 96 turns of 77 mils. wire, both coupled in series, so as to produce the effect of a coil of 192 turns; the secondary consisting of 504 turns of 38 mils. wire, both being coupled in parallel, so as to produce the effect of 504 turns. The resistance of the primary coils was 7.12 and 6.63 ohms respectively, and that of the two secondary coils coupled in parallel was 3.43 ohms. In the secondary circuit was also inserted a rheostat without self induction, and the best results were obtained when the rheostat was set to between 15 and 18 ohms. A Gaulard & Gibbs transformer was used, giving 80 reversals per second. The copper cylinder began to revolve when the primary current was 5 amperes, and with higher currents the velocity could be increased to 900 revolutions per minute, and might have been still further increased but for the somewhat imperfect mechanical arrangements, which occasioned considerable vibrations. To the shaft was applied a small friction dynamometer, and the following table gives the work obtained on the brake by a primary current of 9 amperes at different speeds:

Revolutions per minute:	262	400	546	653	722	770	772	900
Watts obtained on brake:	1.32	2.12	2.65	2.77	2.55	2.40	2.04	0

The maximum energy was obtained at 650 revolutions. Beyond that speed the energy decreased, which is attributed by Professor Ferraris to the imperfect mechanical arrangement of the apparatus, causing a considerable waste of power in vibrations. If it were not for this, the maximum energy would have been obtained at about 1,200 revolutions, whilst at 2,400 revolutions, which is the speed of the revolving resultant field, no energy at all could be obtained. Professor Ferraris suggests that this apparatus may be used for lecture purposes, and as a motor when the power required is small, and it may also be used as an electricity meter. The torque exerted by the revolving field upon the copper cylinder is proportional to the square of the current, and in order that the total number of revolutions performed in a given time may be an indication of the number of coulombs supplied, it is necessary to introduce some opposing force which varies with the square of the velocity. If this can be done, and if the friction of the journals can be sufficiently reduced, an ordinary counter attached to the axis would indicate the quantity of electricity supplied.

Mr. Tesla has produced a practical motor, while Prof. Ferraris has made only a lecture apparatus of no commercial value. The substantial honors belong to Mr. Tesla.

ALTERNATE-CURRENT MOTORS.

Some weeks ago, quoting from a New York contemporary, we were able to direct attention to M. Nikola Tesla's work in connection with the use of alternate currents and motors. At the late meeting of the American Institute of Electrical Engineers, M. Tesla read a paper upon the subject, amply illustrated and descriptive of the work upon which he has been engaged. It is too soon and the materials at command are too scanty to enable a definite conclusion to be arrived at, but whatever further information may bring forth, there is no mistaking the fact that this paper will mark an era in the progress of electrical engineering. The thoughts of many inventors have been directed to the design of alternate current motors, practical men have pointed out the link wanted in the apparatus supplied them, and the supporters of the continuous current system have had their hands considerably strengthened from the fact that no apparatus was discovered whereby energy could be distributed by means of alternate current machines. The advocates of alternate currents pointed out that could such apparatus be devised it would probably lead to a reduction in prices for machines, and decrease the cost of maintenance and the probability of breakdowns. M. Tesla's work, be it crude and impracticable, or fairly perfect and practical, will enforce the dictum that a want has only to be felt, and sooner or later it will be supplied. We have never sided with those who professed such apparatus to be impossible. The greater number of mechanical and continuously rotary movements are obtained by the application of opposite forces at different periods. The maidservant draws a pail of water from the bottom of a well by alternately pushing and pulling on the handle of the windlass. The locomotive goes continuously forward, by reason of the expansive force of steam applied first in one direction then in the opposite direction, and it was doing an injustice to the inventive talent of the world to believe that the push and pull of electricity could not be used to obtain continuous motion in any desired direction. The views expressed by M. Tesla in his paper will be carefully studied, and, without doubt, there will follow many improvements in the direction he has pointed out.

A NEW SYSTEM OF ALTERNATE CURRENT MOTORS AND TRANSFORMERS.*

BY NIKOLA TESLA.

In the presence of the existing diversity of opinion regarding the relative merits of the alternate and continuous current systems, great importance is attached to the question whether alternate currents can be successfully utilised in the operation of motors. The transformers, with their numerous advantages, have afforded us a relatively perfect system of distribution, and although, as in all branches of the art, many improvements are desirable, comparatively little remains to be done in this direction. The transmission of power, on the contrary, has been almost entirely confined to the use of continuous currents, and notwithstanding that many efforts have been made to utilise alternate currents for this purpose, they have, up to the present, at least, as far as known, failed to give the result desired. Of the various motors adapted to be used on alternate current circuits the following have been mentioned :—1. A series motor with subdivided field. 2. An alternate current generator having its field excited by continuous currents. 3. Elihu Thomson's motor. 4. A combined alternate and continuous current motor. Two more motors of this kind have suggested themselves to me. 1. A motor with one of its circuits in series with a transformer and the other in the secondary of the transformer. 2. A motor having its armature circuit connected to the generator and the field coils closed upon themselves. These, however, I mention only incidentally.

The subject which I now have the pleasure of bringing to your notice is a novel system of electric distribution and transmission of power by means of alternate currents, affording peculiar advantages, particularly in the way of motors, which I am confident will at once establish the superior adaptability of these currents to the transmission of power, and will show that many results heretofore unattainable can be reached by their use; results which are very much desired in the practical operation of such systems, and which cannot be accomplished by means of continuous currents.

Before going into a detailed description of this system, I think it necessary to make a few remarks with reference to certain conditions existing in continuous current generators and motors, which, although generally known, are frequently disregarded.

In our dynamo machines, it is well known, we generate alternate currents which we direct by means of a commutator, a complicated device and, it may be justly said, the source of most of the troubles experienced in the operation of the machines. Now, the currents so directed cannot be utilised in the motor, but they must—again by means of a similar unreliable device—be reconverted into their original state of alternate currents. The function of

* Read before the American Institute of Electrical Engineers, May 16.

the commutator is entirely external, and in no way does it affect the external working of the machines. In reality, therefore, all machines are alternate current machines, the currents appearing as continuous only in the external circuit during their transit from generator to motor. In view simply of this fact, alternate currents would commend themselves as a more direct application of electrical energy, and the employment of continuous currents would only be justified if we had dynamos which would primarily generate, and motors which would be directly actuated by such currents.

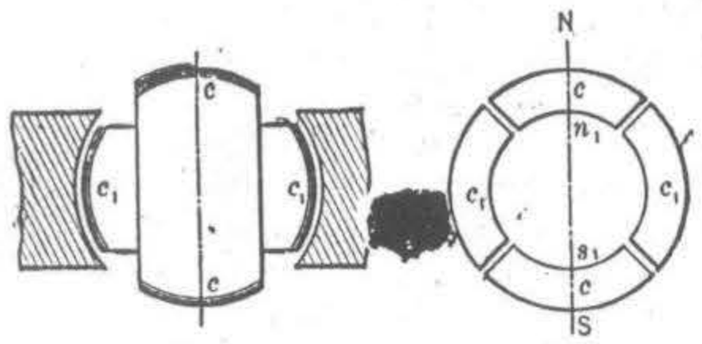

Fig. 1. Fig. 1a.

But the operation of the commutator on a motor is twofold; firstly, it reverses the currents through the motor, and secondly, it effects, automatically, a progressive shifting of the poles of one of its magnetic constituents. Assuming, therefore, that both of the useless operations in the system—that is to say, the directing of the alternate currents on the generator and reversing the direct currents on the motor—be eliminated, it would still be necessary, in order to cause a rotation of the motor, to produce a progressive shifting of the poles of one of its elements, and the question presented itself, How to perform this operation by the direct action of alternate currents? I will now proceed to show how this result was accomplished.

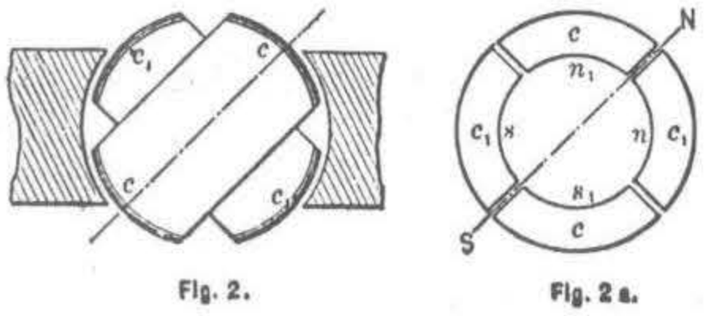

Fig. 2. Fig. 2a.

In the first experiment a drum-armature was provided with two coils at right angles to each other, and the ends of these coils were connected to two pairs of insulated contact rings as usual. A ring was then made of thin insulated plates of sheet iron, and wound with four coils, each two opposite coils being connected together so as to produce free poles on diametrically opposite sides of the ring. The remaining free ends of the coils were then connected to the contact rings of the generator armature so as to form two independent circuits, as indicated in Fig. 9. It may now be seen what results were secured in this combination, and with this view I would refer to the diagrams, Figs. 1 to 8*a*. The field of the generator being independently excited, the rotation of the armature sets up currents

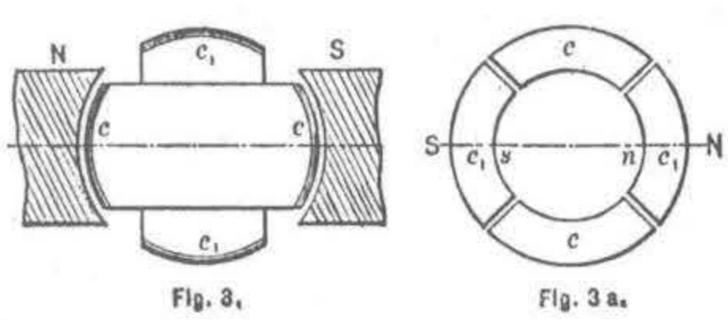

Fig. 3. Fig. 3a.

in the coils *c c* varying in strength and direction in the well-known manner. In the position shown in Fig. 1 the current in coil *c* is nil, while coil c_1 is traversed by its maximum current, and the connections may be such that the ring is magnetised by the coils *c c* as indicated by the letters, N S, in Fig. 1*a*, the magnetising effect of the coils *c c* being nil, since these coils are included in the circuit of coil *c*.

In Fig. 2 the armature coils are shown in a more advanced position, one-eighth of one revolution being completed. Fig. 2*a* illustrates the corresponding magnetic condition of the ring. At this moment the coil *c* generates a current of the same direction as previously, but weaker, producing the poles, n_1, s_1, upon the ring; the coil *c* also generates a current of the same direction, and the connections may be such that the coils *c c* produce the poles *n s*, as shown in Fig. 2*a*. The resulting polarity is indicated by the letters N S, and it will be observed that the poles of the ring have been shifted one-eighth of the periphery of the same.

In Fig. 3 the armature has completed one-quarter of one revolution. In this phase the current in coil *c* is a maximum, and of such direction as to produce the poles N S, in Fig. 3*a*, whereas the current in coil c_1 is nil, this coil being at its neutral position. The poles, N S, in Fig.

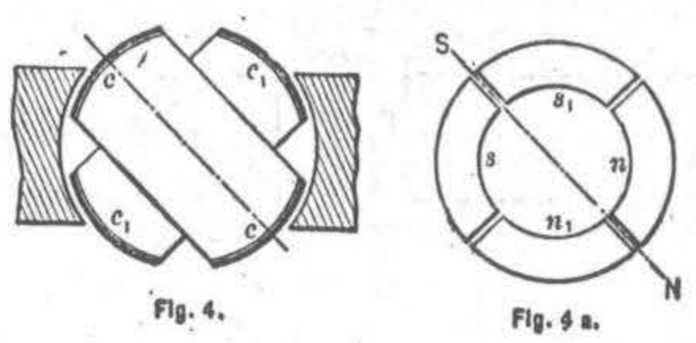

Fig. 4. Fig. 4a.

3*a* are thus shifted one-quarter of the circumference of the ring.

Fig. 4 shows the coils *c c* in a still more advanced position, the armature having completed three-eighths of one revolution. At that moment the coil *c* still generates a current of the same direction as before, but of less strength, producing the comparatively weaker poles *n s*, in Fig. 4*a*. The current in the coil *c* is of the same strength, but of opposite direction. Its effect is, therefore, to produce upon the ring the poles n_1 and s_1 as indicated, and a polarity N S results, the poles now being shifted three-eighths of the periphery of the ring.

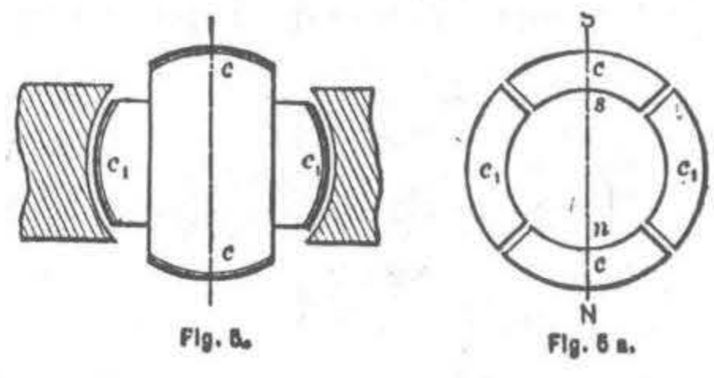

Fig. 5. Fig. 5a.

In Fig. 5, one-half of one revolution of the armature is completed, and the resulting magnetic condition of the ring is indicated in Fig. 5*a*. Now, the current in coil *c* is nil, while the coil c_1 yields its maximum current, which is of the same direction as previously; the magnetising effect is therefore due to the coils c_1 c_1 alone, and, referring to Fig. 5*a*, it will be observed that the poles, N S, are shifted one-half of the circumference of the ring. During the next half-revolution the operations are repeated, as represented in the Figs. 6 to 8*a*.

A reference to the diagrams will make it clear that during one revolution of the armature the poles of the ring are shifted once around its periphery, and each revolution producing like effects, a rapid whirling of the poles in

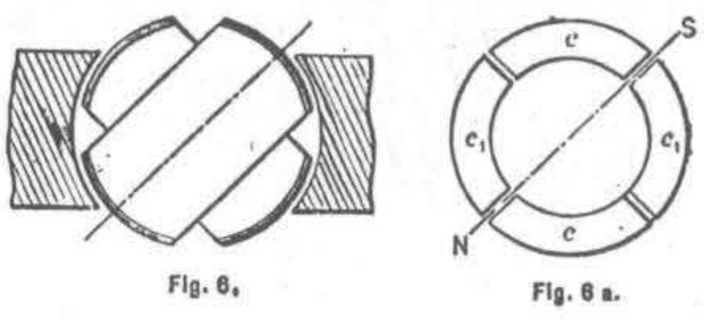

Fig. 6. Fig. 6a.

harmony with the rotation of the armature is the result. If the connections of either one of the circuits in the ring are reversed, the shifting of the poles is made to progress in the opposite direction, but the operation is identically the same. Instead of using four wires, with like result, three wires may be used, one forming a common return for both circuits.

This rotation or whirling of the poles manifests itself in a series of curious phenomena. If a delicately pivoted disc of steel or other magnetic metal, Fig. 9, is approached to the ring, it is set in rapid rotation, the direction of rotation varying with the position of the disc. For instance, noting the direction outside of the ring, it will be found that inside the ring it turns in an opposite direction, while it is unaffected if placed in a position symmetrical to the ring.

This is easily explained. Each time that a pole approaches it induces an opposite pole in the nearest point on the disc, and an attraction is produced upon that point. Owing to this, as the pole is shifted further away from the disc a tangential pull is exerted upon the same, and the action being constantly repeated a more or less rapid rotation of the disc is the result. As the pull is exerted mainly upon that part which is nearest to the ring, the rotation outside and inside, or right and left respectively, is in opposite directions. When placed symmetrically to the ring, the pull on opposite sides of the disc being equal, no rotation

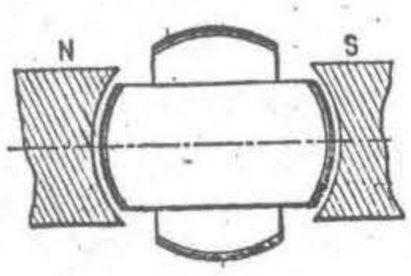

Fig. 7.

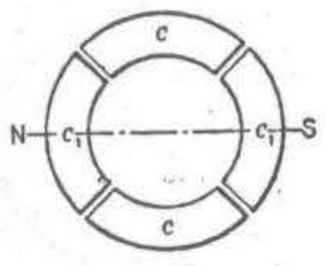

Fig. 7 a.

results. The action is based on the magnetic inertia of the iron; for this reason a disc of hard steel is much more affected than a disc of soft iron, the latter being capable of very rapid variations of magnetism. Such a disc has proved to be a very useful instrument in all these investigations, as it has enabled me to detect any irregularity in the action. A curious effect is also produced upon iron filings. By placing some upon a paper, and holding them externally quite close to the ring, they are set in a vibrating motion, remaining in the same place, although the paper may be moved back and forth; but in lifting the paper to a certain height which seems to be dependent on the intensity of the poles and the speed of rotation, they are thrown away in a direction always opposite to the supposed movement of the poles. If a paper with filings is put flat upon the ring

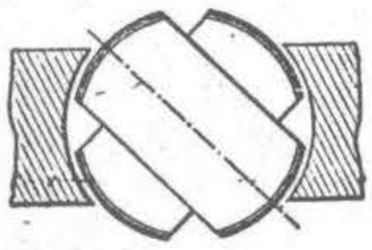

Fig. 8.

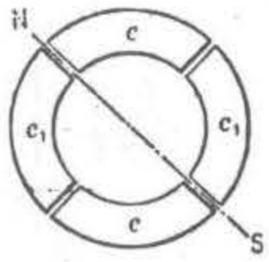

Fig. 8 a.

and the current turned on suddenly, the existence of a magnetic whirl may be easily observed.

To demonstrate the complete analogy between the ring and a revolving magnet, a strongly energised electro-magnet was rotated by mechanical power, and phenomena identical in every particular to those mentioned above were observed.

Obviously, the rotation of the poles produces corre sponding inductive effects, and may be utilised to generate currents in a closed conductor placed within the influence of the poles. For this purpose it is convenient to wind a ring

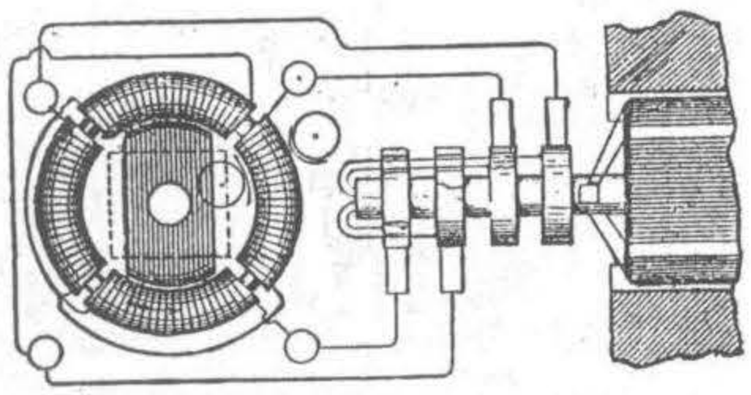

Fig. 9.

with two sets of superimposed coils, forming respectively the primary and secondary circuits. In order to secure the most economical results the magnetic circuit should be completely closed, as shown in Fig. 10, and with this object in view the construction may be modified at will.

The inductive effect exerted upon the secondary coils will be mainly due to the shifting or movement of the magnetic action; but there may also be currents set up in the circuits in consequence of the variations in the intensity of the poles. However, by properly designing the generator and determining the magnetising effect of the primary coils, the latter element may be made to disappear. The intensity of the poles being maintained constant, the action of the apparatus will be perfect, and the same result will be secured as though the shifting were effected by means of a commutator with an infinite number of bars. In such case the theoretical relation between the energising effect of each set of primary coils and their resultant magnetising effect may be expressed by the equation of a circle having its centre coinciding with that of an orthogonal system of axes, and in which the radius represents the resultant and the co-ordinates both of its components. These are then respectively the sine and cosine of the angle, α, between the radius and one of the axes ($o\ x$). Referring to Fig. 11* we have $r^2 = x^2 + y^2$; where $x = r$ cos. α, and $y = r$ sin. α.

Assuming the magnetising effect of each set of coils in the transformer to be proportional to the current—which may be admitted for weak degrees of magnetisation—then $x = \mathrm{K}\,c$ and $y = \mathrm{K}\,c^1$, where K is a constant and c and c^1 the current in both sets of coils respectively. Supposing, further, the field of the generator to be uniform, we have for constant speed $c^1 = \mathrm{K}^1$ sin. α, and $c = \mathrm{K}^1$ sin. $(90° + \alpha) = \mathrm{K}^1$ cos. α, where K^1 is a constant. See Fig. 12.

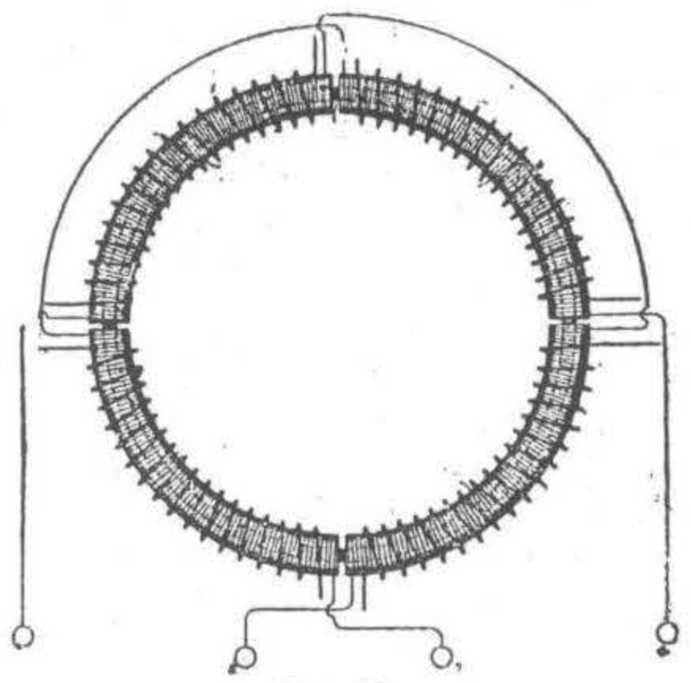

Fig. 10.

Therefore, $x = \mathrm{K}\,c = \mathrm{K}\,\mathrm{K}^1$ cos. α;
$y = \mathrm{K}\,c^1 = \mathrm{K}\,\mathrm{K}^1$ sin. α, and
$\mathrm{K}\,\mathrm{K}^1 = r$.

That is, for a uniform field the disposition of the two coils at right angles will secure the theoretical result, and the intensity of the shifting poles will be constant. But from $r^2 = x^2 + y^2$ it follows that for $y = 0$, $r = x$; it follows that the joint magnetising effect of both sets of coils should be equal to the effect of one set when at its maximum action. In transformers, and in a certain class of motors, the fluctuation of the poles is not of great importance; but in another class of these motors it is desirable to obtain the theoretical result.

In applying this principle to the construction of motors, two typical forms of motor have been developed. First, a form having a comparatively small rotary effort at the

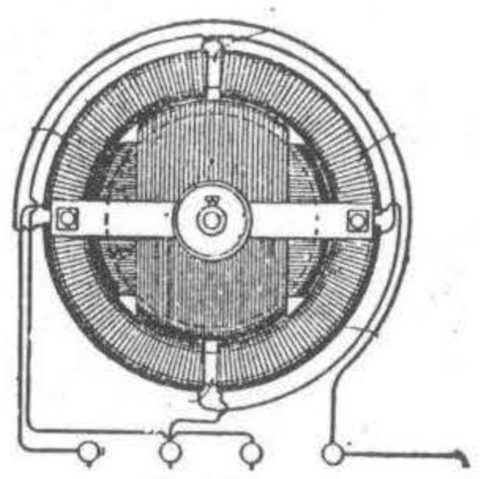

Fig. 14.

start, but maintaining a perfectly uniform speed at all loads, which motor has been termed synchronous. Second, a form possessing a great rotary effort at the start, the speed being dependent on the load.

These motors may be operated in three different ways: 1. By the alternate currents of the source only. 2. By a combined action of these and of induced currents. 3. By the joint action of alternate and continuous currents.

The simplest form of a synchronous motor is obtained by winding a laminated ring provided with pole projections with four coils, and connecting the same in the manner

* By an error of engraver, Figs. 11, 12, and 13 cannot be given. Fortunately Figs. 11 and 12 are simple trigonometrical diagrams which the reader can easily construct from the text—Ed. *E.E.*

before indicated. An iron disc, having a segment cut away on each side, may be used as an armature. Such a motor is shown in Fig. 9. The disc being arranged to rotate freely within the ring in close proximity to the projections, it is evident that as the poles are shifted it will, owing to its tendency to place itself in such a position as to embrace the greatest number of the lines of force, closely follow the movement of the poles, and its motion will be synchronous with that of the armature of the generator—that is, in the peculiar disposition shown in Fig. 9, in which the armature produces by one revolution two current impulses in each of the circuits. It is evident that if, by one revolution of the armature, a greater number of impulses is produced, the speed of the motor will be correspondingly increased. Considering that the attraction exerted upon the disc is greatest when the same is in close proximity to the poles, it follows that such a motor will maintain exactly the same speed at all loads within the limits of its capacity.

To facilitate the starting, the disc may be provided with a coil closed upon itself. The advantage secured by such a coil is evident. On the start, the currents sets up in the coil strongly energise the disc and increase the attraction exerted upon the same by the ring, and currents are generated in the coil as long as the speed of the armature is inferior to that of the poles. Considerable work may be performed by such a motor even if the speed be below normal. The intensity of the poles being constant, no currents will be generated in the coil when the motor is turning at its normal speed.

Instead of closing the coil upon itself, its ends may be connected to two insulated sliding rings, and a continuous current supplied to these from a suitable generator. The proper way to start such a motor is to close the coil upon itself until the normal speed is reached, or nearly so, and then turn on the continuous current. If the disc be very strongly energised by a continuous current, the motor may not be able to start, but if it be weakly energised, or generally so that the magnetising effect of the ring is preponderating, it will start and reach the normal speed. Such a motor will maintain absolutely the same speed at all loads. It has also been found that if the motive power of the generator is not excessive, by checking the motor the speed of the generator is diminished in synchronism with that of the motor. It is characteristic of this form of motor that it cannot be reversed by reversing the continuous current through the coil.

The synchronism of these motors may be demonstrated experimentally in a variety of ways. For this purpose it is best to employ a motor consisting of a stationary field magnet and an armature arranged to rotate within the same, as indicated in Fig. 13. In this case the shifting of the poles of the armature produces a rotation of the latter in the opposite direction. It results therefrom that when the normal speed is reached, the poles of the armature assume fixed position relatively to the field magnet and the same is magnetised by induction, exhibiting a distinct pole on each of the pole pieces. If a piece of soft iron is approached to the field-magnet, it will at the start be attracted with a rapid vibrating motion produced by the reversals of polarity of the magnet; but as the speed of the armature increases the vibrations become less and less frequent, and finally entirely cease. Then the iron is weakly but permanently attracted, showing that the synchronism is reached and the field-magnet energised by induction.

The disc may also be used for the experiment. If held quite close to the armature, it will turn as long as the speed of rotation of the poles exceeds that of the armature; but when the normal speed is reached, or very nearly so, it ceases to rotate and is permanently attracted.

A crude but illustrative experiment is made with an incandescent lamp. Placing the lamp in circuit with the continuous current generator, and in series with the magnet-coil, rapid fluctuations are observed in the light in consequence of the induced currents set up in the coil at the start; the speed increasing, the fluctuations occur at longer intervals, until they entirely disappear, showing that the motor has attained its normal speed.

A telephone receiver affords a most sensitive instrument; when connected to any circuit in the motor the synchronism may be easily detected on the disappearance of the induced currents.

In motors of the synchronous type it is desirable to maintain the quantity of the shifting magnetism constant, especially if the magnets are not properly subdivided.

To obtain a rotary effort in these motors was the subject of long thought. In order to secure this result, it was necessary to make such a disposition that while the poles of one element of the motor are shifted by the alternate currents of the source, the poles produced upon the other elements should always be maintained in the proper relation to the former, irrespective of the speed of the motor. Such a condition exists in a continuous current motor; but in a synchronous motor, such as described, this condition is fulfilled only when the speed is normal.

The object has been attained by placing within the ring a properly subdivided cylindrical iron core wound with several independent coils closed upon themselves. Two coils at right angles are sufficient, as in Fig. 14, but a greater number may be advantageously employed. It results from this disposition that when the poles of the ring are shifted, currents are generated in the closed armature coils. These currents are the most intense at or near the points of the greatest density of the lines of force, and their effect is to produce poles upon the armature at right angles to those of the ring, at least theoretically so; and since this action is entirely independent of the speed—that is, as far as the location of the poles is concerned—a continuous pull is exerted upon the periphery of the armature. In many respects these motors are similar to the continuous current motors. If load is put on, the speed, and also the resistance of the motor, is diminished and more current is made to pass through the energising coils, thus increasing the effect. Upon the load being taken off, the counter-electromotive force increases and less current passes through the primary or energising coils. Without any load the speed is very nearly equal to that of the shifting poles of the field magnet.

It will be found that the rotary effort in these motors fully equals that of the continuous current motors. The effort seems to be greatest when both armature and field-magnet are without any projections; but as in such dispositions the field cannot be very concentrated, probably the best results will be obtained by leaving pole projections on one of the elements only. Generally, it may be stated that the projections diminish the torque and produce a tendency to synchronism.

A characteristic feature of motors of this kind is their capacity of being very rapidly reversed. This follows from the peculiar action of the motor. Suppose the armature to be rotating and the direction of rotation of the poles to be reversed, the apparatus then represents a dynamo machine, the power to drive this machine being the momentum stored up in the armature, and its speed being the sum of the speeds of the armature and the poles. If we now consider that the power to drive such a dynamo would be very nearly proportional to the third power of the speed, for this reason alone the armature should be quickly reversed. But simultaneously with the reversal another element is brought into action; namely, as the movement of the poles with respect to the armature is reversed, the motor acts like a transformer in which the resistance of the secondary circuit would be abnormally diminished by producing in this circuit an additional E.M.F. Owing to these causes the reversal is instantaneous.

If it is desirable to secure a constant speed, and at the same time a certain effort at the start, this result may be easily attained in a variety of ways. For instance, two armatures, one for torque, and the other for synchronism, may be fastened on the same shaft, and any desired preponderance may be given to either one; or an armature may be wound for rotary effort, but a more or less pronounced tendency to synchronism may be given to it by properly constructing the iron core; and in many other ways.

As a means of obtaining the required phase of the currents in both the circuits, the disposition of the two coils at right angles is the simplest, securing the most uniform action; but the phase may be obtained in many other ways, varying with the machine employed. Any of the dynamos

at present in use may be easily adapted for this purpose by making connections to proper points of the generating coils. In closed circuit armatures, such as used in the continuous-current systems, it is best to make four derivations from equi-distant points or bars of the commutator, and to connect the same to four insulated sliding rings on the shaft. In this case each of the motor circuits is connected to two diametrically opposite bars of the commutator. In such a disposition the motor may also be operated at half the potential, and on the three-wire plan, by connecting the motor circuits in the proper order to three of the contact rings.

In multipolar dynamo machines, such as use the converter systems, the phase is conveniently obtained by winding upon the armature two series of coils in such a manner that while the coils of one set or series are at their maximum production of current, the coils of the other will be at their neutral position, or nearly so, whereby both sets of coils may be subjected simultaneously or successively to the inducing action of the field-magnets.

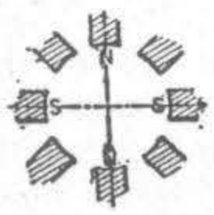

Fig. 15.

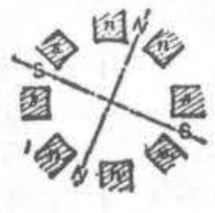

Fig. 16.

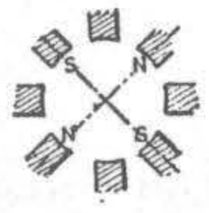

Fig. 17.

Generally, the circuits in the motor will be similarly disposed, and various arrangements may be made to fulfil the requirements; but the simplest and most practicable is to arrange primary circuits on stationary parts of the motor, thereby obviating, at least, in certain forms, the employment of sliding contacts. In such a case the magnet coils are connected alternately in both the circuits; that is, 1, 3, 5 in one, and 2, 4, 6 in the other, Fig. 15, and the coils of each set of series may be connected all in the same manner, or alternately in opposition, Fig. 16. In the latter case a motor, with half the number of poles, will result, and its action will be correspondingly modified, Fig. 17.

The employment of multipolar motors secures in this system an advantage much desired and unattainable in the continuous-current system, and that is, that a motor may be made to run exactly at a predetermined speed irrespective of imperfections in construction of the load, and, within certain limits, of electromotive force and current strength.



Fig. 18.

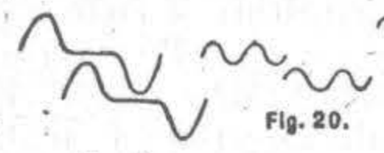

Fig. 19.

Fig. 20.

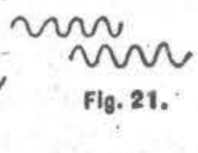

Fig. 21.

In a general distribution system of this kind the following plan should be adopted. At the central station of supply, a generator should be provided having a considerable number of poles. The motors operated from this generator should be of the synchronous type, but possessing sufficient rotary effort to insure their starting. With the observance of proper rules of construction it may be admitted that the speed of each motor will be in some inverse proportion to its size, and the number of poles should be chosen accordingly. Still, exceptional demands may modify this rule. In view of this, it will be advantageous to provide each motor with a greater number of pole projections or coils, the number being preferably a multiple of two and three. By this means, by simply changing the connections of the coils, the motor may be adapted to any probahle demands.

If the number of the poles in the motor is even, the action will be harmonious and the proper result will be obtained; if this is not the case the best plan to be followed is to make a motor with a double number of poles, and connect the same in the manner before indicated, so that half the number of poles result. Suppose, for instance, that the generator has twelve poles and it would be desired to obtain a speed equal to $\frac{12}{7}$ of the speed of the generator. This would require a motor with seven pole projections or magnets, and such a motor could not be properly connected in the circuits unless fourteen armature coils would be provided, which would necessitate the employment of sliding contacts. To avoid this, the motor should be provided with fourteen magnets and seven connected in each circuit, the magnets in each circuits alternating among themselves. The armature should have fourteen closed coils. The action of the motor will not be quite as perfect as in the case of an even number of poles, but the drawback will not be of a serious nature.

However, the disadvantages resulting from this unsymmetrical form will be reduced in the same proportion as the number of the poles is augmented.

If the generator has, say, n, and the motor n_1 poles, the speed of the motor will be equal to that of the generator multiplied by $\frac{n}{n_1}$.

The speed of the motor will generally be dependent on the number of the poles, but there may be exceptions to this rule. The speed may be modified by the phase of the currents in the circuits, or by the character of the current impulses or by intervals between each or between groups of impulses. Some of the possible cases are indicated in the diagrams, Figs. 18, 19, 20 and 21, which are self-explanatory. Fig. 18 represents the condition generally existing, and which secures the best result. In such a case, if the typical form of motor illustrated in Fig. 14 is employed, one complete wave in each circuit will produce one revolution of the motor. In Fig. 19 the same result will be effected by one wave in each circuit; in Fig. 20 by two, and in Fig. 21 by four waves.

By such means any desired speed may be attained; that is, at least within the limits of practical demands. This system possesses this advantage besides others, resulting from simplicity. At full loads, the motors show an efficiency fully equal to that of the continuous current motors. The transformers present an additional advantage in their capability of operating motors. They are capable of similar modifications in construction, and will facilitate the introduction of motors and their adaptation to practical demands. Their efficiency should be higher than that of the present transformers, and I base my assertion on the following:

In a transformer as constructed at present we produce the currents in the secondary circuit by varying the strength of the primary or exciting currents. If we admit proportionality with respect to the iron core, the inductive effect exerted upon the secondary coil will be proportional to the numerical sum of the variations in the strength of the exciting current per unit of time: whence it follows that for a given variation, any prolongation of the primary current will result in a proportional loss. In order to obtain rapid variations in the strength of the current, essential to efficient induction, a great number of undulations are required and employed. From this, various disadvantages result. These are increased cost and diminished efficiency of the generator, more waste of energy in heating the cores, and also diminished output of the transformer, since the core is not properly utilised, the reversals being too rapid. The inductive effect is also very small in certain phases, as will be apparent from a graphic representation, and there may be periods of inaction, if there are intervals between the succeeding current impulses or waves. In producing a shifting of the poles in the transformer, and thereby inducing currents, the induction is of the ideal character, being always maintained at its maximum action. It is also reasonable to assume that by a shifting of the poles less energy will be wasted than by reversals.

A NEW SYSTEM OF ALTERNATE CURRENT MOTORS AND TRANSFORMERS.*

By NIKOLA TESLA.

IN the presence of the existing diversity of opinion regarding the relative merits of the alternating and continuous current systems, great importance is attached to the question whether alternate currents can be successfully utilised in the operation of motors. The transformers, with their numerous advantages, have afforded us a relatively perfect system of distribution, and although, as in all branches of the art, many improvements are desirable, comparatively little remains to be done in this direction. The transmission of power, on the contrary, has been almost entirely confined to the use of continuous currents, and notwithstanding that many efforts have been made to utilise alternate currents for this purpose, they have, up to the present, at least as far as known, failed to give the result desired. Of the various motors adapted to be used on alternate current circuits the following have been mentioned :—1. A series motor with subdivided field. 2. An alternate current generator having its field excited by continuous currents. 3. Elihu Thomson's motor. 4. A combined alternate and continuous current motor. Two more motors of this kind have suggested themselves to me. 1. A motor with one of its circuits in series with a transformer and the other in the secondary of the transformer. 2. A motor having its armature circuit connected to the generator and the field coils closed upon themselves. These, however, I mention only incidentally.

The subject which I now have the pleasure of bringing to your notice is a novel system of electric distribution and transmission of power by means of alternate currents, affording peculiar advantages, particularly in the way of motors, which I am confident will at once establish the superior adaptability of these currents to the transmission of power, and will show that many results heretofore unattainable can be reached by their use; results which are very much desired in the practical operation of such systems, and which cannot be accomplished by means of continuous currents.

Before going into a detailed description of this system, I think it necessary to make a few remarks with reference to certain conditions existing in continuous current generators and motors, which, although generally known, are frequently disregarded.

In our dynamo machine, it is well known, we generate alternate currents, which we direct by means of a commutator, a complicated device, and, it may be justly said, the source of most of the troubles experienced in the operation of the machines. Now, the currents so directed cannot be utilised in the motor, but they must—again by means of a similar unreliable device—be reconverted into their original state of alternate currents. The function of the commutator is entirely external, and in no way does it affect the internal working of the machines. In reality,

* Read before the American Institute of Electrical Engineers, May 16th, 1888.

therefore, all machines are alternate current machines, the currents appearing as continuous only in the external circuit during their transit from generator to motor.

In view simply of this fact, alternate currents would commend themselves as a more direct application of electrical energy, and the employment of continuous currents would only be justified if we had dynamos which would primarily generate, and motors which would be directly actuated by such currents.

But the operation of the commutator on a motor is two-fold; firstly, it reverses the currents through the motor, and secondly, it effects, automatically, a progressive shifting of the poles of one of its magnetic constituents. Assuming, therefore, that both of the useless operations in the system, that is to say the directing of the alternate currents on the generator and reversing the direct currents on the motor, be eliminated, it would still be necessary, in order to cause a rotation of the motor, to produce a progressive shifting of the poles of one of its elements, and the question presented itself, How to perform this operation by the direct action of alternate currents? I will now proceed to show how this result was accomplished.

In the first experiment a drum armature was provided with two coils at right angles to each other, and the ends of these coils were connected to two pairs of insulated contact rings as usual. A ring was then made of thin insulated plates of sheet iron and wound with four coils, each two opposite coils being connected together so as to produce free poles on diametrically opposite sides of the ring. The remaining free ends of the coils were then connected to the contact rings of the generator armature so as to form two independent circuits, as indicated in fig. 9. It may now be seen what results were secured in this combination, and with this view I would refer to the diagrams, figs. 1 to 8*a*. The field of the generator being independently excited, the rotation of the armature sets up currents in the coils, *c*, *c*, varying in strength

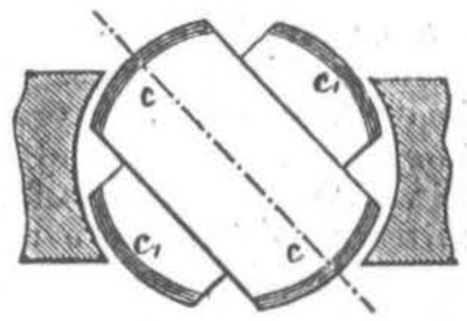

FIG 4.

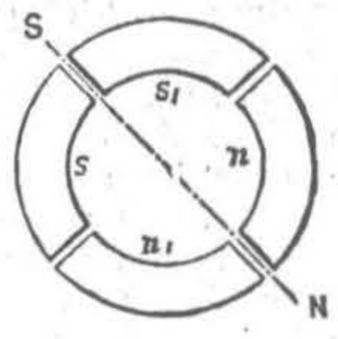

FIG. 4A.

and direction in the well-known manner. In the position shown in fig. 1 the current in coil, *c*, is nil, while coil, c^1, is traversed by its maximum current, and the connections may be such that the ring is magnetised by the coils, *c*, *c*, as indicated by the letters, N, S, in fig. 1*a*, the magnetising effect of the coils, *c*, *c*, being nil, since these coils are included in the circuit of coil, *c*.

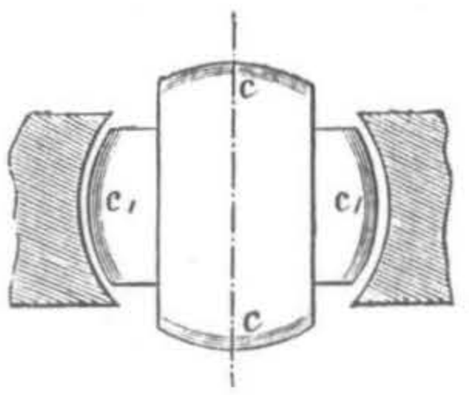

FIG. 1.

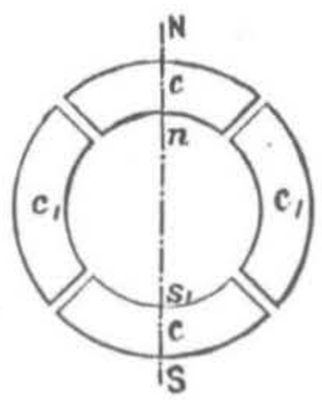

FIG. 1A.

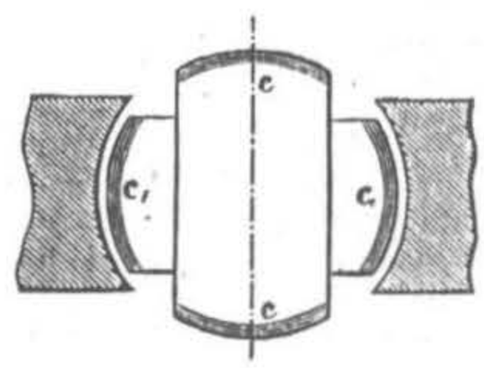

FIG. 5.

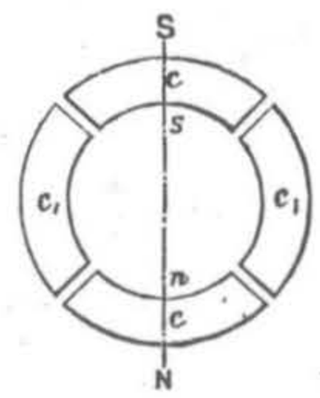

FIG. 5A.

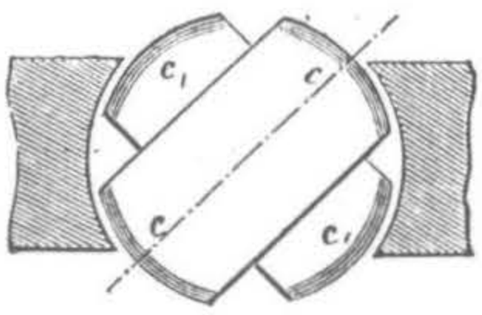

FIG. 2.

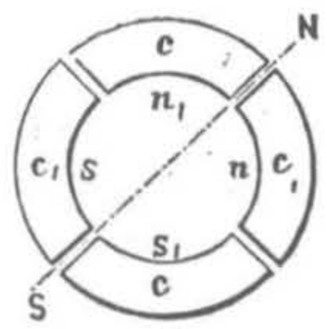

FIG. 2A.

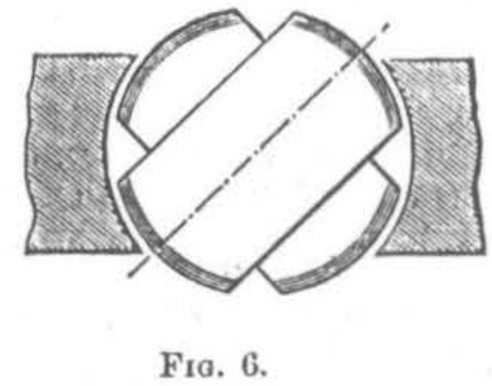

FIG. 6.

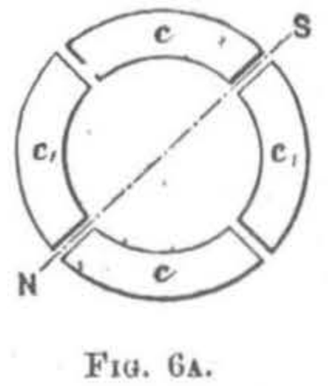

FIG. 6A.

In fig. 2 the armature coils are shown in a more advanced position, one-eighth of one revolution being completed. Fig. 2*a* illustrates the corresponding magnetic condition of the ring. At this moment the coil, *c*, generates a current of the same direction as previously, but weaker, producing the poles, n_1, s_1, upon the ring; the coil, *c*, also generates a current of the same direction,

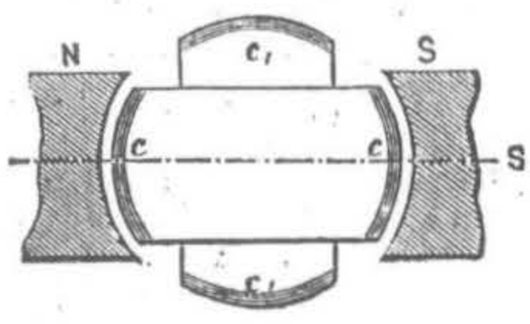

FIG. 3.

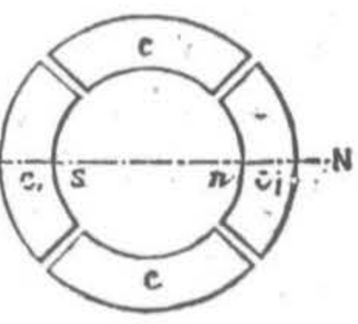

FIG. 3A.

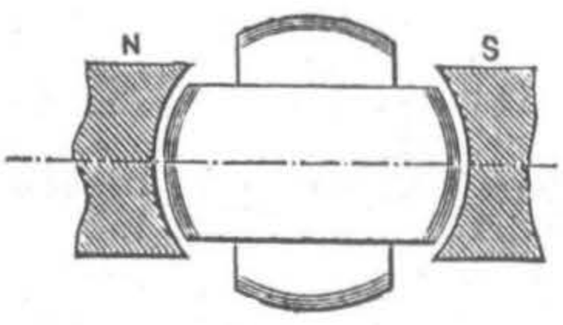

FIG. 7.

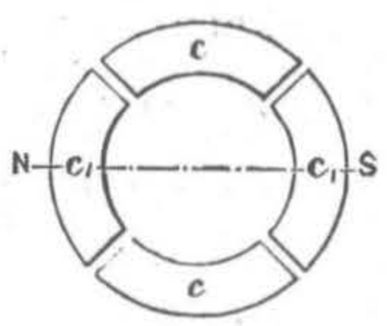

FIG. 7A.

and the connections may be such that the coils, *c*, *c*, produce the poles, *n*, *s*, as shown in fig. 2*a*. The resulting polarity is indicated by the letters, N, S, and it will be observed that the poles of the ring have been shifted one-eighth of the periphery of the same.

In fig. 3 the armature has completed one-quarter of one revolution. In this phase the current in coil, *c*, is a maximum, and of such direction as to produce the poles, N, S, in fig. 3*a*, whereas the current in coil, c_1, is nil, this coil being at its neutral position. The poles, N, S, in fig. 3*a* are thus shifted one-quarter of the circumference of the ring.

Fig. 4 shows the coils, *c*, *c*, in a still more advanced position, the armature having completed three-eighths of one revolution. At that moment the coil, *c*, still generates a current of the same direction as before, but of less strength, producing the comparatively weaker poles, *n*, *s*, in fig. 4*a*. The current in the coil, *c*, is of the same strength, but of opposite direction. Its effect is, therefore, to produce upon the ring the poles, n_1 and s_1, as indicated, and a polarity, N, S, results, the poles now being shifted three-eighths of the periphery of the ring.

In fig. 5 one-half of one revolution of the armature is completed, and the resulting magnetic condition of the ring is indicated in fig. 5*a*. Now, the current in coil, *c*, is nil, while the coil, *c*, yields its maximum current, which is of the same direction as previously; the magnetising effect is therefore due to the coils, *c*, *c*, alone, and, referring to fig. 5*a*, it will be observed that the poles, N, S, are shifted one-half of the circumference of the ring. During the next half revolution the operations are repeated, as represented in the figs. 6 to 8*a*.

A reference to the diagrams will make it clear that during one revolution of the armature the poles of the ring are shifted once around its periphery, and each revolution producing like effects, a rapid whirling of the poles in harmony with the rotation of the armature is the result. If the connection of either one of the circuits in the ring are reversed, the shifting of the poles is made to progress in the opposite direction, but the operation is identically the same. Instead of using four wires, with like result, three wires may be used, one forming a common return for both circuits.

This rotation or whirling of the poles manifests itself in a series of curious phenomena. If a delicately pivotted disc of steel or other magnetic metal is approached to the ring it is set in rapid

rotation, the direction of rotation varying with the position of the disc. For instance, noting the direction outside of the ring it will be found that inside the ring it turns in an opposite direction, while it is unaffected if placed in a position symmetrical to the ring. This is easily explained. Each time that a pole approaches it induces an opposite pole in the nearest point on the disc and an attraction is produced upon that point; owing to this, as the pole is shifted further away from the disc a tangential pull is exerted upon the same, and the action being constantly repeated, a more or less rapid rotation of the disc is the result. As the pull is exerted mainly upon that part which is nearest to the ring, the rotation outside and inside, or right and left, respectively, is in opposite directions. When placed symmetrically to the ring, the pull on opposite sides of the disc being equal, no rotation results. The action is based on the magnetic inertia of the iron; for this reason a disc of hard steel is much more affected than a disc of soft iron, the latter being capable of very rapid variations of magnetism. Such a disc has proved to be a very useful instrument in all these investigations, as it has enabled me to detect any irregularity in the action. A curious effect is also produced upon iron

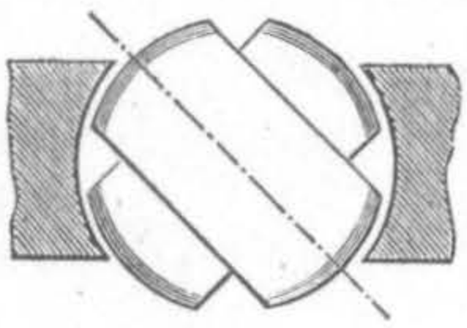

FIG. 8.

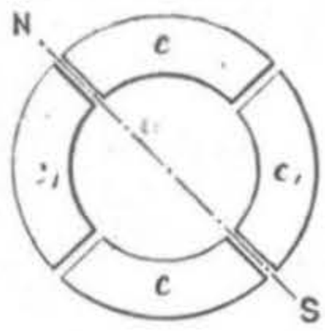

FIG. 8A.

filings. By placing some upon a paper and holding them externally quite close to the ring they are set in a vibrating motion, remaining in the same place, although the paper may be moved back and forth; but in lifting the paper to a certain height which seems to be dependent on the intensity of the poles and the speed of rotation, they are thrown away in a direction always opposite to the supposed movement of the poles. If a paper with filings is put flat upon the ring and the current turned on suddenly, the existence of a magnetic whirl may be easily observed.

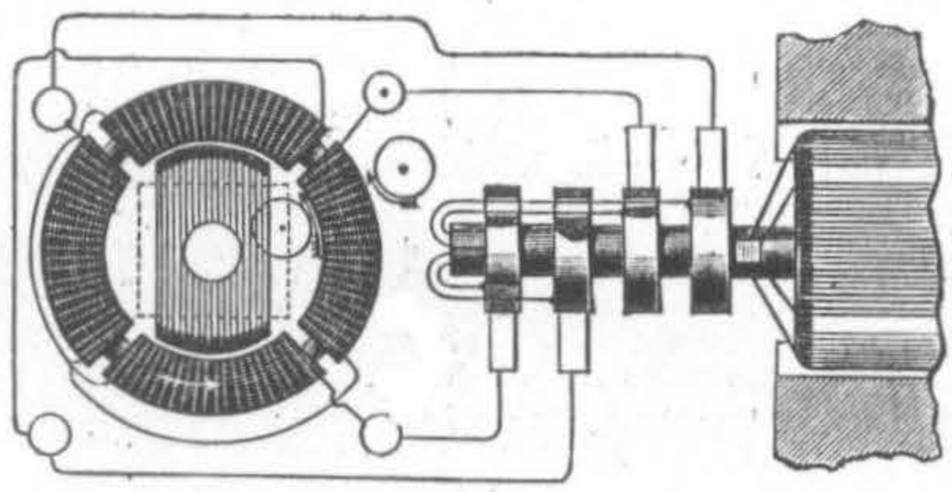

FIG. 9.

To demonstrate the complete analogy between the ring and a revolving magnet, a strongly energised electro-magnet was rotated by mechanical power and phenomena identical in every particular with those mentioned above were observed.

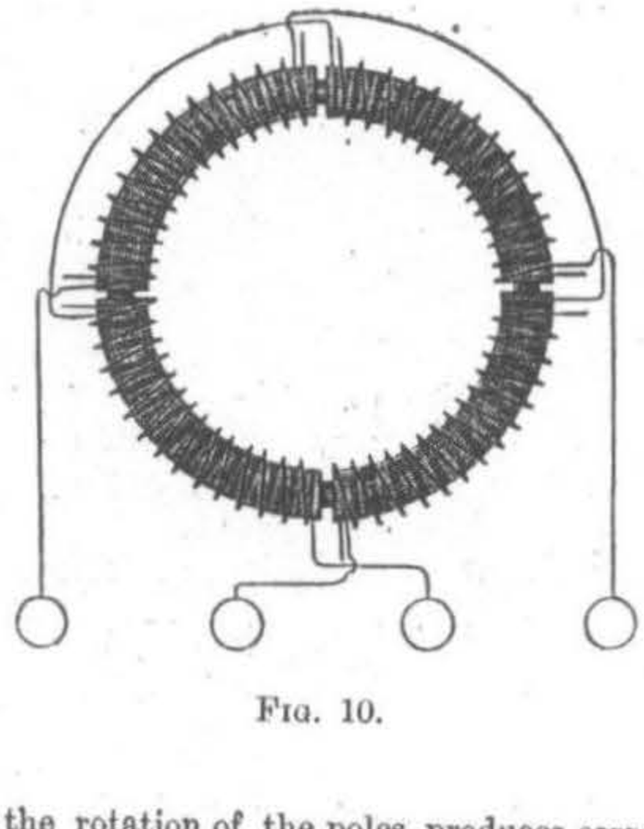

FIG. 10.

Obviously the rotation of the poles produces corresponding inductive effects, and may be utilised to generate currents in a closed conductor placed within the influence of the poles. For this purpose it is convenient to wind a ring with two sets of superimposed coils, forming respectively the primary and secondary circuits. In order to secure the most economical results, the magnetic circuit should be completely closed, as shown in fig. 10, and with this object in view the construction may be modified at will.

The inductive effect exerted upon the secondary coils will be mainly due to the shifting or movement of the magnetic action; but there may also be currents set up in the circuits in consequence of the variations in the intensity of the poles. However, by properly designing the generating and determining the magnetising effect of the primary coils, the latter element may be made to disappear. The intensity of the poles being maintained constant, the action of the apparatus will be perfect, and the same result will be secured as though the shifting were effected by means of a commutator with an infinite number of bars. In such case the theoretical relation between the energising effect of each set of primary coils and their resultant magnetising effect may be expressed by the equation of a circle having its centre coinciding with that of an orthogonal system of axes, and in which the radius represents the resultant, and the co-ordinates both of its components. These are then respectively the sine and cosine of the angle, a, between the radius and one of the axis (o x). Referring to fig. 11 we have $r^2 = x^2 + y^2$; where $x = r \cos a$, and $y = r \sin a$.

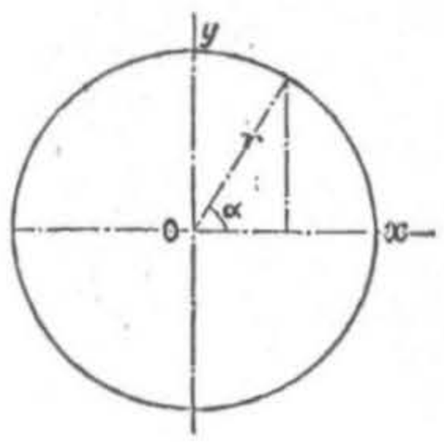

FIG. 11.

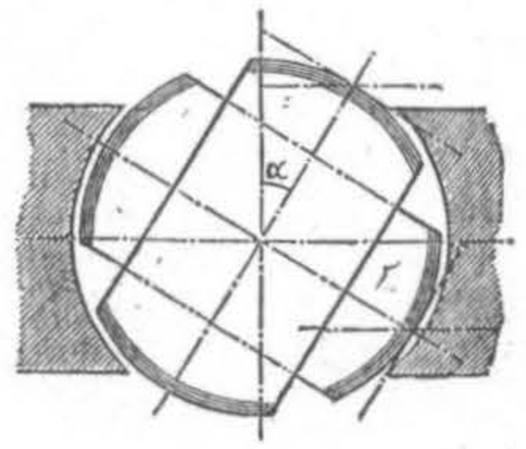

FIG. 12.

Assuming the magnetising effect of each set of coils in the transformer to be proportional to the current—which may be admitted for weak degrees of magnetisation—then $x = \kappa c$ and $y = \kappa c^1$, where κ is a constant and c and c^1 the current in both sets of coils respectively. Supposing further, the field of the generator to be uniform, we have for constant speed $c^1 = \kappa^1 \sin a$ and $c = \kappa^1 \sin (90° + a) = \kappa^1 \cos a$, where κ^1 is a constant. See fig. 12.

Therefore

$$x = \kappa c = \kappa \kappa^1 \cos a,$$
$$y = \kappa c^1 = \kappa \kappa^1 \sin a, \text{ and}$$
$$\kappa \kappa^1 = r.$$

That is, for a uniform field the disposition of the two coils at right angles will secure the theoretical result, and the intensity of the shifting poles will be constant. But from $r^2 = x^2 + y^2$ it follows that for $y = 0$, $r = x$; it follows that the joint magnetising effect of both sets of coils should be equal to the effect of one set when at its maximum action. In transformers and in a certain class of motors the fluctuation of the poles is not of great importance, but in another class of these motors it is desirable to obtain the theoretical result.

(*To be concluded.*)

projections, it is evident that as the poles are shifted it will, owing to its tendency to place itself in such a position as to embrace the greatest nnmber of the lines of force, closely follow the movement of the poles, and its motion will be synchronous with that of the armature of the generator; that is, in the peculiar disposition shown in fig. 9, in which the armature produces by one revolution two current impulses in each of the circuits. It is evident that if, by one revolution of the armature, a greater number of impulses is produced, the speed of the motor will be correspondingly increased. Considering that the attraction exerted upon the disc is greatest when the same is in close proximity to the poles, it follows that such a motor will maintain exactly the same speed at all loads within the limits of its capacity.

To facilitate the starting, the disc may be provided with a coil closed upon itself. The advantage secured by such a coil is evident. On the start the currents set up in the coil strongly energise the disc and increase the attraction exerted upon the same by the ring, and the currents are generated in the coil as long as the speed of the armature is inferior to that of the poles. Considerable work may be performed by such a motor even if the speed be below normal. The intensity of the poles being constant, no currents will be generated in the coil when the motor is turning at its normal speed.

Instead of closing the coil upon itself, its ends may be connected to two insulated sliding rings, and a continuous current supplied to these from a suitable generator. The proper way to start such a motor is to close the coil upon itself until the normal speed is reached, or nearly so, and then turn on the continuous current. If the disc be very strongly energised by a continuous current the motor may not be able to start, but if it be weakly energised, or generally so that the magnetising effect of the ring is preponderating it will start and reach the normal speed. Such a motor will maintain absolutely the same speed at all loads. It has also been found that if the motive power of the generator is not excessive, by checking the motor the speed of the generator is diminished in synchronism with that of the motor. It is characteristic of this form of motor that it cannot be reversed by reversing the continuous current through the coil.

The synchronism of these motors may be demonstrated experimentally in a variety of ways. For this purpose it is best to employ a motor consisting of a stationary field magnet and an armature arranged to rotate within the same, as indicated in fig. 13. In this case the shifting of the poles of the armature pro-

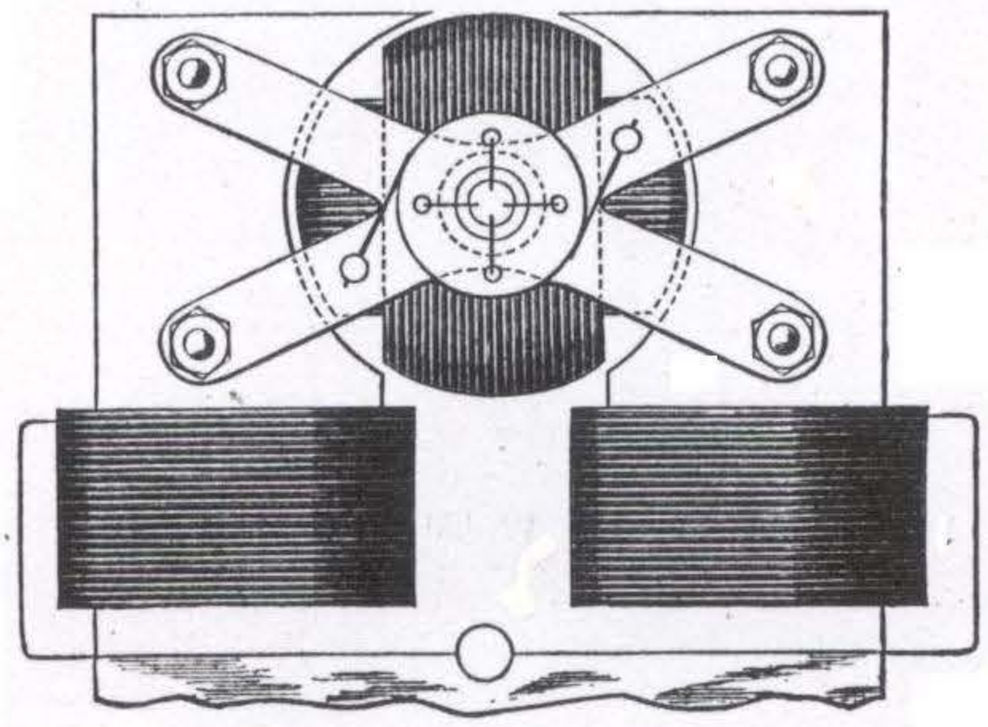

FIG. 13.

duces a rotation of the latter in the opposite direction. It results therefrom that when the normal speed is reached the poles of the armature assume fixed positions relatively to the field magnet and the same is magnetised by induction, exhibiting a distinct pole on each of the pole pieces. If a piece of soft iron is approached to the field magnet it will at the start be attracted with a rapid vibrating motion produced by the reversals of polarity of the magnet, but as the speed of the armature increases the vibrations become less and less frequent and finally entirely cease. Then the iron is weakly but permanently attracted, showing that the synchronism is reached and the field magnet energised by induction.

The disc may also be used for the experiment. If held quite close to the armature it will turn as long as the speed of rotation of the poles exceeds that of the armature; but when the normal speed is reached, or very nearly so, it ceases to rotate and is permanently attracted.

A crude but illustrative experiment is made with an incandescent lamp. Placing the lamp in circuit with the continnous current generator, and in series with the magnet coil, rapid fluctuations are observed in the light in consequence of the induced currents set up in the coil at the start; the speed increasing, the fluctuations occur at longer intervals, until they entirely disappear, showing that the motor has attained its normal speed.

A telephone receiver affords a most sensitive instructive instrument; when connected to any circuit in the motor the synchronism may be easily detected on the disappearance of the induced currents.

A NEW SYSTEM OF ALTERNATE CURRENT MOTORS AND TRANSFORMERS.*

By NIKOLA TESLA.

(*Continued from page* 649.)

In applying this principle to the construction of motors, two typical forms of motor have been developed. First, a form having a comparatively small rotary effort at the start, but maintaining a perfectly uniform speed at all loads, which motor has been termed synchronous. Second, a form possessing a great rotary effort at the start, the speed being dependent on the load.

These motors may be operated in three different ways:—1. By the alternate currents of the source only. 2. By a combined action of these and of induced currents. 3. By the joint action of alternate and continuous currents.

The simplest form of a synchronous motor is obtained by winding a laminated ring provided with pole projections with four coils, and connecting the same in the manner before indicated. An iron disc having a segment cut away on each side may be used as an armature. Such a motor is shown in fig. 9. The disc being arranged to rotate freely within the ring in close proximity to the

* Read before the American Institute of Electrical Engineers, May 16th, 1888.

In motors of the synchronous type it is desirable to maintain the quantity of the shifting magnetism constant, especially if the magnets are not properly subdivided.

To obtain a rotary effort in these motors was the subject of long thought. In order to secure this result it was necessary to make such a disposition that while the poles of one element of the motor are shifted by the alternate currents of the source, the poles produced upon the other element should always be maintained in the proper relation to the former, irrespective of the speed of the motor. Such a condition exists in a continuous current motor; but in a synchronous motor, such as described, this condition is fulfilled only when the speed is normal.

The object has been attained by placing within the ring a properly subdivided cylindrical iron core, wound with several independent coils closed upon themselves. Two coils at right angles are sufficient, but a greater number may be advantageously employed, as in fig. 14. It results from this disposition that when

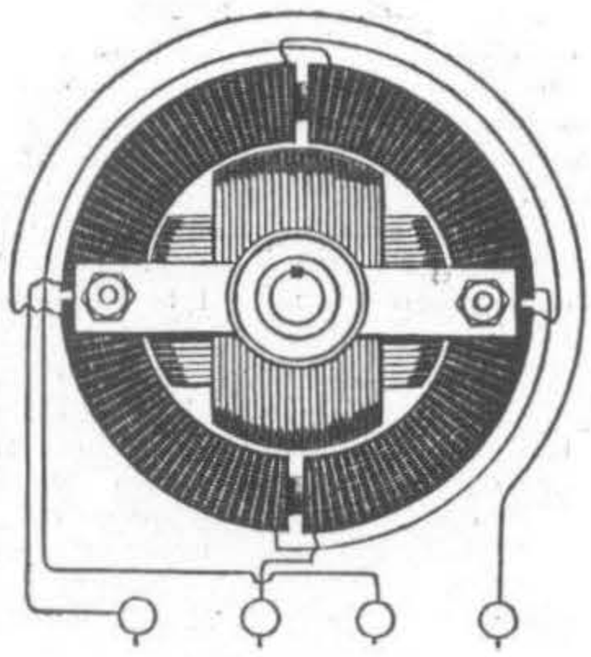

FIG. 14.

the poles of the ring are shifted currents are generated in the closed armature coils. These currents are the most intense at or near the points of the greatest density of the lines of force, and their effect is to produce poles upon the armature at right angles to those of the ring—at least, theoretically so; and since this action is entirely independent of the speed—that is, as far as the location of the poles is concerned—a continuous pull is exerted upon the periphery of the armature. In many respects these motors are similar to the continuous current motors. If load is put on, the speed, and also the resistance of the motor, is diminished, and more current is made to pass through the energising coils, thus increasing the effect. Upon the load being taken off, the counter electromotive force increases, and less current passes through the primary or energising coils. Without any load the speed is very nearly equal to that of the shifting poles of the field magnet.

It will be found that the rotary effort in these motors fully equals that of the continuous current motors. The effort seems to be greatest when both armature and field magnet are without any projections; but as in such dispositions the field cannot be very concentrated, probably the best results will be obtained by leaving pole projections on one of the elements only. Generally it may be stated that the projections diminish the torque and produce a tendency to synchronism.

A characteristic feature of motors of this kind is, their capacity of being very rapidly reversed. This follows from the peculiar action of the motor. Suppose the armature to be rotating and the direction of rotation of the poles to be reversed. The apparatus then represents a dynamo machine, the power to drive this machine being the momentum stored up in the armature, and its speed being the sum of the speeds of the armature and the poles. If we now consider that the power to drive such a dynamo would be very nearly proportional to the third power of the speed, for this reason alone the armature should be quickly reversed. But simultaneously with the reversal another element is brought into action—namely, as the movement of the poles with respect to the armature is reversed, the motor acts like a transformer, in which the resistance of the secondary circuit would be abnormally diminished by producing in this circuit an additional electromotive force. Owing to these causes the reversal is instantaneous.

If it is desirable to secure a constant speed, and at the same time a certain effort at the start, this result may be easily attained in a variety of ways. For instance, two armatures, one for torque and the other for synchronism, may be fastened on the same shaft, and any desired preponderance may be given to either one, or an armature may be wound for rotary effort; but a more or less pronounced tendency to synchronism may be given to it by properly constructing the iron core, and in many other ways.

As a means of obtaining the required phase of the currents in both the circuits the disposition of the two coils at right angles is the simplest, securing the most uniform action; but the phase may be obtained in many other ways, varying with the machine employed. Any of the dynamos at present in use may be easily adapted for this purpose by making connections to proper points of the generating coils. In closed circuit armatures, such as are used in the continuous current systems, it is best to make four derivations from equi-distant points or bars of the commutator, and to connect the same to four insulated sliding rings on the shaft. In this case each of the motor circuits is connected to two diametrically opposite bars of the commutator. In such a disposition the motor may also be operated at half the potential and on the three-wire plan, by connecting the motor circuits in the proper order to three of the contact rings.

In multipolar dynamo machines, such as use the converter systems, the phase is conveniently obtained by winding upon the armature two series of coils in such a manner that while the coils of one set or series are at their maximum production of current, the coils of the other will be at their neutral position, or nearly so, whereby both sets of coils may be subjected simultaneously or successively to the inducing action of the field magnets.

Generally the circuits in the motor will be similarly disposed, and various arrangements may be made to fulfil the requirements; but the simplest and most practicable is to arrange primary circuits on stationary parts of the motor, thereby obviating, at least in certain forms, the employment of sliding contacts. In such a case the magnet coils are connected alternately in both the circuits, that is, 1, 3, 5 in one, and 2, 4, 6 in the other, and the coils of each set of series may be connected, all in the same manner, or alternately in opposition; in the latter case a motor with half the number of poles will result and its action will be correspondingly modified.

The employment of multipolar motors secures in this system an advantage much desired and unattainable in the continuous current system, and that is, that a motor may be made to run exactly at a predetermined speed irrespective of imperfections in construction, of the load, and, within certain limits, of electromotive force and current strength.

In a general distribution system of this kind the following plan should be adopted. At the central station of supply a generator should be provided having a considerable number of poles. The motors operated from this generator should be of the synchronous type, but possessing sufficient rotary effort to insure their starting. With the observance of proper rules of construction it may be admitted that the speed of each motor will be in some inverse proportion to its size, and the number of poles should be chosen accordingly. Still, exceptional demands may modify this rule. In view of this, it will be advantageous to provide each motor with a greater number of pole projections or coils, the number being preferably a multiple of two and three. By this means, by simply changing the connections of the coils, the motor may be adapted to any probable demands.

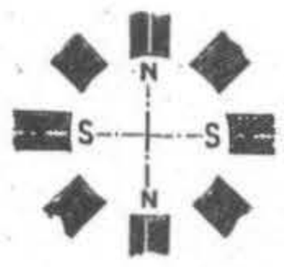

FIG. 15.



FIG. 16.



FIG. 17.

If the number of the poles in the motor is even, the action will be harmonious and the proper result will be obtained; if this is not the case, the best plan to be followed is to make a motor with a double number of poles and connect the same in the manner before indicated, so that half the number of poles result. Suppose, for instance, that the generator has twelve poles and it would be desired to obtain a speed equal to $\frac{1}{7}$ of the speed of the generator. This would require a motor with seven pole projections or magnets, and such a motor could not be properly connected in the circuits, unless fourteen armature coils would be provided, which would necessitate the employment of sliding contacts. To avoid this the motor should be provided with fourteen magnets and seven connected in each circuit, the magnets in each circuit alternating among themselves. The armature should have fourteen closed coils. The action of the motor will not be quite as perfect as in the case of an even number of poles, but the drawback will not be of a serious nature.

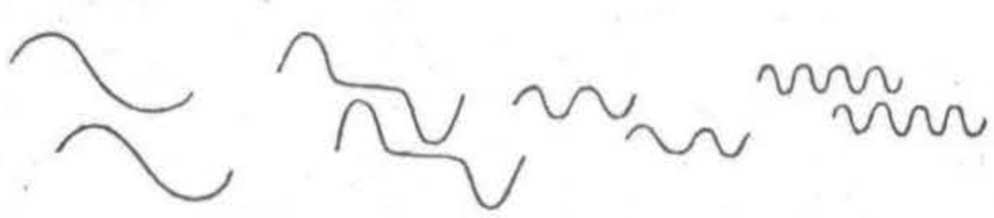

FIG. 18. FIG. 19. FIG. 20. FIG. 21.

However, the disadvantages resulting from this unsymmetrical form will be reduced in the same proportion as the number of the poles is augmented.

If the generator has, say, n, and the motor, n_1, poles, the speed of the motor will be equal to that of the generator multiplied by $\frac{n}{n_1}$.

The speed of the motor will generally be dependent on the number of the poles, but there may be exceptions to this rule. The speed may be modified by the phase of the currents in the circuits or by the character of the current impulses or by intervals between each or between groups of impulses. Some of the possible cases are indicated in the diagrams, figs. 18, 19, 20 and 21,

which are self-explanatory. Fig. 18 represents the condition generally existing, and which secures the best result. In such a case, if the typical form of motor illustrated in fig. 14 is employed, one complete wave in each circuit will produce one revolution of the motor. In fig. 19 the same result will be effected by one wave in each circuit: in fig. 20 by two, and in fig. 21 by four waves.

By such means any desired speed may be attained; that is, at least within the limits of practical demands. This system possesses this advantage besides others, resulting from simplicity. At full loads, the motors show an efficiency fully equal to that of the continuous current motors. The transformers present an additional advantage in their capability of operating motors. They are capable of similar modifications in construction, and will facilitate the introduction of motors and their adaptation to practical demands. Their efficiency should be higher than that of the present transformers, and I base my assertion on the following:—

In a transformer as constructed at present, we produce the currents in the secondary circuit by varying the strength of the primary or exciting currents. If we admit proportionality with respect to the iron core, the inductive effect exerted upon the secondary coil will be proportional to the numerical sum of the variations in the strength of the exciting current per unit of time; whence it follows that for a given variation any prolongation of the primary current will result in a proportional loss. In order to obtain rapid variations in the strength of the current, essential to efficient induction, a great number of undulations are required and employed. From this various disadvantages result. These are, increased cost and diminished efficiency of the generator, more waste of energy in heating the cores, and also diminished output of the transformer, since the core is not properly utilised, the reversals being too rapid. The inductive effect is also very small in certain phases, and there may be periods of inaction, if there are intervals between the succeeding current impulses or waves. In producing a shifting of the poles in the transformer, and thereby inducing currents, the induction is of the ideal character, being always maintained at its maximum action.

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NOTES.

Our issue of the 25th of May contained an abstract of a Paper by Prof. Galileo Ferraris describing a method of producing a revolving resultant magnetic field by means of a pair of coils with their axes at right angles, and traversed by alternating currents, and we drew attention to the possibility that the principle of this apparatus might be applied to the construction of an alternating-current motor. The Paper by Mr. Nicola Tesla, which appears in our columns this week, contains a description of such a motor, founded on exactly the same principle.

A NEW ALTERNATING CURRENT MOTOR.

BY NICOLA TESLA.*

In the presence of the existing diversity of opinion regarding the relative merits of the alternate and continuous current systems, great importance is attached to the question whether alternate currents can be successfully utilised in the operation of motors. The transformers, with their numerous advantages, have afforded us a relatively perfect system of distribution, and although, as in all branches of the art, many improvements are desirable, comparatively little remains to be done in this direction. The transmission of power, on the contrary, has been almost entirely confined to the use of continuous currents, and notwithstanding that many efforts have been made to utilise alternate currents for this purpose, they have, up to the present, at least as far as known, failed to give the result desired. Of the various motors adapted to be used on alternate current circuits the following have been mentioned: (1) A series motor with subdivided field. (2) An alternate-current generator having its field excited by continuous currents. (3) Elihu Thomson's motor. (4) A combined alternate and continuous current motor.

* Paper read before the American Institute of Electrical Engineers, May 15th, 1888.

Two more motors of this kind have suggested themselves to me: (1) A motor with one of its circuits in series with a transformer, and the other in the secondary of the transformer. (2) A motor having its armature circuit connected to the generator, and the field coils closed upon themselves. These, however, I mention only incidentally.

The subject which I now have the pleasure of bringing to your notice is a novel system of electric distribution and transmission of power by means of alternate currents, affording peculiar advantages, particularly in the way of motors, which I am confident will at once establish the superior adaptability of these currents to the transmission of power, and will show that many results heretofore unattainable can be reached by their use, results which are very much desired in the practical operation of such systems, and which cannot be accomplished by means of continuous currents.

Before going into a detailed description of this system I think it necessary to make a few remarks with reference to certain conditions existing in continuous current generators and motors, which, although generally known, are frequently disregarded.

In our dynamo machines, it is well known, we generate alternate currents which we direct by means of a commutator—a complicated device, and, it may be justly said, the source of most of the troubles experienced in the operation of the machines. Now, the currents so directed cannot be utilised in the motor, but they must—again by means of a similar unreliable device—be reconverted into their original state of alternate currents. The function of the commutator is entirely external, and in no way does it affect the internal working of the machines. In reality, therefore, all machines are alternate-current machines, the current appearing as continuous only in the external circuit during their transit from generator to motor. In view simply of this fact, alternate currents would commend themselves as a more direct application of electrical energy, and the employment of continuous currents would only be justified if we had dynamos which would primarily generate, and motors which would be directly actuated by such currents.

But the operation of the commutator on a motor is twofold—firstly, it reverses the currents through the motor; and, secondly, it effects, automatically, a progressive shifting of the poles of one of its magnetic constituents. Assuming, therefore, that both of the useless operations in the system—that is to say, the directing of the alternate currents on the generator, and reversing the direct currents on the motor—be eliminated, it would still be necessary, in order to cause a rotation of the motor, to produce a progressive shifting of the poles of one of its elements, and the question presented itself, how to perform this operation by the direct action of alternate currents. I will now proceed to show how this result was accomplished.

In the first experiment a drum armature was provided with two coils at right angles to each other, and the ends of these coils were connected to two pairs of insulated contact rings, as usual. A ring was then made of thin insulated plates of sheet iron and wound with four coils, each two opposite coils being connected together so as to produce free poles on diametrically opposite sides of the ring. The remaining free ends of the coils were then connected to the contact rings of the generator armature so as to form two independent circuits, as indicated in Fig 9. It may now be seen what results were secured in this combination, and with this view I would refer to the diagrams Figs. 1 to 8A. The field of the generator being independently excited, the rotation of the armature sets up currents in the coils varying in strength and direction in the well-known manner. In the position shown in Fig. 1 the current in coil c is *nil* while c_1 is traversed by its maximum current, and the connections may be such that the ring is magnetised by the coils c_1 c_1, as indicated by the letters N S in Fig. 1A, the magnetising effect of the coils c c being *nil*, since these coils are included in the circuit of coil c.

In Fig. 2 the armature coils are shown in a more advanced position, one-eighth of one revolution being completed. Fig. 2A illustrates the corresponding magnetic condition of the ring. At this moment the coil c_1 generates a current of the same direction as previously, but weaker, producing the poles n_1 s_1 upon the ring; the coil c also generates a current of the same direction, and the connections may be such that the coils c c produce the poles n s, as shown in Fig. 2A. The resulting polarity is indicated by the letters N S, and it will be observed that the poles of the ring have been shifted one-eighth of the periphery.

In Fig. 3 the armature has completed one-quarter of one revolution. In this phase the current in coil c is a maximum, and of such direction as to produce the poles N S in Fig. 3A, whereas the current in coil c_1 is *nil*, this coil being at its neutral position. The poles N S in Fig. 3A are thus shifted one-quarter of the circumference of the ring.

Fig. 4 shows the coils in a still more advanced position, the armature having completed three-eighths of one revolution. At that moment the coil c still generates a current of the same direction as before, but of less strength, producing the comparatively weaker poles n s in Fig. 4A. The current in the coil c_1 is of the same strength, but of opposite direction. Its effect is therefore to pro-

duce upon the ring the poles n_1 and s_1 as indicated, and a polarity N S results, the poles now being shifted three-eighths of the periphery of the ring.

In Fig. 5 one-half of one revolution of the armature is completed, and the resulting magnetic condition of the ring is indicated in Fig. 5A. Now, the current in coil c is *nil*, while the coil c_1 yields its maximum current, which is of the same direction as previously; the magnetising effect is therefore due to the coils c_1 c_1 alone, and referring to Fig. 5A it will be observed that the poles N S are shifted one-half of the circumference of the ring. During the next half revolution the operations are repeated, as represented in the Figs. 6 to 8A.

A reference to the diagrams will make it clear that during one revolution of the armature the poles of the ring are shifted once around its periphery, and each revolution producing like effects a rapid whirling of the poles in harmony with the rotation of the armature is the result. If the connections of either one of the circuits in the ring are reversed, the shifting of the poles is made to progress in the opposite direction; but the operation is identically the same. Instead of using four wires, with like result, three wires may be used, one forming a common return for both circuits.

The rotation or whirling of the poles manifests itself in a series of curious phenomena. If a delicately-pivoted disc of steel or

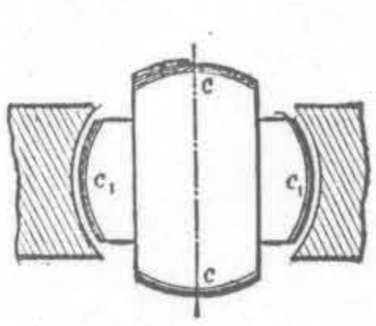


Fig. 1.

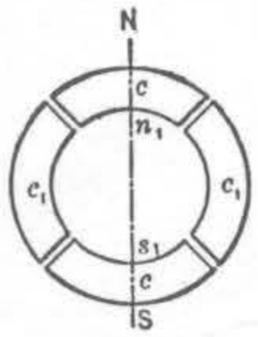


Fig. 1a.

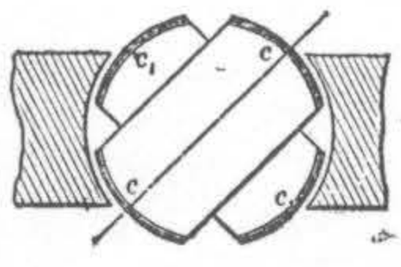


Fig. 2.

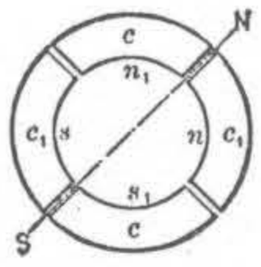


Fig. 2a.

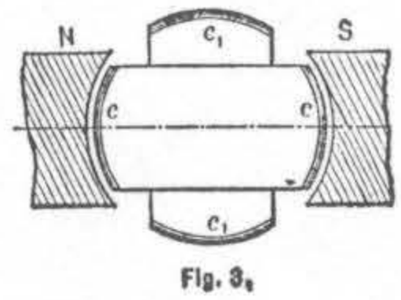


Fig. 3.

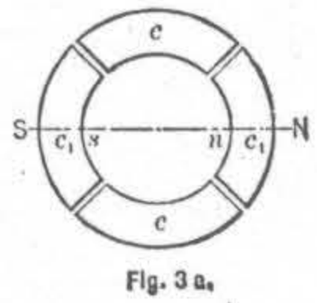


Fig. 3a.

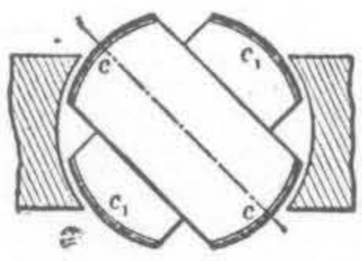


Fig. 4.

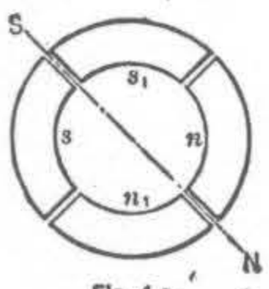


Fig. 4a.

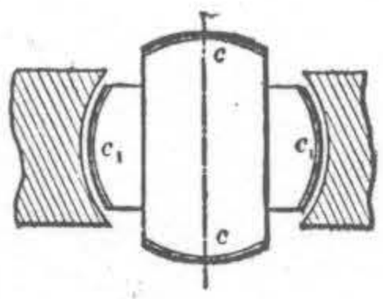


Fig. 5.

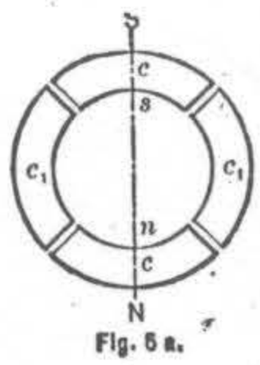
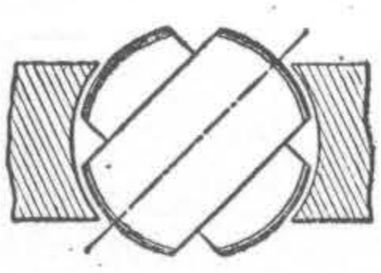


Fig. 5a.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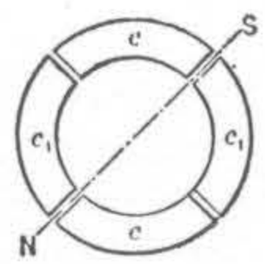


Fig. 6a.

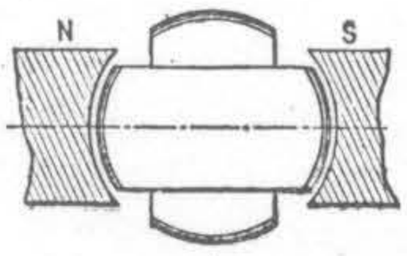


Fig. 7.

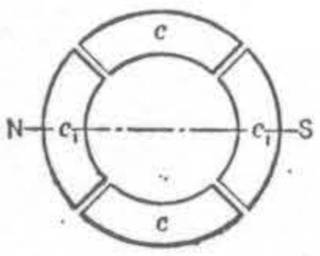


Fig. 7a.

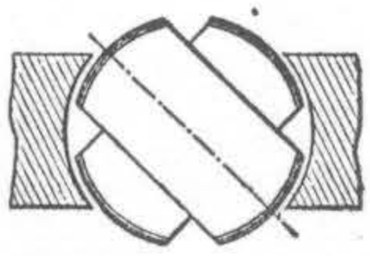


Fig. 8.

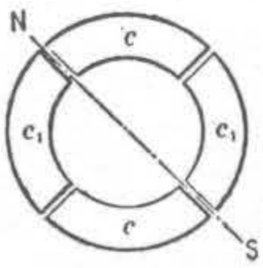


Fig. 8a.

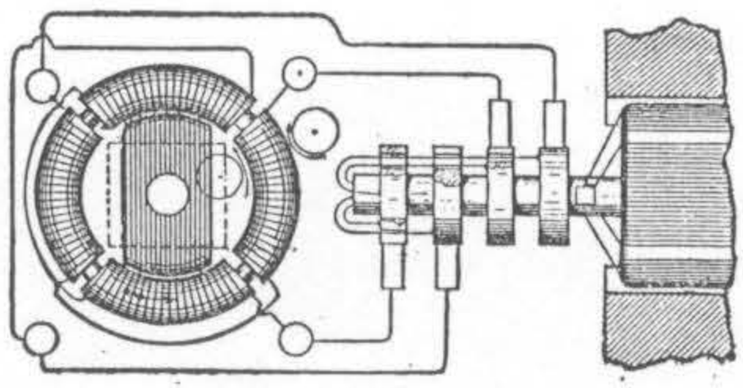


Fig. 9.

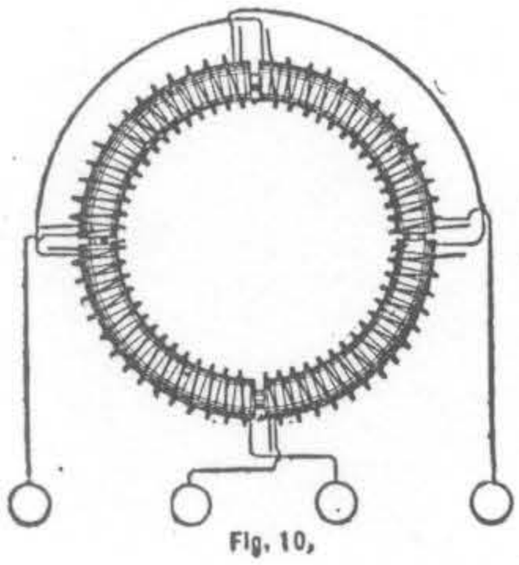


Fig. 10.

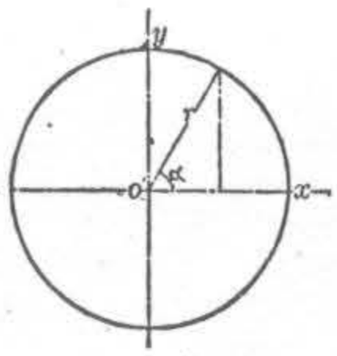
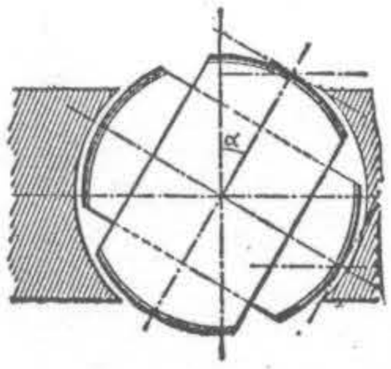


Fig. 11.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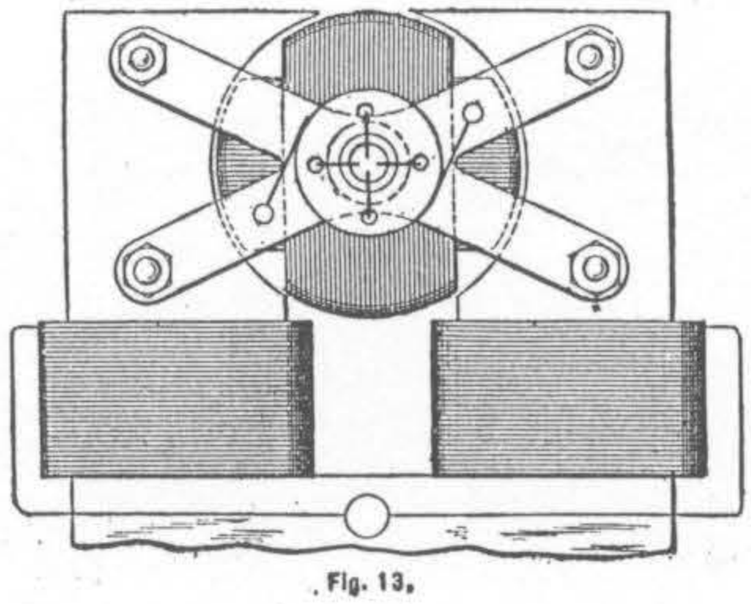
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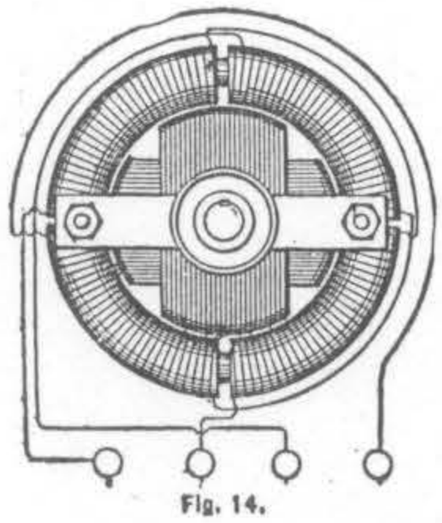
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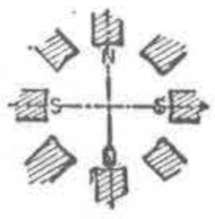
Fig. 15.


Fig. 16.

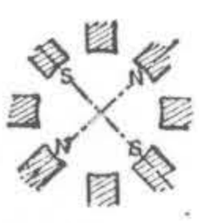
Fig. 17.


Fig. 18.

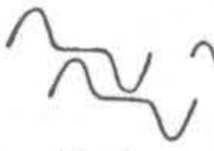
Fig. 19.

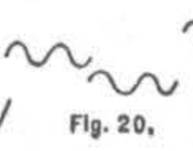
Fig. 20.

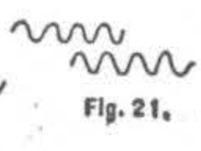
Fig. 21.

other magnetic metal is approached to the ring it is set in rapid rotation, the direction of rotation varying with the position of the disc. For instance, noting the direction outside of the ring, it will be found that inside the ring it turns in an opposite direction, while it is unaffected if placed in a position symmetrical to the ring. This is easily explained. Each time that a pole approaches it induces an opposite pole in the nearest point on the disc, and an attraction is produced upon that point; owing to this, as the pole is shifted further away from the disc, a tangential pull is exerted upon the same, and the action being constantly repeated, a more or less rapid rotation of the disc is the result. As the pull is exerted mainly upon that part which is nearest to the ring, the rotation outside and inside, or right and left, respectively, is in opposite directions. When placed symmetrically to the ring, the pull on opposite sides of the disc being equal, no rotation results. The action is based on the magnetic inertia of the iron; for this reason a disc of hard steel is much more affected than a disc of soft iron, the latter being capable of very rapid variations of magnetism. Such a disc has proved to be a very useful instrument in all these investigations, as it has enabled me to detect any irregularity in the action. A curious effect is also produced upon iron filings. By placing some upon a paper, and holding them externally quite close to the ring, they are set in a vibrating motion, remaining in the same place, although the paper may be moved back and forth; but in lifting the paper to a certain height, which seems to be dependent on the intensity of the poles and the speed of rotation, they are thrown away in a direction always opposite to the supposed movement of the poles. If a paper with filings is put flat upon the ring, and the current turned on suddenly, the existence of a magnetic whirl may be easily observed.

To demonstrate the complete analogy between the ring and a revolving magnet, a strongly energised electromagnet was rotated by mechanical power, and phenomena identical in every particular to those mentioned above were observed.

Obviously, the rotation of the poles produces corresponding inductive effects, and may be utilised to generate currents in a closed conductor placed within the influence of the poles. For this purpose it is convenient to wind a ring with two sets of superimposed coils, forming respectively the primary and secondary circuits. In order to secure the most economical results, the magnetic circuit should be completely closed, as shown in Fig. 10, and with this object in view the construction may be modified at will.

The inductive effect exerted upon the secondary coils will be mainly due to the shifting or movement of the magnetic action; but there may also be currents set up in the circuits in consequence of the variations in the intensity of the poles. However, by properly designing the generator, and determining the magnetising effect of the primary coils, the latter element may be made to disappear. The intensity of the poles being maintained constant, the action of the apparatus will be perfect, and the same result will be secured as though the shifting were effected by means of a commutator with an infinite number of bars. In such case the theoretical relation between the energising effect of each set of primary coils and their resultant magnetising effect may be expressed by the equation of a circle having its centre coinciding with that of an orthogonal system of axes, and in which the radius represents the resultant and the coordinates both of its components. These are then respectively the sine and cosine of the angle a between the radius and one of the axes (OX). Referring to Fig. 11 we have $r^2=x^2+y^2$; where $x=r\cos a$, and $y=r\sin a$.

Assuming the magnetising effect of each set of coils in the transformer to be proportional to the current—which may be admitted for weak degrees of magnetisation—then $x=\mathrm{K}\,c$ and $y=\mathrm{K}\,c_1$, where K is a constant and c and c_1 the current in both sets of coils respectively. Supposing further, the field of the generator to be uniform, we have for constant speed $c_1=\mathrm{K}^1\sin a$ and $c=\mathrm{K}^1\sin(90°+a)=\mathrm{K}^1\cos a$, where K^1 is a constant (*see* Fig. 12). Therefore

$$x=\mathrm{K}\,c=\mathrm{K}\,\mathrm{K}^1\cos a;$$
$$y=\mathrm{K}\,c_1=\mathrm{K}\,\mathrm{K}^1\sin a, \text{ and}$$
$$\mathrm{K}\,\mathrm{K}^1=r.$$

That is, for a uniform field the disposition of the two coils at right angles will secure the theoretical result, and the intensity of the shifting poles will be constant. But from $r^2=x^2+y^2$ it follows that for $y=0$, $r=x$; it follows that the joint magnetising effect of both sets of coils should be equal to the effect of one set when at its maximum action. In transformers and in a certain class of motors the fluctuation of the poles is not of great importance, but in another class of these motors it is desirable to obtain the theoretical result.

In applying this principle to the construction of motors, two typical forms of motor have been developed. First, a form having a comparatively small rotary effort at the start, but maintaining a perfectly uniform speed at all loads, which motor has been termed synchronous. Second, a form possessing a great rotary effort at the start, the speed being dependent on the load.

These motors may be operated in three different ways:—(1) By the alternate currents of the source only; (2) by a combined action of these and of induced currents; (3) by the joint action of alternate and continuous currents.

The simplest form of a synchronous motor is obtained by winding a laminated ring provided with pole projections with four coils, and connecting the same in the manner before indicated. An iron disc having a segment cut away on each side may be used as an armature. Such a motor is shown in Fig. 9. The disc being arranged to rotate freely within the ring, in close proximity to the projections, it is evident that as the poles are shifted it will, owing to its tendency to place itself in such a position as to embrace the greatest number of the lines of force, closely follow the movement of the poles, and its motion will be synchronous with that of the armature of the generator; that is, in the peculiar disposition shown in Fig. 9, in which the armature produces by one revolution two current impulses in each of the circuits. It is evident that if, by one revolution of the armature, a greater number of impulses is produced, the speed of the motor will be correspondingly increased. Considering that the attraction exerted upon the disc is greatest when the same is in close proximity to the poles, it follows that such a motor will maintain exactly the same speed at all loads within the limits of its capacity.

To facilitate the starting, the disc may be provided with a coil closed upon itself. The advantage secured by such a coil is evident. On the start the currents set up in the coil strongly energise the disc, and increase the attraction exerted upon the same by the ring, and currents are generated in the coil as long as the speed of the armature is inferior to that of the poles. Considerable work may be performed by such a motor, even if the speed be below normal. The intensity of the poles being constant, no currents will be generated in the coil when the motor is turning at its normal speed.

Instead of closing the coil upon itself, ends may be connected by two insulated sliding rings, and a continuous current supplied to these from a suitable generator. The proper way to start such a motor is to close the coil upon itself until the normal speed is reached, or nearly so, and then turn on the continuous current. If the disc be very strongly energised by a continuous current the motor may not be able to start; but if it be weakly energised, or generally so that the magnetising effect of the ring is preponderating, it will start and reach the normal speed. Such a motor will maintain absolutely the same speed at all loads. It has also been found that if the motive power of the generator is not excessive, by checking the motor the speed of the generator is diminished in synchronism with that of the motor. It is characteristic of this form of motor that it cannot be reversed by reversing the continuous current through the coil.

The synchronism of these motors may be demonstrated experimentally in a variety of ways. For this purpose it is best to employ a motor consisting of a stationary field-magnet, and an armature arranged to rotate within the same, as indicated in Fig. 13. In this case the shifting of the poles of the armature produces a rotation of the latter in the opposite direction. It results therefrom that when the normal speed is reached, the poles of the armature assume fixed positions relatively to the field-magnet, and the same is magnetised by induction, exhibiting a distinct pole on each of the pole-pieces. If a piece of soft iron is approached to the field-magnet, it will at the start be attracted with a rapid vibrating motion produced by the reversals of polarity of the magnet; but as the speed of the armature increases the vibrations become less and less frequent, and finally entirely cease. Then the iron is weakly but permanently attracted, showing that the synchronism is reached, and the field-magnet energised by induction.

The disc may also be used for the experiment. If held quite close to the armature it will turn as long as the speed of rotation of the poles exceeds that of the armature; but when the normal speed is reached, or very nearly so, it ceases to rotate, and is permanently attracted.

A crude but illustrative experiment is made with an incandescent lamp. Placing the lamp in circuit with the continuous-current generator, and in series with the magnet coil, rapid fluctuations are observed in the light, in consequence of the induced currents set up in the coil at the start; the speed increasing, the fluctuations occur at longer intervals, until they entirely disappear, showing that the motor has attained its normal speed.

A telephone receiver affords a most sensitive instrument; when connected to any circuit in the motor the synchronism may be easily detected on the disappearance of the induced currents.

In motors of the synchronous type it is desirable to maintain the quantity of the shifting magnetism constant, especially if the magnets are not properly subdivided.

To obtain a rotary effort in these motors was the subject of long thought. In order to secure this result it was necessary to make such a disposition that while the poles of one element of the motor

are shifted by the alternate currents of the source, the poles produced upon the other element should always be maintained in the proper relation to the former, irrespective of the speed of the motor. Such a condition exists in a continuous-current motor; but in a synchronous motor, such as described, this condition is fulfilled only when the speed is normal.

The object has been attained by placing within the ring a properly subdivided cylindrical iron core wound with several independent coils closed upon themselves. Two coils at right angles are sufficient; but a greater number may be advantageously employed, as in Fig. 14. It results from this disposition that when the poles of the ring are shifted currents are generated in the closed armature coils. These currents are the most intense at or near the points of the greatest density of the lines of force, and their effect is to produce poles upon the armature at right angles to those of the ring, at least theoretically so; and since this action is entirely independent of the speed—that is, so far as the location of the poles is concerned—a continuous pull is exerted upon the periphery of the armature. In many respects these motors are similar to the continuous current motors. If load is put on, the speed, and also the resistance of the motor, is diminished, and more current is made to pass through the energising coils, thus increasing the effect. Upon the load being taken off, the counter E.M.F. increases, and less current passes through the primary or energising coils. Without any load the speed is very nearly equal to that of the shifting poles of the field-magnet.

It will be found that the rotary effort in these motors fully equals that of the continuous-current motors. The effort seems to be greatest when both armature and field-magnet are without any projections; but as in such dispositions the field cannot be very concentrated, probably the best results will be obtained by leaving pole projections on one of the elements only. Generally, it may be stated that the projections diminish the torque, and produce a tendency to synchronism.

A characteristic feature of motors of this kind is their capacity of being very rapidly reversed. This follows from the peculiar action of the motor. Suppose the armature to be rotating, and the direction of rotation of the poles to be reversed. The apparatus then represents a dynamo machine, the power to drive this machine being the momentum stored up in the armature, and its speed being the sum of the speeds of the armature and the poles. If we now consider that the power to drive such a dynamo would be very nearly proportional to the third power of the speed, for this reason alone the armature should be quickly reversed. But simultaneously with the reversal another element is brought into action, viz., as the movement of the poles with respect to the armature is reversed, the motor acts like a transformer in which the resistance of the secondary circuit would be abnormally diminished by producing in this circuit an additional E.M.F. Owing to these causes the reversal is instantaneous.

If it is desirable to secure a constant speed, and at the same time a certain effort at the start, this result may be easily attained in a variety of ways. For instance, two armatures, one for torque and the other for synchronism, may be fastened on the same shaft, and any desired preponderance may be given to either one, or an armature may be wound for rotary effort; but a more or less pronounced tendency to synchronism may be given to it by properly constructing the iron core, and in many other ways.

As a means of obtaining the required phase of the currents in both the circuits, the disposition of the two coils at right angles is the simplest, securing the most uniform action; but the phase may be obtained in many other ways, varying with the machine employed. Any of the dynamos at present in use may be easily adapted for this purpose by making connections to proper points of the generating coils. In closed-circuit armatures, such as used in the continuous-current systems, it is best to make four derivations from equi-distant points or bars of the commutator, and to connect the same to four insulated sliding rings on the shaft. In this case each of the motor circuits is connected to two diametrically opposite bars of the commutator. In such a disposition the motor may also be operated at half the potential and on the three-wire plan, by connecting the motor circuits in the proper order to three of the contact rings.

In multipolar dynamo machines, such as use the converter systems, the phase is conveniently obtained by winding upon the armature two series of coils, in such a manner that while the coils of one set or series are at their maximum production of current the coils of the other will be at their neutral position, or nearly so, whereby both sets of coils may be subjected simultaneously or successively to the inducing action of the field-magnets.

Generally, the circuits in the motor will be similarly disposed, and various arrangements may be made to fulfil the requirements; but the simplest and most practicable is to arrange primary circuits on stationary parts of the motor, thereby obviating, at least in certain forms, the employment of sliding contacts. In such a case the magnet coils are connected alternately in both the circuits; that is, 1, 3, 5 in one, and 2, 4, 6 in the other, and the coils of each set of series may be connected, all in the same manner, or alternately in opposition; in the latter case, a motor with half the number of poles will result, and its action will be correspondingly modified.

The employment of multipolar motors secures in this system an advantage much desired and unattainable in the continuous current system, and that is, that a motor may be made to run exactly at a pre-determined speed, irrespective of imperfections in construction of the load, and within certain limits, of E.M.F. and current strength.

In a general distribution system of this kind the following plan should be adopted:—At the central station a supply generator should be provided having a considerable number of poles. The motors operated from this generator should be of the synchronous type, but possessing sufficient rotary effort to insure their starting. With the observance of proper rules of construction, it may be admitted that the speed of each motor will be in some inverse proportion to its size, and the number of poles should be chosen accordingly. Still exceptional demands may modify this rule. In view of this, it will be advantageous to provide each motor with a greater number of pole projections or coils, the number being preferably a multiple of two and three. By this means, by simply changing the connections of the coils, the motor may be adapted to any probable demands.

If the number of the poles in the motor is even the action will be harmonious, and the proper result will be obtained; if this is not the case the best plan to be followed is to make a motor with a double number of poles, and connect the same in the manner before indicated, so that half the number of poles result. Suppose, for instance, that the generator has twelve poles, and it would be desired to obtain a speed equal to 12/7 of the speed of the generator. This would require a motor with seven pole projections or magnets, and such a motor could not be properly connected in the circuits unless fourteen armature coils were provided, which would necessitate the employment of sliding contacts. To avoid this, the motor should be provided with fourteen magnets, and seven connected in each circuit, the magnets in each circuit alternating among themselves. The armature should have fourteen closed coils. The action of the motor will not be quite so perfect as in the case of an even number of poles, but the drawback will not be of a serious nature.

However, the disadvantages resulting from this unsymmetrical form will be reduced in the same proportion as the number of the poles is augmented.

If the generator has, say, n, and the motor n_1 poles, the speed of the motor will be equal to that of the generator multiplied by $\frac{n}{n_1}$.

The speed of the motor will generally be dependent on the number of the poles, but there may be exceptions to this rule. The speed may be modified by the phase of the currents in the circuits or by the character of the current impulses, or by intervals between each or between groups of impulses. Some of the possible cases are indicated in the diagrams Figs. 18, 19, 20, and 21, which are self-explanatory. Fig. 18 represents the condition generally existing, and which secures the best result. In such a case, if the typical form of motor illustrated in Fig. 14 is employed, one complete wave in each circuit will produce one revolution of the motor. In Fig. 19 the same result will be effected by one wave in each circuit; in Fig. 20 by two, and in Fig. 21 by four waves.

By such means any desired speed may be attained; that is, at least, within the limits of practical demands. This system possesses this advantage besides others, resulting from simplicity. At full loads the motors show an efficiency fully equal to that of the continuous-current motors. The transformers present an additional advantage in their capability of operating motors. They are capable of similar modifications in construction, and will facilitate the introduction of motors, and their adaptation to practical demands. Their efficiency should be higher than that of the present transformers, and I base my assertion on the following:—

In a transformer as constructed at present we produce the currents in the secondary circuit by varying the strength of the primary or exciting currents. If we admit proportionality with respect to the iron core, the inductive effect exerted upon the secondary coil will be proportional to the numerical sum of the variations in the strength of the exciting current per unit of time; whence it follows that for a given variation any prolongation of the primary current will result in a proportional loss. In order to obtain rapid variations in the strength of the current, essential to efficient induction, a great number of undulations are required and employed. From this various disadvantages result. These are increased cost and diminished efficiency of the generator, more waste of energy in heating the cores and also diminished output of the transformer, since the core is not properly utilised, the reversals being too rapid. The inductive effect is also very small in certain phases, as will be apparent from a graphic representation, and there

may be periods of inaction, if there are intervals between the succeeding current impulses or waves. In producing a shifting of the poles in the transformer, and thereby inducing currents, the induction is of the ideal character, being always maintained at its maximum action. It is also reasonable to assume that by a shifting of the poles less energy will be wasted than by reversals.

NOTE ON THE TESLA ALTERNATING CURRENT MOTOR.

BY DR. LOUIS DUNCAN, OF JOHNS HOPKINS UNIVERSITY.

Since writing my last note on this motor Mr. Tesla has read an interesting description of his system before the Institute of Electrical Engineers, and in his answer to the note referred to he has further described his motors. The study of both of these papers has increased my admiration for the simplicity and success of his system.

The motor discussed in my last note was of the synchronous type with two short-circuited coils at right angles to one another.* Further, Mr. Tesla in his paper before the Institute of Electrical Engineers states that "in a general distributing system of this kind the following plan should be adopted. * * * The motors operated from this generator should be of the synchronous type, but possessing sufficient rotary effort to insure starting." So I will reconsider the statements I made in the previous note with reference to this type and try to see if they should be modified. With respect to my views as to the theory of such a motor, they look at the phenomena from a different standpoint from that taken in Mr. Tesla's paper, and an unfortunate misprint ("It" for "I," the symbol used to represent current), greatly obscures the meaning. Apart from this, my conclusions were, that it was doubtful if such a motor would start under load—meaning to attain its proper number of revolutions—that if a load of great inertia be suddenly applied so that the motor is called on for more than its maximum load, it will stop or take up some slower speed; and finally, that the currents do not decrease in proportion to the load. Now, the first two questions can be settled so easily and simply by experiment that it is hardly worth while attempting to evolve reasons for believing one way or the other. The way I would look at it is this: The motor combines a synchronous and non-synchronous part; the former does little work until the motor reaches its normal speed; the latter does considerable work until the motor reaches a speed lower than the normal by an amount depending on the load. Now, how is the speed to jump from this lower value at which equilibrium is reached, to the normal value? It might do so in a number of cases where the inertia is great—in others I must confess to doubts. As to the second point my objection follows directly from what I have said above.

With respect to the consumption of current at small loads, I think that in any synchronous motor the effect of decreasing load is simply to decrease the difference between two quantities of work; one plus, the other minus, that the motor does. If this is the case the currents should not vary in proportion to the load, but should be greater in proportion with smaller loads.

With respect to the non-synchronous motors, however, I have very little but admiration to express. I cannot help thinking that they can be governed without resorting to synchronism, and in this case they will have advantages that will greatly aid in the advance of electric distribution.

Finally, I must confess to some disappointment that no data has been given as to the performance of Mr. Tesla's motors. One cannot, of course, expect from machines that are just emerging from an experimental state, the efficiency and output that they will finally attain, but a few curves of the currents in the magnets and armature coils under different conditions would tell us more of the possibilities and directions of improvement than could any amount of discussion.

In the meantime I would congratulate Mr. Tesla on the discovery and application of a novel means of obtaining continuous rotation from alternating currents, and I shall watch the further development of his system with interest.

*See description in ELECTRICAL REVIEW of May 26.

THE TESLA ALTERNATE CURRENT MOTOR.

The interest taken in M. Tesla's contributions to electrical apparatus and to electrical literature is so great, and the subject is so important, that we do not hesitate to give further space to the subject. On May 26 a communication on the subject from Dr. Louis Duncan, of Johns Hopkins University, appeared in our American contemporary, the *Electrical Review*, to the following effect:

"We may, for our present purposes, divide motors into two classes: Continuous, in which the armature coils are unsymmetrical with respect to the poles, and which, therefore, give a practically constant torque, and alternating motors, in which the armature coils are symmetrical with respect to the poles, and which, therefore, give a torque varying both in magnitude and sign during a period of the counter E.M.F. The Tesla motor belongs to this latter class.

"In every motor the torque is equal to the rate of change of lines of induction through the armature circuit for a small angular displacement, multiplied by the armature current, or

$$\frac{dm}{dt} \text{ I.}$$

In the Tesla motor the first of these terms is greatest when the coil is opposite a pole and the field currents have their greatest amplitude. It is zero at a point about 45deg. from this, supposing we neglect armature reactions. It depends on several things. The E.M.F. which determines it is due to changes in the number of lines of force passing through the armature circuit caused by (1) changes in the field currents; (2) the motion of the armature. The current depends on these E.M.F.'s, and on the reduced self-induction and resistance of its circuit. The motor can only do work when the first cause of E.M.F. is the greater, for a current in the direction of the ordinary counter E.M.F. would stop the motion. In some parts of a revolution the two E.M.F.'s work together, retarding the motion; in others, the induced E.M.F. produces a current causing the motor to revolve. It is impossible for me, with only a meagre description of the principles of the machine, to give an idea of the relative magnitudes of these effects. Some of the results, however, are the following: Having given a definite number of reversals of the dynamo, there are a number of speeds, multiples of these reversals, at which the motor will govern itself when it is doing a certain amount of work. At one of these speeds, depending on the construction of the motor, the output will be a maximum.

Now I see the statement that 'there is no difficulty whatever attendant upon starting the motor under load.' I cannot reconcile this with above facts. That the torque for a smaller number of revolutions than ordinarily used, might be greater, one can readily see, since the counter E.M.F. is less in proportion to the induced E.M.F., but it must be remembered that for certain speeds even the induced current would tend to stop the motion; how the motor is to pass these critical speeds I do not see. Again, if the maximum load is suddenly thrown on while the motor is running at its proper speed, then, if the inertia be great, the motor will fall behind its point of maximum work, and either stop or take up some slower speed.

"What the possible efficiency and output of the motor may be, only experiment can tell. I have shown* that the output of an ordinary alternating motor is equal to that of a continuous current motor, supplied with a corresponding E.M.F. The efficiency might be great, but it has the disadvantage that about the same current flows for no work and maximum work, so for light loads the efficiency can hardly be very high.

"With our present knowledge of alternating currents it is useless to attempt to calculate from the simple though misleading assumptions ordinarily made, the output, conditions of maximum work, &c., of this machine. Experiment alone can determine its value, and one properly conducted and interpreted set of experiments should enable us to judge both the merit of the invention and its best possible form. I cannot see, however, how, in the form described in the last issue of this journal, the motor can work under conditions of a suddenly varying load as satisfactorily as continuous current motors."

To the above Mr. Tesla replied on June 2 as follows:

"I find in your issue of last week a note of Mr. Duncan referring to my system of alternate current motors.

"As I see that Dr. Duncan has not as yet been made acquainted with the real character of my invention, I cannot consider his article in the light of a serious criticism, and would think it unnecessary to respond; but desiring to express my consideration for him and the importance which I attach to his opinion, I will point out here briefly the characteristic features of my invention, inasmuch as they have a direct bearing on the article above referred to.

"The principle of action of my motor will be well understood from the following: By passing alternate currents in proper manner through independent energising circuits in the motor, a progressive shifting or rotation of the poles of the same is effected. This shifting is more or less continuous according to the construction of the motor and the character and relative phase of the currents employed, and I have indicated the theoretical conditions which should exist in order to secure the most perfect action.

"If a laminated ring be wound with four coils, and the same be connected in proper order to two independent

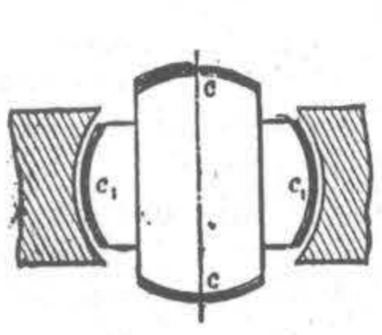

Fig. 1.

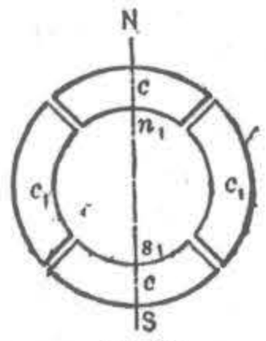

Fig. 2.

circuits of an alternate current generator adapted for this purpose, the passage of the currents through the coils produces theoretically a rotation of the poles of the ring, and in actual practice, in a series of experiments, I have demonstrated the complete analogy between such a ring and a revolving magnet. From the application of this principle to the operation of motors, two forms of motor of a character widely differing have resulted—one designed for constant and the other for variable load. The misunderstanding of Dr. Duncan is due to the fact that the prominent features of each of these two forms have not been specifically stated. In illustration of a representative of the second class, I refer to Fig. 1, given herewith. In this instance, the armature of the motor is provided with two coils at right angles. As it may be believed that a symmetrical arrangement of the coils with respect to the poles is required, I will assume that the armature is provided with a great number of diametrically wound coils or conductors closed upon themselves, and forming as many independent circuits. Let it now be supposed that the ring is permanently magnetised so as to show two poles (N and S) at two points diametrically opposite, and that it is rotated by mechanical power. The armature being stationary, the rotation of the ring magnet will set up currents in the closed armature coils. These currents will be most intense at or near the points of the greatest density of the force, and they will produce poles upon the armature core at right angles to those of the ring. Of course there will be other elements entering into action which will tend to modify this, but for the present they may be left unconsidered. As far as the location of the poles upon the armature core is concerned, the currents generated in the armature coils will always act in the same manner, and will maintain continuously the poles of the core in the same position, with respect to those of the ring in any position of the latter, and independently of the speed. From the attraction between the core and the ring, a continuous rotary effort, constant in all positions, will result, the same as in a continuous current motor with a great number of armature coils. If the armature be allowed to turn, it will revolve in the direction of rotation of the ring magnet, the induced current diminishing as the speed increases, until upon the armature reaching very nearly the speed of the magnet, just enough current will flow through the coils to keep up the rotation. If, instead of rotating the ring by mechanical power, the poles of the same are shifted by the action of the alternate currents in the two circuits, the same results are obtained.

"Now compare this system with a continuous current system. In the latter we have alternate currents in the generator and motor coils, and intervening devices for commutating the currents, which on the motor besides effect automatically a progressive shifting or rotation of the poles of the armature; here we have the same elements and identically the same operation, but without the commutating devices. In view of the fact that these devices are entirely unessential to the operation, such alternate current system will—at least in many respects—show a complete similarity with a continuous current system, and the motor will act precisely like a continuous current motor. If the load is augmented, the speed is diminished and the rotary effort correspondingly increased, as more current is made to pass through the energising circuits; load being taken off, the speed increases, and the current, and consequently the effort, is lessened. The effort, of course, is greatest when the armature is in the state of rest.

"But, since the analogy is complete, how about the maximum efficiency and current passing through the circuits when the motor is running without any load? one will naturally inquire. It must be remembered that we have to deal with alternate currents. In this form the motor simply represents a transformer, in which currents are induced by a dynamic action instead of by reversals, and, as it might be expected, the efficiency will be maximum at full load. As regards the current, there will be—at least, under proper conditions—as wide a variation in its strength as in a transformer, and, by observing proper rules, it may be reduced to any desired quantity. Moreover, the current passing through the motor when running free, is no measure for the energy absorbed, since the instruments indicate only the numerical sum of the direct and induced electromotive forces and currents instead of showing their difference.

"Regarding the other class of these motors, designed for constant speed, the objections of Dr. Duncan are, in a measure applicable to certain constructions, but it should be considered that such motors are not expected to run without any, or with a very light, load; and, if so, they do not, when properly constructed, present in this respect any more disadvantage than transformers under similar conditions. Besides, both features, rotary effort and tendency to constant speed, may be combined in a motor, and any desired preponderance may be given to either one, and in this manner a motor may be obtained possessing any

* Inst. Elec. Engineers, February, 1888.

desired character and capable of satisfying any possible demand in practice.

"In conclusion, I will remark, with all respect to Dr. Duncan, that the advantages claimed for my system are not mere assumptions, but results actually obtained, and that for this purpose experiments have been conducted through a long period, and with an assiduity such as only a deep interest in the invention could inspire; nevertheless, although my motor is the fruit of long labour and careful investigation, I do not wish to claim any other merit beyond that of having invented it, and I leave it to men more competent than myself to determine the true laws of the principle and the best mode of its application. What the result of these investigations will be the future will tell; but whatever they may be, and to whatever this principle may lead, I shall be sufficiently recompensed if later it will be admitted that I have contributed a share, however small, to the advancement of science."

THE TESLA ALTERNATING CURRENT MOTOR.

THE following correspondence has appeared in the *Electrical Review* of New York, upon a subject which is now of very general interest. Dr. Louis Duncan, of Johns Hopkins University, first wrote :

"The Tesla alternating current electromotor has attracted so much notice in the last week or so—a paper describing it having been read before the Boston Society of Arts, another before the American Institute of Electrical Engineers, and a description in the *Electrical Review*—that one is naturally led to enquire as to its possible advantages. The description published in this journal is the only one I have seen, and if one is to accept literally the statement contained in it, the Tesla motor has an unprecedented field of usefulness.

"We may, for our present purposes, divide motors into two classes : Continuous, in which the armature coils are unsymmetrical with respect to the poles, and which, therefore, give a practically constant torque, and alternating motors, in which the armature coils are symmetrical with respect to the poles, and which, therefore, give a torque varying both in magnitude and sign during a period of the counter E.M.F. The Tesla motor belongs to this latter class.

"In every motor the torque is equal to the rate of change of lines of induction through the armature circuit for a small angular displacement, multiplied by the armature current, or

$$\frac{d\,m}{d\,t}\ \text{I}.$$

In the Tesla motor the first of these terms is greatest when the coil is opposite a pole, and the field currents have their greatest amplitude ; it is zero at a point about 45° from this, supposing we neglect armature reactions. It depends on several things ; the E.M.F. which determines it is due to changes in the number of lines of force passing through the armature circuit caused by (1) changes in the field currents ; (2) the motion of the armature. The current depends on these E.M.Fs., and on the reduced self-induction and resistance of its circuit. The motor can only do work when the first cause of E.M.F. is the greater, for a current in the direction of the ordinary counter E.M.F. would stop the motion. In some parts of a revolution the two E.M.Fs. work together, retarding the motion ; in others, the induced E.M.F. produces a current causing the motor to revolve. It is impossible for me, with only a meagre description of the principles of the machine to give an idea of the relative magnitudes of these effects. Some of the results, however, are the following : Having given a definite number of reversals of the dynamo, there are a number of speeds, multiples of these reversals, at which the motor will govern itself when it is doing a certain amount of work. At one of these speeds, depending on the construction of the motor, the output will be a maximum.

"Now I see the statement that 'there is no difficulty whatever attendant upon starting the motor under load.' I cannot reconcile this with above facts. That the torque for a smaller number of revolutions than ordinarily used might be greater one can readily see, since the counter E.M.F. is less in proportion to the induced E.M.F., but it must be remembered that for certain speeds even the induced current would tend to stop the motion ; how the motor is to pass these critical speeds I do not see. Again, if the maximum load is suddenly thrown on while the motor is running at its proper speed. Then, if the inertia be great, the motor will fall behind its point of maximum work and either stop or take up some slower speed.

"What the possible efficiency and output of the motor may be only experiment can tell. I have shown* that the output of an ordinary alternating motor is equal to that of a continuous current motor supplied with a corresponding E.M.F. The efficiency might be great, but it has the disadvantage that about the same current flows for no work and maximum work, so for light loads the efficiency can hardly be very high.

"With our present knowledge of alternating currents it is useless to attempt to calculate from the simple, though misleading, assumptions ordinarily made, the output, conditions of maximum work, &c., of this machine. Experiment alone can determine its value, and one properly conducted and interpreted set of experiments should enable us to judge both the merit of the invention and its best possible form. I cannot see, however, how, in the form described in the last issue of this journal, the motor can work under conditions of a suddenly varying load as satisfactorily as continuous current motors."

To this the inventor, Mr. Nikola Tesla, replied :—

"I find in your issue of last week a note of Mr. Duncan referring to my system of alternate current motors.

"As I see that Dr. Duncan has not as yet been made acquainted with the real character of my invention, I cannot consider his article in the light of a serious criticism, and would think it unnecessary to respond ; but desiring to express my consideration for him and the importance which I attach to his opinion, I will point out here briefly the characteristic features of my invention, inasmuch as they have a direct bearing on the article above referred to.

"The principle of action of my motor will be well understood from the following :—

"By passing alternate currents in proper manner through independent energising circuits in the motor, a progressive shifting or rotation of the poles of the same is effected. This shifting is more or less continuous according to the construction of the motor and the character and relative phase of the currents employed, and I have indicated the theoretical conditions which should exist in order to secure the most perfect action.

"If a laminated ring be wound with four coils, and the same be connected in proper order to two independent circuits of an alternate current generator adapted for this purpose, the passage of the currents through the coils produces theoretically a rotation of the poles of the ring, and in actual practice in a series of experiments, I have demonstrated the complete analogy between such a ring and a revolving magnet. From the application of this principle to the operation of motors, two forms of motor of a character widely differing have resulted, one designed for constant and the other for variable load. The misunderstanding of Dr. Duncan is due to the fact that the prominent features of each of these two forms have not been specifically stated. In illustration of a representative of the second class, I refer to fig. 1, on page 1 of *Electrical Review* of May 12th. In this instance, the armature of the motor is provided with two coils at right angles. As it may be believed that a symmetrical arrangement of the coils with respect to the poles is required, I will assume that the armature is provided with a great number of diametrically wound coils or conductors closed upon themselves, and forming as many independent circuits. Let it now be supposed that the ring is permanently magnetised so as to show two poles (N and S) at two points diametrically opposite, and that it is rotated by mechanical power. The armature being stationary, the rotation of the ring magnet will set up currents in the closed armature coils. These currents will be most intense at or near the points of the greatest density of the force, and they will produce poles upon the armature core at right angles to those of the ring. Of course, there will be other elements entering into action which will tend to modify this, but for the present they may be left unconsidered. As far as the location of the poles upon the armature core is concerned, the currents generated in the armature coils will always act in the same manner, and will maintain continuously the poles of the core in the same position, with respect to those of the ring in any position of the latter, and independently of the speed. From the

* Inst. Elec. Engineers, February, 1888.

attraction between the core and the ring, a continuous rotary effort, constant in all positions, will result, the same as in a continuous current motor with a great number of armature coils. If the armature be allowed to turn, it will revolve in the direction of rotation of the ring magnet, the induced current diminishing as the speed increases, until upon the armature reaching very nearly the speed of the magnet, just enough current will flow through the coils to keep up the rotation. If, instead of rotating the ring by mechanical power the poles of the same are shifted by the action of the alternate currents in the two circuits, the same results are obtained.

"Now compare this system with a continuous current system. In the latter we have alternate currents in the generator and motor coils, and intervening devices for commutating the currents, which on the motor besides effect automatically a progressive shifting or rotation of the poles of the armature; here we have the same elements and identically the same operation, but without the commutating devices. In view of the fact that these devices are entirely unessential to the operation, such alternate current system will—at least in many respects—show a complete similarity with a continuous current system, and the motor will act precisely like a continuous current motor. If the load is augmented the speed is diminished and the rotary effort correspondingly increased, as more current is made to pass through the energising circuits; load being taken off the speed increases and the current, and consequently the effort, is lessened. The effort, of course, is greatest when the armature is in the state of rest.

"But since the analogy is complete, how about the maximum efficiency and current passing through the circuits when the motor is running without any load, one will naturally enquire? It must be remembered that we have to deal with alternate currents. In this form the motor simply represents a transformer in which currents are induced by a dynamic action instead of by reversals, and as it might be expected the efficiency will be maximum at full load. As regards the current, there will be—at least under proper conditions—as wide a variation in its strength as in a transformer, and by observing proper rules, it may be reduced to any desired quantity. Moveover, the current passing through the motor when running free, is no measure of the energy absorbed since the instruments indicate only the numerical sum of the direct and induced electromotive forces and currents instead of showing their difference.

"Regarding the other class of these motors, designed for constant speed, the objections of Dr. Duncan are, in a measure, applicable to certain constructions, but it should be considered that such motors are not expected to run without any, or with a very light load, and, if so, they do not, when properly constructed, present in this respect any more disadvantage than transformers under similar conditions. Besides, both features, rotary effort and tendency to constant speed, may be combined in a motor, and any desired preponderance may be given to either one, and in this manner a motor may be obtained possessing any desired character and capable of satisfying any possible demand in practice.

"In conclusion, I will remark, with all respect to Dr. Duncan, that the advantages claimed for my system are not mere assumptions, but results actually obtained, and that for this purpose experiments have been conducted through a long period, and with an assiduity such as only a deep interest in the invention could inspire; nevertheless, although my motor is the fruit of long labour and careful investigation, I do not wish to claim any other merit beyond that of having invented, and I leave it to men more competent than myself to determine the true laws of the principle and the best mode of its application. What the result of these investigations will be the future will tell; but whatever they may be and to whatever this principle may lead, I shall be sufficiently recompensed if later it will be admitted that I have contributed a share, however small, to the advancement of science."

NOTES.

Alternate Current Motors.—With reference to the recent discoveries by Dr. Ferrari and Nikola Tesla in the direction of alternate current motors, the question of prior invention is cropping up already. We learn on good authority that Prof. Elihu Thomson has had an alternate current motor running in his laboratory for the last twelve months or so.

THE TESLA ALTERNATE CURRENT MOTOR.

Dr. Louis Duncan gives the following further note on the Tesla motor:

"Since writing my last note on this motor Mr. Tesla has read an interesting description of his system before the Institute of Electrical Engineers, and in his answer to the note referred to he has further described his motors. The study of both of these papers has increased my admiration for the simplicity and success of his system.

"The motor discussed in my last note was of the synchronous type with two short-circuited coils at right angles to one another. Further, Mr. Tesla in his paper before the Institute of Electrical Engineers states that 'in a general distributing system of this kind the following plan should be adopted. . . . The motors operated from this generator should be of the synchronous type, but possessing sufficient rotary effort to insure starting.' So I will reconsider the statements I made in the previous note with reference to this type, and try to see if they should be modified. With respect to my views as to the theory of such a motor, they look at the phenomena from a different stantpoint from that taken in Mr. Tesla's paper, and an unfortunate misprint ('It' for 'I,' the symbol used to represent current) greatly obscures the meaning. Apart from this, my conclusions were that it was doubtful if such a motor would start under load—meaning to attain its proper number of revolutions—that if a load of great inertia be suddenly applied so that the motor is called on for more than its maximum load, it will stop or take up some slower speed; and finally, that the currents do not decrease in proportion to the load. Now, the first two questions can be settled so easily and simply by experiment, that it is hardly worth while attempting to evolve reasons for believing one way or the other. The way I would look at it is this: The motor combines a synchronous and non-synchronous part. The former does little work until the motor reaches its normal speed; the latter does considerable work until the motor reaches a speed lower than the normal by an amount depending on the load. Now, how is the speed to jump from this lower value, at which equilibrium is reached, to the normal value? It might do so in a number of cases where the inertia is great; in others I must confess to doubts. As to the second point, my objection follows directly from what I have said above.

"With respect to the consumption of current at small loads, I think that in any synchronous motor, the effect of decreasing load is simply to decrease the difference between two quantities of work—one plus, the other minus—that the motor does. If this is the case, the currents should not vary in proportion to the load, but should be greater in proportion with smaller loads.

"With respect to the non-synchronous motors, however, I have very little but admiration to express. I cannot help thinking that they can be governed without resorting to synchronism, and in this case they will have advantages that will greatly aid in the advance of electric distribution.

"Finally, I must confess to some disappointment that no data has been given as to the performance of Mr. Tesla's motors. One cannot, of course, expect from machines that are just emerging from an experimental state the efficiency and output that they will finally attain, but a few curves of the currents in the magnets and armature coils under different conditions would tell us more of the possibilities and directions of improvement than could any amount of discussion.

"In the meantime, I would congratulate Mr. Tesla on the discovery and application of a novel means of obtaining continuous rotation from alternating currents, and I shall watch the further development of his system with interest."

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The Tesla Motor.

TO THE EDITOR OF ELECTRICAL REVIEW:

I desire to call your attention to an interesting statement to the effect that Tesla's alternating current motor is anticipated by Varley's automatic electric clock system in operation in the Royal Institution, London, England, as I am advised. I am informed by a prominent English electrician, that the Standard Clock has a bob carrying a bobbin which, as the pendulum vibrates, is carried back and forth over permanent magnets, thus generating alternating currents at each of its vibrations. The outlying local clocks are connected by wires through the bobbin circuit of the pendulum, and the motors of these clocks are constructed in almost identically the same manner as those covered by Tesla's inventions. I give you this for what it is worth, and you are at liberty to use it in your journal if you desire.

Very truly yours,

New York, June 20. C. J. KINTNER.

We fail to see the anticipation. Tesla's motor depends upon two separate currents, differing in phase by one-quarter period, and a pendulum bob is hardly capable of generating that particular kind of currents. It is more likely to be a step-by-step motor at the outlying clocks operated by the reversal of the generated currents. However, in the absence of details from our correspondent, only guesses can be made.

An English Opinion of the Tesla Motor.

In our issue of the 18th May, we gave an account of a very interesting investigation made by Professor Galiles Ferraris, of Turin, which had for its object the production of mechanical rotation by the electro-dynamic action of alternating currents. The fundamental principle of the apparatus devised by Ferraris, is a revolving resultant magnetic field produced by two coils, which carry alternating currents, and the axes of which are at right angles to each other. We said in our account of this investigation, that this principle may be applied in the construction of electricity meters to be used on an alternate current supply system, and possibly also in that of motors; though on this point we would not prophesy. It is significant of the enterprise and inventive skill of American electricians, that at the time these lines were being printed, Mr. Nicola Tesla brought before the American Institute of Electrical Engineers an actual solution of the problem which we on this side of the Atlantic merely foreshadowed as possible at some future time. The solution may, perhaps, not be perfect in its present form; but as far as it goes, it is a long step in the direction of applying alternating currents for motive power purposes, and as such it will be appreciated by those of our readers who are interested in the distribution of electricity from central stations. Owing to the importance of the subject, we give herewith Mr. Tesla's paper in full.—*London Industries.*

The Tesla Motor.

To the Editor of Electrical Review:

The Tesla alternating current motor is entirely different from the very old class of devices, to one of which Mr. Kintner refers on page 1 of your issue of June 30, and in all of which devices motion is transmitted by impulses of currents moving in opposite directions in comparatively slow succession. In fact the first telegraph of Gaus and Weber in 1835 was operated by alternate currents acting upon a galvanometer needle, deviating it to the right and left; while Steinheil, in order to make the signals audible, added to this, in 1838, two bells of different pitch which were alternately struck when the needle was deflected right or left, and also in order to make a permanent record, he moved strips of paper by machinery and made dots on it by furnishing the needle with a tube containing ink. (1)

Most of the submarine cables are now worked by means of alternate currents and this for an important additional reason, namely, a long insulated conductor acts like a very elongated Leyden jar and becomes charged at the transmission of every signal, while the following reverse current neutralizes this charge, reducing the time required between the signals, and thus increasing the capacity of the cable. In this case the signs are made visible by attaching to the needle a small mirror which reflects the light of a lamp as a white spot on a scale, and is moving right or left with the alternate movements of the needle impelled by alternate currents. Again, the rapid telegraph system operated by strips of perforated paper, is worked by alternating currents.

The London standard clock, referred to by your correspondent, is only another application of this very same device, being also actuated by currents generated by the action of permanent magnets upon bobbins or coils, as was the case with the telegraph signals of Gaus and Weber in 1835; the only difference being that in the clock the currents alternate continually at equal periods of time.

It is thus seen that the principle upon which Varley's electric clock operates is anticipated by Gaus and Weber's device of 1835, but none of those devices have the least relation to the motor of Mr. Tesla, which is based on the practical application for motive power of the torrent of electric currents produced by an alternating dynamo, which currents succeed one another with the astounding rapidity of some twenty thousand alternations per minute. (2)

It is self-evident that such a current cannot act upon a galvanometer, nor charge electro-magnets, for reason that the opposite currents continually neutralize one another, wherefore they cannot be measured by the ordinary appliances used for continuous currents, nor can such a current give the least movement to any electric motor based upon attraction and repulsion of electro magnets, whatever be its type.

Mr. Tesla's alternating current motor is based on an entirely new principle which must be carefully studied to be understood, and it is only the want of the latter which may cause it to be confounded with the various other devices referred to above, of which the alternations amount to 4 per second at the most, while the Tesla motor works with some 400 alternations per second.

It is evident that the ordinary type of electro-motors is here out of the question, and Mr. Tesla's merit consists in the application of a very differerent principle discovered by him and the construction of a very peculiarly arranged motor invented by him.

While congratulating Mr. Tesla with his success in this new path of pursuit, I cannot leave him without bringing to his notice an oversight he makes in his address on May 16th to the American Society of Electrical Engineers, as published in the Electrical Review of May 20th. He says: "In reality * * * all machines are alternate current machines, the currents appearing as continuous only in the external circuit, during their transit from generator to motor. In view simply of this fact, alternate currents would commend themselves as a more direct application of electric energy, and the employment of continuous currents would only be justified *if we had dynamos which would primarily generate, and motors which would be directly actuated by such currents.*"

The oversight I refer to is that Mr. Tesla only has in view the first machines of Siemens, Halske, Wilde, Ladd, Weston's first electro-plating machine, Moehring, Baur, Brush, and a few others of the same type, in all of which alternate currents are produced, which by the commutator are brought in the same direction. If we had no other machines as such, Mr. Tesla's remark would be correct, but the fact is that *we have dynamos which will primarily generate, and motors which will be directly actuated by such currents.*

This class of dynamos and motors are based on the invention made in 1860 by Pacinotti, of Florence, of a motor of which the acting part consisted of an iron ring placed between two diametrically opposed magnetic poles and which ring revolves around its axis. It was wound with a series of coils, of which the ends were connected together and with a commutator on the axis in such a way that the battery current entered and had exit at two diametrically opposite points, sub-dividing itself over two paths, each of which passed through the coils of half the ring. The result was the formation of two diametrically opposite poles which, when the ring revolved, were continually shifting, and could be adjusted in such a way that there was a continual pull of the permanent magnets, without any reversion of polarity or of current.

It is on record that Pacinotti, by revolving his motor by mechanical means, generated induced currents, which he tested by the constant deviation of the galvanometer needle and of which he said: "A machine of this kind will furnish an uninterrupted current in the same direction without the necessity of any mechanical device, for changing currents running in alternate opposite directions into currents running in the same direction." (3)

Ten years later Jamin reported to the French Academy that Gramme had invented a new magneto electric machine which produced currents in the same direction.(4) This machine was nothing but a Pacinotti ring revolving between the poles of a permanent magnet. It is doubtful if Gramme had any knowledge of Pacinotti's invention, or made his invention independently of such knowledge, but in any case it inaugurated a new era in the production of powerful electric currents, and very soon the great number of possible variations on this principle induced Gramme to construct various machines for galvano-plating, electric lighting, charging storage batteries, etc., and it was not long before real or supposed improvements were made by Fein, Schuckert, Heinrichs, Fitzgerald, Siemens, Halske, Weston, Moehring, Maxim, Niaudet, Wallace—Farmer, Lontin, Buergin, Hefner-Alteneck, Tompson-Houston, and many others.

It was then found that these constant current machines gave more economical results

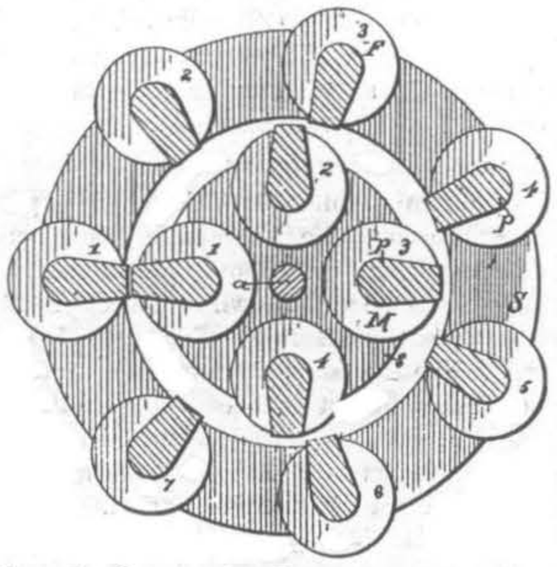

Fig. 3.—Sectional Elevation of a 4-7 Pole Lugo Motor.

than those constructed on the old principle of reversing currents brought in the same direction by a commutator, consequently they became the leading type for several years, until Lontin pointed out that the use of a commutator for bringing alternate reversing currents in the same direction involved a great loss, also that for the production of electric light, it was unnecessary, so that alternating current machines would be far more economical for this purpose, and he proved it by the introduction of his large alternating machine with 24 pole pieces, able to feed a number of 12 or less entirely independent circuits.

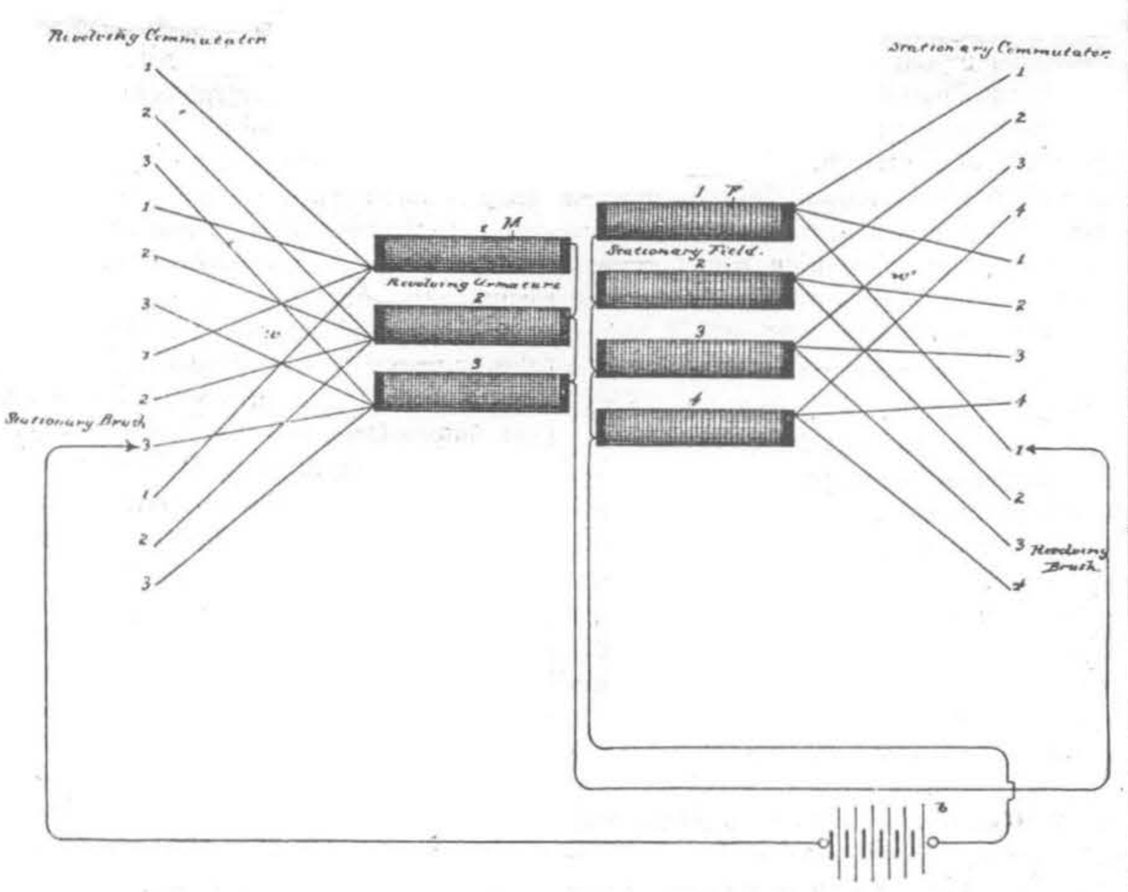

Fig. 2.—Diagram of Commutation of a 3-4 Pole Lugo Motor.

Soon after alternating machines of various types were constructed by Gramme, Siemens, Halske, Hefner-Alteneck and many others, and it was quite natural that attempts were made to extend their sphere of usefulness beyond that of electric illumination; the possibility of their application to electro-motors appeared almost hopeless, until Mr. Tesla came forward with his motor, which no doubt will inaugurate a new era, if not a revolution in electro dynamics.

P. H. Vander Weyde.

New York, July 2.

(1.) See Noad's Electricity, edited by Preece, London, 1879, p. 411.

(2.) If my memory serves me right, the alternating machine with which the welding of iron and steel was performed at the late exhibition of the American Institute Fair made 24 alternations for every revolution, while the latter amounted to 1,500 per minute.

(3.) Comptes rendus, Vol. LXXIII, p. 144 and 175.

(4.) Shellen Magnet and Dynamo Electrischen Machinen. Cologne, 1882, p. 129.

ON THE TESLA ALTERNATING-CURRENT MOTOR.

BY J. SWINBURNE.

The account of Mr. Tesla's invention has received such attention from the technical press, and appears to have satisfied so many people that the problem of alternating-current motors is solved, that a short investigation of the subject may not be amiss.

The problem of alternating-current motors may be divided into two distinct parts—to make a motor that will start, and to make a motor that will work with varying loads, preferably with constant or nearly constant speeds, but certainly with reasonably high efficiency in each case. As those who are accustomed to the usual way of treating dynamo problems will perhaps find a little difficulty in following Mr. Tesla's description, an attempt will be made to describe his apparatus another way.

Suppose an alternating-current dynamo, such, for instance, as the Westinghouse, were taken, the armature has, roughly speaking, only half its periphery covered with wire. If another circuit were wound on, filling up the air spaces, it would also give an alternating current if it had its own collectors, but this alternating current would be a quarter of a period behind the other. The same effect would be got by rigidly coupling two alternate-current machines together so that one is a quarter of a period in advance of the other—that is to say, one has its coils in a maximum field when the others are in their minimum field. The simplest form of such a motor would be an ordinary drum armature wound with two coils at right angles, each coil having its own pair of collector rings. This is the example taken by Mr. Tesla. The magnets, of course, are supposed to embrace a quadrant each, instead of about 150 degrees as is usual in continuous-current machines. For simplicity we will suppose the generator to be made up of two ordinary alternating-current machines, coupled rigidly together as described, with two pairs of conductors, each with its own alternating current, these currents differing by a quarter of a period. If a motor is made up in a similar way by coupling two alternate-current machines together, if once started it will run in exactly the same way as an ordinary alternating-current motor, having all its advantages and disadvantages, with the addition that it needs two sets of leads and a special generator. Its efficiency is the same as an ordinary motor, and it will synchronise in the same way. Of course it will not start.

Suppose now that the alternating motor is varied in construction so that the armatures are stationary, the effect will be just the same. A synchronising motor will be obtained which is not self-starting. Instead of this Mr. Tesla uses what he calls a fixed field-magnet with a rotating field and rotating armature in his motor, but we may perfectly correctly call it a fixed armature and rotating field-magnet. The armature is outside the field-magnet, and may be looked upon as a Gramme ring wound with four coils, the opposite coils being pairs, so that there are two circuits. One is connected to each pair of

leads. The direction of magnetisation is thus made to revolve just as in any alternate or direct current machines in which the armature is fixed and the field revolves, such, for instance, as the Ayrton and Perry motor or new Siemens dynamo. So far the only result is no better than can be got from machines already known.

As to the exceedingly ingenious method of starting, suppose in an ordinary dynamo an armature is revolved, having some short-circuited coils, the armature resists the motion owing to the currents induced. The armature is revolving, and the direction of magnetisation is fixed; but, as motion is relative, we may say that the direction of the magnetisation and the closed coils are moving relatively to each other. This relative motion is opposed by the currents induced in the coils. Now, if Mr. Tesla winds some closed coils on what he calls his armature, and what is here called his field-magnet, when the direction of magnetisation moves round relatively to the closed coils, currents are induced which tend to make the field-magnet revolve.

This ingenious method of making it start is the only advantage Mr. Tesla's motor possesses. In the synchronising form the closed coils of the field-magnets are used till the proper speed is attained, when the machine falls into step, and the exciting current is switched on, so that they become the field-magnet coils in the ordinary sense. In another form the whole motive power is supplied by these closed coils, so that the machine does not actually synchronise, but goes slower at heavy loads.

Taking the first form, or synchronising motor, we get a self-starting motor, but it needs an exciter, and needs also a special dynamo to drive it, with two circuits, involving three or four leads. In the second form the revolving part cannot be so well described as the field-magnet, because it is excited entirely by the armature. Of course an ordinary direct-current dynamo will work as a motor without any field current if the brushes are put forward, the field being then excited by the armature current; but to make such an arrangement efficient, apart from the question of sparking, which does not now concern us, the armature would have to be designed so as to magnetise the field strongly. In Mr. Tesla's arrangement this is impossible unless the machines are of enormous size. This difficulty would be lessened by making both the fixed and revolving parts on the Pacinotti principle. Instead of using two closed coils on a smooth core, there would also be an advantage in simply encasing the armature in solid copper.

The low efficiency is not at all the chief objection to the scheme. The whole arrangement is unpractical, as it demands special alternate-current generators and leads. There are several ways of starting alternate-current motors. The exciter may have laminated field-magnets, and may be put on the alternate-current circuit to get up the speed, as already proposed by the writer, or a small secondary battery may be used in connection with the exciter, which will start the whole system. It would never be worth while to put down special dynamos and special leads just to use a motor that will start, and that has no other advantages. The two circuits would be useless for other purposes. The transformer proposed by Mr. Tesla must be very inefficient. It has consequent poles revolving, and has thus an open magnetic circuit. It would be better to use the two alternating currents separately, putting some of the transformers on one circuit and some on the other; but if two circuits are to be used it would certainly be cheaper to use a direct current for the motors, and have them self-starting, self-regulating, and efficient. Until Mr. Tesla can produce a motor which will work on alternate-current circuits as they are, and do that efficiently even with varying loads, and without difficulty in starting, he can hardly be said to have solved the problem. With the ingenuity he has already shown no doubt he will do it soon, but he cannot be said to have done it yet.

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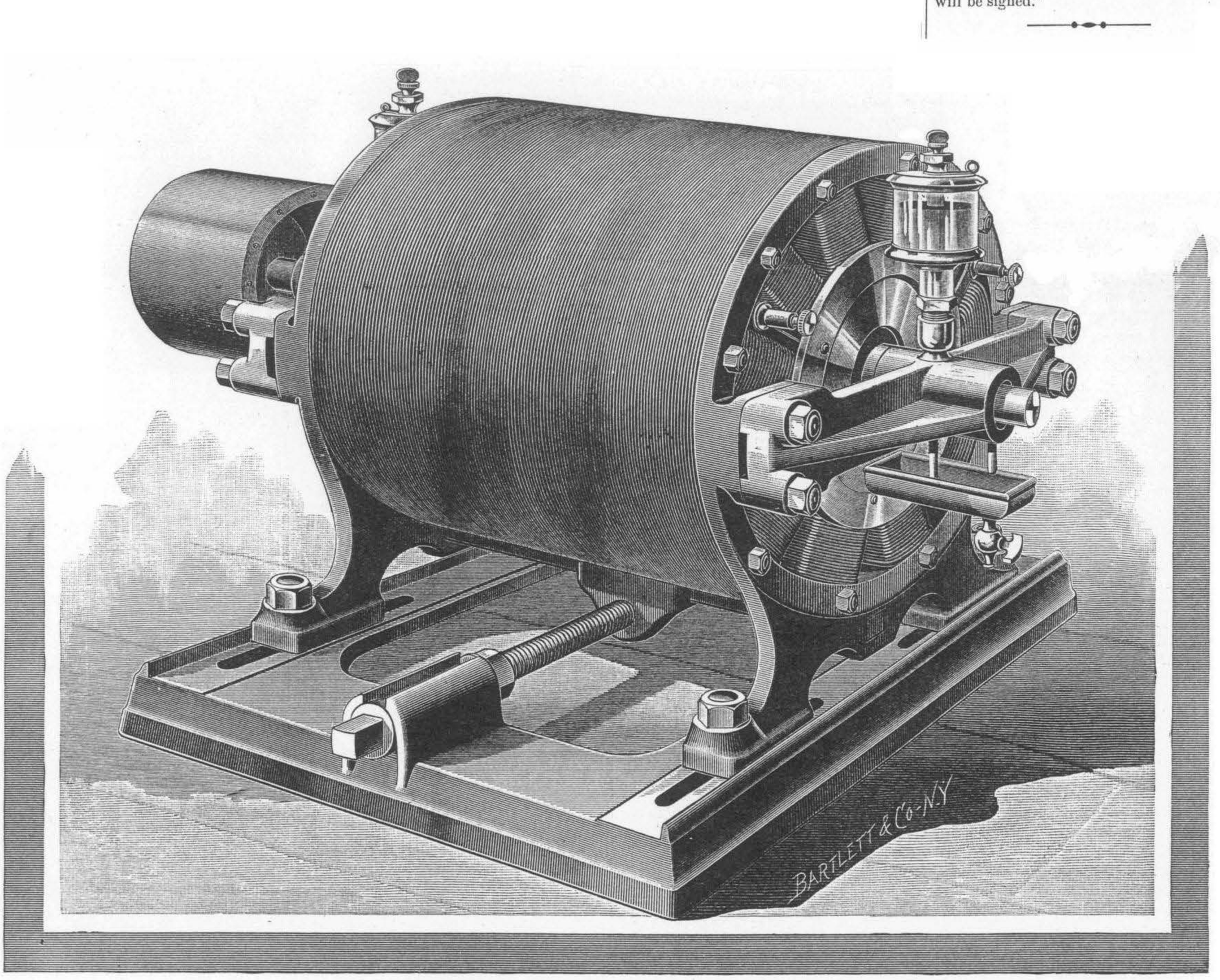
The Westinghouse Company Secures the Tesla Motor.

In the Pittsburgh *Post* of recent date, appears the following notice, which, after making due allowance for the Pittsburgh reporter's enthusiasm, evidently means that the progressive Westinghouse Electric Company has promptly realized the value of the work of the talented young inventor and experimenter, Mr. Nikola Tesla:

"It is safe to say that the Westinghouse Electric Company has a gold mine in its new electric motor. The public, even the electric public, has not yet reached a realization of the importance of the invention The motor was invented by Nikola Tesla, a native of Lika, a town on the border line of Austria and Hungary. He was educated in Austria, and graduated as a civil engineer. Electricity soon claimed his entire attention, and now, though apparently less than 30 years of age, he has a very wide reputation as an electrician. The Westinghouse has contracted for his patents on the new motor, and he has been in the city several weeks proving all he claims for his invention. When the company is satisfied, the contracts will be signed."



THE WESTINGHOUSE ELECTRIC MOTOR.—TESLA PATENT.

NOTES.

The Tesla Motor.—The patents of Mr. Nikola Tesla, whose invention of the alternate current motor were recently described by us, have been purchased by the Westinghouse Company. The manufacturing preliminaries are being pushed forward, and the Tesla motors will soon be in the market.

NOTES.

Its only Rival.—The only final rival to the Tesla motor is the Keeley one; that would beat it, if it would work. The Keeley Company have called upon Mr. Keeley officially to disclose his secret, or henceforth and for ever hold his peace. He offered to do this eighteen months ago, and now is compelled to do so, or fall. And he cannot do it. The Keeley "motor" won't "mote."

Secured a Gold Mine.—"It is safe to say," says the *Pittsburgh Post*, "that the Westinghouse Electric Company has a gold mine in its new electric motor. The public, even the electric public, has not yet reached a realisation of the importance of the invention. The motor was invented by Nikola Tesla, a native of Lika, a town on the border line of Austria and Hungary. He was educated in Austria, and graduated as a civil engineer. Electricity soon claimed his entire attention, and now, though apparently less than 30 years of age, he has a very wide reputation as an electrician. The Westinghouse has contracted for his patents on the new motor, and he has been in Pittsburgh several weeks proving all he claims for his invention."

The Tesla Motor.—It is stated that the Westinghouse Company has purchased the Tesla alternate-current motor patents, and intends shortly to put some of these machines upon the market.

6481. "Improvements relating to the electrical transmission of power and to apparatus therefor." H. H. LAKE. (Communicated from abroad by N. Tesla, of New York.) Dated May 1. 8d. A motor is employed in which there are two or more independent energising circuits through which are passed alternating currents, which effect a progressive shifting of the magnetism or of the "lines of force" which, in accordance with well known theories, produces the action of the motor. The claims are 8 in number.

6502. "Improvements relating to the generation and distribution of electric currents and to apparatus therefor." H. H. LAKE. (Communicated from abroad by N. Tesla, of New York.) Dated May 1. 8d. Relates to those systems of electrical distribution in which a current from a single source of supply in a main or transmitting circuit, is caused to induce, by means of suitable induction coils, a current or currents in an independent working circuit or circuits. The main objects of the invention are the same as have heretofore been obtained by the use of these systems, viz., to divide the current from a single source whereby a number of lamps, motors, or other translating devices may be independently controlled and operated by the same source of current, and in some cases to reduce a current of high potential in the main circuit to one of greater quantity and lower potential in the independent consumption circuit or circuits. The claims are 4 in number.

NOTES.

The Tesla Motor.—The Westinghouse Electric Company, says the *Electrical World*, are making some experiments with the new Tesla motor for street-car service, and are very much encouraged by the prospects. They propose to take up the matter of power immediately, and have this system of motors introduced as rapidly as possible.

WITH EIGHT-PAGE SUPPLEMENT.

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THE WESTINGHOUSE SYSTEM OF ELECTRICAL DISTRIBUTION FOR LIGHT AND POWER.

Owing to the crowded condition of our columns this week we are compelled to issue a supplement in order to give our readers a full exposition of this now splendidly complete system.

As the alternating current motor is perhaps the most interesting of the details, we present it first, illustrating it on page 1 of our regular edition.

The alternating current motor consists of a series of field magnets, wound with two sets of coils, the ends of which are connected to binding posts conveniently located for attachment to the supply circuit. These binding post form the only connection with the current, which current is taken from the regular lighting circuits, with the addition of a single return wire. This return wire makes it possible to send two alternating currents through the field of the motor at the same time, the pulsations of the two currents being similar but not simultaneous. The resultant of these two currents is that a rapidly rotating polarity is given to the field, corresponding in period to that of the current producing it.

The armature is in appearance similar to the ordinary Siemens drum armature, without the commutator. The winding is, however, much simpler, and consists of a few turns of comparatively small wire, the ends of which, instead of being carried out to a collecting ring, or any other form of sliding contact, are soldered together, forming a closed circuit having no connection with the energizing current. The alternating currents in the field induce secondary currents in the armature, and by the attraction between these and the revolving polarity of the field, rotation is produced, the rate of rotation corresponding very nearly with that of the field.

When no work is being done by the motor, the synchronism is exact, or nearly

(*Continued in Supplement.*)

SUPPLEMENT

To the ELECTRICAL REVIEW, October 27, 1888, Containing Illustrations of the Westinghouse System of Electrical Distribution for Light and Power, etc., etc.

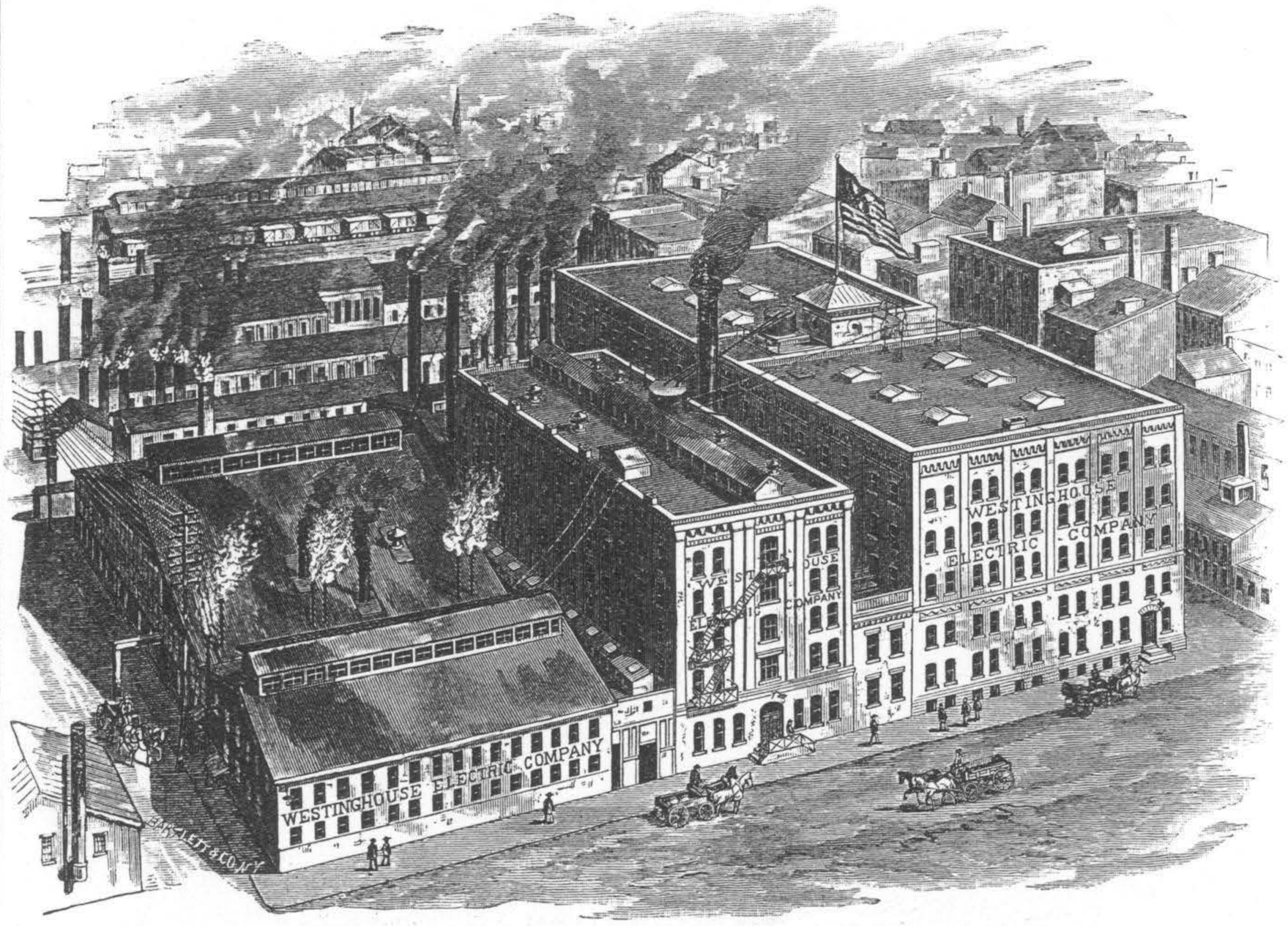
THE WESTINGHOUSE SYSTEM
OF
Electrical Distribution for Light and Power.

(*Continued from page* 1, *Regular Edition.*)

so, and very little current passes either through the armature or field, but as load is put on and the work increases, the armature tends to lag slightly, causing the passage of more current in proportion to the work done. The reaction between the armature and the field is similar to that between the primary and secondary coils of a converter, and the increase of load on the motor causes increased supply of current in a manner exactly as takes place when lamps are added to the secondary-circuit of a converter. The addition of the return wire for the motor circuit can be made easily so as to adapt existing lighting circuits to motor work, and the armature of the dynamo used for driving motors is equally available for lighting purposes.

By an ingenious adaptation of the converter principle, this motor may be regulated in speed and reversed in its direction of motion without the use of switches or resistance coil. The method of operation is exactly similar to the link reversing gear of a locomotive. The extreme position of the reversing lever in one direction corresponds to full speed ahead, from which it can be graduated through every shade of intermediate speed to the reversing point, and from that on to full speed backwards. This is more readily accomplished owing to the absence of brushes, since there can be no sparking or wear due to the passage of current under any circumstances. No attention need be given to the motor beyond the filling and cleaning of the oil cups.

The alternating motor is more compact than the direct current motor, and lighter in proportion to the power delivered. It can be served either through a converter or

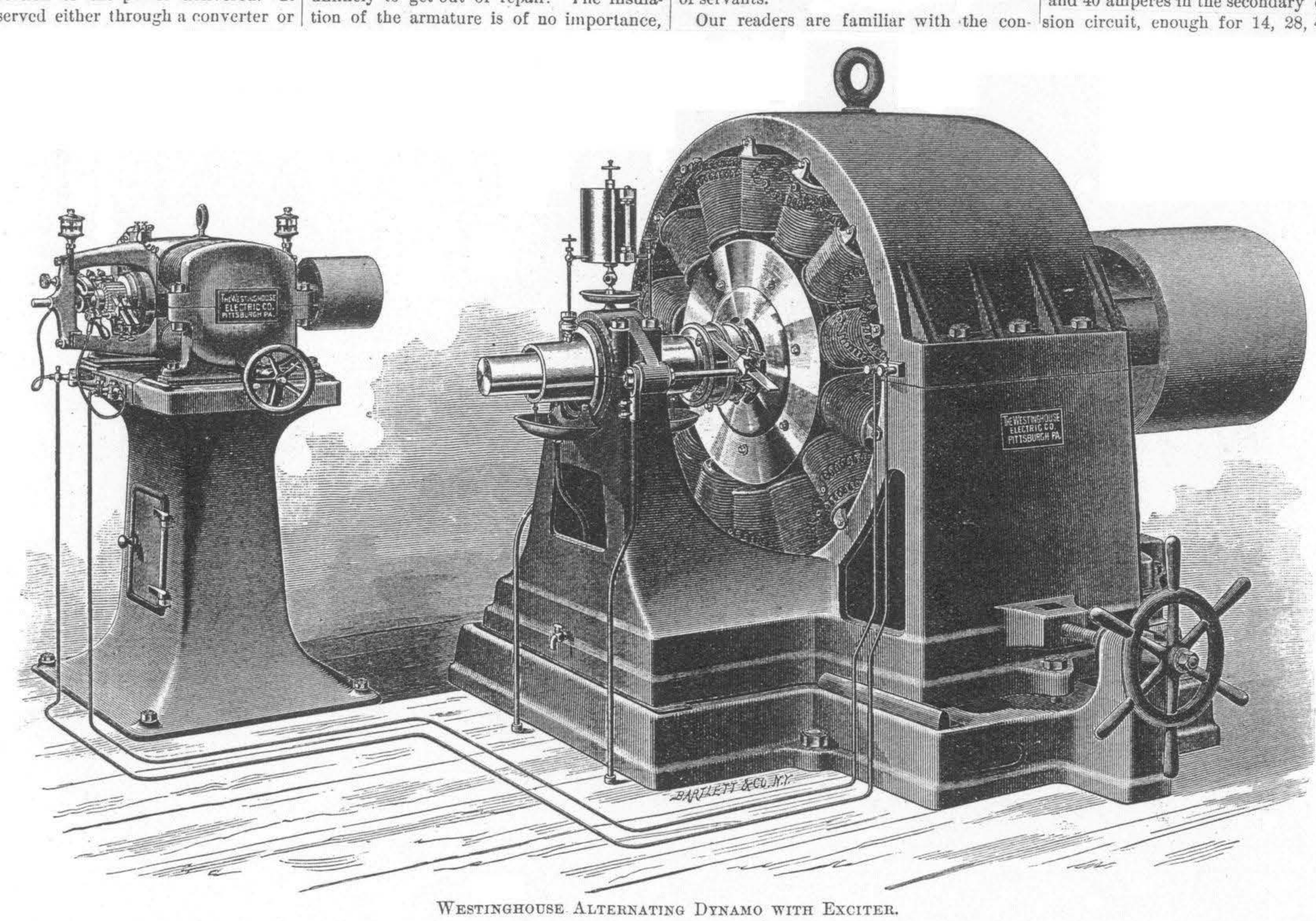


THE FACTORIES OF THE WESTINGHOUSE ELECTRIC COMPANY, PITTSBURGH, PA.

posts need never be touched or even exposed in any way, the use of a high tension current becomes possible. The extreme simplicity of the winding and general construction of this motor makes it very unlikely to get out of repair. The insulation of the armature is of no importance, since the current traversing it is never but a few volts and often less than one volt, regardless of the voltage of the supplying circuits. Absolutely no electrical knowledge is required in its operation, and the connections to the circuit in erecting are so simple that any one of ordinary intelligence can make them with ease and certainty. The alternating current motor is therefore thoroughly practical for manufacturing, commercial and domestic use in the hands of servants.

Our readers are familiar with the construction and details of the salient features of the system, such as the alternating current dynamo exciter and the converter, and we herein illustrate these various parts in their latest development, without further detail or description. Every feature has been designed with great skill indeed

The generators are made in four sizes of a capacity respectively of 500, 750, 1,500 and 3,000 lamps of 16 candles each. The converters are also in four sizes, 10, 20, 30 and 40 amperes in the secondary or low tension circuit, enough for 14, 28, 42 and 56



WESTINGHOUSE ALTERNATING DYNAMO WITH EXCITER.

directly from the primary circuits. The connections may be so protected that no inconvenience or danger can possibly result from direct connection to high tension service should such become desirable. As there are no sliding contacts, and the binding

lamps. The general aim is to do as much distributing as possible with the primary and make the secondary short. The converters are placed on the line poles or on the outer wall of the building, the latter preferred. For very long distance work, a

converter at the station raises the standard E. M. F. to 2,000 volts, and the ordinary line converters are connected at the consumption points, two and two, their primaries in series and secondaries in multiple. The "compensator" is a most ingenious satellite of the alternating system, serving the purpose of the extra "pressure-wire" of direct current systems, to enable the dynamo tender to preserve a constant drop of potential. The ammeters connected through the switchboard by short-circuiting plugs, show the volume of current on the mains. The "ground detector" is an interesting example of careful designing, and is very prompt and reliable. A standard voltmeter forms a very desirable part of every station equipment, and is so constructed as to be constant in its readings. By it the service voltmeters are calibrated.

The station switchboard is a beautiful sample of compactness. The figure shows one arranged for two exciters, two dynamos and four lines. Two exciter rheostats with changing switches have an obvious use, as also two dynamo field rheostats with coupling switch between. Four pairs of trunk wires with two multiple-arcing switches, and six changing switches render any service connection possible in an instant. Four voltmeters and compensators are arranged for instant connection with the respective lines, and two ammeters, by means of the changing switches can be used rapidly, and plugged out instantly. All the devices are guarded by safety catches.

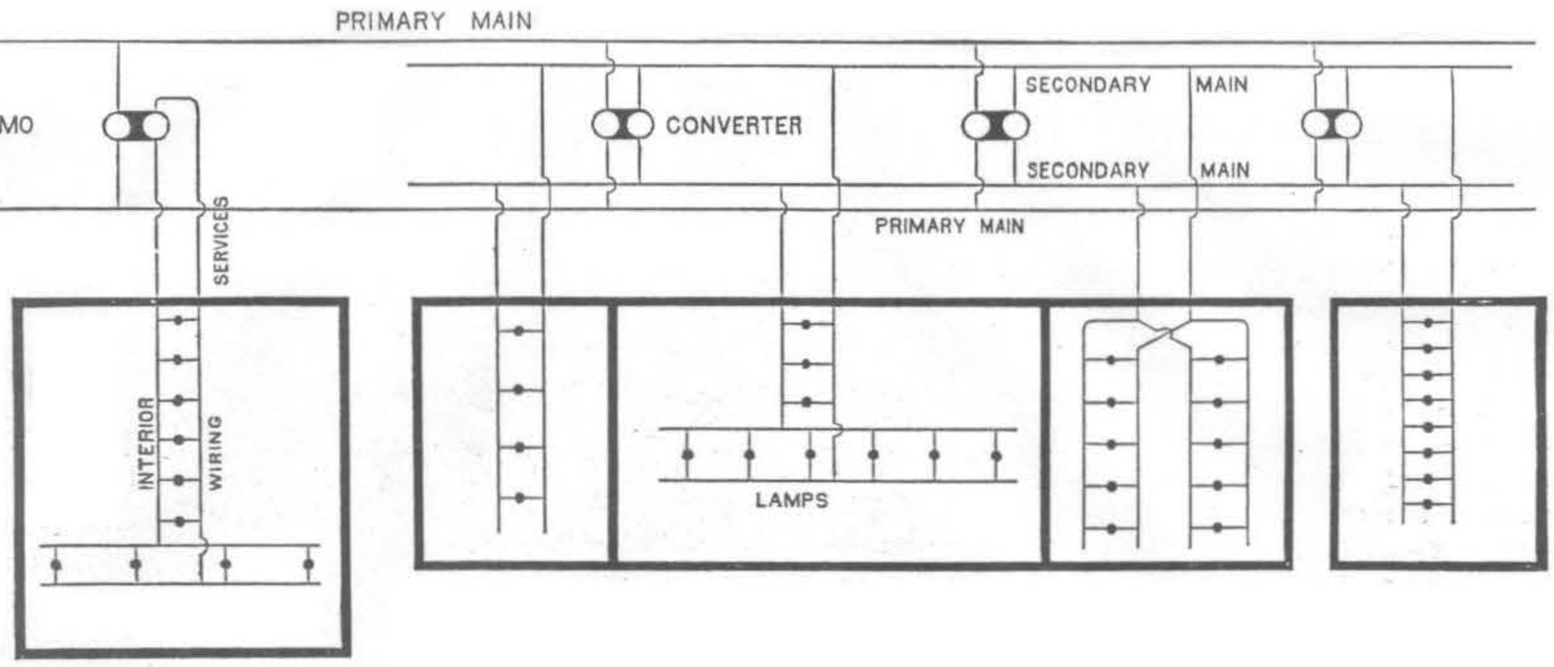
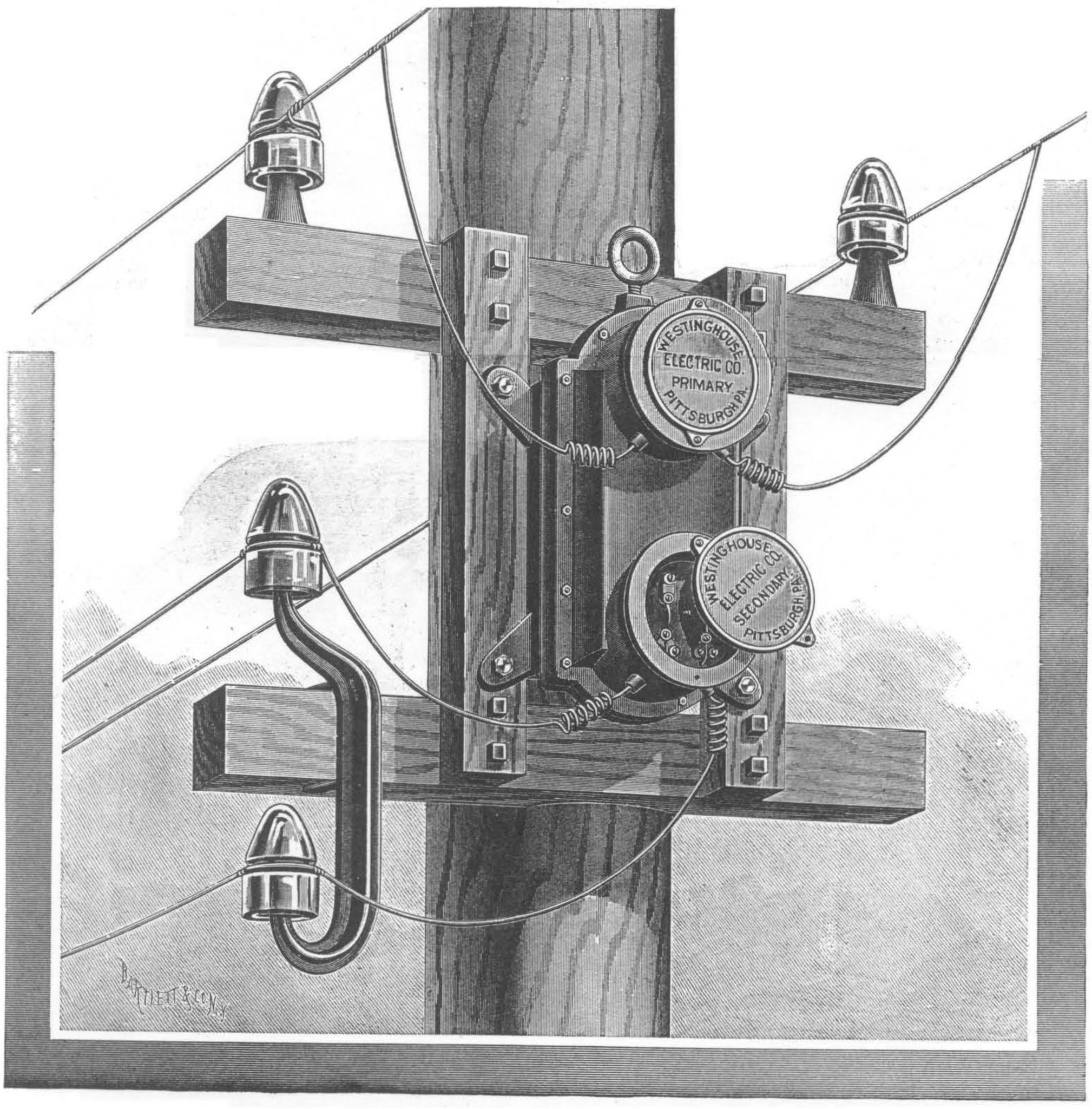
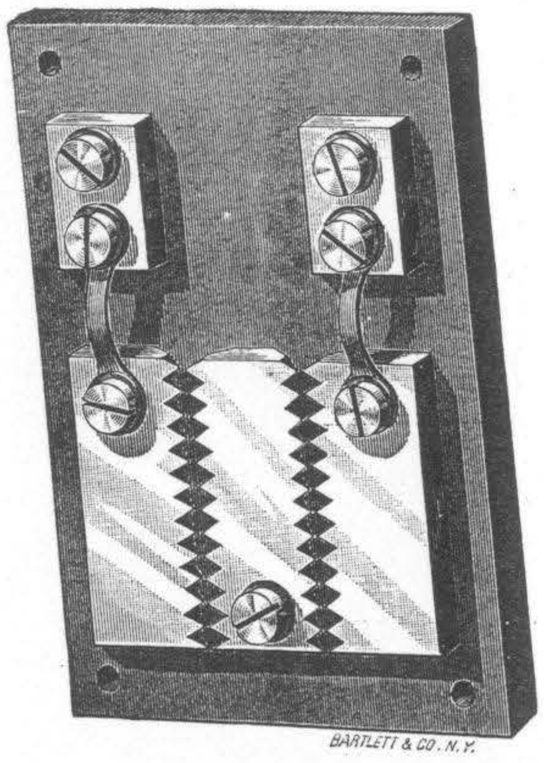


DIAGRAM ILLUSTRATING RELATION OF CONVERTERS TO DYNAMO AND LAMPS.

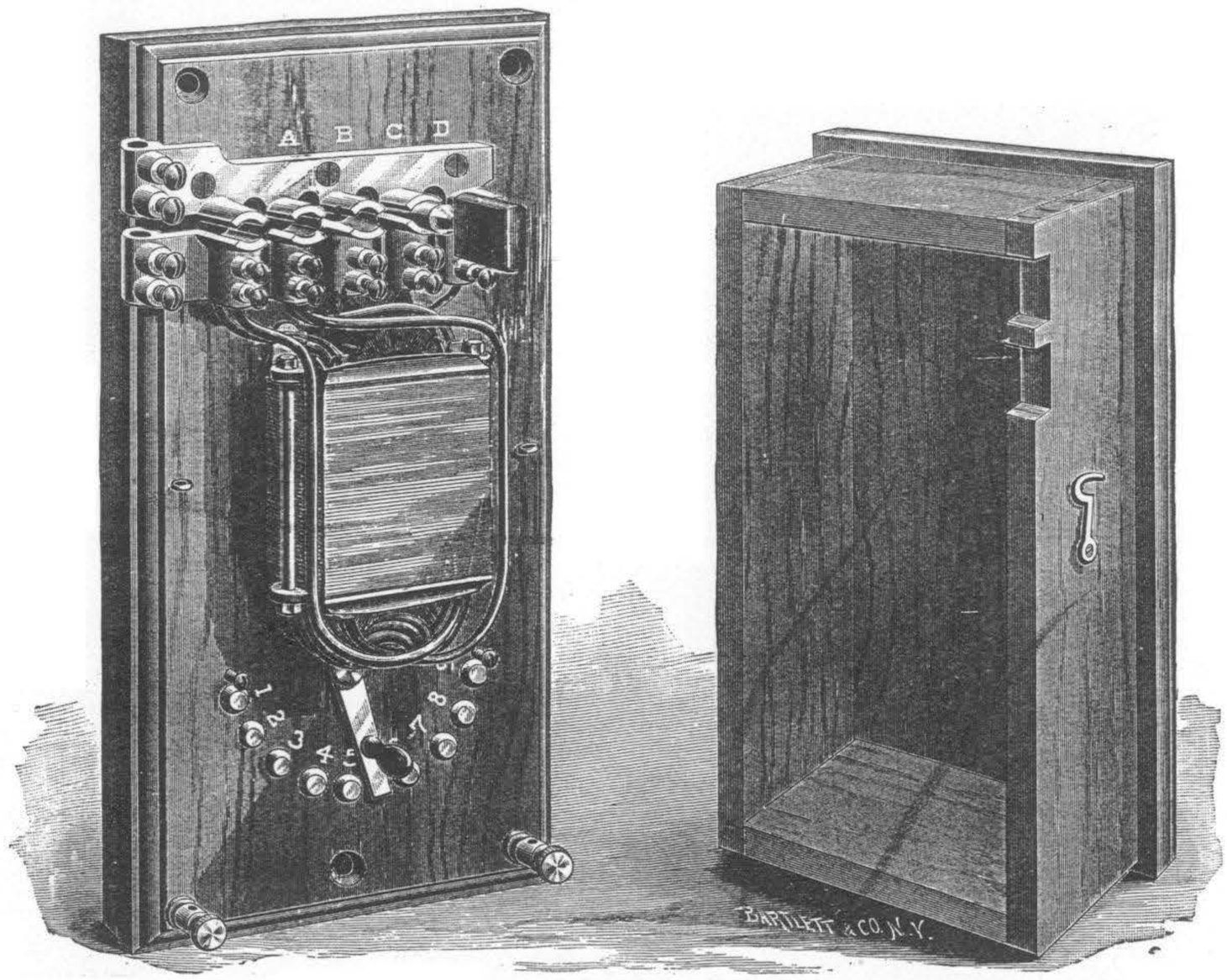


The "stage regulator" admirably illustrates the readiness with which the principles of induction lend themselves to the various purposes of hand regulation and control of



LIGHTNING ARRESTER.

current. The simple movement, in or out, of the rod, raises or lowers the brilliancy of the lamps as required. The "house regulator" serves a similar purpose, but is based on



COMPENSATOR.

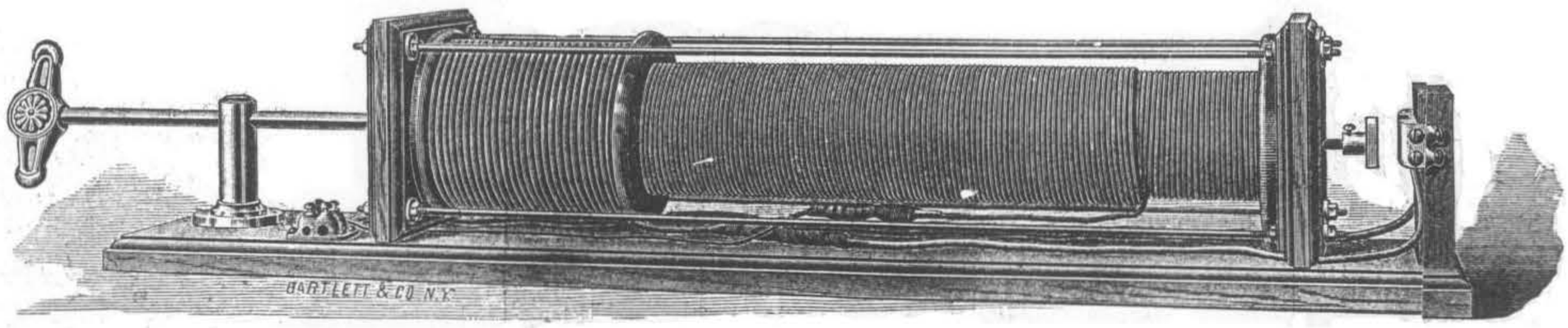


CONVERTERS ON BUILDING.

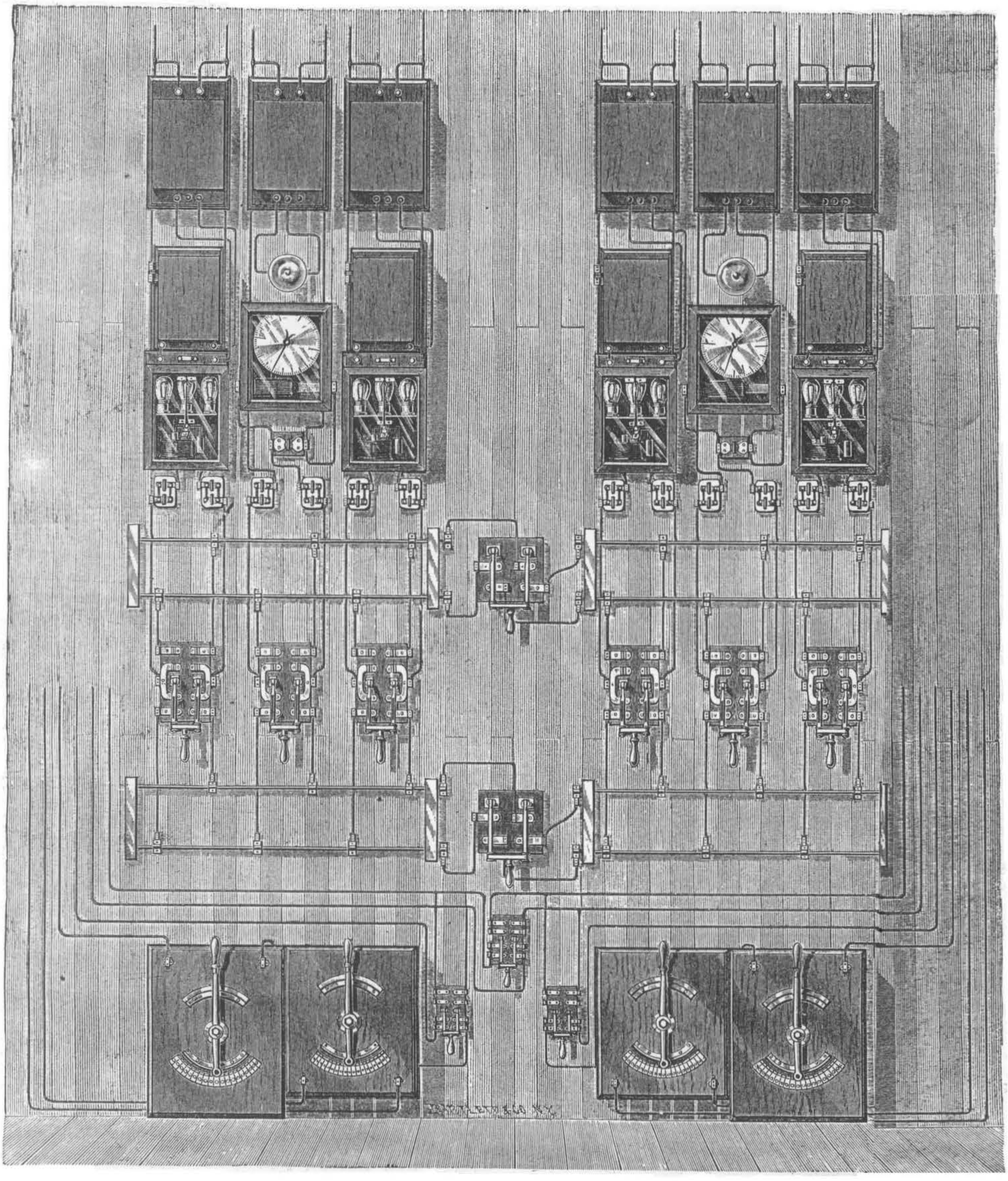
somewhat different principles. The convolutions of the converter are adjustable in their number and the amount of induction thus readily governed.

The alternating current meter is especially deserving of praise. By it a shaft is rotated at a speed proportional to the square of the current, but this is offset to a simple proportion by a fan-wheel, and a certain speed of revolution counts off the ampere hours regularly. The consumer can, therefore, check his own meter readily.

The system, at least in the keen refinements necessary to fit the means to the end, and largely in the conception and designing of the devices themselves, is the work of Mr. O. B. Shallenberger, and the Westinghouse Company is to be congratulated on the possession of an electrician who, while yet young and vigorous, has such judgment and capacity.



STAGE REGULATOR.



THE WESTINGHOUSE SWITCHBOARD.

WESTINGHOUSE TESLA MOTOR.

Our American contemporaries, in their issue of October 27, have described the Westinghouse system and factory. The Westinghouse Company controls a number of very valuable patents, and, as is well known, promises to be one of the most successful companies in the States. We hear that from time to time it is their intention to turn their attention towards developing a business in England. Whether this is the case or not the future will decide. One of the most interesting pieces of apparatus controlled by the company is the Tesla motor. We quote the remarks made by our New York contemporary, the *Electrical Review*, on this machine :

"The alternating current motor consists of a series of field-magnets, wound with two sets of coils, the ends of which are connected to binding posts conveniently located for attachment to the supply circuit. These binding posts form the only connection with the current, which current is taken from the regular lighting circuits, with the addition of a single return wire. This return wire makes it possible to send two alternating currents through the field of the motor at the same time, the pulsations of the two currents being similar, but not simultaneous. The resultant of these two currents is that a rapidly rotating polarity is given to the field, corresponding in period to that of the current producing it.

"The armature is in appearance similar to the ordinary Siemens drum armature, without the commutator. The winding is, however, much simpler, and consists of a few turns of comparatively small wire, the ends of which, instead of being carried out to a collecting ring, or any other form of sliding contact, are soldered together, forming a closed circuit, having no connection with the energising current. The alternating currents in the field induce secondary currents in the armature, and by the attraction between these and the revolving polarity of the field rotation is produced, the rate of rotation corresponding very nearly with that of the field.

"When no work is being done by the motor, the synchronism is exact or nearly so, and very little current passes either through the armature or field, but as load is put on and the work increases, the armature tends to lag slightly, causing the passage of more current in proportion to the work done. The reaction between the armature and the field is similar to that between the primary and secondary coils of a converter, and the increase of load on the motor causes increased supply of current in a manner exactly as takes place when lamps are added to the secondary circuit of a converter. The addition of the return wire for the motor circuit can be made easily so as to adapt existing lighting circuits to motor work, and the armature of the dynamo used for driving motors is equally available for lighting purposes.

"By an ingenious adaptation of the converter principle, this motor may be regulated in speed and reversed in its direction of motion without the use of switches or resistance coil. The method of operation is exactly similar to the link reversing gear of a locomotive. The extreme position of the reversing lever in one direction corresponds to full speed ahead, from which it can be graduated through every shade of intermediate speed to the reversing point, and from that on to full speed backwards. This is more readily accomplished owing to the absence of brushes, since there can be no sparking or wear due to the passage of current under any circumstances. No attention need be given to the motor beyond the filling and cleaning of the oil cups.

"The alternating motor is more compact than the direct current motor, and lighter in proportion to the power delivered. It can be served either through a converter or directly from the primary circuits. The connections may be so protected that no inconvenience or danger can possibly result from direct connection to high-tension service, should such become desirable. As there are no sliding contacts, and the binding posts need never be touched, or even exposed in any way, the use of a high-tension current becomes possible. The extreme simplicity of the windin and general construction of this motor, makes it very unlikely to get out of repair. The insulation of the armature is of no importance, since the current traversing it is never but a few volts, and often less than one volt, regardless of the voltage of the supplying circuits. Absolutely no electrical knowledge is required in its operation, and the connections to the circuit are so simple that anyone of ordinary intelligence can make them with ease and certainty. The alternating current motor is therefore thoroughly practical for manufacturing, commercial, and domestic use in the hands of servants."

THE TESLA MOTOR AND WESTINGHOUSE STATION SWITCH-BOARD ARRANGEMENT.

As announced some time ago, work has been actively prosecuted, says the *Electrical World*, by the Westinghouse Electric Company in the construction of an alternating-current motor by which the value of the alternating system as a method of power distribution is largely increased. This new motor, which is illustrated in the accompanying illustration (Fig. 1), is based on the method of electro-dynamic rotation devised by Mr. Nikola Tesla,* and is so constructed that no commutator or contact brush of any kind is required, the armature being without any external electrical connection, and the rotative effort being exerted entirely from the changing polarity of the field-magnets.

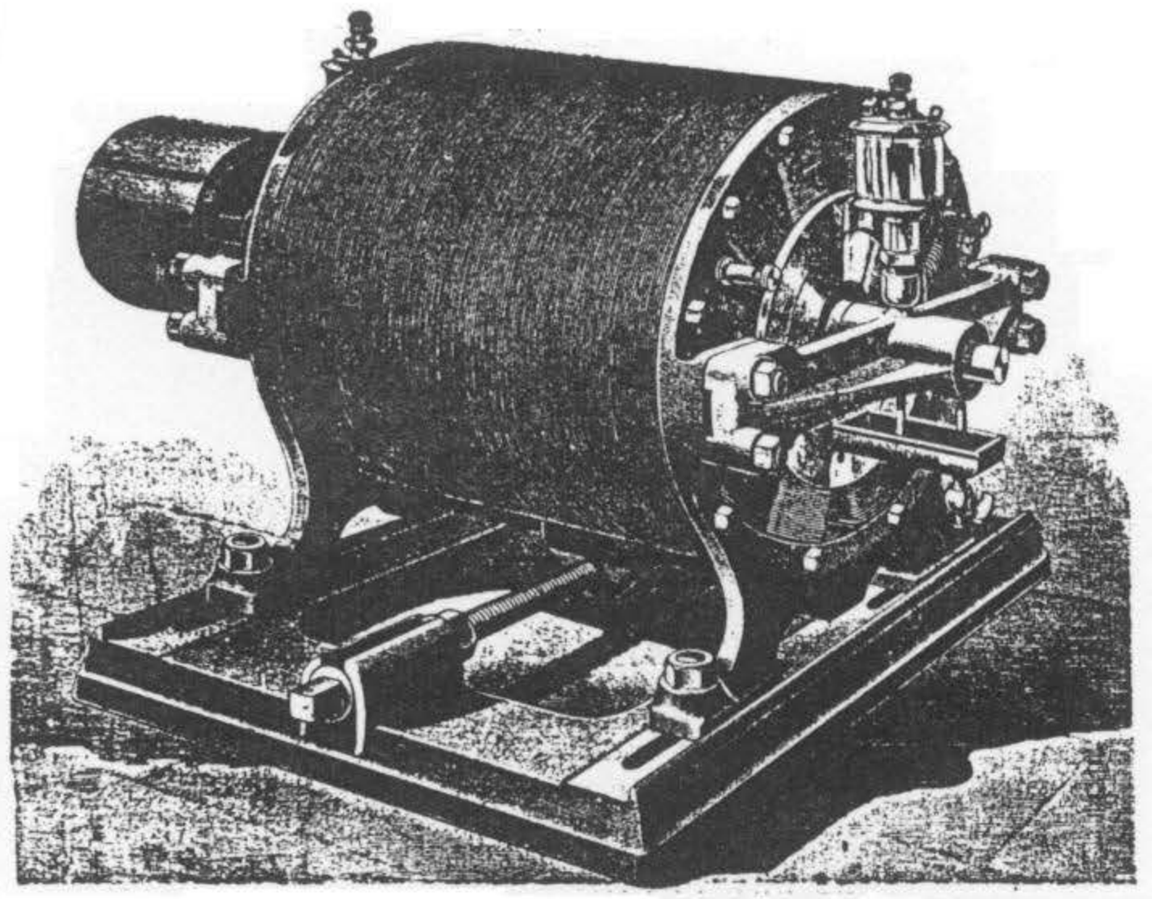


FIG. 1.

The New Westinghouse Alternating-Current Motor.

As will be seen, the motor consists of a series of field-magnets built up of laminated sheet iron and wound with two sets of coils, the ends of which are connected to the two binding posts shown. These binding posts form the only connection with the regular lighting circuits, with the addition of a single return wire. By the aid of this return wire two alternating currents are sent through the field of the motor at the same time, the pulsations of the two currents being equal in strength, but the one lagging a quarter phase behind the other in the two sets of field coils respectively.

* See *The Electrician*, June 15, 1888.

The effect of this is that a rapidly rotating polarity is given to the field, corresponding in period to that of the currents producing it.

The armature core of the motor is of the Siemens drum type, and it is wound with a comparatively few turns of heavy wire, the ends of which are soldered together, forming a closed circuit having no connection with the energising current. The alternating currents in the field induce secondary currents in the armature, and by the attraction between these and the revolving polarity of the field armature rotation is produced, the rate of rotation corresponding very nearly with that of the field. When no work is being done by the motor, the synchronism is exact, or nearly so, and very little current passes either through the armature or field, but as load is put on and the work increases, the armature tends to lag slightly, causing the passage of more current in proportion to the work done. The reaction between the armature and field is therefore similar to that between the primary and secondary of a converter when changes of lamp loads take place in the secondary circuit. The addition of the return wire for the motor circuit can be made easily, so as to adapt existing lighting circuits to motor work.

The speed of the motor, as well as its direction of rotation, may be regulated by an ingenious adaptation of the converter principle, an adjustable "choking coil" arrangement being employed, which avoids the use of resistances and switches. The simplicity of the winding and general construction of the motor makes it unlikely to get out of repair. Thus the insulation of the armature is of no importance, since the current induced in it, though comparatively large in volume, has a potential of but a few volts, and often less than a volt, regardless of the voltage of the supplying circuits.

The standard station switch-board arrangement adopted by the Westinghouse Company is shown in our illustration (Fig. 2), which represents a board arranged for two dynamos and four lines, any greater number of lines or dynamos simply involving an extension.

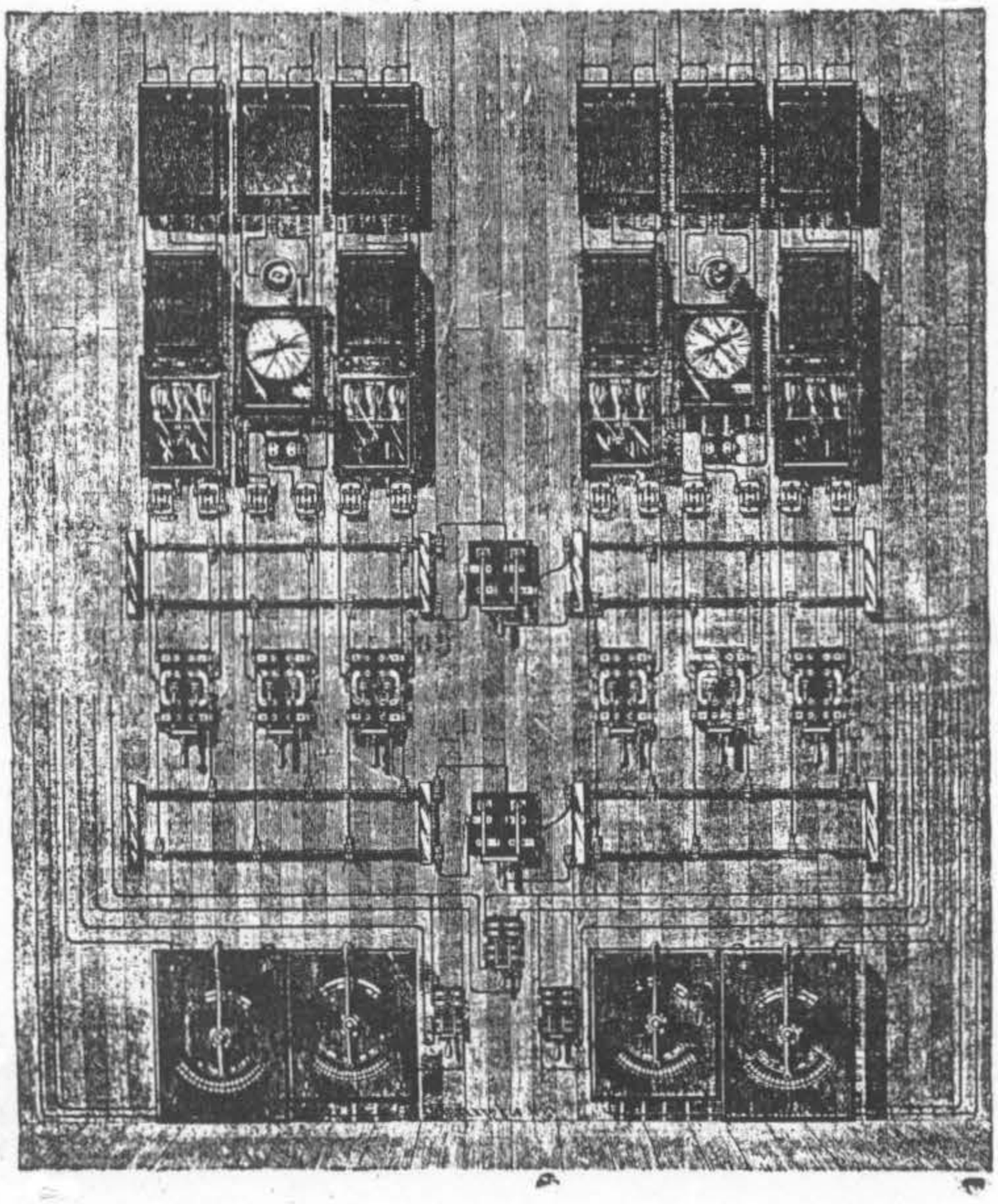


FIG. 2.—Standard Switch-Board for the Westinghouse Alternating-Current Stations.

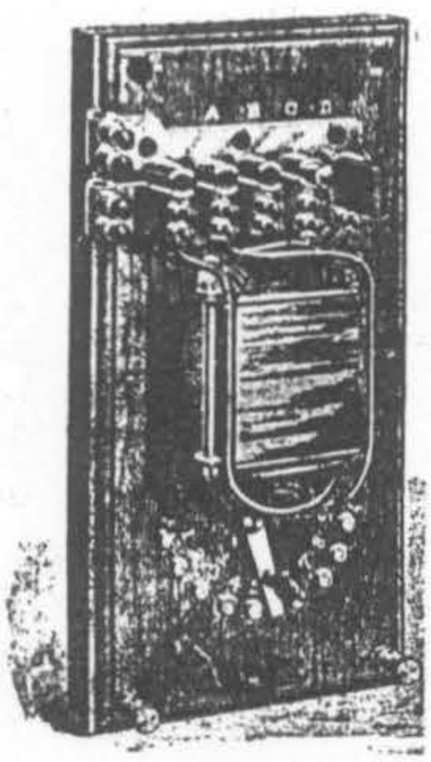


FIG. 3.
Westinghouse Line Pressure Compensator.

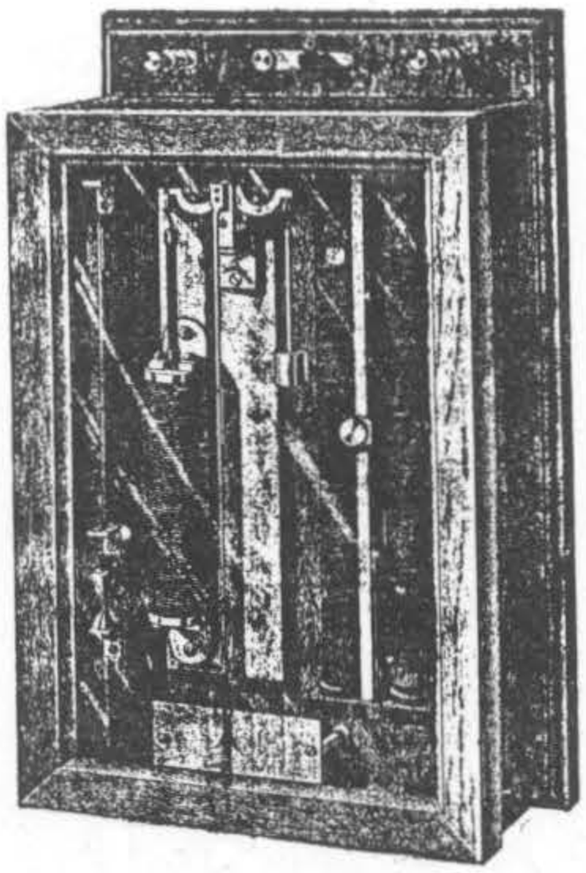


FIG. 4.
Westinghouse Standard Voltmeter.

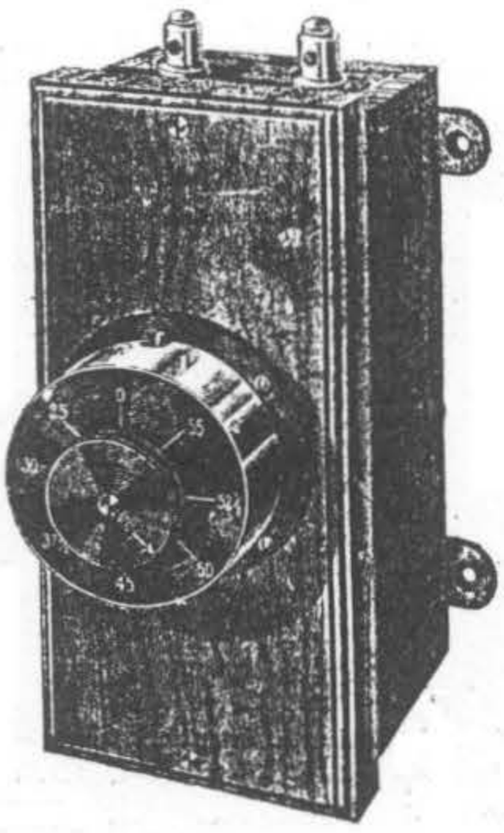


FIG. 5.
Westinghouse House Regulator.

Commencing at the bottom of the switch-board there are four rheostats, the two small ones nearest the centre being in the field circuits of the exciters. The general practice, as is well known, is to provide each dynamo in such a station with anexciter of sufficient capacity to furnish current to both dynamos. Only one exciter is therefore in service at any one time. It follows, therefore, that the governing of the whole station is performed by the movement of the handle of one only of the two smaller rheostats, the other one being for the time out of service. The two larger rheostats are respectively in the field circuits of the two dynamos, and are used only when it is necessary to equalise their voltage for varying loads, which with well-designed lines is seldom required. The regulation of the station in practice is therefore reduced to a slight movement of the handle of one of the smaller rheostats five or six times in the course of a night's run, with one or two adjustments of the larger rheostats to equalise pressure.

Two small changing switches between the rheostats are used for connecting either exciter with either dynamo at will, and the single small switch immediately over them is used for coupling the field circuits of both dynamos together. When the switches are closed, as shown, both exciters are running connected. This arrangement of the switches, therefore, gives complete control of the supply of exciting current, and prepraes for any ordinary emergency.

Over the rheostats are shown four sets of trunk wires, each consisting of two heavy parallel copper rods. Between each upper and lower set are three changing switches. The wires leading to the middle connection of the centre switch come from the dynamo, whose current is, of course, transferred to either pair of trunk wires, according to the position of the switch lever. The two outside switches of each triplet control the two lines respectively, and transfer their connection to either pair of trunk wires as desired.

Between the horizontal sets of trunk wires there are placed two multiple arcing switches, by which the two dynamos may be connected to run together or may be separated at will. By this arrangement either dynamo can serve either line or combination of lines at will, and may be changed by a single movement without interrupting the continuity of the circuit.

Directly over the trunk wires shown there is placed a row of six safety-catch holders, each with double fuses and plug cut-outs. The object of these safety catches is to protect the apparatus behind them from short circuits on the line, and the double fuses provide a ready means for displacement without interruption.

Over the safety catches are placed four voltmeters each with its attendant compensator above it. Each voltmeter registers the voltage on its particular line, and the sole duty of the tender is to see that the needle on the voltmeter does not vary beyond the length of the dotted scale. The compensator, which is shown enlarged in Fig. 3, is in series with the voltmeter, and adjusted at the plug connections to the maximum number of lamps served from it and at a point-switch enclosed within its case to a tabular number depending on the drop in the line. In this manner the indications of the voltmeter are maintained correct for all loads, independent of the varying drop in the line.

Between each pair of voltmeters there is placed an ammeter which indicates the output of the current from the dynamo to which it is connected, and below each ammeter is a short-circuiting plug, which, when plugged in, admits of the ammeter being removed. Over each ammeter is a lamp for the general illumination of the switch-board, and at the top is a row of six small converters, through which the current is reduced for the voltmeter.

Besides the apparatus just described there are several adjuncts to a central station, such as lightning arresters and ground protectors, and a standard voltmeter by which those in daily use are maintained correct.

Our illustration (Fig. 3) shows the enlarged view of the "compensator" above referred to, and Fig. 4 illustrates the standard voltmeter. As it is frequently desirable to reduce the illuminating power of lamps on one circuit without interfering with others, such as in the sleeping apartments at night, the house-regulator shown in Fig. 5 has been designed. This is placed in circuit with each floor-branch of a house, and by setting the pointer, any desired amount of illumination can be obtained without interfering with the remaining lamps in a house.

AMERICAN NOTES.

(FROM OUR OWN CORRESPONDENT.)

NEW YORK, *October 27th*, 1888.

The most important event during this week was the holding of the Seventh Annual Convention of the American Street Railway Association. A year or two ago the meetings of this body were devoted chiefly to the discussion of the care of horses, feed, the protection of hoofs, the different kinds of horseshoes, the disposition of manure, and other similar topics. But now the face of affairs has entirely changed; the veterinary surgeon is rapidly being replaced by the mechanical and electrical engineer, the horse is making way for the cable and the electric motor, and the consequence is that the discussions no longer deal with the horse as a noble animal useful to man, but are largely, if not wholly, concerned with questions relating to the utilisation of mechanical power and the care of machinery. This year the electrical delegation was so large as to excite general comment and attention. While the cable came in for its share in the proceedings, it must be said that electricity was

unquestionably the lion of the hour. Addresses were made by Mr. W. Bracken, of the Julien Company, on the subject of storage battery work, and by Mr. Barr, of Philadelphia, who had obtained some very satisfactory results there with a Wharton-Reckenzaun car; by Mr. Sprague and Mr. Mansfield, in regard to electrical systems in general, and more particularly the overhead method; and by Mr. R. W. Blackwell on working with conduits. In each department material progress was shown. Mr. Bracken gave an interesting statement with regard to the work done with the Julien cars on the Fourth Avenue-road, and convinced his hearers that the demonstration there not only meant something for the present, but was destined to have a great deal of influence in the future. The greatest interest in this particular installation appears to have been taken by the street railway men, who recognise very forcibly the fact that, after all, the storage car presents the fewest difficulties in the adoption of electricity for street car work in large cities. Mr. Blackwell's presentation on behalf of the conduit was also listened to with close attention, and from what was said by him it was evident that large advances have been made in this field as well as in the others. He made an announcement, too, of great importance, to the effect that the obstructions, legal and other, to work on the conduit road for Fulton-street, New York, had all been overcome, and that work would be begun forthwith to lay conduit for that road, equip the plant, and have the whole installation running before the new year.

Mr. Sprague, as usual, made a lively address, full of good points, on the subject of his road at Richmond and elsewhere, and gave details as to a good deal of new work which he has in hand. He stated that the road which he is now building in the suburbs of Boston for the West End Company, on the overhead system, would have twenty cars and two track-cleaning cars. The station would be equipped with 410 horse-power of steam, and 450 horse-power of dynamos. With that equipment sixty or seventy cars could be run, but only one engine would be started up for the initial equipment of twenty cars. He stated that in Richmond the proportion in the central station of horse-power per car on the road was about 5 or 5½ horse-power, and that at Harrisburg it ran up to about 6 horse-power, which was a good factor for large roads, but on smaller roads 8 to 10 horse-power per car was safer. Mr. Sprague exhibited at Washington the new truck which he has adopted for his street car work. The new motor differs from the old Sprague motor employed for cars in being a single horizontal U-shaped machine, with the cores flattened so as to clear the ground as much as possible, the lowest point being only 9in. below the centre of the axle. Each car carries two of these motors mounted on the usual Sprague method, having two bearings on the car axle, and a flexible spring connection with the car body. Power is transmitted from the armature to the car axle by two sets of gearing, with a total reduction of 12 to 1. No oil cups are used about the motor, all the bearings being self-oiling, and requiring attention but once a day at most. These bearings have also a special dust-guard attachment to keep the oil from working out and the dust from working in. The whole machine and gearing are enclosed in a tight rectangular boxing which is attached to the motor, and moves with it. Each motor will take a steady load of 12½ horse-power, and will work easily up to 15. These new types of motors and cars will be used, I understand, in all the coming Sprague street railway work. The Thomson-Houston Company had the advantage of being able to exhibit in Washington a new electric railroad in full operation. Under the supervision and direction of Captain Griffin, U.S.A., and Mr. G. W. Mansfield, work on the road was rushed through at a tremendous pace, and in spite of the lateness of the date at which consent was obtained from Congress, which, as you probably know, runs the city of Washington as a sort of pocket borough, the road was in readiness for the delegates to see how it worked.

One special feature about the road is that over a long stretch at the beginning the poles are set right down the middle of a broad avenue, so that the brackets carrying the overhead wire stand on each side of the pole. At every third pole there are groups of incandescent lamps, red and white, which when lit up at night practically illuminate the avenue. This piece of work is reported as quite trim and handsome, and as being really an ornament to the thoroughfare. On another portion of the road poles are set on one side, and the overhead wire is carried on brackets; and on a third portion the wire is suspended down the middle of the road between two lines of poles. The road is at present nearly two miles in length, and is rapidly being extended. Three or four cars of the Thomson-Houston type, with twin motors, are in operation, and four or five more are to be added. As may be imagined, all this talk and exemplification of what could be done made no small impression on the Convention, and this was shown in a somewhat amusing way. On the second day one of the delegates, who looked like a very good judge of horseflesh and such excellent things, got up and objected warmly to all this talk about cables and electric motors. He had been running a horse car road for some time, and did not make money out of it, and what he had come to the Convention for was to learn how to do so. He thought the members would be using their time better if, instead of discussing the relative advantages and disadvantages of the storage battery and the overhead system and the conduit, they told him how much hay he ought to give each horse, how to keep their coats in good condition, and how to cool them in the summer and to keep them warm in winter. The appeal was wasted on inattentive ears, however, and instead of showing how well acquainted they were, or once had been, with veterinary practice, the members to a man laughed at their friend and trooped off to lunch. After lunch the advocate of the horse was again on his feet, and made another effort, but with no more success than at first. Little things like these show which way the wind is blowing.

The Westinghouse Electric Company have distinguished themselves this week on the top of their tremendous sensation of last week by publishing undoubtedly the finest catalogue ever issued in this country by an electrical light corporation; in fact, so far as I am aware, it will stand comparison for beauty and completeness with any work of the kind in any line of industry. It is simply superb. It is not merely a collection of handsome engravings, nor simply a catalogue of the price list order, but it is essentially a good technical, well and even gracefully written description of the alternate system. As the electrical papers this week publish some of the cuts, and use more or less of the matter, you will be able to form an idea as to what this catalogue is, if you have not received a copy direct from the company. The work includes the Westinghouse alternating machine and exciter and converter, and the Shallenberger meter, descriptions of all of which have appeared. The new matter included with the old deals with such details as the lightning arrester, the compensator switch-board arrangements, regulators for the house and the stage, and last, though by no means least, the alternating motor of the now well-known Tesla type. It is a multipolar machine, and requires three wires. The motor consists of a series of field-magnets built up with laminated sheet iron wound with two sets of coils. The armature core is of the Siemens drum type, without the commutator, of course; the winding, however, is much simpler, and consists of a few turns of a comparatively small wire, the ends of which instead of being carried out to a collecting ring or any other form of sliding contact are soldered together, forming a closed circuit, having no connection with the energising current. The alternating currents in the field induce secondary currents in the armatures, and by the attraction between these and the revolving polarity of the field rotation is produced, the rate of rotation corresponding very nearly to that of the field. When no work is being done by the motor, the synchronism is pretty nearly exact, and very little current passes through either the armature or the field. As the load increases, the armature tends to lag slightly, causing the passage of more current in proportion to the work done. The reaction between the armature and the field is similar to that between the primary and secondary coils of a converter, and the increase of load on the motor causes an increased supply of current in exactly the same manner as when lamps are added to the secondary circuit of a converter. This motor may be regulated in speed, and in-

stantaneously reversed in its direction of running, without the use of switches or resistance coils, and the machine altogether seems to have many recommendations in the department of electric power. The pamphlet concludes with a description of the Westinghouse alternating central station at East Liberty, Pa., and with some very interesting "bits of experience." The East Liberty station has lamps running at a distance of $4\frac{1}{4}$ miles from the dynamo, and the plant has a capacity of about 8,000 lights. It is stated that the permanent market for light which is secured on the first canvass in towns of moderate size averages about one lamp to each eight inhabitants, and that with the station running the demand grows steadily and even rapidly to a limit as yet undetermined. Other conditions being reasonably favourable, the incandescent light can compete with gas, and at a profit, it is stated, when the price of coal per ton is not more than double the current price of gas per thousand feet when no meter is used; but with a meter and a motor service the electric current can be supplied at rates which, if met, must prove unprofitable to the gas companies.

At the meeting of the American Society of Mechanical Engineers at Scranton last week, Prof. Elihu Thomson's process of electric welding was brought under consideration in a Paper by Mr. C. J. H. Woodburn, and the reception accorded it was at once cordial and encouraging. Mr. Jerome Wheelock reported that he had tried the method on screws, and found that the lead of the screw was perfect without any change, while the strength of the metal at the welded point was beyond question as great as ever. Mr. Oberlin Smith had tried the process himself with excellent results, and said that there was not even as much fear of burning the metal as with the blacksmith's fire. It did its work more neatly and uniformly, under much better control, and with a great deal more cleanness. Mr. R. W. Pope spoke of the advantages of the method in setting up electrical circuits, and Mr. Woodbury mentioned a method of making electric welded chains by machinery, passing the rods into the machine, where they are cut, bent and joined, then welding the chain in a thorough manner, and passing it out at the other end of the device.

Among other recent happenings of interest I should mention the lecture last week on "Electricity in Sea Defence," before the Electric Club, by Lieut. Zalinski, and a meeting this week of the New York Electrical Society at Mr. Edison's laboratory at Orange, N.J., when Mr. A. E. Kennelly delivered an interesting address on "Electrical Measurements."

The Tesla Motor.—The experiments that have been conducted by the Westinghouse Electric Company during the last three months with the Tesla motors are said to

have been very satisfactory. A form has been perfected that will work on existing alternating circuits for the running of fans and other light machinery, and also the large motors for tramcar purposes, and for power generally, have been brought to a high degree of perfection and efficiency. For tramway work the Tesla motor, having no brushes or commutator, may probably arrive at the ideal stage before Mr. Sprague attains the wished-for waterpoof point, as its promotors claim that it can be constructed so that even if covered with mud and water no possible danger can occur.

Some Day, Some Day!—The Tesla motor, we hear on the authority of one who knows what he is talking about, really does go well, and is going to be a good thing. When—is the despairing cry of British electrical engineers—are we to have a real live Tesla motor sent over here? When are we to see it working? We have plenty of alternate currents for it to feed upon. And where, oh where! is to be the place where the little wonder to be procured?

The Tesla Motor.—The first exhibition in public of the celebrated Tesla motor took place at the meeting of the City and Guilds Old Students' Association on Wednesday last on the occasion of Mr. Snell's paper, reported elsewhere. The motor in question is a small model, eight or nine inches square, and has never run yet in this country at least, the necessary alternating currents not being obtainable. In has four terminals, and no brushes whatever, the armature simply turning in the varying magnetic field. This specimen was to have been exhibited by Prof. Ayrton at the Bath meeting of the British Association, but did not arrive in time.

Edison Philadelphia Station.—The new Edison electric light station in Philadelphia will soon be in operation. It is six stories high, and was erected at a cost of £30,000. On the first floor will be placed 20 engines of 250 h.p. each. On the second floor there will be 40 dynamos, with a total capacity of 60,000 lights. The third floor will be used for the workshop; the fourth floor for 10 boilers of 500 h.p. each. The fifth floor will accommodate 1,000 tons of coal, which will be fed by pipes to the furnace under each boiler. The sixth floor will be devoted to the general offices of the company. The total cost will be £200,000, including 84 miles of underground cable.

Electric Duel.—The discussion about the danger of alternate current has reached an amusing pitch in New York. Harold P. Brown has challenged Westinghouse to an electric duel; Harold P. to be connected to a direct current machine and Westinghouse to an alternate. Fighting to commence at 100 volts, raising by 50 volts, and maintained for five seconds. Harold P. to take first shock every time till one of the duellists has had enough and publicly admits his error. He warns Westinghouse, however, that death has occurred in his experiments with alternate currents at 160 volts maintained for five seconds, and that men have been killed on the low-tension Jablochkoff alternating system.

NOTES ON THE DESIGN OF ELECTRIC MOTORS.*

BY ALBION T. SNELL.

In discussing the design of electric motors, it will be necessary to, first of all, consider the relation between the dynamo and the motor. The dynamo may be defined as a machine which converts mechanical work into electrical energy. The motor, when supplied with electrical energy, gives out mechanical work. So far, one is the converse of the other, and the dynamo is said to be a *reversible* machine.

The extent to which this is true depends very largely on the size of the machine under consideration. This follows from the fact that no matter how bad the design of motor, how weak the field, or how small the magnets or armature, it is sure to *run*. But a badly designed dynamo—one with relatively weak field-magnets say—will often not excite at all. Or, again, the proportions of armature and field may be relatively correct, but the mass so little that the like result obtains. Why is this, if the dynamo be a reversible machine? It has been shown that the reactions in the dynamo armature are not the same as those in the motor. And it is now generally admitted that the effect of self-induction in the dynamo armature is to increase the lead, while in the motor it tends to diminish it. And Mr. Mordey has pointed out that in the generator the effects of self-induction in the armature windings are opposite to those of the Foucault currents in the core ; but in the motor they tend to increase each other.

The writer has had these differences brought under his notice very forcibly in the course of his experience, having been connected directly or indirectly with the design of more than 400 machines, varying in output from 1 h.p. to 100 h.p., and from 20 watts to 70,000 watts.

The chief cause of this difference between dynamo and motor is to be found in the mutual effects of armature and field. Profs. Ayrton and Perry so far back as 1883 showed, both mathematically and practically, that in the motor the magnetism of the armature and that of the field *might* be added ; in fact, the motor effort is proportional to the magnetic strength of both armature and field-magnets, while in the dynamo the field due to the armature, considered as an independent magnet, must necessarily subtract from that of the magnets. These main distinctions occur in the nature of things. Their magnitude at first seems to be considerable ; but really the effect depends very largely on the actual dimensions and the relative proportions adopted.

An ideal dynamo has an armature with neither internal resistance nor magnetism *per se*. The field-magnets alone are the source of lines of force. This condition may be the more nearly attained as the size and weight of the machine be increased. All text-books tell us that the field-magnet should be as powerful as possible, and the armature relatively weak. The exponents of the "reversible theory," and its carollary, "the better the dynamo the better the motor," appear to have had more experience of large machines than small ones. And their *experimentum crucis* necessarily leads them to such views. When such authorities as Hopkinson and Silvanus Thompson, Kapp and Mordey, assert anything electrical, few venture to disagree. But I beg to submit that an extended experience with small and medium size machines would modify their views, especially if weight-efficiency be an object in the design.

Be this as it may, a motor weighing 70lb. can be made to give a b.h.p. with 70 per cent. efficiency of conversion ; but the same machine run as a dynamo would require nearly 50 per cent. more speed to give an output of 746 watts, and even then the efficiency between output and belt-power would be nowhere near 70 per cent. If this be true, and I think it beyond dispute, the theory and corollary require some modification. The approximation to the same efficiency when used as a dynamo or motor becomes the more apparent as the size of the machine is increased ; but even up to 50 h.p. I prefer to make certain structural differences in the design of dynamos and motors, particularly if they be series-wound. With shunt machines the difference seems to be less marked owing to the field being nearly constant. If I mistake not, both Hopkinson and Mordey have founded their opinions on observations made from large shunt machines.

Much more might be said on this branch of the subject, and numerous actual experiments might be given in support of my views, but this would digress too much from the object of this paper. With these introductory remarks on the character of motors and their relationship to dynamos, I will pass on to the general design of motors.

There are two broad lines on which motors can be designed. They depend entirely whether weight and overall dimensions enter into the problem. It is only necessary to admit that a powerful armature with many ampere-turns and a relatively weak field will give the same torque as a strong field and a weak armature. Granting this, we can design a motor to give a certain torque independently of the total weight to some very considerable extent. We shall be guided in the proportion of armature and field by the work expected of the motor, by the price allowed for production, by the intended cost of future

* Paper read before the City and Guilds of London Institute Old Students' Association, January 16, 1889.

maintenance, and by the desired life. These two methods of design depend on the point of starting. In the *first* we take an armature of given size, select a certain surface velocity, and build the field as small as possible to give the desired torque. In the *second*, a certain type of field iron being determined on, we select an armature of sufficient cross-section to give the required results. The first of these two methods is by far the more scientific, inasmuch as the dimensions of the most costly part of the motor can be made a minimum. The second method, however, will sometimes occur in practice, and it is well to note the possible results of this as well as those of the more general case.

When designing a motor to do particular work the following points should be considered:

(1). What is likely to be the average torque on the motor and driven shaft?

(2). Is the motor to run continuously or only for short periods at more or less frequent intervals?

(3). What variations of load may be expected?

(4). What will be the maximum torque on the motor shaft?

(1) and (4) will determine the characteristic of the motor and the particular part of the curve at which the average torque shall be arranged to fall.

(4) will determine the size of the shaft and strength of the bearings.

(1) gives us the ratio of the speeds between the motor and the driven shaft.

(2) and (3) determine the limiting safe rise of temperature,

While the winding must be designed to satisfy all the conditions as nearly as may be.

It is not possible within the limit of a short paper to thoroughly analyse the different points to be observed. The general method can alone be indicated, and experience must teach the engineering student the rest. I will roughly run through the several conditions of design, and give such hints as appear likely to be of use.

Richmond, United States. That the method is unsatisfactory and can be much improved on there is no doubt, for Mr. Sprague has already (October 2nd, 1888) published drawings of a new tramcar involving two motors with *countershafts*.

Engineers using electric motors seem to forget that a motor, although very efficient at or about a certain speed, is most inefficient at low speeds (*vide* Fig. 1).* Too much stress is laid on the property of a motor exerting a maximum torque at starting. It is forgotten that the efficiency is *nil* under the condition of maximum torque, and that it increases very slowly until the point of 50 per cent. is reached. There are other sides, of course, to the question; but I wish here to strongly emphasise the primary condition of motor design—viz., attention to the torque of motor and main shaft.

Having then determined the torques of the system, the ratio of our gearing is known. Let us suppose that the motor torque be $\frac{1}{10}$th that of the main shaft, and that the gearing be accordingly in the ratio of 1:10. We have now to select an armature that will give us this torque at the speed required, satisfying also the conditions of durability, and that the rise of temperature will not exceed a certain limit—say 60deg. F., above the temperature of the room.

The mathematical expression for the torque of a motor is simple.

Let T be the torque. The output required of the motor at n revolutions per minute is, say, 1 b.h.p.

Then $$T=\frac{B.H.P.}{2\pi n}=\frac{33,000}{2\pi n}=\frac{5,280}{n}\text{lb. ft. }(a).$$

That is, the moment of the forces tending to turn the armature is equal to $\frac{5,280}{n}$lb. acting at a radius of 1ft.

To get the exact pull on the periphery, it will be necessary to multiply this quantity by the ratio $\frac{1}{r}$, where r=the mean radius of the armature in feet.

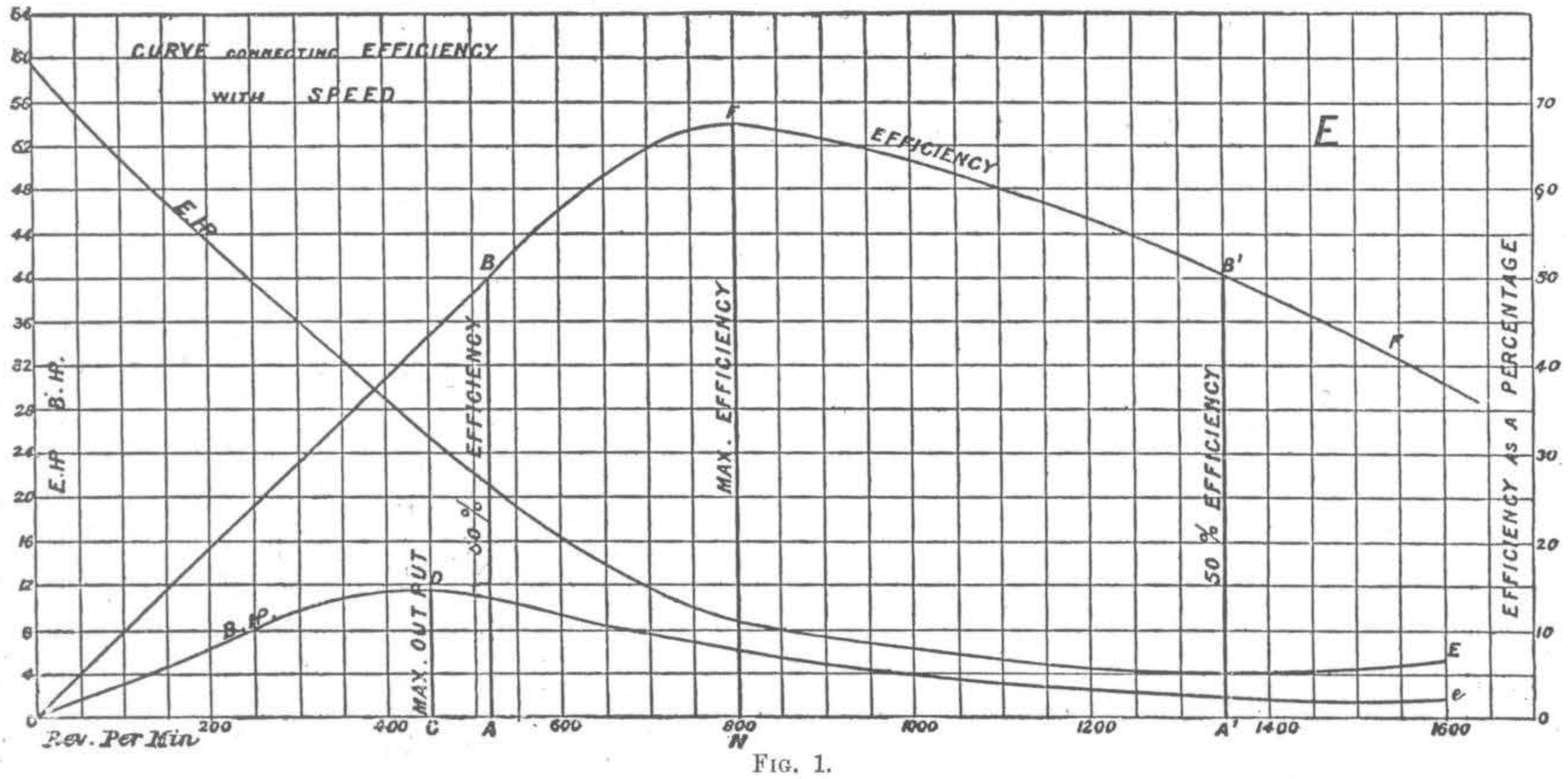


FIG. 1.

The first thing to be noted is the torque on the driven shaft. This is not always an easy thing to get at owing to the want of a little scientific nous in the ordinary mechanic. If, however, this be known, it is possible to determine within a few per cent. the required current, and the best ratio of gearing to get a maximum average efficiency from the motor. If this be accomplished, the motor will be a success. If the motor be designed on the assumption of so much horse-power being required, and gearing be accordingly selected, it probably will happen that, though the estimate of power be fairly correct, the motor will be unsuited to the work. The current, and consequently the torque on the motor-shaft, will probably be excessive. The efficiency of the motor will thus be low, and the e.h.p. absorbed excessive, while, further, the speed will be too slow. The obvious remedy would be an increase of the ratio of the intermediate gearing; but if the surface velocity of the motor be correctly designed the increased speed will be too great, and, consequently, introduce other difficulties; in fact, the motor will be a failure—not from any intrinsic fault, but simply because improperly designed for the work.

Daily one comes across machines driven by electricity, steam, air, or water, in which the same fault appears. The speed of the prime shaft is not properly proportioned to that of the main or driven shaft. The consequent loss in possible efficiency is oftentimes not known, or, if suspected, is ignored. This sort of thing did well enough years ago; but addressing a body of educated men who are likely to occupy leading positions among the engineers of the immediate future, I cannot pass it by without protest. I therefore beg to impress on you the necessity of determining in some way or other the actual number of foot pounds required to make one revolution of the main shaft. Your ingenuity will suggest many ways of doing this in most cases.

As an illustration of my point, I will mention the many attempts to run electric tramcars by direct gearing, *i.e.*, without a countershaft. Nearly every firm that has tried the tramcar problem has made the attempt. The last has been the Sprague motor line at

The tangential strain on the wire is therefore

$$=\frac{5280}{n}\cdot\frac{1}{r}\text{lb. }(\beta)$$

This latter quantity is what we require in designing the motor. In order to obtain the desired couple on our armature, we make $T=\frac{Z_a N t C_a}{2\pi}$ (γ), where Z_a = the number of lines of force passing through the armature, $N t$ = the number of turns of wire counted all round, C_a = current flowing in any one coil of the armature—*i.e.*, half the total current—and r = mean radius of the armature core. It will be noted that the field does not come directly into the question. The function of the field-magnets is only to supply a magnetic field. It will be our care to so arrange the magnets and their windings that the proper value of Z_a is obtained. This is all that is necessary now. I shall have occasion to comment on this assumption later on when considering the field.

We have now to determine the values of Z_a, $N t$, and C_a.

C_a will usually be given us by the condition of supply and the horse-power required.

Z_a can be determined from the equation $Z_a = 2 a b z$ (δ), where z = lines per square inch, a = depth of core in inches, b = the length of armature *less the insulation* in inches.

Experience alone can tell us the best shape and size of armature core, but since the total cross-section $(= 2 a b)$ is known no great difficulty presents itself. The depth of core will be mainly determined

* Curve E E is the value of the e.h.p. for the different speeds, the motor running at constant potential. O e is an approximation to the corresponding b.h.p.; and O F F is the commercial efficiency (plotted to another scale). It will be noted that the efficiency increases at first with the speed, and, after attaining a maximum, slowly decreases, having passed through two points of 50 per cent. efficiency.

by the style of winding and the value of T. For a small torque, a small armature and a large number of revolutions will be chosen ; for a large torque, a large, slow-speed armature is required. It will be necessary to note that a large cylinder or ring armature of short length is equivalent to a long drum of smaller diameter.

Then, assuming that the core be chosen, a, b, and r are known. It only remains to substitute these values in (γ) and solve for N t. If the quantities are properly chosen, N t will have such a value that for a suitable current density the depth of winding will be about 10 per cent. of the core radius for cylinders and 15 per cent. for drums.

If the value of N t be not a rational one, the dimensions of the core must be altered. A few trials will illustrate this important part of the design, but practice alone can give ease and certainty.

In actual practice the matter is much simplified by previous experience and by fixed sizes of cores. It is then customary to select a wire to suit the current given, and to vary the speed so as to make the magnetic density suitable for the work. This is the crucial part of the whole thing. In other words, the motor is designed to give the required torque at a certain part of the characteristic. This point varies with the shape of the curve and with the conditions of work expected. My meaning will be more easily seen when the field-magnets have been discussed.

The best relative dimensions of armature and field cores is an open question. This is apparent from what has already been said. It depends entirely on the object aimed at. If weight efficiency be the desideratum, the armature *must* be relatively powerful, and the cross-section of the cores may be made equal, allowing, of course, for the different permeabilities of the iron used. But if cheapness be the principal object, then a heavy field and a small armature are necessary. Speaking generally, the field strength has to be *relatively* greater as the size of the machine is increased.

The design of the motor field presents some considerable difficult to the student. There are so many shapes and forms in vogue, and the same end seems to be attained with such opposite forms. With few exceptions, too, even old-established firms are continually changing their patterns, often with no apparent effect other than a weakening of the public confidence, and a considerable needless expense. Indeed, the engineering draughtsman seems to be at his wit's end to bring out a new design. Yet there is really no ambiguity on the subject. Text-books tell us the best form of magnet is that, *cæteris paribus*, which offers the least magnetic resistance, with a maximum cross-section and a minimum perimeter. Theory then points to a horseshoe magnet, of circular form and round cross-section. Difficulties of construction, however, render this ideal form too costly, and the matter has to be compromised. It is to this endeavour to balance the advantages of theoretical indication with the necessities of engineering that we owe the numerous types of fields.

The design of the field is, however, not so important with the motor as with the dynamo, and a little consideration will enable the student to determine suitable proportions.

In the first place, the field has to supply a certain number of lines of force to the armature, or is expected to form poles of such strength that, in conjunction with those found in the armature, the necessary torque will be obtained. If gross weight be neglected, and a minimum expenditure of copper be desired, the single horseshoe is chosen. Such machines are common enough, and may be made vertical, horizontal, or inverted. The two first types are the better, since the leakage is less. If a light-weight machine be required, even at the expense of copper, then double horseshoe magnets are used. This type involves twice the number of ampere-turns to give the same strength of pole as the single magnet does ; but yet it has considerable advantages. The resultant magnetic field is likely to be more uniform, and less trouble is given by the brushes as a rule. If the armature be of a large diameter—say more than 24in.—it is better to have a four-pole machine, although the ampere-turns will be double that required with a double magnet, and four times that with a single one, if the same value of Z_a be taken. The Oerlikon dynamos, for the reduction of refractory ores, are made with six poles, and no doubt a more even distribution of magnetism is gained.

Having selected the form of magnet, the question of length and cross-section of limb arises. Here the criterion is simply sufficient space to wind the wire necessary to give the desired strength of poles and area enough to carry the magnetic flux required.

Here the student finds the first real difficulty. Let us review the position. We know the E.M.F. of supply or the allowed number of volts. The current is also approximately known from the b.h.p. and the assumed efficiency of conversion. The torque of the motor has been determined and expressed in terms of the magnetic flux through the armature iron, the effective cross-section, and the number of turns of wire. The dimensions and shape of the core are also agreed upon. So far it is a physical certainty. The problem now, primarily, is to design a field-magnet which, in conjunction with the armature, will give the required number of lines in the armature core. This is strictly all that is necessary. The question of economy of material and labour spent in the building of the field-magnets cannot be discussed here.

The magnetic flux in the magnets, to give a particular value of Z_a, I believe to be unattainable by direct calculation. Let Z_1 be the total lines induced at S in a single horseshoe magnet, and assume the lines to pass through the yoke Y and enter the armature at N (Fig. 2). The leakage which occurs all along the windings, and on the neutral part or yoke, reduces the value of Z_1 to, say Z_2. But Z_2 is still further lessened by leakage of lines from N to S outside of the iron or copper of the armature, and the effective number of lines is reduced to, say Z_3. Now, the ratio of $Z_1:Z_2:Z_3$ will vary according to the shape of iron, the length of cores, the contour of the winding, and the average density of magnetism. The problem is already sufficiently complex, but yet this is not all. We have yet to take into account the useful number of lines induced in the armature by its own windings=say, Z_4. This quantity is usually ignored in text-books, but I know from a large number of experiments, that if we wish to be accurate in our treatment of the subject, this factor must not be neglected. I cannot go into figures, but the

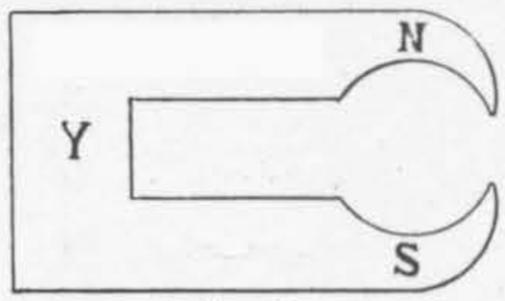


FIG. 2.

importance of the motor-armature, considered as an independent source of magnetism, may be understood from the following considerations :

Take a large series machine designed as a dynamo, having a relatively powerful field and weak armature. Let this be run at such a speed and output that the top of the straight part of the characteristic is just reached. Observe the speed, current, and terminal E.M.F. Then drive it as a motor, using the same number of volts on the terminals, and load the brake till the same value of the current is attained. The speed will usually, I think, be found to be nearly as great as that required as a dynamo.

Next take a smaller machine, designed as a motor—*i.e.*, one with a relatively weak field, etc.—and repeat the experiment It will probably be found that for the same values of current and terminal E.M.F. the motor speed will be considerably *lower*.

This variation in the two speeds is due partly to the lead required in different machines when run as dynamos or motors, and also largely to the relative importance of the armature magnetism. Two simple equations will assist the study of the problem. Neglecting friction, let

E_d be the internal E M.F. of the dynamo.

$E_m = \frac{\text{B.H.P. } 746}{c}$ be the internal E.M.F. of the motor.

E_T be the terminal E.M.F. both of dynamo and motor.

C R be the volts lost over the internal resistance of the machine.

L_d be the value of the reactions of the dynamo armature.

L_m be the value of the reactions of the motor armature.

It will be necessary to note that L_1 and L_m will vary with the lead required.

For the dynamo we have—

$$E_d = E_T + (C R + L_d) \quad . \quad . \quad . \quad . \quad . \quad (I.)$$

For the motor we have—

$$\frac{\text{B.H.P. } 746}{c} = E_m = E_T - (C R + L_m) \quad . \quad . \quad (II.)$$

Now, the speed of the motor varies as E_m, and the speed of the dynamo varies as E_d. It follows, then, that the motor speed should be *less* than the dynamo by a quantity proportional to $(C R + L_d) + (C R + L_m) = 2 C R + L_d + L_m$. If the speed of the motor be *greater* than that given by these equations, L_m, the only quantity that can possibly be varied, must be a factor of importance and, moreover, of *negative sign*. This means that, in the motor, the armature adds magnetism to the resultant field, and thus increases the value of E_m, and, consequently, raises the speed. In the limit $L_m = C R$ and $E_T = E_m$—*see* (II.). Even if these values were possible in practice, E_m would be still less than E_d ; so that the relative values of the speeds can only be seen by examination of the ratios $\frac{E_m}{n_m}$ and $\frac{E d}{n_d}$. It will be found with all normal machines that $\frac{E_m}{n_m}$ is less than $\frac{E d}{n_d}$. One must not confound the question of efficiency with these experiments. The efficiency of a dynamo for a given E.M.F. and current varies *inversely* as the speed, for the torque is clearly proportional to some function of the current, and is nearly independent of speed. The motor efficiency for the same electrical constants varies *directly* as the speed. In fact, we endeavour to make the dynamo speed a minimum, and the motor a maximum.

In the first experiment, say, in a large Edison-Hopkinson dynamo, the efficiency either as dynamo or motor will not differ much, but I should expect the motor to give the better result by a small percentage. The influence of the armature is relatively small, and the lead very little. The only objection to the machine, considered as a motor, is the weight, and, consequently, increased cost of material for a given output.

In the second experiment the armature is large compared with the field. Hence, the lead as a dynamo will be great—probably 30deg. at least in a positive direction ; as a motor, the lead, if any at all, will be much less, perhaps 5deg. in the negative direction. The machine will be inefficient as a dynamo, and require a high speed ; but as a motor it will be *much more* efficient, though the speed will not be so great as that required for the dynamo. The second machine will be a good motor—efficient light, and cheap.

This explanation is very rough, but it will help to explain the reason for considering the armature as an independent magnet in motor design. The Oerlikon plant, described in the technical press some six months ago, illustrates the point. The dynamo and motor have armatures identical both as regards the mass and distribution of iron and copper, but the motor field has 7 per cent. less copper and iron than the dynamo, and I know of many installations where proportionately much smaller motor fields are used with advantage.

Many attempts have been made to predetermine the characteristics

of dynamos and motors ; yet the best seem to be but approximations. From what has already been said, it follows that the difficulty only lies with the number of lines of force in the field. This quantity is indeterminate, chiefly because we have no magnetic insulator. We can get the characteristic of the iron of both field and armature, and we know the resistance of the air space. But we do not know, and cannot as yet predetermine by calculation, the loss of magnetism which will take place over a new type of machine. Mr. Kapp has shown that this leakage is a function of linear dimensions of the machine, and hence varies with every type ; indeed, no matter how small the alteration in design the value of the lost magnetism is changed. Practically this presents no difficulty, as only a few types obtain with most firms, and a few simple experiments will determine the number of ampere turns to give any desired result.

Dr Hopkinson and Mr. Kapp were, perhaps, the first to move in this direction of calculating the amp re turns required in the field to give a definite magnetic flux in the armature. Both methods are well known. but a brief reference will assist us to follow the subject. Mr. Kapp started from a geometrical treatment of the design. and assumed the magnetic resistance of iron to be expressed by a law similar to that of Ohm, and the saturation effect was assumed to follow a tangent function. I have used the Kapp formulæ for many machines, both dynamos and motors ; indeed, I think I was probably the first to apply them to motors ; but the results are not satisfactory, particularly with large machines. The equations do not take into consideration the leakage in a sufficiently accurate manner, and the ampere-turns have to be increased from 25 per cent. to 100 per cent. above the value given by calculation. The characteristic thus obtained usually rises too slowly, and after cutting the real curve about the point of half-saturation of the field-magnet, does not fall sufficiently rapidly. My experience, I believe, is fairly well borne out by other users of the Kapp formulæ.

Hopkinson starts on a different basis. He determines experimentally the curves of saturation of both field and armature iron, and expresses the magnetic flux in terms of absolute magnetising force ($4\pi S i$) per centimetre length of core. The specific resistance of air is also determined by experiment. So far this is perfectly safe ground. But the characteristic of the machine itself is the summation of the curves of the field and armature iron and the air space, modified by the leakage and the reactions of the armature. Hopkinson has now to resort to experiment to find the magnitude of these disturbing influences, and a good deal of approximation or experimenting is required. Indeed, the method is not applicable to a new type of machine without considerable knowledge of the subject.

Prof. Silvanus Thompson, in the third edition of "Dynamo-Electric Machinery," gives a method combining both Hopkinson's curves and Frölich's equation :

$$N = N_1 \frac{S\,i}{S\,i + (S\,i)_1}.$$

N = maximum number of lines in the field-magnet.
N_1 = lines in field-magnets to give the diacritical value.
$S\,i$ = ampere-turns to give N.
$S\,i_1$ = ampere-turns to give N_1.

But this, again, demands an experimental determination of the leakage coefficient, and does not seem to me to advance the subject much.

Mr. Esson employs a modification of Dr. Hopkinson's method. Using the saturation curves of the iron and specific resistance of the air as his starting points, and selecting a definite value of Z_a, he determines the number of ampere-turns per centimetre of magnet core to give this value in the armature, neglecting leakage or self-induction. With a known type of machine this method presents great advantages, for the field-winding is given by simple reference to the curves.

Fortunately for us practical men, there is no pressing need of an exact mathematical solution. With a known type of field, machines of any output can be designed with certainty from previous experience and easy applications of the rule of three.

It may be noted that the slope of the characteristic is mainly determined by the resistance of the air gap. The curves of the field and armature iron do not largely affect the general shape till the diacritical points of either be reached. If the field be so crowded with wire that this point be passed, then the characteristic of the machine will bend rapidly.

Before leaving this part of the subject, I will briefly examine the question of pole-pieces.

Judging from the variety of shapes of polar extensions obtaining in machines in the market to-day. there seems to be no little ambiguity on the subject. Some makers use long poles, extending over nearly 160deg. of the armature periphery. Others cover 90deg. to 100deg. Some machines are to be found with long, thin, sharp extensions, whilst some have short, thick, and rounded ends. Each in its way accomplishes a particular end, but only want of knowledge could lead to the extreme proportions sometimes met with. This variety of dimensions in the pole-pieces and extensions arises from an attempted compromise between theory and simplicity of design.

Theory, on the one hand, points to an extended pole-piece if a low magnetic resistance of the air gap be desired. But since there is a tendency for the magnetic density to increase at the extremities of the poles, an undue lengthening of the arc encircled leads to a distortion of the main field. And, further, the position of commutation becomes a line, whilst really there should be some two or three segments on either side on which the brushes may rest without causing sparking or heating of the coils short-circuited beneath them.

Theoretical considerations, then, compel us to shorten the polar extensions, although we thereby raise the total magnetic resistance. This involves, however, no practical loss, for magnetism is cheap, and a few more ampere-turns will compensate for the weakened field.

It is curious to note how the tendency to shorten the pole-pieces has increased during the last 12 months or so. The Manchester dynamo used to have pole-pieces extending over 139deg. I heard the other day of a Manchester machine with poles not more than 90deg. in length. Messrs. Paterson and Cooper are also making both dynamos and motors with short poles ; so are many other firms.

In some designs there are practical reasons for shortening the poles. If the cores are vertical, it is a convenience to be able to slip the windings over the poles. To attain this, the cores are prolonged and the poles bored out of them, instead of being built up of separate castings. This is applicable to both cast and wrought iron magnets.

Rounded polar extensions are also used in some designs, particularly with high-tension machines I think this was first done in the Weston dynamos. Speaking generally, for motor pole-pieces I would recommend that the arc embraced be not more than 120deg., preferably rather less, and that the poles be rounded at all their extremities. The section of the poles should vary about in proportion to the magnetic flux desired. By a careful attention to this point the field may be properly spread over the whole of the coils beneath the poles, and the E.M.F. induced per coil be approximately the same. This is a matter of no little importance in large machines.

The best way of testing the activity of the different coils is the one first used by Mordey, I believe. By a simple arrangement of two movable brushes, the E.M.F. of coils in different parts of the field is successively measured and the result plotted. This gives the differential curve of potential. From this the integral curve may be obtained, or a direct experiment will give the same result. Fix one lead of the voltmeter to, say, the negative brush, and move the other in contact with the commutator through spaces equal to the angular width of one coil, taking readings at each space. These two curves show at a glance the relative activity of the coils and the distribution of the main field No better method can be devised for showing the exact action of the armature, and the relative advantages of differently shaped poles and polar extensions are at once apparent.

This method is also very useful for showing the difference between the distribution of magnetism in the dynamo and motor field. I have derived considerable assistance from an exhaustive treatment of different machines in this manner. The results obtained are very curious, and serve to explain why it is advisable to make a difference between machines used as dynamos or as motors.

Generally motors are likely to have greater and more sudden variations of load than dynamos, hence the necessity for extra care in designing the pole-pieces. The principal point to be aimed at is to make the position of commutation sufficiently large for the variations likely to occur.

Assuming we have now designed and built our motor on the lines discussed here, it will be necessary to examine the degree of excellence attained. This is best done by brake tests. It will not be necessary to run the motor at a constant potential ; indeed, in practice this is often a matter of no little difficulty. Let our motor be series-wound, and designed to run on a lighting circuit of 100 volts. Measure the ohmic resistance hot. Arrange the motor with a Prony or other absorption brake, and put a suitable resistance in series with the windings, so that any desired E.M.F. may be obtained within the limits of supply.

First, run the motor light—*i.e.*, without the brake, at the highest speed required of it, and note the terminal volts and the amperes. Then place the brake in position and screw down the blocks. Take readings with different loads, varying the current by intervals of one ampere, and noting the corresponding volts and speeds. When the maximum load is reached, we have all the data for calculating the performance of our motor. Arrange ten columns with following headings :

Speed.	Weight	Volts.	Amp.	B.H.P.	E.H.P.	Efficiency.	$\frac{E}{n}$	$\frac{c}{n}$	$\frac{\text{B.H.P. } 746.}{n\,c}$

The first four are filled in from the observations of the test. The b.h p. is calculated from the speed, the brake load, and the brake constant. The e.h.p. and the efficiency speak for themselves. We have now three columns left. From these we purpose to plot three curves that will show how far our method of design is successful.

The first, $\frac{E}{n}$, is the terminal E.M F. divided by the speed obtaining for the particular value of E.

The second, $\frac{c}{n}$, is the so-called back E.M.F. ($= E - C R$) divided by the same value of n.

The third, $\frac{\text{B.H.P. } 746}{n\,c}$, is really of the same order—viz., a definite number of volts absorbed per revolution *in actual work on the brake.*

This requires some explanation. Note that the b.h.p. multiplied by 746 gives the available useful h.p. in watts, *i.e.*, a quantity that can be expressed by the symbol C E. We know the current flowing for any load, but do not know the exact fraction of the applied E.M.F. usefully employed for external work. But if we divide the b.h.p. expressed in watts by the known currents, the value of the unknown volts is given. This quantity is divided by n to reduce it to volts per revolution. The efficiency is thus given us by dividing $\frac{\text{B.H.P. } 746}{n\,c} / \frac{E}{n}$, or efficiency $= \frac{\text{B.H.P.} 746}{c\,E}$. We now take a piece of squared paper, and set off the current as abscissæ, and for ordinates the volts per revolution (Fig. 3). Then we plot against the several currents the corresponding

values of $\frac{E}{n}$, $\frac{e}{n}$, $\frac{B.H.P.\ 746}{n\ c}$. This gives us three curves. Two of these rise from the origin 0; but the third, the curve of useful work, starts at that particular value of c, which is just sufficient to overcome the static resistance of the motor. It will be noted that these curves tend to diverge from parallelism as the load increases. They show on inspection two things of great importance in motor design. The height of the ordinates between $\frac{E}{n}$ and $\frac{e}{n}$ show the E.M.F. lost over the ohmic resistance of the machine when heated to its normal temperature. The distance between $\frac{e}{n}$ and the lowest curve $\frac{B.H.P.\ 746}{n\ c}$ shows the E.M.F. lost from all other causes—viz., material and magnetic friction, and by induction. These three curves give at a glance the value of the motor as a converter of energy, and they show not only where the losses occur, but they give the magnitudes. The several quantities are divided by n, simply because it is practically difficult to make a test with constant speed. Since n is proportional to $\frac{B.H.P.\ 746}{nc}$, and is the same for the three ordinates corresponding to each value of c, no error of importance is introduced.

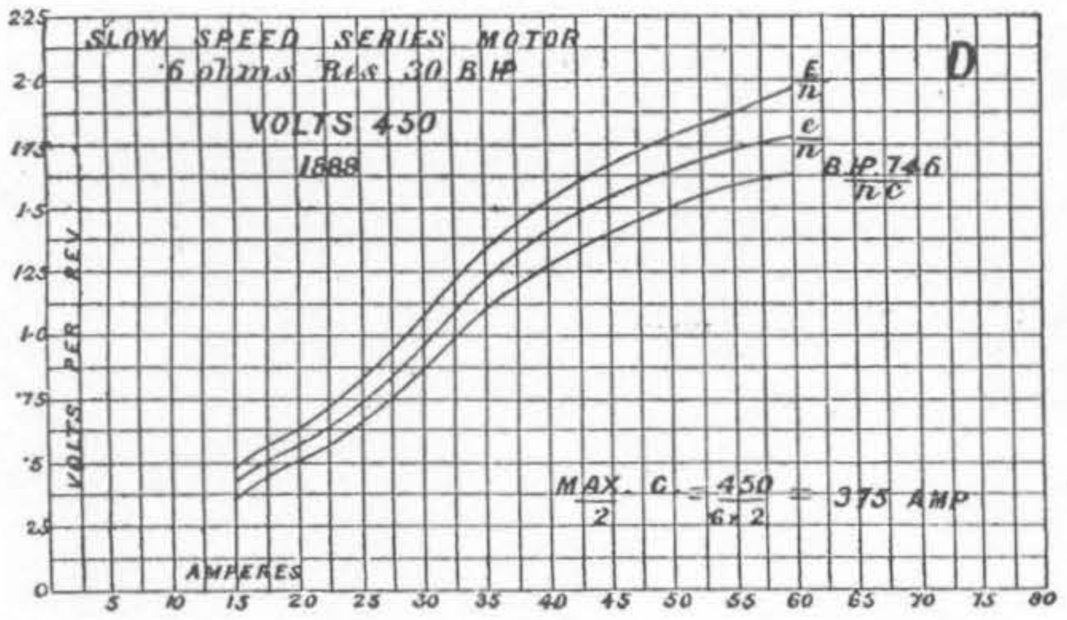


FIG. 3.

We now can see whether the losses, other than those due to the internal resistance, are excessive. The heat waste is a necessary evil, and can only be reduced within certain limits. The area between $\frac{e}{n}$ and the work curve can, however, be made very small. In a really well-designed motor this area should always be considerably less than that proportional to $C^2\ R$.

If the losses due to friction and Foucault currents be larger than those caused by the copper resistance, the machine is badly designed. Our motor, however, will not only have a small value for $C^2\ R$, but its other losses will not exceed $\frac{C^2\ R}{2}$.

With these rough notes I close my paper. I may not have told you much that is new, but I hope to have made clear some of the more general difficulties, and to have put the design of motors on a simple engineering basis.

DISCUSSION.

Mr. W. B. Esson: No one regrets more than I do the fact that Mr. Snell himself was not able to be present, but as I have talked over the paper with Mr. Snell, and he is fully aware of what I am going to say, he will probably be just as able to answer my remarks as if he were here. Taking the principle of reversibility, Mr. Snell finds that for a motor there is no critical current—that is, any current above that requires to overcome its friction will make it run. But for a dynamo a current lower than a certain value, called the critical current, is impossible. From this Mr. Snell seems to think that there is something radically wrong in the principle of reversibility, but I think this is a mistake. I made some experiments years ago to ascertain the effects of the reactions of the armature on the field, and concluded that in both dynamo and motor the effects were exactly similar. The case stands thus: Take a series machine and send a certain current through the field-magnets and armature. There is undoubtedly a delay in magnetisation, as pointed out by Ayrton and Perry some years ago, but I do not attach importance to this effect in continuous current machines. Although negligible in these, in alternate machines, however, the magnetic delay becomes enormously important. Well, neglecting this delay, let us send, in both motor and dynamo, the same current through the magnets and armature; it stands to reason that whichever way the armature turns the reaction must be exactly the same, provided that the back lead in the motor is equal to the forward lead in the dynamo. In a motor the only difference is that the armature runs round the other way, the magnetisation of the system and distribution of the field being the same in both cases. In the experiments mentioned, a dynamo was taken with a Gramme ring. This was run to produce several different currents. As a motor it was run at the same speed, and braked until the same currents flowed as were generated when it ran as a dynamo. With the current flowing in the same direction through the machine, the armature revolved, of course, in the opposite direction, the brushes having the tips rounded so that their ends did not turn up with the reversal. If V_1 and V_2 are the differences of potential at the terminals of the dynamo and motor, then I found in each case that—

$$V_1 + C\,R = V_2 - C\,R,$$

where C was the current and R the resistance of the machine. I concluded from this that the effect of self-induction might be neglected, and that the delay in the magnetisation of the armature core was also inappreciable.

Now we come to self-induction. In this direction I have been making several experiments lately, and find that in armature cores saturated to 18,000 C.G.S. the effect of self-induction may be entirely neglected. The experiments are made thus: The machine is separately excited, and run without any lead on open circuit, the E.M.F. and speed being noted, also the ampere-turns on the field. We now let a current flow through the machine and note the increase of excitement required to bring the E.M.F. to its previous value—that is to say, the difference of potential at the brushes is equal to its previous value *minus* the current into the resistance of the armature. There is no lead to the brushes, and therefore any weakening of the field is due to self-induction; and I find that at 18,000 C.G.S. the number of turns required to bring the potential when the current flows up to its former value is inappreciable, while at lower degrees of saturation a certain number of ampere-turns have to be added, which get larger as the saturation is reduced.

Regarding the effect of the armature lines on the field lines, I disagree entirely with Mr. Snell. It is quite true that Ayrton and Perry showed that the effects due to both might be added if the motor were worked with a forward lead, but if I recollect rightly, Ayrton and Perry stated that under usual conditions of work the brushes must have a negative lead. With this you must have a weakening of the field. You cannot have an increase—it is a physical impossibility. I might say that the very reason of a shunt motor governing so perfectly is due to this weakening effect on the field of the armature windings. As the current rises the field is weakened, and the effect is similar to that of a series coil wound on the magnets in the reverse direction to the shunt. For constant speed we require, therefore, no compound winding, but only a particular relation of field to armature. I have seen a motor in which the speed actually increased as the load was put on.

As to the ratio of field-magnet to armature cross-section, it is worthy of note that the cross-section of armature core can be varied very considerably without affecting to any considerable extent the number of lines of force through it. This arises from the fact that the ampere-turns required for the induction through the core is only a fraction of the total ampere-turns for the whole machine. In investigating this my firm constructed two armatures—one had a cross-section equal to ·6 that of the magnets; the other was ·8. The windings were similar, and so was the length; in fact, the only difference was that the hole in the centre of the armature was in one of them smaller. Although the increase in the cross-section was very considerable, the maximum increase in induction due to similar excitements was in the core of larger section only from 5 to 6 per cent. The gain is therefore so small for considerable increase in weight, that I think it is not worth while making two types.

For "useful" lines induced by the current in the armature core, Mr. Snell ought to substitute "useless," for, as I have already shown, the field is always weakened by them, not strengthened.

I may say that it is a very difficult thing to calculate the magnetic leakage before the machine is built, but it is very simple to measure the leakage afterwards, and from that it is tolerably easy to deduce the leakage in other machines, both of the same and modified types. One point is worthy of remark. Taking the single horseshoe magnet, suppose that in such a machine the ratio of the total lines of force induced in the magnet limbs to those passing through the armature core is 1·32. Now, imagine that you make a mistake in your calculation before the machine is made by assuming the ratio at 1·2, instead of 1·32. The error in the assumed leakage is 10 per cent., but the difference in the E.M.F. of the machine due to having made this error will only be about 2 per cent. The reason of this is that the number of ampere-turns required for the induction in the magnets themselves is fractional as compared with that required for the whole machine.

If the terminal difference of potential = V is the same in both dynamo and motor, their speeds will be in the ratio $V + C\,R : V - C\,R$, the dynamo, of course, being always the higher. I may mention that the efficiency of a motor is always greater than that of a dynamo at the same speed and current, the efficiencies standing in the ratio of $\frac{E}{E + C\,R}$: $\frac{E - C\,R}{E}$ where E is the E.M.F. generated in each case. Of course it makes no difference to the E.M.F. whether the armature is belt driven or current driven, provided the fields are in each case the same.

One of the chief reasons for the ampere-turns having to be increased over that shown by the calculation is, because in the calculation the demagnetising effect of the armature upon the field-magnets is neglected. This weakening effect is due to the lead of the brushes. In the Manchester machine, for instance, Dr. E. Hopkinson tells me that there are as many ampere-turns of series as of shunt wire, and the chief use of the series wire is to compensate the weakening effect produced by the current flowing through the armature.

Mr. Snell says, referring to the method I use, that I neglect leakage and self-induction. As a matter of fact, I neglect nothing, or rather I only neglect those things that are negligible. Self-induction is negligible, and the leakage I take always at one fixed ratio, an error in this producing, as I have shown, very small effect on the output of the machine.

In conclusion, I again express my regret at the absence of the author. Though my remarks have been of a somewhat critical character, it will be understood, I hope, that concerning all the points of which I have not spoken I have only to utter unqualified praise. They are only the points to which I in some degree take exception that I have called attention to.

THE TESLA MOTOR.

Although the theory of the Tesla motor is now so widely known—though doubtless better known than understood—yet the practical construction of the apparatus has not yet been explained. The following brief description will therefore be read with interest :—The field-magnet consists of a laminated ring, with internal projections like Paccinotti teeth. It is wound with two independent circuits, A and B ; in the motor from which the diagram is taken there are 12 sections in all, and the two coils are wound upon every three sections alternately. The three sections on the right of the figure, and the three on the left, the two being joined in series form circuit A. Similarly, the three upper and the three lower sections form circuit B. The resultant fields of each coil independently are shown by the lines $N_A S_A$, $N_B S_B$, respectively. But the currents in these two circuits are relatively displaced by $\frac{1}{4}$ phase. Thus, when the current in A is at a maximum, the current in B is at zero, and the resultant field for both coils passes through $N_A S_A$; so, also, when B is at a maximum and A is at zero, the resultant is $N_B S_B$. But when the two currents are equal the resultant passes through the line N S ; the direction of the resultant is, of course, reversed at the moment when the two currents are equal in value but opposite in direction.

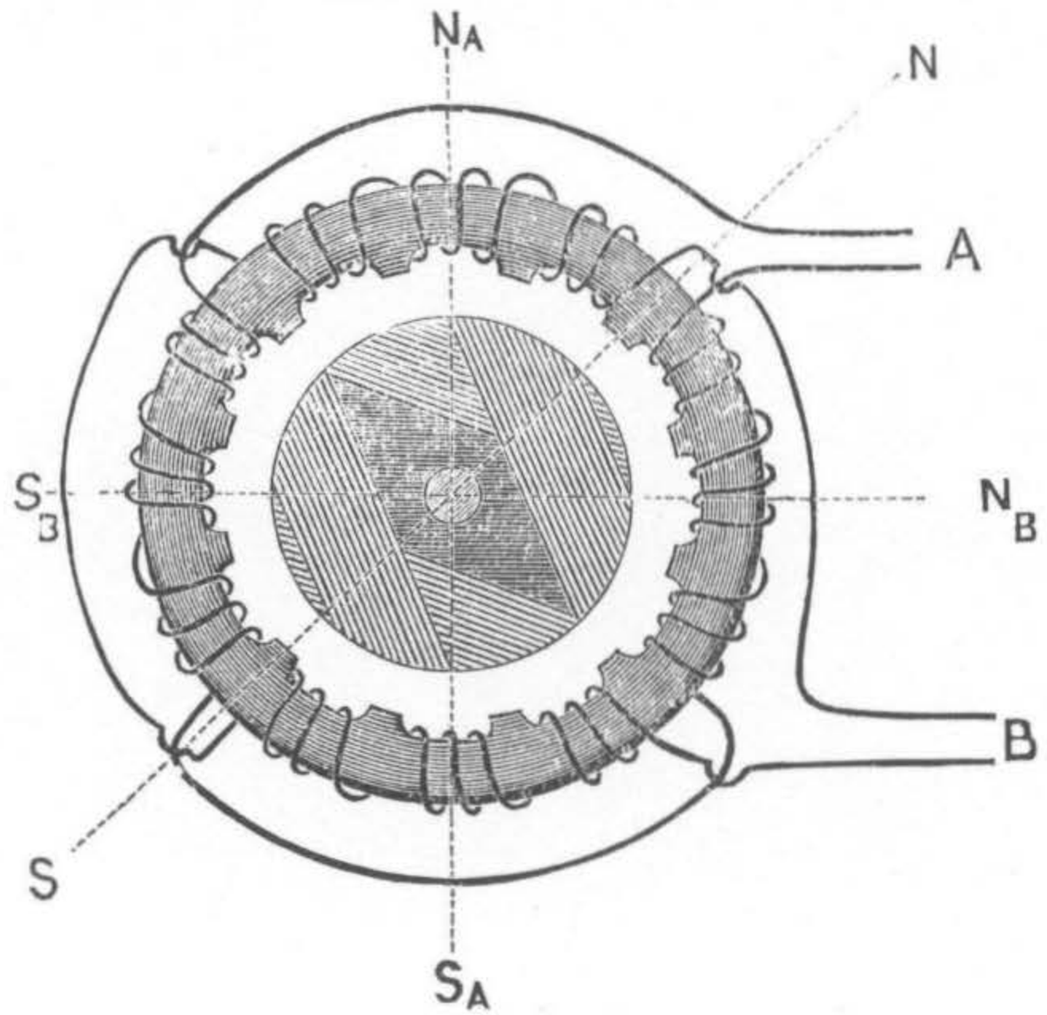


Diagram of Windings of Tesla Motor.

The armature is drum-wound, with four coils, as shown, each being short-circuited on itself. The resultant axis passes through N S.

ALTERNATE CURRENT MOTORS.

EIGHTEEN months ago Professor Galileo Ferraris, of Turin, discovered that a copper cylinder when suspended between two coils, was set in rotary motion by alternating currents of the same period, but of different phase when sent through these coils, which were placed at right angles to each other. The explanation given by the discoverer was, that the resultant field of the two currents revolved round the common centre line of the coils and, by means of eddy currents created in the copper cylinder, dragged the latter after it. This principle, says Mr. Kapp, has been practically developed by Mr. Nicola Tesla and others, and motors have been actually built in which a revolving field causes, by a kind of electro-magnetic drag, an armature to revolve and give off mechanical work. Mr. Kapp in the paper, of which we published an abstract last week, regretted that he was unable to place before the Institution of Civil Engineers details of the Tesla motor, as constructed by the Westinghouse Company. It is now ten months since Mr. Tesla read a paper "On a New System of Alternate Current Motors and Transformers" before the American Institute of Electrical Engineers,* and in this paper the principles involved in the construction of such motors was thoroughly explained. Unfortunately, no figures were published which could give us an idea of the practical value of this invention. We were anxious to know something definite as to the size, power and efficiency of these machines, and we have searched in vain for such data in the papers of Mr. Kapp and Mr. Tesla, nor have we heard as yet of any successful application of alternating current motors. We were in hopes that Prof. Ayrton would have given a clear account of the Tesla motor, "the only one existing in Great Britain or perhaps in Europe," which the Westinghouse Company sent to the Central Institution a few months ago, but all that we could gather from Prof. Ayrton's remarks at the Civil Engineers' meeting, was that this motor has been tested and gave 0·63 of a horse-power at 3,200 revolutions per minute, with 3,720 alternations. The efficiency was not ascertained, therefore we miss one of the most important points, whereby an opinion on the subject might be formed. Prof. Anthony, however, made tests with the same or a similar machine, which Prof. Ayrton quoted, and there we find that "with 6,400 alternations over one horse-power can be obtained at an efficiency of 62 per cent." In this case, again, we lack necessary data, namely, the speed, and energy consumed. We conclude that it was extremely difficult to measure the exact amount of electrical energy used by the motor which was tested at the Central Institution; assuming, however, that an efficiency of 60 per cent. can be obtained with 3,720 alternations, we think that a speed of 3,200 revolutions per minute renders such a motor impracticable for most industrial applications, for to reduce this to a reasonable speed would involve much gearing and its attendent loss of power,

* See ELECTRICAL REVIEW for June 15th, 1888.

so that the resultant efficiency would in some cases not amount to 30 per cent. We also know that this alternating current motor requires two independent circuits for its function; furthermore, we learn from the remarks at the discussion of the American Institute, in May last, that the speed of the motor fell off when the load was increased. Mr. Tesla said "that this was due to the fact that the armature was designed to secure a considerable effort from the start. But if we make an armature which is only designed for synchronism, the speed will always be the same, no matter what the load; only there is a disadvantage that at the outset the rotary effort is so small that it is apt not to start."

The weight of material used in a Tesla motor must be several times as much as that necessary for a continuous current motor to give the same output, rendering such machines very costly.

Thus it would appear that alternating current motors are still a long way off the ideal goal, in spite of the strenuous efforts on the part of some of the smartest people in the world, and we are inclined to think that the solution of the problem may yet have to be sought in an entirely different direction.

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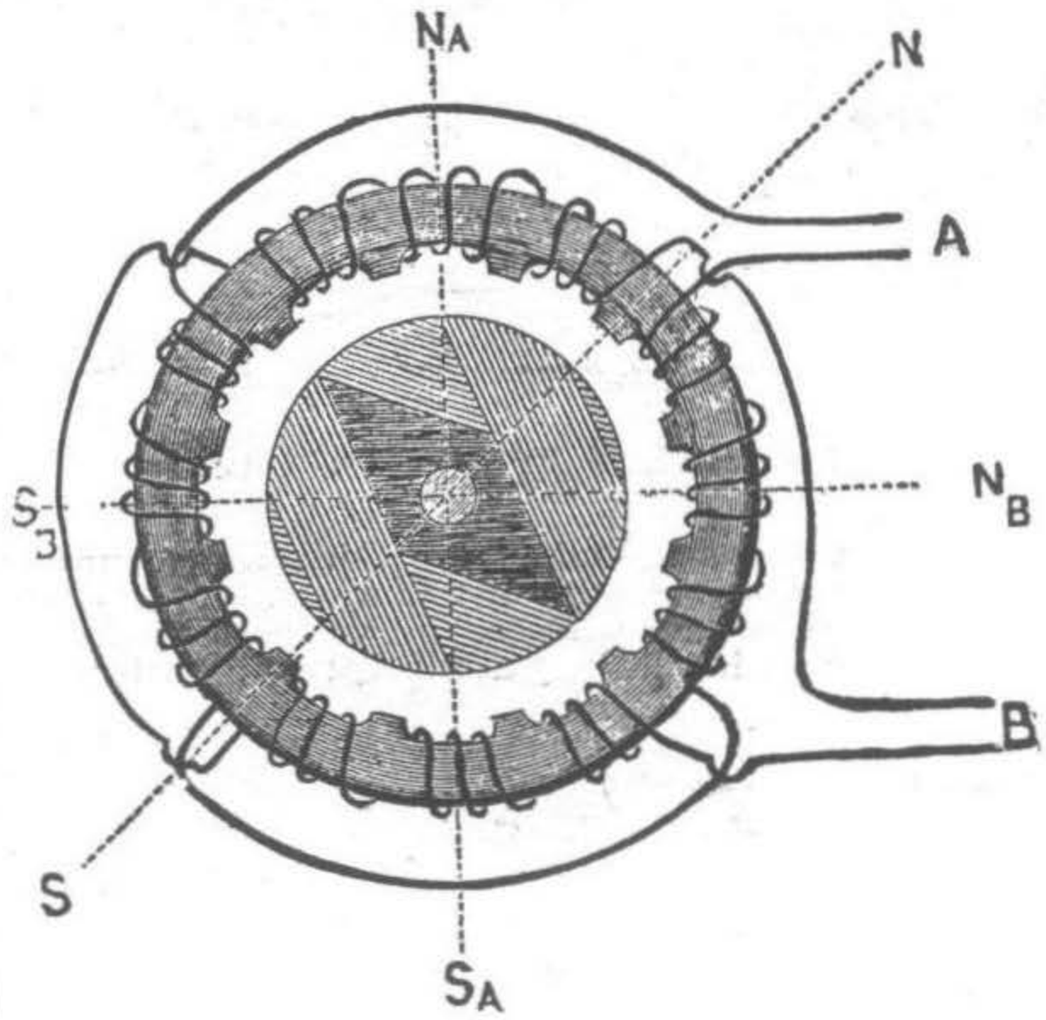

paratus has not yet been explained. The following brief description will therefore be read with interest. The field magnet consists of a laminated ring, with internal projections like Paccinotti teeth. It is wound with two independent circuits, A and B; in the motor from which the diagram is taken there are twelve sections in all, and the two coils are wound upon every three sections alternately. The three sections on the right of the figure, and the three on the left, the two being joined in series, form circuit A. Similarly, the three upper and the three lower sections form circuit B. The resultant fields of each coil independently are shown by the lines $N_A S_A$, $N_B S_B$, respectively. But the currents in these two circuits are relatively displaced by ¼ phase. Thus, when the current in A is at a maximum, the current in B is at zero, and the resultant field for both coils passes through $N_A S_A$; so, also, when B is at a maximum and A is at zero, the resultant is $N_B S_B$. But when the two currents are equal, the resultant passes through the line N S; the direction of the resultant is, of course, reversed at the moment when the two currents are equal in value but opposite in direction. The armature is drum-wound, with four coils, as shown, each being short-circuited on itself. The resultant axis passes through N S.—*The Electrician.*

ALTERNATING CURRENT MOTORS.

WE have received from Messrs. Ganz & Co., of Budapest, a communication on the latest results which have been obtained with alternating current motors since the electricians to this firm, Messrs. Zipernowski, Déri and Bláthy, have been engaged for four years in experiments on various forms and types of such apparatus :—

Turns per minute.	Performance of motor.		Energy apparently consumed.	Effective energy consumed.		Ratio of Watts actually consumed to apparent volt-ampères.	Effective useful effect per cent.
	H.P.	Watts.	Volt-ampères.	Watts.	H.P.		
600	15	11·000	18·000	15·800	21·5	0·88	77·
700	19·8	14·600	24·200	18·600	25·2	0·77	78·5
730	30·7	22·700	29·800	27·700	37·6	0·92	80·9

The circumstance that the apparatus used for these experiments was a model constructed for the purpose of study, in which the attainment of the greatest useful effect was not the main object, but rather the experiments with it were to show how the greatest useful effect can be obtained ; and, secondly, that the motor in the experiments was not working with its normal number of rotations of 750 per minute, but at a lesser speed justify the assumption that in this manner as good a useful effect of the power transferred can be obtained as with the best continuous current motors.

A very important result lies in those figures of the above table, which show that the proportion between the apparent (*i.e.*, ascertained by means of the voltmeter and ammeter) volt-ampères, and the watts actually determined by a watt-meter, which the motor consumed, approach unity ; because therein is a condition fulfilled which has hitherto been sought in vain.

The distribution of the current by means of an alternating current has gained a continually increasing extension—thanks to the transformers—but hitherto it has been rationally available only for the production of light.

The problem of the electric transmission of power by alternating currents involves various difficulties. In the first place the efficiency of alternate current motors has been a long way behind that of the continuous current motor. Secondly, with certain types constant speed regulation was found impossible ; thus, if a motor satisfied the requirements in one direction, it was unfit for purposes where variable power was desired. Thus it happened that when such a motor was, for instance, receiving 5,000 watts from a 100 volt circuit, it did not use 50 ampères but 150 and more ; that is, the motor appeared to consume three times the energy that seemed necessary. This was a great drawback to the employment of alternate current motors, for the cables had to be made several times as large as was necessary with continuous current motors. The generating plant and transformers also had to be made proportionately larger, consequently the existing apparatus, if it had to be utilised for the transmission of power, was found insufficient for the purpose. This was a disadvantage which the advocates of the continuous current system were justified in urging against the alternating current motor.

A solution of the problem was hoped for when Prof. Ferraris published his ingenious experiments, and when soon afterwards Tesla and others made practical use of the already indicated results. Unfortunately in all these systems there are at least three conducting wires requisite, and they require either generators of a special construction, or else two separate machines coupled at a suitable angle.

In how far it has been found possible to remove the above-mentioned disadvantages with alternate current machines we are unable to say, since very little has as yet been published thereon.

A paper in No. 589 of the ELECTRICAL REVIEW of March 8th of the current year on "Alternate Current Motors," shows, on the contrary, that quite recently we were very far distant from being able to show satisfactory results. This communication sums up the opinion which had been formed from previous results :—

"We know also that this alternating current motor requires for its action two independent circuits. We likewise learn from the remarks during the American Institute in May last that the number of rotations of the motor falls when the load is increased. Herr Tesla says that this must be ascribed to the circumstance that the armature had to develop a considerable power when set in motion. If, on the contrary, we produce an armature merely for synchronism the speed will always be the same, however great the load may be ; but one disadvantage here is that the rotary effort is so small that the motor cannot set itself in movement.

"The weight of the material which is expended in a Tesla motor is several times greater than that which is requisite in a continuous current motor for the same duty, which makes the machine in question exceedingly costly. It therefore appears that the alternating current motors are still far removed from the ideal, in spite of the exertions of one of the most capable nations in the world, and we venture to express the opinion that the solution of the problem must be sought for in a quite different direction."

The electricians of Messrs. Ganz & Co. have endeavoured to work out the problem in a different direction, and they appear to have obtained successful results. Their own communications point to the fact that they are fully satisfied, and they consider the solution of the problem as complete. According to their own calculations, alternate current motors now in course of construction at Messrs. Ganz & Co.'s works are expected to give a commercial efficiency of 90 per cent. Since the proportion between the apparent and the actual watts is approximately unity, therefore the comparison between this motor and continuous current motors must hold good, and they expect corresponding results.

We will further point out some peculiarities of the alternating current motor, which are said to confirm its superiority to the continuous current motor.

1. The easy and certain power of regulation, *i.e.*, constant speed with different loads within its working limits.

2. That the high tension current has never to pass through the commutator, since it is possible to bring the alternating current into direct connection with the terminals of the motor and with the fixed armature, whereby the application of far higher tensions in a machine becomes possible, so that it can be more economically effected than in a continuous current motor.

3. The possibility of the distribution of power at greater distances. For although we have already succeeded in setting large continuous current machines in action at great distances with a good result, the size of those motors was still decidedly limited, since it was

not economical to construct small continuous current motors for high tensions, and also because with such small apparatus, if they have to receive a current of high tension, no certainty in working is conceivable. On the contrary, small alternating current motors can be worked economically and safely by means of a current of low tension converted in the transformers.

Lastly, 4. In alternating current machines the insertion of additional resistances is dispensed with, as the self-induction existing in the motor takes their place, which contributes essentially to the simplification of the entire installation.

The production of a good practical alternating current motor is, in fact, the solution of the most important problem of the distribution of power from central stations.

ALTERNATE CURRENT MOTORS.

Eighteen months ago Professor Galileo Ferraris, of Turin, discovered that a copper cylinder when suspended between two coils, was set in rotary motion by alternating currents of the same period, but of different phase when sent through these coils, which were placed at right angles to each other. The explanation given by the discoverer was, that the resultant field of the two currents revolved round the common centre line of the coils and, by means of eddy currents created in the copper cylinder, dragged the latter after it. This principle, says Mr. Kapp, has been practically developed by Mr. Nikola Tesla and others, and motors have been actually built in which a revolving causes, by a kind of electro-magnetic drag, an armature to revolve and give off mechanical work. Mr. Kapp in the paper, of which we published an abstract last week, regretted that he was unable to place before the Institution of Civil Engineers details of the Tesla motor, as constructed by the Westinghouse Company. It is now ten months since Mr. Tesla read a paper "On a New System of Alternate Current Motors and Transformers" before the American Institute of Electrical Engineers, and in this paper the principles involved in the construction of such motors was thoroughly explained. Unfortunately no figures were published which could give us an idea of the practical value of this invention. We were anxious to know something more definite as to the size, power, and efficiency of these machines, and we have searched in vain for such data in the papers of Mr. Kapp and Mr. Tesla, nor have we heard as yet of any successful application of alternating current motors. We were in hopes that Prof. Ayrton would have given a clear account of the Tesla motor, "the only one existing in Great Britain or perhaps in Europe," which the Westinghouse Company sent to the Central Institution a few months ago, but all that we could gather from Prof. Ayrton's remarks at the Civil Engineers' meeting was, that this motor has been tested and gave 0.63 of a horse-power at 3,200 revolutions per minute, with 3,720 alternations. The efficiency was not ascertained, therefore we miss one of the most important points, whereby an opinion on the subject might be formed. Prof. Anthony, however, made tests with the same or a similar machine, which Prof. Ayrton quoted, and there we find that "with 6,400 alternations over one horse-power can be obtained at an efficiency of 62 per cent." In this case, again, we lack necessary data, namely, the speed, and energy consumed. We conclude that it was extremely difficult to measure the exact amount of electrical energy used by the motor which was tested at the Central Institution, assuming however, that an efficiency of 60 per cent. can be obtained with 3,720 alternations, we think that a speed of 3,200 revolutions per minute renders such a motor impracticable for most industrial applications, for to reduce this to a reasonable speed would involve much gearing and its attendant loss of power, so that the resultant efficiency would in some cases not amount to 30 per cent. We also know that this alternating current motor requires two independent circuits for its function; furthermore, we learn from the remarks at the discussion of the American Institute in May last, that the speed of the motor fell off when the load was increased. Mr. Tesla said "that this was due to the fact that the armature was designed to secure a considerable effort from the start. But if we make an armature which is only designed for synchronism, the speed will always be the same, no matter what the load; only there is a disadvantage that at the outset the rotary effort is so small that it is apt not to start."

The weight of material used in the Tesla motor must be several times as much as that necessary for a continuous current motor to give the same output, rendering such machines very costly. Thus it would appear that alternating current motors are still a long way off the ideal goal, in spite of the strenuous efforts on the part of some of the smartest people in the world, and we are inclined to think that the solution of the problem may yet have to be sought in an an entirely different direction.—*Electrical Review* (London).

Alternating Current Motors of Messrs. Ganz & Co., Budapest.

For some time past, electricians working in the department of distribution by means of alternating currents have sought to obtain a motor which could be connected directly to the electric light circuits and which should approximate to the continuous current motor in regard to regulation and economy. The problem which presented itself involved a number of difficulties. In the first place, the efficiency of such a motor appeared to be far below that which is attained in the continuous current motor, and secondly, with certain types of alternating

motors the maintenance of constant speed with varying loads is unattainable. The great drawback consisted in the fact, that if such a motor actually absorbed, say, 5,000 watts of electrical energy on, say, a 100 volt circuit, the ammeter would show, not 50 ampères passing into the motor, but probably 150; *i. e.*, that the motor apparently consumed about three, or more, times the actual number of watts absorbed. This appeared to be a great drawback to the application of alternating current motors, as it entailed an enlargement of the conducting wires, and, indeed, an increase in the size of the transformers, dynamos, etc. This condition of affairs existed when Professor Ferraris published his ingenious experiments, which were paralleled by the motors of Mr. Tesla and others.

Recently the firm of Ganz & Co., of Budapest, have undertaken the construction of alternating current motors, and their electricians, Messrs. Zipernowski, Déri and Bláthy, after experimenting for four years on various types of machines, have succeeded in constructing a practical form. Through the courtesy of the firm we are enabled to publish the following table which gives some details of the new machine. A study of the table will show that the improved result obtained is, that the relation of the apparent energy consumed in the motor, *i. e.*, the energy measured by means of the voltmeter and ammeter, in volt-ampères, is almost equal to the actual number of watts as measured by means of the wattmeter. This ratio of unity between these two quantities shows that the efficiency of the motor is very high. It must be noted that the apparatus upon which these experiments were made was merely an experimental one in which high efficiency was not the principal object sought for; on the contrary, the tests were made with the idea of obtaining some solution of the problem of how to obtain the greatest efficiency. Besides that, the machine was not run at its normal rate of 750 revolutions per minute, but at a lower one. These tests have led to the firm conviction that the efficiency of alternating current motors will eventually be brought up to that of the continuous current. In the new machine but two circuit wires are employed.

Revolutions per minute.	Work of alt. curr. motor.		Apparent energy consumed, volt-ampères.	Actual energy consumed.		Ratio between actual number of watts consumed and apparent number of volt-ampères.	Commercial efficiency in per cent.
	H. P.	Watts.		Watts.	H. P.		
600	15	11,000	18,000	15,800	21.5	0.88	77.0
700	19.8	14,600	24,200	18,600	25.2	0.77	78.5
730	30.4	22,400	29,800	27,700	37.6	0.92	80.9

Mr. Nikola Tesla on Alternating Current Motors.

To the Editor of The Electrical World:

SIR: About a year ago I had the pleasure of bringing before the American Institute of Electrical Engineers the results of some of my work on alternate current motors. They were received with the interest which novel ideas never fail to excite in scientific circles, and elicited considerable comment. With truly American generosity, for which, on my part, I am ever thankful, a great deal of praise through the columns of your esteemed paper and other journals has been bestowed upon the originator of the idea, in itself insignificant. At that time it was impossible for me to bring before the Institute other results in the same line of thought. Moreover, I did not think it probable—considering the novelty of the idea—that anybody else would be likely to pursue work in the same direction. By one of the most curious coincidences, however, Professor Ferraris not only came independently to the same theoretical results, but in a manner identical almost to the smallest detail. Far from being disappointed at being prevented from calling the discovery of the principle exclusively my own, I have been excessively pleased to see my views, which I had formed and carried out long before, confirmed by this eminent man, to whom I consider myself happy to be related in spirit, and toward whom, ever since the knowledge of the facts has reached me, I have entertained feelings of the most sincere sympathy and esteem. In his able essay Prof. Ferraris omitted to mention various other ways of accomplishing similar results, some of which have later been indicated by O. B. Shallenberger, who some time before the publication of the results obtained by Prof. Ferraris and myself had utilized the principle in the construction of his now well known alternate current meter, and at a still later period by Prof. Elihu Thomson and Mr. M. J. Wightman.

Since the original publications, for obvious reasons, little has been made known in regard to the further progress of the invention; nevertheless the work of perfecting has been carried on indefatigably with all the intelligent help and means which a corporation almost unlimited in its resources could command, and marked progress has been made in every direction. It is therefore not surprising that many, unaquainted with this fact, in expressing their views as to the results obtained, have grossly erred.

In your issue of May 4 I find a communication from the electricians of Ganz & Co., of Budapesth, relating to certain results observed in recent experiments with a novel form of alternate current motor. I would have nothing to say in regard to this communication unless it were to sincerely congratulate these gentlemen on any good results which they may have obtained, but for an article, seemingly inspired by them, which appeared in the Lon-

don *Electrical Review* of April 26, wherein certain erroneous views are indorsed and some radically false assertions made, which, though they may be quite unintentional, are such as to create prejudice and affect material interests.

As to the results presented, they not only do not show anything extraordinary, but are, in fact, considerably below some figures obtained with my motors a long time ago. The main stress being laid upon the proposition between the apparent and real energy supplied, or perhaps more directly, upon the ratio of the energy apparently supplied to, and the real energy developed by, the motor, I will here submit, with your permission, to your readers, the results respectively arrived at by these gentlemen and myself.

Energy apparently supplied in watts.		Work performed in watts.		Ratio of the energy apparently supplied to the real energy developed.	
Ganz & Co.	Westinghouse Co.	Ganz & Co.	Westinghouse Co.	Ganz & Co.	Westinghouse Co.
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24,200	30,295	14,600	25,365	0 603	0.836
29,800	43,624	22,700	36,915	0.761	0.846
....	56,800	....	48,675	....	0.856
....	67,500	....	59,440	....	0.88
....	79,100	....	67,365	....	0.851

If we compare these figures we will find that the most favorable ratio in Ganz & Co.'s motor is 0.761, whereas in the Westinghouse, for about the same load, it is 0.836, while in other instances, as may be seen, it is still more favorable. Notwithstanding this, the conditions of the test were not such as to warrant the best possible results.

The factors upon which the apparent energy is mainly dependent could have been better determined by a proper construction of the motor and observance of certain conditions. In fact, with such a motor a current regulation may be obtained which, for all practical purposes, is as good as that of the direct current motors, and the only disadvantage, if it be one, is that when the motor is running without load the apparent energy cannot be reduced quite as low as might be desirable. For instance, in the case of this motor the smallest amount of apparent energy was about 3,000 watts, which is certainly not very much for a machine capable of developing 50 h. p. of work; besides, the amount could have been reduced very likely to 2,000 watts or less.

On the other hand, these motors possess the beautiful feature of maintaining an absolutely constant speed no matter how the load may vary. This feature may be illustrated best by the following experiment performed with this motor. The motor was run empty, and a load of about 100 h. p., far exeeeding the normal load, was thrown on suddenly. Both armatures of the motor and generator were seen to stop for an instant, the belts slipping over the pulleys, whereupon both came up to the normal speed with the full load, not having been thrown out of synchronism. The experiment could be repeated any number of times. In some cases, the driving power being sufficient, I have been enabled to throw on a load exceeding 8 to 9 times that which the motor was designed to carry, without affecting the speed in the least.

This will be easily understood from the manner in which the current regulation is effected. Assuming the motor to be running without any load, the poles of the armature and field have a certain relative position which is that of the highest self-induction or counter electromotive force. If load be thrown on, the poles are made to recede; the self-induction or counter electromotive force is thereby diminished and more current passed through the stationary or movable armature-coils. This regulation is very different from that of a direct current motor. In the latter the current is varied by the motor losing a certain number of revolutions in proportion to the load, and the regulation would be impossible if the speed would be maintained constant; here the whole regulation is practically effected during a fraction of one revolution only. From this it is also apparent that it is a practical impossibility to throw such a motor out of synchronism, as the whole work must be done in an instant, it being evident that if the load is not sufficient to make a motor lose a fraction of the first revolution it will not be able to do so in the succeeding revolutions. As to the efficiency of these motors, it is perfectly practicable to obtain 94 to 95 per cent.

The results above given were obtained on a three-wire system. The same motor has been started and operated on two wires in a variety of ways, and although it was not capable of performing quite as much work as on three wires, up to about 60 h. p. it gave results practically the same as those above-mentioned. In fairness to the electricians of Ganz & Co., I must state here that the speed of this motor was higher than that used in their experiments, it being about 1,500. I cannot make due allowance for this difference, as the diameter of the armature and other particulars of the Ganz & Co. motor were not given.

The motor tested had a weight of about 5,000 lbs. From this it will be seen that the performance even on two wires was quite equal to that of the best direct current motors. The motor being of a synchronous type, it might be implied that it was not capable of starting. On the contrary, however, it had a considerable torque on the start and was capable of starting under fair load.

In the article above referred to the assertion is made that the weight of such alternate current motor, for a given capacity, is "several times" larger than that of a direct current motor. In answer to this I will state here that we have motors which with a weight of about 850 pounds develop 10 h. p. with an efficiency of very nearly 90 per cent., and the spectacle of a direct current motor weighing, say 200–300 pounds and performing the same work, would be very gratifying for me to behold. The motor which I have just mentioned had no commutator or brushes of any kind nor did it require any direct current.

Finally, in order to refute various assertions made at random, principally in the foreign papers, I will take the liberty of calling to the attention of the critics the fact that since the discovery of the principle several types of motors have been perfected and of entirely different characteristics, each suited for a special kind of work, so that while one may be preferable on account of its ideal simplicity, another might be more efficient. It is evidently impossible to unite all imaginable advantages in one form, and it is equally unfair and unreasonable to judge all different forms according to a common standard. Which form of the existing motors is best, time will show; but even in the present state of the art we are enabled to satisfy any possible demand in practice.

NIKOLA TESLA.

PITTSBURGH, Pa.

MR. NIKOLA TESLA ON ALTERNATING CURRENT MOTORS.

THE following letter has been addressed to the New York *Electrical World*:—About a year ago I had the pleasure of bringing before the American Institute of Electrical Engineers the results of some of my work on alternate current motors. They were received with the interest which novel ideas never fail to excite in scientific circles, and elicited considerable comment. With truly American generosity, for which, on my part, I am ever thankful, a great deal of praise through the columns of your esteemed paper and other journals has been bestowed upon the originator of the idea, in itself insignificant. At that time it was impossible for me to bring before the Institute other results in the same line of thought. Moreover, I did not think it probable—considering the novelty of the idea—that anybody else would be likely to pursue work in the same direction. By one of the most curious coincidences, however, Prof. Ferraris not only came independently to the same theoretical results, but in a manner identical almost to the smallest detail. Far from being disappointed at being prevented from calling the discovery of the principle exclusively my own, I have been excessively pleased to see my views, which I had formed and carried out long before, confirmed by this eminent man, to whom I consider myself happy to be related in spirit, and towards whom, ever since the knowledge of the facts has reached me, I have entertained feelings of the most sincere sympathy and esteem. In his able essay Prof. Ferraris omitted to mention various other ways of accomplishing similar results, some of which have later been indicated by O. B. Shallenberger, who some time before the publication of the results obtained by Prof. Ferraris and myself had utilised the principle in the construction of his now well known alternate current meter, and at a still later period by Prof. Elihu Thomson and Mr. M. J. Wightman.

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* Mr. Tesla is correct in assuming that the statements in this article were made upon the responsibility of Messrs. Ganz & Co. —EDS. ELEC. REV.

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...	67,500	...	59,440	..	0·88
...	79,100	...	67,365	...	0·851

"If we compare these figures we will find that the most favourable ratio in Ganz and Co.'s motor is 0·761, whereas in the Westinghouse, for about the same load, it is 0·836, while in other instances, as may be seen, it is still more favourable. Notwithstanding this, the conditions of the test were not such as to warrant the best possible results.

"The factors upon which the apparent energy is mainly dependent could have been better determined by a proper construction of the motor and observance of certain conditions. In fact, with such a motor a current regulation may be obtained which, for all practical purposes, is as good as that of the direct-current motors, and the only disadvantage, if it be one, is that when the motor is running without load the apparent energy cannot be reduced quite as low as might be desirable. For instance, in the case of this motor the smallest amount of apparent energy was about 3,000 watts, which is certainly not very much for a machine capable of developing 90 horse-power of work ; besides, the amount could have been reduced very likely to 2,000 watts or less.

"On the other hand, these motors possess the beautiful feature of maintaining an absolutely constant speed no matter how the load may vary. This feature may be illustrated best by the following experiment performed with this motor. The motor was run empty, and a load of about 100 horse-power, far exceeding the normal load, was thrown on suddenly. Both armatures of the motor and generator were seen to stop for an instant, the belts slipping over the pulleys, whereupon both came up to the normal speed with the full load, not having been thrown out of synchronism. The experiment could be repeated any number of times. In some cases, the driving power being sufficient, I have been enabled to throw on a load exceeding eight to nine times that which the motor was designed to carry, without affecting the speed in the least.

"This will be easily understood from the manner in which the current regulation is effected. Assuming the motor to be running without any load, the poles of the armature and field have a certain relative position which is that of the highest self-induction or counter electromotive force. If the load be thrown on, the poles are made to recede ; the self-induction or counter electromotive force is thereby diminished and more current passed through the stationary or movable armature coils. This regulation is very different from that of a direct-current motor. In the latter the current is varied by the motor losing a certain number of revolutions in proportion to the load, and the regulation would be impossible if the speed would be maintained constant ; here the whole regulation is practically effected during a fraction of one revolution only. From this it is also apparent that it is a practical impossibility to throw such a motor out of synchronism, as the whole work must be done in an instant, it being evident that if the load is not sufficient to make a motor lose a fraction of the first revolution it will not be able to do so in the succeeding revolutions. As to the efficiency of these motors, it is perfectly practicable to obtain 94 to 95 per cent.

"The results above given were obtained on a three-wire system. The same motor has been started and operated on two wires in a variety of ways, and although it was not capable of performing quite as much work as on three wires, up to about 60 horse-power it gave results practically the same as those above mentioned. In fairness to the electricians of Ganz and Co., I must state here that the speed of this motor was higher than that used in their experiments, it being about 1,500. I cannot make due allowance for this difference, as the diameter of the armature and other particulars of the Ganz and Co. motor were not given.

"The motor tested had a weight of about 5,000lb. From this it will be seen that the performance even on two wires was quite equal to that of the best direct-current motors. The motor being of a synchronous type, it might be implied that it was not capable of starting. On the contrary, however, it had a considerable torque on the start and was capable of starting under fair load.

"In the article above referred to the assertion is made that the weight of such alternate-current motor for a given capacity is 'several times' larger than that of a direct-current motor. In answer to this I will state here that we have motors which with a weight of about 850lb. develop 10 horse-power with an efficiency of very nearly 90 per cent., and the spectacle of a direct-current motor weighing, say, 200 to 300lb. and performing the same work would be very gratifying for me to behold. The motor which I have just mentioned had no commutator or brushes of any kind, nor did it require any direct current.

"Finally, in order to refute various assertions made at random, principally in the foreign papers, I will take the liberty of calling to the attention of the critics the fact that since the discovery of the principle several types of motors have been perfected, and of entirely different characteristics, each suited for a special kind of work, so that while one may be preferable on account of its ideal simplicity another might be more efficient. It is evidently impossible to unite all imaginable advantages in one form, and it is equally unfair and unreasonable to judge all different forms according to a common standard. Which form of the existing moters is best time will show ; but even in the present state of the art we are enabled to satisfy any possible demand in practice."

The Tesla Self-Starting Alternating Motor System.

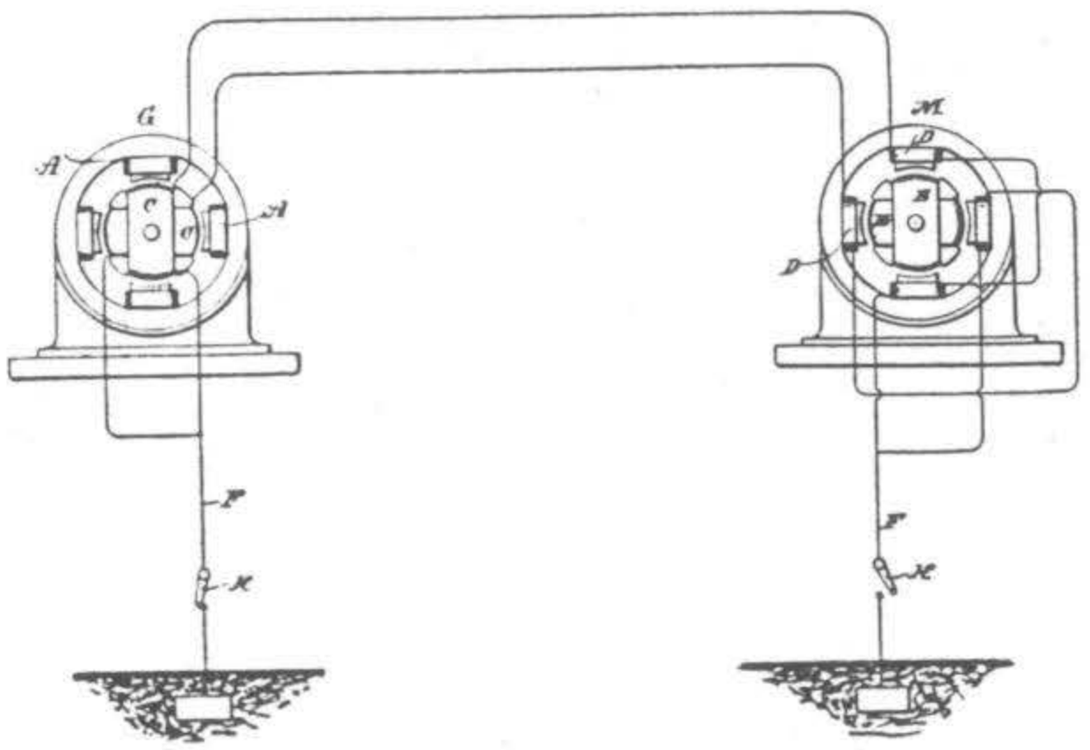
As is well known, certain forms of alternating current machines have the property, when connected in circuit with an alternating current generator, of running as a motor in synchronism therewith; but, while the alternating current will run the motor after it has attained a rate of speed synchronous with that of the generator, it will not start it; hence, where these "synchronizing motors," as they are termed, have been run, some means have been employed to bring the motors up to synchronism with the generator before the alternating current of the generator is applied to drive them. In some instances mechanical appliances have been utilized for this purpose. In others, special forms of motor have been constructed.

With the object of effecting the starting of the alternating motor and bringing it to synchronism without external aid, Mr. Nikola Tesla has devised a simple system in which he employs an earth return during the period of starting only. For this purpose he constructs a generator with two coils or sets of coils and a motor with corresponding energizing coils or sets of coils. By means of two line-wires, one terminal of each generator coil is connected to one terminal of its corresponding motor-coil while the opposite terminals of the generator-coils are joined together, and likewise those of the motor.

To start the motor an electrical connection is temporarily established between the points of connection between the coils in the generator and those in the motor, so that the system becomes an ordinary double-circuit system. When by this plan of connection the motor has attained the desired speed, the earth connection is severed, by which means the system becomes an ordinary single-circuit synchronizing system. The accompanying diagram shows the manner in which this is accomplished, *G* representing an ordinary alternating current generator having four field poles *A*; magnetized by a continuous current, and an armature wound with two coils *C* connected together in series. *M* represents an alternating-current motor with, say, four poles *D*, the coils on which are connected in pairs and the pairs connected in series. The motor-armature should have polar projections and closed coils *E*.

From the common joint or union between the two coils of both the generator and motor an earth-connection *F* is established, while the terminals or ends of the coils which they form are connected to the line-conductors.

Assuming that the motor is a synchronizing motor, or one that has the capability of running in synchronism with the generators, but not of starting, it may be started by the above-described plan by closing the ground-connection from both generator and motor. The system thus becomes one with a two-circuit generator and motor, the ground forming a common return for the currents in the two line wires. When by this arrangement of circuits the motor is brought to speed, the ground connection is broken between the generator or motor, or both, and ground switches *K K* being employed for this purpose. The motor then runs as a synchronizing motor.



TESLA SELF-STARTING ALTERNATING MOTOR.

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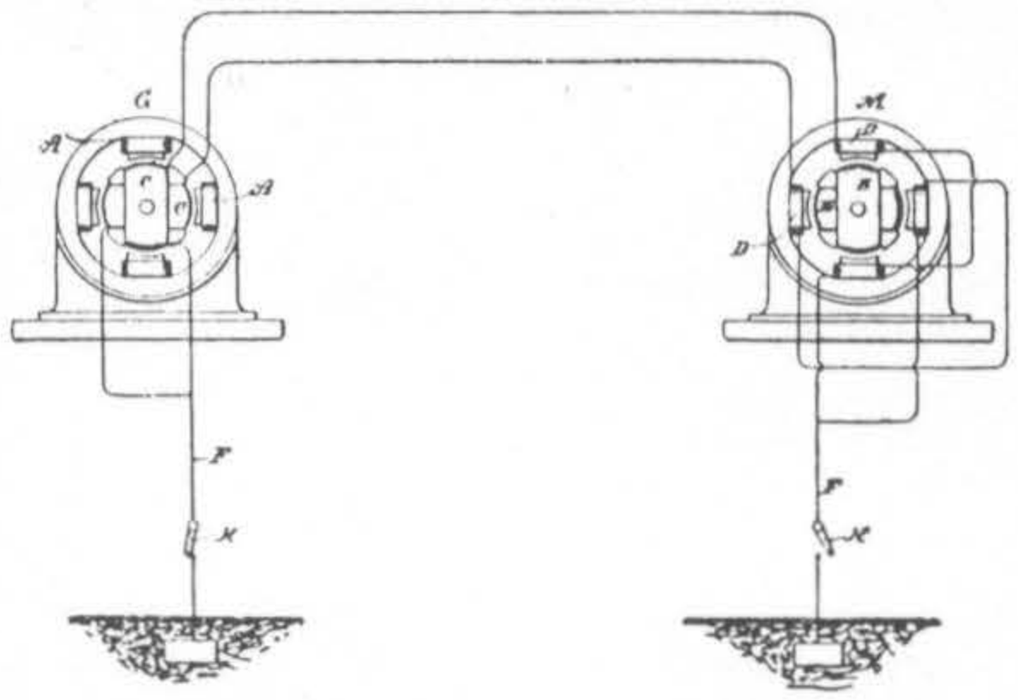

M represents an alternating-current motor with, say, four poles, D, the coils on which are connected in pairs, and the pairs connected in series. The motor armature should have polar projections and closed coils, E.

From the common joint or union between the two coils of both the generator and motor an earth connection, F, is established, while the terminals or ends of the coils which they form are connected to the line-conductors.

Assuming that the motor is a synchronising motor, or one that has the capability of running in synchronism with the generators, but not of starting, it may be started by the above-described plan by closing the ground connection from both generator and motor. The system thus becomes one with a two-circuit generator and motor, the ground forming a common return for the currents in the two-line wires. When by this arrangement of circuits the motor is brought to speed, the ground connection is broken between the generator or motor, or both, and ground switches, K K, being employed for this purpose. The motor then runs as a synchronising motor.—*Electrical World.*

THE TESLA SELF-STARTING ALTERNATING MOTOR SYSTEM.

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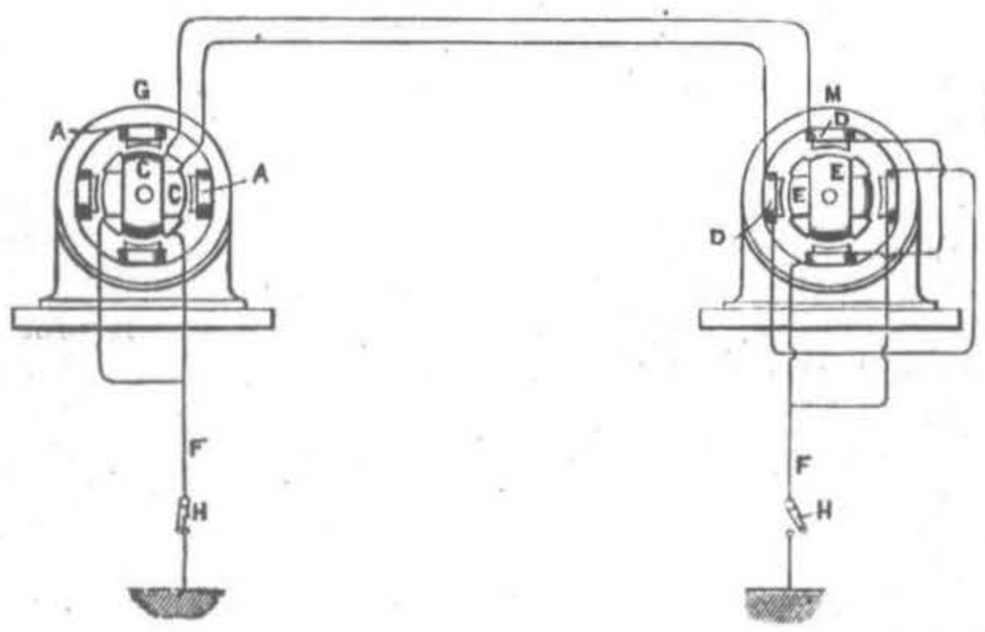

To start the motor an electrical connection is temporarily established between the points of connection, between the coils in the generator and those in the motor, so that the system becomes an ordinary double-circuit system. When by this plan of connection the motor has attained the desired speed, the earth connection is severed, by which means the system becomes an ordinary single-circuit synchronising system. The accompanying diagram from the *Electrical World* shows the manner in which this is accomplished, G representing an ordinary alternating current generator having four field poles, A, magnetised by a continuous current, and an armature wound with two coils, C, connected together in series. M represents an alternating current motor with, say, four poles, D, the coils on which are connected in pairs and the pairs connected in series. The motor armature should have polar projections and closed coils, E.

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OUR New York correspondent this week gives a brief description of a very simple method which has been devised by Mr. NIKOLA TESLA to start a synchronising motor and bring it to synchronism without external aid. Ingenious as the system is, we do not think it will meet with much favour in this country, since it involves the use of an earth return during the period of starting.

AMERICAN NOTES.

(FROM OUR OWN CORRESPONDENT.)

NEW YORK, *July* 6, 1889.

An interesting article is published this month in the *North American Review* by Prof. R. T. Ely, one of our leading political economists, on the telegraph monopoly, advocating that the telegraphs should be turned over to the Government, for the reason that they constitute a natural monopoly, and should be controlled by the State, the only alternative being a private monopoly. Prof. Ely is known as a political economist of the Socialistic order, who believes that the State should own and operate such institutions as the railroads and telegraphs, as well as the post offices, while local communities should own and operate such things as waterworks, street car lines, gas works, and electric light plants. Some few months ago he appeared in print with regard to the advantages to be derived by a community from the operation of its own electric light plant, but the mistakes in his figures were at once pointed out by many of the practical men in the business, and the arguments that Prof. Ely offered are still wanting in a solid basis of fact. With regard to the telegraph question, Prof. Ely holds that there is no middle ground between the two alternatives of a private monopoly and a public monopoly, and as private monopolies are contrary to the spirit of American and English laws and institutions, the owners of the telegraph system must be compelled to relinquish their property and to hand it over to the Government to be operated as a public monopoly. With regard to the modern idea that such institutions as railroads and telegraphs can be left in private hands but may be subjected to Government regulation, Prof. Ely remarks that this means the interference of the Government in private affairs, complicating the Government functions, and opening the flood-gates of corruption. For these reasons he desires Government monopoly of the telegraph business, and thinks it desirable that our Government should purchase existing lines rather than compete with other lines. It follows, therefore, and, in fact, Prof. Ely admits as much, that the Government must not only buy the Western Union and Postal Telegraph Companies' lines and those of pretty well a hundred railroad companies, but must buy up the American Bell Telephone Company, the District Messenger Companies, and the Ticker Services. The Government must in fact go further than this, for Prof. Ely advocates a world telegraph union "that will be another one of those bonds which unite nations and make for national peace." Thus it appears the Government must also buy the Submarine Cables. Just how much money this represents it would be hard to say, but if we figure the telegraph systems of the country at $100,000,000, and the telephone at at least as much, it will be seen that not less than $250,000,000 would be required at the outset in order to enable the Government to follow the example of European countries. Prof. Ely does not think that this addition to the number of public employés would be in any sense a national danger, but holds, on the contrary, that it would at once tend to purify politics, and that the politicians of the country, finding themselves endowed with the disposal of several thousand new offices, would at once call for a most rigid and pure Civil Service system. It is to be feared that Prof. Ely is either of a very sanguine temperament, or else knows very little of "practical politics." As to the effect on the telegraph service of passing from private to public hands, Prof. Ely is of opinion that it would be a material improvement. Most Americans who go abroad have very little to say in favour of the Government telegraphs as they find them in Europe, but Prof. Ely cites one or two personal experiences to show that things are better managed in Europe telegraphically than they are here. Just at the present minute it cannot be said that the question thus agitated again by Prof. Ely is a burning one, but as it has been vigorously discussed before in Congress it may come up again at no distant date. In the meantime it is interesting to note the opinion of one of the Republican leaders, Mr. Chauncey M. Depew, who in an oration before the Law School at Yale, last week, expressed views decidedly opposite to those advocated by Prof. Ely. "The magnitude of modern enterprises," he says, "and the close competitions of business have rendered the massing of the money of the many into one company a necessity which seems to be steadily increasing. The only other suggestion for carrying on the great affairs essential to comfortable living in our complex civilisation is for the Government to conduct them all. But experience has demonstrated that then, as in the German railways, the people get the minimum of service for the maximum of price, and an army of office-holders keeps its party in power and prevents the reform of abuses or the remedy of wrongs. We meet the question better by a compromise, which may be wisely enlarged, of State and national supervision. That the Government should watch the management and bring it to frequent accountability, that it should firmly protect the public, the stockholder and the employés, is the present, if imperfect, solution of the corporation problem." I may say that as far as my own observation extends Mr. Depew's views have public endorsement, and that it is in this direction of Governmental supervision that the question will be settled.

Everybody, of course, admits the fact that there is at the present time a marked tendency towards concentration and consolidation of allied interests, and examples are to be found in the electrical field just as readily as there are in any other. Thus, for example, we have recently seen a combination in one large corporation of all the various Edison electric light interests. We now see a movement on foot for the consolidation of the various Westinghouse interests under one general management, to be known as the Westinghouse Electric and Manufacturing Company. It is stated that a proposition to this effect was made about the middle of last month, and that it came up again for consideration at the meeting of the Westinghouse Company held on June 27. The various electrical interests that will be affected are already large, owing to the phenomenally rapid growth of the Westinghouse Company and its absorption of various systems one after the other. There seems no reason to doubt that when all the affairs are subject to one management even greater progress will be made.

One of the subordinate Westinghouse companies is the Tesla, and I am inclined to think that in securing the services of such

a bright electrician as Mr. Nikola Tesla, Mr. Westinghouse displayed more than his usual shrewdness and foresight. The Tesla motor, which was brought out last year, and was the subject of a remarkable Paper read before the American Institute of Electrical Engineers by Mr. Tesla himself, has already been illustrated and described in your columns from time to time. Mr Tesla is still working away at the general problem, and seems destined to reach remarkable and valuable results before he "gets through." It is well known that one of the difficulties in alternating-current motor work has been to secure some means for bringing the motor up to synchronism with the generator before the alternating-current from the generator can be applied to drive it. In order to effect the starting of the alternating motor, and bring it to synchronism without external aid, Mr. Tesla has now devised a simple system, in which he uses an earth return during the period of starting only, For this purpose he constructs a generator with two coils or sets of coils, and a motor with corresponding energising coils. By means of two line wires one terminal of each generator coil is connected to one terminal of its corresponding motor coil, while the opposite terminals of the generator coils are joined together, and those of the motor also. For starting the motor an electrical circuit is temporarily established between the points of connection of the coils in the generator and motor, so that the system becomes an ordinary double-circuit one. When by this plan the motor has attained the desired speed, the earth connection is severed, by which means the system becomes an ordinary single-circuit synchronising one. I may add that it is reported from Pittsburg, where naturally questions connected with alternating-current motors have unusual interest, that it is proposed to have an alternating motor car in operation this fall, and that great advantages will be gained by dispensing with the commutator and its attendant troubles.

An interesting Paper was read last week at the closing meeting of the season of the American Institute of Electrical Engineers, by Mr. Leo Daft, with regard to work that he has been doing on the New York elevated roads, and some of the results that he has obtained with regard to the question of fuel consumption. So much has been said and printed during the last three or four years with regard to the Daft system of electric propulsion, that Mr. Daft wisely took it for granted that his hearers would be familiar with the details of the system, and he did not therefore enter upon them except to mention that he still adhered, as the result of his work, to the opinion that it would be better to run the train by a single locomotive, as on steam roads, than to adopt the practice of putting one or two motors under each car and dispensing with the locomotive altogether. Mr. Daft also was at some pains to emphasise his belief in the superior tractive effect obtained from the passage of the current between the wheel of the electric locomotive and the track, and he holds that the increased traction is equal to at least 30 per cent., and he has often seen as high as 35 per cent. increase. He says, moreover, that the tractive efficiency of electric locomotives is higher than that of ordinary locomotives for mechanical reasons. With regard to the question of coal consumption, into which Mr. Daft entered very fully, illustrating the points made by numerous diagrams, it would appear that a marked increase of service would be obtained by the use of electric motors, with a coal consumption of not more than one-half that of the steam locomotives now in service on the elevated roads.

Turning from the important question of the successful operation of the elevated roads by electricity, we find that great strides are now being made in the improvement of apparatus intended for the electrical operation of the street railroad. The Sprague Electric Company have just published illustrations and descriptions of their new motor for street railway work.* It certainly appears to be about as compact, solid, and effective a piece of machinery as it is possible to devise at this stage of the art, and one from which any amount of good work may be confidently expected. These machines are already in use on the Sprague roads at Cincinnati, Cleveland, Atlantic City, and elsewhere, and are doing excellent work.

[* An illustrated description of this new motor will be found in another column.—Ed. *E.*]

The electric light companies of this city are now filing their bids for street work. About a month ago these bids were first sent in, but Mayor Grant kicked, with his usual affability, because the companies desired to charge more for the service in the subway districts than they did for that in districts where they could operate by wires and poles. The new bids average from 25 to 30 cents for lamps of 2,000 candle-power in overhead districts, and from 45 to 70 cents for lamps in subway districts. It remains to be seen whether these revised bids will meet with any more favour than the last. It will be noted that the companies remain firm in their intention to collect more money for lamps fed through the subways, and in view of the high charge made for the use of the subways the rate offered by the local companies is not at all out of the way.

It is interesting to note that a general order has just been issued by the Army Department to the effect that the American Morse code will hereafter be used by the army for all purposes of signalling, whether visual or acoustic. The use of the English Morse, or Continental code, is to be discontinued. This action, it appears, is taken on the recommendation of the chief signalling officer, who desires to simplify signalling instruction, and to be able to avail himself readily in war time for signalling of civilian telegraphers. While it is admitted that fewer errors are likely to occur in the use of the English Morse, it is considered that that system is slower than the American, and that its continued use, moreover, would involve the employment of specially-trained experts, whose numbers could not be increased in a hurry if desired.

Circuits for Tesla Alternating Motors.

M. Leblanc, a French electrician, makes an ingenious suggestion in the London *Electrician* for the suppression of the double set of leads of the Tesla motor. He says that it is only necessary to take a transformer and equilibrate the self-induction of its secondary circuit (including in this, of course, the external circuit) by interposing a suitable condenser. The current in this circuit will then be displaced in phase by precisely one-quarter wave length over that of the primary.

The primary coil of the transformer is placed in circuit with one set of the Tesla field coils, the ends of this circuit being connected directly to the two main leads; the secondary is connected with the other field circuit, a suitable condenser being interposed between secondary and set of field coils, and the ends of the circuit are connected together.

We can also, if desired, go a step further and balance the self-induction of the primary also, so as to suppress the apparent increase of resistance of the system with respect to the generator.

Another highly novel suggestion is as follows:

Having an alternating current of given period, to obtain a current of any other required period.

To do this, take a Gramme ring and divide the coils into three circuits *a*, *b*, *c*, in such a way that every alternate coil all round the ring is in circuit *c*, while the remaining coils in each alternate quadrant belong to circuits *a* and *b* respectively. In fact, so far as *a* and *b* are concerned, the circuits are placed exactly as in the Tesla motor, while a coil of circuit *c* intervenes between every pair of coils all round. Through circuits *a* and *b* two independent alternating currents are sent, which differ in phase by 90 degrees again as in the Tesla motor. The coils of circuit *c* are connected to the bars of a Gramme commutator, and upon this, according to M. Leblanc's solution, a pair of brushes is caused to rotate. Now, while the brushes are at rest, the coils *c* are the seat of an induced E. M. F. equal in period and midway in phase to that of the currents in *a* and *b;* but now, if the brushes rotate upon the commutator, it is easy to see that the period may be eithe diminished or increased according to the relative velocity of the brushes as compared with that of the virtual rotation of the poles in the ring caused by the current *a* and *b*.

ALTERNATING CURRENT MOTORS: THE EVOLUTION OF A NEW TYPE.*

BY LIEUT. F. JARVIS PATTEN.

On giving our secretary the title of this paper it was my purpose to treat the subject in a broader light, and to show the progressive steps in a series of experiments which led eventually to the type of machine that I shall bring to your notice this evening. The recent and urgent claims of other work have rendered such a treatment impossible at the present, and I shall limit the paper to a description of a new alternating-current motor, one form of which is shown in the accompanying drawings.

The place that the alternating-current electric motor is destined to fill in the industrial arts is familiar to you all, and the various ways known to the scientific world by which such machines may be rendered operative have been ably considered and elaborately discussed in the institute papers of the past two years by Prof. Thomson, Dr. Duncan, and Mr. Tesla. We are thus all more or less acquainted with the prominent difficulties of the problem.

My experience in common with that of my predecessors teaches that the alternating-current motor has a strong and persistent disposition to stand still, and when persuaded to motion it is apt to be a sort of "go as you please" machine and asserts its inherent right to turn in either direction indifferently, direction of rotation in some cases being purely a matter of chance. I shall not have much to say about efficiency, as my experiments with large machines are not sufficiently advanced to furnish any reliable data, but I will endeavour to give a general solution of the problem designed to meet the following conditions of practice:

1. A machine that will start itself independently of the speed of the generator or number of alternations of current per unit of time.

2. A machine that has but one direction of rotation and cannot reverse under any conditions of current alternation.

3. A machine that is not necessarily synchronous with the generator, revolution for revolution.

4. A machine in which reversals of current direction do not produce corresponding reversals of magnetism in any iron part when the machine is in motion at its normal speed and maximum efficiency.

5. A machine of simple form, having an ordinary continuous wound armature revolving in a single or two-pole field.

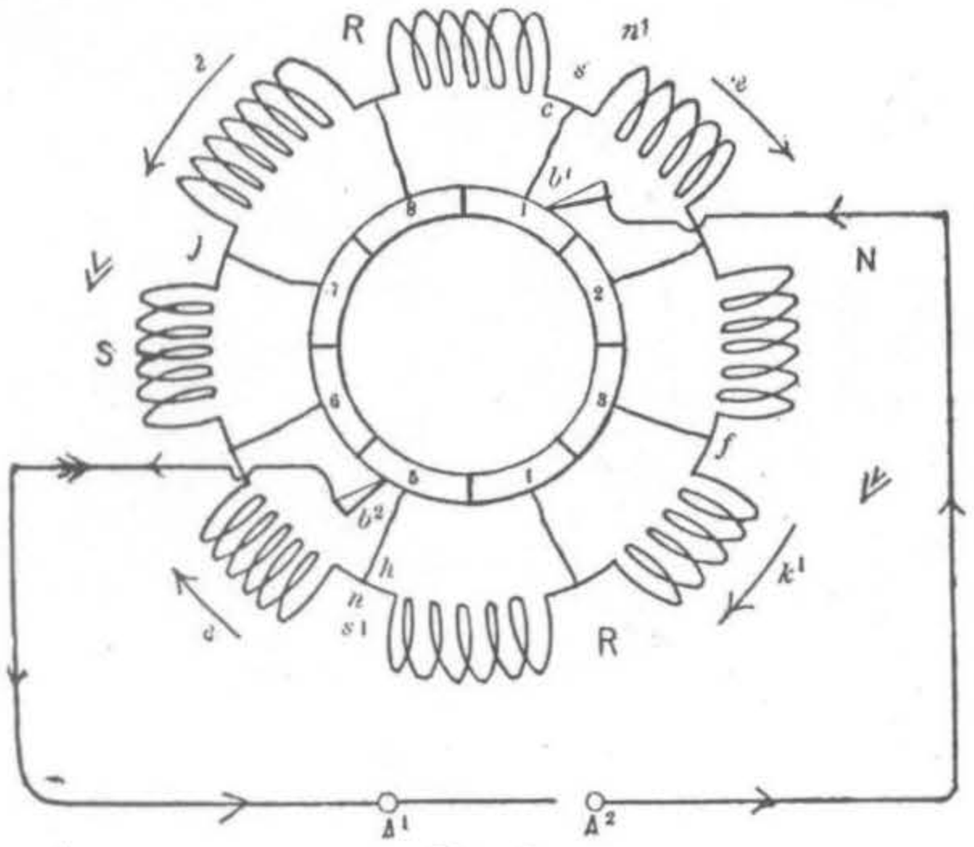

FIG. 1.

Referring, now, to the figures which are simply diagrams of the circuits and operative parts, we have in Fig. 1 an ordinary closed circuit armature shown as a Gramme ring merely for convenience of illustration, the points of the winding intermediate between the eight coils being connected in the usual way to the eight segments or bars of an ordinary Gramme collector, and it may be well in passing to note here the functions of this collector. It is not a commutator in the strict sense of that term, as it does not rectify or redirect reverse or opposed currents. If the brushes, b^1 and b^2, were held upon the outside wire of the ring, the same results would follow, and the Gramme collector, properly so called, singly transfers the brush contact from point to point of the continuous ring winding. If a source of direct current be interposed between the terminals, A^1 and A^2, current will flow continuously from brush b^1 to b^2 downward through the right and left-hand halves of the ring in the direction of the arrows k^1 and k^2, making, say, a south pole in the ring at the upper point, S, and a north pole at the lower point, n. With a continuous current these poles would be continuously maintained and placed in the magnetic field indicated by N and S the armature would continuously revolve in the direction indicated by

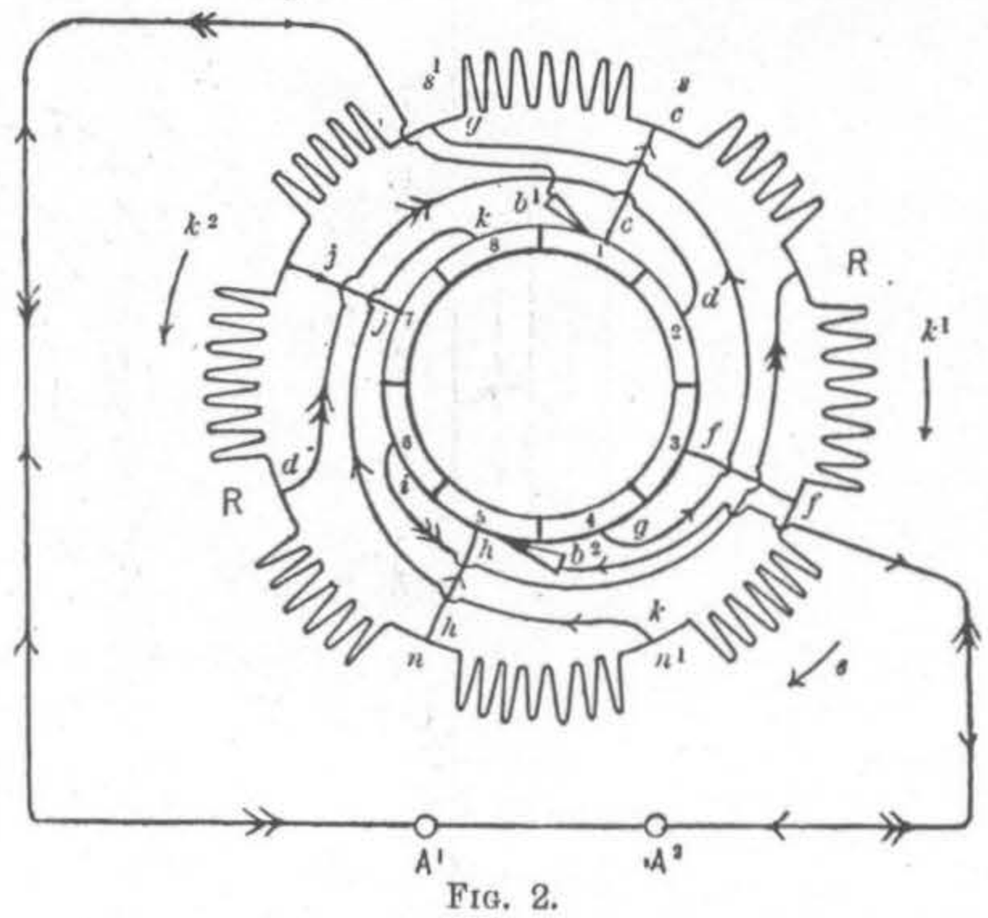

FIG. 2.

the arrows E E. If now a source of alternating current be inserted between the terminals, A^1 and A^2, the polarities of the ring would be reversed at each successive alternation of current, and if a direct impulse indicated by the single arrows in the external circuit produced the poles n and s in the ring, the reverse impulse indicated by the double arrows would produce the opposite polarities, n^1 and s^1, at the same points, and the tendency to motion would be reversed if the fields remained the same, but it will be noted the motion would be in the same direction still if the fields were also reversed by the same reversal of current. If, however, the fields were maintained constant as

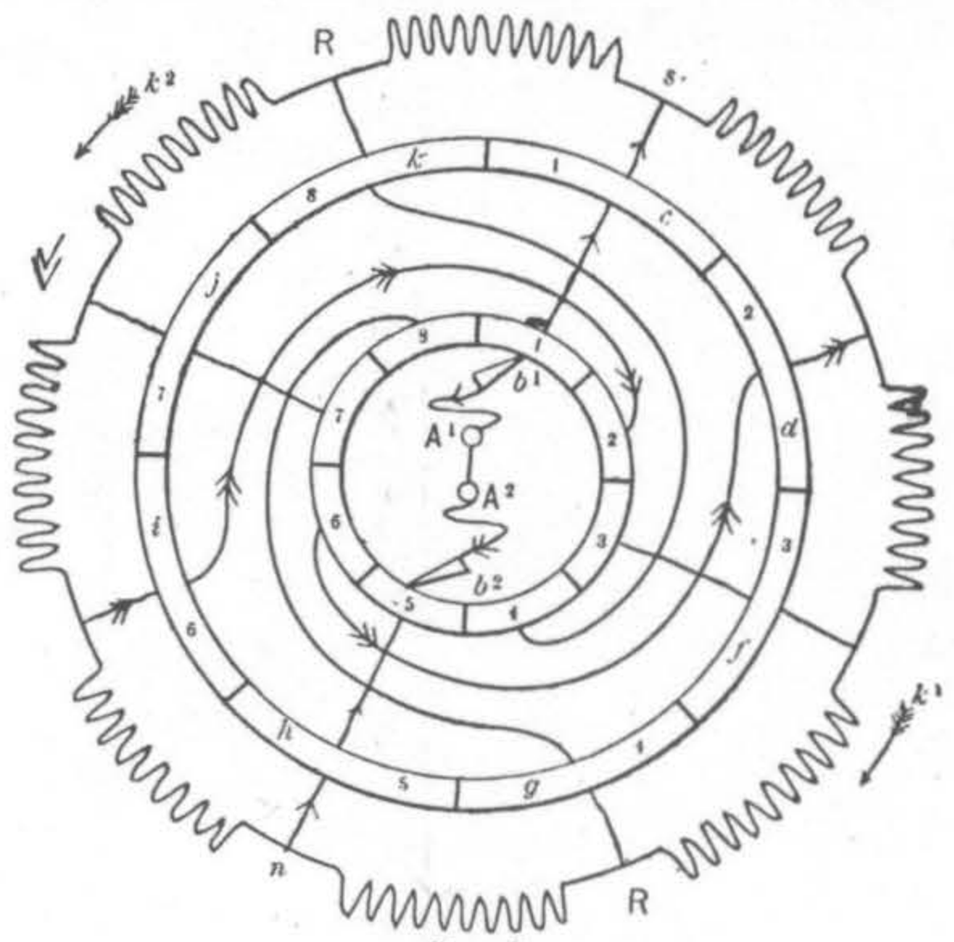

FIG. 3.

indicated by the large letters N and S, and some device could be contrived by which at each reversal of the alternating current, the brushes b^1 and b^2 could be made to change position, either mechanically or otherwise, then with an alternating current a constant polarity, s and n, would be maintained at the upper and lower points of the ring—for then a direct impulse, starting from A^1 to the right, would enter the ring through the brush b^1, flowing down both sides in the direction of the arrows k^1 and k^2, out through brush b^2, and back to the source at A^1. The reverse impulse indicated by the double arrows would start from A^1 to the left, going to brush b^2; and if we now

* Paper read before the American Institute of Electrical Engineers.

suppose this to have changed places with the brush b^1, the reverse current would then enter the ring at s, and flowing down both sides in the direction of the arrows k^1 and k^2, would leave through n and the brush b^1, and so back to the source a^2, maintaining the polarity of the ring the same as before. If the brushes could be thus changed at each alternation, the polarity of the ring would be maintained constant with an alternating current. While, however, it is quite impracticable to thus cause the brushes to change position mechanically at each reversal of current, it is perfectly feasible to produce the same effect without the mechanical change. The means of accomplishing this result are indicated in Fig. 2, which is identical with Fig 1, with a single exception. There are eight coils, as before, and eight bars in the collector; the odd numbered bars, 1, 3, 5, and 7, are connected to the same points of the ring as before c, f, h, and j, but the even numbered bars, 2, 4, 6, 8, are connected respectively to points of the ring diametrically opposite them, bar 2 to the point d, bar 4 to the point g, and so on, each even numbered bar to a correspondingly opposite point of the winding. If now a source of alternating current be interposed between the terminals, A^1 and A^2, and we make the single supposition that the ring shall turn through an arc of the circumference equal to that covered by one bar of the collector during each alternation of current, we shall still maintain a constant polarity at the upper and lower points of the ring without causing the brushes to change position mechanically.

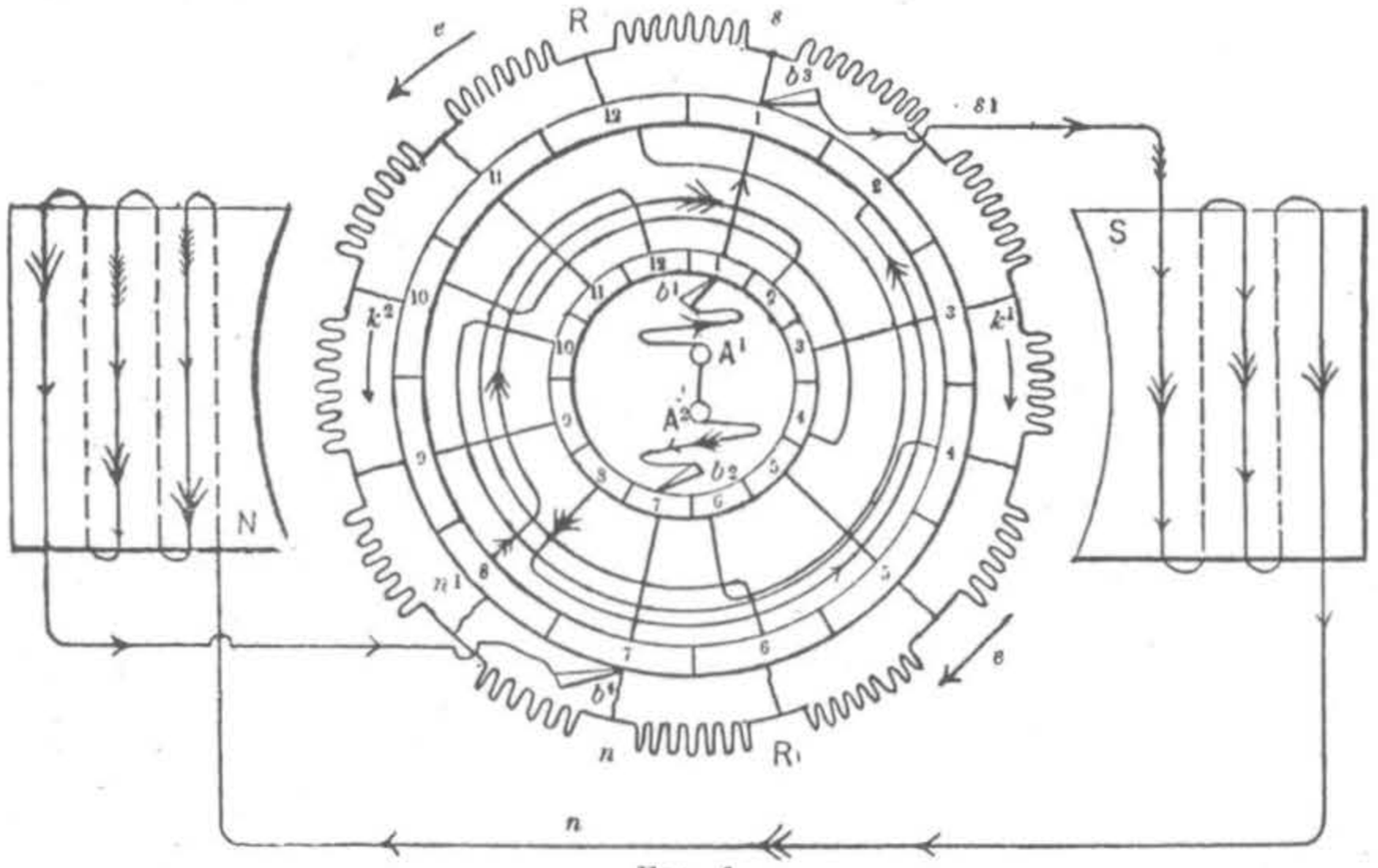

FIG. 4.

Thus a positive impulse starting from A^1 to the left and indicated by single arrows enters the ring at b^1, flows down both sides to n, producing the ring polarities s and n, out brush b^2 and back to source at A^2. The reverse impulse being in the opposite direction will start from A^2 to the right, go to brush b^2, which we will now suppose bearing on segment 4 of the collector, whence it will go by the inverse connection to the opposite point, B^1, of the ring, then down both sides in the same direction as before to the point n^1, thence back to the opposite segment 8, out brush b^1, now bearing on this segment, and back to source at A^1.

The reverse currents, therefore, under the assumed conditions are caused to maintain a constant polarity in the ring, so that in a constant field its tendency to motion would always be in the same direction with an alternating current in the armature. It will be further noted that the alternating current is not redirected or commuted in the strict sense of the word, and we may enunciate the fundamental principle which underlies the construction of this type of machine as follows:

The poles of any closed circuit may be maintained constant with an alternating current by causing opposite impulses to traverse the circuit in opposite directions. The direct and inverse connections, shown in Fig. 2, have precisely this effect, when, as supposed, a single bar of the collector passes under the brushes at each reversal of current. The connections $c\ c$, $d\ d$, $f\ f$, etc. in Fig. 2 may have any form, and other bars may be interposed between their extremities without affecting in any way their functions as connectors. This step is shown, in Fig. 3, where another collector bar, $1c$ $2d$, $3f$, etc., is inserted in each of the connections $c\ c$, $d\ d$, etc., of Fig. 3, thus making another collector shown outside the first to avoid confusion of the drawing, while, for the same reason, the source of alternating current, A^1 A^2, is placed inside the inner ring. As the polarities, s and n, of the ring are maintained constant, as previously described, with an alternating current, and current is constant in direction from s downward

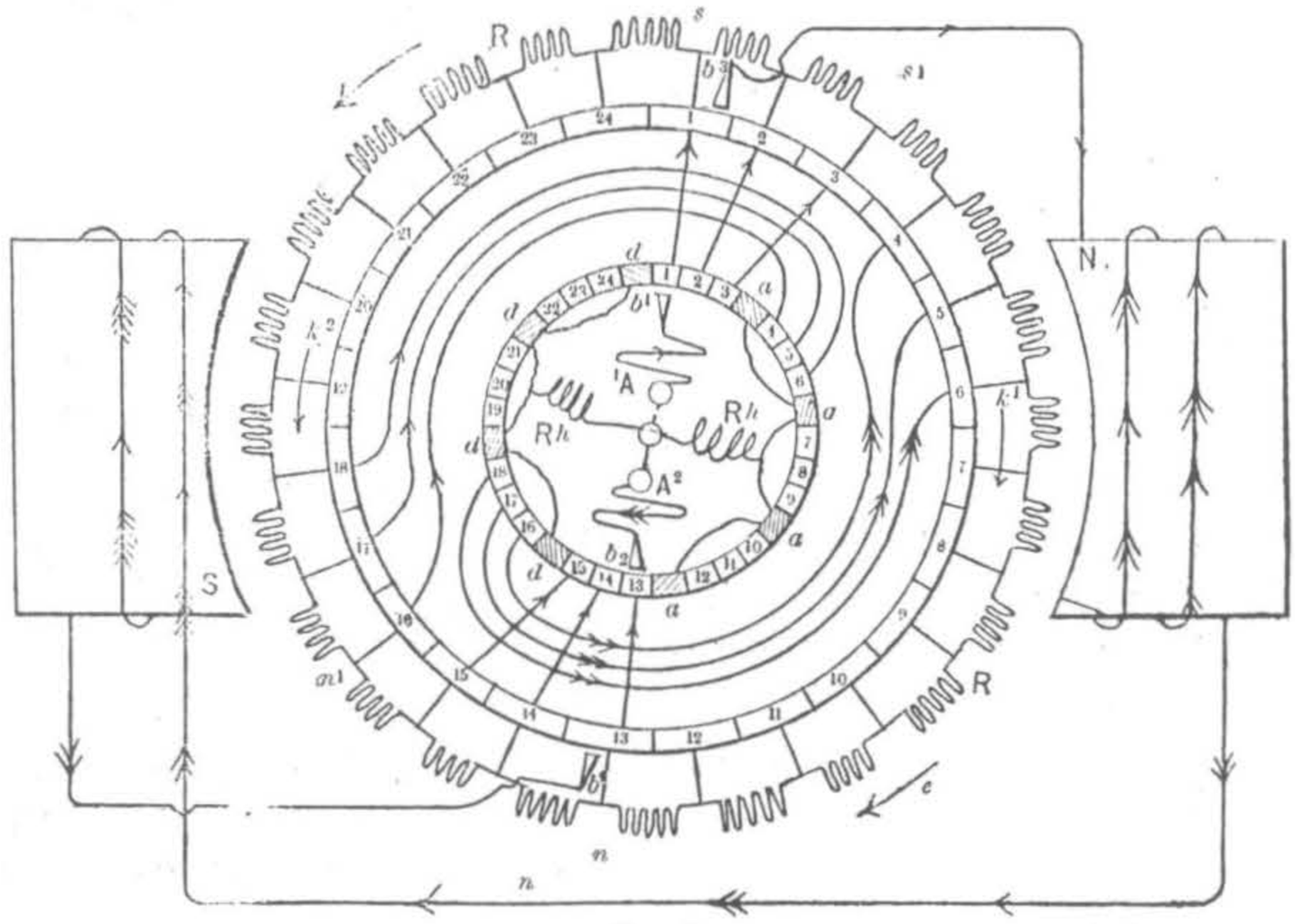

FIG. 5.

through the right and left halves of the rings to n, so must necessarily any current be constant in direction which is led from brushes through any shunt circuit connected to the segments, 1c and 5h, of the outer collector; a field circuit of constant direction may therefore be shunted from this outside collector. This is shown in Fig. 4, in which 12 coils are shown in the ring, and 12 bars in each collector connected alternately direct and inverse, as before. Tracing now two opposite impulses of current, we have the first indicated by the single arrows from source A^1 to segment 1 of the inner collector, thence to segment 1 of outer collector, where the current divides, part going down the right and left-hand halves of the ring to n, and part out brush b^3 through the field circuit, making the poles N and S back to brush b^4, segment 7, of outer, and segment 7 of inner collector to the terminal A^2 of source. If the armature be supposed now to turn through the space covered by one collector bar, the reverse impulse can be traced as follows: Starting at A^2 in the opposite direction to brush b^2, now bearing on segment 8 of the inner collector, thence through the reverse connection to segment 2 of the outer collector, now under brush b^3, where the current divides, going part as before down the right and left halves of the ring, making a south pole at s^1 and a north pole at n^1 as before, and the other part out of brush b^3, through the field circuit in the same direction as before, back to brush b^4, now on segment 8 of the outer ring, thence through the reverse connection back to segment 2 of the inner ring, now in bearing with brush b^1, and so returning to the source at A^1. Thus the two impulses of opposite direction have been made to traverse both armature and field circuits in the same direction. We have, therefore, with an alternating current constant armature polarity and constant field polarity, and therefore a constant tendency to motion in the same direction. Not only this, but the further condition is fulfilled that there are no reversals of magnetism in any iron part so long as one bar in the machine, as shown in Fig. 4, passes under the brushes at each alternation of current. It remains to show how this is brought about. Referring again to Fig. 4, let it be supposed that the first impulse of current did not cause the armature to turn through the arc of the circumference subtended by one segment, but all the branches still bore on the same segments as shown in the figure and the reversals of current continued. By tracing the circuits it will be seen that each reversal of current reverses the polarity of both field and armature, and with either direction of current or rapid reversals there will be a constant tendency to motion always exerted in the same direction. The machine under these conditions becomes therefore simply a direct-current machine on an alternating-current circuit, with a constant tendency to start in one direction. Assuming the machine therefore self-starting, it will continually gain in speed until the condition is fulfilled of one segment passing the brushes at each alternation, for it then becomes in the broad sense a synchronous alternating motor, the current then produces no reversals of magnetism, and there is a true alternating current in the armature circuit, producing, however, no reversal of armature polarity; and a current of constant direction in the field. Under these conditions the motor is self-regulating, moving at a constant speed and with a maximum rotary effort.

It is not, however, essential that one bar should pass the brush at each alternation, as any number may be caused to do this depending upon the speed required and the number of coils upon the armature. This is illustrated in Fig. 5, where the complete machine is shown. There are 24 coils in the armature, 24 bars in the outside collector, and 32 bars in the inside one, this latter being composed of 24 connecting and eight insulating bars. The connecting bars of the inner ring are numbered to correspond with those of the outer ring around to the right from one to 24—the insulating bars, drawn shaded, separate the others into groups of three. In this machine three segments 1, 2, 3, in the outer ring are connected direct to the corresponding segments 1, 2, 3 of the inner ring, likewise the opposite three, 13, 14, 15, of one ring are connected direct to 13, 14, 15 of the other. The next group of three is connected inversely, 4, 5, 6 of the outer ring to the diametrically opposite bars 16, 17 and 18 of the inner ring, and the corresponding opposite group, 16, 17, 18, of the outer ring is likewise connected inversely to the diametrically opposite group 4, 5 and 6, of the inner ring. The remaining segments are connected in the same manner, but the connections are omitted to avoid confusion in the drawing. The operation of the machine is evidently the same as that shown in Fig. 4, except that the required conditions are fulfilled in this instance when three bars of the collector pass under the ring at each alternation of current, and as there are 24 segments, arranged in groups of three, the machine at its normal speed would make one revolution for every eight alternations of current, and connected in a circuit supplied with 16,000 reversals per minute its normal speed would be $\frac{16000}{8} = 2{,}000$ per minute, and with 48 segments arranged in groups of three, its speed would be 1,000 per minute. The blank segments insulating the groups of the inner ring are connected to the extremities of a rheostat, Rh. Rh., which is enclosed inside the commutator, and is designed to offer a path for the alternating current such as there may be, and prevent its absolute rupture at the period of change from one group of segments to the next; they also serve an important purpose in preventing a dangerous short circuit, which would be occasioned by the inner brush bridging two groups of segments oppositely connected.

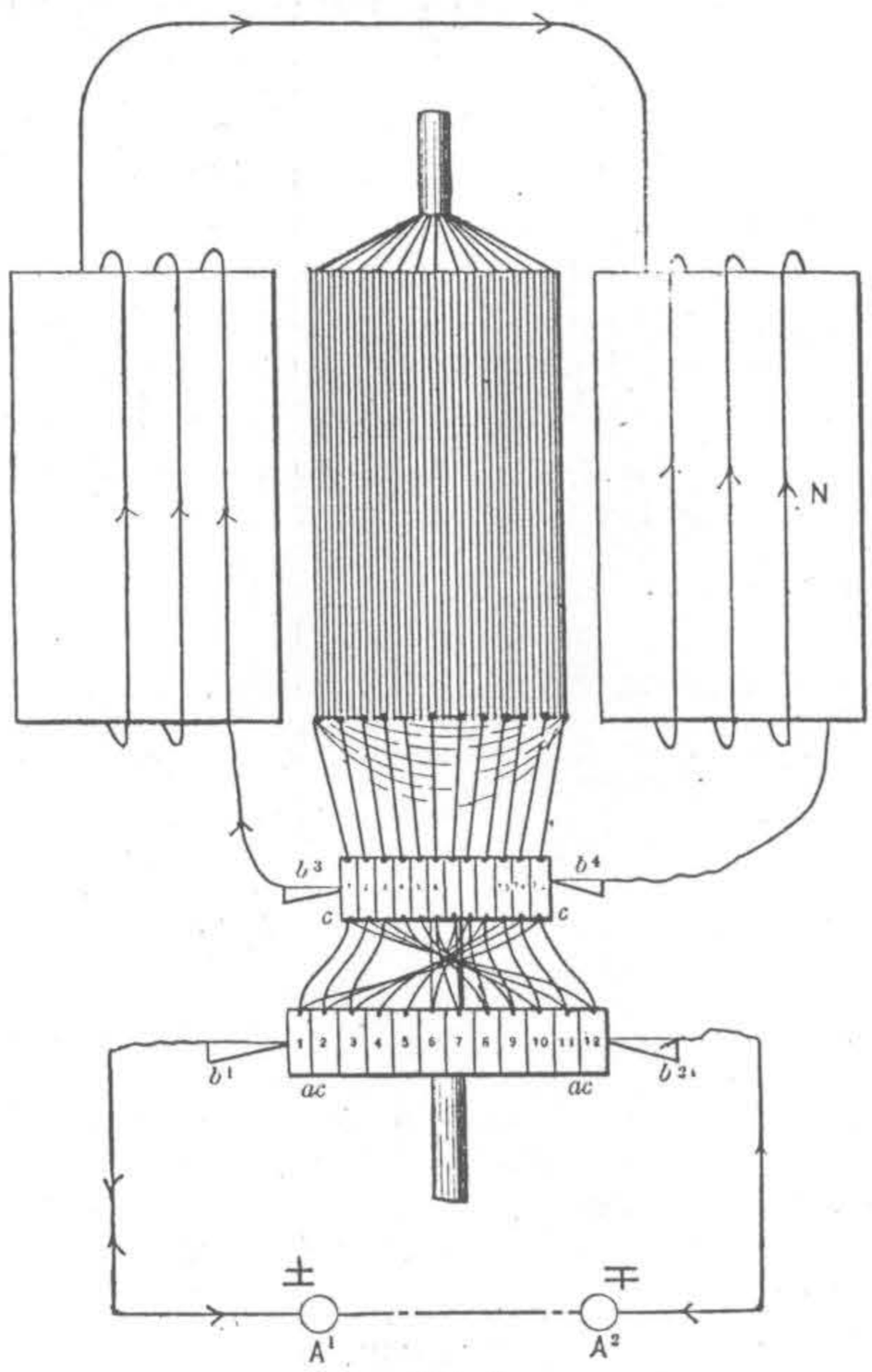

FIG. 6.

It follows, as a matter of course, that as the machine starts as a direct-current motor connected in an alternating circuit, rapid reversals of magnetism will at first be produced in all the iron cores, and these should be made of laminated iron to prevent undue loss by heating at the period of starting. The machine, in fact, starts as a direct-current motor, and automatically changes to a sort of synchronously alternating motor. When it gains its normal speed at this point it is self-regulating, and its capacity of doing work is a maximum.

Fig. 6 shows a plan of the machine as constructed; it consists simply of an ordinary closed circuit armature in a single field; c, c is the ordinary collector, really a part of the armature circuit, from which the brushes, b^3, b^4, take a current of constant direction to the field-shunt; $a\ c$, $a\ c$ is the reversely connected commutator and the brushes, b^1, b^2, bearing upon this commutator are connected to the terminals of the alternating-current circuit.

North American Review November 1889

THE DANGERS OF ELECTRIC LIGHTING.

BY THOMAS A. EDISON.

So MUCH has of late been said and written upon the subject of high-tension electric currents and their probable or possible danger to human life, and so many different opinions have been advanced by men whose positions serve to surround their utterances with an atmosphere of knowledge of the matter under discussion, that the mind of an unscientific public has been unable to come to any definite conclusion upon the basis of "expert" testimony. It is most unfortunate that a practical demonstration in support of the real facts of the case could not have been made in a less tragic manner than was witnessed a few days ago in New York by several thousand people; and yet if the martyrdom of this poor victim results in the application of stringent measures for the protection of life in the future, if the lesson taught is appreciated to the full extent of its fatal meaning, the sacrifice will not have been made in vain. With the increase of electric lighting (which to-day is used only to a very limited extent as compared with its inevitable future use) and the multiplication of wires, these dangers which exist now in a thousand different parts of the city will be manifolded many times. In fact, the opportunities for repetitions of the accident referred to above will be practically unlimited.

I can write upon this subject only as one convinced. I cannot discuss it otherwise. The public would scarcely be interested in the details leading up to the position taken by myself and the conclusions to which I have come, for the reason that it would involve a mass of matter such as they have been attempting to digest during several months past; and, instead of explaining, I might succeed only in adding to the present confusion of popular ideas. But I may say that I have not failed to seek practical demonstration in support of such facts as have been developed,

and I have taken life—not human life—in the belief and full consciousness that the end justified the means.

The currents used for electric lighting at the present time may generally be divided into four classes :

First—The low-tension continuous current, with a pressure not exceeding 200 volts, used for incandescent lighting.

Second—The high tension continuous current, with a pressure of 2,000 volts and over.

Third—The high-tension semi-continuous current, with a pressure of 2,000 volts and over.

Fourth—The alternating current, with a pressure from 1,000 to 3,000 volts and over.

The first is harmless, and can be passed through the human body without producing uncomfortable sensations. The second is dangerous to life. Momentary contact with a conductor of the third results in paralysis or death, as has frequently occurred ; and the passage of the fourth, or alternating, current through any living body means instantaneous death.

These are simple facts which cannot be disproved. There is a record of nearly one hundred deaths, which furnishes an unanswerable argument in support of these statements. Discussion and controversy may serve the questionable purpose of delaying popular faith in them, but they cannot change them ; and the sooner they are accepted and acted upon the less liability will there be of a recurrence of the late horror, which is still fresh in the minds of all those who witnessed or read of it.

It has often been asked why the number of accidents of this nature is larger in the city of New York than in any other city. The reason is that New York has a greater number of wires to the square mile than any other city in the United States. The percentage of deaths in other places will reach that of New York when wires are strung in like numbers ; but if electric lighting under its present conditions extends in the latter city proportionately, its death-rate will have been greatly multiplied by the time other cities reach its present high percentage.

Many suggestions have been made as to the best way in which to remedy the existing evil, and the popular cry seems to be, "Put the wires underground." But, instead of diminishing, this will increase the danger to life and property. There is no known insulation which will confine these high-tension currents for more

than a limited period, and when they are placed beneath the ground, with the present system of conduits, the result will be a series of earth-contacts, the fusion of wires, and the formation of powerful electric arcs, which will extend to other metallic conductors in the same conduit, and a whole mass of wires made to receive this dangerous current and convey it into houses, offices, stores, etc. It is thus evident that the dangers of such circuits are not confined to the wires which convey the high-tension currents, but other wires conducting harmless currents are liable to be rendered as deadly in effect as the former. It is evident, also, that a single wire carrying a current at high pressure would be a constant menace to the safety of all other wires in the same conduit. Even though these dangerous wires be placed in separate tubes in the same conduit with other tubes, the risk is not diminished.

Several instances are on record, and one I have particularly in mind, showing the possibility of serious accident through the crossing of wires. Near the corner of William and Wall Streets, New York, the underground conductors of the Edison Illuminating Company became crossed, and the current which was passing through them at a pressure of only one hundred and ten volts melted not only the wires, but several feet of iron tubing in which they were incased, and reduced the paving-stones within a radius of three or four feet to a molten mass. This system is so arranged that consumers are not affected by such accidents as this. They may and do mean expense to the company, but the public are entirely free from any possibility of danger. The crossing of wires in this way means the concentration of several hundred horse-power of energy in a small space. What would have been the effect of such a cross as I have described had the pressure been two thousand instead of one hundred and ten volts? and what also might be the effect were it to occur in a conduit in close proximity to hundreds of telephone wires and those of other electric-lighting systems? The risk, too, is greatly increased by the fact that consumers who are supplied with currents from a low-tension system are accustomed to handle their electrical appliances freely, knowing them to be harmless. If these are to be rendered at any moment dangerous to life, the result will be appalling. I say nothing of the injustice to vendors of harmless supplies of electricity.

So far, the deaths which have occurred from this source have

been chiefly confined to employees of electric-lighting and telegraph companies—men whose duties have required them to work in close proximity to the conductors of these death-dealing currents. It is true that a number of accidents, many of them attended with fatal results, have occurred to pedestrians on the streets of New York and other cities through the medium of fallen wires; but the risk incurred by the general public with the present system is really less than it would be if these dangerous conductors were placed in closer proximity to the ground. As the earth is approached the danger is multiplied. The connection and crossing of two wires by a line of moisture or liquid contact are just as effective as the contact of one wire with another when overhead.

That this error of judgment is not confined to the public, but is shared in by the officials of the city of New York, is made apparent by a resolution of the Mayor offered at a meeting of the Board of Electrical Control on Monday, October 14, and which is reported in the following form:

"That the numerous deaths caused by the electric light and power wires within the last thirty days, and the shocking manner in which they have occurred, furnish ample and sufficient proof that such wires are not being placed underground with a speed sufficient to insure the safety of the lives of the people of this city," etc., etc.

The logical inference here is that the lives of the people will be safe as soon as the wires have been placed underground. If a nitro-glycerine factory were being operated in the city of New York and the people desired to remove the danger, no one would suggest putting it underground. When it became necessary for the protection of employees and of the public to regulate boiler-pressures in the city, the authorities proceeded on lines entirely different from those which are being followed in connection with electrical pressures; and yet the cases are parallel, and the course of reasoning which resulted in a perfect system for the limitation of steam-pressure and the periodical inspection of boilers should be retraced, and the principle applied to secure safety from a pressure which, uncontrolled as at present, is far more dangerous than the former was before steps were taken to render it harmless.

The insulation of a wire carrying a high-tension current in the most perfect manner known may insure temporary safety; but time is bound to develop defects as the result of the action of the current upon the insulating material, of a change in the molecular structure of the material itself, and for other reasons. The

pulsations or vibrations in an electric conductor cause corresponding vibrations in the insulation. So powerful is this effect that the insulation gives off a sound corresponding to the oscillation of the current. So long as the insulation retains its original elasticity, the current is confined ; but the influence of the air, or of gas and other agents, tends to change the elasticity, and the billions of vibrations to which it has been subjected finally render it very susceptible of being pierced by a spark of static electricity. Thus an avenue for the ingress of moisture is formed, not only in one spot, but in many, through which the current may be communicated to any conductor of electricity near enough to make physical contact, or a circuit may be completed between the two by a line of moisture or the formation of an electric arc, with its subsequent destructive action.

The numerous accidents which have occurred in the city of New York during the past year show to a very large extent the operation of time upon the insulating material which surrounds these wires. When first erected, the current was to a certain extent successfully confined ; but the air is doing its work, abrasions are more easily made, and, without the adoption of genuine methods of control, "accidents" may be looked for in larger numbers as time goes on, due not only to deterioration of insulation, but to the multiplying of electric circuits to supply the popular demand for electric light.

The public may rest absolutely assured that safety will not be secured by burying these wires. The condensation of moisture, the ingress of water, the dissolving influence of coal gas and air-oxidation upon the various insulating compounds will result only in the transfer of deaths to man-holes, houses, stores, and offices, through the agency of the telephone, the low-pressure systems, and the apparatus of the high-tension current itself.

I have no intention, and I am sure none will accuse me, of being an alarmist. When the possibilities of the future are viewed in the light of recent developments, it must be apparent to every one that the time has come when those in authority should adopt proper and adequate measures for the protection of life and property, and my familiarity with the subject enables me to see very clearly the only true remedy which can be applied—namely, the regulation of electrical pressures. Once these pressures are reduced to a point which is harmless, the public may re-

tire in security and leave electricians to discuss the merits or demerits of various methods of insulating, the defects of which will only concern those interested in the commerce of electricity.

There is no plea which will justify the use of high-tension and alternating currents, either in a scientific or a commercial sense. They are employed solely to reduce investment in copper wire and real estate. For instance, in arc-lighting it is customary to put forty lamps on each circuit; each lamp requires a pressure of fifty volts; therefore the total pressure on the circuit is two thousand volts. Now, if, instead of using only one wire for all these lamps, four circuits of ten lamps each were to be established, the pressure on each wire would be only five hundred volts. The weight of copper necessary for these four circuits of ten lamps each would be two and a half times greater than for one circuit of forty lamps—a question, as I have said, simply of investment.

The alternating current under high pressure and direct-current high-pressure systems are also employed, as I have intimated, to save investment in real estate as well as copper. If a certain district is to be supplied with electric light, the natural point from which the current should be distributed is the centre, with wires radiating toward the circumference of the circle of supply; and if, instead of including in any one of these districts an area so large that resort must be had to high pressure in order to reach its limits, the distributing power of a single station be confined to a capacity consistent with safety, and other centres sought from which to furnish current to other areas, the necessity for high electrical pressure vanishes. But real estate in such centres as these is expensive, and the promoters of electric-lighting enterprises which spring into existence with the growth and stability of the mushroom, cannot afford to consider permanency, the security of the public, the requirements of small consumers, or any such questions, which would incidentally involve the investment of larger sums of money; but, seeking the outskirts of a district, where land is cheap, or some abandoned building available for sheltering a few dynamo machines, they run small wires to the area of supply, enormous pressure being necessary to force the current through these small conductors over such long distances.

In the last issue of *The Electrical World*, page 254, is recorded a series of experiments conducted by M. d'Arsonval, a member of the French Academy of Sciences, showing "the effects of

continuous and alternating currents on animals." He says: "A living being is, above all, sensible to a variable state of the current, from which it follows that at a mean equal pressure alternating currents are more dangerous than continuous currents"; and "with a battery of four hundred and twenty volts (continuous current) death is only caused by long-repeated interruptions of the current." In other words, the continuous current of the above pressure could not be made to cause death until it was interrupted or made discontinuous—or perhaps a better expression would be semi-continuous. By a variable state of the current is meant a fluctuation of pressure between different extremes of voltage. The human nerve-system, up to a certain limit of pressure, cannot detect the flow of a continuous current if the voltage be perfectly constant. This constancy is obtained by multiplying the number of commutator bars on the dynamo. The brushes which are set upon the revolving commutator, and conduct the current from the machine to the outside system, rest alternately upon the different bars of the commutator. The greater the number of bars, the less will be the fluctation of the current, which may be likened to a wave-motion, rising and falling, and producing that variable state referred to by the French scientist.

Nearly all dynamo machines used for arc-lighting are constructed with an insufficient number of commutator bars to produce a steady continuous current. The ranges of variable pressure are not, however, nearly as great as in the alternating system. With respect to the latter, M. d'Arsonval says: "An alternating Gramme machine caused death when above one hundred and twenty volts mean potential." This is a small unit to contemplate after the glib manner in which it has been recently stated that this current is harmless at a pressure of one thousand volts. I have myself seen a large healthy dog killed instantly by the alternating current at a pressure of one hundred and sixty-eight volts. It is a simple matter to calculate the ranges of variable pressure in this system. The dynamo machine has no commutator. The armature or "bobbin" is wound in such a way that the whole of the current under a pressure, say, of two thousand volts, is sent out on the wire first in one direction, then is reversed and sent out at the same pressure in the other direction, or passes through the wire in the opposite direction; and these

reversals are generally made about a hundred times in each second.

The variable state of a continuous current at a pressure of two thousand volts means ordinarily a rise from zero point up to two thousand, after which, owing to the action of the commutator, it varies between, say, seventeen hundred and two thousand, while the variable state of the alternating current means a fluctuation from two thousand volts above the zero point to two thousand below it, or a difference of four thousand volts. The danger to life is probably proportionate to the fluctuation of pressures. When an alternating current of fifteen volts is applied to a human being in the most effective manner, the effect upon the nerve system is so violent and the pain produced so great that it is absolutely impossible for any one to stand it.

As I have said before, the only way in which safety can be secured is to restrict electrical pressures. The continuous current should be limited to six hundred or seven hundred volts, with a variable range not exceeding a few volts. As for the alternating current, it is difficult for me to name a safe pressure. Its effect upon muscular action is so great that even at exceedingly low voltage the hand which grasps a conductor cannot free itself, and it is quite possible that in this way the sensitive nervous system of a human being could be shocked for a sufficient length of time to produce death. The electric-lighting company with which I am connected purchased some time ago the patents for a complete alternating system, and my protest against this action can be found upon its minute-book. Up to the present time I have succeeded in inducing them not to offer this system to the public, nor will they ever do so with my consent. My personal desire would be to prohibit entirely the use of alternating currents. They are as unnecessary as they are dangerous. In the city of New York there are many miles of conductors beneath the streets conveying a harmless continuous electric current to thousands of consumers, the maximum pressure on this vast system never exceeding two hundred and twenty volts, which will force so weak a current through the human body that it can barely be detected. Furthermore, it is found to be commercially successful, and I can therefore see no justification for the introduction of a system which has no element of permanency and every element of danger to life and property.

This is no argument in favor of monopoly. If ever there is to be a monopoly of electric lighting in the United States, it will be neither delayed, prevented, nor circumnavigated by such subterfuges as these alternating systems, and their use cannot be justified on that score. I have always consistently opposed high-tension and alternating systems of electric lighting (although perfectly free to use them), not only on account of danger, but because of their general unreliability and unsuitability for any general system of distribution.

In contemplating the efforts of the officials of the city of New York to remedy the evils connected with electric lighting, I have been impressed in a way which must have impressed other onlookers. I refer to the apparent difficulty of determining where the authority to take action rests. The hands of those who wish to act appear to be tied, which is unfortunate, considering the exigencies and urgency of the case. In England they handle these matters better. The Electric-Lighting Act of 1882 provides in section 6

"that the Board of Trade may from time to time make such regulations as they may think expedient for securing the safety of the public from personal injury or from fire or otherwise, . . . and any regulations so made or amended by the Board of Trade shall from and after the date thereof have the like effect in every respect as though they had been originally inserted in the license, order, or special act authorizing the undertaking."

This same section also provides that

"any local authority within any part of whose district electricity is authorized to be supplied under any license, order, or special act, may, in addition to any regulations which may be made under the preceding provisions of this section for securing the safety of the public, from time to time, make, rescind, alter, or repeal by-laws for further securing such safety; and there may be annexed to any breach of such by-laws such penalties to be recovered in a summary manner as they may think necessary. Provided always that no such by-laws shall have any force or effect unless and until they have been confirmed by the Board of Trade and published in such manner as the Board of Trade may direct."

Thus to a responsible body is given discretionary power for the protection of the public, and local authorities (by which is meant any municipality) have the right to apply to this board for relief from any danger which they believe to exist in connection with electric-lighting systems. Certainly the responsibility for the protection of the people of our city should be as definitely placed, and those to whom such authority is given should adopt rigid rules for the restriction of electrical pressures. Perhaps police

control would be even more adequate than the English system. I am not altogether familiar with the details of the system of boiler inspection which prevails in New York, but I believe it is very efficient and would serve as an excellent model for the case under discussion.

When the authorities require electrical pressures to be kept within the limits of safety, and when there is an efficient corps of inspectors, as in the case of boilers, to see that the rules adopted are carried out, the security which the public demand will be attained; but until then nothing better can be looked for than a multiplication of the casualties of the past few months.

THOMAS A. EDISON.

The Tesla Method of Obtaining Direct from Alternating Currents.

The accompanying diagrams illustrate a novel method of obtaining direct from alternating currents. This method which has recently been patented by Nikola Tesla of New York, consists, broadly speaking, in developing, in say, two branches of a circuit from an alternating generator what might be termed "active resistances" of opposite electrical character, so that the current, or current waves, of opposite sign will be diverted through different circuits, those of one sign passing over one branch, and those of the other sign over another. While a number of "active resistances" may be used in the system, which have been classed by the inventor under the heads of "purely electrical," "electro-magnetic," and "magnetic," in this explanation only two plans are described, these being sufficient to illustrate the general principle of the invention. It is assumed, also, in the description that the circuit is divided into but two branches, as any further subdivision involves merely an extension of the general principle.

Fig. 1 represents the simplest application of the method. In this diagram is represented an alternating dynamo feeding a circuit divided into two branches as shown. In one of these branches is inserted a device to create an electromotive force counter to the waves or impulses of current of one sign and in the other branch a similar device is inserted which opposes the waves of the opposite sign. These devices may be assumed to be batteries, primary or secondary, or continuous current dynamos. The action in the system may be explained as follows:

The waves or impulses of opposite direction composing the main current have a natural tendency to divide between the two branches. By reason, however, of the opposite electrical character or effect of the two branches, one will offer an easy passage to a current of a certain direction, while the other will offer a relatively high resistance to the passage of the same current. The result of this disposition is, that the waves of current of one sign will, partly or wholly, pass over one of the paths or branches, while those of the opposite sign pass over the other. There may thus be obtained from an alternating current, two or more direct currents without the employment of any commutator such as has been heretofore regarded as necessary to use. The current in either branch may, therefore, be applied in the same way and for the same purposes as any other direct current.

Fig. 2 illustrates an "electro-magnetic" device for accomplishing a similar result—that is to say, instead of producing directly by a generator an electromotive force in each branch of the circuit, fields of force are established and the branches lead through the same in such manner that an active opposition of opposite effect or direction will be developed therein by the passage, or tendency to pass, of the alternations of current. In Fig. 2, for example, is represented the generator of alternating currents, line-circuit, and the branches over which the alternating currents are directed. In each branch is included the secondary of a transformer or induction coil. The primaries of the induction coils or transformers are connected either in parallel or in series with a source of direct or continuous currents indicated at the left in the diagram, and the number of convolutions is so calculated for the strength of the current that the cores will be saturated. The connections are such that the conditions in the two transformers are of opposite character—that is to say, the arrangement is such that a current wave or impulse corresponding in direction with that of the direct current in one primary is of opposite direction to that in the other primary; hence it results that while one secondary offers a resistance or opposition to the passage through it of a wave of one sign, the other secondary similarly opposes a wave of opposite sign. In consequence the waves of one sign will, to a greater or less extent, pass by way of one branch, while those of opposite sign in like manner pass over the other branch.

In addition to those described the inventor makes use of various arrangements of a similar character. The above description covers, however, the main points of the invention.

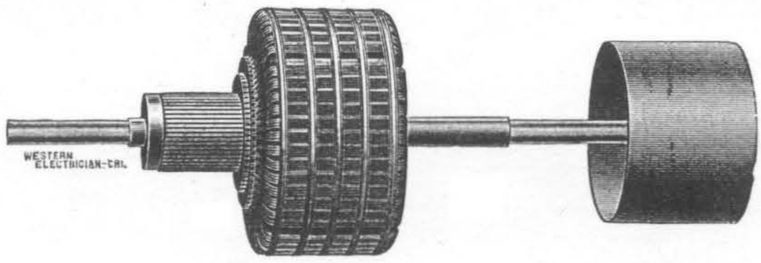

FIG. 2. FREEMAN CONSTANT POTENTIAL DYNAMO.

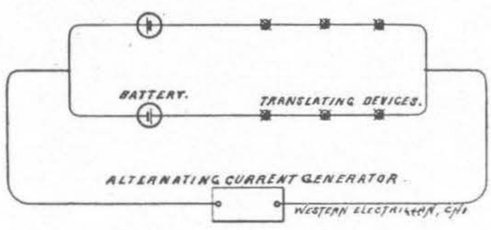

FIG. 1.

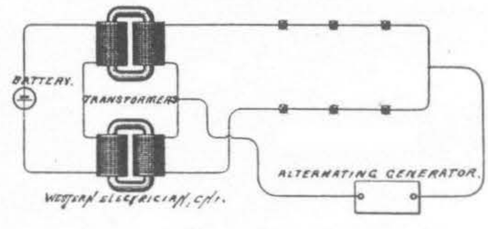

FIG. 2.

THE TESLA METHOD OF OBTAINING DIRECT FROM ALTERNATING CURRENTS.

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NOTES.

Our esteemed contemporary the *Electrical World* devotes an article to describing the methods suggested by M. Nikola Tesla for rectifying alternating currents. We must confess to a certain amount of scepticism as to the availability of these methods for large currents. On another page of the same journal M. A. Gaillard describes an apparatus for effecting the same purpose, which has a close resemblance to a device described by Mr. Lane Fox some years ago intended to do this. It is obvious, however, that anything like mercury cups or spring contacts, however effective for currents of a few amperes in magnitude, will fail when larger currents are used. The commutation of alternating currents by a motionless commutator capable of dealing with currents of all magnitudes and various frequencies is a problem which may well tax the highest inventive skill, but these devices of M. Tesla do not seem very perfect solutions of the question. The method adopted of splitting the alternating current through two coils having magnetically saturated cores is very ingenious, depending as it does on the fact that the self-induction of the coil varies with the permeability of the core, and this varies with the induction through the core.

Continuous Currents from Alternating Currents. — The problem of obtaining continuous currents from alternating is one that has received not a little attention, and various solutions have been offered on both sides of the Atlantic. Mr. Nikola Tesla has applied himself to the matter, and now offers a simple and ingenious solution. His idea and method consist broadly in directing the waves of an alternating current so as to produce continuous currents by developing in the branches of an alternating-current circuit certain manifestations of energy or active opposite resistances by which the alternating-current waves of opposite sign are diverted through different circuits. Thus the currents of different sign are, so to speak, sifted out: those of one sign passing over one branch, and those of an opposite sign over the other. There may thus be obtained from an alternating current two or more direct currents without the employment of a commutator. Mr. Tesla proposes both electrical and electro-magnetic methods for achieving this result. In the electrical method the device to create an electromotive force counter to the waves of current on one side may, for example, be batteries or continuous-current machines. In the electro-magnetic method, instead of producing the electromotive force in each branch of the circuit, a field of force may be established, and the branches be led through it in such a manner that an active opposition will be developed therein by the passage, or tendency to pass, of the alternations of current. Another purely magnetic method is that wherein Mr. Tesla employs two strong permanent magnets, the armatures of which are built up of thin laminæ of soft iron or steel, the amount of magnetic metal which they contain being so calculated that they will be nearly or fully saturated by the magnets.

North American Review December 1889

A REPLY TO MR. EDISON.

BY GEORGE WESTINGHOUSE, JR., PRESIDENT OF THE WESTINGHOUSE ELECTRIC COMPANY.

No one will now question the great benefit of the electric light to the public. By the rays of the brilliant arc lamp our streets are better lighted than ever before, with a corresponding increase in security both to life and property, while the incandescent lamp supplies our homes with the most agreeable artificial illumination known to science, and one which, at the same time, is absolutely free from the deleterious products of combustion incident to the use of gas or oil.

The use of electricity for supplying light and power has now become as much a part of our every-day life as the railway, the steamship, the street-car, or the gas supply. In fact, we live in a time when power is made in every way subservient to the comfort of the people. It is employed in nearly every useful industry, with a full knowledge that such employment has been and always must be attended with an appreciable degree of danger. Electricity is one manifestation of power. It represents a form of mechanical energy capable of being utilized for innumerable purposes. Indeed, were it a question of prohibiting the use not merely of electricity, but of all other things dangerous to life, we would no longer have fires to warm us or light to enable us to see, and, in fact, would be deprived of most of the necessaries and comforts of existence. As has been the case with the utilization of all other forms of energy, the demand for the most economical methods will ultimately prevail, provided these can be made safe, as they most certainly can, by the exercise of proper precautions.

Electric lighting, unlike many other industries protected by patents, has been followed with keen interest at every step by the public at large, but among more immediately interested par-

ties the struggle for the control of the electric light and power business has never been exceeded in bitterness by any of the historical commercial controversies of a former day. Thousands of persons have large pecuniary interests at stake, and, as might be expected, many of them view this great subject solely from the stand-point of self-interest. That the public may to some extent understand the mass of literature now being printed with reference to the use of electric currents of both high and low tension, it is necessary that something of the story of this business rivalry should be told.

The successful use of the Jablochkoff electric light in Paris, in 1878, was the beginning of a new era in a field which had not remained wholly uncultivated during the preceding thirty years, although with unimportant commercial results. In 1877 and 1878 we find William E. Sawyer, Charles F. Brush, Hiram S. Maxim, Edward Weston, Thomas A. Edison, and others entering this alluring field of invention. In 1877 Sawyer took out three patents of more than ordinary importance in view of what has since become the practice in electric lighting. Early in 1878 he associated with himself Albon Man, who became a joint inventor with him of several electric-lighting inventions, the promising results from which led to the formation, on July 8 of that year, of the Electro-Dynamic Light Company of New York. The objects for which this company was formed were stated as follows:

"The production of light and power by means of electricity; the lighting of streets, buildings, and other places; producing, conducting, and distributing electrical currents for lighting and other purposes, and the manufacture and sale of all machinery necessary for or adapted to accomplish the purposes named."

Charles F. Brush early invented and perfected a dynamo, an arc lamp, and a method of operation whereby a number of such arc lamps could be used on one circuit, principally for street-lighting purposes. To make and sell Mr. Brush's inventions, there was organized the Brush Electric-Light Company, of Cleveland, Ohio.

In September, 1878, appeared the first announcement of Mr. Edison's discoveries in electric lighting, and on October 17, three months after the formation of the Electro-Dynamic Company to operate Sawyer and Man's electric-light inventions, the Edison Electric-Light Company, of New York, was organized. To introduce the inventions of Maxim and Weston, there was formed the

United States Electric-Lighting Company, of New York, and thus four large corporations were started almost simultaneously upon a career of competitive business. The energy and money since expended by each of these corporations in efforts to thwart the progress of the others has mutually embittered the interested parties to a degree that can with difficulty be comprehended by those not immediately concerned in the strife.

Mr. Edison, already a well-known inventor in telegraphy, apparently had his attention drawn to this subject by a visit to Mr. William Wallace, of Ansonia, Conn., in September, 1878. There he saw Mr. Wallace's dynamos feeding eight electric lights at one time, and also witnessed the transmission of power by electricity from the Naugatuck River, a quarter of a mile distant. The spirit in which he entered the electric-light business would seem to be indicated in the following extract from the New York *Tribune* of September 28, 1878:

"Mr. Wallace's machines produce electricity which can be made available for electric light." Mr. Edison continued: "I have let the other inventors get the start of me in this matter somewhat, because I have not given much attention to electric lights, but I believe I can catch up to them now." . . . "Now that I have a machine (Wallace's) to make the electricity, I can experiment as much as I please." "I think," he added, smiling, "there is where I can beat the other inventors, as I have so many facilities here for trying experiments." "If you can make the electric light supply the place of gas, you can easily make a great fortune," the reporter suggested. "I don't care so much for a fortune," Mr. Edison replied, "as I do for getting ahead of the other fellows."

Setting out with this determination, it is perhaps no wonder he has worked so energetically. Reviewing his inventions and utterances, it is evident that he believed from the beginning that the system of gas-distribution was the thing to be copied, and that electric conductors could be laid under the streets with branches or connections to each house, supplied by generators located in central stations; but this system necessitated the limitation of the electric pressure to that which the lamps could be made to endure—in practice about 110 volts. The formidable quantities of copper required to conduct the necessary volume of current at this low pressure soon led to the development of what is known as the Edison "three-wire" system of distribution, an improvement founded upon earlier patents of Sawyer and Brush. This system permits a pressure of 220 volts on a circuit equipped with 110-volt lamps, and requires for the whole installation only

one-quarter of the weight of copper conductors necessary with the two-wire system.

It must be constantly borne in mind that the pressure of this direct-current system is necessarily limited to 220 volts by the conditions of the lamp, and also that the underground mains in all directions are interconnected, forming what is termed a mesh-work, analogous to the gas-distribution system, but with very important differences, hereafter explained at length. The cost of copper required for mains of sufficient conductivity to avoid a decrease in light by reason of large consumption, even at moderate distances, was found to be prohibitive, and this fact necessitated a system of "feeders," through which the electricity is forced against a very considerable resistance. These feeders are connected at various points to the mesh-work of mains so as to maintain at such points an approximately constant pressure. The generators at the central stations deliver their product collectively into common feeders and mains, and with a large plant an enormous energy is constantly exerted in these mains.

Any plan of distribution involving the meshing of the mains underneath the streets, with all house wires connected directly thereto, is regarded by the majority of competent electrical engineers as in many respects radically defective; so defective, in fact, that, unless the use of alternating currents can be prohibited, it seems destined to be wholly supplanted by the more scientific and in all respects (so far as concerns the users or occupants of buildings) far safer inductive system. Apparently sensible of this, Mr. Edison does not hesitate to say: "My personal desire would be to prohibit entirely the use of alternating currents."

The fact that the shocking accident which has given rise to the present discussion was, in all probability, the result of a direct continuous current, and that the burning of the unfortunate victim may have resulted from a low-tension current used for telegraphic or power purposes, apparently does not deter Mr. Edison from his self-imposed task of proving the low-pressure system to be the only safe one. It is, nevertheless, a common practice of the Edison Company to use uninsulated overhead wires for its 220-volt current for the purpose of economizing first cost, although it is well known that such a current is capable of burning a body subjected to it as effectually as in the case of lineman Feeks, provided the skin be sufficiently abraded to diminish the electrical resistance of the subject.

Accepting Mr. Edison's classification of the currents used for electric lighting, let us discuss them as follows :

"*First*—The low-tension continuous current, with a pressure not exceeding 200 volts, used for incandescent lighting.

"*Second*—The high-tension continuous current, with a pressure of 2,000 volts and over.

"*Third*—The high-tension semi-continuous, or pulsatory, current, with a pressure of 2,000 volts and over.

"*Fourth*—The alternating current, with a pressure of from 1,000 to 3,000 volts and over."

The first is not dangerous when a person comes into momentary contact with one wire, but no one can endure its passage through the body when the contact is made "in the most effective manner." I have witnessed the roasting of a large piece of fresh beef by a direct continuous current of less than one hundred volts within two minutes. Any one having access to electric lights operated by the low-tension underground system in New York can easily prove to his own satisfaction how much credence ought to be given to the assertion that a current of 200 volts can be passed through the human body without producing uncomfortable sensations. Let him connect a tin pan to one of the electric wires, and place therein a thick piece of beef, and upon this a gridiron of metal connected to the other wire. The electrical energy exhibited in the steaming and cooking of this beef may possibly surprise the experimenter. If the current is from an underground main, the experiment may be varied by connecting the gridiron to a water-pipe with like results. With even less than one hundred volts it is painful beyond endurance to press firmly with the hands the brushes or any bright brass-work of the dynamo, or to grasp any metal connected with the wires.

That a continuous current of moderate tension may produce death when the connection is continued for even a short time is shown by the published record of experiments conducted by Mr. A. E. Kennelly at the Edison Laboratory. With a continuous current of 400 volts a dog weighing fifty-seven and a half pounds was killed in forty seconds ; and in another instance, with 1,000 volts of continuous current, a dog weighing thirteen and a half pounds was killed instantly. That an alternating current of one hundred volts, even when effectively applied, does not kill is shown by two experiments on another dog. A continuous current of 304 volts was applied for thirty seconds, and then an alternating current of one hundred volts for sixty-five seconds ; yet the dog was unhurt.

But mark this important fact: the so-called "alternating current" used for these experiments on animals was not the alternating current of commerce, but was an Edison direct continuous current made alternating by a "pole-changer," producing an effect incomparably more dangerous than the true alternating current under discussion, because of the exaggerated tension resulting from the partial discharge of the field-magnets of the dynamo, which act in this case like a Ruhmkorf coil of enormous dimensions.

The power of destruction residing in the low-tension current under certain conditions is best illustrated by quoting from Mr. Edison's own article, where he says:

"Near the corner of William and Wall Streets, New York, the underground conductors of the Edison Illuminating Company became crossed, and the current which was passing through them at a pressure of only one hundred and ten volts melted not only the wires, but several feet of iron tubing in which they were incased, and reduced the paving-stones within a radius of three or four feet to a molten mass."

He adds: "This system is so arranged that consumers are not affected by such accidents as these." But it is, nevertheless, true that every consumer is directly connected to the mains, so that it is evident that the reverse of this statement would have more truly represented the actual possibilities of the case.

Concerning the three other conditions of current referred to by Mr. Edison, he classes them, and rightly so, as dangerous to life, although momentary contacts have repeatedly been made with wires carrying 1,000 and even 2,000 volts of each of these currents, without fatal results. In fact, there have been hundreds of cases in which momentary contact with an alternating current of 1,000 volts and over, as well as with pulsatory and continuous currents, has resulted only in painful shocks, unaccompanied by permanent injury.

The reader of Mr. Edison's article who is unfamiliar with the alternating system of distribution would naturally infer that in practice the same voltage is carried on the house wires as on the mains, as in the Edison system; but such is never the case under any circumstances. In this complete disconnection of the street and house wires is found the reason of the positive safety both to life and property enjoyed by the users of the alternating system. It is one of the great advantages of this system that it admits of the use of high voltages for the street mains, and of wholly separate and independent currents, with absolutely

safe voltage, for all wires within buildings—a condition which is infallibly secured and maintained by converters, or transformers, located in or near each building. Each transformer of electric energy is composed of two separately-wound and insulated coils, one of thin wire connected to the street mains, and the other of thick wire connected to the wires of the building. One of the most beautiful features of the alternating system is that when currents of electricity are sent back and forth with almost inconceivable rapidity through the coil of thin wire, there is induced in a neighboring coil of thicker wire an equivalent amount of electrical energy, but at the same time so modified that the voltage, which may be 2,000 in the thin coil, need be only fifty in the thick coil, the volume of electricity being as many times increased as the pressure or voltage is diminished. A current of fifty volts is used in practice, as it is now well established that lamps of this capacity are far more durable and give a better light, with much greater economy, than the 100- or 110-volt lamps. The two coils being absolutely separated from each other by effective insulation through which the current in the primary wire cannot possibly penetrate, it follows that the alternating system has an enormous advantage over the direct system in respect of absolute safety to the consumer.

It seems possible that the time is not far distant when the regulations governing the distribution of electricity will rigidly prohibit direct electrical connection between the street wires and the local service-wires inside houses, thereby excluding from dwelling-places all the dangerous effects possible to ensue from accidental leakages in the underground system.

The forebodings of Mr. Edison concerning the results of the leakage of current from the underground mains have perhaps been in great part suggested by difficulties experienced in the working of his own system. The Edison underground lines are made up of a great number of short sections of iron pipe, each containing a copper rod, with a plastic insulating material forced between the copper and the iron. These sections are about sixteen feet long and are laid in trenches, and united at the joints like gas-pipes. These pipes are usually laid above the frost-line, and are necessarily affected by changes of temperature, which cause the iron pipes to move at the joints. It is, therefore, not unusual to find that after a short time the electrical leakage becomes sufficient to light a number of lamps when connection

is made between a water-pipe and one of the mains—a fact well known to insurance inspectors. The Edison Company continues to use this system, although cables are now made capable of withstanding 2,500 volts of either alternating or direct current with even greater security than Mr. Edison has been able to provide for the 220 volts employed in his low-tension system.

One of the most perfect cables of to-day is a copper wire covered with a thick insulation, over which lead is pressed with very great force, thereby expelling air and gases, and solidifying the insulating material between the lead and copper. There is then woven upon the lead a textile envelope saturated with a water- and gas-proof compound. The continuous sections of this cable reach from one man-hole to another, a distance of several hundred feet, and can easily be drawn in and out of the ducts provided for them. Where one piece of cable is joined to another, an electric connection is made and well insulated, then encased in lead, which is afterward soldered to the ends of the respective cables. A cable of this character is uninfluenced by changes of temperature and is subject to little deterioration. To guard against its being pierced by a spark of static electricity, a very simple device is attached to it, offering an easier path for the electricity than through the insulation.

One of the differences alluded to, as existing between the low-tension, continuous-current underground system and a gas-pipe system, is that with reference to leakage. A gas leak is local and incapable of producing effects at a distance. With electricity, however, the aggregate effects of all the leakages from an underground system may be suddenly concentrated at any point within that system, as by one of the house wires coming in contact with a metal pipe, and such a contact may result even from the work of a mouse; whereupon the leakage of the entire net-work, which may amount to a large percentage of the total current, will be concentrated, and the surrounding material affected (although perhaps to a less degree) in the manner described by Mr. Edison in the reference to the currents at the corner of William and Wall Streets.

The interconnection of the conductors for the purpose of reducing the original investment has, in another important respect, a contrary effect from the meshing of gas-mains. In the case of the latter, the fracture of a pipe at one place, while it may cause a considerable leak, does not necessarily extinguish the lights of

all the consumers. The grounding of one of the wires of an underground circuit, however, affects the entire mesh-work; and a cross between the wires may extinguish the lights of an entire district for a considerable time.

As to the accidents from electric currents, the records of deaths in the city of New York show that there were killed by street-cars during the year 1888, 64 persons; by omnibuses and wagons, 55; and by illuminating gas, 23; making the number killed by the electric current (5) insignificant compared with the deaths of individuals from any of the other causes named. The placing of the wires underground would eliminate many of the causes of accidents from electric currents, and they may all be prevented by the employment of reasonable and well-understood safeguards. Mr. Edison's statement that the putting of the wires underground will, instead of diminishing, increase the danger to life, is little less than amazing, at least when considered in connection with his advocacy of his own underground system. The repeated and violent explosions of gas in the man-holes of the Edison system, and in connection with the underground systems of the telephone and telegraph companies, have certainly shown that electricity from any source, either from low-tension electric-light, telephone, or telegraph currents, either of which is capable of producing a spark, may be the cause of a serious catastrophe, although there is no doubt that the accumulation of explosive mixtures within these chambers can be effectually prevented. Inasmuch as Mr. Edison's arguments against underground wires generally are equally applicable to his own system, it would seem, logically, that, if his views are to prevail, all electric wires must cease to serve the public. The experience of the cities of Chicago and Philadelphia in the use of underground cables for high-tension currents, to say nothing of the large number of cables laid underground in Rome, Berlin, Milan, and in other cities, indicates that the success of properly-constructed underground systems, whether for currents of high or low tension, has been established beyond question.

There is one radical difference between the alternating and the continuous low-tension system which should be fully understood. It has been shown that in the alternating system the street mains are absolutely disconnected and detached from the house mains, while the low-tension system necessitates the

meshing of all underground mains into one net-work and the supply of the current to that system by a series of feeders. In fact, it necessitates at times the supply of an enormous electrical energy to supply the demand. With the alternating system the practice is not to mesh the wires, but to run independent pairs of wires connecting the switch board in the station with the thin wires of the converters. These wires are designed to supply only about 1,500 to 2,000 lights per pair, and are made of such a size that there is no appreciable decrease in the lights at the farther end, even if there is a very large consumption of current. Each of these pairs of mains can, therefore, be provided at the station with safety devices which will instantly and automatically cut off the current in the event of a cross-connection taking an abnormal current from the dynamo. Such safety devices cannot be made available with the low-tension system.

Mr. Edison is, moreover, unfortunate in his reference to the use of electric currents abroad. Under the British Electric-Lighting Act of 1888 the Board of Trade has issued a set of regulations. Concerning high-pressure conductors it says:

"9. *High-Pressure Conductors to be Insulated.* Every high-pressure aërial conductor must be continuously insulated with a durable and efficient material, to be approved by the Board of Trade, to a thickness of not less than one-tenth part of an inch, and in cases where the extreme difference of potential in the circuit exceeds 2,000 volts, the thickness of insulation must not be less in inches or parts of an inch than the number obtained by dividing the number expressing the volts by 20,000."

It will be seen that these regulations provide not merely for 2,000 volts, which is double that used in the American alternating system, but for any voltage whatsoever which the electric companies may desire to carry.

In a recent authorized publication it is stated that the main characteristics of the Edison system are as follows:

First—Subdivision of generating units to secure reliability and economy of production.

Second—Meshing of distributing conductors in a common net-work throughout the entire area to be supplied, to secure uniform distribution.

Third—A system of special feeding conductors to apportion equally the supply of energy to the demand throughout the area covered by the system of conductors.

Fourth—A system of indicators to denote in the station variations of pressure at any point in the area of consumption.

Fifth—A system of regulation to compensate for any variation of pressure.

The main characteristics of the alternating system contrast

with these in a marked manner. These characteristics may be stated as follows :

First—Large generators located in central stations at points convenient for coal and water supply, and away from residences.

Second—A series of mains running from the station, each set of mains having a capacity of not exceeding 1,500 lights, and each pair of mains extending to the station, so that the lines are only interconnected at the switch-board in the station.

Third—By reason of the limitation of the number of lights on each circuit, the leakage on any one circuit is reduced to a minimum.

Fourth—The interruption or burning-out of any one circuit can have no effect upon other circuits, the contrary being a most serious defect in a system wherein the wires are meshed.

Fifth—Absence of numerous and costly regulating contrivances.

Sixth—Ability to use within all houses a fifty-volt current, whereby the most efficient lamps can be utilized.

Seventh—Absolute separation of the street mains from the house mains, thereby preventing injury or danger from the leakage from the street mains.

Eighth—The use of a mechanical meter, which accurately records the entire electrical energy consumed in the house.

Ninth—The easy regulation of the current if required, so that the lights may be turned up and down without expensive and wasteful machinery.

There is not on record a solitary instance of a person having been injured or shocked from the consumers' current of an alternating system. This is wholly due to the fact that the converted current within the buildings supplied need not exceed fifty volts, and that the street mains and the house wires are absolutely detached from each other, so that there is no possibility of a shock being received from leakage or short-circuiting in the high-tension street mains.

The fire-risk from electricity is the one most to be feared. With the continuous current, whenever there is occasion to put out a number of lights by the movement of a switch, it not infrequently happens that a dazzling arc of blue flame is formed which has to be blown out. With the alternating system it is impossible to form any considerable arc, even if the switch controls a thousand lights, the rapid reversals of the current having the effect of preventing its establishment.

Mr. Edison's observations concerning the efforts of his competitors in the direction of saving in investment are no less applicable to the desires of the suppliers of his own system. At the annual convention of the Edison Illuminating Companies at Niagara, in August of this year, the following resolutions were offered by Mr. Gilbert, of the Detroit Edison Station:

"*Resolved*, That the Association respectfully call to the attention of the Edison General Electric Company the difficulties under which local companies are now laboring in consequence of the lack of

"1. An efficient and inexpensive arc-light system.

"2. An arc lamp which can be economically operated on the three-wire system.

"3. A flexible method of enlarging the territory which can be profitably covered

from their stations for domestic lighting *by higher pressures* and consequently *less outlay of copper* than that involved by the three-wire method.

"We earnestly appeal to the parent organization to supply these deficiencies."

The proceedings of the convention also contain the following:

"The address of Sir William Thomson, as president of the physical section of the British Association in 1882, contained this memorable passage: 'Nothing above 200 volts, on any account, ever should be admitted into a ship or house or other place where safeguards cannot be made absolutely and forever trustworthy against all possible accident.' This opinion accords with what Mr. Edison has always maintained—that in the long run every system will fail which does not (for domestic service) use a low-pressure current."

This is precisely what the alternating system supplies. The successful use of arc-lamps depends upon high voltages. Neither Mr. Edison nor any other person has yet been able to supply the requirements of the public by means of a low-tension arc-lighting system.

A careful consideration of the whole subject proves that it is possible to light all the buildings within a city by means of electricity distributed by an underground system, wherein there shall be no connection whatever between the underground system and the wires within the buildings. It has been demonstrated that an incandescent lamp operated by a fifty-volt current will give more light at a given cost than a 110-volt lamp; and, these two things being admitted, it follows that, if there are to be any restrictive regulations with reference to electric lighting, they might more properly be: *First*—That the electro-motive force within any building shall never exceed one hundred volts; *Second*—That no underground system shall be placed in electrical connection with the wires in the buildings; *Third*—That no underground system shall be permitted which does not provide for the renewal and repair of the mains without digging up the streets.

In conclusion it is worthy of note that for three years past the purchasers of apparatus for electric lighting, who are at perfect liberty to buy from any company, have, for the most part, preferred to use the alternating system, so that to-day the extension of that system for central-station incandescent lighting is at least five times as great as that of the direct current. If the opinion of these persons, who can have no interest except to purchase that which they believe to be the best, is of any value, then the alternating system has been demonstrated to be the one which can give to the public that which they so much desire—a safe, cheap, efficient, and universally-applicable system of incandescent electric lighting.

GEO. WESTINGHOUSE, JR.

A New Type of Tesla's Alternating Current Motor.

Since Mr. Nikola Tesla's first work in alternating current motors was published by us, he has been busily engaged in working out other types, one of which we describe below. In Mr. Tesla's motors, it will be remembered, two or more energizing circuits are employed, through which alternating currents differing in phase are passed, with the result of producing a progressive shifting or rotation of the poles or points of maximum effect. Various types of alternating motors have been constructed on this principle, the present being one in which the difference of phase is artificially produced, as, for instance, in cases where the motor-circuits are of different resistance and self-induction, so that the same current divided between them will be retarded in one to a greater extent than in the other, and the requisite phase difference secured in this way.

The lag or rotation of the phases of an alternating current is directly proportional to the self-induction and inversely proportional to the resistance of the circuit through which the current flows. Hence, in order to secure the proper difference of phase between the two motor-circuits, it is desirable to make the self-induction in one much higher and the resistance much lower than the self-induction and resistance, respectively, in the other. At the same time the magnetic quantities of the two poles or sets of poles which the two circuits produce should be approximately equal. These requirements, which Mr. Tesla has found to exist in motors of this kind, have led him to the invention of a motor having the following general characteristics: The coils which are included in that energizing circuit which is to have the higher self-induction are made of coarse wire, or a conductor of relatively low resistance, and the greatest wire of higher resistance, is used.

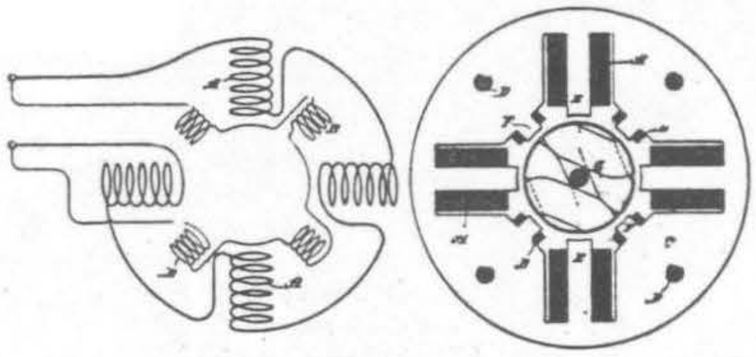
Furthermore, in order to increase the difference of phase in the two circuits, Mr. Tesla provides for the self-induction coils a considerably greater space in order to place a greater amount of copper in these coils, and in addition he envelopes these coils with iron so as to increase by these means the self-induction to the greatest possible value, and he calculates the magnetic qualities so that they are practically equal in both sets of magnets.

These features of construction are shown in the engraving Fig. 2 and the principle is illustrated by the diagram Fig. 1.

In Fig. 1, let *A* represent the coils in one motor-circuit, and *B* those in the other. The circuit *A* is to have the higher self-induction. Mr. Tesla therefore uses a long length or a large number of turns of coarse wire in forming the coils of this circuit. For the circuit *B* he employs a smaller conductor, or a conductor of a higher resistance than copper, such as German silver or iron, and winds the coils with fewer turns. In applying these coils to a motor a field-magnet is built up of plates *C*, of iron or steel. Each plate is formed with four long cores *E*, around which is a space to receive the coil and an equal number of short projections *F* to receive the coils of the resistance-circuit. The plates are generally annular in shape, having an open space in the centre for receiving the armature *G*, which is preferably wound with closed coils.

An alternating current divided between the two circuits is retarded as to its phases in the circuit *A* to a much greater extent than in the circuit *B*. By reason of the relative sizes and disposition of the cores and coils, the magnetic effect of the poles *E* and *F* upon the armature closely approximate.

An important result secured by the construction shown in the motor is, that these coils which are designed to have the higher self-induction are, as above stated, almost completely surrounded by iron, by which the retardation is considerably increased.



FIGS. 1 AND 2.—NEW TESLA ALTERNATING CURRENT MOTOR.

Tesla's Novel Principle of Constructing Electric Motors.

In order to obtain the maximum effective work out of a given weight of copper and iron in an alternating current motor, or any direct current motor, Mr. Nikola Tesla has applied a very important principle in their construction. Mr. Tesla reasons that in any motor the total energy supplied to do the work is equal to the sum of the energies expended in the armature and the field. The power developed, however, is proportionate to the product of these quantities. This product will be greatest when these quantities are equal; hence in constructing a motor Mr. Tesla determines the mass of the armature and field cores and the windings of both, and adapts the two so as to equalize as nearly as possible the magnetic quantities of both. In motors which have closed armature coils, this is only approximately possible, as the energy manifested in the armature is the result of inductive action from the other element; but in motors in which the coils of both armature and field are connected with the external circuit the result can be much more perfectly obtained.

In further explanation of this let it be assumed that the energy as represented in the magnetism in the field of a given motor is 90 and that of the armature 10. The sum of these quantities, which represents the total energy expended in driving the motor, is 100; but, assuming that the motor be so constructed that the energy in the field is represented by 50 and that in the armature by 50, the sum is still 100; but while in the first instance the product is 900, in the second it is 2,500, and as the energy developed is in proportion to these products it is clear that in any motor the best conditions are obtained when at normal load the magnetic quantities in field and armature are equal.

These results Mr. Tesla obtains by using the same amount of copper or ampère turns in both elements when the cores of both are equal and the same current energizes both or in cases where the currents in one element are induced to those of the other, he uses in the induced coils a proper amount of copper.

Tesla Method of Operating Electro-Magnetic Motors.

There has already been presented in the WESTERN ELECTRICIAN a description of Nikola Tesla's method of starting and operating synchronizing motors which involved the transformation of the motor from a torque to a synchronizing motor. This method consists in changing the circuit connections so that on the start the poles or resultant attraction of the field magnets of the motor were shifted or rotated by the action of the current until the motor reached synchronous speed, after which the poles were merely alternated. Mr. Tesla has recently patented another method of accomplishing this result, the main features being as follows: If an alternating current be passed through the field coils only of a motor having two energizing circuits of different self-induction and the armature coils be short circuited, the motor will have a strong torque, but little or no tendency to synchronism with the generator; but if the same current which energizes the field be passed also through the armature coils the tendency to remain in synchronism is very considerably increased. This is due to the fact that the maximum magnetic effects produced in the field and armature more nearly coincide. In other words, a motor is constructed having independent field circuits of different self-induction. These are joined in derivation to a source of alternating currents. The armature is wound with one or more coils, which are connected with the field coils through contact rings and brushes, and around the armature coils is arranged a shunt with means for opening or closing the same. In starting this motor the shunt is closed around the armature coils. When the current is directed through the motor, it divides between the two circuits, which, by reason of their different self-induction, secure a difference of phase between the two currents in the two branches, that produces a shifting or rotation of the poles. By

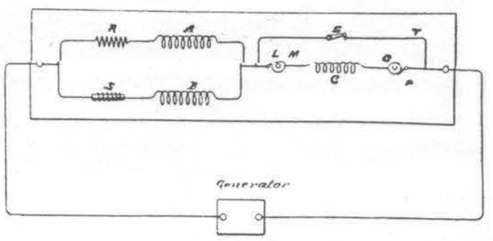


FIG. 1. TESLA METHOD OF OPERATING ELECTRO-MAGNETIC MOTORS.

the alternations of current other currents are induced in the closed—or short-circuited—armature coils and the motor has a strong torque. When the desired speed is reached the shunt around the armature coils is opened and the current directed through both armature and field coils. Under these conditions the motor has a strong tendency to synchronism.

In the accompanying cuts the motor is represented diagrammatically. In Fig. 1 A and B designate the field coils of the motor. As the circuits including these coils are of different self-induction, they are represented by a resistance coil, R, in circuit with A, and a self-induction coil, S, in circuit with B. The same result may of course be secured by the winding of the coils. C is the armature circuit, the terminals of which are rings, M and O. Brushes, L and P bear on these rings and connect with the line and field circuits. T is the shunt or short circuit around the armature. E is the switch in this shunt. The operation of these devices is as above described.

It will be observed that in such a disposition as is illustrated in Fig. 1, the field circuits A and B being of different self-induction, there will always be a greater lag of the current in one than the other, and that, generally, the armature phases will not correspond with either, but with the resultant of both. It is therefore important to observe the proper rule in winding the armature. For instance, if the motor have eight poles—four in each circuit—there will be four resultant poles, and hence the armature winding should be such as to produce four poles, in order to constitute a true synchronizing motor.

It is of advantage in the operation of motors of this kind to construct or wind the armature in such manner that when short circuited on the

start it will have a tendency to reach a higher speed than that which synchronizes with the generator. For example, a given motor having say eight poles, should run, with the armature coil short-circuited, at two thousand revolutions per minute to bring it up to synchronism. It will generaily happen, however, that this speed is not reached, owing to the fact that the armature and field currents do not properly correspond, so that when the current is passed through the armature (the motor not being quite up to synchronism) there is a liability that it would not "hold on," as it is termed. It is therefore prefered to so wind the motor that on the start

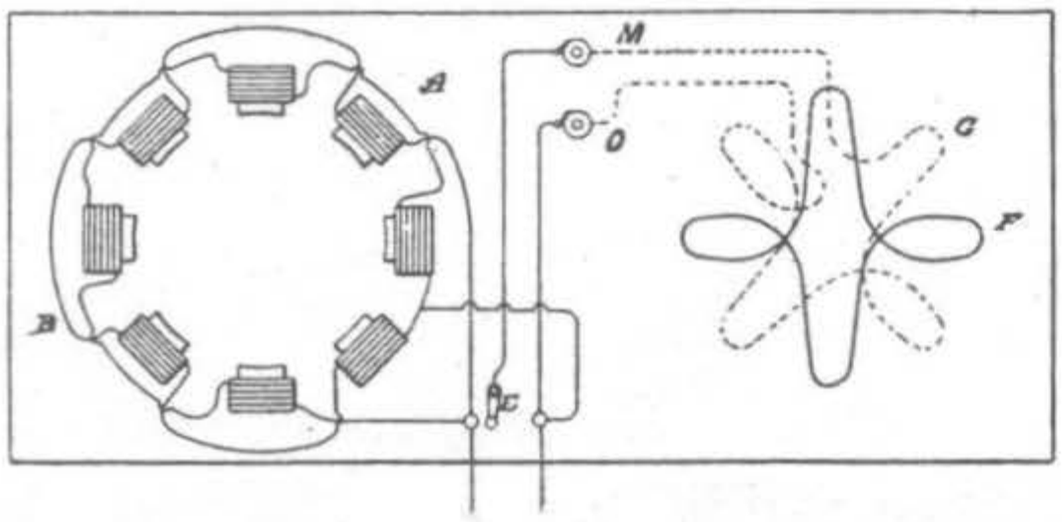


FIG. 2. TESLA METHOD OF OPERATING ELECTRO-MAGNETIC MOTORS.

when the armature coils are short-circuited the motor will tend to reach a speed higher than the synchronous—as, for instance, double the latter. In such case the difficulty above alluded to is not felt, for the motor will always hold up to synchronism if the synchronous speed is reached or passed. This may be accomplished in various ways, but for all practical purposes the following will suffice: The armature is wound with two sets of coils. On the start one only is short circuited, thus producing a number of poles on the armature, which will tend to run the speed up above the synchronous limit. When such limit is reached or passed, the current is directed through the other coil, which by increasing the number of armature poles, tends to maintain synchronism. In Fig. 2 such a disposition is shown. The motor having say, eight poles coutains two field circuits A and B of different self-induction. The armature has two coils F and G. The coil F is closed upon itself while the coil G is connected with the field and line through contact rings M and O, and a switch E. On the start the coil F alone is active and the motor tends to run at a speed above the synchronous, but when the coil, G, is connected to the circuit the number of armature poles is increased while the motor is made a true synchronous motor.

A paper read before the 41st meeting of the American Institute of Electrical Engineers, New York, December. 17, 1889. and discussion thereon. Vice-President T. C. Martin in the chair.

TRANSFORMERS.

BY HARRIS J. RYAN.

THE apparatus by means of which electrical energy of one form may be transformed to that of any other form, few engineers fail to appreciate.

So great have been the anticipated possibilities offered by the application of the modern transformer of alternate current energy that in most cases, in our country especially, has the transformer found immediate application, with but little thought or study of its exact performance. Much experimental work has been done by trial methods to the end that our manufacturers are able to supply transformers that answer for much that is desired practically, with a commercial efficiency that can be made higher than is probably possible by any other transformer of energy.

In electrical engineering, as well as other branches of engineering, for the broad application of one method or another, it is always of the highest importance that the cause and extent of every effect be thoroughly understood with regard to the mutual action and interaction of all forces and materials in relation to themselves, or to energy of one form or another.

It was with a view of obtaining, so far as possible, a clear understanding of all phenomena that take place in the commercial transformer, that the work producing the results here set forth was undertaken. It has not been possible at this time to prepare a paper as complete as has been desired, and we trust that in the near future we may add more data to that which is here presented.

In the outstart of this paper it should be said that the results of the experiments that are here presented were wrought out jointly by Mr. Ernest Merritt, of the department of physics,

Cornell University, and the writer. What we had in mind in the work was an accurate determination of the exact performance of the commercial transformer whereby one should be able to derive results and data that should enable all phases of the performances of transformers to be understood clearly, and that should show the requisite principle of proper design. It may be well to state briefly the general method we employed. A single ten-light transformer that had been made and supplied for commercial purposes for incandescent lighting, with 1,000 volts in the primary and 50 volts in the secondary, was selected as a sample for investigation. It probably represented fairly well the average commercial performance of transformers, and might therefore be said to embody, to a certain extent at least, proportions that have proven by experience and experiment to be best for the particular purpose for which it is supplied.

This transformer was operated under the same impressed E. M. F. supplied from the electric lighting plant in which it had been used for supplying incandescent lamps commercially. It was operated with its secondary open and the same closed through one lamp, five lamps, and ten lamps, and under these several conditions the exact instantaneous values of the ever varying primary impressed E. M. F., primary current, and the E. M. F. at the terminals of the secondary were observed. Again under these several conditions the square roots of the mean squares of the above values and of the secondary current were also observed. Then with these observations, the dimensions and the details of the construction of the transformer, many of the facts and performances that the engineer is concerned with, are brought to light.

Naturally the first thing to be considered is the electrical measurements and how they were made. A point on the armature of an alternator always passes a fixed point in its circumference at a time corresponding to a definite value of the varying E. M. F. and current, alike, with regard to these quantities in the primary feeders, transformer, primary or secondary, etc., so long as the conditions remain constant. In our experiments we were only concerned with the values of the E. M. F. impressed at the terminals of the primary, the primary current and the secondary E. M. F., then by changing the position of the fixed point relative to the machine, the rotating point of reference in the armature

would pass the new position of the fixed point at corresponding different values for the primary E. M. F., primary current, and secondary E. M. F., with respect to themselves and the position of the armature.

In Fig. 1, B, L, is a prism of hard rubber, bearing a projecting strip of brass, B, that on its upper side is filed to a dull edge. This edge is taken as a fixed point on the armature. An arm, F D, is arranged to rotate about D as a centre, a point that is in line with the axis of rotation of the armature. A semi-circular board of hard wood, attached rigidly to the dynamo frame, serves both

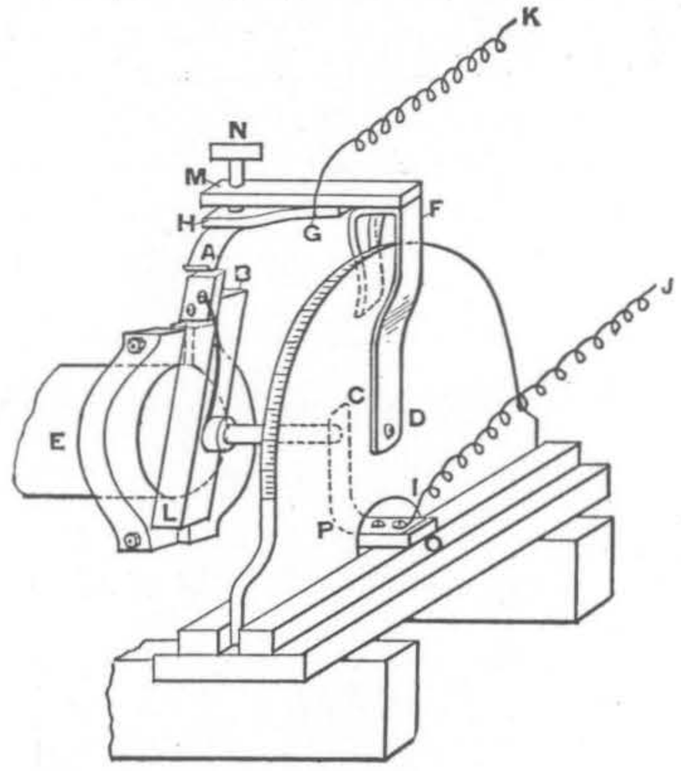


FIG. 1.

as a support for this arm and a circumferential scale whereby the position of the arm may be observed relatively to the machine. The arm is made of brass and given the form shown in the figure. It was bent into a U shape at the top so as to pinch the board and thus remain fixed in any position desired. At the top of this arm is mounted a bar of hard rubber projecting toward the dynamo parallel to the armature axis. On its under side, fastened at G, is a brass strip, a tongue, H, A, of spring brass is attached at the end and at right angles to the brass strip H G, as shown. The position of this part of the apparatus is carefully adjusted so

that the point about which the arm rotates is in line with the axis of rotation of the armature and the sharply upward curved end of the tongue H A, just over the edge of the brass strip at B. Then when the armature is rotated the strip H G may be sprung inward radially by turning the thumb-screw N, until the tip of the tongue A is heard to just lightly touch the edge at B as it passes. The arm may then be adjusted by hand so that the tongue will touch the fixed edge on the armature at any desired phase of the primary E. M. F., primary current or secondary E. M. F. and current. Coaxially with the armature a small brass rod is mounted on the bar of hard rubber B L. It is connected metallically to B by means of a wire. At O, on the frame work supporting the

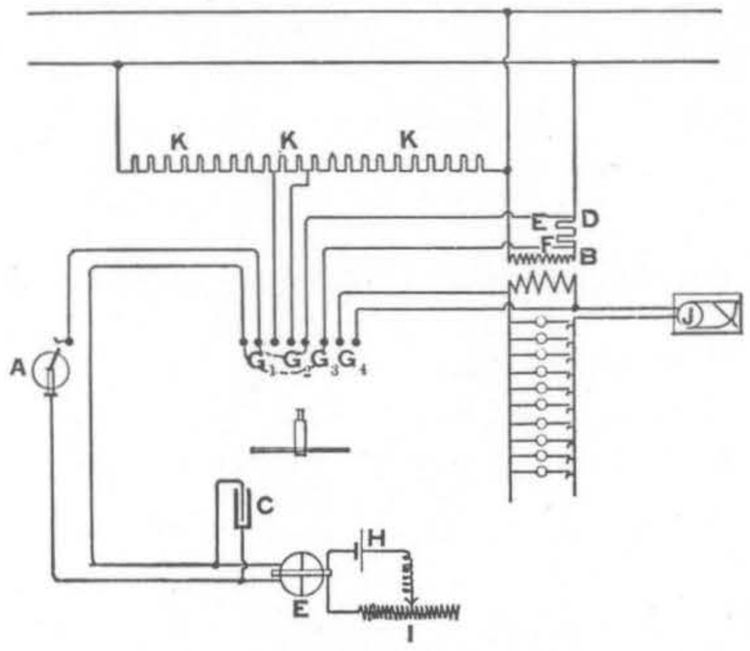


FIG. 2.

semi-circular board, etc., is mounted another piece of hard rubber, insulating and supporting the thin metallic strip, P C, that bears against the above brass rod. G and I then are the terminals of this commutating apparatus.

In Fig. 2, E F is a non-inductive resistance in series with the primary of the transformer which is at work. At A is the apparatus described in Fig. 1, and E is an electrometer reading through a wide range.

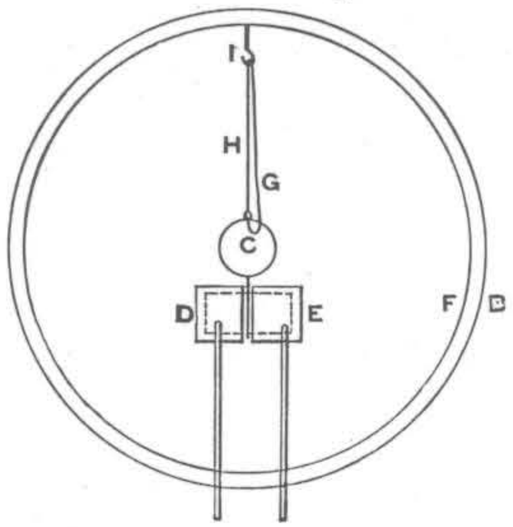
The terminals of the above non-inductive resistance and those of the electrometer are connected together through the commutating apparatus at A. Then it must be evident to all that the electrometer will become charged with a difference of potential equal

to that existing between the terminals of the non-inductive resistance at the instant that the fixed edge on the armature passes the tip of the tongue in the apparatus at A. By reading the indications of the electrometer, therefore, and knowing the value of the non-inductive resistance E F, the value of the primary current corresponding to the particular phase due to the position of the arm in the apparatus at A becomes known. In a similar manner the primary and secondary E. M. F. are observed by changing the connections accordingly at G^1, G^2, G^3, G^4. Then the arm is rotated to another position, corresponding to a different phase, and the corresponding values of E. M. F's and current again observed as before. In this manner we proceed at equal intervals, sufficiently near, so that a curve may be determined by the values thus observed at the several intervals, so that the values of the E. M. F's or currents shall be accurately known at all times throughout a complete period.

A few words with regard to the electrometer at E, are not out of place here. It is the form that the writer devised especially for this and similar purposes. The essential features for an electrometer for these purposes are that it shall have the widest possible range through which it will read with accuracy. Its indications must be unvaried by the absolute potential to which it is subjected as a whole. Its law must be perfectly definite, and it is also desirable that its constant be unchanging.

Fig. 3 illustrates this instrument in diagram. It consists essentially of cylindrical electrometer needle and quadrants E. D. To the upper side of the electrometer needle is attached a magnetized steel mirror that acts as a magnet and as a mirror for observing the position of the same. The needle is hung by a single silk fibre, H, from a hook in the top of the case, as shown. Metallic contact from the needle to the case is made by means of a platinum wire, .0002 inches in diameter. This wire is readily provided in the desired form by using the platinum cored silver wire that is supplied by makers of surveying apparatus. It is cut the desired length, and hooks bent into shape at its terminals. By immersing all of it but the hooked terminals in nitric acid, the silver is dissolved away leaving the fine platinum core terminated by the two silver hooks. One end of this platinum wire thus prepared is linked into a hook into the top of the electrometer case and the other end into a small ring formed by a twist of the

aluminum wire that surrounds the mirror C. The electrometer case is circular and the above needle and quadrants are arranged so that the magnetized mirror is at the centre of the case, and the needle and quadrants below it. About the case, as the figure indicates, is wound a coil, B B, of rather fine insulated copper wire. The magnetic mirror and this coil then, when the latter is in the magnetic meridian, constitute an arrangement similar to that of a tangent galvanometer. In the electrometer, the needle, case, and one set of quadrants are connected together and form one ter-



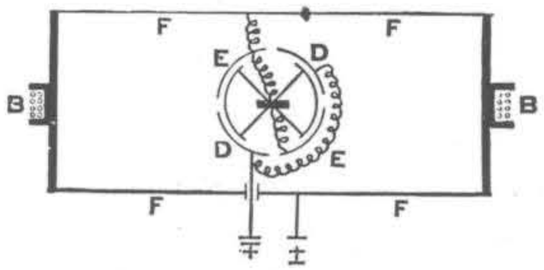


FIG. 3.

minal and the other set of quadrants, being connected together, form the other terminal of the instrument, in the manner set forth in the diagram. Thus then, when the electrometer terminals are subjected to a difference of potential, the needle is acted upon by a couple brought about by the electrostatic forces and is deflected from its position of equilibrium. Then, as is shown in Fig. 2, current from a gravity cell in circuit with a suitable rheostat is sent through the coil on the electrometer in such a direction that the needle is brought toward its zero position by the action of the coil, carrying the current, on the magnetized

mirror. The current is then further adjusted till the needle stands balanced at zero under the mutual action of the electrostatic and the electromagnetic forces. Under such circumstances then the difference of potential is proportional to the square root of the current.

If we can, as was the case when the measurements here presented were made, consider the E. M. F. of our cell constant, the difference of potential is likewise proportional to the square root of the reciprocal of the total resistance in circuit with the cell. Parallel readings, taken with a standard voltmeter throughout a range varying from 3 to 600 volts, gave identical results showing no deviation from the above law and an unvarying constant. On account of the metallic case and its connection to the rest of the apparatus, the indications of the electrometer are so far as could be observed, entirely independent of the absolute potential to which it is subjected as a whole. In Fig. 2, when contact was made at A, and the electrometer charged to the potential difference to which its terminals were then subjected it was found that considerable of the charge was dissipated by leakage during the course of a revolution of the armature, no matter how good the insulation of the apparatus was. A one-half microfarad mica condenser was then placed in multiple arc with the terminals of the electrometer at C. Then after a few revolutions of the armature the condenser became charged to precisely the same difference of potential existing at the terminals of the electrometer D B, as shown in Fig. 2, when the rotating edge on the armature passed the tip of the tongue on the arm at A.

Under these circumstances the leakage that occured was entirely unobservable as compared to the charge in the condenser during the course of time required for the armature to make many revolutions. Thus arranged then the electrometer would give accurate readings of the primary and secondary E. M. F.'s and primary current corresponding to the connection of its terminals and the position of the arm at A. Again, the square root of the mean square of any of these values could at any time be read from the electrometer by short-circuiting the apparatus at A, and cutting out the condenser at C. For the purpose of obtaining the curve of impressed E. M. F. and the $\sqrt{\text{mean}^2}$ of the same, twenty-two 50 volt lamps were put in series across the primary circuit. The $\sqrt{\text{mean}^2}$, of the impressed E. M. F. in the primary was then obtain-

ed by reading, by means of the electrometer with the condenser cut out and the commutating apparatus short circuited the $\sqrt{\text{mean}^2}$ difference of potential existing between each set of two lamps. In this way 11 readings were obtained, the sum of which was the total impressed E. M. F. This served as a calibration of the non-inductive resistance formed by the lamps. At the same time that these observations were made, two lamps were determined upon to be used in all subsequent observations on the total E. M. F. The above observations served then as a calibration for the indications of the two lamps thus to be used. For the constant obtained by the ratio of the above total E. M. F. to the E. M. F. of these lamps taken at the same time always served to deduct the total $\sqrt{\text{mean}^2}$ or any particular value corresponding to a particular phase of the impressed primary E. M. F. when the same had been

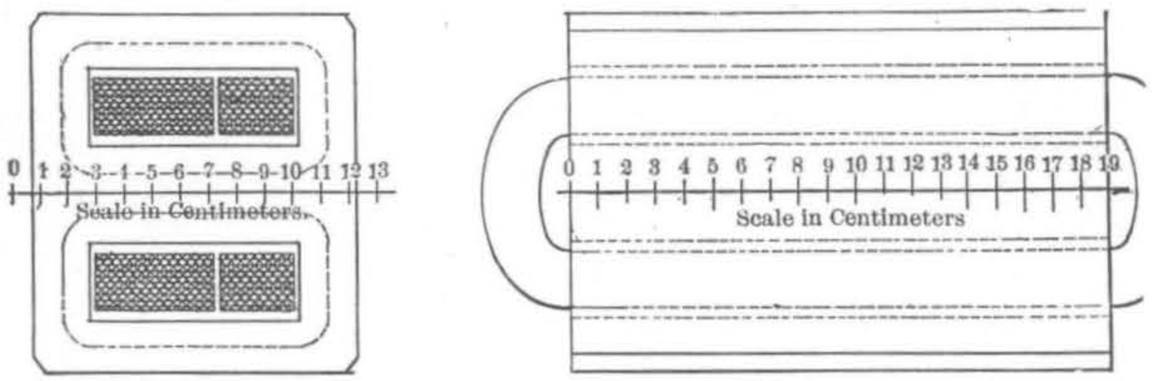


FIG. 4.

observed with regard to the two lamps in the group thus set apart. In this way we avoided the direct measurements of the total impressed E. M. F.

Two 50 volt lamps, E and F, were placed in series with the primary for a non-inductive resistance, and, as previously stated, the $\sqrt{\text{mean}^2}$, and the values corresponding to any particular phase of the fall of potential through these lamps were observed. This gave a measure of the $\sqrt{\text{mean}^2}$ or any particular value corresponding to a particular phase of the primary current, when the resistance of these lamps was known at the temperatures to which they were brought by the current. A curve of resistance corresponding to the range of currents through which we used these lamps was determined carefully by Mr. Merritt, at the Cornell magnetic observatory.

In series with the secondary circuit was placed a gravity ammeter containing a few small turns, and correct in its adjustment. It indicated the $\sqrt{\text{mean}^2}$ in the same way that an electro-dynamometer would have done. The observing of the various values of the secondary E. M. F. required no special arrangement—this was done direct in all cases. Since the secondary was always at work on a circuit possessing almost no inductance, no determinations of the curve of secondary current were made, for it would be found to be so nearly in unison with the secondary E. M. F. and possess all the characteristic variations of the same. The $\sqrt{\text{mean}^2}$ of its value was always known from the indications of the ammeter. As a load for the transformer ten 16 c. p. 50 volt lamps were provided that could be turned on and off as desired, and they were at an average distance from the transformer of not more than five feet.

G^1, G^2, G^3, G^4, represent, in figure 2, the various terminals conveniently arranged on a switch-board for ready adjustment for any desired set of connections. The adjustable resistance at I, consisted of a plug resistance box, enabling one to get any number of ohms in circuit from 100,000 down. It was very conveniently arranged; but a suitable slide rheostat and a dampened magnet on the electrometer needle would have greatly facilitated the rapidity with which observations could be taken. The mode of procedure was to set the brush at some suitable point of starting out, then corresponding to this point readings of the instantaneous values of primary E. M. F. were made. When lamps were turned on in the secondary, the ammeter in that circuit was also read. The brush was then moved forward to a new position and the above readings repeated. This was continued until we had gone over a complete period of two alternations, then the $\sqrt{\text{mean}^2}$ readings of the primary and secondary E. M. F.'s and primary current were made To do this required a period of time covering usually not more than two and one-half hours. Careful observations were made which showed that the insertion of one, two, or three lamps in the primary circuit *did not perceptibly change the relation* of the primary E. M. F. and current and secondary E. M. F. The indications of the ammeter gave data for correcting for variations of the speed of the dynamo, that throughout was not great.

The following data should be given with regard to the transformer that was used by us:—

Number of turns in the primary coil	675
" " " secondary coil	35.
Resistance of the primary	21.8 ohms.
Resistance of the secondary	.04 "

Fig. 4 is furnished with a scale to which it was drawn, so that from it any details as to dimensions of the transformer can be obtained.

The iron discs of the magnetic circuit of the transformer were made one-half millimeter in thickness, their surfaces merely oxidized, so that no special insulating material was provided between the laminations. The total volume of laminated iron used in the transformer was 2,050 cubic cms.

The mean cross-section of the magnetic circuit was 63.3 square cms., and the mean length of the magnetic circuit 30.8 cms.

The following observations with the secondary on open circuit and working on one lamp, five lamps, and 10 lamps were made and have been plotted in Figs. 5, 6, 7 and 8. The corresponding curves located by them, drawn in by the scales designated.

Secondary on open circuit.

(See Fig. 5.)

Brush reading.	Primary. E. M. F.	Current.	Secondary. E. M. F.
21	119	.20	5.5
20	855	.05	62.7
19	1250	.07	63.4
18	1420	.11	70.7
17	1330	.14	66.8
16	900	.19	46.0
15	45	.21	00.0
14	751	.04	37.8
13	1210	.08	62.0
12	1390	.12	72.0
11	1410	.15	72.5
10	1100	.18	57.8
9	355	.21	14.5
8	645	.08	32.3
7	1130	.04	57.8
Observed $\sqrt{\text{mean}^2}$	1025	.14	54.5
Calculated from curves $\sqrt{\text{mean}^2}$	1030	.147	53.5

Secondary closed through one lamp.

Secondary on Open Circuit.

(See Fig. 6.)

Brush reading.	Primary. E. M. F.	Current.	Secondary. E. M. F.
28	605	.225	31.4
27	330	.125	15.3
26	917	.048	45.2
25	1300	.179	67.6
24	1403	.215	71.7
23	1300	.235	67.1
22	820	.239	43.8
21	132	.185	4.7
20	835	.000	3.9
19	1238	.151	61.5
18	1420	.215	71.7
17	1363	.238	68.4
16	1026	.246	52.7
15	170	.215	9.7
14	793	.048	35.6
Observed $\sqrt{\text{mean}^2}$	1053	.196	52.3
Calculated from curves $\sqrt{\text{mean}^2}$	1021	.190	51.4

Mean of ammeter readings.....1.26

Secondary closed through five lamps.

(See Fig. 7.)

Brush reading.	Primary E. M. F.	Current.	Secondary E. M. F.
29	956	.449	40.3
28	41	.250	10.4
27	723	.000	28.9
26	1194	.356	54.8
25	1447	.495	69.1
24	1350	.483	67.2
23	1103	.453	57.6
22	293	.304	21.5
21	560	.000	19.8
20	1110	.318	48.8
19	1383	.464	65.7
18	1429	.511	70.0
17	1228	.500	60.3
16	567	.374	24.0
14.7	585	0.030	23.4
Observed $\sqrt{\text{mean}^2}$	1050	.390	51.0
Calculated from curves $\sqrt{\text{mean}^2}$	1036	.383	50.6

Mean ammeter reading.....5.83

Secondary closed through ten lamps.

(See Fig. 8.)

Brush reading.	Primary E. M. F.	Current.	Secondary E. M. F.
21	138	.242	5.2
20	826	.276	29.7
19	1237	.642	53.5
18	1378	.795	64.0
17	1300	.821	64.3
16	924	.700	51.1
15	63	.340	15.0
14	698	.188	23.7
13	1138	.587	49.0
12	1370	.810	63.7
11	1343	.844	66.0
10	1073	.771	26.5
9	323	.479	26.5
8	590	.000	17.0
7	1117	.538	42.8
Observed $\sqrt{\text{mean}^2}$	1040	.631	49.3
Calculated from curves $\sqrt{\text{mean}^2}$	1020	.634	49.3

Mean ammeter reading.....10.65

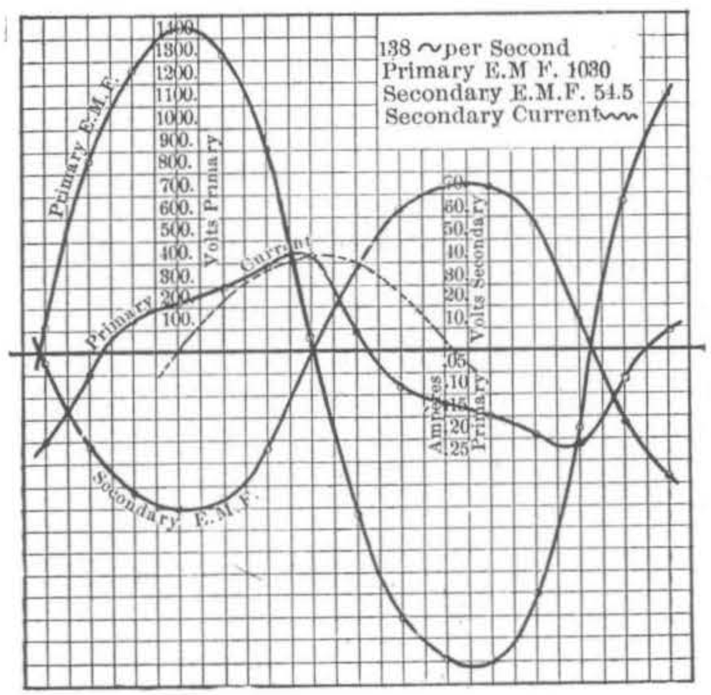


FIG. 5.

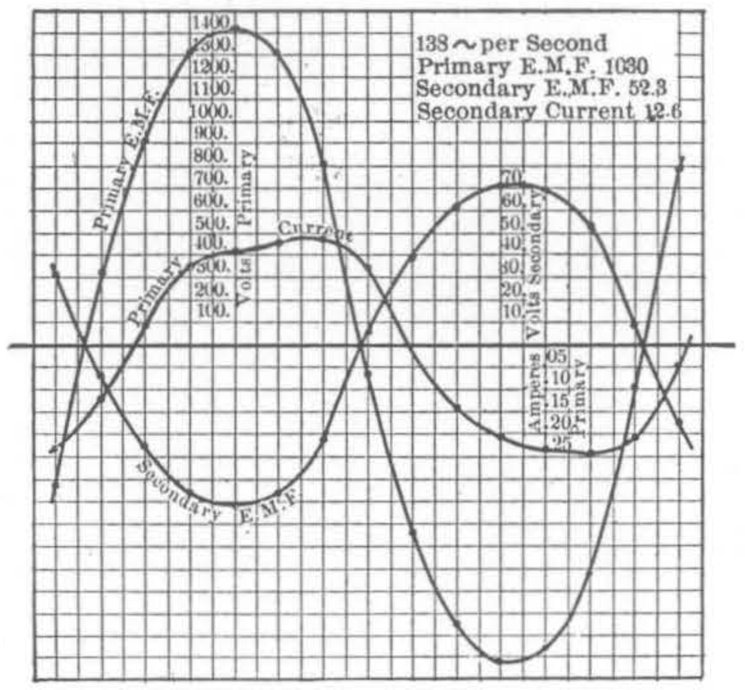


FIG. 6.

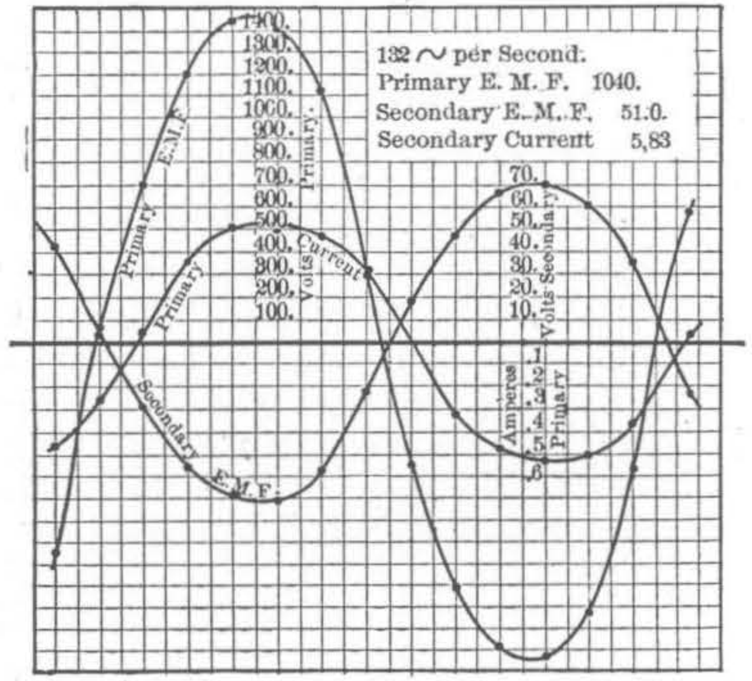


FIG. 7.

In Fig. 9 are plotted curves deduced from the foregoing observations, that show clearly the rate at which energy is given to the transformer, or that the transformer restores to the circuit at all points of a complete alternation for the several conditions

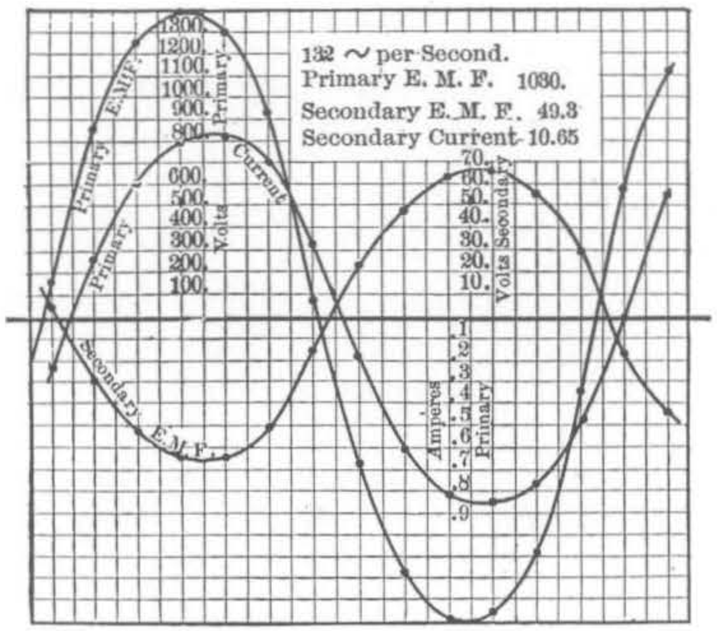


FIG. 8.

under which the transformer was operated. The curves themselves show so clearly this particular part of the performance of the transformer that nothing more need be said about them, except to give the percentages of the work given to the transformer that is restored to the circuit by it under the several foregoing conditions:—

Open circuit.....6.8%
One lamp.....3.9%
Five lamps.....96%
Ten lamps.....36%

The above observations and data are ample wherewith to compute the various losses of energy that take place in the transformer under the several loads and under no load, and the deduction of the corresponding efficiencies. These values have been computed and are given in the following table.

Proper corrections have been applied for the two lamps in series with the primary of the transformer.

Secondary E. M. F.*	Primary watts.	Secondary watts.	Efficiency.	Total loss in watts.	Hyster. loss in watts.	Heating loss. Primary watts.	Heating loss. Secondary watts.
Primary.....10.20							
Secondary, open 52.3	96.1	0.0	0.0	96.1	95.7	0 4	0.0
One lamp.....52.3	159.1	64.3	41.1%	94.8	93.9	0.9	0.0
Five lamps.....50.1	388.6	300.9	77.5%	87.7	83.1	3.3	1.3
Ten lamps.....47.5	607.9	525.0	86.6%	82.9	69.7	8.7	4.5

* The values given in this column have not been corrected for the two lamps in series with the primary for the first three conditions and the one lamp that was used for the last. With 10 lamps, where one lamp was used in the primary this correction amounts to an increase of the secondary E. M. F. of three per cent. On open circuit and one lamp it is negligible and three per cent. increase for five lamps. When this correction is applied the drop of 3.5 volts obtained is what was observed by direct measurement on the secondary.

In Fig. 10 these values have been plotted to scales there indicated, and the respective curves that they determine have been drawn so that one can plainly see the exact performance of the transformer under all loads.

It is interesting to note that this transformer might be loaded to twice its rated capacity and the heating of the coils would still be less than that of the iron, although the heat produced by the iron grows less as the load comes on. Likewise, that its efficiency would not yet have reached its maximum and that it would have a value of 92 per cent. In Fig. 11 the outer curve represents the relation between the magnetizing current in the primary and the degree of magnetization for all points of a complete cycle. The values locating the curve expressing this relation were readily deduced from the observations made when the transformer was working on open circuit. In Fig. 5 the dotted curve represents the curve of primary current that would be found, should Foucault currents be known to be absent, and the relation of ampere turns and magnetization be the same going up as coming down. Then if Foucault currents were present the dotted curve would have a component at a quarter of a period in advance. This would produce a negative lag in the dotted curve. From the position of the actual primary current, it is plainly seen that but a very small component of the above nature is possible, and that the energy that is wasted by eddy currents must therefore be small. The radical departure of the primary exciting current from the approximate sinuous variation of the primary impressed E. M. F. is plainly brought out to be due to *hysteresis*. From the preceding consideration it is also evident that almost the entire advance of the exciting current and, therefore, the corresponding dissipation of energy, is due to the same cause.

It was thought of much interest to see what amount of hysteresis should be indicated by carrying the transformer slowly through the same cycle of magnetization that it went at the rate of 138 cycles per second when at work on the circuit with its secondary open. Accordingly, by Ewing's method modified for the purpose by Dr. Sumpner, Mr. Merritt determined the inner curve shown in Fig. 11. We regret greatly not to have had time for a careful redetermination of this inner curve, and to carry the magnetization to the same maxima that was done in the transformer when on the circuit. The agreement between the cards would have been more marked even than in Fig. 11.

The assumption made by Mr. Swinburne in his remarkable and valuable paper on the "Design of Transformers" (proceedings of the British Association, 1889), would therefore, be fully substantiated. Mr. Mordey's experiments, in which *hysteresis* and *Foucault current* losses producing a common loss was determined, were performed by cycles of magnetization produced by rotation in which the degree of magnetization did not vary in amount but direction, and cannot be said to throw light on the correctness of Mr. Swinburne's assumption. Some, commenting on this paper, have used Mr. Mordey's results as evidence that these assumptions are wrong.

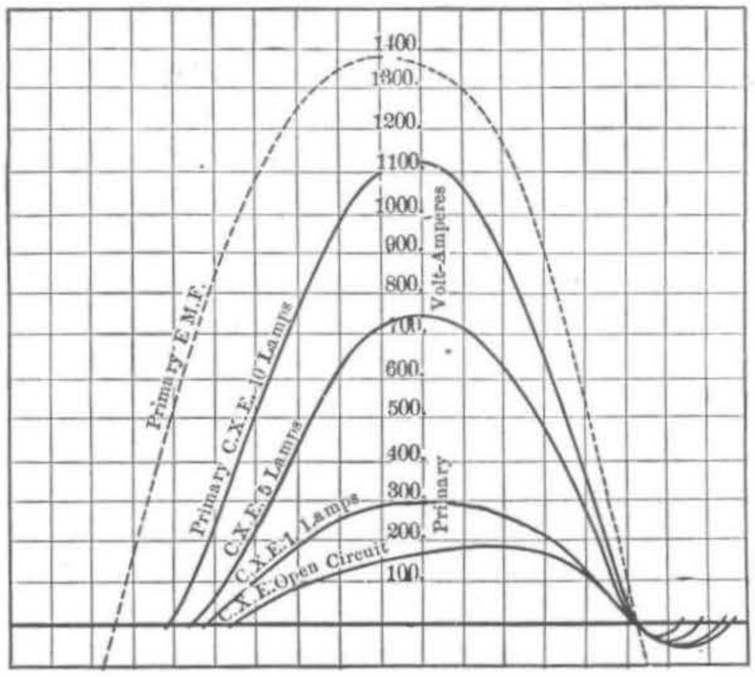


FIG. 9.

By a knowledge then of the magnetic properties of the iron, with which a given transformer is to be built, and the methods made use of by Mr. Swinburne, its efficiency is something that can be correctly predetermined.

The importance of making a transformer produce the same E. M. F. at the terminals of the secondary under all loads, asserts itself when it is used for incandescent lighting. In the transformer, under consideration from the ratios of the primary and secondary turns, the E. M. F.'s that they produce, and the variations of magnetization that had to take place through the primary, in order that the same should produce an E. M. F. equal and opposite to that of the primary impressed E. M. F., the mag-

netization produced through the secondary and the magnetization set up about the primary in its own air space are determined. In the present transformer this "leakage" of magnetism amounted to about 1.2 per cent. When the transformer works on full load, 4.5 times as much current passes through the primary, and the "leakage" of the primary in its own space is 4.5 times as much as on open circuit and becomes 5.4 per cent. This value, together with the small drop due to the actual resistances of the transformer coils, accounts for the fall of 3.5 volts that was observed by turning on all of the ten lamps.

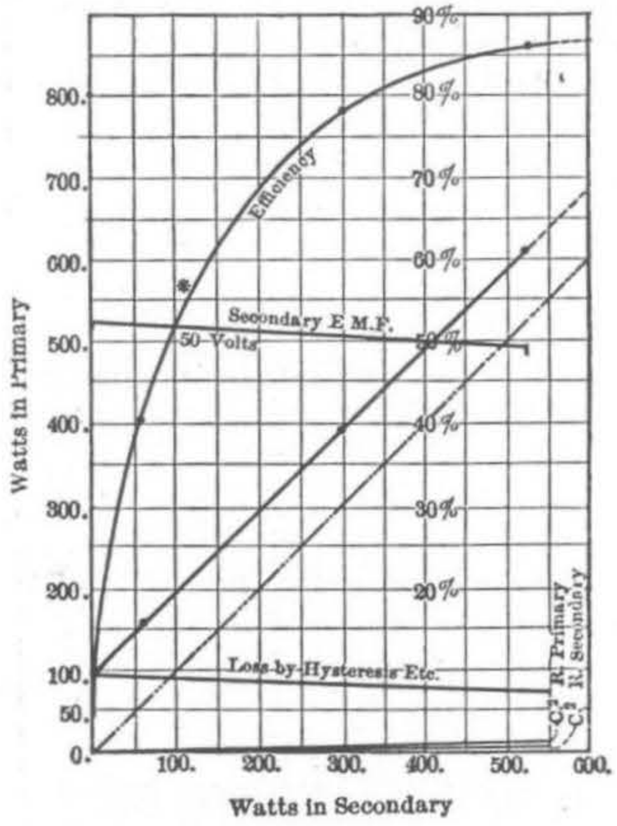


FIG. 10.

Attention might be called to a similar "leakage" in magnetism that takes place in the secondary circuit. It is plainly brought out in Fig. 8 by the lag of the secondary E. M. F. This magnetic "leakage" producing a self-induction is proportional to the secondary current. The rate of change of this quantity then is proportional to the E. M. F. that it produces. This E. M. F. is, therefore, a quarter of a period behind the secondary current, and results in producing a small lag in primary and secondary currents and secondary E. M. F.

Finally, there is a curious behavior of this transformer that remains to be accounted for. This is the considerable decrease in the loss of hysteresis as the transformer is loaded down, that is not to be accounted for by rise of temperature or the falling off of the magnetization due to the increased "leakage" about the primary in its own air space.

The following reason suggested itself to the writer, why this should take place:—

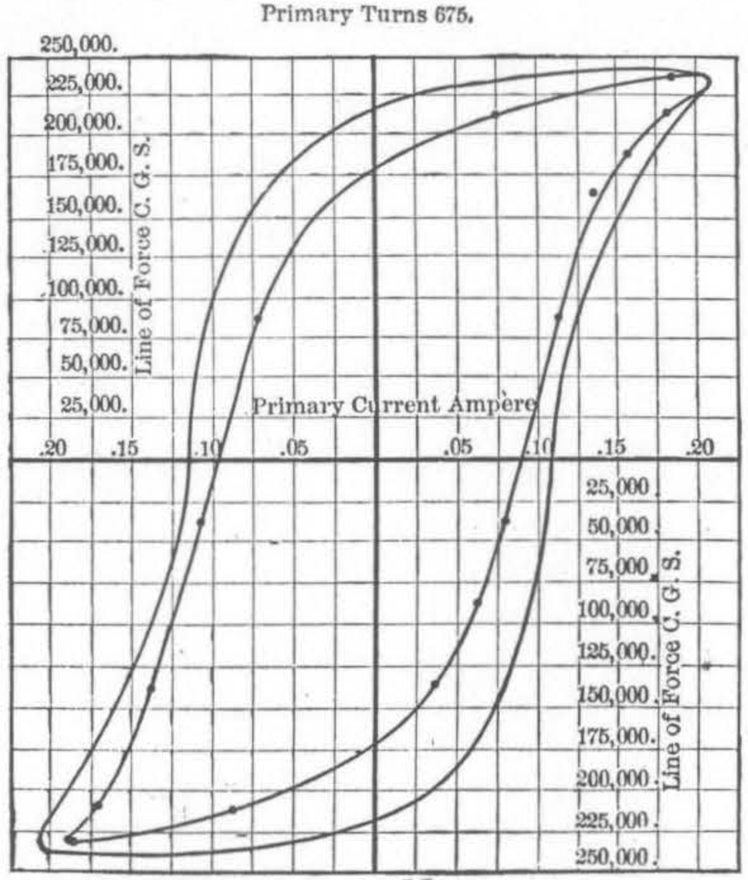


FIG. 11.

Mechanical shock has been shown to greatly reduce loss by hysteresis when iron is passed through cycles of magnetization. Since the currents are at all times opposite each other in the two coils of a transformer, strong repulsion occurs when these currents are at a maximum and no force is exerted when they pass through zero. So it follows that they continually keep thrusting each other apart when at work and add to the disturbance of the laminated iron that already exists on account of its changing magnetization. This increasing of the mechanical vibration of the iron, may therefore account for the above-mentioned phenomenon.

On open circuit the maximum magnetization of the iron per square cm. was 3,850 c. g. s.

Loss by hysteresis per cycle per cubic cm., neglecting Foucault currents, .046 watts at 138 ~ per second.

Coercive force per centimetre of the iron, 2.76 c. g. s.

In conclusion, the writer would say that the data here given show for themselves so clearly the advisability of providing some practical means for breaking the primary circuit of the transformer when not in use, that the strong advice of Mr. Swinburne in concluding his paper need not be repeated.

DISCUSSION.

MR. TOWNSEND WOLCOTT:—Did I understand Professor Ryan to say that the loss of energy is necessarily less where there is mechanical vibration?

PROFESSOR RYAN:—It seemed to us to have been so in this transformer; but we are not sure of it.

MR. WOLCOTT:—On the supposition that it is so, where does the energy come from? The idea is that the reversal of polarity of the iron absorbs a certain amount of energy in any case; is it not?

PROFESSOR RYAN:—The idea, I suggest, amounts to this: that the energy that was taken up in shocking that iron was less than what was saved in the hysteresis. That is, the hysteresis was made less by a greater amount than the energy that was spent in shocking the iron.

MR. WOLCOTT:—That is the way I understood it; but is there any explanation why that should be so?

PROFESSOR RYAN:—Not that I know of. I have not thought of the matter to any great extent, or further than I have indicated.

MR. NIKOLA TESLA:—Professor Ryan has said that the form of the primary current wave departed considerably in certain conditions, from that of the primary electromotive force; and he also stated to what he thought this departure due. I think that this departure of the primary current wave from that of the impressed electromotive force is due, to a considerable extent, to the conditions of the secondary circuit of the transformer, and I regret that Professor Ryan has not shown in the secondary an inductive resistance instead of the lamps. I think that then there would have been found a still greater departure of the primary current

from the primary electromotive force. If we close the secondary circuit through a non-inductive resistance, such as lamps, it diminishes the lag of the primary. If we close it through an inductive resistance it increases the lag of the primary In this way two effects may be produced; first, the primary current wave will depart more or less from that of the electromotive force; second, the secondary electromotive force will lag behind the primary electromotive force, as Professor Ryan has found.

PROFESSOR RYAN:—I would like to ask Mr. Tesla how he would produce that inductive resistance in the secondary circuit?

MR. TESLA:—When you close the secondary circuit through the resistance suppose that you put a coil of wire in the circuit instead of the incandescent lamp.

PROFESSOR RYAN:—Would you not be increasing the hysteresis effect in that way? It seems to me that then just what you say ought to follow. Of course it should be understood that stress is laid merely on the fact that there is a certain component at all times flowing to keep up the magnetism; but, aside from that, whatever current passes is merely the opposite of that which passes the secondary circuit?

MR. TESLA:—You sttud that this departure was due only to the hysteresis.

PROFESSOR RYAN:—Suppose that you use hysteresis in the secondary circuit, and thereby augment the irregularities of the primary circuit; is it not, after all, ultimately due to the hysteresis?

MR. TESLA:—But suppose instead of the incandescent lamp you use a coil of inductive resistance, which would take the same current as the lamp?

PROFESSOR RYAN:—When you use any device by means of which you introduce hysteresis in a secondary circuit, do you not greatly augment the displacement of the primary current?

MR. TESLA:—Of course, as we load the secondary with lamps the primary comes closer and closer to where it ought to be; and I think if you had made a trial with an inductive coil in the secondary circuit instead of the lamps it would have shown some interesting conditions. I believe Professor Ryan stated that the secondary electromotive force commenced at a given point to lag behind the primary electromotive force?

PROFESSOR RYAN:—Of course it is gradual.

MR TESLA:—Have you not noticed, for instance, when this takes place, that it began suddenly?

PROFESSOR RYAN:—No; I have not noticed that it began suddenly.

MR. TESLA:—I should say that when the secondary circuit has a different retardation from that of the primary circuit, then this condition begins. That is to say, if you have a primary coil, and you pass the current through that coil, and you have the secondary circuit closed, you then observe a certain lag of primary current. Now, if you add in the secondary circuit an inductive resistance, you can cause a still greater retardation in the primary. And if you diminish the retardation of the secondary, by inserting lamps, you diminish the retardation of the primary circuit to a greater extent than that of the secondary; thus in both cases causing the secondary electromotive force to lag behind the primary.

PROFESSOR RYAN:—I would like to say that Mr. Merritt and I intend to continue our work in this line, but, of course, we wish to vary the circuits upon which we experiment. As soon as we have done this work on the transformers we expect to take up the action of the condenser in all its relations to circuits possessing inductance, and to circuits not possessing inductance; and will test this matter which Mr. Tesla has just spoken of by working a coil in the secondary circuit, instead of a lamp. I think that a great deal is to be brought out in this way; and that one would be able, by careful study, to predict fairly well what would take place by varying the conditions.

MR. A. E. KENNELLY:—The question of hysteresis is of very great importance from every point of view. We know that we can measure the amount of energy which a converter absorbs in a given time; and we can measure also the amount of energy that it delivers during the same interval. We have then to deal with the remainder of energy absorbed by the converter uselessly; and this is to be found, first, in a purely frictional resistance to the current, whereby the energy is transformed into heat; and second, in the effect of the magnetism there is in the current producing the magnetic lag and eddy currents. It is of the very highest importance that we should be able to separate those two forces; and the paper before us gives very important suggestions by means of which we can carry that differentiation into effect. The Foucault currents can be reduced sufficiently by diminishing the cross-section of metal at every point; and we know that in good transformers such currents can be reduced to a minimum; but what we do not know is the quantity of energy which is being absorbed in the hysteresis under the conflicting conditions which are perpetually occurring.

In mechanical engineering we are brought face to face with the wonderful fact that a very large portion of its application and design lies in the general knowledge of the properties of the molecules of iron in the different conditions where iron is used; and the mystery grows when we remember that in electrical engineering it is not so much the molecular properties of iron, in the mechanical as in the electrical sense, which concerns us, and which vary perpetually in every design for apparatus; because, after a piece of apparatus has passed from the stage where the wonder is no longer new, then the question comes: How much

can we economize and save out of a given mass of iron and copper? And the question, which is coincident with that, of how much we can save of hysteresis in iron becomes of greater and greater importance.

In hysteresis we have two distinct things to deal with; first, we have the fact that the iron will not return immediately to its previous condition after some magnetic effect has been impressed upon it; and, secondly, that it has a frictional resistance, and cannot instantly obey the reversed force. In all slow working transformers, in all pieces of apparatus where the changes are slow and steady, we can generally neglect what is called the frictional hysteresis due to speed, and simply deal with the static hysteresis; but it becomes of the very greatest importance that we should be able to distinguish more clearly the statical hysteresis from the frictional hysteresis. With regard to the question asked as to the effect of mechanical shocks on hysteresis, I think I may suggest a possibility, namely, that it is simply a question of how the magnetism which has been left after a given impulse can be shaken out; and if you can shake that residual magnetism out by any means you will have that loss by hysteresis destroyed. If you will study the hysteresis chart before us you will see that the area of the curve represents actually the amount of energy which is being consumed or delivered per cycle in the iron through its residual magnetic effect; and if you can prevent that taking place the lag would disappear.

I think the question of the differentiation of the frictional hysteresis from the static hysteresis is one which is well within the reach of experimental methods, and has become one of very great importance; and if words were necessary to recommend its importance still further, is it not enough to consider that apart from practical considerations, it has also a very important scientific bearing; because, by the way in which magnetism acts upon iron (the most completely magnetic substance we find in nature) the more readily can we guess at the principles which underly the whole phenomenon of magnetism; and the more completely can we discriminate the different conditions under which that iron acts, the more truthfully shall we be able to guess at the conditions which nature imposes upon that iron.

Dr. Wm. E. Geyer:—I would like to ask Professor Ryan (if he will be kind enough to turn to the chart showing the primary electromotive force) if any peculiarity was ever noticed about half way up in the curve of the primary electromotive force; a sudden departure from the smooth curve.

Professor Ryan:—Yes; as I think of it now.

Dr. Geyer:—Last May and June there was made, under my general supervision, a very similar experiment, where, however, we used a condenser, and discharged the condenser through a galvanometer, and in that way measured the relative dimensions

of the electromotive force. We also got curves which were very smooth indeed (we took points more numerous than those that are drawn on the chart before us), until we got to a point about half way up, where we obtained results which at first were thought irregular and accidental. We skipped that part of the curve and went further up, when again it was extremely regular, until we got down on the other side to about the same height, where again the irregularity began. The irregularity was so persistent that it meant to my mind that it was not a simple accident of the experiment. We then took especial pains to determine points extremely near together just in that region, and persistently obtained a very decided jog in the curve; that is, a sudden upward motion, and a sudden downward motion, at the end of which the perfect regularity of the curve was resumed; and on the other side again there was the same irregularity, and the same jog on the descending curve. I have not found any satisfactory explanation as to the cause of it. If any could be offered by any one present it would be very interesting. I might mention in addition that when these same curves were determined on an open circuit, or on a non-inductive resistance, the irregularities were not noticed. They were only noticed when the transformer was a part of the main circuit.

Mr. Tesla:—May I ask whether the machine was run at a constant number of alternations all the time?

Dr. Geyer:—The machine was run at constant alternations—the regular commercial speed.

Mr. Tesla:—I think if the number of alternations had been varied, greater irregularities would have been observed. I think it will be found that if a higher number of alternations had been chosen, the irregularity would have been more pronounced, until a certain limit was reached. I have run them as high as 15,000 alternations per minute. Where the alternations were very low the irregularities disappeared; but when the same number of alternations, with a longer magnetic circuit in the transformer was employed, they would again appear. So that, as I know that the magnetic lag was varied by the length of the magnetic circuit, I assume that this was the cause of the irregularity. Mr. Kennelly has very ably, and rightly, brought up the importance of the study of hysteresis. I think this is a field in which we should all work and achieve considerable improvement; so much so that certain of my experiments have been rather surprising; and in investigating the cause of the lag of the iron we will find the experiments not only of value to investigators but of real value to us practically.

Mr. Joseph Wetzler:—In reference to the remarks made by Dr. Geyer as to the cause of the notch in the curve, it seems to me that it might principally be due to irregularities in the nature of the field. The field poles may have different intensities over

different parts of the surface, so that if more strongly magnetic all around the edge than at the centre they would produce an irregular field, which would cause a corresponding effect in the current produced; so that all of the curve would not be regular.

Mr. C. O. Mailloux:—I am inclined to believe that the theory advanced by Mr. Wetzler is the correct one; and I think that the notch in the curve is accounted for by the dynamo, rather than by the reaction of the converter upon the impulse. The fact is, that in a dynamo we never have a uniform distribution of the lines of force, from the very fact that towards the centre, the lines of force are more dense than in the area which is contiguous to the edges. The consequence is that when a coil is approaching the edge of the pole it is approaching a spot where the lines of force are more dense; and after it has passed that spot it finds itself in place where the lines of force are not so dense. It again meets towards the middle of the pole, a place or period where the lines are denser; and again as it comes to the outer edge, a place where the lines of force are not so dense. Now, if you bear in mind the fact that the lines of force are merely the exponents or indicators of the condition of the magnetic medium, showing that there is a highly elastic substance under great stress or tension there, then we may replace those lines of force by elastic substances; and you will find on theoretical reasoning that you would naturally expect that the action of the wire, the moment that it begins to have the current in it, would be to react upon the lines of force and displace them at that point. We know that such is the case in continuous current dynamos, but not with alternating currents. We know that the lines of force are distorted and thrown out of their course by the action of the current in the armature itself. Professor Elihu Thomson has shown by experiment that there is such a crowding effect on the lines of force that, as a matter of fact, the area of the coil, or the contour of the coil, should inclose a smaller area than the area of the pole possesses. I should imagine that the notch in the wave of the impressed electromotive force would be due to the fact that, as the current approaches, it first meets with an obstruction which is too stiff for it to bound over, and therefore immediately cuts the lines of force, creating a high tension, which produces a higher electromotive force. Then we come to a place where the field is more uniform, and consequently we get the action which we would naturally expect—a current more nearly uniform, and at a rate more in accordance with some fixed law. Then as we come to the outer edge we must pass through another crust of the lines of force, and we would naturally expect to find another big break and a slight up-wave. Pursuing the same reasoning you will find that this would take place just exactly as Dr. Geyer has found by experiment; and that the speed at which the alternations occur have a great deal of influence upon that. I should have expected that the lines of force, being like all elastic substances, more brittle to a rapidly acting force, would show that effect more perceptibly at higher alternations than at lower ones.

Mr. Tesla:—Just a word before you pass to another subject. That opposition which was alluded to as occasioned by the dynamo machine might not have its cause in the machine; but that very kind of opposition may exist in the transformer itself; and there is where I believe it does exist. I was sometime ago engaged in some work in getting direct currents from an alternating current; and I found that I was able to produce a preponderance of current impulses in one direction over those of another; and then I found that under certain conditions an opposition appeared, exactly as was stated by Mr. Mailloux in regard to the dynamo machine; and that such conditions can be brought about; and that they depend greatly upon the iron, on the number of alternations, and the length of the magnetic circuit. Imagine, for instance, that you have in the magnetic circuit of the transformer, magnetism in one direction set up; certainly if such magnetism exist it will oppose the passage of a current of a certain direction; and in this way a certain modification of the curve would be brought about.

Mr. Mailloux:—I am very glad that Mr. Tesla spoke of that. I might have gone farther, and said that undoubtedly the same phenomenon would occur in the transformer core itself, and that there would be changes of magnetism there under different circumstances; but inasmuch as he has so much more ably explained it than I could, I need not refer to it again. The only other point I wish to advert to is in connection with some of these curves. I would like to ask Professor Ryan whether he has taken the trouble to follow the concomitant variations of the values of the inductance; that is to say, the instantaneous values that we are supposed to get for the inductance at different variations of the electromotive force; so that we might be able to get a means of comparison between theory and practice. As we all know, the theory of the transformer is one thing, while the practice is another thing, quite remote and apart from it; so much so that the theory, although it is not yet complete, is already behind the times. We know also that that innocent looking symbol designated by L, which represents the inductance in a transformer circuit, does not happen to do so in the transformers which we use in practice. It does so on paper, and in mathematical equations, and also in transformers which have no iron. Now it would have been quite interesting if Professor Ryan had undertaken either to calculate or derive the value given for the inductance; so that we might from that calculate the impedance of the circuit; or, in other words, that spurious resistance factor by which we must multiply the square of the virtual current in order to get the energy that appears in the circuit.

Professor Ryan:—If I have understood Mr. Mailloux's question I will answer it in this way: That if you take what is the accepted theory of the transformer up to date, and which assumes always. I believe, that the relation of the current and magnetism of the iron is the same in an up curve, as it is going down; taking that theory as it has been elaborated, and the suggestion made by Lord Rayleigh about a year ago, that is to say, taking the transformer and observing the relation of the magnetism of the iron corresponding to any particular number of ampere turns going up and coming down, to modify that theory (because it is not always the same), and when you have measured the difference that exists in going up and coming down, you will get exactly the state of affairs that is here found actually to exist. The suggestion that was made by Dr. John Hopkinson in a note published in the Proceedings of the Royal Society a few years ago, made a faint suggestion that if you assume the dotted curve in Fig. 5. and substitute for the same a curve as modified by the values which you obtain through *hysteresis*, you will get precisely this state of affairs brought out in Fig. 5 as observed for the primary current. One thing more with regard to the method by means of which you can express the exact shape of those curves mathematically, and therefore proceed by means of mathematical investigation, and by means of the impressed electromotive force that we have here given, to find what it is, and what should follow. I will say that Mr. Merritt has carefully analyzed the properties of those curves, and has shown that the impressed electromotive force curve is made up, in the first place of a sine curve in unison with it, and another curve of the third order running along like *this;* (indicating) of which the equation would be:

$$E_1 = 1{,}500 \sin \theta - 42. \cos \theta + 100. \sin 3.\theta + 28. \cos 3.\theta;$$

and finally one of the fifth order; and if we should carry it one further we should find with it one of the seventh order—in odd orders, the even orders having disappeared, or else the magnetism would be heavier on one side than on the other. But matters of that sort are very technical; and I did not think that these curves, representing the constituents of these various curves, would be of much interest, or I should have brought them with me.

Mr. E. G. Acheson:—I understood Dr. Geyer, in speaking of the notch in the curve, to say that he obtained it only when he had the transformer in. That being the case it can scarcely be due to the machine.

Dr. Geyer:—The notches were not obtained when the dynamo was run on an open circuit.

Mr. Kennelly:—In that case, I venture to say that it must be due either to the magnetic lag or else to a variation in the self-induction. If the processes of self-induction were variable it might be expected. With such variations it is probable that such kinks would follow.

Dr. Geyer:—Am I right in understanding Professor Ryan to say that the efficiency of the transformer was 85 per cent.?

Professor Ryan:—Eighty-six and six-tenths per cent. when working with ten lights in the secondary.

Dr. Geyer:—Was that efficiency tested also in some other way?

Professor Ryan:—No; it merely come in as a secondary matter.

Mr. Mailloux:—It strikes me that Doctor Geyer knows more than he wants to tell us about the transformer tests. I have been told that some extensive work has been going on at Stevens Institute, and it would be interesting to get some information about it.

Dr. Geyer:—What I could say about it has already been published in the *Journal of the Franklin Institute.* It would have been read before this Institute, except that it came late last year, in June, before the summer vacation; and there were so many other papers that it was crowded out. The other tests we made, are very much like those of Professor Ryan, except that we used a condenser as a means of measuring the electromotive force; and we worked a 20 light transformer instead of a 10-light; and the mechanism for taking off the instantaneous electromotive force was slightly different. It is hardly worth while to go through details, as a larger part would be repetition. I have not seen anything in Professor Ryan's charts that differs from those that we obtained. So far as I can see, the results are essentially of the same nature.

The Chairman (Vice-President T. C. Martin)—I understand that Mr. Stillwell, who is Mr. Shallenberger's associate, is here, and if he is moved to speak we would be glad to hear from him before the meeting is closed.

Mr. L. B. Stillwell:—The work that Professor Ryan has introduced to-night is in the general line that we have been working on for two or three years. I had not intended to add anything to the discussion, but there is one point that I might mention which may possibly be of interest, and that is, that we have noticed the point to which Professor Ryan referred in the case of a 10-light transformer, wherein he found that the loss due to the iron decreased as the load is added to the transformer. We have observed that this decrease is more marked in the case of a small one. In a 40-light transformer the iron loss is more nearly a constant; and it seems to me that this fact is in the line of the explanation which has been suggested, as to the shaking out of the magnetism, and the consequent decrease of loss in iron at heavy load in small-sized transformers, as larger ones would be somewhat less liable to mechanical vibration

If I have understood the diagrams correctly, there is one other point which differs slightly from the observations I have made, in

which observations, however, I used the divided electrodynamometer method of measuring the angle of lag. Of course, that method is based upon the assumption that these are sine curves. Applying that method we have found that the lag factor, or cosine, is somewhere in the neighborhood of 70 degrees; and as load is added to the secondary the factor increases more rapidly, than shown by the curves that Professor Ryan has drawn. For example, with five lights on the secondary I have found that the primary and secondary currents are practically 180 degrees apart, the cosine of the angle of lag being about 98 degrees. With that explanation the discrepancy may possibly be due to the irregularity of the primary current, as the diagram by Professor Ryan shows.

I will say that we have also quite recently adopted a method of drawing an accurate diagram of the wave E. M. F. The method is due to Messrs. Scott and Morris, of our laboratory. I have not applied it yet, and have not seen it applied to the purpose of noting accurately the form of wave derived from our ordinary machines, since we have been more especially engaged on new types and various experimental work. The method, however, would afford a very ready means of checking up this observed kink in the curve; and I shall take the trouble to make experiments as soon as possible to throw light on that point. The method in question consists simply in mounting upon the armature shaft a wooden disc with a metallic contact at one point in the periphery, this point being connected with one terminal of a voltmeter, while the other terminal of the voltmeter is attached to one collector of the dynamo. A brush that is connected with the other collector touches the metallic point on the disc once in each revolution. By altering the position of the disc we can get a potential reading on the voltmeter proportional to the electromotive force developed by the machine at any given position of the armature, and moving it gradually through 180 degrees we have obtained surprisingly accurate results—the quantity of current through the voltmeter being large and the time being very slow. The cards I have seen made out in the last week are very accurate, and show perhaps 40 points on a phase diagram. I regret that I have none of the cards here, as they might be interesting in connection with the points brought out.

I would like to add one observation, and it is with regard to the observed efficiency of the transformers. It is, of course, understood that the efficiency of a small transformer is necessarily much less than that of a large one. The conditions heretofore have been such as to compel the use of small transformers, but the tendency as we observe it is very generally towards the use of larger ones. This tendency will do away in a great measure with the implied criticism upon the efficiency of the transformer system.

DR. GEYER:—I might say that three years ago, when the then existing methods of measuring the efficiency of such apparatus were very uncertain, we resorted to some heroic treatment of it. We stripped the transformer of its outer coil (which I think has not much to do with its efficiency) and the whole transformer was immersed in kerosene oil, and the transformed current was also used up in a calorimeter, consisting of a jar of kerosene; and then we found that as the load was increased the proportion of heat in the calorimeter to the total heat produced, was less and less as the load was made greater and greater.

MR. TESLA:—Mr. Stillwell has alluded to a method of tracing the wave. I would like to ask the members if any of them have ever made an attempt to find out whether there is a difference when the laminated sheets of the transformer are loose or tight, and if not I wish some one in his idle hours would investigate that; because I have reason to believe that there is a difference when the sheets are tight and when they are loose. Of course, it might be due to the imperfect contact of loose sheets, which would tend to diminish or increase the circulation of Foucault currents.

Adjourned.

Mr. Tesla's Principle of Designing Motors.

BY A. GAILLARD.

I beg to make a slight remark concerning Mr. Tesla's novel principle of constructing electric motors as described in your issue of Dec. 14. You say : " Mr. Tesla reasons that in any motor the total energy supplied to do the work is equal to the sum of the energies expended in the armature and the field. The power developed, however, is *proportionate* [not more] to the product of these quantities." It is added that this product will be greatest when these quantities are equal.

Very well, this states the fact that two numbers of constant sum give a larger product when made equal. But that we are not concerned in, as what we want is to have not that product to be the largest, but the product of that product by another quantity, which is variable for every system of values of the energies at work in the motor.

In the example given we can easily see how the quantity referred to comes in. Let us assume, as you do, that the energy as represented in the magnetism in the field of a given motor is 90, and that in the armature 10. The sum of these quantities, which represents the total energy expended in driving the motor, is 100.

Now, calling a the quantity to which the power developed is proportionate, we can equate the energies corresponding to the supplied and expended energies as follows :

$$\underbrace{90}_{\text{(spent in field magnets)}} + \underbrace{10}_{\text{(spent in armature)}} = \underbrace{(90 \times 10)\, a}_{\text{(power developed).}}$$

If we suppose that the efficiency of the motor is perfect we see that a is here equal to 1.111. Taking now the second case, in which the field and the armature each consumes 50, we have :

$$\underbrace{50 + 50}_{\text{(power supplied to the motor)}} = \underbrace{(2{,}500)\, a}_{\text{(power furnished by the motor);}}$$

but it is evident that here a can never be equal even to $\frac{1}{25}$.

Consequently, this factor a has not to be summarily thrown aside, even in the most novel principle of constructing electric motors.

ALTERNATING CURRENT MOTORS.

BY W. M. FAIRFAX.

In English patent 4,120 of 1881, to Deprez and Carpentier for "Distributing Electric Currents and Tansmitting Power by Electricity" on page 4, lines 20 *et seq.* is described an arrangement of apparatus in which an alternate current generator (presumably a magneto electric machine) supplies current to a circuit. Connected with the leads of said circuit, either in series or multiple arc, are magneto electric machines, whose armatures have no commutators but simply collector rings, and to these rings are supplied the alternate currents from the source. It is stated that these motors would run at precisely the same speed as the generator. It is evident that these motors would have to be started in order to get them up to "synchronism" before they would run at all. This is the earliest mention, as far as is known to the writer, of running alternate current generators as motors by alternating currents. Nothing seems to have been done in this line until sometime before 1883, when Dr. Hopkinson made an elaborate series of experiments on the action of alternate current generators coupled in various ways.

In the course of experiments he verified the statement made in the English patent No. 4,120 of 1881, before referred to. He found that if an alternate current generator was connected to the circuit of another similar generator supplying alternate currents, the first generator would run as a motor and at precisely the same rate as the armature of the second generator. But the great difficulty was that the motor had to be started by some outside means, and that it would readily get out of synchronism when overloaded.

Dr. Hopkinson's experiments are described in a lecture on electric lighting delivered by him before the British Institution of Civil Engineers in 1883. In the *Journal of the Society of Telegraphic Engineers and Electricians* for 1884, Vol. 13, pages 524 *et seq.* is a report of a lecture by Dr. Siemens in which he stated that by constructing the cores of the armature and field magnet of a direct current dynamo of his own type in the way that Prof. Hughes had suggested in a lecture a year or so before, *i. e.*, by making them of very thin sheets or laminae so that they could be very rapidly magnetized and demagnetized, he could supply such a machine with an alternating current and it would start from rest, and run as a motor would run supplied by a continuous current. He tried connecting the armature and field magnet coils of the machine both in series and shunt, and found that the motor would run in either case. Of course the reason of this was that the current changing in armature and field magnet coils at the same time the cores of both were de-energized and magnetized in the opposite sense at approximately the same time, and hence the poles of both elements always presented the same relative polarity. But there are two difficulties presented in this type of motor. These are:

First: That the cores do not change their polarities at precisely the same time; and

Second: That even though laminated the rapid alternations cause a heating of the cores by waste currents and hence loss of energy.

Next come the noted experiments of Prof. Elihu Thomson described in a paper before the American Institute of Electrical Engineers [1] on "Novel Phenomena of Alternating Currents."

Prof. Thomson found that when a core energized by an alternating current flowing in a coil around it had a closed conductor brought near it the first coil tended to repel the second conductor away from it. The reason given by Prof. Thomson was that the secondary currents induced in the closed conductor were so far retarded by self induction that the currents in alternating coil and the closed conductor during the greater part of each "wave" were in opposite directions and hence repulsion between the respective coils ensued. To utilize this principle Prof. Thomson constructed a motor as follows: A coil with or without a core is mounted upon a shaft, the ends of the coil are connected to two segments of a 4-segment commutator; upon the commutator rest two brushes which are connected to each other by a closed circuit, over this moving coil is mounted a fixed coil with its magnetic axis in the same direction as the first coil. This second coil may or may not have a core. The fixed coil is connected to a source of alternating current. The brushes are so arranged that they rest upon the two segments connected to the ends of the moving coil when said coil is in a position to have the repulsive effect of the other coil come into play, *i. e.*, when the moving coil is at an angle to the plane of the fixed coil. When the removing coil is in other positions, its ends being connected to segments on which the brushes are not resting, it is open and of course no current is then flowing in it.

By increasing the segments in the proper proportion any number of coils may be placed upon the same shaft; the brushes in this case also only closing the circuit of that coil which is in proper position to be acted on. The efficiency of this motor has not been determined. Dr. Duncan of the Johns Hopkins University in a lecture before the American Institute of Electrical Engineers, February 14th, 1888, describes several types of alternating current motors.[2]

Among the various types he mentions, is an alternate generator used as a motor, the armature being supplied with alternating currents uncommutated and its field magnet with the same current rectified by a commutator on the shaft. In this case the motor should have highly laminated field magnet cores, but it will start as Dr. Duncan says, from rest and increase in speed until it reaches synchronism with the generator. For, as long as it is not in synchronism with the generator, the polarity of the field magnet cores will be reversed as often as that of the armature is reversed, until the armature poles get opposite the field magnet poles when the brushes pass from one set of segments to the other and the relation of polarities of the armature and field magnet changes. When the armature gets into synchronism, the field magnet receives practically a continuous current. Dr. Duncan also suggests that, with a synchronizing motor, may be combined several types of the self-starting motors for the purpose of bringing the main motor to speed. Either the alternate current motor with the rectified field magnet current or the Thomson type of motor above described may be used for this purpose. Dr. Duncan thinks a very efficient motor would be the following: construct a motor with both commutator and collector rings, each having its respective set of brushes. Start the motor with a continuous current supplied to the brushes on the commutator, and when the motor has reached a proper speed by changing a switch, break the first circuit, and complete the circuit of the second set of brushes by connecting them to an alternating current source. Thus the motor starts as a direct current motor and then afterwards it becomes an alternating current motor. The objection to this type is that two circuits are necessary, one connected to a continuous current source, and the other to an alternate current source.

Lieut. F. Jarvis Patten, at the same meeting at which Dr. Duncan delivered his lecture, described a motor constructed as follows: two series of copper discs are arranged around the inner side of a frame, the cross section of which is a polygon. These discs form closed circuits of great self induction and form what is called the armature of the machine.

1 Vol. IV of Transactions., 1887, p. 160.

2. "Transactions of American Institute of Electrical Engineers" for April, 1888, Vol. 5, page 229, *et seq.*

Extending lengthwise within this frame through its center is a shaft upon which are arranged, under the discs, two series of poles, wound with coils, the poles of one set occupy circumferentially a position 45° removed from the poles of the other set, so that when one set of poles is directly beneath the discs around said set, the poles of the other set are half way between the discs of the other set. On the shaft is a "sun-flower" commutator upon which rests a brush connected to one of the leads of an alternating current generator. One series of alternate segments of the commutator is connected in one set and the other series of segments in another set by connecting wires. Each series is connected to an independent circuit which includes the coils of one set of poles, the other ends of said circuits being connected to a ring upon which rests a brush connected to the other lead of the generator. By this means, as the commutator rotates, the alternate current will be set, first through one set of polar windings and then through the other.

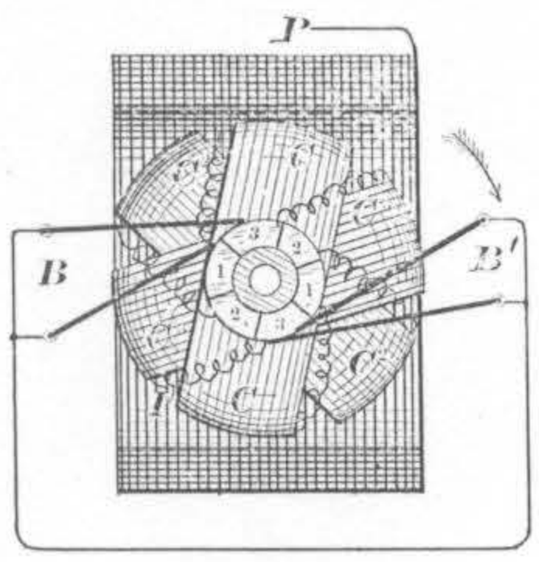


FIG. 1.

B is a stationary coil connected to an alternating current source; C, C1, C2, are coils, the terminals of which are connected to segments 1,1; 2,2; 3,3; respectively of a commutator; upon this commutator rest the brushes, B, B1, which are connected to each other by a conductor. As each of the coils, C, C1, C2, get into the proper position, the brushes B, B1, close the coil upon itself, and then there flows therein an alternating current inducted from primary circuit.

By proper arrangement, each set of poles will be energized at the time the armature closed circuits would have their greatest action or "pull." This motor is obviously a modification of the Thomson repulsion motor.

On the 22nd of April, 1888, in an Italian paper (*L' Elettricita*) devoted to electrical science and its applications, appeared an account of a very remarkable invention by Prof. Ferraris of Turin. The article is called "Electro Dynamic Rotation." In a course of experiments on the action and properties of alternating currents, the professor was led to consider the relationship of currents of different phases to each other, i. e., currents whose periods of maximum strength and electro-motive force do not coincide. In the beginning of the article, the professor proposes to superpose the fields due to two alternating currents of differing phase. He assumes that the direction of said fields is approximately at right angles. He then shows by a short mathematical demonstration that the resultant field would rotate about a center, O, with uniform velocity, and that said field would be of constant intensity. He then goes on to show how the described effect can be produced. It may be accomplished in several ways; one mode is to pass an alternating current through the primary coil of a transformer and to utilize the said primary current and also the secondary current of said transformer as follows: Place two coils with their axes at right angles and send the primary current through one of the coils and the secondary current through the other of the coils. The secondary current from the transformer must of necessity differ in phase from the primary current, for it takes an appreciable time to magnetize the core by the primary current and then for the core to induce a current in the secondary winding. This retardation in most transformers causes the secondary to "lag" behind the primary almost half a phase. To get proper results the currents must differ approximately one-fourth or three-fourths of a phase, i. e., the maximum period of one current must nearly coincide with the minimum period of the other.

In order to get the necessary difference of phase a suitable resistance may be inserted in the secondary circuit. The resultant field due to currents flowing in these two coils will approximate to the theoretical rotary field. Another way to get the two oscillatory component fields is to use the secondary currents produced by two transformers or two portions of one transformer. Of course the secondary windings or the cores of the two transformers, or the two parts of one transformer, must differ enough to cause the required difference of phase, *i. e.*, the secondary windings must differ in the number of convolutions or in cross-section of the wire, or the cores must be of different masses or magnetic susceptibility. A third way, the professor states, is to use currents in two derived circuits of an alternating current circuit. In one of the circuits is introduced a coil of small resistance and high self-induction and in the other a resistance of no self-induction. In the circuit in which the high self-induction coil is placed, the current will lag behind the current in the other circuit.

If in any of the resultant fields a closed conductor is placed, currents will be induced therein which will tend to form poles, which poles will be dragged along by the rotary field, and if the conductor be properly mounted upon a spindle it will rotate with the field.

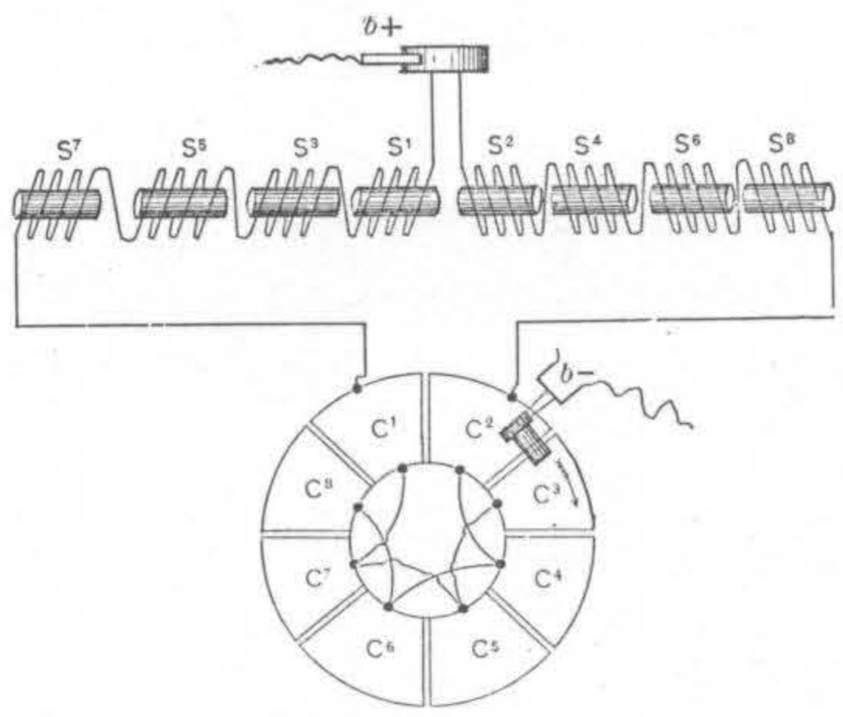


FIG. 2.

The alternating current enters at ring b, then alternately flows through S1, S3, S5, S7, and S2, S4, S6, S8, to the respective sets of commutator segments, C1, C3, C5, C7, and C2, C4, C6, C8. The coils, S, etc., and commutator are mounted on the same shaft, a second brush b resting on the commutator takes off the alternating current; around these revolving coils are the stationary closed circuits on the motor frame concentric around the shaft.

About a month after Professor Ferraris's discovery was announced in *L' Elettricita*, there were issued to Mr. Nikola Tesla, of New York City, several patents which set forth a method of producing rotary motion by alternating currents. The general idea of a rotary resultant field is the underlying principle of these patents, as it is the principle of Ferraris's motive device. As Mr. Tesla well says, in all continuous current motors, there is a progressive shifting of the poles of one element while the poles of the other element are fixed. This will be plain on carefully regarding the action of the current in the armature of a Gramme motor for example. Rotation in such a motor is, of course, produced by the attraction and repulsion of the armature poles by those of the field magnet. The position of the brushes upon the commutator determines the poles of the armature, *i. e.*, the places where the current flows into and out of the armature coils; now, as the armature advances in its rotation the

qrushes are being continually moved back as regards any fixed point in the armature core, and hence the polar points in the same core are being shifted continuously back as regards any point in the core though they are fixed as regards space. Now Mr. Tesla thought that if by means of alternating currents he could produce a continuous shifting of the polarities in one element of a motor he could obtain rotation. This was the problem. Now, he found that if he should at any one instant magnetize two opposite points of a stationary core and then magnetize two opposite points 90° from there, the magnetization of the first points having ceased, then he should again magnetize the first points, but with opposite polarity to that which they before had; and then in time magnetize the second set, but with opposite polarity, he would have the desired rotary field.

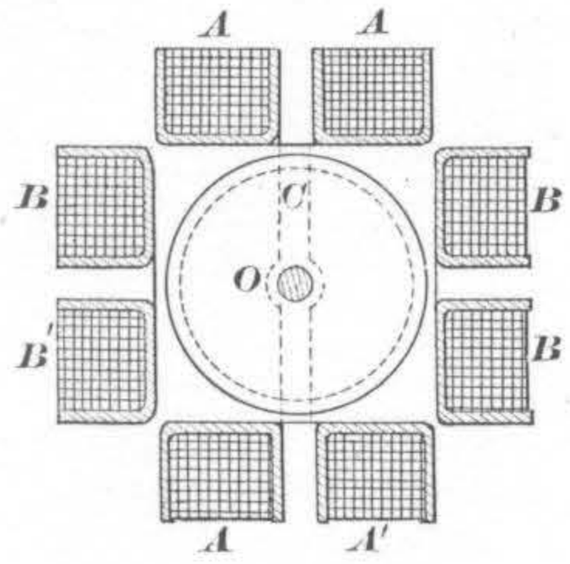


Fig. 3

A, A′ are one set of coils connected to conductors supplying alternating current. B, B′ are another set of coils connected to the other conductors supplying alternate currents whose phases are displaced from those of the first source. C is the conductor (preferably of copper) mounted to rotate through the influence of the rotary field of force.

This he found he could accomplish by two sets of alternating currents, whose phase differed by about 90°, *i. e.*, the maximum periods of one set coinciding with the minimum periods of the other. To produce said currents he wound the core of a drum armature with sets of coils placed at angles to each other and connected the ends of each set with independent rings. The rings of each set were connected to the leads of an independent circuit. As each set of coils occupies a different circumferential position it is evident that each set cuts the maximum number of lines of force at a different time from the other.

Hence the currents in the various sets of coils will differ or be displaced in phase. One of the motor elements is provided with magnetizing coils connected in diametrically opposite pairs or groups to independent terminals. To these independent terminals are connected respectively the independent circuits of the generator.

This element of the motor is usually stationary, but if rotary, then the connection must be made through rings, upon which rest brushes connected to the generator circuits.

As the currents rise and fall in the generator circuits, the motor energizing circuits are energized in succession and the polar points are progressively shifted continuously forward and thus a rotary field is obtained.

The other element of the motor may be a single magnetic body having no coils, a coil wound with closed coils or it may be similar to the first element of the motor. In this case the two poles of the two elements are shifted in opposite directions. Tesla has, in a number of subordinate patents, made many specific improvements. Other inventors have also made advances in this same line.

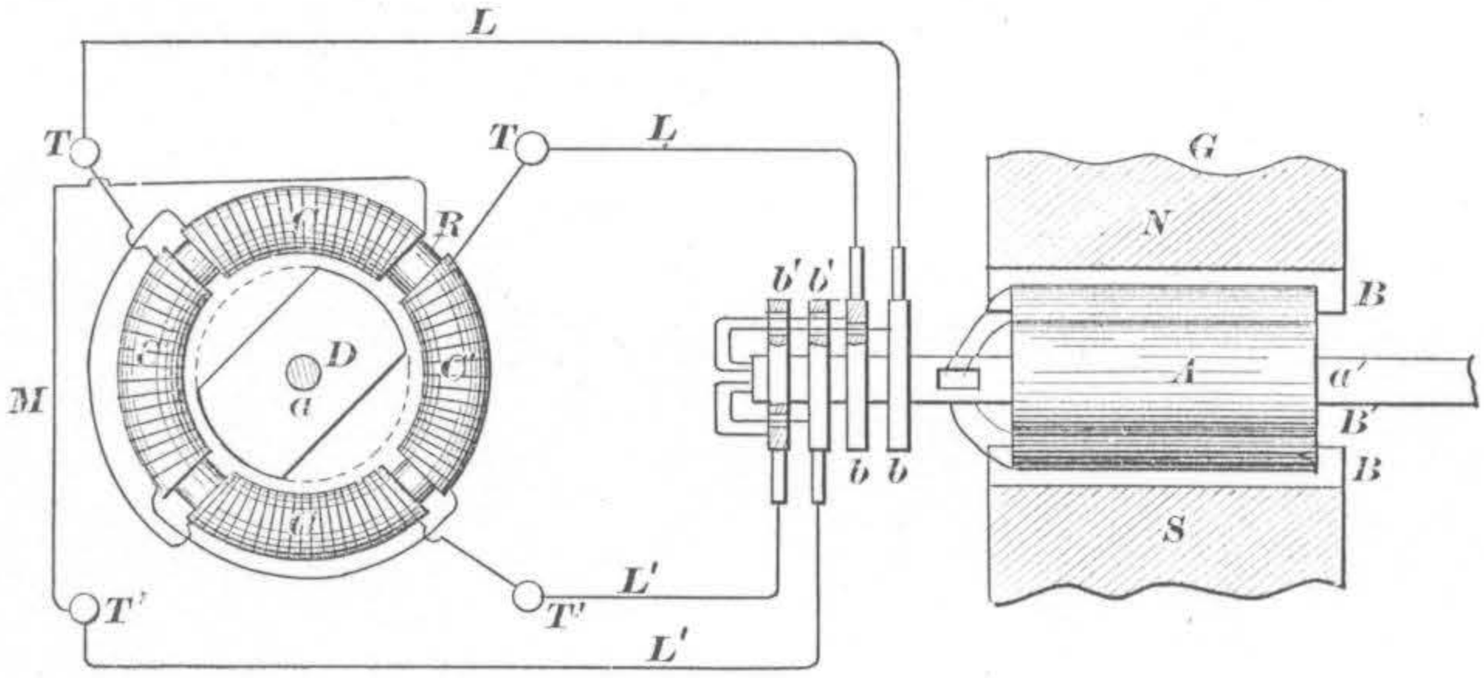


FIG. 4.

G is an alternating current generator having the field magnet with poles, N. S. Upon the armature core is wound the two coils B, B′, at right angles to each other. The ends of the coil, B, are connected to rings, b, b. The ends of coil B′ are connected to rings b′, b′. Upon b, b, rest brushes connected to circuit, L, L. Upon b′, b′, brushes which are connected to circuit, L′, L′. L, L is connected to coils C, C, on one element of the motor, and L′ L′ to coils C′ C′, on the same field magnet, but at right angles to C, C.

D is the other element of the motor. As the generator rotates alternate currents are induced in B and B′, but when the current in B′ is at a maximum, that in B is at a minimum. Hence the circuits L, L′ and L′ L′ receive in succession currents, which flowing to coils C and C′ in turn cause said coils to form poles in the element R, as the coils are at right angles, said poles will be at right angles, one set of poles rising while the other set is falling and hence, as the currents are alternating, produce a constant shifting of the polar points in core, R.

DIRECT FROM ALTERNATING CURRENTS.

BY HAROLD BINNEY.

The interest aroused by the article on the "Tesla System of Obtaining Direct from Alternating Currents without the Use of a Commutator," which appeared in the *Electrical World* of November 2, 1889, p. 290, has led to a reply in the London *Electrical Engineer* for November 15, p. 386.

The English article denies the operativeness of all forms of the device in the following terms: "The great reputation of Mr. Tesla as an ingenious inventor, combined with the excellent character of the journal, which, in all seriousness, puts forward his latest invention, might however lead men to think that, notwithstanding its startling character, this invention is really good, and will work. If so, they will waste much time over a hopeless problem, and it is principally to prevent this that we propose to briefly point out in what the fallacy lies."

I confess that I have been one of the first to give my time to the "hopeless problem" without discovering all the supposed fallacies ; but, on reading the English criticism, I was struck by the utter failure of its author to comprehend the simple principles of the scheme. Has its startling character been too much for the English commentator, or is Mr. Tesla's device as useless as is alleged?

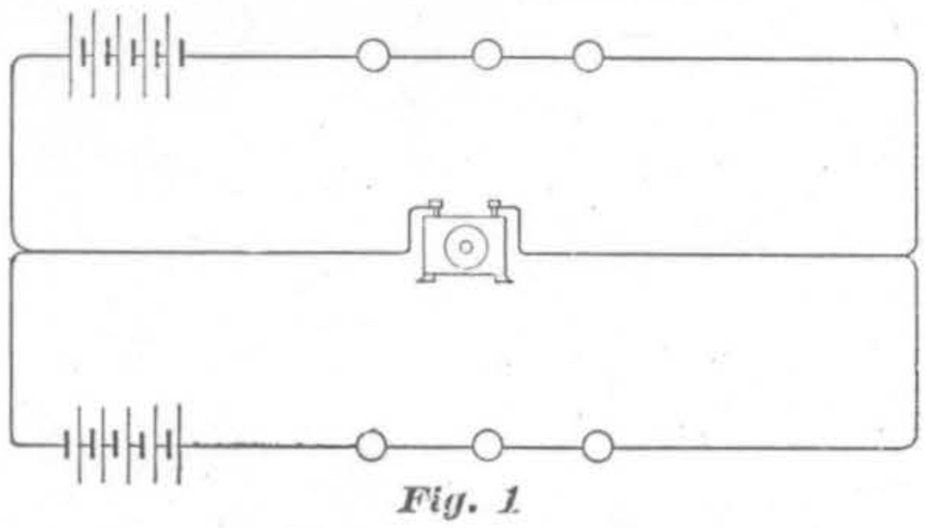


Fig. 1

Take, for example, the diagrammatic illustration of the principle as shown in Figures 1 and 2. The alternate current dynamo circuit is split into two branches, each containing an electro-motive force and translating devices. The electro-motive forces are oppositely directed, and each is of value approximately equal to the generator impulses.

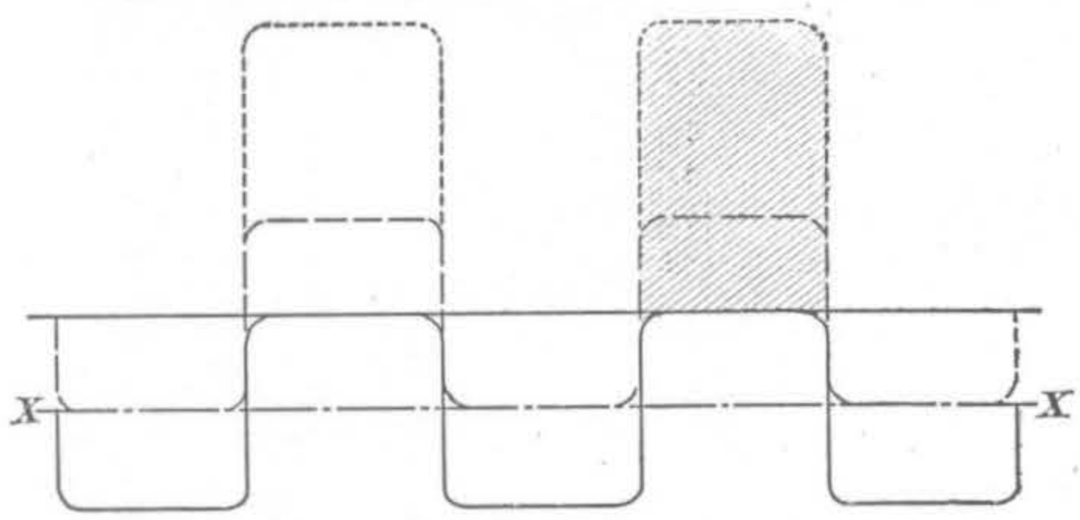


Fig. 2

For the convenience of a graphical analysis of one branch, let us regard the straight line in figure 2 as representing the electro-motive force of the battery in one branch ; the curved line as representing the electro-motive force of the generator, and the dot and dash line as the neutral line. Of course the horizontal coördinates represent time. For convenience the alternating curve has been distorted from its more nearly sinusoidal character. From a consideration of these curves, it is clear that the resultant electro-motive force, in the branch considered, will be represented by the dash line. During one-half the phase the resultant electro-motive force is the difference of the two opposing electro-motive forces, and, during the other half, the sum of the two cumulative electro-motive forces.

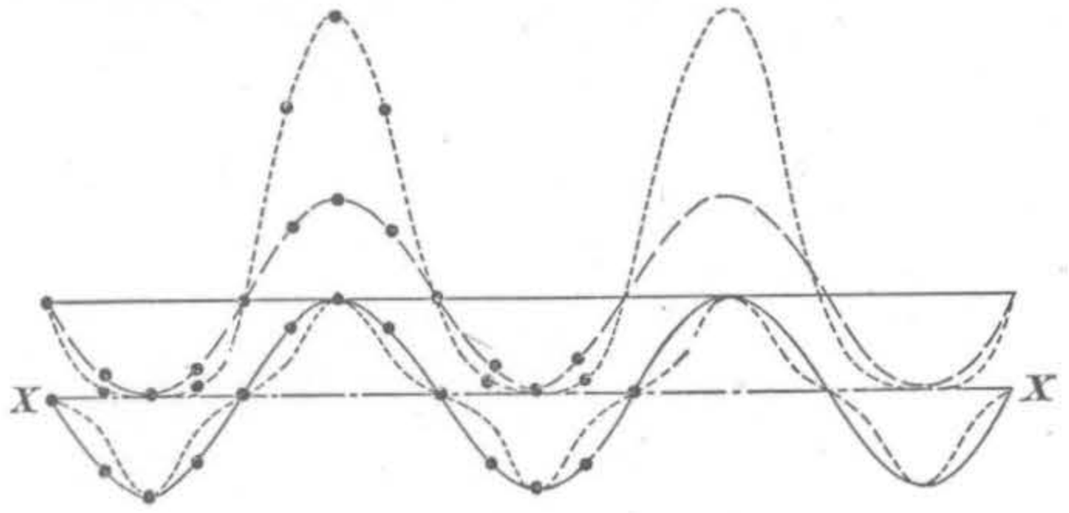


Fig. 3

The English commentator remarks that, "So far there can be no doubt that the arrangement will work, but it is equally clear that whatever electrical energy is developed in the circuit is entirely derived from the two batteries, and the amount of energy would not be altered if we disconnected the machine altogether." This is going ahead rather fast, and the fundamental laws of energy seem quite forgotten. If it be borne in mind that the electrical energy is proportional not to the current strength, but to the square, of the electro-motive force and to the square of the current, is the conclusion still "equally clear"? Let us look again at figure 2, in view of the law that work or energy is proportional to the square of the electro-motive force and to the square of the current:

$$W = C^2 RT = \frac{E^2 T.}{R}$$

Let us call the energy that would be generated by the battery or by the dynamo, if acting alone, in one half phase M. Then in the first half phase, as combined, the electro-motive forces neutralize, and both the electro-motive force and the current strength are nil. W, the energy developed, is nil also. In the second half phase, however, the current strengths and the electro-motive forces are added or doubled. The electrical energy W will now be represented by

$$W = (2C)^2 RT = \frac{(2E)^2 T}{R} = 4\ M,$$

Wherein C and E are the current and electro-motive force due to the machine or battery if acting alone. The total energy developed in the complete phase will be the sum of these two half phases, or

$$^{o} + 4\ M = 4\ M,$$

whereas the battery of the dynamo, alone, would give but

$$M + M = 2\ M,$$

and both together would give

$$2\ M + 2\ M = 4\ M,$$

or exactly what Tesla's system has produced.

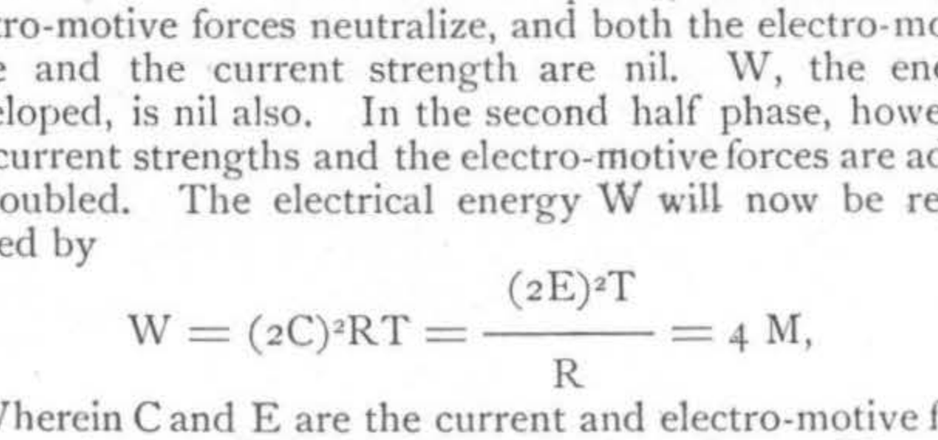


Fig. 4

The energies of the alternate current and of the battery have necessarily, then, been added in the intermittent or undulatory current obtained. The consumption of zinc in the battery and the power required to drive the armature of the dynamo (each depending directly on the current strength) have both heen doubled during the active half phase. This fact is a second proof of the addition of energies. The dotted lines and shaded area in figure 2 represent the resultant energy.

A more accurate illustration of the real action is given in figure 3 ; the curves, which are designated as before, were plotted from the equations,

$$E = K, \text{ and } E' = -K \sin 2\pi Nt.$$

$$\text{Resultant } E = K\ (1 - \sin 2\pi Nt).$$

$$A = K^2 R^{-1} = K^1 \quad \text{and } A' = K^1 \sin^2 2\pi Nt.$$

$$\text{Resultant } A = K^1\ (1 - \sin 2\pi Nt)^2,$$

wherein K is the maximum electro-motive force of the

machine, t the time in seconds, N the number of alternations per second, A the activity or rate of work, and K′ a constant.

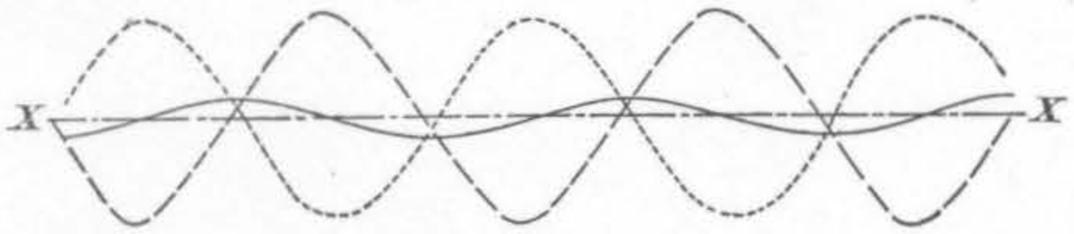


Fig. 5

The second modification of Mr. Tesla's device is that in which the well-known saturation limit of iron cores is to be utilized. The general arrangement is illustrated in figure 4. With one impulse the upper induction coil is super saturated for the purpose of permitting the current to flow, while at the opposing impulse the initial demagnetism is intended to prevent the flow of the current. The commentator, however, says that fallacy lies in this, "that it is assumed that the electro-motive force produced either in one direction or the other acts simultaneously with the current which has produced the change of induction. In reality, however, the electro-motive force lags by a quarter period behind the current and induction." From this he concludes in a series of somewhat arbitrary statements, that Mr. Tesla will not succeed in even "partially wiping out one half" of the impulses. It has been repeatedly shown that in the case of excessive induction that the secondary or inverse electro-motive force lagged almost one half phase behind the primary, while the resulting current was nearly a quarter phase behind the generating electro-motive force. The relation is somewhat similar to that shown in figure 5, wherein the current and magnetic effect are shown in the full line curve (the magnetization unit being so chosen that the curves correspond) while the dash line is the generating and the dot line the counter elèctro-motive force the equations of these curves are at the limit where the current is quite checked :

$$E = K \sin 2\pi Nt : \qquad \text{Counter } E = -K \sin 2\pi Nt.$$

$$C = -K' \cos 2\pi Nt = 0,$$

which is, of course, never quite attained.

In view of these equations, and on the ground that all lines of force, however derived, must cut the conductors in one direction as often as the other, the writer is, though not without much regret, led to doubt the operativeness of the device as baldly illustrated in figure 4. The use of some circuit changer seems absolutely necessary to the production of constant from purely altetnating magneto-electric induction. There seems not the least doubt, on the other hand, that the addition of sufficient constant electro-motive force to overcome the impulse in one direction will produce the result alleged, and with high theoretical efficiency. The heat from wire resistance will be unchanged by doubling the electro-motive force for one-half the total period, while the current, being both undulatory and continuous, may be applied to a vast variety of devices.

The commercial value of the device is a question of practical experience not demonstrable by any laboratory tests ; but, as the *Electrical Engineer* has based its objections on purely theoretical grounds, its conservative methods in regard to foreign innovation (not to say its insular prejudice) seem in the present instance somewhat misdirected.

TESLA METHOD OF OPERATING ELECTRO-MAGNETIC MOTORS.

The *Western Electrician* describes a new design of Mr. Tesla for operating motors, the main features of which are as follows:

"If an alternating current be passed through the field-coils only of a motor having two energising circuits of different self-induction and the armature-coils be short-circuited, the motor will have a strong torque, but little or no tendency to synchronism with the generator; but if the same current which energises the field be passed also through the armature-coils the tendency to remain in synchronism is very considerably increased. This is due to the fact that the maximum magnetic effects produced in the field and armature more nearly coincide. In other words, a motor is constructed having independent field-circuits of different self-induction. These are joined in derivation to a source of alternating currents. The armature is wound with one or more coils, which are connected with the field-coils through contact rings and brushes, and around the armature-coils is arranged a shunt with means for opening or closing the same. In starting this motor the shunt is closed around the armature-coils. When the current is directed through the motor, it divides between the two circuits, which, by reason of their different self-induction, secure a difference of phase between the two currents in the two branches, that produces a shifting or rotation of the poles. By the alternations of current, other currents are induced in the closed, or short-circuited, armature-coils, and the motor has a strong torque. When the desired speed is reached the shunt around the armature-coils is opened, and the current directed through both armature and field coils. Under these conditions the motor has a strong tendency to synchronism.

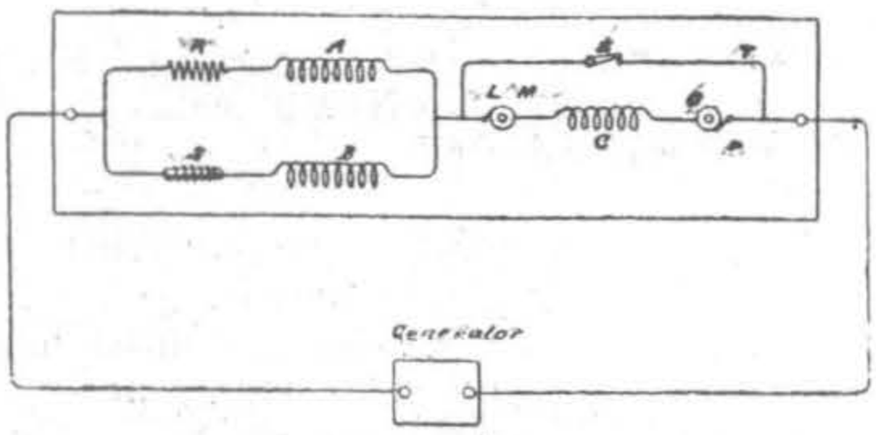


FIG. 1.—Tesla Method of Operating Electromagnetic Motors.

"In the accompanying cuts the motor is represented diagrammatically. In Fig. 1, A and B designate the field-coils of the motor. As the circuits including these coils are of different self-induction, they are represented by a resistance coil, R, in circuit with A, and a self-induction coil, S, in circuit with B. The same result may of course be secured by the winding of the coils. C is the armature circuit, the terminals of which are rings, M and O. Brushes, L and P, bear on these rings, and connect with the line and field-circuits. T is the shunt or short circuit around the armature. E is the switch in this shunt. The operation of these devices is as above described.

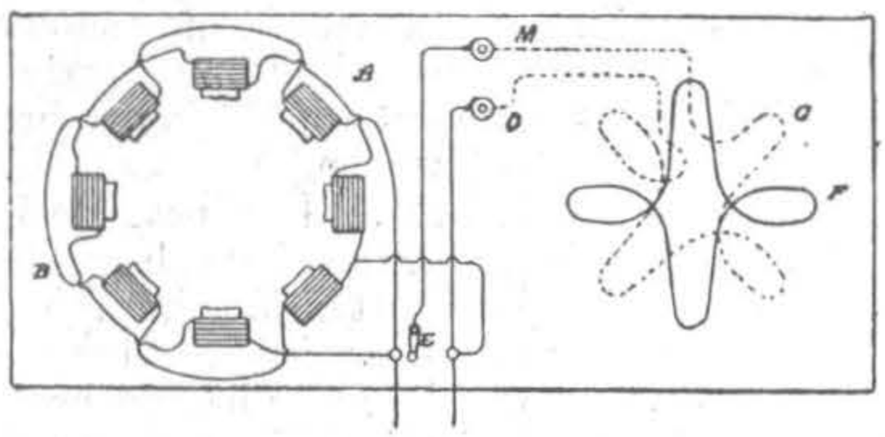


FIG. 2.—Tesla Method of Operating Electromagnetic Motors.

"It will be observed that in such a disposition as is illustrated in Fig. 1, the field-circuits A and B being of different self-induction, there will always be a greater lag of the current in one than the other, and that generally the armature phases will not correspond with either, but with the resultant of both. It is therefore important to observe the proper rule in winding the armature. For instance, if the motor have eight poles—four in each circuit—there will be four resultant poles, and hence the armature winding should be such as to produce four poles, in order to constitute a true synchronising motor.

"It is of advantage in the operation of motors of this kind to construct or wind the armature in such manner that when short-circuited on the start it will have a tendency to reach a higher speed than that which synchronises with the generator. For example, a given motor having, say, eight poles, should run, with the armature coil short circuited, at 2,000 revolutions per minute to bring it up to synchronism. It will generally happen, however, that this speed is not reached, owing to the fact that the armature and field currents do not properly correspond, so that when the current is passed through the armature (the motor not being quite up to synchronism) there is a liability that it would not "hold on," as it is termed. It is therefore preferred to so wind the motor that on the start when the armature coils are short-circuited the motor will tend to reach a speed higher than the synchronous—as, for instance, double the latter. In such case the difficulty above alluded to is not felt, for the motor will always hold up to synchronism if the synchronous speed is reached or passed. This may be accomplished in various ways, but for all practical purposes the following will suffice: The armature is wound with two sets of coils. On the start one only is short-circuited, thus producing a number of poles on the armature, which will tend to run the speed up above the synchronous limit. When such limit is reached or passed, the current is directed through the other coil, which, by increasing the number of armature poles, tends to maintain synchronism. In Fig. 2 such a disposition is shown. The motor having, say, eight poles, contains two field-circuits, A and B, of different self-induction. The armature has two coils, F and G. The coil F is closed upon itself, while the coil G is connected with the field and line through contact rings, M and O, and a switch, E. On the start the coil F alone is active, and the motor tends to run at a speed above the synchronous, but when the coil G is connected to the circuit the number of armature poles is increased, while the motor is made a true synchronous motor."

TESLA'S ALTERNATING CURRENT MOTOR.

SINCE Mr. Nikola Tesla's first work in alternating current motors was published, he has been busily engaged in working out other types, one of which is described below. In Mr. Tesla's motors, it will be remembered, two or more energising circuits are employed, through which alternating currents differing in phase are passed, with the result of producing a progressive shifting or rotation of the poles or points of maximum effect. Various types of alternating motors have been constructed on this principle, the present being one in which the difference of phase is artificially produced, as, for instance, in cases where the motor-circuits are of different resistance and self-induction, so that the same current divided between them will be retarded in one to a greater extent than in the other, and the requisite phase difference secured in this way.

The lag or rotation of the phases of an alternating current is directly proportional to the self-induction and inversely proportional to the resistance of the

circuit through which the current flows. Hence, in order to secure the proper difference of phase between the two motor-circuits, it is desirable to make the self-induction in one much higher and the resistance much lower than the self-induction and resistance, respectively, in the other. At the same time the magnetic quantities of the two poles or sets of poles which the two circuits produce should be approximately equal. These requirements, which Mr. Tesla has found to exist in motors of this kind, have led him to the invention of a motor having the following general characteristics: The coils which are included in that energising circuit which is to have the higher self-induction are made of coarse wire, or a conductor of relatively low resistance and the greatest possible length or number of turns are used. In the other set of coils a comparatively few turns of finer wire, or a wire of higher resistance, is used.

Furthermore, in order to increase the difference of phase in the two circuits, Mr. Tesla provides for the self-induction coils a considerably greater space in order to place a greater amount of copper in these coils, and in addition he envelops these coils with iron so as to increase by these means the self-induction to the greatest possible value, and he calculates the magnetic qualities so that they are practically equal in both sets of magnets.

These features of construction are shown in the

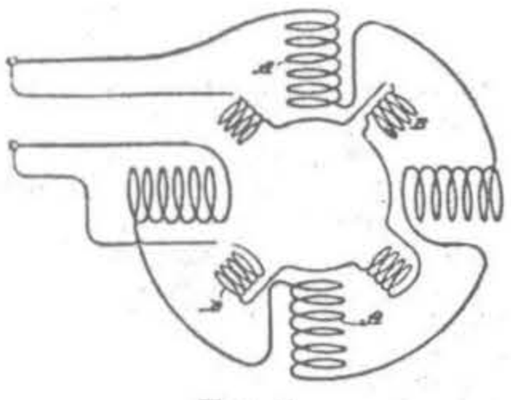


FIG. 1.

engraving Fig. 2, and the principle is illustrated by the diagram Fig. 1.

In Fig. 1, let A represent the coils in one motor-circuit, and B those in the other. The circuit A is to have the higher self-induction. Mr. Tesla therefore uses a long length or a large number of turns of coarse wire in forming the coils of this circuit. For the circuit B he employs a smaller

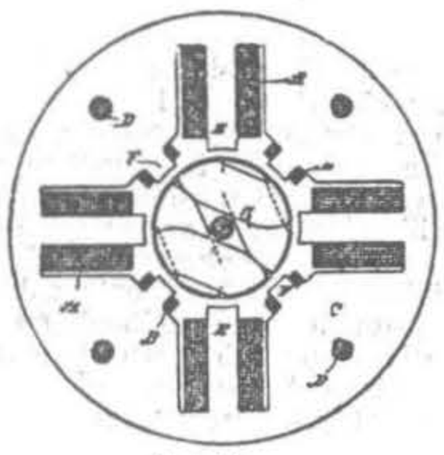


FIG. 2.

conductor, or a conductor of a higher resistance than copper, such as German silver or iron, and winds the coils with fewer turns. In applying these coils to a motor, a field-magnet is built up of plates C, of iron or steel. Each plate is formed with four long cores, E, around which is a space to receive the coil and an equal number of short projections, F, to receive the coils of the resistance-circuit. The plates are generally annular in shape, having an open space in the centre for receiving the armature G, which is preferably wound with closed coils.

An alternating current divided between the two circuits is retarded as to its phases in the circuit A to a much greater extent than in the circuit B. By reason of the relative sizes and disposition of the cores and coils, the magnetic effect of the poles E and F upon the armature closely approximate.

An important result secured by the construction shown in the motor is, that those coils which are designed to have the higher self-induction are, as above stated, almost completely surrounded by iron, by which the retardation is considerably increased.

USEFUL AND SCIENTIFIC NOTES.

Tesla's Novel Principle of Constructing Electric Motors.—In order to obtain the maximum effective work out of a given weight of copper and iron in an alternating current motor, or any direct current motor, Mr. Nikola Tesla has applied a very important principle in their construction. Mr. Tesla reasons that in any motor the total energy supplied to do the work is equal to the sum of the energies expended in the armature and the field. The power developed, however, is proportionate to the product of these quantities. This product will be greatest when these quantities are equal; hence in constructing a motor Mr. Tesla determines the mass of the armature and field cores and the windings of both, and adapts the two so as to equalise as nearly as possible the magnetic quantities of both. In motors which have closed armature coils this is only approximately possible, as the energy manifested in the armature is the result of inductive action from the other element; but in motors in which the coils of both armature and field are connected with the external circuit the result can be much more perfectly obtained. In further explanation of this, let it be assumed that the energy as represented in the magnetism in the field of a given motor is 90, and that of the armature 10. The sum of these quantities, which represents the total energy expended in driving the motor, is 100; but, assuming that the motor be so constructed that the energy in the field is represented by 50 and that in the armature by 50, the sum is still 100; but while in the first instance the product is 900, in the second it is 2,500, and as the energy developed is in proportion to these products, it is clear that in any motor the best conditions are obtained when at normal load the magnetic quantities in field and armature are equal. These results Mr. Tesla obtains by using the same amount of copper or ampère turns in both elements when the cores of both are equal and the same current energises both; or in cases where the currents in one element are induced to those of the other, he uses in the induced coils a proper amount of copper.

American Institute Of Electrical Engineers - Transactions
January 21, 1890

A paper read before the 42nd meeting of the American Institute of Electrical Engineers, New York, January 21st, 1890, and discussion thereon. Treasurer George M. Phelps in the chair.

A REVIEW OF MODERN ELECTRICAL THEORIES.

BY PROFESSOR WM. A. ANTHONY.

The general phenomena of electricity are familiar to us all. As children we learned of attraction and repulsion of electrostatic charges, of condensers, of insulators and conductors, of electric currents and electro-magnets, of telegraphs, and electric fire alarms and electric bells, of the heating of conductors, and even electric lights. We have long been familiar with the effect of the current on a magnetic needle, and with the attraction and repulsion of currents for each other. We have seen that these effects are manifested at a distance from the conductors which carry the currents, and we have been willing to believe that the distances at which these phenomena could be recognized were limited only by the want of sensitiveness of the apparatus through which the effects were manifested. Probably not many of us stop to think *how* these effects were brought about. We were content with a general statement of the relations of the phenomena, or, at least, with the determination of the direction and intensity of the forces due to a given conformation of current. We talked of the attractions and repulsions as action across space, and, if we thought of them at all as requiring any mechanism through which to act, we still felt satisfied when we had discovered and formulated the laws that govern the action of these forces.

It did not matter to us that attraction across empty space was unthinkable; it was enough that action took place, and that we could measure and, to a certain extent, control it. We constructed instruments and computed forces acting under certain conditions; we multiplied experiments and thought we had developed a vast science. But there have not been wanting, even among the earlier philosophers, some who could not feel satisfied with

the idea of action at a distance. Experience gives no clue to any explanation of action of one body upon another at a distance, except through some intervening mechanism, and if we find cases where such intervening mechanism is not apparent, to say that in these cases action at a distance is taking place, is only to say that the action is unexplained.

Gravity acts upon the distant planets, and, we believe, upon the most distant stars; but it is not enough to say that gravity acts, that it decreases as the square of the distance increases, we want to know *how* it acts. By what means or through what medium does our earth reach out to the distant planets and affect their movements? These are the questions that the dissatisfied few have asked in the past, and to-day it is not the few but the many who would be glad to have the question answered. Faraday early taught us that the mere statement of the law of electrical attraction or repulsion was no explanation, and he sought the explanation in the action in the intervening medium. He demonstrated by experiments, that have become classic, that the effect of induction depends upon the nature of the medium intervening between the conductors; a demonstration that here, at least, the intervening medium took part in the action and helped to determine the result. Magnetic and electro-magnetic phenomena were to Faraday also effects propagated through the medium; and Maxwell, following Faraday's work, subjected the whole matter to a searching mathematical analysis. It was necessary, in order to complete the theory, to assume the existence of a medium in which the forces were exerted; but, as a medium had already been assumed to account for the phenomena of light, it would hardly be scientific to assume another to account for electrical phenomena. But would not one medium suffice for electrical and optical phenomena as well? Maxwell showed how the question of the identity of the two media could be tested, and our modern views of electricity are mainly the results of his work. What do we *know* of electrical phenomena? We know that pieces of glass and silk rubbed together and then separated attract each other; that the property of attraction can be imparted to metals if they are insulated; that if two such masses of metal be connected by a wire the power of attracting each other disappears, and at the same time, the wire is warmed and for an instant exerts magnetic forces at right angles with the wire. Numerous other facts we know, but these will suffice as illustrations of the

phenomena. When a metal conductor is discharged by touching it with a wire we say the wire carries a current, and we have been accustomed to ascribe the heating and the magnetic effects to that current. We have looked upon the thing, whatever it is, that takes place in the wire as the origin of all that takes place around it. The current warms the wire, and it confers upon it the property of acting upon magnetic needles; but *how* does it act? We cannot conceive of the action of that wire on that needle, except through something extending from the wire to the needle through which the wire can exert a push or pull. All around that wire the needle is affected; at considerable distances the effect can be exhibited, and we believe it is only want of delicacy of our apparatus that prevents our discovering it at the greatest distances. If the wire acts it acts through a medium in which it

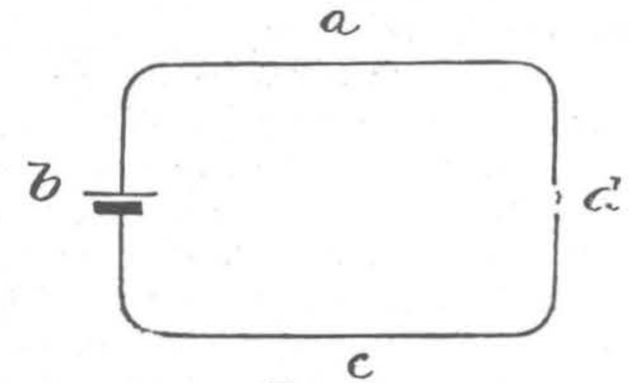


Fig. 1.

creates a disturbance, and the disturbance in turn acts upon the magnetic needle. But are we sure that the action begins with the wire? Is it not possible that the action begins in the medium, and that the wire merely separates portions of the medium and so permits action that would not otherwise take place? Maxwell has proposed a mechanical illustration of the action taking place in space when electrical phenomena occur, and Fleming and Lodge have elaborated it and brought it within the reach of non-mathematical readers. Let us suppose all space to be filled with wheels connected by idle wheels in such a way that when one turns all must turn in the same direction, except that the elasticity of the system permits a small movement of one wheel before the others in the vicinity begin to move. Electromotive force is then something that tends to turn the wheels. Let *b* in Fig. 1, represent some source of electromotive force; *a* and *c* conductors not forming a closed circuit but having an opening at *d*. The electromotive force at *b* tends to turn the wheels, but so

long as the gap exists at d the wheels are connected through all space, and the E. M. F. at b can effect nothing except to turn the wheels through a small angle until the elastic resistance balances the E. M F. In the conductor, the wheels are not supposed to be rigidly connected. They can turn by slipping on each other, and the wheels in space may turn by slipping on the wheels in the conductor; hence, as the ends of a and c approach each other, the connection between the wheels within the enclosure and those of outside space becomes smaller and smaller, and, when the conductors touch, there is no longer anything to prevent the wheels within from turning, and they begin to spin in obedience to the E. M. F. at b. The conductor is heated by the friction due to the slip of the wheels around and within it. The spinning of the wheels constitutes the magnetic forces if we assume the wheels, originally spherical, to become flattened spheroids by the spinning, and to be forced to remain in contact at their poles. Assume the wheels to have inertia, and it will require time for them to reach their full velocity, and the time will be greater as the number of wheels is greater, that is, as the magnetic forces developed are greater. On the other hand, the wheels will not at once stop if the electromotive force is removed, and if the conductor be broken at some point, allowing the rapidly spinning wheels enclosed by it to come in gear at that point with the stationary outside wheels, there will be, for a brief time, until the moving wheels can be brought to rest, a clashing and disruptive action known as the extra spark.

I have spoken of the heating of the conductor as due simply to the friction of the spinning wheels upon the wheels within the conductor. The greater the friction the greater the motion imparted to the wheels within the conductors and the greater the heating. The less the friction the less the heat, and if there were a substance whose wheels could revolve among themselves and against the wheels of space without friction, such substance would form a perfect conductor which would offer no resistance to the motion of the wheels in the space inclosed by it, and however rapidly those wheels might revolve they would have no influence to produce motion within such a conductor. We are led, then, to this, that a perfect conductor, instead of being a substance in which any E. M. F. produces an infinite flow of electricity, may be a substance in which no effect whatever is produced.

I do not present this as representing the real activities involved

in electrical phenomena, or as a theory by which all electrical phenomena may be explained. I give it as bringing prominently into view the activities in the medium surrounding the conductor; whereas, the language in which we usually describe electrical phenomena points to the conductor itself as the seat of the electrical forces. Whatever our theory, we know that something does take place in the medium that surrounds the conductor. We know that were a heavy current to flow through a conductor in the most distant part of this room a delicate needle here on the table would show that a magnetic field was produced here. We are certain that magnetic lines of force from the electric currents on our streets, whether overhead or underground, permeate this room, and traverse our bodies even, though we have no sense through which we can become directly conscious of them. Take in your hands two wires connected to the poles of a battery or dynamo and touch their ends together. You see a flash of light, the wires become warm, they attract iron filings; coiled into a spiral they will attract with great force large masses of iron; two such spirals will attract or repel one another. What more natural than to say: Here in the wire is a new activity which warms it and confers upon it magnetic properties? What more natural than to forget or fail altogether to recognize the activities in the space around; activities that do not impress any of our senses; that do not wrench our arms, or burn our flesh, or blind our eyes; and yet it is well to fix our attention for a while upon the space that the conductor encloses, and recognize the fact which the little delicate needle demonstrates to us, that something is going on in that space, something quite as important, perhaps more important, than that which takes place in the conductor.

Whatever the magnetic forces are, we know they cannot be called into existence instantaneously. Time must always elapse before the full effect of an electric current is felt, and the greater the forces developed the longer are they in reaching the maximum. Moreover, the current in the wire cannot be at once developed; it keeps pace with the magnetic force and reaches a maximum only when the magnetic forces reach a maximum. This is exactly what would follow if magnetic forces result from the setting in motion of wheels possessing inertia. Whatever magnetic forces may be, they begin and end like the motions of massive bodies.

Continuing our hypothesis, an electromotive force would be anything that tends to set the wheels in motion. The wheels are set in motion if a limited number acted upon by the E. M. F. are separated by a conductor from the other wheels of space; but, even if they are not separated, that is, if the conductor does not form a closed circuit, the wheels are rotated through a small angle depending on the elasticity of the wheelwork. This displacement constitutes an electric charge, the tendency of the wheelwork to spring back is *difference of potential*, and this difference of potential is maintained by the E. M. F. Here allow me to call attention to the distinction between difference of potential and E. M. F. I often see statements that indicate that the distinction is not clearly kept in view. In that excellent little volume, the Dictionary of Electrical Terms, the statement occurs that electromotive force is *due to* difference of potential. It should

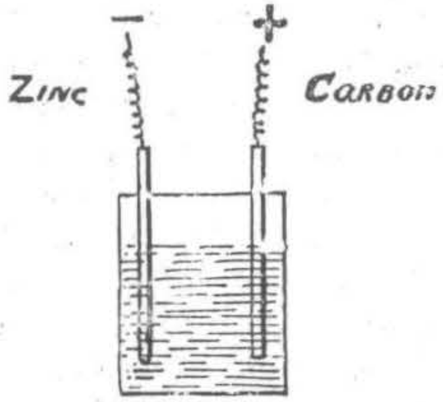


Fig. 2.

rather be difference of potential is due to E. M. F. Difference of potential is *an* electromotive force, but not all electromotive forces are difference of potential; and, furthermore, I can think of no case of difference of potential that does not owe its existence to some other electromotive force, not difference of potential. Difference of potential is a moving force acting from within. Electromotive force acts from without. Difference of potential results from a changed electrical distribution, an electric strain, and represents the tendency to return to the state of equilibrium. Electromotive force is the something from without that produced the electric strain. Consider our wheelwork illustration. I may seize a wheel here and turn it, but I can only turn it through a small angle before the elastic forces, brought into play by the distortion, balance the force that I am able to exert. My force is electromotive force, the elastic forces are difference

of potential. Let Fig. 2 represent a voltaic cell with its copper and zinc plates and dilute acid; we know that something takes place by which the copper becomes positive and the zinc negative, and, if the copper and zinc be joined by a wire, electricity is said to flow from the copper to the zinc through the wire, and from zinc to copper through the liquid. The flow through the liquid used to be explained by assuming the zinc to be positive and the copper negative within the liquid; just the reverse of what we find without. But connect the copper to the zinc by a wire under the liquid, the current flows through the wire from the copper to the zinc. The copper, therefore, is not negative, but everywhere positive. Then why does the current set from the zinc to the copper through the liquid? Because there is an electromotive force, not difference of potential, mind you, for the difference of potential tends to cause a flow the other way, but a something that forces the current through the liquid against the electric pressure. The cell is an electric pump that pumps electricity from the zinc into the copper until the pressure becomes so great that the pump stops. Open a passage from the copper to the zinc by connecting the two by means of a metallic wire, the electricity flows and relieves the pressure, the pump begins to work and so maintains a continuous flow. No; E. M. F. is not difference of potential, although difference of potential is E. M. F. It is even possible to produce an electric current without any difference of potential whatever in any part of the circuit, just as it is possible to produce a flow of fluid without any difference of pressure.

Whatever difference of potential may be, it behaves like a force developed by an elastic displacement in a solid body. Whatever magnetic forces may be, they behave as though produced by the motions of inert masses. An electromotive force, suddenly brought to bear at a given point, has to overcome not only the elastic force but the magnetic inertia. In other words, an electromotive force, tending to produce current, immediately develops a difference of potential against which it must act, and also develops magnetic forces which retard its action; so a *fluid-moving force* meets opposition in the elastic force of the fluid and in the inertia of its particles. But the effect of any such force is propagated through the medium with a finite velocity expressed by the well-known formula.

$$V = \sqrt{\frac{E}{D.}}$$

Electric displacements ought, therefore, to be propagated with a finite velocity which should have some relation to the ratio between the electrostatic effects, analogous to elastic displacements, and the electro-magnetic effects analogous to the effects of moving masses. You all know that it is shown that this velocity is expressed by the ratio of the magnitudes of the electro-magnetic and electrostatic units quantity, and you know also that determinations of this ratio show it to be the velocity of light. This determination gave a very strong support to Maxwell's electro-magnetic theory of light, and, coupled with the fact that observations, so far as they went, indicated that magnetic effects are propagated from the sun to the earth with the same velocity as light, made the theory at least extremely plausible. But within two years the wonderful experiments of Hertz have demonstrated beyond question that electro-magnetic waves travel through space from every source of alternating currents or potentials, and that the waves travel with the velocity of light. In this city there are, I suppose, many alternating current systems. When we think of these in action we are apt to think only of the activity in the conductors of the machines, the lines, the transformers, the lamps, and yet we know that in all the space around there is activity. Waves are chasing each other through this room, through our streets, our houses, our offices. They are everywhere present. We are bathed in this agitated medium every moment, and yet we live, and not only live, but are totally unconscious of the activity that surrounds us. No sense responds to the wave motion that fills this space. And yet, when these waves become short enough and frequent enough, they do affect our sense of vision and a vast array of phenomena that otherwise would have had no existence for us, are made known to us through this special sense. But the eye only responds to waves of $\frac{1}{70000}$ to $\frac{1}{37000}$ of an inch in length, while the length of the waves emitted by one of our alternating current systems is 600 miles. The waves that affect the eye must occur at the inconceivable rate of at least 400 millions of millions per second, while less than 300 waves per second are emitted from our alternating systems. These waves come very far short of the number necessary to affect any of our senses; but we have been able to demonstrate their existence, at least we have been able to show

that something possessing all the characteristics of wave motion exists in the space around a source of alternating currents or potentials. It is something to know that waves of such enormously different lengths and frequencies exist in the medium that is agitated by waves of light. It is something to understand that our sources of alternating currents are centres of radiant energy, differing from light only in wave length; and since we have begun to appreciate this fact, we have often asked ourselves the question: Can the rate of alternation be increased until the whole apparatus should glow with light? Although the enormous rapidity required seems to render this direct solution impossible, it seems to me there must be a way to obtain the light we want without all this waste of energy. I cannot believe it will always be necessary to develop waves of all lengths from many miles down to a hundred thousandth of an inch, in order to obtain the narrow range of wave lengths by which we see. I do not know of any practical way of obtaining the few wave lengths that constitute light without at the same time producing the others, but it *is* done. The glow-worms do it, the fire-flies do it, the lantern beetles do it, and I believe the time is coming when man can do it. Instead of getting 10 16-candle lamps per horse-power we ought to get 200. I don't know how it is to be done. I don't expect we are going to make alternating machines to produce 500 millions of millions of alternations per second. But possibly we may solve the problem indirectly by the use of some substance having a special rate of vibration, such as the gases. Possibly we may be able to exite electrically the fluorescent salts. Possibly we may be able to charge and discharge a condenser and take advantage of the oscillatory discharge to set up vibrations of the frequency required. Possibly we may discover the secret of the glow-worm and fire-fly and substitute electric for the insect energy. I know it will take several fire-flies to equal a 16-candle lamp, but it will also take a good many fire-flies to develop a horse-power. But although I do not see at present any practical solution of the problem, I repeat, I believe the problem can and will be solved. We are not going on forever burning a coal mine whenever we want a little light. Neither are we going on forever converting the energy of coal into heat when it is mechanical or electrical energy we want. From the very nature of things not more than one-fourth or one-third the heat so produced can be transformed into any other form of energy. The energy of

fuel *can* be converted into mechanical energy without first becoming heat. It is so converted in every animal movement. The way exists; let us find it. Find this, and the way to make light only, when it is only light we want, and we shall have lengthened the life of our coal deposits five or ten times. The man who solves either one of these problems will be the greatest discoverer of this or any other age. If he gets a broad patent on it, he will have seventeen years of the grandest litigation the world ever saw.

Now I can imagine that some electrician will consider that the first part of this paper dealt with matters that are of no practical consequence in the use of electric currents. Of what practical consequence is it whether force is conveyed to a distance by means of a medium or simply acts at a distance. What does it matter whether electric energy is conveyed by the conductor or through the dielectric? We know how to proportion and dispose our conductors to produce a given effect, and that is enough. But consider what we have learned already of the intimate connection between light and electricity, and I think you will agree that the more we know of the ultimate nature of electricity the nearer we shall be to the solution of the great problem to which I have referred, and the solution of either one of those problems would revolutionize some of the most important industries of the world. May not the solution of at least one of these problems be accomplished and the results exhibited at the great exhibition to be held in 1892? What a wonderful achievement it would be to light all those great buildings without heat, or drive all that vast array of machinery without a fire!

DISCUSSION.

THE CHAIRMAN, (George M. Phelps):—Professor Anthony has very pleasanty led us into a realm of speculation—not altogether speculation, because it is founded on many things known before, and I am quite sure that some of you will be glad to follow him immediately in treating of the topic that he has so happily opened.

DR. OTTO A. MOSES:—I have to thank Professor Anthony for a most interesting lecture. It has indeed set our thoughts moving. I presume that all of us here have been very deeply interested in those speculations, because though they may be speculations, they are the scaffolding upon which the whole science of electricity has been based. It was the pursuit of a hypothesis that led

Kepler year after year through very patient investigations to the results which revolutionized astronomy. The same course led Faraday, step by step, to those determinations which finally culminated in what we are now first recognizing—the identity of electricity and light. So that I can say that we have all been gradually accustoming ourselves to these speculations, even though many of us may be engaged in the practical uses of electricity.

There are some remarks in Professor Anthony's very interesting observations to which I would like to call particular attention, more especially the last, as bearing upon our practical applications of these speculations. He spoke of the possibility of using the molecular action of gases as a means of transforming wave-lengths. If my memory serves, that has been done ever since the Ruhmkorff coil has been in operation and the Geissler tube has become so perfect an analyzer of the electric current. In that respect we have already anticipated some of these results. Let us consider what we already have. In the Geissler tube you have the attenuated gases; you have two disconnected poles; you have a current passing, and the wave-lengths broken up and the light produced. So that we have right there before us the facts. Whether we can ever utilize the Geissler tube to effect these immense economies that the Professor so pleasantly prophesied is a question to be determined. It has been experimented upon, and I have found in my short experience in life that these things come when they are needed. There are certain groups of ideas that must be exhausted before people will adopt others and investigate them. We have seen it in the development of all the different branches of electric appliances. We have seen it in the telegraph. We have seen, for instance, Morse using Wheatstone's method of transmission; we have seen him abandon it. We saw him commence with underground conductors; we saw him abandon them simply because the art of that day was not perfect enough to allow him to supply them with profit; so that we can unearth many and many a theory now which already existed, but only awaited the development of the arts to be put into practice.

Now there is one thing I would like to add as a brief supplement to Professor Anthony's predictions. It is in no critical spirit that I mention it, because I will be running somewhat counter to the mechanical hypothesis upon which he developed many of his remarks. One, with great humility, must undertake to oppose himself to a theory emanating from such a mind as that of Clerk Maxwell, but one of the difficulties in the minds of all great mathematicians is that they must put their thoughts into mechanical methods in order to be able to weigh and measure directly. If we could only divest ourselves of the fact that they considered all nature to be composed of molecules, we would then come into another range of thought. I see myself no necessity for imagining all nature split up into infinite particles—

infinite in number and infinitely small and large in size. I can readily conceive of a continuity of matter. In fact, that thought is no novelty. It has been woven through all science, only we are so accustomed to limitations in our contact with nature, that we are apt to conceive that those limitations actually exist beyond our mere perception of them. As Professor Anthony said, very properly, there is an immense difference in our sense of observation between a wave length of electricity and one of light, but there is no reason that there is not a perfectly insensible graduation from the wave of electricity into that of light. In fact we see it when the current changes from heating effect into light.

A MEMBER:—There is one point I would like to have explained in the wheel hypothesis: To increase the current of a conductor without increasing the heat waste, it is necessary to increase the area of the conductor. I should think that would increase the number of wheels inclosed in a conductor, and therefore increase the friction and the amount of slip, and thus increase the heat developed instead of decreasing it.

PROFESSOR ANTHONY:—As I understand it, the more wheels there are in a conductor, the less is the amount of energy spent in causing the slip over them, because you have got more surface for slip. What we call a given current is accompanied by certain magnetic effects That would mean that the wheels in space enclosed by the conductor are revolving at a certain rate. Now supposing those all to be revolving at the same rate and increasing the size of the conductor and increasing the number of wheels there are in it, the wheels that are in the conductor will be set revolving at a less rate instead of a greater one, because there will be greater surfaces where the slip can occur.

PROFESSOR M. M. GARVER:—It is rather curious to me that generally speaking all the heat developed in the conductor, as Mr. Heaviside looks at it is an action around the conductor. In that connection I cannot see, if it takes place around the conductor, why the law of temperature should hold as it does in the case of metals. Take for instance, the case of copper; I believe the variation is about two tenths of one per cent. for one degree Fahrenheit. If the same law holds, for 500 deg. below zero Fahrenheit there should be no resistance and no heat developed in the conductor. I believe some experiments have been made in regard to the conductivity of copper at very low temperatures. I would be glad to hear from any one who has knowledge of this subject.

MR. A. E. KENNELLY:—I think it would be unnecessary for me to add my own personal views to what I am sure is the universal sentiment concerning the paper to which we have had the pleasure of listening. But while it is full of food for reflection from both a theoretical and practical point of view, I hope there is one point more that may be permitted to be brought forward, that is, the great difference between what might be called a working theory and an ultimate theory. Tracing back the history of any of the

sciences, as they are so called to-day, we see how very wide-spread they were, how numerous the sciences were, how in the Greek days every activity such as the motion of a cloud and the motion of a body in the air, was supposed to proceed from some superior cause, and gradually as knowledge increased and as investigation pursued its quiet path, those forces were singled out and found to be fewer and fewer, and so to-day, we stand with a certain number which we still hope will be reduced and finally embodied in one. Dr. Moses has given us a very beautiful, I might almost say, a poetic view of what he calls the infinitude of nature, but I think it would be a finer expression perhaps, if he will allow me the correction, if that infinitude be considered as proceeding rather from the unity of nature. In fact if we go back to the days of Polytheism, the old Mahometan cry "There is one God" stands very aptly by comparison. In the theory of heat for example there were what we call now the crudest notions prevalent about four hundred years ago as to what its nature might be. Slowly those views have become clearer, and now perhaps heat is in its theory more complete than any of our other sciences. But the trouble with heat has been the same as it is now with electricity—the difficulty of getting first a theory that was workable and then a theory which would account for the facts clearly and consistently. We have listened to the explanation of a beautiful theory, a theory worthy certainly of the master minds that originated it; but, somehow it does not appear as though that theory were going to be the ultimate one which would satisfy us when we come to consider nature as a whole, and that although it is a good working hypothesis—a peg upon which we can hang our thoughts—that after all we may hope for some simpler and more universal distribution of matter than spinning wheels in space. A vacuum was once supposed to be the absence of everything from space, and nature, as we read in the old books abhorred a vacuum but gradually people began to find out there must be something left, because phenomena take place which could not be accounted for if there were nothing there, for we cannot conceive of action through nothing, and gradually as light came to be considered no longer on a corpuscular theory, it became necessary to invent a new ether and finally the question arose, will not the same ether do for both? Then came the electro-magnetic theory of light and that required a special ether, but that also has been united. Now for the brilliant work of Hertz and Maxwell we see that those two ethers are one and the same; at least we cannot distinguish between their properties. The ether that we suppose will propagate light, is surely not one that we can readily unite with the idea of spinning wheels in space. The mere fact that the thing is difficult to conceive of, is no bar of course to its truth. But we are entitled to the expectation that nature in her infinity is infinitely simple. Surely, it is in this ether that we have to in-

vestigate something which unites more readily the functions of gravitation of light and of electricity. If we have, for example, a vessel full of incompressible fluid—water will answer—and we introduce two little jets, small by reference to the whole vessel, and we cause the vessel to be hermetically sealed, full of water, then if we force water out of one jet, back through the other, causing a circulation to take place, we shall find, if there be no vortex-motion in the liquid, and if all the particles advance in ranks, shoulder to shoulder—that the lines pursued by the individual particles are, strangely enough, the lines which are followed, we have every reason to believe, by magnetism, by heat and by gravitation. Surely there is some grand principle underlying that great class of phenomena which some day in the future will join them all into one coherent principle.

The point that Prof. Garver mentioned about the conductivity of copper at a very low temperature certainly has great practical interest although we are not likely to live in a climate where for the sake of our conductors we submit to two or three hundred degrees below zero. But I think that experiments have been made at minus 40 degrees centigrade which showed a very large increase in the conductivity of copper, and the co-efficient of temperature was very much larger at that point than it was higher up the scale. The late Sir William Siemens had a very interesting theory that the resistance at a very low temperature was very small indeed, but rose rapidly at first and slower and slower afterward. That is contrary to our orthodox views about conductivity of copper at high temperatures, but it is a view which is interesting in itself.

Mr. Townsend Wolcott:—Regarding the existence of a medium, Professor Anthony has given voice to the most general opinion in saying that action at a distance is unthinkable. I believe this is the view which Sir Isaac Newton took; but it must not be forgotten on the other hand that Roger Cotes said that there is no *a priori* reason for disbelieving in action at a distance any more than any other experimental facts that we have, and it is this same Roger Cotes of whom Sir Isaac Newton said in speaking of his untimely death: "Had he lived we should have known something." I think that a part of the difference between these two classes of thinkers arises from their having a different conception of the meaning of the word medium. In the present state of the science, if we do not make the word medium mean too much, it is in my opinion practically demonstrated that there is a medium. If we say that action at a distance through space—vacant space—is unthinkable, what do we mean by space? If we mean simply extension, the concept of extension being simply three dimensions, it is unthinkable. But in conceiving of a medium we are too apt to make the word mean too much. Now, Professor Stokes has shown that the luminiferous ether acts like an elastic solid; that is to say the mathematics of solid elasticity

apply to the ether; but in order that it should be an elastic solid which had the same degree of elasticity as the ether does have, on that hypothesis it would have to be an exceedingly solid kind of a solid. I forget how much pressure there would have to be, but it was something enormous. Now, we know that the ether is not such a solid as that. Again taking the modern theory that the action of the dielectric is a stress, we may apply the same comment to this also. The mathematics of stress are equations similar to the equations that apply to electric phenomena in a dielectric. However, there can be no real stress in the sense in which we understand the word, because the very bodies which can not sustain a stress are the ones which are the best dielectrics. In fact a vacuum, which we do not consider a body at all, is a dielectric, and, according to some electricians, it is the very best of insulators; and metals which generally are capable of sustaining a great deal of stress, are all conductors and, according to theory, are bodies in which the state of dielectric stress cannot exist, but gives way immediately, producing what we know as current.

Dr. Michael Pupin:—I would like to express my feeling of obligation to Prof. Anthony for his able lecture on the modern theories, and with his kind permission to add a few comments as a supplement to his review. We know what ideas Faraday had of dielectrics and the function which they perform in the transmission of the electric action from one part of space to another. We know that Faraday supposed the dielectric to be filled with small conducting particles which have the property of polarity. In what that polarity may consist we do not know. We may suppose it is of the same kind as the magnetic polarity in the case of soft iron. That theory has been worked out by Professor Helmholz, and he deduced the equations for the distribution of the stress in the medium of the dielectric exactly the same as Maxwell did. In fact the equations which Helmholz obtained are a little bit fuller. Now, given that a dielectric consists of very small particles, each one having the properties of polarity and all the electro-static and all the electro-magnetic phenomena can be explained. I do not see that it is necessary to go into the consideration of wheels working within other wheels. To be sure Maxwell did work out the theory in 1862, I think, to which reference was made this evening, but he gave it up, and in his second volume on electricity he refers to this theory in a sort of off-hand way, saying that some years ago he worked out a theory of electricity based on the hypothesis of Sir William Thomson of vortex motion. Helmholz, supposing the medium to have only this property of polarization—these papers are not published yet, but I expect they will be published very soon, though they are not very new, because these things have been worked out before by Sir William Thomson, and I think by Maxwell—shows that if there is any electric disturbance, whether it be an electro-static or electro-magnetic, in the conductor must be propagated

in the whole dielectric, because disturbance in the electric state of the conductor will cause a disturbance of the stress in the dielectric, and that disturbance of the metal gives the electromagnetic action.

Every one of the speakers this evening has spoken of forces. The term force is very elastic and may mean almost anything. In fact, I think every man has his own idea about force. But if we are to discuss and use the term we must have the same definition. I think if we are to treat sciences from the mechanical standpoint, then we must define force mechanically. That is, we must fall back necessarily on the Newtonian definition of force, *i. e.* as producing nothing but motion—this is the elementary definition of force. When we speak of electric and magnetic forces we certainly deal with something which will produce more than motion alone. Take, for example, Ampere's integral law, by which we know that a current flowing through a conductor will act upon a magnetic pole just the same as if the wire was an empty shell having a magnetic moment equal to the strength of the current. But, in every department of science it is always desirable, and in fact it is the highest aim of every physicist to deduce, not the integral law but the differential law. Newton achieved his great success when he found the differential law—the law of universal gravitation. Ampere thought his integral law would be of little use to him if he did not know the differential law, namely, the law which determines the action of each element of one conductor upon each element of any other conductor or upon itself. He said, let us now resolve this integral action into elementary actions. He did it and he found that each element of the conductor acts upon a pole or upon an element of another conductor with a force which is not exerted in the line connecting the two, but perpendicularly to that line. Other differential laws have been deduced in the last twenty years by Maxwell, Weber and Helmholtz. Some of these laws suppose that there is not only a force perpendicular to the line between the two elements, but also that there is something that tends to turn the element, so that we have to deal here not only with forces, which are determined by laws of mechanics, but with forces that lie entirely outside of that. Therefore we are always to carefully distinguish what we mean by force. Is it purely mechanical force, or is it a force which produces, besides motion, something else? We cannot speak of chemical forces in the same way as we speak of mechanical forces, because mechanical forces are limited by the definition of Newton and they produce nothing but the motion of the mass. Chemical force produces heat; it produces chemical composition and decomposition; it produces light and it may produce motion also. We do not deal here with pure forces such as gravitating force which is always exerted in the line connecting the two points acting upon one another.

The other point which I would like to mention refers to conductivity. A gentleman said that the rule—I will not call it a law—is that every metal increases its resistance with temperature, and therefore at a certain low temperature it ought not to offer any resistance at all. The fallacy is self-evident. When we speak of a law we do not mean something absolutely true. Clifford has defined its meaning; a law is true only for those conditions under which the particular phenomena which led to the construction of the law were observed. The law of heat, the law of light, the law of electric current were observed; not in a temperature of several million degrees, but in temperatures which we can get ranging from minus 80 degrees centigrade to perhaps 3000 degrees centigrade, the highest temperature which we could obtain. Therefore the law above those limits may be true or may not be true. Every law may be represented by a certain curve. Where the curve does not run from minus infinity to plus infinity we know a very small space of that curve; the rest we do not know.

PROF. GARVER:—I see I was misunderstood in reference to the conductor. I was speaking of the fact that at first sight it seems that the variation in conductivity due to the temperature in the conductor was at variance with the view that the action took place outside instead of inside the conductor. Since thinking it over I have arrived at what seems to be a plausible answer to my own question, that the conductor, being actuated by heat, the particles are in motion. Now, as the temperature of the conductor goes down, the heat action becomes less and less, and it then approximates to what I believe it is supposed to be—a hole through the medium.

MR. NIKOLA TESLA:—I want to suggest a practical idea on which I have not taken a patent, but which is cheerfully offered in case any gentleman wants to patent it. There seems to be no doubt to-day that light and electricity are one and the same, and that between the two there is only a difference in degree. Now, the question resolves itself into how to produce a sufficient number of undulations to equal those of light. We know that if you put two coils in inductive relation and pass through the primary an undulating current you can produce in the secondary two distinct currents. Then from that secondary we can again act in the same manner upon another coil and so on I have figured that at that rate it would require about 23 conversions. If you assume an efficiency of 80 per cent. in the first you can assume one of 2 per cent. in the last coil which is the twenty-third.

Now there is another thing I wish to mention. That is, that while we are convinced that light and electricity and electromagnetic action are the same, yet there seems to be a difference between light and electricity in that we cannot maintain light in a static state; but we can maintain electricity so. And again light and magnetism are similar in this respect. That when we attempt to store, for instance, magnetism and light—a problem

which is very interesting and would be very valuable if solved—we know well that we can magnetize steel and it will hold magnetism indefinitely. We can also magnetize a soft iron bar but it will lose the magnetism soon. Now there seems to be, from what Prof. Anthony has so admirably set forth, a possibility of producing a magnet of such qualities that it would for an indefinite time, say for a year or more, continuously discharge its magnetism after a cessation of the current which energized it. Then we could store electricity. I attempted in my early days to do that, but it does not work. Another thing in regard to light—if we expose certain bodies to an arc light or a very intense source of light we will find that they will take up light for the first moments, but when the light is intercepted it will instantly fall and the little that remains will gradually disappear, and sometimes it will take considerable time, similar to that little remnant of magnetism in the big bar of iron. If we plot the curves in the two cases we would find them similar, which shows that magnetism and light correspond in this way. Whereas we know that electricity can be stored—I understand now the difference which Prof. Anthony has brought out between potential and electro motive force—I mean we can take the condenser or a Leyden jar and store up electricity in any quantity, so to speak, and keep it there for a considerable time, and then discharge it at will. We cannot do so with light nor with magnetism, and yet we know that all these are really one and the same thing with only a difference of degree.

Dr. Pupin:—I would like to ask Prof. Anthony to define the term electromotive force.

Prof. Anthony:—It is one of the most difficult things in the world to give the definition, and I never pretended to any ability at giving definitions. We all know that in a battery there is something that develops an activity. We know that the conductor gets warm. We know that around the conductor there are what we call magnetic forces, and I believe that there is an activity set up in the whole space around it. Now, whatever there is inside of the battery that gets up this agitation I call electromotive force. Furthermore, we know that if we take a wire and move it across the magnetic lines of force there exists something which, if that wire formed a closed circuit, will produce what we call a flow of electricity. We know it is full of electricity, because, under proper conditions the wire will get warm, because also, there are magnetic effects developed by it. There is something takes place—an agitation is set up in that wire, and I consider that something, I do not pretend to define it or to know what it is, but there is something there in consequence of the movement of that wire across these magnetic lines of force that constitutes what we call electromotive force. It is something, to use the language of electrical theory, that puts electricity in motion, and that is the action I referred to in the paper in which

we may have electricity in motion in a conductor without any difference of potential. Suppose, for instance, I have a perfect circle formed of wire, and then I take a magnet, and suppose I thrust the north pole of the magnet perpendicularly into the very centre of that circle. We know that lines of force cut that circle all around in every part, and when that magnet is thrust through there we know that whatever there is that constitutes a magnetic field acts in some way to set up this current and acts in every part of the wire so that there is a current set up without there being any difference of potential in any place.

Dr Pupin:—How would you measure the heat produced in wire? Is that subject to Joule's law?

Prof. Anthony:—I should say so, certainly.

Dr Pupin:—It is equal to the electromotive force multiplied by the current. What is the electromotive force? It is that which we define mechanically in absolute measures.

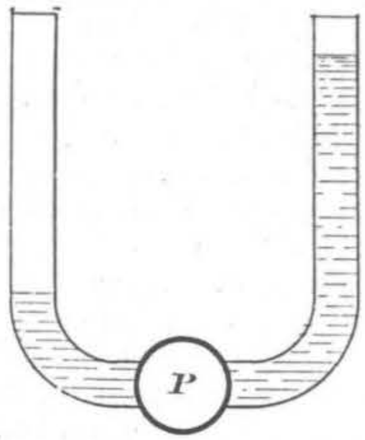


Fig. 3.

Prof. Anthony:—It is whatever sets that current in motion around there.

Dr. Pupin:—Yes, but we know it, we can define it in terms of time, mass and length. It is perfectly definable.

Prof. Anthony:—It is measured in the same terms as difference of potential, of course.

Dr. Pupin:—It must be the same.

Prof. Anthony:—I do not think so any more than in difference of level. We measure difference of pressure, for instance, by difference of level in the case of water. To illustrate it—here I have a U tube with a pump in it. The water is at the same level in both branches. I now set the pump turning and the water falls in this side and goes up in the other. That difference of level will measure the difference of pressure, but that pressure was produced by turning the handle on this pump. Now the turning of the handle I call the water-moving force. This constitutes a difference of potential, a difference of gravity potential which opposes my turning of the handle. (See Fig. 3.)

DR. PUPIN:—Therefore the work done measures the difference of level.

PROF. ANTHONY:—It may be measured by the difference of level.

DR. PUPIN:—But the work done measures the difference. The electromotive force is not a force at all in the usual sense of the word. It is the work done to make the difference of potential and that is what the difference of potential is—the work done.

PROF. ANTHONY:—Suppose that we do not produce any difference of potential, as in the case of the circle of wire with the magnet thrust into it.

DR. PUPIN:—But we do. That is a well-known problem.

PROF. ANTHONY:—The difference of potential is equal to the work done. I may just as well say substitute for each element in that wire an infinitely small Daniell element all around. Of course that is practically impossible, but let us suppose so. We can place infinitely small Daniell elements, connecting them together around the circle so that they will form a closed circuit, where is the difference of potential there? If you have them infinitely small so that each Daniell element acts on each element of the wire then I should say there was no difference of potential from one end to the other, and we have the electromotive force of the Daniell element producing the result entirely and nothing else.

DR. PUPIN:—There is a difference of potential between each two poles in every one of those infinitely small cells. So I may say between the ends of each one of the infinitely small elements of the wire there is a difference of potential and these being connected in series the current runs around them.

PROF. ANTHONY:—Let us take it in another way. Suppose there is a circular tube containing a gas or liquid, whichever you please. Now, can we not conceive of such a thing as something acting simultaneously upon every single element, no matter how many you consider there may be of them, so that every one of those elements will move forward at the same instant, and that there is no difference of pressure anywhere in that case. Now, difference of pressure is what I consider as equivalent to difference of potential. In other words what we call difference of potential electrically is due to a disturbed electrical distribution and until you have a disturbed electrical distribution there is no difference of potential. Now, in this wire where we have a perfect circle and thrust into it the magnetic pole, we act on every element of that wire simultaneously, there is no disturbed condition of potential, and after you have stopped the magnetic pole you can conceive that your electricity has been shifted around through the whole of it without there being a disturbance there—without any difference of potential. You stop the movement of the magnet—the current stops. Your electricity does not fly back again. But let us cut that wire in two and leave an opening in it. Now

force the magnetic pole through the middle and you tend to make a motion around it in the same way. Electricity is heaped up at one end, making pressure there, and the moment your magnet stops the electricity flies back and produces a current the other way.

MR. FRANCIS B. CROCKER:—It seems to me that Prof. Anthony's last illustration will give us a solution of the problem and reconcile both sides of this controversy. He assumes that the wire circle is opened at a certain point, and if you thrust in a magnet you get at that point the total difference of potential which we could calculate and predict from known electric and magnetic effects Now it seems to me that when the circle is closed, you get that difference of potential spread over the entire conductor which produces the current through that resistance. It is heaped up at the point of opening because it cannot pass that point, there being no conductor there. But it appears to me that, if we close the circle at that point and make it uniform as regards resistance, the potential is distributed uniformly around the entire circle. But even when distributed in that way it produces the same effect as it would if it were concentrated, and it would seem that although there is no difference of potential which can be detected yet the same total difference of potential really exists throughout the circle. In other words the integral of the difference of potential is the same in both cases, because the current in the circuit and the Joule effect and all those other electrical phenomena will be precisely those due to the difference of potential which we get when we open the circuit. Theoretically the way to treat such a case is to differentiate—take a certain element and treat it by itself. Taking a certain element there, we have a certain difference of potential, a certain resistance and a certain resulting current. Take for instance that circle and assume it for the purpose of the hypothesis to be divided into a thousand equal portions. Then we have one 1000th of the total difference of potential and one 1000th of the resistance in each element, and therefore we have the same current as with a thousand times the electromotive force and a thousand times the resistance. This seems to me to be merely a particular case—an electrical paradox.

MR. WOLCOTT:—Mr. Crocker's idea of the circulation of current there is a good deal like the relation of east and west on the globe. We can have a point west of New York and by going in the other direction it will be east of New York. If we take Mr. Crocker's view and integrate the difference of potential all around the ring, when we get back to the starting point, that point has two potentials, and so it must be It is like any other cyclic region. One of the most familiar cases of that is the magnetic potential. In an infinitely straight conductor the potential at any point has an infinite number of values, but it is only on some such conception as that, that you can consider there is any difference of potential. Each point has a potential different from itself.

That is by going around until you come back to the same point you have increased the potential, by the cyclic constants of the curve.

MR. KENNELLY:—I think we are very much indebted to Prof. Anthony for having called attention to one of the leading misconceptions of the day. There is a constant conflict between difference of potential and electromotive force, and I think nothing can be better in a society of this kind than to settle such confusions. I think Prof Anthony has given us a very clear solution in this way, that whatever produces a current is electromotive force; that electromotive force may or may not be accompanied by a difference of potential. We do not recognize potential as we recognize current. We are led to it by a series of abstractions. Potential was introduced on a purely theoretical and mathematical basis. The potential function first existed in gravitation. It was introduced into electricity by similarities which exist between gravitation laws and electrical laws in their mathematical form, and the potential is something which causes work to be done, in virtue of which work can be done. The potential is measured by the work done in bringing a unit of electricity to the point whose potential is to be determined.

DR. PUPIN:—I do not agree with the last speaker, that potential is a mathematical conception any more than I would agree with him that work is a mathematical conception. Who would say that to raise a barrel of flour to the gallery above us here is a mathematical conception? To charge a conductor with a certain amount of electricity, we must do a certain amount of work. If we do not stick to this term work, we cannot make a step of progress, because we cannot use the principle of the conservation of energy. Potential is not a mathematical conception. Potential is as concrete as the fact that I am standing here. It is the amount of work done. He said that difference of potential is something which causes work to be done, and a little while before that, he said that electromotive force is the cause of the electric current. Now these two things seem to me to be one and the same, because work must be done to cause the current to flow; but I will not discuss the subject any more, seeing that my colleague has expounded my idea of this circular conductor in a very nice and masterly way.

THE CHAIRMAN:—We certainly have had one of the most interesting evenings in the history of the Institute. I think the discussion has been very suggestive in many ways.

On the 18th of February, will occur the next meeting of the Institute, when a paper will be read by Mr. William Maver, Jr. and the topic will be, "The Practical Working of New York's Electrical Sub-ways." You may expect that to be an extremely interesting paper, full of surprises.

Adjourned.

THE ELECTRICIAN:

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ELECTRICAL ENGINEERING, INDUSTRY AND SCIENCE.

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NOTES.

In the suggestive Paper by Mr. Albion T. Snell on "The Distribution of Electrical Energy over Extended Areas in Mines," which will be found in another column, the employment of alternate-current motors on a commercial scale is placed, not without reason, somewhat *in futuro*. It is interesting to note in this connection that our New York correspondent reports this week that the Hercules Mining Machine Company, of Pittsburgh, have given a large order to the Westinghouse Company for Tesla motors to operate their coal mining machines. The result of this venture will be watched with considerable interest by electrical engineers in this country, who have not up to the present been over-favourably impressed by the performances of this motor so far as they have been made public.

Tesla Motors for Mining Purposes.—Referring to the alternating current apparatus reminds me of the fact that the Westinghouse Company has now entered the field of supplying electrical machines for mining purposes. You will remember that in my last letter I spoke of the imminent boom in this direction, and there is every prospect that the output of electrical apparatus for mining operations during 1890 will be very large. The Westinghouse Company has just secured a very large contract from the Hercules Mining Machine Company of Pittsburgh for a large quantity of generators and Tesla motors. As far as I am aware, this is the first time that alternating motors have been mentioned in connection with any such work, or with any heavy work at all. The apparatus will be used in operating the Hercules coal-mining machines, just lately brought out.

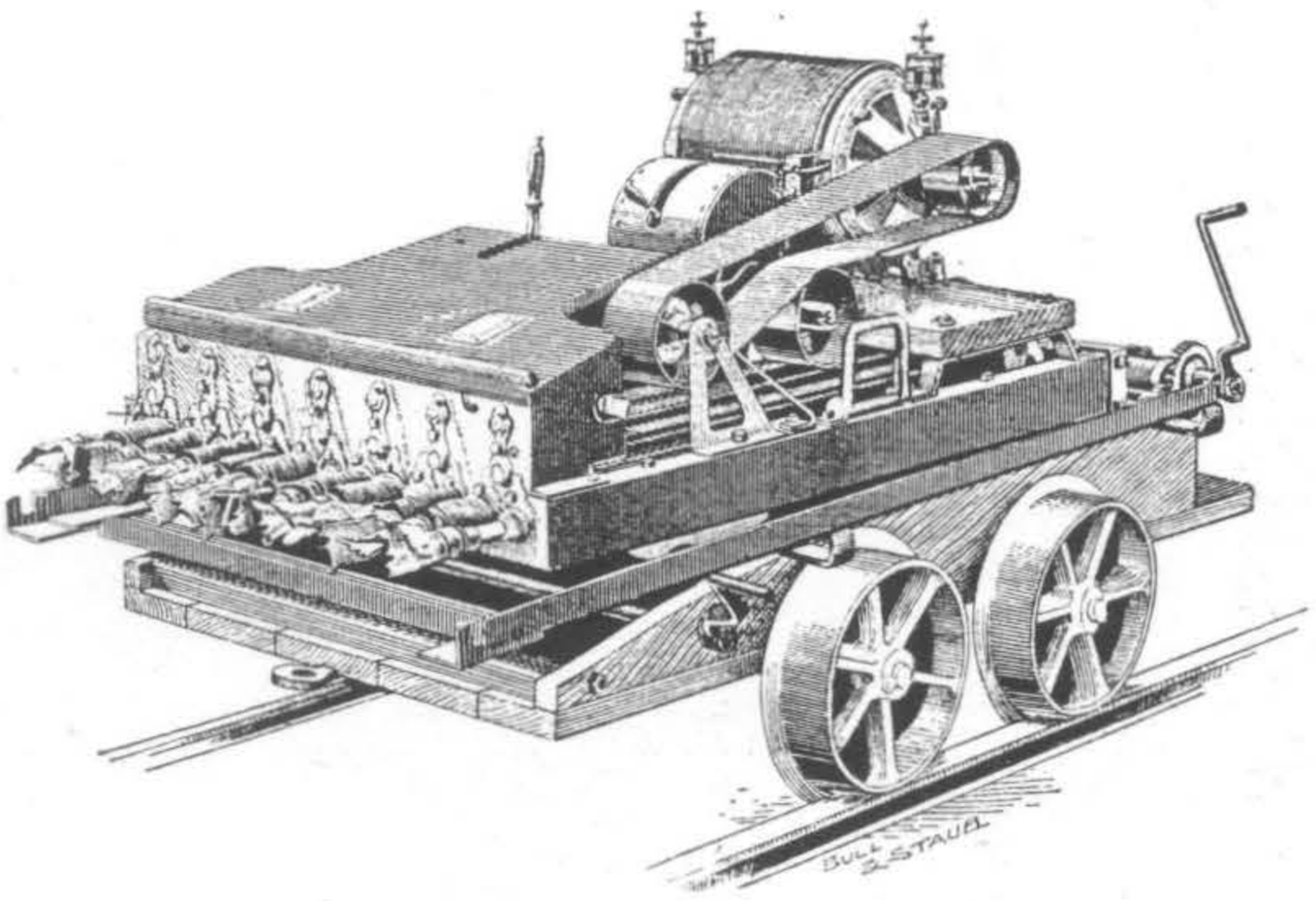
The Hercules Mining Machine and Tesla Motor.

The accompanying illustration represents the Hercules mining machine operated with the Tesla motor of the Westinghouse alternating current system. This is the first application made of the Tesla motor in connection with mining operations; but the fact that it has been such a signal success renders the great future for the motor even in this particular branch a certainty.

The Hercules Mining Machine was invented by Mr. E. E. Carter, a mechanical engineer of Pittsburgh, who sold it to the Hercules Mining Machine Company, a corporation composed of a number of Pittsburgh capitalists, prominent in the coal industry of the Monongahela Valley. The company at once set to work to make the machine a practical success. Experiments were inaugurated in the mines of the First Pool Monongahela Gas Coal Company, and the first problem presenting itself was to find a suitable motive power for the machine. Compressed air was utilized for some time and then abandoned to make room for electricity, which had proved to be much more practicable, and since the application of the motor to the machine nothing could be more satisfactory than the work of both.

As far as the machine itself is concerned, we may state that its dimensions are 36 × 60 inches, with an undercut of 42 inches and a scarf from 3 to 3½ inches high. In operation with the Tesla motor, it is handled by one man only. Its production represents a capacity of 600 square feet (floor space) in ten hours. Its great advantages are less physical labor for the miner and an assurance of an increased profit to the operator, which gives him an opportunity of paying the miner better wages. While the machine is going the man may leave it to itself and attend to the preparations for the next shift.

The success of the experiments have prompted the Monongahela Gas Coal Company to install a large plant of



HERCULES DRILL AND TESLA MOTOR.

the machines at their mines, and the Hercules Mining Machine Company has made a contract with the Westinghouse Electric Company for a large number of Tesla motors, as the prospects are that within the near future a large number of the machines will be disposed of.

Tesla Motors for Mining.—We have been waiting long to hear of the first application of the much talked-of Tesla alternate-current motor in practice. This first practical application has now been made for mining purposes, and seems to have been a thorough success, and the certainty of its extensive adoption appears to be regarded as certain. The Tesla motor was used to drive a Hercules mining machine, invented by Mr. E. E. Carter, of Pittsburg, and used in the coal mines of the Monongahela Gas Coal Company. Compressed air was first used for this coal cutter, but electricity was afterwards suggested, and since the application of the motor nothing could be more satisfactory. In operation with the Tesla motor, it can be worked by one man, and its production represents 600 square feet floor space in 10 hours. The machine wants little attention, and the man may leave it to attend to the next shift. The success of the experiments have induced the coal company to put in a number of machines, and the Hercules Mining Machine Company has made a contract with the Westinghouse Company for a large number of Tesla motors.

ELECTRICAL WORLD PORTRAITS.—XII.

NIKOLA TESLA.

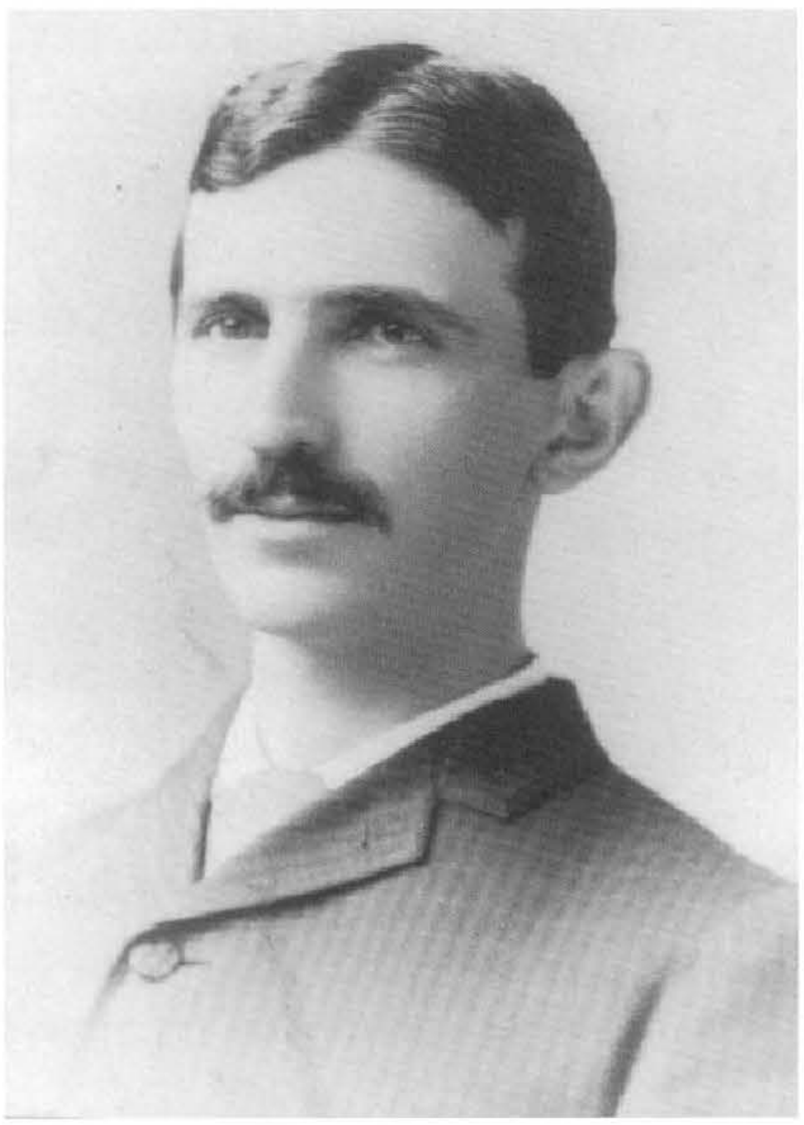
While a large portion of the European family has been surging westward during the last three or four hundred years, settling the vast continents of America, another, but smaller, portion has been doing frontier work in the Old World, protecting the rear by beating back the "unspeakable Turk" and reclaiming gradually the fair lands that endure the curse of Mohammedan rule. For a long-time the Slav people—who, after the battle of Kosovopjolje, in which the Turks defeated the Servians, retired to the confines of the present Montenegro, Dalmatia, Herzegovina and Bosnia and "Borderland" of Austria—knew what it was to deal, as our Western pioneers did, with foes ceaselessly fretting against their frontier; and the races of these countries through their strenuous struggle against the armies of the Crescent, have developed notable qualities of bravery and sagacity, while maintaining a patriotism and independence unsurpassed in any other nation.

It was in this interesting border region and from among these valiant Eastern folk that Nikola Tesla was born; and the fact that he, to-day, finds himself in America and is one of our foremost electricians is striking evidence of the extraordinary attractiveness alike of electrical pursuits and of the country where electricity enjoys its widest application.

Mr. Tesla's native place was Smiljan, Lika, where his father was an eloquent clergyman of the Greek Church, in which, by the way, his family is still prominently represented. His mother enjoyed great fame throughout the country-side for her skill and originality in needlework, and doubtless transmitted her ingenuity to Nikola; though it naturally took another and more masculine direction.

The boy was early put to his books, and upon his father's removal to Gospic he spent four years in the public school, and, later, three years in the Real School, as it is called. His escapades were such as most quickwitted boys go through, although he varied the programme on one occasion by getting imprisoned in a remote mountain chapel, rarely visited for service; and on another occasion by falling headlong into a huge kettle of boiling milk, just drawn from the paternal herds. A third curious episode was that connected with his efforts to fly; when, attempting to navigate the air with the aid of an old umbrella, he had, as might be expected, a very bad fall, and was laid up for six weeks.

About this period he began to take delight in arithmetic and physics. One queer notion he had was to work out everything by three or the powers of three. He would also calculate the cubes of every article of food put on the table at meals, and when in the streets would count every pace. He was now sent to an aunt at Carlstatt, Croatia, to finish his studies in what is known as the Higher Real School. It was there that, coming from rural fastnesses, he saw a steam engine for the first time, with a pleasure that he remembers to this day. At Carlstatt he was so d igent as to compress the four years course in three, and graduated in 1873. Returning home during an epidemic of cholera, he was stricken down by the disease, and suffered so seriously from the consequences that his studies were interrupted for fully two years. But the time was not wasted, for he had become passionately fond of experimenting, and, as much as his means and leisure permitted, devoted his energies to electrical study and investigation. Up to this period it had been his father's intention to make a priest of him, and the idea hung over the young physicist like a very sword of Damocles. Finally he prevailed upon his worthy but reluctant sire to send him to Gratz, in Austria, to finish his studies at the Polytechnic School, and to prepare for work as professor of mathematics and physics. At Gratz he saw and operated a Gramme machine for the first time, and was so struck with the objections to the use of commutators and brushes that he made up his mind there and then to remedy that defect in dynamo-electric machines. In the second year of his course he abandoned the intention of becoming a teacher and took up the engineering curriculum. After three years of absence he returned home, sadly, to see his father die; but, having resolved to settle down in Austria, and recognizing the value of linguistic acquirements, he went to Prague and then to Buda-Pesth, with the view of mastering the languages he deemed necessary. Up to this time he had never realized the enormous sacrifices that his parents had made in promoting his education, but he now began to feel the pinch, and to grow unfamiliar with the image of Francis Joseph the First. There was considerable lag between his dispatches and the corresponding remittances from home; and when the mathematical expression for the value of the lag assumed the shape of an eight laid flat on its back, Mr. Tesla became a very fair example of high thinking and plain living; but he made up his mind to the struggle, and determined to go through depending solely on his own resources. Not desiring the fame of a faster, he cast about for a livelihood, and through the help of friends he secured a berth as assistant in the engineering department of the government telegraphs. The salary was five dollars a week. This brought him into direct contact with practical electrical work and ideas, but it is needless to say that his means did not admit of much experimenting. By the time he had extracted several hundred thousand square and cube roots for the public benefit, the limitations, financial and otherwise, of the position had become painfully apparent, and he concluded that the best thing to do was to make a valuable invention. He proceeded at once to make inventions, but their value was visible only to the eye of faith, and they brought no grist to the mill. Just at this time the telephone made its appearance in Hungary, and the success of that great invention determined his career, hopeless as the profession had thus far seemed to him. He associated himself at once with telephonic work, and made various telephonic inventions, including an operative repeater; but it did not take him long to discover that, being so remote from the scenes of electrical activity, he was apt to spend time on aims and results already reached by others, and to lose touch. Longing for new opportunities and anxious for the development of which he felt himself possible, if once he could place himself within the genial and direct influences of the gulf streams of electrical thought, he broke away from the ties and traditions of the past, and in 1881 made his way to Paris. Arrived in that city, the ardent young Likan obtained employment as an electrical engineer with one of the largest electric lighting companies.



NIKOLA TESLA.

The next year he went to Strasburg to install a plant, and on returning to Paris sought to carry out a number of ideas that had now ripened into inventions. About this time, however, the remarkable progress of America in electrical industry attracted his attention, and, once again staking everything on a single throw, he crossed the Atlantic.

Mr. Tesla buckled down to work as soon as he landed on these shores, put his best thought and skill into it, and soon saw openings for his talent. In a short while a proposition was made to him to start his own company, and, accepting the terms, he at once worked up a practical system of arc lighting, as well as a potential method of dynamo regulation, which in one form is now known as the "third brush regulation." He also devised a thermomagnetic motor and other kindred devices, about which little has yet been published, owing to legal complications. Early in 1887 the Tesla Electric Company of New York was formed, and not long after that Mr. Tesla produced his admirable and epoch-marking motors for alternating current, in which, going back to his ideas of long ago, he evolved machines having neither commutator nor brushes. It will be remembered that about the time that Mr. Tesla brought his motors out and read his thoughtful paper before the American Institute of Electrical Engineers, Prof. Ferraris, in Europe, published his discovery of principles analogous to those enunciated by Mr. Tesla. We may, therefore, mention the fact, as additional evidence of Mr. Tesla's priority in this field, that some months before Mr. Tesla read his paper we were cognizant of his new work, and that we had ourselves the pleasure of seeing his motors in successful operation several weeks before that memorable meeting in May at which his paper was read. His inventions, however, we believe, far antedate even that period.

Mr. Tesla's work in this field was wonderfully timely, and its worth was promptly appreciated in various quarters. The Tesla patents were acquired by the Westinghouse interests, and at the present time the Tesla alternating current motor is being applied by the Westinghouse Electric Company to work of different kinds. A week or two ago we illustrated its use in mining, and its employment in printing, ventilation, etc., has already been shown in our columns.

The immense stimulus that the announcement of Mr. Tesla's work gave to the study of alternating current motors would in itself be enough to stamp him as a leader; but from what we know of him, we do not hesitate to predict that this is not at all the only work by which he will be known and remembered.

Mr. Tesla is only 33 years of age. He is tall and spare, with a clean-cut, thin, refined face, and eyes that recall all the stories one has read of keeness of vision and phenomenal ability to see through things. He is an omnivorous reader, who never forgets; and he possesses the peculiar facility in languages that enables the educated native of eastern Europe to talk and write in at least half a dozen tongues. A more congenial companion cannot be desired for the hours when one "pours out heart affluence in discursive talk," and when the conversation, dealing at first with things near at hand and next to us, reaches out and rises to the greater questions of life, and duty, and destiny.

Nikola Tesla.—The *Electrical World* for February 15 contains a portrait and biography of Nikola Tesla, the talented young electrician whose name suddenly came into prominence from the publication of his work on alternate-current motors. His native place was Smiljan, Lika, in the border regions of Dalmatia and Montenegro, touching Austria. His father was a clergyman of the Greek Church, and he himself was also destined to be a clergyman, but the fates and his own tastes ruled it quite otherwise. He graduated at Carlstatt in 1873, afterwards carrying on his studies at Gratz and at Prague under circumstances of considerable difficulty, taking a berth eventually as assistant in Government telegraph department at a pound or so a week to keep himself going. In 1881 he went to Paris and afterwards to Strasbourg. Then he crossed to America, where he applied himself with indefatigable vigour, and in 1887 the Tesla Electric Company was formed. It was soon after this that his celebrated paper on motors appeared. Mr. Tesla is 33 years of age, tall, spare, and refined, and he speaks at least half-a-dozen languages.

Nikola Tesla.—The *Electrical World*, N.Y., contains a portrait and notice of one of the foremost electricians in the States. Mr. Tesla belongs to the Slav race; his native place was Smiljon, Lika, where his father, according to our contemporary, was an eloquent clergyman of the Greek Church. Mr. Tesla, it seems, was a "quick-witted" boy who varied the monotony of youth by getting imprisoned in a remote mountain chapel rarely visited for service, and on another occasion by "falling headlong into a huge kettle of boiling milk just drawn from the paternal herd"—not "cold drawn," apparently. Our contemporary does not say whether, like St. John, cast into a caldron of boiling oil, Mr. Tesla emerged from his involuntary bath unscathed. A third curious episode was "connected with his efforts to fly" with the aid of an old umbrella, which resulted in his being laid up for six weeks. Mr. Tesla's career as an electrician has been, though brief, a distinguished one. He is only 33 years of age; in person tall and spare with a clean-cut thin face. He is an omniverous reader, and possesses the faculty of languages which is peculiar to the native of Eastern Europe.

American Institute Of Electrical Engineers Engineers - Transactions
March 18, 1890

A paper read before the American Institute of Electrical Engineers, New York, March 18, 1890, and discussion thereon. Vice-President Upton in the chair.

SOME TESTS ON THE EFFICIENCY OF ALTERNATING CURRENT APPARATUS.

BY DR. LOUIS DUNCAN AND MR. W. F. C. HASSON.

Several papers have appeared lately on the efficiency of alternating current transformers, some of which have been of a more or less theoretical nature, while others have given the results of actual tests. I have never, however, seen any tests on alternating current dynamos, excepting the experiments made by Dr. Hopkinson and Professor Adams on a de Meritens machine used for lighthouse work. Even the converter tests have given such varying results that one can hardly be certain as to the real efficiency.

The introduction of the alternating system has been so rapid and is so rapidly increasing that people are apparently well enough pleased with the results not to bother about the smaller question of the reasons for them. But whatever the results may be, it is of value to know just where the losses in any system may come in, so that we may seek how to avoid them; if we are succeeding, it may enable us to increase the profits,—if we are losing, it may help us to avoid further loss.

The apparatus, the measurement of which is the main subject of this paper, consisted of a Westinghouse 750-light No. 1 dynamo, with a No. 2 exciter and an outfit of 40-light converters. This apparatus had been presented by the Westinghouse Electric Company to the Johns Hopkins University, and was tested a couple of months ago. The workmanship of the machines is excellent.

The plant consisted of a 75 h. p. Armington & Sims engine driving the dynamo and exciter through a Tatham transmission dynamometer. Engine, dynamometer and dynamos were firmly secured to heavy parallel timbers which served as a foundation. The converters were banked on a wooden framework at a distance

of some thirty yards from the dynamo, and their primaries were permanently secured to the dynamo circuit, a switch in the latter serving to cut them off when desired. The ammeter belonging to the plant was put in this circuit and was read when efficiency measurements were being taken. The secondaries of the converters were taken to a switch-board and then to incandescent lamps mounted on racks.

Power measurements.—The Armington & Sims engine supplying the power worked regularly and satisfactorily and the governor could be adjusted to give the speed required at the dynamo. The Tatham dynamometer was the one used for power measurements at the Electrical Exhibition, held in Philadelphia, in 1884, where its accuracy was checked by making with it a de-

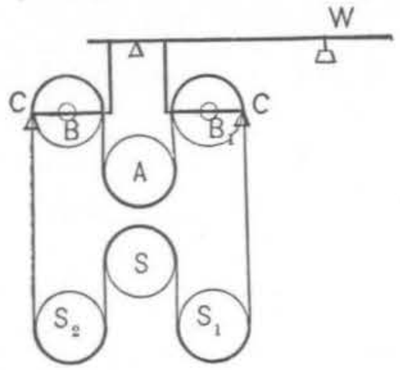


Fig. 1.

termination of the mechanical equivalent of heat. The result obtained in the latter measurement was 772.8 foot pounds per degree Fahr., and shows that the dynamometer is practically accurate. A description of the experiments and of the instrument may be found in the report of the test made to the Franklin Institute, but it will not be out of place to briefly describe the apparatus here.

An endless belt, as shown in Fig. 1, passes over the driven pulley, S, to the shaft of which the engine is belted, round the pulleys S_2 and B, to the driving pulley A, and back over B_1 and S_1 to S, again. The bearings of the pulleys B and B_1 are in cradles pivoted on knife edges, C, at their outer ends, and at the inner ends are connected by links at equal distances on the two sides of a knife edge which supports the scale beam W. The outer side of the belt passes through the line of the knife edges, C, and therefore has no effect on the scale beam, but the tensions of the inner parts of the belt act directly on the scale beam, and as they are on opposite sides of the fulcrum they act against one another. The beam is so graduated that this difference of tension is read

off directly in pounds, and this quantity—the difference of tension of the belt on the two sides of A—multiplied by its circumference and speed, gives the horse-power delivered. A weight travels on the beam, W, and readings can be taken with great accuracy.

Electrical measurements.—The energy in the secondary circuit was measured by means of a Cardew voltmeter and a Thomson ampere balance. As it is not the custom to put a number of secondaries in parallel, each converter had its separate lamp circuit.

Before making an efficiency test, the potential difference in the primary was regulated,—there being a Cardew voltmeter in that circuit,—and a separate measurement of the potential difference and current in each secondary circuit was made. When the test was actually in progress the voltmeter and ampere balance were used in one of the circuits and the currents and P. D.'s in the others were calculated from the readings in this circuit together with the previous measurements. Both the voltmeter and ampere balance were accurately calibrated, the former being checked after each test, while the latter had its constant determined with both continuous and alternating currents. The P. D. at the terminals of a non-inductive german-silver resistance in circuit with the balance was observed, when a continuous current was flowing, and also with an alternating current of the same period as that employed in the test. The current in each case was calculated from the resistance and P. D., and the results gave no appreciable difference in the constant for continuous and alternating currents.

The following tables show at once the order in which the tests were carried out and the results:

HORSE-POWER ABSORBED AT VARYING E. M. F.'s.

	E. M. F.		H. P
	Dynamo	Exciter	
Horse-power for exciter, field not made	0	0	.34
" " " field made	0	110	.75
" " dynamo alone	0		2.73
" " dynamo and exciter	0	0	3.04
" " " " "	0	107	3.51
" " " " "	1376	124	12.5
" " " " "	1168	104	10.1
" " " " "	1099	105	9.60
" " " " "	1040	105	9.0
" " primaries of converters on	1216	105	12.0
" " " " "	1171	104	11.8
" " " " "	1107	104	11.12
" " " " "	1048	104	10.64

TABLE OF EFFICIENCY AT VARYING LOADS

Approximate load.	Exciter.		Dynamo primary		Converters		Horse-power in lamp circuit.	Mechanical horse-power.	Loss, in horse-power.	Efficiency
	E. M. F.	Current.	E. M. F.	Current.	E. M. F.	Current.				
¼	105	9.4	1107	10.	49.5	153.9	16.21	21.83	11.62	46.8%
½	104	10.5	1107	18.9	49 6	338.4	22 50	34.4	11.90	65.4%
¾	101	11	1113	28.6	50.0	520.7	34.9	48.0	13.1	72.7%
Full	112	11.5	1123	38.1	50.9	739.8	50.48	64.44	13.96	78.3%

EFFICIENCY OF CONVERTERS.

No. 8. 40-light Converter.

No. of lamps.	Volts.	Watts in secondary.	Loss in watts.	Loss in iron	Efficiency.
40	50.0	2001	109	.....	94.8
0	50.9	0	84	84	.....

No. 4. 20-light Converter.

No. of Lamps.	Volts.	Watts in secondary.	Loss in watts in secondary.	Loss in iron, watts.	Efficiency.
20	48.8	952	106.	95.2	90.0%
15	52.2	817	114.8	108.9	87 6%
10	50.3	506	101 7	99.2	83 3%
5	51.44	264	109.4	108 7	70.7%
0	52.3	0	110.5	110.5	0. %

The efficiency of the converters was measured by placing them in a metal calorimeter, between the double walls of which water was allowed to flow. The temperatures of exit and entrance were observed, as well as the weight of water which passed through; at the same time the current and P. D. in the secondary circuit of the converter were measured. A separate observation gave the radiation, which was of course allowed for, although it was made as small as possible. A number of converters were experimented on but I give but two of them; a 40-lighter, such as was used in the tests, and a 20-light converter which was very carefully tested by two of my students, Messrs. Bliss and McKeen. In the latter case the observations were made at slightly different P. D.'s, and the results show that the loss in the iron varies as we would expect it to vary, that is, very nearly as the square of the voltage. The variation will not be exact, as the losses due to the reversal of magnetism do not vary quite as fast as the square of the induction.

I would like here to call attention to the fact that in an excellent paper read before this Institute, Professor Ryan, of Cornell, found that the losses in the iron of a 10-light converter decreased greatly as the load increased. This was accounted for by the fact that there was a jar (evidenced by the singing of the converter) at the higher loads, due to the attractions of the secondary and primary coils. While it is true that the losses in the cores of very small converters are not exactly constant, yet they are nearly so, and a large part of the decrease found by Professor Ryan is due to the voltage being greater at the low than at the high loads.

Looking now at the figures given in the tables we are struck by two things; the very large amount of power absorbed in the core of the armature, and the very small loss in the converters

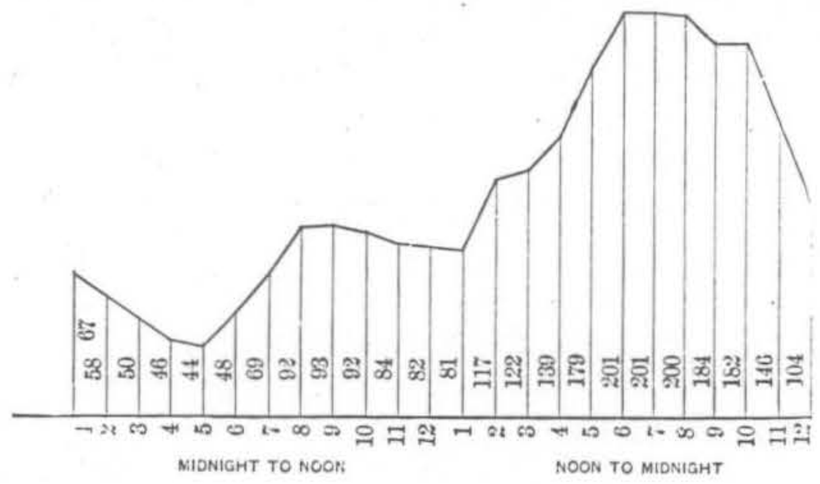


Fig. 2.

on open circuit. The dynamo losses due to reversals of magnetism and eddy currents, at the E. M. F. used in the test are no less than 6 h. p., while the energy due to reversal of magnetism and eddy currents in the 16 converters is only 1.6 h. p. Another rather striking thing is the almost constant ratio of primary and secondary currents over a considerable range. The maximum efficiency is about 78 per cent. It would seem that the losses could be divided into a constant part, and one varying with the current, but this is not true with the older style and smaller converters of the Westinghouse company.

Suppose we have a plant such as is described above, and use it for commercial lighting. Taking data from one of the local companies employed in supplying incandescent lights on this

system we have, for two 2,500 light dynamos, the following outfit of converters:—

Size of Converters	Capacity.	Number in use.	Total Lamps.
No. 1.	5 16 c. p. lamps.	44	220
No. 2.	10 " "	61	610
No. 4.	20 " "	43	860
No. 6.	30 " "	49	1,470
No. 8.	40 " "	64	2,560
Total lamp capacity			5,720
Number of lamps supplied			4,557

I understand that the converters being added are of the larger sizes.

The efficiency of the 30-light converters does not differ greatly from that of the 40 lighters. The accompanying Fig. 2, is a load diagram of this plant, selected from a number of diagrams as giving a fair average curve. If in our 750-light plant we are to work our dynamo to its full capacity, then from the above ratio of converter capacity to lamps supplied we would need converters for about 900 lamps; say 23 forty-light converters.

If, as in our test plant, these converters are 40-lighters, or 30-lighters—for the efficiency of these two sizes is about the same—we would have a mean loss in our plant of, say, 10 h. p. in our dynamos ($9.6 + C^2 R$), and in the converters about 3 h. p. ($2.3 + C^2 R$); or all together about 13 h. p. From the above table we will have 750 lamps supplied, and taking the data from the load curve the average lamp load would correspond to about 20 h. p., and the efficiency of the plant for 24 hours would be $\frac{20}{33} = 61$ per cent., minus the percentage of loss on the lines. This, in a properly installed system, should not average two per cent., so that the final efficiency would be 59 per cent.

A continuous current dynamo supplying the same outfit of lamps, with a maximum loss in the mains of, say, 15 per cent., would have a greater average efficiency. But I wish to point out that the maximum efficiency of the two plants would be about the same, so that they would require the same capacity of station outfit, boilers, engines, dynamos, etc. When more than one dynamo is provided, the efficiency of the alternating plant is increased by using only one of them during the times of minimum supply, and always working as far as possible only a little below the maximum capacity of the machines.

Let us consider these results in view of the present condition of incandescent light distribution in the United States. I take it that what may be called domestic electric lighting is largely a matter of the future—it is certainly not a matter of the present. The majority—the great majority—of the lights in use are in shops, saloons, theatres, offices, etc. Most of the lights wired are in use at one time or another during the 24 hours, and the proportion of energy supplied to the total capacity of the lamps connected is much greater than it would be in the case of house lighting, where, on the average, only a small fraction of the possible lamp-hours are actually in use. Under these circumstances the scheme of alternating current distribution is very different from what it will be when the attempt is made to supply an entire city with light, as they are attempting to supply London at the present time.

If the object of the lighting company is to supply the demand that exists at present, then a system employing a number of small converters is preferable. Such a system is flexible and can be installed with a minimum expense for the more or less scattered demand which is presented in even the most closely settled town. I take it that this is the great difference between the alternating and direct systems as at present installed in this country. The former skims over an extended district, taking advantage of its great flexibility to absorb any business which can be got; while the latter settles itself in a densely built centre, installs a larger plant than is primarily demanded, and works up a business within the limits of economical distribution. Therefore, it is hardly right to compare the present systems of direct and alternating supply, as the latter has not been reduced to a point where entire districts are to be supplied.

To show the disadvantage of the present system for domestic supply, suppose we have an ordinary house such as one of us would live in; it would be necessary to have a converter of at least 20 light capacity. The constant loss is, say, 100 watts; so, leaving out the $C^2 R$ loss, we would have a total loss in 24 hours, of $\frac{2400}{750}$, or about 3 h. p. hours, corresponding to, say, 45 lamp hours. Taking my own experience the actual number of lamp hours used is about 30 lamp hours during 24 hours, so the efficiency of the converter would be something like $\frac{30}{75} = 40$ per cent. It is evident that unless the losses in converters can be greatly

decreased, a house-to-house distribution with a converter in each house would hardly pay.

It would seem, then, that when gas is to be displaced and serious competition with it is to be attempted a different system of distribution will be worked out. We must replace the numerous small converters with one large converter supplying a comparatively extended district, thus decreasing the total converter capacity since the law of average can be taken advantage of, and greatly increasing the efficiency. If an extended secondary network is employed, some of the converters may be disconnected from the mains at the time of minimum demand.

Let us inquire for a moment how the increase in the capacity of converters will modify the designs with which we are familiar. In the first place, if we increase the linear dimensions of any type, since the radiating surface only increases as the square while the volume increases as the cube of the dimension, then we cannot suffer the same loss per cubic centimeter of iron for the large as for the small sizes. We must decrease the intensity of magnetization or we must decrease the periodicity.

Let us take a typical case. Suppose we have a transformer and double all of its dimensions. If we employ the same induction we will need but one quarter the number of turns in the coils, and as the cross-section of the space occupied by the wire is four times as great, the area of the wire may be sixteen times as much. As the length is twice as great, the resistance in this case is one-eighth. But the losses in the iron are, roughly, eight times as great; this we cannot allow, since the radiating surface is but four times as great; hence we must diminish the induction. In fact we must so arrange things that the loss in the larger converter is only four times that in the smaller, in order to work at the same temperature. As at the low induction used the loss due to hysteresis varies nearly as the square of the induction, we may take it roughly that the large converter should have an induction of three-quarters of the smaller one. This will modify our figures. Instead of one-quarter the number of turns we will have one-third, and the resistance of the coils will be one-sixth instead of one eighth, as we can allow four times the loss that we suffered before, we can have, roughly, five times the output.

As a total result we have five times the output with four times the loss, or, as the $C^2 R$ effect is not important as compared with the other losses, we can have six times the output with the same

fall of potential in the secondary. That is, the efficiency of the larger converters will be greater than the smaller ones of the same design and working at the same temperature, but the output per pound of metal will be less.

Suppose when we increase the size we decrease the number of reversals. Take a case, for instance, in which the dimensions are doubled while the reversals are halved, the maximum induction remaining the same. We could have half the turns in the coils, and as they occupy four times the space and are twice as long, the total resistance would be one quarter, and for the same heating effect we would have four times the output.

If we consider losses due to eddy currents these will be constant per cubic centimeter, provided the period and maximum induction are constant and the thickness of the plates is unchanged; otherwise they will vary as the square of the induction, with a constant frequency, or inversely as the square of the period with a constant maximum induction. This in practice would make the values of the output for the larger currents given above somewhat greater. What I wish to show, however, is that we are limited by heating considerations and considerations of fall of potential in our secondary in the output of large converters. If we consider the properties of the materials of which converters are made we would, I think, find it most economical to make converters that reach the temperature limit, except for the very smallest sizes.

Many of us have, I suppose, read Mr. James Swinburne's paper read before the British Association at Newcastle last year on the "Design of Converters," and have been struck by the fact that almost all of the converter dimensions given by him are impracticable, either on account of the disproportionate heating of the larger sizes, or the excessive fall of potential in the secondary. In increasing the size of dynamos we usually increase the output per pound weight, but there is the vital distinction between dynamos and converters, that losses occur through the entire mass of the latter, and as we increase the volume we increase the losses in the same proportion. In the dynamo, on the contrary, there are practically no losses in the heaviest part of the apparatus, *i. e.*, the field magnets. As a result, while we gain in efficiency in the larger sizes, yet we must decrease either our induction or the rate of reversal, and the output per pound is lessened.

DISCUSSION.

THE CHAIRMAN (Vice-President Francis R. Upton):—Gentlemen, you have heard a paper that brings a new set of figures and measurements before the electrical world, and with such accuracy that they will probably stand as facts for certain constructions of apparatus. This paper, of course, brings up the broader questions—the questions of alternating and direct currents, and as far as their economical bearing is concerned, I think discussion directed to this point would be in order. We have Prof. Anthony with us to-night, and we should be pleased to hear from him.

PROF. ANTHONY:—I would prefer to wait and hear some of the others talk about this matter. Alternating currents I have never had anything to do with practically. There are people here to-night who have had to do with them and who know more about the results. I should be glad to hear from them.

MR. NIKOLA TESLA:—Dr. Duncan has brought forward some facts which have not been recognized before, for instance, the fact that the loss in the iron of the converter remains perfectly constant with varying loads. That has not heretofore been acknowledged or known so far as I have heard. But on the other hand, when we consider the action of the converter, I think it ought to be. In converters in which the primary and secondary are put in the closest possible relation, for instance, in the Westinghouse, the increase of the primary and secondary currents is in an almost constant ratio, and since the loss in the iron is due to something like a differential action of both currents, I think the loss of the iron ought to be constant within certain limits

With regard to the excessive loss in the dynamo machine—in the armature that Dr. Duncan has found, I think, that most of us know that this loss is not due to the fact that we must have that loss, but we must sacrifice a certain amount for the regulation of the machine. Now, the same machine that Dr. Duncan has tested any one of us could cause to give a greater output and with a loss in the armature of no more than one or two horsepower. But we must work with a highly saturated field, in order to obtain a constant potential on the converters. On the other hand, the comparison between the single circuit alternating current and the direct current machine is just, and the proportions I believe will be about as Dr. Duncan found them. That is, if we compare a single circuit alternating machine with a direct current machine we will find representing the output of the latter by a number—say by 100—that the alternate current machine with one circuit will give for the same speed and weight about 78, or perhaps less. But we must also consider that we are enabled with alternating current machines to work at a very much higher speed and the simplicity of the apparatus allows us to work with a very much higher electromotive force. On the other hand, if we operated an alternating machine with two circuits then the output of the machine will no longer be inferior

to the direct current machine but it will equal it, if not be greater. I believe that Prof. Anthony some time ago told me that he also found that the loss in the armature by higher field saturation increased more rapidly than we would generally suppose. I have found also if you take a large generator and saturate the field very highly we may by only a few revolutions in a few minutes heat the armature so that the wires will burn out. I think the losses in the armature increase very greatly with the saturation of the field. Now, as regards the general results obtained by Dr. Duncan, I am firmly convinced of their correctness, of course, but I also firmly believe that Dr. Duncan has not had the best converter in hand. For I have myself made tests, and others have made tests, where the efficiency of such converters is shown to be much higher than is shown by Dr. Duncan. With the improvements we have made lately I believe that the new converters have now reached a much higher efficiency.

MR. H WARD LEONARD:—We had some theoretical discussion relative to comparative efficiency of the continuous and alternating currents at Chicago a couple of years ago At that time we had very little beside theory to work on, especially as regards our knowledge of anything in the alternating field. But I was a little interested in looking over the figures, which at that time were arrived at theoretically, and comparing them with those which have been obtained The claim for the continuous current efficiency which was made there was based on a maximum loss of twenty volts on a three wire system, on each side, that is, fifteen per cent.; and the average load was considered as forty per cent. on that maximum. Therefore the average loss in the conductors was considered as six per cent. for twenty-four hours, that is, an average efficiency of ninety-four per cent. With the generators operated as they would be in such a system at full load by cutting off such generators as were not needed, assuming an efficiency for the conductor of ninety-four for the feeders, one per cent. average loss in the mains, one per cent. average in the service and inside wiring, brought the total efficiency of the continuous current system to a figure of 84.7. With the alternating current system the lowest efficiency that was assumed on account of the much higher figures that were claimed was 85 per cent. for the generator, 95 per cent. for the feeder, 90 per cent. for the converter, 99 per cent. for the service and inside wiring, which gave for the total efficiency 74 per cent. I was not fortunate enough to hear the actual efficiency which the present three-wire system showed; but I remember that the Professor gave the efficiency of the alternating as 61, instead of 74. I think that a point which is perhaps the most pertinent and which has been pretty well emphasized of late, is the fact that the average load of a system of lighting generally through a city is such a very small percentage of the connected devices. I know of one instance where the lighting has not yet reached the condition which it

will later as regards supplying a much larger connected load than it has at present, and yet the average load for 24 hours is only about 12 per cent. of the connected load. This, of course, brings into very forcible action the efficiency of devices which are low in efficiency under conditions of light load. In the case that I have mentioned the maximum load is 30 per cent. of the connected devices, and the average load is 40 per cent. of that maximum.

Dr. Wheeler:—Although I may not be able to add anything to the subject of converters, I might say something about the effect of alternating currents with parallel wires. I know of a case in this city where lines ran parallel for about three miles, and where the current pumped up and down continuously, causing the lights to beat just as if they were driven by a steam engine which did not have a heavy enough fly wheel. After a very extensive investigation, it was found that the pumping of the lights was due to the fact that alternations on two circuits were nearly but not quite synchronous. When one set of waves caught up with the set of waves on the next wire while passing them they first drove those waves ahead and then drove them back. This caused the energy of one circuit to first pile up the energy in the other circuit, and then force it down, and thus cause a pumping effect on the lights. That was overcome entirely by placing the wires in pairs properly, that is to say, the two legs of each circuit had not been arranged side by side. One or two of the circuits had been misplaced. But by bringing those together, so that the negative side or "leg" of one circuit was right alongside of the other "leg" of its own circuit and not mixed up with the wires of any other circuit, the induction was completely neutralized, and that left the lights perfectly steady. This has nothing to do with converters, but is about the only thing that I can contribute to the subject. It was quite important. The lights pumped very badly. The company was very much troubled to know what the cause was. I had been formerly driving Edison dynamos with high speed engines and I laughed at the people who were running the lights, and assumed that their fly-wheel was not heavy enough. They suggested that I could go and try the fly-wheel. I made them buy a very expensive speed indicator and put it on, and about as soon as they got it running I made up my mind that the inertia of the indicator mechanism would be too great to allow it to respond quickly enough, that is to say, if the steam engine made about 74 revolutions a minute, as it did, and if its speed varied enough to show a flickering in the light, which would be about two per cent. variation in the middle of each stroke of the engine, it would not be easy to get a speed indicator needle which would show such brief, rapid and small variations as two per cent. variation on every stroke, that is, in less than one second for each. I then tried figuring out the weight of the fly-wheel and how much its speed ought to increase

or decrease between the strokes. Assuming the fly-wheel weighed 30 tons and had a diameter of 30 feet, and 500 horse-power was being drawn off by the belt continuously and was being put into the fly-wheel twice in every stroke by a brief impulse of the pitman with no source of power in the intervals, how much would the wheel slow down in the seventy-fourth of a second? In other words, how much would 500 horse-power slow down a 30 ton fly-wheel of 30 feet in diameter in the seventy-fourth of a second. About the time I made up my mind that this would be a long matter to figure out, I decided to try the plan of substitution, that is, to change all the elements of the system one after the other, until I found to which element—for example, the dynamo, the lines or the engine—the trouble was due. We therefore tried driving the different dynamos by different engines and connecting different lines on to different dynamos. We then found that the trouble went with a particular wire. That surprised me. I had gone so far in the matter then that I decided I was in honor bound to see it through. I went out and counted the number of pulsations in the lights and found that they were about eighty to the minute. I had inspections made and found there were only two parts of the city where the lights pumped in this way. I then immediately compared the pulsations of the other sets of lights and found they were 80 to the minute; the same as the first group. I then concluded there must be some reaction between the lines supplying the two districts. Following the wires out I found that the two sets of wires that supplied these two groups of light were placed in a position where they could act inductively on each other, while the others were so placed that they could neutralize their own effects, and I suggested that one set of wires be changed about. This was done and there was no more pumping. It was clearly due to one set of alternations "beating" with the set on the other wire.

Mr. Tesla:—A point mentioned by Dr. Duncan was, how the construction of the converters would be modified when their size is increased. I had hoped that Dr. Duncan, whose work in that line has always been so valuable, would give us some points on that. It is evident to every one that it is impracticable to increase the size of the converter in the same proportion as its capacity is increased; because, as we operate the converter at a constant number of periods, we would render a long magnetic circuit transformer very inefficient. A plan was proposed by me a year or so ago to introduce this system in the construction of converters to have the same length of magnetic circuit, no matter whether the converter is large or small. I believe that this would be the proper way of constructing all converters on one system, and I believe that the present method of constructing converters is not right, for every different capacity of converter has a different length of magnetic circuit, and we know well that if one converter is adapted to, say 16,000 reversals,

another one with a different length of magnetic circuit is not adapted to the same number of reversals. We started a year ago, I think, to make all converters of the same length of magnetic circuit, so as to render them equally adaptable for the same number of alternations, no matter what their capacity is, and in such case, if we want, for instance, a converter that has ten times the capacity of a small twenty light converter, we will practically put in one converter so many multiple circuits as are required to get the capacity desired. We will allow a somewhat greater capacity to maintain the converters all at the same temperature.

I think that this plan should be followed. In general, I may say that the results obtained by Dr. Duncan refer to an apparatus a considerable time in use, but the advances that have been made in that line the last year only, are so enormous that we would not recognize this plan at all. For instance, I believe that the converters at present can be made to have less than half the leakage that they had previously. In other words, it means practically you can run a converter with a double load—the machines are increased very nearly to double their capacity; and when we consider the short interval in which this has been accomplished, we may fairly assume that in a few years from now there will be little difference between the alternating and direct current, even on short distances. We will wait for that development in the meanwhile.

Dr. Duncan:—In respect to the construction of converters, of course, in increasing the dimensions in the same proportion, I was not following out the proper design for every given converter. Every converter of a given design has its own proper dimensions, and all dimensions do not increase in the same ratio. But I think that Mr. Tesla's idea of keeping the same length of the magnetic circuit is hardly proper. I have worked out for my own amusement the design of a number of converters. For a converter of given capacity, there is a definite period which with the best proportions of iron and copper, corresponds with the maximum efficiency of the converter, but if you simply increase the cross section of the iron without increasing the length of the circuit you keep the same cross section of copper, which is not a good practice. You have to change both the copper and iron, and I did not think it would be very interesting to design a large number of converters for any given output. As for the efficiency of this plant which was tested, the plant was sent on, I think, in November, and was supposed to be the latest plant which was produced by the Westinghouse company. I have since heard that the efficiency of converters has been greatly increased. The losses in the converters could undoubtedly be greatly decreased, especially for larger sizes. As to the relative efficiency of the two plants, it must be remembered that I have simply taken a seven hundred and fifty light plant, and one dynamo is supposed to be always connected with the circuit. In a station of

ordinary capacity, that is of more than twice 750 lamps, we would certainly have the advantage of having at least two dynamos, one of which could be disconnected when the load had reached its minimum and the efficiency would therefore be greatly increased; and also in comparing efficiency of alternating and continuous plants, we must remember that the business that is catered to by these two systems is very different; that the load diagram of the alternating plant is very different from the load diagram of the continuous current plant. An alternating plant takes up the cream of the business, so to speak. It takes up business in which they get the maximum output for a given number of lamps wired, and in that way we must not calculate the efficiency of the alternating and continuous current plants at the same average load in comparing them. If so, we are favoring the continuous plant very much. With the alternating current plant it is simply a commercial question. If you can put into a continuous current station an alternating dynamo which will get business that will pay you, it is undoubtedly proper to put that dynamo in. In the same way if you have an alternating plant and it is so situated that you can run part of the service more economically with a continuous current, then put in a continuous current dynamo. But as the business stands at present a combination of the two plants is undoubtedly the most efficient in many cases.

Mr. O. T. Crosby:—I should like to ask if the advances reported are in the direction of increasing the efficiency of the converter at all loads, or only at some normal loads?

Mr. Tesla:—I said before, that the leakage was reduced to one-half, and I thought it was clear enough that that applied as well to the working of the converters on the full load as on the small load. When I speak of leakage I mean no load at all. But Dr. Duncan said just now—I thought he misunderstood me in regard to the construction of these converters—I proposed not to keep the length the same and vary the section simply, but to vary the section of the copper, at the same time varying the section of the iron. We have plates, for instance which contain so many multiple circuits. These plates are so made that the coils can be just as well put in as one single circuit transformer, a form of construction invented by Mr. Albert Schmidt of the Westinghouse company, and in this way we have practically a number of independent transformers, and the only diminution of the capacity of such transformers is that we have got a somewhat smaller surface. Then we may allow a little higher capacity for that diminished surface. That is all. I think that point is very clear; and there is no doubt at all that this contruction should be followed.

Mr. Fred'k Darlington:—There is one thing which I think merits attention in the discussion of this question, that is that one system uses the 50 volt lamp, and the other system is forced to use a 100 or 110 volt lamp, and that by the same skill of con-

struction of lamps and the same advance in the art of manufacturing lamps, the 50 volt lamps represent about twenty per cent. more efficiency than the 100 volt lamps. That is found in practice. For instance the 100 volt lamps which are being supplied now by one of the large commercial manufacturers of lamps are six-tenths, or a fraction over six-tenths of an ampere and 100 volts; while the manufacturers of 50 volt lamps make a 50 watt lamp and get 50 volts out of the lamp and a better service for the time. I can tell of results that have been obtained by the Westinghouse Electric Company recently in the improvement of converters. They were manufacturing for a considerable time a converter that gave a leak of twelve one-hundredths on every 40 light converter and, recently, since certain analyses have been made of the iron and the quality of the iron has been improved and the method of annealing the iron has been improved, they have reduced that leakage from twelve to seven hundredths of an ampere, and the point that Dr. Duncan mentions that in putting in the alternating system they are able to take out the lamps in the service—certain circuits one gentleman said only about twelve per cent. of the total number of lamps burning on an average—I can state what is given here in New York in the service of the United states Illuminating Company. They are getting out of the total number of lamps wired on a circuit five and eight-tenths hours per lamp, which is about 23 per cent. All those points, I think, if taken into account will make the efficiency of the alternating current come much higher than would appear at first thought.

Mr. Tesla:—Another point of great importance is the fact that in the alternating system you have got an apparatus of almost ideal simplicity. If the armature burns out it is a matter of a few hours' work; and the repairs cost very little. If any part of the apparatus gives out it is easily replaced without trouble. With a direct current system, I think on the average out of 100 armatures, if you take them on a year's run, there will be about fifty that will have some trouble or other. The commutator will wear out in a few years, even with the best attention. I speak, of course, of the average.

The Chairman:—I think we are letting the subject wander a little from the efficiency of the alternating current apparatus. I think we had better keep to that subject.

Mr. Tesla:—I beg to remark on this that the title of the paper of Dr. Duncan was the tests on the efficiency of alternating current apparatus, and I never thought that the other subject would be mentioned. But Dr. Duncan's paper assumed the shape of a comparison of the efficiency and merits of the systems, and if I have wandered a little too far, I beg your pardon; it was not my fault, as the talk drifted in that direction.

Lieutenant John Millis:—I believe in all the alternating systems that are now in practical operation in this country the

rapidity of alternations, that is, the number per second, is practically the same. I would like to inquire what are the considerations which have determined this rate of alternations, whether they are mechanical or electrical, and if so, if Dr. Duncan can briefly explain to us what they are, also what the effect would be if the rapidity of alternations were varied. He touched lightly upon the theory of the effect that would be produced in the output or efficiency of the converter if the rapidity of alternations varied. I would like to ask if this theory has been confirmed by him, or to his knowledge by any one by practical experiment, and what the result of the experiment is.

Dr. Duncan:—The rate of alternation is determined very greatly by the size of the unit in which the distribution is made. For large units a low rate is commonly employed. You will find in most of the continental and English systems that the rate of alternations has been decreased as the size of the converter has been increased. For a large converter a comparatively low rate should be used, and as in this country small converters have generally been employed, the rate is very much greater than where the converter has been large.

Mr. Townsend Wolcott:—Dr. Duncan referred to Prof. Ryan's paper and his idea in regard to diminishing the energy absorbed by hysteresis by vibrating the iron. Mr. Kennelly seemed to have the same idea as Prof. Ryan that you could get rid of the waste of energy very largely. The diagram of the hysteresis for one period as drawn by several experiments is as shown in Fig. 11 of Prof. Ryan's paper, one point at the bottom and the other at the top. Now, if you can come back by the same path as you go, of course, the energy is zero. But Mr. Swinburne divides the hysteresis into two kinds. He speaks of viscous hysteresis and ordinary hysteresis. Previous to the presentation of Prof. Ryan's paper I had the impression that the whole hysteresis worked in the manner which Mr. Swinburne calls viscous hysteresis; that is, like friction, it would resist in both directions. Mr. Swinburne's idea seems to be that the energy absorbed depends to a great extent upon the difference of phase between the magnetism in the iron and the magnetizing force of the current.

Dr Michael I. Pupin:—I would like to ask Dr. Duncan whether he knows of any experiments that have been made lately for the purpose of finding out how much of the lost energy is due to eddy currents and how much to magnetic hysteresis. As far as I am aware, there has been no experimental work of that kind done, and that has been spoken of as a work which it is very desirable to do—to determine the ratios between the two. I think that would also give us a means of testing whether work lost on account of magnetic hysteresis is the same for every period—whether they obtain the same current, as shown in the diagram referred to by Mr. Wolcott.

DR. DUNCAN:—I am not prepared to give any figure on that point because I am experimenting on it at the present time. I am working now to weed out the eddy currents, and to determine the effect of hysteresis for different periods of reversal. There is no data at present to tell whether the loss on the iron is due to viscous or static hysteresis. If we go through the change in magnetic force at a very low speed then losses due to time hysteresis will not come in at all. If we go at a very high speed it will not come in at all. If we go at the present speed it will come in. As I say, at present my work is in trying to weed out the eddy currents. But I have not reached any results; and it is not a part of the paper. It is a very important question, though.

MR. LEONARD:—I take the liberty of speaking for a second on the question of a five hour load. I had been brought to select in the instance I noted the most exceptional one I knew of as being the future condition of supplying loss of all kinds. In New York City, which, of course, is the most exceptional in the other direction, the Edison station here has instead of five, nearer eight hours average load which, however, may be somewhat due to the advantages derived from the sale of motive power.

MR. JUSTUS B. ENTZ:—I would like to inquire if the losses due to eddy currents and hysteresis could not be determined by different thicknesses of discs. By taking two readings and separating them, I think it could be determined—the loss due to the eddy currents, of course, varying as the electromotive force. If the thickness of the disc is doubled the potential is doubled, while the resistance making a watt loss in each disc, varies as the cube, and if the disc in the converter were double in thickness and the same amount of iron, and the loss measured in the two cases, I should think they could be separated.

MR. TESLA:—I should think, gentlemen, that if hysteresis is a distinct element in the loss of the converter it can be only so because it is intimately connected with the generation of the currents in the iron. We cannot go beyond a certain thickness of the iron—say number 38 or 40, which may be yet thick enough to give rise to the currents in the iron. But the results that Dr. Duncan has to-day brought out strengthened me in the idea which I always had, that ultimately the whole loss in the iron resolves itself into the loss due to the currents. The facts he finds show that the principal loss is due to the eddy currents. The loss in the iron is constant at all loads; on the other hand, he finds that the loss is proportioned to the square of the electromotive force, which would be precisely the case if the loss in the iron were due to eddy currents. I think that is an argument for this view.

MR. CROSBY:—It seems to me in that case that we want to know something of the subdivision of the iron, because by a very slight subdivision we might get the eddy current so predominating over the other effects that it might be when the subdivision were finished that they would appear as perhaps the

larger effects. I should like to ask Dr. Duncan what the cubic contents of the iron masses were whose total loss is given in the paper? It may have been stated, but I did not hear it.

DR. DUNCAN:—I think it is possibly in the paper. If not, it is somewhere else, and I would be very glad to give it to Mr. Crosby. As to distinguishing between the hysteresis and eddy currents with different thicknesses of plate, unfortunately Ewing has found that as far as this time hysteresis is concerned, it depends on the thickness of the plate independent of the eddy current. So, it would be impossible to distinguish in that way.

Adjourned.

the principal loss encountered is to be detected in the armature of the dynamo, and this fact, we believe, is now well recognized by the manufacturers of alternate current apparatus, so that improvement of the kind needed may be looked for at no distant date, embodying among other changes the application of the toothed armature instead of the plain cylindrical as heretofore employed. The converters are shown to be quite efficient, and the curious relation is brought out that the loss in their cores is nearly constant for all loads. It is this constancy of relation that, as Mr. Tesla pointed out in the discussion before the American Institute of Electrical Engineers, may ultimately establish the correctness of the hypothesis advanced, that in reality there is practically no loss due to hysteresis, and that the changes of magnetization represent a charging and discharging of molecular energy without entailing an actual expenditure of energy. The losses, then, must be due to eddy currents principally, and the remedy is obvious. Dr. Duncan, in the discussion, also gave expression to his views on the application of the system of distribution, alternating and continuous, which we think are now being generally adopted by intelligent electrical engineers. According to these, the circumstances of each case must dictate which is the more economical to apply, and hence no hard and fast rule can be given. Where the density of population permits of it, the low-tension system of distribution is apparently the more economical; but where the consumers are scattered, as they are in a vast number of towns and cities, and at such distances from the station that direct working would involve too great a loss, the converter system is eminently applicable. Dr. Duncan goes further and gives it as his opinion that the best results could be obtained by a combination of both systems in a central station which would thus be able to accept all the business offered to it independent of distance. That these views are sound is evidenced by the fact that they have already been put into practical operation in a few instances by men of leading, and we cannot but believe that in this direction will be found the settlement of a long-waged and earth-shaking controversy in the industrial domain of electricity.

EFFICIENCY OF ALTERNATING APPARATUS.

Ever since the alternating current apparatus entered the field of electric distribution, a brisk controversy has been carried on as to the efficiency of that class of apparatus as compared with the continuous. Though much acute reasoning was brought to bear on the subject, there has up to the present been little reliable data of an independent source available for a practical comparison, and that in existence related merely to individual devices in connection with the alternating system. Thanks to the labors of Dr. Duncan and Mr. W. F. C. Hasson, however, we are now placed in possession of data which is undoubtedly reliable, and which, while giving the tests of all the individual apparatus of the alternating system, includes the efficiency of the system as a whole from the dynamo pulley to the lamp. The analysis of the results would seem to show that

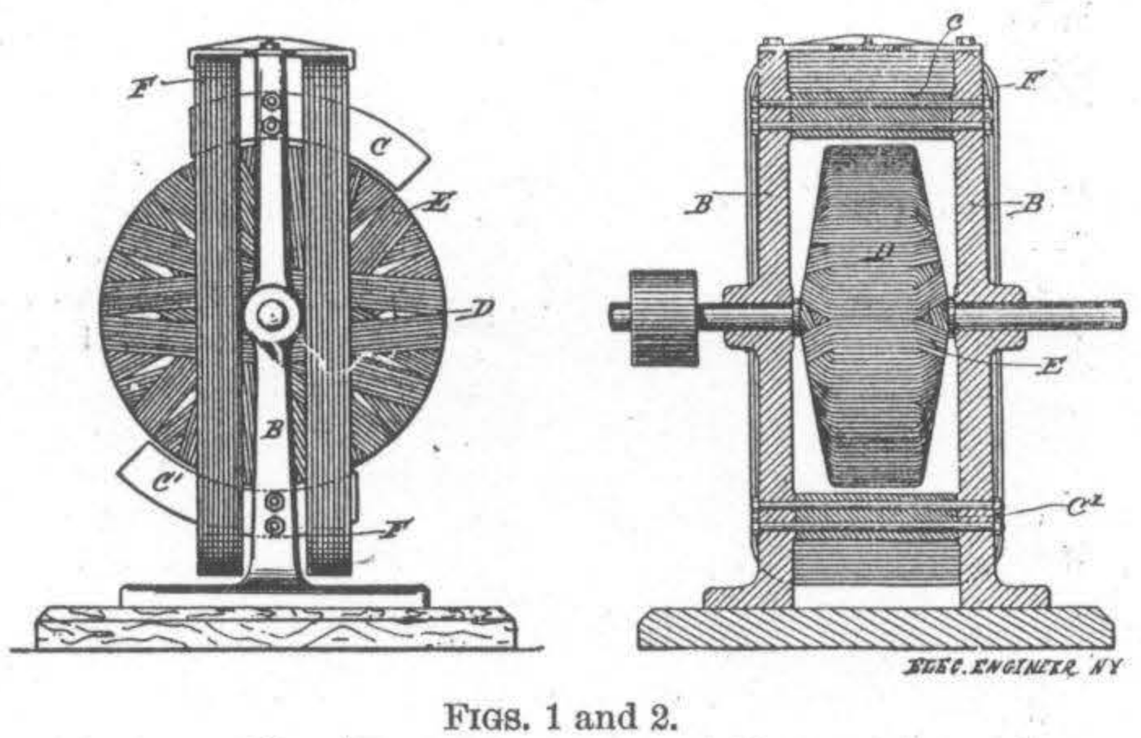
A NEW TESLA ALTERNATING MOTOR.

Our readers are already acquainted with the Tesla alternating current motor, which has now gone into practical application, and the operation of one type of which is based upon the fact that when an alternating current is passed through the coils of such a motor, the field magnets or poles do not appear to manifest their attractive effect upon the armature simultaneously, the magnetic attraction of some appearing to lag behind that of others, with the result of producing a torque and rotation of the motor.

Mr. Tesla has, however, developed another form of these so-called "magnetic lag" motors, but in operation it differs from those just described, in that the attractive effects or phases of the poles, while lagging behind the phases of current which produce them, are manifested simultaneously and not successively.

The manner in which this is carried out, is shown in the accompanying illustrations, Figs. 1 and 2, which represent respectively an elevation and side view of the motor.

As will be seen, the motor has two laminated magnetic pole-pieces c c′ of soft iron or steel. The laminated disc-



Figs. 1 and 2.
New Tesla Alternating Motor.

armature d is mounted between the pole-pieces c c′, which are curved to conform to the circular shape of the armature. The latter is provided with a closed coil winding. The main energizing coils f f are arranged so as to include within their magnetizing influence both the pole-pieces c c′ and the armature d, the pole-pieces c c′ projecting out beyond the coils f f on opposite sides, as shown.

If an alternating current be passed through the coils f f, rotation of the armature will be produced, and this rotation is explained as follows :—

An impulse of current in the coils f f, establishes two polarities in the motor. The protruding end of pole-piece c, for instance, will be of one sign, and the corresponding end of pole-piece c′ will be of the opposite sign. The armature also exhibits two poles at right angles to the coils f f, like poles to those in the pole-pieces being on the same side of the coils. While the current is flowing there is no appreciable tendency to rotation developed; but after each current impulse ceases or begins to fall, the magnetism in the armature and in the ends of the pole-pieces c c′ lags or continues to manifest itself, which produces a rotation of the armature by the repellent force between the more closely approximating points of maximum magnetic effect. This effect is continued by the reversal of current, the polarities of field and armature being simply reversed.

One or both of the elements—the armature or field—may be wound with closed induced coils to intensify this effect. Although in the motor shown there is but one of the fields, each element of the motor really constitutes a field, wound with the closed coils, the currents being induced mainly in those convolutions or coils which are parallel to the coils f f.

Mr. Tesla has designed various types of motors on this

principle, among them one having a number of fields, which is particularly adapted to a rate of alternations corresponding to those now in general use on alternating circuits.

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undergoing magnetic changes entirely independent of any currents generated therein.

Now it is difficult to reconcile these views with our present notions on the constitution of matter generally. The molecules of iron cannot be connected together by anything but elastic forces, since they are separated by an intervening elastic medium through which the forces act; and this being the case is it not reasonable to assume that if a given amount of energy is taken up to bring the molecules out of their original position an equivalent amount of energy should be restored by the molecules reassuming their original positions, as we know is the case in all molecular displacements? We cannot imagine that an appreciable amount of energy should be wasted by the elastically connected molecules swinging back and forth from their original positions, which they must constantly tend to assume, at least within the limit of elasticity, which in all probability is rarely surpassed. The losses cannot be attributed to mere displacement, as this would necessitate the supposition that the molecules are connected rigidly, which is quite unthinkable.

A current cannot act upon the particles unless it acts upon currents in the same, either previously existing or set up by it, and since the particles are held together by elastic forces the losses must be ascribed wholly to the current generated. The remarkable discovery of Ewing that the magnetization is greater on the descent than on the ascent for the same values of the magnetizing force strongly points to the fact that hysteresis is intimately connected with the generation of currents either in the molecules individually or in groups of them through the space intervening. The fact observed accords perfectly with our experience on current induction, for we know that on the descent any current set up must be of the same direction with the inducing current, and, therefore, must join with the same in producing a common effect; whereas, on the ascent the contrary is the case.

Dr. Duncan stated that the ratio of increase of primary and secondary current is constant. This statement is, perhaps, not sufficiently expressive, for not only is the ratio constant but, obviously, the differential effect of primary and secondary is constant. Now any current generated—molecular or Foucault currents in the mass—must be in amount proportionate to the difference of the inductive effect of the primary and secondary, since both currents add algebraically—the ratio of windings duly considered,—and as this difference is constant the loss, if wholly accounted for in this manner, must also be constant. Obviously I mean here the transformers under consideration, that is, those with a closed magnetic circuit, and I venture to say that the above will be more pronounced when the primary and secondary are wound one on top of the other than when they are wound side by side; and generally it will be the more pronounced the closer their inductive relation.

Dr. Duncan's figures also show that the loss is proportionate to the square of the electromotive force. Again this ought to be so, for an increased electromotive force causes a proportionately increased current which, in accordance with the above statements, must entail a loss in the proportion of the square.

Certainly, to account for all the phenomena of hysteresis, effects of mechanical vibration, the behavior of steel and nickel alloy, etc., a number of suppositions must be made; but can it not be assumed that, for instance, in the case of steel and nickel alloys the dissipation of energy is modified by the modified resistance; and to explain the apparent inconsistency of this view we only need to remember that the resistance of a body as a whole is not a measure of the degree of conductivity of the particles of which it is composed.

N. TESLA.

New York City.

LETTERS TO THE EDITOR.

Notice to Correspondents.

We do not hold ourselves responsible for the opinions of our correspondents.
Anonymous communications cannot be noticed.
The Editor respectfully requests that all communications may be drawn up as briefly and as much to the point as possible.
In order to facilitate reference, correspondents, when referring to any letter previously inserted will oblige by mentioning the serial number of such letter, and of the page on which it appears.
Sketches and drawings for illustrations should be on separate pieces of paper.
All communications should be addressed EDITOR OF THE ELECTRICAL ENGINEER, 150 *Broadway, New York city.*

THE LOSSES DUE TO HYSTERESIS IN TRANSFORMERS.

[121.]—In your issue of April 2, in referring to certain remarks made by me at the recent meeting of the American Institute of Electrical Engineers on the subject of hysteresis you make the statement: "It is this constancy of relation that, as Mr. Tesla pointed out * * * may ultimately establish the correctness of the hypothesis advanced, that in reality there is no loss due to hysteresis, and that the changes of magnetization represent a charging and discharging of molecular energy without entailing an actual expenditure of energy."

I do not recollect having made such a statement, and as I was evidently misunderstood, you will greatly oblige me by inserting the following few lines, which express the idea I meant to advance:

Up to the present no satisfactory explanation of the causes of hysteresis has been given. In the most exhaustive and competent treatise on the theory of transformers, by Fleming, static hysteresis is explained by supposing that "the magnetic molecules or molecular magnets, the arrangement of which constitutes magnetization, move stiffly, and the dissipation of energy is the work done in making the necessary magnetic displacement against a sort of magnetic friction." Commonly it is stated that this is a distinct element in the loss of energy in an iron core

PHENOMENA OF ALTERNATING CURRENT INDUCTION.*

BY PROF. ELIHU THOMSON.

About three years ago I had the pleasure of bringing to the attention of the American Institute of Electrical Engineers at its annual meeting, certain phenomena of the repulsive action between conductors such as coils of wire traversed by alternating electric currents. It was then noted that if such a current be sent through a circuit wound as a coil, and either provided with an iron core, or not so provided, and permitted to induce in another coil or circuit a current under conditions which allowed a lag or displacement of phase of the latter from its theoretical position, a repulsive effort would be exerted, tending to remove one coil from proximity with the other, or to deflect one of them to a position such that the plane of the coils would be at right angles one to the other.

Many modifications of the arrangements of the coils were described and apparatus based upon the principle of inductive repulsion, as I called it, were touched upon. I need not now enlarge upon these matters. It may suffice to say that current indicators and potential indicators or voltmeters have been constructed embodying the principle as applied to the quantitative measurement of alternating currents. Arc lamps have been made in which the regulation of the carbons has been effected by the repulsive action of a coil traversed by the current fed to the lamp, or by a derived current around the arc, acting on a closed band or circuit movable with the regulating and feeding frame of the lamp. Various forms of alternating-current motors have been made in which the revolving portion is composed of coils arranged to be closed upon themselves, and inductively acted upon by the currents in what may be called the field or inducing coils connected with the alternating current source. The principle has been applied in other apparatus,

* Abstract of a lecture delivered before the American Institute of Electrical Engineers at Columbia College, April 2, 1890.

such as regulating mechanism for alternating currents and in electric meters.

It is my purpose this evening to bring before the institute some experimental apparatus showing the action of inductive repulsion in some of its phases, following this by a brief account of a number of other effects somewhat allied to it, with experimental demonstrations of the same. Some of these experiments were to be seen at the Paris Exposition of last year in connection with my exhibit there, and others of them are more recent still, while still others have never been shown at all in public. The field is a fruitful one, and there is not time to touch upon other than the more striking and perhaps interesting phases of the actions exhibited, which are susceptible of modification to a great extent by changes in proportion and arrangement of apparatus.

I may here revert to one experiment, which is almost a repetition of one I made about five years ago. If a copper disc or closed coil be balanced in front of another coil and parallel thereto, it will be noticed that on passing a current into the second coil the disc or closed coil will be repelled slightly, and if the current be afterwards shunted or cut off there will be a slight attraction. By opening and closing the shunt so as to put the current successively on and off the coil, there will be alternate repulsions and attractions exhibited. Let the current, however, be so put on and off very quickly, and the attractive effect will become less than the repulsive effect, and the disc or closed coil will be driven away or bodily repelled. Replace, now, the intermittent current by an alternating current, which reverses many times per second, and the repulsive effect alone is noticed, provided that the disc or closed coil is of sufficient mass and conductivity to allow currents of high self-induction to be set up in it, whereby such disc or coil or current in it may, as it were, exert a controlling influence upon the magnetic field in immediate proximity to it.

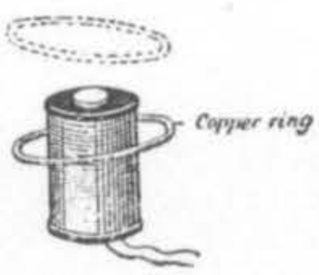

FIG. 1.



FIG. 2.

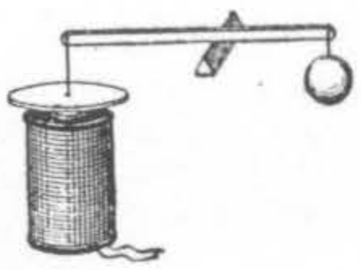

FIG. 3.

The amount of this repulsive effect may, under favourable circumstances, become so great as to give with moderate-current densities a very considerable pressure or force.

I have selected some particular instances of this action for our experiments, as it will be understood that time is too short to show many variations of the effect as found in numerous experimental trials.

Placing a copper ring over a coil which has been wound upon an iron core, and passing an alternating current through the coil, gives so much repulsive effect that the ring is thrown forcibly away and up into the air (Fig. 1). Or, again, the ring may be supported for a moment in free air, though its condition is one of unstable equilibrium. Further, we may arrange a string or thread to so guide the ring that it cannot move laterally though free to fall towards the alternating-current coil (Fig. 2). It is in this case supported in the magnetic field of the coil and away from it. It takes a position of balance between the repulsive effect and its own weight, which are opposed forces. As a curious variation, another copper ring (Fig. 2) may be added under the former, to which it seems to be attracted as though magnetised, after which both rings are supported as one. The explanation is very simple. The currents induced in both rings are in the same direction at any instant and produce attraction. The bearing of this will be seen in later experiments where rotary actions are produced.

Copper plates are but imperfect discs and act as closed coils. Aluminium rings, having much less weight than copper, might at first be expected to be more readily supported, but it must be remembered that the conductivity of aluminium is much less than that of copper, and hence that since the effect depends on current induced and retardation of phase or lag of such current, copper is the better on account of its high conductivity.

By attaching the closed ring or coil to a balance beam (Fig. 3), we are able to measure the amount of force exerted with different currents, and the different materials or constructions.

Such measurements show very decidedly that the repulsive effort depends on the strength of the current in the inducing coil, and in the ring or closed coil, and on the relation of the position of the waves of induced current in the closed coil or ring with those of the inducing coil. The effects are, properly considered, magnetic repulsive effects of the opposing fields of the induced and inducing currents relatively.

When the closed coil or disc is mounted so that it can only turn on an axis in its plane then the repulsion resolves itself into a deflection of its plane to a position at right angles to the plane of the inducing coil, or, more strictly, to parallelism with the direction of the magnetic lines set up by such inducing coil. The effect of the control exhibited by such a closed circuit of good conducting power over the magnetic field of the inducing coil, is seen by interposing such closed circuits between the inducing coil and another coil acting as a secondary and feeding an incandescent lamp (Fig. 4). The light of the lamp is cut down and extinguished thereby, as the alternating field is now almost completely shielded from the secondary. The coil feeding the lamp undergoes a slight repulsion. This is easily exhibited by placing in a glass jar with water a lamp and coil, the lamp wires being connected with the coil terminals, and so loading it that it just sinks to the bottom of the jar. Placing this above the inducing coil so as to bring it into the alternating magnetic field is attended not only with the lighting



FIG. 4.

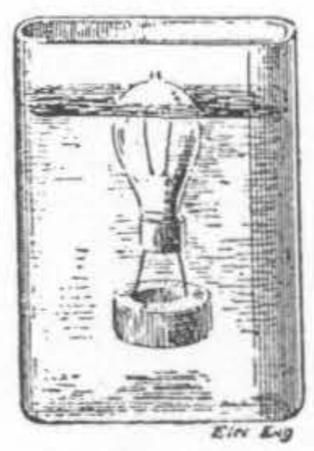

FIG. 5.



FIG. 5a.

of the lamp under water, but there is noticed a repulsion or floating of the lamp to a certain point (Fig. 5), at which its tendency to sink just balances the repulsion exerted. So long as the lamp remains so suspended in the water its brilliancy is constant, notwithstanding that the strength of the inducing current be raised or lowered considerably. It is, of course, unnecessary to use water to balance the lamp coil; a beam and counterpoise weight will suffice (Fig. 5a).

In utilising the repulsive action for obtaining movement from alternating currents, the closed coil or circuit may be mounted in various ways.

A convenient form is one in which a bent core of iron wire or plates which may be a ring is wound over with insulated wire at a portion only of its surface. A closed band or secondary is pivotally mounted, so as to pass over the curved core, and also over the wire-covered portion if moved around the pivot by a suitable carrier (Fig. 6). A spring or weight may tend to cause the closed band to pass over the wire-covered portion of the core. Currents sent in the wire coil produce repulsion and movement of the closed band about the pivots to a position on the core removed from the coil.

This apparatus, and some of its modifications, is a valuable reactive coil, which gives a smooth variation, and hence is called a "smoothly-acting reactive coil," for it enables us by changing the relation of the closed band or secondary circuit to affect the inductive resistance, as it may be termed, or the impedance of the coil wound on the core, the changes being made by swinging the closed band on its pivotal support by a suitable operating handle. It so varies the effects in an alternating circuit as to represent those of variable resistance in a continuous-current circuit,

but it does this without much loss of energy, and not by steps, but through the finest gradations. The power is greatly increased by the provision of a movable iron armature for the core, centrally placed and pivoted, carrying the closed secondary coil upon it.

It is easy to see that by placing on a laminated armature core a series of coils which can be suitably short-circuited by a commutator, and placing such armatures between poles of alternating magnetic polarity, or, better, surrounding such armature by coils for producing directly in it an alternation of magnetic states, while the magnetic circuit is completed by an outside magnetic circuit of laminated iron, we have obtained a rotary motor for alternating currents which may be termed a transformer-motor, since the armature currents are induced and not obtained from the outside.

But by properly constructing such a machine, it is not necessary to have a commutator if we are content to start the motor initially by some means, for we may close the armature coils on themselves, pass alternating current through the field coils so as to establish an alternating field in which the armature exists, and it will be found that the machine will turn in the direction in which it has been started and run up to a speed depending on the construction. I have constructed a number of such machines, some of which are self-starting without a commutator. They are made self-starting by special features of construction. Whether they can be made of high or fair efficiency remains to be seen. Using only one alternating current they can, of course, be used on existing lines.

There are a number of curious effects to be described which depend on a shifting or propagation of magnetic lines of force.

Many of these effects were worked out conjointly by Mr. M. J. Wightman and myself, and some of the ways of exhibiting them are due to the skill of my workmen carrying on the construction of apparatus.

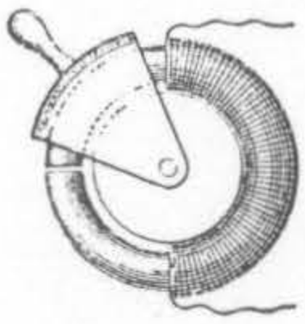

FIG. 6.

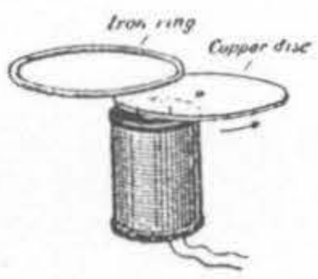

FIG. 7.

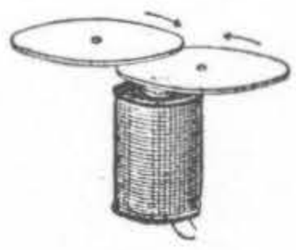

FIG. 8.

The principles may be briefly stated as follows:

1. If two or more closed circuits are similarly affected inductively by an alternating magnetic field, they will attract one another and tend to move into parallelism.

2. Iron or steel masses placed in an alternating magnetic field give rise to shifting magnetism, or lines of force moving laterally, and may, therefore, act to move closed circuits in the path of such shifting lines.

3. Closed circuits in alternating magnetic fields, or fields of varying intensity, give rise to shifting magnetism or lines of force moving laterally to their direction, and may, therefore, act to move other closed circuits in the path of such lines.

4. Iron or steel masses may, when placed in an alternating magnetic field, interact with other such masses, or with closed electric circuits, so as to produce movement of such masses or circuits relatively, or give rise to tendencies to so move, the effects depending on continual adaptations of shifting magnetism and retained magnetism relatively.

The experimental demonstration of these principles can be carried out with very simple apparatus. The explanations of the actions which occur in accordance with known principles are in many cases very evident, and in others are arrived at with a little study. Nevertheless, the experiments illustrate, in a marked manner, properties of matter and peculiarities of magnetic action which will probably never be fully understood unless the nature of the ether and its relations to what we call matter are discovered.

We will return to the case of the ring attracting another ring to it. Here we have the case of like currents in parallel direction producing attraction. Such an action can be made continuous. We have only to place a ring or plate over the alternating-current coil or pole of its core and then bring a copper disc free to revolve on pivots into proper position relatively thereto. This can best be done by placing the ring or plate so as to be somewhat to one side of the pole, so as to shade it in part, as it were, while a part of the pivoted disc is placed under it, or over it, in front of the alternating field pole (Fig. 7). The disc then revolves from the unshaded portion of the pole towards the shaded portion where the closed ring or plate is placed.

The actions are due to lines of magnetic force at each alternation of current in the magnetising coil below meeting a retarding influence or opposition to their development over that part of the pole shaded by the copper ring or plate owing to currents induced therein. The copper disc is the seat of similar currents, but chiefly about those portions not shaded by the ring or plate. Owing to self-induction, these currents in ring and plate tend to persist into the period of reversal of the field. This gives rise to a movement of those portions of the disc where current is flowing into a position directly adjacent to the ring or the currents flowing in it, an action which is repeated at every alternation and results in a revolution of the disc. While this explanation is probably the simplest it must be borne in mind that it is but an expression of a set of magnetic actions or changes in the magnetic field; such magnetic field being the resultant of the changing force of the original alternating inducing field and of the magnetic effects of the currents set up in a ring or plate and the disc, both of which latter have a retarding action due to self-induction of the currents in them.

If, now, two discs be used instead of one (Fig. 8), it will be found that they may each shade a portion of the pole, and that the discs, if made to overlap, will both revolve in opposite directions relatively.

An iron disc may be substituted for one of the discs above and used with the fixed plate or ring below it, and

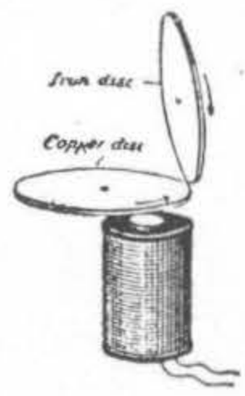

FIG. 9.

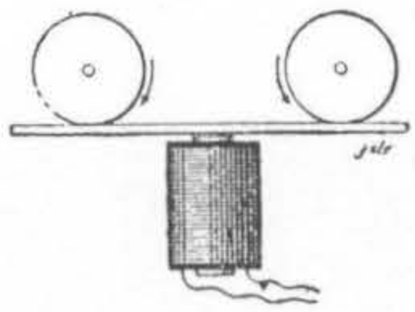

FIG. 10.

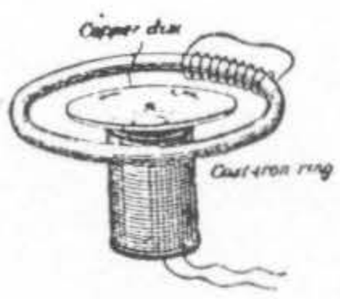

FIG. 11.

so be caused to revolve, and its position can be changed so that it is in a plane vertical to the plane of the plate or ring (Fig. 9). Also, it may be similarly used in relation to the revolving copper disc. In fact, the positions of two copper discs pivoted so as to be revolvable, or of a copper and iron disc, may be greatly varied and effects of rotation obtained.

If we vary the experiment by placing a closed coil around a part of an iron core upon which is also wound a coil which can be put into an alternating-current circuit the effects obtainable are similar to those described above—that is, the structure becomes capable of revolving copper or iron discs held near it. The direction of revolution is such as to indicate a propagation of magnetism or magnetic polarity at a retarded rate through that portion of the iron core covered by the closed coil. In this respect a bar of iron unlaminated, or not divided, is the same as a core surrounded by a closed coil, for it is also capable of causing the rotation of the discs, when such a bar is abutted to a laminated core alternatively magnetised, or when such a bar is surrounded at part of its length only by the magnetising coil. A bar of steel substituted for the iron, even if well laminated, is able to cause brisk rotations of the copper or iron discs.

With hardened steel the action is the more marked, a file serving for the experiment. Here the "hys eresis," or coercive force, or magnetic friction retards the propagation of the magnetic wave. By laying a large file flatwise against the alternating magnet pole at about the middle of the file (Fig. 10) two discs of copper or iron may be kept revolving, or one each of copper and iron held over those portions of the file projecting from the pole of the magnet over which it is laid will revolve. The iron disc may be

held vertically, and the copper horizontally or flatwise to the file.

Cast iron behaves like steel, though more feebly. A ring of cast iron, having a closed coil wound on one part (Fig. 11), can be laid on the pole of the alternating magnet coil, and it will rotate an iron disc concentric with it if the placing of the closed coil portion of the ring is not made so as to bring it either over the pole or diametrically opposite that point, the best effect being obtained when it is alongside of the pole.

(To be continued.)

PHENOMENA OF ALTERNATING CURRENT INDUCTION.*

BY PROF. ELIHU THOMSON.

(Concluded from page 335.)

A small motor of a curious type has been made, utilising the principle of shading the pole by closed circuits. A laminated ring (Fig. 12) is wound over with wire, but has a slot cut through it, dividing the ring, and causing it to present two pole faces opposite to each other at the cut part. Each pole is arranged by a set of closed copper bands to be "shaded," as I term it. A copper disc free to turn introduced by one edge into the slot turns rapidly and exerts some power.

Removing the disc it is found that a silver coin can be inserted into the slot and will be drawn into it and propelled with some force through the same, while a lead coin, or coin of base metal, will be scarcely affected. This is due to the vigorous currents which can exist in the silver, owing to its high conductivity, while the very low effect of the lead is due to the opposite cause.

To obtain a rotary effect on a copper disc we can, however, simplify matters very much by using no closed circuit at all, nor even a steel piece. We may place the disc partly over the alternating pole and then hold over the disc a bundle of iron wires or unwound core, taking care to offset its axes to some extent from that of the pole towards which it and the disc are presented. The result is at once a rapid revolution of the disc in the direction of the offsetting.

* Abstract of a lecture delivered before the American Institute of Electrical Engineers at Columbia College, April 2, 1890.

The rotary effects are utilised in the construction of electric motors and meters of more or less merit. They are capable of very great variation by changing the forms and relations of the devices used.

Some curious modifications of the effects are found in the revolution of copper balls or cylinders. A hollow copper ball may be laid on a plate of copper (Fig. 13), or within a ring of the same metal, and set in gyratory movement, its direction of rotation as well as the position of its axis of rotation depending on the relation of the ball and the plate on which it rests or the ring which encloses it in relation to the alternating pole which is used to set it in movement.

It will even rotate on a horizontal axis while resting on a plate of copper; this requires that it rub its equator upon such surface and overcome the friction.

Placing the ball in a vase of water in which it floats and supporting the vase over the pole upon which has been laid a plate of copper partly covering the pole, gives vigorous rotation of the ball in the water. Several balls of various sizes may be placed in the vase, or a copper dish substituted for the plate, or the ball and dish both used together (Fig. 14). The effects of these latter are both amusing and instructive.

We need scarcely stop to consider that these actions are brought about just as the movements of the discs were set up by induced currents and shifting magnetic lines that are retarded by the closed circuit currents set up in the plates, rings, etc., which have been employed to modify the field.

But, as we have shown, it is not necessary for obtaining some of these effects that the field be modified by closed circuit currents. Slight changes in the position or shape of parts may be sufficient to give rise to rotary effects. Thus

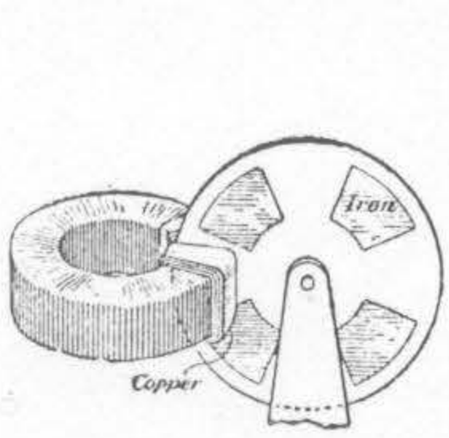

FIG. 12.

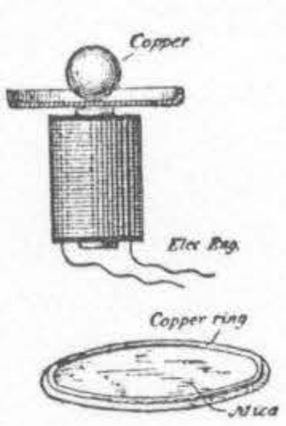

FIG. 13.

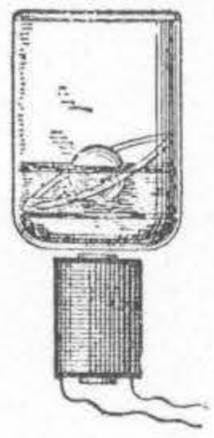

FIG. 14.

we may place a cone or wedge of iron on the alternating pole (Fig. 15), and hold near it a copper ring mounted so as to be able to revolve. The ring in this case is best provided with a laminated iron interior, which supports it and enables it to be easily mounted on a shaft. The copper cylinder revolves, and its direction is such that it seems to be blown around by a blast from the edge of the wedge or point of the cone.

A curious electrical gyroscope is constructed as follows: A vertical pivot projects from the centre of the alternating pole (Fig. 16), upon which pivot is hung a horizontal rod, bearing on one side of the pivot a copper frame, in which is carried a copper ring or wheel with an iron inner portion, such ring or wheel being delicately pivoted in the frame in the usual way. The rod bears on its other end the counterpoise or balance weight. The copper frame bearing the ring is placed in an inclined direction with reference to the horizontal. Under these circumstances rotation is given by the alternating field in which the instrument is placed, and the properties of the gyroscope are exhibited. It is needless to say that a little ingenuity may modify the instrument in form, or lead to the construction on similar principles of a variety of curious devices, receiving their movements from the actual space, as it were, in which they are placed, and without direct connections of an electrical or mechanical character.

There is a growing tendency among electricians to regard the effects of what is called an electrical current in a conductor to be due, in large part, at least, to a movement of particles, or to a transmitted strain which has its place entirely outside the wire or conductor, and in the space around such conductor. The wire and current in it are regarded simply as the central core of a set of disturbances in the medium surrounding it, by which medium the energy of the current is actually transmitted, if the current itself is not merely an effect of such a set of disturbances in the surrounding medium.

Viewed in this light the phenomena we have been considering are seen to be simply the result of modifying these outside effects by conducting or magnetic masses placed in the medium subject to disturbance. The coil conveying the current sets up a changing set of strains in the ether around it, or rather the coil itself is only the centre of such strains transmitted into the medium surrounding the wire from the source of current used, which may be a dynamo located in a central supply station. The changing set of strains around the coil used in the experiments can set up current in other conductors than the coil subject to their action. Thus are produced the induced currents in the copper rings, balls, plates, etc., used. Such currents react on the medium, and modify the distribution of strains, and so give rise to the movements and other phenomena displayed.

The relation which exists between a primary inducing coil and a secondary coil in an inductive apparatus or transformer is of the same nature. The secondary coil is merely a conductor immersed in the medium which surrounds the primary coil. The latter and the wire leading to it from the source of current is but the core of a set of disturbances or strains in the ether surrounding it, and in which the secondary coil is immersed. Hence, the coils, though insulated from each other, are yet both immersed in the medium whose transmitted strains are the real expression of electrical energy transmitted. The result of this relation is that were it not for the fact that the coils must necessarily be made of imperfect conductors, the amount of energy transmitted to a secondary coil from its primary could be unlimited, it might be thousands of horse-power, and the iron core of the transformer be only of such size as to be easily lifted in the hand.

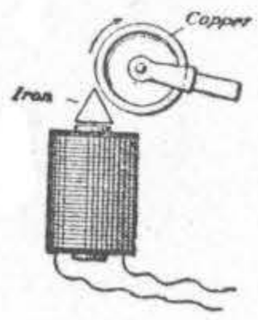

FIG. 15.

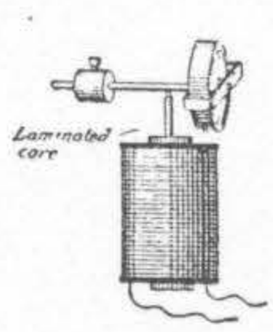

FIG. 16.

Let us imagine the primary and secondary coils of an induction apparatus made of pipe, through which a refrigerant is circulated, or around which a powerful refrigerating action is exerted, such as might be obtained by the evaporation of liquefied gases, and in such case the resistance of the coils would become very small indeed. The coils could carry large currents without loss, and the amount of energy obtained in the secondary would almost keep pace with the energy supplied to the primary. A remarkable example of this wonderful capacity for energy transmission is seen in some transformers for electric welding, in which 20,000 to 30,000 watts, or from 30 to 40 h.p., are transferred to the secondary coil from the primary, apparently, while the iron core or magnetisable core is of quite moderate dimensions. In fact, the iron core has but little to do with the capacity for transmission of energy by induction, though it effects the E.M.F. set up in the turns of wire of the coils.

Could we imagine an open coil without iron, composed of two interwound coils of copper wire or tubes insulated from each other, and kept at the lowest possible temperature, so as to practically abolish the resistance of the copper, we would have an apparatus of the very highest efficiency for the transfer of electrical energy from one circuit to another, and one which could be of very moderate size and yet transfer enormous amounts of such energy, to be used for lighting, metal working or other purposes.

There has only been time in this discussion to touch upon a few salient features of our subject, about which a volume might be written at the present time, the object being to bring to the notice of the institute rather the experimental demonstrations only, stripped of such theoretical considerations as would, if incorporated in this paper, have taken up much more than the space allotted to it, and perhaps have exhausted the interest of the hearers.

A NEW TESLA ALTERNATING MOTOR.

In its issue of April 9th the *Electrical Engineer* of New York describes the latest type of alternate-current motor devised by Mr. Nikola Tesla.

The motor (Figs. 1 and 2) has two laminated magnetic pole-pieces, C C′, of soft iron or steel. The laminated disc-armature

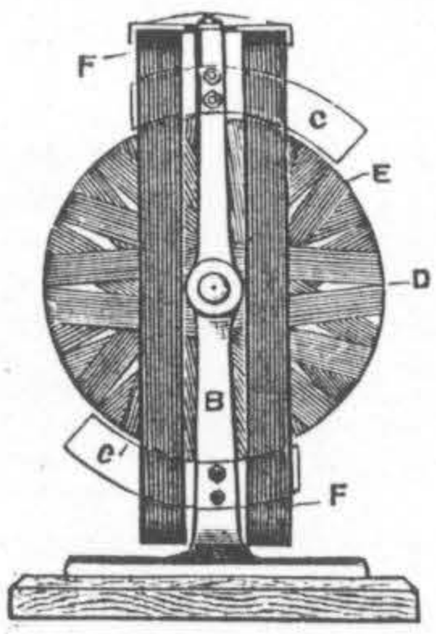

FIG. 1.—New Tesla Alternating Motor. Side view.

D is mounted between the pole-pieces C C′, which are curved to conform to the circular shape of the armature. The latter is provided with a closed coil winding. The main energising coils F F are arranged so as to include within their magnetising influence both the pole-pieces C C′ and the armature D, the pole-pieces C C′ projecting out beyond the coils F F on opposite sides, as shown.

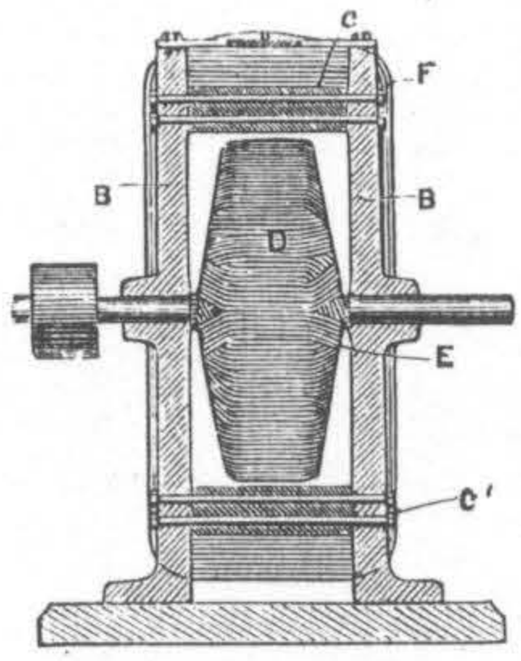

FIG. 2.—New Tesla Alternating Motor. Elevation.

If an alternating current be passed through the coils F F, rotation of the armature will be produced by the repellant force between the more closely approximating points of maximum magnetic effect. This effect is continued by the reversal of current, the polarities of field and armature being simply reversed.

One or both of the elements—the armature or field—may be wound with closed induced coils to intensify the effect. Although in the motor shown there is but one of the fields, each element of the motor really constitutes a field, wound with the closed coils, the currents being induced mainly in those convolutions or coils which are parallel to the coils F F.

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Addresses.—*Business letters should be addressed and drafts, checks and post-office orders made payable to the order of* THE ELECTRICAL ENGINEER. *Communications for the attention of the editors should be addressed,* EDITOR OF THE ELECTRICAL ENGINEER, 150 *Broadway, New York city.*

Communications *suitable for our columns will be welcomed from any quarter. Discussions of subjects relating to all branches of electro-technical work, by persons practically acquainted with them, are especially desired. Unavailable and rejected manuscripts will be returned only when accompanied by the necessary postage.*

Advertisements.—*We can entertain no proposition to publish anything for pay, or in consideration of advertising patronage, except in our advertising columns. Our editorial columns will express our own opinions only, and we shall present in other columns only such matter as we consider of interest or value to our readers*

VOL. IX. NEW YORK, APRIL 30, 1890. No. 104

Nothing is so good as an experiment which, while it sets an error right, gives as a reward for our humility in being reproved, an absolute advancement in knowledge.—Faraday,

LOSS BY HYSTERESIS.

THE communication by Professor Elihu Thomson in our columns this week in reply to thatof Mr. Nikola Teslaon the loss due to hysteresis in transformers is well worthy of careful study, as it embodies an expression of opinion on a subject which is of foremost interest at the present time. Leaving out of consideration the purely controversial part of Professor Thomson's letter, it will be found to give his views on the probable origin of the heat generated by a change in magnetism, independent of the Foucault currents generated thereby. Professor Thomson uses a beautiful analogy to explain the difference in the heat generated by the current in various conducting bodies and that generated in distorting them mechanically; the heat in both cases depending upon whether the ether strain can be transmitted from molecule to molecule without much disturbance of their positions, or without causing a swinging-out of position back and forth. The subject is one that offers wide scope for speculation, and we shall probably find many theories advanced before the light of actual facts is thrown on the true explanation of the phenomena of hysteresis.

LETTERS TO THE EDITOR.

Notice to Correspondents.

We do not hold ourselves responsible for the opinions of our correspondents.
Anonymous communications cannot be noticed.
The Editor respectfully requests that all communications may be drawn up as briefly and as much to the point as possible.
In order to facilitate reference, correspondents, when referring to any letter previously inserted will oblige by mentioning the serial number of such letter, and of the page on which it appears.
Sketches and drawings for illustrations should be on separate pieces of paper.
All communications should be addressed EDITOR OF THE ELECTRICAL ENGINEER, 150 *Broadway, New York city.*

LOSS BY HYSTERESIS.

[124]—In his letter (121) appearing in your issue of April 9, page 221, Mr. N. Tesla in discussing the losses due to hysteresis in transformers takes the ground that such losses outside of the generation of electrical currents, or independent thereof, are "difficult to reconcile with our present notions on the constitution of matter generally." Further on he says: "We cannot imagine that an appreciable amount of energy should be *wasted* by the elastically connected molecules swinging back and forth from their original position," etc. While I agree with Mr. Tesla that the actual loss referred to may be due to molecular currents, yet we have no proof of such fact. Again Mr. Tesla seems to forget that *loss, waste,* and such terms, are more scientifically rendered, by the words "*conversion into heat,*" and that in nature nothing is wasted or lost, but merely converted.

Now we may consistently amend his quoted statement as follows, and see how it reads: "We cannot imagine that an appreciable amount of energy should be converted into heat by the elastically connected molecules swinging back and forth from their original positions," etc

Heat action is that swinging back and forth referred to, namely, "molecular vibration," and if we find that such swinging takes place we must have heat as a result. When the molecules can polarize or turn without being given a swinging movement or vibration, no conversion into heat takes place. The difference then between very soft iron and hard steel so far as magnetic waste goes, is, apparently, that in the soft iron there is less disturbance of position of the molecules during magnetization and reversal then in steel, assuming the degree of magnetization or polarization to be equal in each. The *waste* or conversion due to electrical resistance is of the same nature. Whenever the ether strain can be transmitted from molecule to molecule of the conductor without much disturbance of their positions or without causing a swinging out of position back and forth, the conductivity is great and the reverse is true with bad conductors.

In like manner, bending a bar of tempered steel back and forth within limits is mechanically efficient because very little conversion of motion into heat takes place, and this is a result of the relative positions of the molecules being preserved; while,

bending a bar of inelastic metal, as a copper rod of moderate hardness, produces heat by disturbance and swinging of molecules. Such bending is inefficient.

There is then to my mind no more difficulty in understanding that a conversion into heat may be produced magnetically than electrically, or mechanically. Indeed, if, as seems probable, these actions are but variations of ether strain phenomena they are reducible to a single effect, and represent the molecular disturbances produced by transmission of ether strains. Cohesion, gravitation and forces acting between molecules, must of course be recognized as results of ether strains.

Molecules themselves, or matter itself, may be resolvable into ether movements or vortices, and we may be able to put "energy indestructible" in place of "matter indestructible" and mean as much. We need to forget the universe as made up of pieces, entities or particles, put together and allowed to interact and react, and learn to regard it as a consistent whole from which nothing can be taken without disturbing the balance or equilibrium of what remains. It is in my view more legitimate to attribute the heating effects of Foucault currents and other currents to a general molecular friction or hysteresis of conduction, if we may use such a term, than to assume the production of molecular currents in the heating or conversion of magnetic hysteresis. We have no present need of currents in accounting for heat conversion of mechanical friction and molecular friction of inelastic bodies when bent or distorted by mechanical force. Neither can we deny that theoretically such conversion into heat may be accompanied by molecular electric currents similar to eddy currents or Foucault currents, but infinitely more restricted as to length of circuit. On these points and others of equal interest we may speculate, but are in need of more facts to confirm our speculations.

ELIHU THOMSON.

LYNN, MASS.

TESLA'S THERMO-MAGNETIC GENERATOR.

The phenomenon that iron loses its magnetic properties suddenly at about a red heat and as suddenly regains them on cooling below that point has long been known, but it is only comparatively recently that advantage has been taken of it for its practical utilization. It is evident that by placing a coil of wire under the influence of a magnet alternately rapidly heated and cooled above the critical magnetic point, induction currents will be set up in the coil, due to the variation of the magnetism of the core.

This principle has already been applied in a number of ways in the construction of what are known as thermo-magnetic generators, or motors, and we are now enabled to describe another form designed by Mr. Nikola Tesla, who, it is interesting to note, obtained the first patent for a thermo-magnetic motor in the United States. The machine here described embodies several novel features of construction, which constitute a marked departure from the forms hertofore shown, and which consist first, in the employment of a closed magnetic circuit and an enclosed source of heat. The advantages gained by this arrangement will be apparent when it is considered that by the employment of a closed magnetic circuit a more effective magnetic change may be obtained and that by enclosing the source of heat and cooling the heated portion of the magnetic circuit the conversion may be rendered far more efficient. Other novel features are the employment of an armature of enormous cooling surface and steam as a cooling medium.

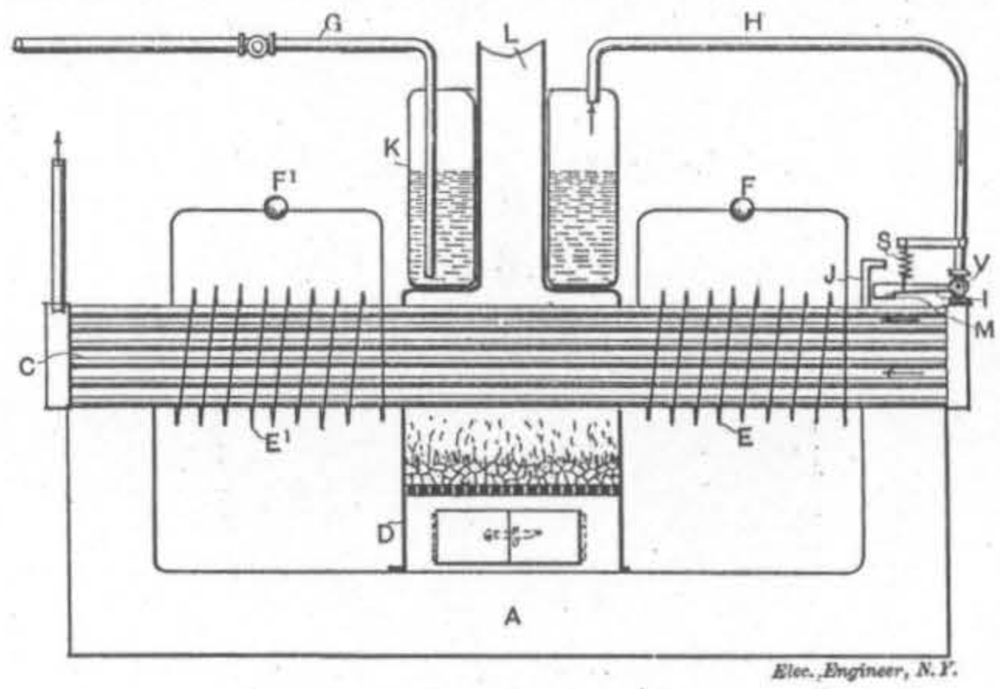
The accompanying engraving Fig. 1 shows a longitudinal section of the generator, and Fig. 2 a cross section of the magnetic armature core employed.

The generator is provided with a magnetized core or permanent magnet A, the poles of which are bridged by an armature core composed of a shell B, enclosing a number of hollow iron tubes G. Around this core are wound the conductors E E, forming the coils in which the currents are developed.

D is a furnace or closed fire box through which the central portion of the core B extends, and above the fire is a boiler K containing water. The latter is supplied by means of the pipe G, and the steam exhaust pipe H communicates with all the tubes C in the armature so that steam escaping from the boiler will pass through these tubes.

In the steam exhaust pipes is a valve V to which is connected the lever I, by the movement of which the valve is opened or closed. The lever carries an armature M, and is held up in position to close the valve V by means of a spring S. Stops are provided for limiting the movement of the lever, and the armature M is in proximity to the core B, so that it may be attracted towards the same, as will be described presently.

In its normal condition the armature B is magnetic along its entire length, and closes the magnetic circuit of the magnet A. Very little external or free magnetism is therefore exhibited, and the attraction upon the armature M is insufficient to draw it down against the force of the spring S. The steam exhaust, in consequence, remains



Elec. Engineer, N.Y.

THE TESLA THERMO-MAGNETIC GENERATOR.

closed. When, by the fire in the furnace, the temperature of the central part of core B has been raised to about from 900° to 1,000° C., the magnetic circuit of magnet A is broken, and, in consequence, the external magnetism of core B greatly increased. This attracts the armature M and allows steam to pass through the tubes C, of the core. This lowers the temperature of the surface of the tubes at once and restores to a corresponding degree their magnetic condition, whereupon the armature M is retracted and the steam cut off.

This operation is continued, effecting a successive heating and cooling of the core, with the result of making and breaking the magnetic circuit. This entails a corresponding movement of the magnetic lines with reference to the coils E E, in consequence of which currents are developed in them.

It will be noted that by the construction adopted the source of heat is enclosed and the portions of the iron which are heated are not exposed to the air. The armature which closes the magnetic circuit is made of very thin tubes or laminae and by this means an enormous cooling surface can be obtained.

Steam is used for cooling in preference to air, partly because it is easier obtainable under pressure than air, and again, because it is more effective in consequence of its

partial dissociation for which a large amount of heat is required.

Although the thermo-magnetic conversion itself may not be highly efficient, yet, since the steam used for cooling may be used for other purposes the system may be rendered economical under certain conditions.

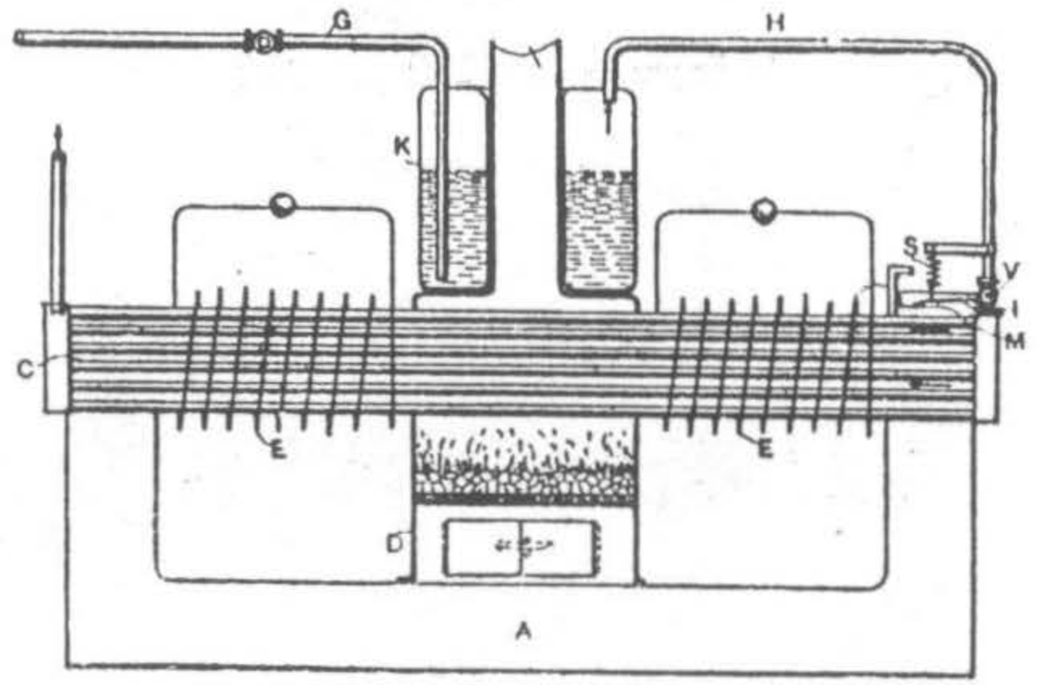
NOTES.

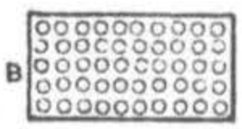
Tesla Motor for Mining.—The Tesla motor is to be introduced in the coal mines of the State of New York. The management of the Shawmut coal mines has just made a contract with the Westinghouse Electric Company for seven of these alternate-current motors and one 30 h.p. generator. The apparatus is to be used in connection with the Hercules mining machine.

The Tesla Motor.—This is now being introduced in the coal mines of the State of New York.

THE TESLA THERMO-MAGNETIC GENERATOR.

The accompanying engravings show respectively a longitudinal section and a cross section of the magnetic armature core employed in a thermo-magnetic generator just brought out by Mr. Nikola Tesla.





The Tesla Thermo-Magnetic Generator.

The generator, says the *Electrical Engineer* of New York, from which we take the account, is provided with a magnetised core or permanent magnet, A, the poles of which are bridged by an armature core composed of a shell B, enclosing a number of hollow iron tubes, C. Around this core are wound the conductors E E, forming the coils in which the currents are developed. D is a closed fire-box, and above the fire is a boiler, K, containing water. The latter is supplied by means of the pipe G, and the steam exhaust pipe H communicates with all the tubes C in the armature, so that steam escaping from the boiler will pass through these tubes. In the steam exhaust pipes is a valve, V, to which is connected the lever I, by the movement of which the valve is opened or closed. The lever

carries an armature, M, and is held up in position to close the valve V by means of a spring, S.

In its normal condition, the armature B is magnetic along its entire length, and closes the magnetic circuit of the magnet A. Very little external magnetism is therefore exhibited, and the attraction upon the armature M is insufficient to draw it down against the force of the spring S. The steam exhaust, in consequence, remains closed. When the temperature of the central part of core B has been raised to about from 900° to 1,000° C., the magnetic circuit of magnet A is broken, and, in consequence, the external magnetism of core B greatly increased. This attracts the armature M, and allows steam to pass through the tubes C of the core. This lowers the temperature of the surface of the tubes at once, and restores, to a corresponding degree, their magnetic condition, whereupon the armature M is retracted and the steam cut off. This operation is continued, effecting a successive heating and cooling of the core, with the result of making and breaking the magnetic circuit. This entails a corresponding movement of the magnetic lines with reference to the coils E E, in consequence of which currents are developed in them.

It will be noted that by the construction adopted the source of heat is enclosed and the portions of the iron which are heated are not exposed to the air. The armature which closes the magnetic circuit is made of very thin tubes, and by this means an enormous cooling surface can be obtained. Steam is used for cooling in preference to air, partly because it is easier obtainable under pressure than air, and again, because it is more effective in consequence of its partial dissociation for which a large amount of heat is required.

New Types of Tesla Motors.

SINCE Mr. Tesla read his classical paper on alternating current motors before the American Institute of Electrical Engineers, in 1888, he has devoted considerable time to perfecting these machines, and as a result has produced numerous forms, which, though having a distinct individuality, are but developments of the original idea embodied in that paper. In the present issue we describe a number of interesting forms of these later types which demonstrate particularly various interesting ways of operating these motors from a single source of alternating current by the use of two wires only. In these forms, it will be noted, Mr. Tesla obtains the necessary phase difference by shielding one of the circuits by a thin film of iron, either in the motor or in a transformer used in connection with a motor.

TESLA'S NEW ALTERNATING MOTORS.

For some time past Mr. Nikola Tesla, whose previous work in alternating current motors is well known, has been engaged upon the study of these machines in order to develop efficient methods for operating them on two wires instead of three, and still without the use of a commutator.

The general principle upon which these machines are designed is based on the well-known fact that if a magnetic core, even if laminated, be wound with a coil and a current be sent through, the magnetization of the entire core does not immediately ensue, the magnetizing effect not being exhibited in all parts simultaneously. This Mr. Tesla attributes to the fact that the action of the current is to energize first those laminæ or parts of the core nearest the surface and adjacent to the exciting coil, and from thence the action progresses towards the interior. A certain interval of time, therefore, elapses between the manifestation of magnetism in the external and the internal sections or layers of the core.

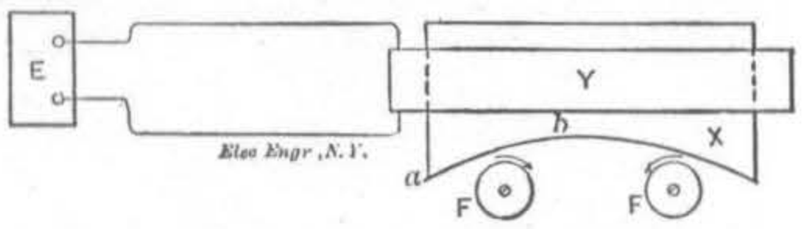


FIG. 1.—TESLA ALTERNATING MOTOR.

If the core be thin or of small mass this effect may be inappreciable, but in the case of a thick core, or even of a comparatively thin one, if the number of alternation be very great, the time interval occurring between the manifestations of magnetism in the interior of the core and in those parts adjacent to the coil is more marked, and in the construction of such apparatus as motors which are designed to be run by alternating currents, Mr. Tesla has found it desirable, and even necessary, to give due consideration to this phenomenon and to make special provisions in order to obviate its consequences.

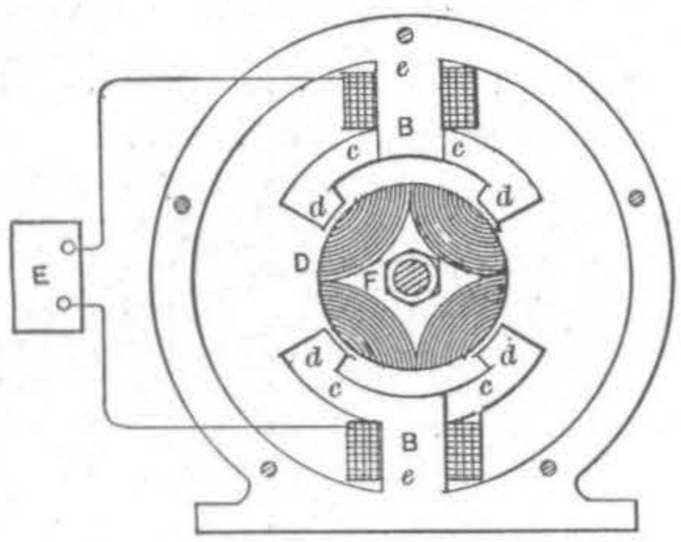


FIG. 2.—TESLA ALTERNATING MOTOR.

On the other hand, by taking advantage of this very action or effect, and, by rendering it more pronounced, Mr. Tesla utilizes it in the operation of motors in general. This he effects by constructing a field in which the parts of the core that exhibit at different intervals of time the magnetic effect imparted to them by alternating currents in an energizing coil are so placed with relation to a rotating armature as to exert thereon their attractive effect successively in the order of their magnetization. By this means there is secured a result similar to that which Mr. Tesla has heretofore attained in the previous types of his motor, in which, by means of one or more alternating currents, he produces a rotation or progression of the magnetic poles or points of maximum attraction of the field of force.

The general principle involved in the action above mentioned is illustrated in the simple motor shown in Fig. 1. Here X represents a large iron core composed of a number of sheets or laminæ of soft iron or steel. Surrounding this core is a coil, Y, which is connected with a source, E, of rapidly varying currents.

Let us consider now the magnetic conditions existing in this core at any point, as *b*, at or near the centre, and any other point, as *a*, nearer the surface. According to Mr. Tesla, when a current impulse is started in the magnetizing coil, Y, the section, at *a*, being close to the coil, is immediately energized, while the section, at *b*, which, to use a convenient expression, is "protected" by the intervening sections or layers between *a* and *b*, does not at once exhibit its magnetism. However, as the magnetization of *a* increases, *b* becomes also affected, reaching finally its maximum strength some time later than *a*.

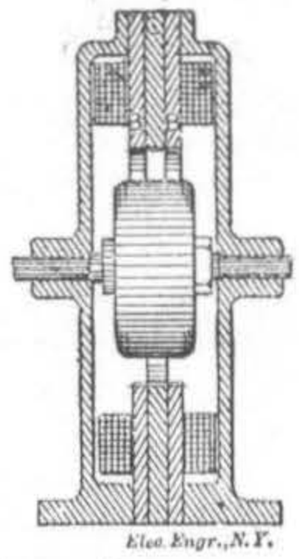


FIG. 3.—TESLA ALTERNATING MOTOR.

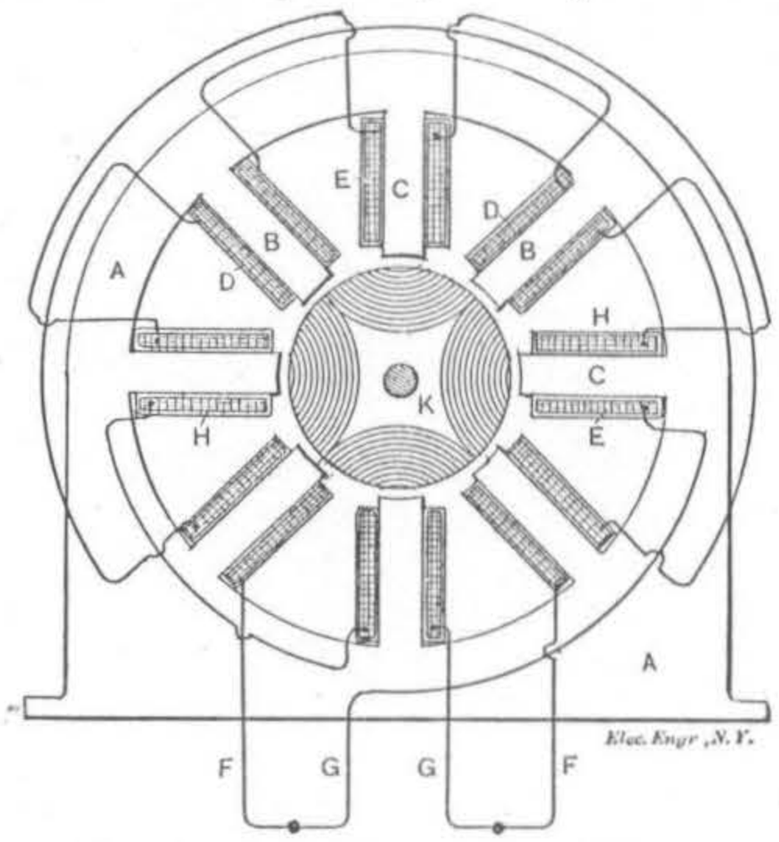


FIG. 4.—TESLA ALTERNATING MOTOR.

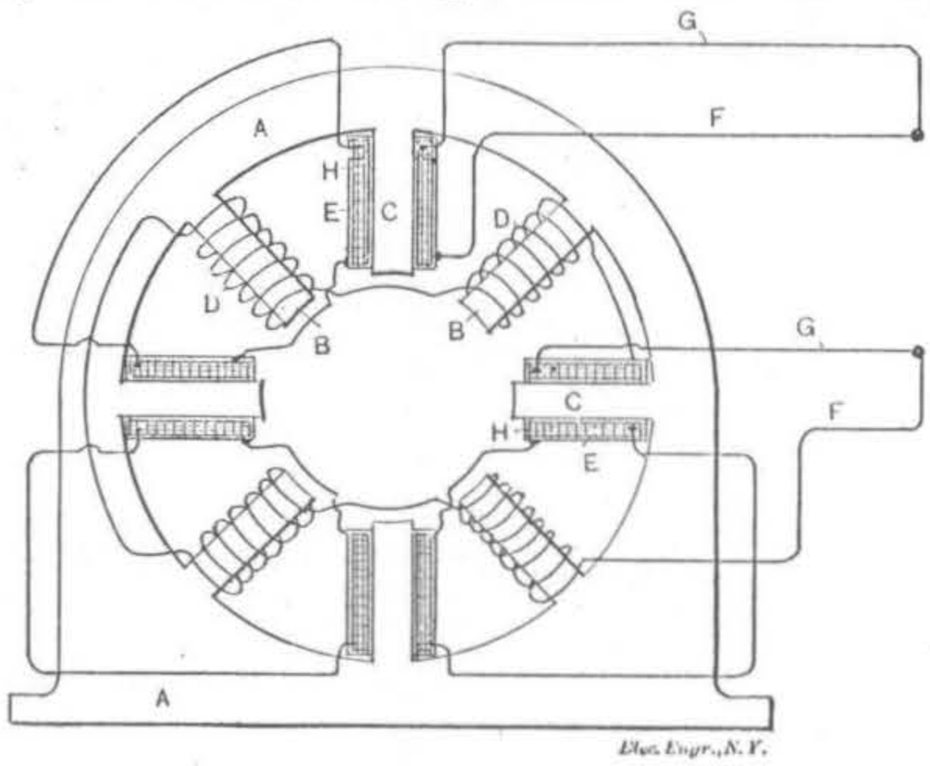


FIG. 5.—TESLA ALTERNATING MOTOR.

Upon the weakening of the current the magnetization of *a* first diminishes, while *b* still exhibits its maximum strength, but the continued weakening of *a* is attended by a subsequent weakening of *b*. Assuming the current to be an alternating one, *a* will now be reversed while *b* still continues of the polarity first imparted. This action contin-

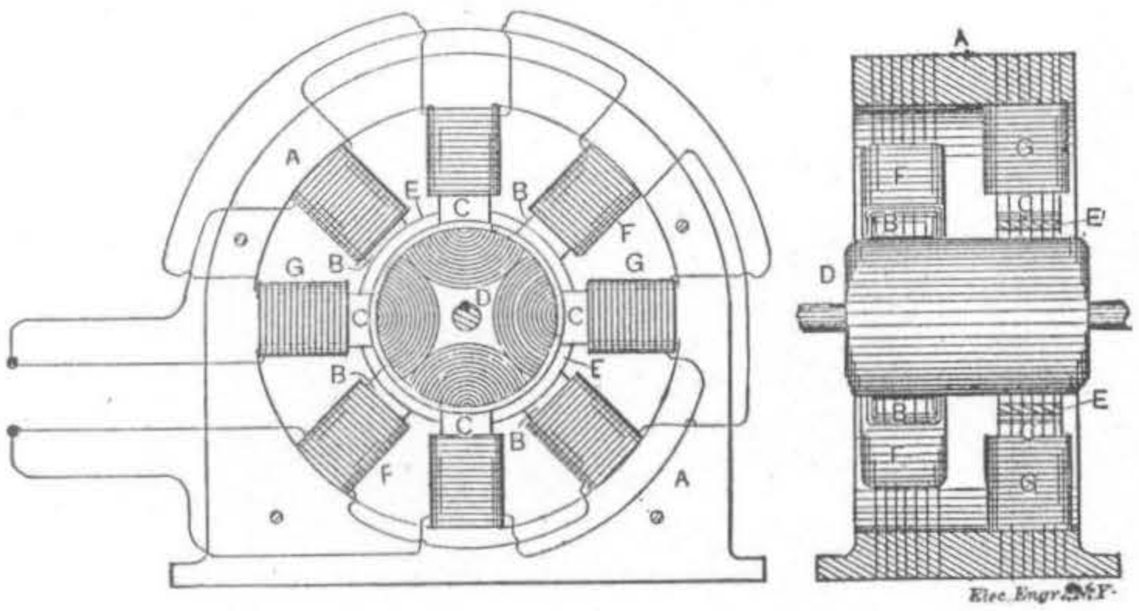
ues, the magnetic condition of *b* following that of *a* in the manner above described.

If an armature, for instance, a simple disk mounted to rotate freely on an axis, be brought into proximity to the core, a movement of rotation will be imparted to the disk, the direction depending upon its position relatively to the core, the tendency being to turn the position of the disk nearest to the core from *a* to *b*, as indicated in Fig. 1.

This action or principle of operation has been embodied in a practicable form of motor, which is illustrated in Fig. 2. Here A represents a circular frame of iron, from diametrically opposite points of the interior of which the cores project.

Each core is composed of three main parts B, B and C, and they are similarly made with a straight portion *e*, around which the energizing coil is wound, a curved arm or extension *c* and an inwardly projecting pole *d*.

Each core is made of two parts B B, with their polar extensions reaching in one direction and a part C between the other two and with its polar extension reaching in the opposite direction. These cores are wound with coils D, which are connected in the same circuit either in parallel or series and supplied with an alternating current by a generator E represented diagramatically. Between the cores or their polar extensions is mounted an armature F wound with magnetizing coils G that are closed upon themselves, similar to those in the older types of Mr. Tesla's motors.



FIGS. 6 AND 7.—TESLA ALTERNATING MOTOR.

The operation of the motor is as follows: When a current impulse or alternation is sent through the coils D, the sections B B of the cores being on the surface, and in close proximity to the coils, are immediately energized. The sections C, on the other hand, are protected from the magnetizing influence of the coil by the interposed layers of iron B B.

As the magnetism of B B increases, however, the sections C are also energized, but they do not attain their maximum strength until acertain time subsequent to the exhibition by the sections B B of their maximum.

Upon the weakening of the current the magnetic strength of B B first diminishes while the sections C have still their maximum strength; but as B B continue to weaken, the interior sections are similarly weakened.

B B may then begin to exhibit an opposite polarity, which is followed later by a similar change on C, and this action continues.

B B and C may, therefore, be considered as separate field magnets, being extended so as to act on the armature in the most efficient positions, and the effect is similar to that in Mr. Tesla's other forms of motor, viz., a rotation or progression of the maximum points of the field of force. Any armature, such, for instance, as a disc mounted in this field, would rotate from the pole first, to exhibit its magnetism to that which exhibits it later.

In following out the ideas stated above, Mr. Tesla has applied them to a class of motors in which two or more sets of energizing magnets are employed and in which by artificial means a certain interval of time is made to elapse between the respective maximum or minimum periods of their magnetic attraction or effect. This has already been applied to the operation of Mr. Tesla's three-wire motors. In the present instance Mr. Tesla employs a motor with two sets of energizing or field magnets, each wound with coils connected with a source of alternating currents, but forming two separate paths or circuits. The magnets of one set are protected to a certain extent from the energizing action of the current by means of a magnetic shield or screen of laminated iron interposed between the magnet and its energizing coil.

The shield is properly adapted to the conditions of particular cases so as to shield or protect the main core from magnetization until it has become itself saturated and no longer capable of containing all the lines of force produced by the current. By this means it will be seen that the energizing action begins in the protected set of magnets, a certain arbitrarily determined period of time later than in the other, and that by this means a practically economical difference of magnetic phase may readily be secured.

The nature and operation of this motor will be readily understood by reference to the accompanying illustration.

The engraving, Fig. 4, shows the simplest form of this type of machine. The cores B form one set of magnets and are energized by coils D, while the cores C, forming the other set, are energized by coils E, and the coils are connected in series with one another, in two derived or branched circuits F G respectively.

Each coil E, it will be noted, is surrounded by a magnetic shield H, which is composed of an annealed insulated or oxidized iron wire wound on the coils in the manner indicated, so as to form a closed magnetic circuit around the coils and between the same and the magnetic cores C.

Between the pole pieces or cores B C is mounted the armature of the closed-circuit coil type.

The operation resulting from this arrangement is as follows: If a current impulse be directed through the two circuits of the motor, it will quickly energize the cores B, but not so the cores C, for the reason that in passing through the coils E there is encountered the influence of the closed magnetic circuits formed by the shields H. The first effect is to effectively retard the current impulse in circuit G, while at the same time the proportion of current which does pass does not magnetize the cores C, which are shielded or screened by the shields H.

As the increasing electromotive force then urges more current through the coils E, the iron wire H becomes magnetically saturated and incapable of carrying all the lines of force, and hence ceases to protect the cores C, which become magnetized, developing their maximum effect after an interval of time subsequent to the similar manifestation of strength in the other set of magnets, the extent of which may be arbitrarily determined by the thickness of the shield H, and other well known conditions.

From the above it will be seen that the apparatus or device acts in two ways. First, by retarding the current, and second by retarding the magnetization of one set of cores, from which its effectiveness will readily be seen.

Many modifications of the principle here embodied have been made by Mr. Tesla, one only more of which we may notice here. This is illustrated in Fig. 5, and is similar in all respects to that above described, except that the iron wire H, which is wrapped around the coils E, is in this case connected in series with the coils D. The iron wire coils are connected and wound so as to have little or no self-induction, and, being added to the resistance of the circuit F, the action of the current in that circuit will be accelerated while in the other circuit G it will be retarded.

Still another type of motor constructed by Mr. Tesla is one with a field magnet having two sets of poles or inwardly projecting cores and placed side by side so as practically to form two fields of force, and alternately ar-

ranged, that is to say, with the poles of one set or field opposite the spaces between the other. The free ends of one set of poles are then connected by means of laminated iron bands or bridge pieces of considerably smaller cross-section than the cores themselves, so that the cores all form parts of complete magnetic circuits.

When the coils on each set of magnets are connected in multiple circuits from an alternating machine electromotive forces are set up in each circuit simultaneously, but the coils on the magnetically bridged or shunted cores will have, by reason of the closed magnetic circuits, a high self-induction which retards the current, permitting at the beginning of each impulse but little current to pass. On the other hand, no such opposition being encountered in the other set of coils, the current passes freely through them, magnetizing the poles on which they are wound.

As soon, however, as the laminated bridges become saturated and incapable of carrying all the lines of force, which the rising electromotive force, and consequently *increased* current, produce, free poles are developed at the ends of the cores, which, acting in conjunction with the others, produce rotation of the armature.

The construction by which this is accomplished is shown in the accompanying engravings, Figs. 6 and 7.

The frame of the motor A, is built up of sheets of iron punched out to the desired shape and bolted together with insulation between the sheets. When complete the frame makes a field magnet with inwardly projecting pole pieces B and C. To adapt them to the requirements of this particular case, these pole pieces are out of line with one another, those marked B surrounding one end of the armature, and the others C the opposite end, and they are arranged alternately; that is to say, the pole pieces of one are set in line with the spaces between those of the other sets.

The pole pieces C are connected or shunted by bridge pieces E.

The coils F and G are connected in series, respectively, in two circuits which are branches of a circuit from an alternating machine, and they are so wound that the circuit of coils G will have a higher self-induction than the other circuit or branch.

The function of the shunts or bridges E, is that they shall form with the cores C a closed magnetic circuit for a current up to a predetermined strength, so that when saturated by such current and unable to carry more lines of force than such a current produces, they will, to no further appreciable extent, interfere with the development by a stronger current of free magnetic poles at the ends of the cores C.

In such a motor the current is so retarded in the coils G and the manifestation of the free magnetism in the poles C is delayed beyond the periods of maximum magnetic effect in poles B. The result is that a strong torque is produced and the motor operates with approximately the power developed in a motor of this kind energized by independently generated currents differing by a full quarter phase.

TESLA'S TRANSFORMER FOR MOTOR WORK AND FOR CONSTANT CURRENT.

In the early forms of alternating motor brought out by Mr. Tesla the construction embodied a series of coils traversed by currents differing a quarter phase from one another. This has in some forms required three wires from the generator to the motor, but in order to avoid this Mr. Tesla has recently constructed a converter specially designed to be used in connection with his motor, and in which the difference of phase required is spontaneously brought about. This converter also possesses the valuable property that it operates with a constant current for all loads imposed upon the secondary.

In transformers as at present constructed it is found that the electromotive force of the secondary very nearly coincides with that of the primary, being, however, of opposite sign. At the same time the currents, both primary and secondary, lag behind their respective electromotive forces, but as this lag is practically the same in the case of each, it follows that the maximum and minimum of the primary and secondary currents will nearly coincide, but differ in sign or direction, provided the secondary be not loaded, or if it contain devices having the property of self-induction.

On the other hand, the lag of the primary behind the impressed electromotive force may be diminished by loading the secondary with a non-inductive or dead resistance, such as incandescent lamps, whereby the time interval between the maximum or the minimum periods of the primary and secondary currents is increased. This time interval, however, is limited, and the results obtained by phase difference in the operation of such devices as Mr. Tesla's alternating current motors can only be approximately realized by such means of producing or securing this difference, as above indicated. For it is desirable in such cases that there should exist between the primary and secondary currents, a difference of phase of 90 degrees, or in other words, the current in one circuit should be maximum when that in the other circuit is minimum.

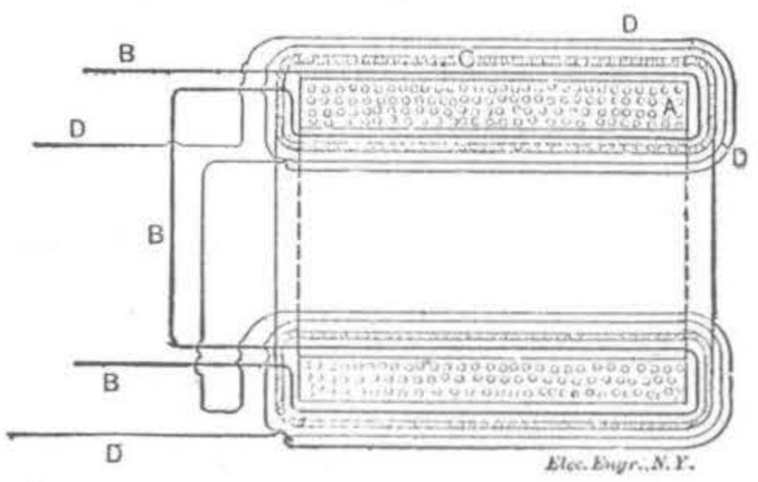


FIG. 1.—NEW TESLA CONSTANT CURRENT TRANSFORMER.

To more nearly and perfectly attain to this condition Mr. Tesla secures an increased retardation of the secondary

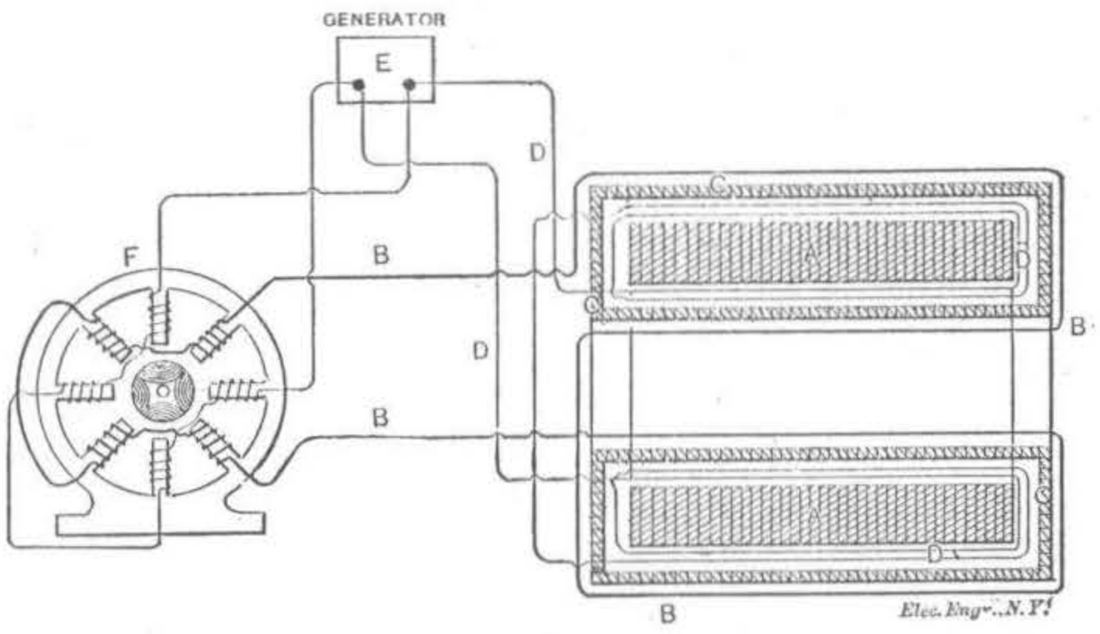


FIG. 2.—NEW TESLA CONSTANT CURRENT TRANSFORMER.

current in the following manner: Instead of bringing the primary and secondary coils or circuits of a transformer into the closest possible relations, as has hitherto been done, he protects in a measure the secondary from the inductive effect of the primary by surrounding either the primary or the secondary with a comparatively thin magnetic shield or screen.

Under these conditions, as long as the primary current has a small value the shield protects the secondary, but as soon as the primary current has reached a certain strength, which is arbitrarily determined, the protecting magnetic shield becomes saturated and the inductive action upon the secondary begins. It results, therefore, that the secondary current begins to flow at a certain fraction of a period later than it would without the interposed shield, and since this retardation may be obtained without necessarily re-

tarding the primary current also, an additional lag is secured and the time interval between the maximum or minimum periods of the primary and secondary currents is increased.

Mr. Tesla has also discovered that such a transformer, may, by properly proportioning its elements, be made to yield a constant current at all loads.

In the accompanying illustrations, Fig. 1 is a cross-section of a transformer embodying the above idea.

A A is the main core of the transformer composed of a ring of annealed iron wire. Upon this core is wound the secondary circuit B B. This latter is then covered with a layer of annealed iron wires C C, wound in a direction at right angles to the secondary coil. Over the whole is then wound the primary coil D D.

From the nature of this construction it will be obvious that as long as the shield formed by the wires C is below magnetic saturation, the secondary coil or circuit is effectually protected or shielded from the inductive influence of the primary.

When the strength of the primary reaches a certain value, the shield C, becoming saturated, ceases to protect the secondary from inductive action and current is in consequence developed therein. For similar reasons, when the primary current weakens, the weakening of the secondary is retarded to the same extent.

In the engraving, Fig. 2, the core A is built up of insulated iron plates or disks. The primary circuit D is wound next to core A. Over this is applied the shield C, which in this case is made up of thin plates of iron properly insulated and surrounding the primary, forming a closed magnetic circuit. The secondary B is wound over the shield C.

In Fig. 2, the primary of the transformer is connected with the circuit of the generator. F is a two-circuit alternating current motor, one of the circuits being connected with the main circuit from the source E, the other being supplied with currents from the secondary of the transformer.

Western Electrician.

EVERY SATURDAY.

Vol. VII. CHICAGO, AUGUST 9, 1890. No. 6

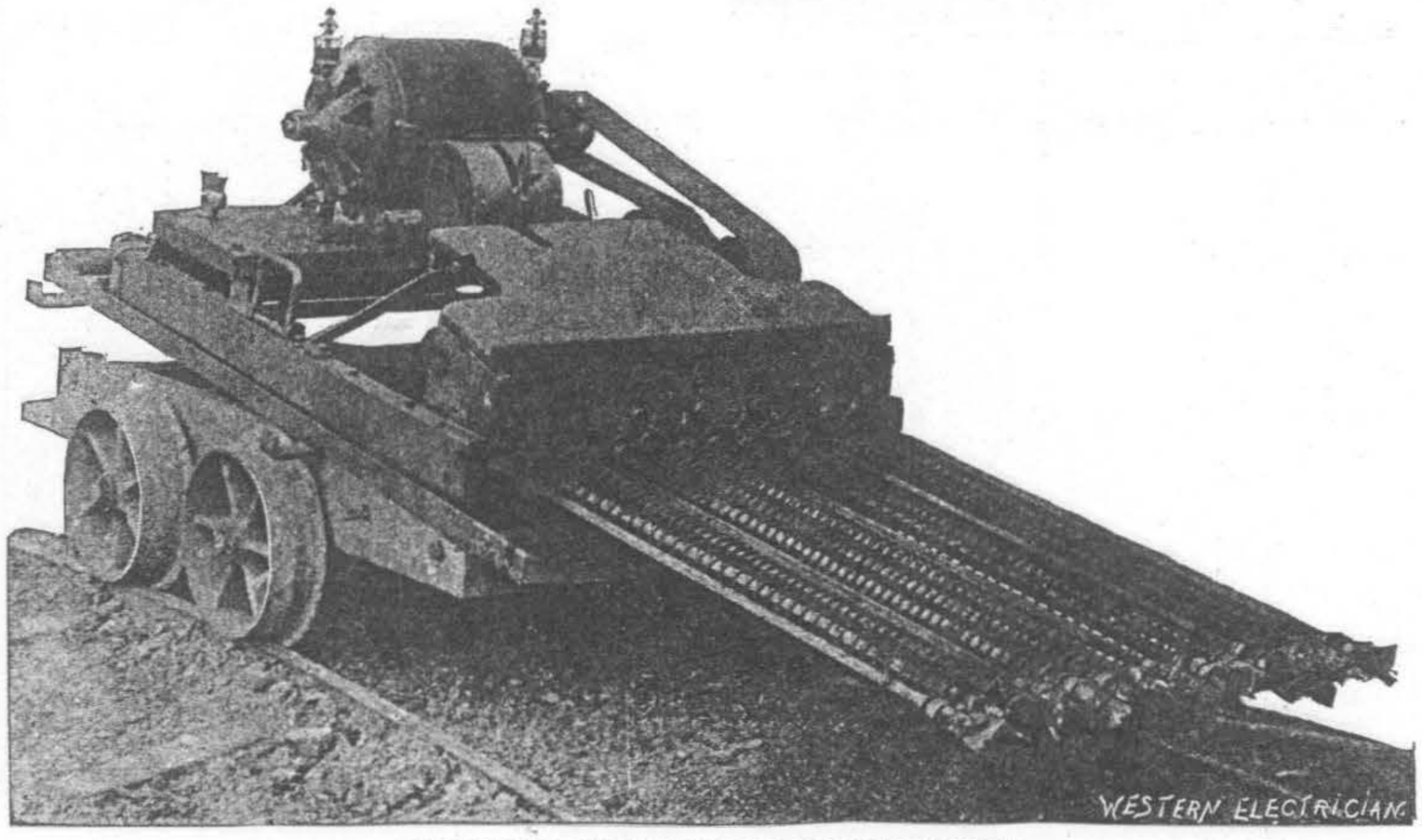
Alternating Current Motors for Mining Work.

The Willock mine, belonging to the Monongahela Gas Coal company and situated in the first pool of the Monongahela coal region is now operated with a complete alternating current motor plant. The machines furnish power in the production of coal, the working of the pump and also in the operation of an enormous ventilator which keeps a constant draught of pure air in the mine. In addition the mine is illuminated by the alternating current system.

The cut represents the Hercules mining machine equipped with the Tesla alternating current motor of the Westinghouse company used in the mine. This is the first mine in the Pennsylvania coal region where the alternating current system is utilized extensively. A correspondent of the WESTERN ELECTRICIAN who recently visited the mine was much indebted to John Werner, the mine foreman, a man who is himself a mechanical genius of no mean standing. During a conversation with him, he said: "I believe that electric mining has no greater prospects anywhere than just in the coal fields of Pennsylvania. The reasons for this are so many that I hardly know where to commence to enumerate them. Coal mining in Pennsylvania was never such a poor trade as it is now, in fact it is so bad that a native born American will have nothing more to do with the work. The result has been that the business has fallen into the hands of foreigners of the very lowest class, such as Hungarians, Poles and Italians. Then again the price of coal has gone down to such an extent, the result of course of competition, that it is impossible to get any intelligent men who will do the work for the small wages a miner is able to make. This condition of affairs caused the coal operators to hail the application of electricity to a coal mine with great satisfaction and I believe that it will not be long before every mine in the country will be operated by electricity. The advantages afforded by electricity in the operation of a mine are so manifold that its use is bound to become general. For instance, where a coal digger was able to earn on the average $2.25 per day, the machine miner makes $3. Why? because while the operator pays the miner less for the production of each ton of coal, the man can produce so much more with the aid of his machine that he can make better wages now and the work is less laborious. The operator pays the coal digger $0.79 per ton of coal, but the production of each ton with the aid of electricity costs him only $0.49, so you see there is a pure gain for the operator of $0.30 for each ton."

The electric plant consists of a thirty horse power quarter phase generator of a capacity sufficient to carry seven motors when cutting coal, at the limit of the capacity of the coal company. The generator is self-acting, self-regulating, and so wound that as the load increases, the e. m. f. rises. By the aid of a hand rheostat, the adjustments can be so made that the falling off in the speed of the engine and the drop in the line may be compensated for and a very close approximation to constant e. m. f. at the motors is obtained. After the hand rheostat is once adjusted, it is unnecessary to make further adjustments for the self-regulating devices are automatic. Three wires from the collector at the end generator shaft pass from the switch-board and main line switches directly into the mine. On the switch-board is a direct reading voltmeter and an ammeter. The e. m. f. at the motor is 300 volts, in this installation.

Where the distance becomes very great, a higher e. m. f. may of course be used. The mine is wired with high class rubber covered wire and the insulation of each wire is practically continuous from the time the wire leaves the main switch in the power house until it reaches the end of the circuit. At the entrance of each room and also at convenient points through the mine, switches are located and safety catches inserted. This insures safety from short-circuiting and also allows any portion of the circuit to be cut off from the generator without interfering with the work in other parts of the mine. From the switch in the room to the coal-cutting machine the current is carried by a three-wire cable. This cable is highly insulated and covered with a protecting braid, so that though it is frequently allowed to lie on the damp floor and even in pools of water, yet no inconvenience is noticed arising from this. It is necessary only to have a jaw switch at the motor with which the circuit can be opened and closed. No regulator of any kind is used. The only auxiliary apparatus connected with the motor, with which the operator of the machine has anything to do, is the switch to turn the current on and off. The motor is completely covered and there is no possible chance of getting a shock through careless handling, it is claimed.



ALTERNATING CURRENT MOTORS FOR MINING WORK.

THE TESLA MOTOR IN MINING WORK.

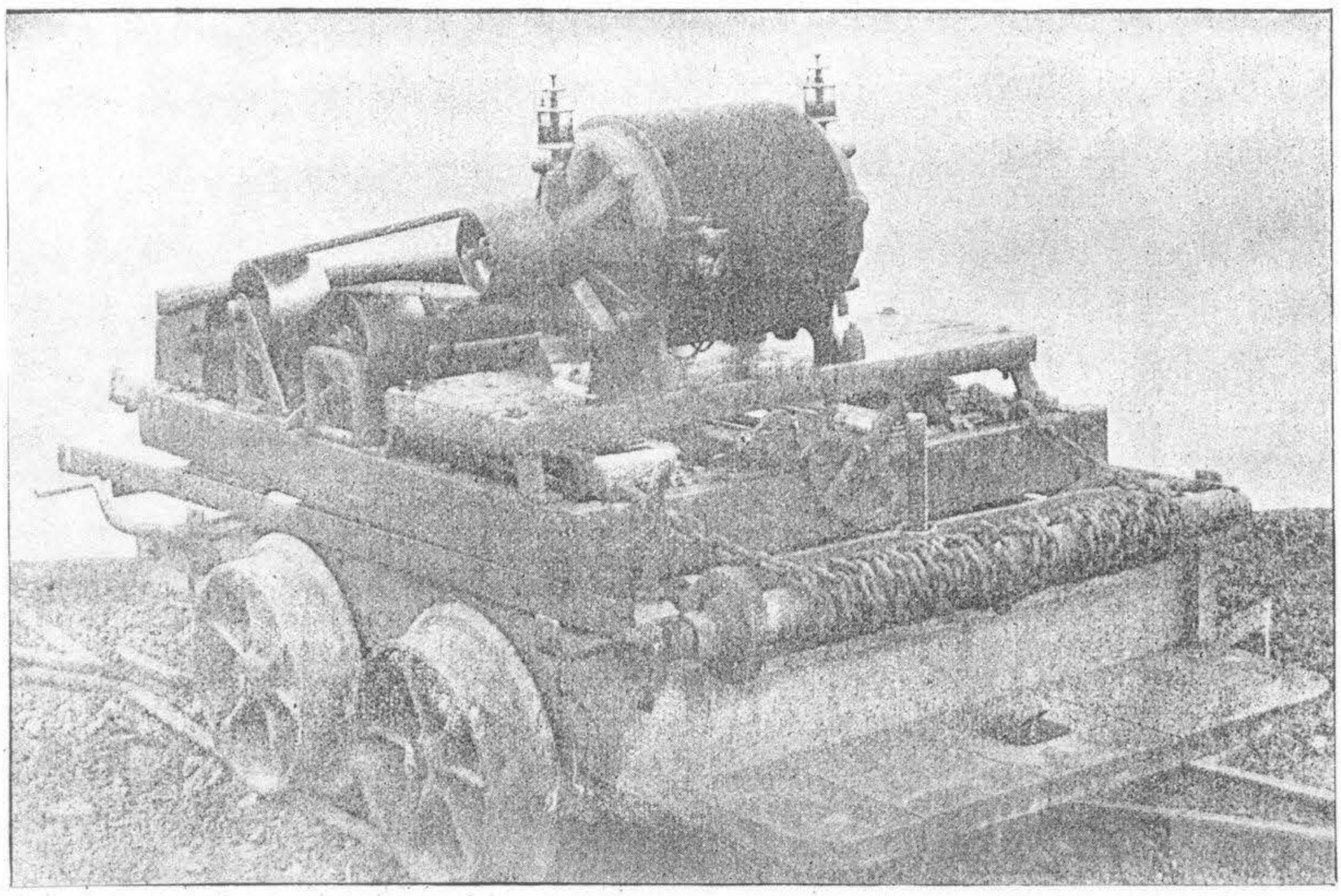
THE alternating current system of electrical distribution has recently demonstrated its great usefulness on a new field by proving a wonderful success in mining work.

The Willock mine, belonging to the Monongahela Gas Coal Company and situated in the first pool of the Monongahela coal region, is now operated with a complete plant of this system. Alternating current motors are utilized as a source of power in the production of the coal, the working of the pump and also in the manipulation of an enormous ventilator which keeps a constant draught of pure air in the mine. In addition to that, the mine is also illuminated by the alternate current system.

Inasmuch as this is the first mine in the Pennsylvania coal region where the alternating current system is utilized very extensively, our correspondent made a visit to the mine in order to make a personal investigation of the success of the plant. He was very much aided in his efforts, by Mr. John Werner, the mill boss, who believes that electric mining has no greater prospect anywhere than just in the coal fields of Pennsylvania. The reasons for this are many. In the first place, coal mining in Pennsylvania was never such a poor trade as it is now; in fact, it is so bad that a native born American will have nothing more to do with the work. The result has been that the business has fallen into the hands of foreigners of the very lowest class, such as Hungarians, Poles and Italians. Then again, the price of coal has gone down to such an extent, induced of course by competition, that it is impossible to get any intelligent men who will do the work for the small wages a miner is able to make. This condition of affairs caused the coal operators to hail the advent of electricity as a coal miner with great delight, and it will probably not be very long before every mine in the country will be operated by electricity.

The advantages afforded by electricity in the operation of a mine are so manifold that its use is bound to become general. For instance, where a coal digger was able to earn on the average $2.25 per day, the machine miner makes $3. This is possible, because, while the operator pays the miner less for the production of each ton of coal, the man can produce so much more with the aid of his machine that he can make better wages now and the work is less laborious. The operator pays the coal digger 79 cents per ton of coal, but the production of each ton with the aid of electricity costs him only 49 cents, so that there is a pure gain for the operator of 30 cents for each ton.

The plant consists of a thirty h. p. Tesla quarter-phase generator of a capacity sufficient to carry seven motors when cutting coal, at the limit of the capacity of the coal company. The generator is self-excting, self-regulating, and so wound that as the load increases, the E.M.F. rises. By the aid of a hand rheostat, the adjustments can be so made that the falling off in the speed of the engine and the drop in the line may be compensated for, so that at the motors a very close approximation to constant E.M.F. is obtained. After the hand rheostat is once adjusted, it is unnecessary to make further adjustments, for the self-regulating devices



THE TESLA MOTOR DRIVING A HERCULES MINING MACHINE.

are automatic. Three wires are carried from the collector at the end of the generator shaft to the switch board and pass through the switch board instruments and main line switches directly into the mine. On the switch board is a direct reading voltmeter and an ammeter. The E.M.F. at the motor is 300 volts in this installation. Where the distances becomes very great, a higher E.M.F. may, of course, be used.

The mine is wired with high class rubber-covered wire, and the insulation of each wire is practically continuous from the point where the wire leaves the main switch in the power house until it reaches the end of the circuit. At the entrance of each room, and also at convenient points throughout the mine, switches are located and safety catches inserted. This insures safety from short-circuiting and also allows any portion of the circuit to be cut off from the generator without interfering with the work in other parts of the mine. From the switch in the room to the coal cutting machine the current is carried by a three-wire cable. This cable is highly insulated and covered with a protecting braid, and though it is frequently allowed to lie on a damp floor and even in pools of water,

no inconvenience is noticed arising from this usage. Owing to the simplicity of the alternate current motor it is necessary only to have a jaw switch at the motor with which the circuit can be opened and closed. No regulator of any kind is used, and the only auxiliary apparatus connected with the motor, with which the operator of the machine has anything to do, is the switch to turn the current on and off. The motor is completely covered and the chance of getting a shock through careless handling is nil. Our illustration shows the motor mounted on the drill.

The mine owners are well satisfied with the performance of the plant and the men bring out from 45 to 50 tons of lump coal with each machine per day.

The coal mining machine used at this mine is the Hercules machine, and the entire electrical equipment was carried out by the Mill and Mine Electric Equipment Co., of Pittsburgh, Pa.

ELECTRICAL REVIEW

ILLUSTRATED.

A WEEKLY JOURNAL OF

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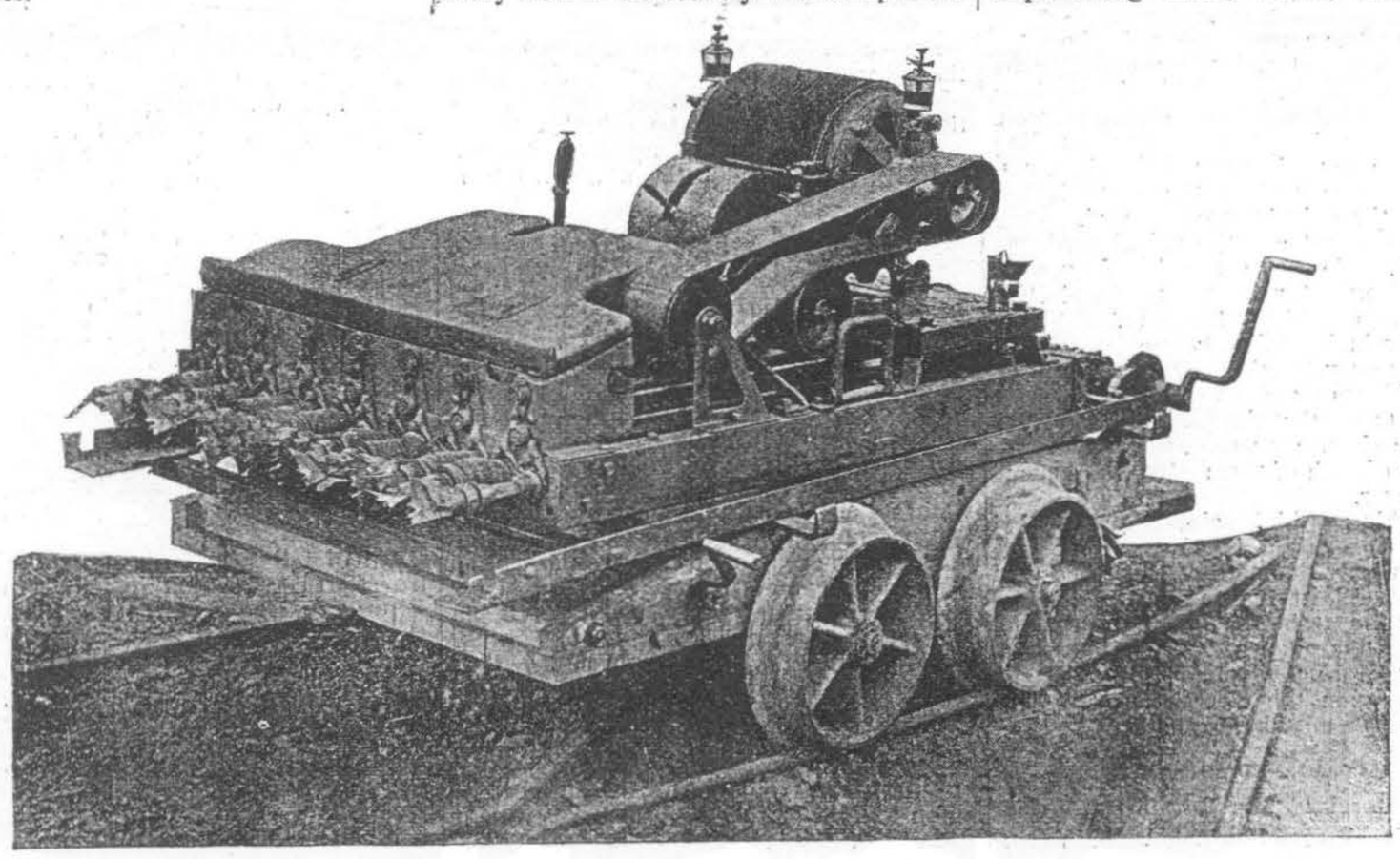
Electric Cooking.

State Chemist Dr. Charles W. Drew and Edward R. Francis gave an interesting exhibition of heating and cooking by electricity in Minneapolis, last week, which was attended by quite a number of local electricians. The methods of heating water for stewing and boiling were particularly noticed by the spectators, as well as the oven for heating purposes alone. Dr. Drew placed a piece of cardboard over the aperture at the top of the oven, and by applying the thermometer, the temperature was found to reach over 400 degrees, while that of the toasting apparatus, which is the latest invented article of the outfit, forced the mercury to 320 degrees. The workings were practically illustrated with the ordinary kitchen supplies and proved very satisfactory, the heating oven, however, seeming to be the best perfected arrangement. Some further additions are to be made to several portions of the apparatus, which will make them of especial use for the general purposes intended. Patents have been issued to Messrs. Drew and Francis for their appliances.



THE TESLA MOTOR IN COAL MINING.

The Alternating Current Motor in Mining Work.

The alternating current system of electrical distribution has just demonstrated its usefulness in a new field by proving a wonderful success in mining work.

The Willock mine, belonging to the Monongahela Gas Coal Company, and situated in the first pool of the Monongahela coal regions, is now operated by a complete plant of alternating current motors, utilized as the power in the production of coal, the working of the pump, and also in the manipulation of an enormous ventilator which keeps a constant draught of pure air in the mine. In addition to that, the mine is also illuminated by the alternating current system.

Inasmuch as this is the first mine in the Pennsylvania coal region where the alternating current system is utilized very extensively, your correspondent made a visit to the mine in order to make a personal investigation of the success of the plant. He was very much aided in his efforts through the courtesy of Mr. John Werner, the mill boss, a man who is himself a mechanical genius of ability. During a conversation with him, he said: "I believe that electric mining has no greater prospects anywhere than just in the coal fields of Pennsylvania. The reasons for this are so many that I hardly know where to commence to enumerate them. Coal mining in Pennsylvania was never such a poor trade as it is now, in fact, it is so bad that a native-born American will have nothing more to do with the work. The result has been that the business has fallen into the hands of foreigners of the very lowest class, such as Hungarians, Poles and Italians. Then again, the price of coal has gone down to such an extent, induced, of course, by competition, that it is impossible to get many intelligent men who will do the work for the small wages a miner is able to make. This condition of affairs caused the coal operators to hail the advent of electricity as a coal miner with great delight, and I believe that it will not be very long before every mine in the country will be operated by electricity. The advantages afforded by electricity in the operation of a mine are so manifold that its use is bound to become general. For instance, where a coal digger was able to earn on the average $2.25 per day, the machine miner makes $3. Why? Because while the operator pays the miner less for the production of each ton of coal, the man can produce so much more with the aid of his machine that he can make better wages now and the work is less laborious. The operator pays the coal digger 79 cents per ton of coal, but the production of each ton with the aid of electricity costs him only 49 cents, so you see there is a pure gain for the operator of 30 cents for each ton."

The plant consists of a 30 horse-power quarter phase generator of a capacity sufficient to carry seven motors when cutting coal, at the limit of the capacity of the coal company. The generator is self-exciting, self-regulating, and so wound that as the load increases, the E. M. F. rises. By the aid of a hand rheostat, the adjustments can be so made that the falling off in the speed of the engine and the drop in the line may be compensated for so that at the motors a very close approximation to constant E. M. F. is obtained. After the hand rheostat is once adjusted, it is unnecessary to make further adjustments, for the self-regulating devices are automatic. Three wires are carried from the collector at the end of the generator shaft to the switchboard, and pass through the switchboard instruments and main line switches directly into the mine. On the switchboard is a direct reading voltmeter and an ammeter. The E. M. F. at the motor is 300 volts.

Where the distances become very great, a higher E. M. F. may, of course, be used. The mine is wired with high class rubber covered wire, and the insulation of each wire is practically continuous from the time the wire leaves the main switch in the power house until it reaches the end of the circuit. At the entrance of each room, and also at convenient points throughout the mine, switches are located and safety catches inserted. This insures safety from short-circuiting, and also allows any portion of the circuit to be cut off from the generator without interfering with the work in other parts of the mine. From the switch in the room to the coal-cutting machine, the current is carried by a three-wire cable. This cable is highly insulated and covered with a protecting braid, which, though frequently allowed to lie on a damp floor and even in pools of water, yet always works well.

It is necessary only to have a jaw switch at the motor with which the circuit can be opened and closed. No regulator of any kind is used. The only auxiliary apparatus connected with the motor, with which the operator of the machine has anything to do, is the switch to turn the current on and off. The motor is completely covered, and the chance of getting a shock through careless handling is simply *nil*.

When Mr. Werner expressed himself as highly pleased with the Tesla motor, he said: "Miners are not usually educated for electricians, and, in consequence, they want to handle a motor without having to go through a course of lectures and instructions. Here we have no brushes and no commutators, very valuable advantages, because those things get out of order, or else the man gets into close contact with them. The Tesla motor is also more efficient than any other we have ever tried. With it our men bring out from 45 to 50 tons of lump coal with each machine per day."

The coal mining machine used in this mine is the Hercules machine.

Some New Types of Alternating Current Motors.

Among the few prominent workers in the development of the alternating current motor is Mr. Nikola Tesla. His early work in this line, presented in a paper read before the American Institute of Electrical Engineers two years ago,* justly excited widespread interest not only because of what had already been accomplished but for the influence which his suggestive researches would have in stimulating others to take up similar lines of investigation. Since that time Mr. Tesla has not relaxed his efforts to produce a more efficient alternating current motor, and each of his inventions has been a step in advance along a line where progress has been extremely difficult.

The latest types of alternating current motor produced by Mr. Tesla have been designed with a view to their economical adaptation to a two-wire system of alternating current distribution, without the use of a commutator. He has utilized for this purpose the well known fact that the magnetization of the entire core of an electro-magnet does not take place instantaneously upon the passage of a current through the surrounding coil. This phenomenon is attributed by Mr. Tesla to the fact that the action of the current is to energize first those laminæ or parts of the core nearest the surface and adjacent to the exciting coil, and from thence the action progresses toward the interior. A certain interval of time therefore elapses between the manifestation of magnetism in the external and the internal sections or layers of the core. If the core be thin or of small mass, this effect may be inappreciable; but in the case of a thick core, or even of a comparatively thin one, if the number of alternations be very great, the time interval occurring between the manifestations of magnetism in the interior of the core and those parts adjacent to the coil is more marked, and in the construction of such apparatus as motors which are designed to be run by alternating or equivalent currents, it has been found desirable and even necessary to give due consideration to this phenomenon and make special provisions in order to obviate its consequences.

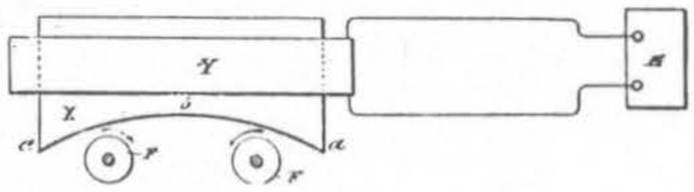


FIG. 1.

Mr. Tesla takes advantage of this well known phenomenon and utilizes it in the construction of his motors, even using special means by which the action may be exaggerated and rendered more pronounced. This he attains by constructing a field magnet in which the parts of the core or cores that exhibit at different intervals of time the magnetic effect imparted to them by alternating or equivalent currents in an energizing coil are so placed with relation to a rotating armature as to exert upon it the attractive effect successively in the order of their magnetization. By this means he secures a similar result to that which he has attained in other forms of motor in which by means of one or more alternating currents a rotation or progression of the magnetic poles or points of maximum attraction of the field of force is secured.

A diagrammatic representation of a very simple form of

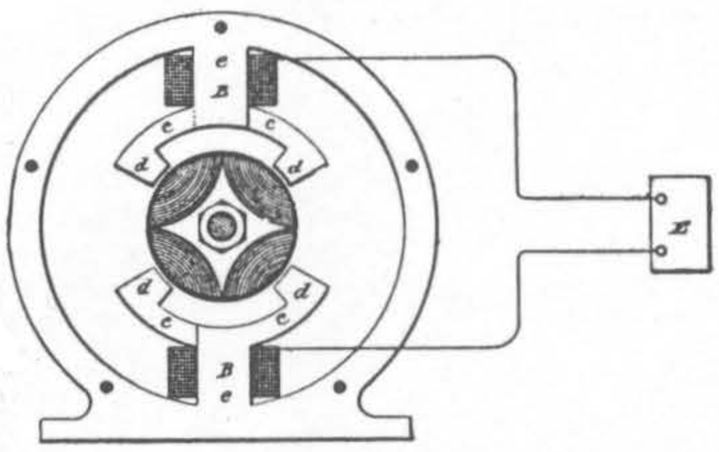


FIG. 2.

motor, by means of which Mr. Tesla illustrates the application of this principle, is shown in Fig. 1. Here X represents a large iron core made up of any number of thin laminæ of soft iron or steel. If we consider the magnetic conditions existing in this core at any point, as b, at or near the centre, and any other point, as a, nearer the surface, it will be seen that when a current impulse is started in the magnetizing coil Y, the section or part at a, being close to the coil, is immediately energized, while the section at b, which may be said to be "protected" by the intervening layers between a and b, does not at once exhibit its magnetism. However, as the magnetization of a increases, b becomes also affected, reaching finally its maximum strength some time later than a. Upon the weakening of the current the magnetization of a first diminishes, while b still exhibits its maximum strength; but the continued weakening of a is attended by a subsequent weakening of b. Assuming the current to be an alternating one, a will now be reversed, while b still continues of the first imparted polarity. This action continues, the magnetic condition of b following that of a in the manner above described. If an armature—for instance, a simple disc F, mounted to rotate freely on an axis—be brought into proximity to the core, a movement of rotation will be imparted to the disc, the direction depending upon its position relatively to the core, the tendency being to turn the portion of the disc nearest to the core from a to b, as indicated in Fig. 1.

Fig. 2 shows a side elevation of a form of motor in which Mr. Tesla embodies this principle of operation. Fig. 3 is a vertical section of the same through the axis of rotation. Here A represents a circular frame of iron, and from its interior, at diametrically opposite points, the cores project. Each core is composed of three main parts, as shown in the section in Fig. 3, and they are similarly made with a straight portion e, around which the energizing coil is wound, a curved arm or extension c and an inwardly projecting pole d, as seen in fig. 2. Each core is made of two exterior parts with their polar extensions reaching in one direction and a central part between the other two and with its polar extension reaching in the opposite direction. These cores are wound with coils which are connected in the same circuit either in parallel or series and supplied with an alternating current by a generator E represented diagramatically. Between the cores or their polar extensions is mounted an armature wound with magnetizing coils that are closed upon themselves, similar to those in the earlier types of Mr. Tesla's motors.

The operation of the motor is as follows: When a current impulse is sent through the magnet coils the sections of the cores on the surface and in close proximity to the coils are immediately energized. The interior sections, on the other hand, are protected from the magnetizing influence of the coil by the interposed layers of iron. As the magnetism of the exterior increases, however, the sections

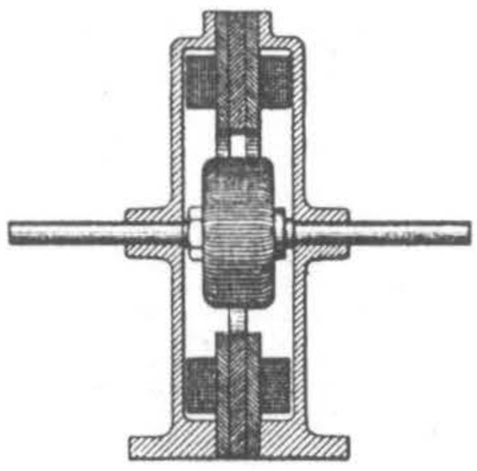


FIG. 3.

on the interior are also energized, but they do not attain their maximum strength until some time after the external sections of the core have reached their maximum magnetization. Upon the weakening of the current the magnetic strength of the exterior layers first diminishes while the interior sections have still their maximum strength; but as they continue to weaken, the interior sections are similarly weakened. The interior and exterior layers of iron may, therefore, be considered as separate field magnets, being extended so as to act on the armature in the most efficient positions, and the effect is similar to that obtained in Mr. Tesla's other form of motor, viz., a rotation or progression of the maximum points of the field of force. Any armature, such, for instance, as a disc mounted in this field, would rotate from the pole first to exhibit its magnetism to that which exhibits it later.

Following out these ideas still further Mr. Tesla has applied them to a class of motors in which two or more sets of energizing magnets are employed and in which by artificial means a certain interval of time is made to elapse between the respective maximum or minimum periods of their magnetic attraction or effect. In this case Mr. Tesla employs a motor with two sets of energizing or field magnets, each wound with coils connected with a source of alternating currents, but forming two separate paths or circuits. The magnets of one set are protected to a certain extent from the energizing action of the current by means of a magnetic shield or screen of laminated iron interposed between the magnet and its energizing coil.

The shield is properly adapted to the conditions of particular cases so as to shield or protect the main core from magnetization until it has become itself saturated and no longer capable of containing all the lines of force produced by the current. By this means it will be seen that the energizing action begins in the protected set of magnets a certain arbitrarily determined period of time later than in the other, and that by this means a practically economical difference of magnetic phase may readily be secured.

Fig. 4 shows the simplest form of this type of machine. The cores B form one set of magnets and are energized by coils D, while the cores C, forming the other set, are energized by coils E, and the coils are connected in series with one another, in two derived or branched circuits F and G respectively. Each coil E is surrounded by a magnetic shield H, which is composed of an annealed, insulated, or oxidized iron wire wound on the coils in the manner indicated, so as to form a closed magnetic circuit around the coils and between the same and the magnetic cores C. Between the pole pieces or cores B C is mounted the armature, which in this case is of the closed-circuit coil type.

The operation resulting from this arrangement is as follows: If a current impulse be directed through the two circuits of the motor, it will quickly energize the cores B, but not so the cores C, for the reason that in passing through the coils E there is encountered the influence of the closed magnetic circuits formed by the shields H.

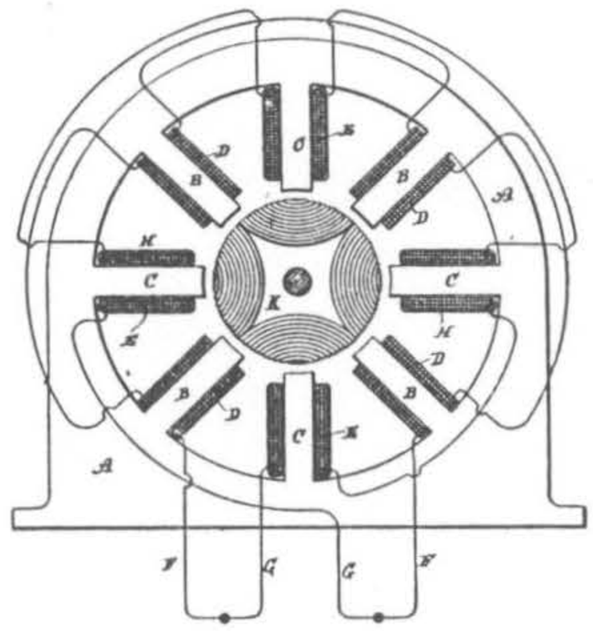


FIG. 4.

The first effect is to effectively retard the current impulse in circuit G, while at the same time the proportion of current which does pass does not magnetize the cores C, which are shielded or screened by the shields H. As the increasing electromotive force then urges more current through the coils E, the iron wire H becomes magnetically saturated and incapable of carrying all the lines of force, and hence ceases to protect the cores C, which become magnetized, developing their maximum effect after an interval of time subsequent to the similar manifestation of strength in the other set of magnets, the extent of which is arbitrarily determined by the thickness of the shield E, as well as by other conditions. It will be seen, therefore, that the apparatus or device acts in two ways. First, by retarding the current, and second by retarding the magnetization of one set of cores.

Fig. 5 shows another form of motor which embodies the same principle, and is similar in all respects to that described above, except that the iron wire H, which is wrapped around the coils E, is in this case connected in series with the coils D. The iron wire coils are connected and wound so as to have little or no self-induction, and, being added to the resistance of the circuit F, the action of the current in that circuit will be accelerated, while in the other circuit G it will be retarded.

Still another type of motor, Fig. 6 and 7, constructed by Mr. Tesla, is one with a field magnet having two sets of poles or inwardly projecting cores, and placed side by side so as practically to form two fields of force, and alternately arranged, that is to say, with the poles of one set or field opposite the spaces between the other. The free ends of one set of poles are then connected by means of laminated iron bands or bridge pieces of considerably smaller cross-

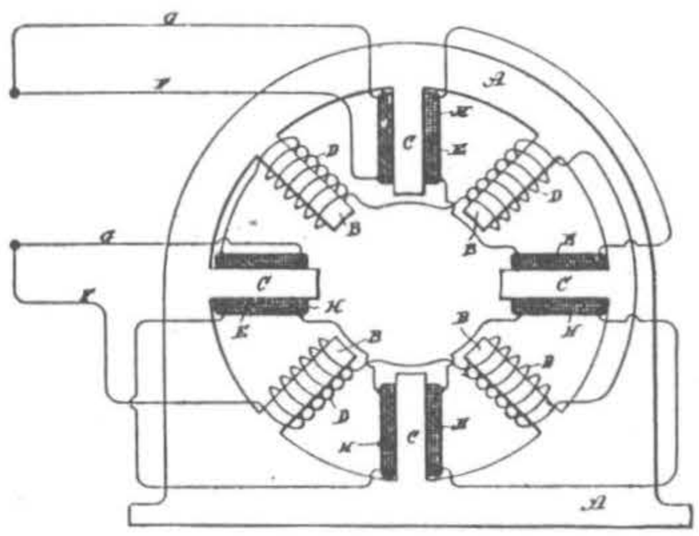


FIG. 5.

section than the cores themselves, so that the cores all form parts of complete magnetic circuits. When the coils on each set of magnets are connected in multiple circuits from an alternating machine, electromotive forces are set up in each circuit simultaneously, but the coils on the magnetically bridged or shunted cores will have, by reason of the closed magnetic circuits, a high self-induction which retards the current, permitting at the beginning of each impulse but little current to pass. On the other hand, no such opposition being encountered in the other set of coils, the current passes freely through them, magnetizing the poles on which they are wound. As soon, however, as the laminated bridges become saturated and incapable of carrying all the lines of force, which the rising electromotive force, and consequently increased current, produce, free poles are developed at the ends of the cores, which, acting in conjunction with the others, produce rotation of the armature.

Figs. 6 and 7 show respectively a side elevation and a vertical cross section of this form of motor. The frame of

* See THE ELECTRICAL WORLD, Vol. XI., page 231, June 2, 1888.

the motor *A* is built up of sheets of iron punched out to the desired shape and bolted together with insulation between the sheets. When complete the frame makes a field magnet with inwardly projecting pole pieces *B* and *C*. To adapt them to the requirements of this particular case, these pole pieces are out of line with one another, those marked *B* surrounding one end of the armature, and the others *C* the opposite end, and they are arranged alternately; that is to say, the pole pieces of one set are in line with the spaces

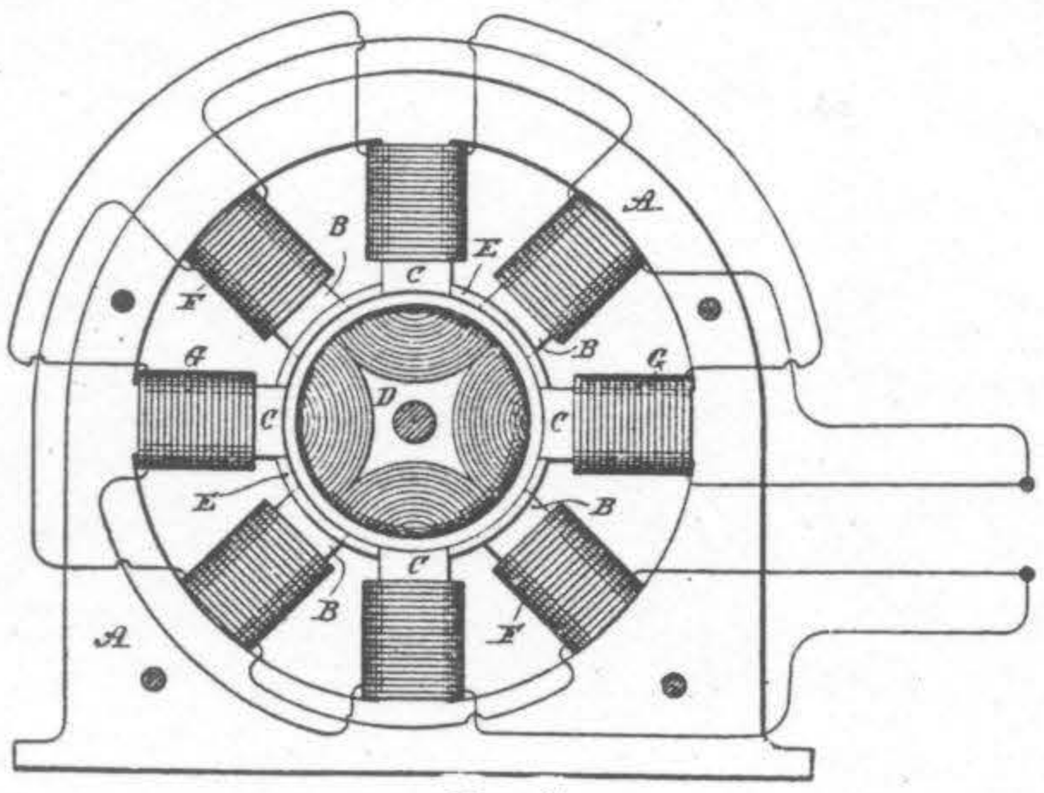


FIG. 6.

between those of the other sets. The armature is of the cylindrical closed circuit type. The pole pieces *C* are connected or shunted by bridge pieces *E*. The coils *F* and *G* are connected in series, respectively, in two circuits which are branches of a circuit from an alternating machine, and they are so wound that the circuit of coils *G* will have a higher self-induction than the other circuit or branch.

The function of the shunts or bridges *E* is that they shall form with the cores *C* a closed magnetic circuit for a current up to a predetermined strength, so that when saturated by such current and unable to carry more lines of force than such a current produces, they will, to no further appreciable extent, interfere with the development by a stronger current of free magnetic poles at the ends of the cores *C*.

In such a motor the current is so retarded in the coils *G* and the manifestation of the free magnetism in the poles *C*

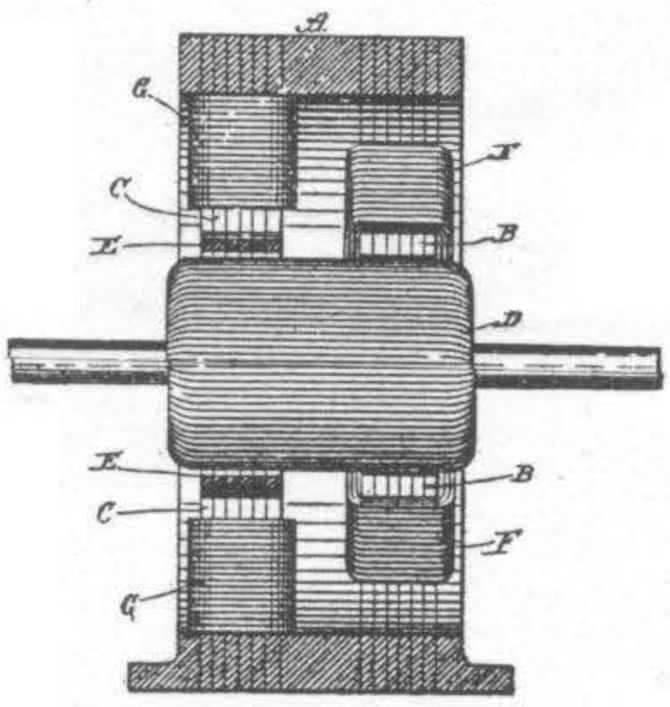


FIG. 7.

is delayed beyond the periods of maximum magnetic effect in poles *B*. The result is that a strong torque is produced and the motor operates with approximately the power developed in a motor of this kind energized by independently generated currents differing by a full quarter phase.

The Tesla Transformer.

An interesting type of transformer has recently been designed by Mr. Nikola Tesla for the purpose of securing a phase difference between the primary and secondary currents adapted to the operation of his new types of alternating current motors, and also to secure a constant current in the primary for all loads imposed upon the secondary. Instead of bringing the primary and secondary coils or circuits of a transformer into the closest possible relations, as

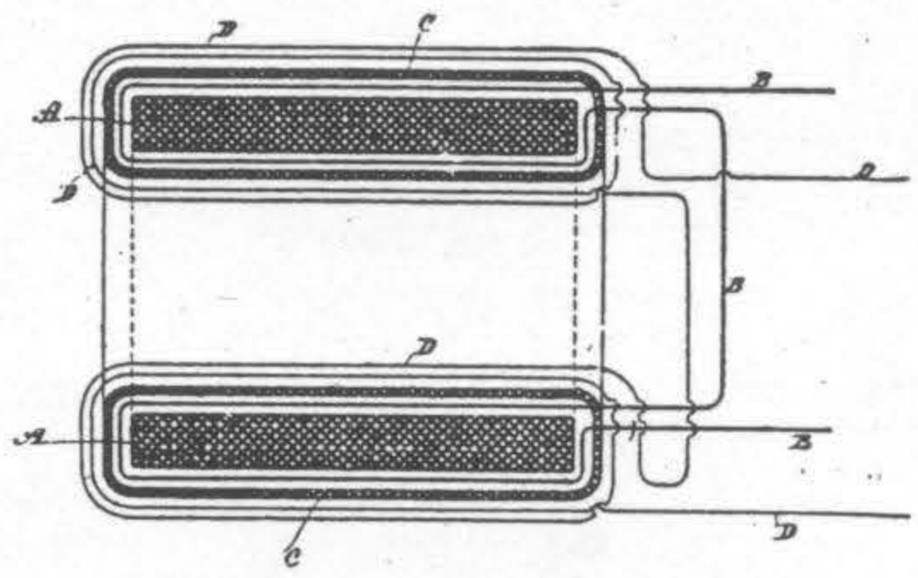


FIG. 1.—TESLA TRANSFORMER.

has hitherto been done, he protects in a measure the secondary from the inductive effect of the primary by surrounding either the primary or the secondary with a comparatively thin magnetic shield or screen.

Under these conditions, as long as the primary current has a small value the shield protects the secondary, but as soon as the primary current has reached a certain strength, which is arbitrarily determined, the protecting magnetic shield becomes saturated and the inductive action upon the secondary begins. It results, therefore, that the secondary current begins to flow at a certain fraction of a period later than it would without the interposed shield, and since this retardation may be obtained without necessarily retarding the primary current also, an additional lag is secured and the time interval between the maximum or minimum periods of the primary and secondary currents is increased.

Fig. 1 is a cross-section of a transformer embodying the above idea. *A A* is the main core of the transformer composed of a ring of annealed iron wire. Upon this core is wound the secondary circuit *B B*, covered with a layer of annealed iron wires *C C*, wound in a direction at right angles to the secondary coil. Over the whole is then wound the primary coil *D D*.

From the nature of this construction it will be obvious that as long as the shield formed by the wires *C* is below magnetic saturation, the secondary coil is effectually protected or shielded from the inductive influence of the pri-

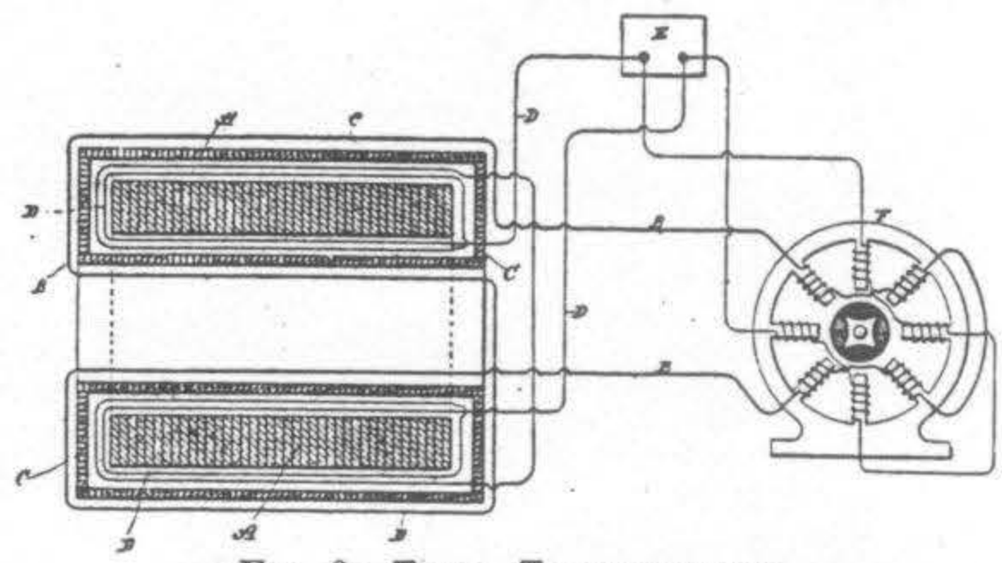


FIG. 2.—TESLA TRANSFORMER.

mary. When the strength of the primary reaches a certain value, the shield *C*, becoming saturated, ceases to protect the secondary from inductive action and current is in consequence developed therein. For similar reasons, when the primary current weakens, the weakening of the secondary is retarded to the same extent.

Fig. 2 shows a modified form with connections to a two-circuit alternating current motor. The core *A* is built up of insulated iron plates. The primary circuit *D* is wound next to core *A*. Over this is applied the shield *C*, which in this case is made up of thin plates of iron properly insulated and surrounding the primary, forming a closed magnetic circuit. The secondary *B* is wound over the shield *C*.

TESLA'S NEW ALTERNATING MOTORS.

For some time past Mr. Nikola Tesla, whose previous work in alternating-current motors is well known has been engaged upon the study of these machines in order to develop efficient methods for operating them on two wires instead of three, and still without the use of a commutator.

The general principle upon which these machines are designed is based on the well-known fact that if a magnetic core, even if laminated, be wound with a coil and a current be sent through, the magnetisation of the entire core does not immediately ensue, the magnetising effect not being exhibited in all parts simultaneously. This Mr. Tesla attributes to the fact that the action of the current is to energise first those laminæ or parts of the core nearest the surface and adjacent to the exciting coil, and from thence the action progresses towards the interior. A certain interval of time, therefore, elapses between the manifestation of magnetism in the external and the internal sections or layers of the core.

If the core be thin or of small mass this effect may be inappreciable, but in the case of a thick core, or even of a comparatively thin one, if the number of alternation be very great, the time interval occurring between the manifestations of magnetism in the interior of the core and in those parts adjacent to the coil is more marked, and in the construction of such apparatus as motors which are designed to be run by alternating currents, Mr. Tesla has found it desirable, and even necessary, to give due consideration to this phenomenon and to make special provisions in order to obviate its consequences.

On the other hand, by taking advantage of this very action or effect, and by rendering it more pronounced, Mr. Tesla utilises it in the operation of motors in general. This he effects by constructing a field in which the parts of the core that exhibit at different intervals of time the magnetic effect imparted to them by alternating currents in an energising coil are so placed with relation to a rotating

armature as to exert thereon their attractive effect successively in the order of their magnetisation. By this means there is secured a result similar to that which Mr. Tesla has heretofore attained in the previous types of his motor, in which by means of one or more alternating currents he produces a rotation or progression of the magnetic poles or points of maximum attraction of the field of force.

The general principle involved in the action above mentioned is illustrated in the simple motor shown in Fig. 1. Here X represents a large iron core composed of a number of sheets or laminæ of soft iron or steel. Surrounding this core is a coil, Y, which is connected with a source, E, of rapidly varying currents.

Let us consider now the magnetic conditions existing in this core at any point, as *b*, at or near the centre, and any other point, as *a*, nearer the surface. According to Mr. Tesla, when a current impulse is started in the magnetising coil, Y, the section at *a*, being close to the coil, is immediately energised, while the section at *b*, which, to use a convenient expression, is "protected" by the

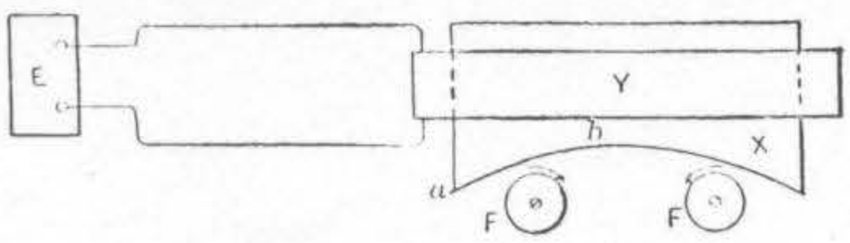


FIG. 1.

intervening sections or layers between *a* and *b*, does not at once exhibit its magnetism. However, as the magnetisation of *a* increases *b* becomes also affected, reaching finally its maximum strength some time later than *a*. Upon the weakening of the current the magnetisation of *a* first diminishes, while *b* still exhibits its maximum strength, but the continued weakening of *a* is attended by a subsequent weakening of *b*. Assuming the current to be an alternating one, *a* will now be reversed, while *b* still continues of the polarity first imparted. This action continues, the magnetic condition of *b* following that of *a* in the manner above described.

If an armature, for instance, a simple disc mounted to rotate freely on an axis, be brought into proximity to the core, a movement of rotation will be imparted to the disc, the direction depending upon its position relatively to the core, the tendency being to turn the position of the disc nearest to the core from *a* to *b*, as indicated in Fig 1.

This action or principle of operation has been embodied in a practical form of motor, which is illustrated in Fig. 2.

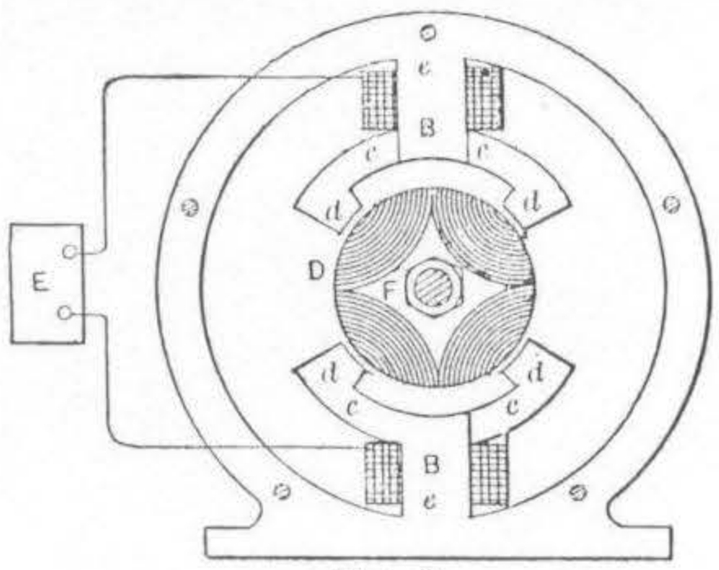


FIG. 2.

Here A represents a circular frame of iron, from diametrically opposite points of the interior of which the cores project.

Each core is composed of three main parts, B B and C, and they are similarly made with a straight portion, *e*, around which the energising coil is wound, a curved arm or extension, *c*, and an inwardly projecting pole, *d*.

Each core is made of two parts, B B, with their polar extensions reaching in one direction and a part, C, between the other two and with its polar extension reaching in the opposite direction. These cores are wound with coils, D, which are connected in the same circuit either in parallel or series and supplied with an alternating current by a generator, E, represented diagrammatically. Between the cores or their polar extensions is mounted an armature, F wound with magnetising coils, G, that are closed upon them selves, similar to those in the older types of Mr. Tesla's motors.

The operation of the motor is as follows: When a current impulse or alternation is sent through the coils, D, the sections, B B, of the cores being on the surface, and in close proximity to the coils, are immediately energised. The sections C, on the other hand, are protected from the magnetising influence of the coil by the interposed layers of iron, B B. As the magnetism of B B increases, however, the sections C are also energised, but they do not attain their maximum strength until a certain time subsequent to the exhibition by the sections B B of their maximum. Upon the weakening of the current the magnetic strength of B B

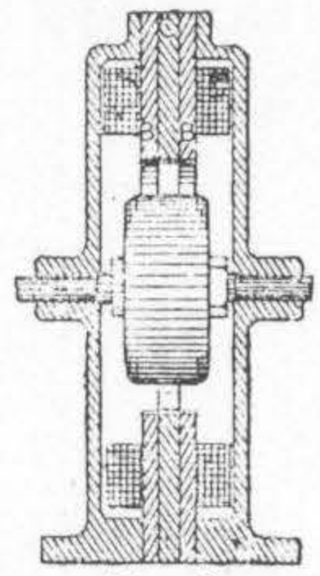


FIG 3.

first diminishes while the sections C have still their maximum strength; but as B B continue to weaken, the interior sections are similarly weakened. B B may then begin to exhibit an opposite polarity, which is followed later by a similar change on C, and this action continues. B B and C may, therefore, be considered as separate field-magnets, being extended so as to act on the armature in the most efficient positions, and the effect is similar to that in Mr. Tesla's other forms of motor—viz., a rotation or progression of the maximum points of the field of force. Any armature, such, for instance, as a disc mounted in this field, would rotate from the pole first, to exhibit its magnetism to that which exhibits it later. In follow

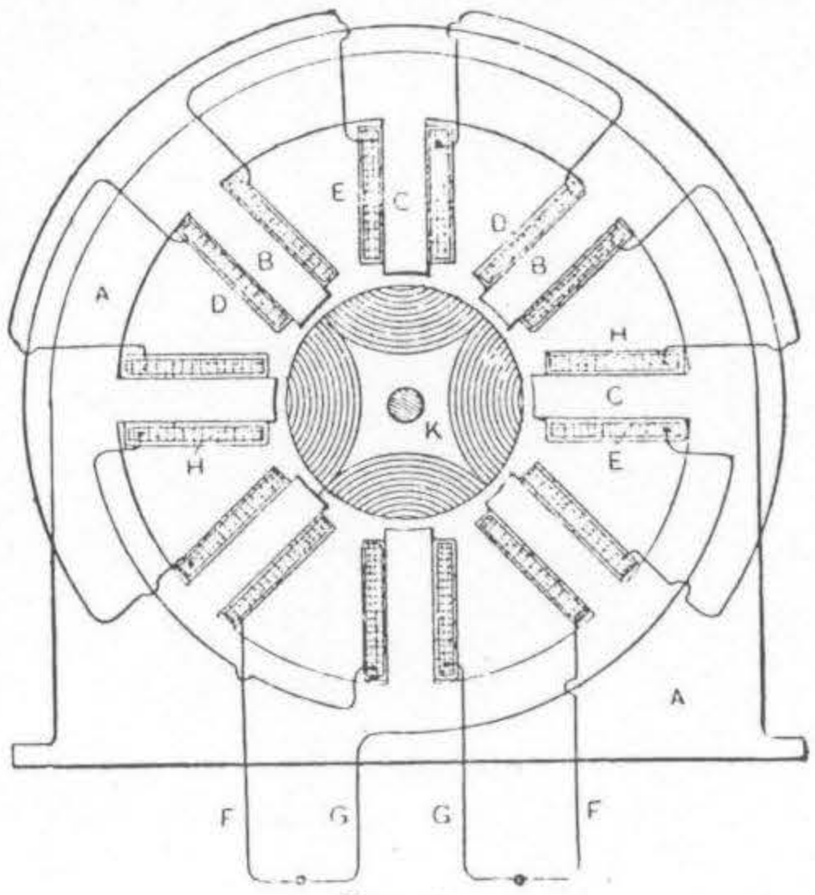


FIG. 4.

ing out the ideas stated above, Mr. Tesla has applied them to a class of motors in which two or more sets of energising magnets are employed and in which by artificial means a certain interval of time is made to elapse between the respective maximum or minimum periods of their magnetic attraction or effect. This has already been applied to the operation of Mr. Tesla's three-wire motors. In the present instance Mr. Tesla employs a motor with two sets of energising or field-magnets, each wound with coils connected with a source of alternating currents, but forming two separate paths or circuits. The magnets of one set are protected to a certain extent from the energising action of the current by means of a magnetic shield or screen of laminated iron interposed between the magnet and its energising coil.

The shield is properly adapted to the conditions of par

ticular cases so as to shield or protect the main core from magnetisation until it has become itself saturated, and no longer capable of containing all the lines of force produced by the current. By this means it will be seen that the energising action begins in the protected set of magnets, a certain arbitrarily-determined period of time later than in the other, and that by this means a practically economical difference of magnetic phase may readily be secured.

The nature and operation of this motor will be readily understood by reference to the accompanying illustration. The engraving, Fig. 4, shows the simplest form of this type of machine. The cores B form one set of magnets, and are energised by coils D, while the cores C, forming the other set, are energised by coils E, and the coils are connected in series with one another, in two derived or branched circuits, F G, respectively. Each coil E, it will be noted, is surrounded by a magnetic shield, H, which is composed of an annealed insulated or oxidised iron wire wound on the coils in the manner indicated, so as to form a closed magnetic circuit around the coils, and between the same and the magnetic cores C. Between the pole-pieces or cores, B C, is mounted the armature of the closed circuit coil type.

The operation resulting from this arrangement is as follows : If a current impulse be directed through the two circuits of the motor, it will quickly energise the cores B, but not so the cores C, for the reason that in passing through the coils E there is encountered the influence of the closed magnetic circuits formed by the shields, H. The

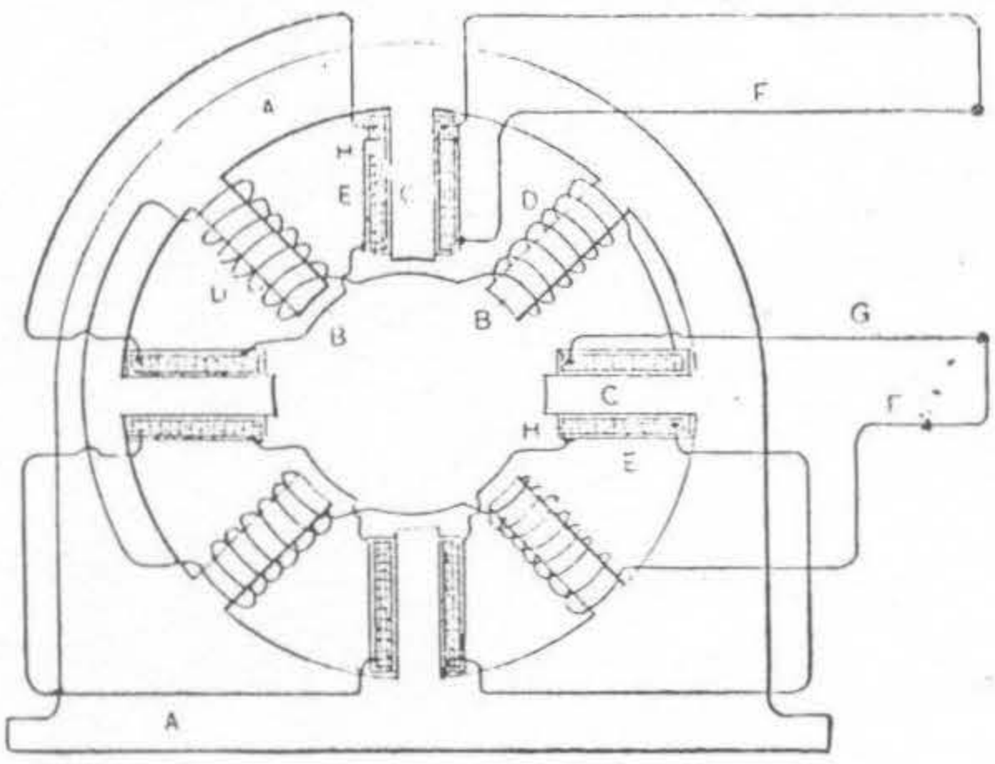


FIG. 5.

first effect is to effectively retard the current impulse in circuit G, while at the same time the proportion of current which does pass does not magnetise the cores C, which are shielded or screened by the shields, H.

As the increasing E.M.F. then urges more current through the coils E, the iron wire, H, becomes magnetically saturated and incapable of carrying all the lines of force, and hence ceases to protect the cores C, which become magnetised, developing their maximum effect after an interval of time subsequent to the similar manifestation of strength in the other set of magnets, the extent of which may be arbitrarily determined by the thickness of the shield, H, and other well-known conditions.

From the above it will be seen that the apparatus or device acts in two ways. First, by retarding the current, and second by retarding the magnetisation of one set of cores, from which its effectiveness will readily be seen.

Many modifications of the principle here embodied have been made by Mr. Tesla, one only more of which we may notice here. This is illustrated in Fig. 5, and is similar in all respects to that above described, except that the iron wire, H, which is wrapped around the coils E is in this case connected in series with the coils D. The iron wire coils are connected and wound so as to have little or no self-induction, and being added to the resistance of the circuit F, the action of the current in that circuit will be accelerated, while in the other circuit, G, it will be retarded.

Still another type of motor, constructed by Mr. Tesla is one with a field-magnet having two sets of poles or inwardly projecting cores, and placed side by side so as practically to form two fields of force, and alternately arranged—that is to say, with the poles of one set or field opposite the spaces between the other. The free ends of one set of poles are then connected by means of laminated iron bands or bridge-pieces of considerably smaller cross-section than the cores themselves, so that the cores all form parts of complete magnetic circuits.

When the coils on each set of magnets are connected in multiple circuits from an alternating machine E.M.F.'s are set up in each circuit simultaneously, but the coils on the magnetically bridged or shunted cores will have, by reason of the closed magnetic circuits, a high self-induction which retards the current, permitting at the beginning of each impulse but little current to pass. On the other hand, no such opposition being encountered in the other set of coils, the current passes freely through them, magnetising the poles on which they are wound.

As soon, however, as the laminated bridges become saturated and incapable of carrying all the lines of force which the rising E.M.F., and consequently increased current, produce, free poles are developed at the ends of the cores, which, acting in conjunction with the others, produce rotation of the armature. The construction by which this is accomplished is shown in the accompanying engravings, Figs. 6 and 7.

The frame of the motor, A, is built up of sheets of iron punched out to the desired shape and bolted together with insulation between the sheets. When complete the frame makes a field magnet with inwardly projecting pole-pieces, B and C. To adapt them to the requirements of this particular case, these pole-pieces are out of line with one another, those marked B surrounding one end of the armature, and the others, C, the opposite end, and they are arranged alternately—that is to say, the pole-pieces of one are set in line with the spaces between those of the other sets. The pole-pieces, C, are connected or shunted by

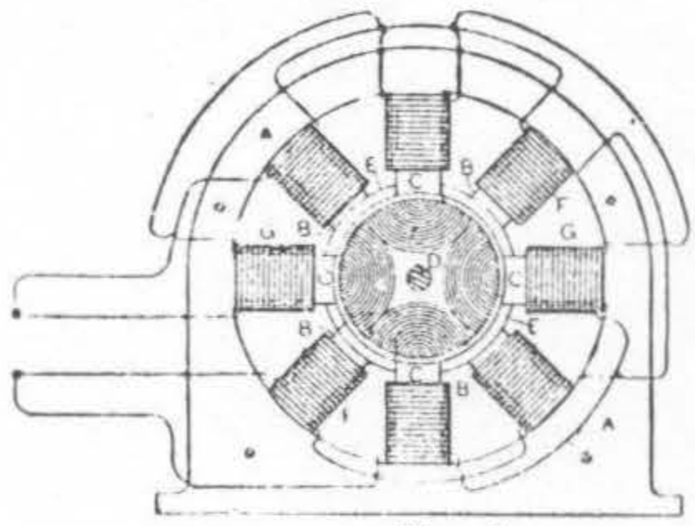


FIG. 6.

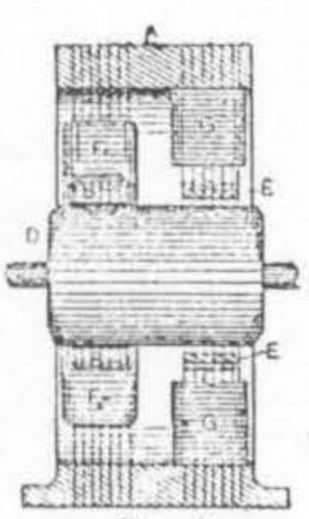


FIG. 7.

bridge-pieces, E. The coils, F and G, are connected in series, respectively, in two circuits which are branches of a circuit from an alternating machine, and they are so wound that the circuit of coils G will have a higher self-induction than the other circuit or branch.

The function of the shunts or bridges, E, is that they shall form with the cores, C, a closed magnetic circuit for a current up to a predetermined strength, so that when saturated by such current and unable to carry more lines of force than such a current produces, they will, to no further appreciable extent, interfere with the development by a stronger current of free magnetic poles at the ends of the cores, C.

In such a motor the current is so retarded in the coils G, and the manifestation of the free magnetism in the poles C, is delayed beyond the periods of maximum magnetic effect in poles B. The result is that a strong torque is produced and the motor operates with approximately the power developed in a motor of this kind energised by independently generated currents differing by a full quarter phase. *Electrical Engineer* (New York).

TESLA'S TRANSFORMER FOR MOTOR WORK AND FOR CONSTANT CURRENT.

In the early forms of alternating motor brought out by Mr. Tesla the construction embodied a series of coils traversed by currents differing a quarter phase from one another. This has in some forms required three wires from the generator to the motor, but in order to avoid this Mr. Tesla has recently constructed a converter specially designed to be used in connection with his motor, and in which the difference of phase required is spontaneously brought about. This converter also possesses the valuable property that it operates with a constant current for all loads imposed upon the secondary.

In transformers as at present constructed it is found that the E.M.F. of the secondary very nearly coincides with that of the primary, being, however, of opposite sign. At the same time the currents, both primary and secondary, lag behind their respective E.M.F.'s, but as this lag is practically the same in the case of each, it follows that the maximum and minimum of the primary and secondary currents will nearly coincide, but differ in sign or direction, provided the secondary be not loaded, or if it contain devices having the property of self-induction.

On the other hand, the lag of the primary behind the impressed E.M.F. may be diminished by loading the secondary with a non-inductive or dead resistance—such as incandescent lamps—whereby the time interval between the maximum or the minimum periods of the primary and secondary currents is increased. This time interval, however, is limited, and the results obtained by phase difference in the operation of such devices as Mr. Tesla's alternating-current motors can only be approximately realised by such means of producing or securing this difference, as above indicated. For it is desirable in such cases that there should exist between the primary and secondary currents a difference of phase of 90deg., or, in other words, the current in one circuit should be maximum when that in the other circuit is minimum.

To more nearly and perfectly attain to this condition Mr. Tesla secures an increased retardation of the secondary current in the following manner: Instead of bringing the primary and secondary coils or circuits of a transformer into the closest possible relations, as has hitherto been done, he protects in a measure the secondary from the inductive effect of the primary by surrounding either the primary or the secondary with a comparatively thin magnetic shield or screen.

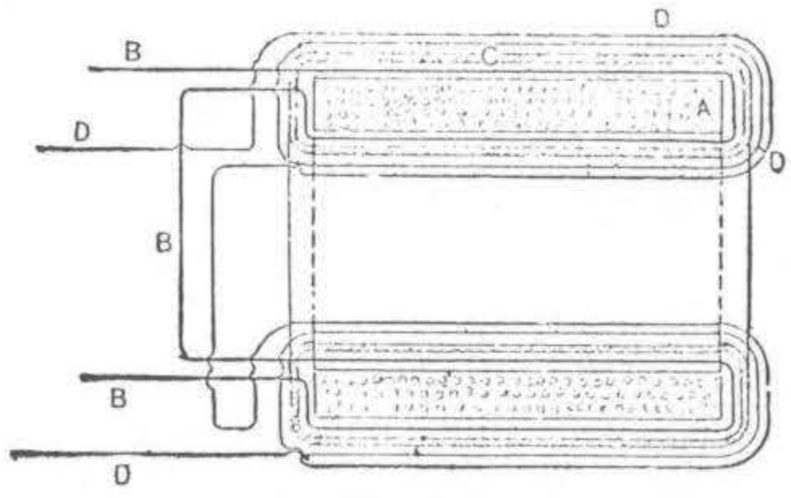


FIG. 1.

Under these conditions, as long as the primary current has a small value the shield protects the secondary, but as soon as the primary current has reached a certain strength, which is arbitrarily determined, the protecting magnetic shield becomes saturated and the inductive action upon the secondary begins. It results, therefore, that the secondary current begins to flow at a certain fraction of a period later than it would without the interposed shield, and since this retardation may be obtained without necessarily retarding the primary current also, an additional lag is secured, and the time interval between the maximum or minimum periods of the primary and secondary currents is increased.

Mr. Tesla has also discovered that such a transformer may by properly proportioning its elements be made to yield a constant current at all loads.

In the accompanying illustrations Fig. 1 is a cross-section of a transformer embodying the above idea. A A is the main core of the transformer composed of a ring of annealed iron wire. Upon this core is wound the secondary circuit, B B. This latter is then covered with a layer of annealed iron wires, C C, wound in a direction at right angles to the secondary coil. Over the whole is then wound the primary coil, D D.

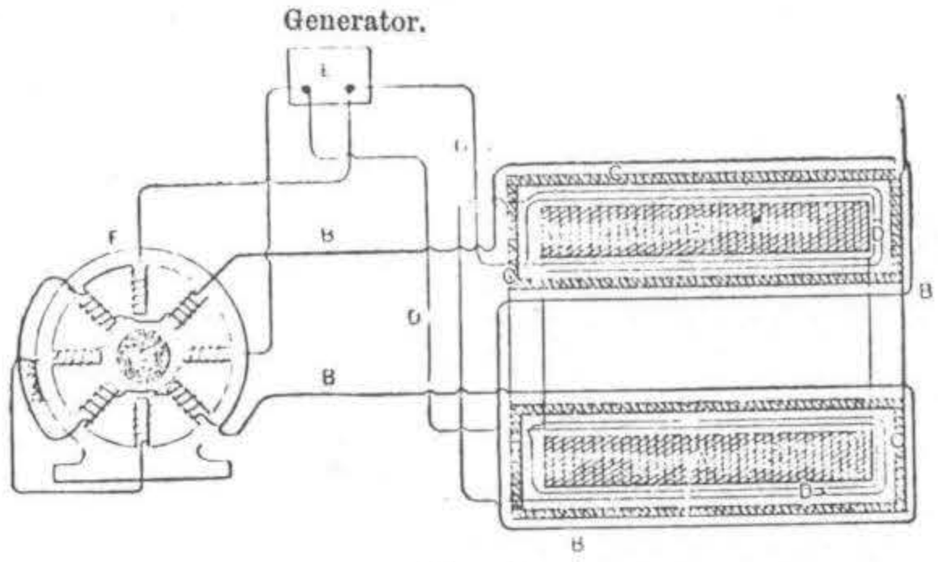


FIG. 2.

From the nature of this construction it will be obvious that as long as the shield formed by the wires, C, is below magnetic saturation, the secondary coil or circuit is effectually protected or shielded from the inductive influence of the primary.

When the strength of the primary reaches a certain value, the shield, C, becoming saturated, ceases to protect the secondary from inductive action, and current is in consequence developed therein. For similar reasons, when the primary current weakens, the weakening of the secondary is retarded to the same extent.

In the engraving, Fig. 2, the core, A, is built up of insulated iron plates or discs. The primary circuit, D, is wound next to core, A. Over this is applied the shield, C, which in this case is made up of thin plates of iron properly insulated and surrounding the primary, forming a closed

magnetic circuit. The secondary, B, is wound over the shield, C.

In Fig. 2 the primary of the transformer is connected with the circuit of the generator. F is a two-circuit alternating-current motor, one of the circuits being connected with the main circuit from the source, E, the other being supplied with currents from the secondary of the transformer.—*Electrical Engineer* (New York).

TESLA'S NEW ALTERNATING MOTORS.*

FOR some time past Mr. Nikola Tesla, whose previous work in alternating current motors is well known, has been engaged upon the study of these machines, in order to develop efficient methods for operating them on two wires instead of three, and still without the use of a commutator.

The general principle upon which these machines are designed is based on the well-known fact that if a magnetic core, even if laminated, be wound with a coil, and a current be sent through, the magnetisation of the entire core does not immeditely ensue, the magnetising effect not being exhibited in all parts simultaneously. This Mr. Tesla attributes to the fact that the action of the current is to energise first those laminæ or parts of the core nearest the surface and adjacent to the exciting coil, and from thence the action progresses towards the interior. A certain interval of time, therefore, elapses between the manifestation of magnetism in the external and the internal sections or layers of the core.

If the core be thin or of small mass, this effect may be inappreciable, but in the case of a thick core, or even of a comparatively thin one, if the number of alternation be very great, the time interval occurring between the manifestations of magnetism in the interior of the core and in those parts adjacent to the coil is more marked, and in the construction of such apparatus as motors which are designed to be run by alternating currents, Mr. Tesla has found it desirable, and even necessary, to give due consideration to this phenomenon and to make special provisions in order to obviate its consequences.

On the other hand, by taking advantage of this very action or effect, and, by rendering it more pronounced, Mr. Tesla utilises it in the operation of motors in general. This he effects by constructing a field in which the parts of the core that exhibit at different intervals of time the magnetic effect imparted to them by alternating currents in an energising coil are so placed with relation to a rotating armature as to exert thereon their attractive effect successively in the order of their magnetisation. By this means there is secured a result similar to that which Mr. Tesla has heretofore attained in the previous types of his motor, in which, by means of one or more alternating currents, he produces a rotation or progression of the magnetic poles or points of maximum attraction of the field of force.

The general principle involved in the action above mentioned is illustrated in the simple motor shown in fig. 1. Here X represents a large iron core composed of a number of sheets or laminæ of soft iron or steel. Surrounding this core is a coil, Y, which is connected with a source, E, of rapidly varying currents.

Let us consider now the magnetic conditions existing in this core at any point, as *b*, at or near the centre, and any other point, as *a*, nearer the surface. According to Mr. Tesla, when a current impulse is started in the magnetising coil, Y, the section, at *a*, being close to the coil, is immediately energised, while the section, at *b*, which, to use a convenient expression, is "protected" by the intervening sections or layers between *a* and *b*, does not at once exhibit its magnetism. However, as the magnetisation of *a* increases, *b* becomes also affected, reaching finally its maximum strength some time later than *a*. Upon the weakening of the current the magnetisation of *a* first diminishes, while *b* still exhibits its maximum strength, but the continued weakening of *a* is attended by a subsequent weakening of *b*. Assuming the current to be an alternating one, *a* will now be reversed, while *b* still continues of the polarity first imparted. This action continues, the magnetic condition of *b* following that of *a* in the manner above described.

If an armature, for instance, a simple disc mounted to rotate freely on an axis, be brought into proximity to the core, a movement of rotation will be imparted to the disc, the direction depending upon its position relatively to the core, the tendency being to turn the position of the disc nearest to the core from *a* to *b*, as indicated in fig. 1.

This action or principle of operation has been embodied in a practicable form of motor, which is illustrated in fig. 2. Here A represents a circular frame of iron, from diametrically opposite points of the interior of which the cores project.

Each core is composed of three main parts, B, B, and C, and they are similarly made with a straight portion, *e*, around which the energising coil is wound, a curved arm or extension, *c*, and an inwardly projecting pole, *d*.

Each core is made of two parts, B, B, with their polar extensions reaching in one direction and a part, C, between the other two and with its polar extension reaching in the opposite direction. These cores are wound with coils, D, which are connected in the same circuit either in parellel or series and supplied with an alternating current by a generator, E, represented diagramatically. Between the cores or their polar extensions is mounted an armature, F, wound with magnetising coils, G, that are closed upon themselves, similar to those in the older types of Mr. Tesla's motors.

The operation of the motor is as follows :—When a current impulse or alternation is sent through the coils, D, the sections, B, B, of the cores being on the surface, and in close proximity to the coils, are immediately energised. The sections, C, on the other hand, are protected from the magnetising influence of the coil by the interposed layers of iron, B, B.

As the magnetism of B, B increases, however, the sections, C, are also energised, but they do not attain their maximum strength until a certain time subsequent to the exhibition by the sections, B, B, of their maximum.

Upon the weakening of the current, the magnetic strength of B, B first diminishes while the sections, C, have still there maximum strength ; but as B, B continue to weaken, the interior sections are similarly weakened.

B, B may then begin to exhibit an opposite polarity, which is followed later by a similar change on C, and this action continues.

B, B and C may, therefore, be considered as separate field magnets, being extended so as to act on the armature in the most efficient positions, and the effect is similar to that in Mr. Tesla's other forms of motor, viz., a rotation or progression of the maximum points of the field of force. Any armature, such, for instance, as a disc mounted in this field, would rotate from the pole first, to exhibit its magnetism to that which exhibits it later.

In following out the ideas stated above, Mr. Tesla has applied them to a class of motors in which two or more sets of energising magnets are employed, and in which by artificial means a certain interval of time is made to elapse between the respective maximum or minimum periods of their magnetic attraction or effect. This has already been applied to the operation of Mr. Tesla's three-wire motors. In the present instance Mr. Tesla employs a motor with two sets of energising or field

* *Electrical Engineer.*

magnets, each wound with coils connected with a source of alternating currents, but forming two separate paths or circuits. The magnets of one set are protected to a certain extent from the energising action of the current by means of a magnetic shield or screen of laminated iron interposed between the magnet and its energising coil.

The shield is properly adapted to the conditions of particular cases so as to shield or protect the main core from magnetisation until it has become itself saturated, and no longer capable of containing all the lines of force produced by the current. By this means it will be seen that the energising action begins in the protected set of magnets, a certain arbitrarily determined period of time later than in the other, and that by this means a practically economical difference of magnetic phase may readily be secured.

The nature and operation of this motor will be readily understood by reference to the accompanying illustration.

The engraving, fig. 4, shows the simplest form of this type of machine. The cores, B, form one set of magnets, and are energised by coils, D, while the cores, C, forming the other set, are energised by coils, E, and the coils are connected in series with one another, in two derived or branched circuits, F, G, respectively.

Each coil, E, it will be noted, is surrounded by a magnetic shield, H, which is composed of an annealed insulated or oxidised iron wire wound on the coils in the manner indicated, so as to form a closed magnetic circuit around the coils, and between the same and the magnetic cores, C. Between the pole pieces or cores, B, C, is mounted the armature of the closed circuit coil type.

The operation resulting from this arrangement is as follows :—If a current impulse be directed through the two circuits of the motor, it will quickly energise the cores, B, but not so the cores, C, for the reason that in passing through the coils, E, there is encountered the influence of the closed magnetic circuits formed by the

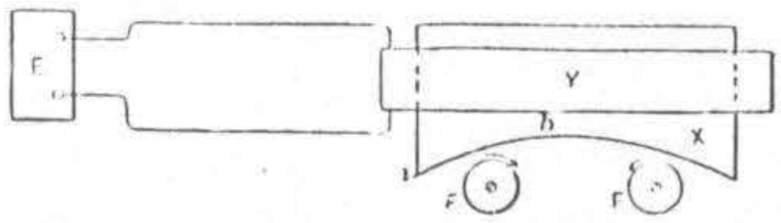


FIG. 1.—TESLA ALTERNATING MOTOR.

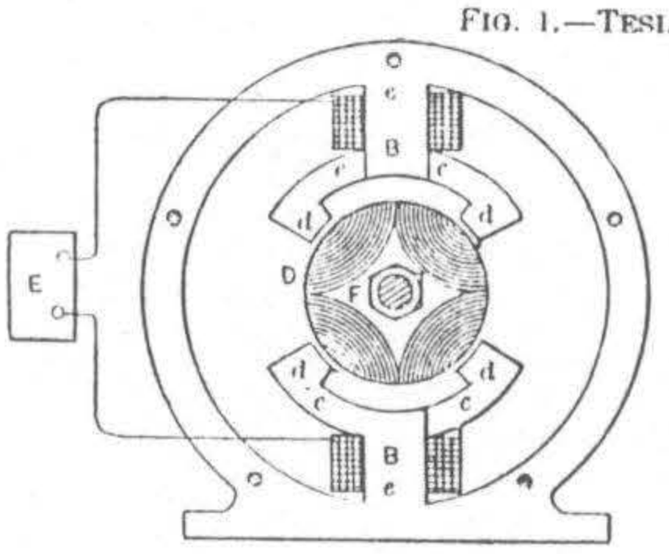


FIG. 2.—TESLA ALTERNATING MOTOR.

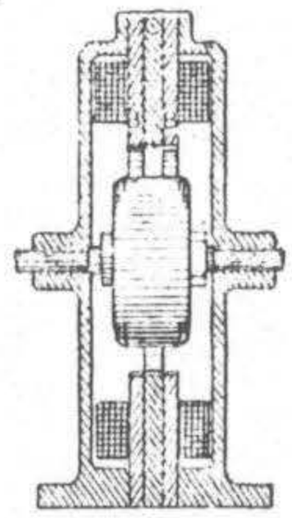


FIG. 3.—TESLA ALTERNATING MOTOR.

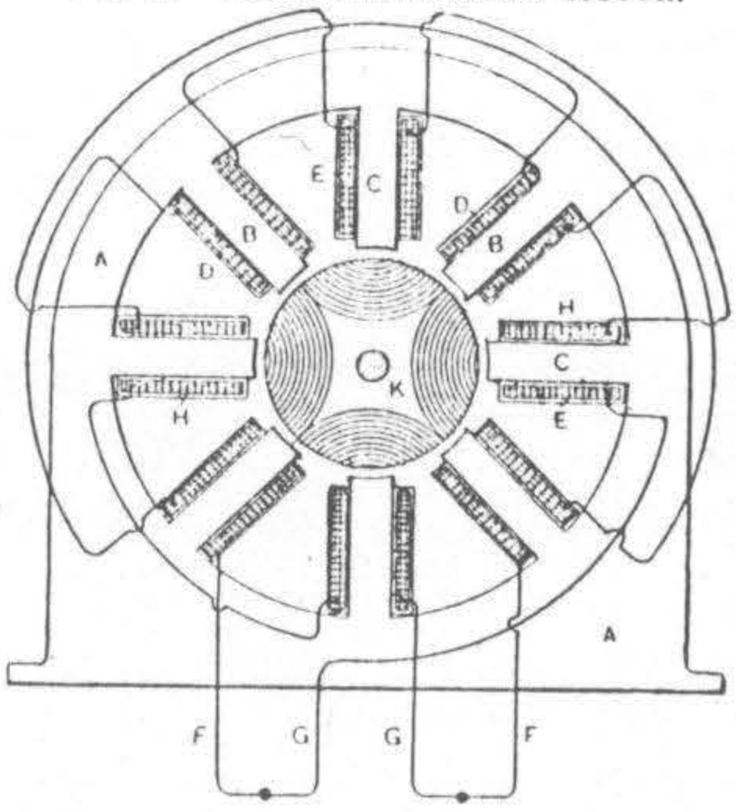


FIG. 4.—TESLA ALTERNATING MOTOR.

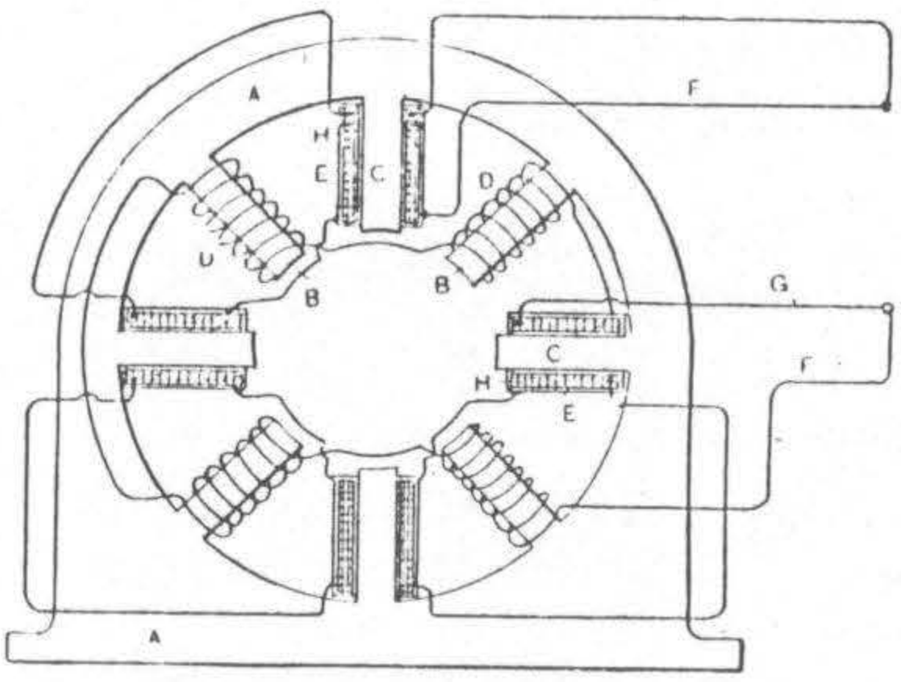
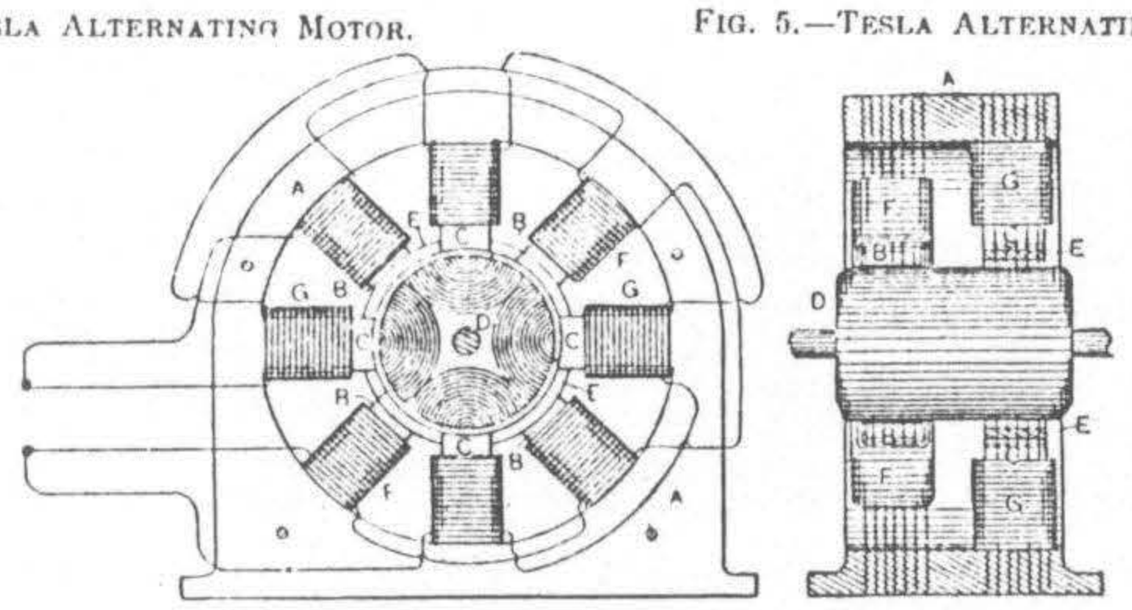


FIG. 5.—TESLA ALTERNATING MOTOR.



FIGS. 6 AND 7.—TESLA ALTERNATING MOTOR.

shields, H. The first effect is to effectively retard the current impulse in circuit, G, while at the same time the proportion of current which passes does not magnetise the cores, C, which are shielded or screened by the shields, H.

As the increasing electromotive force then urges more current through the coils, E, the iron wire, H, becomes magnetically saturated and incapable of carrying all the lines of force, and hence ceases to protect the cores, C, which become magnetised, developing their maximum effect after an interval of time subsequent to the similar manifestation of strength in the other set of magnets, the extent of which may be arbitrarily determined by the thickness of the shield, H, and other well-known conditions.

From the above it will be seen that the apparatus or device acts in two ways. First, by retarding the current, and second by retarding the magnetisation of one set of cores, from which its effectiveness will readily be seen.

Many modifications of the principle here embodied have been made by Mr. Tesla, one only more of which we may notice here. This is illustrated in fig. 5, and is similar in all respects to that above described, except that the iron wire, H, which is wrapped around the coils, E, is in this case connected in series with the coils, D. The iron wire coils are connected and wound so as to have little or no self-induction, and, being added to the resistance of the circuit, F, the action of the current in that circuit will be accelerated, while in the other circuit, G, it will be retarded.

Still another type of motor constructed by Mr. Tesla is one with a field magnet having two sets of poles or inwardly projecting cores, and placed side by side so as practically to form two fields of force, and alternately arranged, that is to say, with the poles of one set or field opposite the spaces between the other. The free ends of one set of poles are then connected by means of laminated iron bands or bridge pieces of considerably smaller cross-section than the cores themselves, so that the cores all form parts of complete magnetic circuits.

When the coils on each set of magnets are connected in multiple circuits from an alternating machine electromotive forces are set up in each circuit simultaneously, but the coils on the magnetically bridged or shunted cores will have, by reason of the closed magnetic circuits, a high self-induction which retards the current, permitting at the beginning of each impulse but little current to pass. On the other hand, no such opposition being encountered in the other set of coils, the current passes freely through them, magnetising the poles on which they are wound.

As soon, however, as the laminated bridges become saturated and incapable of carrying all the lines of force, which the rising electromotive force, and consequently *increased* current, produce, free poles are developed at the ends of the cores, which, acting in conjunction with the others, produce rotation of the armature.

The construction by which this is accomplished is shown in the accompanying engravings, figs. 6 and 7.

The frame of the motor, A, is built up of sheets of iron, punched out to the desired shape and bolted together with insulation between the sheets. When complete, the frame makes a field magnet with inwardly projecting pole-pieces, B and C. To adapt them to the requirements of this particular case, these pole-pieces are out of line with one another, those marked, B, surrounding one end of the armature, and the others, C, the opposite end, and they are arranged alternately; that is to say, the pole pieces of one are set in line with the spaces between those of the other sets.

The pole-pieces, C, are connected or shunted by bridge pieces, E.

The coils, F and G, are connected in series, respectively, in two circuits, which are branches of a circuit from an alternating machine, and they are so wound that the circuit of coils, G, will have a higher self-induction than the other circuit or branch.

The function of the shunts or bridges, E, is that they shall form with the cores, C, a closed magnetic circuit for a current up to a predetermined strength, so that when saturated by such current, and unable to carry more lines of force than such a current produces, they will, to no further appreciable extent, interfere with the development by a stronger current of free magnetic poles at the ends of the cores, C.

In such a motor, the current is so retarded in the coils, G, and the manifestation of the free magnetism in the poles, C, is delayed beyond the periods of maximum magnetic effect in poles, B. The result is that a strong torque is produced, and the motor operates with approximately the power developed in a motor of this kind, energised by independently generated currents, differing by a full quarter phase.

MR. TESLA'S LATEST MOTORS AND TRANSFORMERS.

In the *Electrical Engineer* of New York Mr. Nicola Tesla explains some modifications of his motor, and a curious transformer. The motor depends on a shifting of the poles under certain conditions, a principle which has been already employed by Mr. A. Wright in his alternating current meter. If a bar of iron has a coil at one end, and if the core is perfectly laminated, on starting a current in the coil the induction all along the iron corresponds to the excitation at that instant unless there is a microscopic time lag, of which there is no evidence. If a second coil is wound in the middle of the bar, and short-circuited as soon as the iron through it begins to be magnetised it starts up a demagnetising current. The

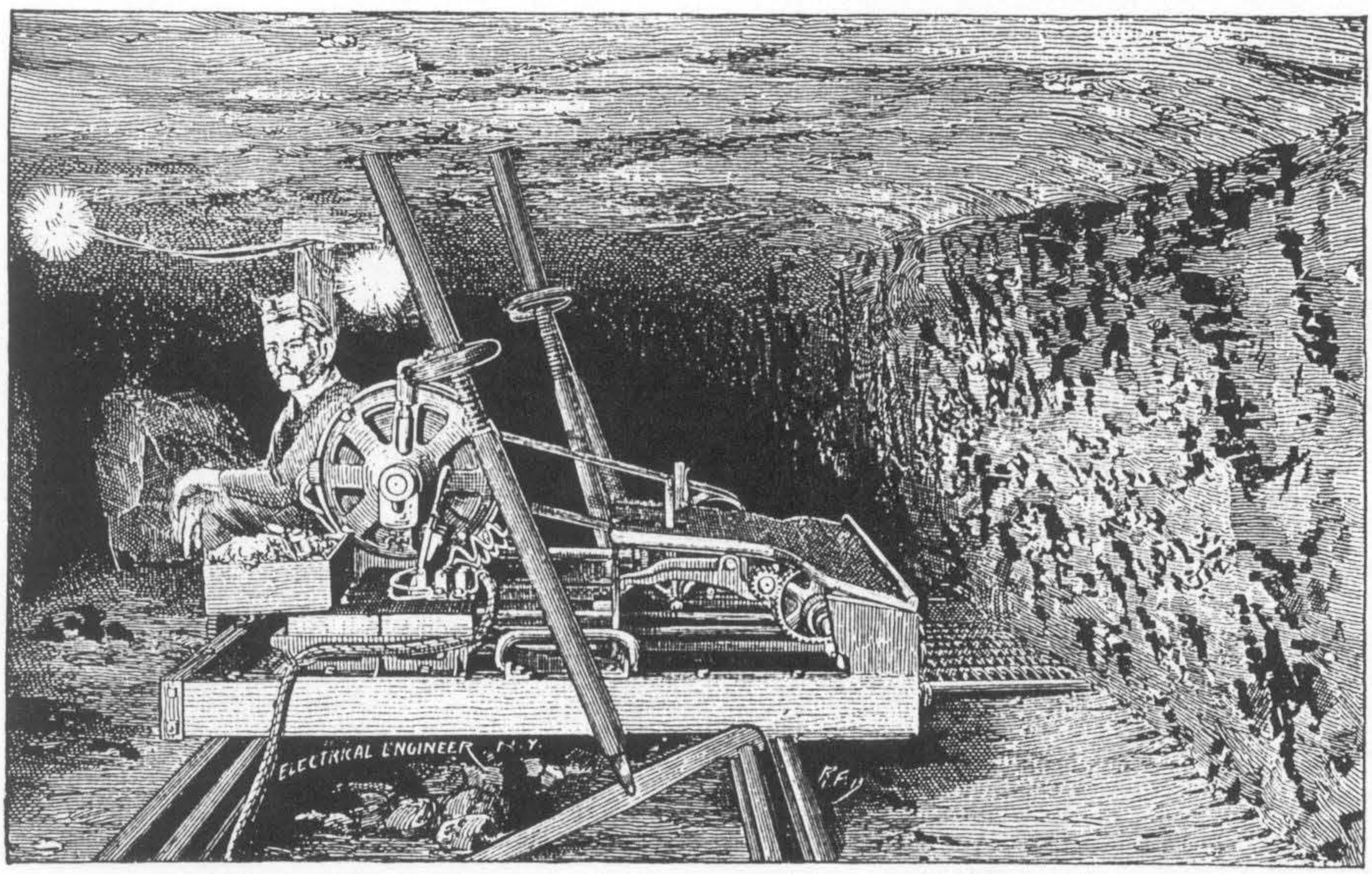
Industries, 22nd August, 1890.

bar then has a consequent pole in the middle, and even when the primary current has reached its maximum the other end of the bar has not reached its final stage. As the secondary current dies away, the end gets fully magnetised, and the consequent pole in the middle disappears. The effect is as if the pole moved along slowly from the middle to the end. Mr. Tesla has worked out some more or less complicated motors on this principle, but the curious point is that he has completely misunderstood the theory of the phenomena, and has got hold of the old fallacy of "screening." He winds his secondary of iron instead of copper, and thinks the effect is produced magnetically. He also makes a lagging transformer on the same principle. A ring of laminated iron is wound with a secondary. It is then encased in iron laminated in the wrong direction, and the primary is wound outside this. The layer of iron between the primary and secondary is supposed to screen the coil. Of course it cannot do so; such a thing is unthinkable. As far as it is a conductor, it will act as an extra short-circuited secondary; as far as it is magnetised it will have no effect on the core, but will act as an extra core not included in the secondary—that is to say, it will act as if it were made up as a choking coil wound in series with the primary. That is why it gives some approximation to constant current in the secondary. It is questionable whether the Tesla motor can ever be a success. Such motors will go round, of course, and will give outputs, but their efficiency is doubtful; and if they need three-wire circuits and special dynamos, there is no object in using them, as a direct current motor can be run instead with advantage.

that no metallic part is exposed. All wood work of the switches is made thoroughly waterproof and the switch handle is detachable and carried by the motor man. This prevents the switch being tampered with by meddlesome persons.

The wire used in these mines is all of the Clark rubber-covered special mine finish type, and all wire connections are made with McIntire connectors. All wood work is made waterproof with P. & B. compound. The coal cutting motors in the rooms are connected to the main line by a specially made insulated flexible cable, which can be coiled on a special reel and taken to another room in a few minutes. This cable when in use is supported by glass hook insulators made for this purpose.

Six "Hercules" coal mining machines, with 3 H.P. Tesla motors mounted thereon, as shown in the engraving, are now in operation in these mines. The machine and motor complete weighs about 1,000 pounds and is easily handled and shifted from room to room by one man. A specially designed truck is used in conveying machine from one room to another.



TESLA MOTOR DRIVING HERCULES COAL MINING MACHINE.

AN ELECTRIC COAL MINING EQUIPMENT.

A HIGHLY interesting electric plant was recently put in operation in the First Pool Monongahela Gas Coal Co.'s mines at Willock Station, Pa. This electric equipment was designed and installed by the Mill and Mine Electric Equipment Co., of Pittsburgh, Pa., under the supervision of Mr. W. A. Giles, general manager and electrical engineer for the company, who has supplied the following interesting particulars regarding the plant to the New York *Electrical Engineer*.

The power plant consists of two 12 × 20 Carter engines and one 30 H.P. 3-wire, 4-pole Westinghouse self-exciting, alternating generator. All switches, meters, &c., are mounted on a switchboard in a most convenient location to be easily handled. The voltage on the main line is about 300 volts. Inserted in the main line at convenient locations are several specially designed mine switches with safety catch attachments, and all switches used in these mines are so designed

These machines, by means of a set of gang bits or augers, make an undercut 3 inches high, 36 inches wide by 42 inches deep. One man with this machine will average 40 cuts, or about 43 tons of clean cut coal in 10 hours. This is equal to the product of 12 to 14 pick miners.

The ventilating outfit in this mine consists of a 12 feet Pollock fan, with a capacity of 30,000 cubic feet per minute. It is situated at the bottom of a shaft 75 feet deep, and is so arranged that the fan can be changed from an exhaust to a blower in five minutes. This fan is also run with a 3 H.P. Tesla motor.

The pumping outfit consists of a centrifugal pump of a capacity of 90 gallons per minute, mounted on the same truck with 3 H.P. Tesla motor and connected to the same by means of a belt. This pump and motor can be taken to any part of mine and connected to the power line in a few minutes.

These mines have an incandescent electric light plant, consisting of a United States 300 volt, automatic incandescent dynamo, running 150 Sawyer-Man lamps,

mounted in special waterproof mine sockets with rubber insulating joints. These lamps are connected in loops of three in series across the main circuit, and placed along the main entry at a distance of 80 to 90 feet, and three 16-C.P. lamps are placed in each room. This gives perfectly satisfactory illumination and demonstrates the great importance of better light in coal mines.

The following record shows the large amount of work which can be accomplished with but a few machines. Indeed it has been demonstrated that they can work faster than the rooms can be cleaned up of the coal which is brought down. The record, which is taken from the company's books, extends from July 1st to August 8th, and each cut represents about $1\frac{1}{10}$ ton of nut coal.

	No. of machines at work.	No. of cuts made.	No. of machine-hours run.
July 1	5	113	35½
,, 2	4	119	34½
,, 3	4	107	29
,, 7	4	117	32½
,, 8	4	109	31
,, 9	4	140	37
,, 10	4	127	34½
,, 11	4	134	35½
,, 12	4	135	35½
,, 14	4	130	35
,, 15	4	134	36½
,, 16	4	134	36
,, 17	4	140	38
,, 18	3	55	14
,, 19	3	31	8
,, 21	3	69	17
,, 22	4	80	20½
,, 23	4	101	29
,, 24	4	134	36
,, 25	4	69	19
,, 26	3	45	12½
,, 28	4	124	35½
,, 29	4	103	28½
,, 30	4	75	21
,, 31	3	55	16½
Aug. 1	4	118	30½
,, 2	4	124	33½
,, 5	4	116	35½
,, 6	4	127	34
,, 7	4	141	36
,, 8	4	130	38

The Mill and Mine Electric Equipment Company is now putting a similar equipment in Mr. Frank Armstrong's Summer Hill Mines at Woodville, Pa.

Tesla Alternating Current Motors.

In a recent issue we described at length some new forms of alternating current motors designed by Mr. Nikola Tesla, and involving some novel methods for producing motion in contiguous circuits acted upon by alternating currents. In a short review of this article appearing in our excellent contemporary, *Industries*, a writer accuses Mr. Tesla of holding to the old fallacy of the screening action of the iron to explain the action of his machine. A careful study of our original article makes it apparent, however, that our contemporary has misunderstood the character of the machines described. It would take us too long to point out the error into which our contemporary has fallen, and to state in exact terms just what is accomplished by the construction adopted in Mr. Tesla's machine, but in answer to the closing remark of our contemporary, it is incumbent upon us to state that machines constructed on Mr. Tesla's principles are in actual commercial operation at the present time with no small measure of success.

WORK OF THE TESLA MOTOR.—One of the Tesla motors of the Westinghouse Electric and Manufacturing Company, of this city, has been set up at the company's exhibit at the Pittsburgh Exposition. It is connected with and runs without difficulty a Hercules mining machine, a "Baby" carpet loom, stone crusher, a 6-foot circular saw and a soap and caramel wrapper.

SWINBURNE'S "HEDGEHOG" TRANSFORMER.

BY NIKOLA TESLA.

Some time ago Mr. Swinburne advanced certain views on transformers which have elicited some comment. In The Electrical Engineer of Sept. 10. there are brought out further arguments on behalf of his open circuit, or, as he calls it, "hedgehog" transformer, claiming for this type a higher average efficiency than is attainable with the closed circuit forms. In regard to this, I say with Goethe, "Die Botschaft hör' ich wohl, allein mir fehlt der Glaube—I hear the message, but I lack belief."

Many of Mr. Swinburne's arguments are in my opinion erroneous. He says: "In calculating the efficiencies of transformers, the loss in the iron has generally been left completely out of account, and the loss in copper alone considered; hence, the efficiencies of 97 and 98 per cent. claimed for closed iron circuit forms." This is a statement little complimentary to those who have made such estimates, and perhaps Mr. Swinburne would be very much embarassed to cite names on behalf of his argument. He assumes the loss in the iron in the closed circuit forms to be 10 per cent. of the full load, and further "that in most stations the average use of lamps is less than two hours a day, including all lamps installed," and arrives at some interesting figures in regard to efficiency. Mr. Swinburne seems not to be aware of the improvements made in the iron. The loss with the best quality of iron will, I believe, not reach 6 per cent. of the full load by an intelligent use of the transformer, and there is no doubt that further improvements will be made in that direction.

As regards the second part of his assumption, I think that it is exaggerated. It must be remembered that in most central stations or large plants due care is taken that the load is favorably distributed and in many cases the wiring is such that entire circuits may be shut off at certain hours so that there is during these hours no loss whatever in the transformers.

In his "hedgehog" form of transformer Mr. Swinburne reduces the iron considerably and comes to the conclusion that even in small transformers the iron loss is under one per cent. of the full load, while in the closed circuit forms, it is, according to him, 10 per cent. It would strengthen this argument if the iron would be dispensed with altogether. Mr. Swinburne does not appreciate fully the disadvantages which the open circuit form, operated at the *usual period*, entails. In order that the loss in the iron should be reduced to one-tenth, it is necessary to reduce the weight of the iron core to one-tenth and subject every unit length of the same to the same magneto-motive force. If a higher magneto-motive force is used the loss in the core will—within certain limits, at least—be proportionate to the *square* of the magneto-motive force. The remark of Mr. Swinburne, "If the iron circuit is opened, the sides of the embracing core can be removed, so the loss by hysteresis is divided by three," is therefore not true; the loss will be divided by $3 \times \frac{F'^2}{F_1'^2}$ where $F_1 > F$. If the iron of the open circuit form is made up in a closed ring the advantage will be at once apparent, for, since the magnetic resistance will be much reduced, the magneto-motive force required will be correspondingly smaller. It is probable that, say, four Swinburne transformers may be joined in such a way as to form a closed magnetic circuit. In this case the amount of iron and copper would remain the same, but an advantage will be gained as the total magnetic resistance will be diminished. The four transformers will now demand less excitation and since—under otherwise equal conditions—the gain depends on the square of the existing current, it is by no means insignificant. From the above comparison it is evident that the core of such open circuit transformer should be very short, by far shorter than it appears from the cut in The Electrical Engineer.

Mr. Swinburne is in error as to the motives which have caused the tendency to shorten the magnetic circuit in closed circuit transformers. It was principally on account of practical considerations and not to reduce the magnetic resistance, which has little to do with efficiency. If a ring be made of, say, 10 centimetres mean length and 10 square centimetres cross-section, and if it be wound *all over* with the primary and secondary wires, it will be found that it will give the best result with a certain number of alternations. If, now, a ring is made of the same quality of iron but having, say, 20 centimetres mean length and 10 square centimetres section it will give again the best result with the *same number of alternations*, and the efficiency will be the same as before, provided that the ring is wound *all over* with the primary and secondary wires. The space inside of the ring will, in the second case, be increased in proportion to the square of the diameter, and there will be no difficulty in winding on it all the wire required. So the length may be indefinitely increased and a transformer of any capacity made, as long as the ring is completely covered by the primary and secondary wires.

If the wires be wound side by side the ring of smaller diameter will give a better result, and the same will be the case if a certain fraction of the ring is not covered by the wires. It then becomes important to shorten the magnetic circuit. But, since in practice it is necessary to enclose the transformer in a casting, if such a ring be made, it would have to be protected with a layer of laminated iron, which would increase the cost and loss. It may be inclosed in jars of some insulating material, as Mr. Swinburne does, but this is less practicable.

Owing to this, the constructors of the most practical forms, such, for instance, as the Westinghouse transformer, to which the Swinburne reasoning applies, have been prompted to enclose the wires as much as possible with the laminated iron, and then it became important to shorten the magnetic circuit, because in this form only a part of the magnetic circuit is surrounded by the wires, as well as for other practical considerations.

In practice it is desirable to get along with the least length of copper conductor on account of cheapness and regulation. Mr. Swinburne states that in his transformer the loss in iron is under one per cent. of the full load; all the balance of loss must, therefore, be in the copper. But since, according to him, the wires are of larger section, his transformer can hardly be an improvement in that direction. The gun-metal casting is also objectionable. There is no doubt some loss going on in the same, and besides it increases the resistance of the wires by a factor $\sqrt{\frac{S}{S_1}}$ where S is the total cross-section of the core and S_1 the section of the iron wires. There is one important point which seems to have escaped Mr. Swinburne's attention. Whether the open circuit transformer is an improvement, or not, will depend principally on the period. The experience of most electrical engineers has resulted in the adoption of the closed circuit transformer. I believe that I was the first to advocate an open circuit form, but to improve its efficiency I had to use a much higher period; at usual periods the closed circuit form is preferable.

Mr. Swinburne makes some other obscure statements upon which I need not dwell, as they have no bearing on the main question.

LETTERS TO THE EDITOR.

Notice to Correspondents.

We do not hold ourselves responsible for the opinions of our correspondent.
Anonymous communications cannot be noticed.
The Editor respectfully requests that all communications may be drawn up as briefly and as much to the point as possible.
In order to facilitate reference, correspondents, when referring to any letter previously inserted will oblige by mentioning the serial number of such letter, and of the page on which it appears.
Sketches and drawings for illustrations should be on separate pieces of paper.
All communications should be addressed EDITOR OF THE ELECTRICAL ENGINEER, 150 *Broadway, New York city.*

TESLA'S NEW ALTERNATING MOTORS.

[139.]—I hope you will allow me the privilege to say in the columns of your esteemed journal a few words in regard to an article which appeared in *Industries* of August 22, to which my attention has been called. In this article an attempt is made to criticise some of my inventions, notably those which you have described in your issue of August 6, 1890.

The writer begins by stating: "The motor depends on a shifting of the poles under certain conditions, a principle which has been *already*[1] employed by Mr. A. Wright in his alternating current meter." This is no surprise to me. It would rather have surprised me to learn that Mr. Wright has *not yet* employed the principle in his meter, considering what, before its appearance, was known of my work on motors, and more particularly of that of Schallenberger on meters. It has cost me years of thought to arrive at certain results, by many believed to be unattainable, for which there are now numerous claimants, and the number of these is rapidly increasing, like that of the colonels in the South after the war.

The writer then good-naturedly explains the theory of action of the motive device in Wright's meter, which has greatly benefited me, for it is so long since I have arrived at this, and similar theories, that I had almost forgotten it. He then says: "Mr. Tesla has worked out some more or less complicated motors on this principle, but the curious point is that he has completely misunderstood the theory of the phenomena, and has got hold of the old fallacy of screening." This may be *curious*, but how much *more curious* it is to find that the writer in *Industries* has *completely misunderstood* everything himself. I like nothing better than just criticism of my work, even if it be severe, but when the critic assumes a certain "l'état c'est moi" air of unquestioned competency I want him to know what he is writing about. How little the writer in *Industries* seems to know about the matter is painfully apparent when he connects the phenomenon in Wright's meter with the subject he has under consideration. His further remark, "He (Mr. Tesla) winds his secondary of iron instead of copper and thinks the effect is produced magnetically," is illustrative of the care with which he has perused the description of the devices contained in the issue of THE ELECTRICAL ENGINEER above referred to.

I take a motor having, say eight poles, and wrap the exciting coils of four alternate cores with fine insulated iron wire. When the current is started in these coils it encounters the effect of the closed magnetic circuit and is retarded. The magnetic lines set up at the start close to the iron wire around the coils and no free poles appear at first at the ends of the four cores. As the current rises in the coils more lines are set up, which crowd more and more in the fine iron wire until finally the same becomes saturated, or nearly so, when the shielding action of the iron wire ceases and free poles appear at the ends of the four protected cores. The effect of the iron wire, as will be seen, is two-fold. First, it retards the energizing current; and second, it delays the appearance of the free poles. To produce a still greater difference of phase in the magnetization of the protected and unprotected cores, I connect the iron wire surrounding the coils of the former in series with the coils of the latter, in which case, of course, the iron wire is preferably wound or connected differentially, after the fashion of the resistance coils in a bridge, so as to have no appreciable self-induction. In other cases I obtain the desired retardation in the appearance of the free poles on one set of cores by a magnetic shunt, which produces a greater retardation of the current and takes up at the start a certain number of the lines set up, but becomes saturated when the current in the exciting coils reaches a predetermined strength.

In the transformer the same principle of shielding is utilized. A primary conductor is surrounded with a fine layer of laminated iron, consisting of fine iron wire or plates properly insulated and interrupted. As long as the current in the primary conductor is so small that the iron enclosure can carry all the lines of force set up by the current, there is very little action exerted upon a secondary conductor placed in vicinity to the first; but just as soon as the iron enclosure becomes saturated, or nearly so, it loses the virtue of protecting the secondary and the inducing action of the primary practically begins. What, may I ask, has all this to do with the "old fallacy of screening?"

With certain objects in view—the enumeration of which would

1. All italics are mine.—N. T.

lead me too far—an arrangement was shown in THE ELECTRICAL ENGINEER, about which the writer in *Industries* says: "A ring of laminated iron is wound with a secondary. It is then encased in iron laminated in the *wrong direction* and the primary is wound outside of this. The layer of iron between the primary and secondary is supposed to screen the coil. Of course it cannot do so, such a thing is unthinkable." This reminds me of the man who had committed some offense and engaged the services of an attorney. "They cannot commit you to prison for that," said the attorney. Finally the man *was* imprisoned. He sent for the attorney. "Sir," said the latter, "I tell you they *cannot* imprison you for that." "But, sir," retorted the prisoner, "they *have* imprisoned me." It *may not* screen, in the opinion of the writer in *Industries*, but just the same it *does*. According to the arrangement the *principal* effect of the screen may be either a retardation of the action of the primary current upon the secondary circuit or a deformation of the secondary current wave with similar results for the purposes intended. In the arrangement referred to by the writer in *Industries* he seems to be certain that the iron layer acts like a choking coil; there again he is mistaken; it does not act like a choking coil, for then its capacity for maintaining constant current would be very limited. But it acts more like a magnetic shunt in constant current transformers and dynamos, as, in my opinion, it ought to act.

There are a good many more things to be said about the remarks contained in *Industries*. In regard to the magnetic time lag the writer says: "If a bar of iron has a coil at one end, and if the core is perfectly laminated, on starting a current in the coil the induction *all along the iron* corresponds to the excitation at that instant, unless there is a microscopic time lag, *of which there is no evidence.*" Yet a motor was described, the very operation of which is dependent on the time lag of magnetization of the different parts of a core. It is true the writer uses the term "perfectly laminated" (which, by the way, I would like him to explain), but if he intends to make such a "perfectly laminated" core I venture to say there is trouble in store for him. From his remarks I see that the writer completely overlooks the importance of the size of the core and of the number of the alternations pointed out; he fails to see the stress laid on the saturation of the screen, or shunt, in some of the cases described; he does not seem to recognize the fact that in the cases considered the formation of current is reduced as far as practicable in the screen, and that the same, therefore, so far as its quality of screening is concerned, has no role to perform as *a conductor*. I also see that he would want considerable information about the time lag in the magnetization of the different parts of a core, and an explanation why, in the transformer he refers to, the screen is laminated in the *wrong direction*, etc.—but the elucidation of all these points would require more time than I am able to devote to the subject. It is distressing to find all this in the columns of a leading technical journal.

In conclusion, the writer shows his true colors by making the following withering remarks: "It is questionable whether the Tesla motor will ever be a success. Such motors will go round, of course, and will give outputs, but their efficiency is doubtful; and if they need three-wire circuits and special generators there is no object in using them, as a direct current motor can be run instead with advantage."

No man of broad views will feel certain of the success of any invention, however good and original, in this period of feverish activity, when every day may bring new and unforseen developments. At the pace we are progressing the permanence of all our apparatus it its present forms becomes more and more problematical. It is impossible to foretell what type of motor will crystalize out of the united efforts of many able men; but it is my conviction that at no distant time a motor having commutator and brushes will be looked upon as an antiquated piece of mechanism. Just how much the last quoted remarks of the writer of *Industries*—considering the present state of the art—are justified, I will endeavor to show in a few lines.

First, take the transmission of power in isolated places. A case frequently occurring in practice and attracting more and more the attention of engineers is the transmission of large powers at considerable distances. In such a case the power is very likely to be cheap, and the cardinal requirements are then the reduction of the cost of the leads, cheapness of construction and maintenance of machinery and constant speed of the motors. Suppose a loss of only 25 per cent. in the leads, at full load, be allowed. If a direct current motor be used, there will be, besides other difficulties, considerable variation in the speed of the motor—even if the current is supplied from a series dynamo—so much so that the motor may not be well adapted for many purposes, for instance, in cases where direct current transformation is contemplated with the object of running lights or other devices at constant potential. It is true that the condition may be bettered by employing proper regulating devices, but these will only further complicate the already complex system, and in all probability fail to secure such perfection as will be desired. In using an ordinary single-circuit alternate current motor the disadvantage is that the motor has no starting torque and that, for equal weight, its output and efficiency are more or less below that of a direct current motor. If, on the contrary, the armature of any alternator or direct current machine—large, low-speed, two-pole machines will give the best results—is wound with two circuits, a motor is at once obtained which possesses sufficient torque to start under considerable load; it runs in absolute synchronism with the generator—an advantage much desired and hardly ever to be attained with regulating devices; it takes current in proportion to the load, and its plant efficiency within a few per cent. is equal to that of a direct current motor of the same size. It will be able, however, to perform more work than a direct current motor of the same size, first, because there will be no change of speed, even if the load be doubled or tripled, within the limits of available generator power; and, second, because it can be run at a higher electromotive force, the commutator and the complication and difficulties it involves in the construction and operation of the generators and motors being eliminated from the system. Such a system will, of course, require three leads, but since the plant efficiency is practically equal to that of the direct current system, it will require the same amount of copper which would be required in the latter system, and the disadvantage of the third lead will be comparatively small, if any, for three leads of smaller size may perhaps be more convenient to place than two larger leads. When more machines have to be used there may be no disadvantage whatever connected with the third wire; however, since the simplicity of the generators and motors allows the use of higher electromotive forces, the cost of the leads may be reduced below the figure practicable with the direct current system.

Considering all the practical advantages offered by such an alternating system, I am of an opinion quite contrary to that of the author of the article in *Industries*, and think that it can quite successfully stand the competition of any direct current system, and this the more, the larger the machines built and the greater the distances.

Another case frequently occurring in practice is the transmission of small powers in numerous isolated places, such as mines, etc. In many of these cases simplicity and reliability of the apparatus are the principal objects. I believe that in many places of this kind my motor has so far proved a perfect success. In such cases a type of motor is used possessing great starting torque, requiring for its operation only alternating current and having no sliding contacts whatever on the armature, this advantage over other types of motors being highly valued in such places. The plant efficiency of this form of motor is, in the present state of perfection, inferior to that of the former form, but I am confident that improvements will be made in that direction. Besides, plant efficiency is in these cases of secondary importance, and in cases of transmission at considerable distances, it is no drawback, since the electromotive force may be raised as high as practicable on converters. I can not lay enough stress on this advantageous feature of my motors, and should think that it ought to be fully appreciated by engineers, for to high electromotive forces we are surely coming, and if they must be used, then the fittest apparatus will be employed. I believe that in the transmission of power with such commutatorless machines, 10,000 volts, and even more, may be used, and I would be glad to see Mr. Ferranti's enterprise succeed. His work is in the right direction, and, in my opinion, it will be of great value for the advancement of the art.

As regards the supply of power from large central stations in cities or centres of manufacture, the above arguments are applicable, and I see no reason why the three-wire motor system should not be successful. In putting up such a station, the third wire would be but a very slight drawback, and the system possesses enough advantages to over-balance this and any other disadvantage. But this question will be settled in the future, for as yet comparatively little has been done in that direction, even with the direct current system. The plant efficiency of such a three-wire system would be increased by using, in connection with the ordinary type of my motor, other types which act more like inert resistances. The plant efficiency of the whole system would, in all cases, be greater than that of each individual motor—if like motors are used—owing to the fact that they would possess different self-induction, according to the load.

The supply of power from lighting mains is, I believe, in the opinion of most engineers, limited to comparatively small powers, for obvious reasons. As the present systems are built on the two-wire plan, an efficient two-wire motor without commutator is required for this purpose, and also for traction purposes. A large number of these motors, embodying new principles, have been devised by me and are being constantly perfected. On lighting stations, however, my three-wire system may be advantageously carried out. A third wire may be run for motors and the old connections left undisturbed. The armatures of the generators may be rewound, whereby the output of the machines will be increased about 35 per cent., or even more in machines with cast iron field magnets. If the machines are worked at the same capacity, this means an increased efficiency. If power is available at the station, the gain in current may be used in motors. Those who object to the third wire, may remember that the old two-wire direct system is almost entirely superseded by the three-wire system, yet my

three-wire system offers to the alternating system relatively greater advantages, than the three-wire direct possesses over the two-wire. Perhaps, if the writer in *Industries* would have taken all this in consideration, he would have been less hasty in his conclusions.

NIKOLA TESLA.

NEW YORK, Sept. 17, 1890.

TESLA'S NEW ALTERNATING MOTORS.

Our note on this subject on page 186 in our issue of the 22nd of August has called forth three or four columns of comment from Mr. Tesla in other journals, but he has not even favoured us with an advance proof of his critical remarks. This is perhaps an oversight.

The main difference of opinion, we think, lies in a nutshell. Mr. Tesla holds that if an increasing excitation is applied to an iron core it affects the outside first, and the lines of induction, or lines of force, accumulate in the outside till the iron becomes more or less saturated, and then penetrate to the inside. The outside thus magnetically screens the inside. If the core is laminated, so that there are no Foucault currents, this cannot occur. The line integral of the magnetic force taken round any circuit interlinked with the magnetising coils is $4\pi n C$, where n is the number of turns and C the current in C.G.S. This interlinked circuit may be taken through the centre of the core or near the outside, and has the same value in each case. This value is independent of the time. If the iron is not laminated, Foucault currents will be generated in a direction opposed to the primary electromotive force, and these will introduce a time lag. At any instant the integral of magnetic force round a circuit passing along the outside of the core is still $4\pi n C$, but along any circuit cutting the iron it is $4\pi n C + 4\pi C^1$, where C^1 is the surface integral of the Foucault current interlinked with the circuit in question, C and C^1 having positive or negative values according to their direction. As C^1 depends on the time rate of change of C there is thus a time lag. For instance, if a current is suddenly turned on a solid cored electromagnet, currents in the opposite direction circulate in the iron, so that at first they partly demagnetise the centre. They die away gradually, and the centre is then magnetised as fully as the outside. The lag is here produced entirely electrically, not by any sort of magnetic screening. Mr. Tesla develops his magnetic screening in this way. He wants to get a set of poles on a motor to lag behind another set. He therefore excites the leading poles with an alternating current in the usual way. The lagging poles have their cores wound with iron wire first. The iron wire is not wound parallel to the induction in the core, but at right angles to it, and is referred to as a closed magnetic circuit. Why is not clear, for it is not interlinked with any exciting circuit whatever. Outside this is wound the exciting coils proper. Mr. Tesla thinks this coil of iron wire screens magnetically. We think it acts as a secondary electric circuit. It gets slightly magnetised also, but the direction of magnetisation is at right angles to the wire at every point, not round what Mr. Tesla calls a closed magnetic circuit.

Mr. Tesla also described a transformer. In this a ring of iron wire is taken as core, as usual. It is wound with secondary, also as usual. The secondary is then coated with iron wire. Apparently we were in error when, in our previous note, we said this shield was laminated in the wrong direction; the lamination in the wrong direction—that is, not parallel to the induction—is in the motor, and, from the description, one at least of the transformers has its "screen" laminated in the right direction. Over this "screen" is wound the primary. Mr. Tesla thinks this intermediate layer of iron acts as a magnetic screen. If it is laminated in the right direction, so as to have no Foucault currents, the induction at any instant in the inner core is $(4\pi n C + 4\pi n^1 C^1)\,\mu/l$, where n^1 and C^1 are the secondary turns and current, and l the length of the core circuit. The induction in the outer "screen" is $4\pi n C \mu/l$, and there is no time lag. The effect of such an arrangement is that the primary coil is interlinked with more iron than the secondary, so the effect is just the same as putting a choking coil in series with the primary of an ordinary transformer. Mr. Tesla says triumphantly we are wrong, for it does screen; we say that he has misinterpreted his results.

As to the success of the Tesla motor, we are quite aware that it is in commercial use; we have seen many accounts of it, and have seen it working in the States. We do not deny its utility in many of the cases he brings forward; but the Tesla motor was heralded as a solution of the alternating current motor problem, and here we think it has failed. Nobody is readier than we are to accord Mr. Tesla full credit for his ingenuity and facility in inventing and designing curious motors. We feel, however, that his explanations of the phenomena even in his own inventions are somewhat eccentric. However, great inventions have before now been made on unsound theories.

Letters to the Editor.

TESLA'S NEW ALTERNATING MOTORS.

To the Editor of "Industries."

Sir,—In your issue of the 10th October I find an article relating to some remarks made by me in other journals. You say "it is perhaps an oversight" on my part that I have not forwarded you an advanced proof of my remarks.

I admit the justice of this remark, and beg you to accept my apology. But while I do this I must say that I do not agree with some of your statements. You still misunderstand me on some points about the motor which you have made the subject of your criticism. Is it because my explanations and views are "eccentric," or perhaps even unsound?

In the motor you refer to, the four coils are wrapped transversely with the fine iron wire—that is, the axis of the wire is parallel with the lines of force or induction set up by the current through the coils. This arrangement was referred to by me as a closed magnetic circuit, and is so for all practical purposes.

My statement was that on the start, and as long as the current through the coils has a small value, the few lines set up close through the iron wire, and thus the two effects mentioned by me are brought about, namely, the current through the coils is retarded, and the appearance of the free poles delayed. I believe that it is proper to say that, in this case, the "screening" is effected "magnetically," since the formation of the secondary currents in the "screen" is reduced as far as practicable.

You seem to overlook that in advancing the views in question I have, as far as my recollection goes, nowhere stated that the "screening" might not be *due* to Foucault currents, which are formed no matter how finely the core may be subdivided. Whatever was said referred to the fact observed, and not to what may have caused it. If I observe that the outside of a core is magnetised first, I think that I should be allowed to say in a popular way that the magnetic action affects the outside first and progresses towards the interior.

As to the Foucault currents being concerned in the phenomena, I had, obviously, views similar to your own. In exploring the field of a motor by means of a rotating disc, I have several times observed what one might call "magnetic eddies." In some places within the field the disc would rotate in the proper direction, in other places—the axis of the disc being always parallel with the axis of the armature of the motor—it would not rotate, or it would even rotate in the opposite direction, though with less force in other places of the field. Yet the cores were well laminated, and the field coils properly connected.

I explained this by assuming that, on the start of the current through the coils, secondary currents are formed throughout the cores. These currents in each core might be replaced by a single current sheet somewhere beneath the surface. The space between this current sheet and the surface of the core would then be magnetised jointly by the primary and secondary currents, whereas the centre is demagnetised by the secondary. As there is a difference of phase besides, it occurs sometimes that the centre acquires a polarity opposite to that which would be imparted to it by the primary current. The core may then be thought to consist of two independent parts, and these phenomena of rotation occur.

Motors were constructed by me on this and similar plans. The only trouble with this view is that I have observed these and other phenomena with well-laminated cores. I have, therefore, tried to explain the phenomena in many other ways more or less in accordance with the facts observed, and I do not agree with you in the opinion that it is *necessary* to assume the action to be due to Foucault currents, I mean currents circulating in paths of measurable length.

The magnetic force around a conductor conveying current diminishes with the distance. The magnetisation being an arrangement displacement or orientation of parts possessing weight and inertia requires time. When a sudden magnetising force is applied to the core (by passing a current through the coil surrounding the core) it may occur that the outside—that is, the side nearest to the coil—is magnetised first, though the force appears in every part of the core without loss of time, but different in intensity. The magnetisation thus spreads towards the portions of the core where the force is less intense. As the current sinks down to zero and reverses, a wave of magnetisation passes from the stronger to the weaker magnetised parts, partly on account of the tendency to equalisation throughout the core when the same is magnetised and left to itself, and partly because of the repulsion which is exerted by the current upon the existing polarity. The changing permeability of the parts may also be of more or less influence. Various other explanations, more or less "eccentric," have suggested themselves to me.

You state that I have misinterpreted my results, and it looks as though you believe my views to be unsound. Your arguments are those of an eminent scholar. I was myself a fair scholar. For years I pondered, so to speak, day and night over books, and filled my head with sound views—very sound ones, indeed—those of others. But I could not get to practical results. I then began to work and think independently. Gradually my views became unsound, but they conducted me to some sound results.

Yours, &c.,
Nikola Tesla.

Astor House, New York, U.S.A.,
28th October, 1890.

TESLA'S NEW ALTERNATING MOTORS.

REPLYING to the exceptions taken by Mr. N. Tesla[1] to the criticisms of *Industries* on some of his more recent designs of alternating motors that journal has the following in a recent issue:

The main difference of opinion, we think, lies in a nut-shell. Mr. Tesla holds that if an increasing excitation is applied to an iron core it affects the outside first, and the lines of induction, or lines of force, accumulate in the outside till the iron becomes more or less saturated, and then penetrate to the inside. The outside thus magnetically screens the inside. If the core is laminated, so that there are no Foucault currents, this cannot occur. The line integral of the magnetic force taken round any circuit interlinked with the magnetizing coils is $4 \pi n C$, where n is the number of turns and C the current in C. G. S. This interlinked circuit may be taken through the centre of the core or near the outside, and has the same value in each case. This value is independent of the time. If the iron is not laminated, Foucault currents will be generated in a direction opposed to the primary electromotive force, and these will introduce a time lag. At any instant the integral of magnetic force round a circuit passing along the outside of the core is still $4 \pi n C$, but along any circuit cutting the iron itis $4 \pi n C + 4 \pi n^1 C^1$, where C^1 is the surface integral of the Foucault current interlinked with the circuit in question, C and C^1 having positive or negative values according to their direction. As C^1 depends on the time rate of change of C there is thus a time lag. For instance, if a current is suddenly turned on a solid cored electromagnet, currents in the opposite direction circulate in the iron, so that at first they partly demagnetize the centre. They die away gradually, and the centre is then magnetized as fully as the outside. The lag is here produced entirely electrically, not by any sort of magnetic screening. Mr. Tesla develops his magnetic screening in this way. He wants to get a set of poles on a motor to lag behind another set. He therefore excites the leading poles with an alternating current in the usual way. The lagging poles have their cores wound with iron wire first. The iron wire is not wound parallel to the induction in the core, but at right angles to it, and is referred to as a closed magnetic circuit. Why is not clear, for it is not interlinked with any exciting circuit whatever. Outside this is wound the exciting coils proper. Mr. Tesla thinks this coil of iron wire screens magnetically. We think it acts as a secondary electric circuit. It gets slightly magnetized also, but the direction of magnetization is at right angles to the wire at every point, not round what Mr. Tesla calls a closed magnetic circuit.

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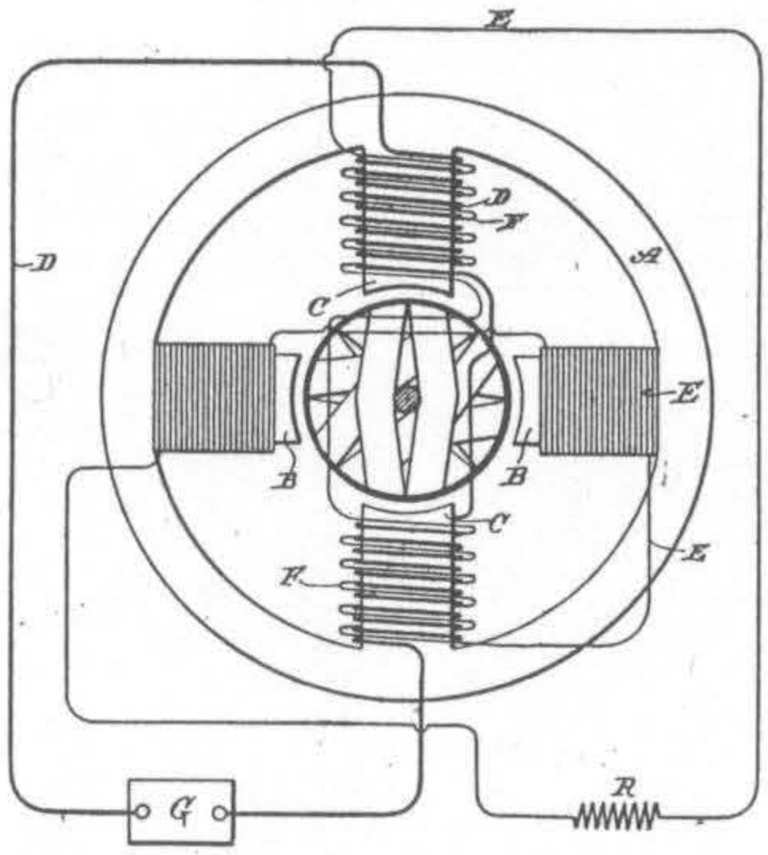
NOTES.

Mr. Tesla on Sound Views.—In a letter to *Industries* on alternating motors, Mr. Nikola Tesla concludes an able letter as follows :—" You state that I have misinterpreted my results, and it looks as though you believe my views to be unsound. Your arguments are those of an eminent scholar. I was myself a fair scholar. For years I pondered, so to speak, day and night over books, and filled my head with sound views—very sound ones, indeed—those of others. But I could no get to practical results. I then began to work and think independently. Gradually my views became unsound, but they conducted me to some sound results."

NEW TESLA ALTERNATING MOTOR.

We have already described a number of different forms of alternating current motors designed by Mr. Nikola Tesla, depending upon a variety of phenomena met with



Tesla Alternating Motor.

in the employment of alternating currents. One general type of these consists of a machine with, say, four poles, between which is mounted an armature, generally wound with closed coils. On two opposite poles of the field are primary coils connected up in the main circuit. On the same cores are also wound secondary coils which are closed through coils on the other pair of poles. When an alternating current is caused to pass through the primary coils, it energizes directly one set of poles, and induces currents in the secondary coils, which in turn energize the other poles; but the phases of the current in the secondary coils may differ in time from those of the primary current, and hence a shifting of the poles is effected, that imparts a rotation to the motor.

In the new motor designed by Mr. Tesla, however, two energizing circuits are brought into inductive relation in the motor itself, and the employment of an external in-

duction device is thus avoided. The operation is dependent upon the existence of a certain difference of phase between the currents of the primary and secondary coils, and will be readily understood by reference to the accompanying diagram.

Here A represents the field magnet of a motor, which is built up of sections or plates. B and C are polar projections upon which the coils are wound. Upon one pair of these poles, as C, are wound the primary coils D, which are directly connected to the circuit of an alternating-current generator. The secondary coils, F, are wound on the same poles with the primary, and connected with other coils, E, which surround the poles B.

The current in both the primary and secondary coils will lag behind the impressed electromotive force, but to secure the proper difference in phase between the primary and secondary currents themselves, the resistance of the circuit of the secondary is increased, so as to reduce as much as possible its self induction. This is accomplished by making the coils E of comparatively small wire, having but few turns around the cores, or by inserting in the secondary circuit an artificial resistance, R.

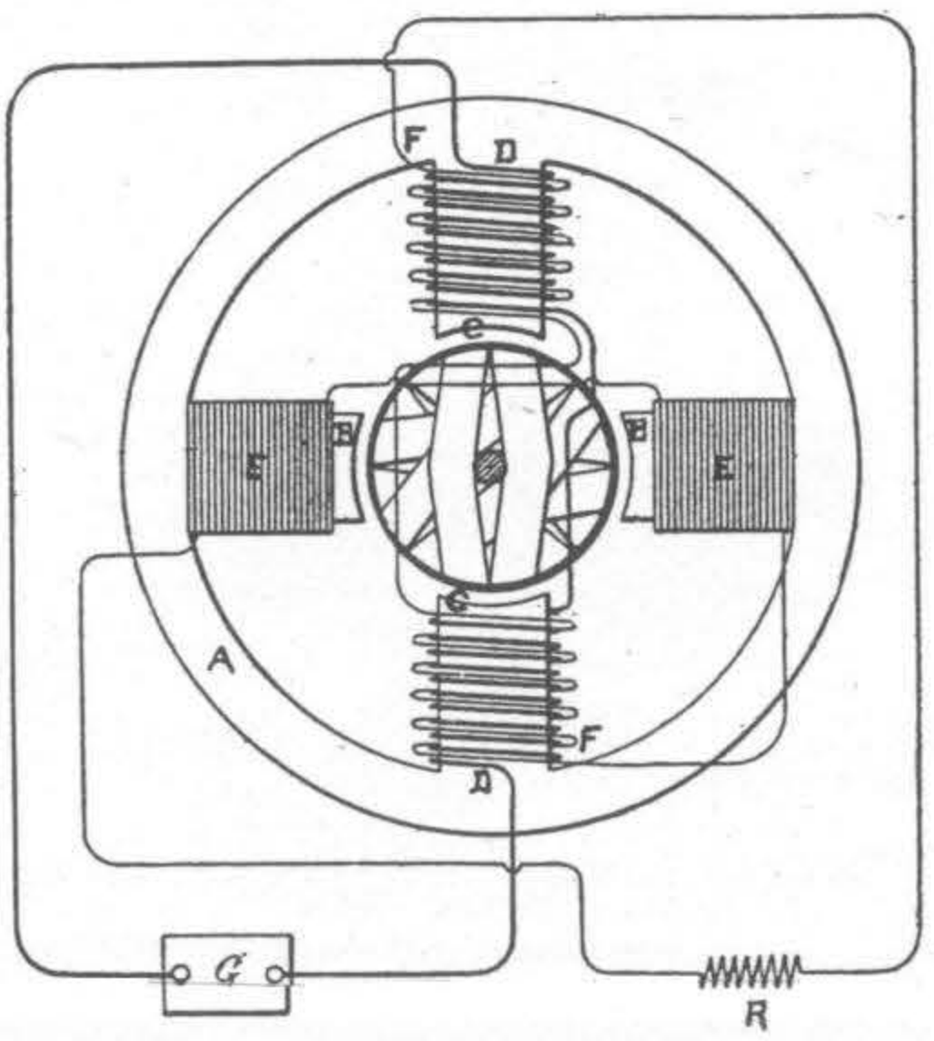
In practice, it has been found desirable to wind the armature with closed coils, in which currents are induced by the action of the primaries.

Improved Tesla Alternating Current Motor.

Among the various forms of alternating current motors invented by Nikola Tesla is one which is constructed as follows: A field core is built with, say, four poles, between which is mounted an armature that is generally wound with closed coils. On two of the opposite poles of the field primary coils are wound, which are connected up in the main circuit. On the same cores are also wound secondary coils, which are closed through coils on the other pair of poles. In this motor when an alternating current is caused to pass through the primary coils it energizes directly one set of poles and induces currents in the secondary coils, which act to energize the other poles; but the phases of the current in the secondary coils may differ in time from those of the primary current, and hence a rotation or shifting of the poles is effected that imparts rotation to the motor.

In the motors constructed in accordance with this principle two energizing circuits are brought into inductive relation in the motor itself—that is to say, the secondary currents which energize one set of the field-cores are induced in the motor itself, and the employment of an external induction device is thus avoided. The operation of these motors, however, is dependent upon the existence of a certain difference of phase between the currents in the primary and secondary coils. To obtain a difference of phase or lag that is suited to working conditions is the specific object of the construction employed in the present case.

Referring to the cut let *A* designate the field magnet of a motor, built up of sections or plates. *B C* are polar projections upon which the coils are wound. Upon one pair of these poles, as *C*, are wound primary coils *D*, which are directly connected to the circuit of an alternating-current generator *G*. On the same poles are also wound secondary coils *F* which are connected with other coils *E*, which surround the poles *BB*. The current in both primary and secondary coils in such a motor will lag behind



IMPROVED TESLA ALTERNATING CURRENT MOTOR.

the impressed electromotive force; but to secure a proper difference in phase between the primary and secondary currents themselves the resistance of the circuit of the secondary is increased and its self-induction is reduced as much as practicable. This action is obtained by using for the secondary circuit, particularly in the coils *E*, wire of comparatively small diameter and having but few turns around the cores; or some conductor of higher specific resistance such as German silver is used. Thus the self-induction of the secondary is kept down and its resistance increased with the result of decreasing the lag between the impressed electromotive force and the current in the primary coils, and increasing the difference of phase between the primary and secondary currents.

NEW TESLA ALTERNATING MOTOR.

We have already described a number of different forms of alternating-current motors designed by Mr. Nikola Tesla, depending upon a variety of phenomena met with in the employment of alternating currents. One general type of these consists of a machine with, say, four poles, between which is mounted an armature, generally wound with closed coils. On two opposite poles of the field are primary coils connected up in the main circuit. On the same cores are also wound secondary coils, which are closed through coils on the other pair of poles. When an alternating current is caused to pass through the primary coils, it energises directly one set of poles, and induces currents in the secondary coils, which in turn energise the other poles; but the phases of the current in the secondary coils may differ in time from those of the primary current, and hence a shifting of the poles is effected that imparts a rotation to the motor.

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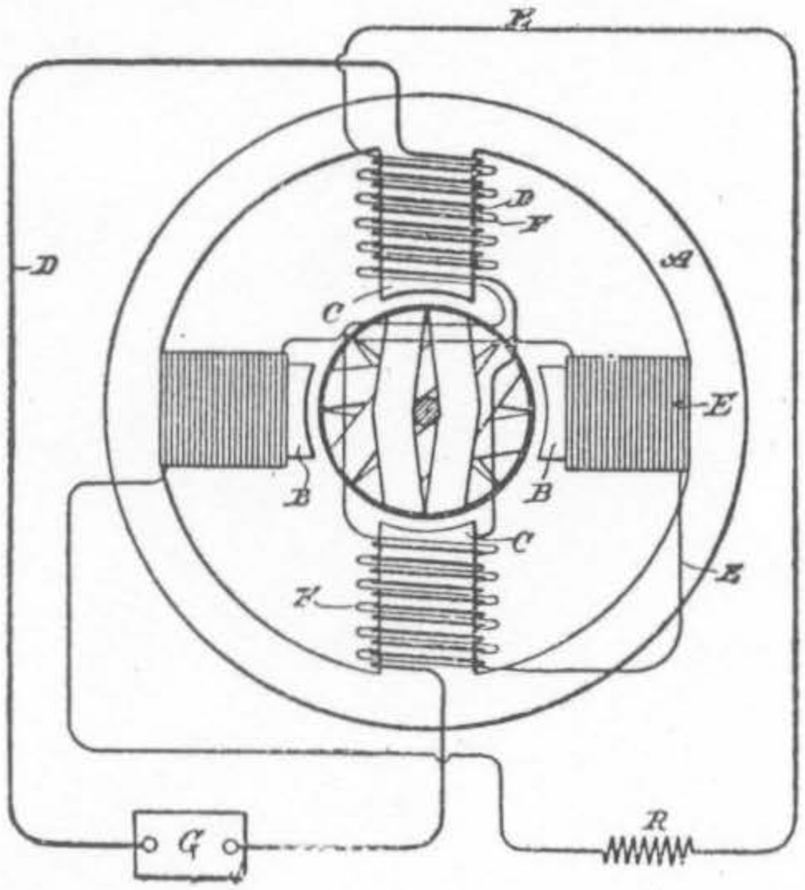

Here A represents the field magnet of a motor, which is built up of sections or plates. B and C are polar projections upon which the coils are wound. Upon one pair of these poles, as C, are wound the primary coils, D, which are directly connected to the circuit of an alternating-current generator. The secondary coils, F, are wound on the same poles with the primary, and connected with other coils, E, which surround the poles B.

The current in both the primary and secondary coils will lag behind the impressed E.M.F., but to secure the proper difference in phase between the primary and secondary currents themselves, the resistance of the circuit of the secondary is increased, so as to reduce as much as possible its self-induction. This is accomplished by making the coils E of comparatively small wire, having but few turns around the cores, or by inserting in the secondary circuit an artificial resistance, R.

In practice, it has been found desirable to wind the armature with closed coils, in which currents are induced by the action of the primaries.—*Electrical Engineer*, New York.

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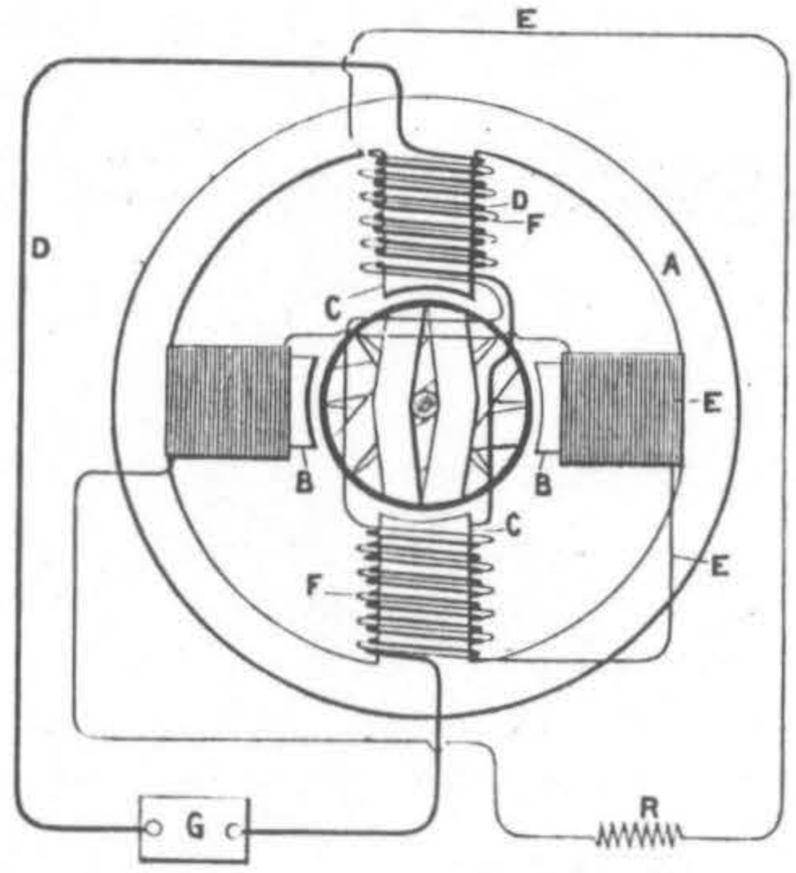

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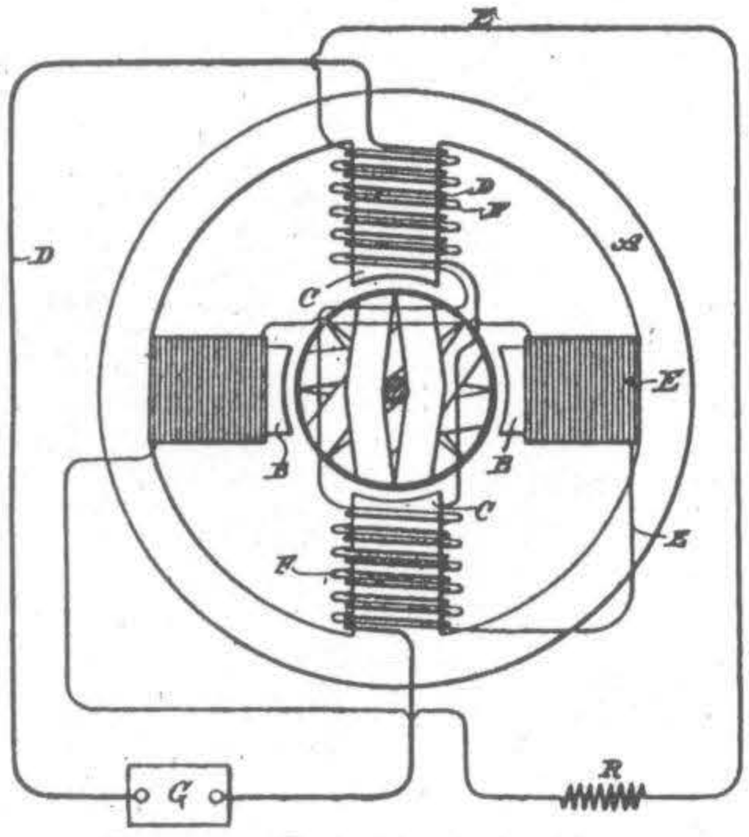

Diagram of Tesla Alternating Motor.

paratively small wire, having but few turns around the cores, or by inserting in the secondary circuit an artifical resistance, R. In practice, it has been found desirable to wind the armature with closed coils, in which currents are induced by the action of the primaries.

Phenomena of Alternating Currents of Very High Frequency.

BY NIKOLA TESLA.

ALTERNATE CURRENT MACHINES OF HIGH FREQUENCY; CURIOUS EXPERIMENTS WITH GEISSLER TUBES AND LAMPS; AN EXPLODED NOTION; NOISELESS ALTERNATING ARCS; CONSTANT CURRENT AND CONSTANT POTENTIAL; INTERESTING EXPERIMENT WITH A CONDENSER; THE FERRANTI-MAIN EFFECT; DA LIEGT DER HASE IM PFEFFER BEGRABEN; SUGGESTIONS OF MR. SWINBURNE.

Electrical journals are getting to be more and more interesting. New facts are observed and new problems spring up daily which command the attention of engineers. In the last few numbers of the English journals, principally in the *Electrician*, there have been several new matters brought up which have attracted more than usual attention. The address of Professor Crookes has revived the interest in his beautiful and skillfully performed experiments, the effect observed on the Ferranti mains has elicited the expressions of opinion of some of the leading English electricians, and Mr. Swinburne has brought out some interesting points in connection with condensers and dynamo excitation.

The writer's own experiences have induced him to venture a few remarks in regard to these and other matters, hoping that they will afford some useful information or suggestion to the reader.

Among his many experiments Professor Crookes shows some performed with tubes devoid of internal electrodes, and from his remarks it must be inferred that the results obtained with these tubes are rather unusual. If this be so, then the writer must regret that Professor Crookes, whose admirable work has been the delight of every investigator, should not have availed himself in his experiments of a properly constructed alternate current machine—namely, one capable, of giving, say, 10,000 to 20,000 alternations per second. His researches on this difficult but fascinating subject would then have been even more complete. It is true that when using such a machine in connection with an induction coil the distinctive character of the electrodes—which is desirable, if not essential, in many experiments—is lost, in most cases both the electrodes behaving alike; but, on the other hand, the advantage is gained that the effects may be exalted at will. When using a rotating switch or commutator the rate of change obtainable in the primary current is limited. When the commutator is more rapidly revolved the primary current diminishes, and if the current be increased, the sparking, which cannot be completely overcome by the condenser, impairs considerably the virtue of the apparatus. No such limitations exist when using an alternate current machine, as any desired rate of change may be produced in the primary current. It is thus possible to obtain excessively high electromotive forces in the secondary circuit with a comparatively small primary current; moreover, the perfect regularity in the working of the apparatus may be relied upon.

The writer will incidentally mention that any one who attempts for the first time to construct such a machine will have a tale of woe to tell. He will first start out, as a matter of course, by making an armature with the required number of polar projections. He will then get the satisfaction of having produced an apparatus which is fit to accompany a thoroughly Wagnerian opera. It may besides possess the virtue of converting mechanical energy into heat in a nearly perfect manner. If there is a reversal in the polarity of the projections, he will get heat out of the machine; if there is no reversal, the heating will be less, but the output will be next to nothing. He will then abandon the iron in the armature, and he will get from the Scylla to the Charybdis. He will look for one difficulty and will find another, but, after a few trials, he may get nearly what he wanted.

Among the many experiments which may be performed with such a machine, of not the least interest are those performed with a high-tension induction coil. The character of the discharge is completely changed. The arc is established at much greater distances, and it is so easily affected by the slightest current of air that it often wriggles around in the most singular manner. It usually emits the rhythmical sound peculiar to the alternate current arcs, but the curious point is that the sound may be heard with a number of alternations far above ten thousand per second, which by many is considered to be about the limit of audition. In many respects the coil behaves like a static machine. Points impair considerably the sparking interval, electricity escaping from them freely, and from a wire attached to one of the terminals streams of light issue, as though it were connected to a pole of a powerful Toepler machine. All these phenomena are, of course, mostly due to the enormous differences of potential obtained. As a consequence of the self-induction of the coil and the high frequency, the current is minute while there is a corresponding rise of pressure. A current impulse of some strength started in such a coil should persist to flow no less than four ten-thousandths of a second. As this time is greater than half the period it occurs that an opposing electromotive force begins to act while the current is still flowing. As a consequence, the pressure rises as in a tube filled with liquid and vibrated rapidly around its axis. The current is so small that, in the opinion and involuntary experience of the writer, the discharge of even a very large coil cannot produce seriously injurious effects, whereas, if the same coil were operated with a current of lower frequency, though the electromotive force would be much smaller, the discharge would be most certainly injurious. This result, however, is due in part to the high frequency. The writer's experiences tend to show that the higher the frequency the greater the amount of electrical energy which may be passed through the body without serious discomfort; whence it seems certain that human tissues act as condensers.

One is not quite prepared for the behavi or of the coil when connected to a Leyden jar. One, of course, anticipates that since the frequency is high the capacity of the jar should be small. He therefore takes a very small jar, about the size of a small wine-glass, but he finds that even with this jar the coil is practically short-circuited. He then reduces the capacity until he comes to about the capacity of two spheres, say, ten centimetres in diameter and two to four centimetres apart. The discharge then assumes the form of a serrated band exactly like a succession of sparks viewed in a rapidly revolving mirror; the serations, of course, corresponding to the condenser discharges. In this case one may observe a queer phenomenon. The discharge starts at the nearest points, works gradually up, breaks somewhere near the top of the spheres, begins again at the bottom, and so on. This goes on so fast that several serrated bands are seen at once. One may be puzzled for a few minutes, but the explanation is simple enough. The discharge begins at the nearest points, the air is heated and carries the arc upward until it breaks, when it is re-established at the nearest points, etc. Since the current passes easily through a condenser of even small capacity, it will be found quite natural that connecting only one terminal to a body of the some size, no matter how well insulate', impairs considerably the striking distance of the arc.

Experiments with Geissler tubes are of special interest. An exhausted tube, devoid of electrodes of any kind, will light up at some distance from the coil. If a tube from a vacuum pump is near the coil the whole of the pump is brilliantly lighted. An incandescent lamp approached to the coil lights up and gets perceptibly hot. If a lamp have the terminals connected to one of the binding posts of the coil and the hand is approached to the bulb, a very curious and rather unpleasant discharge from the glass to the hand takes place, and the filament may become incandescent. The discharge resembles to some extent the stream issuing fr om the plates of a powerful Toepler machine, but is of incomparably greater quantity. The lamp in this case acts as a condenser, the rarefied gas being one coating, the operator's hand the other. By taking the globe of a lamp in the hand, and by bringing the metallic terminals near to or in contact with a conductor connected to the coil, the carbon is brought to bright incandescence and the glass is rapidly heated. With a 100-volt 10 c. p. lamp one may without great discomfort stand as much current as will bring the lamp to a considerable brilliancy; but it can be held in the hand only for a few minutes, as the glass is heated in an incredibly short time. When a tube is lighted by bringing it near to the coil it may be made to go out by interposing a metal plate or the hand between the coil and tube; but if the metal plate be fastened to a glass rod or otherwise insulated, the tube may remain lighted if the plate be interposed, or may even increase in luminosity. The effect depends on the position of the plate and tube relatively to the coil and may be always easily foretold by *assuming* that conduction takes place from one terminal of the coil to the other. According to the position of the plate, it may either divert from or direct the current to the tube.

In another line of work the writer has in frequent experiments maintained incandescent lamps of 50 or 100 volts burning at any desired candle power with both the terminals of each lamp connected to a stout copper wire of no more than a few feet in length. These experiments seem interesting enough, but they are not more so than the queer experi ment of Faraday, which has been revived and made much of by recent investigators, and in which a discharge is made to jump between two points of a bent copper wire. An experiment may be cited here which may seem equally interesting. If a Geissler tube, the terminals of which are joined by a copper wire, be approached to the coil, certainly no one would be prepared to see the tube light up. Curiously enough, it does light up, and, what is more, the wire does not seem to make much difference. Now one is apt to think in the first moment that the impedance of the wire might have something to do with the phenomenon. But this is of course immediately rejected, as for this an enormous frequency would be required. The result, however, seems puzzling only at first; for upon reflection it is quite clear that the wire can make but little difference. It may be explained in more than one way, but it agrees perhaps best with observation to assume that conduction takes place from the terminals of the coil through the space. On this assumption, if the tube with the wire be held in any position, the wire can divert little more than the current which passes through the space occupied by the wire and the metallic terminals of the tube; through the adjacent space the current passes practically undisturbed. For this reason, if the tube be held in any position at right angles to the line joining the binding posts of the coil, the wire makes hardly any difference, but in a position more

or less parallel with that line it impairs to a certain extent the brilliancy of the tube and its facility to light up. Numerous other phenomena may be explained on the same assumption. For instance, if the ends of the tube be provided with washers of sufficient size and held in the line joining the terminals of the coil, it will not light up, as then nearly the whole of the current, which would otherwise pass uniformly through the space between the washers, is diverted through the wire. But if the tube be inclined sufficiently to that line, it will light up in spite of the washers. Also, if a metal plate be fastened upon a glass rod and held at right angles to the line joining the binding posts, and nearer to one of them, a tube held more or less parallel with the line will light up instantly when one of its terminals touches the plate and will go out when separated from the plate. The greater the surface of the plate up to a certain limit, the easier the tube will light up. When a tube is placed at right angles to the straight line joining the binding posts, and then rotated, its luminosity steadily increases until it is parallel with that line. The writer must state, however, that he does not favor the idea of a leakage or current through the space any more than as a suitable explanation, for he is convinced that all these experiments could not be performed with a static machine yielding a constant difference of potential, and that condenser action is largely concerned in these phenomena.

It is well to take certain precautions when operating a Ruhmkorff coil with very rapidly alternating currents. The primary current should not be turned on too long, else the core may get so hot as to melt the gutta-percha or paraffin, or otherwise injure the insulation, and this may occur in a surprisingly short time, the current's strength considered. The primary current being turned on, the fine wire terminals may be joined without great risk, the impedence being so great that it is difficult to force enough current through the fine wire so as to injure it, and in fact the coil may be on the whole much safer when the terminals of the fine wire are connected than when they are insulated; but special care should be taken when the terminals are connected to the coatings of a Leyden jar, for with anywhere near the critical capacity, which just counteracts the self-induction at the existing frequency, the coil might meet the fate of St. Polycarpus. If an expensive vacuum pump is lighted up by being near to the coil or touched with a wire connected to one of the terminals, the current should be left on no more than a few moments, else the glass will be cracked by the heating of the rarefied gas in one of the narrow passages—in the writer's own experience *quod erat demonstrandum.**

There are a good many other points of interest which may be observed in connection with such a machine. Experiments with the telephone, a conductor in a strong field or with a condenser or arc seem to afford certain proof that sounds far above the usual accepted limit of hearing would be perceived. A telephone will emit notes of twelve to thirteen thousand vibrations per second, then the inability of the core to follow such rapid alternations begins to tell. If, however, the magnet and core be replaced by a condenser and the terminals connected to the high-tension secondary of a transformer higher notes may still be heard. If the current be sent around a finely laminated core and a small piece of thin sheet iron be held gently against the core, a sound may be still heard with thirteen to fourteen thousand alternations per second, provided the current is sufficiently strong. A small coil, however, tightly packed between the poles of a powerful magnet, will emit a sound with the above number of alternations, and arcs may be audible with still a higher frequency. The limit of audition is variously estimated. In Sir William Thomson's writings it is stated somewhere that ten thousand per second, or nearly so, is the limit. Other, but less reliable, sources give it as high as twenty four thousand per second. The above experiments have convinced the writer that notes of an incomparably higher number of vibrations per second would be perceived provided they could be produced with sufficient power. There is no reason why it should not be so. The condensations and rarefactions of the air would necessarily set the diaphragm in a corresponding vibration and some sensation would be produced whatever—within certain limits—the velocity of transmission to their nerve centres, though it is probable that for want of exercise the ear would not be able to distinguish any such high note. With the eye it is different; if the sense of vision is based upon some resonance effect, as many believe, no amount of increase in the intensity of the ethereal vibration could extend our range of vision on either side of the visible spectrum.

The limit of audition of an arc depends on its size. The greater the surface by a given heating effect in the arc the higher the limit of audition. The highest notes are emitted by the high-tension discharges of an induction coil in which the arc is, so to speak, all surface. If R be the resistance of an arc, and C the current, and the linear dimensions be n times increased, then the resistance is $\frac{R}{n}$, and with the same current density the current would be n^2C; hence the heating effect is n^3 times greater, while the surface is only n^2 times as great. For this reason very large arcs would not emit any rhythmical sound even with a very low frequency. It must be observed, however, that the sound emitted depends to some extent also on the composition of the carbon. If the carbon contain highly refractory material, this when heated tends to maintain the temperature of the arc uniform and the sound is lessened; for this reason it would seem that an alternating arc requires such carbons.

With currents of such high frequencies it is possible to obtain noiseless arcs, but the regulation of the lamp is rendered extremely difficult on account of the excessively small attractions or repulsions between conductors conveying these currents.

An interesting feature of the arc produced by these rapidly alternating currents is its persistency. There are two causes for it, one of which is always present, the other sometimes only. One is due to the character of the current and the other to a property of the machine. The first cause is the more important one, and is due directly to the rapidity of the alternations. When an arc is formed by a periodically undulating current, there is a corresponding undulation in the temperature of the gaseous column, and, therefore, a corresponding undulation in the resistance of the arc. But the resistance of the arc varies enormously with the temperature of the gaseous column, being practically infinite when the gas between the electrodes is cold. The persistence of the arc, therefore, depends on the inability of the column to cool. It is for this reason impossible to maintain an arc with the current alternating only a few times a second. On the other hand, with a practically continuous current, the arc is easily maintained, the column being constantly kept at a high temperature and low resistance. The higher the frequency the smaller the time interval during which the arc may cool and increase considerably in resistance. With a frequency of 10,000 per second or more in an arc of same size excessively small variations of temperature are superimposed upon a steady temperature, like ripples on the surface of a deep sea. The heating effect is practically continuous and the arc behaves like one produced by a continuous current, with the exception, however, that it may not be quite as easily started, and that the electrodes are equally consumed; though the writer has observed some irregularities in this respect.

The second cause alluded to, which possibly may not be present, is due to the tendency of a machine of such high frequency to maintain a practically constant current. When the arc is lengthened the electromotive force rises in proportion and the arc appears to be more persistent.

Such a machine is eminently adapted to maintain a constant current, but it is very unfit for a constant potential. As a matter of fact, in certain types of such machines a nearly constant current is an almost unavoidable result. As the number of poles or polar projections is greatly increased, the clearance becomes of great importance. One has really to do with a great number of very small machines. Then there is the impedence in the armature, enormously augmented by the high frequency. Then, again, the magnetic leakage is facilitated. If there are three or four hundred alternate poles the leakage is so great that it is virtually the same as connecting, in a two-pole machine, the poles by a piece of iron. This disadvantage, it is true, may be obviated more or less by using a field throughout of the same polarity, but then one encounters difficulties of a different nature. All these things tend to maintain a constant current in the armature circuit.

In this connection it is interesting to notice that even to-day engineers are astonished at the performance of a constant current machine, just as, some years ago, they used to consider it an extraordinary performance if a machine was capable of maintaining a constant potential difference between the terminals. Yet one result is just as easily secured as the other. It must only be remembered that in an inductive apparatus of any kind, if constant potential is required, the inductive relation between the primary or exciting and secondary or armature circuit must be the closest possible; whereas, in an apparatus for constant current just the opposite is required. Furthermore, the opposition to the current's flow in the induced circuit must be as small as possible in the former and as great as possible in the latter case. But opposition to a current's flow may be caused in more than one way. It may be caused by ohmic resistance or self induction. One may make the induced circuit of a dynamo machine or transformer of such high resistance that when operating devices of considerably smaller resistance within very wide limits a nearly constant current is maintained. But such high resistance involves a great loss in power, hence it is not practicable. Not so self-induction. Self-induction does not necessarily mean loss of power. The moral is, use self-induction instead of resistance. There is, however, a circumstance which favors the adoption of this plan, and this is, that a very high self-induction may be obtained cheaply by surrounding a comparatively small length of wire more or less completely with iron, and, furthermore, the effect may be exalted at will by causing a rapid undulation of the current. To sum up, the requirements for constant current are: Weak magnetic connection between the induced and inducing circuits, greatest possible self-induction with the least resistance, greatest practicable rate of change of the current. Constant potential, on the other hand, requires: Closest magnetic connection between the circuits, steady induced current, and, if possible, no reaction. If the latter conditions could be fully satisfied in a constant potential machine, its output would surpass many times that of a machine primarily designed to give constant current. Unfortunately, the type of machine in which these conditions may be satisfied is of little practical value, owing to the small electromotive force obtainable and the difficulties in taking off the current.

With their keen inventor's instinct, the now successful arc-light men have early recognized the desideratums of a constant current machine. Their arc light machines have weak fields, large armatures, with a great length of copper wire and few commutator segments to produce great variations in the current's strength and to bring self-induction into play. Such machines may maintain within considerable limits of variation in the resistance of the circuit a practically constant current. Their output is of course correspondingly diminished, and, perhaps, with the object in view not to cut down the output too much, a simple device compensating exceptional variations is employed. The undulation of the current is almost essential to the commercial success of an arc-light system. It introduces in the circuit a steadying element taking the place of a large ohmic resistance, without involving a great loss in power, and, what is more important, it allows the use of simple clutch lamps, which with a current of a certain number of impulses per second, best suitable for each particular lamp, will, if properly attended to, regulate even better than the finest clock-work lamps. This discovery has been made by the writer—several years too late.

It has been asserted by competent English electricians that in a constant current machine or transformer the regulation is effected by varying the phase of the secondary current. That this view is erroneous may be easily proved by using, instead of lamps, devices each possessing self-induction and capacity or self-induction and resistance—that is, retarding and accelerating components—in such proportions as to not affect materially the phase of the secondary current. Any number of such devices may be inserted or cut out, still it will be found that the regulation occurs, a constant current being maintained while the electromotive force is varied with the number of the devices. The change of phase of the secondary current is simply a result following from the changes in resistance, and, though secondary reaction is always of more or less importance, yet the real cause of the regulation lies in the existence of the conditions above enumerated. It should be stated, however, that in the case of a machine the above remarks are to be restricted to the cases in which the machine is independently excited. If the excitation be effected by commutating the armature current, then the fixed position of the brushes makes any shifting of the neutral line of the utmost importance, and it may not be thought immodest of the writer to mention that, as far as records go he seems to have been the first who has successfully regulated machines in providing a bridge connection between a point of the external circuit and the commutator by means of a third brush. The armature and field being properly proportioned and the brushes placed in their determined positions, a constant current or constant potential resulted from the shifting of the diameter of commutation by the varying loads.

In connection with machines of such high frequencies the condenser affords an especially interesting study. It is easy to raise the electromotive force of such a machine to four or five times the value by simply connecting the condenser to the circuit, and the writer has continually used the condenser for the purposes of regulation as suggested by Blakesley in his book on alternate currents, in which he has treated the most frequently occurring condenser problems with exquisite simplicity and clearness. The high frequency allows the use of small capacities and renders investigation easy. But, although in most of the experiments the result may be foretold, yet some phenomena observed seem at first curious. One experiment performed three or four months ago with such a machine and a condenser may serve as illustration. A machine was used giving about 20,000 alternations per second. Two bare wires of about 20 feet long and two millimetres diameter, in close proximity to each other, were connected to the terminals of the machine on the one end, and to a condenser on the other. A small transformer without an iron core, of course, was used to bring the reading within the range of a Cardew voltmeter by connecting the voltmeter to the secondary. On the terminals of the condenser the electromotive force was about 120 volts, and from there inch by inch it gradually fell until on the terminals of the machine it was about 65 volts. It was virtually as though the condenser were a generator, and the line and armature circuit simply a resistance connected to it. The writer looked for a case of resonance, but he was unable to augment the effect by varying the capacity very carefully and gradually or by changing the speed of the machine. A case of pure resonance he was unable to obtain. When a condenser was connected to the terminals of the machine—the self-induction of the armature being first determined in the maximum and minimum position and the mean value taken—the capacity which gave the highest electromotive force corresponded most nearly to that which just

* It is thought necessary to remark that, although the induction coil may give quite a good result when operated with such rapidly alternating currents, yet its construction, quite irrespective of the iron core, makes it very unfit for such high frequencies, and to obtain the best results the construction should be greatly modified

counteracted the self-induction with the existing frequency. If the capacity was increased or diminished the electromotive force fell as expected.

With frequencies as high as the above mentioned the condenser effects are of enormous importance. The condenser becomes a highly efficient apparatus capable of transferring considerable energy.

The writer has thought that machines of high frequencies may find use at least in cases when transmission at great distances is not contemplated. The increase of the resistance may be reduced in the conductors and exalted in the devices when heating effects are wanted, transformers may be made of higher efficiency and greater outputs and valuable results may be secured by means of condensers. In using machines of high frequency the writer has been able to observe condenser effects which would have other wise escaped his notice. He has been very much interested in the phenomenon observed on the Ferranti main which has been so much spoken of. Opinions have been expressed by competent electricians, but up to the present all still seems to be conjecture. Undoubtedly in the views expressed the truth must be contained, but as the opinions differ some must be erroneous. Upon seeing the diagram of M. Ferranti in the *Electrician* of Dec. 19 the writer has formed his opinion of the effect. In the absence of all the necessary data he must content himself to express in words the process which, in his opinion, must undoubtedly occur. The condenser brings about two effects: (1) It changes the phases of the currents in the branches; (2) it changes the strength of the currents. As regards the change in phase, the effect of the condenser is to accelerate the current in the secondary at Deptford and to retard it in the primary at London. The former has the effect diminishing the self-induction in the Deptford primary, and this means lower electromotive force on the dynamo. The retardation of the primary at London, as far as merely the phase is concerned, has little or no effect since the phase of the current in the secondary in London, is not arbitrarily kept.

Now, the second effect of the condenser is to increase the current in both the branches. It is immaterial whether there is equality between the currents or not; but it is necessary to point out, in order to see the importance of the Deptford step-up transformer, that an increase of the current in both the branches produces opposite effects. At Deptford it means further lowering of the electromotive force at the primary, and at London it means increase of the electromotive force at the secondary. Therefore, all the things co-act to bring about the phenomenon observed. Such actions, at least, have been formed to take place under similar conditions. When the dynamo is connected directly to the main, one can see that no such action can happen.

The writer has been particularly interested in the suggestions and views expressed by Mr. Swinburne. Mr. Swinburne has frequently honored him by disagreeing with his views. Three years ago, when the writer, against the prevailing opinion of engineers, advanced an open circuit transformer, Mr. Swinburne was the first to condemn it by stating in the *Electrician*: "The (Tesla) transformer must be inefficient; it has magnetic poles revolving, and has thus an *open* magnetic circuit." Two years later Mr. Swinburne becomes the champion of the open circuit transformer, and offers to convert him. But, *tempora mutantur et nos mutamur in illis.*

The writer cannot believe in the armature reaction theory as expressed in *Industries*, though undoubtedly there is some truth in it. Mr. Swinburne's interpretation, however, is so broad that it may mean anything.

Mr. Swinburne seems to have been the first who has called attention to the heating of the condensers. The astonishment expressed at that by the ablest electrician is a striking illustration of the desirability to execute experiments on a large scale. To the scientific investigator, who deals with the minutest quantities, who observes the faintest effects, far more credit is due than to one who experiments with apparatus on an industrial scale; and indeed history of science has recorded examples of marvelous skill, patience and keenness of observation. But however great the skill, and however keen the observer's perception, it can only be of advantage to magnify an effect and thus facilitate its study. Had Faraday carried out but one of his experiments on dynamic induction on a large scale it would have resulted in an incalculable benefit.

In the opinion of the writer, the heating of the condensers is due to three distinct causes: first, leakage or conduction; second, imperfect elasticity in the dielectric, and, third, surging of the charges in the conductor.

In many experiments he has been confronted with the problem of transferring the greatest possible amount of energy across a dielectric. For instance, he has made incandescent lamps the ends of the filaments being completely sealed in glass, but attached io interior condenser coatings so that all the energy required had to be transferred across the glass with a condenser surface of no more than a few centimetres square. Such lamps would be a practical success with sufficiently high frequencies. With alternations as high as 15,000 per second it was easy to bring the filaments to incandescence. With lower frequencies this could also be effected, but the potential difference had, of course, to be increased. The writer has then found that the glass gets, after a while, perforated and the vacuum is impaired. The higher the frequency the longer the lamp can withstand. Such a deterioration of the dielectric always takes place when the amount of energy transferred across a dielectric of definite dimensions and by a given frequency is too great. Glass withstands best, but even glass is deteriorated. In this case the potential difference on the plates is of course too great and losses by conduction and imperfect elasticity result. If it is desirable to produce condensers capable to stand great differences of potential, then the only dielectric which will involve no losses is a gas under pressure. The writer has worked with air under enormous pressures, but there a are great many practical difficulties in that direction. He thinks that, in order to make the condensers of considerable practical utility, higher frequencies should be used; though such a plan has besides others the great disadvantage that the system would become very unfit for the operation of motors.

If the writer does not err, Mr. Swinburne has suggested a way of exciting an alternator by means of a condenser.

For a number of years past the writer has carried on experiments with the object in view of producing a practical self-exciting alternator. He has in a variety of ways succeeded in producing some excitation of the magnets by means of alternating currents, which were not commutated by mechanical devices. Nevertheless, his experiments have revealed a fact which stands as solid as the rock of Gibraltar. No practical excitation can be obtained with a single periodically varying and not commutated current. The reason is that the changes in the strength of the exciting current produce corresponding changes in the field strength, with the result of inducing currents in the armature; and these currents interfere with those produced by the motion of the armature through the field, the former being a quarter phase in advance of the latter. If the field be laminated, no excitation can be produced; if it be not laminated, some excitation is produced, but the magnets are heated. By combining two exciting currents displaced by a quarter phase, excitation may be produced in both cases, and if the magnet be not laminated the heating effect is comparatively small, as a uniformity in the field strength is maintained, and, were it possible to produce a perfectly uniform field, excitation on this plan would give quite practical results. If such results are to be secured by the use of a condenser, as suggested by Mr. Swinburne, it is necessary to combine two circuits separated by a quarter phase; that is to say, the armature coils must be wound in two sets and connected to one or two independent condensers. The writer has done some work in that direction, but must defer the description of the devices for some future time.

ALTERNATE CURRENT TRANSMISSION.

During the third and the last of this series of Cantor lectures at the Society of Arts, Mr. Gisbert Kapp dealt very fully with the probabilities of transmission of power electrically by means of alternate currents. The limits of transmission by direct currents is reached when it is necessary to employ two or three thousand volts pressure, and therefore future development will probably—nay, must—be in the direction of alternate currents. In a most graphic and admirable manner Mr. Kapp described the position as it exists. He showed how Ferraris first of all pointed out the right way to get an alternate-current motor that was self-starting, and how Tesla and others had worked in the direction indicated by Ferraris, and, finally, how a three-pole alternate-current motor had been produced that would start, keep in step, and also pick up again though momentarily overloaded. He showed how this was done with the use of—not two—but three line wires to the motor. But the most interesting point was that Mr. Brown, of the Oerlikon Works, was now constructing an alternate-current plant whereby to transmit the whole of the power required by the Oerlikon Works. Here the power will be transmitted from Bulach to Oerlikon, a distance of 15 miles, under a pressure of 25,000 volts. This installation of Mr. Brown's will be watched with the greatest interest throughout the civilised world, for upon its success will depend the introduction of similar plant in many districts where natural water power must be transmitted over considerable distances, if it is to be rendered serviceable to the inhabitants. We have not thought it necessary to give abstracts of these lectures of Mr. Kapp, because they will ere long be published fully in the *Journal* of the society, and when complete can be better discussed than from mere abstracts. Still, the experiment to be made at Oerlikon deserves the widest possible notice, in order that those interested in the subject may know where to obtain information.

Alternating Current Motors.

FOR several years past, from the days of Prof. Ferrari's investigations, which were followed by those of Tesla, Zipernowsky, and a host of imitators, we have periodically heard of the question of alternating current motors being solved. More than once have we questioned the solution of this difficult problem, and certain enthusiastic inventors had the free use of our pages for the ventilation of their pet theories, yet we are not aware of the existence of any commercially successful motor, one which gives a good efficiency with a reasonable speed at variable loads, and which is entirely self-starting. If those gentlemen, who then contradicted our assertions, can now show us any radical improvements, we shall be glad to record them. Mr. Kapp spoke of several types of small alternating current motors with two and three wires, but he has not pointed out any successful applications. We were particularly struck with Mr. Kapp's ingenious model for illustrating the theory of rotation by alternating currents. This model consisted of two cranks capable of revolving simultaneously two connecting rods and a disc movable on its centre. The centres of the cranks and the centre of the upper junction of the connecting rods formed a triangle. The pin through the eyes of the connecting rods represented a "phantom magnet" influencing the motion of the disc. By varying the relative angle between the cranks, the pin (phantom magnet) described straight lines, circles, or ellipses, dragging with it the disc which revolved with more or less regularity according as there was any slip, such slip indicating loss of energy. We had to imagine that the crank angles corresponded to the position of the wire coils on the armature relatively to each other.

PHENOMENA OF ALTERNATING CURRENTS OF VERY HIGH FREQUENCY.

BY NIKOLA TESLA.

Alternate current machines of high frequency; curious experiments with Geissler tubes and lamps; an exploded notion; noiseless alternating arcs; constant current and constant potential; interesting experiment with a condenser; the Ferranti-main effect; Da liegt der Hase im Pfeffer begraben; suggestions of Mr. Swinburne.

ELECTRICAL journals are getting to be more and more interesting. New facts are observed and new problems spring up daily which command the attention of engineers. In the last few numbers of the English journals, there have been several new matters brought up which have attracted more than usual attention. The address of Professor Crookes has revived the interest in his beautiful and skilfully performed experiments, the effect observed on the Ferranti mains has elicited the expressions of opinion of some of the leading English electricians, and Mr. Swinburne has brought out some interesting points in connection with condensers and dynamo excitation.

The writer's own experiences have induced him to venture a few remarks in regard to these and other matters, hoping that they will afford some useful information or suggestion to the reader. (*Electrical World.*)

Among his many experiments Professor Crookes shows some performed with tubes devoid of internal electrodes, and from his remarks it must be inferred that the results obtained with these tubes are rather unusual. If this be so, then the writer must regret that Professor Crookes, whose admirable work has been the delight of every investigator, should not have availed himself in his experiments of a properly constructed alternate current machine—namely, one capable of giving, say, 10,000 to 20,000 alternations per second. His researches on this difficult but fascinating subject would then have been even more complete. It is true that when using such a machine in connection with an induction coil the distinctive character of the electrodes—which is desirable, if not essential, in many experiments—is lost, in most cases both the electrodes behaving alike; but, on the other hand, the advantage is gained that the effects may be exalted at will. When using a rotating switch or commutator the rate of change obtainable in the primary current is limited. When the commutator is more rapidly revolved the primary current diminishes, and if the current be increased, the sparking, which cannot be completely overcome by the condenser, impairs considerably the virtue of the apparatus. No such limitations exist when using an alternate current machine, as any desired rate of change may be produced in the primary current. It is thus possible to obtain excessively high electromotive forces in the secondary circuit with a comparatively small primary current; moreover, the perfect regularity in the working of the apparatus may be relied upon.

The writer will incidentally mention that any one who attempts for the first time to construct such a machine will have a tale of woe to tell. He will first start out, as a matter of course, by making an armature with the required number of polar projections. He will then get the satisfaction of having produced an apparatus which is fit to accompany a thoroughly Wagnerian opera. It may besides possess the virtue of converting mechanical energy into heat in a nearly perfect manner. If there is a reversal in the polarity of the projections, he will get heat out of the machine; if there is no reversal, the heating will be less, but the output will be next to nothing. He will then abandon the iron in the armature, and he will get from the Scylla to the Charybdis. He will look for one difficulty and will find another, but, after a few trials, he may get nearly what he wanted.

Among the many experiments which may be performed with such a machine, of not the least interest are those performed with a high tension induction coil. The character of the discharge is completely changed. The arc is established at much greater distances, and it is so easily affected by the slightest current of air that it often wriggles around in the most singular manner. It usually emits the rhythmical sound peculiar to the alternate arcs, but the curious

point is that the sound may be heard with a number of alternations far above 10,000 per second, which by many is considered to be about the limit of audition. In many respects the coil behaves like a static machine. Points impair considerably the sparking interval, electricity escaping from them freely, and from a wire attached to one of the terminals streams of light issue, as though it were connected to a pole of a powerful Toepler machine. All these phenomena are, of course, mostly due to the enormous differences of potential obtained. As a consequence of the self-induction of the coil and the high frequency, the current is minute while there is a corresponding rise of pressure. A current impulse of some strength started in such a coil should persist to flow no less than four ten-thousandths of a second. As this time is greater than half the period it occurs that an opposing electromotive force begins to act while the current is still flowing. As a consequence, the pressure rises as in a tube filled with liquid and vibrated rapidly around its axis. The current is so small that, in the opinion and involuntary experience of the writer, the discharge of even a very large coil cannot produce seriously injurious effects, whereas, if the same coil were operated with a current of lower frequency, though the electromotive force would be much smaller, the discharge would be most certainly injurious. This result, however, is due in part to the high frequency. The writer's experiences tend to show that the higher the frequency the greater the amount of electrical energy which may be passed through the body without serious discomfort; whence it seems certain that human tissues act as condensers.

One is not quite prepared for the behaviour of the coil when connected to a Leyden jar. One, of course, anticipates that since the frequency is high the capacity of the jar should be small. He therefore takes a very small jar, about the size of a small wine glass, but he finds that even with this jar the coil is practically short-circuited. He then reduces the capacity until he comes to about the capacity of two spheres, say, 10 centimetres in diameter and two to four centimetres apart. The discharge then assumes the form of a serrated band exactly like a succession of sparks viewed in a rapidly-revolving mirror; the serations, of course, corresponding to the condenser discharges. In this case one may observe a queer phenomenon. The discharge starts at the nearest points, works gradually up, breaks somewhere near the top of the spheres, begins again at the bottom, and so on. This goes on so fast that several serrated bands are seen at once. One may be puzzled for a few minutes, but the explanation is simple enough. The discharge begins at the nearest points, the air is heated and carries the arc upward until it breaks, when it is re-established at the nearest points, &c. Since the current passes easily through a condenser of even small capacity, it will be found quite natural that connecting only one terminal to a body of the same size, no matter how well insulated, impairs considerably the striking distance of the arc.

Experiments with Geissler tubes are of special interest. An exhausted tube, devoid of electrodes of any kind, will light up at some distance from the coil. If a tube from a vacuum pump is near the coil the whole of the pump is brilliantly lighted. An incandescent lamp approached to the coil lights up and gets perceptibly hot. If a lamp have the terminals connected to one of the binding posts of the coil and the hand is approached to the bulb, a very curious and rather unpleasant discharge from the glass to the hand takes place, and the filament may become incandescent. The discharge resembles to some extent the stream issuing from the plates of a powerful Toepler machine, but is of incomparably greater quantity. The lamp in this case acts as a condenser, the rarefied gas being one coating, the operator's hand the other. By taking the globe of a lamp in the hand, and by bringing the metallic terminals near to or in contact with a conductor connected to the coil, the carbon is brought to bright incandescence and the glass is rapidly heated. With a 100-volt 10-C.P. lamp one may without great discomfort stand as much current as will bring the lamp to a considerable brilliancy; but it can be held in the hand only for a few minutes, as the glass is heated in an incredibly short time. When a tube is lighted by bringing it near to the coil it may be made to go out by interposing a metal plate or the hand between the coil and the tube; but if the metal plate be fastened to a glass rod or otherwise insulated, the tube may remain lighted if the plate be interposed, or may even increase in luminosity. The effect depends on the position of the plate and tube relatively to the coil, and may be always easily foretold by *assuming* that conduction takes place from one terminal of the coil to the other. According to the position of the plate, it may either divert from or direct the current to the tube.

In another line of work the writer has in frequent experiments maintained incandescent lamps of 50 or 100 volts burning at any desired candle-power with both the terminals of each lamp connected to a stout copper wire of no more than a few feet in length. These experiments seem interesting enough, but they are not more so than the queer experiment of Faraday, which has been revived and made much of by recent investigators, and in which a discharge is made to jump between two points of a bent copper wire. An experiment may be cited here which may seem equally interesting. If a Geissler tube, the terminals of which are joined by a copper wire, be approached to the coil, certainly no one would be prepared to see the tube light up. Curiously enough, it does light up, and, what is more, the wire does not seem to make much difference. Now, one is apt to think in the first moment that the impedance of the wire might have something to do with the phenomenon. But this is of course immediately rejected, as for this an enormous frequency would be required. The result, however, seems puzzling only at first; for upon reflection it is quite clear that the wire can make but little difference. It may be explained in more than one way, but it agrees perhaps best with observation to assume that conduction takes place from the terminals of the coil through the space. On this assumption, if the tube with the wire be held in any position, the wire can divert little more than the current which passes through the space occupied by the wire and the metallic terminals of the tube; through the adjacent space the current passes practically undisturbed. For this reason, if the tube be held in any position at right angles to the line joining the binding posts of the coil, the wire makes hardly any difference, but in a position more or less parallel with that line it impairs to a certain extent the brilliancy of the tube and its facility to light up. Numerous other phenomena may be explained on the same assumption. For instance, if the ends of the tube be provided with washers of sufficient size, and held in the line joining the terminals of the coil, it will not light up, as then nearly the whole of the current, which would otherwise pass uniformly through the space between the washers, is diverted through the wire. But if the tube be inclined sufficiently to that line, it will light up in spite of the washers. Also, if a metal plate be fastened upon a glass rod, and held at right angles to the line joining the binding posts, and nearer to one of them, a tube held more or less parallel with the line will light up instantly when one of its terminals touches the plate, and will go out when separated from the plate. The greater the surface of the plate up to a certain limit, the easier the tube will light up. When a tube is placed at right angles to the straight line joining the binding posts, and then rotated, its luminosity steadily increases until it is parallel with that line. The writer must state, however, that he does not favour the idea of a leakage or current through the space any more than as a suitable explanation, for he is convinced that all these experiments could not be performed with a static machine yielding a constant difference of potential, and that condenser action is largely concerned in these phenomena.

It is well to take certain precautions when operating a Rhumkorff coil with very rapidly alternating currents. The primary current should not be turned on too long, else the core may get so hot as to melt the gutta-percha or paraffin, or otherwise injure the insulation, and this may occur in a surprisingly short time, the current's strength considered. The primary current being turned on, the fine wire terminals may be joined without great risk, the impedance being so great that it is difficult to force enough current through the fine wire so as to injure it, and, in fact, the coil may be on the whole much safer when the terminals of the fine wire are connected, than when they are insulated; but special care should be taken when the terminals are connected to the coatings of a Leyden jar, for with anywhere near the critical capacity, which just counteracts the self-induction at the existing frequency, the coil might meet the fate of St. Polycarpus. If an expensive vacuum pump is lighted up by

being near to the coil, or touched with a wire connected to one of the terminals, the current should be left on no more than a few moments, else the glass will be cracked by the heating of the rarified gas in one of the narrow passages—in the writer's own experience *quod erat demonstrandum*.*

There are a good many other points of interest which may be observed in connection with such a machine. Experiments with the telephone, a conductor in a strong field or with a condenser or arc seem to afford certain proof that sounds far above the usual accepted limit of hearing would be perceived. A telephone will admit notes of twelve to thirteen thousand vibrations per second, then the inability of the core to follow such rapid alternations begins to tell. If, however, the magnet and core be replaced by a condenser and the terminals connected to the high-tension secondary of a transformer higher notes may still be heard. If the current be sent round a finely laminated core and a small piece of thin sheet iron be held gently against the core, a sound may be still heard with thirteen to fourteen thousand alternations per second, provided the current is sufficiently strong. A small coil, however, tightly packed between the poles of a powerful magnet, will emit a sound with the above number of alternations, and arcs may be audible with still a higher frequency. The limit of audition is variously estimated. In Sir William Thomson's writings it is stated somewhere that ten thousand per second, or nearly so, is the limit. Other, but less reliable sources, give it as high as twenty-four thousand per second. The above experiments have convinced the writer that notes of an incomparably higher number of vibrations per second would be perceived provided they could be produced with sufficient power. There is no reason why it should not be so. The condensations and rarefactions of the air would necessarily set the diaphragm in a corresponding vibration and some sensation would be produced whatever—within certain limits—the velocity of transmission to their nerve centres, though it is probable that for want of exercise the ear would not be able to distinguish any such high note. With the eye it is different; if the sense of vision is based upon some resonance effect, as many believe, no amount of increase in the intensity of the ethereal vibration could extend our range of vision on either side of the visible spectrum.

The limit of audition of an arc depends on its size. The greater the surface by a given heating effect in the arc the higher the limit of audition. The highest notes are emitted by the high-tension discharges of an induction coil in which the arc is, so to speak, all surface. If R be the resistance of an arc, and C the current, and the linear dimensions be n times increased, then the resistance is $\frac{R}{n}$, and with the same current density the current would be n^2C; hence the heating effect is n^3 times greater, while the surface is only n^2 times as great. For this reason very large arcs would not emit any rythmical sound even with a very low frequency. It must be observed, however, that the sound emitted depends to some extent also on the composition of the carbon. If the carbon contain highly refractory material, this when heated tends to maintain the temperature of the arc uniform and the sound is lessened; for this reason it would seem that an alternating arc requires such carbons.

With currents of such high frequencies it is possible to obtain noiseless arcs, but the regulation of the lamp is rendered extremely difficult on account of the excessively small attractions or repulsions between conductors conveying these currents.

An interesting feature of the arc produced by these rapidly alternating currents is its persistency. There are two causes for it, one of which is always present, the other sometimes only. One is due to the character of the current and the other to the property of the machine. The first cause is the more important one, and is due directly to the rapidity of the alternations. When an arc is formed by a periodically undulating current, there is a corresponding undulation in the temperature of the gaseous column, and, therefore, a corresponding undulation in the resistance of the arc. But the resistance of the arc varies enormously with the temperature of the gaseous column, being practically infinite when the gas between the electrodes is cold. The persistence of the arc, therefore, depends on the inability of the column to cool. It is for this reason impossible to maintain an arc with the current alternating only a few times a second. On the other hand, with a practically continuous current, the arc is easily maintained, the column being constantly kept at a high temperature and low resistance. The higher the frequency the smaller the time interval during which the arc may cool and increase considerably in resistance. With a frequency of 10,000 per second or more in an arc of same size excessively small variations of temperature are superimposed upon a steady temperature, like ripples on the surface of a deep sea. The heating effect is practically continuous, and the arc behaves like one produced by a continuous current, with the exception, however, that it may not be quite as easily started, and that the electrodes are equally consumed; though the writer has observed some irregularities in this respect.

The second cause alluded to, which possibly may not be present, is due to the tendency of a machine of such high frequency to maintain a practically constant current. When the arc is lengthened the electromotive force rises in proportion and the arc appears to be more persistent.

Such a machine is eminently adapted to maintain a constant current, but it is very unfit for a constant potential. As a matter of fact, in certain types of such machines a nearly constant current is an almost unavoidable result. As the number of poles or polar projections is greatly increased, the clearance becomes of great importance. One has really to do with a great number of very small machines. Then there is the impedance in the armature, enormously augmented by the high frequency. Then, again, the magnetic leakage is facilitated. If there are three or four hundred alternate poles the leakage is so great that it is virtually the same as connecting, in a two-pole machine, the poles by a piece of iron. This disadvantage, it is true, may be obviated more or less by using a field throughout of the same polarity, but then one encounters difficulties of a different nature. All these things tend to maintain a constant current in the armature circuit.

In this connection it is interesting to notice that even to-day engineers are astonished at the performance of a constant current machine, just as, some years ago, they used to consider it an extraordinary performance if a machine was capable of maintaining a constant potential difference between the terminals. Yet one result is just as easily secured as the other. It must only be remembered that in an inductive apparatus of any kind, if constant potential is required, the inductive relation between the primary or exciting and secondary or armature circuit must be the closest possible; whereas, in an apparatus for constant current just the opposite is required. Furthermore, the opposition to the current's flow in the induced circuit must be as small as possible in the former and as great as possible in the latter case. But opposition to a current's flow may be caused in more than one way. It may be caused by ohmic resistance or self-induction. One may make the induced circuit of a dynamo machine or transformer of such high resistance that when operating devices of considerably smaller resistance within very wide limits a nearly constant current is maintained. But such high resistance involves a great loss in power, hence it is not practicable. Not so self-induction. Self-induction does not necessarily mean loss of power. The moral is, use self-induction instead of resistance. There is, however, a circumstance which favours the adoption of this plan, and this is, that a very high self-induction may be obtained cheaply by surrounding a comparatively small length of wire more or less completely with iron, and, furthermore, the effect may be exalted at will by causing a rapid undulation of the current. To sum up, the requirements for constant current are: Weak magnetic connection between the induced and inducing circuits, greatest possible self-induction with the least resistance, greatest practicable rate of change of the current. Constant potential, on the other hand, requires closest magnetic connection between the circuits, steady induced current, and, if possible, no reaction. If the latter conditions could be fully satisfied in a constant potential machine, its output would surpass many times that of a machine primarily designed to give constant current. Unfortunately, the type of machine in which these conditions may

* It is thought necessary to remark that, although the induction coil may give quite a good result when operated with such rapidly alternating currents, yet its construction, quite irrespective of the iron core, makes it very unfit for such high frequencies, and to obtain the best results the construction should be greatly modified.

be satisfied is of little practical value, owing to the small electromotive force obtainable and the difficulties in taking off the current.

With their keen inventor's instinct, the now successful arc light men have early recognised the desideratums of a constant current machine. Their arc light machines have weak fields, large armatures, with a great length of copper wire and few commutator segments to produce great variations in the current's strength and to bring self-induction into play. Such machines may maintain within considerable limits of variation in the resistance of the circuit a practically constant current. Their output is, of course, correspondingly diminished, and, perhaps, with the object in view not to cut down the output too much, a simple device compensating exceptional variations is employed. The undulation of the current is almost essential to the commercial success of an arc-light system. It introduces in the circuit a steadying element taking the place of a large ohmic resistance, without involving a great loss in power, and, what is more important, it allows the use of simple clutch lamps, which with a current of a certain number of impulses per second, best suitable for each particular lamp, will, if properly attended to, regulate even better than the finest clockwork lamps. This discovery has been made by the writer—several years too late.

It has been asserted by competent English electricians that in a constant current machine or transformer the regulation is effected by varying the phase of the secondary current. That this view is erroneous may be easily proved by using, instead of lamps, devices, each possessing self-induction and capacity, or self-induction and resistance—that is, retarding and accelerating components—in such proportions as to not affect materially the phase of the secondary current. Any number of such devices may be inserted or cut out; still it will be found that the regulation occurs, a constant current being maintained, while the electromotive force is varied with the number of the devices. The change of phase of the secondary current is simply a result following from the changes in resistance, and, though secondary reaction is always of more or less importance, yet the real cause of the regulation lies in the existence of the conditions above enumerated. It should be stated, however, that in the case of a machine the above remarks are to be restricted to the cases in which the machine is independently excited. If the excitation be effected by commutating the armature current, then the fixed position of the brushes makes any shifting of the neutral line of the utmost importance, and it may not be thought immodest of the writer to mention that, as far as records go, he seems to have been the first who has successfully regulated machines in providing a bridge connection between a point of the external circuit and the commutator by means of a third brush. The armature and field being properly proportioned, and the brushes placed in their determined positions, a constant current or constant potential resulted from the shifting of the diameter of commutation by the varying loads.

In connection with machines of such high frequencies the condenser affords an especially interesting study. It is easy to raise the electromotive force of such a machine to four or five times the value by simply connecting the condenser to the circuit, and the writer has continually used the condenser for the purposes of regulation as suggested by Blakesley in his book on alternate currents, in which he has treated the most frequently occurring condenser problems with exquisite simplicity and clearness. The high frequency allows the use of small capacities and renders investigation easy. But, although in most of the experiments the result may be foretold, yet some phenomena observed seem at first curious. One experiment performed three or four months ago with such a machine and a condenser may serve as illustration. A machine was used giving about 20,000 alternations per second. Two bare wires of about 20 feet long and two millimetres diameter, in close proximity to each other, were connected to the terminals of the machine on the one end, and to a condenser on the other. A small transformer without an iron core, of course, was used to bring the reading within the range of a Cardew voltmeter by connecting the voltmeter to the secondary. On the terminals of the condenser the electromotive force was about 120 volts, and from there inch by inch it gradually fell until on the terminals of the machine it was about 65 volts. It was virtually as though the condenser were a generator, and the line and armature circuit simply a resistance connected to it. The writer looked for a case of resonance, but he was unable to augment the effect by varying the capacity very carefully and gradually or by changing the speed of the machine. A case of pure resonance he was unable to obtain. When a condenser was connected to the terminals of the machine—the self-induction of the armature being first determined in the maximum and minimum position and the mean value taken—the capacity which gave the highest electromotive force corresponded most nearly to that which just counteracted the self-induction with the existing frequency. If the capacity was increased or diminished, the electromotive force fell as expected.

With frequencies as high as the above-mentioned, the condenser effects are of enormous importance. The condenser becomes a highly efficient apparatus capable of transferring considerable energy.

The writer has thought that machines of high frequencies may find use at least in cases when transmission at great distances is not contemplated. The increase of the resistance may be reduced in the conductors and exalted in the devices when heating effects are wanted; transformers may be made of higher efficiency and greater outputs, and valuable results may be secured by means of condensers. In using machines of high frequency the writer has been able to observe condenser effects which would have otherwise escaped his notice. He has been very much interested in the phenomenon observed on the Ferranti main, which has been so much spoken of. Opinions have been expressed by competent electricians, but up to the present all still seems to be conjecture. Undoubtedly in the views expressed the truth must be contained, but, as the opinions differ, some must be erroneous. Upon seeing the diagram of M. Ferranti in the *Electrician* of December 19th, the writer has formed his opinion of the effect. In the absence of all the necessary data he must content himself to express in words the process which, in his opinion, must undoubtedly occur. The condenser brings about two effects: (1) it changes the phases of the currents in the branches; (2) it changes the strength of the currents. As regards the change in phase, the effect of the condenser is to accelerate the current in the secondary at Deptford, and to retard it in the primary at London. The former has the effect of diminishing the self-induction in the Deptford primary, and this means lower electromotive force on the dynamo. The retardation of the primary at London, as far as merely the phase is concerned, has little or no effect, since the phase of the current in the secondary in London is not arbitrarily kept.

Now, the second effect of the condenser is to increase the current in both the branches. It is immaterial whether there is equality between the currents or not; but it is necessary to point out, in order to see the importance of the Deptford step-up transformer, that an increase of the current in both the branches produces opposite effects. At Deptford it means further lowering of the electromotive force at the primary, and at London it means increase of the electromotive force at the secondary. Therefore all the things co-act to bring about the phenomenon observed. Such actions, at least, have been formed to take place under similar conditions. When the dynamo is connected directly to the main, one can see that no such action can happen.

The writer has been particularly interested in the suggestions and views expressed by Mr. Swinburne. Mr. Swinburne has frequently honoured him by disagreeing with his views. Three years ago, when the writer, against the prevailing opinion of engineers, advanced an open circuit transformer, Mr. Swinburne was the first to condemn it by stating in the *Electrician*; "The (Tesla) transformer must be inefficient; it has magnetic poles revolving, and has thus an *open* magnetic circuit." Two years later Mr. Swinburne becomes the champion of the open circuit transformer, and offers to convert him. But, *tempora mutantur, et nos mutamur in illis.*

The writer cannot believe in the armature reaction theory as expressed in *Industries*, though undoubtedly there is some truth in it. Mr. Swinburne's interpretation, however, is so broad that it may mean anything.

Mr. Swinburne seems to have been the first who has called attention to the heating of the condensers. The astonishment expressed at that by the ablest electrician is a striking

illustration of the desirability to execute experiments on a large scale. To the scientific investigator, who deals with the minutest quantities, who observes the faintest effects, far more credit is due than to one who experiments with apparatus on an industrial scale; and indeed history of science has recorded examples of marvellous skill, patience and keenness of observation. But however great the skill, and however keen the observer's perception, it can only be of advantage to magnify an effect and thus facilitate its study. Had Faraday carried out but one of his experiments on dynamic induction on a large scale it would have resulted in an incalculable benefit.

In the opinion of the writer the heating of the condensers is due to three distinct causes: first, leakage or conduction; second, imperfect elasticity in the dielectric, and, third, surging of the charges in the conductor.

In many experiments he has been confronted with the problem of transferring the greatest possible amount of energy across a dielectric. For instance, he has made incandescent lamps the ends of the filaments being completely sealed in glass, but attached to interior condenser coatings so that all the energy required had to be transferred across the glass with a condenser surface of no more than a few centimetres square. Such lamps would be a practical success with sufficiently high frequencies. With alternations as high as 15,000 per second it was easy to bring the filaments to incandescence. With lower frequencies this could also be effected, but the potential difference had, of course, to be increased. The writer has then found that the glass gets, after a while, perforated and the vacuum is impaired. The higher the frequency the longer the lamp can withstand. Such a deterioration of the dielectric always takes place when the amount of energy transferred across a dielectric of definite dimensions and by a given frequency is too great. Glass withstands best, but even glass is deteriorated. In this case the potential difference on the plates is of course too great and losses by conduction and imperfect elasticity result. If it is desirable to produce condensers capable to stand great differences of potential, then the only dielectric which will involve no losses is a gas under pressure. The writer has worked with air under enormous pressures, but there are a great many practicai difficulties in that direction. He thinks that, in order to make the condensers of considerable practical utility, higher frequencies should be used; though such a plan has besides others the great disadvantage that the system would become very unfit for the operation of motors.

If the writer does not err, Mr. Swinburne has suggested a way of exciting an alternator by means of a condenser.

For a number of years past the writer has carried on experiments with the object in view of producing a practical self-exciting alternator. He has in a variety of ways succeeded in producing some excitation of the magnets by means of alternating currents, which were not commutated by mechanical devices. Nevertheless, his experiments have revealed a fact which stands as solid as the rock of Gibraltar. No practical excitation can be obtained with a single periodically varying and not commutated current. The reason is that the changes in the strength of the exciting current produce corresponding changes in the field strength, with the result of inducing currents in the armature; and these currents interfere with those produced by the motion of the armature through the field, the former being a quarter phase in advance of the latter. If the field be laminated, no excitation can be produced; if it be not laminated, some excitation is produced, but the magnets are heated. By combining two exciting currents displaced by a quarter phase, excitation may be produced in both cases, and if the magnet be not laminated the heating effect is comparatively small, as a uniformity in the field strength is maintained, and, were it possible to produce a perfectly uniform field, excitation on this plan would give quite practical results. If such results are to be secured by the use of a condenser, as suggested by Mr. Swinburne, it is necessary to combine two circuits separated by a quarter phase; that is to say, the armature coils must be wound in two sets and connected to one or two independent condensers. The writer has done some work in that direction, but must defer the description of the devices for some future time.

PHENOMENA OF ALTERNATING CURRENTS OF VERY HIGH FREQUENCY.*

BY NIKOLA TESLA.

Among his many experiments Prof. Crookes shows some performed with tubes devoid of internal electrodes, and from his remarks it must be inferred that the results obtained with these tubes are rather unusual. If this be so, then the writer must regret that Prof. Crookes, whose admirable work has been the delight of every investigator, should not have availed himself in his experiments of a properly constructed alternate-current machine—viz., one capable of giving say, 10,000 to 20,000 alternations per second. His researches on this difficult but fascinating subject would then have been even more complete. It is true that when using such a machine in connection with an induction coil the distinctive character of the electrodes—which is desirable, if not essential, in many experiments is lost, in most cases both the electrodes behaving alike ; but, on the other hand, the advantage is gained that the effects may be exalted at will. It is possible to obtain excessively high electromotive forces in the sccondary circuit with a comparatively small primary current ; moreover, the perfect regularity in the working of the apparatus may be relied upon.

The writer will incidentally mention that anyone who attempts for the first time to construct such a machine will have a tale of woe to tell. He will first start out, as a matter of course, by making an armature with the required number of polar projections. He will then get the satisfaction of having produced an apparatus which is fit to accompany a thoroughly Wagnerian opera. It may, besides, possess the virtue of converting mechanical energy into heat in a nearly perfect manner. If there is a reversal in the polarity of the projections, he will get heat out of the machine ; if there is no reversal, the heating will be less, but the output will be next to nothing. He will then abandon the iron in the armature, and he will get from the Scylla to the Charybdis. He will look for one difficulty and will find another, but, after a few trials, he may get nearly what he wanted.

Among the many experiments which may be performed with such a machine, of not the least interest are those performed with a high-tension induction coil. The character of the discharge is completely changed. The arc is established at much greater distances, and it is so easily affected by the slightest current of air that it often wriggles around in the most singular manner. It usually emits the rhythmical sound peculiar to the alternate current arcs, but the curious point is that the sound may be heard with a number of alternations far above 10,000 per second, which by many is considered to be about the limit of audition. In many respects the coil behaves like a static machine. Points impair considerably the sparking interval, electricity escaping from them freely, and from a wire attached to one of the terminals streams of light issue, as though it were connected to a pole of a powerful Toepler machine. All these phenomena are, of course, mostly due to the enormous differences of potential obtained. As a consequence of the self-induction of the coil and the high frequency, the current is minute, while there is a corresponding rise of pressure. A current impulse of some strength started in such a coil should persist to flow no less than four ten-thousandths of a second. As this time is greater than half the period it occurs that an opposing electromotive force begins to act while the current is still flowing. As a consequence, the pressure rises as in a tube filled with liquid and vibrated rapidly around its axis. The writer's experiences tend to show that the higher the frequency the greater the amount of electrical energy which may be passed through the body without serious discomfort ; whence it seems certain that human tissues act as condensers.

Experiments with Geissler tubes are of special interest. An exhausted tube, devoid of electrodes of any kind, will light up at some distance from the coil. If a tube from a vacuum pump is near the coil the whole of the pump is brilliantly lighted. An incandescent lamp approached to the coil lights up and gets perceptibly hot. If a lamp have the terminals connected to one of the binding posts of the coil and the hand is approached to the bulb, a very curious and rather unpleasant discharge from the glass to the hand takes place, and the filament may become incandescent. The discharge resembles to some extent the stream issuing from the plates of a powerful Toepler machine, but is of incomparably greater quantity. The lamp in this case acts as a condenser, the rarefied gas being one coating, the operator's hand the other. By taking the globe of a lamp in the hand, and by bringing the metallic terminals near to or in contact with a conductor connected to the coil, the carbon is brought to bright incandescence and the glass is rapidly heated. With a 100-volt 10 candle-power lamp one may without great discomfort stand as much current as will bring the lamp to a considerable brilliancy ; but it can be held in the hand only for a few minutes, as the glass is heated in an incredibly short time. When a tube is lighted by bringing it near to the coil, it may be made to go out by interposing a metal plate or the hand between the coil and tube ; but if the metal plate be fastened to a glass rod or otherwise insulated, the tube may remain lighted if the plate be interposed, or may even increase in luminosity. The effect depends on the position of the plate and tube relatively to the coil, and may be always easily foretold by *assuming* that conduction takes place from one terminal of the coil to the other. According to the position of the plate, it may either divert from or direct the current to the tube.

In another line of work the writer has in frequent experiments maintained incandescent lamps of 50 or 100 volts burning at any desired candle-power with both the terminals of each lamp connected to a stout copper wire of no more than a few feet in length. These experiments seem interesting enough, but they are not more so than the queer experiment of Faraday, which has been revived and made much of by recent investigators, and in which a discharge is made to jump between two points of a bent copper wire. An experiment may be cited here which may seem equally interesting. If a Geissler tube, the terminals of which are joined by a copper wire, be approached to the coil, certainly no one would be prepared to see the tube light up. Curiously enough it does light up, and, what is more, the wire does not seem to make much difference. Now one is apt to think in the first moment that the impedance of the wire might have something to do with the phenomenon. But this is of course immediately rejected, as for this an enormous frequency would be required. The result, however, seems puzzling only at first ; for upon reflection it is quite clear than the wire can make but little difference. It may be explained in more than one way, but it agrees perhaps best with observation to assume that conduction takes place from the terminals of the coil through the space. On this assumption, if the tube with the wire be held in any position, the wire can divert little more than the current which passes through the space occupied by the wire and the metallic terminals of the tube ; through the adjacent space the current passes practically undisturbed. For this reason, if the tube be held in any position at right angles to the line join the binding posts of the coil, the wire makes hardly any difference, but in a position more or less parallel with that line, it impairs to a certain extent the brilliancy of the tube and its facility to light up.

It is well to take certain precautions when operating a Ruhmkorff coil with very rapidly alternating currents. The primary current should not be turned on too long, else the core may get so hot as to melt the gutta-percha or paraffin, or otherwise injure the insulation, and this may occur in a surprisingly short time, the current's strength considered. The primary current being turned on, the fine wire terminals may be joined without great risk, the impedence being so great that it is difficult to force enough current through the fine wire so as to injure it, and in fact the coil may be on the whole much safer when the terminals of the fine wire are connected than when they are insulated ; but special care should be taken when the terminals are connected to the coating of a Leyden jar with anywhere near the critical capacity.

The limit of audition of an arc depends on its size. The greater the surface by a given heating effect in the arc the higher the limit of audition. The highest notes are emitted by the high tension discharges of an induction coil in which the arc is, so to speak, all surface. If R be the resistance of an arc, and C the current, and the linear dimensions be n times increased, then the resistance is $\frac{R}{n}$, and with the same current density the current would be $n^2 C$; hence the heating effect is n^3 times greater, while the surface is only n^2 times as great. For this reason very large arcs would not emit any rhythmical sound even with a very low frequency. It must be observed, however, that the sound emitted depends to some extent also on the composition of the carbon. If the carbon contain highly refractory material, this when heated tends to maintain the temperature of the arc uniform, and the sound is lessened ; for this reason it would seem that an alternating arc requires such carbons. With currents of such high frequencies it is possible to obtain noiseless arcs, but the regulation of the lamp is rendered extremely difficult on account of the excessively small attractions or repulsions between conductors conveying these currents. An interesting feature of the arc produced by these rapidly alternating currents is its persistency. There are two causes for it, one of which is always present, the other sometimes only. One is due to the character of the current, and the other to a property of the machine. The first cause is the more important one, and is due directly to the rapidity of the alternations. The heating effect is practically continuous and the arc behaves like one produced by a continual current, with the exception, however, that it may not be quite as easily started, and that the electrodes are equally consumed, though the writer has observed some irregularities in this respect.

The second cause alluded to, which possibly may not be present, is due to the tendency of a machine of such high frequency to maintain a practically constant current. When the arc is lengthened the electromotive force rises in proportion, and the arc appears

* Abstract from the *Electrical World* of New York.

to be more peristent. Such a machine is eminently adapted to maintain a constant current, but it is very unfit for a constant potential. As a matter of fact, in certain types of such machines a nearly constant current is an almost unavoidable result. As the number of poles or polar projections is greatly increased, the clearance becomes of great importance. One has really to do with a great number of very small machines. . Then there is the impedence in the armature, enormously augmented by the high frequency. Then, again, the magnetic leakage is facilitated. If there are three or four hundred alternate poles the leakage is so great that it is virtually the same as connecting in a two-pole machine the poles by a piece of iron. This disadvantage, it is true, may be obviated more or less by using a field throughout of the same polarity, but then one encounters difficulties of a different nature. All these things tend to maintain a constant current in the armature circuit.

In this connection it is interesting to notice that even to-day engineers are astonished at the performance of a constant-current machine, just, as some years ago, they used to consider it an extraordinary performance if a machine was capable of maintaining a constant potential difference between the terminals. Yet one result is just as easily secured as the other. It must only be remembered that in an inductive apparatus of any kind, if constant potential isrequired, the inductive relation between the primary or exciting and secondary or armature circuit must be the closest possible ; whereas, in an apparatus for constant current just the opposite is required. Furthermore, the opposition to the current's flow in the induced circuit must be as small as possible in the former and as great as possible in the latter case. But opposition to a current's flow may be caused in more than one way. It may be caused by ohmic resistance or self-induction. One may make the induced circuit of a dynamo machine or transformer of such high resistance than when operating devices of considerably smaller resistance within very wide limits a nearly constant current is maintained. But such high resistance involves a great loss in power, hence it is not practicable. Not so self-induction. Self-induction does not necessarily mean loss of power. The moral is, use self-induction instead of resistance. There is, however, a circumstance which favours the adoption of this plan, and this is, that a very high self-induction may be obtained cheaply by surrounding a comparatively small length of wire more or less completely with iron, and furthermore, the effect may be exalted at will by causing a rapid undulation of the current. To sum up, the requirements for constant current are :—Weak magnetic connection between the induced and inducing circuits, greatest possible self-induction with the least resistance, greatest practicable rate of change of the current. Constant potential, on the other hand, requires : Closest magnetic connection between the circuits, steady induced current, and, if possible, no reaction. If the latter conditions could be fully satisfied in a constant potential machine, its output would surpass many times that of a machine primarily designed to give constant current. Unfortunately, the type of machine in which these conditions may be satisfied is of little practical value, owing to the small electromotive force obtainable and the difficulties in taking off the current.

With their keen inventor's instinct, the now successful arc-light men have early recognised the desiderata of a constant current machine. Their arc-light machines have weak fields, large armatures, with a great length of copper wire and few commutator segments to produce great variations in the current's strength and to bring self-induction into play. Such machines may maintain within considerable limits of variation in the resistance of the circuit a practically constant current. Their output is of course correspondingly diminished, and, perhaps, with the object in view not to cut down the output too much, a simple device compensating exceptional variations is employed. The undulation of the current is almost essential to the commercial success of an arc-light system. It introduces in the circuit a steadying element taking the place of a large ohmic resistance, without involving a great loss in power, and, what is more important, it allows the use of simple clutch lamps, which, with a current of a certain number of impulses per second, best suitable for each particular lamp, will, if properly attended to, regulate even better than the finest clockwork lamps. This discovery has been made by the writer—several years too late.

It has been asserted by competent English electricians that in a constant-current machine or transformer the regulation is effected by varying the phase of the secondary current. That this view is erroneous may be easily proved by using, instead of lamps, devices each possessing self-induction and capacity or self-induction and resistance—that is, retarding and accelerating components—in such proportions as to not affect materially the phase of the secondary current. Any number of such devices may be inserted or cut out, still it will be found that the regulation occurs, a constant current being maintained, while the electromotive force is varied with the number of the devices. The change of phase of the secondary current is simply a result following from the changes in resistance, and, though secondary reaction is always of more or less importance, yet the real cause of the regulation lies in the existence of the conditions above enumerated. It should be stated, however, that in the case of a machine the above remarks are to be restricted to the cases in which the machine is independently excited. If the excitation be effected by commutating the armature current, then the fixed position of the brushes makes any shifting of the neutral line of the utmost importance, and it may not be thought immodest of the writer to mention that, as far as records go, he seems to have been the first who has successfully regulated machines in providing a bridge connection between a point in the external circuit and the commutator by means of a third brush. Tht armature and field being properly proportioned and the brushes placed in their determined positions, a constant current or constant potential resulted from the shifting of the diameter of commutation by the varying loads.

In connection with machines of such high frequencies, the condenser affords an especially interesting study. One experiment performed three or four months ago with such a machine and a condenser may serve as illustration. A machine was used giving about 20,000 alternations per second. Two bare wires of about 20ft. long and two millimetres diameter, in close proximity to each other, were connected to the terminals of the machine on the one end, and to a condenser on the other. A small transformer without an iron core, of course, was used to bring the reading within the range of a Cardew voltmeter by connecting the voltmeter to the secondary. On the terminals of the condenser the electromotive force was about 120 volts, and from there inch by inch it gradually fell until on the terminals of the machine it was about 65 volts. It was virtually as though the condenser were a generator, and the line and armature circuit simply a resistance connected to it. The writer looked for a case of resonance, but he was unable to augment the effect by varying the capacity very carefully and gradually or by changing the speed of the machine. A case of pure resonance he was unable to obtain. When a condenser was connected to the terminals of the machine—the self-induction of the armature being first determined in the maximum and minimum position and the mean value taken—the capacity which gave the highest electromotive force corresponded most nearly to that which just counteracted the self-induction with the existing frequency. If the capacity was increased or diminished the electromotive force fell as expected. With frequencies as high as the above-mentioned, the condenser effects are of enormous importance. The condenser becomes a highly efficient apparatus capable of transferring considerable energy.

The writer has thought that machines of high frequencies may find use at least in cases when transmission at great distances is not contemplated. The increase of the resistance may be reduced in the conductors and exalted in the devices when heating effects are wanted, transformers may be made of higher efficiency and greater outputs and valuable results may be secured by means of condensers. In using machines of high frequency, the writer has been able to observe condenser effects which would have otherwise escaped his notice. He has been very much interested in the phenomenon observed on the Ferranti main which has been so much spoken of. Opinions have been expressed by competent electricians, but up to the present all still seems to be conjecture. Undoubtedly in the views expressed the truth must be contained, but as the opinions differ some must be erroneous. Upon seeing the diagram of M. Ferranti in *The Electrician* of December 19th the writer has formed his opinion of the effect. In the absence of all the necessary data, he must content himself to express in words the process which, in his opinion, must undoubtedly occur. The condenser brings about two effects. (1) It changes the phases of the currents in the branches ; (2) it changes the strength of the currents. As regards the change in phase, the effect of the condenser is to accelerate the current in the secondary at Deptford and to retard it in the primary at London. The former has the effect of diminishing the self-induction in the Deptford primary, and this means lower electromotive force on the dynamo. The retardation of the primary at London, as far as merely the phase is concerned, has little or no effect, since the phase of the current in the secondary in London is not arbitrarily kept. Now, the second effect of the condenser is to increase the current in both the branches. It is immaterial whether there is equality between the currents or not ; but it is necessary to point out, in order to see the importance of the Deptford step-up transformer, that an increase of the current in both the branches produces opposite effects. At Deptford it means further lowering of the electromotive force at the primary, and at London it means increase of the electromotive force at the secondary. Therefore, all the things co-act to bring about the phenomenon observed. Such actions, at least, have been formed to take place under similar conditions. When the dynamo is connected directly to the main, one can see that no such action can happen.

The writer cannot believe in the armature-reaction theory as expressed in *Industries*, though undoubtedly there is some truth in it. Mr. Swinburne's interpretation, however, is so broad that it may mean anything. Mr. Swinburne seems to have been the first who has called attention to the heating of the condensers. In the

opinion of the writer, the heating of the condensers is due to three distinct causes: first, leakage or conduction; second, imperfect elasticity in the dielectric, and, third, surging of the charges in the conductor.

In many experiments he has been confronted with the problem of transferring the greatest possible amount of energy across a dielectric. For instance, he has made incandescent lamps, the ends of the filaments being completely sealed in glass, but attached to interior condenser coatings, so that all the energy required had to be transferred across the glass with a condenser surface of no more than a few centimetres square. Such lamps would be a practical success with sufficiently high frequencies. With alternations as high as 15,000 per second it was easy to bring the filaments to incandescence. With lower frequencies this could also be effected, but the potential difference had, of course, to be increased. The writer has then found that the glass gets, after a while, perforated and the vacuum is impaired. The higher the frequency the longer the lamp can withstand. Such a deterioration of the dielectric always takes place when the amount of energy transferred across a dielectric of definite dimensions and by a given frequency is too great. Glass withstands best, but even glass is deteriorated. In this case the potential difference on the plates is of course too great, and losses by conduction and imperfect elasticity result. If it is desirable to produce condensers capable to stand great differences of potential, then the only dielectric which will involve no losses is a gas under pressure. The writer has worked with air under enormous pressures, but there are a great many practical difficulties in that direction. He thinks that, in order to make the condensers of considerable practical utility, higher frequencies should be used, though such a plan has besides others the great disadvantage that the system would become very unfit for the operation of motors.

[FROM THE ELECTRICAL WORLD.]

PHENOMENA OF ALTERNATING CURRENTS OF VERY HIGH FREQUENCY.

By NIKOLA TESLA.

ELECTRICAL journals are getting to be more and more interesting. New facts are observed and new problems spring up daily which command the attention of engineers.

In the last few numbers of the English journals, principally in the *Electrician*, there have been several new matters brought up which have attracted more than usual attention. The address of Professor Crookes has revived the interest in his beautiful and skillfully performed experiments, the effect observed on the Ferranti mains has elicited the expressions of opinion of some of the leading English electricians, and Mr. Swinburne has brought out some interesting points in connection with condensers and dynamo excitation.

The writer's own experiences have induced him to venture a few remarks in regard to these and other matters, hoping that they will afford some useful information or suggestion to the reader.

Among his many experiments Professor Crookes shows some performed with tubes devoid of internal electrodes, and from his remarks it must be inferred that the results obtained with these tubes are rather unusual. If this be so, then the writer must regret that Professor Crookes, whose admirable work has been the delight of every investigator, should not have availed himself in his experiments of a properly constructed alternate current machine—namely, one capable of giving say 10,000 to 20,000 alternations per second. His researches on this difficult but fascinating subject would then have been even more complete. It is true that when using such a machine in connection with an induction coil the distinctive character of the electrodes—which is desirable, if not essential, in many experiments—is lost, in most cases both the electrodes behaving alike; but, on the other hand, the advantage is gained that the effects may be exalted at will. When using a rotating switch or commutator, the rate of change obtainable in the primary current is limited. When the commutator is more rapidly revolved, the primary current diminishes, and if the current be increased, the sparking, which cannot be completely overcome by the condenser, impairs considerably the virtue of the apparatus. No such limitations exist when using an alternate current machine, as any desired rate of change may be produced in the primary current. It is thus possible to obtain excessively high electromotive forces in the secondary circuit with a comparatively small primary current; moreover, the perfect regularity in the working of the apparatus may be relied upon.

The writer will incidentally mention that any one who attempts for the first time to construct such a machine will have a tale of woe to tell. He will first start out, as a matter of course, by making an armature with the required number of polar projections. He will then get the satisfaction of having produced an apparatus which is fit to accompany a thoroughly Wagnerian opera. It may besides possess the virtue of converting mechanical energy into heat in a nearly perfect manner. If there is a reversal in the polarity of the projections, he will get heat out of the machine; if there is no reversal, the heating will be less, but the output will be next to nothing. He will then abandon the iron in the armature, and he will get from the Scylla to the Charybdis. He will look for one difficulty and will find another, but, after a few trials, he may get nearly what he wanted.

Among the many experiments which may be performed with such a machine, of not the least interest are those performed with a high tension induction coil. The character of the discharge is completely changed. The arc is established at much greater distances, and it is so easily affected by the slightest current of air that it often wriggles around in the most singular manner. It usually emits the rhythmical sound peculiar to the alternate current arcs but the curious point is that the sound may be heard with a number of alternations far above ten thousand per second, which by many is considered to be about the limit of audition. In many respects the coil behaves like a static machine. Points impair considerably the sparking interval, electricity escaping from them freely, and from a wire attached to one of the terminal streams of light issue, as though it were connected to a pole of a powerful Toepler machine. All these phenomena are, of course, mostly due to the enormous differences of potential obtained. As a consequence of the self-induction of the coil and the high frequency, the current is minute, while there is a corresponding rise of pressure. A current impulse of some strength started in such a coil should persist to flow no less than four ten-thousandths of a second. As this time is greater than half the period, it occurs that an opposing electromotive force begins to act while the current is still flowing. As a consequence, the pressure rises as in a tube filled with liquid and vibrated rapidly around its axis. The current is so small that, in the opinion and involuntary experience of the writer, the discharge of even a very large coil cannot produce seriously injurious effects; whereas, if the same coil were operated with a current of lower frequency, though the electromotive force would be much smaller, the discharge would be most certainly injurious. This result, however, is due in part to the high frequency. The writer's experiences tend to show that the higher the frequency the greater the amount of electrical energy which may be passed through the body without serious discomfort; whence it seems certain that human tissues act as condensers.

One is not quite prepared for the behavior of the coil when connected to a Leyden jar. One, of course, anticipates that since the frequency is high the capacity of the jar should be small. He therefore takes a very small jar, about the size of a small wine-glass, but he finds that even with this jar the coil is practically short-circuited. He then reduces the capacity until he comes to about the capacity of two spheres say ten centimeters in diameter and two to four centimeters apart. The discharge then assumes the form of a serrated band exactly like a succession of sparks viewed in a rapidly revolving mirror; the serrations, of course, corresponding to the condenser discharges. In this case one may observe a queer phenomenon. The discharge starts at the nearest points, works gradually up, breaks somewhere near the top of the spheres, begins again at the bottom, and so on. This goes on so fast that several serrated bands are seen at once. One may be puzzled for a few minutes, but the explanation is simple enough. The discharge begins at the nearest points, the air is heated and carries the arc upward until it breaks, when it is re-established at the nearest points, etc. Since the current passes easily through a condenser of even small capacity, it will be found quite natural that connecting only one terminal to a body of the same size, no matter how well insulated, impairs considerably the striking distance of the arc.

Experiments with Geissler tubes are of special interest. An exhausted tube, devoid of electrodes of any kind, will light up at some distance from the coil. If a tube from a vacuum pump is near the coil, the whole of the pump is brilliantly lighted. An incandescent lamp approached to the coil lights up and gets perceptibly hot. If a lamp have the terminals connected to one of the binding posts of the coil and the hand is approached to the bulb, a very curious and rather unpleasant discharge from the glass to the hand takes place, and the filament may become incandescent. The discharge resembles to some extent the stream issuing from the plates of a powerful Toepler machine, but is of incomparably greater quantity. The lamp in this case acts as a condenser, the rarefied gas being one coating, the operator's hand the other. By taking the globe of a lamp in the hand, and by bringing the metallic terminals near to or in contact with a conductor connected to the coil, the carbon is brought to bright incandescence and the glass is rapidly heated. With a 100-volt 10 c. p. lamp one may without great discomfort stand as much current as will bring the lamp to a considerable brilliancy; but it can be held in the hand only for a few minutes, as the glass is heated in an incredibly short time. When a tube is lighted by bringing it near to the coil, it may be made to go out by interposing a metal plate or the hand between the coil and tube; but if the metal plate be fastened to a glass rod or otherwise insulated, the tube may remain lighted if the plate be interposed, or may even increase in luminosity. The effect depends on the position of the plate and tube relatively to the coil, and may be always easily foretold by *assuming* that conduction takes place from one terminal of the coil to the other. According to the position of the plate, it may either divert from or direct the current to the tube.

In another line of work the writer has in frequent experiments maintained incandescent lamps of 50 or 100 volts, burning at any desired candle power, with both the terminals of each lamp connected to a stout copper wire of no more than a few feet in length. These experiments seem interesting enough, but they are not more so than the queer experiment of Faraday, which has been revived and made much of by recent investigators, and in which a discharge is made to jump between two points of a bent copper wire. An experiment may be cited here which may seem equally interesting. If a Geissler tube, the terminals of which are joined by a copper wire, be approached to the coil, certainly no one would be prepared to see the tube light up. Curiously enough, it does light up, and, what is more, the wire does not seem to make much difference. Now one is apt to think in the first moment that the impedence of the wire might have something to do with the phenomenon. But this is of course immediately rejected, as for this an enormous frequency would be required. The result, however, seems puzzling only at first; for upon reflection it is quite clear that the wire can make but little difference. It may be explained in more than one way, but it agrees perhaps best with observation to assume that conduction takes place from the terminals of the coil through the space. On this assumption, if the tube with the wire be held in any position, the wire can divert little more than the current which passes through the space occupied by the wire and the metallic terminals of the tube; through the adjacent space the current passes practically undisturbed. For this reason, if the tube be held in any position at right angles to the line joining the binding posts of the coil, the wire makes hardly any difference, but in a position more or less parallel with that line it impairs to a certain extent the brilliancy of the tube and its facility to light up. Numerous other phenomena may be explained on the same assumption. For instance, if the ends of the tube be provided with washers of sufficient size and held in the line joining the terminals of the coil, it will not light up, as then nearly the whole of the current, which would otherwise pass uniformly through the space between the washers, is diverted through the wire. But if the tube be inclined sufficiently to that line, it will light up in spite of the washers. Also, if a metal plate be fastened upon a glass rod and held at right angles to the line joining the binding posts, and nearer to one of them, a tube held more or less parallel with the line will light up instantly when one of its terminals touches the plate and will go out when separated from the plate. The greater the surface of the plate up to a certain limit, the easier the tube will light up. When a tube is placed at right angles to the straight line joining the binding posts, and then rotated, its luminosity steadily increases until it is parallel with that line. The writer must state, however, that he does not favor the idea of a leakage or current through the space any more than as a suitable explanation, for he is convinced that all these experiments could not be performed with a static machine yielding a constant difference of potential, and that condenser action is largely concerned in these phenomena.

It is well to take certain precautions when operating a Ruhmkorff coil with very rapidly alternating currents. The primary current should not be turned on too long, else the core may get so hot as to melt the gutta percha or paraffin, or otherwise injure the insulation, and this may occur in a surprisingly short time, the current's strength considered. The primary current being turned on, the fine wire terminals may be joined without great risk, the impedence being so great that it is difficult to force enough current through the fine wire so as to injure it, and in fact the coil may be on the whole much safer when the terminals of the fine wire are connected than when they are insulated; but special care should be taken when the terminals are connected to the coatings of a Leyden jar, for with anywhere near the critical capacity, which just counteracts the self-induction at the existing frequency, the coil might meet the fate of St. Polycarpus. If an expensive vacuum pump is lighted up by being near to the coil or touched with a wire connected to one of the terminals, the current should be left on no more than a few moments, else the glass will be cracked by the heating of the rarefied gas in one of the narrow passages—in the writer's own experience *quod erat demonstrandum*.*

There are a good many other points of interest which may be observed in connection with such a machine. Experiments with the telephone, a conductor in a strong field or with a condenser or arc seem to afford certain proof that sounds far above the usual accepted limit of hearing would be perceived. A telephone will emit notes of twelve to thirteen thousand vibrations per second, then the inability of the core to follow such rapid alternations begins to tell. If, however, the magnet and core be replaced by a condenser and the terminals connected to the high-tension secondary of a transformer, higher notes may still be heard. If the current be sent around a finely laminated core and a small piece of thin sheet iron be held gently against the core, a sound may be still heard with thirteen to fourteen thousand alternations per second, provided the current is sufficiently strong. A small coil, however, tightly packed between the poles of a powerful magnet, will emit a sound with the above number of alternations, and arcs may be audible with still a higher frequency. The limit of audition is variously estimated. In Sir William Thomson's writings it is stated somewhere that ten thousand per second, or nearly so, is the limit. Other, but less reliable, sources give it as high as twenty-four thousand per second. The above experiments have convinced the writer that notes of an incomparably higher number of vibrations per second would be perceived, provided they could be produced with sufficient power. There is no reason why it should not be so. The condensations and rarefactions of the air would necessarily set the diaphragm in a corresponding vibration, and some sensation would be produced whatever—within certain limits—the velocity of transmission to their nerve centers, though it is probable that for want of exercise the ear would not be able to distinguish any such high note. With the eye it is different; if the sense of vision is based upon some resonance effect, as many believe, no amount of increase in the intensity of the ethereal vibration could extend our range of vision on either side of the visible spectrum.

The limit of audition of an arc depends on its size. The greater the surface by a given heating effect in the arc, the higher the limit of audition. The highest notes are emitted by the high-tension discharges of an induction coil in which the arc is, so to speak, all surface. If R be the resistance of an arc, and C the current, and the linear dimensions be n times increased, then the resistance is $\frac{R}{n}$, and with the same current density the current would be n^2C; hence the heating effect is n^3 times greater, while the surface is only n^2 times as great. For this reason very large arcs would not emit any rhythmical sound even with a very low frequency. It must be observed, however, that the sound emitted depends to some extent also on the composition of the carbon. If the carbon contain highly refractory material, this when heated tends to maintain the temperature of the arc uniform, and the sound is lessened; for this reason it would seem that an alternating arc requires such carbons.

With currents of such high frequencies it is possible to obtain noiseless arcs, but the regulation of the lamp is rendered extremely difficult on account of the excessively small attractions or repulsions between conductors conveying these currents.

An interesting feature of the arc produced by these rapidly alternating currents is its persistency. There are two causes for it, one of which is always present, the other sometimes only. One is due to the character of the current, and the other to a property of the machine. The first cause is the more important one, and is due directly to the rapidity of the alternations. When an arc is formed by a periodically undulating current, there is a corresponding undulation in the temperature of the gaseous column, and, therefore, a corresponding undulation in the resistance of the arc. But the resistance of the arc varies enormously with the temperature of the gaseous column, being practically infinite when the gas between the electrodes is cold. The persistence of the arc, therefore, depends on the inability of the column to cool. It is for this reason impossible to maintain an arc with the current alternating only a few times a second. On the other hand, with a practically continuous current, the arc is easily maintained, the column being constantly kept at a high temperature and low resistance. The higher the frequency, the smaller the time interval during which the arc may cool and increase considerably in resistance. With a frequency of 10,000 per second or more in an arc of same size, excessively small variations of temperature are superimposed upon a steady temperature, like ripples on the surface of a deep sea. The heating effect is practically continuous and the arc behaves like one produced by a continuous current, with the exception, however, that it may not be quite as easily started, and that the electrodes are equally consumed; though the writer has observed some irregularities in this respect.

The second cause alluded to, which possibly may not be present, is due to the tendency of a machine of such high frequency to maintain a practically constant current. When the arc is lengthened the electromotive force rises in proportion, and the arc appears to be more persistent.

Such a machine is eminently adapted to maintain a constant current, but it is very unfit for a constant potential. As a matter of fact, in certain types of such machines a nearly constant current is an almost unavoidable result. As the number of poles or polar projections is greatly increased, the clearance becomes of great importance. One has really to do with a great number of very small machines. Then there is the impedence in the armature, enormously augmented by the high frequency. Then, again, the magnetic leakage is facilitated. If there are three or four hundred alternate poles, the leakage is so great that it is virtually the same as connecting, in a two-pole machine, the

* It is thought necessary to remark that, although the induction coil may give quite a good result when operated with such rapidly alternating currents, yet its construction, quite irrespective of the iron core, makes it very unfit for such high frequencies, and to obtain the best results the construction should be greatly modified.

poles by a piece of iron. This disadvantage, it is true, may be obviated more or less by using a field throughout of the same polarity, but then one encounters difficulties of a different nature. All these things tend to maintain a constant current in the armature circuit.

In this connection it is interesting to notice that even to day engineers are astonished at the performance of a constant current machine, just as, some years ago, they used to consider it an extraordinary performance if a machine was capable of maintaining a constant potential difference between the terminals. Yet one result is just as easily secured as the other. It must only be remembered that in an inductive apparatus of any kind, if constant potential is required, the inductive relation between the primary or exciting and secondary or armature circuit must be the closest possible; whereas, in an apparatus for constant current just the opposite is required. Furthermore, the opposition to the current's flow in the induced circuit must be as small as possible in the former and as great as possible in the latter case. But opposition to a current's flow may be caused in more than one way. It may be caused by ohmic resistance or self-induction. One may make the induced circuit of a dynamo machine or transformer of such high resistance that when operating devices of considerably smaller resistance within very wide limits a nearly constant current is maintained. But such high resistance involves a great loss in power, hence it is not practicable. Not so self-induction. Self-induction does not necessarily mean loss of power. The moral is, use self-induction instead of resistance. There is, however, a circumstance which favors the adoption of this plan, and this is that a very high self-induction may be obtained cheaply by surrounding a comparatively small length of wire more or less completely with iron. and, furthermore, the effect may be exalted at will by causing a rapid undulation of the current. To sum up, the requirements for constant current are: Weak magnetic connection between the induced and inducing circuits, greatest possible self-induction with the least resistance, greatest practicable rate of change of the current. Constant potential, on the other hand, requires: Closest magnetic connection between the circuits, steady induced current, and, if possible, no reaction. If the latter conditions could be fully satisfied in a constant potential machine, its output would surpass many times that of a machine primarily designed to give constant current. Unfortunately, the type of machine in which these conditions may be satisfied is of little practical value, owing to the small electromotive force obtainable, and the difficulties in taking off the current.

With their keen inventor's instinct, the now successful arc light men have early recognized the desiderata of a constant current machine. Their arc light machines have weak fields, large armatures, with a great length of copper wire and a few commutator segments to produce great variations in the current's strength, and to bring self-induction into play. Such machines may retain within considerable limits of variation in the resistance of the circuit a practically constant current. Their output is, of course, correspondingly diminished, and, perhaps, with the object in view not to cut down the output too much, a simple device compensating exceptional variations is employed. The undulation of the current is almost essential to the commercial success of an arc light system. It introduces in the circuit a steadying element, taking the place of a large ohmic resistance, without involving a great loss in power, and, what is more important, it allows the use of simple clutch lamps, which with a current of a certain number of impulses per second, best suitable for each particular lamp, will, if properly attended to, regulate even better than the finest clockwork lamps. This discovery has been made by the writer—several years too late.

It has been asserted by competent English electricians that in a constant current machine or transformer the regulation is effected by varying the phase of the secondary current. That this view is erroneous may be easily proved by using, instead of lamps devices each possessing self-induction and capacity or self-induction and resistance—that is, retarding and accelerating components—in such proportions as to not affect materially the phase of the secondary current. Any number of such devices may be inserted or cut out, still it will be found that the regulation occurs, a constant current being maintained, while the electromotive force is varied with the number of the devices. The change of phase of the secondary current is simply a result following from the changes in resistance, and, though secondary reaction is always of more or less importance, yet the real cause of the regulation lies in the existence of the conditions above enumerated. It should be stated, however, that in the case of a machine the above remarks are to be restricted to the cases in which the machine is independently excited. If the excitation be effected by commutating the armature current, then the fixed position of the brushes makes any shifting of the neutral line of the utmost importance, and it may not be thought immodest of the writer to mention that, as far as records go, he seems to have been the first who has successfully regulated machines in providing a bridge connection between a point of the external circuit and the commutator by means of a third brush. The armature and field being properly proportioned, and the brushes placed in their determined positions, a constant current or constant potential resulted from the shifting of the diameter of commutation by the varying loads

In connection with machines of such high frequencies the condenser affords an especially interesting study. It is easy to raise the electromotive force of such a machine to four or five times the value by simply connecting the condenser to the circuit, and the writer has continually used the condenser for the purposes of regulation as suggested by Blakesley in his book on alternate currents, in which he has treated the most frequently occurring condenser problems with exquisite simplicity and clearness. The high frequency allows the use of small capacities and renders investigation easy. But, although in most of the experiments the result may be foretold, yet some phenomena observed seem at first curious. One experiment performed three or four months ago with such a machine and a condenser may serve as an illustration. A machine was used giving about 20,000 alternations per second. Two bare wires of about 20 feet long and two millimeters diameter, in close proximity to each other, were connected to the terminals of the machine on the one end, and to a condenser on the other. A small transformer without an iron core, of course, was used to bring the reading within the range of a Cardew voltmeter by connecting the voltmeter to the secondary. On the terminals of the condenser the electromotive force was about 120 volts, and from there inch by inch it gradually fell until on the terminals of the machine it was about 65 volts. It was virtually as though the condenser were a generator, and the line and armature circuit simply a resistance connected to it. The writer looked for a case of resonance, but he was unable to augment the effect by varying the capacity very carefully and gradually or by changing the speed of the machine. A case of pure resonance he was unable to obtain. When a condenser was connected to the terminals of the machine—the self-induction of the armature being first determined in the maximum and minimum position and the mean value taken—the capacity which gave the highest electromotive force corresponded most nearly to that which just counteracted the self-induction with the existing frequency. If the capacity was increased or diminished, the electromotive force fell as expected.

With frequencies as high as the above mentioned the condenser effects are of enormous importance. The condenser becomes a highly efficient apparatus, capable of transferring considerable energy.

The writer has thought that machines of high frequencies may find use at least in cases when transmission at great distances is not contemplated. The increase of the resistance may be reduced in the conductors and exalted in the devices when heating effects are wanted, transformers may be made of higher efficiency, and greater outputs and valuable results may be secured by means of condensers. In using machines of high frequency the writer has been able to observe condenser effects which would have otherwise escaped his notice. He has been very much interested in the phenomenon observed on the Ferranti main which has has been so much spoken of. Opinions have been expressed by competent electricians, but up to the present all still seems to be conjecture. Undoubtedly in the views expressed the truth must be contained, but as the questions differ, some must be erroneous. Upon seeing the diagram of M. Ferranti in the *Electrician* of Dec. 19 the writer has formed his opinion of the effect. In the absence of all the necessary data he must content himself to express in words the process which, in his opinion, must undoubtedly occur. The condenser brings about two effects: (1) It changes the phases of the currents in the branches; (2) it changes the strength of the currents. As regards the change in phase, the effect of the condenser is to accelerate the current in the secondary at Deptford and to retard it in the primary at London. The former has the effect of diminishing the self-induction in the Deptford primary, and this means lower electromotive force on the dynamo. The retardation of the primary at London, as far as merely the phase is concerned, has little or no effect, since the phase of the current in the secondary in London is not arbitrarily kept.

Now, the second effect of the condenser is to increase the current in both the branches. It is immaterial whether there is equality between the currents or not; but it is necessary to point out, in order to see the importance of the Deptford step up transformer, that an increase of the current in both the branches produces opposite effects. At Deptford it means further lowering of the electromotive force at the primary, and at London it means increase of the electromotive force at the secondary. Therefore all the things co-act to bring about the phenomenon observed. Such actions, at least, have been found to take place under similar conditions. When the dynamo is connected directly to the main, one can see that no such action can happen.

The writer has been particularly interested in the suggestions and views expressed by Mr. Swinburne. Mr. Swinburne has frequently honored him by disagreeing with his views. Three years ago, when the writer, against the prevailing opinion of engineers, advanced an open circuit transformer, Mr. Swinburne was the first to condemn it by stating in the *Electrician:* "The (Tesla) transformer must be inefficient; it has magnetic poles revolving, and has thus an *open* magnetic circuit." Two years later Mr. Swinburne becomes the champion of the open circuit transformer, and offers to convert him. But, *tempora mutantur et nos mutamur in illis.*

The writer cannot believe in the armature reaction theory as expressed in *Industries*, though undoubtedly there is some truth in it. Mr. Swinburne's interpretation, however, is so broad that it may mean anything.

Mr Swinburne seems to have been the first who has called attention to the heating of the condensers The astonishment expressed at that by the ablest electrician is a striking illustration of the desirability to execute experiments on a large scale. To the scientific investigator, who deals with the minutest quantities, who observes the faintest effects, far more credit is due than to one who experiments with apparatus on an industrial scale, and indeed the history of science has recorded examples of marvelous skill, patience and keenness of observation. But however great the skill, and however keen the observer's perception, it can only be of advantage to magnify an effect and thus facilitate its study. Had Faraday carried out but one of his experiments on dynamic induction on a large scale, it would have resulted in an incalculable benefit.

In the opinion of the writer, the heating of the condensers is due to three distinct causes: first, leakage or conduction; second, imperfect elasticity in the dielectric; and third, surging of the charges in the conductor.

In many experiments he has been confronted with the problem of transferring the greatest possible amount of energy across a dieletric. For instance, he has made incandescent lamps, the ends of the filaments being completely sealed in glass, but attached to interior condenser coatings, so that all the energy required had to be transferred across the glass with a condenser surface of no more than a few centimeters square. Such lamps would be a practical success with sufficiently high frequencies. With alternations as high as 15,000 per second it was easy to bring the filaments to incandescence. With lower frequencies this could also be effected, but the potential difference had, of course, to be increased. The writer has then found that the glass gets, after a while, perforated and the vacuum is impaired. The higher the frequency, the longer the lamp can withstand. Such a deterioration of the dielectric always takes place when the amount of energy transferred across a dielectric of definite dimensions and by a given frequency is too great. Glass withstands best, but even glass is deteriorated. In this case the potential difference on the plates is of course too great, and losses by conduction and imperfect elasticity result. If it is desirable to produce condensers capable to stand great differences of potential, then the only dielectric which will involve no losses is a gas under pressure. The writer has worked with air under enormous pressures, but there are a great many practical difficulties in that direction. He thinks that, in order to make the condensers of considerable practical utility, higher frequencies should be used; though such a plan has, besides others, the great disadvantage that the system would become very unfit for the operation of motors.

If the writer does not err, Mr. Swinburne has suggested a way of exciting an alternater by means of a condenser.

For a number of years past the writer has carried on experiments with the object in view of producing a practical self-exciting alternater. He has in a variety of ways succeeded in producing some excitation of the magnets by means of alternating currents, which were not commutated by mechanical devices. Nevertheless his experiments have revealed a fact which stands as solid as the rock of Gibraltar. No practical excitation can be obtained with a single periodically varying and not commutated current. The reason is that the changes in the strength of the exciting current produce corresponding changes in the field strength, with the result of inducing currents in the armature, and these currents interfere with those produced by the motion of the armature through the field, the former being a quarter phase in advance of the latter. If the field be laminated, no excitation can be produced; if it be not laminated, some excitation is produced, but the magnets are heated.

By combining two exciting currents displaced by a quarter phase, excitation may be produced in both cases, and if the magnet be not laminated the heating effect is comparatively small, as a uniformity in the field strength is maintained, and, were it possible to produce a perfectly uniform field, excitation on this plan would give quite practical results. If such results are to be secured by the use of a condenser, as suggested by Mr. Swinburne, it is necessary to combine two circuits separated by a quarter phase; that is to say, the armature coils must be wound in two sets and connected to one or two independent condensers. The writer has done some work in that direction, but must defer the description of the devices for some future time.

NOTES ON ALTERNATING CURRENTS OF VERY HIGH FREQUENCY.

BY

Elihu Thomson

THE interesting account of the novel experiments given by Mr. Nikola Tesla in the *Electrical World* of Feb. 21, 1891, and relating to the phenomena of alternating currents of very high frequency, lead me to make a statement of some of my own obervations while working in similar directions. The highest number of alternations which I have had at my disposal up to the present have been 8,000 to the second, a rate somewhat below that which Mr. Tesla has obtained, but which, nevertheless, shows properties and brings about actions and results similar to those which he described. The physiological actions of these rapidly alternating currents have been very ably investigated by Dr. Edward Tatum, some of the results of whose work I have presented in a separate communication.

Mr. Tesla's experiences in relation to the static effects of these currents of high frequency are similar to those noted by myself, particularly the small surface of the condenser which is able to transfer, or permit to be transferred, a considerable amount of energy through a dielectric, owing to the exceedingly high rate at which the changes of direction of charge are made.

The following experiment which was tried by me some months ago, is interesting in this connection. An incandescent lamp bulb was constructed, in which only a single platinum leading-in wire was used, on the end of which, inside the bulb, was mounted a single slip of carbon, two or three inches in length, it being one leg of a broken incandescent lamp filament. Two-thirds of the lamp bulb was now immersed in an outer vessel of water, leaving the single wire above the water for attachment to the source of alternating currents at one terminal, and the other terminal was connected with the outside water, which was rendered slightly conducting by salt dissolved therein. The water surrounding the lamp bulb formed, of course, an outer condenser coating, while the vacuous space and straight slip of carbon were the means for the conveyance of a charge to and from the inside surface of the bulb, which was, of course, exhausted to the ordinary vacuous condition, as found in an incandescent lamp. When an alternating potential of about 1,000 volts, and with a rate of alternations up to 5,000 per second, was applied to the carbon strip, the filament was brought to bright incandescence simply by the bombarding action of the residual gas, as in the Crookes tubes, while, of course, no complete circuit existed, the condenser action of the lamp bulb allowing sufficient current to flow. At the same time the glass of the lamp bulb not immersed in the water, became rapidly heated, indicating that that portion which was immersed in the water would have become equally heated had it not been subjected to the cooling action of the water itself.

The retention of the arc, as with direct currents, and the high note evolved by it, have been noted from the beginning of my experiments with these high period currents. Mr. Tesla expresses surprise that he was enabled to hear the note from an arc in which the alternations of current were more than 10,000 per second. Mr. Tesla will pardon me for calling his attention to the the fact that he is taking as the limit of audition in this case sounds from 5,000 to 10,000 complete waves per second, which is far below the limit at which sounds become inaudible to ordinary ears, cases existing in which a pitch corresponding to over 30,000 per second has been heard, according to some authorities.

The cause of the persistence of the arc with very high period alternations as stated by Mr. Tesla is undoubtedly the correct one, *i. e.*, that the gas stream has no time to cool between the alternations, and its variations of temperature must therefore be quite slight. The conductivity of the vapor or gas stream constituting the arc therefore remains nearly constant when the rapidity of alternations is sufficiently great.

The characteristics, stated by Mr. Tesla, as requisite to be possessed by machines suitable for obtaining constant current for the working of arc lights, are of course connected with the fact that in such machines the characteristic curve indicates a drop or fall in the electromotive force developed on a slight excess of current above the normal and, on a decrease of current, a raising of the electromotive force to a point above the normal.

It is not, however, in accordance with my experience, that the undulation of the current is almost essential to the success of an arc light system, nor do I think that properly constructed clutch lamps depend for their success any more than do finely constructed clockwork lamps, on the presence of a rapidly varying current due to a small number of armature coils and correspondingly small number of segments in the commutator. In fact, I have run with perfect success clutch lamps in circuit with coils of such large self-induction that any but very slight fluctuations were wiped out, and without introducing any particular difference in the behavior of the lamps. It probably is true, however, that slight gentle fluctuations occurring at very moderate intervals may be of benefit in the working of clutch lamps by keeping, as it were, the clutch mechanism in a state of vibration or tendency to open or close, but it can scarcely be doubted that if this benefit exists for such lamps a similar benefit would exist on the operation of clockwork lamps, as a similar fluctuation would give rise to a continual tendency in such lamps to keep the detent or escapement free enough for delicately letting-go teeth for the feed; but the fact that large numbers of lamps are in use in which the feeding of the carbon, either by clutch or by clockwork, is under the control of a derived circuit magnet only, and that such lamps operate with the greatest satisfaction, shows that the undulations mentioned by Mr. Tesla are not necessarily a factor to be considered. In such cases the self-induction of the arc branch is negligible as compared with that of the derived circuit magnet controlling mechanism, and the fluctuations therefore would pass through the arc without affecting the said magnet to a perceptible degree, particularly as the potential around the normal arc with slightly different current strengths flowing is nearly constant.

I may add that the experiments of Mr. Tesla in relation to the action of the condenser and the elevation of potential brought about by it are decidedly interesting and point to the possibility of obtaining a pure resonance effect. This would require, however, that the periodicity of the alternations be preserved very rigidly during the experiments, and involves the production of an unvarying or perfectly constant speed in driving the generating machine, a condition not easily obtained in practice.

In making the above notes on the highly interesting and valuable account given by Mr. Tesla, I desire to state that in whatever way my notes may appear as criticism of Mr. Tesla's views, they are not made in any unfriendly spirit, but with the desire of reaching the exact facts which it is the object of scientific investigation and discussion to ascertain.

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THE ELECTRICAL WORLD.

Alternating Currents of Short Period.

ELSEWHERE in our columns will be found two brief and pertinent papers by Prof. Elihu Thomson on some experiments with alternating currents of very high frequency. They follow directly upon Mr. Tesla's discussion of the same subject in THE ELECTRICAL WORLD of Feb. 21. Prof. Thomson's work was done with a machine having 100 armature coils, constructed on the plan recently devised by him, wherein no wire moves and the only revolving part of the machine is a mass of laminated iron having poles projecting radially outward. The highest number of alternations obtained from this apparatus was about 8,000 per second, and, therefore, far lower than the enormous frequencies reached by Mr. Tesla. The phenomena observed by the two experimenters were naturally similar: the higher frequency giving the more striking and remarkable results, as might have been anticipated. The most interesting addition to our knowledge, however, is to be found in the brief report by Prof. Thomson of Dr. Tatum's experiments on the physiological effects of very rapid alternations. Prof. Thomson placed his alternator at the disposal of Dr. Tatum, and the latter continued the experiments which have been several times reported in our columns on the action of high-tension currents upon animal life. His results have rendered it highly probable that the fatality of the alternating current varies nearly inversely with its frequency. At 4,500 alternations per second the current required to kill dogs was 20 times the strongest current survived at 120 alternations per second. The same difference in effect, though in a less degree, was observed when the alternations were raised even to 300 per second. The cause of this really extraordinary state of affairs cannot be assigned in the present state of our knowledge of the subject. Certain experiments make it appear probable that it is physiological rather than produced by any difference of current distribution in the case of the higher frequencies. This latter point, however, cannot be regarded as entirely settled until further experiments are tried, because of our very limited information as to the distribution of current through the body in any case. The deduction to be drawn from the results is that rapid alternations are probably less dangerous to human life than slower ones. It is likely that the well-known deadly effects of open-circuit direct-current arc light machines may be due to the decidedly violent fluctuations of the current at a rather low frequency. Color is lent to this hypothesis by the behavior of closed-coil arc machines. In one case recently reported a contact through the two hands across mains having a difference of potential of 3,100 volts did not produce any very serious results. There is, therefore, strong evidence now in hand that the undoubted danger that attends the use of high-tension alternating currents could be somewhat reduced by the simple and very valuable expedient of increasing the frequency. Danger aside, with very high frequencies it becomes possible to obtain the transformation of very large amounts of electrical energy in converters of diminutive size. It is also practicable to use the condenser form of converter without the need of very large capacity, and the principal convenience sacrificed is the ability to use single wires of large diameter. For currents of very high frequency, stranded wires or flat strips become absolutely necessary in order to avoid loss from anti-effective copper. Another possible disadvantage would be the effect of the violent static displacement currents, that are produced at very high frequencies, on the insulation of the wires. Elaborate experiments covering these two points, the largest permissible size of wire and durability of insulation, would possess great commercial value. And if frequencies of 500, and perhaps even 1,000, per second can be successfully employed the usefulness of the alternating current will be very considerably increased. Probably the practical limit of frequency would be determined, however, by the highest number of alternations at which motors can be successfully operated. Beyond a certain point of frequency the alternating motor is not likely to work successfully for magnetic reasons. This limit is, however, certainly far above the frequency that is to-day generally employed. It is altogether probable that there will be a decided gain in employing a periodicity five or possibly even ten times that of our present commercial alternators. At all events the subject is one that should be most carefully investigated from a practical standpoint.

Notes on Alternating Currents of Very High Frequency.

BY ELIHU THOMSON.

The interesting account of his novel experiments given by Mr. Nikola Tesla in THE ELECTRICAL WORLD of Feb. 21, 1891, relating to the phenomena of alternating currents of very high frequency, leads me to make a statement of some of my own observations while working in similar directions. The highest number of alternations which I have had at my disposal up to the present is 8,000 per second, a rate somewhat below that which Mr. Tesla has obtained, but which, nevertheless, shows properties and brings about actions and results similar to those which he describes. The physiological actions of these rapidly alternating currents have been very ably investigated by Dr. Edward Tatum, some of the results of whose work I have presented in a separate communication. Mr. Tesla's experiences in relation to the static effects of these currents of high frequency are similar to those noted by myself, particularly the small surface of the condenser, which is able to transfer, or permit to be transferred, a considerable amount of energy through a dielectric, owing to the exceedingly high rate at which the changes of direction of charge are made.

The following experiment, which was tried by me some months ago, is interesting in this connection: An incandescent lamp bulb was constructed in which only a single platinum leading-in wire was used, on the end of which, inside the bulb, was mounted a single slip of carbon of two or three inches in length, it being one leg of a broken incandescent lamp filament. Two-thirds of the lamp bulb was now immersed in an outer vessel of water, leaving the single wire above the water for attachment to the source of alternating currents at one terminal, and the other terminal was connected with the outside water, which was rendered slightly conducting by salt dissolved therein. The water surrounding the lamp bulb formed, of course, an outer condenser coating, while the vacuous space and straight slip of carbon were the means for the conveyance of a charge to and from the inside surface of the bulb, which was, of course, exhausted to the ordinary vacuous condition, as found in an incandescent lamp. When an alternating potential of about 1,000 volts, and with a rate of alternations up to 5,000 per second, was applied to the carbon strip, the filament was brought to bright incandescence simply by the bombarding action of the residual gas, as in the Crookes tubes, while of course no complete circuit existed, but only the condenser action of the lamp bulb, allowing sufficient current to flow. At the same time the glass of the lamp bulb not immersed in the water became rapidly heated, indicating that that portion which was immersed in the water would have become equally heated had it not been subjected to the cooling action of the water itself.

The retention of the arc, as with direct currents, and the high note evolved by it have been noted from the beginning of my experiments with these high-period currents. Mr. Tesla expresses surprise that he was enabled to hear the note from an arc in which the alternations of current were more than 10,000 per second. Mr. Tesla will pardon me for calling his attention to the fact that he is taking as the limit of audition in this case sounds of from 5,000 to 10,000 complete waves per second, which is far below the limit at which sounds become inaudible to ordinary ears, cases existing in which a pitch corresponding to over 30,000 per second has been heard, according to some authorities.

The cause of the persistence of the arc with very high-period alternations, as stated by Mr. Tesla, is undoubtedly the correct one, *i. e.*, that the gas stream has no time to cool between the alternations, and its variations of temperature must therefore be quite slight. The conductivity of the vapor or gas stream constituting the arc therefore remains nearly constant when the rapidity of alternations is sufficiently great.

The characteristics stated by Mr. Tesla as requisite to be possessed by machines suitable for obtaining constant current for the working of arc lights are, of course, connected with the fact that in such machines the characteristic curve indicates a drop or fall in the electromotive force developed on a slight excess of current above the normal, and on a decrease of current arising of the electromotive force to a point above the normal. It is not, however, in accordance with my experience that the undulation of the current is almost essential to the success of an arc-light system; nor do I think that properly constructed clutch lamps depend for their success, any more than do finely constructed clockwork lamps, on the presence of a rapidly varying current due to a small number of armature coils and correspondingly small number of segments in the commutator. In fact, I have run with perfect success clutch lamps in circuit with coils of such large self-induction that any but very slight fluctuations were wiped out and without introducing any particular difference in the behavior of the lamps. It probably is true, however, that slight gentle fluctuations occurring at very moderate intervals may be of benefit in the working of clutch lamps by keeping the clutch mechanism in a state of vibration or tendency to open or close; but it can scarcely be doubted that if this benefit exists for such lamps a similar benefit would exist on the operation of clockwork lamps, as a similar fluctuation would give rise to a continual tendency in such lamps to keep the detent or escapement free enough for delicately letting go teeth for the feed; but the fact that large numbers of lamps are in use in which the feeding of the carbon either by clutch or by clockwork is under the control of a derived circuit magnet only, and that such lamps operate with the greatest satisfaction, shows that the undulations mentioned by Mr. Tesla are not necessarily a factor to be considered. In such cases the self-induction of the arc branch is negligible as compared with that of the derived circuit magnet controlling mechanism, and the fluctuations, therefore, would pass through the arc without affecting the said magnet to a perceptible degree, particularly as the potential around the mound arc with slightly different current strengths flowing is nearly constant. I may add that the experiments of Mr. Tesla in relation to the action of the condenser and the elevation of potential brought about by it are decidedly interesting, and point to the possibility of obtaining a pure resonance effect. This would require, however, that the periodicity of the alternations be preserved very rigidly during the experiments, and involves the production of an unvarying or perfectly constant speed in driving the generating machine, a condition not easily obtained in practice.

In making the above notes on the highly interesting and valuable account given by Mr. Tesla, I desire to state that, in whatever way my notes may appear as criticism of Mr. Tesla's views, they are not made in any unfriendly spirit, but with the desire of reaching the exact facts which it is the object of scientific investigation and discussion to ascertain.

EXPERIMENTS WITH ALTERNATING CURRENTS OF HIGH FREQUENCY.

BY

Nikola Tesla

In The Electrical Engineer issue of 11th inst., I find a note of Prof. Elihu Thomson relating to some of my experiments with alternating currents of very high frequency.

Prof. Thomson calls the attention of your readers to the interesting fact that he has performed some experiments in the same line. I was not quite unprepared to hear this, as a letter from him has appeared in the *Electrician* a few months ago, in which he mentions a small alternate current machine which was capable of giving, I believe, 5,000 alternations per second, from which letter it likewise appears that his investigations on that subject are of a more recent date.

Prof. Thomson describes an experiment with a bulb enclosing a carbon filament which was brought to incandescence by the bombardment of the molecules of the residual gas when the bulb was immersed in water "rendered slightly conducting by salt dissolved therein," (?) and a potential of 1,000 volts alternating 5,000 time a second applied to the carbon strip. Similar experiments have, of course, been performed by many experimenters, the only distinctive feature in Prof. Thomson's experiment being the comparatively high rate of alternation. These experiments can also be performed with a steady difference of potential between the water and the carbon strip in which case, of course, conduction through the glass takes place, the difference of potential required being in proportion to the thickness of the glass. With 5,00 alternations per second, conduction still takes place, but the condenser effect is preponderating. It goes, of course, without saying that the heating of the glass in such a case is principally due to the bombardment of the molecules, partly also to leakage or conduction, but it is an undeniable fact that the glass may also be heated merely by the molecular displacement. The interesting feature in my experiments was that a lamp would light up when brought near to an induction coil, and that it could be held in the hand and the filament brought to incandescence.

Experiments of the kind described I have followed up for a long time with some practical objects in view. In connection with the experiment described by Prof. Thomson, it may be of interest to mention a very pretty phenomenon which may be observed with an incandescent lamp If a lamp be immersed in water as far as practicable and the filament and the vessel connected to the terminals of an induction coil operated from a machine such as I have used in my experiments, one may see the dull red filament surrounded by a very luminous globe around which there is a less luminous space. The effect is probably due to reflection, as the globe is sharply defined, but may also be due to a "dark space;" at any rate it is so pretty that it must be seen to be appreciated.

Prof. Thomson has misunderstood my statement about the limit of audition. I was perfectly well aware of the fact that opinions differ widely on this point. Nor was I surprised to find that arcs of about 10,000 impulses per second, emit a sound. My statement "the *curious* point is," etc. was only made in deference to an opinion expressed by Sir William Thomson. There was absolutely no stress laid on the precise number. The popular belief was that something like 10,000 to 20,000 per second, or 20,000 to 40,000, at the utmost was the limit. For my argument this was immaterial. I contended that sounds of an incomparably greater number, that is, many times even the highest number, could be heard if they could be produced with sufficient power. My statement was only speculative, but I have devised means which I think may allow me to learn something definite on that point. I have not the least doubt that it is simply a question of power. A very short arc may be silent with 10,000 per second, but just as soon as it is lengthened it begins to emit a sound. The vibrations are the same in number, but more powerful.

Prof. Thomson states that I am taking as the limit of "audition sounds from 5,000 to 10,000 complete waves per second." There is nothing in my statements from which the above could be inferred, but Prof. Thomson has perhaps not thought that there are two sound vibrations for each complete current wave, the former being independent of the direction of the current.

I am glad to learn that Prof. Thomson agrees with me as to the causes of the persistence of the arc. Theoretical considerations considerable time since have led me to the belief that arcs produced by currents of such high frequency would possess this and other desirable features. One of my objects in this direction has been to produce a practicable small arc. With these currents, for many reasons, much smaller arcs are practicable.

The interpretation by Prof. Thomson of my statements about the arc system leads me *now*, he will pardon me for saying so, to believe that what is most essential to the success of an arc system is a good management. Nevertheless I feel confident of the correctness of the views expressed. The conditions in practice are so manifold that it is impossible for any type of machine to prove best in all the different conditions.

In one case, where the circuit is many miles long, it is desirable to employ the most efficient machine with the least internal resistance; in another case such a machine would not be the best to employ. It will certainly be admitted that a machine of any type must have a greater resistance if intended to operate arc lights than if it is designed to supply incandescent lamps in series. When arc lights are operated and the resistance is small, the lamps are unsteady, unless a type of lamp is employed in which the carbons are separated by a mechanism which has no further influence upon the feed, the feeding being effected by an independent mechanism; but even in this case the resistance must be considerably greater to allow a quiet working of the lamps. Now, if the machine be such as to yield a steady current, there is no way of attaining the desired result except by putting the required resistance somewhere either inside or outside of the machine. The latter is hardly practicable, for the customer may stand a hot machine, but he looks with suspicion upon a hot resistance box. A good automatic regulator of course improves the machine and allows us to reduce the internal resistance to some extent, but not as far as would be desirable. Now, since resistance is loss, we can advantageously replace resistance in the machine by an equivalent impedence. But to produce a great impedence with small ohmic resistance, it is necessary to have self-induction and variation of current, and the greater the self-induction and the rate of change of the current, the greater the impedence may be made, while the ohmic resistance may be very small. It may also be remarked that the impedence of the circuit external to the machine is likewise increased. As regards the increase in ohmic resistance in consequence of the variation of the current, the same is, in the commercial machines now in use, very small. Clearly then a great advantage is gained by providing self induction in the machine circuit and undulating the current, for it is possible to replace a machine which has a resistance of, say, 16 ohms by one which has no more than 2 or 3 ohms, and the lights will work even steadier. It seems to me therefore, that my saying that self-induction is essential to the commercial success of an arc system is justified. What is still more important, such a machine will cost considerably less. But to realize fully the benefits, it is preferable to employ an alternate current machine, as in this case a greater rate of change in the current is obtainable. Just what the ratio of resistance to impedence is in the Brush and Thomson

machines is nowhere stated, but I think that it is smaller in the Brush machine, judging from its construction.

As regards the better working of clutch lamps with undulating currents, there is, according to my experience, not the least doubt about it. I have proved it on a variety of lamps to the complete satisfaction not only of myself, but of many others. To see the improvement in the feed due to the jar of the clutch at its best it is desirable to employ a lamp in which an independent clutch mechanism effects the feed, and the release of the rod is independent of the up and down movement. In such a lamp the clutch has a small inertia and is very sensitive to vibration, whereas, if the feed is effected by the up and down movement of the lever carrying the rod, the inertia of the system is so great that it is not affected as much by vibration, especially if, as in many cases, a dash pot is employed. During the year 1885 I perfected such a lamp which was calculated to be operated with undulating currents. With about 1,500 to 1,800 current impulses per minute the feed of this lamp is such that absolutely no movement of the rod can be observed, even if the arc be magnified fifty-fold by means of a lens; whereas, if a steady current is employed, the lamp feeds by small steps. I have, however, demonstrated this feature on other types of lamps, among them being a derived circuit lamp such as Prof. Thomson refers to. I conceived the idea of such a lamp early in 1884, and when my first company was started, this was the first lamp I perfected. It was not until the lamp was ready for manufacture that, on receiving copies of applications from the Patent Office, I learned for the first time, not having had any knowledge of the state of the art in America, that Prof. Thomson had anticipated me and had obtained many patents on this principle, which, of course, greatly disappointed and embarrassed me at that time. I observed the improvement of the feed with undulating currents on that lamp, but I recognized the advantage of providing a light and independent clutch unhampered in its movements. Circumstances did not allow me to carry out at that time some designs of machines I had in mind, and with the existing machines the lamp has worked at a great disadvantage. I cannot agree with Prof. Thomson that small vibrations would benefit a clockwork lamp as much as a clutch lamp; in fact, I think that they do not at all benefit a clockwork lamp.

It would be interesting to learn the opinion of Mr. Charles F. Brush on these points.

Prof. Thomson states that he has run with perfect success clutch lamps "in circuit with coils of such large self-induction that any but very slight fluctuations were wiped out." Surely Prof. Thomson does not mean to say that self-induction wiped out the periodical fluctuations of the current. For this, just the opposite quality, namely, capacity, is required. The self-induction of the coils in this case simply augmented the impedence and prevented the great variations occurring at large time intervals, which take place when the resistance in circuit with the lamps is too small, or even with larger resistance in circuit when the dash pots either in the lamps or elsewhere are too loose.

Prof. Thomson further states that in a lamp in which the feed mechanism is under the control of the derived circuit magnet only, the fluctuations pass through the arc without affecting the magnet to a perceptible degree. It is true that the variations of the resistance of the arc, in consequence of the variations in the current strength, are such as to dampen the fluctuation. Nevertheless, the periodical fluctuations are transmitted through the derived circuit, as one may convince himself easily of, by holding a thin plate of iron against the magnet.

In regard to the physiological effects of the currents I may state that upon reading the memorable lecture of Sir William Thomson, in which he advanced his views on the propagation of the alternate currents through conductors, it instantly occurred to me that currents of high frequencies would be less injurious. I have been looking for a proof that the mode of distribution through the body is the cause of the smaller physiological effects. At times I have thought to have been able to locate the pain in the outer portions of the body, but it is very uncertain. It is most certain, however, that the feeling with currents of very high frequencies is somewhat different from that with low frequencies. I have also noted the enormous importance of one being prepared for the shock or not. If one is prepared, the effect upon the nerves is not nearly as great as when unprepared. With alternations as high as 10,000 per second and upwards, one feels but little pain in the central portion of the body. A remarkable feature of such currents of high tension is that one receives a burn instantly he touches the wire, but beyond that the pain is hardly noticeable.

But since the potential difference across the body by a given current through it is very small, the effects can not be very well ascribed to the surface distribution of the current, and the excessively low resistance of the body to such rapidly varying currents speak rather for a condenser action.

In regard to the suggestion of Dr. Tatum, which Prof. Thomson mentions in another article in the same issue, I would state that I have constructed machines up to 480 poles, from which it is possible to obtain about 30,000 alternations per second, and perhaps more. I have also designed types of machines in which the field would revolve in an opposite direction to the armature, by which means it would be possible to obtain from a similar machine 60,000 alternations per second or more.

I highly value the appreciation of Prof. Thomson of my work, but I must confess that in his conclusion he makes a most astounding statement as to the motives of his critical remarks. I have never for a moment thought that his remarks would be dictated by anything but friendly motives. Often we are forced in daily life to represent opposing interests or opinions, but surely in the higher aims the feelings of friendship and mutual consideration should not be affected by such things as these.

TESLA'S ALTERNATING GENERATORS FOR HIGH FREQUENCY.

It has now become a common practice to run arc lamps by alternating or pulsating, as distinguished from continuous, currents; but an objection which has been raised to such systems exists in the fact that the arcs emit a pro-

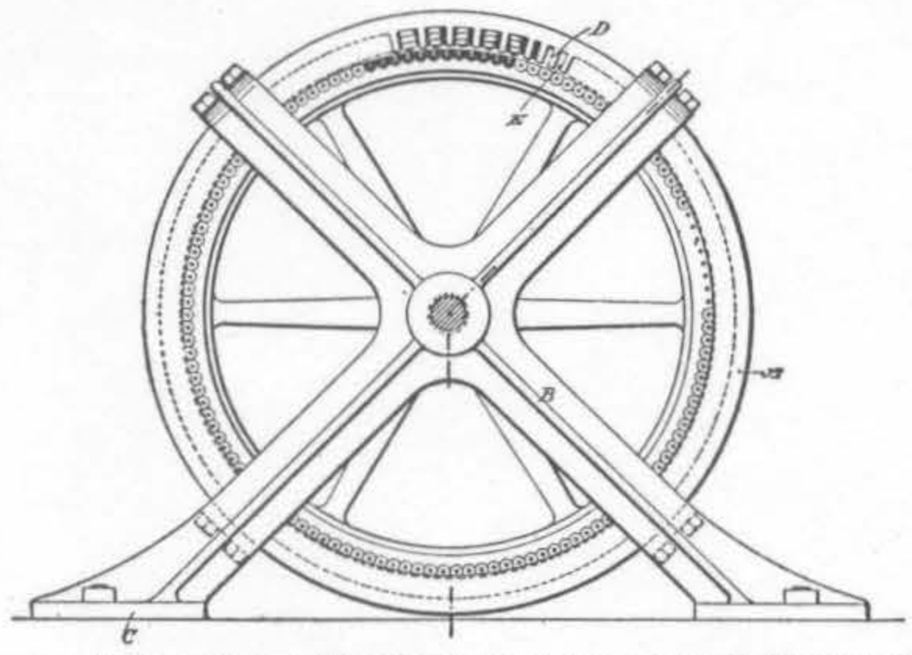
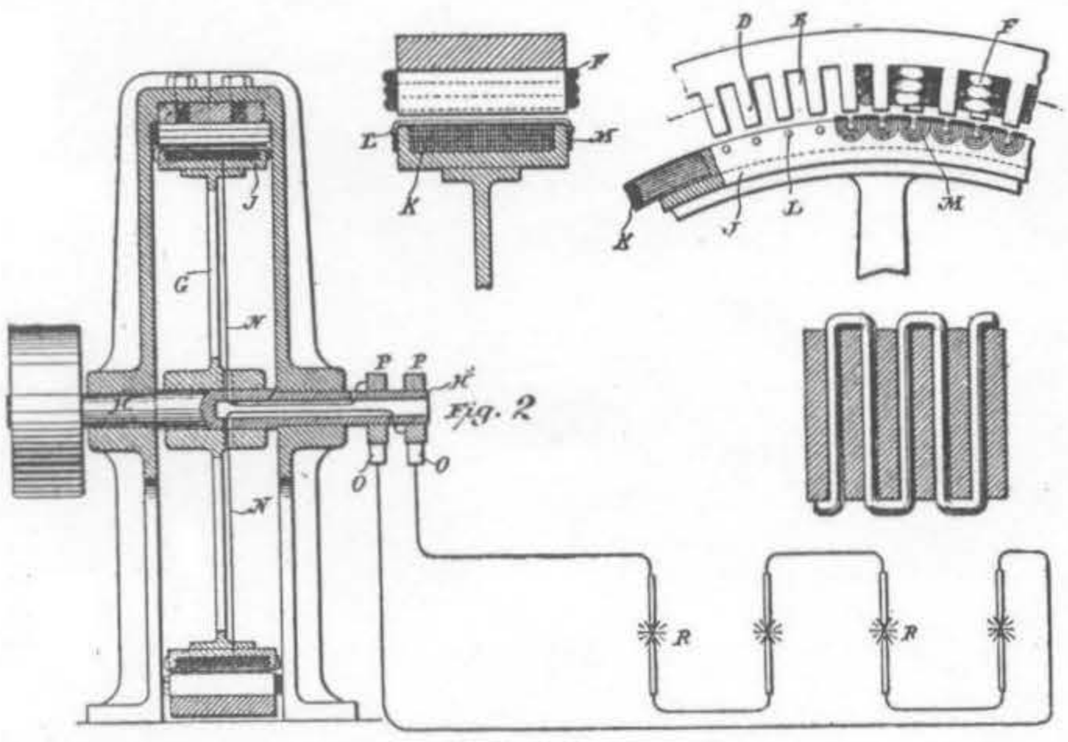


FIG. 1.—TESLA HIGH FREQUENCY ALTERNATING GENERATOR.

nounced sound, varying with the rate of the alternations or pulsations of current, for which, up to the present, no effective remedy has been found. This noise is due to the rapidly alternating heating and cooling, and consequent expansion and contraction, of the gaseous matter forming the arc which corresponds with the periods or impulses of the current. Another disadvantageous feature is found in the difficulty of maintaining an alternating current arc in consequence of the periodical increase in resistance corresponding to the periodical working of the current. This feature entails a further disadvantag· namely, that small arcs are impracticable.

Theorectical considerations have led Mr. Tesla to the belief that these disadvantageous features could be obviated by employing currents of a sufficiently high number of alternations and his anticipations have been confirmed in practice. These rapidly alternating currents render it possible to maintain small arcs which, besides, possess the advantages of silence and persistency. The latter quality is due to the necessarily rapid alternations, in consequence



FIGS. 2, 3, 4, 5.—TESLA HIGH FREQUENCY ALTERNATING GENERATOR.

of which the arc has no time to cool, and is always maintained at a high temperature and low resistance.

At the outset of his experiments Mr. Tesla encountered great difficulties in the construction of these machines. A generator of this kind is described here, which, though constructed quite some time ago, is well worthy of a detailed description.

In the accompanying engravings, Figs. 1 and 2 show the the machine, respectively, in side elevation and vertical cross-section; Figs. 3, 4 and 5 showing enlarged details of construction. As will be seen, A is an annular magnetic frame, the interior of which is provided with a large number of pole-pieces D.

Owing to the very large number and small size of the poles and the spaces between them, the field coils are applied by winding an insulated conductor F zigzag through the grooves, as shown in Fig. 5, carrying the wire around the annulus to form as many layers as is desired. In this way the pole-pieces D will be energized with alternately opposite polarity around the entire ring.

For the armature, Mr. Tesla employs a spider carrying a ring J, turned down, except at its edges, to form a trough-like receptacle for a mass of fine annealed iron wires K, which are wound in the groove to form the core proper for the armature-coils. Pins L are set in the sides of the ring J, and the coils M are wound over the periphery of the armature-structure and around the pins. The coils M are connected together in series, and these terminals N carried through the hollow shaft H to contact-rings P P, from whence the currents are taken off by brushes O.

In this way a machine with a very large number of poles may be constructed. It is easy, for instance, to obtain in this manner three hundred and seventy-five to four hundred poles in a machine that may be safely driven at a speed of fifteen hundred or sixteen hundred revolutions per minute, which will produce ten thousand or eleven thousand alternations of current per second. Arc lamps R R are shown in diagram as connected up in series with the machine in Fig. 2. If such a current be applied to running arc lamps, the sound produced by or in the arc becomes practically inaudible, for, by increasing the rate of change in the current, and consequently, the number of vibrations per unit of time of the gaseous material of the arc up to, or beyond, ten thousand or eleven thousand per second, or to what is regarded as the limit of audition, the sound due to such vibrations will not be audible. The exact number of changes or undulations necessary to produce this result will vary somewhat according to the size of the arc—that is to say, the smaller the arc the greater the number of changes that will be required to render it inaudible within certain limits. It should also be stated that the arc should not exceed a certain length.

The difficulties encountered in the construction of these machines are of a mechanical as well as an electrical nature. The machine may be designed on two plans: the field may be formed either of alternating poles, or of polar projections of the same polarity. Up to about 15,000 alternations per second in an experimental machine, the former plan may be followed, but a more efficient machine is obtained on the second plan.

In the machine above described, which was capable of running two arcs of normal candle power, the field was composed of a ring of wrought iron 32 inches outside diameter, and about one inch thick. The inside diameter was 30 inches. There were 384 polar projections. The wire was wound in zigzag form, but two wires were wound so as to completely envelop the projections. The distance between the projections is about $\frac{3}{16}$ inch, and they are a little over $\frac{1}{16}$ inch thick. The field magnet was made relatively small so as to adapt the machine for a constant current. There are 384 coils connected in two series. It was found impracticable to use any wire much thicker than No. 26 B. and S. gauge, on account of the local effects. In such a machine the clearance should be as small as possible; for this reason the machine was made only $1\frac{1}{4}$ inch wide, so that the binding wires might be obviated. The armature wires must be wound with great care as they are apt to fly off in consequence of the great peripheral speed. In various experiments this machine has been run as high as 3,000 revolutions per minute. Owing to the great speed it was possible to obtain as high as 10 amperes out of the machine. The electromotive force was regulated by means of an adjustable condenser within very wide limits, the limits

being the greater, the greater the speed. This machine was frequently used to run Mr. Tesla's shop lights.

The machine above described was only one of many other types constructed. It serves well for an experimental machine, but if still higher alternations are required and higher efficiency is necessary, then a machine on a plan described in Figs. 6 to 9, is preferable. The principal advantage of this type of machine is that there is not much

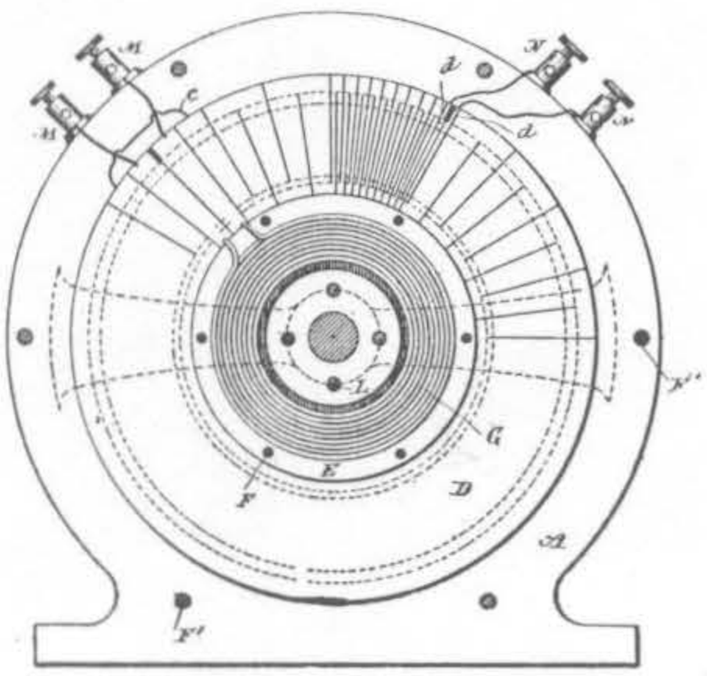


FIG. 6.—TESLA HIGH FREQUENCY ALTERNATING GENERATOR.

magnetic leakage, and that a field may be produced, varying greatly in intensity in places not much distant from each other.

In these engravings, Figs. 6 and 7 illustrate a machine in which the armature conductor and field coils are stationary, while the field magnet core revolves. Fig. 8 shows a machine embodying the same plan of construction, but having a stationary field magnet and rotary armature.

The conductor in which the currents are induced may be arranged in various ways; but Mr. Tesla prefers the folfowing method: He employs an annular plate of copper D, and by means of a saw cuts in it radial slots from one edge nearly through to the other, beginning alternately from opposite edges. In this way a continuous zigzag conductor is formed. When the polar projections are $\frac{1}{8}$ inch wide, the width of the conductor should not, under any

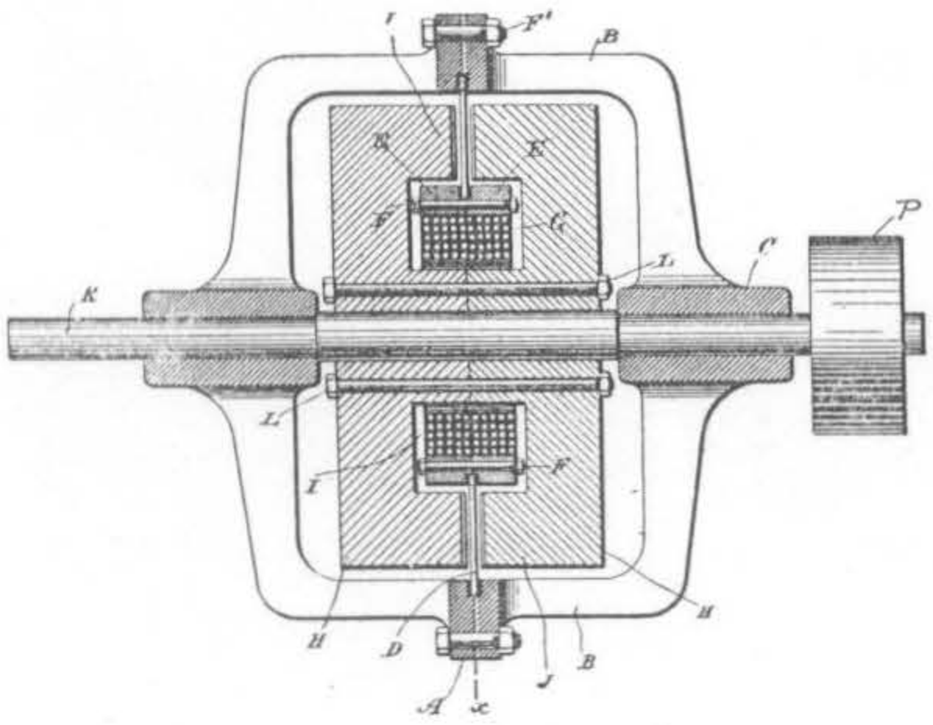


FIG 7.—TESLA HIGH FREQUENCY ALTERNATING GENERATOR.

circumstances, be more than $\frac{1}{32}$ inch wide; even then the eddy effect is considerable.

To the inner edge of this plate are secured two rings of non-magnetic metal E, which are insulated from the copper conductor, but held firmly thereto by means of the bolts F. Within the rings E is then placed an annular coil G, which is the energizing coil for the field magnet. The conductor D and the parts attached thereto are supported by means of the cylindrical shell or casting A A, the two parts of which are brought together and clamped to the outer edge of the conductor D.

The core for the field magnet is built up of two circular parts H H, formed with annular grooves I, which, when the two parts are brought together, form a space for the reception of the energizing coil G. The hubs of the cores are trued off, so as to fit closely against one another, while the outer portions or flanges which form the polar faces J J, are reduced somewhat in thickness to make room for the conductor D, and are serrated on their faces. The number of serrations in the polar faces is arbitrary; but there must exist between them and the radial portions of the conductor D a certain relation, which will be understood by reference to Fig. 9, in which N N represent the projections or points on one face of the core of the field, and S S the points of the other face. The conductor D, is shown in this figure in section a a' designating the radial portions of the conductor, and b the insulating divisions between the same. The relative width of the parts a a' and the space between any two adjacent points N N or S S is such that when the radial portions a of the conductor are passing between the opposite points N S, where the field is

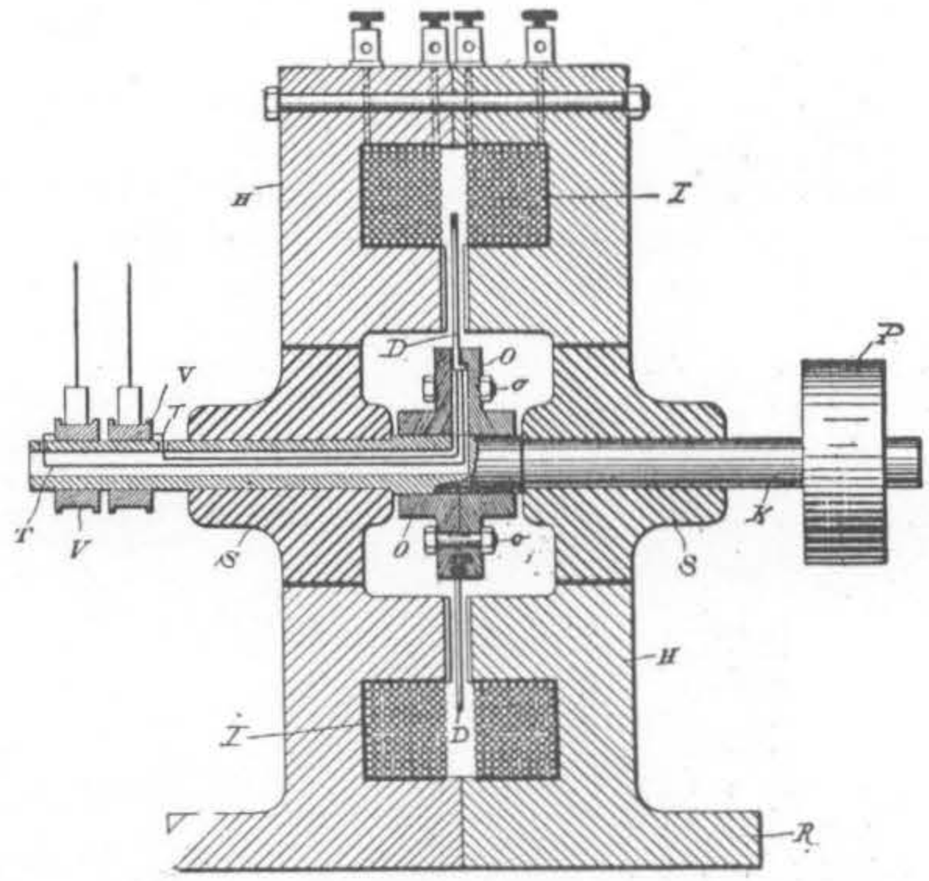


FIG. 8 TESLA HIGH FREQUENCY ALTERNATING GENERATOR.

strongest, the intermediate radial portions a' are passing through the widest spaces midway between such points and where the field is weakest. Since the core on one side is of opposite polarity to the part facing it, all the projections of one polar face will be of opposite polarity to those of the other face. Hence, although the space between any two adjacent points on the same face may be extremely small, there will be no leakage of the magnetic lines between any two points of the same name, but the lines of force will pass across from one set of points to the other. The construction followed obviates to a great degree the distortion of the magnetic lines by the action of the current in the conductor D, in which it willl be observed the current is flowing at any given time from the centre toward the periphery in one set of radial parts a and in the opposite direction in the adjacent parts a'.

In order to connect the energizing coil G with a source of continuous current, Mr. Tesla utilizes two adjacent radial portions of the conductor D for connecting the terminals of the coil G with two binding posts M. For this purpose the plate D is cut entirely through, as shown, and the break thus made is bridged over by a short conductor C. The plate D is cut through to form two terminals d, which are connected to binding posts N. The core H H, when rotated by the driving pulley, generates in the conductors D an alternating current, which is taken off from the binding posts N.

When it is desired to rotate the conductor between the

faces of a stationary field-magnet, the construction shown in Fig. 8 is adopted. The conductor D in this case is made in substantially the same manner as above described by slotting an annular conducting-plate. The field-magnet in this case consists of two annular parts H H, provided with annular grooves I for the reception of the coils. The flanges surrounding the annular groove are brought together, while the inner flanges are serrated, as in the previous case, and form the polar faces.

In a type of machine of this kind, constructed by Mr. Tesla, the field had 480 polar projections on each side, and from this machine it was possible to obtain 30,000 alternations per second. As the polar projections must necessarily be very narrow, very thin wires or sheets must be used to avoid the eddy current effects. Mr. Tesla has thus constructed machines with a stationary armature and rotating field,

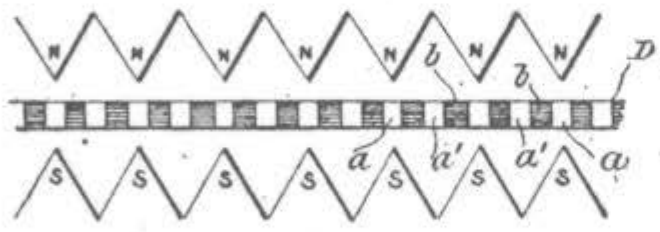


FIG. 9.—TESLA HIGH FREQUENCY ALTERNATING GENERATOR.

in which case also the field-coil was supported so that the revolving part consisted only of a wrought iron body devoid of any wire, and also machines with a rotating armature and stationery field. It is left to the judgment of the experimenter which plan is best to follow, each promising certain advantageous features. These machines may be constructed on the drum or disc plan, but the experience of Mr. Tesla shows that the latter plan is preferable.

Prof. Elihu Thomson's Pioneer Experiences.—In his address on "Pioneers' Day" at the recent meeting of the National Electric Association at Providence (R.I.), Prof. Elihu Thomson gave the following interesting account of his early experiences :—Recounting my own experience in electric lighting, I may say that I built a small dynamo about 1876 to run an arc light. It was a success, and it led to the construction of other dynamos. When I came, however, to the commercial part of the business, which began in 1878 or 1879, I found that there were many difficulties to overcome, and not the least of these difficulties was the getting of steady power to run the machines. The first Thomson-Houston three-coil armature machine intended for commercial use was capable of running from four to eight lights in series. I carefully examined every inch of the wire, and insulated the whole thing myself. Our first machine was put up in a bakery in Philadelphia, where it was used all night, and it was rather tenderly nursed by us. Sometimes we were up all night tending to this baby, and under conditions which were not altogether agreeable in the summer, as there is a good deal of waste heat in a bakery. The temperature was sometimes as high as 140 deg. After running these machines some time a Company was organised, which is now the Thomson-Houston Electric Company. It was organised in a modest way in New Britain, Conn. I became electrician of this small Company, and the apparatus was made in New Britain in an old basket shop. This was the beginning of our experiences. We soon got into another shop and began the construction of apparatus for commercial use. After we got into operation our difficulties were not, by any means, over. We had to develop all sorts of devices. We had to overcome conditions constantly arising to discourage us. When one thing was accomplished we were met by other reverses. The Brush Company saw our beginnings of success and tried to buy up a majority interest in our little Company in New Britain, apparently for the purpose of entirely swallowing us. Subsequently, however, in the same year, certain parties in Lynn purchased a majority interest in the stock, and what was the American Electric Company of New Britain started operations in Lynn. The Brush Company, as you are probably aware, has been swallowed up by us, the infant they tried to swallow. Such is fate. We have the firmest confidence in the expansion of the electrical industries. We are absolutely certain that the business is going to be greater and greater as time goes by. We have calls now for machines and dynamos up to 500 and 1,000 H.P., where a few years ago we thought it an unusual thing to have 100 and 200 H.P. machines, and it looks very much as though in the near future machines of much larger capacity would be demanded for the work of installation.

NOTES ON ALTERNATING CURRENTS OF VERY HIGH FREQUENCY.*

BY ELIHU THOMSON.

The interesting account of the novel experiments given by Mr. Nikola Tesla in the *Electrical World* of February 21, 1891 (see also *The Electrician*, March 6, p. 549), relating to the phenomena of alternating currents of very high frequency, leads me to make a statement of some of my own observations while working in similar directions. The highest number of alternations which I have had at my disposal up to the present is 8,000 per second, a rate somewhat below that which Mr. Tesla has obtained, but which, nevertheless, shows properties and brings about actions and results similar to those which he describes. The physiological actions of these rapidly alternating currents have been very ably investigated by Dr. Edward Tatum, some of the results of whose work I have presented in a separate communication. Mr. Tesla's experiences in relation to the static effects of these currents of high frequency are similar to those noted by myself, particularly the small surface of the condenser, which is able to transfer, or permit to be transferred, a considerable amount of energy through a dielectric, owing to the exceedingly high rate at which the changes of direction of charge are made.

The following experiment, which was tried by me some months ago, is interesting in this connection: An incandescent lamp bulb was constructed in which only a single platinum leading-in wire was used, on the end of which, inside the bulb, was mounted a single slip of carbon of two or three inches in length, it being one leg of a broken incandescent lamp filament. Two-thirds of the

* From the *Electrical World* of New York.

lamp bulb was now immersed in an outer vessel of water, leaving the single wire above the water for attachment to the source of alternating currents at one terminal, and the other terminal was connected with the outside water, which was rendered slightly conducting by salt dissolved therein. The water surrounding the lamp bulb formed, of course, an outer condenser coating, while the vacuous space and straight slip of carbon were the means for the conveyance of a charge to and from the inside surface of the bulb, which was, of course, exhausted to the ordinary vacuous condition, as found in an incandescent lamp. When an alternating potential of about 1,000 volts, and with a rate of alternations up to 5,000 per second, was applied to the carbon strip, the filament was brought to bright incandescence simply by the bombarding action of the residual gas, as in the Crooke's tubes, while, of course, no complete circuit existed, but only the condenser action of the lamp bulb allowing sufficient current to flow. At the same time the glass of the lamp bulb not immersed in the water became rapidly heated, indicating that that portion which was immersed in the water would have become equally heated had it not been subjected to the cooling action of the water itself.

The retention of the arc, as with direct currents, and the high note evolved by it have been noted from the beginning of my experiments with these high-period currents. Mr. Tesla expresses surprise that he was enabled to hear the note from an arc in which the alternations of current were more than 10,000 per second. Mr. Tesla will pardon me for calling his attention to the fact that he is taking as the limit of audition in this case sounds of from 5,000 to 10,000 complete waves per second, which is far below the limit at which sounds become inaudible to ordinary ears, cases existing in which a pitch corresponding to over 30,000 per second has been heard, according to some authorities. The cause of the persistence of the arc with very high-period alternations, as stated by Mr. Tesla, is undoubtedly the correct one, *i.e.*, that the gas stream has no time to cool between the alternations, and its variations of temperature must therefore be quite slight. The conductivity of the vapour or gas stream constituting the arc therefore remains nearly constant when the rapidity of alternations is sufficiently great.

The characteristics stated by Mr. Tesla as requisite to be possessed by machines suitable for obtaining constant current for the working of arc lights are, of course, connected with the fact that in such machines the characteristic curve indicates a drop or fall in the electromotive force developed on a slight excess of current above the normal, and on a decrease of current arising of the electromotive force to a point above the normal. It is not, however, in accordance with my experience that the undulation of the current is almost essential to the success of an arc-light system; nor do I think that properly constructed clutch lamps depend for their success, any more than do finely constructed clock-work lamps, on the presence of a rapidly varying current due to a small number of armature coils and correspondingly small number of segments in the commutator. In fact, I have run with perfect success clutch lamps in circuit with coils of such large self-induction that any but very slight fluctuations were wiped out and without introducing any particular difference in the behaviour of the lamps. It probably is true, however, that slight gentle fluctuations occurring at very moderate intervals may be of benefit in the working of clutch lamps by keeping the clutch mechanism in a state of vibration or tendency to open or close; but it can scarcely be doubted that if this benefit exists for such lamps a similar benefit would exist on the operation of clockwork lamps, as a similar fluctuation would give rise to a continual tendency in such lamps to keep the detent or escapement free enough for delicately letting go teeth for the feed; but the fact that large numbers of lamps are in use in which the feeding of the carbon either by clutch or by clockwork is under the control of a derived circuit magnet only, and that such lamps operate with the greatest satisfaction, shows that the undulations mentioned by Mr. Tesla are not necessarily a factor to be considered. In such cases the self-induction of the arc branch is negligible as compared with that of the derived circuit magnet controlling mechanism, and the fluctuations, therefore, would pass through the arc without affecting the said magnet to a perceptible degree, particularly as the potential around the arc with slightly different current strengths flowing is nearly constant. I may add that the experiments of Mr. Tesla in relation to the action of the condenser and the elevation of potential brought about by it are decidedly interesting, and point to the possibility of obtaining a pure resonance effect. This would require, however, that the periodicity of the alternations be preserved very rigidly during the experiments, and involves the production of an unvarying or perfectly constant speed in driving the generating machine, a condition not easily obtained in practice.

In making the above notes on the highly interesting and valuable account given by Mr. Tesla, I desire to state that, in whatever way my notes may appear as criticism of Mr. Tesla's views, they are not made in any unfriendly spirit, but with the desire of reaching the exact facts which it is the object of scientific investigation and discussion to ascertain.

Phenomena of Alternating Currents of Very High Frequency.

BY NIKOLA TESLA.

In the issue of THE ELECTRICAL WORLD of March 14 I find a note of Prof. Elihu Thomson relating to some of my experiments with alternating currents of very high frequency which have been described in THE ELECTRICAL WORLD of Feb. 21, 1891.

Prof. Thomson calls attention to the interesting fact that he has performed some experiments in the same line. I was not quite unprepared to hear this, as a letter from him appeared in *The Electrician* (London) a few months ago in which he mentioned a small alternate current machine which was capable of giving, I believe, 5,000 alternations per second, from which letter it likewise appears that his investigations on that subject are of a more recent date.

Prof. Thomson describes an experiment with a bulb inclosing a carbon filament which was brought to incandescence by the bombardment of the molecules of the residual gas when the bulb was immersed in water rendered slightly conducting by salt dissolved therein (?) and a potential of 1,000 volts, alternating 5,000 times a second, applied to the carbon strip. Similar experiments have, of course, been performed by many experimenters, the only distinctive feature in Prof. Thomson's experiment being the comparatively high rate of alternation. These experiments can also

be performed with a steady difference of potential between the water and the carbon strip, in which case, of course, conduction through the glass takes place, the difference of potential required being in proportion to the thickness of the glass. With 5,000 alternations per second conduction still takes place, but the condenser effect is preponderating. It goes, of course, without saying that the heating of the glass in such a case is principally due to the bombardment of the molecules, partly also to leakage or conduction, but it is an undeniable fact that the glass may also be heated merely by the molecular displacement. The interesting feature in my experiment was that a lamp would light up when brought near to an induction coil, and that it could be held in the hand and the filament brought to incandescence.

Experiments of the kind described I have followed up for a long time with some practical objects in view. In connection with the experiment described by Prof. Thomson, it may be of interest to mention a very pretty phenomenon which may be observed with an incandescent lamp. If a lamp be immersed in water as far as practicable, and the filament and the vessel connected to the terminals of an induction coil operated from a machine such as I have used in my experiments, one may see the dull red filament surrounded by a very luminous globe, around which there is a less luminous space. The effect is probably due to reflection, as the globe is sharply defined, but may also be due to a "dark space;" at any rate it is so pretty that it must be seen to be appreciated.

Prof. Thomson has misunderstood my statement about the limit of audition. I was perfectly well aware of the fact that opinions widely differ on this point. Nor was I surprised to find that arcs of about 10,000 impulses per second emit a sound. My statement, "the curious is," etc., was only made in deference to an opinion expressed by Sir William Thomson. There was absolutely no stress laid on the precise number. The popular belief was that something like 10,000 to 20,000 per second, or 20,000 to 40,000 at the utmost, was the limit. For my argument this was immaterial; I contended that sounds of an incomparably greater number, that is, many times even the highest number, could be heard if they could be produced with sufficient power. My statement was only speculative, but I have devised means which I think may allow me to learn something definite on this point. I have not the least doubt that it is simply a question of power. A very short arc may be silent with 10,000 impulses per second, but just as soon as it is lengthened it begins to emit a sound. The vibrations are the same in number, but more powerful.

Prof. Thomson states that I am taking as the limit of "audition" sounds from 5,000 to 10,000 complete waves per second. There is nothing in my statements from which the above could be inferred, but Prof. Thomson has, perhaps, not thought that there are two sound vibrations for each complete current wave, the former being independent of the direction of the current.

I am glad to learn that Prof. Thomson agrees with me as to the causes of the persistence of the arc. Theoretical considerations a considerable time since had led me to the belief that arcs produced by currents of such high frequency would possess this and other desirable features. One of my objects in this direction has been to produce a practicable small arc. With these currents for many reasons much smaller arcs are practicable.

The interpretation by Prof. Thomson of my statements about the arc system leads me now—he will pardon me for saying it—to believe that what is most essential to the success of an arc system is good management. Nevertheless I feel confident of the correctness of the views expressed. The conditions in practice are so manifold that it is impossible for any type of machine to prove best under all the different conditions.

In one case when the circuit is many miles long, it is desirable to employ the most efficient machine with the least internal resistance; in another case such a machine would not be the best to employ. It will certainly be admitted that a machine of any type must have a greater resistance if intended to operate arc lights than if it is designed to supply incandescent lamps in series. When arc lights are operated and the resistance is small, the lamps are unsteady, unless a type of lamp is employed in which the carbons are separated by a mechanism which has no further influence upon the feed, the feeding being effected by an independent mechanism; but even in this case the resistance must be considerably greater to allow a quiet working of the lamps. Now, if the machine be such as to yield a steady current there is no way of attaining the desired result except by putting the required resistance somewhere either inside or outside of the machine. The latter is hardly practicable, for the customer may stand a hot machine, but he looks with suspicion upon a hot resistance box. A good automatic regulator, of course, improves the machine and permits the reduction of the internal resistance to some extent, but not as far as would be desirable. Now since resistance is loss, we can advantageously replace resistance in the machine by any equivalent impedance. But to produce a great impedance with small ohmic resistance it is necessary to have self-induction and variation of current, and the greater the self-induction and the rate of change of the current, the greater the impedance may be made, while the ohmic resistance may be very small. It must also be remarked that the impedance of the circuit external to the machine is likewise increased. As regards the increase in ohmic resistance in consequence of the variation of the current, this is, in the commercial machines now in use, very small. Clearly then a great advantage is gained by providing self-induction in the machine circuit and undulating the current, for it is possible to replace a machine which has a resistance of, say, 16 ohms by one which has no more than 2 or 3 ohms, and the lights will work even steadier. It seems to me, therefore, that my saying that self-induction is essential to the commercial success of an arc system is justified. What is still more important, such a machine will cost considerably less. But to realize fully the benefits it is preferable to employ an alternate current machine, as in this case a greater rate of change in the current is obtainable. Just what the ratio of resistance to impedance is in the Brush and Thomson machines is nowhere stated, but I think that it is smaller in the Brush machine, judging from its construction.

As regards the better working of clutch lamps with undulating currents, there is, according to my experience, not the least doubt about it. I have proved it on a variety of lamps to the complete satisfaction not only of myself but of many others. To see the improvement in the feed due to the jar of the clutch at its best it is desirable to employ a lamp in which an independent clutch mechanism effects the feed, and the release of the rod is independent of the up and down movement. In such a lamp the clutch has a small inertia and is very sensitive to vibrations, whereas if the feed is affected by the up and down movement of the lever carrying the rod, the inertia of the system is so great that it is not affected as much by vibrations, especially if, as in many cases, a dash-pot is employed. During the year 1885 I perfected such a lamp which was calculated to be operated with undulating currents. With about 1,500 to 1,800 current impulses per minute, the feed of this lamp is such that absolutely no movement of the rod can be observed, even if the arc be magnified fifty-fold by means of a lens, whereas if a steady current is employed the lamp feeds by small steps. I have, however, demonstrated this feature on other types of lamps, among them being a derived circuit lamp such as Prof. Thomson refers to I conceived the idea of such a lamp early in 1884, and when my first company was started this was the first lamp I perfected. It was not until the lamp was ready for manufacture that, on receiving copies of application from the Patent Office, I learned for the first time, not having had any knowledge of the state of the art in America, that Prof. Thomson had anticipated me and had obtained many patents on this principle, which, of course, greatly disappointed and embarrassed me at that time. I observed the improvement of the feed with undulating currents on that lamp, but I recognized the advantage of providing a light and independent clutch unhampered in its movements. Circumstances did not allow me to carry out at that time some designs of machines I had in mind, and with the existing machines the lamp has worked at a great disadvantage. I cannot agree with Prof. Thomson that small vibrations would benefit a clockwork lamp as much as a clutch lamp; in fact, I think that they do not at all benefit a clockwork lamp. It would be interesting to learn the opinion of Mr. Charles F. Brush on these points.

Prof. Thomson states that he has run with perfect success clutch lamps "in circuit with coils of such large self-induction that any but very slight fluctuations were wiped out." Surely Prof. Thomson does not mean to say that self-induction wiped out the periodical fluctuation of the current. For this just the opposite quality, namely, capacity, is required. The self-induction of the coils in this case simply increased the impedance and variations occurring at large time intervals, which take place when the resistance in circuit with the lamps is too small, or even with larger resistance in circuit when the dash-pots either in the lamps or elsewhere are too loose.

Prof. Thomson further states that, in a lamp in which the feed mechanism is under the control of the derived circuit magnet only, the fluctuations pass through the arc without affecting the magnet to a perceptible degree. It is true that the variations of the resistance of the arc in consequence of the variations in the current strength are such as to dampen the fluctuation. Nevertheless, the periodical fluctuations are transmitted through the derived circuit, as one may convince himself easily by holding a thin plate of iron against the magnet.

In regard to the physiological effects of the currents, I may state that upon reading the memorable lecture of Sir William Thomson, in which he advanced his views on the propagation of the alternate current through conductors, it instantly occurred to me that currents of high frequencies would be less injurious. I have been looking for a proof that the mode of distribution through the body is the cause of the smaller physiological effects. At times I have thought that I was able to locate the pain in the outer portions of the body, but it is very uncertain. It is most certain, however, that the feeling with currents of very high frequencies is somewhat different from that with low frequencies. I have also noted the enormous importance of one being prepared for the shock or not. If one is prepared the effect upon the nerves is not nearly as great as when unprepared. With alternations as high as 10,000 per second and upward, one feels but little pain in the central portion of the body. A remarkable feature of such currents of high tension is that one receives a burn instantly he touches the wire, but beyond that the pain is hardly noticeable.

But since the potential difference across the body by a given current through it is very small, the effects cannot be very well ascribed to the surface distribution of the current, and the excessively low resistance of the body to such rapidly varying currents speaks rather for a condenser action.

In regard to the suggestion of Dr. Talum, which Prof. Thomson mentions in another article in the same issue of The Electrical World, I would state that I have constructed machines with as many as 480 poles, from which it is possible to obtain about 30,000 alternations per second, and perhaps more. I have also designed types of machines in which the field would revolve in an opposite direction to the armature, by which means it would be possible to obtain from a similar machine 60,000 alternations per second or more.

I value highly the appreciation by Prof. Thomson of my work, but I must confess that in his conclusion he makes a most astounding statement as to the motives of his critical remarks. I have never for a moment thought that his remarks would be dictated by anything but friendly motives. Often we are forced in daily life to represent opposing interests or opinions, but surely in the higher aims the feelings of friendship and mutual consideration should not be affected by such things as these.

PHYSIOLOGICAL EFFECTS OF ALTERNATING CURRENTS OF HIGH FREQUENCY.

BY ELIHU THOMSON.

The following is an abstract of a Paper of which an advance proof was kindly sent us by Prof. Elihu Thomson :—

In connection with an experimental investigation of the properties of alternating currents of high frequency, and the phenomena which they present, it had occurred to me that it would be desirable to obtain data concerning the physiological effects of these currents as compared with the effects of currents of ordinary frequency. I had constructed a machine on the type of my new alternating dynamo, accounts of which were published some time last year. In this machine an iron mass only is revolved, the central portion of which carries projections which pass near to the coils in which the currents are induced, which may be termed the armature coils, carried on the inner face of a laminated structure, in turn supported by the outer frame work of the machine. The machine, with 100 armature coils and a speed of 5,000 revolutions per minute, gives a little over 8,000 alternations per second. The publication of brief notices of some of the results obtained in the operation of this machine led Dr. Edward Tatum, of Yonkers, N.Y., to correspond with me with the view of finding out whether I had intended to conduct any physiological experiments with the currents, and indicating his desire to experiment in this direction if the machinery for obtaining the currents could be placed at his disposal for a short time. Accordingly the machine was sent to Dr. Tatum some time last fall, and was used by him in making a series of experiments, the results of which cannot fail to be of the highest interest to electricians and physiologists.

"The most definite and perhaps the most striking, as well as physiologically instructive result has been in regard to the fatal efficiency of such rapidly alternating currents. When the circuit is formed through the head and body (of dogs) death occurs in the same manner as with other sources of current (which are made strong enough to kill by a closure lasting not more than two or three seconds)—that is, by primary arrest and paralysis of the heart; but, taking the fatal efficiencies of different sorts of currents as inversely proportional to the current strengths required to kill under otherwise similar conditions, a rate of 4,500 per second is not only far less efficient than rates of a few hundred, but it is distinctly less efficient than a continuous battery current. It is remarkable that rates of 300 and of 120 alternations per second are fatally efficient at very nearly the inverse ratio of the numbers but, still more remarkable, that the very highest rates should also present a strikingly near approach to a similar ratio. It must be noted, however, that no such ratio can hold throughout the whole range, for 36 alternations per second (from the same machine as furnished 120 and the 300 rates) are again distinctly less efficient than 120—something like two-thirds as efficient."

Dr. Tatum goes on to point out that a potential of 450 volts was survived at the high rate of alternations, and the fatal current reached only at 495 volts, while 45 volts at 120 alternations similarly applied to the dog suffices to pass a fatal current. Dr. Tatum also determined the ratio of pressure or potential to current in the dog just after the cessation of respiration, using in rotation, twice repeated, first, a continuous pressure or potential; secondly, an alternating one at a rate of 120; and, thirdly, an alternating potential at a rate of 4,500 per second, at about 100 volts, and states:—"This ratio was so uniform (the extremes observed differing by less than 3 per cent.) as to dispose of any suspicion that the high-period currents distributed themselves essentially different from others in the animal's body.

". . . In regard to the physiological as distinguished from the fatal characteristics of the high-period machine, I am only able to state the results in terms of pressure instead of terms of current, as I should prefer. The limits of voluntary toleration for alternating pressures (applied with sponge electrodes) seems to depend very little on the frequency of alternation. For all the frequencies I have mentioned the limit has been found between 10 and 15 volts for applications about the face and head, and between 40 and 50 volts between the hands, without any decided preference in either case for one rate more than another.

"The cause of the pain which limits voluntary toleration seems to be in all cases chiefly in the muscular contraction produced. At 4,500 this muscular contraction is usually free from the thrill experienced even at 300; resembling, on the temples, nothing I can think of so much as firm pressure with the knuckles.

"The cutaneous nerves are distinctly less painfully affected at the high rate. The visual mechanism cannot be excited at the high rate, even by a pressure of 15 volts, so as to cause a sensation of flashes of light, although two or three volts similarly applied at 120 alternations causes such flashes very energetically. Sensations of taste are also absent."

In presenting these results I take occasion to express my sincere regret that his ill-health has prevented the continuance of the work in the direction laid out by the Doctor himself, and to express, also, the hope that he may be able to take up the further investigations at some other future time.

ALTERNATING CURRENTS OF HIGH FREQUENCY.—A REPLY TO MR TESLA.

BY

Elihu Thomson

In regard to the comments of Mr. Tesla published in The Electrical Engineer of March 18, concerning my note in your issue of the 11th, I think it desirable that I should make a few remarks. Mr. Tesla appears to infer that my investigations of the properties of alternating currents of high periods must have been subsequent to the note which was published in the *Electrician* a few months ago stating that I had constructed a high period machine. I would say that as soon as that machine was completed I made quite a number of investigations in relation to the properties of these currents, but did not have time to put them in shape for publication.

In regard to the experiments with the incandescent lamp bulb and the strip of filament mounted on a single wire, I cannot agree with Mr. Tesla at all that conduction through the glass has anything to do with the phenomenon it presents. It is well known that an incandescent lamp bulb if held in the hand is capable of acting as a Leyden jar and will receive and retain a charge from a static machine of very high potential, and that a very violent Leyden jar shock, with a long spark, may be obtained by bringing the free hand towards the neck while holding the bulb after charging, as mentioned. If conduction through the glass were a possibility this action could not occur.

Mr. Tesla thinks that I have misunderstood his statement about the limit of audition. From my point of view I think that he has misunderstood my statement about it. He had stated that he had experimented with 10,000 to 20,000 alternations per second. I pointed out that this would correspond to 5,000 to 10,000 complete waves of sound, and equally, I may now say, complete waves of current. The limit he had adopted, or suggested, was about 10,000 waves a second. It is evident that his experimenting with from 5,000 to 10,000 complete waves would be working below this limit of audition, even taking the low value which he had suggested for it. I have heard sounds of 20,000 complete waves per second. The physical cabinet of the Central High School, at Philadelphia, contained, at the time of my connection with the institution, apparatus which enabled a test of one's hearing powers in this respect to be easily made.

I agree with Mr. Tesla that the success of an arc light system depends upon good management; and I include in the term good management, good design, good construction, good supervision, and good commercial work, which includes the ability to stand considerable bad management in the running.

Five or six years ago it occurred to me to try the construction of a dynamo for constant current in which the armature coils were of a highly efficient type, that is, of comparatively short wire length for the voltage and moving in a dense magnetic field. Exteriorly to the coils, and to the field, I had placed (in the circuit of each coil) an impedance coil, which consisted of an iron core wound with a considerable length of wire and connected directly in circuit with the armature coil. I thus obtained, as I thought, the property of considerable self induction along with efficient current generation, and by separate devices, I expected that possibly the effects would be very much the same as those obtainable from the regularly constructed arc apparatus. In this I was disappointed. The effect was to shift the diameter of commutation forward and to lower the capacity of the machine, while the properties otherwise were not so greatly changed. The requirement in the arc machine is simply that there shall be a droop or dip in the characteristic curve at about the point of normal current, and at a rate dependent upon the character of the lamps used with the machine. Differential lamps require for stability less droop or dip than lamps feeding entirely by the shunt or derived circuit. Without doubt, arc machines give better effects when the field magnets are in series, not only on account of the resistance of such magnets, but also because of their self induction tending to smooth out and obliterate vibrations or undulations of current which would otherwise have a direct passage from the commutator brushes to the circuit.

Mr. Tesla has evidently misunderstood my meaning when I spoke of the introduction of a coil of large self induction in series with arc lamps as not affecting their feeding. I had no reference to any instability of current "involving large variations, and occurring at large time intervals," in this case, as the machinery I used was of a stable character and did not give rise to the instability at which he here seems to hint. I meant that a coil of large self induction cut down, or wiped out, vibrations or undulations of current and reduced them to a very slight amount, *i. e.*, prevented them from existing in the circuit, just as such coils will wipe out the waves of speech in a telephone circuit, only the effect here is, of course, on a larger scale.

In relation to the feeding of a lamp which operates by a clutch, I do not deny that a slight vibration of the parts will, or may, benefit the feed, but I think the same slight vibration will benefit the feed of the clock-work lamp also. On this point Mr. Tesla contented himself by simply saying that he cannot agree with me, and that he thinks these vibrations do not at all benefit a clock-work lamp. I disagree with him there, because I think they *must*, as the vibration tends to keep all the moving parts free to act and avoid the sluggish effect of starting friction. In the clutch arc lamps of the Thomson-Houston Electric Company for many years past, the clutch has been attached only to the feed regulating lever by an elastic spring, and the result of this spring suspension or elastic connection (the properties of which I discovered as far back as 1879 or 1880) was that the feeding action by clutches was greatly improved; not, however, because the spring served to damp vibrations, though it undoubtedly did so act, but because it secured an action of the clutch which was equivalent to an automatic slip instead of a free release. In this connection I may mention that I have built and used very many forms of arc lamps of both the clutch and clock-work types.

I have frequently operated clock-work lamps of Mr. Wood's construction on Thomson-Houston arc machines, and clutch lamps on machines of the Gramme type, and have, moreover, frequently run mixed circuits of lamps with several types of lamps in the same circuit on either type of machine indiscriminately. The lamps, so far as could be determined by an inspection of the arcs, worked very satisfactorily and in no way different from their normal behavior. I doubt not that there are arc plants in operation in which machines of different makes and types are interchanged, and in which lamps of different makes and different types are found mixed on the same circuit, and while this may not be very desirable always, still there is no reason why the results obtained should not be satisfactory, if the types of apparatus are good, well made and properly taken care of.

While I think it possible that the smaller physiological effect of high period alternating currents may be due to some difference in distribution, still the experiments of Dr. Tatum do not give any indication of such a result, though he sought for it. I cannot say that his experiments were perfectly conclusive on this point. From the fact, however, that the sensory nerves are to be found on the exterior of the animal body in the greatest abundance, and adapted to receive outside impressions, it would seem that the experiments of Dr. Tatum, which show that a greater amount of current at a high period could be tolerated voluntarily, are at least indicative of the fact that the current did not traverse the cuticle where the nerves are so

sensitive. In such a comparatively poor conductive material as animal tissue, it appears to me very probable that the distribution of current will be determined largely by conductivity of the layers, and not by self induction to any great extent, especially as the amount or density of the current which may in any case be supported is so very small.

I confess that my statement as to the motive of my critical remarks may have been out of place. They were elicited, however, by Mr. Tesla having on a former occasion misunderstood my motives and having acted on that misunderstanding.

CORRESPONDENCE.

ALTERNATE-CURRENT MOTORS.

SIR,—In your issue of March 6 I find the passage: "Mr. Kapp described the position as it exists. He showed how Ferraris first of all pointed out the right way to get an alternating-current motor that was self-starting, and how Tesla and others had worked in the direction indicated by Ferraris," etc.

I would be very glad to learn how Mr. Kapp succeeded in showing this. I may call his attention to the fact that the date of filing of my American patent anticipates the publication of the results of Prof. Ferraris in Italy by something like six months. The date of filing of my application is, therefore, the first public record of the invention. Considering this fact, it seems to me that it would be desirable that Mr. Kapp should modify his statement.—Yours, etc.

NIKOLA TESLA.

New York, 17th March, 1891.

CORRESPONDENCE.

Electro-motors.

Fifteen or sixteen years ago, when I was pursuing my course at the college, I was told by an eminent physicist that a motor could not be operated without the use of brushes and commutators, or mechanical means of some kind for commutating the current. It was then I determined to solve the problem.

After years of persistent thought I finally arrived at a solution. I worked out the theory to the last detail, and confirmed all of my theoretical conclusions by experiments. Recognising the value of the invention, I applied myself to the work of perfecting it, and after long continued labour I produced several types of practical motors.

Now all this I did long before anything whatever transpired in the whole scientific literature—as far as it could be ascertained—which would have even pointed at the possibility of obtaining such a result, but quite contrary at a time when scientific and practical men alike considered this result unattainable. In all civilised countries patents have been obtained almost without a single reference to anything which would have in the least degree rendered questionable the novelty of the invention. The first published essay—an account of some laboratory experiments by Prof. Ferraris—was published in Italy six or seven months after the date of filing of my applications for the foundation patents. The date of filing of my patents is thus the first public record of the invention. Yet in your issue of March 6th I read the passage: "For several years past, from the days of Prof. Ferraris's investigations, which were followed by those of Tesla, Zipernowsky and a host of imitators," &c.

No one can say that I have not been free in acknowledging the merit of Prof. Ferraris, and I hope that my statement of facts will not be misinterpreted. Even if Prof. Ferraris's essay would have anticipated the date of filing of my application, yet, in the opinion of all fair-minded men, I would have been entitled to the credit of having been the first to produce a practical motor; for Prof. Ferraris himself denies in his essay the value of the invention for the transmission of power, and only points out the possibility of using a properly-constructed generator, which is the only way of obtaining the required difference of phase without losses; for even with condensers—by means of which it is possible to obtain a quarter phase—there are considerable losses, the cost of the condensers not considered.

Thus, in the most essential features of the system—the generators with the two or three circuits of differing phase, the three-wire system, the closed coil armature, the motors with direct current in the field, &c.—I would stand alone, even had Prof. Ferraris's essay been published many years ago.

As regards the most practicable form of two-wire motor, namely, one with a single energising circuit and induced circuits, of which there are now thousands in use, I likewise stand alone.

Most of these facts, if not all, are perfectly well known in England; yet, according to some papers, one of the leading English electricians does not hesitate to say that I have worked in the direction indicated by Prof. Ferraris, and in your issue above referred to it seems I am called an imitator.

Now, I ask you where is that world-known English fairness? I am a pioneer, and I am called an imitator. I am not an imitator. I produce original work or none at all.

Nikola Tesla.

New York, *March* 17*th*, 1891.

Phenomena of Alternating Currents of Very High Frequency.

BY ELIHU THOMSON.

In regard to the comments of Mr. Tesla published in your issue of March 18, concerning my note in your issue of the 11th, I think it desirable that I should make a few remarks. Mr. Tesla appears to infer that my investigation of the properties of alternating currents of high periods must have been subsequent to the note which was published in *The Electrician* (London) a few months ago stating that I had constructed a high-period machine. I would say that as soon as that machine was completed I made quite a number of investigations in relation to the properties of these currents, but did not have time to put them in shape for publication. In regard to the experiments with the incandescent lamp bulb and the strip of filament mounted on a single wire I cannot agree with Mr. Tesla at all that conduction through the glass has anything to do with the phenomenon it presents. It is well known that an incandescent lamp bulb if held in the hand is capable of acting as a Leyden jar and will receive and retain a charge from a static machine of very high potential, and that a very violent Leyden jar shock, with a long spark, may be obtained by bringing the free hand toward the neck while holding the bulb after charging, as mentioned. If conduction through the glass were a possibility this action could not occur.

Mr. Tesla thinks that I have misunderstood his statement about the limit of audition. From my point of view I think that he has misunderstood *my* statement about it. He had stated that he had experimented with 10,000 to 20,000 alternations per second. I pointed out that this would correspond to 5,000 to 10,000 complete waves of sound, and equally—I may now say—complete waves of current. The limit he had adopted or suggested was about 10,000 waves a second. It is evident that his experimenting with from 5,000 to 10,000 complete waves would be working below this limit of audition, even taking the low value which he had suggested for it. I have heard sounds of 20,000 complete waves per second. The physical cabinet of the Central High School, at Philadelphia, contained, at the time of my connection with the institution, apparatus which enabled a test of one's hearing powers in this respect to be easily made.

I agree with Mr. Tesla that the success of an arc light system depends upon good management, and I include in the term "good management" good design, good construction, good supervision and good commercial work, which include the ability to stand considerable bad management in the running.

Five or six years ago it occurred to me to try the construction of a dynamo for constant current in which the armature coils were of highly efficient type; that is, of comparatively short wire length for the voltage and moving in a dense magnetic field. Exteriorly to the coils and to the field I had placed (in the circuit of each coil) an impedance coil, which consisted of an iron core wound with a considerable length of wire and connected directly in circuit with the armature coil. I thus obtained, as I thought, the property of considerable self-induction, along with efficient current generation, and by separate devices. I expected that possibly the effects would be very much the same as those obtainable from the regularly constructed arc apparatus. In this I was disappointed. The effect was to shift the diameter of commutation forward and to lower the capacity of the machine, while the properties otherwise were not so greatly changed. The requirement in the arc machine is simply that there shall be a droop or dip in the characteristic curve at about the point of normal current, and at a rate dependent upon the character of the lamps used with the machine. Differentia lamps require for stability less droop or dip than lamps feeding entirely by the shunt or derived circuit. Without doubt arc machines give better effects when the field magnets are in series, not only on account of the resistance of such magnets, but also because of their self-induction tending to smooth out and obliterate vibrations or undulations of current which would otherwise have a direct passage from the commutator brushes to the circuit.

Mr. Tesla has evidently misunderstood my meaning when I spoke of the introduction of a coil of large self-induction in series with arc lamps as not affecting their feeding. I had no reference to any instability of current "involving large variations and occurring at large time intervals" in this case, as the machinery I used was of a stable character, and did not give rise to the instability at which he here seems to hint. I meant that a coil of large self-induction cut down or wiped out vibrations or undulations of current, and reduced them to a very slight amount,—*i. e.*, prevented them from existing in the circuit,—just as such coils will wipe out the waves of speech in a telephone circuit, only the effect here is of course on a larger scale.

In relation to the feeding of a lamp which operates by a clutch I do not deny that a slight vibration of the parts will or may benefit the feed, but I think the same slight vibration will benefit the feed of the clockwork lamp also. On this point Mr. Tesla contented himself by simply saying that he cannot agree with me, and that he thinks these vibrations do not at all benefit a clockwork lamp. I disagree with him here because I think they *must*, as the vibration tends to keep all the moving parts free to act and voids the sluggish effect of starting friction. In the clutch arc lamps of the Thomson-Houston Electric Company, for many years past the clutch has been attached only to the feed-regulating lever by an elastic spring, and the result of using this spring suspension or elastic connection (the properties of which I discovered as far back as 1879 or 1880) was that the feeding action by clutches was greatly improved, not, however, because the spring served to damp vibrations, though it undoubtedly did so act, but because it secured an action of the clutch which was equivalent to an automatic slip instead of a free release. In this connection I may mention that I have built and used very many forms of arc lamps of both the clutch and clockwork types.

I have frequently operated clockwork lamps of Mr. Wood's construction on Thomson-Houston arc machines, and clutch lamps on machines of the Gramme type, and have, moreover, frequently run mixed circuits of lamps with several types of lamps in the same circuit on either type of machine indiscriminately. The lamps, so far as could be determined by an inspection of the arcs, worked very satisfactorily, and in no way different from their normal behavior. I doubt not that there are arc plants in operation in which machines of different makes and types are found mixed on the same circuit; and while this may not be very desirable always, still there is no reason why the results obtained should not be satisfactory if the types of apparatus are good, well made and properly taken care of.

While I think it possible that the smaller physiological effect of high-period alternating currents may be due to some difference in distribution, still the experiments of Dr. Tatum do not give any indication of such a result, though he sought for it. I cannot say that his experiments were perfectly conclusive on this point. From the fact, however, that the sensory nerves are to be found on the exterior of the animal body in the greatest abundance, and adapted to receive outside impressions, it would seem that the experiments of Dr. Tatum, which show that a greater amount of current at a high period could be tolerated voluntarily, are at least indicative of the fact that the current did not traverse the cuticle where the nerves are so sensitive. In such a comparatively poor conductive material as animal tissue it appears to me very probable that the distribution of current will be determined largely by conductivity of the layers and not by self-induction to any great extent, especially as the amount or density of the current which may in any case be supported is so very small.

I confess that my statement as to the motive of my critical remarks may have been out of place. They were elicited, however, by Mr. Tesla having on a former occasion misunderstood my motives and having acted on that misunderstanding.

Letters to the Editor.

PHENOMENA OF CURRENTS OF HIGH FREQUENCY.

I cannot pass without comment the note of Prof. Thomson in your issue of April 1, although I dislike very much to engage in a prolonged controversy. I would gladly let Prof. Thomson have the last word, were it not that some of his statements render a reply from me necessary.

I did not mean to imply that, whatever work Prof. Thomson has done in alternating currents of very high frequency, he had done subsequent to his letter published in the *Electrician*. I thought it possible, and even probable, that he had made his experiments some time before, and my statement in regard to this was meant in this general way. It is more than probable that quite a number of experimenters have built such machines and observed effects similar to those described by Prof. Thomson. It is doubtful, however, whether, in the absence of any publication on this subject, the luminous phenomena described by me have been observed by others, the more so, as very few would be likely to go to the trouble I did, and I would myself not have done so had I not had beforehand the firm conviction, gained from the study of the works of the most advanced thinkers, that I would obtain the results sought for. Now, that I have indicated the direction, many will probably follow, and for this very purpose I have shown some of the results I have reached.

Prof. Thomson states decisively in regard to experiments with the incandescent lamp bulb and the filament mounted on a single wire, that he cannot agree with me at all that conduction through the glass has anything to do with the phenomenon observed. He mentions the well-known fact that an incandescent lamp acts as a Leyden jar and says that "if conduction through the glass were a possibility this action could not occur." I think I may confidently assert that very few electricians will share this view. For the possibility of the condenser effect taking place it is only necessary that the rate at which the charges can equalize through the glass by conduction should be somewhat below the rate at which they are stored.

Prof. Thomson seems to think that conduction through the glass is an impossibility. Has he then never measured insulation resistance, and has he then not measured it by means of a conduction current? Does he think that there *is* such a thing as a perfect non-conductor among the bodies we are able to perceive? Does he *not* think that as regards conductivity there can be question only of degree? If glass were a perfect non-conductor, how could we account for the leakage of a glass condenser when subjected to steady differences of potential?

While not directly connected with the present controversy, I would here point out that there exists a popular error in regard to the properties of dielectric bodies. Many electricians frequently confound the theoretical dielectric of Maxwell with the dielectric bodies in use. They do not stop to think that the only perfect dielectric is ether, and that all other bodies, the existence of which is known to us, must be conductors, judging from their physical properties.

My statement that conduction is concerned to some, although perhaps negligible, extent in the experiment above described was, however, made not only on account of the fact that all bodies conduct more or less, but principally on account of the heating of the glass during the experiment. Prof. Thomson seems to overlook the fact that the insulating power of glass diminishes enormously with the increase in temperature, so much so, that melted glass is comparatively an excellent conductor. I have, moreover, stated in my first reply to Prof. Thomson in your issue of March 18, that the same experiment can be performed by means of an unvarying difference of potential. In this case it must be assumed that some such process as conduction through the glass takes place, and all the more as it is possible to show by experiment, that with a sufficiently high steady difference of potential, enough current can be passed through the glass of a condenser with mercury coating to light up a Geissler tube joined in series with the condenser. When the potential is alternating, the condenser action comes in and conduction becomes insignificant, and the more so, the greater the rate of alternation or change per unit of time. Nevertheless, in my opinion, conduction must always exist, especially if the glass is hot, though it may be negligible with very high frequencies.

Prof. Thomson states, further, that from his point of view I have misunderstood his statement about the limit of audition. He says that 10,000 to 20,000 alternations correspond to 5,000 to 10,000 complete waves of sound. In my first reply to Prof. Thomson's remarks (in your issue of March 18,) I avoided pointing out directly that Prof. Thomson was mistaken, but now I see no way out of it. Prof. Thomson will pardon me if I call his attention to the fact he seems to disregard, namely, that 10,000 to 20,000 alternations of current in an arc—which was the subject under discussion—do not mean 5,000 to 10,000, but 10,000 to 20,000 *complete waves of sound.*

He says that I have adopted or suggested as the limit of audition 10,000 waves per second, but I have neither adopted nor suggested it. Prof. Thomson states that I have been working with 5,000 to 10,000 complete waves, while I have nowhere made any such statement. He says that this would be working below the limit of audition, and cites as an argument that at the Central High School, in Philadelphia, he has heard 20,000 waves per second; but he wholly overlooks a point on which I have dwelt at some length, namely, that the limit of audition of an arc is something entirely different from the limit of audition in general.

Prof. Thomson further states, in reply to some of my views expressed in regard to the constant current machines that five or six years ago it occurred to him to try the construction of a dynamo for constant current, in which "the armature coils were of a highly efficient type, that is, of comparatively short wire length for the voltage and moving in a dense magnetic field." Exteriorly to the coils and to the field he had placed in the circuit of each coil an impedance coil which consisted of an iron core wound with a considerable length of wire and connected directly in circuit with the armature coil. He thus obtained, he thought, "the property of considerable self-induction along with efficient current generation." Prof. Thomson says he expected "that possibly the effects would be very much the same as those obtainable from the regularly constructed apparatus." But he was disappointed, he adds. With all the consideration due to Prof. Thomson, I would say that, to expect a good result from such a combination, was rather sanguine. Earth is not farther from Heaven than this arrangement is from one, in which there would be a length of wire, sufficient to give the same self-induction, wound on the armature and utilized to produce useful E. M. F., instead of doing just the opposite, let alone the loss in the iron cores. But it is, of course, only fair to remember that this experiment was performed five or six years ago, when even the foremost electricians lacked the necessary information in these and other matters.

Prof. Thomson seems to think that self-induction wipes out the periodical undulations of current. Now self-induction does not produce any such effect, but, if anything, it renders the undulation more pronounced. This is self-evident. Let us insert a self-induction coil in a circuit traversed by an undulating current and see what happens. During the period of the greatest rate of change, when the current has a small value, the self-induction opposes more than during the time of the small rate of change when the current is at, or near, its maximum value. The consequence is, that with the same frequency the maximum value of the current becomes the greater, the greater the self-induction. As the sound in a telephone depends only on the maximum value, it is clear that self-induction is the very thing required in a telephone circuit. The larger the self-induction, the louder and clearer the speech, provided the same current is passed through the circuit. I have had ample opportunity to study this subject during my telephone experience of several years. As regard the fact that a self-induction coil in series with a telephone diminishes the loudness of the sound, Prof. Thomson seems to overlook the fact that this effect is wholly due to the impedance of the coil, *i. e.*, to its property of diminishing the *current strength.* But while the current strength is diminished the undulation is rendered only more pronounced. Obviously, when comparisons are made they must be made with the same current.

In an arc machine, such as that of Prof. Thomson's, the effect is different. There, one has to deal with a make and break. There are then two induced currents, one in the opposite, the other in the same direction with the main current. If the function of the mechanism be the same whether a self-induction coil be present or not, the undulations could not possibly be wiped out. But Prof. Thomson seems, likewise, to forget that the effect is wholly due to the defect of the commutator; namely, the induced current of the break, which is of the same direction with the main current and of great intensity, when large self-induction is present, simply bridges the adjacent commutator segments, or, if not entirely so, at least shortens the interval during which the circuit is open and thus reduces the undulation.

In regard to the improvement in the feeding of the lamps by vibrations or undulations, Prof. Thomson expresses a decisive opinion. He now says that the vibrations *must* improve the feeding of a clock-work lamp. He says that I "contented myself by simply saying," that I cannot agree with him on that point.

Now, *saying it*, is not the only thing I did. I have passed many a night watching a lamp feed, and I leave it to any skilled experimenter to investigate whether my statements are correct. My opinion is, that a clock-work lamp, that is, a lamp in which the descent of the carbon is regulated not by a clutch or friction mechanism, but by an escapement, cannot feed any more perfectly than tooth by tooth, which may be a movement of, say, $\frac{1}{64}$ of an inch or less. Such a lamp will feed in nearly the same manner whether the current be perfectly smooth or undulating, providing the conditions of the circuit are otherwise stable. If there is any advantage, I think it would be in the use of a smooth current, for, with an undulating current, the lamp is likely to miss some time and feed by more than one tooth. But in a lamp in which the descent of the carbon is regulated by friction mechanism, an indulating current of the proper number of undulations per second will always give a better result. Of course, to

realize fully the benefits of the undulating current the release ought to be effected independently of the up-and-down movement I have pointed out before.

In regard to the physiological effects, Prof. Thomson says, that in such a comparatively poor conductive material as animal tissue the distribution of current cannot be governed by self-induction to any appreciable extent, but he does not consider the two-fold effect of the large cross-section, pointed out by Sir William Thomson. As the resistance of the body to such currents is low, we must assume either condenser action or induction of currents in the body.

NIKOLA TESLA.

NEW YORK, April 4, 1891.

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ALTERNATING CURRENTS OF HIGH FREQUENCY.* A REPLY TO MR. TESLA.

BY ELIHU THOMSON.

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Mr. Tesla thinks that I have misunderstood his statement about the limit of audition. From my point of view I think that he has misunderstood my statement about it. He had stated that he had experimented with 10,000 to 20,000 alternations per second. I pointed out that this would correspond to 5,000 to 10,000 complete waves of sound, and equally, I may now say, complete waves of current. The limit he had adopted, or suggested, was about 10,000 waves a second. It is evident that his experimenting with from 5,000 to 10,000 complete waves would be working below this limit of audition, even taking the low value which he had suggested for it. I have heard sounds of 20,000 complete waves per second. The physical cabinet of the Central High School, at Philadelphia, contained, at the time of my connection with the Institution, apparatus which enabled a test of one's hearing powers in this respect to be easily made.

I agree with Mr. Tesla that the success of an arc light system depends upon good management; and I include in the term good management, good design, good construction, good supervision, and good commercial work, which includes the ability to stand considerable bad management in the running.

Five or six years ago it occurred to me to try the construction of a dynamo for constant current in which the armature coils were of a highly efficient type, that is, of comparatively short wire length for the voltage and moving in a dense magnetic field. Exteriorly to the coils, and to the field, I had placed (in the circuit of each coil) an impedance coil, which consisted of an iron core wound with a considerable length of wire and connected directly in circuit with the armature coil. I thus obtained, as I thought, the property of considerable self-induction along with efficient current generation, and by separate devices, I expected that possibly the effects would be very much the same as those obtainable from the regularly constructed arc apparatus. In this I was disappointed. The effect was to shift the diameter of commutation forward and to lower the capacity of the machine, while the properties otherwise were not so greatly changed. The requirement in the arc machine is simply that there shall be a droop or dip in the characteristic curve at about the point of normal current, and at a rate dependent upon the character of the lamps used with the machine. Differential lamps require for stability less droop or dip than lamps feeding entirely by the shunt or derived circuit. Without doubt, arc machines give better effects when the field magnets are in series, not only on account of the resistance of such magnets, but also because of their self-induction tending to smooth out and obliterate vibrations or undulations of current which would otherwise have a direct passage from the commutator brushes to the circuit.

Mr. Tesla has evidently misunderstood my meaning when I spoke of the introduction of a coil of large self-induction in series with arc lamps as not affecting their feeding. I had no reference to any instability of current "involving large variations, and occurring at large time intervals," in this case, as the machinery I used was of a stable character and did not give rise to the instability at which he here seems to hint. I meant that a coil of large self-induction cut down, or wiped out vibrations or undulations of current and reduced them to a very slight amount, *i.e.*, prevented them from existing in the circuit, just as such coils will wipe out the waves of speech in a telephone circuit, only the effect here is, of course, on a larger scale.

In relation to the feeding of a lamp which operates by a clutch, I do not deny that a slight vibration of the parts will, or may, benefit the feed, but I think the same slight vibration will benefit the feed of the clock-work lamp also. On this point Mr. Tesla contented himself by simply saying that he cannot agree with me, and that he thinks these vibrations do not at all benefit a clock-work lamp. I disagree with him there, because I think they *must*, as the vibration tends to keep all the moving parts free to act and avoid the sluggish effect of starting friction. In the clutch arc lamps of the Thomson-Houston Electric Company for many years past, the clutch has been attached only to the feeding regulating lever by an elastic spring, and the result of this spring suspension or elastic connection (the properties of which I discovered as far back as 1879 or 1880) was that the feeding action by clutches was greatly improved; not, however, because the spring served to damp vibrations, though it undoubtedly did so act, but because it secured an action of the clutch which was equivalent to an automatic slip instead of a free release. In this connection I may mention that I have built and used very many forms of arc lamps of both the clutch and the clock-work types.

I have frequently operated clock-work lamps of Mr. Wood's construction on Thomson-Houston arc machines, and clutch lamps on machines of the Gramme type, and have, moreover, frequently run mixed circuits of lamps with several types of lamps in the same circuit on either type of machine indiscriminately. The lamps, so far as could be determined by an inspection of the arcs, worked very satisfactorily and in no way different from their normal behaviour. I doubt not that there are arc plants in operation in which machines of different makes and types are interchanged, and in which lamps of different makes and different types are found mixed on the same circuit, and while this may not be very desirable always, still there is no reason why the results obtained should not be satisfactory, if the types of apparatus are good, well made and properly taken care of.

While I think it possible that the smaller physiological effect of high period alternating currents may be due to some difference in distribution, still the experiments of Dr. Tatum do not give any indication of such a result, though he sought for it. I cannot say that his experiments were perfectly conclusive on this point. From the fact, however, that the sensory nerves are to be found on the exterior of the animal body in the greatest abundance, and adapted to receive outside impressions, it would seem that the experiments of Dr. Tatum, which show that a greater amount of current at a high period could be tolerated voluntarily, are at least indicative of the fact that the current did not traverse the cuticle where the nerves are so sensitive. In such a comparatively poor conductive material as animal tissue, it appears to me very probable that the distribution of current will be determined largely by conductivity of the layers, and not by self-induction to any great extent, especially as the amount or density of the current which may in any case be supported is so very small.

I confess that my statement as to the motive of my critical remarks may have been out of place. They were elicited, however, by Mr. Tesla having on a former occasion misunderstood my motives and having acted on that misunderstanding.

BY CHAS. STEINMETZ.*

I read, with great interest, Mr. Tesla's and Prof. E. Thomson's account of their experiments with alternating

* See ELECTRICAL REVIEW, for April 3rd, 1891.

* New York *Electrical Review*.

currents of very high frequency; the greater, as my experience with high speed alternating machinery enabled me to fully appreciate the enormous difficulties connected with the mechanical production of such enormous frequencies.

Indeed, in my experiments, I never went by far so high as they did, and I am not musician enough to judge whether such a machine would be fit to accompany a thoroughly Wagnerian opera, as Mr. Tesla thinks; but, at least, I doubt it, because the one machine—of a design somewhat similar to his—which I once built, gave out a howling resembling much more an Indian war whoop, only a little more frightening, than anything else. And it was a very remarkable machine, too; the boys in the shop called it the "humming bird," and it goes now by this name. Perhaps I shall refer at a later occasion to the interesting experiments made with this machine, which, among other features, gave continuous magnetisation from alternating currents without commutation.

It seems, indeed, that the advantages of reaching such high frequencies, not by static discharges, but with machines powerful enough to yield perceptible *currents* of electricity, amply compensate for all the difficulties encountered therewith. Because these experiments made with frequencies of 20,000 to 30,000 per second form the connecting link between the phenomena of the alternate currents used in practical engineering, and those electric disturbances of millions or hundreds of millions of vibrations per second, which give rise to the Hertzian ether waves of radiating electricity.

And this fact explains all the experiments shown by Mr. Tesla and Prof. Thomson. Most of them, indeed, show truly static effects of oscillating electric disturbances, like the oscillating discharge of the induction coil in Hertz's experiments, only that in this case where the electric disturbances are backed by *currents*, which count by horse-powers, much more brilliant effects appear.

Is is certainly not *conduction* through the air which makes an incandescent lamp, entirely disconnected from the machine, light up, but it is the action of the radiating energy of the electric ether waves. Not the secondary current of the induction coil is felt by the hand which holds the incandescent lamp, but the electric charge influenced in the hand as the outer condenser coating, just as we draw sparks from the outer coating of a Leyden jar when the inner coating is charged by a static-electric machine, and feel every spark which jumps over from the machine conductor to the inner coating.

Various forms of the screening effect of metals, with regard to those waves, are shown by Mr. Tesla. Reflection and refraction, indeed, he could hardly expect to observe, because, even with 30,000 alternations per second, the wave length of the electric disturbance in space amounts still to something like seven miles.

But the whole space surrounding such a machine has to be considered as an electro-magnetic field of force, and a very powerful one, too, because of the enormous strain exerted upon the dielectric by the high pressure of the induction coil.

It is only to be regretted that in all the reports of Mr. Tesla's experiments nowhere anything is stated about the E.M.F. of those electric secondary currents. This omission rather impairs the value of these experiments somewhat. The E.M.F. of the primary current Mr. Tesla gives as 500 volts. But how did he measure the alternating pressure of 30,000 vibrations per second; by static electrometer? Because any dynamometer would be unreliable under these circumstances.

I think, although any closed circuit voltmeter would be entirely out of question for such high frequencies, a modified electro-meter, built for very low capacity, would, perhaps, answer the purpose of measuring the secondary E.M.F., and could be built so that it could be used for determining the E.M.F. and also the electric energy, that is, the power consumed by the circuit. This seems to me of very great importance, because it would give the means to determine by experiment the amount of electric energy which radiates into space as electric ether waves, that is, the time hysteresis of air.

I should suggest to determine the whole energy of the electric current by an electrostatic wattmeter, and the energy converted into heat in the conductor by a calorimeter. The difference would give the energy of radiation. Indeed, enormous practical difficulties would have to be overcome to carry out this scheme.

The condenser, such an inefficient and cumbersome apparatus for circuits with the usual number of periods, becomes very powerful and compendious for such high frequencies as 30,000 per second, and systems of electric distribution by means of condensers would be very well conceivable, if much higher frequencies than now could be used in practical engineering. Already some years ago such a system of distribution by condensers, with a frequency of, I believe, 800 per second, was proposed by a European electrician, but never tried, I suppose. (Account of it is to be found somewhere in the "Centralblatt für Electrotechnik," Munich, Germany.)

However, I believe that for electric light and power distribution such frequencies as Mr. Tesla used are quite out of question, and I am much more inclined to think that even the frequencies now in vogue in this country, of in maximo 138 complete periods per second (Westinghouse), or 16,000 alternations per *minute*, will not be kept much longer, but will be reduced as soon as possible. They are now used only because of the small unit of converters found in this country, which for efficient work need a high frequency.

But I entirely agree with Mr. Stanley that it is most desirable for efficient work to proceed to larger converter units, and that then a reduction of the number of alternations will be made. In the old country, where the practice is to use the converter as a kind of secondary station and to feed a whole district from one converter or a bunch of converters, the converter unit is much larger generally, and therefore a much lower frequency, only 42 complete periods per second, permissible. This reduces the loss by hysteresis very greatly, and this loss is known as the most important factor, because of being about the same for no load as for full load, and especially determines the all-day efficiency.

Indeed, even in this country, for arc lighting by means of alternating currents and series converters, the number of alternations has been reduced already to one-half, 8,000 reversals per minute, in the Stanley-Westinghouse constant current alternator, I think, because it was very difficult to work any electro-magnetic regulating mechanism with the frequencies of incandescent light currents.

It is not the question whether magnetism can be produced at all by very rapidly varying currents, but the question of *self-induction*, that is, whether a current strong enough to work the regulating mechanism can be forced through its energising coil against the counter E.M.F. of self-induction, without consuming too much pressure, which limits the number of vibrations permissible in electro-magnets and motors.

I will not try to decide which is the highest number of periods permissible for effective working of alternating motors, and whether this limit is higher than the number of periods practically used; but it must be borne in mind that until now no alternate current motor is on the market which runs with halfway fair efficiency with the number of alternations used for incandescent light circuits, 16,000 per minute, while in Europe, where a much lower number of alternations, only 5,000 per minute (Ganz & Co.) is used, alternate current motors are already on the market and in practical use and reach a very fair efficiency. And, nevertheless, in the use of electricity as motive power, the United States are undoubtedly a long way ahead of other countries.

As before said, it is not the impossibility of producing magnetism by rapidly varying currents which makes them unfit to run motors, but the enormous self-induction, which necessitates the waste of an enormous pressure to send even a small current through the inductive resistance.

For magnetism is produced with still much more rapidly oscillating currents than those which Mr. Tesla had at his disposition, as the fact proves that magnetisation, and even permanent magnetisation of steel rods, has been produced by oscillating condenser discharges and lighting strokes. Steel rods were found permanently magnetised at such occasions, and the curious phenomena was, that by grinding off the surface of the steel rod, the magnetism decreased—reached zero, reversed its polarity—increased by further grinding off to a maximum in the opposite direction as that of the magnetism of the integer rod, and then decreased again and even reversed its polarity once more.

The explanation for this phenomenon is that the discharge was oscillating, with increasing wave length but decreasing intensity. The first wave magnetised only the very surface of the steel rod strongly, but because of its very short duration and the screening effect of the metal, did not enter

deeper into it. The second wave, of opposite direction, was not strong enough to reverse the magnetism produced by the first wave, and only weakened it somewhat; but because of its longer duration it entered deeper into the steel and magnetised the layer underneath in the opposite direction to the surface, so that by grinding off the surface layer the magnetic moment of the rod reversed; and if the resistance of the electric circuit was low enough to allow a third wave to be produced with perceptible intensity, underneath the second layer a third one was found, magnetised in the same direction as the surface. This phenomenon shows that even such very rapid oscillations produce magnetism.

I was very much interested in reading the arguments which Prof. Thomson proffered for the existence of carbon vapour in the electric arc, and I must consider the arguments as very strong. The only fact which seems to me not quite in agreement with the existence of carbon vapour, is the spectrum of the electric arc. The copper arc, the iron arc, show the characteristic spectra of those metals, with their many lines. The carbon arc, if containing carbon vapour, ought to show the—until now unknown—carbon spectrum. But nothing of that kind; it gives an entirely continuous spectrum, quite similar to the spectrum of glowing solids.

This fact, I believe, needs still a satisfactory explanation, and I should like to hear how Prof. Thomson explains the absence of a characteristic carbon spectrum in the electric arc.

I should like to hear, also, whether any experiments have been made to determine the exact temperature of the arc and the glowing carbons. The only temperature determinations of which I know are already of rather old date and made by an Italian, Rosetti, which measured the heat radiation by means of a thermopile and found the temperature of the tip of the positive carbon to 3,900° C., the tip of the negative carbon to 3,150° C., but the temperature of the flame higher —4,800 to 4,844° C. These figures do not agree with the data given by Prof. Thomson, who considers the positive carbon as the hottest part of the circuit. Rosetti used currents from 3 to 6 ampères.

The explanation of the instability of the electric alternating arc, because of the alternating cooling off of the carbons during the zero period of the current is certainly the nearest one, and, therefore, generally accepted. But whether it agrees with the real proceedings must still be doubted. Theoretically, at least, these fluctuations of temperature should be expected to be so small that they could have no influence on the conductivity of the arc.

An experiment to determine the fluctuations of temperature of an electric conductor, caused by the alternations of the current, was made on a piece of copper wire, one millimetre thick and 657 centimetres long. A current of 6·4 ampères was sent through with only 5,840 alternations per minute, and the lengthening of the wire measured. The increase of temperature was 37° C.; but the maximum variation of temperature calculated to only ·019 degree C., that is, one-twentieth per cent. of the whole rise of temperature. ("Das Gesetz zwischen Ausdehnung und Stromstärke für einen von galvanischen Wechselströmen durchflassenen Leiter," von Dr. Cranz, Zeitschrift für Mathematik und Physik, Dresden, 1889, p. 92.) Although this calculation is not quite conclusive for the somewhat different conditions in the electric arc, it is sufficient for making the assumption of so great and rapid cooling down of the arc during the time zero current doubtful.

But if we consider the energy consumption of the arc as caused by a counter E.M.F., a kind of polarisation, and at the hand of the facts must assume that this counter E.M.F. of the arc in very wide limits is nearly independent of the current strength, then the apparent resistance of the arc must vary inversely as the current intensity, and in consequence of this, in an ordinary alternating arc light circuit, the height of the current wave must be increased at its crest, decreased near its minimum position, so that the time of minimum current is greatly increased, and the shade of the wave becomes more triangular.

But if the alternator is so well self-regulating that the current wave, in spite of the varying resistance, is kept sinusoidal, that is, regulating in time so short that it is small even in comparison with the wave length of the alternating current, as is the case in the Stanley-Westinghouse constant current alternator, then the alternating arc should become just as steady as the continuous current arc. Now, in Mr. Tesla's high frequency machine this condition was certainly fulfilled, its self-induction being very large, as the tendency of yielding constant current shows, and self-induction regulated the impressed E.M.F., according to the sine wave of the current producing the rectangular shape of the wave of impressed E.M.F., as shown in the curves given by Messrs. Tobey and Walbridge, for the Stanley-Westinghouse alternator, in their paper read before the American Institute of Electrical Engineers.

This particular shape of E.M.F. and current might have a great deal to do with the steadiness and unsteadiness of the arc.

Therefore, it would be of very great interest, in the same way as it has been done in Cornell University with the Stanley-Westinghouse alternator, to determine the shape of the E.M.F. and the current wave for an alternator of very low self-induction, for instance, with a disc armature, running arc light. Then I should expect to find the opposite phenomenon; the impressed E.M.F. retaining its sinusoidal form, and the current wave assuming a more triangular, shape, at the same time causing unsteadiness of the arc.

Yonkers, N.Y., *March 26th*, 1891.

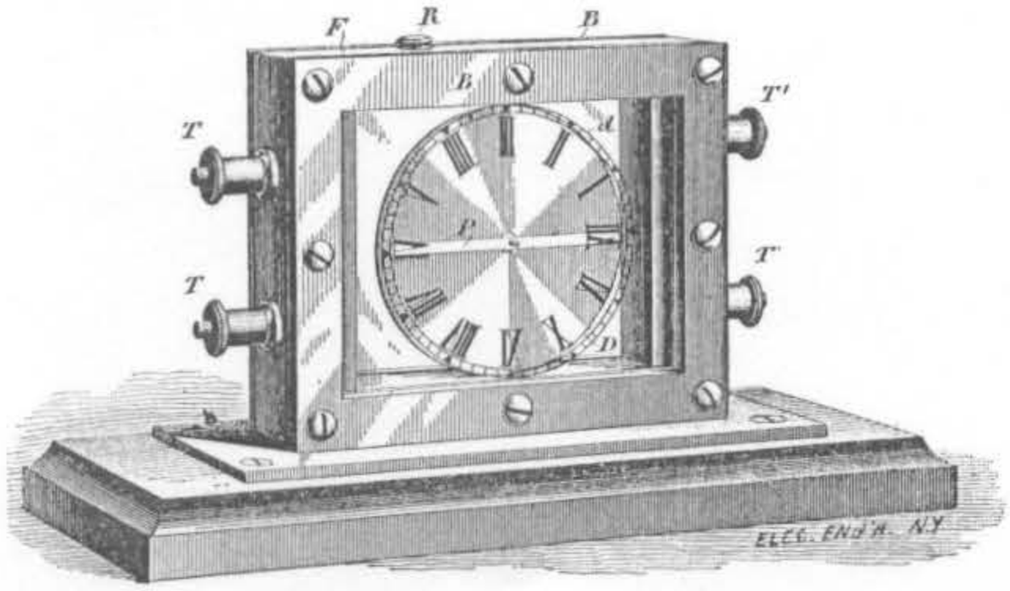
AN ELECTROLYTIC CLOCK.

BY

Nikola Tesla

If a delicately pivoted and well-balanced metal disc or cylinder be placed in a proper plating solution midway between the anode and cathode, one half of the disc becomes electro positive and the other half electro negative. Owing to this fact metal is deposited on one, and taken off from the other half, and the disc is caused to rotate under the action of gravity. As the amount of metal deposited and taken off is proportionate to the current strength, the speed of rotation, if it be small, is proportionate to the current.

The first device of this kind was operated by me early in 1888, in the endeavor to construct an electric meter. Upon learning, however, that I had been anticipated by others, as far as the principle is concerned,[1] I devised the apparatus illustrated in the accompanying engraving. Here F is a rectangular frame of hard rubber which is fastened upon a wooden base. This frame is about ½ inch thick, 6 inches long and 5 inches high. On both of its upright sides are fastened thick metal plates which serve as the electrodes. These plates are held firmly against the rubber frame by the binding posts T T and T' T.' On the lateral sides of the frame are fastened the brass plates B and B,' respectivly, of the same shape as the rubber frame F. These brass plates serve to keep in place two plates of



TESLA'S ELECTROLYTIC CLOCK.

polished glass, and the vessel is hermetically sealed by placing a soft rubber washer under and above each of the glass plates. In this manner the plates may be screwed on tight without fear of breaking them.

The plating solution, which in this case is a concentrated solution of sulphate of copper, is poured in through an opening on the top of the rubber frame, which is closed by a plug R.

In the center of the vessel is placed a light and delicately balanced copper disc D, the axis of which is supported by a capillary glass tube which is fixed to one of the glass plates by means of sealing wax, or other material not attacked by the liquid. To diminish the friction as much as possible, the capillary tube which serves as a bearing contains a drop of oil. The center of the disc should be equi-distant from both the electrodes. To one side of the axis of the disc is fastened a very light indicator or pointer consisting preferably of a thin glass thread. The glass plate next to this pointer has a circle with the usual hour divissions engraved upon it, as on a clock dial. This circle may be movable so that it can be put in any position relatively to the pointer. If the dial is not movable then a thin wire of annealed iron may be used as on a pointer. The wire should then be so placed that it is exactly in the centre of the solution. By means of a horse-shoe magnet the disc may then be rotated and set in proper position.

The copper solution being carefully poured in, and the plug R replaced, the terminals of a constant current battery are connected to the binding-posts T T', and from time to time the rotation of the disc is observed. A shunt is connected to the other two binding-posts T T', and by varying the resistance of this shunt, or other disc, the speed of rotation is regulated until it is made to correspond to the division of the dial; that is, until, for instance, one turn is made in 12 hours.

Obviously this instrument was not devised for a practical purpose. Neither will it be quite exact in its indications. There are certain errors, unavoidable from the principle; for instance, the friction, which cannot be completely overcome. But the device is interesting as a means of indicating time in a novel manner. It will, however, be found that by a careful construction, constant current, and a temperature compensator, it may be made to rotate with almost perfect uniformity. The current density should, of course, be very small to secure the best results, and the disc of about 3 inches diameter should turn once in 6 hours. It is probable that with a silver solution and a silver plate better results would be obtained.

It is very interesting to note the appearance of the solution and disc in such a narrow transparent vessel. The solution appears a clear blue, one side of the disc seems to be silver white in a certain position, and the other half is dark like tarnished silver. There is no line of demarcation, but the shades melt beautifully together.

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1 The same invention is attributed to J. T. Sprague and T. A Edison.

ALTERNATE CURRENT ELECTRO-STATIC INDUCTION APPARATUS.

BY

Nikola Tesla

About a year and a half ago while engaged in the study of alternate currents of short period, it occurred to me that such currents could be obtained by rotating charged surfaces in close proximity to conductors. Accordingly I devised various forms of experimental apparatus of which two are illustrated in the accompanying engravings.

In the apparatus shown in Fig. 1, A is a ring of dry shellacked hard wood provided on its inside with two sets of tin-foil coatings, a and b, all the a coatings and all the b coatings being connected together, respectively, but independent from each other. These two sets of coatings are connected to two terminals, T. For the sake of clearness only a few coatings are shown. Inside of the ring A, and in close proximity to it there is arranged to rotate a cylinder B, likewise of dry, shellacked hard wood, and provided with two similar sets of coatings, a^1 and b^1, all the coatings a^1 being connected to one ring and all the others, b^1, to another marked + and —. These two sets, a^1 and b^1 are charged to a high potential by a Holtz or Wimshurst machine, and may be connected to a jar of some capacity. The inside of ring A is coated with mica in order to increase the induction and also to allow higher potentials to be used.

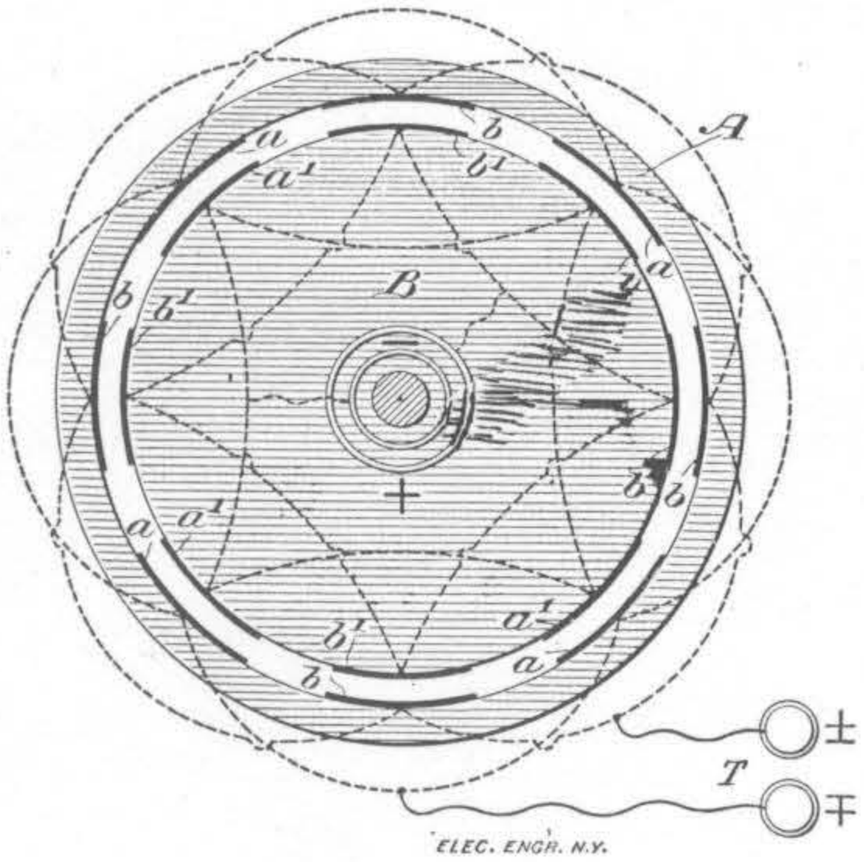

FIG. 1.—TESLA ALTERNATING ELECTROSTATIC INDUCTION APPARATUS.

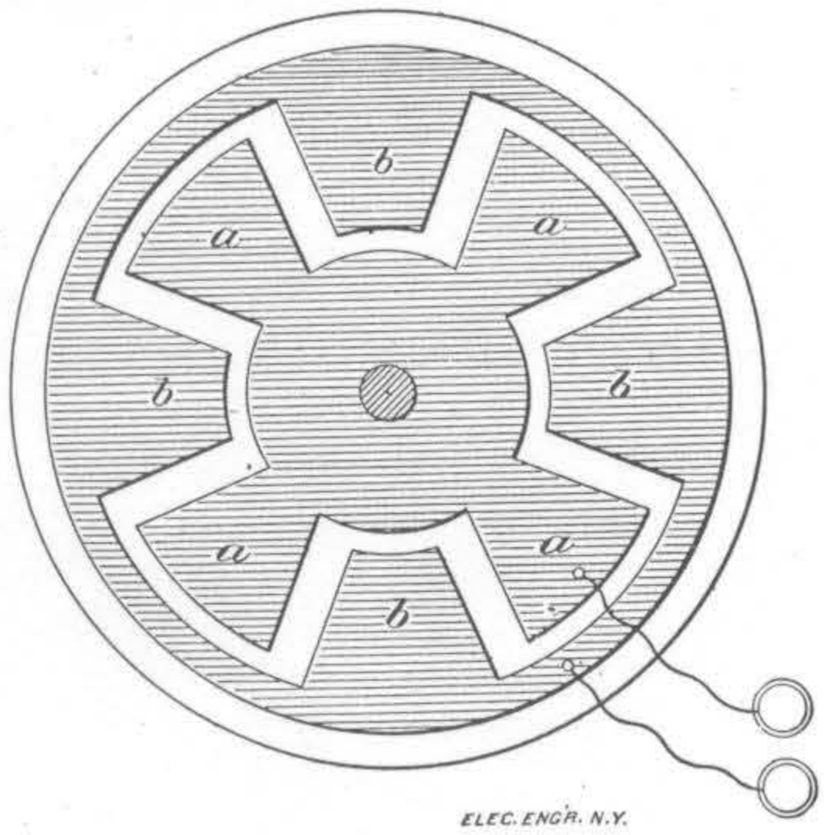

FIG. 2.—TESLA ALTERNATING ELECTROSTATIC INDUCTION APPARATUS.

When the cylinder B with the charged coatings is rotated, a circuit connected to the terminals T is traversed by alternating currents. Another form of apparatus is illustrated in Fig. 2. In this apparatus the two sets of tin-foil coatings are glued on a plate of ebonite, and a similar plate which is rotated, and the coatings of which are charged as in Fig. 1, is provided.

The output of such an apparatus is very small, but some of the effects peculiar to alternating currents of short periods may be observed. The effects, however, cannot be compared with those obtainable with an induction coil which is operated by an alternate current machine of high frequency, some of which were described by me a short while ago.

Annual and General Meeting of the American Institute of Electrical Engineers.

The spring meetings of the Institute will be held on May 19, 20 and 21, at its headquarters, No. 12 West Thirty-first Street, New York City. The preliminary programme as arranged by the Committee on Papers and Meetings and the Local Committee of Arrangements, is as follows:

The regular monthly meeting of council will be held in the secretary's office at 5 P. M., May 19. The annual meeting for the presentation of reports, election of officers and other business will follow at 8 P. M. on the same date.

The morning session, May 20, will assemble at 10 o'clock, when the following papers will be read: "The Development of the Dynamo," by Prof. Harris J. Ryan; "Evolution of the Stationary Electric Motor," by Dr. S. S. Wheeler; "Some Data Concerning the Photometry of the Arc Lamp," by Prof. E. L. Nichols. At the afternoon session of the same day the following papers will be presented: "A New Graphical Method of Calculating Leads for Wiring," by Carl Hering; "Street Car Motor Design," by H. F. Parshall; "Some Recent Improvements in Printing Telegraphs," by Henry Van Hoevenbergh; "A Proposed Electrical Equipment for the Coming Rapid Transit System of New York City," by Frank J. Sprague. The evening session will be held at Columbia College. This will consist of "Experiments with Alternating Currents of High Frequency," by Nikola Tesla.

Thursday morning, May 21, the members will meet at the Crocker-Wheeler Motor Company's factory, 430 West Fourteenth street. After an inspection of this establishment the meeting will re-assemble at 12 West Thirty-first street, when the following papers will be read: "A New Device for the Measurement of Alternating Current Potential," by Prof. Geo. S. Moler; "A Study of the Fluctuations of E. M. F. in the Open-Coil Armature of a Constant-Current Machine," by M. E. Thompson; "Some Results in the practical Utilization of Electric Welding," by Dr. F. A. C. Perrine. The papers to be read at the afternoon session, May 21, are: "Electric Meters," G. W. Walker; an address by Dr. W. H. Wahl on "The Aluminium Problem, Retrospective and Prospective"; also a paper entitled "Shall Aluminium be 'Alium,'" by Oberlin Smith. In connection with this subject there will be an exhibit of aluminium products. Thursday evening a reception will be tendered to the Institute by the New York Electric Club.

Visits to the different electrical establishments and objects of interest will also be arranged for Friday, May 22, an announcement of which will be published in the official programme.

Alternating Current Electric Motors.—I.

BY DR. LOUIS DUNCAN, JOHNS HOPKINS UNIVERSITY.

The electric transmission of power presents to-day two very distinct problems: distribution in comparatively small units from central stations, and isolated or special transmissions. For the first, alternating current motors are used hardly at all, but in special cases and especially for long distance transmissions in large units the alternating current presents many advantages, and will come into extended use.

It is difficult to write about alternating current electric motors. There are no experimental data available, in fact very little has been obtained. Different inventors have worked with their own machines, but I have never seen one fully described, and the tests published have been mere statements of results. It is particularly embarrassing to an outsider to attempt to criticise a machine of which he has no knowledge excepting that obtained from a patent specification, or a conventional description; but if the inventor is irritated into refuting the outsider by facts and data, a commendable object has been achieved.

Alternating current electric motors may be divided into two broad types. In the first there is but one transformation in the machine, that of the electric energy of the armature current into the mechanical energy of the armature's rotation. In the second there are two transformations in the machine: one is a transfer of electrical energy from the main circuit into the electrical energy of the armature current; the other of the electric energy of the armature current into mechanical energy. The first type is best exemplified by the ordinary alternating dynamo reversed; the second type by Tesla's or Thomson's motors.

In considering these transformations we must keep clearly in mind the fact that when electrical energy is changed into any other form the amount transferred from a circuit is equal to $e\,i$, where i is the current flowing in the circuit and e is the counter electromotive force, or fall of potential due to the transfer. This is true, of course, whether the transformation is into heat, or mechanical energy, or the energy of the magnetic field, or into any other possible form.

To take up the first type of motor—that in which the current from the main circuit flows in the motor armature—we will find a number of forms patented or described. The simplest and most obvious is the ordinary alternating dynamo reversed. The theory of this type has been discussed more or less fully by Dr. Hopkinson, Mr. Mordey, Mr. Swinburne, and others, but as no one of the writers on the subject agrees with any of the rest, and as the views of some of them must differ very widely from what actually happens, we can hardly congratulate ourselves on having been taught very much about the subject.

There seems to be so much confusion about the matter of reversed alternating dynamos that a very brief statement of the problem may not be out of place.

In 1884, Dr. John Hopkinson, in a paper before the Institution of Electrical Engineers (London), showed theoretically that two alternating machines could not be run on series unless they were rigidly connected—as they would tend to control one another, so their electromotive forces would be opposed. He also showed that two such machines could be run in parallel, and that one could run another as a motor, and he gave the equations for the work done on such a motor connected between a pair of mains carrying alternating currents.

Suppose we have an alternating machine, and after starting it to its normal speed join it to mains, the period

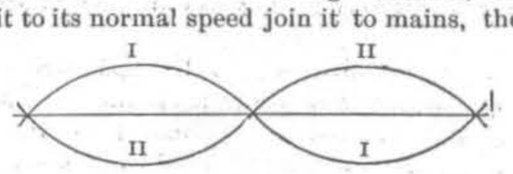

FIG. 1.—CURVES OF ALTERNATOR WHEN IT IS DOING NO WORK.

of the E. M. F. of our machine being that of the E. M. F. applied to the main. If our alternator is doing no mechanical work—we will suppose for a moment that there are no losses—the condition of affairs will be given by the curves in Fig. 1, where I is the E. M. F. of the mains, II that of the motor, the latter lagging 180 degrees behind the former, so that if the two electromotive forces are equal there will be no flow of current. Suppose that a load be put on the motor, it will tend to slow down and still further increase the lag of its E. M. F. There will now be a current due to the difference of the E. M. Fs. as shown in Fig. 2. Here I is the line E. M. F.; II the motor E. M. F.; III the effective E. M. F. in the motor circuit. If there is no self-induction the armature current will follow III, and in this case the work done on the motor armature—which is the product of the current by II—is not negative; that is, the motor is not transforming electrical into mechanical energy. If, however, there is self-induction in the armature circuit the current will lag behind the effective E. M. F. III, and take up some position.

Now the product of IV by II is negative and the motor does mechanical work. It would seem that self-induction is necessary for the successful working of such a machine. If we increase the load on the motor gradually, the lag of e (the motor E. M. F.) will gradually increase until $\tan. = \frac{2\pi}{T}\frac{L}{R} - L$, being the self-induction and R the resistance of the armature circuit when the output is a maximum. If we still further increase the load the motor will stop. We may represent the state of things by a curve in which the loads are ordinates and the corresponding lags of e are abscissæ. This curve may really be called the "characteristic" of an alternator. After the maximum point a is reached a further increase of φ will correspond to a decrease in the power of doing work, and the motor stops.

The equations for the output of a motor on an alternating circuit have been worked out, as has the maximum value of the work in different cases. For instance, Messrs. Wilkes and Hutchinson find that the maximum output of a motor is independent of its self-induction and is equal to $\frac{E^2}{8R}$; provided $\frac{2\pi}{T}L = R$, $\tan.\ \varphi = \frac{2\pi}{T}\frac{L}{R}$ and $l_o = \frac{E_o}{2}\sqrt{1 + \frac{p^2 L^2}{R^2}}$, where ε_o and E_o are respectively the maxima of the motor and line E. M. Fs. and $p = \frac{2\pi}{T}$. That is, if the self-induction and E. M. F. of the motor be given the proper values, the output of an alternating motor is equal to that of a continuous current motor supplied from a source with an equal effective E. M. F. Now a continuous motor can—from heating and efficiency considerations—be worked at only a small fraction of its

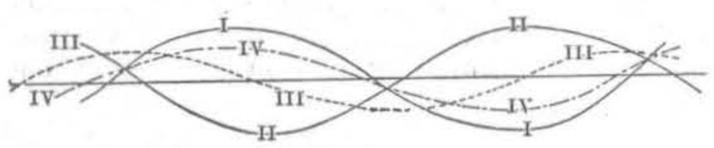

FIG. 2.—CURVES OF ALTERNATOR WHEN LOADED.

maximum possible output, so it would seem that an alternating motor with a load equal to that of a corresponding continuous machine would be so far from its maximum output that there would be very little danger of its ever falling behind the point a and stopping. Yet it would seem that they do stop when a load is applied, so evidently the motors are badly designed or the above explanation is not entirely true, and the fact is that both of these suppositions are correct.

The above very brief sketch gives about the condition of things until a paper by Mr. Mordey was read before the English Institute of Electric Engineers. In treating the subjecting of alternating current working, Mr. Mordey took the ground that an alternator would synchronize best and run best as a motor if its resistance and self-induction were as small as possible. He gave some excellent results, unfortunately with very little data attached, obtained with a machine which he seemed to think had no self-induction. But Prof. Ayrton had the self-induction measured and the value was .03; the resistance, from a remark in Mr. Mordey's paper, I estimate at 5.0 ohms; T was $\frac{1}{100}$ sec. The best value of the self-induction, from $\frac{2\pi}{T}L = R$ would have been roughly .008; so instead of having no self-induction the machine had considerably too much. The maximum output of the machine described by Mr. Mordey connected to mains of an E. M. F. equal to its own would be, roughly $(e = 2{,}000\ R = 5.0\ L = .03)\ \frac{E^2}{10R} =$ 80,000 watts, over 100 h. p., while the machine was only intended to and did run at 50 h. p. The performance is not surprising.

In fact, no experiments have been brought forward that clearly disprove Dr. Hopkinson's theory, although the difficulties experienced in practice show that it has not been followed or that it is wrong. For myself, I consider it fairly satisfactory for a number of machines, although it confessedly fails to take into account changes in coefficients of self-induction, armature reactions, etc., for the special case of a load very gradually applied. There are machines in which the armature reactions are not great and the value of L is reasonably constant, and these should fit the theory quite well.

When the load is suddenly applied, however—and this is very often the case in practical working—the condition of affairs is different, and is not taken into account in the ordinary theory. A continuous current machine may slow down a turn or so while it is taking its load without any harm being done; but an alternating motor can only while its load is being taken through an angle $\varphi_0 - \varphi$, the difference between the position when the load is applied and the position of maximum output. If the machinery to be driven has any considerable inertia the motor will very probably stop unless some friction clutch arrangement or other device which will gradually start the machinery is used. Between the throwing on of the driven machinery and the time when it reaches its normal speed, the motor must supply enough energy not only to overcome the resistance of the machine during the interval, but to store up in it the energy due to its inertia and velocity. To do this the inertia of the motor can only be called slightly into play, for it is essential that its speed should decrease very little and then but for an instant.

The condition of affairs for a half period in the motor is roughly this: On the application of the load, the armature or field slows down; this causes a reduction of the motor E. M. F. for two reasons: the speed is decreased, and the reaction of the armature current weakens the field both because of the changed position of the coils and the increased strength of the current. The period of the motor E. M. F. is also increased, and the increase is not necessarily small, for, although the armature lags through a small angle, yet it is in a very short time. The effect on the effective E. M. F. in the armature circuit is twofold: its value is very rapidly increased, due to the decrease of the counter E. M. F. and the shifting of phase of the latter with respect to the line E. M. F., while its period is for an instant changed and its form will differ considerably from that of a sine curve. The rush of current corresponding to this effective E. M. F. will be opposed by the resistance and self-induction of the armature circuit, *but the proportionate effect of the latter will be greater than under normal circumstances*, for our current curve is for an instant *sharper* than an ordinary sine curve. It would be outside of our mathematics to combine this current with the motor E. M. F., since they have for the instant different periods; but we may say in a general way that a smaller value of the self-induction than is given by the ordinary equations is required to resist the stopping effect of suddenly applied loads. We have seen that a well-designed machine working at a practical load is within the maximum load limit for steady or slowly applied loads. The danger of stopping is when a load is suddenly applied, and this is best resisted when the self-induction of the motor is low. I imagine it will be hard in practice to make it as low as we could wish.

I have spoken of the state of affairs for a half period. It is evident that if the load is more slowly applied the shifting of the motor curve will occupy a number of periods and our current curve will not be so sharp. The lag will approach its maximum value and then decrease again to a position corresponding to the work to be done. But, whatever the special case may be, Mr. Mordey worked in the right direction when he opposed the idea which seemed to be prevalent that a great deal of self-induction was necessary for alternating motors.

Lately Mr. Swinburne read a paper on the subject of alternating currents, in which he accounts for all the phenomena which he believes to occur by "armature reactions." He has at times complained that Dr. Hopkinson neglected armature reactions or included them in his term "self-induction." Mr. Swinburne retaliates by including self-induction and other effects in "armature reactions."

Those who have read Mr. Swinburne's paper have noticed that he treats the running of alternators in parallel or as motors under two headings: "Running according to the orthodox hypothesis," and "Running according to the armature reaction theory." He extends the work already done under the first heading by finding the increment of power corresponding to a small increment of current, and then finding "the value of L which makes the result a maximum." L unfortunately disappears before its value can be found, and really the results could be of no value, for we have seen that just at the moment that Mr. Swinburne uses the equations—when the load is changed—these equations do not in any way hold. As far as the second heading goes, Mr. Swinburne abandons everything but armature reactions. The effect of the armature current, provided the alternations are rapid enough, is twofold. It causes "the current to lag relatively to the position of the field magnets, and then lessens the pressure as a whole." The first of these does not affect the steady working of the machine, for it is the relative position of the current with respect to the resultant field, not of the poles, that is of importance; the second increases, within limits, the output of the machine for a given lag. But the result is not equivalent to a self-induction. On this theory a machine with a saturated field would not work, while in reality—if we may believe statements on the matter—these machines work very well.

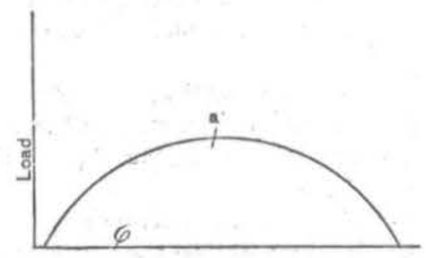

FIG. 3.—CURVE SHOWING EFFECT OF INCREASING THE LOAD.

In England there seem, then, to be several opinions with respect to the best value of the self-induction for reversed alternating dynamos. Dr. Hopkinson holds that $\frac{2\pi}{T}L$ should be equal to R; Mr. Kapp, Prof. Forbes and others seem to hold that the self-induction should be large (they do not seem wedded to any especial value); Mr. Mordey holds that it should be zero, if possible; Mr. Swinburne seems to have lost L altogether through differentiation, and is, therefore, presumably indifferent as to its value. For myself, I believe that L should have a value large enough to make the maximum output of the motor greater than the normal output, but should be less than the value given by $\frac{2\pi}{T}L = R$. That the resistance should be as small as possible goes without saying, and it is equally evident that if the motor is to be run on light loads its E. M. F. should be approximately equal to that of the line.

There are some things that are attractive in this type of motor. The iron in the field magnets is not reversed as in many other types; the efficiency should approximate to that of an alternating dynamo, which is quite satisfactory, and no change is required in an ordinary transformer system of distribution. The practical difficulties lie in the

fact that the motor must be brought to almost its normal speed by some means outside of the alternating current; and a continuous or redressed current must be supplied to the fields. In a paper read early in 1888, the author proposed to remedy these troubles by running with the alternating circuit an auxiliary continuous current circuit to excite the fields and start the motors. The latter function was performed by commutating the armature coils until the motor had attained normal speed, when the commutator was thrown out and the machine ran as an alternating motor. It was also proposed to use a friction pulley to prevent a suddenly applied load stopping the machine. Most of these suggestions have since been patented (not by the author), and some results may follow, although they do not seem to have been applied. They seem to me practical enough.

Alternating Current Electric Motors.—II.

BY DR. LOUIS DUNCAN, JOHNS HOPKINS UNIVERSITY.

To turn from an example of class I. to the best example of class II. of alternating motors, I will try to discuss the novel and admirable machine invented by Mr. Tesla.

The problems involved are not very different from converter problems, and I confess that I approach them with something of ill-humor. I evolved the calorimeter method* of testing transformers, and it has been absorbed by an eminent English electrician; with Messrs. Wilkes and Hutchinson I produced† a method for obtaining simultaneous current and E. M. F. curves in the primaries and secondaries of converters. Another set of experimenters has since used the method and appropriated the credit. These are small matters, but they cause irritation. I imagine the results were somewhat too early. The editor of an electrical periodical, in reproducing one of the irregular primary curves (see the paper referred to, or Prof. Ryan's work), remarked on the singular want of symmetry in the construction of our dynamo.

In its simplest form the Tesla motor consists of an armature rotating in a magnetic field, which is the resultant of two fields at right angles to one another, excited by two alternating currents differing in phase by $\frac{\pi}{2}$. The resultant field rotates with a period equal to that of the exciting currents. The armature coils are short-circuited on themselves, and currents are induced in them in a direction to cause the armature to rotate with the field. Let us consider the simple case of a Tesla motor without iron, the armature of which has a large number of coils on it.

Let the two fields be as shown in Fig. 4, and let one of the armature coils make an angle α with the horizontal. We will consider what takes place in this coil. We have in the first place an E. M. F. due to the induction of the two circuits 1 and 2, and in the second place a counter E. M. F. due to the motion of the coil in the fields of 1 and 2. The current is of course due to the difference of these two E. M. Fs. and the energy transformed is the product of the current and the counter E. M. F.

Let

i_1 = current in field 1.
i_2 = " " 2.
I = maximum value of current.
E_1 = E. M. F. induced in coil from 1.
E_2 = " " " " 2.
e_1 = counter = E. M. F. due to rotation in field of 1.
e_2 = " " " " " 2.
M = maximum mutual induction between coil and 1 or 2.

Then if

$i_1 = I \sin pt$, $i_2 = I \cos pt$, and if the induction varies with the current,

$$\left.\begin{aligned} E_1 &= M \cos\alpha \frac{di}{dt} = MIp \cos pt \cos\alpha \\ E_2 &= M \sin\alpha \frac{di_2}{dt} = MIp \sin pt \sin\alpha \end{aligned}\right\} \left\{ E_1 + E_2 = MIp \cos(pt - \alpha) = E. \right.$$

$$\varepsilon_1 = -MI \sin pt \sin\alpha \frac{d\alpha}{dt}.$$

$$\varepsilon_2 = -MI \cos pt \cos\alpha \frac{d\alpha}{dt}.$$

Now $\frac{d\alpha}{dt}$ is equal to $\frac{2\pi}{T^1}$, where T^1 is the time of revolution of the armature; so we may put the above, p^1 being equal to $\frac{2\pi}{T^1}$.

$$\left.\begin{aligned} \varepsilon_1 &= -MIp^1 \sin pt \sin\alpha \\ \varepsilon_2 &= -MIp^1 \cos pt \cos\alpha \end{aligned}\right\} \varepsilon_1 + \varepsilon_2 = -MIp^1 \cos(pt - \alpha) = \varepsilon.$$

Adding all these E. M. F's. and noting that α may be determined by $\alpha = p^1 t$ if our zero time be properly chosen,

$$E_1 + E_2 + e_1 + e_2 = MI(p - p^1) \cos(p - p^1)t = e_0.$$

The maximum value of the current due to this E. M. F. is $\frac{MI(p - p^1)}{(R^2 + (p - p^1)^2 L^2)^{\frac{1}{2}}}$, where R and L refer to the coil under discussion. The total energy transformed is $\frac{1}{2} \frac{\varepsilon_0 M^2 I^2 p^1 (p - p^1)}{(R^2 + (p - p^1)^2 L^2)^{\frac{1}{2}}} \cos\theta$, where $\tan\theta = (p - p^1)\frac{L}{R}$.

The energy used in heating is $\frac{1}{2} \frac{M^2 I^2 (p - p^1)^2}{R^2 + (p^1 - p)^2 L^2} R$, and the armature efficiency is $\frac{p^1}{p}$. This last is true because the applied and counter E. M. F's. are 180 degrees different in phase, and they are therefore equally distant from the current. If we multiply the maximum values of E and e by one-half the maximum value of the current and by the cosine of θ, we will have in the first case the electrical energy applied to the armature, and in the second the electrical energy transformed into mechanical energy. The ratio of these products—the angle being the same—is simply $\frac{p^1}{p}$.

Looking at the value of the total energy transformed, we see that as L increases both the increase of the impedance and the decrease of $\cos\theta$ will necessitate—for a given output—a decrease of p^1. This, of course, lowers the efficiency. As the expression for the output contains $p^1(p - p^1)$ it is evident that with no self-induction the maximum output is when $p^1 = \frac{1}{2} p$; the efficiency being 50 per cent. If the motor has a self-induction, however, it is easily seen from the equation that the maximum output is for a value of $p^1 > \frac{1}{2} p$; there is no need of giving the value.

The induced E. M. F. in the armature and the effective E. M. F. are in the same phase, while the counter-E. M. F. differs from them in phase by π. If there were no self-induction the armature current would follow the impressed E. M. F., and the condition of affairs would be the best possible, for the maximum current would fit in with the maximum counter E. M. F., as it should. The effect of self-induction is to shift the current back from its best position and decrease the output for a given heating effect. Now, the permissible current in a machine of this kind is entirely determined by heating effects; so the self-induction should be as small as possible. The ratio of the heating effect to the output of the motor is $\frac{p - p^1}{p} \frac{R}{\sqrt{R^2 + (p - p^1) L^2}}$ sec θ. For a given current $\frac{p - p^1}{p}$ is proportional to R, and we seen that $\tan\theta = (p - p^1)\frac{L}{R}$. It goes without saying that if R is decreased, the ratio given in the equation also decreases, and the efficiency and output of the machine increases.

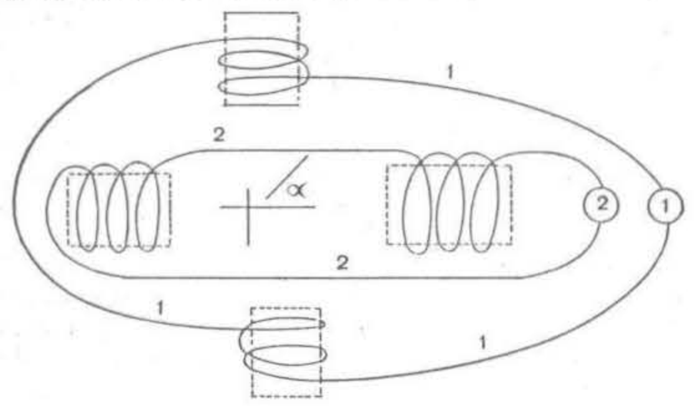

FIG. 4.—DIAGRAM ILLUSTRATING THE ACTION OF A TESLA MOTOR WITHOUT IRON.

Before discussing the matter further let us look at the armature actions in a different way. Consider a line whose azimuth is fixed and equal to α, and think of the condition of the coils in this azimuth. We have an applied E. M. F. equal, as we have seen, to

$$MIp \cos(pt - \alpha)$$

and a counter E. M. F. equal to

$$MIp^1 \cos(pt - \alpha).$$

As far as the line is concerned we have impressed on it—α is now fixed—an E. M. F. of period p instead of the period $p - p^2$ of the E. M. F. in a particular wire. But the current does not lag behind the E. M. F. by an angle $\theta = \tan^{-1} p\frac{L}{R}$, but by an angle $\theta = \tan^{-1} p - p^1 \frac{L}{R}$, for we must remember that the wire which at any given instant has in it the maximum induced E. M. F. is rotating in the same direction as the counter E. M. F.; and when the current reaches its maximum it is closer to the counter E. M. F. by the angle through which it has rotated.

Comparing our results to those obtained in a transformer, we have an impressed E. M. F. in the moving wires which bears the ratio $\frac{p - p^1}{p}$ to the impressed E. M. F. that would exist if there were no rotation. In the same way $\tan\theta$ is now $(p - p^1)\frac{L}{R}$, instead of $p\frac{L}{R}$, as it would be if the motor were still. Our current is $\frac{MI(p - p^1)}{(R^2 + (p - p^1)^2 L^2)^{\frac{1}{2}}}$, instead of $\frac{MIp}{(R^2 + p^2 L^2)^{\frac{1}{2}}}$ The result is the same as if we hold the motor and change its armature resistance in the ratio of p to $p - p^1$. As far as the transfer of energy from the field coils is concerned, we may reduce it to the case of two separate converters, each consisting of one pair of field coils for a primary, with a secondary made by winding one-half the armature coils at right angles to the magnetic field of the primary, the magnetic circuit being that corresponding to the pair of coils we are considering. There is no reason that the efficiency should not be high. The secondary of this converter may be considered to have in its circuit a non-inductive resistance equal to $\frac{p}{p - p^1} R$.

To take a specific case—and it is hard to find data on the subject—in the paper by Messrs. Hutchinson, Wilkes and myself referred to above, I find for a Westinghouse 10-light converter the following figures: Resistance of primary, 50 ohms; of secondary, .1 ohm; self-induction of primary, 1.96 henrys; of secondary, .0047 henrys. Under these circumstances, if our motor had the same constants we would have as a first approximation $\frac{p}{p - p^1} = 50$ (I suppose 50 volts and 10 ampères). If there are 100 periods per second, $\theta = \tan.^{-1}(p - p^1)\frac{L}{R} =$ about 30°, or the "plant efficiency" (= $\cos\theta$) is about 86 per cent. This being the case, p^1 would be less than the value assumed, and further approximations would increase the efficiency. I need not remark that the case chosen is a favorable one. The period chosen is impossible for a practical machine, and a lower one would be less advantageous.

Now let us consider what will happen if we increase all the linear dimensions of our machine. If we have a turn of wire around an iron ring, and increase the dimensions of the ring, both the self-induction and resistance will increase in the same proportion; that is, directly with the linear change. For if we suppose the permeability of the iron constant, the magnetic force due to a unit current in the wire would decrease in the ratio $\frac{1}{e}$, while the area inclosed by the wire would increase as l^2; the self-induction would therefore increase as l, which is of course a well-known fact. But in the case of our motor, as we increase the diameter of our armature we increase the space which our wire occupies; and keeping the same thickness of winding and the same number of turns we increase the area of our wire l times and therefore decrease its resistance by the same amount. But if all the linear dimensions of the motor have increased, our thickness of wire can increase, so our resistance will again decrease by l. Our self-induction has increased l times; our resistance has decreased by the same amount. If we now decrease the number of turns in a coil n times, both L and R decrease as n^2. If we let the speed of our motor vary inversely as its dimensions, and the induction remains constant, then for the same E. M. F. $n = l$, and L varies finally as $\frac{1}{l}$ and R varies as $\frac{1}{l^3}$. The ratio of L to R increases as our output increases, the increase being as l^3. To take a specific case; in the example cited above, if we double the dimensions of the motor we had imagined as corresponding to the transformer whose data were given, then on the assumptions we have just made, if the output be increased eight (2^3) times the percentage loss in the armature will not be changed. This being the case $p - p^1$ is 2 (2π) as before; but at the same time $\frac{L}{R}$ has four times its old value; so the tangent of the angle θ is four times as great for the small motor. Practically we would not care to reduce our speed as much as we have imagined.

The Tesla motor is in reality very nearly a synchronous motor—not that I consider the fact much of an objection—and like all synchronous motors there are times when its coils act as dynamo coils, thereby reducing its efficiency and output. The speed may be decreased by increasing the number of poles, but it always bears an approximately fixed ratio to that of the dynamo. We cannot, however, run on one circuit a number of motors at an indefinite number of speeds.

As compared with a continuous-current motor the armature efficiency and the output for a corresponding armature will be less. The iron in both field and armature is reversed—the former at a rate corresponding to p, the latter at a rate corresponding to $p - p^1$. The loss in the armature from eddy currents and hysteresis will be less than in a continuous current motor, but the loss in the field magnets would much more than counterbalance this gain, the mass of the magnets being usually much greater than that of the armature core. At the high periods that have been used the induction that could be economically used would be comparatively low. It would be interesting to know if the jarring of the machine, with the open magnetic circuit due to the air gap, materially decreases hysteresis losses. One of the most important of the practical objections to this motor is the fact that two independent circuits must be used to magnetize the fields, so it cannot be used on ordinary lighting circuits. I will refer to this in a moment.

The great advantages of the motor lie in the fact that it has no commutator, and it permits the use of very high voltages. In the future, power will be transmitted electrically at voltages that will make machines with the commutators next to useless, while the Tesla motor will offer many advantages for such transmission.

Since bringing out his first motor, Mr. Tesla, with great industry and ingenuity, has attempted to remedy the defects in the original machine. Perhaps the most serious of these is the inability to use the simple form of motor on ordinary alternating circuits. Mr. Tesla has attempted to get the required difference of phase between the magnetizing circuits, using a single circuit from the dynamo. I have no space to describe all of these; indeed they have already been described in the technical journals. The objection I have to most of them is that they cannot give a definite phase difference for different loads on the motor. Even the plan that has been proposed of using the primary of a converter for one magnetizing circuit, with the secondary as the other circuit, the latter having a condenser

* THE ELECTRICAL WORLD, 1887. It was copied in English journals at the time.
† THE ELECTRICAL WORLD, March 31, April 28, and May 19, 1888.

connected with it to neutralize its self-induction, will not work perfectly. For, even supposing a satisfactory practical condenser could be found, it must be remembered that the self-induction of the magnetizing coil will change as the load on the motor changes, so the phase of the magnetizing currents will not differ by $\frac{\pi}{2}$ except for some one load.

In another type of motor by the same inventor there are two sets of coils on one of the pairs of field magnet. One set is connected with the dynamo circuit; the other, in the relation of secondary to the first, is wound on the other pair of poles. A condenser or resistance will make the currents in the two circuits differ in phase by nearly $\frac{\pi}{2}$. This plan does not differ much from the one just described; the extra transformation is performed in the motor instead of in a converter.

Still another plan of Mr. Tesla is to take advantage of the fact that magnetization soaks gradually into a solid core as current soaks into a wire. Some one, writing in *Industries*, has denied this; it is, however, true, and he obtains a difference in phase between his magnetic fields from this fact.

EVENING SESSION,

AT COLUMBIA COLLEGE, NEW YORK CITY,

June 20th, 1891

THE CHAIRMAN (Vice-President Thomas D. Lockwood):—I have the honor now of introducing to you Mr. Nikola Tesla, who will deliver a lecture on "Experiments with Alternating Currents of High Frequency." Members of the Institute will recollect that it was Mr. Tesla who first brought before the Institute and the public at large the possibility and probability of electric motors operated by alternating currents. I am quite sure that the lecture he has to give us this evening and the experiments which will illustrate it, will be worthy of our most earnest consideration and our most profound attention. I wish to call attention on this occasion to the fact that the circumstance that Mr. Tesla is not an American-born is only one more ingredient in the history of electricity which shows that electricity is cosmopolitan. The different mile stones of progress in electricity as applied to the arts, show us nothing more clearly than they show that. From the time when electricity was given its name by Gilbert, to the present, every civilized nation and many individuals of many nations have contributed to the grand whole.

American Institute Of Electrical Engineers - Transactions
May 20, 1891

A lecture delivered before the American Institute of Electrical Engineers, at Columbia College, N. Y., May 20th, 1891. Vice-President Lockwood in the Chair.

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION.

BY NIKOLA TESLA.

There is no subject more captivating, more worthy of study than nature. To understand this great mechanism, to discover the forces which are active, and the laws which govern them, is the highest aim of the intellect of man.

Nature has stored up in the universe infinite energy. The eternal recipient and transmitter of this infinite energy is the ether. The recognition of the existence of ether, and of the functions it performs, is one of the most important results of modern scientific research. The mere abandoning of the idea of action at a distance, the assumption of a medium pervading all space and connecting all gross matter, has freed the minds of thinkers of an ever present doubt and by opening a new horizon —new and unforeseen possibilities—has given fresh interest to phenomena with which we are familiar of old. It has been a great step towards the understanding of the forces of nature and their multifold manifestations to our senses. It has been for the enlightened student of physics what the understanding of the mechanism of the firearm or of the steam engine was for the barbarian. Phenomena upon which we used to look as wonders baffling explanation, we now see in a different light. The spark of an induction coil, the glow of an incandescent lamp, the manifestations of the mechanical forces of currents and magnets are no longer beyond our grasp; instead of the incomprehensible, as before, their observation suggests now in our

minds a simple mechanism, and although as to its precise nature all is still conjecture, yet we know that the truth cannot be much longer hidden, and instinctively we feel that the understanding is dawning upon us. We still admire these beautiful phenomena, these strange forces, but we are helpless no longer; we can in a certain measure explain them, account for them, and we are hopeful of finally succeeding in unraveling the mystery which surrounds them.

In how far we can understand the world around us is the ultimate thought of every student of nature. The coarseness of our senses prevents us from recognizing the ulterior construction of matter, and astronomy this grandest and most positive of natural sciences, can only teach us something that happens, as it were, in our immediate neighborhood; of the remoter portions of the boundless universe, with its numberless stars and suns, we know nothing. But far beyond the limit of perception of our senses the spirit still can guide us, and so we may hope, that even these unknown worlds—infinitely small and great—may in a measure become known to us. Still, even if this knowledge should reach us, the searching mind will find a barrier, perhaps forever unsurpassable, to *true* recognition of that which *seems* to be, the mere *appearance* of which is the only and slender basis of all our philosophy.

Of all the forms of nature's immeasurable, all-pervading energy, which ever and ever changing and moving, like a soul animates the inert universe, those of electricity and magnetism are perhaps the most fascinating. The effects of gravitation of heat and light we observe daily, and soon we get accustomed to them, and soon they lose for us the character of the marvelous and wonderful; but electricity and magnetism, with their singular relationship, with their seemingly dual character unique among the forces in nature, with their phenomena of attractions, repulsions and rotations, strange manifestations of mysterious agents, stimulate and excite the mind to thought and research. What is electricity, and What is magnetism? These questions have been asked again and again. The most able intellects have ceaselessly wrestled with the problem; still the question has not as yet been fully answered. But while we cannot even to-day state what these singular forces are, yet we have made good headway towards the solution of the problem. We are now confident that electric and magnetic phenomena are attributable to ether, and

we are perhaps justified in saying, that the effects of static electricity are effects of ether under strain and those of dynamic electricity and electro-magnetism effects of ether in motion. But this still leaves the question, as to what electricity and magnetism are, unanswered.

First, we naturally inquire, What is electricity, and is there such a thing as electricity? In interpreting electric phenomena, we may speak of electricity or of an electric condition, state or effect. If we speak of electric effects, we must distinguish two such effects opposite in character and neutralizing each other, as observation shows that two such opposite effects exist. This is unavoidable, for in a medium of the properties of ether, we cannot possibly exert a strain, or produce a displacement or motion of any kind, without causing in the surrounding medium an equivalent and opposite effect. But if we speak of electricity, meaning a *thing*, we must, I think, abandon the idea of two electricities, as the existence of two such things is highly improbable. For how can we imagine that there should be two things, equivalent in amount, alike in their properties, but of opposite character, both clinging to matter, both attracting and completely neutralizing each other? Such an assumption, though suggested by many phenomena, though most convenient for explaining them, has little to commend it. If there *is* such a thing as electricity, there can be only *one* such thing, and, excess and want of that one thing, possibly, but more probably its condition determines the positive and negative character. The old theory of Franklin, though falling short in some respects, is, from a certain point of view, after all, the most plausible one. Still, in spite of this, the theory of the two electricities is generally accepted, as it apparently explains electric phenomena in a more satisfactory manner. But a theory which explains better the facts is not necessarily true. Ingenious minds will invent theories to suit observation, and almost every independent thinker has his own views on the subject.

It is not with the object of advancing an opinion, but with the desire of acquainting you better with some of the results, which I will describe, to show you the reasoning I have followed, the departures I have made—that I venture to express, in a few words, the views and convictions which have led me to these results.

I adhere to the idea that there is a thing which we have been in the habit of calling electricity. The question is, What is that

thing? or, What, of all things, the existence of which we know, have we the best reason to call electricity? We know that it acts like an incompressible fluid; that there must be a constant quantity of it in nature; that it can be neither produced nor destroyed; and, what is more important, the electro-magnetic theory of light and all facts observed teach us that electric and other phenomena are identical. The idea at once suggests itself, therefore, that electricity might be called ether. In fact, this view has in a certain sense been advanced by Dr. Lodge. His interesting work has been read by everyone and many have been convinced by his arguments. His great ability and the interesting nature of the subject, keep the reader spellbound; but when the impressions fade, one realizes that he has to deal only with ingenious explanations. I must confess, that I cannot believe in two electricities, much less in a doubly constituted ether. The puzzling behavior of the ether as a solid to waves of light and heat, and as a fluid to the motion of bodies through it, is certainly explained in the most natural and satisfactory manner, by assuming it to be in motion, as Sir William Thomson has suggested; but regardless of this, there is nothing which would enable us to conclude with certainty that, while a fluid is not capable of transmitting transverse vibrations of a few hundred or thousand per second, it might not be capable of transmitting such vibrations when they range into hundreds of million millions per second. Nor can any one prove that there are transverse ether waves emitted from an alternate current machine, giving a small number of alternations per second; to such slow disturbances, the ether, if at rest, may behave as a true fluid.

Returning to the subject, and bearing in mind that the existence of two electricities is, to say the least, highly improbable, we must remember, that we have no evidence of electricity, nor can we hope to get it unless gross matter is present. Electricity, therefore, cannot be called ether in the broad sense of the term; but nothing would seem to stand in the way of calling electricity ether associated with matter, or bound ether; or, in other words, that the so-called static charge of the molecule is ether associated in some way with the molecule. Looking at it in that light, we would be justified in saying, that electricity is concerned in all molecular actions.

Now, precisely what the ether surrounding the molecules is, wherein it differs from ether in general, can only be conjectured.

It cannot differ in density, ether being incompressible; it must, therefore, be under some strain or in motion, and the latter is the most probable. To understand its functions, it would be necessary to have an exact idea of the physical construction of matter, of which, of course, we can only form a mental picture.

But of all the views of nature, the one which assumes one matter and one force, and a perfect uniformity throughout, is the most scientific and most likely to be true. An infinitesimal world, with the molecules and their atoms spinning and moving in orbits, in much the same manner as celestial bodies, carrying with them and probably spinning with them ether, or in other words, carrying with them static charges, seems to my mind the most probable view, and one which, in a plausible manner, accounts for most of the phenomena observed. The spinning of the molecules and their ether sets up ether tensions or electrostatic strains; the equalization of ether tensions sets up ether motions or electric currents, and the orbital movements produce the effects of electro and permanent magnetism.

About fifteen years ago, Prof. Rowland demonstrated a most interesting and important fact, namely, that a static charge carried around produces the effects of an electric current. Leaving out of consideration the precise nature of the mechanism, which produces the attraction and repulsion of currents, and conceiving the electrostatically charged molecules in motion, this experimental fact gives us a fair idea of magnetism. We can conceive lines or tubes of force which physically exist; being formed of rows of directed moving molecules; we can see that these lines must be closed; that they must tend to shorten and expand, etc. It likewise explains in a reasonable way, the most puzzling phenomenon of all, permanent magnetism, and, in general, has all the beauties of the Ampere theory without possessing the vital defect of the same, namely, the assumption of molecular currents. Without enlarging further upon the subject, I would say, that I look upon all electrostatic current and magnetic phenomena as being due to electrostatic molecular forces.

The preceding remarks I have deemed necessary to a full understanding of the subject as it presents itself to my mind.

Of all these phenomena the most important to study are the current phenomena, on account of the already extensive and ever-growing use of current for industrial purposes. It is now a century since the first practical source of current has been produced,

and, ever since, the phenomena which accompany the flow of currents have been diligently studied, and through the untiring efforts of scientific men the simple laws which govern them have been discovered. But these laws were found to hold good only when the currents are of a steady character. When the currents are rapidly varying in strength quite different phenomena, often unexpected, present themselves, and quite different laws hold good, which even now have not been determined as fully as is desirable, though through the work principally of English scientists, enough knowledge has been gained on the subject to enable us to treat simple cases, which now present themselves in daily practice.

The phenomena which are peculiar to the changing character of the currents are greatly exalted when the rate of change is increased, hence the study of these currents is considerably facilitated by the employment of properly constructed apparatus. It was with this and other objects in view that I constructed alternate current machines capable of giving more than two million reversals of current per minute, and to this circumstance it is principally due that I am able to bring to your attention some of the results thus far reached, which I hope will prove to be a step in advance on account of their direct bearing upon one of the most important problems, namely, the production of a practical and efficient source of light.

The study of such rapidly alternating currents is very interesting. Nearly every experiment discloses something new. Many results may, of course, be predicted, but many more are unforeseen. The experimenter makes many interesting observations. For instance, we take a piece of iron and hold it against a magnet. Starting from low alternations and running up higher and higher, we feel the impulses succeed each other faster and faster, get weaker and weaker, and finally disappear. We then observe a continuous pull; the pull, of course, is not continuous; it only appears so to us—our sense of touch is imperfect.

We may next establish an arc between the electrodes and observe as the alternations rise, that the note which accompanies alternating arcs gets shriller and shriller, gradua'ly weakens, and finally ceases. The air vibrations of course continue, but they are too weak to be perceived—our sense of hearing fails us.

We observe the small physiological effects, the rapid heating of the iron cores and conductors, curious inductive effects, interesting condenser phenomena, and still more interesting light phenomena with a high tension induction coil. All these experiments and observations would be of the greatest interest to the student, but their description would lead me too far from the principal subject. Partly for this reason and partly on account of the vastly greater importance, I will confine myself to the description of the light effects produced by these currents.

In the experiments to this end, a high tension induction coil or equivalent apparatus for converting currents of comparatively low into currents of high tension is used.

If you will be sufficiently interested in the results I shall describe, as to enter into an experimental study of this subject; if you will be convinced of the truth of the arguments I shall advance, your aim will be to produce high frequencies and high potentials—in other words, powerful electrostatic effects. You will then encounter many difficulties which, if completely overcome, would allow us to produce truly wonderful results.

First will be met the difficulty of obtaining the required frequencies by means of mechanical apparatus, and if they be obtained otherwise, obstacles of a different nature will present themselves. Next, it will be found difficult to provide the requisite insulation without considerably increasing the size of the apparatus, for the potentials required are high, and owing to the rapidity of the alternations the insulation presents peculiar difficulties. So, for instance, when a gas is present, the discharge may work through by the molecular bombardment of the gas and consequent heating, through as much as an inch of the best solid insulating material, such as glass, hard rubber, porcelain, sealing wax, etc.; in fact, through any known insulating substance. The chief requisite in the insulation of the apparatus is, therefore, the exclusion of any gaseous matter.

In general, my experience tends to show that bodies which possess the highest specific inductive capacity such as glass, afford a rather inferior insulation to others which, while they are good insulators, have a much smaller specific inductive capacity, such as oils, for instance, the dielectric losses being no doubt greater in the former. The difficulty of insulating, of course, only exists when the potentials are excessively high, for with potentials such as a few thousand volts there is no particular difficulty encountered in conveying currents from a machine giving say 20,000 alternations per second, to quite a distance. This num-

ber of alternations, however, is by far too small for many purposes, though quite sufficient for some practical applications This difficulty of insulating is fortunately not a vital drawback; it affects mostly the size of the apparatus, for when excessively high potentials would be used, the light-giving devices would be located not far from the apparatus and often they would be quite close to it. As the air-bombardment of the insulated wire is dependent on condenser action, the loss may be reduced to a trifle by using excessively thin wires heavily insulated.

Another difficulty which will be encountered in the capacity and self-induction necessarily possessed by the coil. If the coil be large—that is, if it contain a great length of wire, it will be generally unsuited for excessively high frequencies; if it be small, it may be well adapted for such frequencies, but the potential might then not be as high as desired. A good insulator, and preferably one possessing a small specific inductive capacity, would afford a two-fold advantage. First, it would enable us to construct a very small coil capable of withstanding enormous differences of potential; and secondly, such a small coil, by reason of its smaller capacity and self-induction, would be capable of a quicker and more vigorous vibration. The problem, then, of constructing a coil or induction apparatus of any kind, possessing the requisite qualities, I regard as one of no small importance, and it has occupied me for a considerable time.

The investigator who desires to repeat the experiments which I will describe, with an alternate current machine capable of supplying currents of the desired frequency, and an induction coil, will do well to take the primary coil out and mount the secondary in such a manner as to be able to look through the tube upon which the secondary is wound. He will then be able to observe the streams which pass from the primary to the insulating tube, and from their intensity he will know how far he can strain the coil. Without this precaution, he is sure to injure the insulation. This arrangement permits, however, an easy exchange of the primaries, which is desirable in these experiments.

The selection of the type of machine best suited for the purpose, must be left to the judgment of the experimenter There are here illustrated three distinct types of machines which, besides others, I have used in my experiments.

Fig. 1 represents the machine used in my experiments before this Institute. The field magnet consists of a ring of wrought-

iron with 384 pole projections. The armature comprises a steel disc to which is fastened a thin, carefully-welded rim of wrought-iron. Upon the rim are wound several layers of fine, well-annealed iron wire which, when wound is passed through shellac. The armature wires are wound around brass pins wrapped with silk thread. The diameter of the armature wire in this type of machine should not be more than one-sixth of the thickness of the pole projections, else the local action will be considerable.

Fig. 2 represents a larger machine of a different type. The field magnet of this machine consists of two like parts which

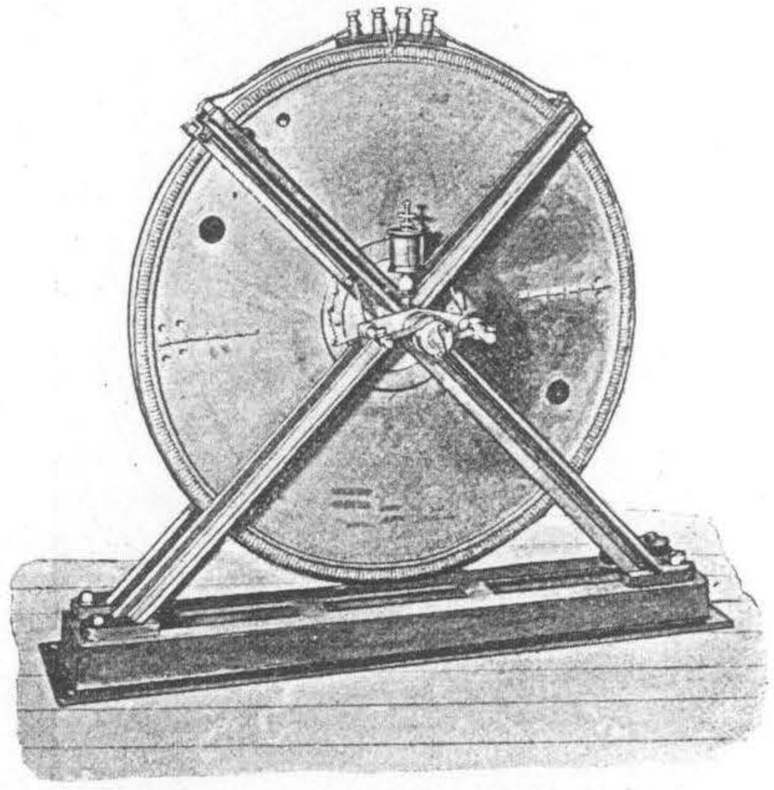

FIG. 1.—High Frequency Alternator with Drum Armature.

either inclose an exciting coil or else are independently wound. Each part has 480 pole projections, the projections of one facing those of the other. The armature consists of a wheel of hard bronze, carrying the conductors which revolve between the projections of the field magnet. To wind the armature conductors, I have found it most convenient to proceed in the following manner: I construct a ring of hard bronze of the required size. This ring and the rim of the wheel are provided with the proper number of pins and both fastened upon a plate. The armature conductors being wound, the pins are cut off and the ends of the

conductors fastened by two rings which screw to the bronze ring and the rim of the wheel respectively. The whole may then be taken off and forms a solid structure. The conductors in such a type of machine should consist of sheet copper, the thickness of which, of course, depends on the thickness of the pole projections; or else twisted thin wires should be employed.

Fig. 3 is a smaller machine, in many respects similar to the former, only here the armature conductors and the exciting coil are kept stationary, while only a block of wrought-iron is revolved.

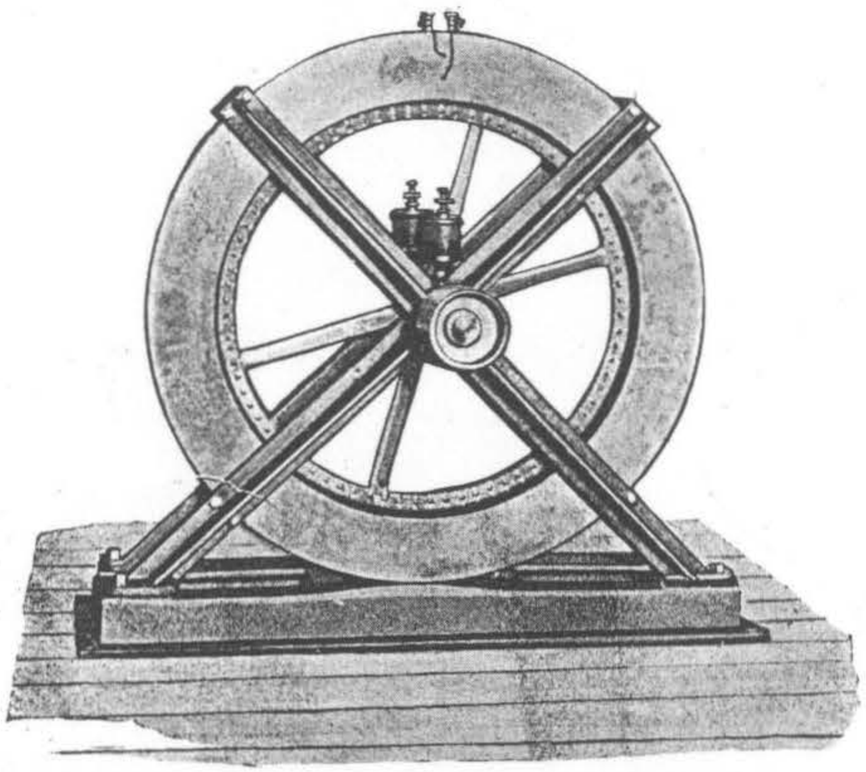

FIG. 2.—High Frequency Alternator with Revolving Disc Armature.

It would be uselessly lengthening this description were I to dwell more on the details of construction of these machines. Besides, they have been described somewhat more elaborately in the *Electrical Engineer* of March 18, 1891. I deem it well, however, to call the attention of the investigator to two things, the importance of which, though self-evident, he is nevertheless apt to underestimate, namely, to the local action in the conductors, which must be carefully avoided, and to the clearance, which must be small. I may add that since it is desirable to use very high peripheral speeds, the armature should be of very large

diameter in order to avoid impracticable belt speeds. Of the several types of these machines which have been constructed by me, I have found that the type illustrated in Fig. 1 caused me the least trouble in construction as well as in maintenance and, on the whole, it has been a good experimental machine.

In operating an induction coil with very rapidly alternating currents, among the first luminous phenomena noticed are naturally those presented by the high tension discharge. As the number of alternations per second is increased, or as—the number being high—the current through the primary is varied, the discharge gradually changes in appearance.. It would be difficult to describe the minor changes which occur and the conditions

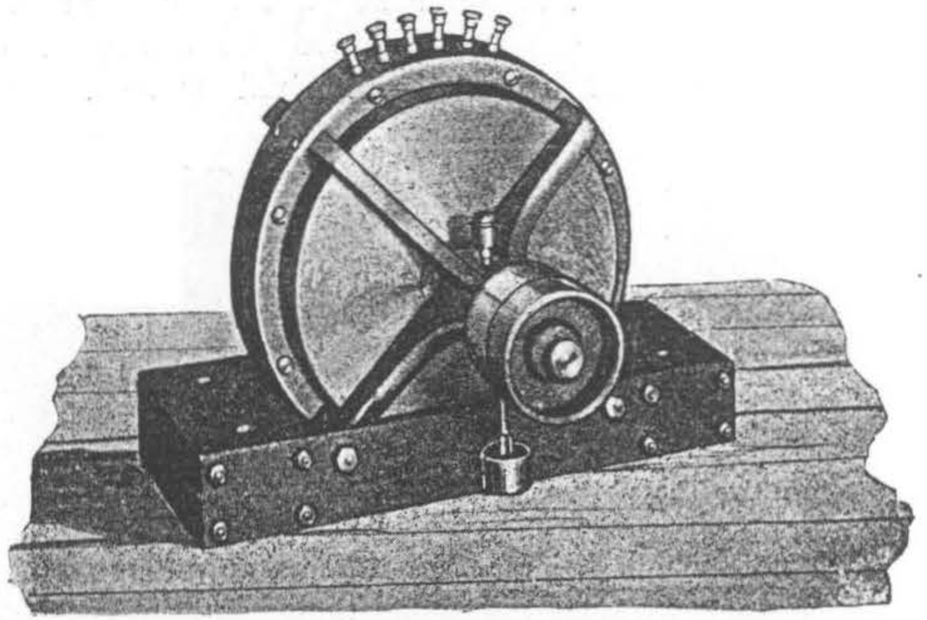

FIG. 3.—High Frequency Alternator with Stationary Disc Armature and Stationary Exciting Coil.

which bring them about, but one may note five distinct forms of the discharge.

First, one may observe a weak, sensitive discharge in the form of a thin feeble-colored thread. (Fig. 4.) It always occurs when, the number of alternations per second being high, the current through the primary is very small. In spite of the excessively small current, the rate of change is great and the difference of potential at the terminals of the secondary is therefore considerable, so that the arc is established at great distances; but the quantity of "electricity" set in motion is insignificant, barely sufficient to maintain a thin, threadlike arc. It is exces-

sively sensitive and may be made so to such a degree that the mere act of breathing near the coil will affect it, and unless it is perfectly well protected from currents of air, it wriggles around constantly. Nevertheless, it is in this form excessively persistent, and when the terminals are approached to, say one-third of the striking distance, it can be blown out only with difficulty. This exceptional persistency, when short, is largely due to the arc being excessively thin; presenting, therefore, a very small surface to the blast. Its great sensitiveness, when very long, is probably due to the motion of the particles of dust suspended in the air.

When the current through the primary is increased the discharge gets broader and stronger, and the effect of the capacity of the coil becomes visible until, finally, under proper conditions, a white flaming arc, Fig. 5, often as thick as one's finger and striking across the whole coil, is produced. It develops remarkable heat, and may be further characterized by the absence of

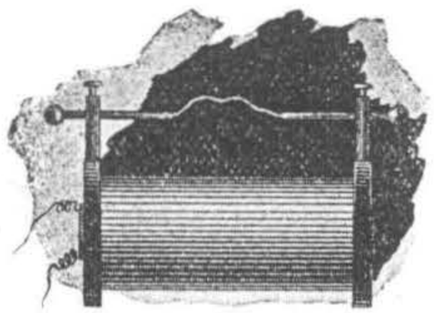

FIG. 4.—Sensitive Thread Discharge.

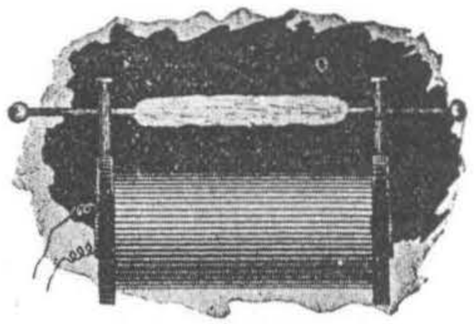

FIG. 5.—Flaming Discharge.

the high note which accompanies the less powerful discharges. To take a shock from the coil under these conditions would not be advisable, although under different conditions, the potential being much higher, a shock from the coil may be taken with impunity. To produce this kind of discharge the number of alternations per second must not be too great for the coil used; and, generally speaking, certain relations between capacity, self-induction and frequency must be observed.

The importance of these elements in an alternate current circuit is now well known, and under ordinary conditions the general rules are applicable. But in an induction coil exceptional conditions prevail. First, the self-induction is of little importance before the arc is established, when it asserts itself, but perhaps never as prominently as in ordinary alternate current-circuits, because capacity is distributed all along the coil, and by reason

of the fact that the coil usually discharges through very great resistances; hence the currents are exceptionally small. Secondly, the capacity goes on increasing continually as the potential rises, in consequence of absorption which takes place to a considerable extent. Owing to this there exists no critical relationship between these quantities, and ordinary rules would not seem to be applicable. As the potential is increased either in consequence of the increased frequency or of the increased current through the primary, the amount of the energy stored becomes greater and greater and the capacity gains more and more in importance. Up to a certain point the capacity is beneficial, but after that it begins to be an enormous drawback. It follows from this that each coil gives the best result with a given frequency and primary current. A very large coil when operated with currents of very high frequency may not give as much as $\frac{1}{8}$ inch spark. By adding capacity to the terminals the condition may be improved, but what the coil really wants is a lower frequency.

When the flaming discharge occurs, the conditions are evidently such that the greatest current is made to flow through the circuit. These conditions may be attained by varying the frequency within wide limits, but the highest frequency at which the flaming arc can still be produced determines, for a given primary current, the maximum striking distance of the coil. In the flaming discharge, the *eclat* effect of the capacity is not perceptible. The rate at which the energy is being stored then just equals the rate at which it can be disposed of through the circuit. This kind of discharge is the severest test for a coil; the break, when it occurs, is of the nature of that in an overcharged Leyden jar. To give a rough approximation, I would state that with an ordinary coil, of say 10,000 ohms resistance, the most powerful arc would be produced with about 12,000 alternations per second.

When the frequency is increased beyond that rate, the potential of course rises, but the striking distance may nevertheless diminish, paradoxical as it may seem. As the potential rises, the coil attains more and more the properties of a static machine, until, finally, one may observe the beautiful phenomenon of the streaming discharge, Fig. 6, which may be produced across the whole length of the coil. At that stage, streams begin to issue freely from all points and projections. These streams will also be seen to pass in abundance in the space between the primary and the

insulating tube. When the potential is excessively high, they will always appear, even if the frequency be low, and even if the primary be surrounded by as much as an inch of wax, hard rubber, glass or any other insulating substance. This limits greatly the output of the coil, but I will later show how I have been able to overcome to a considerable extent this disadvantage in the ordinary coil.

Besides the potential, the intensity of the streams depends on the frequency; but if the coil be very large they show themselves no matter how low the frequencies used. For instance, in a very large coil of resistance of 67,000 ohms, constructed by me some time ago, they appear with as low as 100 alternations per second and less, the insulation of the secondary being $\frac{3}{4}$ inch of ebonite. When very intense, they produce a noise similar to that pro-

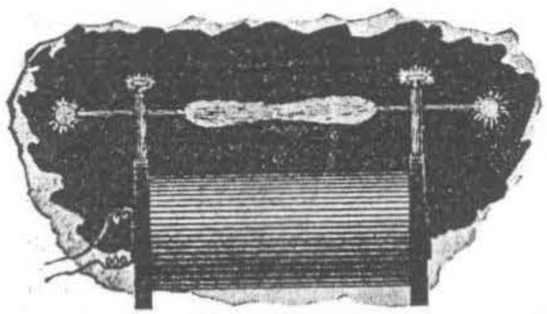

FIG. 6.—Streaming Discharge.

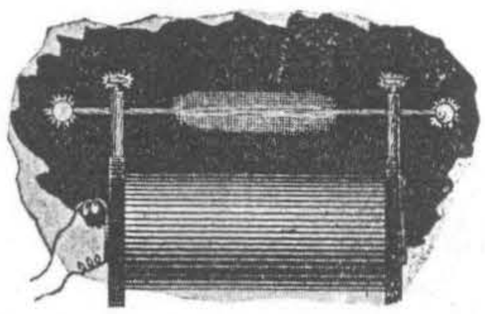

FIG. 7.—Brush and Spray Discharge.

duced by the charging of a Holtz machine, but much more powerful, and they emit a strong smell of ozone. The lower the frequency, the more apt they are to suddenly injure the coil. With excessively high frequencies, they may pass freely without producing any other effect than to heat the insulation slowly and uniformly.

The existence of these streams shows the importance of constructing an expensive coil, so as to permit of one's seeing through the tube surrounding the primary, and the latter should be easily exchangeable, or else the space between the primary and secondary should be completely filled up with insulating material, so as to exclude all air. The non-observance of this simple rule in the construction of the commercial coils, is responsible for the destruction of many an expensive coil.

At the stage when the streaming discharge occurs, or with somewhat higher frequencies, one may by approaching the terminals considerably and regulating properly the effect of capacity, produce a veritable spray of small silver-white sparks or a

bunch of excessively thin silvery threads [Fig. 7] amidst a powerful brush—each spark or thread possibly corresponding to one alternation. This, when produced under proper conditions, is probably the most beautiful discharge, and when an air blast is directed against it, it presents a singular appearance. The spray of sparks, when received through the body, causes some inconvenience, whereas when the discharge simply streams, nothing at all is likely to be felt if large conducting objects are held in the hands to protect them from receiving small burns.

If the frequency is still more increased, then the coil refuses to give any spark unless at comparatively small distances, and the fifth typical form of discharge may be observed [Fig. 8]. The tendency to stream out and dissipate is then so great that when the brush is produced at one terminal, no sparking occurs even if, as I have repeatedly tried, the hand, or any conducting object, is

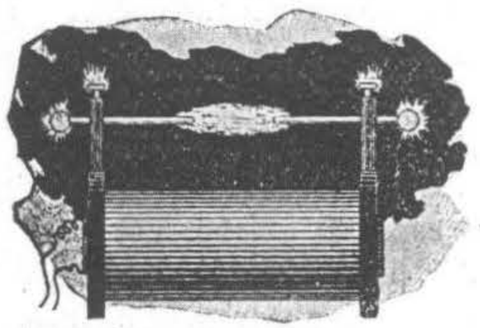

FIG. 8.—Fifth Typical Form of Discharge.

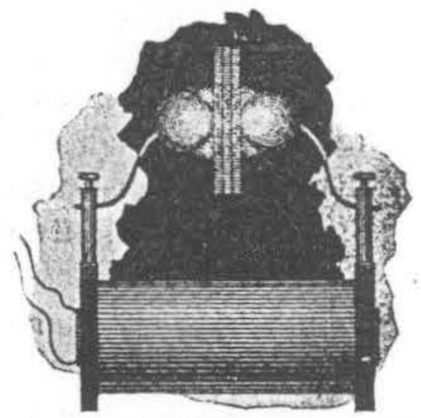

FIG. 9.—Luminous Discharge with Interposed Insulators.

held within the stream; and what is more singular, the luminous stream is not at all easily deflected by the approach of a conducting body.

At this stage, the streams seemingly pass with the greatest freedom through considerable thicknesses of insulators, and it is particularly interesting to study their behavior. For this purpose it is convenient to connect to the terminals of the coil two metallic spheres, which may be placed at any desired distance [Fig. 9.] Spheres are preferable to plates, as the discharge can be better observed. By inserting dielectric bodies between the spheres, beautiful discharge phenomena may be observed. If the spheres be quite close and a spark be playing between them, by interposing a thin plate of ebonite between the spheres the spark instantly ceases and the discharge spreads into an intensely lumi-

nous circle several inches in diameter, provided the spheres are sufficiently large. The passage of the streams heats and, after a while, softens the rubber so much that two plates may be made to stick together in this manner. If the spheres are so far apart that no spark occurs even if they are far beyond the striking distance, by inserting a thick plate of glass the discharge is instantly induced to pass from the spheres to the glass in the form of luminous streams. It appears almost as though these streams pass *through* the dielectric. In reality this is not the case, as the streams are due to the molecules of the air which are violently agitated in the space between the oppositely charged surfaces of the spheres. When no dielectric other than air is present, the bombardment goes on but is too weak to be visible; by inserting a dielectric, the inductive effect is much increased and, besides, the projected air molecules find an obstacle and the bombardment becomes so intense that the streams become luminous. If by any mechanical means we could effect such a violent agitation of the molecules, we could produce the same phenomenon. A jet of air escaping through a small hole under enormous pressure and striking against an insulating substance, such as glass, may be luminous in the dark, and it might be possible to produce phosphorescence of the glass or other insulators in this manner.

The greater the specific inductive capacity of the interposed dielectric, the more powerful the effect produced. Owing to this, the streams show themselves with excessively high potentials even if the glass be as much as one and one-half to two inches thick. But besides the heating due to bombardment, some heating goes on undoubtedly in the dielectric, being apparently greater in glass than in ebonite. I attribute this to the greater specific inductive capacity of the glass, in consequence of which, with the same potential difference, a greater amount of energy is taken up in it than in rubber. It is like connecting to a battery a copper and a brass wire of the same dimensions. The copper wire, though a more perfect conductor, would heat more by reason of its taking more current. Thus what is otherwise considered a virtue of the glass, is here a defect. Glass usually gives way much quicker than ebonite; when it is heated to a certain degree, the discharge suddenly breaks through at one point, assuming then the ordinary form of an arc.

The heating effect produced by molecular bombardment of the dielectric would, of course, diminish as the pressure of the air is

increased, and at enormous pressure it would be negligible, unless the frequency would increase correspondingly.

It will be often observed in these experiments that when the spheres are beyond the striking distance, the approach of a glass plate, for instance, may induce the spark to jump between the spheres. This occurs when the capacity of the spheres is somewhat below the critical value which gives the greatest difference of potential at the terminals of the coil. By approaching a dielectric the specific inductive capacity of the space between the spheres is increased, producing the same effect as if the capacity of the spheres were increased. The potential at the terminals may then rise so high that the space is cracked. The experiment is best performed with dense glass or mica.

Another interesting observation is that a plate of insulating material, when the discharge is passing through it, is strongly attracted by either of the spheres, that is, by the nearer one, this being obviously due to the smaller mechanical effect of the bombardment on that side, and perhaps also to the greater electrification.

From the behavior of the dielectrics in these experiments, we may conclude that the best insulator for these rapidly alternating currents would be the one possessing the smallest specific inductive capacity and at the same time one capable of withstanding the greatest differences of potential; and thus two diametrically opposite ways of securing the required insulation are indicated, namely, to use either a perfect vacuum or a gas under great pressure, but the former would be preferable. Unfortunately, neither of these two ways is easily carried out in practice.

It is especially interesting to note the behavior of an excessively high vacuum in these experiments. If a test tube, provided with external electrodes, and exhausted to the highest possible degree, be connected to the terminals of the cell, Fig. 10, the electrodes of the tube are instantly brought to a high temperature and the glass at each end of the tube is rendered intensely phosphorescent, but the middle appears comparatively dark and for a while remains cool.

When the frequency is so high that the discharge shown in Fig. 8 is observed, considerable dissipation no doubt occurs in the coil. Nevertheless, the coil may be worked for a long time, as the heating is gradual.

In spite of the fact that the difference of potential may be enor-

mous, little is felt when the discharge is passed through the body, provided the hands are armed. This is to some extent due to the higher frequency, but principally to the fact that less energy is available externally, when the difference of potential reaches an enormous value, owing to the circumstance that with the rise of potential the energy absorbed in the coil increases as the square of the potential. Up to a certain point, the energy available externally, increases with the rise of potential, then it begins to fall off rapidly. Thus, with the ordinary high-tension induction coil, the curious paradox exists that while with a given current through the primary the shock might be fatal, with many times that current it might be perfectly harmless, even if the frequency be the same. With high frequencies and excesssively high potentials, when the terminals are not connected to bodies of some size, practically all the energy supplied to the primary is taken

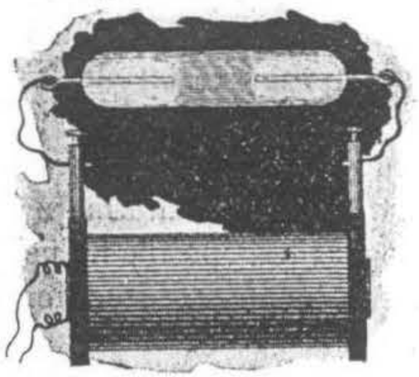

FIG. 10.—Discharge Through Highest Vacuum.

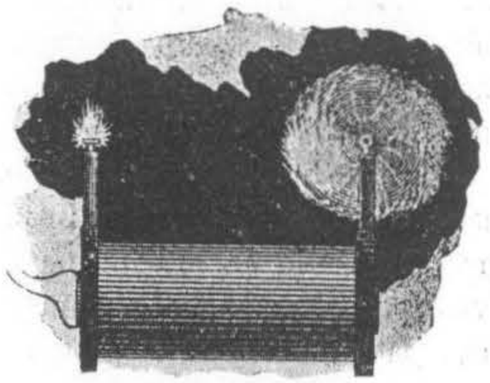

FIG. 11.—Pinwheel driven by a Powerful Brush.

up by the coil. There is no breaking through, no local injury, but all the material, insulating and conducting, is uniformly heated.

To avoid misunderstanding in regard to the physiological effect of alternating currents of very high frequency, I think it necessary to state that while it is an undeniable fact that they are incomparably less dangerous than currents of low frequencies, yet it should not be thought that they are altogether harmless. What has just been said refers only to currents from an ordinary high-tension induction coil, which currents are necessarily very small; if received directly from a machine or from a secondary of low resistance, they produce more or less powerful effects and may cause serious injury, especially when used in conjunction with condensers.

The streaming discharge of a high-tension induction coil differs in many respects from that of a powerful static machine. In color it has neither the violet of the positive nor the brightness of the negative static discharge, but lies somewhere between, being, of course, alternatively positive and negative. But since the streaming is more powerful when the point or terminal is electrified positively than when electrified negatively, it follows that the point of the brush is more like the positive and the root more like the negative static discharge. In the dark, when the brush is very powerful, the root may appear almost white. The wind produced by the escaping streams, though it may be very strong—often, indeed, to such a degree that it may be felt quite a distance from the coil—is, nevertheless, considering the quantity of the discharge, smaller than that produced by the positive

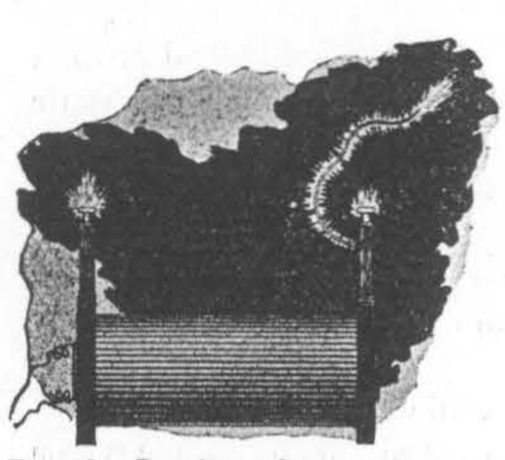

FIG. 12.—Luminous Streams Escaping From a Cotton-Covered Wire.

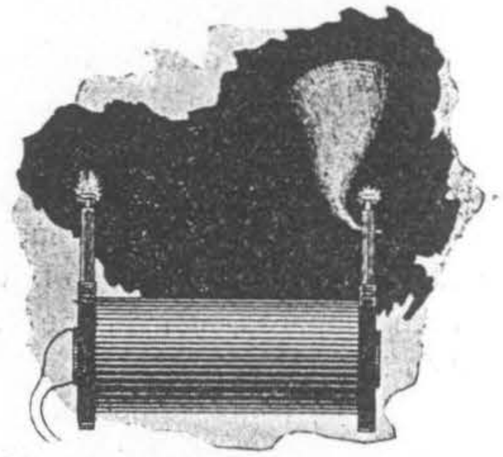

FIG. 13.—Aspect Presented by a Very Thin Wire Attached to a Terminal of the Coil.

brush of a static machine, and it affects the flame much less powerfully. From the nature of the phenomenon, we can conclude that the higher the frequency, the smaller must, of course, be the wind produced by the streams, and with sufficiently high frequencies no wind at all would be produced at the ordinary atmospheric pressures. With frequencies obtainable by means of a machine, the mechanical effect is sufficiently great to revolve with considerable speed large pin-wheels, which in the dark present a beautiful appearance, owing to the abundance of the streams [Fig. 11].

In general, most of the experiments usually performed with a static machine can be performed with an induction coil when operated with very rapidly alternating currents. The effects pro-

duced, however, are much more striking, being of incomparably greater power. When a small length of ordinary cotton-covered wire [Fig. 12] is attached to one terminal of the coil, the streams issuing from all points of the wire may be so intense as to produce a considerable light effect. When the potentials, and frequencies are very high, a wire insulated with gutta-percha or rubber and attached to one of the terminals, appears to be covered with a luminous film. A very thin bare wire when attached to a terminal emits powerful streams and vibrates continually to and fro, or spins in a circle, producing a singular effect [Fig. 13]. Some of these experiments have been described by me in the *Electrical World* of February 21, 1891.

Another peculiarity of the rapidly alternating discharge of the induction coil, is its radically different behavior with respect to points and rounded surfaces.

If a thick wire, provided with a ball at one end and with a point at the other, be attached to the positive terminal of a static machine, practically all the charge will be lost through the point, on account of the enormously greater tension, dependent on the radius of curvature. But if such a wire is attached to one of the terminals of the induction coil, it will be observed that with very high frequencies streams issue from the ball almost as copiously as from the point [Fig. 14].

It is hardly conceivable that we could produce such a condition to an equal degree in a static machine, for the simple reason that the tension increases as the square of the density, which in turn is proportional to the radius of curvature. Hence, with a steady potential, an enormous charge would be required to make streams issue from a polished ball while it is connected with a point. But with an induction coil, the discharge of which alternates with great rapidity, it is different. Here we have to deal with two distinct tendencies. First, there is a tendency to escape which exists in a condition of rest and which depends on the radius of curvature; second, there is the tendency to dissipate into the surrounding air by condenser action, which depends on the surface. When one of these tendencies is at a maximum, the other is at a minimum. At the point, the luminous stream is principally due to the air molecules coming bodily in contact with the point; they are attracted and repelled, charged and discharged, and their atomic charges being thus disturbed, vibrate and emit light waves. At the ball, on the contrary, there is no

doubt that the effect is to a great extent produced inductively, the air molecules not necessarily coming in contact with the ball, though they undoubtedly do so. To convince ourselves of this, we need only to exalt the condenser action, for instance, by enveloping the ball at some distance by a better conductor than the surrounding medium, the conductor being, of course, insulated; or else by surrounding it with a better dielectric and approaching an insulated conductor. In both cases the streams will break forth more copiously. Also the larger the ball with a given frequency, or the higher the frequency, the more will the ball have the advantage over the point. But since a certain intensity of action is required to render the streams visible, it is obvious that in the experiment described the ball should not be taken too large.

In consequence of this two-fold tendency, it is possible to pro-

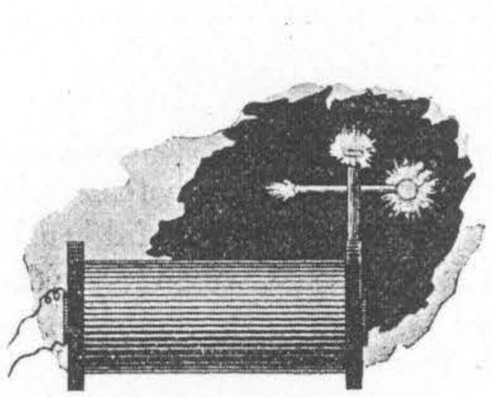

FIG. 14.—Effect of Ball and Point.

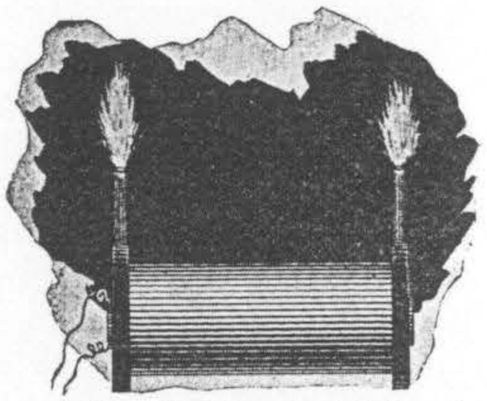

FIG. 15.—Aspect of Coil under Powerful Brush Discharge.

duce by means of points, effects identical to those produced by capacity. Thus, for instance, by attaching to one terminal of the coil a small length of coiled wire, presenting many points and offering great facility to escape, the potential of the coil may be raised to the same value as by attaching to the terminal a polished ball of a surface many times greater than that of the wire.

An interesting experiment, showing the effect of the points, may be performed in the following manner: Attach to one of the terminals of the coil a cotton covered wire, about two feet in length, and adjust the conditions so that streams issue from the wire. In this experiment the primary coil should be preferably placed so that it extends only about half way into the secondary coil. Now touch the free terminal of the secondary with a conducting object held in the hand, or else connect it to an insulated

body of some size. In this manner the potential on the wire may be enormously raised. The effect of this will be to either increase, or to diminish the streams. If they increase, the wire is too short; if they diminish, it is too long. By adjusting the length of the wire, a point is found, where the touching of the other terminal does not at all affect the streams. In this case the rise of potential is exactly counteracted by the drop through the coil. It will be observed that small lengths of wire produce considerable difference in the magnitude and luminosity of the streams. The primary coil is placed sidewise for two reasons: First, to increase the potential at the wire, and second, to increase the drop through the coil. The sensitiveness is thus augmented.

There is still another and far more striking peculiarity of the brush discharge produced by very rapidly alternating currents. To observe this it is best to replace the usual terminals of the coil by two metal columns insulated with a good thickness of ebonite. It is also well to close all fissures and cracks with wax so that the brushes cannot form anywhere except at the tops of the columns. If the conditions are carefully adjusted—which, of course, must be left to the skill of the experimenter—so that the potential rises to an enormous value, one may produce two powerful brushes several inches long; nearly white at their roots, which in the dark bear a striking resemblance to two flames of a gas escaping under pressure [Fig. 15]. But they do not only *resemble*, they *are* veritable flames, for they are hot. Certainly they are not as hot as a gas flame, *but they would be so if the frequency and the potential should be sufficiently high*. Produced with, say twenty thousand alternations per second, the heat is easily perceptible, even if the potential is not excessively high. The heat developed is, of course, due to the impact of the air molecules against the terminals and against each other. As, at the ordinary pressures, the mean free path is excessively small, it is possible that in spite of the enormous initial speed imparted to each molecule upon coming in contact with the terminal, its progress—by collision with other molecules—is retarded to such an extent, that it does not get away far from the terminal, but may strike the same many times in succession. The higher the frequency the less the molecule is able to get away, and this the more so, as for a given effect the potential required is smaller; and a frequency is conceivable —perhaps even obtainable—at which practically the same molecules would strike the terminal. Under such conditions the exchange of the molecules would be very slow, and the heat produced at and very near the terminal would be excessive. But if the frequency would go on increasing constantly, the heat produced would begin to diminish for obvious reasons. In the positive brush of a static machine the exchange of the molecules is very rapid, the stream is constantly of one direction, and there are fewer collisions; hence the heating effect must be very small. Anything that impairs the facility of exchange tends to increase the local heat produced. Thus, if a bulb be held over the terminal of the coil so as to enclose the brush, the air contained in the bulb is very quickly brought to a high temperature. If a glass tube be held over the brush so as to allow the draught to carry the brush upward, scorching hot air escapes at the top of the tube. Anything held within the brush is, of course, rapidly heated, and the possibility of using such heating effects for some purpose or other suggests itself.

When contemplating this singular phenomenon of the hot brush, we cannot help being convinced that a similar process must take place in the ordinary flame, and it seems strange that after all these centuries past, of familiarity with the flame, now, in the era of electric lighting and heating, we are finally led to recognize that since time immemorial we have after all, always had "electric light and heat" at our disposal. It is also of no little interest to contemplate that we have a possible way of producing —by other than chemical means—a veritable flame, which would give light and heat without any material being consumed, without any chemical process taking place, and to accomplish this we only need to perfect methods of producing enormous frequencies and potentials. I have no doubt that if the potential could be made to alternate with sufficient rapidity and power, the brush formed at the end of a wire would lose its electrical characteristics and would become flamelike. The flame must be due to electrostatic molecular action.

This phenomenon now explains in a manner which can hardly be doubted, the frequent accidents occurring in storms. It is well known that objects are often set on fire without the lightning striking them. We shall presently see how this can happen. On a nail in a roof, for instance, or on a projection of any kind more or less conducting or rendered so by dampness, a powerful brush may appear. If the lightning strikes somewhere in the neighborhood, the enormous potential may be made to alternate or fluctu-

ate perhaps many million times a second. The air molecules are violently attracted and repelled, and by their impact produce such a powerful heating effect that a fire is started. It is conceivable that a ship at sea may in this manner catch fire at many points at once. When we consider that even with the comparatively low frequencies obtained from a dynamo machine, and with potentials of no more than one or two hundred thousand volts, the heating effects are considerable, we may imagine how much more powerful they must be with frequencies and potentials many times greater, and the above explanation seems, to say the least, very probable. Similar explanations may have been suggested, but I am not aware that up to the present the heating effects of a brush produced by a rapidly alternating potential, have been experimentally demonstrated, at least not to such a remarkable degree.

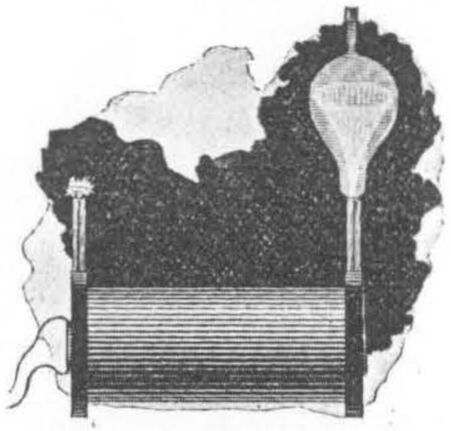

FIG. 16.—Incandescent Wire or Filament Spinning in an Unexhausted Globe.

By preventing completely the exchange of the air molecules, the local heating effect may be so exalted as to bring a body to incandescence. Thus, for instance, if a small button or, preferably, a very thin wire or filament be enclosed in an unexhausted globe and connected with the terminal of the coil, it may be rendered incandescent. The phenomenon is made much more interesting by the rapid spinning around in a circle of the top of the filament, thus presenting the appearance of a luminous funnel, [Fig. 16], which widens when the potential is increased. When the potential is small, the end of the filament may perform irregular motions, suddenly changing from one to the other, or it may describe an ellipse But when the potential is very high it always spins in a circle, and so does generally a thin straight wire attached freely to the terminal of the coil. These motions are,

of course, due to the impact of the molecules and the irregularity in the distribution of the potential owing to the roughness and dis-symmetry of the wire or filament. With a perfectly symmetrical and polished wire such motions would probably not occur. That the motion is not likely to be due to other causes is evident from the fact that it is not of a definite direction and that in a very highly exhausted globe it ceases altogether. The possibility of bringing a body to incandescence in an unexhausted globe, or even when not at all enclosed, would seem to afford a possible way of obtaining lighter effects, which in perfecting methods of producing rapidly alternating potentials might be rendered available for useful purposes.

In employing a commercial coil, the production of very powerful brush effects is attended with considerable difficulties, for when these high frequencies and enormous potentials are used,

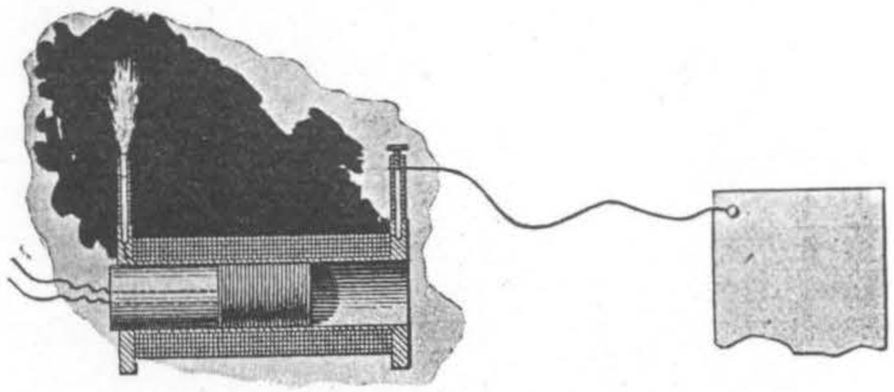

FIG. 17A.—Coil Arranged for Powerful Brush Effects.

the best insulation is apt to give way. Usually the coil is insulated well enough to stand the strain from convolution to convolution, since two double silk covered paraffined wires will withstand a pressure of several thousand volts; the difficulty lies principally in preventing the breaking through from the secondary to the primary, which is greatly facilitated by the streams issuing from the latter. In the coil, of course, the strain is greatest from section to section, but usually in a larger coil there are so many sections that the danger of a sudden giving way is not very great. No difficulty will generally be encountered in that direction, and besides the liability of injuring the coil internally is very much reduced by the fact that the effect most likely to be produced is simply a gradual heating, which, when far enough advanced, could not fail to be observed. The principal necessity is then, to prevent the streams between the primary and the tube,

not only on account of the heating and possible injury, but also because the streams may diminish very considerably the potential difference available at the terminals. A few hints as to how this may be accomplished will probably be found useful in most of these experiments with the ordinary induction coil.

One of the ways is to wind a short primary, [Fig. 17 A], so that the difference of potential is not at that length great enough to cause the breaking forth of the streams through the insulating tube. The length of the primary should be determined by experiment. Both the ends of the coil should be brought out on one end through a plug of insulating material fitting in the tube as illustrated. In such a disposition, one terminal of the secondary is attached to a body, the surface of which is determined with the greatest care so as to produce the greatest rise in the potential.

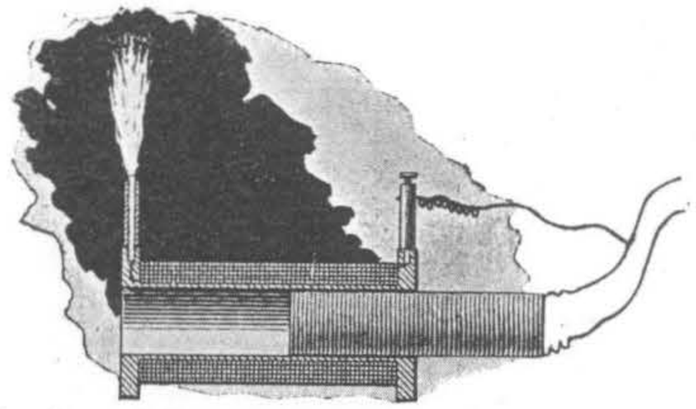

FIG. 17B.—Coil Arranged for Powerful Brush Effects.—St. Elmo's Hot Fire.

At the other terminal a powerful brush appears which may be experimented upon.

The above plan necessitates the employment of a primary of comparatively small size, and it is apt to heat when powerful effects are desirable for a certain length of time. In such a case it is better to employ a larger coil, [Fig. 17 B], and introduce it from one side of the tube, until the streams begin to appear. In this case the nearest terminal of the secondary may be connected to the primary or to the ground, which is practically the same thing, if the primary is connected directly to the machine. In the case of ground connections it is well to determine experimentally the frequency which is best suited under the conditions of the test. Another way of obviating the streams, more or less, is to make the primary in sections and supply it from separate well insulated sources.

In many of these experiments, when powerful effects are wanted for a short time it is advantageous to use iron cores with the primaries In such case a very large primary coil may be wound and placed side by side with the secondary, and the nearest terminal of the latter being connected to the primary, a laminated iron core is introduced through the primary into the secondary as far as the streams will permit. Under these conditions an excessively powerful brush, several inches long, which may be appropriately called "St. Elmo's hot fire," may be caused to appear at the other terminal of the secondary, producing striking effects. It is a most powerful ozonizer, so powerful indeed, that only few minutes are sufficient to fill the whole room with the smell of ozone, and it undoubtedly possesses the quality of exciting chemical affinities.

For the production of ozone, alternating currents of very high frequency are eminently suited, not only on account of the advantages they offer in the way of conversion, but also because of the fact, that the ozonizing action of a discharge is dependent on the frequency as well as on the potential, this being undoubtedly confirmed by observation.

In these experiments if an iron core is used, it should be carefully watched, as it is apt to get excessively hot in an incredibly short time. To give an idea of the rapidity of the heating, I will state, that by passing a powerful current through a coil with many turns, the inserting within the same of a thin iron wire for no more than one second's time is sufficient to heat the wire to something like 100° C.

But this rapid heating does not need to discourage us in the use of iron cores in connection with rapidly alternating currents. I have for a long time been convinced, that in the industrial distribution by means of transformers some such plan as the following might be practicable. We may use a comparatively small iron core, subdivided, or perhaps not even subdivided. We may surround this core with a considerable thickness of material which is fire proof and conducts the heat poorly, and on top of that we may place the primary and secondary windings. By using either higher frequencies or greater magnetizing forces, we may by hystersis and eddy currents heat the iron core so far as to bring it nearly to its maximum permeability, which, as Hopkinson has shown, may be as much as sixteen times greater than that at ordinary temperatures. If the iron core were perfectly enclosed it

would not be deteriorated by the heat, and if the enclosure of fire proof material would be sufficiently thick only a limited amount of energy could be radiated in spite of the high temperature. Transformers have been constructed by me on that plan, but for lack of time, no thorough tests have as yet been made.

Another way of adapting the iron core to rapid alternations, or, generally speaking, reducing the frictional losses, is to produce by continuous magnetization a flow of something like seven thousand or eight thousand lines per square centimetre through the core, and then work with weak magnetizing forces and preferably high frequency around the point of greatest permeability. A higher efficiency of conversion and greater output are obtainable in this manner. I have also employed this principle in connection with machines in which there is no reversal of polarity. In these types of machines, as long as there are only few pole projections, there is no great gain, as the maxima and minima of magnetization are far from the point of maximum permeability, but when the number of the pole projections is very great, the required rate of change may be obtained, without the magnetization varying so far as to depart greatly from the point of maximum permeability, and the gain is considerable.

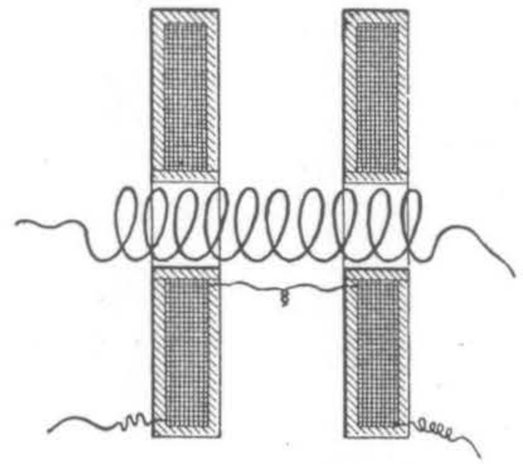

FIG. 18.—Coil for Producing Very High Difference of Potential.

The above-described arrangements refer only to the use of commercial coils as ordinarily constructed. If it is desired to construct a coil for the express purpose of performing with it such experiments as I have described, or generally rendering it capable of withstanding the greatest possible difference of potential, then a construction as indicated in Fig. 18, will be found of advantage. The coil in this case is formed of two independent parts which are wound oppositely, the connection between both being made near the primary. The potential in the middle being zero, there is not much tendency to jump to the primary and not much insulation is required. In some cases the middle point may, however, be connected to the primary or to the ground. In such a coil the places of greatest difference of potential are far apart and the coil is capable of withstanding an enormous strain. The two parts may be movable so as to allow a slight adjustment of the capacity effect.

As to the manner of insulating the coil, it will be found convenient to proceed in the following way: First, the wire should be boiled in paraffin until all the air is out; then the coil is wound by running the wire through melted paraffin, merely for the purpose of fixing the wire. The coil is then taken off from the spool, immersed in a cylindrical vessel filled with pure melted wax and boiled for a long time, until the bubbles cease to appear. The whole is then left to cool down thoroughly, and then the mass is taken out of the vessel and turned up in a lathe. A coil made in this manner and with care, is capable of withstanding enormous potential differences.

It may be found convenient to immerse the coil in paraffin oil or some other kind of oil; it is a most effective way of insulating, principally on account of the perfect exclusion of air, but it may be found that after all a vessel filled with oil is not a very convenient thing to handle in a laboratory.

If an ordinary coil can be dismounted, the primary may be taken out of the tube and the latter plugged up on one end, filled with oil, and the primary reinserted. This affords an excellent insulation and prevents the formation of the streams.

Of all the experiments which may be performed with rapidly alternating currents, the most interesting are those which concern the production of a practical luminant. It cannot be denied that the present methods, though they were brilliant advances, are very wasteful. Some better methods must be invented—some more perfect apparatus devised. Modern research has opened new possibilities for the production of an efficient source of light and the attention of all has been turned in the direction indicated by able pioneers. Many have been carried away by the enthusiasm and passion to discover, but in their zeal to reach results many have been misled. Starting with the idea of producing

electro-magnetic waves, they turned their attention perhaps too much to the study of electro-magnetic effects and neglected the study of electrostatic phenomena. Naturally, nearly ever investigator availed himself of an apparatus similar to that used in earlier experiments. But in those forms of apparatus, while the electro-magnetic inductive effects are enormous, the electrostatic effects are excessively small.

In the Hertz experiments, for instance, a high-tension induction coil is short-circuited by an arc, the resistance of which is very small; the smaller, the more capacity is attached to the terminals; and the difference of potential at these is enormously diminished. On the other hand, when the discharge is not passing between the terminals the static effects may be considerable, but only qualitively so, not quantitatively, since their rise and fall is very sudden and since their frequency is small. In neither case, therefore, are powerful electrostatic effects perceivable. Similar conditions exist when, as in some interesting experiments of Dr. Lodge, Leyden jars are discharged disruptively. It has been thought—and I believe asserted—that in such cases most of the energy is radiated into space. In the light of the experiments, which I have described above, it will now not be thought so. I feel safe in asserting, that in such cases most of the energy is partly taken up and converted into heat in the arc of the discharge and in the conducting and insulating material of the jar, some energy being, of course, given off by electrification of the air; but the amount of the directly radiated energy is very small.

When a high-tension induction coil, operated by currents alternating only 20,000 times a second, has its terminals closed through even a very small jar, practically all the energy passes through the dielectric of the jar, which is heated, and the electrostatic effects manifest themselves outwardly only to a very weak degree. Now the external circuit of a Leyden jar, that is, the arc and the connections of the coatings may be looked upon as a circuit, generating alternating currents of excessively high frequency and fairly high potential, which is closed through the coatings and the dielectric between them, and from the above it is evident that the external electrostatic effects must be very small, even if a recoil circuit be used. These conditions make it appear, that with the apparatus usually at hand the observation of powerful electrostatic effects was impossible, and what

experience has been gained in that direction is only due to the great ability of the investigators.

But powerful electrostatic effects are *sine qua non* of light productions on the lines indicated by theory. Electro-magnetic effects are primarily unavailable, for the reason that to produce the required effects we would have to pass current impulses through a conductor which, long before the required frequency of the impulses could be reached, would cease to transmit them. On the other hand, electro-magnetic waves many times longer than those of light and producible by sudden discharges of a condenser could not be utilized, it would seem, except we avail ourselves of their effect upon conductors as in the present methods, which are wasteful. We could not affect by means of such waves, the static molecular or atomic charges of a gas, cause them to vibrate and to emit light. Long transverse waves cannot, apparently, produce such effects, since excessively small electro-magnetic disturbances may pass readily through miles of air. Such dark waves, unless they are of the length of true light waves, cannot, it would seem, excite luminous radiation in a Geissler tube, and the luminous effect, which are producible by induction in a tube devoid of electrodes, I am inclined to consider as being of an electrostatic nature.

To produce such luminous effects, straight electrostatic thrusts are required; these, whatever be their frequency, may disturb the molecular charges and produce light. Since current impulses of the required frequency cannot pass through a conductor of measurable dimensions, we must work with a gas and then the production of powerful electrostatic effects becomes an imperative necessity.

It has occurred to me, however, that electrostatic effects are in many ways available for the production of light. For instance, we may place a body of some refractory material in a closed and, preferably, more or less exhausted globe, connect it to a source of high, rapidly alternating potential, causing the molecules of the gas to strike it many times a second at enormous speeds, and in this manner, with trillions of invisible hammers, pound it until it gets incandescent; or we may place a body in a very highly exhausted globe, in a non-striking vacuum, and by employing very high frequencies and potentials, transfer sufficient energy from it to other bodies in the vicinity or in general to the surroundings, to maintain it at any degree of incandescence; or we may, by

means of such rapidly alternating high potentials, disturb the ether carried by the molecules of a gas or their static charges, causing them to vibrate and to emit light.

But electrostatic effects being dependent upon the potential and frequency to produce the most powerful action, it is desirable to increase both as far as practicable. It may be possible to obtain quite fair results by keeping either of these factors small, provided the other is sufficiently great; but we are limited in both directions. My experience demonstrates that we cannot go below a certain frequency, for, first, the potential then becomes so great that it is dangerous; and, secondly, the light production is less efficient.

I have found that by using the ordinary low frequencies, the physiological effect of the current required to maintain, at a certain degree of brightness, a tube four feet long, provided at the ends with outside and inside condenser coatings, is so powerful that I think it might produce serious injury to those not accustomed to such shocks; whereas, with twenty thousand alternations per second the tube may be maintained at the same degree of brightness without any effect being felt. This is due principally to the fact that a much smaller potential is required to produce the same light effect, and also to the higher efficiency in the light production. It is evident that the efficiency in such cases is the greater the higher the frequency, for the quicker the process of charging and discharging the molecules, the less energy will be lost in the form of dark radiation. But, unfortunately, we can not go beyond a certain frequency, on account of the difficulty of producing and conveying the effects.

I have stated above, that a body enclosed in an unexhausted bulb may be intensely heated by simply connecting it with a source of rapidly alternating potential. The heating in such a case is in all probability due mostly to the bombardment of the molecules of the gas contained in the bulb. When the bulb is exhausted, the heating of the body is much more rapid and there is no difficulty whatever in bringing a wire or filament to any degree of incandescence by simply connecting it to one terminal of a coil of the proper dimensions. Thus, if the well known apparatus of Prof. Crookes, consisting of a bent platinum wire with vanes mounted over it [Fig. 19], be connected to one terminal of the coil—either one or both ends of the platinum wire being connected—the wire is rendered almost instantly incandescent and

the mica vanes are rotated as though a current from a battery were used. A thin carbon filament or, preferably, a button of some refractory material [Fig. 20], even if it be a comparatively poor conductor, enclosed in an exhausted globe, may be rendered highly incandescent; and in this manner a simple lamp capable of giving any desired candle power is provided.

The success of lamps of this kind would depend largely on the selection of the light-giving bodies contained within the bulb. Since, under the conditions described, refractory bodies—which are very poor conductors and capable of withstanding for a long time excessively high degrees of temperature—may be used, such illuminating devices may be rendered successful.

It might be thought at first that if the bulb containing the filament or button of refractory material, be perfectly well exhausted

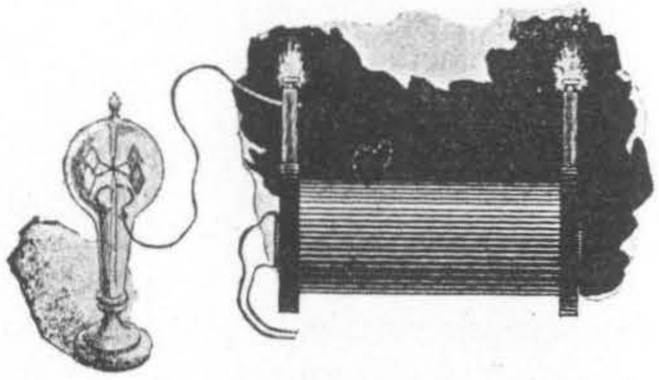

FIG. 19.—The Crookes Experiment on Open Circuit.



FIG. 20.—Lamp with Single Block of Refractory Material.

—that is, as far as it can be done by the use of the best apparatus—the heating would be much less intense, and that in perfect vacuum it could not occur at all. This is not confirmed by my experience. Quite the contrary; the better the vacuum, the easier the bodies are brought to incandescence. This result is interesting for many reasons.

At the outset of this work, the idea presented itself to me, whether two bodies of refractory material enclosed in a bulb, exhausted to such a degree that the discharge of a large induction coil operated in the usual manner cannot pass through, could be rendered incandescent by mere condenser action. Obviously, to reach this result enormous potential differences and very high frequencies are required, as is evident from a simple calculation.

But such a lamp would possess a vast advantage over an ordinary incandescent lamp in regard to efficiency. It is well known that the efficiency of a lamp is to some extent a function of the degree of incandescence and that could we but work a filament at many times higher degrees of incandescence the efficiency would be much greater. In an ordinary lamp this is impracticable, on account of the destruction of the filament, and it has been determined by experience how far it is advisable to push the incandescence. It is impossible to tell how much higher efficiency could be obtained if the filament could withstand indefinitely, as the investigation to this end obviously cannot be carried beyond a certain stage; but there are reasons for believing that it would be very considerably higher. An improvement might be made in the ordinary lamp by employing a short and thick carbon; but then the leading-in wires would have to be thick and, besides, there are many other considerations which render such a modification entirely impracticable. But in a lamp as above described, the leading-in wires may be very small, the incandescent refractory material may be in the shape of blocks offering a very small radiating surface, so that less energy would be required to keep them at the desired incandescence; and in addition to this, the refractory material need not be carbon, but may be manufactured from mixtures of oxides, for instance, with carbon or other material, or may be selected from bodies which are practically non-conductors and capable of withstanding enormous degrees of temperature.

All this would point to the possibility of obtaining a much higher efficiency with such a lamp than is obtainable in ordinary lamps. In my experience it has been demonstrated that the blocks are brought to high degrees of incandescence with much lower potentials than those determined by calculation, and the blocks may be set at greater distances from each other. We may freely assume, and it is probable, that the molecular bombardment is an important element in the heating, even if the globe be exhausted with the utmost care, as I have done; for although the number of the molecules is, comparatively speaking, insignificant, yet on account of the mean free path being very great, there are fewer collisions and the molecules may reach much higher speeds, so that the heating effect due to this cause may be considerable, as in the Crookes experiments with radiant matter.

But it is likewise possible that we have to deal here with an

increased facility of losing the charge in very high vacuum, when the potential is rapidly alternating, in which case most of the heating would be directly due to the surging of the charges in heated bodies Or else the observed fact may be largely attributable to the effect of the points which I have mentioned above, in consequence of which the blocks or filaments contained in the vacuum are equivalent to condensers of many times greater surface than that calculated from their geometrical dimensions. Scientific men still differ in opinion as to whether a charge should, or should not, be lost in a perfect vacuum, or in other words, whether ether is, or is not, a conductor. If the former were the case, then a thin filament enclosed in a perfectly

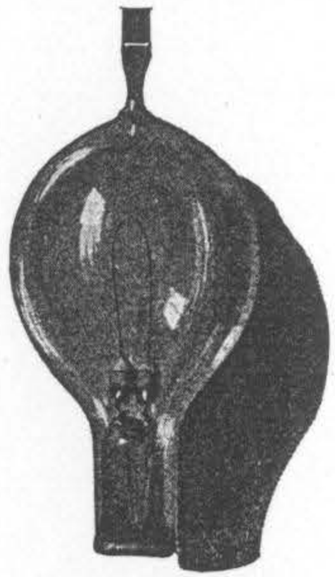

FIG. 21.—Lamp with Two Filaments in Highest Vacuum with Leading-in Wires.

exhausted globe and connected to a source of enormous, steady potential would be brought to incandescence.

Various forms of lamps on the above described principle, with the refractory bodies, in the form of filaments Fig. 21, or blocks, Fig. 22, have been constructed and operated by me, and investigations are being carried on in this line. There is no difficulty in reaching such high degrees of incandescence that ordinary carbon is to all appearance melted and volatilized. If the vacuum could be made absolutely perfect, such a lamp, although inoperative with apparatus ordinarily used, would, if operated with currents of the required character, afford an illuminant which would never be destroyed and which would be far more efficient than an ordinary incandescent lamp. This perfection can, of course, never

be reached and a very slow destruction and gradual diminution of the size always occurs, as in incandescent lamps; but there is no possibility of a sudden and premature disabling which occurs in the latter by the breaking of the filament, especially when the incandescent bodies are in the shape of blocks.

With these rapidly alternating potentials there is, however, no necessity of enclosing two blocks in a globe, but a single block, as in Fig. 20, or filament, Fig. 23, may be used. The potential in this case must of course be higher, but it is easily obtainable and besides it is not necessarily dangerous.

The facility with which the button or filament in such a

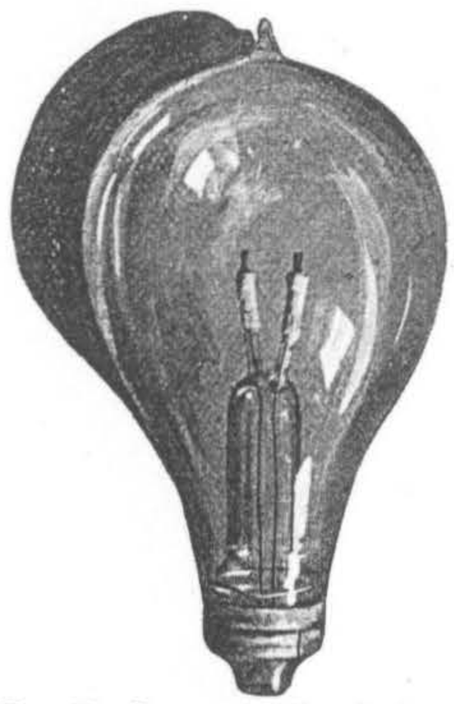

FIG. 22.—Lamp with Two Refractory Blocks in Highest Vacuum.

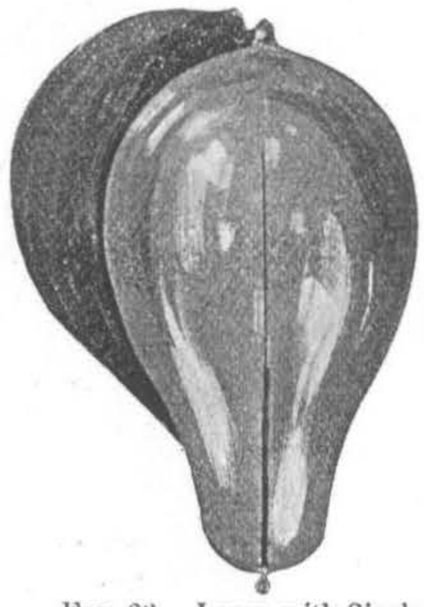

FIG. 23.—Lamp with Single Straight Filament and one Leading-in Wire.

lamp is brought to incandescence, other things being equal, depends on the size of the globe. If a perfect vacuum could be obtained, the size of the globe would not be of importance, for then the heating would be wholly due to the surging of the charges and all the energy would be given off to the surroundings by radiation. But this can never occur in practice. There is always some gas left in the globe and although the exhaustion may be carried to the highest degree, still the space inside of the bulb must be considered as conducting when such high potentials are used, and I assume, that in estimating the energy that may be given off from the filament to the surroundings, we may consider

the inside surface of the bulb as one coating of a condenser, the air and other objects surrounding the bulb forming the other coating. When the alternations are very low there is no doubt that a considerable portion of the energy is given off by the electrification of the surrounding air.

In order to study this subject better, I carried on some experiments with excessively high potentials and low frequencies. I then observed that when the hand is approached to the bulb,—the filament being connected with one terminal of the coil,—a powerful vibration is felt, being due to the attraction and repulsion of the molecules of the air which are electrified by induction through the glass. In some cases when the action is very intense I have been able to hear a sound, which must be due to the same cause.

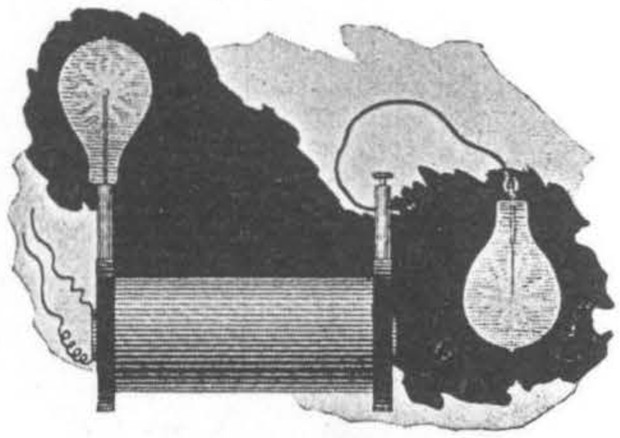

FIG. 24.—Lamps wtih One Leading-in Wire Rendered Incandescent.

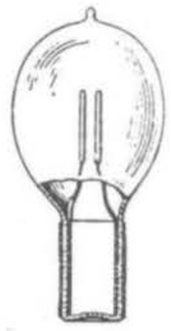

FIG. 25.—Lamp with two Blocks or Filaments and a Pair of Independent Inside and Outside Condenser Coatings.

When the alternations are low, one is apt to get an excessively powerful shock from the bulb. In general, when one attaches bulbs or objects of some size to the terminals of the coil, one should look out for the rise of potential, for it may happen that by merely connecting a bulb or plate to the terminal, the potential may rise to many times its original value. When lamps are attached to the terminals, as illustrated in Fig. 24, then the capacity of the bulbs should be such as to give the maximum rise of potential under the existing conditions. In this manner one may obtain the required potential with fewer turns of wire.

The life of such lamps as described above depends, of course, largely on the degree of exhaustion, but to some extent also on the shape of the block of refractory material. Theoretically it would seem, that a small sphere of carbon enclosed in a sphere of

glass would not suffer deterioration from molecular bombardment, for the matter in the globe, being radiant, the molecules would move in straight lines and would seldom strike the sphere obliquely. An interesting thought in connection with such a lamp is, that in it "electricity" and electrical energy apparently must move in the same lines.

The use of alternating currents of very high frequency makes it possible to transfer by electrostatic or electromagnetic induction through the glass of a lamp sufficient energy to keep a filament at incandescence and so do away with the leading-in wires.



FIG. 26A.

FIG. 26B.

Lamp with One Filament, One Inside and One Outside Condenser Coating.

Such lamps have been proposed, but for want of proper apparatus they have not been successfully operated. Many forms of lamps on this principle with continuous and broken filaments have been constructed by me and experimented upon. When using a secondary enclosed within the lamp a condenser is advantageously combined with the secomdary. When the transference is effected by electrostatic induction the potentials used are, of course, very high with frequencies obtainable from a machine. For instance, with a condenser surface of forty centimetres square, which is not

impracticably large, and with glass of good quality, 1 mm. thick, using currents alternating twenty thousand times a second, the potential required is approximately 9,000 volts. This may seem large, but since each lamp may be included in the secondary of a transformer of very small dimensions it would not be inconvenient and, moreover, it would not produce fatal injury. The transform, ers would all be preferably in series. The regulation would offer no difficulties, as with currents of such frequencies it is very easy to maintain a constant current.

In the accompanying engravings some of the types of lamps of this kind are shown. Fig. 25 is such a lamp with a broken filament, and Fig 26 A and 26 B one with a single inside and outside coat-



FIG. 27.—Lamp with One Filament and Leading-in Wire and External Condenser Coating.



FIG. 28.—Lamp with One Filament, One Inside and One Outside Condenser Coating, and Auxiliary Coating.

ing and a single filament. I have also made lamps with two outside and inside coatings and a continuous loop connecting the latter. Such lamps have been operated by me with current impulses of the enormous frequencies obtainable by the disruptive discharge of condensers.

The disruptive discharge of a condenser is especially suited for operating such lamps—with no outward electrical connections—by means of electro-magnetic induction, the electro-magnetic inductive effects being excessively high; and I have been able to produce the desired incandescence with only a few short turns of wire. Incandescence may also be produced in this manner in a simple closed filament.

Leaving, now, out of consideration the practicability of such lamps, I would only say that they possess a beautiful and desirable feature, namely, that they can be rendered, at will, more or less brilliant simply by altering the relative position of the outside and inside condenser coatings or inducing and induced circuits.

When a lamp is lighted by connecting it to one terminal only of the source, this may be facilitated by providing the globe with an outside condenser coating, which serves at the same time as a reflector, and connecting this to an insulated body of some size. Lamps of this kind are illustrated in Fig. 27 and Fig. 28. Fig. 29 shows the plan of connections. The brilliancy of the lamp may in this case be regulated within wide limits by varying the size of the insulated metal plate to which the coating is connected.

It is likewise practicable to light with one leading wire, lamps

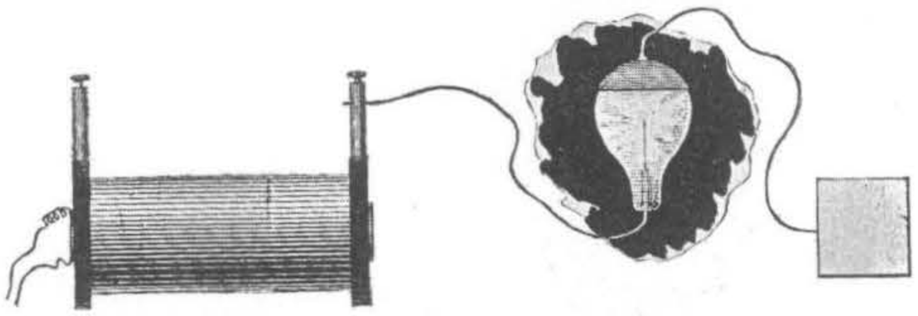

FIG. 29.—Increasing the Brilliancy of Lamp on One Wire.

such as illustrated in Fig. 21 and Fig. 22, by connecting one terminal of the lamp to one terminal of the source and the other to an insulated body of the required size. In all cases the insulated body serves to give off the energy into the surrounding space and is equivalent to a return wire. Obviously, in the two last-named cases, instead of connecting the wires to an insulated body, connections may be made to the ground.

The experiments which will prove most suggestive and of most interest to the investigator, are probably those performed with exhausted tubes. As might be anticipated, a source of such rapidly alternating potentials is capable of exciting the tubes at a considerable distance and the light effects produced are remarkable.

During my investigations in this line, I endeavored to excite tubes devoid of any electrodes, by electromagnetic induction, making the tube the secondary of the induction device and passing through the primary the discharges of a Leyden jar. These tubes were made of many shapes and I was able to obtain luminous effects which I then thought were due wholly to electromagnetic induction. But on carefully investigating the phenomena, I found that the effects produced were more of an electrostatic nature. It may be attributed to this circumstance that this mode of exciting tubes is very wasteful, namely, the primary circuit being closed, the potential, and consequently the electrostatic inductive effect, is much diminished.

When an inductive coil, operated as above described, is used, there is no doubt that the tubes are excited by electrostatic induction and that electromagnetic induction has little, if anything, to do with the phenomena.

This is evident from many experiments. For instance, if a tube be taken in one hand, the observer being near the coil, it is brilliantly lighted and remains so no matter in what position it is held relatively to the observer's body. Were the action electromagnetic, the tube could not be lighted when the observer's body is interposed between it and the coil, or at least its luminosity should be considerably diminished. When the tube is held exactly over the centre of the coil—the latter being wound in sections and the primary placed symmetrically to the secondary—it may remain completely dark, whereas it is rendered intensely luminous by moving it slightly to the right or left from the centre of the coil. It does not light because in the middle, both halves of the coil neutralize each other and the electric potential is zero. If the action were electromagnetic, the tube should light best in the plane through the centre of the coil, since the electromagnetic effect there should be a maximum. When an arc is established between the terminals, the tubes and lamps in the vicinity of the coil go out, but light up again when the arc is broken, on account of the rise of potential. Yet the electromagnetic effect should be practically the same in both cases.

By placing a tube at some distance from the coil and nearer to one terminal—preferably at a point on the axis of the coil—one may light it by touching the remote terminal with an insulated body of some size or with the hand, thereby raising the potential at that terminal nearer to the tube. If the tube is shifted nearer to the coil, so that it is lighted by the action of the nearer terminal, it may be made to go out by holding on an insulated support the end of a wire connected to the remote terminal, in the

vicinity of the nearer terminal, by this means counteracting the action of the latter upon the tube. These effects are evidently electrostatic. Likewise, when a tube is placed at a considerable distance from the coil, the observer may, standing upon an insulated support between coil and tube, light the latter by approaching the hand to it; or he may even render it luminous by simply stepping between it and the coil. This would be impossible with electromagnetic induction, for the body of the observer would act as a screen.

When the coil is energized by excessively weak currents, the experimenter may, by touching one terminal of the coil with the tube, extinguish the latter, and may again light it by bringing it out of contact with the terminal and allowing a small arc to form. This is clearly due to the respective lowering and raising of the potential at that terminal In the above experiment, when the tube is lighted through a small arc it may go out when the arc is broken, because the electrostatic inductive effect alone is too weak though the potential may be much higher; but when the arc is established, the electrification of the end of the tube is much greater, and it consequently lights.

If a tube is lighted by holding it near to the coil, and in the hand which is remote, by grasping the tube anywhere with the other hand, the part between the hands is rendered dark, and the singular effect of wiping out the light of the tube may be produced by passing the hand quickly along the tube and at the same time withdrawing it slightly from the coil, judging properly the distance, so that the tube remains dark afterwards.

If the primary coil is placed sidewise, as in Fig. 17 B, for instance, and an exhausted tube be introduced from the other side in the hollow space, the tube is lighted most intensely because of the increased condenser action, and in this position the striæ are most sharply defined. In all these experiments described and in many others, the action is clearly electrostatic.

The effects of screening also indicate the electrostatic nature of the phenomena and show something of the nature of electrification through the air. For instance, if a tube be placed in the direction of the axis of the coil and an insulated metal plate be interposed the tube will generally increase in brilliancy, or if it be too far from the coil to light, it may even be rendered luminous by interposing an insulated metal plate. The magnitude of

the effects depends to some extent on the size of the plate. But if the metal plate be connected by a wire to the ground its interposition will always make the tube go out even if it be very near the coil. In general, the interposition of a body between the coil and tube increases, or diminishes, the brilliancy of the tube or its facility to light up. according to whether it increases or diminishes the electrification. When experimenting with an insulated plate, the plate should not be taken too large, else it will generally produce a weakening effect by reason of its great facility for giving off energy to the surroundings.

If a tube be lighted at some distance from the coil and a plate of hard rubber or other insulating substance be interposed, the tube may be made to go out. The interposition of the dielectric in this case only slightly increases the inductive effect, but diminishes considerably the electrification through the air.

In all the cases, then, when we excite luminosity in exhausted tubes by means of such a coil the effect is due to the rapidly alternating electrostatic potential; and, furthermore, it must be attributed to the harmonic alternation produced directly by the machine and not to any superimposed vibration which might be thought to exist. Such superimposed vibrations are impossible when we work with an alternate current machine. If a spring be gradually tightened and released it does not perform independent vibrations; for this a sudden release is necessary. So with the alternate currents from a dynamo machine; the medium is harmonically strained and released, this giving rise to only one kind of waves; a sudden contact or break, or a sudden giving way of the dielectric, as in the disruptive discharge of a Leyden jar, are essential for the production of superimposed waves.

In all the last described experiments, tubes devoid of any electrodes may be used and there is no difficulty in producing by their means sufficient light to read by. The light effect is, however, considerably increased by the use of phosphorescent bodies such as yttria, uranium glass, etc. A difficulty will be found when the phosphorescent material is used, for with these powerful effects, it is carried gradually away, and it is preferable to use material in the form of a solid.

Instead of depending on induction at a distance, to light the tube, the same may be provided with an external—and, if desired, also with an internal—condenser coating and may then be suspended anywhere in the room from a conductor connected to one

terminal of the coil, and in this manner a soft illumination may be provided.

The ideal way of lighting a hall or room would, however, be to produce such a condition in it that an illuminating device

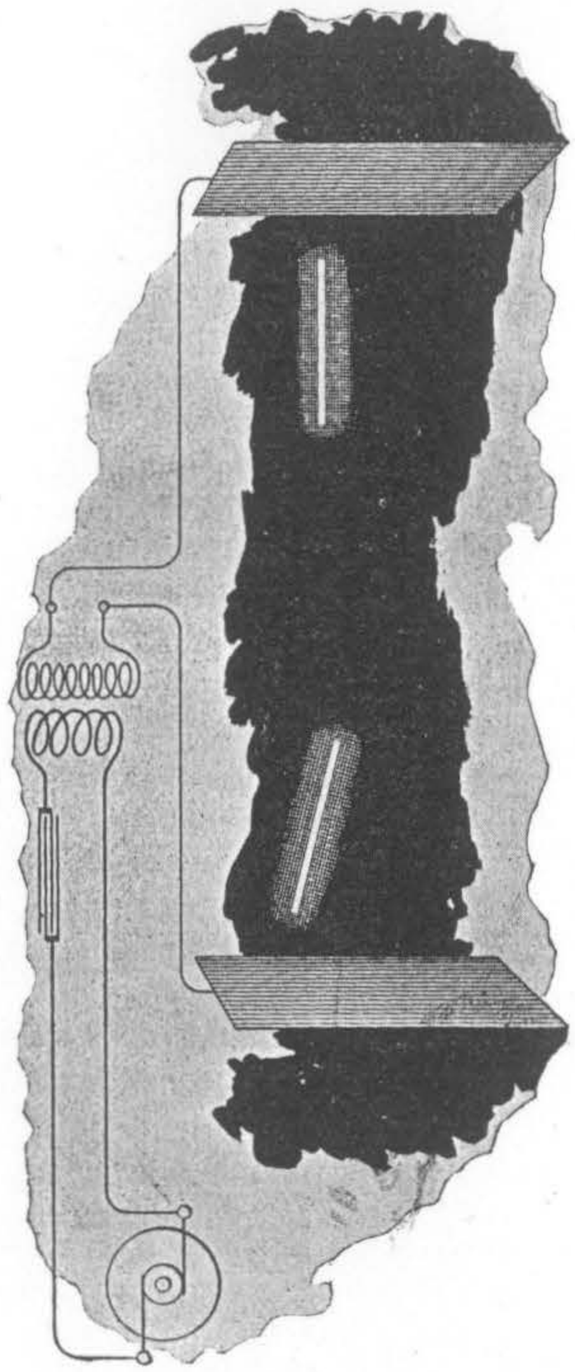

FIG. 30.—Ideal Method of Lighting a Room —Tubes Devoid of Any Electrodes Rendered Brilliant in an Alternating Electrostatic Field.

could be moved and put anywhere and that it is lighted, no matter where it is put and without being electrically connected to anything. I have been able to produce such a condition by creating in the room a powerful, rapidly alternating electrostatic

field. For this purpose I suspend a sheet of metal a distance from the ceiling on insulating cords and connect it to one terminal of the induction coil, the other terminal being preferably connected to the ground. Or else I suspend two sheets as illustrated in Fig. 30, each sheet being connected with one of the terminals of the coil, and their size being carefully determined. An exhausted tube may then be carried in the hand anywhere between the sheets or placed anywhere, even a certain distance beyond them; it remains always luminous.

In such an electrostatic field interesting phenomena may be observed, especially if the alternations are kept low and the potentials excessively high. In addition to the luminous phenomena mentioned, one may observe that any insulated conductor gives sparks when the hand or another object is approached to it, and the sparks may often be powerful. When a large conducting object is fastened on an insulating support and the hand approached to it, a vibration due to the rythmical motion of the air molecules is felt, and luminous streams may be perceived when the hand is held near a pointed projection. When a telephone receiver is made to touch with one or both of its terminals an insulated conductor of some size, the telephone emits a loud sound; it also emits a sound when a length of wire is attached to one or both terminals, and with very powerful fields a sound may be perceived even without any wire.

How far this principle is capable of practical application, the future will tell. It might be thought that electrostatic effects are unsuited for such action at a distance. Electromagnetic inductive effects, if available for the production of light, might be thought better suited. It is true the electrostatic effects diminish nearly with the cube of the distance from the coil, whereas the electromagnetic inductive effects diminish simply with the distance. But when we establish an electrostatic field of force the condition is very different, for then instead of the differential effect of both the terminals, we get their conjoint effect. Besides, I would call attention to the fact that in an alternating electrostatic field, a conductor, such as an exhausted tube, for instance, tends to take up most of the energy, whereas in an electromagnetic alternating field the conductor tends to take up the least energy, the waves being reflected with but little loss. This is one reason why it is difficult to excite an exhausted tube at a distance by electromagnetic induction. I have wound coils of very large

diameter and of many turns of wire, and connected a Geissler tube to the ends of the coil with the object of exciting the tube at a distance; but even with the powerful inductive effects producible by Leyden jar discharges, the tube could not be excited unless at a very small distance, although some judgment was used as to the dimensions of the coil. I have also found that even the most powerful Leyden jar discharges are capable of exciting only feeble luminous effects in a closed exhausted tube, and even these effects, upon thorough examination, I have been forced to consider of an electrostatic nature.

How, then, can we hope to produce the required effects at a distance by means of electromagnetic action, when even in the closest proximity to the source of disturbance, under the most advantageous conditions, we can excite but faint luminosity? It is true that when acting at a distance, we have the resonance to help us out. We can connect an exhausted tube or whatever the illuminating device may be, with an insulated system of the proper capacity, and so it may be possible to increase the effect qualitatively, and only qualitatively, for we would not get more energy through the device. So we may, by resonance effect, obtain the required electromotive force in an exhausted tube and excite faint luminous effects, but we cannot get enough energy to render the light practically available, and a simple calculation, based on experimental results, shows that even if all the energy which a tube would receive at a certain distance from the source, would be wholly converted into light, it would hardly satisfy the practical requirements. Hence the necessity of directing, by means of a conducting circuit, the energy to the place of transformation. But in so doing, we cannot very sensibly depart from present methods, and all we could do would be to improve the apparatus.

From these considerations, it would seem that if this ideal way of lighting is to be rendered practicable, it will be only by the use of electrostatic effects. In such a case, the most powerful electrostatic inductive effects are needed; the apparatus employed must, therefore, be capable of producing high electrostatic potentials changing in value with extreme rapidity. High frequencies are especially wanted, for practical considerations make it desirable to keep down the potential. By the employment of machines or, generally speaking, of any mechanical apparatus, but low frequencies can be reached; recourse must, therefore, be had to some

other means. The discharge of a condenser affords us a means of obtaining frequencies by far higher than are obtainable mechanically, and I have accordingly employed condensers in the experiments to the above end.

When the terminals of a high-tension induction coil [Fig. 31] are connected to a Leyden jar and the latter is discharging disruptively into a circuit, we may look upon the arc playing between the knobs as being a source of alternating or, generally speaking, undulating currents, and then we have to deal with the familiar system of a generator of such currents, a circuit connected to it and a condenser bridging the circuit. The condenser in such case is a veritable transformer, and since the frequency is excessive, most any ratio in the strength of the currents in both the branches may be obtained. In reality the analogy is not quite complete, for in the disruptive discharge we have most generally a fundamental instantaneous variation of comparatively low frequency

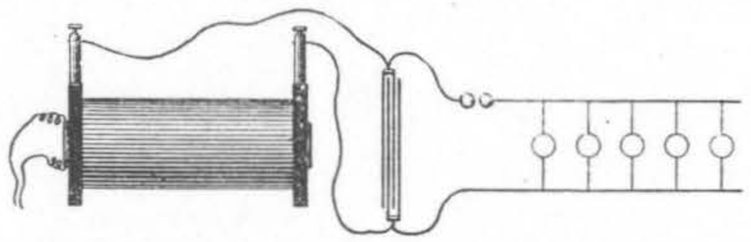

FIG. 31—Diagram of Connections for Converting from High to Low Tension by Means of the Disruptive Discharge.

and a superimposed harmonic vibration, and the laws governing the flow of currents are not the same for both.

In converting in this manner, the ratio of conversion should not be too great, for the loss in the arc between the knobs increases with the square of the current, and if the jar be discharged through very thick and short conductors, with the view of obtaining a very rapid oscillation, a very considerable portion of the energy stored is lost. On the other hand, too small ratios are not practicable for many obvious reasons.

As the converted currents flow in a practically closed circuit, the electrostatic effects are necessarily small, and I therefore convert them into currents or effects of the required character. I have effected such conversions in several ways. The preferred plan of connections is illustrated in Fig. 32. The manner of operating renders it easy to obtain, by means of a small and inexpensive apparatus, enormous differences of potential which have been usually

obtained by means of large and expensive coils. For this it is only necessary to take an ordinary small coil, adjust to it a condenser and discharging circuit forming the primary of an auxiliary small coil, and convert upwards. As the inductive effect of the primary currents is excessively great, the second coil need have comparatively but very few turns. By properly adjusting the element, remarkable results may be secured.

In endeavoring to obtain the required electrostatic effects in this manner, I have, as might be expected, encountered many difficulties which I have been gradually overcoming, but I am not as yet prepared to dwell upon my experiences in this direction.

I believe that the disruptive discharge of a condenser will play an important part in the future, for it offers vast possibilities not only in the way of producing light in a more efficient manner and in line indicated by theory, but also in many other respects.

For years the efforts of inventors have been directed towards

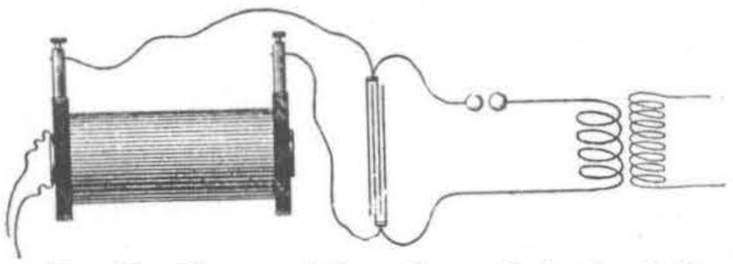

FIG. 29.—Manner of Operating an Induction Coil

obtaining electrical energy from heat by means of the thermopile. It might seem invidious to remark that but few know what is the real trouble with the thermopile. It is not the inefficiency or small output—though these are great drawbacks—but the fact that the thermopile has its phylloexra--that is, that by constant use it is deteriorated, which has thus far prevented its introduction on an industrial scale. Now that all modern research seems to point with certainty to the use of electricity of excessively high tension, the question must present itself to many whether it is not possible to obtain in a practicable manner this form of energy from heat. We have been used to look upon an electrostatic machine as a plaything, and somehow we couple with it the idea of the inefficient and impractical. But now we must think differently, for now we know that everywhere we have to deal with the same forces and that it is a mere question of inventing proper methods or apparatus for rendering them available.

In the present systems of electrical distribution the employment

of the iron with its wonderful magnetic properties, allows us to reduce considerably the size of the apparatus; but in spite of this it is still very cumbersome. The more we progress in the study of electric and magnetic phenomena, the more we become convinced that the present methods will be short lived. For the production of light at least, such heavy machinery would seem to be unnecessary. The energy required is very small, and if light can be obtained as efficiently, as theoretically it appears possible, the apparatus need have but a very small output. There being a strong probability that the illuminating methods of the future will involve the use of very high potentials, it seems very desirable to perfect a contrivance capable of converting the energy of heat into energy of the requisite form. Nothing to speak of has been done towards this end, for the thought that electricity of some 50,000 or 100,000 volts' pressure or more, even if obtained would be unavailable for practical purposes, has deterred inventors from working in this direction.

In Fig. 31, a plan of connections is shown for converting currents of high into currents of low tension, by means of the disruptive discharge of a condenser. This plan has been used by me frequently for operating a few incandescent lamps required in the laboratory. Some difficulties have been encountered in the arc of the discharge, which I have been able to overcome to a great extent; besides this and the adjustment necessary for the proper working, no other difficulties have been met with, and it was easy to operate ordinary lamps and even motors in this manner. The line being connected to the ground, all the wires could be handled with perfect impunity, no matter how high the potentials at the terminals of the condenser. In these experiments, a high-tension induction coil, operated from a battery or from an alternate current machine, was employed to charge the condenser; but the induction coil might be replaced by an apparatus of a different kind, capable of giving electricity of such high tension. In this manner direct or alternating currents may be converted, and in both cases the current-impulses may be of any desired frequency. When the currents charging the condenser are of the same direction, and it is desired that the converted currents should also be of one direction, the resistance of the discharging circuit should, of course, be so chosen that there are no oscillations.

In operating devices on the above plan, I have observed curious phenomena of impedance which are of interest. For instance, if

a thick copper bar be bent as indicated in Fig. 33, and shunted by ordinary incandescent lamps, then by passing the discharge between the knobs, the lamps may be brought to incandescence, although they are short-circuited. When a large induction coil is employed, it is easy to obtain nodes on the bar which are rendered evident by the different degree of brilliancy of the lamps, as shown roughly in Fig. 33. The nodes are never clearly pronounced, but there are simply maxima and minima of potential along the bar. This is probably due to the irregularity of the

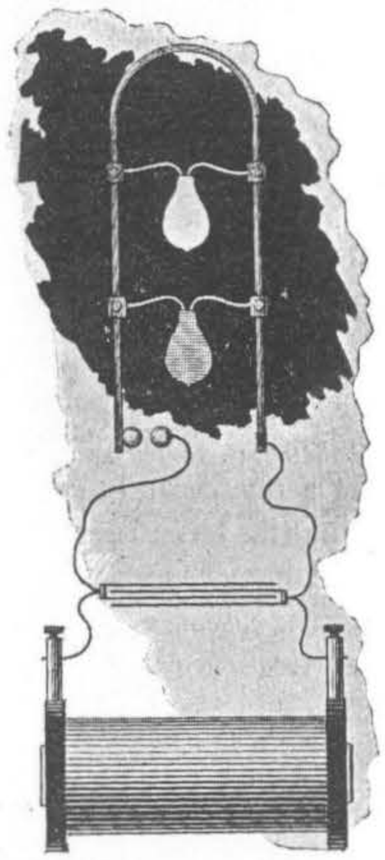

FIG. 33.—Lamp Kept at Incandescence across a Thick Copper Bar—Showing Nodes.

arc between the knobs. In general, when the above-described plan of conversion from high to low tension is used, the behavior of the disruptive discharge may be closely studied. The nodes may also be investigated by means of an ordinary Cardew voltmeter, which should be well insulated. Geissler-tubes may also be lighted across the points of the bent bar. In this case, of course, it is better to employ smaller capacities. I have found it practicable to light up in this manner a lamp and even a Geissler tube shunted by a short, heavy block of metal, and this result seems at first very curious. In fact, the thicker the copper bar in Fig. 33,

the better it is for the success of the experiments, as they appear more striking. When lamps with long slender filaments are used, it will be often noted that the filaments are from time to time violently vibrated, the vibration being smallest on the nodal points. This vibration seems to be due to an electrostatic action between the filament and the glass of the bulb.

In some of the above experiments it is preferable to use special lamps having a straight filament, as shown in Fig. 34. When such a lamp is used a still more curious phenomenon than those described may be observed. The lamp may be placed across the copper bar and lighted, and by using somewhat larger capacities or, in other words, smaller frequencies, or smaller impulsive impedances, the filament may be brought to any desired degree of incandescence. But when the impedance is increased, a point is reached when comparatively little current

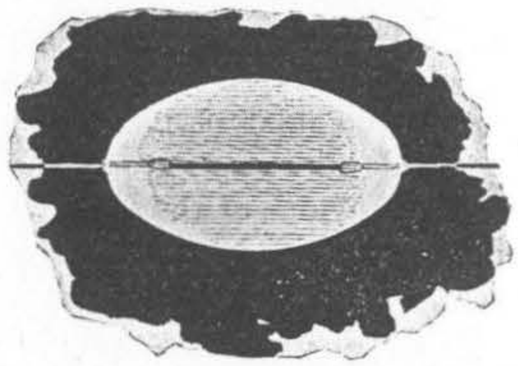

FIG. 34.—Phenomenon of Impedance in an Incandescent Lamp.

passes through the carbon and most of it through the rarefied gas, or perhaps it may be more correct to state that the current divides nearly evenly through both, in spite of the enormous difference in the resistance, and this would be true unless the gas and the filament behave differently. It is then noted that the whole bulb is brilliantly illuminated and the ends of the leading-in wires become incandescent and often throw off sparks in consequence of the violent bombardment; but the carbon filament remains dark. This is illustrated in Fig. 34. Instead of the filament, a single wire extending through the whole bulb may be used, and in this case the phenomenon would seem to be still more interesting.

From the above experiment it will be evident that when ordinary lamps are operated by the converted currents, those should be preferably taken in which the platinum wires are far apart and

the frequencies used should not be too great, else the discharge will occur at the ends of the filament or in the base of the lamp between the leading-in wires, and the lamp might then be damaged.

In presenting to you these results of my investigation on the subject under consideration, I have paid only a passing notice to facts upon which I could have dwelt at length, and among many observations I have selected only those which I thought most likely to interest you. The field is wide and completely unexplored, and at every step a new truth is gleaned, a novel fact observed.

How far the results here borne out are capable of practical applications, will be decided in the future. As regards the production of light, some results already reached are encouraging and make me confident in asserting that the practical solution of the problem lies in the direction I have endeavored to indicate. Still, whatever may be the immediate outcome of these experiments, I am hopeful that they will only prove a step to further development towards the ideal and final perfection. The possibilities which are opened by modern research are so vast that even the most reserved must feel sanguine of the future. Eminent scientists consider the problem of utilizing one kind of radiation without the others, a rational one. In an apparatus designed for the production of light by conversion of any form of energy into that of light, such a result can never be reached, for no matter what the process of producing the required vibrations, be it electrical, chemical or any other, it will not be possible to obtain the higher light vibrations without going through the lower heat vibrations. It is the problem of imparting to a body a certain velocity without passing through all lower velocities. But there is a possibility of obtaining energy not only in the form of light, but motive power and energy of any other form in some more direct way from the medium. The time will be when this will be accomplished, and the time has come when one may utter such words before an enlightened audience, without being considered a visionary. We are whirling through the endless space with an inconceivable speed; all around us everything is spinning, everything is moving, everywhere is energy. There *must* be some way of availing ourselves of this energy more directly; then, with the light obtained from the medium, with the power derived from it, with every

form of energy obtained without effort from the store forever inexhaustible, humanity will advance with giant strides. The mere contemplation of these magnificent possibilities expands our minds, strengthens our hopes and fills our hearts with supreme delight.

PHENOMENA OF ALTERNATING CURRENTS OF VERY HIGH FREQUENCY.*

BY NIKOLA TESLA.

THE following letter refers to Prof. Thomson's reply, published in our issue of April 17th :—

I cannot pass without comment the note of Prof. Thomson in *The Electrical World* of April 4th, although I dislike very much to engage in a prolonged controversy. I would gladly let Prof. Thomson have the last word, were it not that some of his statements render a reply from me necessary.

I did not mean to imply that whatever work Prof. Thomson has done in alternating currents of very high frequency was subsequent to his letter published in *The Electrician*. I thought it possible, and even probable, that he had made his experiments some time before, and my statement in regard to this was meant in this general way. It is more than probable that quite a number of experimenters have built such machines and observed effects similar to those described by Professor Thomson. It is doubtful, however, whether, in the absence of any publication on this subject, the luminous phenomena described by me have been observed by others, the more so as very few would be likely to go to the trouble I did, and I would myself not have done so had I not had an advance of firm conviction gained from the study of the works of the most advanced thinkers that I would obtain the results sought for. Now that I have indicated the direction, many will probably follow, and for this very purpose I have shown some of the results I have reached.

Prof. Thomson states decisively in regard to the experiment with the incandescent lamp bulb and the filament mounted on a single wire that he cannot agree with me at all that conduction through the glass has anything to do with the phenomenon observed. He mentions the well-known fact that an incandescent lamp acts as a Leyden jar and says that "if conduction through the glass were a possibility this action could not occur." I think I may confidently assert that very few electricians will share this view. For the possibility of the condenser effect taking place it is only necessary that the rate at which the charges can equalise through the glass by conduction should be somewhat below the rate at which they are so stored.

Prof. Thomson seems to think that conduction through the glass is an impossibility. Has he then never measured insulation resistance, and has he then not measured it by means of a conduction current? Does he think that there *is* such a thing as a perfect non-conductor among the bodies we are able to perceive? Does he *not* think that as regards conductivity there can be question only of degree? If glass were a perfect non-conductor, how could we account for the conduction through a glass condenser when subjected to steady differences of potential?

While not directly connected with the present controversy, I would here point out that there exists a popular error in regard to the properties of dielectric bodies. Many electricians frequently confound the theoretical dielectric of Maxwell with the dielectric bodies in use. They do not stop to think that the only perfect dielectric is ether, and that all other bodies, the existence of which is known to us, must be conductors, judging from their physical properties.

My statement that conduction is concerned to some, though perhaps negligible, extent in the experiment above described was, however, made not only on account of the fact that all bodies conduct more or less, but principally on

* *Electrical World.*

account of the heating of the glass during the experiment. Prof. Thomson seems to overlook the fact that the insulating power of glass diminishes enormously with the increase in temperature, so much so that melted glass is comparatively an excellent conductor. I have, moreover, stated in my first reply to Prof. Thomson in *The Electrical World* of March 21st, 1891, that the same experiment can be performed by means of an unvarying difference of potential. In this case it must be assumed that some such process as conduction through the glass takes place, and all the more as it is possible to show by experiment that with a sufficiently high steady difference of potential enough current can be passed through the glass of a condenser with mercury coatings to light up a Geissler tube joined in series with the condenser. When the potential is alternating the condenser action comes in, and conduction becomes insignificant, and the more so the greater the rate of alternation or change per unit of time. Nevertheless, in my opinion, conduction must always exist, especially if the glass is hot, although it may be negligible with very high frequencies.

Prof. Thomson states further that, from his point of view, I have misunderstood his statement about the limit of audition. He says that 10,000 to 20,000 alternations correspond to 5,000 to 10,000 complete waves of sound. In my first reply to Prof. Thomson's remarks (in the *Electrical World* of March 21st, 1891) I avoided pointing out directly that Prof. Thomson was mistaken, but now I see no way out of it. Prof. Thomson will pardon me if I call his attention to the fact he seems to disregard, namely, that 10,000 to 20,000 alternations of current in an arc—which was the subject under discussion—does not mean 5,000 to 10,000, but 10,000 to 20,000 *complete waves of sound.*

He says that I have adopted or suggested as the limit of audition 10,000 waves per second; but I have neither adopted nor suggested it. Prof. Thomson states that I have been working with 5,000 to 10,000 complete waves, while I have nowhere made any such statement. He says that this would be working below the limit of audition, and cites as an argument that at the Central High School in Philadelphia he has heard 20,000 waves per second; but he wholly overlooks a point on which I have dwelt at some length—namely, that the limit of audition of an arc is something entirely different from the limit of audition in general.

Prof. Thomson further states, in reply to some of my views expressed in regard to the constant current machines, that five or six years ago it occurred to him to try the construction of a dynamo for constant current, in which "the armature coils were of a highly efficient type, that is, of comparatively short wire length for the voltage and moving in a dense magnetic field." Exteriorly to the coils and to the field he had placed in the circuit of each coil an impedance coil which consisted of an iron core wound with a considerable length of wire and connected directly in circuit with the armature coil. He thus obtained, he thought, "the property of considerable self-induction along with efficient current generation." Prof. Thomson says he expected "that possibly the effects would be very much the same as those obtainable from the regularly constructed apparatus." But he was *disappointed*, he adds. With all the consideration due to Prof. Thomson, I would say that to expect a good result from such a combination was rather sanguine. Earth is not farther from heaven than this arrangement is from one in which there would be a length of wire sufficient to give the same self-induction wound on the armature and utilised to produce useful E.M.F. instead of doing just the opposite, let alone the loss in the iron cores. But it is, of course, only fair to remember that this experiment was performed five or six years ago, when even the foremost electricians lacked the necessary information in these and other matters.

Prof. Thomson seems to think that self-induction wipes out the periodical undulations of current. Now self-induction does not produce any such effect, but if anything, it renders the undulations more pronounced. This is self-evident. Let us insert a self-induction coil in a circuit traversed by an undulating current and see what happens. During the period of the greatest rate of change when the current has a small value, the self-induction opposes more than during the time of the small rate of change and when the current is at or near its maximum value. The consequence is that with the same frequency the maximum value of the current becomes the greater, the greater the self-induction. As the sound in a telephone depends only on the maximum value, it is clear that self-induction is the very thing required in a telephone circuit. The larger the self-induction the louder and clearer the speech, provided the same current is passed through the circuit. I have had ample opportunity to study this subject during my telephone experience of several years. As regards the fact that a self-induction coil in series with a telephone diminishes the loudness of the sound, Prof. Thomson seems to overlook that this effect is wholly due to the impedance of the coil, *i.e.*, to its virtue of diminishing the *current's strength*. But while the current's strength is diminished the undulation is rendered only more pronounced. Obviously, when comparisons are made they must be made with the same current.

In an arc machine, such as that of Professor Thomson's, the effect is different. There one has to deal with a make and break. There are then two induced currents, one in the opposite the other in the same direction with the main current. If the function of the mechanism be the same, whether self-induction coil be present or not, the undulations could not possibly be wiped out. But Prof. Thomson seems likewise to forget that the effect is wholly due to the defect of the commutator; namely, the induced current of break—which is of the same direction with the main current and of great intensity when large self-induction is present—simply bridges the adjacent commutator segments, or if not entirely so, at least shortens the interval during which the circuit is open, and thus reduces the undulation.

In regard to the improvement in the feeding of the lamps by vibration or undulations, Prof. Thomson expresses a decisive opinion. He now says that the vibrations *must* improve the feeding of a clockwork lamp. He says that I "contented myself by simply saying" that I cannot agree with him on that point.

Now, *saying it* is not the only thing I did. I have passed many a night watching a lamp feed, and I leave it to any skilled experimenter to investigate whether my statements are correct. My opinion is that a clockwork lamp—that is, a lamp in which the descent of the carbon is regulated not by a clutch or friction mechanism, but by an escapement—cannot feed any more perfectly than tooth by tooth, which may be a movement of, say, one-sixty-fourth of an inch or less. Such a lamp will feed in nearly the same manner, whether the current be perfectly smooth or undulating, provided the conditions of the circuit are otherwise stable. If there is any advantage I think it would be in the use of a smooth current, for with an undulating current the lamp is likely to miss some time and feed by more than one tooth. But a lamp in which the descent of the carbon is regulated by friction mechanism, an undulating current of the proper number of undulations per second will always give a better result. Of course to realise fully the benefits of the undulating current the release ought to be effected independently of the up and down movement, as I have pointed out before.

In regard to the physiological effects Prof. Thomson says that in such a comparatively poor conductive material as animal tissue the distribution of current cannot be governed by self-induction to any appreciable extent, but he does not consider the two-fold effect of the large cross-section pointed out by Sir William Thomson. As the resistance of the body to such currents is low, we must assume either condenser action or induction of currents in the body.

BY ELIHU THOMSON.

IT is not from any desire to have the last word that I have answered Mr. Tesla's statements as they appeared.* It has simply been to correct misunderstandings. In regard to the experiment which I mentioned as performed by immersing in water a lamp bulb in which a single strip of carbon had been mounted, and connecting the water and the filament to a source of high potential alternating current at high frequencies, and whereby the strip of carbon was brought to bright incandescence, I simply said that conduction through the glass could not have had any effect in this experiment. I made no general denial that a slight conduction occurred

* See the *Electrical World*, April 11th, 1891.

with even the best dielectrics. The glass in my experiment being immersed in water, the assumption of high temperature which Mr. Tesla makes, as increasing the conductivity of the glass, is not to be considered in this case. The glass was only heated where it was not so immersed, and where, therefore, no connection with the circuit existed.

Mr. Tesla bases a long statement about dielectrics, insulation resistance, perfect conductors, degrees of conductivity, &c., on the statement I made in relation to the experiment and the phenomenon it presented; and he even asks whether I have "then never measured insulation resistance" and "by a conduction current." Similar irrelevant questions follow this typical one. I had said that "if conduction through the glass were a possibility" (in the experiment and accounted for the phenomenon presented) "this action" (of charging a lamp bulb as a Leyden jar and receiving a charge therefrom) "could not occur." Mr. Tesla does me the injustice of applying a statement, which related to a particular experiment and phenomenon, to classes and conditions of phenomena which any one at all familiar with the circumstances would rule out. Mr. Tesla says: "My statement that conduction is concerned to some, *though perhaps negligible*, extent in the experiment above described was, however, made not only on account of the fact that all bodies conduct more or less, but principally on account of the *heating of the glass* during the experiment." The italics are mine. In the experiment the glass was immersed in cold water and only that portion not immersed and not in contact with the current conductor or the surrounding water was warmed. This disposes of the paragraph of contentions of Mr. Tesla based on heated glass in the experiment.

In regard to the estimate of the number of complete waves of sound corresponding to a given number of alternations, I freely confess that I was in error, and that the number given by Mr. Tesla is correct. The number of complete sound waves does, as Mr. Tesla points out, correspond to the number of alternations, as the expansion and the contraction of the arc stream corresponding to wave condensation and rarefaction occur with each alternation. This is a point which I had missed in the former consideration of the matter, but, of course, if the limit of audition is above any of the rates considered, it would not affect the argument except as it relates to the degree of approximation to that limit.

Without calling upon Mr. Tesla to state how far "earth is from heaven" in his view, I will simply state that my experiment of five or six years ago, which called forth his remark, certainly did teach me something then, and added somewhat to my information in certain directions.

I was perfectly well aware of the effects of self-induction, including impedance, pointed out by Mr. Tesla, when I spoke of the insertion of a coil of large self-induction into a circuit of arc lights as steadying the current and lessening its undulations. In regard to the effects of self-induction, I may state that the property of impedance I have always regarded as one of those effects. It is not true, as stated by Mr. Tesla, that self-induction "renders the undulations more pronounced." Whether it will do so or not depends on the shape of the wave of undulation. Not all shapes of wave have the greatest rate of change when the current has a small value. What is true in this respect of a sine curve would not be true of a saw-tooth wave. But the point under discussion, originally, was the effect of a large self-induction interposed in a circuit of arc lights, in which the current was of a fluctuating character. The current may be considered in this case as made up of a steady current of an average current value, upon which has been superimposed an alternating current of small value, or it may be considered as made up of a steady current of less than the average value with a pulsating current of small value superimposed. These assumptions to be exact, of course, are made on the basis that in the fluctuations the strength of the current does not change very greatly, or that the minimum current and the maximum current values are not far removed from the average value.

Now, the effect of self-induction introduced into such a circuit with arc lights is, by its impedance, to diminish the value of that portion of the current which is, so to speak, alternating or fluctuating, and whether the waves of alternating or pulsating currents, so greatly diminished in amplitude, will be sharpened or smoothed out by self-induction will depend upon their original form. It is the effect of self-induction in producing impedance, and, therefore, restricting the value of the fluctuating or alternating current strength, superimposed on the much larger constant or steady current, to which I referred in speaking of the smoothing action. Mr. Tesla was right in his general statements of principle, but wrong in his application of them to the case in point. He was not right, however, in separating the effect of impedance from self-induction in the case under discussion.

I have no desire to prolong this discussion, and will leave out of consideration any reference to effects on clutch or clockwork lamps, or to the physiological effects of currents. I have in the above comments confined myself strictly to those matters which it seemed necessary to have cleared up in some way. I hope that, in stating my position in relation to the matter, I have made myself clear so as to avoid further misunderstandings.

PHYSICAL SOCIETY.

At the meeting of the Physical Society, held at Cambridge in the Cavendish Laboratory, on Saturday, May 9th, the following communications were made :—

"Some Experiments on the Electric Discharge in Vacuum Tubes."

BY PROF. J. J. THOMSON, M.A., F.R.S

The phenomena of vacuum discharges were, he said, greatly simplified when their path was wholly gaseous, the complication of

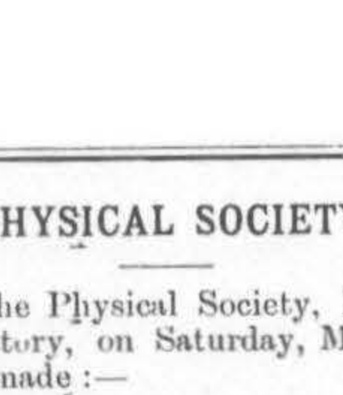

FIG. 1.—Coil of glass tube for vacuum discharge experiments. The primary coils are filled with mercury, the secondary coils form continuous closed circuits.

the dark space surrounding the negative electrode and the stratifications so commonly observed in ordinary vacuum tubes being absent. To produce discharges in tubes devoid of electrodes was, however, not easy to accomplish, for the only available means of producing an electromotive force in the discharge circuit was by electro-magnetic induction. Ordinary methods of producing variable induction were valueless, and recourse was had to the oscillatory discharge of a Leyden jar, which combines the two essentials of a current whose maximum value is enormous, and whose rapidity of alternation is immensely great. The discharge circuits, which may take the shape of bulbs, or of tubes bent in the form of coils, were placed in close proximity to glass tubes filled with mercury, which formed the path of the oscillatory discharge. The parts thus corresponded to the windings of an induction coil, the vacuum tubes being the secondary and the tubes filled with mercury the primary. In such an apparatus the Leyden jar need not be large, and neither primary nor secondary need have many turns, for this would increase the self-induction of the former and lengthen the discharge path in the latter. Increasing the self-induction of the primary reduces the E.M.F. induced in the secondary, whilst lengthening the secondary does not increase the E.M.F. per unit length. Two or three turns (Fig 1) in each were found to be quite sufficient, and, on discharging the Leyden jar between two highly-polished knobs in the primary circuit, a plain uniform band of light was seen to pass round the secondary. An exhausted bulb (Fig. 2) containing traces of oxygen was placed within a primary spiral of three turns, and, on passing the jar discharge, a circle of light was seen within the bulb in close proximity to the primary circuit, accompanied by a purplish glow, which lasted for a second or more. On heating the bulb the duration of the glow was greatly diminished, and it could be instantly extinguished by the presence of an electro-magnet. Another exhausted bulb (Fig. 3), surrounded by a primary spiral, was contained in a bell-jar, and when the pressure of air in the jar was about that of the atmosphere the secondary discharge occurred in the bulb, as is ordinarily the case. On exhausting the jar, however, the luminous discharge grew fainter, and a point was

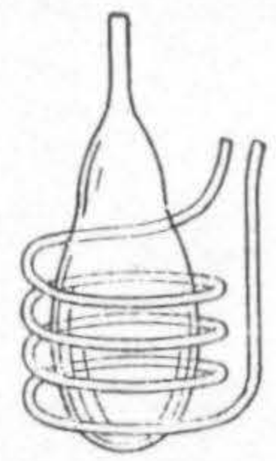

FIG. 2.—Exhausted bulb surrounded by primary spiral consisting of a coiled glass tube containing mercury.

reached at which no secondary discharge was visible. Further exhaustion of the jar caused the secondary discharge to appear outside the bulb. The fact of obtaining no luminous discharge either in the bulb or jar the author could only explain on two suppositions, viz., that under the conditions then existing the specific inductive capacity of the gas was very great, or that a discharge could pass

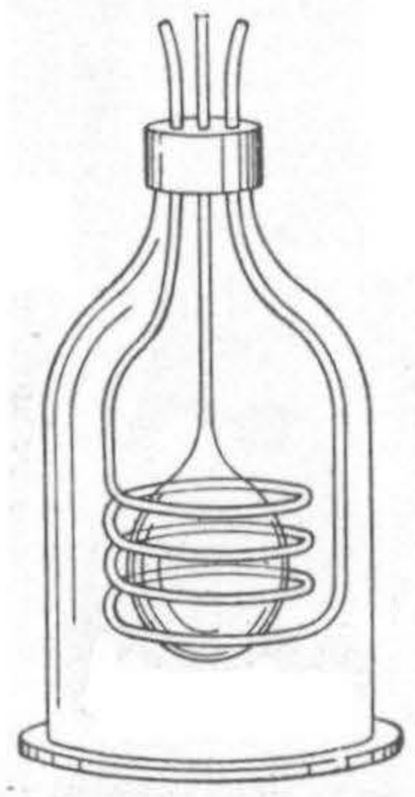

FIG. 3.—Exhausted bulb surrounded by primary coils, enclosed in bell jar.

without being luminous. The author had also observed that the conductivity of a vacuum tube without electrodes increased as the pressure diminished until a certain point was reached, and afterwards diminished again, thus showing that the high resistance of a nearly perfect vacuum is in no way due to the presence of the

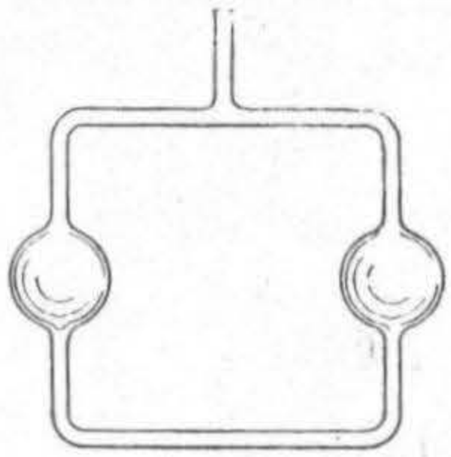

FIG. 4.—Exhausted secondary coil of one loop containing bulbs. The discharge passed along the inner side of the bulbs, the primary coils being placed within the secondary.

electrodes. One peculiarity of the discharges was their local nature, the rings of light being much more sharply defined than was to be expected. They were also found to be most easily produced when the chain of molecules in the discharge were all of the same kind. For example, a discharge could be easily sent through a tube many

feet long, but the introduction of a small pellet of mercury in the tube stopped the discharge, although the conductivity of the mercury was much greater than that of the vacuum. In some cases he had noticed that a very fine wire placed within a tube on the side remote from the primary circuit would prevent a luminous discharge in that tube.

"Some Experiments on the Velocities of the Ions."

BY W. C. D. WHETHAM, B.A.

In studying electrolysis, the question as to whether there is any transference of solvent when a porous wall is absent presented itself to the author. The ordinary methods of testing for transference, such as by increase of pressure, or by overflow, not being available, when there is no diaphragm, the author used different coloured solutions of the same salt, such as cobalt chloride in water and in alcohol, the former of which is red and the latter blue. By putting the solutions into a kind of U-shaped tube (Fig. 5), any change

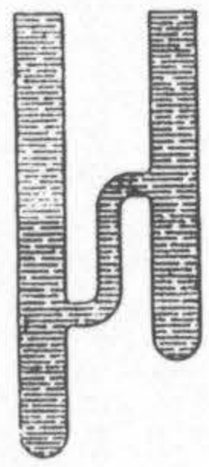

FIG. 5.—U Tube for measuring velocities of ions.

in the position of the line of junction of the two liquids could be measured. Two aqueous solutions in which the anion was the same were also tried, one combination being cupric chloride and common salt, and in this case the line of demarcation traversed about 7in. in three hours. The results hitherto obtained by this method agreed fairly with those found by Kohlrausch.

'On the Resistance of some Mercury Standards."

BY R. T. GLAZEBROOK, M.A., F.R.S.

In 1885 M. Benoit, of Paris, supplied the author with three mercury standards, nominally representing the Paris Congress ohm, now commonly known as the legal ohm. Tests of these standards were described in a Paper read before the Physical Society in 1885 by the present author. Recently he had occasion to compare two of the standards with the British Association coils. The mean of many concordant results gave the resistance of one of the mercury standards (No. 37) as 1·01106 B.A.U.; whilst that of the other (No. 39) was 1·01032 B.A.U. Expressing them in legal ohms the present resistances are (No. 37) ·99986 and (No. 39) ·99913, whilst in 1885 the values obtained were (No. 37) ·99990 and (No. 39) ·99917. This shows that within the limits of experimental error the ratios of the mercury standards to the B.A. coils have remained practically unchanged during six years. The numbers given above are based on Lord Rayleigh's determination of the specific resistance of mercury which differs appreciably from that found by Mascart and other observers. Taking the mean of the later concordant determinations the value of the mercury standards expressed in legal ohms become (No. 37) 1·00033 and (No. 39) ·99959. The values given by the maker were 1·00045 and ·99954 respectively, showing a very close agreement. The author also found that refilling No. 37 from the same sample of mercury produced no appreciable change in its resistance whilst No. 39 was somewhat affected by a similar operation. Experiments on the co-efficient of increase of resistance of mercury with temperature gave the value ·000872, as the mean co-efficient between 0° and 10° C., a number rather less than that obtained by Kohlrausch.

DISCUSSION.

In the discussion on Prof. Thomson's Paper, Prof. FITZGERALD said the beautiful experiments were likely to lead to very important results. He did not quite understand how placing a fine wire in a vacuum tube could prevent the luminous discharge; for, if the wire was on the side remote from the primary, and if there was any great increase in specific inductive capacity, he would have expected the air to screen the wire.

Prof. LODGE asked for further information as to the action of the magnet in preventing the afterglow, and in some cases precipitating a luminous discharge. The experiment with the exhausted bulb within the bell-jar was also difficult to understand, and he did not see why one of Prof. Thomson's two suppositions must necessarily be true.

The PRESIDENT (Prof. Ayrton) inquired whether Prof. Thomson had tried Mr. Crookes' experiment, in which the electric pressure necessary to produce a discharge was greatly lessened by putting a phosphorescent material in the tube.

Prof. THOMSON, in reply, said he had not tried the experiment, but the phosphorescence he had observed was of quite a different character to that produced in Mr. Crookes' tubes. To Prof. Fitzgerald he said the action of the wire was probably a question of time, and thought the whole field was in some way thrown on the wire, and thus discharged. In reply to Prof. Lodge, he had not ascertained the true nature of the effect of a magnet on the glow; but he believed the glow to be due to a combination which might be prevented or facilitated by the action of the magnet causing the density to be different in different parts of the bulb.

On the motion of Prof. AYRTON, seconded by Prof. RUCKER, a hearty vote of thanks was accorded to the authors for their valuable and interesting communications, and for the kind manner in which the Society had been received and entertained by the Cambridge members. Prof. Thomson and Mr. Glazebrook acknowledged the vote.

The New York Times May 24, 1891

A TALK BY NIKOLA TESLA.

HE DELIVERS AN INTERESTING LECTURE TO ELECTRICAL ENGINEERS.

The *Electrical Engineer* of this week will contain an interesting account of the session of the American Institute of Electrical Engineers held at Columbia College last Wednesday evening, at which some really wonderful experiments were shown by Nikola Tesla, the recognized leading expert on alternating currents. For these experiments Mr. Tesla used an alternating machine with 400 poles, which when run at full speed permitted him to obtain 20,000 alternations per second. The currents were first run through a condenser. The machine was set up in the electrical workshop of the college and was driven by an electric motor, the speed of which could be regulated from the platform.

Mr. Tesla, at the beginning of his lecture, said that modern science had been able to make rapid strides by the recognition of ether as the medium of transmission of vibrations of various forms. The answer to the question, "What is electricity?" could not yet be given, but the assumption was justifiable that electric phenomena were ether phenomena, and the phenomena of static electricity could be considered as the phenomena of ether under strain, and those of dynamic and electro-magnetism as phenomena of ether in motion.

Alluding to the electro-magnetic theory of light, Mr. Tesla said that he considered the electro-magnetic waves as unavailable for the production of luminous effects, for the reason that long before the necessary frequency could be reached, the conductor would become opaque to the passage of the waves. Electro-magnetic waves, unless they had the frequency of true light waves, he thought could not produce luminous effects. The electrostatic waves, or thrusts, however, no matter what their frequency, could excite luminous radiation. The static effects in the Hertz and Lodge experiments were excessively small, owing to the fact that they were produced in a practically closed coil, the potential being depressed. To obtain the desired difference of potential, there must be an open circuit generator of high potential and of high frequency to enhance the electrostatic effects.

In carrying out the idea of obtaining enormous differences of potential Mr. Tesla met the difficulty of obtaining the requisite insulation for the induction coil. His experience demonstrated that what are generally considered the best insulators, as glass and rubber, are inferior to others not so considered, as oil and wax. He started the spark coil in action, the primary of which was in connection with his alternator, speeded at about 10,000 alternations a second. As the discharges took place between the terminals of the coil an exhausted Geissler tube held near the discharge did not light, but on blowing out the arc the tube lighted up, this being due to the rise of the potential caused by the rupture of the arc. This effect Mr. Tesla considered purely electrostatic.

To still further verify his conclusions that electrostatic effects alone are active, Mr. Tesla placed a Geissler tube at right angles to the coil and at its centre. It did not light up, but when placed at th ends gave sufficient light to read by. He afterward adjusted conditions so that by touching one terminal with a brass sphere he raised the potential of the coil so enormously that a stream of light came out on the other terminal.

He estimated the difference of potential to be nearly 250,000 volts, and then received the total discharge in his body protecting his hands from burning by holding brass balls.

TESLA'S EXPERIMENTS WITH ALTERNATING CURRENTS OF HIGH FREQUENCY.

THE Wednesday evening session of the American Institute of Electrical Engineers was held in Prof. Dwight's room, Columbia College, and will long be remembered by those present, not only on account of the brilliant experiments shown, but also for the many possibilities which it suggested in the development of the artificial illumination of the future. For the purpose of his experiments, Mr. Tesla employed the alternating machine with 384 poles, described in THE ELECTRICAL ENGINEER of March 18, 1891, which, when run at full speed, permitted him to obtain 20,000 alternations per second. The currents of this machine in all of Mr. Tesla's experiments were first run through a condenser in order to avoid the possibility of injury to the machine. The machine itself was set up in the electrical workshop of the college and was driven by an electric motor, the speed of which could be varied by a switch on the lecture platform.

Mr. Tesla introduced his subject by the remark that modern science has been able to make rapid strides by the recognition of ether as the medium of transmission of vibrations of various forms which manifest themselves to our senses. We are therefore now able to see things in a different light than was formerly the case, and, being tolerably well able to explain them, the truth cannot be hidden much longer. The answer to the question, "What is Electricity?" we were not yet prepared to give. We were justified in assuming, however, that electric phenomena are ether phenomena, and we may consider the phenomena of static electricity as phenomena of ether under strain, and those of dynamic electricity and electro-magnetism as phenomena of ether in motion.

Mr. Tesla, while expressing the highest consideration for the work of Dr. Lodge, was not in entire accord with the views advanced by him, which he considered to be more of the nature of ingenious explanations than of a probable theory, Mr. Tesla contending that there can be no two electricities.

Alluding further to the electro-magnetic theory of light, and to the Hertz experiments and those of Dr. Lodge and their application to the production of an efficient source of light, Mr. Tesla considered the electro-magnetic waves as unavailable for the production of luminous effects, for the reason that long before we could reach the necessary frequency the conductor would become opaque to the passage of the waves. Mr. Tesla thought that electro-magnetic waves, unless they have the frequency of true light waves, cannot produce luminous effects, Not so, however, with the electrostatic waves or thrusts. These, no matter what their frequency, can excite luminous radiation. He reasoned that the static effects in the Hertz and Lodge experiments were excessively small, due to the fact that they were produced in a practically closed coil, the spark acting as a bridge, making the coil practically continuous and depressing the potential. To obtain the desired difference of potential we must work with an open circuit generator of high potential of high frequency to enhance the electrostatic effects, and it was the recognition of this fact which led Mr. Tesla to the results he showed.

In carrying out this idea of obtaining enormous differences of potential, Mr. Tesla at once encountered the difficulty of obtaining the requisite insulation for the induction coil employed by him. His experience demonstrated that what we consider the best insulators, such as glass and rubber are inferior to others, not formerly so considered, such as oil and wax. Mr. Tesla then started a spark coil in action, the primary of which was in connection with his alternator which was speeded to give from 10,000 to 11,000 alternations per second. The coil emitted a clear note, which rose as the number of alternations was increased. As the discharges took place between the terminals of the coil, an exhausted Geissler tube held in proximity to the discharge did not light, but upon blowing out the arc the tube lighted up, which was due to the rise of potential caused by the rupture of the arc. This effec Mr. Tesla considered as purely electrostatic.

Mr. Tesla then showed the influence of insulated bodies having considerable size upon the spark length, demonstrating the effect of capacity upon the nature of the discharge. Thus when we attach an insulated body to the terminal of the coil, the potential may be raised or lowered. He showed this by wrapping an insulated wire of about one foot in length about one terminal of the coil, and touching the other terminal with a brass sphere held in the hand; under these conditions streams of light emanated from all sides of the wire. When the sphere was removed, however, the streams disappeared almost entirely. He then cut off the wire in successive lengths, and the stream discharges became more marked and brilliant. He then attached a fine platinum wire to the terminal, which also showed the streams to a remarkable degree, and kept up a continuous vibration to and fro. He also showed a pinwheel effect, the wheel being rapidly rotated with streams issuing from the two points. Another experiment consisted in attaching two spheres of about four inches diameter to the terminals. The spark passes first between the two points nearest to each other on the spheres, then works up toward their tops, is extinguished and is re-established at the first point, this being continuously repeated. The neighboring exhausted tubes and lamps were illuminated and extinguished in unison with the action of the spark between the spheres. These Mr. Tesla pointed out were not electro-magnetic vibrations like the Hertz waves. He showed how by the use of the dielectric the spark is induced to jump between the separated spheres, due to the increase in the specific inductive capacity of the medium, and he also demonstrated that the streaming discharge passed easily through thick glass plates, rubber plates and a book. Mr. Tesla then showed these static effects in a non-striking vacuum. A tube of this nature when connected to the machine glowed brightly, and the terminals became incandescent. Mr. Tesla then remarked that if, instead of using a filament in a lamp—which necessarily limited us in the degree of incandescence which we could practically employ,—we could employ solid blocks of carbon, much higher efficiency could be obtained. Based upon this reasoning, he had constructed a lamp which he showed, containing two blocks of carbon in a non-striking vacuum. When connecting these two carbons to the two terminals of the coil or one to one terminal and the other to a body of some size, the blocks can be raised to high incandescence.

Mr. Tesla also showed a lamp with but a single rod filament in a non-striking vacuum with no outward connection. The energy is entirely transferred by condenser action through the medium of condenser coatings in the base of the lamp. He also pointed out how the brilliancy of the lamp could be varied by simply altering the relative positions of the condenser coatings. This Mr. Tesla followed by demonstration of the phenomena with an unexhausted globe, and a single filament mounted therein. The filament when connected to one terminal of the coil heats up to bright incandescence and spins around in the globe. He also demonstrated the heating by the use of Crookes' well-known apparatus consisting of mica vanes mounted above a platinum wire, which was brought to incandescence by connection with one terminal of the coil, and rotated the mica vanes.

In order to still further verify the conclusions that the electrostatic effects are alone active, Mr. Tesla placed a Geissler tube at right angles to the coil and at its centre. In this position the tube did not light up. When placed at the ends, however, the tube lit up brilliantly and gave sufficient light to read by. Mr. Tesla showed both uranium and yttria tubes.

He then showed how exhausted tubes could be made to glow in an electrostatic field. For this purpose two large sheets of zinc were connected to the terminals of the machine at a distance of about 15 feet apart. The tube when placed between these sheets glowed brilliantly and could be moved about freely. Mr. Tesla remarked that, by merely creating such a field in a room, the mere suspension of the tubes in the room would afford the desired illumination.

Coming to the physiological effects, Mr. Tesla adjusted the conditions so that by touching one terminal with a brass sphere he raised the potential of the coil so enormously that a stream of light came out on the other terminal, and he estimated the difference of potential to be nearly 250,000 volts, and then performed the remarkable experiment of receiving the total discharge through his body, protecting his hands from burning by the brass balls held in his hands.

He then lit up lamps by holding them in contact with one terminal or near to the coil.

The lecturer then came to another class of experiments. He stated that he had used a system of conversion from high tension to low with the enormous frequencies of the condenser discharges. Mr. Tesla then showed an interesting experiment which consisted in passing the converted currents, produced in the manner just described, through a copper bar $\frac{3}{8}$ inch in diameter and bent into a loop. Ordinarily such a bar would constitute a short circuit, but Mr. Tesla succeeded in bringing lamps stretched across the parallel sides of the bar to incandescence, demonstrating that the impedance in the loop connecting the two sides was so great as to practically prevent the current from passing through it and hence acting upon the lamps in the manner described. He also pointed out the existence of modes on the bar. His method consists in continuously charging and disruptively discharging a condenser into the working circuit, the charging of the condenser being effected by a coil operated either by alternating or direct currents. By this means any desired higher frequency may be obtained from any lower frequency.

Mr. Tesla concluded his experiments by exhibiting in action a simple alternate current arc lamp, operated by currents direct from the machine giving 20,000 alternations per second. The light was beautifully steady and the arc entirely free from the hum accompanying arcs operated with currents of low frequency.

We have given but the merest outline of the many beautiful and highly suggestive experiments made by Mr. Tesla. Notwithstanding the fact that Mr. Tesla excited the intensest interest of his audience for three hours, he was nevertheless unable, for lack of time, to bring before them many experiments, some of which, he said, were even of a more striking nature than those brought out.

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VOL. XI. NEW YORK, MAY 27, 1891. No. 160.

Many valuable inventions have been founded on the discovery of simple facts, but such inventions can never be perfected unless the principles of science upon which they are based are known.—Joseph Henry.

THE TESLA EXPERIMENTS.

WHILE the interest in all the papers of the annual meeting of the American Institute of Electrical Engineers was sustained throughout the sessions, there can be no question that most interest centred upon the lecture delivered by Mr. Tesla on the phenomena of alternating currents of high frequency. Mr. Tesla's recent utterances on this subject had served to excite the curiosity of many, and we believe that a thorough analysis of the work accomplished by Mr. Tesla, as exhibited in the experiments shown by him, will lead to the conclusion that those expectations have been more than realized. The brilliant researches and experiments inaugurated by Dr. Hertz, and followed up by Lodge and others, which served to verify the theory that the phenomena of light were referable to electro-magnetic vibrations of the ether, seemed to point out an apparently easy way of obtaining illumination directly through the medium of electro-magnetic vibrations. It has remained for Mr. Tesla, however, to recognize that for the production of light, electrostatic effects are needed. He reasoned that it was impossible to obtain primarily the desired electro-magnetic effects, since we must work with bodies of infinitesimal dimensions which can be acted upon only electrostatically, it being evident that an electro-magnetic wave cannot excite luminous radiation unless it be a true light wave. To produce longer electro-magnetic waves would, therefore, be of no avail; but this is not the case with electrostatic waves or thrusts. These, no matter what their length, Mr. Tesla demonstrates, can excite luminous radiation by disturbing molecular or atomic charges, causing the molecules or atoms to vibrate and to emit light; and since electrostatic effects are dependent upon the conjoint effects of potential and frequency, this reasoning led him to the investigations, the results of which were shown.

Continuing the train of reasoning followed by Mr. Tesla, we see that he has recognized further, that electrostatic effects of such character are available in many ways for the production of light. Thus he showed that if a filament in a globe be connected with only a single terminal of the source, in consequence of the rapidly alternating potential, the molecules of the gas are strongly attracted and repelled, and in this manner by their impact a filament may be kept at incandescence with only one wire. With these facts before him, and recognizing further that the employment of a filament is a bar to the attainment of higher efficiency on account of the limited degree of incandescence at which it can be run, Mr. Tesla reasoned that two blocks of a refractory material may be placed in a perfectly exhausted globe and sufficient energy transferred by condenser action to keep the blocks at incandescence, thus allowing a much higher efficiency in the production of light by reason of the possibility thus afforded of maintaining the carbons at a much higher degree of incandescence. Mr. Tesla has also shown that it is perfectly practicable to transfer sufficient energy to the medium, from a single block or filament placed in a perfectly exhausted globe and connected with one wire to the source, to keep the filament at the desired incandescence. Another and most important fact which he demonstrated was the practicability of using tubes of rarified gas without any terminals as practical sources of illumination by simply creating an electrostatic field near them, and also of using lamps without leading-in wires. All these results can evidently only be obtained by the use of enormous frequencies and potentials, or, in other words, powerful electrostatic effects, the study of which was made difficult in consequence of the fact that in previous experiments, looking to this end, the static effects were excessively small, owing to the fact that the coil was short-circuited through the low resistance discharge between the knobs of the discharger. The method of conversion devised by Mr. Tesla, allowing of the use of any frequency, enables us to undertake a much more exact and easy study of the effects of short waves. Again, his experiments with the lamps burning when connected with their terminals to a short, thick copper bar, are extremely interesting. The possibility of verifying nodes on the bar by simply using a Cardew voltmeter will be of great value in investigating these phenomena. His experiments also prove that while, with alternating currents of low frequency, such as are now generally employed, the effects of self-induction must be largely considered, those of high frequency accentuate largely the condenser effects which have to be allowed for accordingly.

It would lead us too far to enter into all of the numerous points suggested by Mr. Tesla's lecture, but he showed enough to warrant the assertion that in a comparatively short time the practical application of these principles to the production of artificial illumination will be an accomplished fact.

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NEW YORK, MAY 30, 1891.

It all came off as the REVIEW said it would. The general meeting of the Institute was a pronounced success; the average quality of the papers read was remarkably high, and the attendance throughout was very good. All who attended Mr. Tesla's brilliant lecture on Wednesday evening will remember that occasion as one of the scientific treats of their lives. Even studious men who follow carefully every advance made in the study of our science must have felt astounded at the strides which Mr. Tesla has made in the comparatively unexplored fields in which he is so able a pioneer. The reception at the Electric Club on Thursday evening was simply beyond all praise. The remarkable exhibit of curious old books and relics must have been a surprise to everyone who inspected it; few would have imagined that such an exhibition could have been got together in such a short space of time and with so few sources to draw upon.

ALTERNATING CURRENTS OF HIGH FREQUENCY.

THE BRILLIANT EXPERIMENTS OF NIKOLA TESLA, THE ABLE AND PROGRESSIVE YOUNG INVENTOR.

One of the prominent features of the general meeting of the American Institute of Electrical Engineers, was the lecture by Mr. Nikola Tesla, on "Alternating Currents of High Frequency." Wednesday evening of last week, Professor Dwights' room at Columbia College, was filled to overflowing with an expectant audience eager to learn some of the results of Mr. Tesla's patient labors in a field that he has made particularly his own.

Mr. Tesla began by pointing out that the highest aim of the human intellect is to discover the secrets of nature, and dwelt upon the fact that discoveries in the domain of pure science are invariably accompanied or rapidly followed by practical applications which redound to the benefit of mankind. Approaching the subject in hand he called attention to the fact that while the experiments and theories of such able investigators as Drs. Hertz and Lodge had greatly increased our knowledge of electric waves, their production, behavior and effects, yet these able physicists had devoted themselves more particularly to the study of electromagnetic waves, leaving on one side the static effects, which he, the lecturer, thought were of as great, if not even of greater importance.

With an alternating current of high potential and high frequency a very powerful electric field can be generated, capable of producing very startling effects, as Mr. Tesla proceeded to show. The machine for producing the current used in the experiments was an alternator, having 400 poles, and, although Mr. Tesla did not give the actual number of revolutions per minute, he stated that the periphery of the armature was traveling at about the speed of a bullet.

The frequency was stated to be about 18,000 to 20,000 complete alternations per second. By means of a large induction coil the tension of the current from this machine was raised to the extraordinary figure of 250,000 volts. Although the very sound of the words "a quarter of a million volts" raised a feeling of uneasiness in the minds of even the more experienced of Mr. Tesla's hearers, the lecturer demonstrated the harmlessness of the high frequency current by grasping the two poles of the induction coil, one in either hand, and taking the full current of the secondary without apparently feeling the slightest ill effect.

One of Mr. Tesla's strong points was the important part that condensers will play in the distribution of alternating currents of high frequency, and quite a number of his very beautiful experiments were designed to illustrate this effect. For instance, with the secondary circuit of the induction coil open, he showed that by grasping a metal sphere connected to one pole the discharge was greatly increased. This effect was due to the introduction of the extremely small capacity of the human body, which resulted in raising the potential of the secondary current, thereby producing the effect described. This action of a very small capacity was shown in a number of ways, and an extremely beautiful illustration was given by twisting a short length of cotton covered wire round one pole of the induction coil, bending the wire upward in the form of a twig. The lights being turned completely out, the discharge was seen to take place along the whole length of the piece of wire, and when the lecturer's capacity was connected to the other pole of the coil the discharge was increased to a brilliant shower of sparks from the piece of wire.

To describe all of Mr. Tesla's experiments, and all that he said could be done with alternating currents of high frequency, in the space we have at command, and writing as we do from memory only, would be manifestly impossible. He showed in many ways the effect of capacity on the current and thoroughly revelled in the electric field generated by his 400 pole alternator and powerful induction coil. Geissler tubes three feet long were converted into brilliant beams of light by being held near the coil or near a large sheet of tin-plate connected to one of its poles. The lecturer stated that had the time at his command permitted him to make the necessary arrangements, he could have produced an electric field capable of lighting up the whole room by means of similar tubes or lamps suspended at intervals from the ceiling.

With lamps, similar extraordinary experiments were shown. Here Mr. Tesla seemed to act the part of a veritable magician. It seemed to make little difference whether the lamps were lying on the table or whether they were connected by one terminal to one pole of the coil, or whether the lecturer took a lamp in each hand and held one to each pole of the coil, or whether he short-circuited them across a stout copper conductor (bent in the shape of a tall arch), which was being traversed by the current; in each and every case the filaments were brought to incandescence, to the supreme delight of the spectators.

Probably the interest of the various members of the audience varied according to their electrical knowledge or their thirst for it; to many of those present the experiments may have seemed somewhat in the line of a brilliant exhibition of fireworks. To others, who appreciated the true inwardness of what was being done and shown, and who followed the lecturer with rapt attention for three hours, it was evident that a distinct advance had been made in scientific research and that a vista of yet more wonderful results than those we have briefly alluded to above was opened up.

We understand, that even in the considerable time which Mr. Tesla devoted to our enlightenment, he was unable to show us all, or nearly all, that he was able to and had hoped to. In this case we trust that the Institute will prevail upon him to bring the subject again before its members, all of whom must assuredly be anxious to learn further what the results of his labors and investigations have been.

We take it for granted that Mr. Tesla has advanced his work on alternating currents of high frequency to within a measurable distance of elaborating practical applications for the production of light. Probably one of the most formidable difficulties will be found in the vexed problem of insulation. Mr. Tesla, for instance, showed that the discharge passed with the greatest ease through plates of hard rubber or glass and even through a thick book, considerable heat being developed in the operation, resulting sometimes in the welding together of the plates of hard rubber, if several were used.

It is questionable, however, whether the discharge in this case actually passes through the dielectric, piercing it. The more probable explanation of what takes place is that it is due to condenser effect, the discharge passing by reason of induction from plate to plate, or, from one side of the plate to the other, actual perforation of the plate only taking place when the dielectric is sufficiently heated by the rapid discharges to cause its conversion into a moderately good conductor.

TESLA'S EXPERIMENTS WITH ALTERNATING CURRENTS OF HIGH FREQUENCY.

We have received the following advance abstract from the New York *Electrical Engineer* of a remarkable lecture by Mr. Tesla, which has created extreme interest in America:

The Wednesday evening session of the American Institute of Electrical Engineers was held in Prof. Dwight's room, Columbia College, and will long be remembered by those present, not only on account of the brilliant experiments shown, but also for the many possibilities which it suggested in the development of the artificial illumination of the future. For the purpose of his experiments, Mr. Tesla employed the alternating machine with 400 poles, already alluded to, which, when run at full speed, permitted him to obtain 20,000 alternations per second. The currents of this machine in all of Mr. Tesla's experiments were first run through a condenser in order to avoid the possibility of injury to the machine. The machine itself was set up in the electrical workshop of the college and was driven by an electric motor, the speed of which could be varied by a switch on the lecture platform.

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Alluding further to the electromagnetic theory of light, and to the Hertz experiments and those of Dr. Lodge and their application to the production of an efficient source of

light, Mr. Tesla considered the electromagnetic waves as unavailable for the production of luminous effects, for the reason that long before we could reach the necessary frequency the conductor would become opaque to the passage of the waves. Mr. Tesla thought that electromagnetic waves, unless they have the frequency of true light waves, cannot produce luminous effects. Not so, however, with the electrostatic waves or thrusts. These, no matter what their frequency, can excite luminous radiation. He reasoned that the static effects in the Hertz and Lodge experiments were excessively small, due to the fact that they were produced in a practically closed coil, the spark acting as a bridge, making the coil practically continuous and depressing the potential. To obtain the desired difference of potential we must work with an open-circuit generator of high potential of high frequency to enhance the electrostatic effects, and it was the recognition of this fact which led Mr. Tesla to the results he showed.

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TESLA'S EXPERIMENTS.

We give in another column an account of a remarkable lecture given by Mr. Tesla, which seems to promise the inauguration of a new field of practical research and usefulness by the use of alternating currents of very high frequency. Mr.

Tesla's attitude is described as that of a veritable magician, holding his hearers wonderstruck for hours. With lamps it seemed to make little difference whether they were lying on the table, or were connected by one pole only, or were short-circuited across the terminals by a thick piece of copper wire traversed by the current. In each and all cases the filaments were brought to incandescence, to the wonder and delight of his audience. He seems even able to bring blocks of carbon in a vacuum to high incandescence by condenser action, with a far higher illuminating efficiency than is possible with filaments. It is too early as yet to judge deliberately of the effect these experiments and researches may have, but it seems to be thought that their practical usefulness is quite within immediate reach. The full text and illustrations of the paper will be awaited with great interest.

TESLA'S EXPERIMENTS WITH ALTERNATING CURRENTS OF HIGH FREQUENCY.

THE Wednesday evening session (May 20th) of the American Institute of Electrical Engineers was held in Prof. Dwight's room, Columbia College, and will long be remembered by those present, not only on account of the brilliant experiments shown, but also for the many possibilities which it suggested in the development of the artificial illumination of the future. For the purpose of his experiments Mr. Tesla employed the alternating machine with 400 poles, which, when run at full speed, permitted him to obtain 20,000 alternations per second. The currents of this machine in all of Mr. Tesla's experiments were first run through a condenser in order to avoid the possibility of injury to the machine. The machine itself was set up in the electrical workshop of the college and was driven by an electric motor, the speed of which could be varied by a switch on the lecture platform.

Mr. Tesla introduced his subject by the remark that modern science has been able to make rapid strides by the recognition of ether as the medium of transmission of vibrations of various forms which manifest themselves to our senses. We are therefore able now to see things in a different light than was formerly the case, and being tolerably well able to explain them, the truth cannot be hidden much longer. The answer to the question, "What is Electricity?" we were not yet prepared to give. We were justified in assuming, however, that electric phenomena are ether phenomena, and we may consider the phenomena of static electricity as phenomena of ether under strain, and those of dynamic electricity and electro-magnetism as phenomena of ether in motion.

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Alluding further to the electro-magnetic theory of light, and to the Hertz experiments and those of Dr. Lodge and their application to the production of an efficient source of light, Mr. Tesla considered the electro-magnetic waves as unavailable for the production of luminous effects, for the reason that long before we could reach the necessary frequency, the conductor would become opaque to the passage of the waves. Mr. Tesla thought that electro-magnetic waves, unless they have the frequency of true light waves, cannot produce luminous effects. Not so, however, with the electrostatic waves or thrusts. These, no matter what their frequency, can excite luminous radiation. He reasoned that the static effects in the Hertz and Lodge experiments were excessively small, due to the fact that they were produced in a practically closed coil, the spark acting as a bridge, making the coil practically continuous, and depressing the potential. To obtain the desired difference of potential, we must work with an open circuit generator of high potential of high frequency to enhance the electrostatic effects, and it was the recognition of this fact which led Mr. Tesla to the results he showed.

In carrying out this idea of obtaining enormous differences of potential, Mr. Tesla at once encountered the difficulty of obtaining the requisite insulation for the induction coil employed by him. His experience demonstrated that what we consider the best insulators, such as glass and rubber, are inferior to others, not formerly so considered, such as oil and wax. Mr. Tesla then started a spark coil in action, the primary of which was in connection with his alternator, which was speeded to give from 10,000 to 11,000 alternations per second. The coil emitted a clear note, which rose as the number of alternations was increased. As the discharges took place between the terminals of the coil, an exhausted Geissler tube, held in proximity to the discharge, did not light, but upon blowing out the arc, the tube lighted up, which was due to the rise of potential caused by the rupture of the arc. This effect Mr. Tesla considered as purely electrostatic.

Mr. Tesla then showed the influence of insulated bodies having considerable size upon the spark length, demonstrating the effect of capacity upon the nature of the discharge. Thus, when we attach an insulated body to the terminal of the coil, the potential may be raised or lowered. He showed this by wrapping an insulated wire of about 1 foot in length about one terminal of the coil, and touching the other terminal with a brass sphere held in the hand; under these conditions streams of light emanated from all sides of the wire. When the sphere was removed, however, the streams disappeared almost entirely. He then cut off the wire in successive lengths, and the stream discharges became more marked and brilliant. He then attached a fine platinum wire to the terminal, which also showed the streams to a remarkable degree, and kept up a continuous vibration to and fro. He also showed a pinwheel effect, the wheel being rapidly rotated, with streams issuing from the two points. Another experiment consisted in attaching two spheres of about 4 inches diameter to the terminals. The spark passes first between the two points nearest to each other on the spheres, then works up toward their tops, is extinguished and is re-established at the first point, this being continuously repeated. The neighbouring exhausted tubes and lamps were illuminated and extinguished in unison with the action of the spark between the spheres. These, Mr. Tesla pointed out, were not electro-magnetic vibrations like the Hertz waves. He showed how, by the use of the dielectric, the spark is induced to jump between the separated spheres due to the increase in the specific inductive capacity of the medium, and he also demonstrated that the streaming discharge passed easily through thick glass plates, rubber plates, and a book. Mr. Tesla then showed the static effects in a non-striking vacuum. A tube of this nature when connected to the machine glowed brightly, and the terminals became incandescent. Mr. Tesla then remarked that if, instead of using a filament in a lamp—which necessarily limited us in the degree of incandescence which we could practically employ—we could employ solid blocks of carbon, much higher efficiency could be obtained. Based upon this reasoning, he has constructed a lamp, which he showed, containing two blocks of carbon in non-striking vacuum. When connecting these two carbons to the two terminals of the coil, or one to one terminal and the other to a body of some size, the blocks can be raised to high incandescence.

Mr. Tesla also showed a lamp with but a single rod filament in a non-striking vacuum with no outward connection. The energy is entirely transferred by condenser action through the medium of condenser coatings in the base of the lamp. He also pointed out how the brilliancy of the lamp could be varied by simply altering the relative positions of the condenser coatings. This Mr. Tesla followed by demonstration of the phenomena with an unexhausted globe, and a single filament mounted therein. The filament when connected to one terminal of the coil heats up to bright incandescence and spins around in the globe. He also demonstrated the heating by the use of Crookes's well-known apparatus consisting of mica vanes mounted above a platinum wire, which was brought to incandescence by connection with one terminal of the coil, and rotated the mica vanes.

In order to still further verify the conclusions that the electrostatic effects are alone active, Mr. Tesla placed a Geissler tube at right angles to the core and at its centre. In this position the tube did not light up. When placed at the ends, however, the tube lit up brilliantly, and gave sufficient light to read by. Mr. Tesla showed both uranium and yttria tubes.

He then showed how exhausted tubes could be made to glow in an electrostatic field. For this purpose two large sheets of zinc were connected to the terminals of the machine at a distance of about 15 feet apart. The tube when placed between these sheets glowed brilliantly, and could be moved about freely. Mr. Tesla remarked that, by merely creating such a field in a room, the mere suspension of the tubes in the room would afford the desired illumination.

Coming to the physiological effects, Mr. Tesla adjusted the conditions so that by touching one terminal with a brass sphere he raised the potential of the coil so enormously that a stream of light came out on the other terminal, and he estimated the difference of potential to be nearly 230,000 volts, and then performed the remarkable experiment of receiving the total discharge in his body, protecting his hands from burning by the brass balls held in his hands.

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The lecturer then came to another class of experiments. He stated that he had used a system of conversion from high tension to low with the enormous frequencies of the condenser discharges. Mr. Tesla then showed an interesting experiment which consisted in passing the converted currents, produced in the manner just described, through a copper bar $\frac{3}{8}$ inch in diameter and bent into a loop. Ordinarily such a bar would constitute a short circuit, but Mr. Tesla succeeded in bringing lamps stretched across the parallel sides of the bar to incandescence, demonstrating that the impedance in the loop connecting the two sides was so great as to practically prevent the current from passing through it and hence acting upon the lamps in the manner described. He also pointed out the existence of nodes on the bar. His method consists in continuously charging and disruptively discharging a condenser into the working circuit, the charging of the condenser being effected by a coil operated either by alternating or direct currents. By this means any desired higher frequency may be obtained from any lower frequency.

We have given but the merest outline of the many beautiful and highly suggestive experiments made by Mr. Tesla. Notwithstanding the fact that Mr. Tesla excited the intensest interest of his audience for three hours, he was nevertheless unable, for lack of time, to bring before them many experiments, some of which, he said, were even of a more striking nature than those brought out.

Tesla's Experiments with Alternating Currents.—We are obliged to the editors of the New York *Electrical Engineer* for an advance proof of an abstract of Mr. Tesla's remarkable lecture, which has created considerable sensation in that city. The complete lecture will not be ready for some time, but the abstract will, we hope, keep our readers *au courant* with the subject.

EXPERIMENTS WITH ALTERNATING CURRENTS OF HIGH FREQUENCY.*

THE recent meeting of the American Institute of Electrical Engineers will long be remembered by those present, not only on account of the brilliant experiments shown in connection with a lecture given by Mr. Nikola Tesla, but also for the many possibilities which it suggested in the development of the artificial illumination of the future. For the purpose of his experiments, Mr. Tesla employed an alternating machine with 400 poles, which, when run at full speed, permitted him to obtain 20,000 alternations per second. The currents of this machine in all of Mr. Tesla's experiments were first run through a condenser in order to avoid the possibility of injury to the machine. The machine itself was set up in the electrical workshop of the college, and was driven by an electric motor, the speed of which could be varied by a switch on the lecture platform.

Mr. Tesla introduced his subject by the remark that modern science has been able to make rapid strides by the recognition of ether as the medium of transmission of vibrations of various forms which manifest themselves to our senses. We are therefore able now to see things in a different light than was formerly the case, and being tolerably well able to explain them, the truth cannot be hidden much longer. The answer to the question, "What is Electricity?" we were not yet prepared to give. We were justified in assuming, however, that electric phenomena are ether phenomena, and we may consider the phenomena of static electricity as phenomena of ether under strain, and those of dynamic electricity and electromagnetism as phenomena of ether in motion. The lecturer, while expressing the highest consideration for the work of Dr. Lodge, was not in entire accord with the views advanced by him, which he considered to be more of the nature of ingenious explanations than of a probable theory, the lecturer contending that there can be no two electricities. Alluding further to the electromagnetic theory of light, and to the Hertz experiments and those of Dr. Lodge, and their application to the production of an efficient source of light, the lecturer considered the electromagnetic waves as unavailable for the production of luminous effects, for the reason that long before we could reach the necessary frequency the conductor would become opaque to the passage of the waves. The lecturer thought that electromagnetic waves, unless they have the frequency of true light waves, cannot produce luminous effects. Not so, however, with the electrostatic waves or thrusts. These, no matter what their frequency, can excite luminous radiation. He reasoned that the static effects in the Hertz and Lodge experiments were excessively small, due to the fact that they were produced in a practically closed coil, the spark acting as a bridge, making the coil practically continuous and depressing the potential. To obtain the desired difference of potential we must work with an open circuit generator of high potential of high frequency to enhance the electrostatic effects, and it was the recognition of this fact which led the lecturer to the results he showed.

In carrying out this idea of obtaining enormous differences of potential, the lecturer at once encountered the difficulty of obtaining the requisite insulation for the induction coil employed by him. His experience demonstrated that what we consider the best insulators, such as glass and rubber, are inferior to others, not formerly so considered, such as oil and wax. The lecturer then started a spark coil in action, the primary of which was in connection with his alternator which was speeded to give from 10,000 to 11,000 alternations per second. The coil emitted a clear note, which rose as the number of alternations was increased. As the discharges took place between the terminals of the coil, an exhausted Geissler tube held in proximity to the discharge did not light, but upon blowing out the arc the tube lighted up, which was due to the rise of potential caused by the rupture of the arc. This effect the lecturer considered as purely electrostatic.

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(To be continued.)

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(*Concluded from page* 546.)

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Coming to the physiological effects, Mr. Tesla adjusted the conditions so that by touching one terminal with a brass sphere he raised the potential of the coil so enormously that a stream of light came out on the other terminal, and he estimated the difference of potential to be nearly 250,000 volts, and then performed the remarkable experiment of receiving the total discharge in his body, protecting his hands from burning by the brass balls held in his hands. He then lit up lamps by holding them in contact with one terminal or near to the coil.

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ALTERNATING CURRENT PHENOMENA.

ALTERNATING currents are the El Dorado of the electrician. It is with them that he is able to produce his most startling results, and to discover new phenomena that at first sight appear little short of miraculous. The most successful experimenters in this branch have been M. Hertz, on the Continent; Professor Oliver Lodge, in England; and Professor Thomson, in America. The latter created an immense sensation at the Paris Exhibition by his wonderful experiments in repulsion, which have since been repeated in this country by Dr. Fleming. More recently M. Nikola Tesla has taken up the subject, and in the *Electrical World* (New York) of February 21, he gave an account of what he had done, with some exposition of his views of the theories involved. This led to an animated correspondence between himself and Professor Elihu Thomson, with no very decided results. Since then M. Tesla has shown his experiments in public, at a meeting of the American Institute of Electrical Engineers, held in Professor Dwight's room, Columbia College. There was employed an alternate current machine of 400 poles, which, when run at full speed, gave 20,000 alternations per second. This machine was driven by an electric motor, the speed of which could be adjusted from the platform by a switch.

M. Tesla commenced his lecture by the question, "What is electricity?" and in answer stated that this much could be assumed—that electric phenomena are ether phenomena; that the phenomena of static electricity are the phenomena of ether under strain, and that those of dynamic electricity and electro-magnetism are the phenomena of ether in motion. Naturally he turned to the question that is occupying the attention of all scientific electricians, the direct production of light by the effect of electro-magnetic waves in the ether. In regard to this he differs from Hertz and Lodge, asserting that the electro-magnetic waves are unavailable for the production of luminous effects for the reason that long before the necessary frequency was reached the conductor would become opaque to the passage of the rays. It is to the electrostatic waves, or thrusts, that M. Tesla looks for the solution of the problem, for these, no matter what their frequency, can excite luminous radiation. The conditions of success require the use of an open circuit generator of high potential and of high frequency to enhance the electrostatic effects, and it was for the purpose of securing these that he constructed the machine used in his researches.

The current from the generator was sent through the primary of an induction coil, and was speeded 10,000 to 11,000 alternations per second. The coil emitted a clear note which rose as the number of alternations was increased. As the discharges took place between the terminals of the coil, an exhausted Geissler tube held in proximity to the discharge did not light, but on blowing out the arc the tube lighted up, which was due to the rise of potential caused by the rupture of the arc. This effect M. Tesla considered purely electrostatic. He then went on to show the changes produced in the discharge, by altering the capacity of the body from which it emanated. He wrapped an insulated wire a foot long around one terminal of the induction coil and touched the other terminal by a brass sphere held in the hand. Streams of light emanated from all sides of the wire until the sphere was removed, when they immediately ceased. As the length of the wire was gradually reduced by cutting off successive pieces, the stream discharges became more marked and brilliant. The substitution of a small platinum wire still further increased the effect. When small spheres, 4 in. in diameter, were attached to each terminal, the spark passed first across the shortest distance, and then gradually ascended to the highest point, when it went out and recommenced below. This was due to the heating of the air between the spheres.

The next experiments were designed to show static effects in a non-striking vacuum. A tube of this kind, when connected to the machine, glowed brightly and the terminals became incandescent. M. Tesla then remarked that if, instead of using a filament in a lamp—which necessarily limits us in the degree of incandescence which we can practically employ—we could employ solid blocks of carbon, much higher efficiency could be obtained. Based upon this reasoning, he has constructed a lamp which he showed, containing two blocks of carbon in non-striking vacuum. By connecting these two carbons to the two terminals of the coil or one to one terminal and the other to a body of some size, the blocks can be raised to high incandescence.

M. Tesla also showed a lamp with but a single rod filament in a non-striking vacuum with no outward connection. The energy is entirely transferred by condenser action through the medium of condenser coatings in the base of the lamp. He also pointed out how the brilliancy of the lamp could be varied by simply altering the relative positions of the condenser coatings. This M. Tesla followed by demonstration of the phenomena with an unexhausted globe, and a single filament mounted therein. The filament, when connected to one terminal of the coil, heats up to bright incandescence and spins around in the globe.

In further demonstration of his theory that the electrostatic effects that are active, M. Tesla hung two large sheets of zinc to the terminals of the machine at a distance of 15 ft. apart. A Geissler tube placed between the sheets glowed brilliantly, and could be moved about freely. Finally, M. Tesla explained a system of conversion from high tension to low, with the enormous frequencies of the condenser discharge. This consists in continuously charging and disruptively discharging a condenser into the working circuit, the charging of the condenser being effected by a coil operated either by alternating or direct currents. He stated that by this means any desired frequency could be obtained from any lower frequency.

The experiments, a part only of which we have noticed, occupied a long time, and were watched with the keenest attention. Whatever we may think of M. Tesla's theories, the very greatest interest attaches to all researches of this kind, as they appear to point in the direction of obtaining artificial light with less expenditure of energy than at present. The miserably low efficiency of all kinds of lighting apparatus at present in use, including electric lamps, is no credit to science, and every avenue that promises better results is being eagerly explored. Of course the end is not in view at present, and all that can be done is to grope in various directions in the hope that some clue may be found that will lead to success. If an electric lamp could be produced having an efficiency of 50 per cent., or more, artificial light would become absurdly cheap.

TESLA'S SYSTEM OF ELECTRIC LIGHTING WITH CURRENTS OF HIGH FREQUENCY.

In his lecture delivered before the American Institute of Electrical Engineers,[1] Mr. Nikola Tesla dwelt at length upon the fact that the direct application of electro-magnetic waves to the production of luminous effects was impracticable and that for this purpose electro-static waves or thrusts must be employed. To make these effects available in practice, however, it is necessary to employ currents of very high frequency and of very high potential.

In a patent just issued to Mr. Tesla on this method of electric illumination, he draws attention to the mechanical difficulty of obtaining the necessary high frequency of alternations, and hence he avails himself of the principle of the disruptive discharge. The current of high frequency is produced by the disruptive discharge of the accumulated energy of a condenser maintained by continuously charging the condenser and discharging it disruptively, in connection with an induction coil which generates the high potentials required.

The accompanying diagram, Fig. 1, illustrates the method employed by Mr. Tesla, the generator in this case

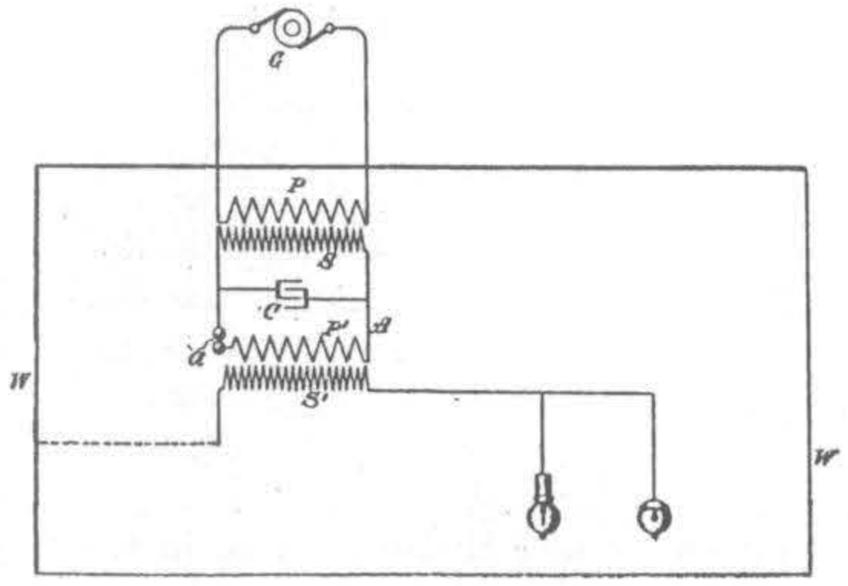


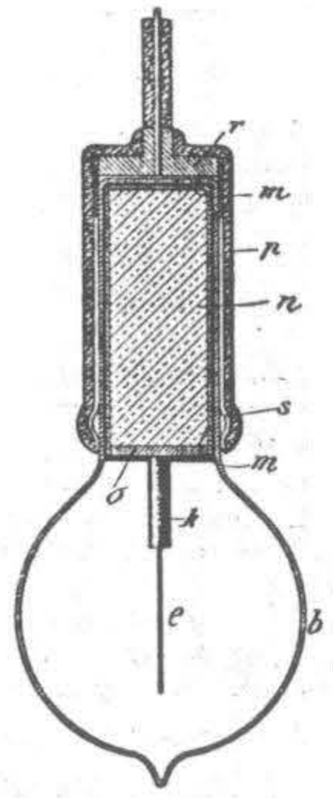
FIG. 1.—TESLA'S NEW SYSTEM OF ELECTRIC LIGHTING.

being one delivering alternate currents of comparatively low potential. The potential of the current is raised by means of an induction-coil having a primary P and a secondary S. Then by the current developed in this secondary a condenser C is charged and this condenser discharged into a circuit A, having an air-gap *a*. By the means above described, a current of enormous frequency is produced. It is next necessary to convert this into a working-circuit of very high potential, for which purpose there is connected up in the circuit A the primary P′ of an induction-coil having a long fine wire secondary S′. The current in the primary P′ develops in the secondary S′ a current or electrical effect of corresponding frequency, but of enormous difference of potential, and the secondary S′ thus becomes the source of the energy to be applied to the purpose of producing light.

1. THE ELECTRICAL ENGINEER, May 27, 1891.

The light-giving devices may be connected to either terminal of the secondary S′. If desired, one terminal may be connected to a conducting-wall W of the room to be lighted and the other arranged for connection of the lamps therewith. In such case the walls should be coated with some metallic or conducting substance in order that they may have sufficient conductivity.

Mr. Tesla has devised several forms of lamps to be used



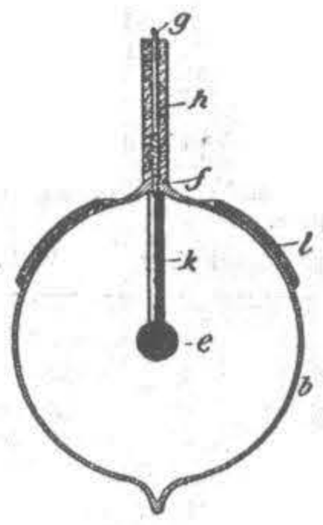


FIG. 2.—TESLA'S LAMP WITH STRAIGHT FILAMENT, ONE INSIDE AND ONE OUTSIDE CONDENSER COATING, AND ONE CONDUCTOR.

FIG. 3.—TESLA'S LAMP WITH INCANDESCENT BALL AND ONE CONDUCTOR.

in connection with his system, two forms of which are shown in the engravings Figs. 2 and 3. In the former the globe *b* is formed with a cylindrical neck, within which is a tube or sheet *m* of conducting material on the side and over the end of a cylinder or plug *n* of insulating material. The lower edges of this tube are in electrical contact with a metallic plate *o*, secured to the cylinder *n*, all the exposed surfaces of the plate and of the other conductors being carefully coated and protected by insulation. The light-giving body *e*, a straight stem of carbon, is electrically connected with the plate by a conductor *f*, which is coated with a refractory insulating material *k*. The neck of the globe fits into a socket composed of an insulating tube or cylinder *p*, with a more or less complete metallic lining *s*, electrically connected by a metallic plate *r* with a conductor *g*, that is attached to one pole of the source of current. The metallic lining *s* and the sheet *m* thus compose the plates of a condenser.

Fig. 3 shows a lamp containing an incandescent body *e* which is connected to one pole of the source of current. Outside of the globe the conducting-wires are protected by a coating of insulation *h*, and inside the globe the supporting-wire is inclosed in and insulated by a coating *k* of a refractory insulating substance, such as pipe-clay. A reflecting-plate *l* is shown applied to the outside of the globe *b*. This form of lamp is a type of those designed for direct electrical connection with one terminal of the source of current; but, as in the case of the lamp, Fig. 2, there need not be a direct connection, for the carbon or other illuminating body may be rendered luminous by inductive action of the current thereon.

ELECTRICITY THE THING.—Discussing the work of the electric car, the Minneapolis *Tribune* says: "Here it is heartily welcomed as a convenience, a civilizer, and a boomer of real estate values."

Mr. Tesla's New System of Illumination.

PENDING the publication of the full report of Mr. Tesla's lecture before the American Institute of Electrical Engineers, we give this week the essential principles embodied in a new system of illumination as embodied in a patent which has just been issued to him. It will be noted that what Mr. Tesla had set before him was to obtain in the first place, alternations of very high frequency by charging and disruptively discharging a condenser, and then raising the potential enormously by means of an induction coil. In other words, Mr. Tesla accomplishes the desired results by exalting the effects which have heretofore been produced in but a feeble manner. It will be noted that though employing alternations in the primary generating apparatus far exceeding those at present in vogue, Mr. Tesla does not depend upon even this high frequency to effect the desired purpose, but introduces the disruptive discharge of the Leyden jar with its well-known enormous frequency as the means for obtaining the required rapidity of alternation. With the method now clearly pointed out, we believe that it will take but a comparatively short time to work out and present to the public the practical details necessary for the general application of such a system.

ELECTRIC DISCHARGE IN VACUUM TUBES.

BY

Nikola Tesla

In The Electrical Engineer of June 10, I have noted the description of some experiments of Prof. J. J. Thomson, on the "Electric Discharge in Vacuum Tubes," and in your issue of June 24 Prof. Elihu Thomson describes an experiment of the same kind. The fundamental idea in these experiments is to set up an electromotive force in a vacuum tube—preferably devoid of any electrodes—by means of electro-magnetic induction, and to excite the tube in this manner.

As I view the subject, I should think that to any experimenter who has carefully studied the problem confronting us and who has attempted to find a solution of it, this idea must present itself as naturally, as, for instance, the idea of replacing the tinfoil coatings of a Leyden jar by rarefied gas and exciting luminosity in the condenser thus obtained by repeatedly charging and discharging it. The idea being

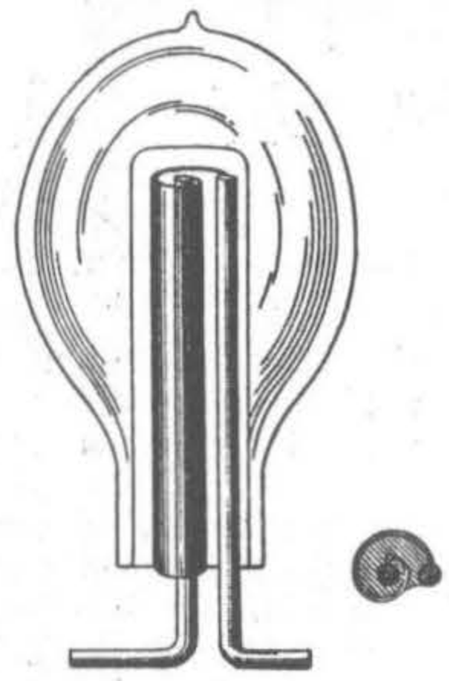


Fig. 1.

obvious, whatever merit there is in this line of investigation must depend upon the completeness of the study of the subject and the correctness of the observations. The following lines are not penned with any desire on my part to put myself on record as one who has performed similar experiments, but with a desire to assist other experimenters by pointing out certain peculiarities of the phenomena observed, which, to all appearances, have not been noted by Prof. J. J. Thomson, who, however, seems to have gone about systematically in his investigations and who has been the first to make his results known. These peculiarities noted by me would seem to be at variance with the views of Prof. J. J. Thomson, and present the phenomena in a different light.

My investigations in his line occupied me principally during the winter and spring of the past year. During this time many different experiments were performed, and in my exchanges of ideas on this subject with Mr. Alfred S. Brown, of the Western Union Telegraph Company, various different dispositions were suggested which were carried out by me in practice. Fig. 1 may serve as an example of one of the many forms of apparatus used. This consisted of a large glass tube sealed at one end and projecting into an ordinary incandescent lamp bulb. The primary, usually consisting of a few turns of thick, well-insulated copper sheet was inserted within the tube, the inside space of the bulb furnishing the secondary. This form of apparatus was arrived at after some experimenting and was used principally with the view of enabling me to place a polished reflecting surface in the inside of the tube, and for this purpose the last turn of the primary was covered with a thin silver sheet. In all forms of apparatus used there was no special difficulty in exciting a luminous circle or cylinder in proximity to the primary.

As to the number of turns, I cannot quite understand why Prof. J. J. Thomson should think that a few turns were "quite sufficient," but lest I should impute to him an opinion he may not have, I will add that I have gained

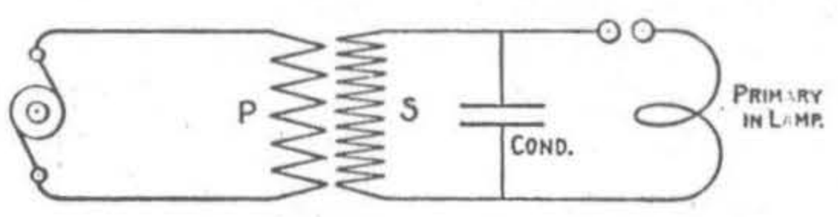


Fig. 2.

this impression from the reading of the published abstracts of his lecture. Clearly, the number of turns which gives the best result in any case, is dependent on the dimensions of the apparatus, and, were it not for various considerations, one turn would always give the best result.

I have found that it is preferable to use in these experiments an alternate current machine giving a moderate number of alternations per second to excite the induction coil for charging the Leyden jar which discharges through the primary—shown diagrammatically in Fig. 2,—as in such case, before the disruptive discharge takes place the tube or bulb is slightly excited and the formation of the luminous circle is decidedly facilitated. But I have also used a Wimshurst machine in some experiments.

Prof. J. J. Thomson's view of the phenomena under consideration seems to be that they are wholly due to electromagnetic action. I was, at one time, of the same opinion, but upon carefully investigating the subject I was led to the conviction that they are more of an electrostatic nature. It must be remembered that in these experiments we have to deal with primary currents of an enormous frequency or rate of change and of a high potential, and that the secondary conductor consists of a rarefied gas, and that under such conditions electrostatic effects must play an important part.

In support of my view I will describe a few experiments made by me. To excite luminosity in the tube it is not

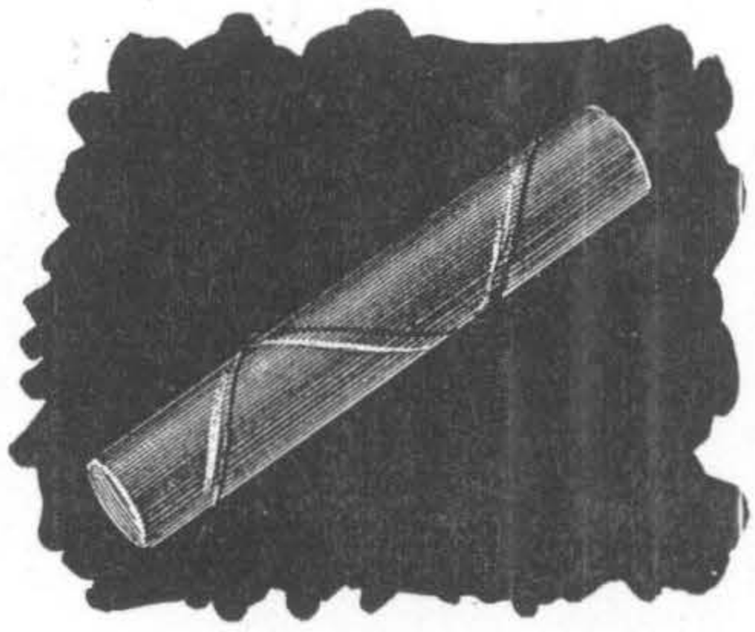


Fig. 3.

absolutely necessary that the conductor should be closed. For instance, if an ordinary exhausted tube (preferably of large diameter) be surrounded by a spiral of thick copper wire serving as the primary, a feebly luminous spiral may be induced in the tube, roughly shown in Fig. 3. In one of these experiments a curious phenomenon was observed; namely, two intensely luminous circles, each of them close to a turn of the primary spiral, were formed inside of the tube, and I attributed this phenomenon to the existence of nodes on the primary. The circles were connected by a faint luminous spiral parallel to the primary and in close proximity to it. To produce this effect I have found it necessary to strain the jar to the utmost. The turns of the spiral tend to close and form circles, but this, of course,

would be expected, and does not necessarily indicate an electro-magnetic effect; whereas the fact that a glow can be produced along the primary in the form of an open spiral argues for an electrostatic effect.

In using Dr. Lodge's recoil circuit, the electrostatic action is likewise apparent. The arrangement is illustrated

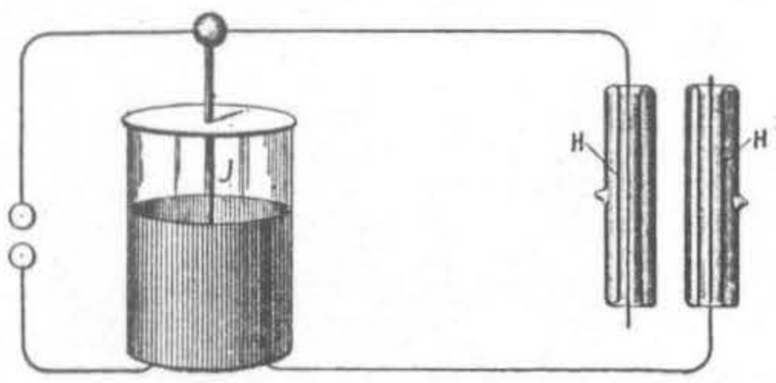


FIG. 4.

in Fig. 4. In his experiment two hollow exhausted tubes H H were slipped over the wires of the recoil circuit and upon discharging the jar in the usual manner luminosity was excited in the tubes.

Another experiment performed is illustrated in Fig. 5. In this case an ordinary lamp-bulb was surrounded by one or two turns of thick copper wire P and a luminous circle L excited in the bulb by discharging the jar through the primary. The lamp-bulb was provided with a tinfoil coating on the side opposite to the primary and each time the tinfoil coating was connected to the ground or to a large object the luminosity of the circle was considerably increased. This was evidently due to electrostatic action.

In other experiments I have noted that when the primary touches the glass the luminous circle is easier produced and is more sharply defined; but I have not noted that, generally speaking, the circles induced were very sharply defined, as Prof. J. J. Thomson has observed; on the contrary, in my experiments they were broad and often the whole of the bulb or tube was illuminated; and in one case I have observed an intensely purplish glow, to which Prof. J. J. Thomson refers. But the circles were always in close proximity to the primary and were considerably easier pro-

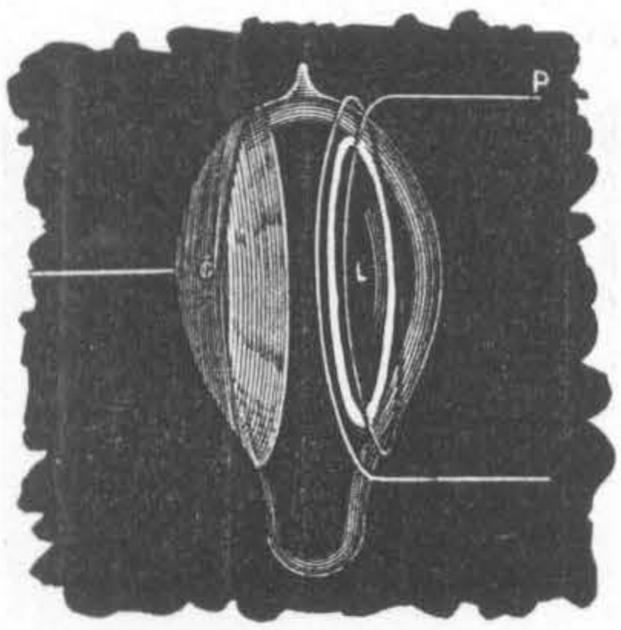


FIG. 5.

duced when the latter was very close to the glass, much more so than would be expected assuming the action to be electromagnetic and considering the distance; and these facts speak for an electrostatic effect.

Furthermore I have observed that there is a molecular bombardment in the plane of the luminous circle at right angles to the glass—supposing the circle to be in the plane of the primary—this bombardment being evident from the rapid heating of the glass near the primary. Were the bombardment not at right angles to the glass the heating could not be so rapid. If there is a circumferential movement of the molecules constituting the luminous circle, I have thought that it might be rendered manifest by placing within the tube or bulb, radially to the circle, a thin plate of mica coated with some phosphorescent material, and another such plate tangentially to the circle. If the molecules would move circumferentially, the former plate would be rendered more intensely phosphorescent. For want of time I have, however, not been able to perform the experiment.

Another observation made by me was that when the specific inductive capacity of the medium between the primary and secondary is increased, the inductive effect is augmented. This is roughly illustrated in Fig. 6. In this case luminosity was excited in an exhausted tube or bulb B and a glass tube T slipped between the primary and the bulb, when the effect pointed out was noted. Were the action wholly electromagnetic no change could possibly have been observed.

I have likewise noted that when a bulb is surrounded by a wire closed upon itself and in the plane of the primary, the formation of the luminous circle within the bulb is not prevented. But if instead of the wire a broad strip of tinfoil is glued upon the bulb, the formation of the luminous band was prevented because then the action was distributed over a greater surface. The effect of the closed tinfoil was no doubt of an electrostatic nature, for it pre-

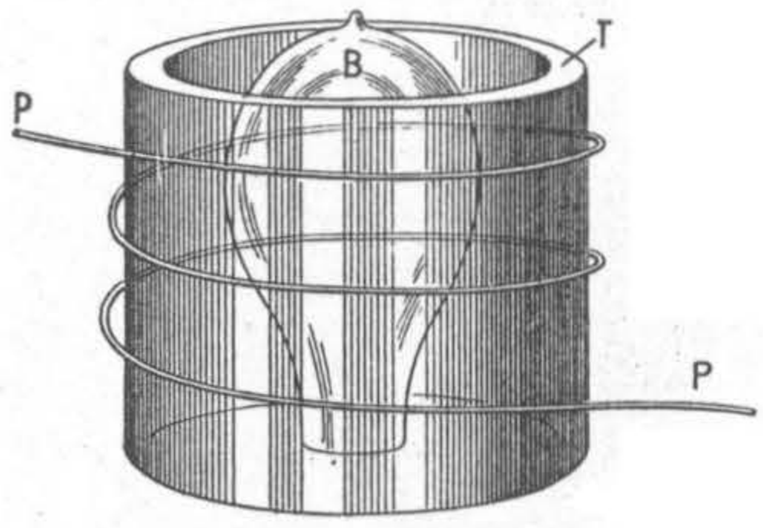


FIG. 6.

sented a much greater resistance than the closed wire and produced therefore a much smaller electromagnetic effect.

Some of the experiments of Prof. J. J. Thomson also would seem to show some electrostatic action. For instance, in the experiment with the bulb enclosed in a bell jar, I should think that when the latter is exhausted so far that the gas enclosed reaches the maximum conductivity, the formation of the circle in the bulb and jar is prevented because of the space surrounding the primary being highly conducting; when the jar is further exhausted the conductivity of the space around the primary diminshes and the circles appear necessarily first in the bell jar as the rarefied gas is nearer to the primary. But were the inductive effect very powerful they would probably appear in the bulb also. If, however, the bell jar were exhausted to the highest degree they would very likely show themselves in the bulb only, that is, supposing the vacuous space to be non-conducting. On the assumption that in these phenomena electrostatic actions are concerned we find it easily explicable why the introduction of mercury or the heating of the bulb prevents the formation of the luminous band or shorten the after-glow; and also why in some cases a platinum wire may prevent the excitation of the tube. Nevertheless some of the experiments of Prof. J. J. Thomson would seem to indicate an electro-magnetic effect. I may add that in one of my experiments in which a vacuum was produced in the Toricellian method, I was unable to produce the luminous band, but this may have been due to the weak exciting current employed.

My principal argument is the following: I have experimentally proved that if the same discharge which is barely sufficient to excite a luminous band in the bulb when passed through the primary circuit be so directed as to exalt the electrostatic inductive effect—namely, by converting upwards—an exhausted tube, devoid of electrodes, may be excited at a distance of several feet.

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VOL. XII. NEW YORK, JULY 8, 1891. No. 166.

It is not enough for a physical investigation that we have the simple idea, which may be embodied in a mathematical equation; we must see clearly in the mind's eye the operations in nature, and how the phenomena are produced in accordance with the well-known laws of force and motion.—Joseph Henry.

MR. TESLA'S LECTURE.

NOW that we have the full text of Mr. Tesla's paper before us, we are better able to judge of the character and scope of his work. The ground covered by Mr. Tesla is so vast that even in his somewhat extended paper he has, as he states, only been able to pay passing notice to many facts, each one of which might have been made the subject of a separate paper; and it is to be hoped that he may shortly find time to enter more into the detail of the various points brought out.

Although Mr. Tesla's work has relation to many matters of the highest importance and discloses some startling possibilities, yet its immediate bearing on the question of producing light economically is perhaps that which will appeal most strongly to the electrical engineer.

Taking up the course of reasoning followed by Mr. Tesla, it will be noted that he started out with the recognition of the fact, which he has now experimentally demonstrated, that for the production of light waves, primarily, electrostatic effects must be brought into play, and continued study has led him to the opinion that all electrical and magnetic effects may be referred to electrostatic molecular forces. This opinion finds a singular confirmation in one of the most striking experiments which he describes, namely, the production of a veritable flame by the agitation of electrostatically charged molecules. It is of the highest interest to observe that this result points out a way of obtaining a flame which consumes no material and in which no chemical action whatever takes place. It also throws a light on the nature of the ordinary flame, which Mr. Tesla believes to be due to electrostatic molecular actions, which, if true, would lead us directly to the idea that even chemical affinities might be electrostatic in their nature and that, as has already been suggested, molecular forces in general may be referable to one and the same cause. This singular phenomenon accounts in a plausible manner for the unexplained fact that buildings are frequently set on fire during thunder-storms without having been at all struck by lightning. It may also explain the total disappearance of ships at sea.

One of the striking proofs of the correctness of the ideas advanced by Mr. Tesla is the fact that, notwithstanding the employment of the most powerful electromagnetic inductive effects, but feeble luminosity is obtainable, and this only in close proximity to the source of disturbance; whereas, when the electrostatic effects are intensified, the same initial energy suffices to excite luminosity at considerable distances from the source. That there are only electrostatic effects active seems to be clearly proved by Mr. Tesla's experiments with an induction coil operated with alternating currents of very high frequency. He shows how tubes may be made to glow brilliantly at considerable distances from any object when placed in a powerful, rapidly alternating, electrostatic field, and he describes many interesting phenomena observed in such a field. His experiments open up the possibility of lighting an apartment by simply creating in it such an electrostatic field, and this, in a certain way, would appear to be the ideal method of lighting a room, as it would allow the illuminating device to be freely moved about. The power with which these exhausted tubes, devoid of any electrodes, light up is certainly remarkable.

That the principle propounded by Mr. Tesla is a broad one is evident from the many ways in which it may be practically applied. We need only refer to the variety of the devices shown or described, all of which are novel in character and will, without doubt, lead to further important results at the hands of Mr. Tesla and other investigators. The experiment, for instance, of lighting up a single filament or block of refractory material with a single wire, is in itself sufficient to give Mr. Tesla's work the stamp of originality, and the numerous other experiments and effects which may be varied at will are equally new and interesting. Thus, the incandescent filament spinning in an unexhausted globe, the well-known Crookes experiment on open circuit, and the many others suggested will not fail to interest the reader. Mr. Tesla has made an exhaustive study of the various forms of the discharge presented by an induction coil when operated with these rapidly alternating currents, starting from the thread-like discharge and passing through various stages to the true electric flame.

A point of great importance in the introduction of high tension alternating current which M. Tesla brings out is the necessity of carefully avoiding all gaseous matter in the high tension apparatus. He shows that, at least with very rapidly alternating currents of high potential, the discharge may work through almost any practicable

thickness of the best insulators, if air is present. In such cases the air included within the apparatus is violently agitated and by molecular bombardment the parts may be so greatly heated as to cause a rupture of the insulation. The practical outcome of this is, that, whereas with steady currents, any kind of insulation may be used, with rapidly alternating currents oils will probably be the best to employ, a fact which has been observed, but not until now satisfactorily explained. The recognition of the above fact is of special importance in the construction of the costly commercial induction coils which are often rendered useless in an unaccountable manner. The truth of these views of Mr. Tesla is made evident by the interesting experiments illustrative of the behavior of the air between charged surfaces, the luminous streams formed by the charged molecules appearing even when great thicknesses of the best insulators are interposed between the charged surfaces. These luminous streams afford in themselves a very interesting study for the experimenter. With these rapidly alternating currents they become far more powerful and produce beautiful light effects when they issue from a wire, pinwheel or other object attached to a terminal of the coil; and it is interesting to note that they issue from a ball almost as freely as from a point, when the frequency is very high.

From these experiments we also obtain a better idea of the importance of taking into account the capacity and self-induction in the apparatus employed and the possibilities offered by the use of condensers in conjunction with alternate currents, the employment of currents of high frequency, among other things, making it possible to reduce the condenser to practicable dimensions. Another point of interest and practical bearing is the fact, proved by Mr. Tesla, that for alternate currents, especially those of high frequency, insulators are required possessing a small specific inductive capacity, which at the same time have a high insulating power.

Mr. Tesla also makes interesting and valuable suggestion in regard to the economical utilization of iron in machines and transformers. He shows how, by maintaining by continous magnetization a flow of lines through the iron, the latter may be kept near its maximum permeability and a higher output and economy may be secured in such apparatus. This principle may prove of considerable commercial importance in the development of alternating systems. Mr. Tesla's suggestion that the same result can be secured by heating the iron by the hysteresis and eddy currents, and increasing the permeability in this manner, while it may appear less practical, nevertheless opens another direction for investigation and improvement.

The demonstration of the fact that with alternating currents of high frequency sufficient energy may be transmitted under practicable conditions through the glass of an incandescent lamp by electrostatic or electromagnetic induction may lead to a departure in the construction of such devicces. Another important experimental result achieved is the operation of lamps, and even motors, with the discharges of condensers, this method affording a means of converting direct or alternating currents. In this connection Mr. Tesla advocates the perfecting of apparatus capable of generating electricity of high tension from heat energy, believing this to be a better way of obtaining electrical energy for practical purposes, particularly for the production of light.

While we were prepared to encounter curious phenomena of impedance in the use of a condenser discharged disruptively, the experiments shown were extremely interesting on account of their paradoxical character.

The burning of an incandescent lamp at any candle power when connected across a heavy metal bar, the existence of nodes on the bar and the possibility of exploring the bar by means of an ordinary Cardew voltmeter, are all curious developments, but perhaps the most interesting observation is the phenomenon of impedance observed in the lamp with a straight filament, which remains dark while the bulb glows.

Mr. Tesla's manner of operating an induction coil by means of the disruptive discharge, and thus obtaining enormous differences of potential from comparatively small and inexpensive coils, will be appreciated by experimenters and will find valuable application in laboratories. Indeed, his many suggestions and hints in regard to the construction and use of apparatus in these investigations will be highly valued and will aid materially in future research.

Looked at from the standpoint of scientific research we believe that Mr. Tesla's paper will be conceded to be one of the most remarkable productions of recent years, and worthy of a very high rank among the classical publications on electricity. In addition to its great scientific value, however, it opens up possibilities not only in the production of light, but of power, the contemplation of which, as Mr. Tesla eloquently puts it, "expands our minds, strengthens our hopes and fills our hearts with supreme delight."

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION.[1]

BY NIKOLA TESLA.



THERE is no subject more captivating, more worthy of study, than nature. To understand this great mechanism, to discover the forces which are active, and the laws which govern them, is the highest aim of the intellect of man.

Nature has stored up in the universe infinite energy. The eternal recipient and transmitter of this infinite energy is the ether. The recognition of the existence of ether, and of the functions it performs, is one of the most important results of modern scientific research. The mere abandoning of the idea of action at a distance, the assumption of a medium pervading all space and connecting all gross matter, has freed the minds of thinkers of an ever-present doubt, and, by opening a new horizon—new and unforeseen possibilities—has given fresh interest to phenomena with which we are familiar of old. It has been a great step towards the understanding of the forces of nature and their multifold manifestations to our senses. It has been for the enlightened student of physics what the understanding of the mechanism of the firearm or of the steam engine was for the barbarian. Phenomena upon which we used to look as wonders baffling explanation, we now see in a different light. The spark of an induction coil, the glow of an incandescent lamp, the manifestations of the mechanical forces of currents and magnets are no longer beyond our grasp; instead of the incomprehensible, as before, their observation suggests now in our minds a simple mechanism, and although as to its precise nature all is still conjecture, yet we know that the truth cannot be much longer hidden, and instinctively we feel that the understanding is dawning upon us. We still admire these beautiful phenomena, these strange forces, but we are helpless no longer; we can in a certain measure explain them, account for them, and we are hopeful of finally succeeding in unraveling the mystery which surrounds them.

In how far we can understand the world around us is the ultimate thought of every student of nature. The coarseness of our senses prevents us from recognizing the ulterior construction of matter, and astronomy, this grandest and most positive of natural sciences, can only teach us something that happens, as it were, in our immediate neighborhood: of the remoter portions of the boundless universe, with its numberless stars and suns, we know nothing. But far beyond the limit of perception of our senses the spirit still can guide us, and so we may hope, that even these unknown worlds—infinitely small and great—may in a measure become known to us. Still, even if this knowledge should reach us, the searching mind will find a barrier, perhaps forever unsurpassable, to the *true* recognition of that which *seems* to be, the mere *appearance* of which is the only and slender basis of all our philosophy.

Of all the forms of nature's immeasurable, all-pervading energy, which ever and ever changing and moving, like a soul animates the inert universe, those of electricity and magnetism are perhaps the most fascinating. The effects of gravitation, of heat and light we observe daily, and soon we get accustomed to them, and soon they lose for us the character of the marvelous and wonderful; but electricity and magnetism, with their singular relationship, with their seemingly dual character, unique among the forces in nature, with their phenomena of attractions, repulsions and rotations, strange manifestations of mysterious agents, stimulate and excite the mind to thought and research. What is electricity, and What is magnetism? These questions have been asked again and again. The most able intellects have ceaselessly wrestled with the problem; still the question has not as yet been fully answered. But while we cannot even to-day state what these singular forces are, yet we have made good headway towards the solution of the problem. We are now confident that electric and magnetic phenomena are attributable to ether, and we are perhaps justified in saying, that the effects of static electricity are effects of ether under strain, and those of dynamic electricity and electro-magnetism effects of ether in motion. But this still leaves the question, as to what electricity and magnetism are, unanswered.

First, we naturally inquire, What is electricity, and is there such a thing as electricity? In interpreting electric phenomena, we may speak of electricity or of an electric condition, state or effect. If we speak of electric effects, we must distinguish two such effects, opposite in character and neutralizing each other, as observation shows that two such opposite effects exist. This is unavoidable, for in a medium of the properties of ether, we cannot possibly exert a strain, or produce a displacement or motion of any kind, without causing in the surrounding medium an equivalent and opposite effect. But if we speak of electricity, meaning a *thing*, we must, I think, abandon the idea of two electricities, as the existence of two such things is highly improbable. For how can we imagine that there should be two things, equivalent in amount, alike in their properties, but of opposite character, both clinging to matter, both attracting and completely neutralizing each other? Such an assumption, though suggested by many phenomena, though most convenient for explaining them, has little to commend it. If there *is* such a thing as electricity, there can be only *one* such thing, and, excess and want of that one thing, possibly; but more probably its condition determines the positive and negative character. The old theory of Franklin, though falling short in some respects, is, from a certain point of view, after all, the most plausible one. Still, in spite of this, the theory of the two electricities is generally accepted, as it apparently explains electric phenomena in a more satisfactory manner. But a theory which better explains the facts is not necessarily true. Ingenious minds will invent theories to suit observation, and almost every independent thinker has his own views on the subject.

It is not with the object of advancing an opinion, but with the desire of acquainting you better with some of the results, which I will describe, to show you the reasoning I have followed, the departures I have made—that I venture to express, in a few words, the views and convictions which have led me to these results.

I adhere to the idea that there is a thing which we have been in the habit of calling electricity. The question is, What is that thing? or, What, of all things, the existence of which we know, have we the best reason to call electricity? We know that it acts like an incompressible fluid; that there must be a constant quantity of it in nature; that it can be neither produced nor destroyed; and, what is more important, the electro-magnetic theory of light and all facts observed teach us that electric and ether phenomena are identical. The idea at once suggests itself, therefore, that electricity might be called ether. In fact, this view has in a certain sense been advanced by Dr. Lodge. His interesting work has been read by everyone and many have been convinced by his arguments. His great ability and the interesting nature of the subject, keep the reader spellbound; but when the impressions fade, one realizes that he has to deal only with ingenious explanations. I must confess, that I cannot believe in two electricities, much less in a doubly-constituted ether. The puzzling behavior of the ether as a solid to waves of light and heat, and as a fluid to the motion of bodies through it, is certainly explained in the most natural and satisfactory manner by assuming it to be in motion, as Sir William Thomson has suggested; but regardless of this, there is nothing which would enable us to conclude with certainty that, while a fluid is not capable of transmitting transverse vibrations of a few hundred or thousand per second, it might not be capable of transmitting such vibrations when they range into hundreds of million millions per second. Nor can anyone prove that there are transverse ether waves emitted from an alternate current machine, giving a small number of alternations per second; to such slow disturbances, the ether, if at rest, may behave as a true fluid.

Returning to the subject, and bearing in mind that the existence of two electricities is, to say the least, highly improbable, we must remember, that we have no evidence of electricity, nor can we hope to get it, unless gross matter is present. Electricity, therefore, cannot be called ether in the broad sense of the term; but nothing would seem to stand in the way of calling electricity ether associated with matter, or bound ether; or, in other words, that the so-called static charge of the molecule is ether associated in some way with the molecule. Looking at it in that light, we would be justified in saying, that electricity is concerned in all molecular actions.

Now, precisely what the ether surrounding the molecules is, wherein it differs from ether in general, can only be conjectured. It cannot differ in density, ether being incompressible; it must, therefore, be under some strain or in motion, and the latter is the most probable. To understand its functions, it would be necessary to have an exact idea of the physical construction of matter, of which, of course, we can only form a mental picture.

But of all the views on nature, the one which assumes one matter and one force, and a perfect uniformity throughout, is the most scientific and most likely to be true. An infinitesimal world, with the molecules and their atoms spinning and moving in orbits, in much the same manner as celestial bodies, carrying with them and probably spinning with them ether, or in other words, carrying with them static charges, seems to my mind the most probable view, and one which, in a plausible manner, accounts for most of the phenomena observed. The spinning of the molecules and their ether sets up ether tensions or electrostatic strains; the equalization of ether tensions sets up ether motions or electric currents,

1. A lecture delivered before the American Institute of Electrical Engineers, at Columbia College, N. Y., May 20, 1891.

and the orbital movements produce the effects of electro and permanent magnetism.

About fifteen years ago, Prof. Rowland demonstrated a most interesting and important fact, namely, that a static charge carried around produces the effects of an electric current. Leaving out of consideration the precise nature of the mechanism, which produces the attraction and repulsion of currents, and conceiving the electrostatically charged molecules in motion, this experimental fact gives us a fair idea of magnetism. We can conceive lines or tubes of force which physically exist, being formed of rows of directed moving molecules; we can see that these lines must be

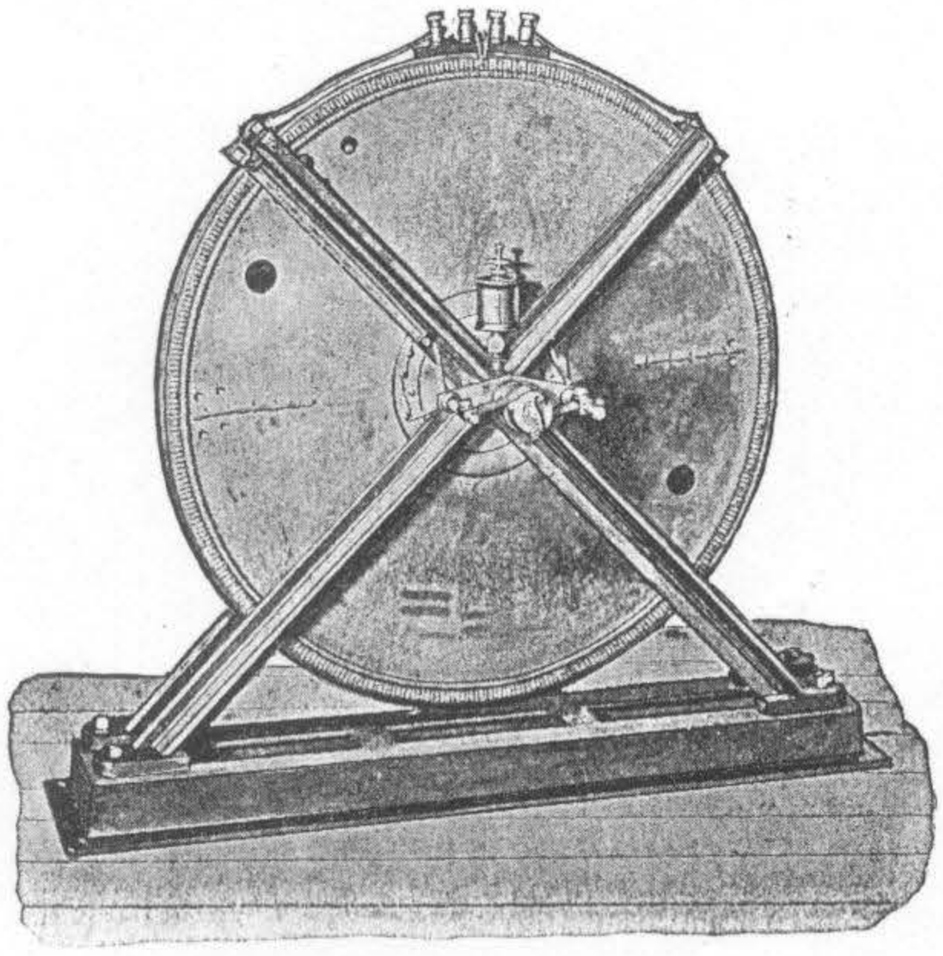

FIG. 1.—HIGH FREQUENCY ALTERNATOR WITH DRUM ARMATURE.

closed; that they must tend to shorten and expand, etc. It likewise explains in a reasonable way, the most puzzling phenomenon of all, permanent magnetism, and, in general, has all the beauties of the Ampere theory without possessing the vital defect of the same, namely, the assumption of molecular currents. Without enlarging further upon the subject, I would say, that I look upon all electrostatic, current and magnetic phenomena as being due to electrostatic molecular forces.

The preceding remarks I have deemed necessary to a full understanding of the subject as it presents itself to my mind.

Of all these phenomena the most important to study are the current phenomena, on account of the already extensive and ever-growing use of currents for industrial purposes. It is now a century since the first practical source of current has been produced, and, ever since, the phenomena which accompany the flow of currents have been diligently studied, and through the untiring efforts of scientific men the simple laws which govern them have been discovered. But these laws were found to hold good only when the currents are of a steady character When the currents are rapidly varying in strength, quite different phenomena, often unexpected, present themselves, and quite different laws hold good, which even now have not been determined as fully as is desirable, though through the work, principally of English scientists, enough knowledge has been gained on the subject to enable us to treat simple cases which now present themselves in daily practice.

The phenomena which are peculiar to the changing character of the currents are greatly exalted when the rate of change is increased, hence the study of these currents is considerably facilitated by the employment of properly constructed apparatus. It was with this and other objects in view that I constructed alternate current machines capable of giving more than two million reversals of current per minute, and to this circumstance it is principally due, that I am able to bring to your attention some of the results thus far reached, which I hope will prove to be a step in advance on account of their direct bearing upon one of the most important problems, namely, the production of a practical and efficient source of light.

The study of such rapidly alternating currents is very interesting. Nearly every experiment discloses something new. Many results may, of course, be predicted, but many more are unforeseen. The experimenter makes many interesting observations. For instance, we take a piece of iron and hold it against a magnet. Starting from low alternations and running up higher and higher we feel the impulses succeed each other faster and faster, get weaker and weaker, and finally disappear. We then observe a continuous pull; the pull, of course, is not continuous; it only appears so to us; our sense of touch is imperfect.

We may next establish an arc between the electrodes and observe as the alternations rise, that the note which accompanies alternating arcs gets shriller and shriller, gradually weakens, and finally ceases. The air vibrations, of course, continue, but they are too weak to be perceived; our sense of hearing fails us.

We observe the small physiological effects, the rapid heating of the iron cores and conductors, curious inductive effects, interesting condenser phenomena, and still more interesting light phenomena with a high tension induction coil. All these experiments and observations would be of the greatest interest to the student, but their description would lead me too far from the principal subject. Partly for this reason, and partly on account of the vastly greater importance, I will confine myself to the description of the light effects produced by these currents.

In the experiments to this end a high tension induction coil or equivalent apparatus for converting currents of comparatively low into currents of high tension is used.

If you will be sufficiently interested in the results I shall describe as to enter into an experimental study of this subject; if you will be convinced of the truth of the arguments I shall advance, your aim will be to produce high frequencies and high potentials; in other words, powerful electrostatic effects. You will then encounter many difficulties, which, if completely overcome, would allow us to produce truly wonderful results.

First will be met the difficulty of obtaining the required frequencies by means of mechanical apparatus, and, if they be obtained otherwise, obstacles of a different nature will present themselves. Next it will be found difficult to provide the requisite insulation without considerably increasing the size of the apparatus, for the potentials required are high, and, owing to the rapidity of the alternations, the insulation presents peculiar difficulties. So, for instance, when a gas is present, the discharge may work, by the molecular bombardment of the gas and consequent heating, through as much as an inch of the best solid insulating material, such as glass, hard rubber, porcelain, sealing wax, etc.; in fact, through any known insulating substance. The chief requisite in the insulation of the apparatus is, therefore, the exclusion of any gaseous matter.

In general my experience tends to show that bodies which possess the highest specific inductive capacity, such as glass, afford a rather inferior insulation to others, which, while they are good insulators, have a much smaller specific inductive capacity, such as oils, for instance, the dielectric losses being no doubt greater in the former. The difficulty of insulating, of course, only exists when the potentials are excessively high, for with potentials such as a few thousand volts there is no particular diffi-

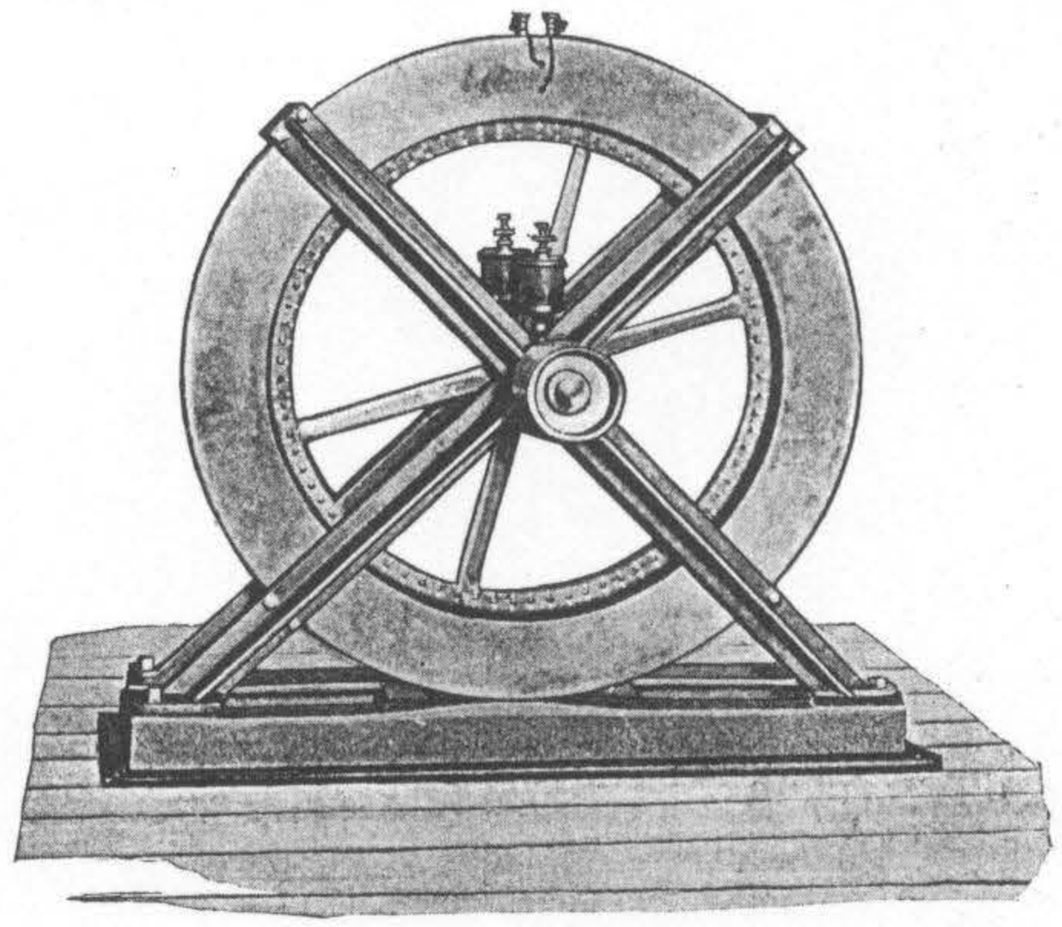

FIG. 2.—HIGH FREQUENCY ALTERNATOR WITH REVOLVING DISC ARMATURE.

culty encountered in conveying currents from a machine giving, say, 20,000 alternations per second, to quite a distance. This number of alternations, however, is by far too small for many purposes, though quite sufficient for some practical applications. This difficulty of insulating is fortunately not a vital drawback; it affects mostly the size of the apparatus, for, when excessively high potentials would be used, the light-giving devices would be located not far from the apparatus, and often they would be quite close to it. As the air-bombardment of the insulated wire is

dependent on condenser action, the loss may be reduced to a trifle by using excessively thin wires heavily insulated.

Another difficulty will be encountered in the capacity and self-induction necessarily possessed by the coil. If the coil be large, that is, if it contain a great length of wire, it will be generally unsuited for excessively high frequencies; if it be small, it may be well adapted for such frequencies, but the potential might then not be as high as desired. A good insulator, and preferably one possessing a small specific inductive capacity, would afford a two-fold advantage. First, it would enable us to construct a very small coil capable of withstanding enormous differences of potential; and secondly, such a small coil, by reason of its smaller capacity and self-induction, would be capable of a quicker and more vigorous vibration. The problem then of constructing a coil or induction apparatus of any kind possessing the requisite qualities I regard as one of no small importance, and it has occupied me for a considerable time.

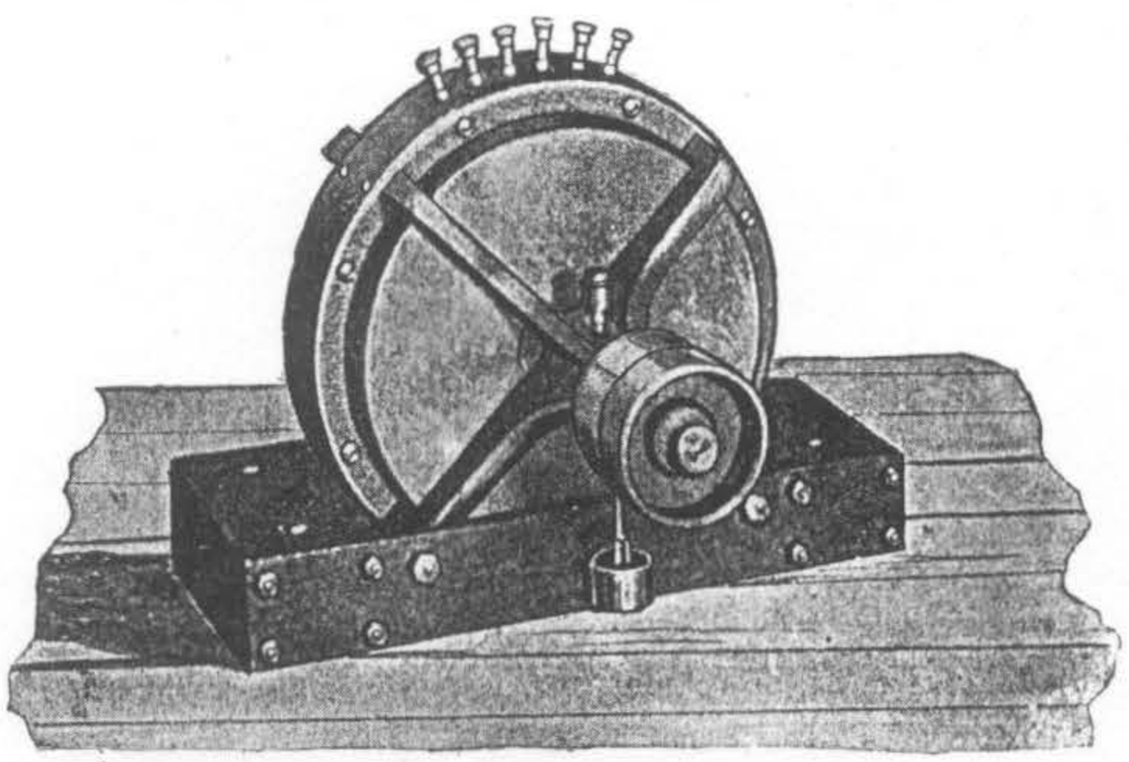

FIG. 3.—HIGH FREQUENCY ALTERNATOR WITH STATIONARY DISC ARMATURE AND STATIONARY EXCITING COIL.

The investigator who desires to repeat the experiments which I will describe, with an alternate current machine, capable of supplying currents of the desired frequency, and an induction coil, will do well to take the primary coil out and mount the secondary in such a manner as to be able to look through the tube upon which the secondary is wound. He will then be able to observe the streams which pass from the primary to the insulating tube, and from their intensity he will know how far he can strain the coil. Without this precaution he is sure to injure the insulation. This arrangement permits, however, an easy exchange of the primaries, which is desirable in these experiments.

The selection of the type of machine best suited for the purpose, must be left to the judgment of the experimenter. There are here illustrated three distinct types of machines, which, besides others, I have used in my experiments.

Fig. 1 represents the machine used in my experiments before this Institute. The field, magnet consists of a ring of wrought iron with 384 pole projections. The armature comprises a steel disc to which is fastened a thin, carefully welded rim of wrought iron. Upon the rim are wound several layers of fine, well annealed iron wire, which, when wound, is passed through shellac. The armature wires are wound around brass pins, wrapped with silk thread. The diameter of the armature wire in this type of machine should not be more than $\frac{1}{6}$ of the thickness of the pole projections, else the local action will be considerable.

Fig. 2 represents a larger machine of a different type. The field-magnet of this machine consists of two like parts which either enclose an exciting coil, or else are independently wound. Each part has 480 pole projections, the projections of one facing those of the other. The armature consists of a wheel of hard bronze, carrying the conductors which revolve between the projections of the field magnet. To wind the armature conductors, I have found it most convenient to proceed in the following manner: I construct a ring of hard bronze of the required size. This ring and the rim of the wheel are provided with the proper number of pins, and both fastened upon a plate. The armature conductors being wound, the pins are cut off and the ends of the conductors fastened by two rings which screw to the bronze ring and the rim of the wheel respectively. The whole may then be taken off and forms a solid structure. The conductors in such a type of machine should consist of sheet copper, the thickness of which, of course, depends on the thickness of the pole projections; or else twisted thin wires should be employed.

Fig. 3 is a smaller machine, in many respects similar to the former, only here the armature conductors and the exciting coil are kept stationary, while only a block of wrought iron is revolved.

It would be uselessly lengthening this description were I to dwell more on the details of construction of these machines. Besides, they have been described somewhat more elaborately in THE ELECTRICAL ENGINEER, of March 18, 1891. I deem it well, however, to call the attention of the investigator to two things, the importance of which, though self evident, he is nevertheless apt to underestimate; namely, to the local action in the conductors which must be carefully avoided, and to the clearance which must be small. I may add, that since it is desirable to use very high peripheral speeds, the armature should be of very large diameter in order to avoid impracticable belt speeds. Of the several types of these machines which have been constructed by me, I have found that the type illustrated in Fig. 1 caused me the least trouble in construction, as well as in maintenance, and, on the whole, it has been a good experimental machine.

In operating an induction coil with very rapidly alternating currents, among the first luminous phenomena noticed are naturally those presented by the high-tension discharge. As the number of alternations per second is increased, or as—the number being high—the current through the primary is varied, the discharge gradually changes in appearance. It would be difficult to describe the minor changes which occur, and the conditions which bring them about, but one may note five distinct forms of the discharge.

First, one may observe a weak, sensitive discharge in the form of a thin, feeble-colored thread. (Fig. 4.) It always occurs when, the number of alternations per second being high, the current through the primary is very small. In spite of the excessively small current, the rate of change is great, and the difference of potential at the terminals of the secondary is therefore considerable, so that the arc is established at great distances; but the quantity of "electricity" set in motion is insignificant, barely sufficient to maintain a thin, threadlike arc. It is excessively sensitive and may be made so to such a degree that the mere act of breathing near the coil will affect it, and unless it is perfectly well protected from currents of air, it wriggles around constantly. Nevertheless, it is in this form excessively persistent, and when the terminals are approached to, say, one-third of the striking distance, it can be blown out only with difficulty. This exceptional persistency, when short, is largely due to the arc being excessively thin; presenting, therefore, a very small surface to the blast. Its great sensitiveness, when very long, is probably due to the motion of the particles of dust suspended in the air.

When the current through the primary is increased, the discharge gets broader and stronger, and the effect of the capacity of the coil becomes visible until, finally, under proper conditions, a white flaming arc, Fig. 5, often as thick as one's finger, and striking across the whole coil, is produced. It develops remarkable heat, and may be further characterized by the absence of the high note which accompanies the less powerful discharges. To take a shock from the coil under these conditions would not be advisable, although under different conditions, the potential being much higher, a shock from the coil may be taken with impunity To produce this kind of discharge the number of alternations per

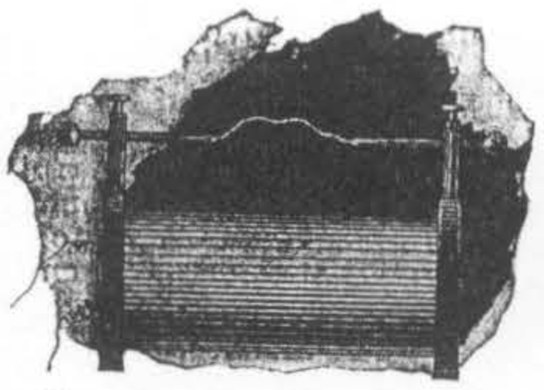

FIG. 4.—SENSITIVE THREAD DISCHARGE.

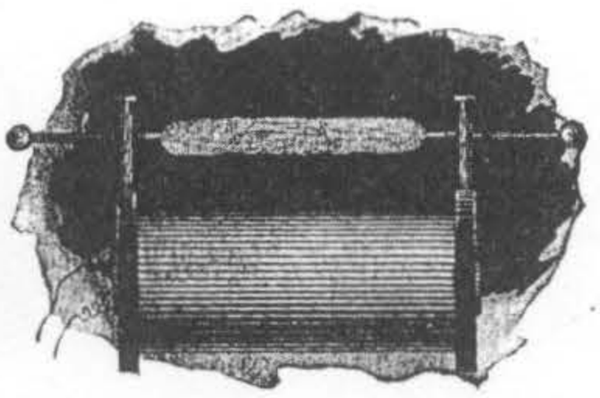

FIG. 5.—FLAMING DISCHARGE.

second must not be too great for the coil used; and, generally speaking, certain relations between capacity, self-induction and frequency must be observed.

The importance of these elements in an alternate current circuit is now well-known, and, under ordinary conditions, the general rules are applicable. But in an induction coil exceptional conditions prevail. First, the self-induction is of little importance before the arc is established, when it asserts itself, but perhaps never as prominently as in ordinary alternate current circuits, because capacity is distributed all along the coil, and by reason of the fact that the coil usually discharges through very great resistances; hence the currents are exceptionally small. Secondly, the capacity goes on increasing continually as the potential rises, in consequence of absorption which takes place to a considerable extent. Owing to this there exists no critical relationship between these quantities, and ordinary rules would not seem to be applicable. As the potential is increased either in consequence of the

increased frequency or of the increased current through the primary, the amount of the energy stored becomes greater and greater, and the capacity gains more and more in importance. Up to a certain point the capacity is beneficial, but after that it begins to be an enormous drawback. It follows from this that each coil gives the best result with a given frequency and primary current. A very large coil, when operated with currents of very high frequency, may not give as much as ⅛ inch spark. By adding capacity to the terminals, the condition may be improved, but what the coil really wants is a lower frequency.

When the flaming discharge occurs, the conditions are evidently such that the greatest current is made to flow through the circuit. These conditions may be attained by varying the frequency within wide limits, but the highest frequency at which the flaming arc can still be produced, determines, for a given primary current, the maximum striking distance of the coil. In the flaming discharge the *éclat* effect of the capacity is not perceptible; the rate at which the energy is being stored then just equals the rate at which it can be disposed of through the circuit. This kind of discharge is the severest test for a coil; the break, when it occurs, is of the nature of that in an overcharged Leyden jar. To give a rough approximation I would state that, with an ordinary coil of, say 10,000 ohms resistance, the most powerful arc would be produced with about 12,000 alternations per second.

When the frequency is increased beyond that rate, the potential, of course, rises, but the striking distance may, nevertheless, diminish, paradoxical as it may seem. As the potential rises the coil attains more and more the properties of a static machine until, finally, one may observe the beautiful phenomenon of the streaming discharge, Fig. 6, which may be produced across the whole length of the coil. At that stage streams begin to issue freely from all points and projections. These streams will also be seen to pass in abundance in the space between the primary and the insulating tube. When the potential is excessively high they will always appear, even if the frequency be low, and even if the primary be surrounded by as much as an inch of wax, hard rubber, glass, or any other insulating substance. This limits greatly the output of the coil, but I will later show how I have been able to overcome to a considerable extent this disadvantage in the ordinary coil.

Besides the potential, the intensity of the streams depends on the frequency; but if the coil be very large they show themselves, no matter how low the frequencies used. For instance, in a very large coil of a resistance of 67,000 ohms, constructed by mesome time ago, they appear with as low as 100 alternations per second and less, the insulation of the secondary being ¾ inch of ebonite. When very intense they produce a noise similar to that produced by the charging of a Holtz machine, but much more powerful, and they emit a strong smell of ozone. The lower the frequency, the more apt they are to suddenly injure the coil, With excessively high frequencies they may pass freely without producing any other effect than to heat the insulation slowly and uniformly.

The existence of these streams shows the importance of constructing an expensive coil so as to permit of one's seeing through the tube surrounding the primary, and the latter should be easily exchangeable; or else the space between the primary and secondary should be completely filled up with insulating material so as to exclude all air. The non-observance of this simple rule in the construction of the commercial coils is responsible for the destruction of many an expensive coil.

At the stage when the streaming discharge occurs, or with somewhat higher frequencies, one may, by approaching the terminals considerably and regulating properly the effect of capacity, produce a veritable spray of small silver-white sparks or a bunch of excessively thin silvery threads (Fig. 7) amidst a powerful brush—each spark or thread possibly corresponding to one alternation. This, when produced under proper conditions, is probably the most beautiful discharge, and when an air blast is directed against it, it presents a singular appearance. The spray of sparks, when received through the body, causes some inconvenience, whereas, when the discharge simply streams, nothing at all is likely to be felt if large conducting objects are held in the hands to protect them from receiving small burns.

If the frequency is still more increased, then the coil refuses to give any spark unless at comparatively small distances, and the fifth typical form of discharge may be observed (Fig. 8). The tendency to stream out and dissipate is then so great that when the brush is produced at one terminal no sparking occurs, even if, as I have repeatedly tried, the hand, or any conducting object, is held within the stream ; and, what is more singular, the luminous stream is not at all easily deflected by the approach of a conducting body.

At this stage the streams seemingly pass with the greatest freedom through considerable thicknesses of insulators, and it is particularly interesting to study their behavior. For this purpose it is convenient to connect to the terminals of the coil two metallic spheres which may be placed at any desired distance, Fig. 9. Spheres are preferable to plates, as the discharge can be better observed. By inserting dielectric bodies between the spheres, beautiful discharge phenomena may be observed. If the spheres be quite close and a spark be playing between them, by interposing a thin plate of ebonite between the spheres the spark instantly ceases and the discharge spreads into an intensely luminous circle several inches in diameter, provided the spheres are sufficiently large. The passage of the streams heats, and, after a while, softens, the rubber so much that two plates may be made to stick together in this manner. If the spheres are so far apart that no spark occurs, even if they are far beyond the striking distance, by inserting a thick plate of glass the discharge is instantly induced to pass from the spheres to the glass in the form of luminous streams. It appears almost as though these streams pass *through* the dielectric. In reality this is not the case, as the streams are due to the molecules of the air which are violently agitated in the space between the oppositely charged surfaces of the spheres. When no dielectric other than air is present, the bombardment goes on, but is too weak to be visible ; by inserting a dielectric the inductive effect is much increased, and besides, the projected air molecules find an obstacle and the bombardment becomes so intense that the streams become luminous. If by any mechanical means we could effect such a violent agitation of the molecules we could produce the same phenomenon. A jet of air escaping through a small hole under enormous pressure and striking against an insulating substance, such as glass, may be luminous in the dark, and it might be possible to produce phosphorescence of the glass or other insulators in this manner.

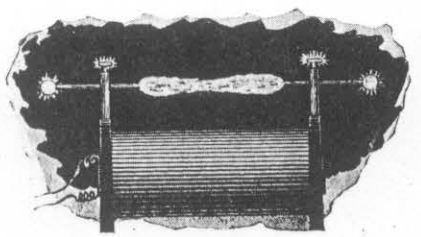

FIG. 6.—STREAMING DISCHARGE.

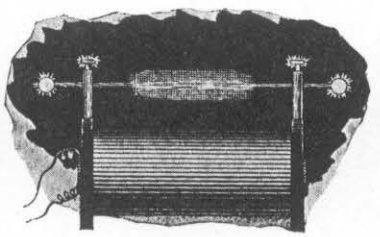

FIG. 7.—BRUSH AND SPRAY DISCHARGE.

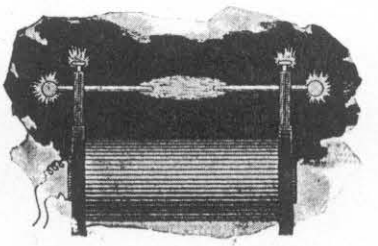

FIG. 8.—FIFTH TYPICAL FORM OF DISCHARGE.

The greater the specific inductive capacity of the interposed dielectric, the more powerful the effect produced. Owing to this, the streams show themselves with excessively high potentials even if the glass be as much as one and one-half to two inches thick. But besides the heating due to bombardment, some heating goes on undoubtedly in the dielectric, being apparently greater in glass than in ebonite. I attribute this to the greater specific inductive capacity of the glass, in consequence of which, with the same same potential difference, a greater amount of energy is taken up in it than in rubber. It is like connecting to a battery a copper and a brass wire of the same dimensions. The copper wire, though a more perfect conductor, would heat more by reason of its taking more current. Thus what is otherwise considered a virtue of the glass is here a defect. Glass usually gives way much quicker than ebonite ; when it is heated to a certain degree, the discharge suddenly breaks through at one point, assuming then the ordinary form of an arc.

The heating effect produced by molecular bombardment of the dielectric would, of course, diminish as the pressure of the air is increased, and at enormous pressures it would be negligible, unless the frequency would increase correspondingly.

It will be often observed in these experiments that when the spheres are beyond the striking distance, the approach of a glass plate, for instance, may induce the spark to jump between the spheres. This occurs when the capacity of the spheres is somewhat below the critical value which gives the greatest difference of potential at the terminals of the coil. By approaching a dielectric, the specific inductive capacity of the space between the spheres is increased, producing the same effect as if the capacity of the spheres were increased. The potential at the terminals may then rise so high that the air space is cracked. The experiment is best performed with dense glass or mica.

Another interesting observation is that a plate of insulating material, when the discharge is passing through it, is strongly attracted by either of the spheres, that is, by the nearer one, this being obviously due to the smaller mechanical effect of the bombardment on that side, and perhaps also to the greater electrification.

From the behavior of the dielectrics in these experiments we may conclude, that the best insulator for these rapidly alternating currents would be the one possessing the smallest specific inductive capacity and at the same time one capable of withstanding the greatest differences of potential; and thus two diametrically opposite ways of securing the required insulation are indicated, namely, to use either a perfect vacuum or a gas under great pressure; but the former would be preferable. Unfortunately neither of these two ways is easily carried out in practice.

It is especially interesting to note the behavior of an excessively high vacuum in these experiments. If a test tube, provided with external electrodes and exhausted to the highest possible degree, be connected to the terminals of the coil, Fig. 10, the electrodes of the tube are instantly brought to a high temperature and the glass at each end of the tube is rendered intensely phosphorescent, but the middle appears comparatively dark, and for a while remains cool.

When the frequency is so high that the discharge shown in Fig. 8 is observed, considerable dissipation no doubt occurs in the coil. Nevertheless the coil may be worked for a long time, as the heating is gradual.

In spite of the fact that the difference of potential may be enormous, little is felt when the discharge is passed through the body, provided the hands are armed. This is to some extent due to the higher frequency, but principally to the fact that less energy is available externally, when the difference of potential reaches an enormous value, owing to the circumstance that, with the rise of potential, the energy absorbed in the coil increases as the square of the potential. Up to a certain point the energy available externally increases with the rise of potential, then it begins to fall off rapidly. Thus, with the ordinary high tension induction coil, the curious paradox exists, that, while with a given current through the primary the shock might be fatal, with many times that current it might be perfectly harmless, even if the frequency be the same. With high frequencies and excessively high potentials when the terminals are not connected to bodies of some size, practically all the energy supplied to the primary is taken up by the coil. There is no breaking through, no local injury, but all the material, insulating and conducting, is uniformly heated.

To avoid misunderstanding in regard to the physiological effect of alternating currents of very high frequency, I think it necessary to state that, while it is an undeniable fact that they are incomparably less dangerous than currents of low frequencies, yet it should not be thought that they are altogether harmless. What has just been said refers only to currents from an ordinary high tension induction coil, which currents are necessarily very small; if received directly from a machine or from a secondary of low resistance, they produce more or less powerful effects, and may cause serious injury, especially when used in conjunction with condensers.

The streaming discharge of a high tension induction coil differs in many respects from that of a powerful static machine. In color it has neither the violet of the positive, nor the brightness of the negative, static discharge, but lies somewhere between, being, of course, alternatively positive and negative. But since the streaming is more powerful when the point or terminal is electrified positively, than when electrified negatively, it follows that the point of the brush is more like the positive, and the root more like the negative, static discharge. In the dark, when the brush is very powerful, the root may appear almost white. The wind produced by the escaping streams, though it may be very strong—often indeed to such a degree that it may be felt quite a distance from the coil—is, nevertheless, considering the quantity of the discharge, smaller than that produced by the positive brush of a static machine, and it affects the flame much less powerfully. From the nature of the phenomenon we can conclude that the higher the frequency, the smaller must, of course, be the wind produced by the streams, and with sufficiently high frequencies no wind at all would be produced at the ordinary atmospheric pressures. With frequencies obtainable by means of a machine, the mechanical effect is sufficiently great to revolve, with considerable speed, large pin-wheels, which in the dark present a beautiful appearance owing to the abundance of the streams (Fig. 11).

In general, most of the experiments usually performed with a static machine can be performed with an induction coil when operated with very rapidly alternating currents. The effects produced, however, are much more striking, being of incomparably greater power. When a small length of ordinary cotton covered wire, Fig. 12, is attached to one terminal of the coil, the streams issuing from all points of the wire may be so intense as to produce a considerable light effect. When the potentials and frequencies are very high, a wire insulated with gutta percha or rubber and attached to one of the terminals, appears to be covered with a luminous film. A very thin bare wire when attached to a terminal emits powerful streams and vibrates continually to and fro or spins in a circle, producing a singular effect (Fig. 13). Some of these experiments have been described by me in *The Electrical World*, of February 21, 1891.

Another peculiarity of the rapidly alternating discharge of the induction coil is its radically different behavior with respect to points and rounded surfaces.

If a thick wire, provided with a ball at one end and with a point at the other, be attached to the positive terminal of a static machine, practically all the charge will be lost through the point, on account of the enormously greater tension, dependent on the radius of curvature. But if such a wire is attached to one of the terminals of the induction coil, it will be observed that with very high frequencies streams issue from the ball almost as copiously as from the point (Fig. 14).

It is hardly conceivable that we could produce such a condition to an equal degree in a static machine, for the simple reason, that the tension increases as the square of the density, which in turn is proportional to the radius of curvature; hence, with a steady potential an enormous charge would be required to make streams issue from a polished ball while it is connected with a point. But with an induction coil the discharge of which alternates with great rapidity, it is different. Here we have to deal with two distinct tendencies. First, there is the tendency to escape which exists in a condition of rest, and which depends on the radius of curvature; second, there is the tendency to dissipate into the surrounding air by condenser action, which depends on the surface. When one of these tendencies is a maximum, the other is at a minimum. At the point the luminous stream is principally due to the air molecules coming bodily in contact with the point; they are attracted and repelled, charged and discharged, and, their atomic charges being thus disturbed, vibrate and emit light waves. At the ball, on the contrary, there is no doubt that the effect is to a great extent produced inductively, the air molecules not *necessarily* coming in contact with the ball, though they undoubtedly do so. To convince ourselves of this we only need to exalt the condenser action, for instance, by enveloping the ball, at some distance, by a better conductor than the surrounding medium, the conductor being, of course, insulated; or else by surrounding it with a better dielectric and approaching an insulated conductor; in both cases the streams will break forth more copiously. Also, the larger the ball with a given frequency, or the higher the frequency, the more will the ball have the advantage over the point. But, since a certain intensity of action is required to render the streams visible, it is obvious that in the experiment described the ball should not be taken too large.

In consequence of this two-fold tendency, it is possible to produce by means of points effects identical to those produced by capacity. Thus, for instance, by attaching to one terminal of the coil a small length of soiled wire, presenting many points and

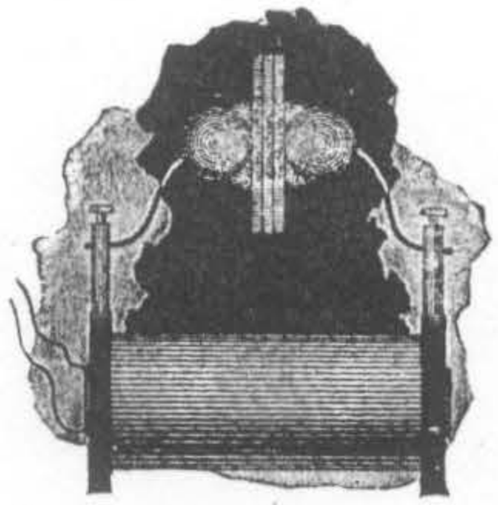

FIG. 9.—LUMINOUS DISCHARGE WITH INTERPOSED INSULATORS.

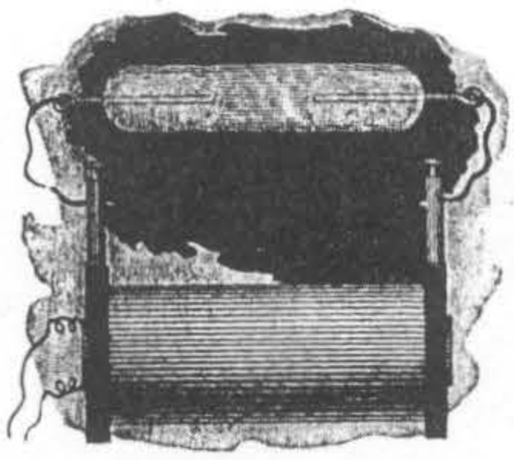

FIG. 10.—DISCHARGE THROUGH HIGHEST VACUUM.

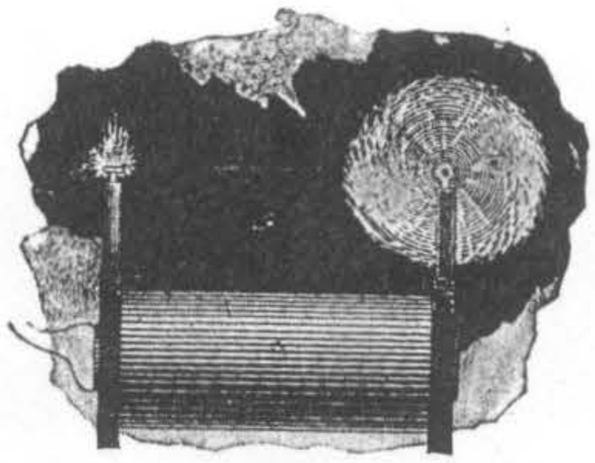

FIG. 11.—PINWHEEL DRIVEN BY A POWERFUL BRUSH.

offering great facility to escape, the potential of the coil may be raised to the same value as by attaching to the terminal a polished ball of a surface many times greater than that of the wire.

An interesting experiment, showing the effect of the points, may be performed in the following manner : Attach to one of the terminals of the coil a cotton covered wire about two feet in length,

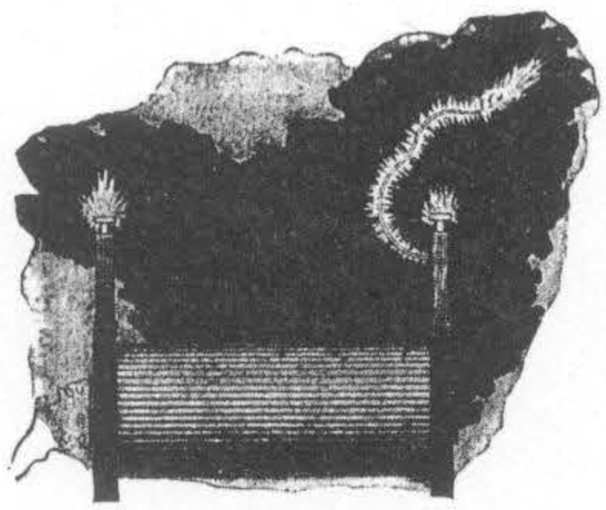

FIG. 12.—LUMINOUS STREAMS ESCAPING FROM A COTTON-COVERED WIRE.

and adjust the conditions so that streams issue from the wire. In this experiment the primary coil should be preferably placed so that it extends only about half way into the secondary coil. Now touch the free terminal of the secondary with a conducting object held in the hand, or else connect it to an insulated body of some size. In this manner the potential on the wire may be enormously raised. The effect of this will be to either increase, or to diminish, the streams. If they increase, the wire is too short; if they diminish, it is too long. By adjusting the length of the wire, a point is found where the touching of the other terminal does not at all affect the streams. In this case the rise of potential is exactly counteracted by the drop through the coil. It will be observed that small lengths of wire produce considerable difference in the magnitude and luminosity of the streams. The primary coil is placed sidewise for two reasons : First, to increase the potential at the wire and, second, to increase the drop through the coil. The sensitiveness is thus augmented.

There is still another and far more striking peculiarity of the brush discharge produced by very rapidly alternating currents. To observe this it is best to replace the usual terminals of the coil by two metal columns insulated with a good thickness of ebonite. It is also well to close all fissures and cracks with wax so that the brushes cannot form anywhere except at the tops of the columns. If the conditions are carefully adjusted—which, of course, must be left to the skill of the experimenter—so that the potential rises to an enormous value, one may produce two powerful brushes several inches long, nearly white at their roots, which in the dark bear a striking resemblance to two flames of a gas escaping under pressure (Fig. 15). But they do not only *resemble*, they *are* veritable flames, for they are hot. Certainly they are not as hot as a gas burner, *but they would be so if the frequency and the potential would be sufficiently high.* Produced with, say, twenty thousand alternations per second, the heat is easily perceptible even if the potential is not excessively high. The heat developed is, of course, due to the impact of the air molecules against the terminals and against each other. As, at the ordinary pressures, the mean free path is excessively small, it is possible that in spite of the enormous initial speed imparted to each molecule upon coming in contact with the terminal, its progress—by collision with other molecules—is retarded to such an extent, that it does not get away far from the terminal, but may strike the same many times in succession. The higher the frequency, the less the molecule is able to get away, and this the more so, as for a given effect the potential required is smaller ; and a frequency is conceivable —perhaps even obtainable—at which practically the same molecules would strike the terminal. Under such conditions the exchange of the molecules would be very slow, and the heat produced at, and very near, the terminal would be excessive. But if the frequency would go on increasing constantly, the heat produced would begin to diminish for obvious reasons. In the positive brush of a static machine the exchange of the molecules is very rapid, the stream is constantly of one direction, and there are fewer collisions ; hence the heating effect must be very small. Anything that impairs the facility of exchange tends to increase the local heat produced. Thus, if a bulb be held over the terminal of the coil so as to enclose the brush, the air contained in the bulb is very quickly brought to a high temperature. If a glass tube be held over the brush so as to allow the draught to carry the brush upwards, scorching hot air escapes at the top of the tube. Anything held within the brush is, of course, rapidly heated, and the possibility of using such heating effects for some purpose or other suggests itself.

When contemplating this singular phenomenon of the hot brush, we cannot help being convinced that a similar process must take place in the ordinary flame, and it seems strange that after all these centuries past of familiarity with the flame, now, in this era of electric lighting and heating, we are finally led to recognize, that since time immemorial we have, after all, always had "electric light and heat" at our disposal. It is also of no little interest to contemplate, that we have a possible way of producing —by other than chemical means—a veritable flame, which would give light and heat without any material being consumed, without any chemical process taking place, and to accomplish this, we only need to perfect methods of producing enormous frequencies and potentials. I have no doubt that if the potential could be made to alternate with sufficient rapidity and power, the brush formed at the end of a wire would lose its electrical characteristics and would become flamelike. The flame must be due to electrostatic molecular action.

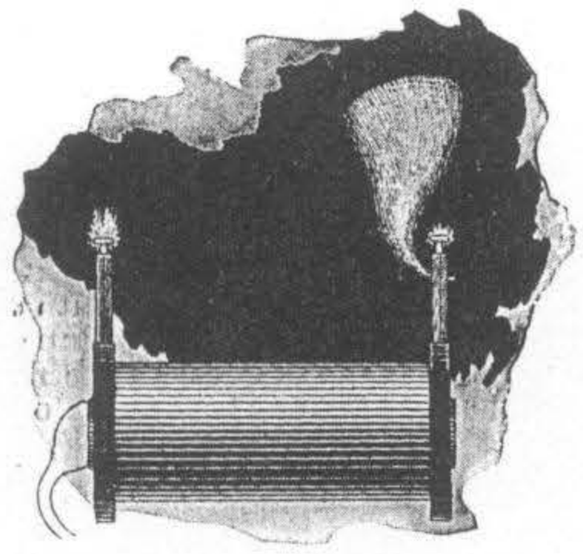

FIG. 13.—ASPECT PRESENTED BY A VERY THIN WIRE ATTACHED TO A TERMINAL OF THE COIL.

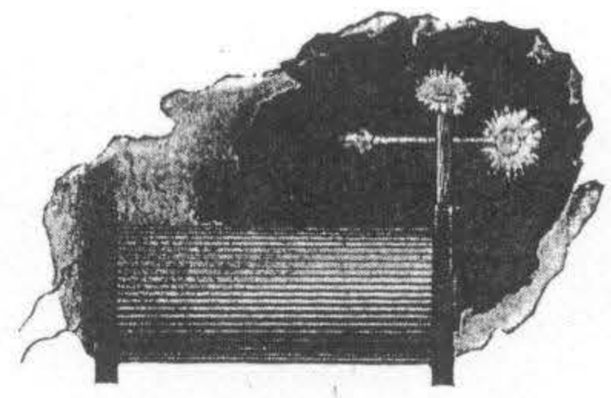

FIG. 14.—EFFECT OF BALL AND POINT.

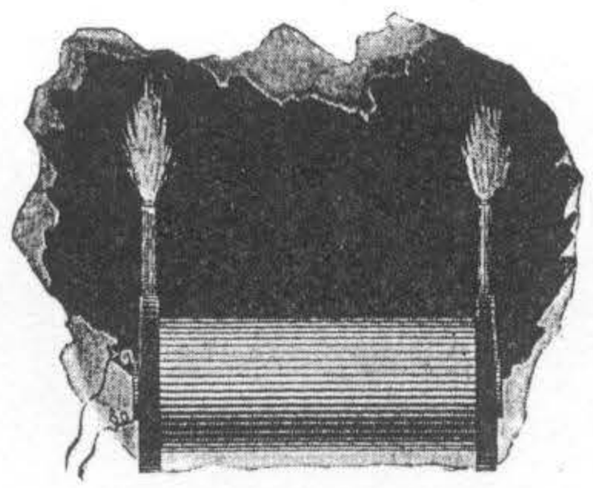

FIG. 15.—ASPECT OF COIL UNDER POWERFUL BRUSH DISCHARGE.

This phenomenon now explains in a manner which can hardly be doubted the frequent accidents occurring in storms. It is well known that objects are often set on fire without the lightning striking them. We shall presently see how this can happen. On a nail in a roof, for instance, or on a projection of any kind, more or less conducting, or rendered so by dampness, a powerful brush may appear. If the lightning strikes somewhere in the neighborhood the enormous potential may be made to alternate or fluctu-

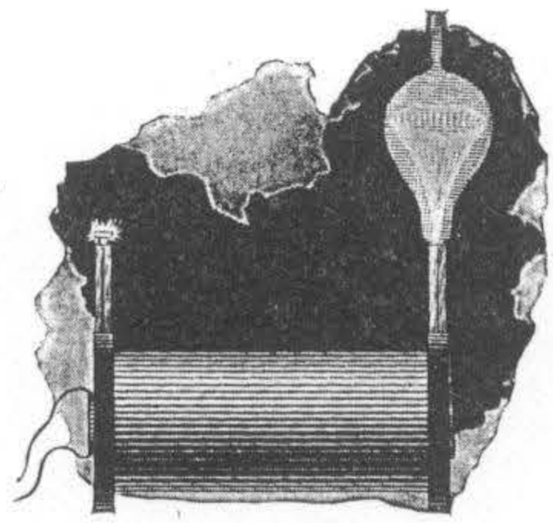

FIG. 16.—INCANDESCENT WIRE OR FILAMENT SPINNING IN AN UNEXHAUSTED GLOBE

ate perhaps many million times a second. The air molecules are violently attracted and repelled, and by their impact produce such a powerful heating effect that a fire is started. It is conceivable that a ship at sea may, in this manner, catch fire at many points at once. When we consider, that even with the comparatively low frequencies obtained from a dynamo machine, and with potentials of no more than one or two hundred thousand volts, the heating effects are considerable, we may imagine how much more powerful they must be with frequencies and potentials many times greater, and the above explanation seems, to say the least, very probable. Similar explanations may have been suggested, but I am not aware that, up to present, the heating effects of a brush produced by a rapidly alternating potential have been experimentally demonstrated, at least not to such a remarkable degree.

By preventing completely the exchange of the air molecules the local heating effect may be so exalted as to bring a body to incandescence. Thus, for instance, if a small button, or preferably a very thin wire or filament be enclosed in an unexhausted globe and connected with the terminal of the coil, it may be rendered incandescent. The phenomenon is made much more interesting by the rapid spinning round in a circle of the top of the filament, thus presenting the appearance of a luminous funnel, Fig. 16, which widens when the potential is increased. When the potential is small the end of the filament may perform irregular motions, suddenly changing from one to the other, or it may describe an ellipse; but when the potential is very high it always spins in a circle; and so does generally a thin straight wire attached freely to the terminal of the coil. These motions are, of course, due to the impact of the molecules, and the irregularity in the distribution of the potential, owing to the roughness and dissymmetry of the wire or filament. With a perfectly symmetrical and polished wire such motions would probably not occur. That the motion is not likely to be due to other causes is evident from the fact that it is not of a definite direction, and that in a very highly exhausted globe it ceases altogether. The possibility of

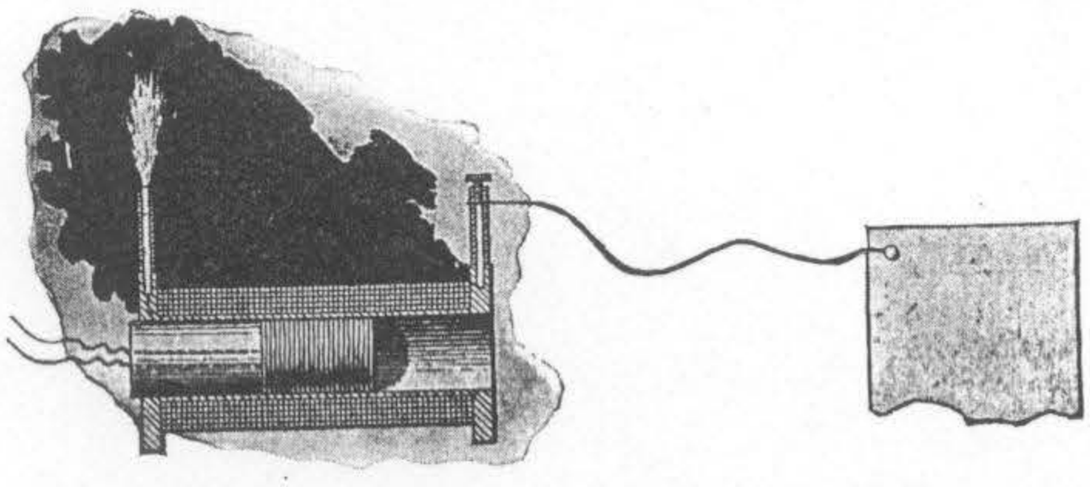

FIG. 17A.—COIL ARRANGED FOR POWERFUL BRUSH EFFECTS.

bringing a body to incandescence in an unexhausted globe, or even when not at all enclosed, would seem to afford a possible way of obtaining light effects, which, in perfecting methods of producing rapidly alternating potentials, might be rendered available for useful purposes.

In employing a commercial coil, the production of very powerful brush effects is attended with considerable difficulties, for when these high frequencies and enormous potentials are used, the best insulation is apt to give way. Usually the coil is insulated well enough to stand the strain from convolution to convolution, since two double silk covered paraffined wires will withstand a pressure of several thousand volts; the difficulty lies principally in preventing the breaking through from the secondary to the primary, which is greatly facilitated by the streams issuing from the latter. In the coil, of course, the strain is greatest from section to section, but usually in a larger coil there are so many sections that the danger of a sudden giving way is not very great. No difficulty will generally be encountered in that direction, and besides, the liability of injuring the coil internally is very much reduced by the fact that the effect most likely to be produced is simply a gradual heating, which, when far enough advanced, could not fail to be observed. The principal necessity is then to prevent the streams between the primary and the tube, not only on account of the heating and possible injury, but also because the streams may diminish very considerably the potential difference available at the terminals. A few hints as to how this may be accomplished will probably be found useful in most of these experiments with the ordinary induction coil.

One of the ways is to wind a short primary, Fig. 17 A, so that the difference of potential is not at that length great enough to cause the breaking forth of the streams through the insulating tube. The length of the primary should be determined by experiment. Both the ends of the coil should be brought out on one end through a plug of insulating material fitting in the tube as illustrated. In such a disposition one terminal of the secondary is attached to a body the surface of which is determined with the greatest care so as to produce the greatest rise in the potential. At the other terminal a powerful brush appears, which may be experimented upon.

The above plan necessitates the employment of a primary of comparatively small size, and it is apt to heat when powerful effects are desirable for a certain length of time. In such a case it is better to employ a larger coil, Fig. 17 B, and introduce it from one side of the tube, until the streams begin to appear. In this case the nearest terminal of the secondary may be connected to the primary or to the ground, which is practically the same

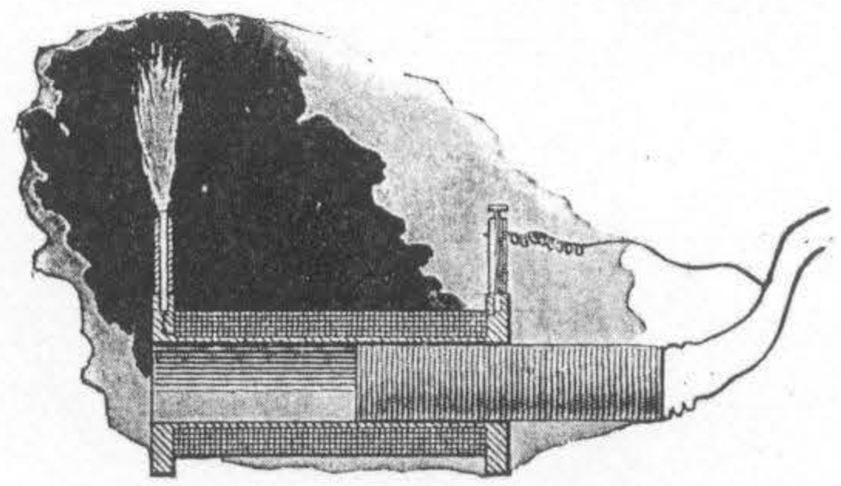

FIG. 17B.—COIL ARRANGED FOR POWERFUL BRUSH EFFECTS.—ST. ELMO'S HOT FIRE.

thing, if the primary is connected directly to the machine. In the case of ground connections it is well to determine experimentally the frequency which is best suited under the conditions of the test. Another way of obviating the streams, more or less, is to make the primary in sections and supply it from separate well insulated sources.

In many of these experiments, when powerful effects are wanted for a short time, it is advantageous to use iron cores with the primaries. In such case a very large primary coil may be wound and placed side by side with the secondary, and, the nearest terminal of the latter being connected to the primary, a laminated iron core is introduced through the primary into the secondary as far as the streams will permit. Under these conditions an excessively powerful brush, several inches long, which may be appropriately called "St. Elmo's hot fire," may be caused to appear at the other terminal of the secondary, producing striking effects. It is a most powerful ozonizer, so powerful indeed, that only a few minutes are sufficient to fill the whole room with the smell of ozone, and it undoubtedly possesses the quality of exciting chemical affinities.

For the production of ozone, alternating currents of very high frequency are eminently suited, not only on account of the advantages they offer in the way of conversion but also because of the fact, that the ozonizing action of a discharge is dependent on the frequency as well as on the potential, this being undoubtedly confirmed by observation.

In these experiments if an iron core is used it should be carefully watched, as it is apt to get excessively hot in an incredibly short time. To give an idea of the rapidity of the heating, I will state, that by passing a powerful

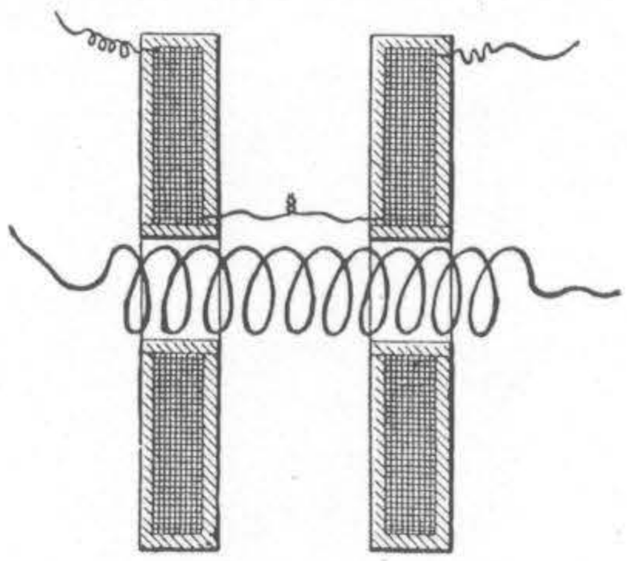

FIG. 18.—COIL FOR PRODUCING VERY HIGH DIFFERENCE OF POTENTIAL.

current through a coil with many turns, the inserting within the same of a thin iron wire for no more than one second's time is sufficient to heat the wire to something like 100° C.

But this rapid heating does not need to discourage us in the use of iron cores in connection with rapidly alternating currents. I have for a long time been convinced, that in the industrial distribution by means of transformers, some such plan as the following might be practicable. We may use a comparatively small iron core, subdivided, or perhaps not even subdivided. We may sur-

round this core with a considerable thickness of material which is fire-proof and conducts the heat poorly, and on top of that we may place the primary and secondary windings. By using either higher frequencies or greater magnetizing forces, we may by hystersis and eddy currents heat the iron core so far as to bring it nearly to its maximum permeability, which, as Hopkinson has shown, may be as much as sixteen times greater than that at ordinary temperatures. If the iron core were perfectly enclosed it would not be deteriorated by the heat, and, if the enclosure of fire-proof materi ıl would be sufficiently thick, only a limited amount of energy could be radiated in spite of the high temperature. Transformers have been constructed by me on that plan, but for lack of time, no thorough tests have as yet been made.

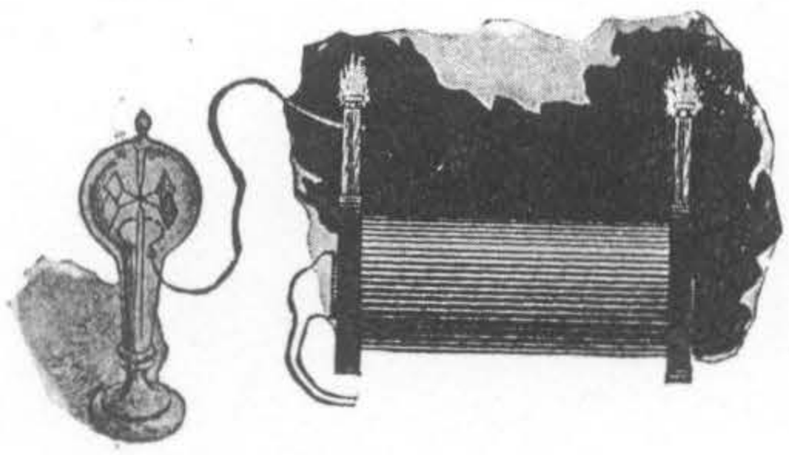

FIG. 19.—THE CROOKES EXPERIMENT ON OPEN CIRCUIT.

Another way of adapting the iron core to rapid alternations, or, generally speaking, reducing the frictional losses, is to produce by continuous magnetization a flow of something like seven thousand or eight thousand lines per square centimetre through the core, and then work with weak magnetizing forces and preferably high frequencies around the point of greatest permeability. A higher efficiency of conversion and greater output are obtainable in this manner. I have also employed this principle in connection with machines in which there is no reversal of polarity. In these types of machines, as long as there are only few pole projections, there is no great gain, as the maxima and minima of magnetization are far from the point of maximum permeabilty; but when the number of the pole projections is very great, the required rate of change may be obtained, without the magnetization varying so far as to depart greatly from the point of maximum permeability, and the gain is considerable.

The above described arrangements refer only to the use of commercial coils as ordinarily constructed. If it is desired to construct a coil for the express purpose of performing with it such experiments as I have described, or, generally, rendering it capable of withstanding the greatest possible difference of potential, then a construction as indicated in Fig. 18 will be found of advantage. The coil in this case is formed of two independent parts which are wound oppositely, the connection between both being made near the primary. The potential in the middle being zero, there is not much tendency to jump to the primary and not much insulation is required. In some cases, the middle point may, however, be connected to the primary or to the ground. In such a coil the places of greatest difference of potential are far apart and the coil is capable of withstanding an enormous strain. The two parts may be movable so as to allow a slight adjustment of the capacity effect.



FIG. 20.—LAMP WITH SINGLE BLOCK OF REFRACTORY MATERIAL.

As to the manner of insulating the coil, it will be found convenient to proceed in the following way: First the wire should be boiled in paraffine, until all the air is out; then the coil is wound by running the wire through melted paraffine, merely for the purpose of fixing the wire. The coil is then taken off from the spool, immersed in a cylindrical vessel filled with pure melted wax and boiled for a long time until the bubbles cease to appear. The whole is then left to cool down thoroughly, and then the mass is taken out of the vessel and turned up in a lathe. A coil made in this manner and with care is capable of withstanding enormous potential differences.

It may be found convenient to immerse the coil in paraffine oil or some other kind of oil; it is a most effective way of insulating, principally on account of the perfect exclusion of air, but it may be found that, after all, a vessel filled with oil is not a very convenient thing to handle in a laboratory.

If an ordinary coil can be dismounted, the primary may be taken out of the tube and the latter plugged up on one end, filled with oil, and the primary reinserted. This affords an excellent insulation and prevents the formation of the streams.

Of all the experiments which may be performed with rapidly alternating currents the most interesting are those which concern the production of a practical illuminant. It cannot be denied, that the present methods, though they were billiant advances, are very wasteful. Some better methods must be invented, some more perfect apparatus devised. Modern research has opened new possibilities for the production of an efficient source of light, and the attention of all has been turned in the direction indicated by able pioneers. Many have been carried away by the enthusiasm and passion to discover, but in their zeal to reach results, many have been misled. Starting with the idea of producing electro-magnetic waves, they turned their attention, perhaps, too much to the study of electro-magnetic effects, and neglected the study of electrostatic phenomena. Naturally, nearly every investigator availed himself of an apparatus similar to that used in earlier experiments. But in those forms of apparatus, while the electro-magnetic inductive effects are enormous, the electrostatic effects are excessively small.

In the Hertz experiments, for instance, a high tension induction coil is short circuited by an arc, the resistance of which is very small, the smaller, the more capacity is attached to the terminals; and the difference of potential at these is enormously

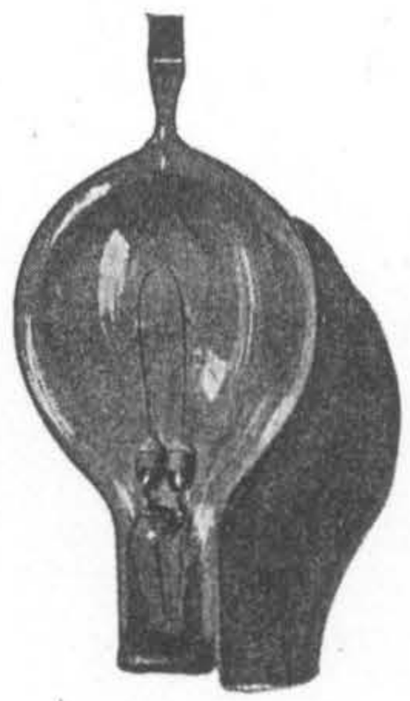

FIG. 21.—LAMP WITH TWO FILAMENTS IN HIGHEST VACUUM WITH LEADING-IN WIRES.

diminished. On the other hand, when the discharge is not passing between the terminals, the static effects may be considerable, but only qualitatively so, not quantitatively, since their rise and fall is very sudden, and since their frequency is small. In neither case, therefore, are powerful electrostatic effects perceivable. Similar conditions exist when, as in some interesting experiments of Dr. Lodge, Leyden jars are discharged disruptively. It has been thought—and I believe asserted—that in such cases most of the energy is radiated into space. In the light of the experiments, which I have described above, it will now not be thought so I feel safe in asserting, that in such cases most of the energy is partly taken up and converted into heat in the arc of the discharge and in the conducting and insulating material of the jar, some energy being, of course, given off by electrification of the air; but the amount of the directly radiated energy is very small.

When a high tension induction coil, operated by currents alternating only 20,000 times a second, has its terminals closed through even a very small jar, practically all the energy passes through the dielectric of the jar, which is heated, and the electrostatic effects manifest themselves outwardly only to a very weak degree. Now the external circuit of a Leyden jar, that is, the arc and the connections of the coatings may be looked upon as a circuit generating alternating currents of excessively high frequency and fairly high potential, which is closed through the coatings and the dielectric between them, and from the above it is evident that the external electrostatic effects must be very small, even if a recoil circuit be used. These conditions make it appear, that with the apparatus usually at hand the observation of powerful electrostatic effects was impossible, and what experience has been gained

in that direction is only due to the great ability of the investigators.

But powerful electrostatic effects are a *sine qua non* of light production on the lines indicated by theory. Electro-magnetic effects are primarily unavailable, for the reason that to produce the required effects we would have to pass current impulses through a conductor which, long before the required frequency of the impulses could be reached, would cease to transmit them. On the other hand, electro-magnetic waves many times longer than those of light, and producible by sudden discharges of a condenser, could not be utilized, it would seem, except we avail ourselves of their effect upon conductors as in the present methods, which are wasteful. We could not affect by means of such waves the static molecular or atomic charges of a gas, cause them to vi-



FIG. 22.—LAMP WITH TWO REFRACTORY BLOCKS IN HIGHEST VACUUM.

brate and to emit light. Long transverse waves cannot, apparently, produce such effects, since excessively small electro-magnetic disturbances may pass readily through miles of air. Such dark waves, unless they are of the length of true light waves, cannot, it would seem, excite luminous radiation in a Geissler tube, and the luminous effects, which are producible by induction in a tube devoid of electrodes, I am inclined to consider as being of an electrostatic nature.

To produce such luminous effects, straight electrostatic thrusts are required; these, whatever be their frequency, may disturb the molecular charges and produce light. Since current impulses of the required frequency cannot pass through a conductor of measurable dimensions, we must work with a gas, and then the production of powerful electrostatic effects becomes an imperative necessity.

It has occurred to me, however, that electrostatic effects are in many ways available for the production of light. For instance, we may place a body of some refractory material in a closed, and preferably more or less exhausted, globe, connect it to a source of high, rapidly alternating, potential, causing the molecules of the gas to strike it many times a second at enormous speeds, and in this manner, with trillions of invisible hammers, pound it until it gets incandescent; or, we may place a body in a very highly exhausted globe, in a non-striking vacuum, and, by employing very high frequencies and potentials, transfer sufficient energy from it to other bodies in the vicinity, or in general to the surroundings, to maintain it at any degree of incandescence; or, we may, by means of such rapidly alternating high potentials, disturb the ether carried by the molecules of a gas or their static charges, causing them to vibrate and to emit light.

But, electrostatic effects being dependent upon the potential and frequency, to produce the most powerful action it is desirable to increase both as far as practicable. It may be possible to obtain quite fair results by keeping either of these factors small, provided the other is sufficiently great; but we are limited in both directions. My experience demonstrates that we cannot go below a certain frequency, for, first, the potential then becomes so great that it is dangerous; and, secondly, the light production is less efficient.

I have found that, by using the ordinary low frequencies, the physiological effect of the current required to maintain at a certain degree of brightness a tube four feet long, provided at the ends with outside and inside condenser coatings, is so powerful that, I think, it might produce serious injury to those not accustomed to such shocks; whereas, with twenty thousand alternations per second, the tube may be maintained at the same degree of brightness without any effect being felt. This is due principally to the fact that a much smaller potential is required to produce the same light effect, and also to the higher efficiency in the light production. It is evident that the efficiency in such cases is the greater, the higher the frequency, for the quicker the process of charging and discharging the molecules, the less energy will be lost in the form of dark radiation. But, unfortunately, we cannot go beyond a certain frequency on account of the difficulty of producing and conveying the effects.

I have stated above, that a body enclosed in an unexhausted bulb may be intensely heated by simply connecting it with a source of rapidly alternating potential. The heating in such a case is, in all probability, due mostly to the bombardment of the molecules of the gas contained in the bulb. When the bulb is exhausted the heating of the body is much more rapid, and there is no difficulty whatever in bringing a wire or filament to any degree of incandescence by simply connecting it to one terminal of a coil of the proper dimensions. Thus, if the well-known apparatus of Prof. Crookes, consisting of a bent platinum wire with vanes mounted over it (Fig. 19), be connected to one terminal of the coil—either one or both ends of the platinum wire being connected—the wire is rendered almost instantly incandescent and the mica vanes are rotated as though a current from a battery were used. A thin carbon filament, or, preferably, a button of some refractory material (Fig. 20), even if it be a comparatively poor conductor, enclosed in an exhausted globe, may be rendered highly incandescent; and in this manner a simple lamp capable of giving any desired candle-power is provided.

The success of lamps of this kind would depend largely on the selection of the light-giving bodies contained within the bulb. Since, under the conditions described, refractory bodies—which are very poor conductors and capable of withstanding for a long time excessively high degrees of temperature—may be used, such illuminating devices may be rendered successful.

It might be thought at first that if the bulb, containing the filament or button of refractory material, be perfectly well exhausted—that is, as far as it can be done by the use of the best apparatus—the heating would be much less intense, and that in a perfect vacuum it could not occur at all. This is not confirmed by my experience; quite the contrary, the better the vacuum the more easily the bodies are brought to incandescence. This result is interesting for many reasons.

At the outset of this work the idea presented itself to me, whether two bodies of refractory material enclosed in a bulb exhausted to such a degree that the discharge of a large induction coil, operated in the usual manner, cannot pass through, could be rendered incandescent by mere condenser action. Obviously, to reach this result enormous potential differences and very high frequencies are required, as is evident from a simple calculation.

But such a lamp would possess a vast advantage over an ordinary incandescent lamp in regard to efficiency. It is well-known

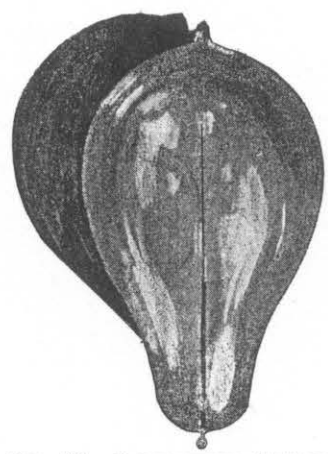

FIG. 23.—LAMP WITH SINGLE STRAIGHT FILAMENT AND ONE LEADING-IN WIRE.

that the efficiency of a lamp is to some extent a function of the degree of incandescence, and that, could we but work a filament at many times higher degrees of incandescence, the efficiency would be much greater. In an ordinary lamp this is impracticable on account of the destruction of the filament, and it has been determined by experience how far it is advisable to push the incandescence. It is impossible to tell how much higher efficiency could be obtained if the filament could withstand indefinitely, as the investigation to this end obviously cannot be carried beyond a certain stage; but there are reasons for believing that it would be very considerably higher. An improvement might be made in the ordinary lamp by employing a short and thick carbon;

but then the leading-in wires would have to be thick, and, besides, there are many other considerations which render such a modification entirely impracticable. But in a lamp as above described, the leading-in wires may be very small, the incandescent refractory material may be in the shape of blocks offering a very small radiating surface, so that less energy would be required to keep them at the desired incandescence; and in addition to this, the refractory material need not be carbon, but may be manufactured from mixtures of oxides, for instance, with carbon or other material, or may be selected from bodies which are practically non-

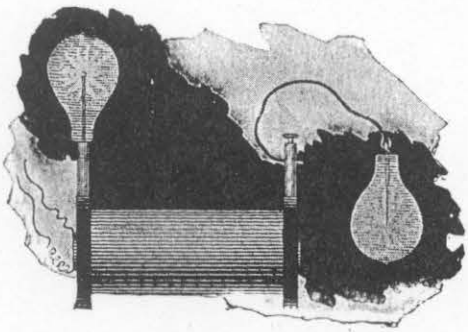

FIG. 24.—LAMPS WITH ONE LEADING-IN WIRE RENDERED INCANDESCENT.

conductors, and capable of withstanding enormous degrees of temperature.

All this would point to the possibility of obtaining a much higher efficiency with such a lamp than is obtainable in ordinary lamps. In my experience it has been demonstrated that the blocks are brought to high degrees of incandescence with much lower potentials than those determined by calculation, and the blocks may be set at greater distances from each other. We may freely assume, and it is probable, that the molecular bombardment is an important element in the heating, even if the globe be exhausted with the utmost care as I have done; for although the number of the molecules is, comparatively speaking, insignificant, yet on account of the mean free path being very great, there are fewer collisions, and the molecules may reach much higher speeds, so that the heating effect due to this cause may be considerable, as in the Crookes experiments with radiant matter.

But it is likewise possible that we have to deal here with an increased facility of losing the charge in very high vacuum, when the potential is rapidly alternating, in which case most of the heating would be directly due to the surging of the charges in the heated bodies. Or else the observed fact may be largely attributable to the effect of the points which I have mentioned above, in consequence of which the blocks or filaments contained in the vacuum are equivalent to condensers of many times greater surface than that calculated from their geometrical dimensions. Scientific men still differ in opinion as to whether a

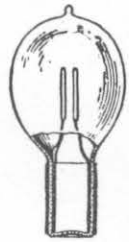

FIG. 25.—LAMP WITH TWO BLOCKS OR FILAMENTS AND A PAIR OF INDEPENDENT INSIDE AND OUTSIDE CONDENSER COATINGS.

charge should, or should not, be lost in a perfect vacuum, or in other words, whether ether is, or is not, a conductor. If the former were the case, then a thin filament enclosed in a perfectly exhausted globe, and connected to a source of enormous, steady potential, would be brought to incandescence.

Various forms of lamps on the above described principle, with the refractory bodies in the form of filaments, Fig. 21, or blocks, Fig. 22, have been constructed and operated by me, and investigations are being carried on in this line. There is no difficulty in reaching such high degrees of incandescence that ordinary carbon is to all appearance melted and volatilized. If the vacuum could be made absolutely perfect, such a lamp, although inoperative with apparatus ordinarily used, would, if operated with currents of the required character, afford an illuminant which would never be destroyed, and which would be far more efficient than an ordinary incandescent lamp. This perfection can, of course, never be reached, and a very slow destruction and gradual diminution of the size always occurs, as in incandescent lamps; but there is no possibility of a sudden and premature disabling which occurs in the latter by the breaking of the filament, especially when the incandescent bodies are in the shape of blocks.

With these rapidly alternating potentials there is, however, no necessity of enclosing two blocks in a globe, but a single block, as in Fig. 20, or filament, Fig. 23, may be used. The potential in this case must of course be higher, but it is easily obtainable, and besides it is not necessarily dangerous.

The facility with which the button or filament in such a lamp is brought to incandescence, other things being equal, depends on the size of the globe. If a perfect vacuum could be obtained, the size of the globe would not be of importance, for then the heating would be wholly due to the surging of the charges, and all the energy would be given off to the surroundings by radiation. But this can never occur in practice. There is always some gas left in the globe, and although the exhaustion may be carried to the highest degree, still the space inside of the bulb must be considered as conducting when such high potentials are used, and I assume that, in estimating the energy that may be given off from the filament to the surroundings, we may consider

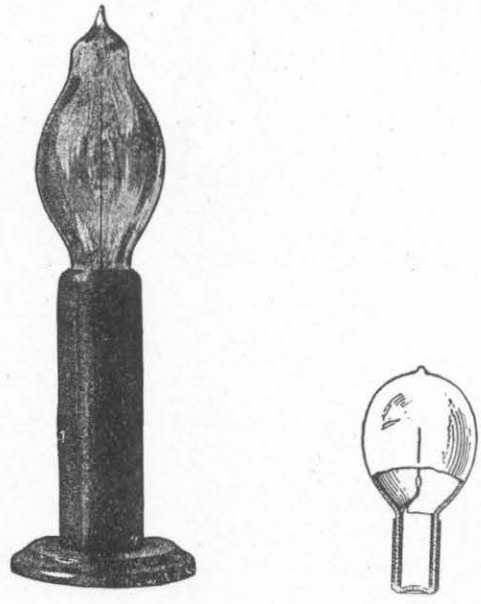

FIG. 26A. FIG. 26B.

LAMP WITH ONE FILAMENT, ONE INSIDE AND ONE OUTSIDE CONDENSER COATING.

the inside surface of the bulb as one coating of a condenser, the air and other objects surrounding the bulb forming the other coating. When the alternations are very low there is no doubt that a considerable portion of the energy is given off by the electrification of the surrounding air.

In order to study this subject better, I carried on some experiments with excessively high potentials and low frequencies. I then observed that when the hand is approached to the bulb,—the filament being connected with one terminal of the coil,—a powerful vibration is felt, being due to the attraction and repulsion of the molecules of the air which are electrified by induction through the glass. In some cases when the action is very intense I have been able to hear a sound, which must be due to the same cause.

When the alternations are low, one is apt to get an excessively powerful shock from the bulb. In general, when one attaches bulbs or objects of some size to the terminals of the coil, one should look out for the rise of potential, for it may happen that by merely connecting a bulb or plate to the terminal, the potential may rise to many times its original value. When lamps are attached to the terminals, as illustrated in Fig. 24, then the capacity of the bulbs should be such as to give the maximum rise of potential under the existing conditions. In this manner one may obtain the required potential with fewer turns of wire.

The life of such lamps as described above depends, of course, largely on the degree of exhaustion, but to some extent also on the shape of the block of refractory material. Theoretically it would seem that a small sphere of carbon enclosed in a sphere of

glass would not suffer deterioration from molecular bombardment, for, the matter in the globe being radiant, the molecules would move in straight lines, and would seldom strike the sphere obliquely. An interesting thought in connection with such a lamp is, that in it "electricity" and electrical energy apparently must move in the same lines.

The use of alternating currents of very high frequency makes it possible to transfer, by electrostatic or electromagnetic induction through the glass of a lamp, sufficient energy to keep a filament at incandescence and so do away with the leading-in wires. Such lamps have been proposed, but for want of proper apparatus they have not been successfully operated. Many forms of lamps on this principle with continuous and broken filaments have been constructed by me and experimented upon. When using a secondary enclosed within the lamp, a condenser is advantageously combined with the scondary. When the transference is effected by electrostatic induction, the potentials used are, of course, very high with frequencies obtainable from a machine. For instance, with a condenser surface of forty centimetres square, which is not impracticably large, and with glass of good quality 1 mm. thick, using currents alternating twenty thousand times a second, the potential required is approximately 9,000 volts. This may seem large, but since each lamp may be included in the secondary of a transformer of very small dimensions, it would not be inconvenient, and, moreover, it would not produce fatal injury. The transformers would all be preferably in series. The regulation would offer no difficulties, as with currents of such frequencies it is very easy to maintain a constant current.

In the accompanying engravings some of the types of lamps of this kind are shown. Fig. 25 is such a lamp with a broken filament, and Fig. 26 A and 26 B one with a single outside and inside coating and a single filament. I have also made lamps with two outside and inside coatings and a continuous loop connecting the latter. Such lamps have been operated by me with current impulses of the enormous frequencies obtainable by the disruptive discharge of condensers.

The disruptive discharge of a condenser is especially suited for operating such lamps—with no outward electrical connections—by means of electromagnetic induction, the electromagnetic inductive effects being excessively high; and I have been able to produce the desired incandescence with only a few short turns of wire. Incandescence may also be produced in this manner in a simple closed filament.

Leaving now out of consideration the practicability of such lamps, I would only say that they possess a beautiful and desirable feature, namely, that they can be rendered, at will, more or

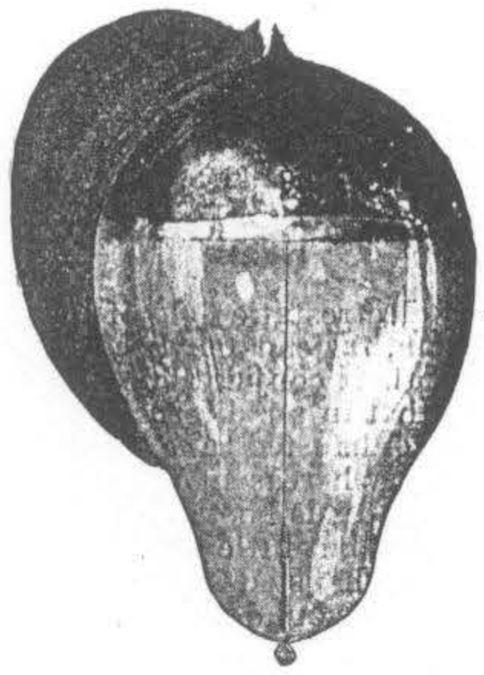

FIG. 27.—LAMP WITH ONE FILAMENT AND LEADING-IN WIRE AND EXTERNAL CONDENSER COATING.

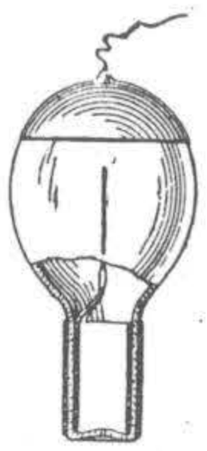

FIG. 28.—LAMP WITH ONE FILAMENT, ONE INSIDE AND ONE OUTSIDE CONDENSER COATING, AND AUXILIARY COATING.

less brilliant simply by altering the relative position of the outside and inside condenser coatings, or inducing and induced circuits.

When a lamp is lighted by connecting it to one terminal only of the source, this may be facilitated by providing the globe with an outside condenser coating, which serves at the same time as a reflector, and connecting this to an insulated body of some size. Lamps of this kind are illustrated in Fig. 27 and Fig. 28. Fig. 29 shows the plan of connections. The brilliancy of the lamp may, in this case, be regulated within wide limits by varying the size of the insulated metal plate to which the coating is connected.

It is likewise practicable to light with one leading wire lamps such as illustrated in Fig. 21 and Fig. 22, by connecting one terminal of the lamp to one terminal of the source, and the other to an insulated body of the required size. In all cases the insulated body serves to give off the energy into the surrounding space, and is equivalent to a return wire. Obviously, in the two last-named cases, instead of connecting the wires to an insulated body, connections may be made to the ground.

The experiments which will prove most suggestive and of most interest to the investigator are probably those performed with exhausted tubes. As might be anticipated, a source of such rapidly alternating potentials is capable of exciting the tubes at a considerable distance, and the light effects produced are remarkable.

During my investigations in this line I endeavored to excite tubes, devoid of any electrodos, by electromagnetic induction, making the tube the secondary of the induction device, and passing through the primary the discharges of a Leyden jar. These tubes were made of many shapes, and I was able to obtain luminous effects which I then thought were due wholly to electromagnetic induction. But on carefully investigating the phenomena I found that the effects produced were more of an electrostatic nature. It may be attributed to this circumstance that this mode of exciting tubes is very wasteful, namely, the primary circuit being closed, the potential, and consequently the electrostatic inductive effect, is much diminished.

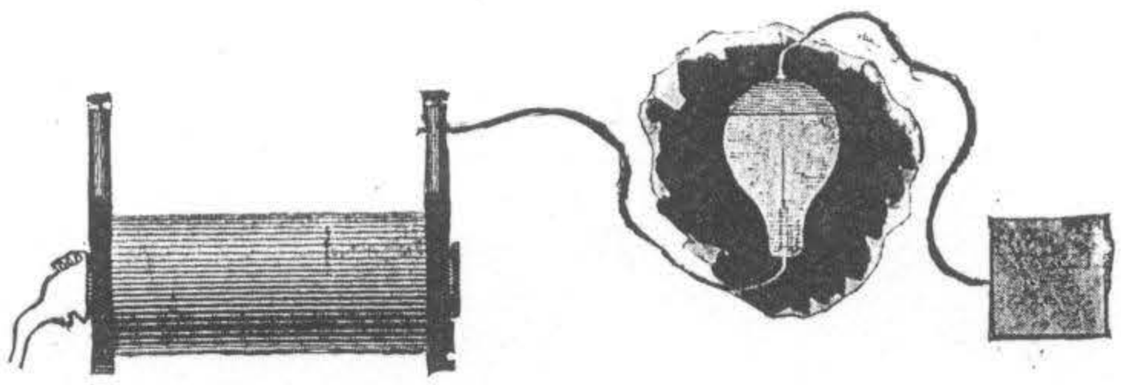

FIG. 29.—INCREASING THE BRILLIANCY OF LAMP ON ONE WIRE.

When an induction coil, operated as above described, is used, there is no doubt that the tubes are excited by electrostatic induction, and that electromagnetic induction has little, if anything, to do with the phenomena.

This is evident from many experiments. For instance, if a tube be taken in one hand, the observer being near the coil, it is brilliantly lighted and remains so no matter in what position it is held relatively to the observer's body. Were the action electromagnetic, the tube could not be lighted when the observer's body is interposed between it and the coil, or at least its luminosity should be considerably diminished. When the tube is held exactly over the centre of the coil—the latter being wound in sections and the primary placed symmetrically to the secondary—it may remain completely dark, whereas it is rendered intensely luminous by moving it slightly to the right or left from the centre of the coil. It does not light because in the middle both halves of the coil neutralize each other, and the electric potential is zero. If the action were electromagnetic, the tube should light best in the plane through the centre of the coil, since the electromagnetic effect there should be a maximum. When an arc is established between the terminals, the tubes and lamps in the vicinity of the coil go out, but light up again when the arc is broken, on account of the rise of potential. Yet the electromagnetic effect should be practically the same in both cases.

By placing a tube at some distance from the coil, and nearer to one terminal—preferably at a point on the axis of the coil—one may light it by touching the remote terminal with an insulated body of some size or with the hand, thereby raising the potential at that terminal nearer to the tube. If the tube is shifted nearer to the coil so that it is lighted by the action of the nearer terminal, it may be made to go out by holding, on an insulated support, the end of a wire connected to the remote terminal, in the vicinity of the nearer terminal, by this means counteracting the action of the latter upon the tube. These effects are evidently electrostatic. Likewise, when a tube is placed at a considerable distance from the coil, the observer may, standing upon an insulated support, between coil and tube, light the latter by approaching the hand to it; or he may even render it luminous by simply stepping between it and the coil. This would be impossible with electromagnetic induction, for the body of the observer would act as a screen.

When the coil is energized by excessively weak currents, the experimenter may, by touching one terminal of the coil with the tube, extinguish the latter, and may again light it by bringing it out of contact with the terminal and allowing a small arc to form. This is clearly due to the respective lowering and raising of the potential at that terminal. In the above experiment, when the tube is lighted through a small arc, it may go out when the arc is broken, because the electrostatic inductive effect alone is too weak, though the potential may be much higher; but when the arc is established, the electrification of the end of the tube is much greater, and it consequently lights.

If a tube is lighted by holding it near to the coil, and in the hand which is remote, by grasping the tube anywhere with the other hand, the part between the hands is rendered dark, and the singular effect of wiping out the light of the tube may be pro-

duced by passing the hand quickly along the tube and at the same time withdrawing it gently from the coil, judging properly the distance so that the tube remains dark afterwards.

If the primary coil is placed sidewise, as in Fig. 17 B for instance, and an exhausted tube be introduced from the other side in the hollow space, the tube is lighted most intensely because of the increased condenser action, and in this position the striæ are most sharply defined. In all these experiments described, and in many others, the action is clearly electrostatic.

The effects of screening also indicate the electrostatic nature of the phenomena and show something of the nature of electrification through the air. For instance, if a tube be placed in the direction of the axis of the coil, and an insulated metal plate be interposed, the tube will generally increase in brilliancy, or if it be too far from the coil to light, it may even be rendered luminous by interposing an insulated metal plate. The magnitude of the effects depends to some extent on the size of the plate. But if the metal plate be connected by a wire to the ground, its interposition will always make the tube go out even if it be very near the coil. In general, the interposition of a body between the coil and tube, increases or diminishes the brilliancy of the tube, or its facility to light up, according to whether it increases or diminishes the electrification. When experimenting with an insulated plate, the plate should not be taken too large, else it will generally produce a weakening effect by reason of its great facility for giving off energy to the surroundings.

If a tube be lighted at some distance from the coil, and a plate of hard rubber or other insulating substance be interposed, the tube may be made to go out. The interposition of the dielectric in this case only slightly increases the inductive effect, but diminishes considerably the electrification through the air.

field. For this purpose I suspend a sheet of metal a distance from the ceiling on insulating cords and connect it to one terminal of the induction coil, the other terminal being preferably connected to the ground. Or else I suspend two sheets as illustrated in Fig. 30, each sheet being connected with one of the terminals of the coil, and their size being carefully determined. An exhausted tube may then be carried in the hand anywhere between the sheets or placed anywhere, even a certain distance beyond them; it remains always luminous.

In such an electrostatic field interesting phenomena may be observed, especially if the alternations are kept low and the potentials excessively high. In addition to the luminous phenomena mentioned, one may observe that any insulated conductor gives sparks when the hand or another object is approached to it, and the sparks may often be powerful. When a large conducting object is fastened on an insulating support, and the hand approached to it a vibration, due to the rythmical motion of the air molecules is felt, and luminous streams may be perceived when the hand is held near a pointed projection. When a telephone receiver is made to touch with one or both of its terminals an insulated conductor of some size, the telephone emits a loud sound; it also emits a sound when a length of wire is attached to one or both terminals, and with very powerful fields a sound may be perceived even without any wire.

How far this principle is capable of practical application, the future will tell. It might be thought that electrostatic effects are unsuited for such action at a distance. Electromagnetic inductive effects, if available for the production of light, might be thought better suited. It is true the electrostatic effects diminish nearly with the cube of the distance from the coil, whereas the electromagnetic inductive effects diminish simply with the dis-

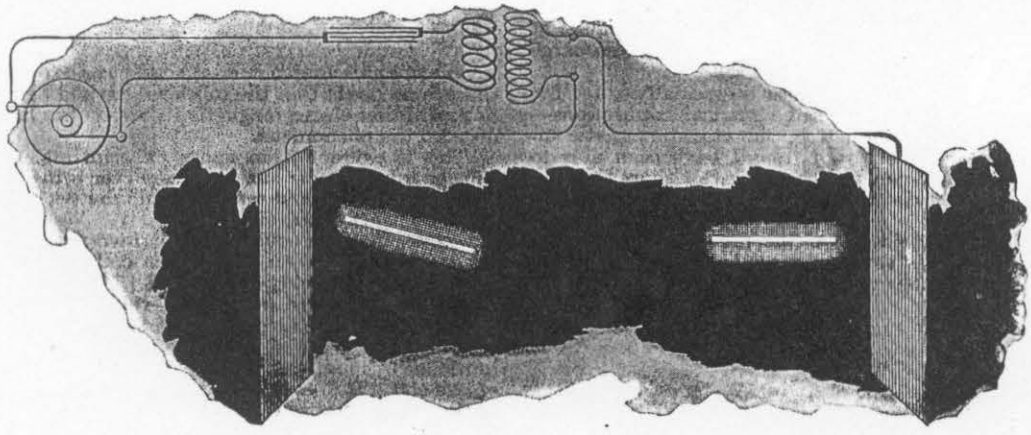

FIG. 30.—IDEAL METHOD OF LIGHTING A ROOM.—TUBES DEVOID OF ANY ELECTRODES RENDERED BRILLIANT IN AN ALTERNATING ELECTROSTATIC FIELD.

In all the cases, then, when we excite luminosity in exhausted tubes by means of such a coil, the effect is due to the rapidly alternating electrostatic potential; and, furthermore, it must be attributed to the harmonic alternation produced directly by the machine, and not to any superimposed vibration which might be thought to exist. Such superimposed vibrations are impossible when we work with an alternate current machine. If a spring be gradually tightened and released, it does not perform independent vibrations; for this a sudden release is necessary. So with the alternate currents from a dynamo machine; the medium is harmonically strained and released, this giving rise to only one kind of waves; a sudden contact or break, or a sudden giving way of the dielectric, as in the disruptive discharge of a Leyden jar, are essential for the production of superimposed waves.

In all the last described experiments, tubes devoid of any electrodes may be used, and there is no difficulty in producing by their means sufficient light to read by. The light effect is, however, considerably increased by the use of phosphorescent bodies such as yttria, uranium glass, etc. A difficulty will be found when the phosphorescent material is used, for with these powerful effects, it is carried gradually away, and it is preferable to use material in the form of a solid.

Instead of depending on induction at a distance to light the tube, the same may be provided with an external—and, if desired, also with an internal—condenser coating, and it may then be suspended anywhere in the room from a conductor connected to one terminal of the coil, and in this manner a soft illumination may be provided.

The ideal way of lighting a hall or room would, however, be to produce such a condition in it that an illuminating device could be moved and put anywhere, and that it is lighted, no matter where it is put and without being electrically connected to anything. I have been able to produce such a condition by creating in the room a powerful, rapidly alternating electrostatic

tance. But when we establish an electrostatic field of force, the condition is very different, for then, instead of the differential effect of both the terminals, we get their conjoint effect. Besides, I would call attention to the fact, that in an alternating electrostatic field, a conductor, such as an exhausted tube, for instance, tends to take up most of the energy, whereas in an electromagnetic alternating field the conductor tends to take up the least energy, the waves being reflected with but little loss. This is one reason why it is difficult to excite an exhausted tube, at a distance, by electromagnetic induction. I have wound coils of very large diameter and of many turns of wire, and connected a Geissler tube to the ends of the coil with the object of exciting the tube at a distance; but even with the powerful inductive effects producible by Leyden jar discharges, the tube could not be excited unless at a very small distance, although some judgment was used as to the dimensions of the coil. I have also found that even the most powerful Leyden jar discharges are capable of exciting only feeble luminous effects in a closed exhausted tube, and even these effects upon thorough examination I have been forced to consider of an electrostatic nature.

How then can we hope to produce the required effects at a distance by means of electromagnetic action, when even in the closest proximity to the source of disturbance, under the most advantageous conditions, we can excite but faint luminosity? It is true that when acting at a distance we have the resonance to help us out. We can connect an exhausted tube, or whatever the illuminating device may be, with an insulated system of the proper capacity, and so it may be possible to increase the effect qualitatively, and only qualitatively, for we would not get *more* energy through the device. So we may, by resonance effect, obtain the required electromotive force in an exhausted tube, and excite faint luminous effects, but we cannot get enough energy to render the light practically available, and a simple calculation, based on experimental results, shows that even if all the energy

which a tube would receive at a certain distance from the source should be wholly converted into light, it would hardly satisfy the practical requirements. Hence the necessity of directing, by means of a conducting circuit, the energy to the place of transformation. But in so doing we cannot very sensibly depart from present methods, and all we could do would be to improve the apparatus.

From these considerations it would seem that if this ideal way of lighting is to be rendered practicable it will be only by the use of electrostatic effects. In such a case the most powerful electrostatic inductive effects are needed; the apparatus employed must, therefore, be capable of producing high electrostatic potentials changing in value with extreme rapidity. High frequencies are

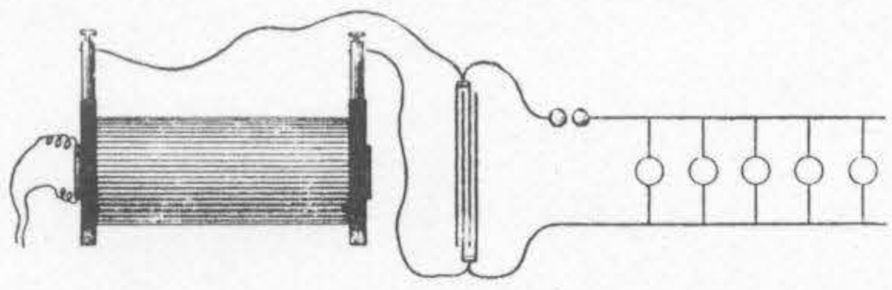

FIG. 31.—DIAGRAM OF CONNECTIONS FOR CONVERTING FROM HIGH TO LOW TENSION BY MEANS OF THE DISRUPTIVE DISCHARGE.

especially wanted, for practical considerations make it desirable to keep down the potential. By the employment of machines, or, generally speaking, of any mechanical apparatus, but low frequencies can be reached; recourse must, therefore, be had to some other means. The discharge of a condenser affords us a means of obtaining frequencies by far higher than are obtainable mechanically, and I have accordingly employed condensers in the experiments to the above end.

When the terminals of a high tension induction coil, Fig. 31, are connected to a Leyden jar, and the latter is discharging disruptively into a circuit, we may look upon the arc playing between the knobs as being a source of alternating, or generally speaking, undulating currents, and then we have to deal with the familiar system of a generator of such currents, a circuit connected to it, and a condenser bridging the circuit. The condenser in such case is a veritable transformer, and since the frequency is excessive, almost any ratio in the strength of the currents in both the branches may be obtained. In reality the analogy is not quite complete, for in the disruptive discharge we have most generally a fundamental instantaneous variation of comparatively low frequency, and a superimposed harmonic vibration, and the laws governing the flow of currents are not the same for both.

In converting in this manner, the ratio of conversion should not be too great, for the loss in the arc between the knobs increases with the square of the current, and if the jar be discharged through very thick and short conductors, with the view of obtaining a very rapid oscillation, a very considerable portion of the energy stored is lost. On the other hand, too small ratios are not practicable for many obvious reasons.

As the converted currents flow in a practically closed circuit, the electrostatic effects are necessarily small, and I therefore convert them into currents or effects of the required character. I have effected such conversions in several ways. The preferred plan of connections is illustrated in Fig. 32. The manner of operating renders it easy to obtain by means of a small and inexpensive apparatus enormous differences of potential which have been

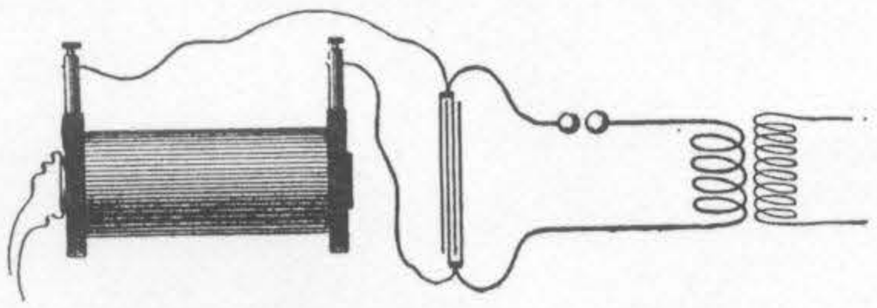

FIG. 32.—MANNER OF OPERATING AN INDUCTION COIL.

usually obtained by means of large and expensive coils. For this it is only necessary to take an ordinary small coil, adjust to it a condenser and discharging circuit, forming the primary of an auxiliary small coil, and convert upward. As the inductive effect of the primary currents is excessively great, the second coil need have comparatively but very few turns. By properly adjusting the elements, remarkable results may be secured.

In endeavoring to obtain the required electrostatic effects in this manner, I have, as might be expected, encountered many difficulties which I have been gradually overcoming, but I am not as yet prepared to dwell upon my experiences in this direction.

I believe that the disruptive discharge of a condenser will play an important part in the future, for it offers vast possibilities, not only in the way of producing light in a more efficient manner and in the line indicated by theory, but also in many other respects.

For years the efforts of inventors have been directed towards obtaining electrical energy from heat by means of the thermopile. It might seem invidious to remark that but few know what is the real trouble with the thermopile. It is not the inefficiency or small output—though these are great drawbacks—but the fact that the thermopile has its phylloxera, that is, that by constant use it is deteriorated, which has thus far prevented its introduction on an industrial scale. Now that all modern research seems to point with certainty to the use of electricity of excessively high tension, the question must present itself to many whether it is not possible to obtain in a practicable manner this form of energy from heat. We have been used to look upon an electrostatic machine as a plaything, and somehow we couple with it the idea of the inefficient and impractical. But now we must think differently, for now we know that everywhere we have to deal with the same forces, and that it is a mere question of inventing proper methods or apparatus for rendering them available.

In the present systems of electrical distribution, the employment of the iron with its wonderful magnetic properties allows us to reduce considerably the size of the apparatus; but, in spite of this, it is still very cumbersome. The more we progress in the study of electric and magnetic phenomena, the more we become convinced that the present methods will be short-lived. For the production of light, at least, such heavy machinery would seem

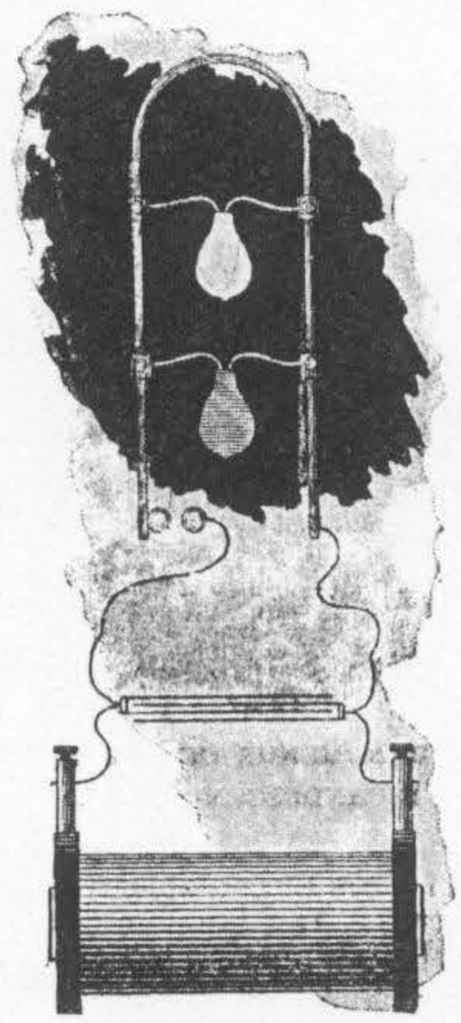

FIG. 33.—LAMP KEPT AT INCANDESCENCE ACROSS A THICK COPPER BAR—SHOWING NODES.

to be unnecessary. The energy required is very small, and if light can be obtained as efficiently as, theoretically, it appears possible, the apparatus need have but a very small output. There being a strong probability that the illuminating methods of the future will involve the use of very high potentials, it seems very desirable to perfect a contrivance capable of converting the energy of heat into energy of the requisite form. Nothing to speak of has been done towards this end, for the thought that electricity of some 50,000 or 100,000 volts pressure or more, even if obtained, would be unavailable for practical purposes, has deterred inventors from working in this direction.

In Fig. 31 a plan of connections is shown for converting currents of high, into currents of low, tension by means of the disruptive discharge of a condenser. This plan has been used by me frequently for operating a few incandescent lamps required in the laboratory. Some difficulties have been encountered in the arc of the discharge which I have been able to overcome to a great extent; besides this, and the adjustment necessary for the proper working, no other difficulties have been met with, and it was easy to operate ordinary lamps, and even motors, in this manner. The line being connected to the ground, all the wires could be handled with perfect impunity, no matter how high the potential at the terminals of the condenser. In these experiments a high tension induction coil, operated from a battery or from an alternate current machine, was employed to charge the condenser; but the induction coil might be replaced by an apparatus of a different kind, capable of giving electricity of such high tension. In this manner, direct or alternating currents may be converted,

and in both cases the current-impulses may be of any desired frequency. When the currents charging the condenser are of the same direction, and it is desired that the converted currents should also be of one direction, the resistance of the discharging circuit should, of course, be so chosen that there are no oscillations.

In operating devices on the above plan I have observed curious phenomena of impedance which are of interest. For instance if a thick copper bar be bent, as indicated in Fig. 33, and shunted by ordinary incandescent lamps, then, by passing the discharge between the knobs, the lamps may be brought to incandescence although they are short-circuited. When a large induction coil is employed it is easy to obtain nodes on the bar, which are rendered evident by the different degree of brilliancy of the lamps, as shown roughly in Fig. 33. The nodes are never clearly defined, but there are simply maxima and minima of potentials along the bar. This is probably due to the irregularity of the arc between the knobs. In general when the above described plan of conversion from high to low tension is used, the behavior of the disruptive discharge may be closely studied. The nodes may also be investigated by means of an ordinary Cardew voltmeter which should be well insulated. Geissler-tubes may also be lighted accross the points of the bent bar; in this case, of course, it is better to employ smaller capacities. I have found it practicable to light up in this manner a lamp, and even a Geissler tube, shunted by a short heavy block of metal, and this result seems at first very curious. In fact, the thicker the copper bar in Fig. 33, the better it is for the success of the experiments, as they appear more striking. When lamps with long slender filaments are used it will be often noted that the filaments are from time to time violently vibrated, the vibration being smallest at the nodal points. This vibration seems to be due to an electrostatic action between the filament and the glass of the bulb.

In some of the above experiments it is preferable to use special lamps having a straight filament as shown in Fig. 34. When such

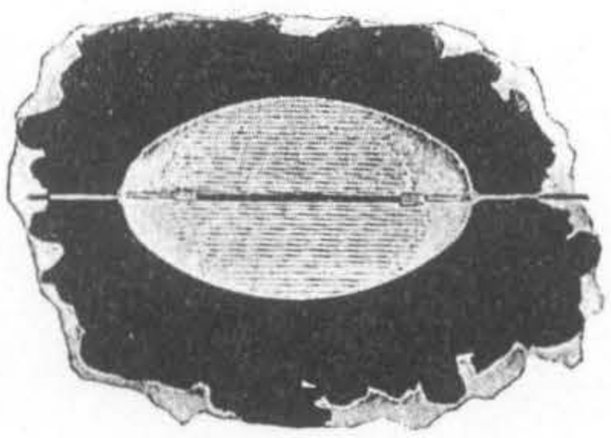

FIG. 34.—PHENOMENON OF IMPEDANCE IN AN INCANDESCENT LAMP.

a lamp is used a still more curious phenomenon than those described may be observed. The lamp may be placed across the copper bar and lighted, and by using somewhat larger capacities, or, in other words, smaller frequencies, or smaller impulsive impedances, the filament may be brought to any desired degree of incandescence. But when the impedance is increased, a point is reached when comparatively little current passes through the carbon, and most of it through the rarefied gas; or perhaps it may be more correct to state that the current divides nearly evenly through both, in spite of the enormous difference in the resistance, and this would be true unless the gas and the filament behave differently. It is then noted that the whole bulb is brilliantly illuminated, and the ends of the leading-in wires become incandescent and often throw off sparks in consequence of the violent bombardment, but the carbon filament remains dark. This is illustrated in Fig. 34. Instead of the filament a single wire extending through the whole bulb may be used, and in this case the phenomenon would seem to be still more interesting.

From the above experiment it will be evident, that when ordinary lamps are operated by the converted currents, those should be preferably taken in which the platinum wires are far apart, and the frequencies used should not be too great, else the discharge will occur at the ends of the filament or in the base of the lamp between the leading-in wires, and the lamp might then be damaged.

In presenting to you these results of my investigation on the subject under consideration, I have paid only a passing notice to facts upon which I could have dwelt at length, and among many observations I have selected only those which I thought most likely to interest you. The field is wide and completely unexplored, and at every step a new truth is gleaned, a novel fact observed.

How far the results here borne out are capable of practical applications will be decided in the future. As regards the production of light, some results already reached are encouraging and make me confident in asserting that the practical solution of the problem lies in the direction I have endeavored to indicate. Still, whatever may be the immediate outcome of these experiments I am hopeful that they will only prove a step to further development towards the ideal and final perfection. The possibilities which are opened by modern research are so vast that even the most reserved must feel sanguine of the future. Eminent scientists consider the problem of utilizing one kind of radiation without the others a rational one. In an apparatus designed for the production of light by conversion from any form of energy into that of light, such a result can never be reached, for no matter what the process of producing the required vibrations, be it electrical, chemical or any other, it will not be possible to obtain the higher light vibrations without going through the lower heat vibrations. It is the problem of imparting to a body a certain velocity without passing through all lower velocities. But there is a possibility of obtaining energy not only in the form of light, but motive power, and energy of any other form, in some more direct way from the medium. The time will be when this will be accomplished, and the time has come when one may utter such words before an enlightened audience without being considered a visionary. We are whirling through endless space with an inconceivable speed, all around us everything is spinning, everything is moving, everywhere is energy. There *must* be some way of availing ourselves of this energy more directly. Then, with the light obtained from the medium, with the power derived from it, with every form of energy obtained without effort, from the store forever inexhaustible, humanity will advance with giant strides. The mere contemplation of these magnificent possibilities expands our minds, strengthens our hopes and fills our hearts with supreme delight.

The New York Times July 9, 1891

WIRELESS ELECTRIC LAMPS

MR. TESLA'S EXPERIMENTS WITH HIGH FREQUENCY ALTERNATIONS.

The electrical world is just now experiencing a thrill of delight because of the remarkable experiments of Nikola Tesla, a young Austro-Hungarian, who has made this city his home and who promises to become famous in his profession. The particular subject upon which this gentleman has so wonderfully perfected himself is that of alternating currents of high frequency, a subject on which he recently delivered a lecture at Columbia College before the American Institute of Electrical Engineers.

While there was much in Mr. Tesla's paper that applied to the most occult branches of theoretical electricity, there was also much that appealed to the layman because of the great promise it gave of future commercial importance. Mr. Tesla is now engaged in perfecting an improved system of electric lighting by which from a given amount of electrical energy, a light many times stronger than any yet produced may be secured without wires or pipes of any kind connecting with the light itself. Wires from a station leading to the building to be lighted will still be employed, and much of the machinery that is now used in an ordinary incandescent-lighting plant will be used, but with the difference that the lamps may be carried about in the hand, that the walls and ceilings will not be defaced by wires and pipes, and that the light will be very much stronger than that now in use. The methods by which Mr. Tesla was led to these conclusions are obtained from his paper, which has just been made public.

His attention was first drawn to an ordinary induction coil from which sparks are developed similar to those evolved from a static frictional electric machine. The currents that operated these coils were alternating, with from 100 to 200 vibrations a second. In order to obtain greatly increased effects Mr. Tesla constructed a machine which produced 20,000 alternations per second. This experiment resulted in several interesting phenomena.

By attaching a wire to one of the terminals of such a coil streams of light issued in all directions, showing how intense was the nature of the forces at work. He then placed a fine platinum wire in a glass bulb and the tremendous force of the current set the platinum to spinning about in a veritable cone of illumination. This led to the construction o a practical form of lamp, consisting of a glass bulb from which the air had been exhausted, and which contained a button of some refractory material connected with a wire leading to the outside of the bulb. This lamp glowed brightly. It established the first point of Mr. Tesla's experiments by doing away with the two-wire system now in use.

This, however, by no means satisfied him. "The use of alternating currents of very high frequency," he says, "makes it possible to transfer by electrostatic or electromagnetic induction through the glass of a lamp sufficient energy to keep a filament at incandescence, and so do away with the leading-in wires." In other words, he contemplated the creation of a lamp without external connections of any sort, which, placed anywhere in an apartment, should glow brightly. He produces a sketch showing the manner in which he proposes to carry out such a system in practice. There is a primary electric generator at the central station, with wires leading to the building or apartment where the light is desired. At this point there is placed in the circuit an apparatus similar in principle to the Leyden jar, called a condenser.

An induction coil close to it converts the currents of low potential coming from the machine to those of the very high potential required in the new method. The room which is to be lighted contains two sheets of metal, which may be suspended from the ceiling or placed within opposite walls. The electric impulses thrown out by the metallic plates fill the room with an electrical force. The force becomes especially manifest when there is exposed in the room a medium especially susceptible to its action, such as tubes exhausted of air. With such plates properly placed in the room "an exhausted tube," says Mr. Tesla "may be carried in the hand anywhere between the sheets or placed anywhere, even at a certain distance beyond them; it remains always luminous."

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NEW YORK, JULY 11, 1891.

TESLA'S RESEARCHES IN RAPID ALTERNATION AT HIGH TENSION.

The full text of Nikola Tesla's lecture on high frequency and high tension currents for electric lighting is given in this issue of the REVIEW. The paper is of unusual length but is of transcendant interest and we have made special efforts to present the entire paper in one number. The subject matter discussed is pioneer work, the results are very striking; in general they have been already published in the REVIEW. They will set hundreds of explorers at work in a new and promising field of investigation; whether or not a commercial system of lighting will grow out of it remains to be seen. The lecturer indicates that a condenser can be utilized to increase at will the frequency of alternation; that a mere change of its static capacity will be followed by a corresponding change of frequency. The system of distribution recently patented by Mr. Tesla, and described in the last REVIEW, is based upon this principle. A comparatively low tension current of ordinary periodicity—such a current as furnished by commercial alternators now in use—can be generated at the power station, and conveyed to the point of consumption and there raised both in tension and frequency by a local device comprising a condenser and an induction coil. Whether currents of such enormous tension could, after conversion, be conveyed with safety through a building, or be kept upon the conductor; whether the leakage which must inevitably occur would not lower the efficiency of the system until it would be crowded out of sight in competition with the systems of lighting now in use; whether the self-induction of a few hundred feet of wire would not militate seriously against a successful result, and necessitate a converting, tension-raising, period-transforming device for every lamp used, are questions not discussed in the lecture, but readily capable of experimental demonstration. Mr. Tesla covered a vast experimental territory in his investigation, as the great variety of results clearly shows. The work will now be followed by numerous minds in such a variety of ways that its commercial possibilities cannot long remain in doubt.

Experiments with Alternate Currents of Very High Frequency and their Application to Methods of Artificial Illumination.

A LECTURE DELIVERED BEFORE THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, AT COLUMBIA COLLEGE, MAY 20, 1891, BY NIKOLA TESLA.

There is no subject more captivating, more worthy of study, than nature. To understand this great mechanism, to discover the forces which are active, and the laws which govern them, is the highest aim of the intellect of man.

Nature has stored up in the universe infinite energy. The eternal recipient and transmitter of this infinite energy is the ether. The recognition of the existence of ether, and of the functions it performs, is one of the most important results of modern scientific research. The mere abandoning of the idea of action at a distance, the assumption of a medium pervading all space and connecting all gross matter, has freed the minds of thinkers of an ever-present doubt, and, by opening a new horizon—new and unforeseen possibilities—has given fresh interest to phenomena with which we are familiar of old. It has been a great step towards the understanding of the forces of nature and their multifold manifestations to our senses. It has been for the enlightened student of physics what the understanding of the mechanism of the firearm or of the steam engine was for the barbarian. Phenomena upon which we used to look as wonders baffling explanation, we now see in a different light. The spark of an induction coil, the glow of an incandescent lamp, the manifestations of the mechanical forces of currents and magnets are no longer beyond our grasp; instead of the incomprehensible, as before, their observation suggests now in our minds a simple mechanism, and although as to its precise nature all is still conjecture, yet we know that the truth cannot be much longer hidden, and instinctively we feel that the understanding is dawning upon us. We still admire these beautiful phenomena, these strange forces, but we are helpless no longer; we can in a certain measure explain them, account for them, and we are hopeful of finally succeeding in unraveling the mystery which surrounds them.

In how far we can understand the world around us is the ultimate thought of every student of nature. The coarseness of our senses prevents us from recognizing the ulterior construction of matter, and astronomy, this grandest and most positive of natural sciences, can only teach us something that happens, as it were, in our immediate neighborhood; of the remoter portions of the boundless universe, with its numberless stars and suns, we know nothing. But far beyond the limit of perception of our senses the spirit still can guide us, and so we may hope that even these unknown worlds—infinitely small and great—may in a measure become known to us. Still, even if this knowledge should reach us, the searching mind will find a barrier, perhaps forever unsurpassable, to the *true* recognition of that which *seems* to be, the mere *appearance* of which is the only and slender basis of all our philosophy.

Of all the forms of nature's immeasurable, all-pervading energy, which, ever and ever changing and moving, like a soul animates the inert universe, those of electricity and magnetism are perhaps the most fascinating. The effects of gravitation, of heat and light we observe daily, and soon we get accustomed to them, and soon they lose for us the character of the marvelous and wonderful; but electricity and magnetism, with their singular relationship, with their seemingly dual character, unique among the forces in nature, with their phenomena of attractions, repulsions and rotations, strange manifestations of mysterious agents, stimulate and excite the mind to thought and research. What is electricity, and what is magnetism? These questions have been asked again and again. The most able intellects have ceaselessly wrestled with the problem; still the question has not as yet been fully answered. But, while we cannot even to day state what these singular forces are, yet we have made good headway towards the solution of the problem. We are now confident that electric and magnetic phenomena are attributable to ether; and we are, perhaps, justified in saying that the effects of static electricity are effects of ether under strain, and those of dynamic electricity and electro-magnetism effects of ether in motion. But this still leaves the question, as to what electricity and magnetism are, unanswered.

First, we naturally inquire, What is electricity, and is there such a thing as electricity? In interpreting electric phenomena, we may speak of electricity or of an electric condition, state or effect. If we speak of electric effects we must distinguish two such effects opposite in character, and neutralizing each other, as observation shows that two such opposite effects exist. This is unavoidable, for in a medium of the properties of ether, we cannot possibly exert a strain, or produce a displacement or motion of any kind, without causing in the surrounding medium an equivalent and opposite effect. But if we speak of electricity, meaning a *thing*, we must, I think, abandon the idea of two electricities, as the existence of two such things is highly improbable. For how can we imagine that there should be two things, equivalent in amount, alike in their properties, but of opposite character, both clinging to matter, both attracting and completely neutralizing each other? Such an assumption, though suggested by many phenomena, though most convenient for explaining them, has little to commend it. If there *is* such a thing as electricity, there can be only *one* such thing, and, excess and want of that one thing, possibly, but more probably its condition, determines the positive and negative character. The old theory of Franklin, though falling short in some respects, is, from a certain point of view, after all, the most plausible one. Still, in spite of this, the theory of the two electricities is generally accepted, as it apparently explains electric phenomena in a more satisfactory manner. But a theory which explains better the facts is not necessarily true. Ingenious minds will invent theories to suit observation, and almost every independent thinker has his own views on the subject.

It is not with the object of advancing an opinion, but with the desire of acquainting you better with some of the results which I will describe, to show you the reasoning I have followed, the departures I have made, that I venture to express, in a few words, the views and convictions which have led me to these results.

I adhere to the idea that there is a thing which we have been in the habit of calling electricity. The question is, What is that thing? or, What, of all things, the existence of which we know, have we the best reason to call electricity? We know that it acts like an incompressible fluid; that there must be a constant quantity of it in nature; that it can be neither produced nor destroyed; and, what is more important, the electromagnetic theory of light and all facts observed teach us that electric and ether phenomena are identical. The idea at once suggests itself, therefore, that electricity might be called ether. In fact, this view has in a certain sense been advanced by Dr. Lodge. His interesting work has been read by every one, and many have been convinced by his arguments. His great ability and the interesting nature of the subject, keep the reader spellbound; but when the impressions fade one realizes that he has to deal only with ingenious explanations. I must confess, that I cannot believe in two electricities, much less in a doubly constituted ether. The puzzling behavior of the ether as a solid to waves of light and heat, and as a fluid to the motion of bodies through it, is certainly explained in the most natural and satisfactory manner by assuming it to be in motion, as Sir William Thomson has suggested; but regardless of this, there is nothing which would enable us to conclude with certainty that, while a fluid is not incapable of transmitting transverse vibrations of a few hundred or thousand per second, it might not be capable of transmitting such vibrations when they range into hundreds of million millions per second. Nor can any one prove that there are transverse ether waves emitted from an alternate current machine, giving a small number of alternations per second; to such slow disturbances the ether, if at rest, may behave as a true fluid.

Returning to the subject, and bearing in mind that the existence of two electricities is, to say the least, highly improbable, we must remember, that we have no evidence of electricity, nor can we hope to get it, unless gross matter is present. Electricity, therefore, cannot be called ether in the broad sense of the term; but nothing would seem to stand in the way of calling electricity ether associated with matter, or bound ether; or, in other words, that the so-called static charge of the molecule is ether associated in some way with the molecule. Looking at it in that light, we would be justified in saying, that electricity is concerned in all molecular action.

Now, precisely what the ether surrounding the molecules is, wherein it differs from ether in general, can only be conjectured. It cannot differ in density, ether being incompressible; it must, therefore, be under some strain or in motion, and the latter is the most probable. To understand its functions, it would be necessary to have an exact idea of the physical construction of matter, of which, of course, we can only form a mental picture.

But of all the views of nature, the one which assumes one matter and one force, and a perfect uniformity throughout, is the most scientific and most likely to be true. An infinitesimal world, with the molecules and their atoms spinning and moving in orbits, in much the same manner as celestial bodies, carrying with them and probably spinning with them ether, or in other words, carrying with them static charges, seems to my mind the most probable view, and one which, in a plausible manner, accounts for most of the phenomena observed. The spinning of the molecules and their ether sets up ether tensions or electrostatic strains; the equalization of ether tensions sets up ether motions or electric currents, and the orbital movements produce the effects of electro and permanent magnetism.

About 15 years ago, Professor Rowland demonstrated a most interesting and important fact, namely, that a static charge carried around produces the effects of an electric current. Leaving out of consideration the precise nature of the mechanism which produces the attraction and repulsion of currents, and conceiving the electrostatically charged molecules in motion, this experimental fact gives us a fair idea of magnetism. We can conceive lines or tubes of force which physically exist, being formed of rows of directed moving molecules; we can see that these lines must be closed; that they must tend to shorten and expand, etc. It likewise explains in a reasonable way, the most puzzling phenomenon of all, permanent magnetism, and, in general, has all the beauties of the Ampere theory without possessing the vital defect of the same, namely, the assumption of molecular currents. Without enlarging further upon the subject, I would say, that I look upon all electrostatic, current and magnetic phenomena as being due to electrostatic molecular forces.

The preceding remarks I have deemed necessary to a full understanding of the subject as it presents itself to my mind.

Of all these phenomena the most important to study are the current phenomena, on account of the already extensive and ever-growing use of currents for industrial purposes. It is now a century since the first practical source of current has been produced, and, ever since, the phenomena which accompany the flow of currents have been diligently studied, and through the untiring efforts of scientific men the simple laws which govern them have been discovered. But these laws were found to hold good only when the currents are of a steady character. When the currents are rapidly varying in strength quite different phenomena, often unexpected, present themselves, and quite different laws hold good, which even now have not been determined as fully as is desirable, though through the work, principally, of English scientists, enough knowledge has been gained on the subject to enable us to treat simple cases, which now present themselves in daily practice.

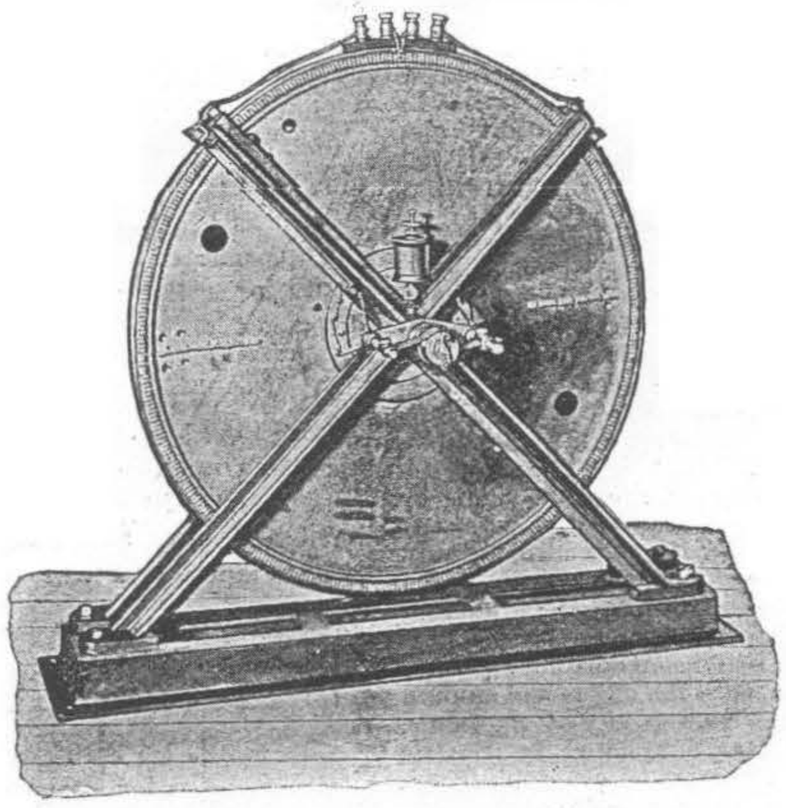

FIG. 1.—HIGH FREQUENCY ALTERNATOR WITH DRUM ARMATURE.

The phenomena which are peculiar to the changing character of the currents are greatly exalted when the rate of change is increased, hence the study of these currents is considerably facilitated by the employment of properly constructed apparatus. It was with this and other objects in view that I constructed alternate current machines capable of giving more than two million reversals of current per minute, and to this circumstance it is principally due that I am able to bring to your attention some of the results thus far reached, which I hope will prove to be a step in advance on account of their direct bearing upon one of the most important problems, namely, the production of a practical and efficient source of light.

The study of such rapidly alternating currents is very interesting. Nearly every experiment discloses something new. Many results may, of course, be predicted, but many more are unforeseen. The experimenter makes many interesting observations. For instance, we take a piece of iron and hold it against a magnet. Starting from low alternations and running up higher and higher we feel the impulses succeed each other faster and faster, get weaker and weaker, and finally disappear. We then observe a continuous pull; the pull, of course, is not continuous; it only appears so to us; our sense of touch is imperfect.

We may next establish an arc between the electrodes and observe as the alternations rise, that the note which accompanies alternating arcs gets shriller and shriller, gradually weakens, and finally ceases. The air vibrations, of course, continue, but they are too weak to be perceived; our sense of hearing fails us.

We observe the small physiological effects, the rapid heating of the iron cores and conductors, curious inductive effects, interesting condenser phenomena and still more interesting light phenomena with a high tension induction coil. All these experiments and observations would be of the greatest interest to the student, but their description would lead me too far from the principal subject. Partly for this reason, and partly on account of the vastly greater importance, I will confine myself to the description of the light effects produced by these currents.

In the experiments to this end a high tension induction coil or equivalent apparatus for converting currents of comparatively low into currents of high tension is used.

If you will be sufficiently interested in the results I shall describe as to enter into an experimental study of this subject; if you will be convinced of the truth of the arguments I shall advance, your aim will be to produce high frequencies and high potentials; in other words, powerful electrostatic effects. You will then encounter many difficulties, which, if completely overcome, would allow us to produce truly wonderful results.

First will be met the difficulty of obtaining the required frequencies by means of mechanical apparatus, and, if they be obtained otherwise, obstacles of a different nature will present themselves. Next it will be found difficult to provide the requisite insulation without considerably increasing the size of the apparatus, for the potentials required are high, and owing to the rapidity of the alternations, the insulation presents peculiar difficulties. So, for instance, when a gas is present the discharge may work through by the molecular bombardment of the gas and consequent heating, through as much as an inch of the best solid insulating material, such as glass, hard rubber, porcelain, sealing wax, etc.; in fact, through any known insulating substance. The chief requisite in the insulation of the apparatus is, therefore, the exclusion of any gaseous matter.

In general my experience tends to show that bodies which possess the highest specific inductive capacity, such as glass, afford a rather inferior insulation to others, which, while they are good insulators, have a much smaller specific inductive capacity, such as oils, for instance, the dielectric losses being no doubt greater in the former. The difficulty of insulating, of course, only exists when the potentials are excessively high, for with potentials such as a few thousand volts there is no particular difficulty encountered in conveying currents from a machine giving, say, 20,000 alternations per second to quite a distance. This number of alternations, however, is by far too small for many purposes, though quite sufficient for some practical applications. This difficulty of insulating is fortunately not a vital drawback; it affects mostly the size of the apparatus, for, when excessively high potentials would be used, the light-giving devices would be located not far from the apparatus, and often they would be quite close to it. As the air bombardment of the insulated wire is dependent on condenser action, the loss may be reduced to a trifle by using excessively thin wires heavily insulated.

Another difficulty which will be encountered is the capacity and self induction necessarily possessed by the coil. If the coil be

large, that is, if it contains a great length of wire, it will be generally unsuited for excessively high frequencies; if it be small, it may be well adapted for such frequencies, but the potential might then not be as high as desired. A good insulator, and preferably

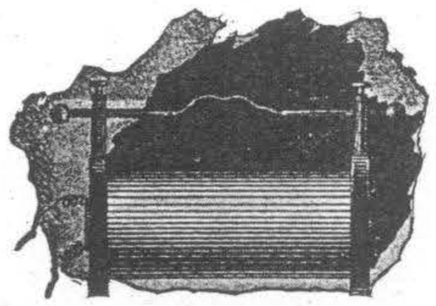

FIG. 4.—SENSITIVE THREAD DISCHARGE.

one possessing a small specific inductive capacity, would afford a two-fold advantage. First, it would enable us to construct a very small coil capable of withstanding enormous differences of potential; and secondly, such a small coil, by reason of its smaller capacity and self-induction, would be capable of a quicker and more vigorous vibration. The problem, then, of constructing a coil or induction apparatus of any kind possessing the requisite qualities I regard as one of no small importance, and it has occupied me for a considerable time.

The investigator who desires to repeat the experiments which I will describe, with an alterate current machine, capable of supplying currents of the desired frequency, and an induction coil, will do well to take the primary coil out and mount the secondary in such a manner as to be able to look through the tube upon which the secondary is wound. He will then be able to observe the streams which pass from the primary to the insulating tube, and from their intensity he will know how far he can strain the coil. Without this precaution he is sure to injure the insulation. This arrangement permits, however, an easy exchange of the primaries, which is desirable in these experiments.

The selection of the type of machine best suited for the purpose, must be left to the judgment of the experimenter. There are

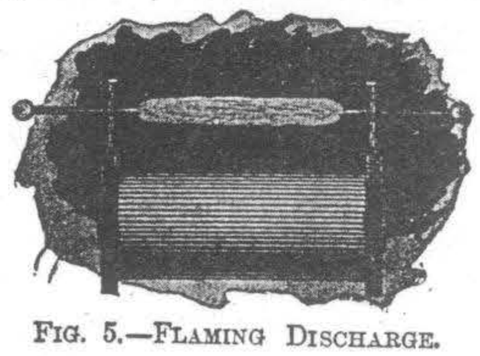

FIG. 5.—FLAMING DISCHARGE.

here illustrated three distinct types of machines, which, besides others, I have used in my experiments.

Fig. 1 represents the machine used in my experiments before this Institute. The field-magnet consists of a ring of wrought iron with 384 pole projections. The armature comprises a steel disk to which is fastened a thin, carefully welded rim of wrought iron. Upon the rim are wound several layers of fine, well annealed iron wire, which, when wound, is passed through shellac. The armature wires are wound around brass pins, wrapped with silk thread. The diameter of the armature wire in this type of machine should not be more than one-sixth of the thickness of the pole projections, else the local action will be considerable.

Fig. 2 represents a larger machine of a different type. The field-magnet of this machine consists of two like parts which either enclose an exciting coil, or else are independently wound. Each part has 480 pole projections, the projections of one facing those of the other. The armature consists of a wheel of hard bronze, carrying the conductors which revolve between the projections of the field-magnet. To wind the armature conductors, I have found it most convenient to proceed in the following manner: I construct a ring of hard bronze of

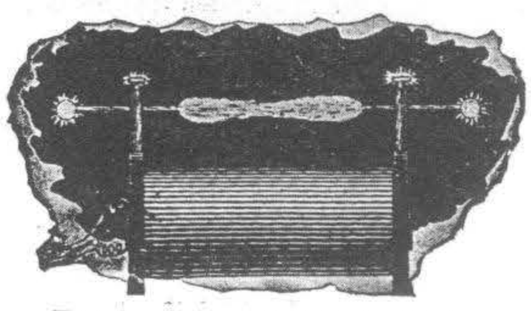

FIG. 6.—STREAMING DISCHARGE.

the required size. This ring and the rim of the wheel are provided with the proper number of pins, and both fastened upon a plate. The armature conductors being wound, the pins are cut off, and the ends of the conductors fastened by two rings which screw to the bronze ring and the rim of the wheel, respectively. The whole may then be taken off, and forms a solid structure. The conductors in such a type of machine should consist of sheet copper, the thickness of which, of course, depends on the thickness of the pole projections; or else twisted thin wires should be employed.

Fig. 3 is a smaller machine, in many respects similar to the former, only here the armature conductors and the exciting coil are kept stationary, while only a block of wrought iron is revolved.

It would be uselessly lengthening this description were I to dwell more on the details of construction of these machines. Besides, they have been described somewhat more elaborately in *The Electrical Engineer*, of March 18, 1891. I deem it well, however, to call the attention of the investigator to two things, the importance of which, though self-evident, he is nevertheless apt to underestimate; namely, to the local action in the conductors, which must be carefully avoided, and to the clear-

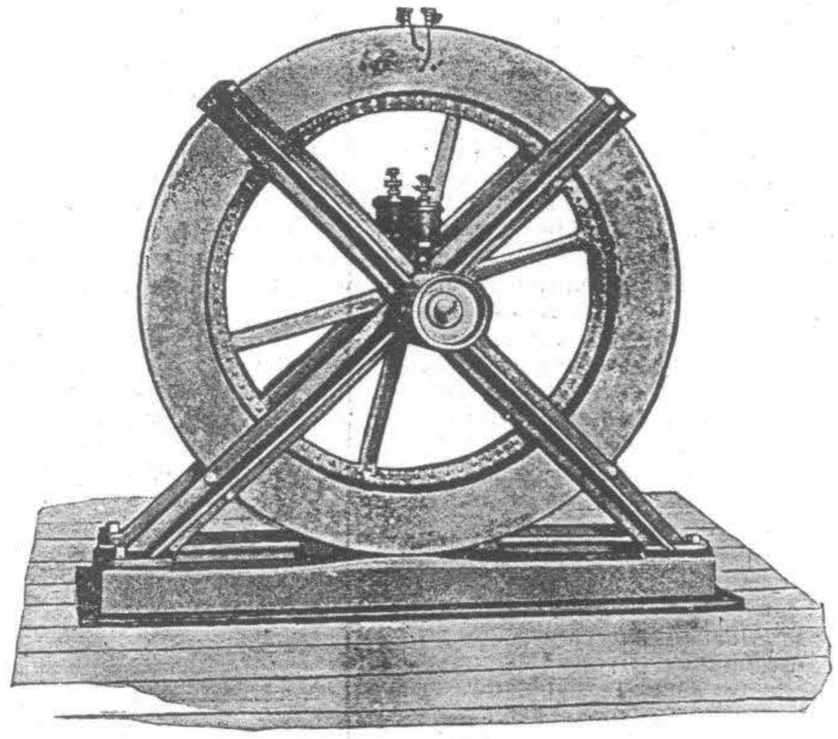

FIG. 2.—HIGH FREQUENCY ALTERNATOR WITH REVOLVING DISC ARMATURE.

ance, which must be small. I may add, that since it is desirable to use very high peripheral speeds, the armature should be of very large diameter in order to avoid impracticable belt speeds. Of the several types of these machines which have been constructed by me, I have found that the type illustrated in Fig. 1 caused me the least trouble in construction as well as in maintenance, and, on the whole, it has been a good experimental machine.

In operating an induction coil with very rapidly alternating currents, among the first luminous phenomena noticed are naturally those presented by the high tension discharge. As the number of alternations per second is increased, or as—the number being high—the current through the primary is varied, the discharge gradually changes in appearance. It would be difficult to describe

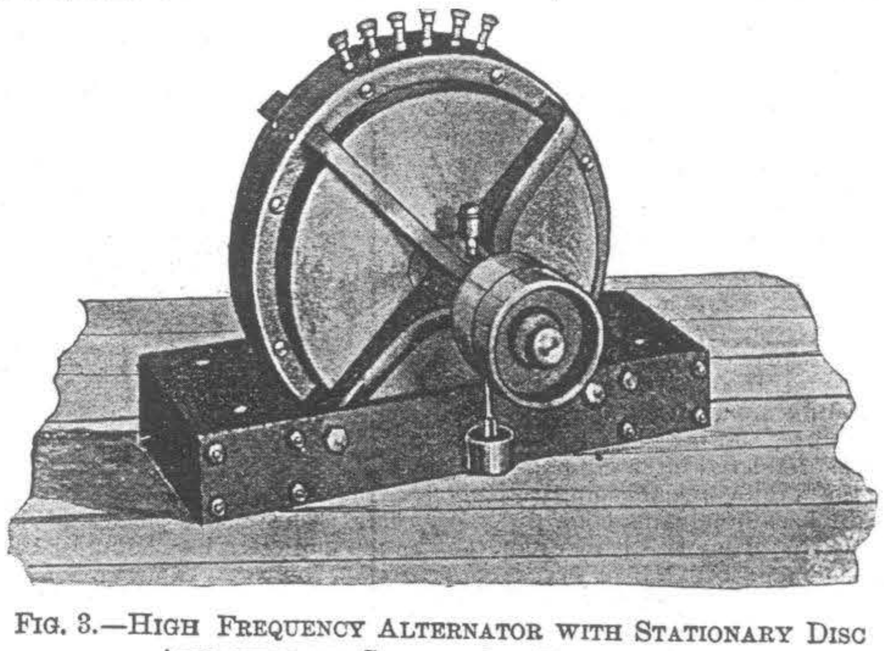

FIG. 3.—HIGH FREQUENCY ALTERNATOR WITH STATIONARY DISC ARMATURE AND STATIONARY EXCITING COIL.

the minor changes which occur and the conditions which bring them about, but one may note five distinct forms of the discharge.

First, one may observe a weak, sensitive discharge in the form of a thin feeble-colored thread. (Fig. 4.) It always occurs when the number of alternations per second being high, the current through the primary is very small. In spite of the excessively small current, the rate of change is great and the difference of potential at the terminals of the secondary is therefore considerable, so that the arc is established at great distances; but the quantity of "electricity" set in motion is insignificant, barely sufficient to maintain a thin, threadlike arc. It is excessively sensitive, and may be made so to such a degree that the mere act of breathing near the coil will affect it, and unless it is perfectly well protected from currents of air, it wriggles around constantly. Nevertheless, it is in this form excessively persistent, and when the terminals are approached to, say, one-third of the striking distance, it can be blown out only with difficulty. This exceptional persistency, when short, is largely due to the arc being excessively thin; presenting, therefore, a very small surface to the blast. Its great sensitiveness, when very long, is probably due to the motion of the particles of dust suspended in the air.

When the current through the primary is increased the discharge gets broader and stronger, and the effect of the capacity of the coil becomes visible until, finally, under proper conditions, a white flaming arc, Fig. 5, often as thick as one's finger and striking across the whole coil, is produced. It develops remarkable heat, and may be further characterized by the absence of the high note which accompanies the less powerful discharges. To take a shock from the coil under these conditions would not be advisable, although under different conditions, the potential being much higher, a shock from the coil may be taken with impunity. To produce this kind of discharge the number of alternations per second must not be too great for the coil used; and, generally speaking, certain relations between capacity, self-induction and frequency must be observed.

The importance of these elements in an alternate current circuit is now well known, and under ordinary conditions the general rules are applicable. But in an induction coil exceptional conditions prevail. First, the self-induction is of little importance before the arc is established, when it asserts itself, but perhaps never as prominently as in ordinary alternate current circuits, because capacity is distributed all along the coil, and by reason of the fact that the coil usually discharges through very great resistances; hence the currents are exceptionally small. Secondly, the capacity goes on increasing continually as the potential rises, in consequence of absorption, which takes place to a considerable extent. Owing to this there exists no critical relationship between these quantities, and ordinary rules would not seem to be applicable. As the potential is increased, either in consequence of the increased frequency or of the increased current through the primary, the amount of the energy stored becomes greater and greater and the capacity gains more and more in importance. Up to a certain point the capacity is beneficial, but after that it begins to be an enormous drawback. It follows from this that each coil gives the best result with a given frequency and primary current. A very large coil when operated with currents of very high frequency may not give as much as one-eighth inch spark. By adding capacity to the terminals the condition may be improved, but what the coil really wants is a lower frequency.

When the flaming discharge occurs the conditions are evidently such that the greatest current is made to flow through the circuit. These conditions may be attained by varying the frequency within wide limits, but the highest frequency at which the flaming arc can still be produced determines,

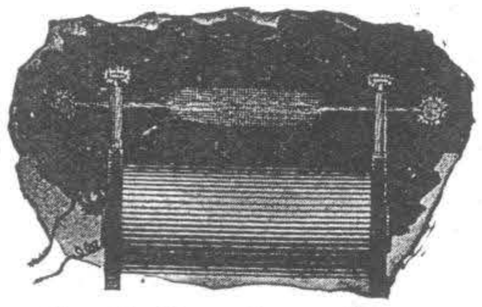

FIG. 7.—BRUSH AND SPRAY DISCHARGE.

for a given primary current, the maximum striking distance of the coil. In the flaming discharge the *éclat* effect of the capacity is not perceptible; the rate at which the energy is being stored then just equals the rate at which it can be disposed of through the circuit. This kind of discharge is the severest test for a coil; the break, when it occurs, is of the nature of that in an overcharged Leyden jar. To give a rough approximation I would state that, with an ordinary coil of, say 10,000 ohms resistance, the most powerful arc would be produced with about 12,000 alternations per second.

When the frequency is increased beyond that rate the potential, of course, rises, but the striking distance may, nevertheless, diminish, paradoxical as it may seem. As the potential rises the coil attains more and more the properties of a static machine until, finally, one may observe the beautiful phenomenon of the streaming discharge, Fig. 6, which may be produced across the whole length of the coil. At that stage streams begin to issue freely from all points and projections. These streams will also be seen to pass in abundance in the space between the primary and the insulating tube. When the potential is excessively high they will always appear, even if the frequency be low, and even if the primary be surrounded by as much as an inch of wax, hard rubber, glass or any other insulating substance.

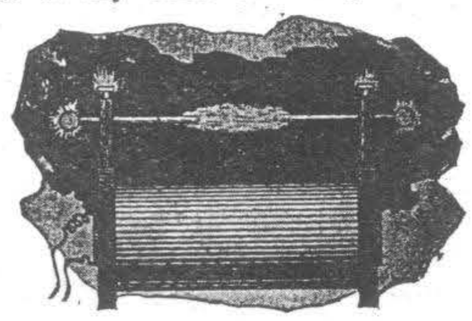

FIG. 8.—FIFTH TYPICAL FORM OF DISCHARGE.

This limits greatly the output of the coil, but I will later show how I have been able to overcome to a considerable extent this disadvantage in the ordinary coil.

Besides the potential, the intensity of the streams depends on the frequency; but if the coil be very large they show themselves, no matter how low the frequencies used. For instance, in a very large coil of resistance of 67,000 ohms, constructed by me some time ago, they appear with as low as 100 alternations per second and less, the insulation of the secondary being three-fourths inch of ebonite. When very intense they produce a noise similar to that produced by the charging of a Holtz machine, but much more powerful, and they emit a strong smell of ozone. The lower the frequency, the more apt they are to suddenly injure the coil. With excessively high frequencies they may pass freely without producing any other effect than to heat the insulation slowly and uniformly.

The existence of these streams shows the importance of constructing an expensive coil so as to permit of one's seeing through the tube surrounding the primary, and the latter

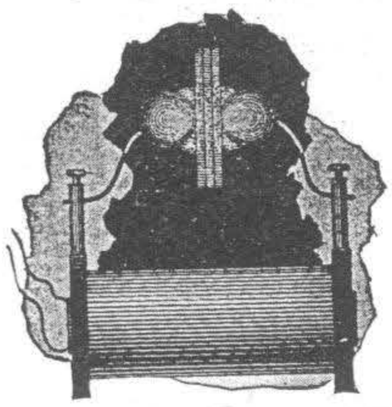

FIG. 9.—LUMINOUS DISCHARGE WITH INTERPOSED INSULATORS.

should be easily exchangeable; or else the space between the primary and secondary should be completely filled up with insulating material so as to exclude all air. The non-observance of this simple rule in the construction of the commercial coils is responsible for the destruction of many an expensive coil.

At the stage when the streaming discharge occurs, or with somewhat higher frequencies, one may, by approaching the terminals considerably and regulating properly the effect of capacity, produce a veritable spray of small silver-white sparks or a bunch of excessively thin silvery threads (Fig. 7) amidst a powerful brush—each spark or thread possibly corresponding to one alternation. This, when produced under proper conditions, is probably the most beautiful discharge, and when an air blast is directed against it, it presents a singular appearance. The spray of sparks, when received through the body, causes some inconvenience, where-

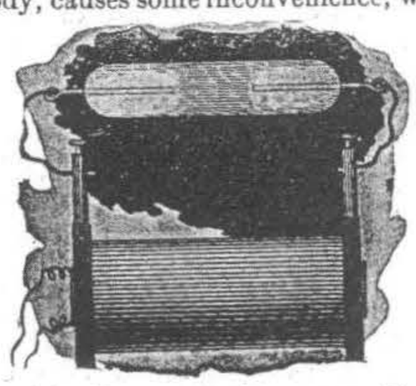

FIG. 10.—DISCHARGE THROUGH HIGHEST VACUUM.

as, when the discharge simply streams nothing at all is likely to be felt if large conducting objects are held in the hands to protect them from receiving small burns.

If the frequency is still more increased, then the coil refuses to give any spark unless at comparatively small distances, and the fifth typical form of discharge may be observed (Fig. 8). The tendency to stream out and dissipate is then so great that when the brush is produced at one terminal no sparking occurs even if, as I have repeatedly tried, the hand, or any conducting object, is held within the stream; and, what is more singular, the luminous stream is not at all easily deflected by the approach of a conducting body.

At this stage the streams seemingly pass with the greatest freedom through considerable thicknesses of insulators, and it is particularly interesting to study their behavior. For this purpose it is convenient to connect to the terminals of the coil two metallic spheres which may be placed at any desired distance (Fig. 9). Spheres are preferable to plates, as the discharge can be better observed. By inserting dielectric bodies between the spheres beautiful discharge phenomena may be observed. If the spheres be quite close and a spark be playing between them, by interposing a thin plate of ebonite between the spheres the spark instantly ceases and the discharge spreads into an intensely luminous circle several inches in diameter, provided the spheres are sufficiently large. The passage of the streams heats, and, after awhile, softens the rubber so much that two plates may be made to stick together in this manner. If the spheres are so far apart that no spark occurs, even if they are far beyond the striking distance, by inserting a thick plate of glass the discharge is instantly induced to pass from the spheres to the glass in the form of luminous streams. It appears almost as though these streams pass *through* the dielectric. In reality this is not the case, as the streams are due to the molecules of the air, which are violently agitated in the space between the oppositely charged surfaces of the spheres. When no dielectric other than air is present, the bombardment goes on, but is too weak to be visible; by inserting a dielectric the inductive effect is much increased, and, besides the projected air molecules find an obstacle and the bombardment becomes so intense that the streams become luminous.

If, by any mechanical means we could effect such a violent agitation of the molecules, we could produce the same phenomenon. A jet of air escaping through a

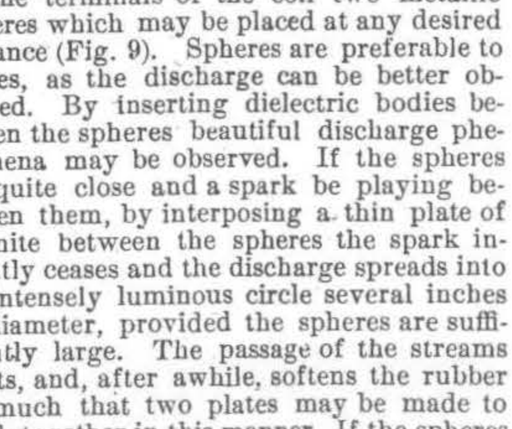

FIG. 11.—PINWHEEL DRIVEN BY A POWERFUL BRUSH.

small hole under enormous pressure and striking against an insulating substance, such as glass, may be luminous in the dark, and it might be possible to produce phosphorescence of the glass or other insulators in this manner.

The greater the specific inductive capacity of the interposed dielectric, the more powerful the effect produced. Owing to this, the streams show themselves with excessively high potentials, even if the glass be as much as one and one-half to two inches thick. But besides the heating due to bombardment, some heating goes on undoubtedly in the dielectric, being apparently greater in glass than in ebonite. I attribute this to the greater specific inductive capacity of the glass, in consequence of which, with the same potential difference, a greater amount of energy is taken up in it than in rubber. It is like connecting to a battery a copper and a brass wire of the same dimensions. The copper wire, though a more perfect conductor, would heat more by reason of its taking more current. Thus, what is otherwise considered a virtue of the glass is here a defect. Glass usually gives way much quicker than ebonite; when it is heated to a certain degree, the discharge suddenly breaks through at one point, assuming then the ordinary form of an arc.

The heating effect produced by molecular bombardment of the dielectric would, of course, diminish as the pressure of the air is increased, and at enormous pressures it would be negligible, unless the frequency would increase correspondingly.

It will be often observed in these experiments that when the spheres are beyond the striking distance, the approach of a glass plate, for instance, may induce the spark to jump between the spheres. This occurs when the capacity of the spheres is somewhat below the critical value which gives the greatest difference of potential at the terminals of the coil. By approaching a dielectric the specific inductive capacity of the space between the spheres is increased, producing the same effect as if the capacity of the spheres were increased. The potential at the terminals may then rise so high that the space is cracked. The experiment is best performed with dense glass or mica.

Another interesting observation is that a plate of insulating material, when the discharge is passing through it, is strongly attracted by either of the spheres, that is, by the nearer one, this being obviously due to the smaller mechanical effect of the bombardment on that side, and perhaps also to the greater electrification.

From the behavior of the dielectrics in these experiments we may conclude that the best insulator for these rapidly alternating currents would be the one possessing the smallest specific inductive capacity, and at the same time one capable of withstanding the greatest differences of potential; and

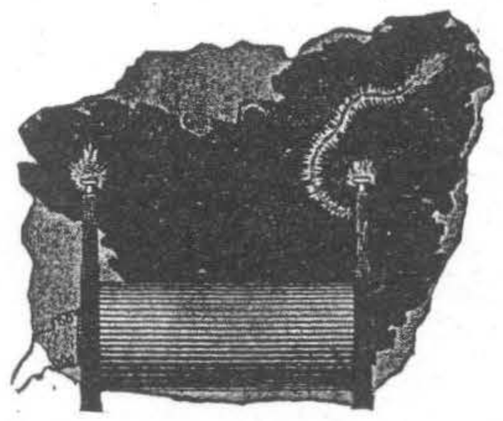

FIG. 12.—LUMINOUS STREAMS ESCAPING FROM A COTTON-COVERED WIRE.

thus two diametrically opposite ways of securing the required insulation are indicated, namely, to use either a perfect vacuum or a gas under great pressure; but the former would be preferable. Unfortunately, neither of these two ways is easily carried out in practice.

It is especially interesting to note the behavior of an excessively high vacuum in these experiments. If a test tube provided with external electrodes and exhausted to the highest possible degree be connected to the terminals of the coil, Fig. 10, the electrodes of the tube are instantly brought to a high temperature, and the glass at each end of the tube is rendered intensely phosphorescent, but the middle appears comparatively dark, and for a while remains cool.

When the frequency is so high that the discharge shown in Fig. 8 is observed, considerable dissipation no doubt occurs in the coil. Nevertheless, the coil may be worked for a long time, as the heating is gradual.

In spite of the fact that the difference of potential may be enormous, little is felt when the discharge is passed through the body, provided the hands are armed. This is to some extent due to the higher frequency, but principally to the fact that less energy is available externally, when the difference of potential reaches an enormous value, owing to the circumstance that with the rise of potential the energy absorbed in the coil increases as the square of the potential. Up to a certain point the energy available externally increases with the rise of potential, then it begins to fall off rapidly. Thus, with the ordinary high tension induction coil, the curious paradox exists that, while with a given current through the primary the shock might be fatal, with many times that current it might be perfectly harmless, even if the frequency be the same. With high frequencies and excessively high potentials when the terminals are not connected to bodies of some size, practically all the energy supplied to the primary is taken up by the coil. There is no breaking through, no local injury, but all the material, insulating and conducting, is uniformly heated.

To avoid misunderstanding in regard to the physiological effect of alternating currents of very high frequency, I think it necessary to state that while it is an undeniable fact that they are incomparably less dangerous than currents of low frequencies, yet it should not be thought that they are altogether harmless. What has just been said refers only to currents from an ordinary high tension induction coil, which currents are necessarily very small; if received directly from a machine or from a secondary of low resistance they produce more or less powerful effects and may cause serious injury, especially when used in conjunction with condensers.

The streaming discharge of a high tension induction coil differs in many respects from that of a powerful static machine. In color it has neither the violet of the positive nor the brightness of the negative static discharge, but lies somewhere between, being, of course, alternatively positive and negative. But since the streaming is more powerful when the point or terminal is electrified positively than when electrified negatively, it follows that the point of the brush is more like the positive, and the root more like the negative static discharge. In the dark, when the brush is very powerful, the root may appear almost white. The wind produced

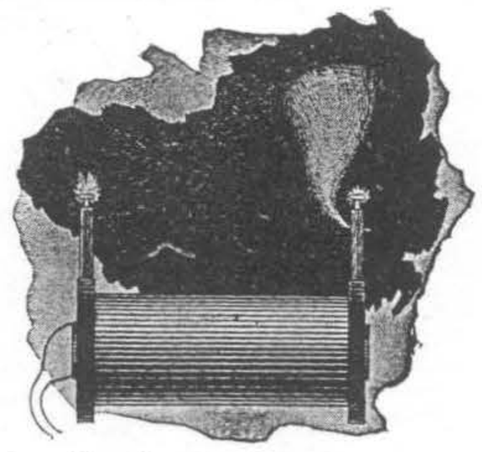

FIG. 13.—ASPECT PRESENTED BY A VERY THIN WIRE ATTACHED TO A TERMINAL OF THE COIL.

by the escaping streams, though it may be very strong—often indeed to such a degree that it may be felt quite a distance from the coil—is, nevertheless, considering the quantity of the discharge, smaller than that produced by the positive brush of a static machine, and it affects the flame much less powerfully. From the nature of the phenomenon we can conclude that the higher the frequency, the smaller must, of course, be the wind produced by the streams, and with sufficiently high frequencies no wind at all would be produced at the ordinary atmospheric pressures. With frequencies obtainable by means of a machine the mechanical effect is sufficiently great to revolve, with considerable speed, large pin-wheels, which in the dark present a beautiful appearance owing to the abundance of the streams (Fig. 11).

In general, most of the experiments usually performed with a static machine can be performed with an induction coil, when operated with very rapidly alternating cur-

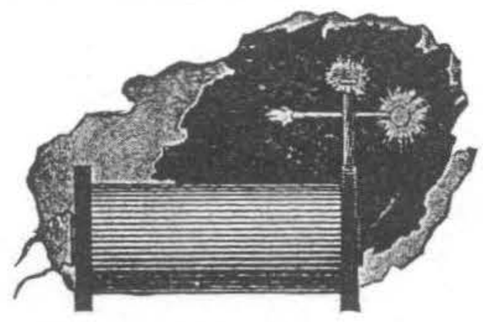

FIG. 14.—EFFECT OF BALL AND POINT.

rents. The effects produced, however, are much more striking, being of incomparably greater power. When a small length of ordinary cotton-covered wire (Fig. 12) is attached to one terminal of the coil, the streams issuing from all points of the wire may be so intense as to produce a considerable light effect. When the potentials and frequencies are very high, a wire insulated with gutta-percha or rubber, and attached to one of the terminals, appears to be covered with a luminous film. A very thin bare wire, when attached to a terminal, emits powerful streams, and vibrates continually to and fro, or spins in a circle, producing a singular effect (Fig. 13). Some of these experiments have been described by me in *The Electrical World* of February 21, 1891.

Another peculiarity of the rapidly alternating discharge of the induction coil is its radically different behavior with respect to points and rounded surfaces.

If a thick wire, provided with a ball at one end, and with a point at the other, be attached to the positive terminal of a static machine, practically all the charge will be lost through the point, on account of the enormously greater tension dependent on the radius of curvature. But if such a wire is attached to one of the terminals of the induction coil, it will be observed that with very high frequencies streams issue from the ball almost as copiously as from the point (Fig. 14).

It is hardly conceivable that we could produce such a condition to an equal degree in a static machine, for the simple reason that the tension increases as the square of the density, which in turn is proportional to the radius of curvature; hence, with a steady potential an enormous charge would be required to make streams issue from a polished ball while it is connected with a point. But with an induction coil the discharge of which alternates with great rapidity, it is different. Here we have to deal with two distinct ten-

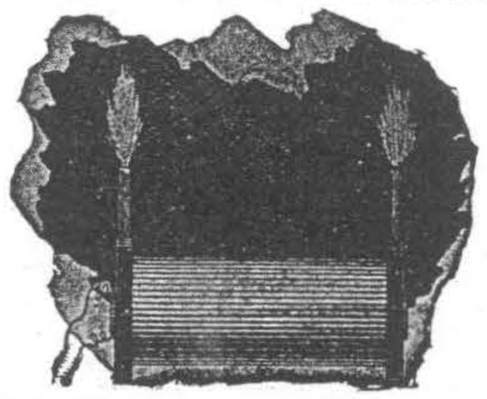

FIG. 15.—ASPECT OF COIL UNDER POWERFUL BRUSH DISCHARGE.

dencies. First, there is the tendency to escape, which exists in a condition of rest and which depends on the radius of curvature; second, there is the tendency to dissipate into the surrounding air by condenser action, which depends on the surface. When one of these tendencies is a maximum, the other is at a minimum. At the point the luminous stream is principally due to the air molecules coming bodily in contact with the point; they are attracted and repelled, charged and discharged, and, their atomic charges being thus disturbed, vibrate and emit light waves. At the ball, on the contrary, there is no doubt that the effect is to a great extent produced inductively, the air molecules not *necessarily* coming in contact with the ball, though they undoubtedly do so. To convince ourselves of this we only need to exalt the condenser action, for instance, by enveloping the ball, at some distance, by a better conductor than the surrounding medium, the conductor being, of course, insulated; or else by surrounding it with a better dielectric and approaching an insulated conductor; in both cases the streams will break forth more copiously. Also, the larger the ball with a given frequency, or the higher the frequency, the more will the ball have the advantage over the point. But, since a certain intensity of action is required to render the stream visible, it is obvious that in the experiment described the ball should not be taken too large.

In consequence of this two-fold tendency it is possible to produce by means of points, effects identical to those produced by capacity. Thus, for instance, by attaching to one terminal of the coil a small length of coiled wire, presenting many points and offering great facility to escape, the potential of the coil may be raised to the same value as by attaching to the terminal a polished ball of a surface many times greater than that of the wire.

An interesting experiment showing the effect of the points may be performed in the following manner: Attach to one of the terminals of the coil a cotton covered wire about two feet in length and adjust the conditions so that streams issue from the wire. In this experiment the primary coil should be preferably placed so that it extends only about half-way into the secondary coil. Now touch the free terminal of the secondary with a conducting object held in the hand, or else connect it to an insulated body of some size. In this manner the potential on the wire may be enormously raised.

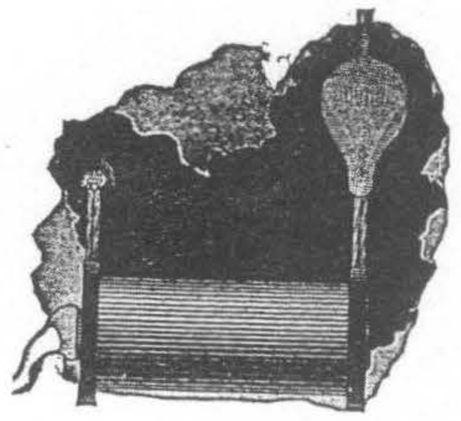

FIG. 16.—INCANDESCENT WIRE OR FILAMENT SPINNING IN AN UNEXHAUSTED GLOBE.

The effect of this will be to either increase or to diminish the streams. If they increase, the wire is too short; if they diminish, it is too long. By adjusting the length of the wire a point is found where the touching of the other terminal does not at all affect the streams. In this case the rise of potential is exactly counteracted by the drop through the coil. It will be observed that small lengths of wire produce considerable difference in the magnitude and luminosity of the streams. The primary coil is placed sidewise for two reasons: First, to increase

the potential at the wire and, second, to increase the drop through the coil. The sensitiveness is thus augmented.

There is still another and far more striking peculiarity of the brush discharge produced by very rapidly alternating currents. To observe this it is best to replace the usual terminals of the coil by two metal columns insulated with a good thickness of ebonite. It is also well to close all fissures and cracks with wax so that the brushes cannot form

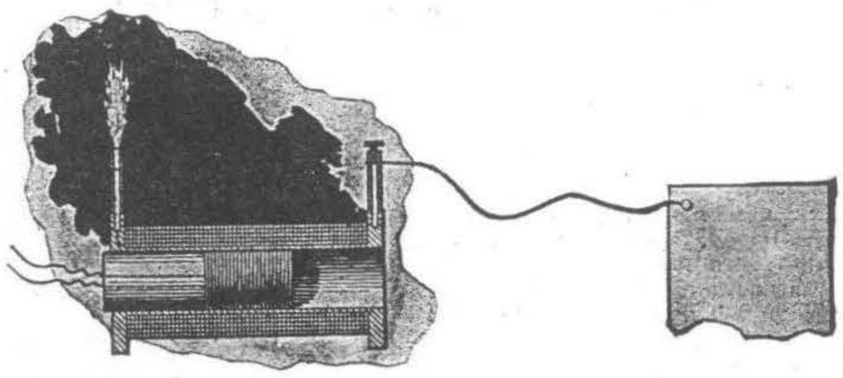

FIG. 17A.—COIL ARRANGED FOR POWERFUL BRUSH EFFECTS.

anywhere except at the tops of the columns. If the conditions are carefully adjusted—which, of course, must be left to the skill of the experimenter—so that the potential rises to an enormous value, one may produce two powerful brushes several inches long, nearly white at their roots, which in the dark bear a striking resemblance to two flames of a gas escaping under pressure (Fig. 15). But they do not only *resemble*, they *are* veritable flames, for they are hot. Certainly they are not as hot as a gas burner, *but they would be so if the frequency and the potential would be sufficiently high.* Produced with, say, 20,000 alternations per second, the heat is easily perceptible, even if the potential is not excessively high. The heat developed is, of course, due to the impact of the air molecules against the terminals and against each other. As, at the ordinary pressures, the mean free path is excessively small, it is possible that in spite of the enormous initial

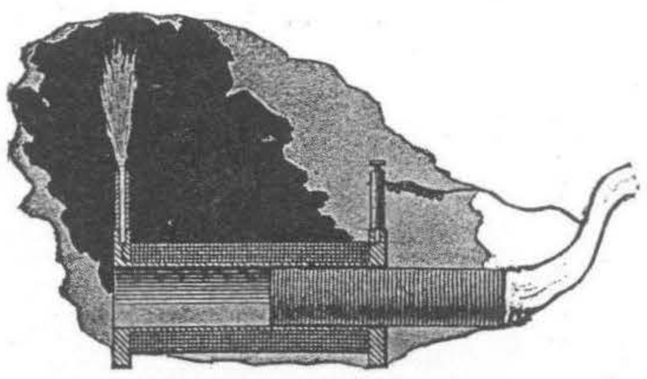

FIG. 17B.—COIL ARRANGED FOR POWERFUL BRUSH EFFECTS.—ST. ELMO'S HOT FIRE.

speed imparted to each molecule upon coming in contact with the terminal, its progress—by collision with other molecules—is retarded to such an extent, that it does not get away far from the terminal, but may strike the same many times in succession. The higher the frequency the less the molecule is able to get away, and this the more so, as for a given effect the potential required is smaller; and a frequency is conceivable—perhaps, even obtainable—at which practically the same molecules would strike the terminal. Under such conditions the exchange of the molecules would be very slow and the heat produced at and very near the terminal would be excessive. But if the frequency would go on increasing constantly, the heat produced would begin to diminish for obvious reasons. In the positive brush of a static machine the exchange of the molecules is very rapid, the stream is constantly of one direction, and there are fewer collisions; hence, the heating effect must be very small. Anything that impairs

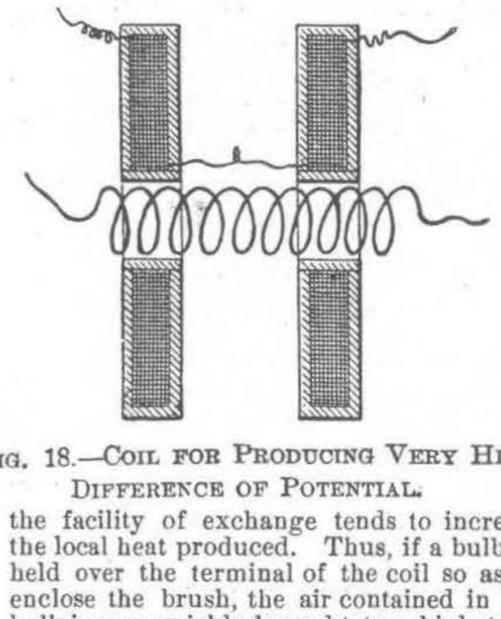

FIG. 18.—COIL FOR PRODUCING VERY HIGH DIFFERENCE OF POTENTIAL.

the facility of exchange tends to increase the local heat produced. Thus, if a bulb be held over the terminal of the coil so as to enclose the brush, the air contained in the bulb is very quickly brought to a high temperature. If a glass tube be held over the brush so as to allow the draught to carry the brush upwards, scorching hot air escapes at the top of the tube. Anything held within the brush is, of course, rapidly heated, and the possibility of using such heating effects for some purpose or other suggests itself.

When contemplating this singular phenomenon of the hot brush, we cannot help being convinced that a similar process must take place in the ordinary flame, and it seems strange that after all these centuries past of familiarity with the flame, now, in this era of electric lighting and heating, we are finally led to recognize, that since time immemorial we have, after all, always had "electric light and heat" at our disposal. It is also of no little interest to contemplate that we have a possible way of producing—by other than chemical means—a veritable flame, which would give light and heat without any material being consumed, without any chemical process taking place, and to accomplish this, we only need to perfect methods of producing enormous frequencies and potentials. I have no doubt that if the potential could be made to alternate with sufficient rapidity and power, the brush formed at the end of a wire would lose its electrical characteristics and would become flamelike. The flame must be due to electrostatic molecular action.

This phenomenon now explains in a manner which can hardly be doubted the frequent accidents occurring in storms. It is well known that objects are often set on fire without the lightning striking them. We shall presently see how this can happen. On a nail in a roof, for instance, or on a projection of any kind, more or less conducting or rendered so by dampness, a powerful brush may appear. If the lightning strikes somewhere in the neighborhood the enormous potential may be made to alternate or fluctuate, perhaps, many million times a second. The air molecules are violently attracted and repelled, and by their impact produce such a powerful heating effect that a fire is started. It is conceivable that a ship at sea may, in this manner, catch fire at many points at once. When we consider that even with the comparatively low frequencies obtained from a dynamo machine and with potentials of no more than one or two hundred thousand volts the heating effects are considerable, we may imagine how much more powerful they must be with frequencies and potentials many times greater, and the above explanation seems, to say the least, very probable. Similar explanations may have been suggested, but I am not aware that up to the present the heating effects of a brush produced by a rapidly alternating potential have been experimentally demonstrated, at least not to such a remarkable degree.

By preventing completely the exchange of the air molecules the local heating effect may be so exalted as to bring a body to incandescence. Thus, for instance, if a small button or, preferably, a very thin wire or filament be enclosed in an unexhausted globe and connected with the terminal of the coil, it may be rendered incandescent. The phenomenon is made much more interesting by the rapid spinning round in a circle of the top of the filament, thus presenting the appearance of a luminous funnel, Fig. 16, which widens when the potential is increased. When the potential is small the end of the filament may perform irregular motions, suddenly changing from one to the other, or it may describe an ellipse; but when the potential is very high it always spins in a circle; and so does generally a thin straight wire attached freely to the terminal of the coil. These motions are, of course, due to the impact of the molecules and the irregularity in the distribution of the potential owing to the roughness and dissymmetry of the wire or filament. With a perfectly symmetrical and polished wire such motions would probably not occur. That the motion is not likely to be due to other causes is evident from the fact that it is not of a definite direction and that in a very highly exhausted globe it ceases altogether. The possibility of bringing a body to incandescence in an unexhausted globe, or even when not at all enclosed, would seem to afford a possible way of obtaining lighter effects, which in perfecting methods of producing rapidly alternating potentials might be rendered available for useful purposes.

In employing a commercial coil, the production of very powerful brush effects is attended with considerable difficulties, for when these high frequencies and enormous potentials are used, the best insulation is apt to give way. Usually the coil is insulated well enough to stand the strain from convolution to convolution, since two double silk-covered paraffined wires will withstand a pressure of several thousand volts; the difficulty lies, principally, in preventing the breaking through from the secondary to the primary, which is greatly facilitated by the streams issuing from the latter. In the coil, of course, the strain is greatest from section to section, but usually in a larger coil there are so many sections that the danger of a sudden giving way is not very great. No difficulty will generally be encountered in that direction, and, besides, the liability of injuring the coil internally is very much reduced by the fact that the effect most likely to be produced is simply a gradual heating, which, when far enough advanced, could not fail to be observed. The principal necessity is, then, to prevent the streams between the primary and the tube, not only on account of the heating and possible injury, but also because the streams may diminish very considerably the potential difference available at the terminals. A few hints as to how this may be accomplished will probably be found useful in most of these experiments with the ordinary induction coil.

One of the ways is to wind a short primary (Fig. 17 A) so that the difference of potential is not at that length great enough to cause the breaking forth of the streams through the insulating tube. The length of the primary should be determined by experiment. Both the ends of the coil should be brought out on one end through a plug of insulating material fitting in the tube as illustrated. In such a disposition one terminal of the secondary is attached to a body, the surface of which is determined with the greatest care, so as to produce the greatest rise in the potential. At the other terminal a powerful brush appears, which may be experimented upon.

The above plan necessitates the employment of a primary of comparatively small size, and it is apt to heat when powerful effects are desirable for a certain length of time. In such a case it is better to employ a larger coil (Fig. 17 B), and introduce it from one side of the tube, until the streams begin to appear. In this case the nearest terminal of the secondary may be connected to the primary or to the ground, which is practically the same thing, if the primary is connected directly to the machine. In the case of ground connections it is well to determine experimentally the frequency which is best suited under the conditions of the test. Another way of obviating the streams, more or less, is to make the primary in sections, and supply it from separate well-insulated sources.

In many of these experiments, when powerful effects are wanted for a short time, it is advantageous to use iron cores with the primaries. In such case a very large primary coil may be wound and placed side by side with the secondary, and, the nearest terminal of the latter being connected to the primary, a laminated iron core is introduced through the primary into the secondary as far as the streams will permit. Under these conditions an excessively powerful brush, several inches long, which may be appropriately called "St. Elmo's hot fire," may be caused to appear at the other terminal of the secondary, producing striking effects. It is a most powerful ozonizer, so powerful indeed, that only a few minutes are sufficient to fill the whole room with the smell of ozone, and it undoubtedly possesses the quality of exciting chemical affinities.

For the production of ozone, alternating currents of very high frequency are eminently suited, not only on account of the advantages they offer in the way of conversion, but also because of the fact that the ozonizing action of a discharge is dependent on the frequency as well as on the potential, this being undoubtedly confirmed by observation.

In these experiments if an iron core is used it should be carefully watched, as it is apt to get excessively hot in an incredibly short time. To give an idea of the rapidity of the heating, I will state, that by passing a powerful current through a coil with many turns, the inserting within the same of a thin iron wire for no more than one second's time is sufficient to heat the wire to something like 100° C.

But this rapid heating does not need to discourage us in the use of iron cores in connection with rapidly alternating currents. I have for a long time been convinced, that in the industrial distribution by means of transformers, some such plan as the following might be practicable. We may use a comparatively small iron core, subdivided, or perhaps not even subdivided. We may surround this core with a considerable thickness of material which is fire-proof and conducts the heat poorly, and on top of that we may place the primary and secondary windings. By using either higher frequencies or greater magnetizing forces, we may by hysteresis and eddy currents heat the iron core so far as to bring it nearly to its maximum permeability, which, as Hopkinson has shown, may be as much as 16 times greater than that at ordinary temperatures. If the iron core were perfectly enclosed it would not be deteriorated by the heat, and if the enclosure of fire-proof material would be sufficiently thick, only a limited amount of energy could be radiated in spite of the high temperature. Transformers have been constructed by me on that plan, but for lack of time no thorough tests have as yet been made.

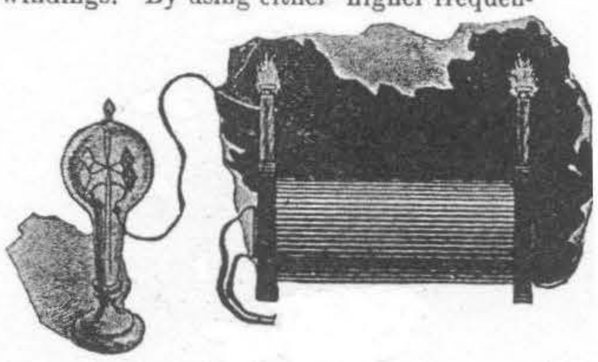

FIG. 19.—THE CROOKES EXPERIMENT ON OPEN CIRCUIT.

Another way of adapting the iron core to rapid alternations, or generally speaking, reducing the frictional losses, is to produce by continuous magnetization a flow of something like 7,000 or 8,000 lines per square centimetre through the core and then work with weak magnetizing forces and preferably high frequencies around the point of greatest permeability. A higher efficiency of conversion and greater output are obtainable



FIG. 20.—LAMP WITH SINGLE BLOCK OF REFRACTORY MATERIAL.

in this manner. I have also employed this principle in connection with machines in which there is no reversal of polarity. In these types of machines, as long as there are only few pole projections, there is no great gain, as the maxima and minima of magnetization are far from the point of maximum permeabilty; but when the number of the pole projections is very great, the required rate of change may be obtained without the magnetization varying so far as to depart greatly from the point of maximum permeability, and the gain is considerable.

The above described arrangements refer only to the use of commercial coils as ordinarily constructed. If it is desired to construct a coil for the express purpose of performing with it such experiments as I have described, or, generally, rendering it capable of withstanding the greatest possible difference of potential, then a construction as indicated in Fig. 18 will be found of advantage. The coil in this case is formed of two independent parts, which are wound oppositely, the connection between both being made near the primary. The potential in the middle being zero, there is not much tendency to jump to the primary and not much insulation is required. In some cases the middle point may, however, be connected to the primary or to the ground. In such a



FIG. 21.—LAMP WITH TWO FILAMENTS IN HIGHEST VACUUM WITH LEADING-IN WIRES.

coil the places of greatest difference of potential are far apart and the coil is capable of withstanding an enormous strain. The two parts may be movable so as to allow a slight adjustment of the capacity effect.

As to the manner of insulating the coil, it will be found convenient to proceed in the following way: First the wire should be boiled in paraffine until all the air is out; then the coil is wound by running the wire through the melted paraffine, merely for the



FIG. 22.—LAMP WITH TWO REFRACTORY BLOCKS IN HIGHEST VACUUM.

purpose of fixing the wire. The coil is then taken off from the spool, immersed in a cylindrical vessel filled with pure melted wax and boiled for a long time until the bubbles cease to appear. The whole is then left to cool down thoroughly, and then the mass is taken out of the vessel and turned up in a lathe. The coil made in this manner and with care is capable of withstanding enormous potential differences.

It may be found convenient to immerse the coil in paraffine oil or some other kind of oil; it is a most effective way of insulating, principally on account of the perfect exclusion of air, but it may be found that after all a vessel filled with oil is not a very convenient thing to handle in a laboratory.

If an ordinary coil can be dismounted, the primary may be taken out of the tube and the latter plugged up on one end, filled with oil, and the primary re-inserted. This affords an excellent insulation and prevents the formation of the streams.

Of all the experiments which may be performed with rapidly alternating currents the most interesting are those which concern the production of a practical illuminant. It cannot be denied that the present methods, though they were brilliant advances, are very wasteful. Some better methods must be invented, some more perfect apparatus devised. Modern research has opened new possibilities for the production of an efficient source of light, and the attention of all has been turned in the direction indicated by able pioneers. Many have been carried away by the enthusiasm and passion to discover, but in their zeal to reach results many have been misled. Starting with the idea of producing electromagnetic waves, they turned their attention, perhaps, too much to the study of eiectromagnetic effects and neglected the study of electrostatic phenom-



FIG. 23.—LAMP WITH SINGLE STRAIGHT FILAMENT AND ONE LEADING-IN WIRE.

ena. Naturally, nearly every investigator availed himself of an apparatus similar to that used in earlier experiments. But in those forms of apparatus, while the electromagnetic inductive effects are enormous, the electrostatic effects are excessively small.

In the Hertz experiments, for instance, a high tension induction coil is short circuited by an arc, the resistance of which is very small; the smaller, the more capacity is attached to the terminals, and the difference of potential at these is enormously diminished. On the other hand, when the discharge is not passing between the terminals the static effects may be considerable, but only qualitatively so, not quantitatively, since their rise and fall is very sudden and since their frequency is small. In neither case, therefore, are powerful electrostatic effects perceivable. Similar conditions exist when, as in some interesting experiments of Dr. Lodge, Leyden jars are discharged disruptively. It has been thought—and I believe asserted—that in such cases most of the energy is radiated into space. In the light of the experiments which I have described above, it will now not be thought so. I feel safe in asserting that in such cases most of the energy is partly taken up and converted into heat in the arc of the discharge and in the conducting and insulating material of the jar, some energy being, of course, given off by electrification of the air; but the amount of the directly radiated energy is very small.

When a high tension induction coil, operated by currents alternating only 20,000 times a second, has its terminals closed through even a very small jar, practically all the energy passes through the dielectric of the jar, which is heated, and the electrostatic effects manifest themselves outwardly only to a very weak degree. Now, the external circuit of a Leyden jar, that is, the arc and the connections of the coatings, may be looked upon as a circuit generating alternating currents of excessively high frequency and fairly high potential, which is closed through the coatings and the dielectric between them, and from the above it is evident that the external electrostatic effects must be very small, even if a recoil circuit be used. These conditions make it appear that with the apparatus usually at hand the observation of powerful electrostatic effects was impossible, and what experience has been gained in that direction is only due to the great ability of the investigators.

But powerful electrostatic effects are *sine qua non* of light production on the lines indicated by theory. Electromagnetic effects are primarily unavailable, for the reason that

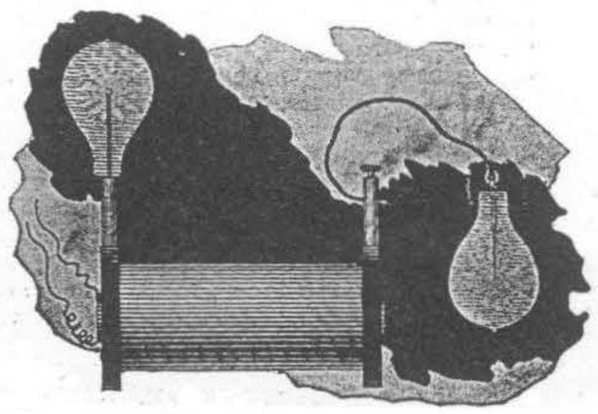

FIG. 24.—LAMPS WITH ONE LEADING-IN WIRE RENDERED INCANDESCENT.

to produce the required effects we would have to pass current impulses through a conductor which, long before the required frequency of the impulses could be reached, would cease to transmit them. On the other hand, electromagnetic waves many times longer than those of light and producible by sudden discharges of a condenser could not be utilized, it would seem, except we avail ourselves of their effect upon conductors, as in the present methods, which are wasteful. We could not effect by means of such waves the static molecular or atomic charges of a gas, cause them to vibrate and to emit light. Long transverse waves cannot, apparently, produce such effects, since excessively small electromagnetic disturbances may pass readily through miles of air. Such dark waves, unless they are of the length of true light waves, cannot, it would seem, excite luminous radiation in a Geissler tube, and the luminous effect, which are producible by induction in a tube devoid of electrodes, I am inclined to consider as being of an electrostatic nature.

To produce such luminous effects straight electrostatic thrusts are required; these, whatever be their frequency, may disturb the molecular charges and produce light. Since current impulses of the required frequency cannot pass through a conductor of measurable dimensions, we must work with a gas and then the production of powerful electrostatic effects becomes an imperative necessity.

It has occurred to me, however, that electrostatic effects are in many ways available for the production of light. For instance, we may place a body of some refractory material in a closed, and preferably more or less exhausted, globe, connect it to a source of high, rapidly alternating potential, causing the molecules of the gas to strike it many times a second at enormous speeds, and in this manner, with trillions of invisible hammers, pound it until it gets incandescent; or, we may place a body in a very highly exhausted globe, in a non-striking vacuum, and by employing very high frequencies and potentials, transfer sufficient energy from it to other bodies in the vicinity or in general to the surroundings, to maintain it at any degree of incandescence; or, we may, by means of such rapidly alternating high potentials, disturb the ether carried by the molecules of a gas or their static charges, cause them to vibrate and to emit light.

But electrostatic effects being dependent upon the potential and frequency, to produce the most powerful action, it is desirable to increase both as far as practicable. It may be possible to obtain quite fair results by keeping either of these factors small, provided the other is sufficiently great; but we are limited in both directions. My experience demonstrates that we cannot go below a certain frequency, for, first, the potential then becomes so great that it is dangerous; and, secondly, the light production is less efficient.

I have found that, by using the ordinary low frequencies, the physiological effect of the current required to maintain at a certain degree of brightness a tube four feet long, provided at the ends with outside and inside condenser coatings, is so powerful that, I think, it might produce serious injury to those not accustomed to such shocks; whereas, with 20,000 alternations per second the tube may be maintained at the same degree of brightness without any effect being felt. This is due principally to the fact that a much smaller potential is required to produce the same light effect, and also to the higher efficiency in the light production. It is evident that the efficiency in such cases is the greater, the higher the frequency, for the quicker the process of charging and discharging the molecules, the less energy will be lost in the form of dark radiation. But, unfortunately, we cannot go beyond a certain frequency on account of the difficulty of producing and conveying the effects.

I have stated above that a body enclosed in an unexhausted bulb may be intensely heated by simply connecting it with a source of rapidly alternating potential. The heating in such a case is, in all probability, due mostly to the bombardment of the molecules of the gas contained in the bulb. When the

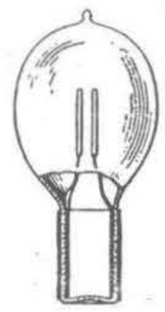

FIG. 25.—LAMP WITH TWO BLOCKS OR FILAMENTS AND A PAIR OF INDEPENDENT INSIDE AND OUTSIDE CONDENSER COATINGS.

bulb is exhausted the heating of the body is much more rapid and there is no difficulty whatever in bringing a wire or filament to any degree of incandescence by simply connecting it to one terminal of a coil of the proper dimensions. Thus, if the well-known apparatus of Professor Crookes, consisting of a bent platinum wire with vanes mounted over it (Fig. 19), be connected to one terminal





FIG. 26A. FIG. 26B.

LAMP WITH ONE FILAMENT, ONE INSIDE AND ONE OUTSIDE CONDENSER COATING.

of the coil—either one or both ends of the platinum wire being connected—the wire is rendered almost instantly incandescent and the mica vanes are rotated as though a current from a battery were used. A thin carbon filament, or, preferably, a button of some refractory material (Fig. 20), even if it be a comparatively poor conductor, enclosed in an exhausted globe, may be rendered highly incandescent; and in this manner a simple lamp capable of giving any desired candle-power is provided.

The success of lamps of this kind would depend largely on the selection of the light-giving bodies contained within the bulb. Since, under the conditions described, refractory bodies—which are very poor conductors and capable of withstanding for a long time excessively high degrees of temperature—may be used, such illuminating devices may be rendered successful.

It might be thought at first that if the



FIG. 27.—LAMP WITH ONE FILAMENT AND LEADING-IN WIRE AND EXTERNAL CONDENSER COATING.

bulb containing the filament or button of refractory material, be perfectly well exhausted—that is, as far as it can be done by the use of the best apparatus—the heating would be much less intense, and that in perfect vacuum it could not occur at all. This is not confirmed by my experience; quite the contrary, the better the vacuum the easier the bodies are brought to incandescence. This result is interesting for many reasons.

At the outset of this work the idea presented itself to me, whether two bodies of refractory material enclosed in a bulb exhausted to such a degree that the discharge of a large induction coil operated in the usual manner cannot pass through, could be rendered incandescent by mere condenser action. Obviously, to reach this result enormous potential differences and very high frequencies are required, as is evident from a simple calculation.

But such a lamp would possess a vast advantage over an ordinary incandescent lamp in regard to efficiency. It is well known that the efficiency of a lamp is to some extent a function of the degree of incandescence and that could we but work a filament at many times higher degrees of incandescence the efficiency would be much greater. In an ordinary lamp this is impracticable on account of the destruction of the filament, and it has been determined by experience how far it is advisable to push the incandescence. It is impossible to tell how much higher efficiency could be obtained if the filament could withstand indefinitely, as the investigation to this end obviously cannot be carried beyond a certain stage; but there are reasons for believing that it would be very considerably higher. An improvement might be made in the ordinary lamp by employing a short and thick carbon; but then the leading-in wires would have to be thick, and, besides, there are many other considerations which render such a modification entirely impracticable. But in a lamp as above described, the leading-in wires may be very small, the incandescent refractory material may be in the shape of blocks offering a very small radiating surface, so that less energy would be required to keep them at the desired incandescence; and in addition to this the refractory material need not be carbon, but may be manufactured from mixtures of oxides, for instance, with carbon or other material, or may be selected from bodies which are practically non-conductors and capable of withstanding enormous degrees of temperature.

All this would point to the possibility of obtaining a much higher efficiency with such a lamp than is obtainable in ordinary lamps. In my experience it has been demonstrated that the blocks are brought to high degrees of incandescence with much lower potentials than those determined by calculation, and the blocks may be set at greater dis-

tances from each other. We may freely assume, and it is probable, that the molecular bombardment is an important element in the heating even if the globe be exhausted with the utmost care, as I have done; for although the number of the molecules is, comparatively speaking, insignificant, yet on account of the mean free path being very great there are fewer collisions and the molecules may reach much higher speeds, so that the heating effect due to this cause may be considerable, as in the Crookes experiments with radiant matter.

But it is likewise possible that we have to deal here with an increased facility of los-

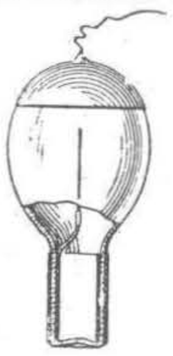

FIG. 28.—LAMP WITH ONE FILAMENT, ONE INSIDE AND ONE OUTSIDE CONDENSER COATING AND AUXILIARY COATING.

ing the charge in very high vacuum, when the potential is rapidly alternating, in which case most of the heating would be directly due to the surging of the charges in the heated bodies. Or else the observed fact may be largely attributable to the effect of the points which I have mentioned above, in consequence of which the blocks or filaments contained in the vacuum are equivalent to condensers of many times greater surface than that calculated from their geometrical dimensions. Scientific men still differ in opinion as to whether a charge should, or should not, be lost in a perfect vacuum; or, in other words, whether ether is, or is not, a conductor. If the former were the case, then a thin filament enclosed in a perfectly exhausted globe, and connected to a source of enormous, steady potential, would be brought to incandescence.

Various forms of lamps on the above described principle, with the refractory bodies in the form of filaments, Fig. 21, or blocks, Fig. 22, have been constructed and operated by me, and investigations are being carried on in this line. There is no difficulty in reaching such high degrees of incandescence that ordinary carbon is to all appearance melted and volatilized. If the vacuum could be made absolutely perfect, such a lamp, although inoperative with apparatu ordinarily used, would, if operated with currents of the required character, afford an illuminant which would never be destroyed, and which would be far more efficient than an ordinary incandescent lamp. This perfection can, of course, never be reached, and a very slow destruction and gradual diminution of the size always occurs, as in incandescent lamps; but there is no possibility of a sudden and premature disabling, which occurs in the latter by the breaking of the filament, especially when the incandescent bodies are in the shape of blocks.

With these rapidly alternating potentials there is, however, no necessity of enclosing two blocks in a globe, but a single block, as in Fig. 20, or filament, Fig. 23, may be used. The potential in this case must, of course, be higher, but it is easily obtainable, and besides it is not necessarily dangerous.

The facility with which the button or filament in such a lamp is brought to incandescence, other things being equal, depends on the size of the globe. If a perfect vacuum could be obtained the size of the globe would not be of importance, for then the heating would be wholly due to the surging of the charges, and all the energy would be given off to the surroundings by radiation. But this can never occur in practice. There is always some gas left in the globe, and although the exhaustion may be carried to the highest degree, still the space inside of the bulb must be considered as conducting when such high potentials are used; and I assume that in estimating the energy that may be given off from the filament to the surroundings, we may consider the inside surface of the bulb as one coating of a condenser, the air and other objects surrounding the bulb forming the other coating. When the alternations are very low, there is no doubt that a considerable portion of the energy is given off by the electrification of the surrounding air.

In order to study this subject better, I carried on some experiments with excessively high potentials and low frequencies. I then observed that when the hand is approached to the bulb—the filament being connected with one terminal of the coil—a powerful vibration is felt, being due to the attraction and repulsion of the molecules of the air, which are electrified by induction through the glass. In some cases, when the action is very intense, I have been able to hear a sound, which must be due to the same cause.

When the alternations are low, one is apt to get an excessively powerful shock from the bulb. In general, when one attaches bulbs or objects of some size to the terminals of the coil, one should look out for the rise of potential, for it may happen that by merely connecting a bulb or plate to the terminal, the potential may rise to many times its original value. When lamps are attached to the terminals, as illustrated in Fig. 24, then the capacity of the bulbs should be such as to give the maximum rise of potential under the existing conditions. In this manner one may obtain the required potential with fewer turns of wire.

The life of such lamps, as described above, depends, of course, largely on the degree of exhaustion, but to some extent also on the shape of the block of refractory material. Theoretically it would seem that a small sphere of carbon enclosed in a sphere of glass would not suffer deterioration from molecular bombardment, for the matter in the globe, being radiant, the molecules would move in straight lines and would seldom strike the sphere obliquely. An interesting thought in connection with such a lamp is, that in it "electricity" and electrical energy apparently must move in the same lines.

The use of alternating currents of very high frequency makes it possible to transfer by electrostatic or electromagnetic induction through the glass of a lamp sufficient energy to keep a filament at incandescence and so do away with the leading-in wires. Such lamps have been proposed, but for want of proper apparatus they have not been successfully operated. Many forms of lamps on this principle with continuous and broken filaments have been constructed by me and experimented upon. When using a secondary enclosed within the lamp a condenser is advantageously combined with the secondary. When the transference is effected by electrostatic induction the potentials used are, of course, very high with frequencies obtainable from a machine. For instance,

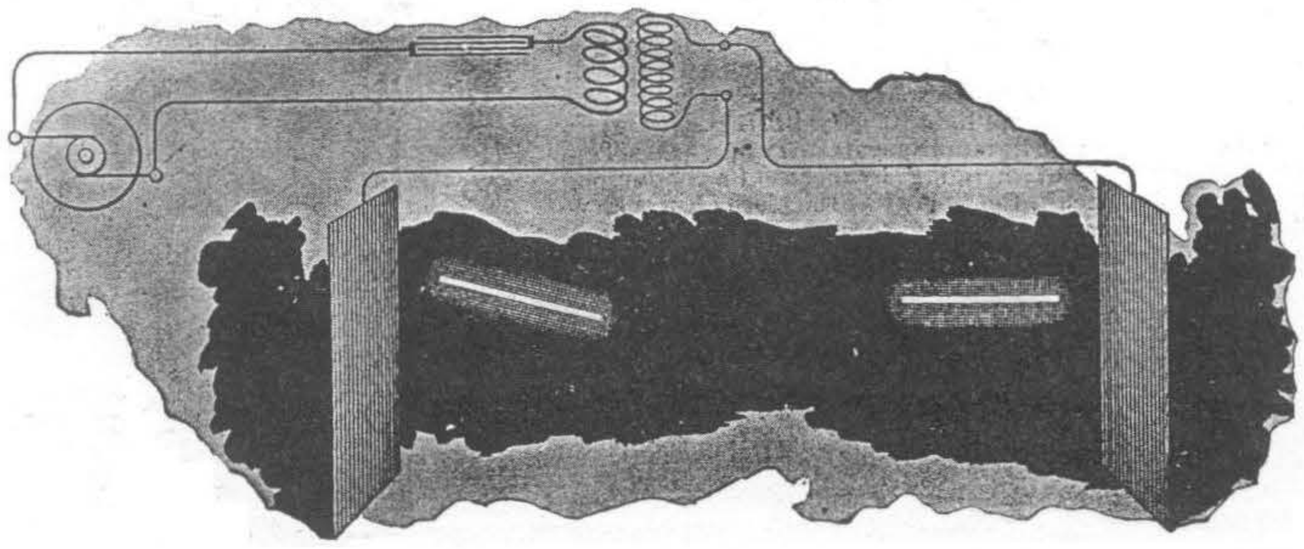

FIG. 30.—IDEAL METHOD OF LIGHTING A ROOM.—TUBES DEVOID OF ANY ELECTRODES RENDERED BRILLIANT IN AN ALTERNATING ELECTROSTATIC FIELD.

with a condenser surface of 40 centimeters square, which is not impracticably large, and with glass of good quality 1 mm. thick, using currents alternating 20,000 times a second, the potential required is approximately 9,000 volts. This may seem large, but since each lamp may be included in the secondary of a transformer of very small dimensions, it would not be inconvenient, and, moreover, it would not produce fatal injury. The transformers would all be preferably in series. The regulation would offer no difficulties, as with currents of such frequencies it is very easy to maintain a constant current.

In the accompanying engravings some of the types of lamps of this kind are shown. Fig. 25 is such a lamp with a broken filament, and Fig. 26A and 26B one with a single outside and inside coating and a single filament. I have also made lamps with two outside and inside coatings and a continuous loop connecting the latter. Such lamps have been operated by me with current impulses of the enormous frequencies obtainable by the disruptive discharge of condensers.

The disruptive discharge of a condenser is especially suited for operating such lamps—with no outward electrical connections—by means of electromagnetic induction, the electromagnetic inductive effects being excessively high; and I have been able to produce the desired incandescence with only a few short turns of wire. Incandescence may also be produced in this manner in a simple closed filament.

Leaving, now, out of consideration the practicability of such lamps, I would only say that they possess a beautiful and desirable feature, namely, that they can be rendered, at will, more or less brilliant simply by altering the relative position of the outside and inside condenser coatings or inducing and induced circuits.

When a lamp is lighted by connecting it to one terminal only of the source this may be facilitated by providing the globe with an outside condenser coating, which serves at the same time as a reflector, and connecting this to an insulated body of some size. Lamps of this kind are illustrated in Fig. 27 and Fig. 28. Fig. 29 shows the plan of connections. The brilliancy of the lamp may, in this case, be regulated within wide limits by varying the size of the insulated metal plate to which the coating is connected.

It is likewise practicable to light with one leading wire lamps such as illustrated in Fig. 21 and Fig. 22, by connecting one terminal of the lamp to one terminal of the source and the other to an insulated body of the required size. In all cases the insulated body serves to give off the energy into the surrounding space, and is equivalent to a return wire. Obviously, in the two last-named cases, instead of connecting the wires to an insulated body, connections may be made to the ground.

The experiments which will prove most suggestive and of most interest to the investigator are probably those performed with exhausted tubes. As might be anticipated, a source of such rapidly alternating potentials is capable of exciting the tubes at a considerable distance and the light effects produced are remarkable.

During my investigations in this line I endeavored to excite tubes, devoid of any electrodes, by electromagnetic induction, making the tube the secondary of the induction device, and passing through the primary the discharges of a Leyden jar. These tubes were made of many shapes, and I was able to obtain luminous effects which I then thought were due wholly to electromagnetic induction. But on carefully investigating the phenomena I found that the effects produced were more of an electrostatic nature. It may be attributed to this circumstance that this mode of exciting tubes is very wasteful, namely, the primary circuit being closed, the potential and, consequently, the electrostatic inductive effect is much diminished.

When an induction coil, operated as above described, is used, there is no doubt that the tubes are excited by electrostatic induction and that electromagnetic induction has little, if anything, to do with the phenomena.

This is evident from many experiments. For instance, if a tube be taken in one hand, the observer being near the coil, it is brilliantly lighted and remains so no matter in what position it is held relatively to the observer's body. Were the action electromagnetic the tube could not be lighted when the observer's body is interposed between it and the coil, or at least its luminosity should be considerably diminished. When the tube is held exactly over the center of the coil—the latter being wound in sections and the primary placed symmetrically to the secondary—it may remain completely dark, whereas, it is rendered intensely luminous by moving it slightly to the right or left from the center of the coil. It does not light because in the middle both halves of the coil neutralize each other and the electric potential is zero. If the action were electromagnetic, the tube should light best in the plane through the center of the coil, since the electromagnetic effect there should be a maximum. When an arc is established between the terminals, the tubes and lamps in the vicinity of the coil go out, but light up again when the arc is broken on account of the rise of potential. Yet the electromagnetic effect should be practically the same in both cases.

By placing a tube at some distance from the coil, and nearer to one terminal—preferably at a point on the axis of the coil—one may light it by touching the remote terminal with an insulated body of some size or with the hand, thereby raising the potential at that terminal nearer to the tube. If the tube is shifted nearer to the coil so that it is lighted by the action of the nearer terminal, it may be made to go out by holding, on an insulated support, the end of a wire connected to the remote terminal, in the vicinity of the nearer terminal, by this means counteracting the action of the latter upon the tube. These effects are evidently electrostatic. Likewise, when a tube is placed at considerable distance from the coil, the observer may, standing upon an insulated support, between coil and tube, light the latter by approaching the hand to it; or he may even render it luminous by simply stepping between it and the coil. This would be impossible with electromagnetic induction, for the body of the observer would act as a screen.

When the coil is energized by excessively weak currents, the experimenter may, by touching one terminal of the coil with the tube, extinguish the latter, and may again light it by bringing it out of contact with the terminal and allowing a small arc to form. This is clearly due to the respective lowering and raising of the potential at that terminal. In the above experiment when the tube is lighted through a small arc it may go out when the arc is broken, because the electrostatic inductive effect alone is too weak, though the potential may be much higher; but when the arc is established the electrification of the end of the tube is much greater and it consequently lights.

If a tube is lighted by holding it near to the coil, and in the hand which is remote, by grasping the tube anywhere with the other hand, the part between the hands is rendered dark and the singular effect of wiping out the light of the tube may be produced by passing the hand quickly along the tube and at the same time withdrawing it slightly from the coil, judging properly the distance so that the tube remains dark afterward.

If the primary coil is placed sidewise, as in Fig. 17B, for instance, and an exhausted tube be introduced from the other side in the hollow space, the tube is lighted most intensely because of the increased condenser action, and in this position the striæ are most sharply defined. In all these experiments described and in many others the action is clearly electrostatic.

The effects of screening also indicate the electrostatic nature of the phenomena and show something of the nature of electrification through the air. For instance, if a tube be placed in the direction of the axis of the coil and an insulated metal plate be interposed the tube will generally increase in brilliancy, or if it be too far from the coil to light, it may even be rendered luminous by interposing an insulated metal plate. The magnitude of the effects depends to some extent on the size of the plate. But if the metal plate be connected by a wire to the ground its interposition will always make the tube go out, even if it be very near the coil. In general, the interposition of a body between the coil and tube increases or diminishes the brilliancy of the tube or its facility to light up, according to whether it increases or diminishes the electrification. When experimenting with an insulated plate, the plate should not be taken too large else it will generally produce a weakening effect by reason of its great facility for giving off energy to the surroundings.

If a tube be lighted at some distance from the coil and a plate of hard rubber or other insulating substance be interposed, the tube may be made to go out. The interposition of the dielectric in this case only slightly increases the inductive effect, but diminishes considerably the electrification through the air.

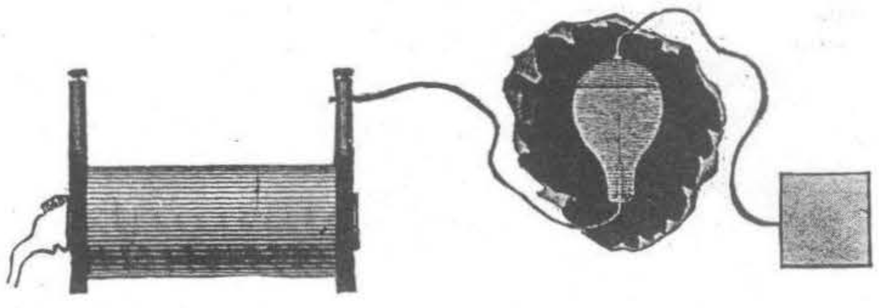

FIG. 29.—INCREASING THE BRILLIANCY OF LAMP ON ONE WIRE.

In all cases, then, when we excite luminosity in exhausted tubes by means of such a coil the effect is due to the rapidly alternating electrostatic potential; and, furthermore, it must be attributed to the harmonic alternation produced directly by the machine and not to any superimposed vibration which might be thought to exist. Such superimposed vibrations are impossible when we work with an alternate current machine.

If a spring be gradually tightened and released it does not perform independent vibra-

tions; for this a sudden release is necessary. So with the alternate currents from a dynamo machine; the medium is harmonically strained and released, this giving rise to only one kind of waves; a sudden contact or break, or a sudden giving way of the dielectric, as in the disruptive discharge of a Leyden jar, are essential for the production of superimposed waves.

In all the last described experiments, tubes devoid of any electrodes may be used, and there is no difficulty in producing by their means sufficient light to read by. The light effect is, however, considerably increased by the use of phosphorescent bodies, such as yttria, uranium glass, etc. A difficulty will be found when the phosphorescent material is used, for with these powerful effects it is carried gradually away, and it is preferable to use material in the form of a solid.

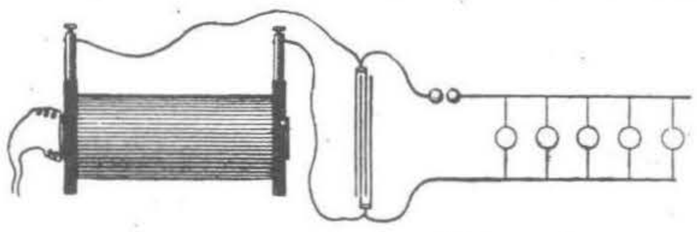

FIG. 31.—DIAGRAM OF CONNECTIONS FOR CONVERTING FROM HIGH TO LOW TENSION BY MEANS OF THE DISRUPTIVE DISCHARGE.

Instead of depending on induction at a distance to light the tube, the same may be provided with an external—and, if desired, also with an internal—condenser coating, and may then be suspended anywhere in the room from a conductor connected to one terminal of the coil, and in this manner a soft illumination may be provided.

The ideal way of lighting a hall or room would, however, be to produce such a condition in it that an illuminating device could be moved and put anywhere, and that it is lighted, no matter where it is put, and without being electrically connected to anything. I have been able to produce such a condition by creating in the room a powerful, rapidly alternating electrostatic field. For this purpose, I suspend a sheet of metal a distance from the ceiling on insulating cords, and connect it to one terminal of the induction coil, the other terminal being preferably connected to the ground. Or else, I suspend two sheets, as illustrated in Fig. 30, each sheet being connected with one of the terminals of the coil, and their size being carefully determined. An exhausted tube may then be carried in the hand anywhere between the sheets, or placed anywhere, even a certain distance beyond them; it remains always luminous.

In such an electrostatic field interesting phenomena may be observed, especially if the alternations are kept low and the potentials excessively high. In addition to the luminous phenomena mentioned, one may observe that any insulated conductor gives sparks when the hand or another object is approached to it, and the sparks may often be powerful. When a large conducting object is fastened on an insulating support and the hand approached to it a vibration, due to the rythmical motion of the air molecules, is felt and luminous streams may be perceived when the hand is held near a pointed projection. When a telephone receiver is made to touch with one or both of its terminals an insulated conductor of some size, the telephone emits a loud sound; it also emits a sound when a length of wire is attached to one or both terminals, and with very powerful fields a sound may be perceived even without any wire.

How far this principle is capable of practical application the future will tell. It might be thought that electrostatic effects are unsuited for such action at a distance. Electromagnetic inductive effects, if available for the production of light, might be thought better suited. It is true the electrostatic effects diminish nearly with the cube of the distance from the coil, whereas, the electromagnetic inductive effects diminish simply with the distance. But when we establish an electrostatic field of force the condition is very different, for then, instead of the differential effect of both the terminals, we get their conjoint effect. Besides, I would call attention to the fact that in an alternating electrostatic field a conductor, such as an exhausted tube, for instance, tends to take up most of the energy, whereas, in an electromagnetic alternating field the conductor tends to take up the least energy, the waves being reflected with but little loss. This is one reason why it is difficult to excite an exhausted tube at distance by electrostatic induction, I have been forced to consider of an electrostatic nature.

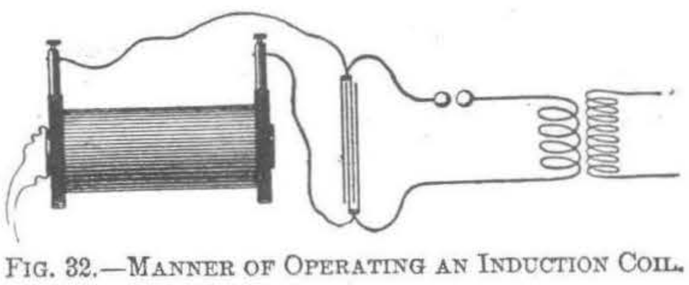

FIG. 32.—MANNER OF OPERATING AN INDUCTION COIL.

How, then, can we hope to produce the required effects at a distance by means of electromagnetic action, when even in the closest proximity to the source of disturbance, under the most advantageous conditions, we can excite but faint luminosity? It is true that when acting at a distance we have the resonance to help us out. We can connect an exhausted tube, or whatever the illuminating device may be, with an insulated system of the proper capacity, and so it may be possible to increase the effect qualitatively, and only qualitatively, for we would not get *more* energy through the device. So we may, by resonance effect, obtain the required electromotive force in an exhausted tube and excite faint luminous effects, but we cannot get enough energy to render the light practically available, and a simple calculation, based on experimental results, shows that even if all the energy which a tube would receive at a certain distance from the source would be wholly converted into light, it would hardly satisfy the practical requirements. Hence, the necessity of directing by means of a conducting circuit, the energy to the place of transformation. But in so doing we cannot very sensibly depart from present methods, and all we could do would be to improve the apparatus.

From these considerations it would seem that if this ideal way of lighting is to be rendered practicable it will be only by the use of electrostatic effects. In such a case the most powerful electrostatic inductive effects are needed; the apparatus employed must, therefore, be capable of producing high electrostatic potentials changing in value with extreme rapidity. High frequencies are especially wanted, for practical considerations make it desirable to keep down the potential. By the employment of machines, or, generally speaking, of any mechanical apparatus, but low frequencies can be reached; recourse must, therefore, be had to some other means. The discharge of a condenser affords us a means of obtaining frequencies by far higher than are obtainable mechanically, and I have accordingly employed condensers in the experiments to the above end.

When the terminals of a high tension induction coil, Fig. 31, are connected to a Leyden jar and the latter is discharging disruptively into a circuit, we may look upon the arc playing between the knobs as being a source of alternating or, generally speaking, undulating currents, and then we have to deal with the familiar system of a generator of such currents, a circuit connected to it and a condenser bridging the circuit. The condenser in such case is a veritable transformer and since the frequency is excessive, most any ratio in the strength of the currents in both the branches may be obtained. In reality the analogy is not quite complete, for in the disruptive discharge we have most generally a fundamental instantaneous variation of comparatively low frequency and a superimposed harmonic vibration, and the laws governing the flow of currents are not the same for both.

In converting in this manner, the ratio of conversion should not be too great, for the loss in the arc between the knobs increases with the square of the current, and if the jar be discharged through very thick and short conductors, with the view of obtaining a very rapid oscillation, a very considerable portion of the energy stored is lost. On the other hand, too small ratios are not practicable for many obvious reasons.

As the converted currents flow in a practically closed circuit the electrostatic effects are necessarily small, and I, therefore, convert them into currents or effects of the required character. I have effected such conversions in several ways. The preferred plan of connections is illustrated in Fig. 32. The manner of operating renders it easy to obtain by means of a small and inexpensive apparatus enormous differences of potential which have been usually obtained by means of large and expensive coils. For this it is only necessary to take an ordinary small coil, adjust it to a condenser and discharging circuit, forming the primary of an auxiliary small coil, and convert upwards. As the inductive effect of the primary currents is excessively great, the second coil need have comparatively but very few turns. By properly adjusting the elements, remarkable results may be secured.

In endeavoring to obtain the required electrostatic effects in this manner, I have, as might be expected, encountered many difficulties which I have been gradually overcoming, but at present I am not as yet prepared to dwell upon my experience in this direction.

I believe that the disruptive discharge of a condenser will play an important part in the future, for it offers vast possibilities, not only in the way of producing light in a more efficient manner and in line indicated by theory, but also in many other respects.

For years the efforts of inventors have been directed towards obtaining electrical energy from heat by means of the thermopile. It might seem invidious to remark that but few know what is the real trouble with the thermopile. It is not the inefficiency or small output — though these are great drawbacks—but the fact that the thermopile has its phylloxera, that is, that by constant use it is deteriorated, which has thus far prevented its introduction on an industrial scale. Now that all modern research seems to point with certainty to the use of electricity of excessively high tension, the question must present itself to many whether it is not possible to obtain in a practicable manner this form of energy from heat. We have been used to look upon an electrostatic machine as a plaything and somehow we couple with it the idea of the inefficient and impractical. But now we must think differently, for now we know that everywhere we have to deal with the same forces and that it is a mere question of inventing proper methods or apparatus for rendering them available.

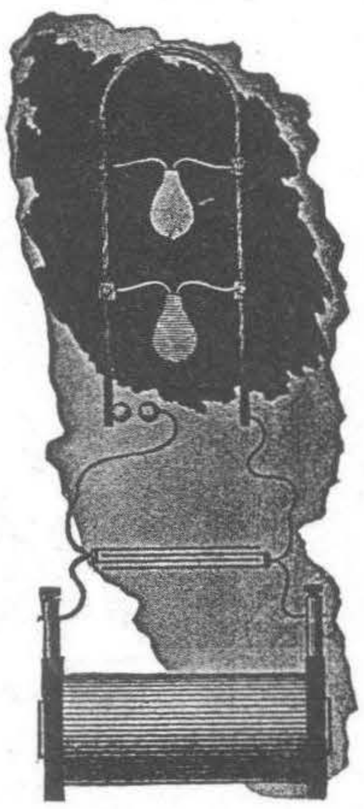

FIG. 33.—LAMP KEPT AT INCANDESCENCE ACROSS A THICK COPPER BAR—SHOWING NODES.

In the present systems of electrical distribution, the employment of the iron, with its wonderful magnetic properties, allows us to reduce considerably the size of the apparatus; but, in spite of this, it is still very cumbersome. The more we progress in the study of electric and magnetic phenomena, the more we become convinced that the present methods will be short-lived. For the production of light, at least, such heavy machinery would seem to be unnecessary. The energy required is very small, and if light can be obtained as efficiently as theoretically it appears possible, the apparatus need have but a very small output. There being a strong probability that the illuminating methods of the future will involve the use of very high potentials, it seems very desirable to perfect a contrivance capable of converting the energy of heat into energy of the requisite form. Nothing to speak of has been done towards this end, for the thought that electricity of some 50,000 or 100,000 volts pressure, or more, even if obtained, would be unavailable for practical purposes, has deterred inventors from working in this direction.

In Fig. 31 a plan of connections is shown for converting currents of high into currents of low tension by means of the disruptive discharge of a condenser. This plan has been used by me frequently for operating a few incandescent lamps required in the laboratory. Some difficulties have been encountered in the arc of the discharge, which I have been able to overcome to a great extent; besides this, and the adjustment necessary for the proper working, no other difficulties have been met with, and it was easy to operate ordinary lamps, and even motors in this manner. The line being connected to the ground, all the wires could be handled with perfect impunity, no matter how high the potential at the terminals of the condenser. In these experiments, a high tension induction coil, operated from a battery, or from an alternate current machine, was employed to charge the condenser; but the induction coil might be replaced by an apparatus of a different kind, capable of giving electricity of such high tension. In this manner direct or alternating currents may be converted, and in both cases the current impulses may be of any desired frequency. When the currents charging the condenser are of the same direction, and it is desired that the converted currents should also be of one direction, the resistance of the discharging circuit should, of course, be so chosen that there are no oscillations.

In operating devices on the above plan I have observed curious phenomena of impedance which are of interest. For instance, if a thick copper bar be bent as indicated in Fig. 33 and shunted by ordinary incandescent lamps, then by passing the discharge between the knobs the lamps may be brought to incandescence although they are short-circuited. When a large induction coil is employed it is easy to obtain nodes on the bar which are rendered evident by the different degree of brilliancy of the lamps, as shown roughly in Fig. 33. The nodes are never clearly pronounced, but there are simply maxima and minima of potential along the bar. This is probably due to the irregularity of the arc between the knobs. In general when the above described plan of conversion from high to low tension is used, the behavior of the disruptive discharge may be closely studied. The nodes may also be investigated by means of an ordinary Cardew voltmeter, which should be well insulated. Geissler tubes may also be lighted across the points of the bent bar; in this case, of course, it is better to employ smaller capacities. I have found it practicable to light up in this manner a lamp and even a Geissler tube shunted by a short heavy block of metal, and this result seems at first very curious. In fact, the thicker the copper bar in Fig. 33, the better it is for the success of the experiments as they appear more striking. When lamps with long slender filaments are used it will be often noted that the filaments are from time to time violently vibrated, the vibration being smallest on the nodal points. This vibration seems to be due to an electrostatic action between the filament and the glass of the bulb.

In some of the above experiments it is preferable to use special lamps having a straight filament, as shown in Fig. 34. When such a lamp is used a still more curious phenomenon than those described may be observed. The lamp may be placed across the copper bar and lighted, and by using somewhat larger capacities, or, in other words, smaller frequencies, or smaller impulsive impedances, the filament may be brought to any desired degree of incandescence. But when the impedance is increased, a point is reached when comparatively little current passes through the carbon and most of it through the rarefied gas; or, perhaps, it may be more correct to state that the current divides nearly evenly through both, in spite of the enormous difference in the resistance, and this would be true unless the gas and the filament behave differently. It is then noted that the whole bulb is brilliantly illuminated and the ends of the leading-in wires become incandescent and often

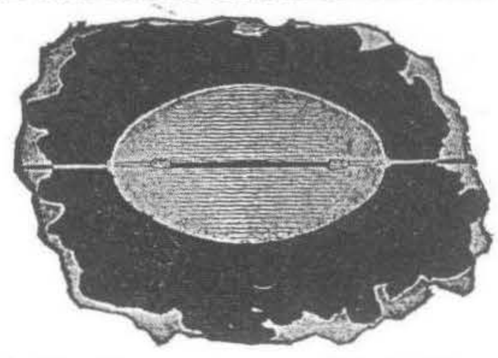

FIG. 34.—PHENOMENON OF IMPEDANCE IN AN INCANDESCENT LAMP.

throw off sparks in consequence of the violent bombardment; but the carbon filament remains dark. This is illustrated in Fig. 34. Instead of the filament a single wire extending through the whole bulb may be used, and in this case the phenomenon would seem to be still more interesting.

From the above experiment it will be evident that when ordinary lamps are operated by the converted currents, those should be preferably taken in which the platinum wires are far apart and the frequencies used should not be too great, else the discharge will occur at the ends of the filament, or in the base of the lamp between the leading-in wires, and the lamp might then be damaged.

In presenting to you these results of my investigation on the subject under consideration I have paid only a passing notice to facts upon which I could have dwelt at length, and among many observations I have selected only those which I thought most likely to interest you. The field is wide and completely unexplored, and at every step a new truth is gleaned, a novel fact observed.

How far the results here borne out are capable of practical applications will be decided in the future. As regards the production of light some results a'ready reached are encouraging and make me confident in asserting that the practical solution of the problem lies in the direction I have endeavored to indicate. Still, whatever may be the immediate outcome of these experiments, I am hopeful that they will only prove a step to further development towards the ideal and final perfection. The possibilities which are opened by modern research are so vast that even the most reserved must feel sanguine of the future. Eminent scientists consider the problem of utilizing one kind of radiation without the others a rational one. In an apparatus designed for the production of light by conversion from any form of energy into that of light such a result can never be reached, for no matter what the process of producing the required vibrations, be it electrical, chemical or any other, it will not be possible to obtain the higher light vibrations without going through the lower heat vibrations. It is the problem of imparting to a body a certain velocity without passing through all lower velocities. But there is a possibility of obtaining energy, not only in the form of light, but motive power and energy of any other form, in some more direct way from the medium. The time will be when this will be accomplished and the time has come when one may utter such words before an enlightened audience without being considered visionary. We are whirling through the endless space with an inconceivable speed, all around us everything is spinning, everything is moving, everywhere is energy. There *must* be some way of availing ourselves of this energy more directly. Then, with the light obtained from the medium, with the power derived from it, with every form of energy obtained without effort, from the store forever inexhaustible, humanity will advance with giant strides The mere contemplation of these magnificent possibilities expands our minds, strengthens our hopes and fills our hearts with supreme delight.

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High Frequency Alternations.

AT last, after protracted delay, Mr. Nikola Tesla's paper before the American Institute of Electrical Engineers at its annual meeting is ready for publication. The period of waiting, however, is more than compensated by the finished form in which Mr. Tesla's research appears. It is hard in any reasonable space to give an adequate idea of the suggestiveness of the very remarkable work that he has done. It contains not only hints bearing on the most occult portions of theoretical electricity, but also gives promise of future commercial importance. To search out the nature of the forces that appear in electricity and magnetism is the most fascinating, as it is perhaps the most difficult, problem before the scientific man of to-day. During the past ten years not a few brilliant minds have been turned toward its solution, but as yet very little has actually been accomplished, although much is to-day promised. The clever speculations of Lodge, and the magnificent experimental work of Hertz and others, have thrown a flood of light on portions of the subject that has heretofore been wrapped in profound darkness. Nevertheless, as Mr. Tesla very properly suggests, much of this work is rather ingenious than satisfying. To a certain extent one cannot help feeling that it bears some resemblance to the theory of epicycles advanced by the early astronomers; it was a clever conception, and by the very simple device of subdividing the motions, as Lodge subdivided the ether, it was possible to account for very many of the curious anomalies in planetary motion. It remained for Kepler, to show that the epicycles were only a complicated system for translating into terms of circular motion the elliptic orbits of the heavenly bodies. In a similar way we may find, indeed probably shall find, that the machinery of positive and negative electricities, of a subdivided ether and atomic charges, are merely modes of expressing certain phases of a reality by no means so complicated. Perhaps it may be that we speak now of positive and negative electricities much as one would have spoken 40 years ago of the north and south poles of a solenoid, and similarly it is probable that the hypothesis of an atomic charge is only another way of asserting the dynamical equivalence of all atoms of a particular kind. As regards the commercial possibilities of Mr. Tesla's work, it is not easy to predict anything with certainty; it is a promising direction in which to work, but the difficulties in the way are many. Chief among them is that of distributing currents of high frequency, at least of as high frequency as were employed by Mr. Tesla in his experiments. For such currents an ordinary solid wire is but poorly adapted on account of its high self-induction, and one is confronted by the possibility of hollow wires, of cables composed of thin strips, and other forms of conductor that are not altogether attractive from a commercial point of view. And then comes the condenser, the most beautiful of all transforming devices, provided it can be made cheap and durable; and after all this comes the question of suitable lamps for utilizing the currents after they are obtained and distributed. From the standpoint of economy the vacuum tube type shown by Mr. Tesla is by all odds the most promising. Lamps with filaments brought to incandescence by induced currents would have no special advantage in economy of illumination over those made in the ordinary way, but if it were possible to obtain a mass of luminous gas that would give a clear and steady light it might be that a far greater percentage of luminous radiation could be procured from it than has ever been obtained from a mere heated solid, and this is the direction in which work is needed. Prof. Langley has shown that luminous radiation almost pure, and therefore of maximum efficiency, is emitted by the firefly. The incandescent lamp, on the other hand, gives, so to speak, a minimum of radiant illumination with a maximum of heat rays. Mr. Tesla is working industriously on the problem of substituting for the last-mentioned inefficient arrangement some form of induction tube in which one may at least simulate in character the glow of the firefly, and thus obtain, from a given amount of electrical energy, perhaps a dozen times more light than has ever yet been secured. The field of investigation is a most fascinating one and promises great things in the future. Meanwhile, Mr. Tesla's present paper gives an admirable summary of the results he has attained up to date and the varied course of his beautiful investigations.

Experiments with Alternate Currents of Very High Frequency, and Their Application to Methods of Artificial Illumination.*

BY NIKOLA TESLA.

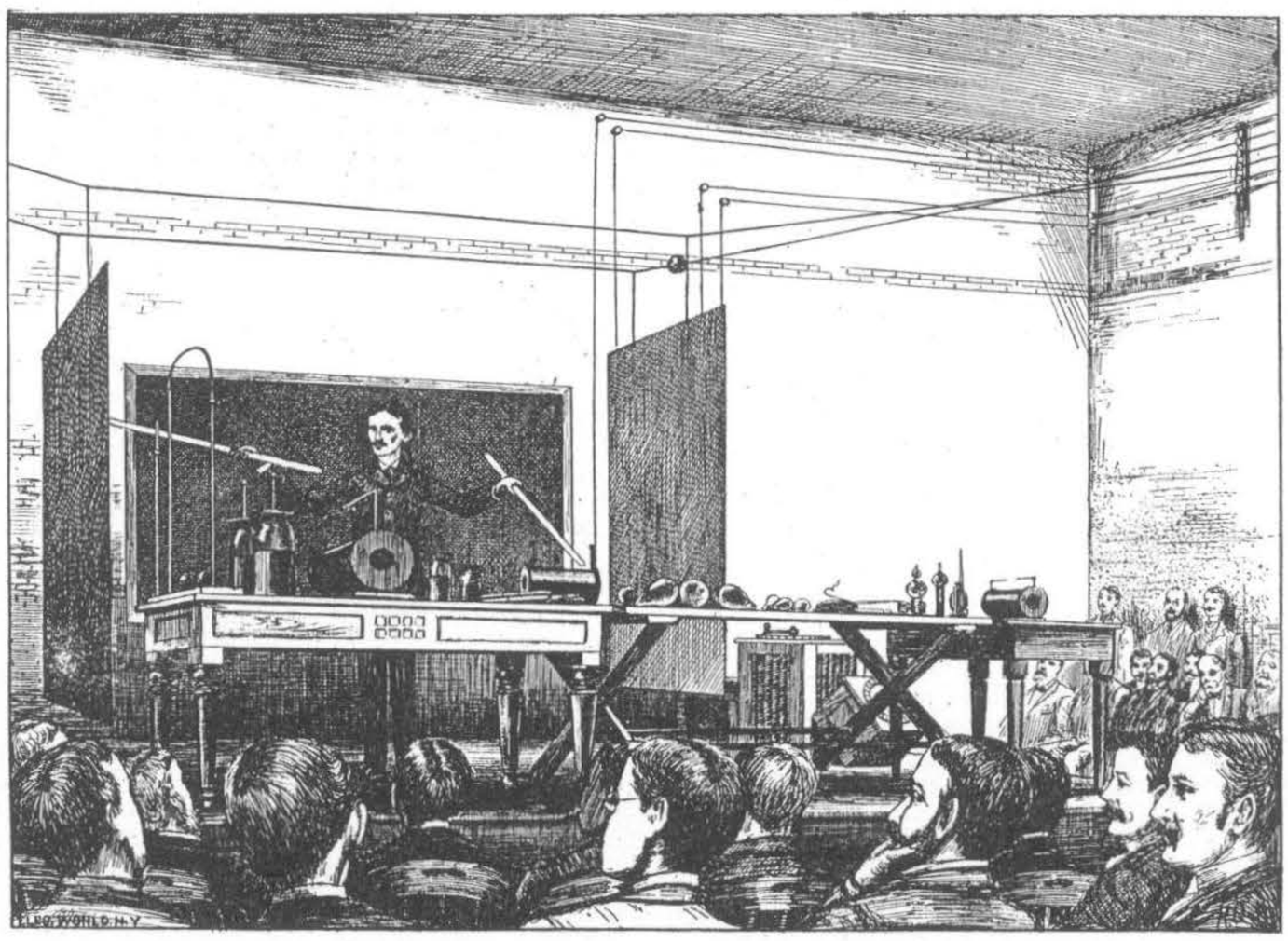
There is no subject more captivating, more worthy of study, than nature. To understand this great mechanism, to discover the forces which are active, and the laws which govern them, is the highest aim of the intellect of man.

Nature has stored up in the universe infinite energy. The eternal recipient and transmitter of this infinite energy is the ether. The recognition of the existence of ether, and of the functions it performs, is one of the most important results of modern scientific research. The mere abandoning of the idea of action at a distance, the assumption of a medium pervading all space and connecting all gross matter, has freed the minds of thinkers of an ever-present doubt, and, by opening a new horizon—new and unforeseen possibilities—has given fresh interest to phenomena with which we are familiar of old. It has been a great step toward the understanding of the forces of nature and their multifold manifestations to our senses. It has been for the enlightened student of physics what the understanding of the mechanism of the firearm or of the steam engine was for the barbarian. Phenomena upon which we used to look as wonders baffling explanation we now see in a different light. The spark of an induction coil, the glow of an incandescent lamp, the manifestations of the mechanical forces of currents, and magnets are no longer beyond our grasp; instead of the incomprehensible, as before, their observation suggests now in our minds a simple mechanism, and although as to its precise nature all is still conjecture, yet we know that the truth cannot be much longer hidden, and instinctively we feel that the understanding is dawning upon us. We still admire these beautiful phenomena, these strange forces, but we are helpless no longer; we can in a certain measure explain them, account for them, and we are hopeful of finally succeeding in unraveling the mystery which surrounds them.

In how far we can understand the world around us is the ultimate thought of every student of nature. The coarseness of our senses prevents us from recognizing the ulterior construction of matter, and astronomy, this grandest and most positive of natural sciences, can only teach us something that happens, as it were, in our immediate neighborhood; of the remoter portions of the boundless universe, with its numberless stars and suns, we know nothing. But far beyond the limit of perception of our senses the spirit still can guide us, and so we may hope that even these unknown worlds—infinitely small and great—may in a measure become known to us. Still, even if this knowlege should reach us, the searching mind will find a barrier, perhaps forever unsurpassable, to the *true* recognition of that which *seems* to be, the mere *appearance* of which is the only and slender basis of all our philosophy.

Of all the forms of nature's immeasurable, all-pervading energy, which, ever and ever changing and moving, like a soul animates the inert universe, those of electricity and magnetism are perhaps the most fascinating. The effects of gravitation of heat and light we observe daily, and soon we get accustomed to them, and soon they lose for us the character of the marvelous and wonderful; but electricity and magnetism, with their singular relationship, with their seeming dual character unique among the forces in nature, with their phenomena of attractions, repulsions and rotations, strange manifestations of mysterious agents, stimulate and excite the mind to thought and research. What is electricity, and what is magnetism? These questions have been asked again and again. The most able intellects have ceaselessly wrestled with the problem; still the question has not as yet been fully answered. But while we cannot even to-day state what these singular forces are, yet we have made good headway toward the solution of the problem. We are now confident that electric and magnetic phenomena are attributable to ether, and we are perhaps justified in saying that the effects of static electricity are effects of ether under strain and those of dynamic electricity and electro-magnetism effects of ether in motion. But this still leaves the question, as to what electricity and magnetism are, unanswered.

First, we naturally inquire, What is electricity, and is there such a thing as electricity? In interpreting electric phenomena we may speak of electricity or of an electric condition, state or effect. If we speak of electric effects, we must distinguish two such effects opposite in character and neutralizing each other, as observation shows that two such opposite effects exist. This is unavoidable, for in a medium of the properties of ether we cannot possibly exert a strain or produce a displacement or motion of any kind without causing in the surrounding medium an equivalent and opposite effect. But if we speak of electricity, meaning a *thing*, we must, I think, abandon the idea of two electricities, as the existence of two such things is highly improbable. For how can we imagine that there should be two things, equivalent in amount, alike in their properties, but of opposite character, both clinging to matter, both attracting and completely neutralizing each other? Such an assumption, though suggested by many phenomena, though most convenient for explaining them, has little to commend it. If there *is* such a thing as electricity, there can be only *one* such thing, and excess and want of that one thing possibly, but more probably its condition determines the positive and negative character. The old theory of Franklin, though falling short in some respects, is, from a certain point of view, after all, the most plausible one. Still, in spite of this, the theory of the two electricities is generally accepted, as it apparently explains electric phenomena in a more satisfactory manner. But a theory which explains better the facts is not necessarily true. Ingenious minds will invent theories to suit observation, and almost every independent thinker has his own views on the subject.



MR. NIKOLA TESLA'S LECTURE BEFORE THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

It is not with the object of advancing an opinion, but with the desire of acquainting you better with some of the results which I will describe, to show you the reasoning I have followed, the departures I have made, that I venture to express in a few words the views and convictions which have led me to these results.

I adhere to the idea that there is a thing which we have been in the habit of calling electricity. The question is, What is that thing? or, What, of all things the existence of which we know, have we the best reason to call electricity? We know that it acts like an incompressible fluid; that there must be a constant quantity of it in nature; that it can be neither produced nor destroyed; and, what is more important, the electro-magnetic theory of light and all facts observed teach us that electric and ether phenomena are identical. The idea at once suggests itself, therefore, that electricity might be called ether. In fact, this view has in a certain sense been advanced by Dr. Lodge. His interesting work has been read by every one and many have been convinced by his arguments. His great ability and the interesting nature of the subject keep the reader spellbound; but when the impressions fade one realizes that he has to deal only with ingenious explanations. I must confess that I cannot believe in two electricities, much less in a doubly constituted ether. The puzzling behavior of the ether as a solid to waves of light and heat, and as a fluid to the motion of bodies through it, is certainly explained in the most natural and satisfactory manner by assuming it to be in motion, as Sir William Thomson has suggested; but regardless of this, there is nothing which would enable us to conclude with certainty that, while a fluid is not capable of transmitting transverse vibrations of a few hundred or thousand per second, it might not be capable of transmitting such vibrations when they range into hundreds of million millions per second. Nor can any one prove that there are transverse ether waves emitted from an alternate current machine, giving a small number of alternations per second; to such slow disturbances the ether, if at rest, may behave as a true fluid.

Returning to the subject, and bearing in mind that the existence of two electricities is, to say the least, highly improbable, we must remember that we have no evidence of electricity, nor can we hope to get it, unless gross matter is present. Electricity, therefore, cannot be called ether in the broad sense of the term; but nothing would seem to stand in the way of calling electricity ether associated with matter, or bound ether; or, in other words, that the so-called static charge of the molecule is ether associated in some way with the molecule. Looking at it in that light, we would be justified in saying that electricity is concerned in all molecular actions.

Now, precisely what the ether surrounding the molecules is, wherein it differs from ether in general, can only be conjectured. It cannot differ in density, ether being incompressible; it must, therefore, be under some strain or in motion, and the latter is the most probable. To understand its functions, it would be necessary to have an exact idea of the physical construction of matter, of which, of course, we can only form a mental picture.

But of all the views on nature, the one which assumes one matter and one force, and a perfect uniformity throughout, is the most scientific and most likely to be true. An infinitesimal world, with the molecules and their atoms spinning and moving in orbits, in much the same manner as celestial bodies, carrying with them and probably spinning with them ether, or, in other words, carrying with them static charges, seems to my mind the most probable view, and one which, in a plausible manner, accounts for most of the phenomena observed. The spinning of the molecules and their ether sets up ether tensions or electrostatic strains; the equalization of ether tensions sets up ether motions or electric currents, and the orbital movements produce the effects of electro and permanent magnetism.

About fifteen years ago Prof. Rowland demonstrated a most interesting and important fact, namely, that a static charge carried around produces the effects of an electric current. Leaving out of consideration the precise nature of the mechanism which produces the attraction and repulsion of currents, and conceiving the electrostatically charged molecules in motion, this experimental fact gives us a fair idea of magnetism. We can conceive lines or tubes of force which physically exist, being formed of rows of directed moving molecules; we can see that these lines must be closed; that they must tend to shorten and expand, etc. It likewise explains in a reasonable way the most puzzling phenomenon of all, permanent magnetism, and, in general, has all the beauties of the Ampère theory without possessing the vital defect of the same, namely, the assumption of molecular currents. Without enlarging further upon the subject, I would say that I look upon all electrostatic, current and magnetic phenomena as being due to electrostatic molecular forces.

The preceding remarks I have deemed necessary to a full understanding of the subject as it presents itself to my mind.

Of all these phenomena the most important to study are the current phenomena, on account of the already extensive and ever-growing use of currents for industrial purposes. It is now a century since the first practical source of current was produced, and ever since the phenomena which accompany the flow of currents have been diligently studied, and through the untiring efforts of scientific men the simple laws which govern them have been discovered. But these laws were found to hold good only when the currents are of a steady character. When the currents are rapidly varying in strength quite different phenomena, often unexpected, present themselves, and quite different laws hold good, which even now have not been determined as fully as is desirable, though through the work principally of English scientists enough knowledge has been gained on the subject to enable us to treat simple cases which now present themselves in daily practice.

The phenomena which are peculiar to the changing character of the currents are greatly exalted when the rate of change is increased, hence the study of these currents is considerably facilitated by the employment of

*A lecture delivered before the American Institute of Electrical Engineers, at Columbia College, May 20, 1891.

properly constructed apparatus. It was with this and other objects in view that I constructed alternate-current machines capable of giving more than two million reversals of current per minute, and to this circumstance it is principally due that I am able to bring to your attention some of the results thus far reached, which I hope will prove to be a step in advance on account of their direct bearing upon one of the most important problems, namely, the production of a practical and efficient source of light.

The study of such rapidly alternating currents is very interesting. Nearly every experiment discloses something new. Many results may, of course, be predicted, but many more are unforeseen. The experimenter makes many interesting observations. For instance, we take a piece of iron and hold it against a magnet. Starting from low alternations and running up higher and higher we feel the impulses succeed each other faster and faster, get weaker and weaker, and finally disappear. We then observe a continuous pull; the pull, of course, is not continuous; it only appears so to us; our sense of touch is imperfect.

We may next establish an arc between the electrodes and observe, as the alternations rise, that the note which accompanies alternating arcs gets shriller and shriller, gradually weakens, and finally ceases. The air vibrations, of course, continue, but they are too weak to be perceived; our sense of hearing fails us.

We observe the small physiological effects, the rapid heating of the iron cores and conductors, curious inductive effects, interesting condenser phenomena, and still more interesting light phenomena with a high-tension induction coil. All these experiments and observations would be of the greatest interest to the student, but their description would lead me too far from the principal subject. Partly for this reason, and partly on account of their vastly greater importance, I will confine myself to the description of the light effects produced by these currents.

In the experiments to this end a high-tension induction coil or equivalent apparatus for converting currents of comparatively low into currents of high tension is used.

If you will be sufficiently interested in the results I shall describe as to enter into an experimental study of this subject; if you will be convinced of the truth of the arguments I shall advance, your aim will be to produce high frequencies and high potentials; in other words, powerful electrostatic effects. You will then encounter many difficulties, which, if completely overcome, would allow us to produce truly wonderful results.

First will be met the difficulty of obtaining the required frequencies by means of mechanical apparatus, and, if they be obtained otherwise, obstacles of a different nature will present themselves. Next it will be found difficult to provide the requisite insulation without considerably increasing the size of the apparatus, for the potentials required are high, and owing to the rapidity of the alternations the insulation presents peculiar difficulties. So, for instance, when a gas is present the discharge may work through by the molecular bombardment of the gas and consequent heating, through as much as an inch of the best solid insulating material, such as glass, hard rubber, porcelain, sealing wax, etc.; in fact, through any known insulating substance. The chief requisite in the insulation of the apparatus is, therefore, the exclusion of any gaseous matter.

In general my experience tends to show that bodies which possess the highest specific inductive capacity, such as glass, afford a rather inferior insulation to others which, while they are good insulators, have a much smaller specific inductive capacity, such as oils, for instance, the dielectric losses being no doubt greater in the former. The difficulty of insulating, of course, only exists when the potentials are excessively high, for with potentials such as a few thousand volts there is no particular difficulty encountered in conveying currents from a machine giving, say, 20,000 alternations per second to quite a distance. This number of alternations, however, is by far too small for many purposes, though quite sufficient for some practical applications. This difficulty of insulating is fortunately not a vital drawback; it affects mostly the size of the apparatus, for, when excessively high potentials would be used, the light-giving devices would be located not far from the apparatus, and often they would be quite close to it. As the air bombardment of the insulated wire is dependent on condenser action, the loss may be reduced to a trifle by using excessively thin wires heavily insulated.

Another difficulty which will be encountered is the capacity and self-induction necessarily possessed by the coil. If the coil be large, that is, if it contains a great length of wire, it will be generally unsuited for excessively high frequencies; if it be small, it may be well adapted for such frequencies, but the potential might then not be as high as desired. A good insulator, and preferably one possessing a small specific inductive capacity, would afford a two-fold advantage. First, it would enable us to construct a very small coil capable of withstanding enormous differences of potential; and secondly, such a small coil, by reason of its smaller capacity of self-induction, would be capable of a quicker and more vigorous vibration. The problem, then, of constructing a coil or induction apparatus of any kind possessing the requisite qualities I regard as one of no small importance, and it has occupied me for considerable time.

The investigator who desires to repeat the experiments which I describe, with an alternate current machine, capable of supplying currents of the desired frequency, and an induction coil, will do well to take the primary coil out and mount the secondary in such a manner as to be able to look through the tube upon which the secondary is wound. He will then be able to observe the streams which pass from the primary to the insulating tube, and from their intensity he will know how far he can strain the coil. Without this precaution he is sure to injure the insulation. This arrangement permits, however, an easy exchange of the primaries, which is desirable in these experiments.

The selection of the type of machine best suited for the purpose must be left to the judgment of the experimenter. There are here illustrated three distinct types of machines, which, besides others, I have used in my experiments.

Fig. 1 represents the machine used in my experiments before this institute. The field magnet consists of a ring of wrought iron with 384 pole projections. The armature comprises a steel disc to which is fastened a thin, carefully welded rim of wrought iron. Upon the rim are wound several layers of fine, well annealed iron wire, which, when wound, is passed through shellac. The armature wires are wound around brass pins, wrapped with silk thread. The diameter of the armature wire in this type of machine should not be more than one-sixth of the thickness of the pole projections, else the local action will be considerable.

Fig. 2 represents a larger machine of a different type. The field magnet of this machine consists of two like parts which either inclose an exciting coil or else are independently wound. Each part has 480 pole projections, the projections of one facing those of the other. The armature consists of a wheel of hard bronze carrying the conductors which revolve between the projections of the field magnet. To wind the armature conductors, I have found it most convenient to proceed in the following manner: I construct a ring of hard bronze of the required size. This ring and the rim of the wheel are provided with the proper number of pins and both fastened upon a plate. The

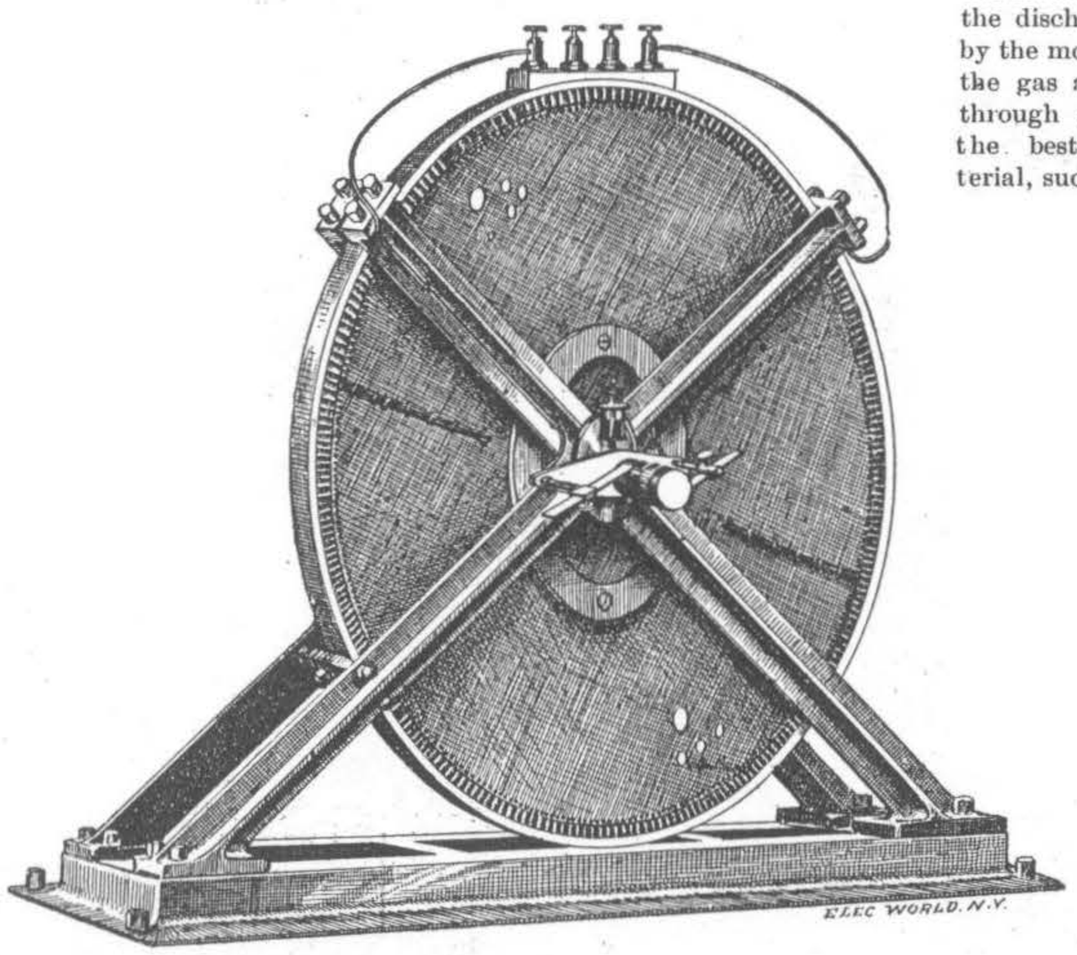


FIG. 1.—HIGH FREQUENCY ALTERNATING CURRENT MACHINE WITH DRUM ARMATURE.

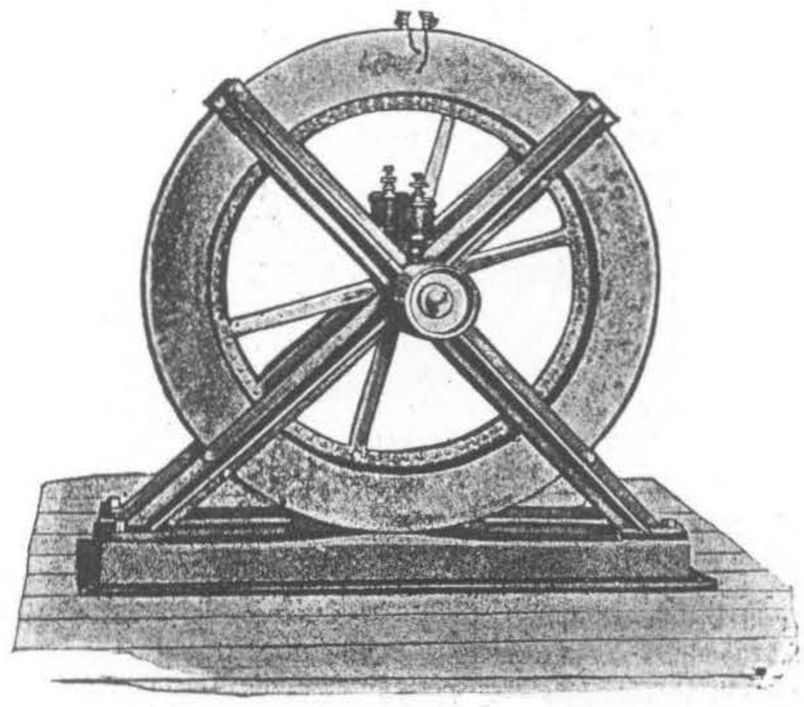


FIG. 2.—HIGH FREQUENCY ALTERNATOR WITH REVOLVING DISC ARMATURE.

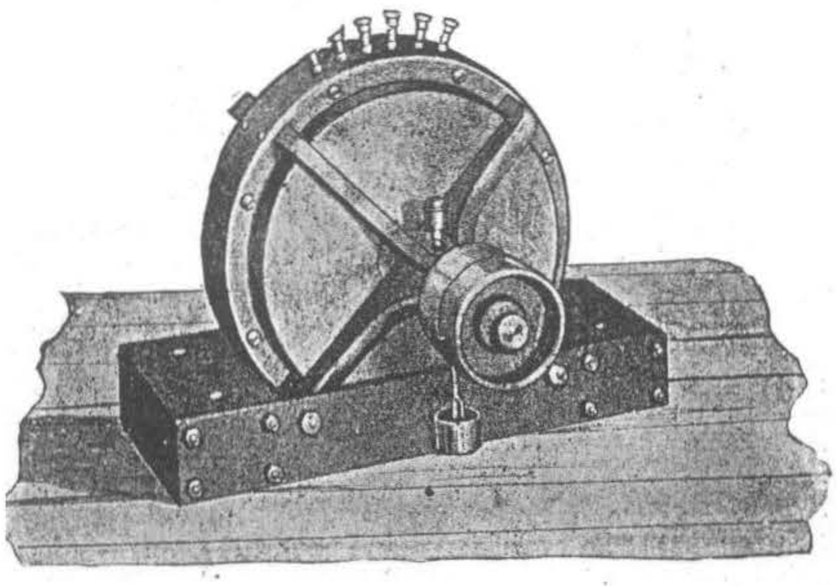


FIG. 3.—HIGH FREQUENCY ALTERNATOR WITH STATIONARY DISC ARMATURE AND STATIONARY EXCITING COIL.

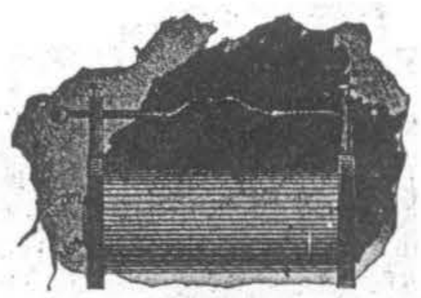


FIG. 4.—SENSITIVE THREAD DISCHARGE.

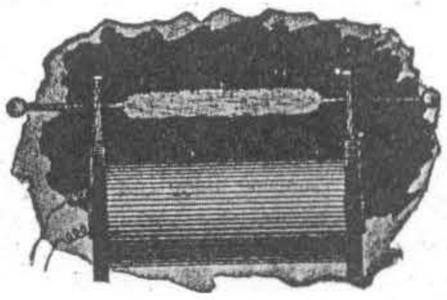


FIG. 5A.—FLAMING DISCHARGE.

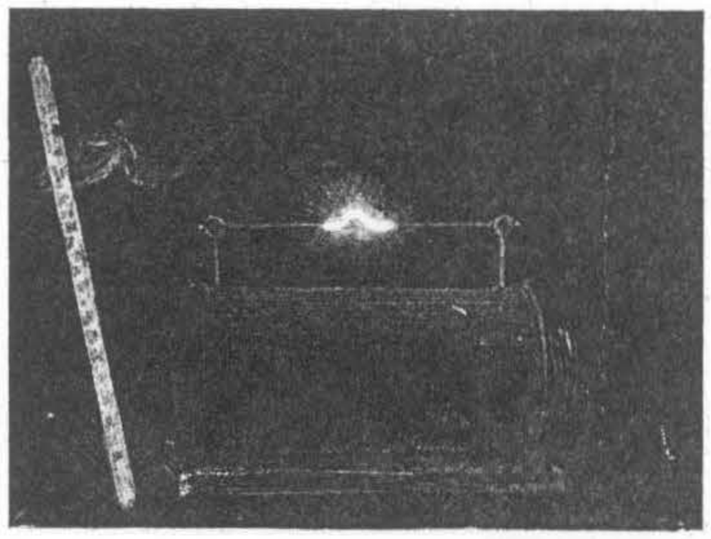


FIG. 5B.—FLAMING DISCHARGE FROM THE TERMINAL OF A HIGH TENSION COIL.

armature conductors being wound, the pins are cut and the ends of the conductors fastened by two off rings which screw to the bronze ring and the rim of the wheel respectively. The whole may then be taken off and forms a solid structure. The conductors in such a type of machine should consist of sheet copper, the thickness of which, of course, depends on the thickness of the pole projections; or else twisted thin wires should be employed.

Fig. 3 is a smaller machine, in many respects similar to the former, only here the armature conductors and the exciting coil are kept stationary, while only a block of wrought iron is revolved.

It would be uselessly lengthening this description were I to dwell more on the details of construction of these machines. I deem it well, however, to call the attention of the investigator to two things, the importance of which, though self-evident, he is nevertheless apt to underestimate: namely, to the local action in the conductors, which must be carefully avoided, and to the clearance, which must be small. I may add, that since it is desirable to use very high peripheral speeds, the armature should be of very large diameter in order to avoid impracticable belt speeds. Of the several types of these machines which have been constructed by me, I have found that the type illustrated in Fig. 1 caused me the least trouble in construction as well as in maintenance, and, on the whole, it has been a good experimental machine.

In operating an induction coil with very rapidly alternating currents, among the first luminous phenomena noticed are naturally those presented by the high-tension discharge. As the number of alternations per second is increased, or as—the number being high—the current through the primary is varied, the discharge gradually changes in appearance. It would be difficult to describe

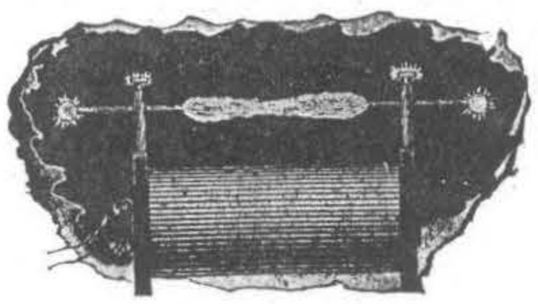


FIG. 6.—STREAMING DISCHARGE.

the minor changes which occur and the conditions which bring them about, but one may note five distinct forms of the discharge.

First, one may observe a weak, sensitive discharge in the form of a thin, feeble-colored thread (Fig. 4). It always occurs when, the number of alternations per second being high, the current through the primary is very small. In spite of the excessively small current, the rate of change is great and the difference of potential at the terminals of the secondary is therefore considerable, so that the arc is established at great distances; but the quantity of "electricity" set in motion is insignificant, barely sufficient to maintain a thin, thread-like arc. It is excessively sensitive and may be made so to such a degree that the mere act of breathing near the coil will affect it, and unless it is perfectly well protected from currents of air it wriggles around constantly. Nevertheless, it is in this form excessively persistent, and when the terminals are approached to, say, one-third of the striking distance, it can be blown out only with difficulty. This exceptional persistency, when short, is largely due to the arc being excessively thin; presenting, therefore, a very small surface to the blast. Its great sensitiveness, when very long, is probably due to the motion of the particles of dust suspended in the air.

When the current through the primary is increased the discharge gets broader and stronger, and the effect of the capacity of the coil becomes visible, until, finally, under proper conditions, a white flaming arc, Fig. 5, often as thick as one's finger and striking across the whole coil, is produced. It develops remarkable heat, and may be further characterized by the absence of the high note which accompanies the less powerful discharges. To take a shock from the coil under these conditions would not be advisable, although under different conditions, the potential being much higher, a shock from the coil may be taken with impunity. To produce this kind of discharge the number of alternations per second must not be too great for the coil used; and, generally speaking, certain relations between capacity, self-induction and frequency must be observed.

The importance of these elements in an alternate current circuit is now well known, and under ordinary conditions the general rules are applicable. But in an induction coil exceptional conditions prevail. First, the self-induction is of little importance before the arc is established, when it asserts itself, but perhaps never as prominently as in ordinary alternate current circuits, because capacity is distributed all along the coil, and by reason of the fact that the coil usually discharges through very great resistances; hence the currents are exceptionally small. Secondly, the capacity goes on increasing continually as the potential rises, in consequence of absorption which takes place to a considerable extent. Owing to this there exists no critical relationship between these quantities, and ordinary rules would not seem to be applicable. As the potential is increased either in consequence of the increased frequency or of the increased current through the primary, the amount of the energy stored becomes greater and greater and the capacity gains more and more in importance. Up to a certain point the capacity is beneficial, but after that it begins to be an enormous drawback. It follows from this that each coil gives the best result with a given frequency and primary current. A very large coil when operated with currents of very high frequency may not give as much as one-eighth inch spark. By adding capacity to the terminals the condition may be improved, but what the coil really wants is a lower frequency.

When the flaming discharge occurs the conditions are evidently such that the greatest current is made to flow through the circuit. These conditions may be attained by varying the frequency within wide limits, but the highest frequency at which the flaming arc can still be produced

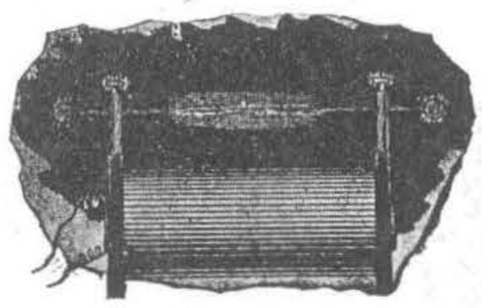


FIG. 7.—BRUSH AND SPRAY DISCHARGE.

determines, for a given primary current, the maximum striking distance of the coil. In the flaming discharge the effect of the capacity is not perceptible; the rate at which the energy is being stored then just equals the rate at which it can be disposed of through the circuit. This kind of discharge is the severest test for a coil; the break, when it occurs, is of the nature of that in an overcharged Leyden jar. To give a rough approximation, I would state that with an ordinary coil of, say, 10,000 ohms resistance, the most powerful arc would be produced with about 12,000 alternations per second.

When the frequency is increased beyond that rate the potential, of course, rises, but the striking distance may, nevertheless, diminish, paradoxical as it may seem. As the potential rises the coil attains more and more the properties of a static machine, until, finally, one may observe the beautiful phenomenon of the streaming discharge, Fig. 6, which may be produced across the whole length of the coil. At that stage streams begin to issue freely from all points and projections. These streams will also be seen to pass in abundance in the space between the primary and the insulating tube. When the potential is excessively high they will always appear, even if the frequency be low, and if even the primary be surrounded by as much as an inch of wax, hard rubber, glass or any other insulating substance. This limits greatly the output of the coil, but I will later show how I have been able to overcome to a considerable extent this disadvantage in the ordinary coil.

Besides the potential, the intensity of the streams depends on the frequency; but if the coil be very large they show themselves, no matter how low the frequencies used.

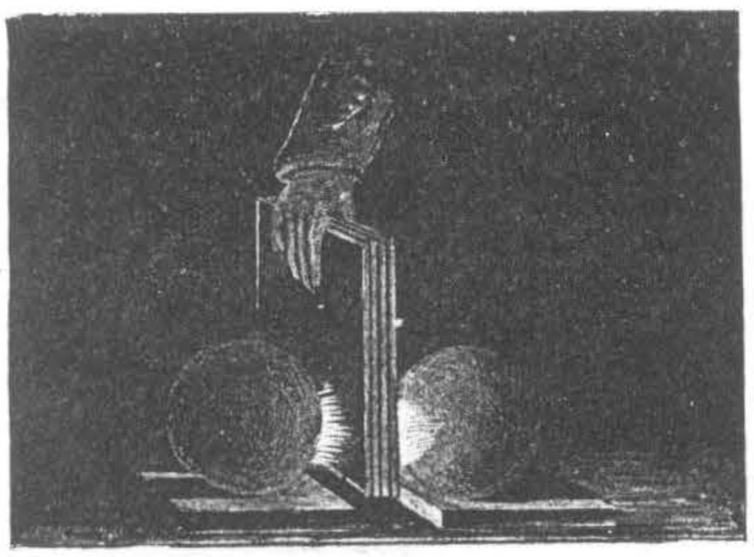


FIG. 9.—LUMINOUS DISCHARGE WITH INTERPOSED INSULATORS.

For instance, in a very large coil of a resistance of 67,000 ohms, constructed by me some time ago, they appear with as low as 100 alternations per second and less, the insulation of the secondary being three-quarter inch of ebonite. When very intense they produce a noise similar to that produced by the charging of a Holtz machine, but much more powerful, and they emit a strong smell of ozone. The lower the frequency, the more apt they are to suddenly injure the coil. With excessively high frequencies they may pass freely without producing any other effect than to heat the insulation slowly and uniformly.

The existence of these streams shows the importance of constructing an expensive coil so as to permit of one's seeing through the tube surrounding the primary, and the latter should be easily exchangeable, or else the space between the primary and secondary should be completely filled up with insulating material so as to exclude all air. The non-observance of this simple rule in the construction of the commercial coils is responsible for the destruction of many an expensive coil.

At the stage when the streaming discharge occurs, or with somewhat higher frequencies, one may, by approaching the terminals considerably and regulating properly the effect of capacity, produce a veritable spray of small silver-white sparks or a bunch of excessively thin silvery threads (Fig. 7) amidst a powerful brush—each spark or thread possibly corresponding to one alternation. This, when produced under proper conditions, is probably the most beautiful discharge, and when an air blast is directed against it it presents a singular appearance. The spray of sparks, when received through the body, causes some inconvenience, whereas, when the discharge simply streams nothing at all is likely to be felt if large conducting objects are held in the hands to protect them from receiving small burns.

If the frequency is still more increased, then the coil refuses to give any spark unless at comparatively small distances, and the fifth typical form of discharge may be observed (Fig. 8). The tendency to stream out and dissipate is then so great that when the brush is produced at one terminal no sparking occurs even if, as I have repeatedly tried, the hand, or any conducting object, is held within the stream; and, what is more singular, the luminous stream is not at all easily deflected by the approach of a conducting body.

At this stage the streams seemingly pass with the greatest freedom through considerable thicknesses of insulators, and it is particularly interesting to study their behavior. For this purpose it is convenient to connect to the terminals of the coil two metallic spheres which may be placed at any desired distance (Fig. 9). Spheres are preferable to plates, as the discharge can be better observed. By inserting dielectric bodies between the spheres beautiful discharge phenomena may be observed. If the spheres be quite close and a spark be playing between them, by interposing a thin plate of ebonite between the spheres the spark instantly ceases and the discharge spreads into an intensely luminous circle several inches in diameter, provided the spheres are sufficiently large. The passage of the stream heats, and, after a while, softens the rubber so much that two plates may be made to stick

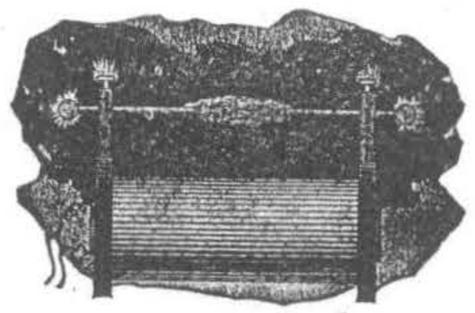


FIG. 8.—FIFTH TYPICAL FORM OF DISCHARGE.

together in this manner. If the spheres are so far apart that no spark occurs, even if they are far beyond the striking distance, by inserting a thick plate of glass the discharge is instantly induced to pass from the spheres to the glass in the form of luminous streams. It appears almost as though these streams pass *through* the dielectric. In reality this is not the case, as the streams are due to the molecules of the air which are violently agitated in the space between the oppositely charged surfaces of the spheres. When no dielectric other than air is present, the bombardment goes on, but is too weak to be visible; by inserting a dielectric the inductive effect is much increased and, besides, the projected air molecules find an obstacle, and the bombardment becomes so intense that the streams become luminous. If by any mechanical means we could effect such a violent agitation of the molecules we could produce the same phenomenon. A jet of air escaping through a small hole under enormous pressure and striking against an insulating substance, such as glass, may be luminous in the dark, and it might be possible to produce phosphorescence of the glass or other insulators in this manner.

The greater the specific inductive capacity of the interposed dielectric the more powerful the effect produced. Owing to this, the streams show themselves with excessively high potentials even if the glass be as much as one and one-half to two inches thick. But besides the heating due to bombardment, some heating goes on undoubtedly in the dielectric, being apparently greater in glass than in ebonite. I attribute this to the greater specific inductive capacity of the glass, in consequence of which, with the same potential difference, a greater amount of energy is taken up in it than in rubber. It is like connecting to a battery a copper and a brass wire of the same dimensions. The copper wire, though a more perfect conductor, would heat more by reason of its taking more current. Thus what is otherwise considered a virtue of the glass is here a defect. Glass usually gives way much quicker than ebonite; when it is heated to a certain degree the discharge suddenly breaks through at one point, assuming then the ordinary form of an arc.

The heating effect produced by molecular bombardment of the dielectric would, of course, diminish as the pressure of the air is increased, and at enormous pressures it would be negligible, unless the frequency should increase correspondingly.

It will be often observed in these experiments that when the spheres are beyond the striking distance the approach of a glass plate, for instance, may induce the spark to jump between the spheres. This occurs when the capacity of the spheres is somewhat below the critical value which gives the greatest difference of potential at the terminals of the coil. By approaching a dielectric the specific inductive capacity of the space between the spheres is increased, producing the same effect as if the capacity of the spheres were increased. The potential at the terminals may then

rise so high that the space is cracked. The experiment is best performed with dense glass or mica.

Another interesting observation is that a plate of insulating material, when the discharge is passing through it, is strongly attracted by either of the spheres; that is, by the nearer one, this being obviously due to the smaller mechanical effect of the bombardment on that side, and perhaps also to the greater electrification.

From the behavior of the dielectrics in these experiments we may conclude that the best insulator for these rapidly alternating currents would be the one possessing the smallest specific inductive capacity, and at the same time one capable of withstanding the greatest differences of potential; and thus two diametrically opposite ways of securing the required insulation are indicated, namely, to use either a perfect vacuum or a gas under great pressure; but the former would be preferable. Unfortunately, neither of these two ways is easily carried out in practice.

It is especially interesting to note the behavior of an excessively high vacuum in these experiments. If a test tube provided with external electrodes and exhausted to the

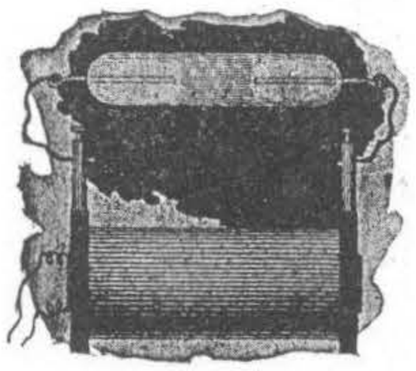


Fig. 10.—Discharge Through Highest Vacuum.

highest possible degree be connected to the terminals of the coil, Fig. 10, the electrodes of the tube are instantly brought to a high temperature, and the glass at each end of the tube is rendered intensely phosphorescent, but the middle appears comparatively dark, and for a while remains cool.

When the frequency is so high that the discharge shown in Fig. 8 is observed, considerable dissipation no doubt occurs in the coil. Nevertheless the coil may be worked for a long time, as the heating is gradual.

In spite of the fact that the difference of potential may be enormous, little is felt when the discharge is passed through the body, provided the hands are armed (see Fig. 18B). This is to some extent due to the higher frequency, but principally to the fact that less energy is available externally, when the difference of potential reaches an enormous value, owing to the circumstance that with the rise of potential the energy absorbed in the coil increases as the square of the potential. Up to a certain point the energy available externally increases with the rise of potential, then it begins to fall off rapidly. Thus, with the ordinary high tension induction coil, the curious paradox exists, that, while with a given current through the primary the shock might be fatal, with many times that current it might be perfectly

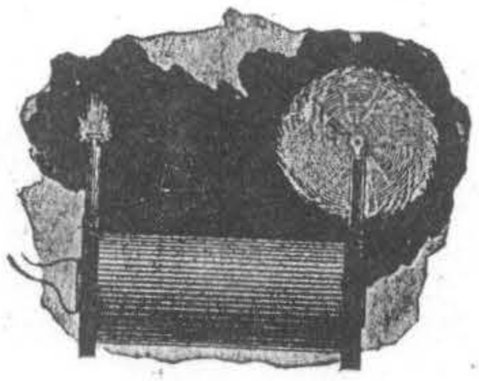


Fig. 11A.—Pinwheel Driven by a Powerful Brush.

harmless, even if the frequency be the same. With high frequencies and excessively high potentials when the terminals are not connected to bodies of some size, practically all the energy supplied to the primary is taken up by the coil. There is no breaking through, no local injury, but all the material, insulating and conducting, is uniformly heated.

To avoid misunderstanding in regard to the physiological effect of alternating currents of very high frequency, I think it necessary to state that while it is an undeniable fact that they are incomparably less dangerous than currents of low frequencies, yet it should not be thought that they are altogether harmless. What has just been said refers only to currents from an ordinary high-tension induction coil, which currents are necessarily very small; if received directly from a machine or from a secondary of low resistance they produce more or less powerful effects and may cause serious injury, especially when used in conjunction with condensers.

The streaming discharge of a high tension induction coil differs in many respects from that of a powerful static machine. In color it has neither the violet of the positive nor the brightness of the negative static discharge, but lies somewhere between, being, of course, alternatively positive and negative. But since the streaming is more powerful when the point of the terminal is electrified positively than when electrified negatively, it follows that the point of the brush is more like the positive, and the root more like the negative static discharge. In the dark, when the brush is very powerful, the root may appear almost white. The wind produced by the escaping streams, though it may be very strong—often, indeed, to such a degree that it may be felt quite a distance from the coil—is, nevertheless, considering the quantity of the discharge, smaller than that produced by the positive brush of a static machine, and it affects the flame much less powerfully. From the nature of the phenomenon we can conclude that the higher the frequency, the smaller must, of course, be the wind produced by the streams, and with sufficiently high frequen-

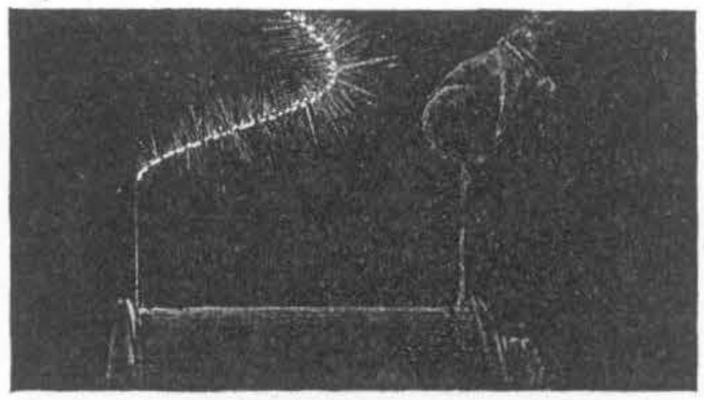


Fig. 12.—Luminous Streams Escaping from a Cotton-Covered Wire.

cies no wind at all would be produced at the ordinary atmospheric pressures. With frequencies obtainable by means of a machine the mechanical effect is sufficiently great to revolve, with considerable speed, large pin-wheels, which in the dark present a beautiful appearance, owing to the abundance of the streams (Figs. 11A and B)

In general, most of the experiments usually performed with a static machine can be performed with an induction coil when operated with very rapidly alternating currents. The effects produced, however, are much more striking, being of incomparably greater power. When a small length of ordinary cotton-covered wire (Fig. 12) is attached

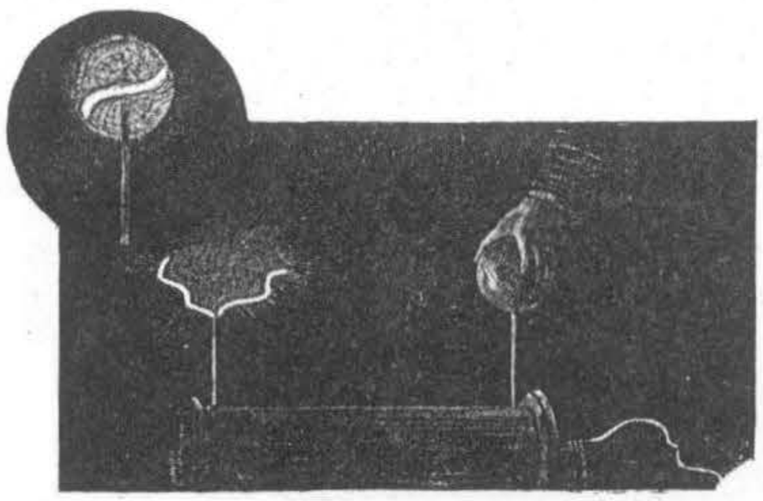


Fig. 11B.—Rotating Wire and Finwheel Effects.

to one terminal of the coil the streams issuing from all points of the wire may be so intense as to produce a considerable light effect. When the potentials and frequencies are very high, a wire insulated with gutta percha or rubber and attached to one of the terminals appears to be covered with a luminous film. A very thin bare wire when attached to a terminal emits powerful streams and vibrates continually to and fro or spins in a circle, producing a singular effect (Fig. 13). Some of these experiments have been described by me in The Electrical World of Feb. 21, 1891.

Another peculiarity of the rapidly alternating discharge

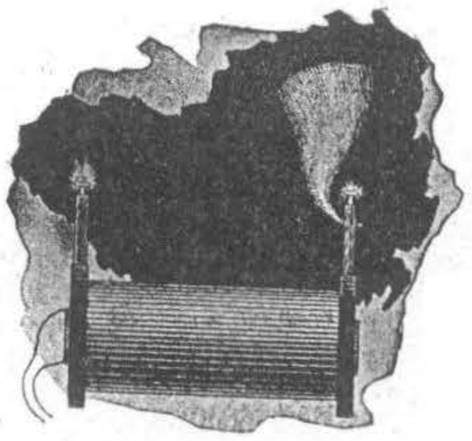


Fig. 13.—Aspect Presented by a very Thin Wire Attached to a Terminal of the Coil.

of the induction coil is its radically different behavior with respect to points and rounded surfaces.

If a thick wire, provided with a ball at one end and with a point at the other, be attached to the positive terminal of a static machine, practically all the charge will be lost through the point, on account of the enormously greater tension, dependent on the radius of curvature. But if such a wire is attached to one of the terminals of the induction coil it will be observed that with very high frequencies streams issue from the ball almost as copiously as from the point (Fig. 14).

It is hardly conceivable that we could produce such a condition to an equal degree in a static machine, for the simple reason that the tension increases as the square of the density, which in turn is proportional to the radius of curvature; hence, with a steady potential an enormous charge would be required to make streams issue from a polished ball while it is connected with a point. But with an induction coil, the discharge of which alternates with great rapidity, it is different. Here we have to deal with two distinct tendencies: First, there is the tendency to escape which exists in a condition of rest, and which depends on the radius of curvature; second, there is the tendency to dissipate into the surrounding air by condenser action, which depends on the surface. When one of these tendencies is at a maximum, the other is at a minimum. At the point the luminous stream is principally due to the air molecules coming bodily in contact with the point; they are attracted and repelled, charged and discharged, and, their atomic charges being thus disturbed, vibrate and emit light waves. At the ball, on the contrary, there is no doubt that the effect is to a great extent produced inductively, the air molecules not *necessarily* coming in contact with the ball, though they undoubtedly do so. To convince ourselves of this, we only need to exalt the condenser action, for instance, by enveloping the ball at some distance by a better conductor than the surrounding medium, the con-

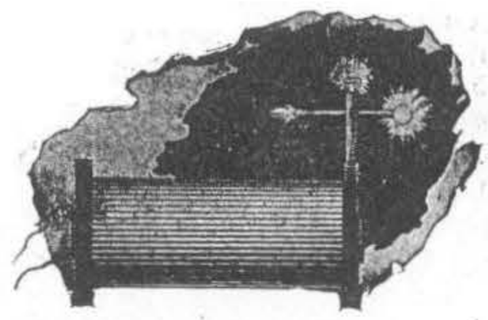


Fig. 14.—Effect of Ball and Point.

ductor being, of course, insulated; or else by surrounding it with a better dielectric and approaching an insulated conductor; in both cases the streams will break forth more copiously. Also, the larger the ball with a given frequency, or the higher the frequency, the more will the ball have the advantage over the point. But since a certain intensity of action is required to render the streams visible, it is obvious that in the experiment described the ball should not be taken too large.

In consequence of this twofold tendency it is possible to produce by means of points effects identical to those produced by capacity. Thus, for instance, by attaching to one terminal of the coil a small length of coiled wire, presenting many points and offering great facility to escape, the potential of the coil may be raised to the same value as by attaching to the terminal a polished ball of a surface many times greater than that of the wire.

An interesting experiment showing the effect of the points may be performed in the following manner: Attach to one of the terminals of the coil a cotton-covered wire about two feet in length and adjust the conditions so that streams issue from the wire. In this experiment the primary coil should be preferably placed so that it extends only about half way into the secondary coil. Now touch

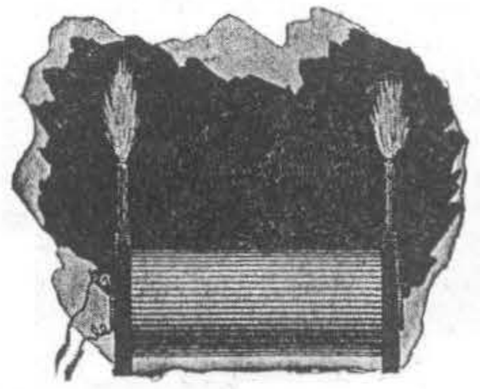


Fig. 15.—Aspect of Coil Under Powerful Brush Discharge.

the free terminal of the secondary with a conducting object held in the hand, or else connect it to an insulated body of some size. In this manner the potential on the wire may be enormously raised. The effect of this will be to either increase or to diminish the streams. If they increase, the wire is too short; if they diminish, it is too long. By adjusting the length of the wire a point is found where the touching of the other terminal does not at all affect the streams. In this case the rise of potential is exactly counteracted by the drop through the coil. It will be observed that small lengths of wire produce considerable difference in the magnitude and luminosity of the streams. The primary coil is placed sidewise for two reasons: First, to increase the potential at the wire, and, second, to increase the drop through the coil. The sensitiveness is thus augmented.

There is still another and far more striking peculiarity of the brush discharge produced by very rapidly alternating currents. To observe this it is best to replace the usual terminals of the coil by two metal columns insulated with a good thickness of ebonite. It is also well to close all fissures and cracks with wax so that the brushes cannot form anywhere except at the tops of the columns. If the conditions are carefully adjusted—which, of course, must be left to the skill of the experimenter—so that the potential rises to an enormous value, one may produce two powerful brushes several inches long, nearly white at their

roots, which in the dark bear a striking resemblance to two flames of a gas escaping under pressure (Fig. 15). But they do not only *resemble*, they *are* veritable flames, for they are hot. Certainly they are not as hot as a gas burner, *but they would be so if the frequency and the potential should be sufficiently high.* Produced with, say, twenty thousand alternations per second, the heat is easily perceptible even if the potential is not excessively high. The heat developed is, of course, due to the impact of the air molecules against the terminals and against each other. As, at the ordinary pressures, the mean free path is excess-

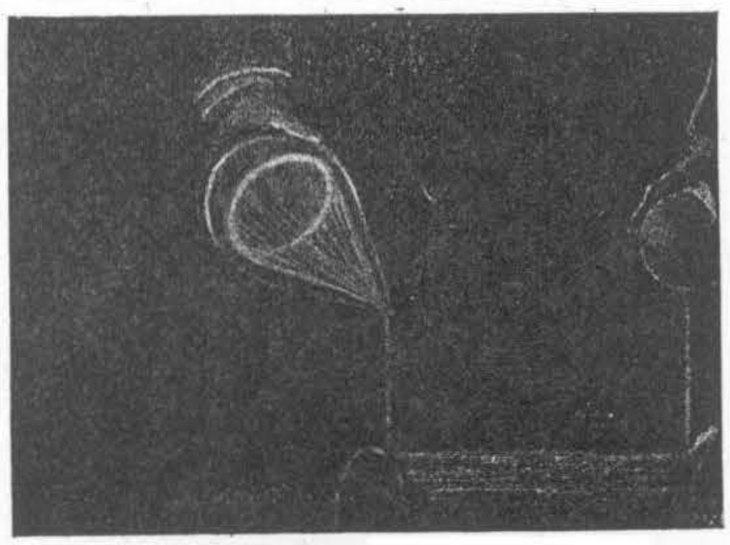


FIG. 16.—INCANDESCENT WIRE OR FILAMENT SPINNING IN AN UNEXHAUSTED GLOBE.

ively small, it is possible that in spite of the enormous initial speed imparted to each molecule upon coming in contact with the terminal, its progress—by collision with other molecules—is retarded to such an extent that it does not get away far from the terminal, but may strike upon it many times in succession. The higher the frequency the less the molecule is able to get away, and this the more so as for a given effect the potential required is smaller; and a frequency is conceivable—perhaps even obtainable—at which practically the same molecules would strike the terminal. Under such conditions the exchange of the molecules would be very slow and the heat produced at, and very near, the terminal would be excessive. But if the frequency should go on increasing constantly, the heat produced would begin to diminish for obvious reasons. At the positive brush of a static machine the exchange of the molecules is very rapid, the stream is constantly of one direction, and there are fewer collisions; hence the heating effect must be very small. Anything that impairs the facility of exchange tends to increase the local heat produced. Thus, if a bulb be held over the terminal of the coil so as to inclose the brush, the air contained in the bulb is very quickly brought to a high temperature. If a glass tube be held over the brush so as to allow the draught to carry the brush upward, scorching hot air escapes at the top of the tube. Anything held within the brush is, of course, rapidly heated, and the possibility of using such heating effects for some purpose or other suggests itself.

When contemplating this singular phenomenon of the hot brush, we cannot help being convinced that a similar process must take place in the ordinary flame, and it seems strange that after all these centuries past of familiarity with the flame, now, in this era of electric lighting and heating, we are finally led to recognize that since time immemorial we have, after all, always had "electric light and heat" at our disposal. It is also of no little interest to contemplate, that we have a possible way of producing—by other than

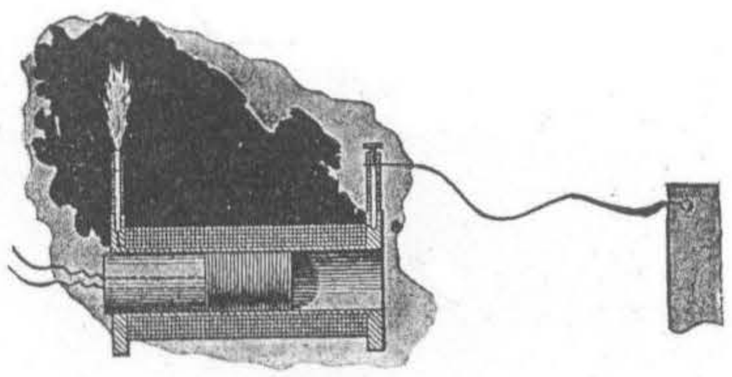


FIG. 17A.—COIL ARRANGED FOR POWERFUL BRUSH EFFECTS.

chemical means—a veritable flame, which would give light and heat without any material being consumed, without any chemical process taking place, and to accomplish this we only need to perfect methods of producing enormous frequencies and potentials. I have no doubt that if the potential could be made to alternate with sufficient rapidity and power, the brush formed at the end of a wire would lose its electrical characteristics and would become flamelike. The flame must be due to electrostatic molecular action.

This phenomenon now explains in a manner which can hardly be doubted the frequent accidents occurring in storms. It is well known that objects are often set on fire without the lightning striking them. We shall presently see how this can happen. On a nail in a roof, for instance, or on a projection of any kind, more or less conducting or rendered so by dampness, a powerful brush may appear. If the lightning strikes somewhere in the neighborhood the enormous potential may be made to alternate or fluctuate perhaps many million times a second. The air molecules are violently attracted and repelled, and by their impact produce such a powerful heating effect that a fire is started. It is conceivable that a ship at sea may, in this manner, catch fire at many points at once. When we consider that even with the comparatively low frequencies obtained from a dynamo machine, and with potentials of no more than one or two hundred thousand volts, the heating effects are considerable, we may imagine how much more powerful they must be with frequencies and potentials many times greater; and the above explanation seems, to say the least, very probable. Similar explanations may have been suggested, but I am not aware that up to the present the heating effects of a brush produced by a rapidly alternating potential have been experimentally demonstrated, at least not to such a remarkable degree.

By preventing completely the exchange of the air molecules the local heating effect may be so exalted as to bring a body to incandescence. Thus, for instance, if a small button, or preferably a very thin wire or filament, be inclosed in an unexhausted globe and connected with the terminal of the coil, it may be rendered incandescent. The phenomenon is made much more interesting by the rapid spinning round in a circle of the top of the filament, thus presenting the appearance of a luminous funnel, Fig. 16, which widens when the potential is increased. When

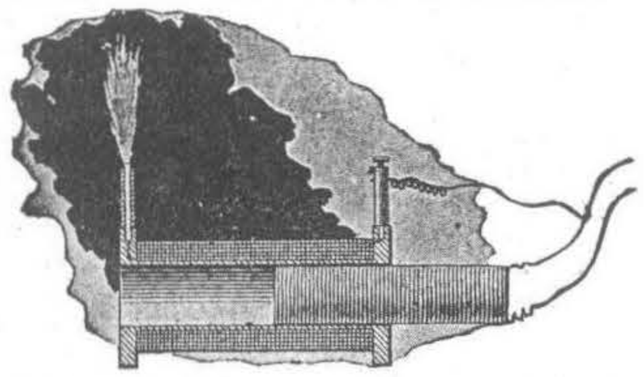


FIG. 17B.—COIL ARRANGED FOR POWERFUL BRUSH EFFECTS. —ST. ELMO'S HOT FIRE.

the potential is small the end of the filament may perform irregular motions, suddenly changing from one to the other, or it may describe an ellipse; but when the potential is verry high it always spins in a circle; and so does generally a thin, straight wire attached freely to the terminal of the coil. These motions are, of course, due to the impact of the molecules and the irregularity in the distribution of the potential, owing to the roughness and dissymmetry of the wire or filament. With a perfectly symmetrical and polished wire such motions would probably not occur. That the motion is not likely to be due to other causes is evident from the fact that it is not of a definite direction, and that in a very highly exhausted globe it ceases altogether. The possibility of bringing a body to incandescence in an unexhausted globe, or even when not at all inclosed, would seem to afford a possible way of obtaining lighting effects, which by perfecting methods of producing rapidly alternating potentials might be rendered available for useful purposes.

In employing a commercial coil, the production of very powerful brush effects is attended with considerable diffi-

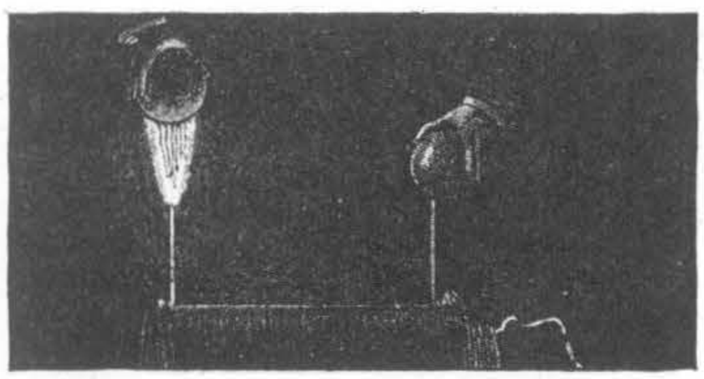


FIG. 18B.—TAKING A SHOCK OF A QUARTER OF A MILLION VOLTS.

culties, for when these high frequencies and enormous potentials are used, the best insulation is apt to give way. Usually the coil is insulated well enough to stand the strain from convolution to convolution, since two double silk-covered paraffined wires will withstand a pressure of several volts; the difficulty lies principally in preventing the breaking through from the secondary to the primary, which is greatly facilitated by the streams issuing from the latter. In the coil, of course, the strain is greatest from section to section, but usually in a larger coil there are so many sections that the danger of a sudden giving way is not very great. No difficulty will generally be encountered in that direction, and besides the liability of injuring the coil internally is very much reduced by the fact that the effect most likely to be produced is simply a gradual heating, which, when far enough advanced, could not fail to be observed. The principal necessity is then to prevent the streams between the primary and the tube, not only on account of the heating and possible injury, but also because the streams may diminish very considerably the potential difference available at the terminals. A few hints as to how this may be accomplished will probably be found useful in most of these experiments with the ordinary induction coil.

One of the ways is to wind a short primary, Fig. 17 *A*, so that the difference of potential is not at that length great enough to cause the breaking forth of the streams through the insulating tube. The length of the primary should be determined by experiment. Both the ends of the coil should be brought out on one end through a plug of insulating material fitting in the tube as illustrated. In such a disposition one terminal of the secondary is attached to a body the surface of which is determined with the greatest care so as to produce the greatest rise in the potential. At the other terminal a powerful brush appears, which may be experimented upon.

The above plan necessitates the employment of a primary of a comparatively small size, and it is apt to heat when powerful effects are desirable for a certain length of time.

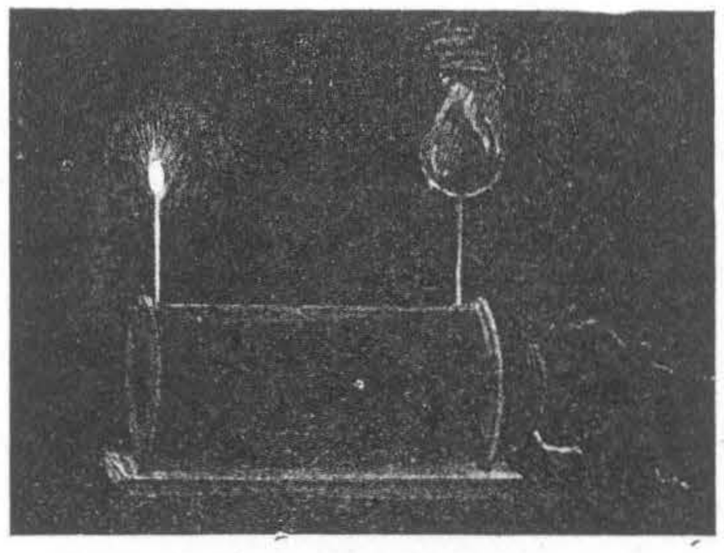


FIG. 17C.—COIL ARRANGED FOR POWERFUL BRUSH EFFECTS.

In such a case it is better to employ a larger coil in Fig. 17 *B*, and introduce it from one side of the tube until the streams begin to appear. In this case the nearest terminal of the secondary may be connected to the primary or to the ground, which is practically the same thing, if the primary is connected directly to the machine. In the case of ground connections it is well to determine experimentally the frequency which is best suited under the conditions of the test. Another way of obviating the streams, more or less, is to make the primary in sections and supply it from separate well-insulated sources.

In many of these experiments, when powerful effects are wanted for a short time it is advantageous to use iron cores with the primaries. In such case a very large primary coil may be wound and placed side by side with the secondary, and, the nearest terminal of the latter being connected to the primary, a laminated iron core is introduced through the primary into the secondary as far as the streams will permit. Under these conditions an excessively powerful brush, several inches long, which may be appropriately called "St. Elmo's hot fire," may be caused to appear at the other terminal of the secondary, producing striking effects. It is a most powerful ozonizer, so powerful, indeed, that only a few minutes are sufficient to fill the whole room with the smell of ozone, and it undoubtedly possesses the quality of exciting chemical affinities.

For the production of ozone alternating currents of very high frequency are eminently suited, not only on account of the advantages they offer in the way of conversion, but also because of the fact that the ozonizing action of a discharge is dependent on the frequency as well as on the potential, this being undoubtedly confirmed by observation.

In these experiments, if an iron core is used it should be carefully watched, as it is apt to get excessively hot in an incredibly short time. To give an idea of the rapidity of the heating, I will state that by passing a powerful current

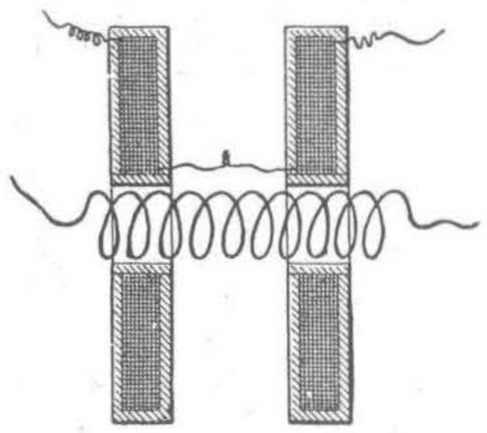


FIG. 18A.—COIL FOR PRODUCING VERY HIGH DIFFERENCE OF POTENTIAL.

through a coil with many turns, the inserting within the same of a thin iron wire for no more than one second's time is sufficient to heat the wire to something like 100 degrees centigrade.

But this rapid heating does not need to discourage us in the use of iron cores in connection with rapidly alternating currents. I have for a long time been convinced that in the industrial distribution by means of transformers some such plan as the following might be practicable. We may use a comparatively small iron core, subdivided, or perhaps not even subdivided. We may surround this core with a considerable thickness of material which is fireproof and conducts the heat poorly, and on top of that we may place the primary and secondary windings. By using either higher frequencies or greater magnetizing forces, we may by hysteresis and eddy currents heat the iron core so far as to bring it nearly to its maximum permeability, which, as Hopkinson has shown, may be as much as six-ty times greater than that at ordinary temperatures. If

the iron core were perfectly inclosed it would not be deteriorated by the heat, and if the inclosure of fireproof material would be sufficiently thick only a limited amount of energy could be radiated in spite of the high temperature. Transformers have been constructed by me on that plan, but for lack of time no thorough tests have as yet been made.

Another way of adapting the iron core to rapid alternations, or, generally speaking, reducing the frictional losses, is to produce by continuous magnetization a flow of something like 7,000 or 8,000 lines per square centimetre through the core and then work with weak magnetizing forces and preferably high frequencies around the point of greatest permeability. A higher efficiency of conversion and greater output are obtainable in this manner. I have also employed this principle in connection with machines in which there is no reversal of polarity. In these types of machines, as long as there are only a few

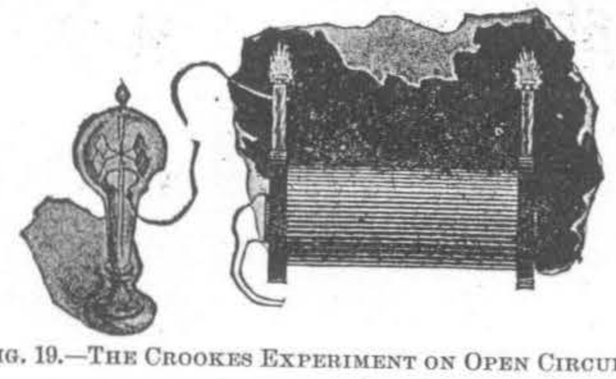


Fig. 19.—The Crookes Experiment on Open Circuit.

pole projections there is no great gain, as the maxima and minima of magnetization are far from the point of maximum permeability; but when the number of the pole projections is very great, the required rate of change may be obtained without the magnetization varying so far as to depart greatly from the point of maximum permeability, and the gain is considerable.

The above described arrangements refer only to the use of commercial coils as ordinarily constructed. If it is desired to construct a coil for the express purpose of performing with it such experiments as I have described, or, generally, rendering it capable of withstanding the greatest possible difference of potential, then a construction as indicated in Fig. 18A will be found of advantage. The coil in this case is formed of two independent parts which are wound oppositely, the connection between both being made near the primary. The potential in the middle being zero, there is not much tendency to jump to the primary and not much insulation is required. In some cases the middle point may, however, be connected to the primary or to the ground. In such a coil the places of greatest difference of potential are far apart and the coil is capable of withstanding an enormous strain. The two parts may be movable so as to allow a slight adjustment of the capacity effect.

As to the manner of insulating the coil, it will be found convenient to proceed in the following way: First the wire should be boiled in paraffine until the air is out; then the coil is wound by running the wire through melted paraffine merely for the purpose of fixing the wire. The coil is then taken off from the spool, immersed in a cylindrical vessel filled with pure melted wax and boiled for a long time until the bubbles cease to appear. The whole is then left to cool down thoroughly, and then the mass is taken out

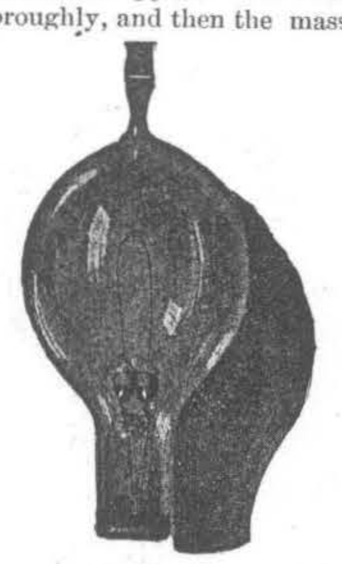


Fig. 21.—Lamp with Two Filaments in Highest Vacuum with Leading-in Wires.

of the vessel and turned up in a lathe. A coil made in this manner and with care is capable of withstanding enormous potential differences.

It may be found convenient to immerse the coil in paraffine oil or some other kind of oil; it is a most effective way of insulating, principally on account of the perfect exclusion of air, but it may be found that after all a vessel filled with oil is not a very convenient thing to handle in a laboratory.

If an ordinary coil can be dismounted, the primary may be taken out of the tube and the latter plugged up on one end, filled with oil, and the primary reinserted. This affords an excellent insulation, and prevents the formation of the streams.

Of all the experiments which may be performed with rapidly alternating currents, the most interesting are those which concern the production of a practical illuminant. It cannot be denied that the present methods, though they were brilliant advances, are very wasteful. Some better methods must be invented, some more perfect apparatus devised. Modern research has opened new possibilities for the production of an efficient source of light, and the attention of all has been carried in the direction indicated by able pioneers. Many have been carried away by the enthusiasm and passion to discover, but in their zeal to reach results many have been misled. Starting with the idea of producing electromagnetic waves, they turned their attention perhaps too much to the study of electromagnetic effects and neglected the study of electrostatic phenomena. Naturally, nearly every investigator availed himself of an apparatus similar to that used in earlier experiments. But in those forms of apparatus, while the electro-magnetic inductive effects are enormous, the electrostatic effects are excessively small.

In the Hertz experiments, for instance, a high tension induction coil is short circuited by an arc, the resistance of which is very small; the smaller, the more capacity is attached to the terminals; and the difference of potential at these is enormously diminished. On the other hand, when the discharge is not passing between the terminals the static effects may be considerable, but only qualitatively so, not quantitatively, since their rise and fall is very sudden and since their frequency is small. In neither case, therefore, are powerful electrostatic effects perceivable. Similar conditions exist when, as in some interesting experiments of Dr. Lodge, Leyden jars are discharged disruptively. It has been thought—and I believe asserted—that in such cases most of the energy is radiated into space. In the light of the experiments which I have described above, it will not now be thought so. I feel safe in asserting that in such cases most of the energy is partly taken up and converted into heat in the arc of the discharge and in the conducting and insulating material of the jar, some energy being, of course, given off by electrification of the air, but the amount of the directly radiated energy is very small.

When a high tension induction coil, operated by currents alternating only 20,000 times a second, has its terminals closed through even a very small jar, practically all the energy passes through the dielectric of the jar, which is heated, and the electrostatic effects manifest themselves

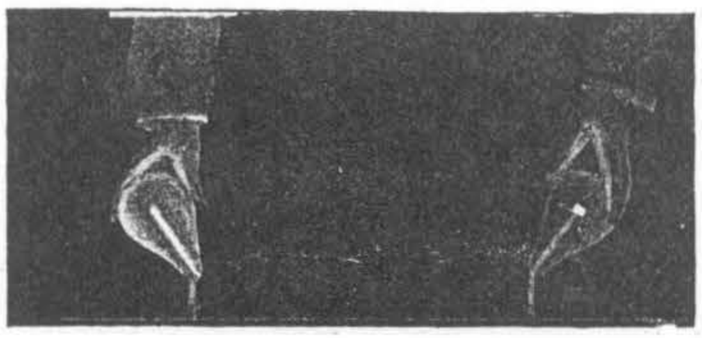


Fig. 20.—Lamp with Single Block of Refactory Material, and Single Filament Lamp.

outwardly only to a very weak degree. Now the external circuit of a Leyden jar—that is, the arc and the connections of the coatings—may be looked upon as a circuit generating alternating currents of excessively high frequency and fairly high potential, which is closed through the coatings and the dielectric between them, and from the above it is evident that the external electrostatic effects must be very small, even if a recoil circuit be used. These conditions make it appear that with the apparatus usually at hand the observation of powerful electrostatic effects was impossible, and what experience has been gained in that direction is only due to the great ability of the investigators.

But powerful electrostatic effects are the *sine qua non* of light production on the lines indicated by theory. Electromagnetic effects are primarily unavailable, for the reason that to produce the required effects we would have to pass current impulses through a conductor which, long before the required frequency of the impulses could be reached, would cease to transmit them. On the other hand, electromagnetic waves many times longer than those of light and producible by sudden discharges of a condenser could not be utilized, it would seem, except we avail ourselves of their effect upon conductors as in the present methods, which are wasteful. We could not affect by means of such waves the static molecular or atomic charges of a gas, cause them to vibrate and to emit light. Long transverse waves apparently cannot produce such effects, since excessively small electromagnetic disturbances may pass readily through miles of air. Such dark waves, unless they are of the length of true light waves, cannot, it would seem, excite luminous radiation in a Geissler tube, and the luminous effects which are producible by induction in a tube devoid of electrodes I am inclined to consider as being of an electrostatic nature.

To produce such luminous effects straight electrostatic thrusts are required; these, whatever be their frequency, may disturb the molecular charges and produce light. Since current impulses of the required frequency cannot pass through a conductor of measurable dimensions, we must work with a gas, and then the production of powerful electrostatic effects becomes an imperative necessity.

It has occurred to me, however, that electrostatic effects are in many ways available for the production of light. For instance, we may place a body of some refractory material in a closed, and preferably more or less exhausted, globe, connect it to a source of high, rapidly alternating potential, causing the molecules of the gas to strike it many times a second at enormous speeds, and in this manner, with trillions of invisible hammers, pound it until it gets incandescent; or we may place a body in a very highly exhausted globe, in a non-striking vacuum, and by employing very high frequencies and potentials transfer sufficient energy from it to other bodies in the vicinity or in general to the surroundings, to maintain it at any degree of incandescence; or we may, by means of such rapidly alternating high potentials, disturb the ether carried by the molecules of a gas or their static charges and cause them to vibrate and to emit light.

But the electrostatic effects being dependent upon the potential and frequency, to produce the most powerful action it is desirable to increase both as far as practicable.



Fig. 22.—Lamp with Two Refractory Blocks in Highest Vacuum.

It may be possible to obtain quite fair results by keeping either of these factors small, provided the other is sufficiently great; but we are limited in both directions. My experience demonstrates that we cannot go below a certain frequency, for, first, the potential then becomes so great that it is dangerous; and, secondly, the light production is less efficient.

I have found that by using the ordinary low frequencies the physiological effect of the current required to maintain at a certain degree of brightness a tube four feet long provided at the ends with outside and inside condenser coatings, is so powerful that it might produce serious injury to those not accustomed to such shocks; whereas, with 20,000 alternations per second the tube may be maintained at the same degree of brightness without any effect being felt. This is due principally to the fact that a much smaller potential is required to produce the same light effect, and also to the higher efficiency in the light production. It is evident that the efficiency in such cases is the greater, the higher the frequency; for the quicker the process of charging and discharging the molecules, the less energy will be lost in the form of dark radiation. But, unfortunately, we cannot go beyond a certain frequency on account of the difficulty of producing and conveying the effects.

I have stated above that a body inclosed in an unexhausted bulb may be intensely heated by simply connecting it with a source of rapidly alternating potential. The heating in such a case is in all probability due mostly to the bombardment of the molecules of the gas contained in the bulb. When the bulb is exhausted the heating of the body



Fig. 23.—Lamp with Single Straight Filament and One Leading-in Wire.

is much more rapid, and there is no difficulty whatever in bringing a wire or filament to any degree of incandescence by simply connecting it to one terminal of a coil of the proper dimensions. Thus, if the well-known apparatus of Prof. Crookes, consisting of a bent platinum wire with vanes mounted over it (Fig. 19), be connected to one terminal of the coil—either one or both ends of the platinum wire being connected—the wire is rendered almost instantly incandescent, and the mica vanes are rotated as though a current from a battery were used. A thin carbon filament, or, preferably, a button of some refractory material (Fig. 20), even if it be a comparatively poor conductor, inclosed in an exhausted globe, may be rendered highly incandescent; and in this manner a simple lamp capable of giving any desired candle power is provided.

The success of lamps of this kind would depend largely on the selection of the light-giving bodies contained within the bulb. Since, under the conditions described, refractory bodies—which are very poor conductors and capable

of withstanding for a long time excessively high degrees of temperature—may be used, such illuminating devices may be rendered successful.

It might be thought at first that if the bulb containing the filament or button of refractory material be perfectly well exhausted—that is, as far as it can be done by the use of the best apparatus—the heating would be much less intense, and that in perfect vacuum it could not occur at all. This is not confirmed by my experience; quite the contrary; the better the vacuum the easier the bodies are brought to incandescence. This result is interesting for many reasons.

At the outset of this work the idea presented itself to me,

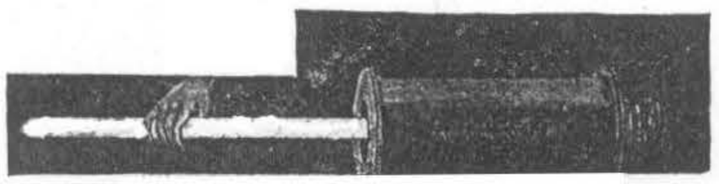


FIG. 29B.—LIGHTING UP AN EXHAUSTED TUBE.

whether two bodies of refractory material inclosed in a bulb exhausted to such a degree that the discharge of a large induction coil operated in the usual manner cannot pass through, could be rendered incandescent by mere condenser action. Obviously, to reach this result enormous potential differences and very high frequencies are required, as is evident from a simple calculation.

But such a lamp would possess a vast advantage over an ordinary incandescent lamp in regard to efficiency. It is well known that the efficiency of a lamp is to some extent a function of the degree of incandescence, and that could we but work a filament of many times higher degrees of incandescence the efficiency would be much greater. In an ordinary lamp this is impracticable on account of the destruction of the filament, and it has been determined by experience how far it is advisable to push the incandescence. It is impossible to tell how much higher efficiency could be obtained if the filament could withstand indefinitely, as the investigation to this end obviously cannot be carried beyond a certain stage; but there are reasons for believing that it would be very considerably higher. An improvement might be made in the ordinary lamp by employing a short and thick carbon; but then the leading-in wires would have to be thick, and, besides, there are many other considerations which render such a modification entirely impracticable. But in a lamp as above described the leading-in wires may be very small, the incandescent refractory material may be in the shape of blocks offering a very small radiating surface, so that less energy would be required to keep them at the desired incandescence; and in addition to this the refractory material need not be carbon, but may be manufactured from mixtures of oxides, for instance, with carbon or other material, or may be selected from bodies which are practically non-conductors and capable of withstanding enormous degrees of temperature.

All this would point to the possibility of obtaining a much higher efficiency with such a lamp than is obtainable in



FIG. 26A.



FIG. 26B.

LAMP WITH ONE FILAMENT, ONE INSIDE AND ONE OUTSIDE CONDENSER COATING.

ordinary lamps. In my experience it has been demonstrated that the blocks are brought to high degrees of incandescence with much lower potentials than those determined by calculation, and the blocks may be set at greater distances from each other. We may freely assume, and it is probable that the molecular bombardment is an important element in the heating, even if the globe be exhausted with the utmost care as I have done; for although the number of the molecules is, comparatively speaking, insignificant, yet on account of the mean free path being very great there are fewer collisions and the molecules may reach much higher speeds, so that the heating effect due to this cause may be considerable, as in the Crookes experiments with radiant matter.

But it is likewise possible that we have to deal here with an increased facility of losing the charge in very high vacuum, when the potential is rapidly alternating, in which case most of the heating would be directly due to the surging of the charges in the heated bodies; or else the observed fact may be largely attributable to the effect of the points which I have mentioned above, in consequence of which the blocks or filaments contained in the vacuum are equivalent to condensers of many times greater surface than that calculated from their geometrical dimensions. Scientific men still differ in opinion as to whether a charge should or should not be lost in a perfect vacuum, or, in other words, whether either is or is not a conductor. If the former were the case, then a thin filament inclosed in a perfectly exhausted globe and connected to a source of enormous, steady potential would be brought to incandescence.

Various forms of lamps on the above-described principle with the refractory bodies in the form of filaments, Fig. 21, or blocks, Fig. 22, have been constructed and operated by me, and investigations are being carried on in this line. There is no difficulty in reaching such high degrees of incandescence that ordinary carbon is to all appearance melted and volatilized. If the vacuum could be made absolutely perfect such a lamp, although inoperative with apparatus ordinarily used, would, if operated with currents of the required character, afford an illuminant which would never be destroyed and which would be far more efficient than an ordinary incandescent lamp. This perfection can, of course, never be reached and a very slow destruction

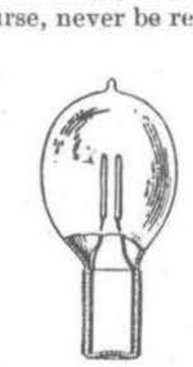


FIG. 25.—LAMP WITH TWO BLOCKS OR FILAMENTS AND A PAIR OF INDEPENDENT INSIDE AND OUTSIDE CONDENSER COATINGS.

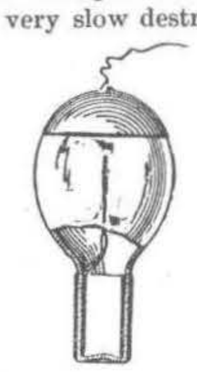


FIG. 28.—LAMP WITH ONE FILAMENT, ONE INSIDE AND ONE OUTSIDE CONDENSER COATING, AND AUXILIARY COATING.

and gradual diminution of the size always occurs, as in incandescent lamps; but there is no possibility of a sudden and premature disabling which occurs in the latter by the breaking of the filament, especially when the incandescent bodies are in the shape of blocks.

With these rapidly alternating potentials there is, however, no necessity of inclosing two blocks in a globe, but a single block, as in Fig. 20, or filament, Fig. 23, may be used. The potential in this case must of course be higher, but it is easily obtainable, and besides it is not necessarily dangerous.

The facility with which the button or filament in such a lamp is brought to incandescence, other things being equal, depends on the size of the globe. If a perfect vacuum

FIG. 24.—LAMPS WITH ONE LEADING-IN WIRE RENDERED INCANDESCENT.

could be obtained, the size of the globe would not be of importance, for then the heating would be wholly due to the surging of the charges and all the energy would be given off to the surroundings by radiation. But this can never occur in practice. There is always some gas left in the globe, and although the exhaustion may be carried to the highest degree still the space inside of the bulb must be considered as conducting when such high potentials are used, and I assume that in estimating the energy that may be given off from the filament to the surroundings we may consider the inside surface of the bulb as one coating of a condenser, the air and other objects surrounding the bulb forming the other coating. When the alternations are very low there is no doubt that a considerable portion of the energy is given off by the electrification of the surrounding air.

In order to study this subject better I carried on some experiments with excessively high potentials and low frequencies. I then observed that when the hand is approached to the bulb—the filament being connected with one terminal of the coil—a powerful vibration is felt, being due to the attraction and repulsion of the molecules of the air which are electrified by induction through the glass. In some cases when the action is very intense I have been able to hear a sound, which must be due to the same cause.

When the alternations are low, one is apt to get an excessively powerful shock from the bulb. In general, when one attaches bulbs or objects of some size to the terminals of the coil one should look out for the rise of potential, for it may happen that by merely connecting a bulb or plate to the terminal the potential may rise to many times its original value. When lamps are attached to the terminals, as illustrated in Fig. 24, then the capacity of the bulbs should be such as to give the maximum rise of potential under the existing conditions. In this manner one may obtain the required potential with fewer turns of wire.

The life of such lamps as described above depends, of course, largely on the degree of exhaustion, but to some extent also on the shape of the block of refractory material. Theoretically it would seem that a small sphere of carbon inclosed in a sphere of glass would not suffer deterioration from molecular bombardment, for the matter in the globe being radiant, the molecules would move in straight lines and would seldom strike the sphere obliquely. An interesting thought in connection with such a lamp is, that in it

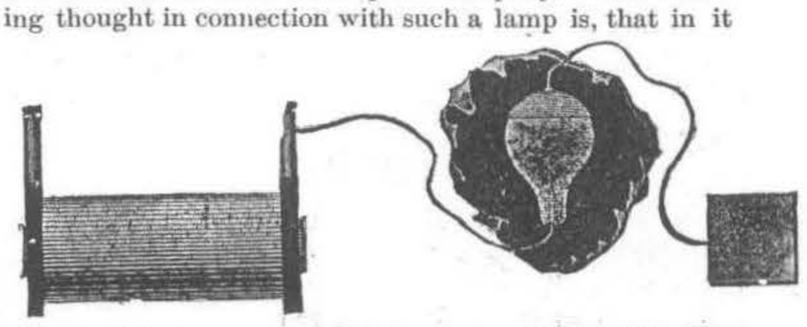


FIG. 29A.—INCREASING THE BRILLIANCY OF LAMP ON ONE WIRE.

"electricity" and electrical energy apparently must move in the same lines.

The use of alternating currents of very high frequency makes it possible to transfer by electrostatic or electromagnetic induction through the glass of a lamp sufficient energy to keep a filament at incandescence, and so do away with the leading-in wires. Such lamps have been proposed, but for want of proper apparatus they have not been successfully operated. Many forms of lamps on this principle with continuous and broken filaments have been constructed by me and experimented upon. When using a secondary inclosed within the lamp a condenser is advantageously combined with the secondary. When the transference is effected by electrostatic induction the potentials used are, of course, very high with frequencies obtainable from a machine. For instance, with a condenser surface of 40 centimetres square, which is not impracticably large, and with glass of good quality 1 millimetre thick, using currents alternating twenty thousand times a second, the potential required is approximately 9,000 volts. This may seem large, but since each lamp may be included in the secondary of a transformer of very small dimensions, it would not be inconvenient, and, moreover, it would not produce fatal injury. The transformers would all be preferably in series. The regulation would offer no difficulties, as with currents of such frequencies it is very easy to maintain a constant current.

In the accompanying engravings some of the types of lamps of this kind are shown. Fig. 25 is such a lamp with a broken filament, and Figs. 26 *A* and 26 *B* one with a single outside and inside coating and a single filament. I have also made lamps with two outside and inside coatings and a continuous loop connecting the latter. Such lamps have been operated by me with current impulses of the enormous frequencies obtainable by the disruptive discharge of condensers.

The disruptive discharge of a condenser is especially suited for operating such lamps—with no outward electrical connections—by means of electromagnetic induction, the electromagnetic inductive effects being excessively high; and I have been able to produce the desired incandescence with only a few short turns of wire. In-



FIG. 27.—LAMP WITH ONE FILAMENT AND LEADING-IN WIRE AND EXTERNAL CONDENSER COATING.

candescence may also be produced in this manner in a simple closed filament.

Leaving now out of consideration the practicability of such lamps, I would only say that they possess a beautiful and desirable feature, namely, that they can be rendered, at will, more or less brilliant simply by altering the relative position of the outside and inside condenser coatings or inducing and induced circuits.

When a lamp is lighted by connecting it to one terminal only of the source, this may be facilitated by providing the globe with an outside condenser coating, which serves at the same time as a reflector, and connecting this to an insulated body of some size. Lamps of this kind are illustrated in Fig. 27 and Fig. 28. Fig. 29A shows the plan of connections. The brilliancy of the lamp may, in this case, be regulated within wide limits by varying the size of the insulated metal plate to which the coating is connected.

It is likewise practicable to light with one leading wire lamps such as illustrated in Fig. 21 and Fig 22, by con-

necting one terminal of the lamp to one terminal of the source, and the other to an insulated body of the required size. In all cases the insulated body serves to give off the energy into the surrounding space, and is equivalent to a return wire. Obviously, in the two last-named cases, instead of connecting the wires to an insulated body, connections may be made to the ground.

The experiments which will prove most suggestive and of most interest to the investigator are probably those performed with exhausted tubes. As might be anticipated, a source of such rapidly alternating potentials is capable of exciting the tubes at a considerable distance and the light effects produced are remarkable.

During my investigations in this line I endeavored to excite tubes, devoid of any electrodes, by electromagnetic induction, making the tube the secondary of the induction device and passing through the primary the discharges of a Leyden jar. These tubes were made of many shapes, and I was able to obtain luminous effects which I then thought were due wholly to electromagnetic induction. But on carefully investigating the phenomena I found that the effects produced were more of an electrostatic nature. It may be attributed to this circumstance that this mode of exciting tubes is very wasteful; namely, the primary circuit being closed, the potential, and consequently the electrostatic inductive effect, is much diminished.

When an induction coil, operated as above described, is used, there is no doubt that the tubes are excited by electrostatic induction, and that electromagnetic induction has little, if anything, to do with the phenomena.

This is evident from many experiments. For instance, if a tube be taken in one hand, the observer being near the coil, it is brilliantly lighted, and remains so, no matter in what position it is held relatively to the observer's body. Were the action electromagnetic, the tube could not be lighted when the observer's body is interposed between it and the coil, or at least its luminosity should be considerably diminished. When the tube is held exactly over the centre of the coil—the latter being wound in sections and the primary placed symmetrically to the secondary—it may remain completely dark, whereas it is rendered intensely luminous by moving it slightly to the right or left from the centre of the coil. It does not light because in the middle both halves of the coil neutralize each other and the electric potential is zero. If the action were electromagnetic, the tube should light best in the plane through the centre of the coil, since the electromagnetic effect there should be a maximum. When an arc is established between the terminals, the tubes and lamps in the vicinity of the coil go out, but light up again when the arc is broken on account of the rise of potential. Yet the electromagnetic effect should be practically the same in both cases.

By placing a tube at some distance from the coil, and nearer to one terminal—preferably at a point on the axis of the coil—one may light it by touching the remote terminal with an insulated body of some size or with the hand, thereby raising the potential at that terminal nearer to the tube. If the tube is shifted nearer to the coil, so that it is lighted by the action of the nearer terminal, it may be made to go out by holding, on an insulated support, the end of a wire connected to the remote terminal in the vicinity of the nearer terminal, by this means counteracting the action of the latter upon the tube. These effects are evidently electrostatic. Likewise, when a tube is placed at considerable distance from the coil, the observer may, standing upon an insulated support, between the coil and tube, light the latter by approaching the hand to it; or he may even render it luminous by simply stepping between it and the coil. This would be impossible with electromagnetic induction, for the body of the observer would act as a screen.

When the coil is energized by excessively weak currents, the experimenter may, by touching one terminal of the coil with the tube, extinguish the latter, and may again light it by bringing it out of contact with the terminal and allowing a small arc to form. This is clearly due to the respective lowering and raising of the potential at that terminal. In the above experiment, when the tube is lighted through a small arc it may go out when the arc is broken, because the electrostatic inductive effect alone is too weak, though the potential may be much higher; but when the arc is established the electrification of the end of the tube is much greater and it consequently lights.

If a tube is lighted by holding it near to the coil, and in the hand which is remote, by grasping the tube anywhere with the other hand the part between the hands is rendered dark, and the singular effect of wiping out the light of the tube may be produced by passing the hand quickly along the tube and at the same time withdrawing it slightly from the coil, judging properly the distance so that the tube remains dark afterward.

If the primary coil is placed sidewise, as in Fig. 17 *B*, for instance, and an exhausted tube be introduced from the other side in the hollow space, the tube is lighted most intensely because of the increased condenser action, and in this position the striæ are most sharply defined. In all these experiments described and in many others the action is clearly electrostatic.

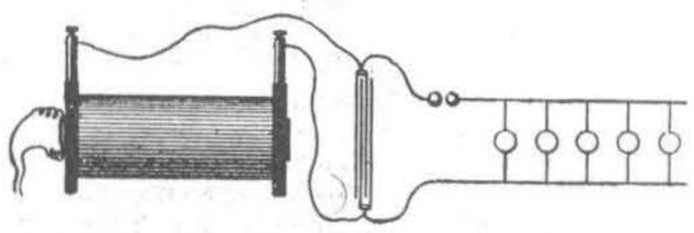


FIG. 31.—DIAGRAM OF CONNECTIONS FOR CONVERTING FROM HIGH TO LOW TENSION BY MEANS OF THE DISRUPTIVE DISCHARGE.

The effects of screening also indicate the electrostatic nature of the phenomena and show something of the nature of electrification through the air. For instance, if a tube be placed in the direction of the axis of the coil and an insulated metal plate be interposed, the tube will generally increase in brilliancy, or if it be too far from the coil to light, it may even be rendered luminous by interposing an insulated metal plate. The magnitude of the effects depends to some extent on the size of the plate. But if the metal plate be connected by a wire to the ground, its interposition will always make the tube go out, even if it be very near the coil. In general, the interposition of a body between the coil and tube increases or diminishes the brilliancy of the tube or its facility to light up, according to whether it increases or diminishes the electrification. When experimenting with an insulated plate the plate should not be taken too large, else it will generally produce a weakening effect by reason of its great facility for giving off energy to the surroundings.

If a tube be lighted at some distance from the coil and a plate of hard rubber or other insulating substance be interposed, the tube may be made to go out. The interposition of the dielectric in this case only slightly increases the inductive effect, but diminishes considerably the electrification through the air.

In all the cases, then, when we excite luminosity in exhausted tubes by means of such a coil, the effect is due to the rapidly alternating electrostatic potential; and, furthermore, it must be attributed to the harmonic alternation produced directly by the machine and not to any superimposed vibration which might be thought to exist. Such superimposed vibrations are impossible when we work with an alternate current machine. If a spring be gradually tightened and released it does not perform independent vibrations; for this a sudden release is necessary. So with the alternate currents from a dynamo machine; the medium is harmonically strained and released, this giving rise to only one kind of waves; a sudden contact or break, or a sudden giving way of the dielectric, as in the disruptive discharge of a Leyden jar, are essential for the production of superimposed waves.

In all the last described experiments tubes devoid of any electrodes may be used and there is no difficulty in producing by their means sufficient light to read by. The light effect is, however, considerably increased by the use of phosphorescent bodies such as yttria, uranium glass, etc. A difficulty will be found when the phosphorescent material is used, for with these powerful effects it is carried gradually away, and it is preferable to use material in the form of a solid.

Instead of depending on induction at a distance to light the tube, the same may be provided with an external—and, if desired, also with an internal—condenser coating, and may then be suspended anywhere in the room from a conductor connected to one terminal of the coil, and in this manner a soft illumination may be provided.

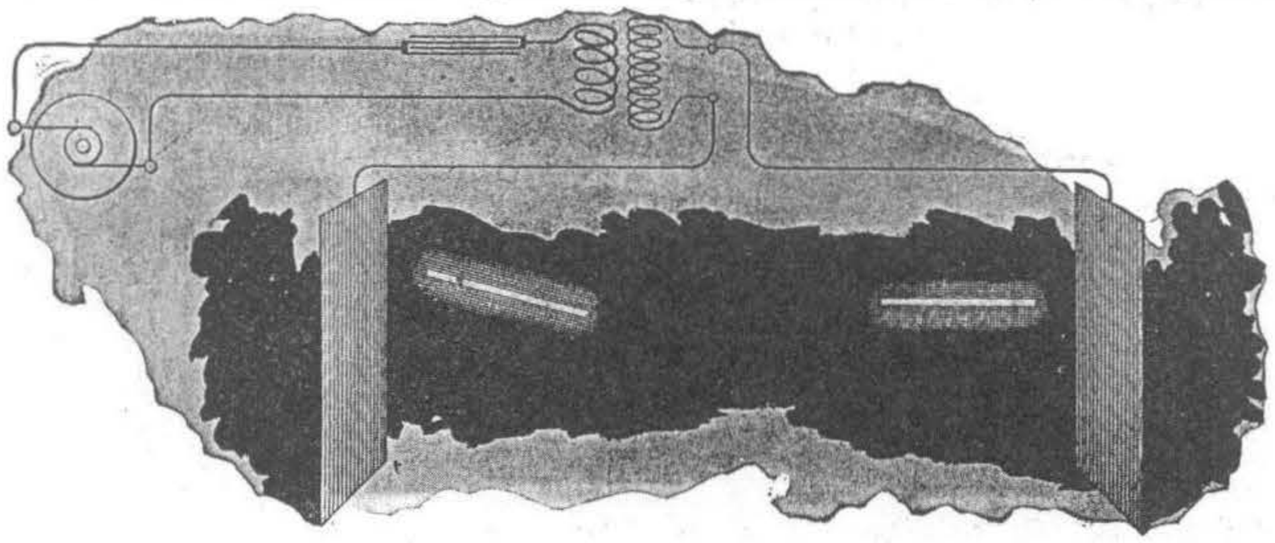


FIG. 30.—IDEAL METHOD OF LIGHTING A ROOM—TUBES DEVOID OF ANY ELECTRODES RENDERED BRILLIANT IN AN ALTERNATING ELECTROSTATIC FIELD.

The ideal way of lighting a hall or room would, however, be to produce such a condition in it that an illuminating device could be moved and put anywhere, and that it is lighted no matter where it is put and without being electrically connected to anything. I have been able to produce such a condition by creating in the room a powerful, rapidly alternating electrostatic field. For this purpose I suspend a sheet of metal at a distance from the ceiling on insulating cords and connect it to one terminal of the induction coil, the other terminal being preferably connected to the ground. Or else I suspend two sheets as illustrated in Fig. 30, each sheet being connected with one of the terminals of the coil, and their size being carefully determined. An exhausted tube may then be carried in the hand anywhere between the sheets or placed anywhere, even a certain distance beyond them; it remains always luminous.

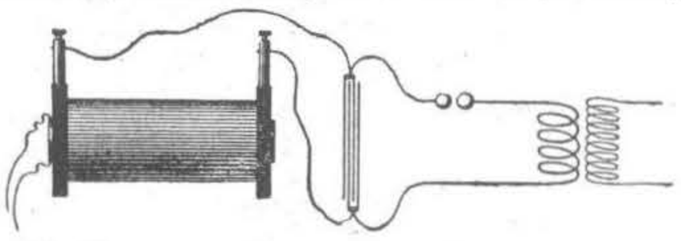


FIG. 32.—MANNER OF OPERATING AN INDUCTION COIL.

In such an electrostatic field interesting phenomena may be observed, especially if the alternations are kept low and the potentials excessively high. In addition to the luminous phenomena mentioned, one may observe that any insulated conductor gives sparks when the hand or another object is approached to it, and the sparks may often be powerful. When a large conducting object is fastened on an insulating support and the hand approached to it, a vibration, due to the rhythmical motion of the air molecules, is felt, and luminous streams may be perceived when the hand is held near a pointed projection. When a telephone receiver is made to touch with one or both of its terminals an insulated conductor of some size, the telephone emits a loud sound; it also emits a sound when a length of wire is attached to one or both terminals, and with very powerful fields a sound may be perceived even without any wire.

How far this principle is capable of practical application the future will tell. It might be thought that electrostatic effects are unsuited for such action at a distance. Electromagnetic inductive effects, if available for the production of light, might be thought better suited. It is true the electrostatic effects diminish nearly with the cube of the distance from the coil, whereas the electromagnetic inductive effects diminish simply with the distance. But when we establish an electrostatic field of force the condition is very different, for then instead of the differential effect of both the terminals we get their conjoint effect. Besides, I would call attention to the fact, that in an alternating electrostatic field, a conductor, such as an exhausted tube, for instance, tends to take up most of the energy, whereas in an electromagnetic alternating field the conductor tends to take up the least energy, the waves being reflected with but little loss. This is one reason why it is difficult to excite an exhausted tube at a distance by electromagnetic induction. I have wound coils of very large diameter and of many turns of wire and connected a Geissler tube to the ends of the coil with the object of exciting the tube at a distance; but even with the powerful inductive effects producible by Leyden-jar discharges the tube could not be excited unless at a very small distance, although some judgment was used as to the dimensions of the coil. I have also found that even the most powerful Leyden-jar discharges are capable of exciting only feeble luminous effects in a closed exhausted tube, and even these effects upon thorough examination I have been forced to consider of an electrostatic nature.

How, then, can we hope to produce the required effects at a distance by means of electromagnetic action, when even in the closest proximity to the source of disturbance, under the most advantageous conditions, we can excite but faint luminosity? It is true that when acting at a distance we have the resonance to help us out. We can connect an exhausted tube or whatever the illuminating device may be with an insulated system of the proper capacity, and so it may be possible to increase the effect qualitatively, and only qualitatively, for we would not get *more* energy through the device. So we may, by resonance effect, obtain the required electromotive force in an exhausted tube and excite faint luminous effects, but we cannot get enough energy to render the light practically available, and a simple calculation, based on experimental results, shows that even if all the energy which a tube would receive at a certain distance from the source would be wholly converted into light, it would hardly satisfy the practical requirements. Hence the necessity of directing by means of a conducting circuit the energy to the place of transformation. But in so doing we cannot very sensibly depart from present methods, and all we could do would be to improve the apparatus.

From these considerations it would seem that if this ideal way of lighting is to be rendered practicable it will be only by the use of electrostatic effects. In such a case the most powerful electrostatic inductive effects are needed; the apparatus employed must, therefore, be capable of producing high electrostatic potentials, changing in value with extreme rapidity. High frequencies are especially

wanted, for practical considerations make it desirable to keep down the potential. By the employment of machines, or, generally speaking, of any mechanical apparatus, but low frequencies can be reached; recourse must, therefore, be had to some other means. The discharge of a condenser affords us a means of obtaining frequencies by far higher than are obtainable mechanically, and I have accordingly employed condensers in the experiments to the above end.

When the terminals of a high tension induction coil, Fig. 31, are connected to a Leyden jar and the latter is discharging disruptively into a circuit, we may look upon the arc playing between the knobs as being a source of alternating, or, generally speaking, undulating currents, and then we have to deal with the familiar system of a generator of such currents, a circuit connected to it and a condenser bridging the circuit. The condenser in such case is a vertical transformer, and since the frequency is excessive, almost any ratio in the strength of the currents in both the branches may be obtained. In reality the analogy is not quite complete, for in the disruptive discharge we have most generally a fundamental instantaneous variation of comparatively low frequency and a superimposed harmonic vibration, and the laws governing the flow of currents are not the same for both.

In converting in this manner the ratio of conversion should not be too great, for the loss in the arc between the knobs increases with the square of the current, and if the jar be discharged through very thick and short conductors, with the view of obtaining a very rapid oscillation, a very considerable portion of the energy stored is lost. On the other hand, too small ratios are not practicable for many obvious reasons.

As the converted currents flow in a practically closed circuit the electrostatic effects are necessarily small, and I therefore convert them into currents or effects of the required character. I have effected such conversions in several ways. The preferred plan of connections is illustrated in Fig. 32. The manner of operating renders it easy to obtain by means of a small and inexpensive apparatus enormous differences of potential which have been usually obtained by means of large and expensive coils. For this it is only necessary to take an ordinary small coil, adjust to it a condenser and discharging circuit forming the primary of an auxiliary small coil, and convert upward. As the inductive effect of the primary currents is excessively great, the second coil need have comparatively but very few turns. By properly adjusting the elements remarkable results may be secured.

In endeavoring to obtain the required electrostatic effects in this manner, I have, as might be expected, encountered many difficulties which I have been gradually overcoming, but at present I am not prepared to dwell upon my experiences in this direction.

I believe that the disruptive discharge of a condenser will play an important part in the future, for it offers vast possibilities not only in the way of producing light in a more efficient manner and in the line indicated by theory, but also in many other respects.

For years the efforts of inventors have been directed towards obtaining electrical energy from heat by means of the thermopile. It might seem invidious to remark that but few know what is the real trouble with the thermopile. It is not the inefficiency or small output—though these are great drawbacks—but the fact that the thermopile has its phylloxera, that is, that by constant use it is deteriorated, which has thus far prevented its introduction on an industrial scale. Now that all modern research seems to point with certainty to the use of electricity of excessively high tension, the question must present itself to many whether it is not possible to obtain in a practicable manner this form of energy from heat. We have been used to look upon an electrostatic machine as a plaything, and somehow we couple with it the idea of the inefficient and impractical. But now we must think differently, for we know that everywhere we have to deal with the same forces, and that it is a mere question of inventing proper methods or apparatus for rendering them available.

In the present systems of electrical distribution the employment of iron, with its wonderful magnetic properties, allows us to reduce considerably the size of the apparatus; but, in spite of this, it is still very cumbersome. The more we progress in the study of electric and magnetic phenomena, the more we become convinced that the present methods will be short-lived. For the production of light, at least, such heavy machinery would seem to be unnecessary. The energy required is very small, and if light can be obtained as efficiently as theoretically appears possible, the apparatus need have but a very small output. There being a strong probability that the illuminating methods of the future will involve the use of very high potentials, it seems very desirable to perfect a contrivance capable of converting the energy of heat into energy of the requisite form. Nothing to speak of has been done toward this end, for the thought that electricity of some 50,000 or 100,000 volts pressure or more, even if obtained, would be unavailable for practical purposes, has deterred inventors from working in this direction.

In Fig. 31 a plan of connections is shown for converting currents of high into currents of low tension by means of the disruptive discharge of a condenser. This plan has been used by me frequently for operating a few incandescent lamps required in the laboratory. Some difficulties have been encountered in the arc of the discharge, which I have been able to overcome to a great extent; besides this, and the adjustment necessary for the proper working, no other difficulties have been met with, and it was easy to operate ordinary lamps and even motors in this manner. The line being connected to the ground, all the wires could be handled with perfect impunity, no matter how high the potential at the terminals of the condenser. In these experiments a high tension induction coil, operated from a battery or from an alternate current machine, was employed to charge the condenser; but the induction coil might be replaced by an apparatus of a different kind, capable of giving electricity of such high tension. In this

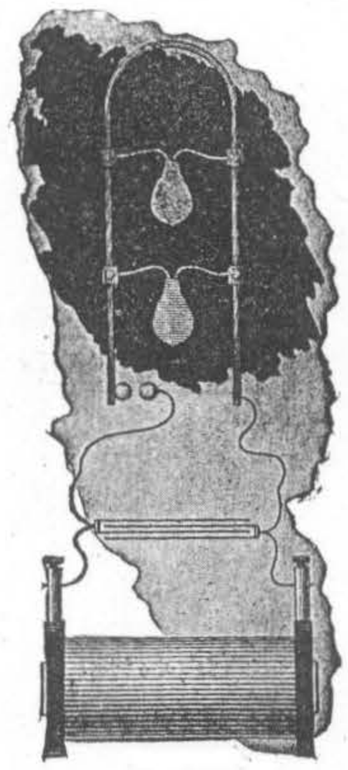


FIG. 33.—LAMP KEPT AT INCANDESCENCE ACROSS A THICK COPPER BAR—SHOWING NODES.

manner, direct or alternating currents may be converted, and in both cases the current impulses may be of any desired frequency. When the currents charging the condenser are of the same direction, and it is desired that the converted currents should also be of one direction, the resistance of the discharging circuit should, of course, be so chosen that there are no oscillations.

In operating devices on the above plan I have observed curious phenomena of impedance which are of interest. For instance, if a thick copper bar be bent as indicated in Fig. 33 and shunted by ordinary incandescent lamps, then by passing the discharge between the knobs the lamps may be brought to incandescence although they are short circuited. When a large induction coil is employed it is easy to obtain nodes on the bar which are rendered evident by the different degrees of brilliancy of the lamps, as shown roughly in Fig. 33. The nodes are never clearly pronounced, but there are simply maxima and minima of potential along the bar. This is probably due to the irregularity of the arc between the knobs. In general, when the above described plan of conversion from high to low tension is used, the behavior of the disruptive discharge may be closely studied. The nodes may also be investigated by

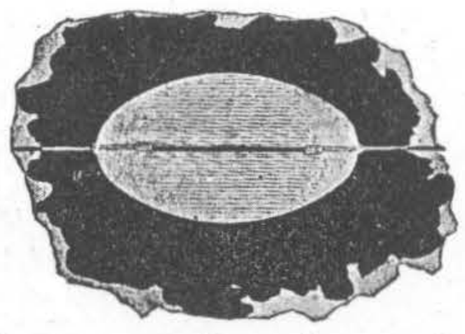


FIG. 34.—PHENOMENON OF IMPEDANCE IN AN INCADESCENT LAMP.

means of an ordinary Cardew voltmeter, which should be well insulated. Geissler tubes may also be lighted across the points of the bent bar; in this case of course it is better to employ smaller capacities. I have found it practicable to light up in this manner a lamp and even a Geissler tube shunted by a short, heavy block of metal, and this result seems at first very curious. In fact, the thicker the copper bar in Fig. 33 the better it is for the success of the experiments, as they appear more striking. When lamps with long, slender filaments are used it will be often noted that the filaments are from time to time violently vibrated, the vibration being smallest on the nodal points. This vibration seems to be due to an electrostatic action between the filament and the glass of the bulb.

In some of the above experiments it is preferable to use special lamps having a straight filament as shown in Fig. 34. When such a lamp is used a still more curious phenomenon than those described may be observed. The lamp may be placed across the copper bar and lighted, and by using somewhat larger capacities, or, in other words, smaller frequencies, or smaller impulsive impedances, the filament may be brought to any desired degree of incandescence. But when the impedance is increased, a point is reached when comparatively little current passes through the carbon and most of it through the rarefied gas; or perhaps it may be more correct to state that the current divides nearly evenly through both, in spite of the enormous difference in the resistance, and this would be true unless the gas and the filament behave differently. It is then noted that the whole bulb is brilliantly illuminated, and the ends of the leading-in wires become incandescent and often throw off sparks in consequence of the violent bombardment; but the carbon filament remains dark. This is illustrated in Fig. 34. Instead of the filament a single wire extending through the whole bulb may be used, and in this case the phenomenon would seem to be still more interesting.

From the above experiment it will be evident that when ordinary lamps are operated by the converted currents, those should be preferably taken in which the platinum wires are far apart, and the frequencies used should not be too great, else the discharge will occur at the ends of the filament or in the base of the lamp between the leading-in wires, and the lamp might then be damaged.

In presenting to you these results of my investigation on the subject under consideration I have paid only a passing notice to facts upon which I could have dwelt at length, and among many observations I have selected only those which I thought most likely to interest you. The field is wide and completely unexplored, and at every step a new truth is gleaned, a novel fact observed.

How far the results here borne out are capable of practical applications will be decided in the future. As regards the production of light some results already reached are encouraging and make me confident in asserting that the practical solution of the problem lies in the direction I have endeavored to indicate. Still, whatever may be the immediate outcome of these experiments I am hopeful that they will only prove a step to further development toward the ideal and final perfection. The possibilities which are opened by modern research are so vast that even the most reserved must feel sanguine of the future. Eminent scientists consider the problem of utilizing one kind of radiation without the others a rational one. In an apparatus designed for the production of light by conversion from any form of energy into that of light such a result can never be reached, for no matter what the process of producing the required vibrations, be it electrical, chemical or any other, it will not be possible to obtain the higher light vibrations without going through the lower heat vibrations. It is the problem of imparting to a body a certain velocity without passing through all lower velocities. But there is a possibility of obtaining energy, not only in the form of light, but motive power and energy of any other form in some more direct way from the medium. The time will be when this will be accomplished, and the time has come when one may utter such words before an enlightened audience without being considered a visionary. We are whirling through the endless space with an inconceivable speed; all around us everything is spinning, everything is moving, everywhere is energy. There *must* be some way of availing ourselves of this energy more directly. Then, with the light obtained from the medium, with the power derived from it, with every form of energy obtained without effort, from the store forever inexhaustible, humanity will advance with giant strides. The mere contemplation of these magnificent possibilities expands our minds, strengthens our hopes and fills our hearts with supreme delight.

ELECTRIC LAMPS

FED FROM SPACE, AND FLAMES THAT DO NOT CONSUME.

BY JOSEPH WETZLER, M.E.

THE honors in electrical discovery and invention have hitherto been pretty evenly divided among the nations, but of late America has bid fair to leave little for the rest of the world to own or cultivate in this wonderful vided among the nations, but of late America has bid fair to leave little for the rest of the world to own or cultivate in this wonderful new domain of the arts and sciences. The modern telegraph is largely American. The telephone is wholly so. The great successful systems of electric light and power bear American names, and now American methods of operating electric railroads have begun to go around the globe, conquering and to conquer.

Columbia College a few weeks ago gave a remarkable exemplification of this significant state of affairs when, in the presence of an enthusiastic gathering of the foremost electrical talent of the country, a modest young Likan, Nikola Tesla by name, delivered a lecture in English on his discoveries of results with alternating currents of high frequency. At one bound he placed himself abreast of such men as Edison, Brush, Elihu Thomson, and Alexander Graham Bell. Yet only four or five years ago, after a period of struggle in France, this stripling from the dim mountain border-land of Austro-Hungary landed on our shores, entirely unknown, and poor in everything save genius and training, and courage inherited from many a chieftain who shed his blood in the ceaseless warfare with the unspeakable Turk. Work and recognition came slowly, but they came; and it needed simply that he should fall in the way of Mr. George Westinghouse, Jun., to have some of his earliest inventions here appreciated. Those inventions, dealing as they do with the difficult problems of the utilization of alternating currents for motive power, are in themselves fundamental and far-reaching; but Mr. Tesla has now utterly eclipsed them by his experiments and methods for obtaining the electric light electrostatically. In a word, his lecture at Columbia—which merely as a rhetorical performance touched on the marvellous, as coming from a foreigner, by its lucid explanations in pure, nervous English of subtle ideas and obscure phenomena—showed two things very clearly. It showed not only that he had gone far beyond the two distinguished European scientists Dr. Lodge and Professor Hertz in grasp of the electro-magnetic theory of light, but that he had actually made apparatus by which electrostatic waves or "thrusts" would give light for ordinary every-day uses.

On the occasion of this memorable lecture Mr. Tesla held his audience in complete captivity of attention and admiration for over three hours. Since that time the mere report of the nature of his experiments has aroused the intensest curiosity in Europe, and the full text of his lecture, of which this article affords but suggestive outline, is awaited there most anxiously. It is felt by all who are conversant with the subject that the point of new departure in all our work for introducing electricity universally as a means of interior illumination must be taken from the revelations at Columbia. There is given us, moreover, many a fascinating glimpse of facts and truths still in the background.

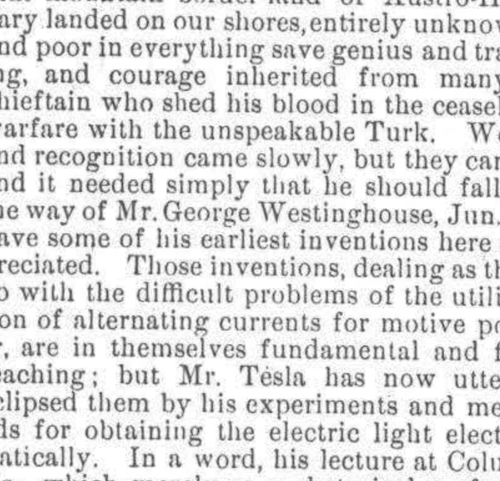


FIG. 1.—WIRE STREAMING OUT LIGHT.

The transition from the tallow dip to the candle and the oil lamp marked one stage in the march of improvement, which, passing on to the introduction of gas, has, in our day, reached the high form of development exhibited in the little incandescent lamp of 16-candle-power, and the powerful arc lamp ranging up to 100,000-candle-power and more, and sending its beams from the light-house, in some instances, as far as 60 miles. We have characterized the present electrical methods as highly developed forms of illumination, and so they are, compared with those which have gone before; but Mr. Tesla's discoveries leave no room for doubt that before long we shall see further improvements, which cannot fail to have a marked influence on the methods which will be adopted in the future. The faint glow exhibited in the Geissler tube, which has for a long time constituted one of the stock experiments of every lecturer on physics, has frequently been suggested as one of the methods by which we could

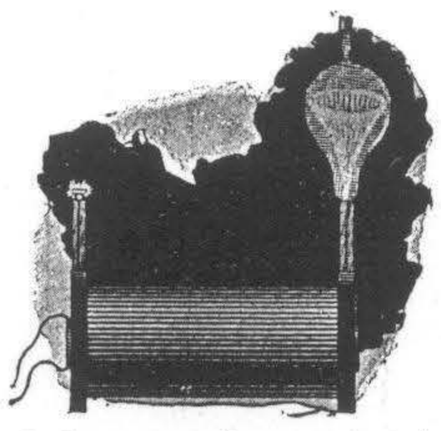


FIG. 2.—INCANDESCENT FILAMENT SPINNING IN UNEXHAUSTED GLOBE.

obtain the ideal form of illumination—light without heat. Experiments in this direction had, however, led to very little, and even the remarkable experiments of Professor Crookes on radiant matter, which will be fresh in the minds of many, and which were first brought out nearly twenty years ago, led us no nearer the desired goal. More recent experimenters, among them Dr. Hertz and Dr. Lodge, had struck out in a line which promised good results; but it has remained for Mr. Tesla to crystallize and define the methods and the apparatus by which, in all probability, the difficult problem will be solved.

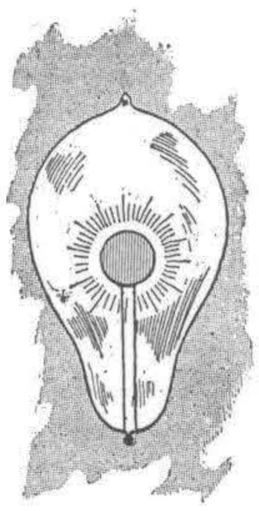


FIG. 3.—LAMP WITH BUTTON OF REFRACTORY MATERIAL.

Before entering into a description of Mr. Tesla's methods it will be well to explain in brief the steps which have led to the results which we are now about to consider. He began by taking what is known as an induction or spark coil, capable of generating electric sparks similar to those which we are all familiar with in connection with the static frictional electric machine, and which is described in every school-book on physics. These spark coils have heretofore been operated by means of currents which were periodically interrupted only a few times per second, or by what are called alternating currents, such as those largely used in our present forms of electric lighting, and which vibrate or alternate from 100 to 200 times a second. Mr. Tesla reasoned that if we could increase the number of vibrations or alternations in the current far above the number just mentioned, we would obtain greatly increased effects, and for this purpose he constructed a machine which gave him no less than 20,000 alternations per second. A few experiments convinced him that his theory was correct. The character of the spark or electrical discharge between the knobs connected to the coil operated with currents of this nature exhibited qualities quite different from those heretofore observed. In fact, as the alternations are increased, no less than five distinct kinds of discharge may be noticed, beginning with a thin thread-like discharge, until finally the character of the discharge is changed to that of a hot flame issuing from the discharge knob.

In the course of these experiments Mr. Tesla observed a large number of interesting phenomena. One of these is illustrated in the accompanying engraving Fig. 1. By attaching a wire to one of the terminals of such a coil, streams of light issue not only from the end, but from all sides, showing the intense nature of the action which is going on. Another experiment is illustrated in Fig. 2.

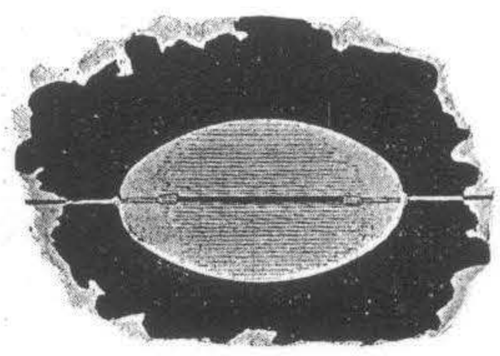


FIG. 5.—AN APPARENT PARADOX—ILLUMINATED GLOBE WITH DARK FILAMENT.

Here a very fine platinum wire is placed in a glass bulb. The intense action of the current sets the fine thread of platinum spinning around in the bulb, forming a veritable funnel of light. These experiments led Mr. Tesla later to a practical form of lamp, and one of these is shown in the engraving Fig. 3. This consists merely of a glass bulb from which the air has been exhausted, and which contains a simple button of some refractory material, from which a single wire leads to the outside of the bulb. Such a lamp attached merely to one wire glows brightly, and at one stroke obviates the necessity of having two wires connected to each lamp. He also demonstrated that such a lamp could be made to glow without leading the wire through the glass.

But Mr. Tesla was not satisfied with these results, brilliant as they were. He had set himself no less a task than to create a lamp which, without any external connection to wires or conductors of any sort, should glow brightly when placed anywhere in an apartment.

As illustrating the manner in which he carried out such a system in practice, the engraving Fig. 4 shows the arrangement of apparatus. Here A represents the primary electric generator, which would be placed at the central station, with wires leading, as usual, to the place where the light is required. At this point there is inserted in the circuit what is technically called a condenser, C, an apparatus similar in principle to that of the Leyden-jar. Close to it is an induction coil,

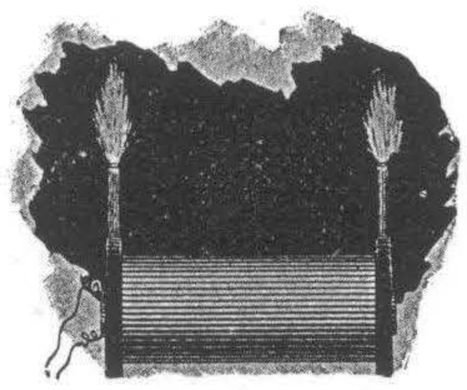


FIG. 6.—ELECTRICAL FLAMES WHICH CONSUME NOTHING.

B, which converts the currents of low potential coming from the machine to those of the very high potential required in the new method. The room into which the wires from the coil B are led has two metallic sheets placed within its opposite walls, or a metallic wall-paper may be used for the same purpose. With such an arrangement glass tubes properly exhausted glow brightly, and can be freely moved anywhere in the apartment, just like hand or oil lamps. The electric impulses thrown out from the metallic disks create within the entire room an electrical field which exerts its influence on everything within it, and which becomes manifest in a medium specially adapted to the exhibition of its forces, such as tubes exhausted of air.

By a further close course of reasoning he became convinced that such a system could be still further improved by using a far higher number of alternations of the current than he was able to obtain with his machines, although some of them gave as high as 35,000 reversals of current per second. How, then, was the desired result to be accomplished? It has long been known that the spark discharged from a static frictional machine or a Leyden-jar, and also that of the lightning, is one which vibrates many million times per second, and it is this phenomenon which Mr. Tesla has availed himself of in order to obtain the high rate of vibrations upon which his latest results are based.

It would lead me too far to enter into the details of the apparatus employed by Mr. Tesla, simple as it is; but suffice it to say that by interposing in an electric circuit an apparatus by which a spark discharge is continually maintained between a pair of knobs, the current in the wires is thrown into the enormously high rate of vibration necessary to obtain the desired results.

The possibilities of such a method of illumination need hardly be dwelt upon; suffice it to say that without wires or pipes of any kind to hamper the artist or decorator, effects may be produced which will bring fairy-land within our homes.

The question will naturally be asked: What effect will this new method, when perfected, have upon our existing methods of electric lighting? Will it make useless all our machines and the wires which now form an indispensable part of our methods of electrical distribution? In answer to this, it may be said that such a result is hardly to be expected immediately. The immediate change which will be wrought when the system devised by Mr. Tesla is brought to practical perfection will probably be one required within the buildings to be illuminated. Wires from the station to the building will still be necessary, and much of the machinery at present in use will still be available with the new method.

In order to show the difference in character between the currents of the low number of vibrations heretofore used, as compared with those employed by Mr. Tesla, we need cite only one experiment, which presents the apparent paradox seen in the illustration Fig. 5. It will be noticed that a lamp having a carbon conductor similar to that employed in the usual electric lamp, remains perfectly dark while the entire interior of the bulb becomes brightly illuminated. Mr. Tesla's experiments, however, while marking a distinct epoch in the history of electric illumination, have a most important bearing in many other directions. It was mentioned before that the discharge obtained from the coil assumed the form of a hot flame, as illustrated in Fig. 6, and this at once reveals a method of producing a flame without consuming any material, not even the oxygen of the atmosphere, which is the main element in the combustion of all fuels. The currents employed by Mr. Tesla are also of great value in the production of ozone, one of the most powerful disinfectants known; and it is fair to assume that the introduction of such currents into our houses will go far towards increasing their sanitary condition.

We might speculate at length upon the possibilities which lie before us, but enough has been said to convince the reader that we have discerned the shores of discoveries in electricity which will go far towards the realization of results that the most advanced prophet of the Bellamy school has not yet ventured to predict.

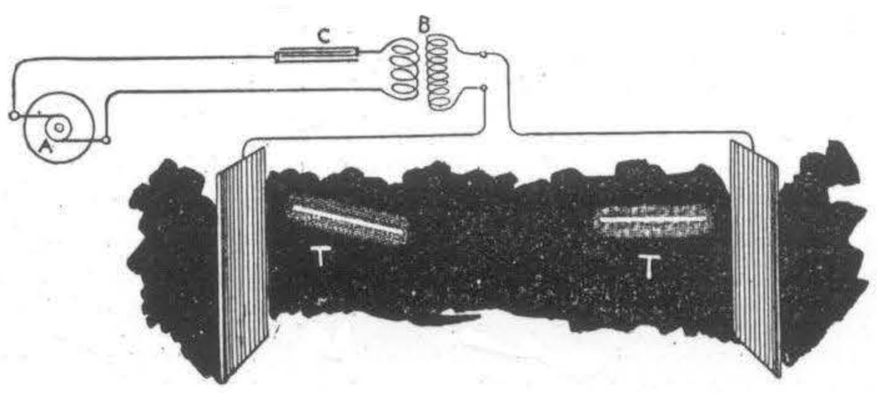


FIG. 4.—IDEAL WAY OF LIGHTING A ROOM.

A. Dynamo. B. Induction Coil. C. Condenser. T. T. Illuminated Tubes without Wires.

TESLA'S METHOD OF OPERATING ALTERNATING CURRENT MOTORS WITH CONDENSERS.

If the terminals or plates of a condenser be connected with two points of a circuit, the potentials of which are made to rise and fall in rapid succession, the condenser allows the passage, or, more strictly speaking, the transferrence of a current, although its plates or armatures may be so carefully insulated as to prevent almost completely the passage of a current of unvarying strength or direction and of moderate electromotive force; again, if a circuit, the terminals of which are connected with the plates of the condenser, possess a certain self-induction, the condenser will overcome or counteract to a greater or less degree, dependent upon well-understood conditions, the effects of such self-induction; third, if two points of a closed or complete circuit through which a rapidly rising and falling current flows, be shunted or bridged by a condenser, a variation in the strength of the currents in the branches, and also a difference of phase of the currents therein, is produced.

These effects Mr. Tesla has utilized and applied in a variety of ways in the construction and operation of his well-known alternating motors, as, by producing a difference in phase in the two energizing circuits of an alternating-current motor by connecting the two circuits in derivation, and connecting up a condenser in series in one of the circuits.

In an alternating-current motor of the type which has an armature coil or circuit closed upon itself, however, the latter represents not only an inductive resistance, but one which is periodically varying in value, both of which facts

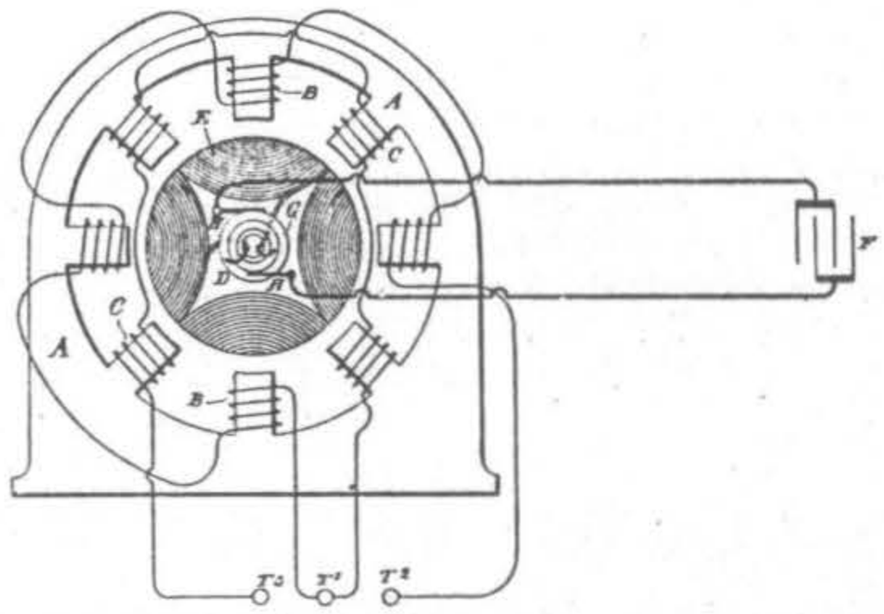


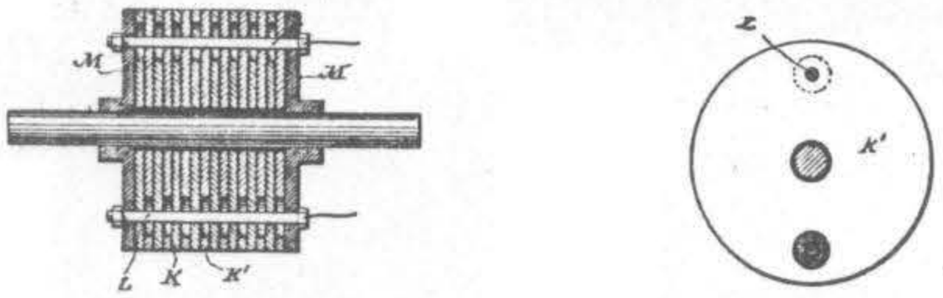
FIG. 1.—TESLA'S NEW ALTERNATING MOTOR WITH CONDENSER.

complicate, and render difficult, the attainment of the conditions best suited to the most efficient working of the motors. The most efficient working conditions, in other words, require, first, that for a given inductive effect upon the armature there should be the greatest possible current through the armature or induced coils, and, second, that there should always exist between the currents in the energizing and the induced circuits a given relation of phase. Hence whatever tends to decrease the self-induction and increase the current in the induced circuits will, other things being equal, increase the output and efficiency of the motor, and the same will be true of causes that operate to maintain the mutual attractive effect between the field-magnets and armature at its maximum. He secures these results by connecting with the induced circuit a condenser, and also by constructing the motor in a special manner.

The general plan of operation adopted by Mr. Tesla is illustrated in Fig. 1. A A in this figure represent the frame and field-magnets of an alternating-current motor, the poles or projections of which are wound with coils B and C, so that the alternating currents flowing through the circuits, respectively, will have a difference of phase. Within the influence of this field is an armature-core D, wound with coils E. In Mr. Tesla's motors of this description, heretofore these coils have been closed upon themselves, or con-

nected in a closed series; but in the present case each coil or the connected series of coils terminates in the opposite plates of a condenser F. For this purpose the ends of the series of coils are brought out through the shaft to collecting-rings G, which are connected to the condenser by contact brushes H, the condenser being independent of the machine. The armature-coils are wound or connected in such a manner that adjacent coils produce opposite poles.

The action of this motor and the effect of the plan followed in its construction are as follows: The motor being started in operation and the coils of the field-magnets being



FIGS. 3 AND 4.—COMBINED ARMATURE AND CONDENSER.

traversed by alternating currents, currents are induced in the armature coils by one set of field coils, as B, and the poles thus established are acted upon by the other set, C. The armature coils, however, have necessarily a high self-induction, which opposes the flow of the currents thus set up. The condenser F not only permits the passage or transferrence of these currents, but also counteracts the effects of self-induction, and by a proper adjustment of the capacity of the condenser, the self-induction of the coils, and the periods of the currents, the condenser may be made to overcome entirely the effect of the self-induction.

It is preferable on account of the undesirability of using sliding contacts of all kinds to combine the condenser with the armature directly, or make it a part of the armature. In some cases, as shown in Fig. 2, Mr. Tesla builds up the armature of annular plates K K, held by bolts L between heads M, which are secured to the driving shaft, and in the hollow space thus formed is placed a condenser F, generally by winding the two insulated plates spirally around the shaft. In other cases he utilizes the plates of the core itself as the plates of the condenser, as shown in Figs. 3 and 4.

In motors in which the armature coils are closed upon themselves—as, for example, in any form of alternating-current motor in which one armature coil or set of coils is in the position of maximum induction with respect to the field coils or poles, while the other is in the position of

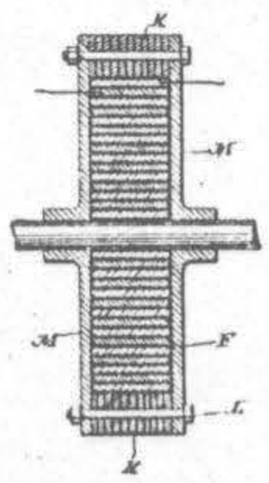


FIG. 2.

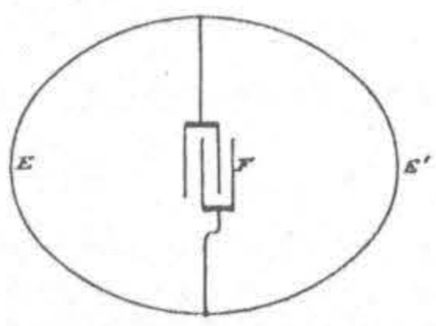


FIG. 5.

minimum induction—the coils are connected in one series, and two points of the circuit thus formed are bridged by a condenser. This is illustrated in Fig. 5, in which E represents one set of armature coils and E′ the other. Their points of union are joined through a condenser F. It will be observed that in this disposition the self-induction of the two branches E and E′ varies with their position relatively to the field-magnet, and that each branch is alternately the predominating source of the induced current. Hence the effect of the condenser F is twofold. First, it increases the current in each of the branches alternately, and, secondly, it alters the phase of the currents in the branches, this being the well-known effect which results from such a disposition of a condenser with a circuit, as above described. This effect is favorable to the proper working of the motor, because it increases the flow of current in the armature circuits due to a given inductive effect, and also because it brings more nearly into coincidence the maximum magnetic effects of the coacting field and armature poles. This method of operation is more particularly adapted to systems in which a very high rate of alternation or change is maintained.

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VOL. XII. NEW YORK, JULY 15, 1891. No. 167.

The first requisite of an observer is that his mind should be actively awakened to the phenomena of nature with which he is surrounded.—Joseph Henry.

CONDENSERS IN ALTERNATING CURRENT WORK.

ONE of the most noteworthy developments in the domain of alternate current working is the prominence which has been given within a comparatively short time to the condenser and its action in relation to circuits possessing high self-induction. Heretofore regarded seriously as a working device only by the telegraph and telephone engineer, the condenser has suddenly risen to occupy a place such that it would be difficult to predict to what uses it may hereafter be put. As another illustration of its present wide application we note this week its use by Mr. Tesla in his well-known alternating motor. In alternating motors of this type the induced circuit in the armature represents an inductive resistance which has a considerable value and which is constantly changing with the varying position of the coil with respect to the field magnets. Such a motor is virtually a transformer, and anything that tends to increase its output will, other things being equal, improve it. Evidently one of the chief requisites in a motor in which currents are induced in the armature is to pass through the armature circuit the greatest possible current which can be produced by a given impressed E. M. F., or, in other words, by a given inductive effect of the field. Mr. Tesla accomplishes this by placing a condenser in the armature circuit, thereby counteracting the self-induction and hence permitting a larger volume of current to pass through the induced circuit. In order to permit of the rotation of the

condenser Mr. Tesla places it in the armature, or very ingeniously connects the armature plates so as to form a condenser. Mr. Tesla, we may add, also uses a like connection in other forms of induction apparatus, such as converters.

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION.*

BY NIKOLA TESLA.

There is no subject more captivating, more worthy of study, than nature. To understand this great mechanism, to discover the forces which are active, and the laws which govern them, is the highest aim of the intellect of man.

Nature has stored up in the universe infinite energy. The eternal recipient and transmitter of this infinite energy is the ether. The recognition of the existence of ether, and of the functions it performs, is one of the most important results of modern scientific research. The mere abandoning of the idea of action at a distance, the assumption of a medium prevadingall space and connecting all gross matter, has freed the minds of thinkers of an ever present doubt,and by opening a new horizon—new and unforeseen possibilities—has given fresh interest to phenomena with which we are familiar of old It has been a great step towards the understanding of the forces of nature and their multifold manifestations to our senses. It has been for the enlightened student of physics what the understanding of the mechanism of the firearm or of the steam engine was for the barbarian. Phenomena upon which we used to look as wonders baffling explanation we now see in a different light. The spark of an induction coil, the glow of an incandescent lamp, the manifestations of the mechanical forces of currents and magnets, are no longer beyond our grasp. Instead of the incomprehensible, as before, their observation suggests now in our minds a simple mechanism, and although as to its precise nature all is still conjecture, yet we know that the truth cannot be much longer hidden, and instinctively we feel that the understanding is dawning upon us. We still admire these beautiful phenomena, these strange forces, but we are helpless no longer; we can, in a certain measure, explain them, account for them, and we are hopeful of finally succeeding in unravelling the mystery which surrounds them.

In how far we can understand the world around us is the ultimate thought of every student of nature. The coarseness of our senses prevents us from recognising the ulterior construction of matter, and astronomy, this grandest and most positive of natural sciences, can only teach us something that happens, as it were, in our immediate neighbourhood; of the remoter portions of the boundless universe, with its numberless stars and suns, we know nothing. But far beyond the limit of perception of our senses the spirit still can guide us, and so we may hope that even these unknown worlds—infinitely small and great—may in a measure become known to us. Still, even if this knowledge should reach us, the searching mind will find a barrier, perhaps for ever unsurpassable, to the true recognition of that which seems to be, the mere appearance of which is the only and slender basis of all our philosophy.

Of all the forms of nature's immeasurable, all-pervading energy, which, ever and ever changing and moving, like a soul animates the inert universe, those of electricity and magnetism are perhaps the most fascinating. The effects of gravitation, of heat and light we observe daily, and soon we get accustomed to them, and soon they lose for us the character of the marvellous and wonderful; but electricity and magnetism, with their singular relationship, with their seemingly dual character, unique among the forces in nature, with their phenomena of attractions, repulsions and rotations, strange manifestations of mysterious agents, stimulate and excite the mind to thought and research. What is electricity? and What is magnetism? These questions have been asked again and again. The most able intellects have ceaselessly wrestled with the problem; still the question has not as yet been fully answered. But while we cannot even to-day state what these singular forces are, yet we have made good headway towards the solution of the problem. We are now confident that electric and magnetic phenomena are attributable to ether, and we are perhaps justified in saying that the effects of static electricity are effects of ether under strain, and those of dynamic electricity and electromagetism effects of ether in motion. But this still leaves the question, as to what electricity and magnetism are, unanswered.

First, we naturally enquire, What is electricity, and is there such a thing as electricity? In interpreting electric phenomena, we may speak of electricity or of an electric condition, state or effect. If we speak of electric effects, we must distinguish two such effects, opposite in character and neutralising each other, as observation shows that two such opposite effects exist. This is unavoidable, for in a medium of the properties of ether we cannot possibly exert a strain, or produce a displacement or motion of any kind, without causing in the surrounding medium an equivalent and opposite effect. But if we speak of electricity, meaning a thing, we must, I think, abandon the idea of two electricities, as the existence of two such things is highly improbable. For how can we imagine that there should be two things, equivalent in amount, alike in their properties, but of opposite character, both clinging to matter, both attracting and completely neutralising each other? Such an assumption, though suggested by many phenomena, though most convenient for explaining them, has little to commend it. If there is such a thing as electricity, there can be only one such thing, and, excess and want of that one thing, possibly; but more probably its connection determines the positive and negative character. The old theory of Franklin, though falling short in some respect, is, from a certain point of view, after all, the most plausible one. Still, in spite of this, the theory of the two electricities is generally accepted, as it apparently explains electric phenomena in a more satisfactory manner. But a theory which better explains the facts is not necessarily true. Ingenious minds will invent theories to suit observation, and almost every independent thinker has his own views on the subject.

It is not with the object of advancing an opinion, but with the desire of acquainting you better with some of the results, which I will describe, to show you the reasoning I have followed, the departures I have made—that I venture to express, in a few words, the views and convictions which have led me to these results.

I adhere to the idea that there is a thing which we have been in the habit of calling electricity. The question is, What is that thing? or, What, of all things, the existence of which we know, have we the best reason to call elec-

* Lecture delivered before the American Institute of Electrical Engineers at Columbia College, New York, May 20.

tricity? We know that it acts like an incompressible fluid; that there must be a constant quantity of it in nature; that it can be neither produced nor destroyed; and, what is more important, the electromagnetic theory of light and all facts observed teach us that electric and ether phenomena are identical. The idea at once suggests itself, therefore, that electricity might be called ether. In fact, this view has in a certain sense been advanced by Dr. Lodge. His interesting work has been read by everyone, and many have been convinced by his arguments. His great ability, and the interesting nature of the subject, keep the reader spellbound; but when the impressions fade, one realises that he has to deal only with ingenious explanations. I must confess that I cannot believe in two electricities, much less in a doubly constituted ether. The puzzling behaviour of the ether as a solid to waves of light and heat, and as a fluid to the motion of bodies through it, is certainly explained in the most natural and satisfactory manner by assuming it to be in motion, as Sir William Thomson has suggested; but, regardless of this, there is nothing which would enable us to conclude with certainty that, while a fluid is not capable of transmitting transverse vibrations of a few hundred or thousand per second, it might not be capable of transmitting such vibrations when they range into hundreds of million millions per second. Nor can anyone prove that there are transverse ether waves emitted from an alternate-current machine, giving a small number of alternations per second; to such slow disturbances, the ether, if at rest, may behave as a true fluid.

Returning to the subject, and bearing in mind that the existence of two electricities is, to say the least, highly improbable, we must remember that we have no evidence of electricity, nor can we hope to get it, unless gross matter is present. Electricity, therefore, cannot be called ether in the broad sense of the term: but nothing would seem to stand in the way of calling electricity ether associated with matter, or bound ether; or, in other words, that the so-called static charge of the molecule is ether associated in some way with the molecule. Looking at it in that light, we would be justified in saying that electricity is concerned in all molecular actions.

Now, precisely what the ether surrounding the molecules is, wherein it differs from ether in general, can only be conjectured. It cannot differ in density, ether being incompressible; it must, therefore, be under some strain or in motion, and the latter is the most probable. To understand its functions, it would be necessary to have an exact idea of the physical construction of matter, of which, of course, we can only form a mental picture.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION.*

BY NIKOLA TESLA.

(Continued from page 64.)

But of all the views on nature, the one which assumes one matter and one force, and a perfect uniformity throughout, is the most scientific and most likely to be true. An infinitesimal world, with the molecules and their atoms spinning and moving in orbits, in much the same manner as celestial bodies, carrying with them and probably spinning with them ether, or in other words, carrying with them static charges, seems to my mind the most probable view, and one which, in a plausible manner, accounts for most of the phenomena observed. The spinning of the molecules and their ether sets up ether tensions or electrostatic strains; the equalisations of ether tensions sets up ether motions or electric currents, and the orbital movements produce the effects of electro and permanent magnetism.

About 15 years ago Prof. Rowland demonstrated a most interesting and important fact—namely, that a static charge carried around produces the effects of an electric current. Leaving out of consideration the precise nature of the mechanism which produces the attraction and repulsion of currents, and conceiving the electrostatically charged molecules in motion, this experimental fact gives us a fair idea of magnetism. We can conceive lines or tubes of force which physically exist, being formed of rows of directed moving molecules; we can see that these lines must be closed; that they must tend to shorten and expand, etc. It likewise explains in a reasonable way the most puzzling phenomenon of all, permanent magnetism, and, in general, has all the beauties of the Ampère theory without possessing the vital defect of the same—namely, the assumption of molecular currents. Without enlarging further upon the subject, I would say that I look upon all electrostatic current and magnetic phenomena as being due to electrostatic molecular forces.

The preceding remarks I have deemed necessary to a full understanding of the subject as it presents itself to my mind.

Of all these phenomena the most important to study are the current phenomena, on account of the already extensive and ever-growing use of currents for industrial purposes. It is now a century since the first practical source of current has been produced, and ever since the phenomena which accompany the flow of currents have been diligently studied, and through the untiring efforts of scientific men

* Lecture delivered before the American Institute of Electrical Engineers at Columbia College, New York, May 20.

the simple laws which govern them have been discovered. But these laws were found to hold good only when the currents are of a steady character. When the currents are rapidly varying in strength, quite different phenomena, often unexpected, present themselves, and quite different laws hold good, which even now have not been determined as fully as is desirable, though through the work, principally of English scientists, enough knowledge has been gained on the subject to enable us to treat simple cases which now present themselves in daily practice.

The phenomena which are peculiar to the changing character of the currents are greatly exalted when the rate of change is increased, hence the study of these currents is considerably facilitated by the employment of properly constructed apparatus. It was with this and other objects in view that I constructed alternate-current machines capable of giving more than two million reversals of current per minute, and to this circumstance it is principally due that I am able to bring to your attention some of the results thus far reached, which I hope will prove to be a step in advance on account of their direct bearing upon one of the most important problems—namely, the production of a practical and efficient source of light.

The study of such rapidly alternating currents is very interesting. Nearly every experiment discloses something new. Many results may, of course, be predicted, but many more are unforeseen. The experimenter makes many interesting observations. For instance, we take a piece of iron and hold it against a magnet. Starting from low alternations and running up higher and higher, we feel the impulses succeed each other faster and faster, get weaker and weaker, and finally disappear. We then observe a continuous pull; the pull, of course, is not continuous; it only appears so to us; our sense of touch is imperfect.

We may next establish an arc between the electrodes and observe as the alternations rise that the note which accompanies alternating arcs gets shriller and shriller, gradually weakens, and finally ceases. The air vibrations, of course, continue, but they are too weak to be perceived; our sense of hearing fails us.

We observe the small physiological effects, the rapid heating of the iron cores and conductors, curious inductive effects, interesting condenser phenomena, and still more interesting light phenomena with a high-tension induction coil. All these experiments and observations would be of the greatest interest to the student, but their description would lead me too far from the principal subject. Partly for this reason, and partly on account of the vastly greater importance, I will confine myself to the description of the light effects produced by these currents.

In the experiments to this end a high-tension induction coil or equivalent apparatus for converting currents of comparatively low into currents of high tension is used.

If you will be sufficiently interested in the results I shall describe as to enter into an experimental study of this subject; if you will be convinced of the truth of the arguments I shall advance, your aim will be to produce high frequencies and high potentials—in other words, powerful electrostatic effects. You will then encounter many difficulties, which, if completely overcome, would allow us to produce truly wonderful results.

First will be met the difficulty of obtaining the required frequencies by means of mechanical apparatus, and, if they be obtained otherwise, obstacles of a different nature will present themselves. Next it will be found difficult to provide the requisite insulation without considerably increasing the size of the apparatus, for the potentials required are high, and owing to the rapidity of the alternations the insulation presents peculiar difficulties. So, for instance, when a gas is present, the discharge may work by the molecular bombardment of the gas and consequent heating, through as much as an inch of the best solid insulating material, such as glass, hard rubber, porcelain, sealing-wax, etc., in fact, through any known insulating substance. The chief requisite in the insulation of the apparatus is, therefore, the exclusion of any gaseous matter.

In general, my experience tends to show that bodies which possess the highest specific inductive capacity, such as glass, afford a rather feeble insulation to others, which, while they are good insulators, have a much smaller specific inductive capacity, such as oils, for instance, the dielectric losses being no doubt greater in the former. The difficulty of insulating, of course, only exists when the potentials are excessively high, for with potentials such as a few thousand volts there is no particular difficulty encountered in conveying currents from a machine giving, say, 20,000 alternations per second, to quite a distance. This number of alternations, however, is by far too small for many purposes, though quite sufficient for some practical applications. This difficulty of insulating is fortunately not a vital drawback; it affects mostly the size of the apparatus, for, when excessively high potentials would be used, the light-giving devices would be located not far from the apparatus, and often they would be quite close to it. As the air-bombardment of the insulated wire is dependent on condenser action, the loss may be reduced to a trifle by using excessively thin wires heavily insulated.

Another difficulty will be encountered in the capacity and self-induction necessarily possessed by the coil. If the coil be large—that is, if it contain a great length of wireit—will be generally unsuited for excessively high frequencies; if it be small, it may be well adapted for such frequencies, but the potential might then not be as high as desired. A good insulator, and preferably one possessing a small specific inductive capacity, would afford a twofold advantage. First, it would enable us to construct a very small coil capable of withstanding enormous differences of

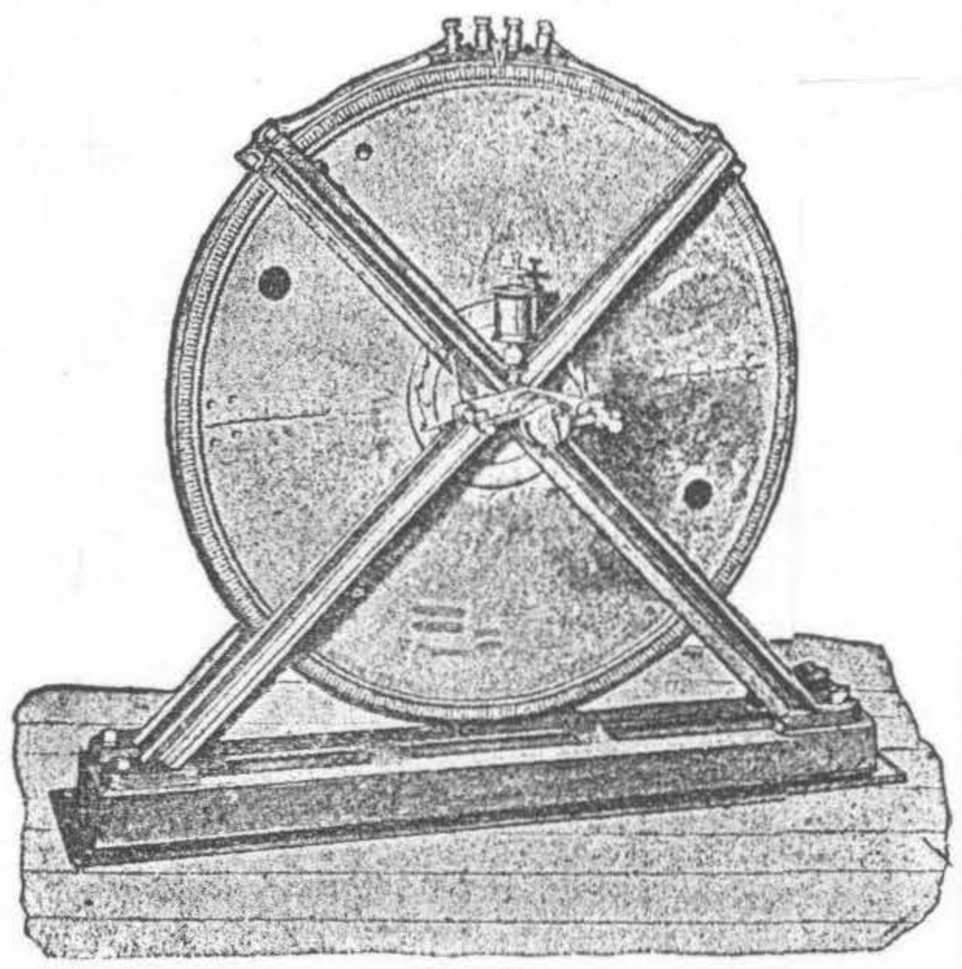


FIG. 1.

potential; and secondly, such a small coil, by reason of its smaller capacity and self-induction, would be capable of a quicker and more vigorous vibration. The problem then of constructing a coil or induction apparatus of any kind possessing the requisite qualities I regard as one of no small importance, and it has occupied me for a considerable time.

The investigator who desires to repeat the experiments which I will describe, with an alternate-current machine, capable of supplying currents of the desired frequency, and an induction coil, will do well to take the primary coil out and mount the secondary in such a manner as to be able to look through the tube upon which the secondary is wound. He will then be able to observe the streams which pass from the primary to the insulating tube, and from their intensity he will know how far he can strain the coil. Without this precaution he is sure to injure the insulation. This arrangement permits, however, an easy exchange of the primaries, which is desirable in these experiments.

The selection of the type of machine best suited for the purpose must be left to the judgment of the experimenter. There are here illustrated three distinct types of machines, which, besides others, I have used in my experiments.

Fig. 1 represents the machine used in my experiments before this institute. The field magnet consists of a ring of wrought iron with 384 pole projections. The armature comprises a steel disc to which is fastened a thin, carefully welded rim of wrought iron. Upon the rim are wound

several layers of fine, well annealed iron wire, which, when wound, is passed through shellac. The armature wires are wound around brass pins, wrapped with silk thread. The diameter of the armature wire in this type of machine should not be more than one-sixth of the thickness of the pole projections, else the local action will be considerable.

Fig. 2 represents a larger machine of a different type. The field-magnet of this machine consists of two like parts which either enclose an exciting coil, or else are independently wound. Each part has 480 pole projections, the

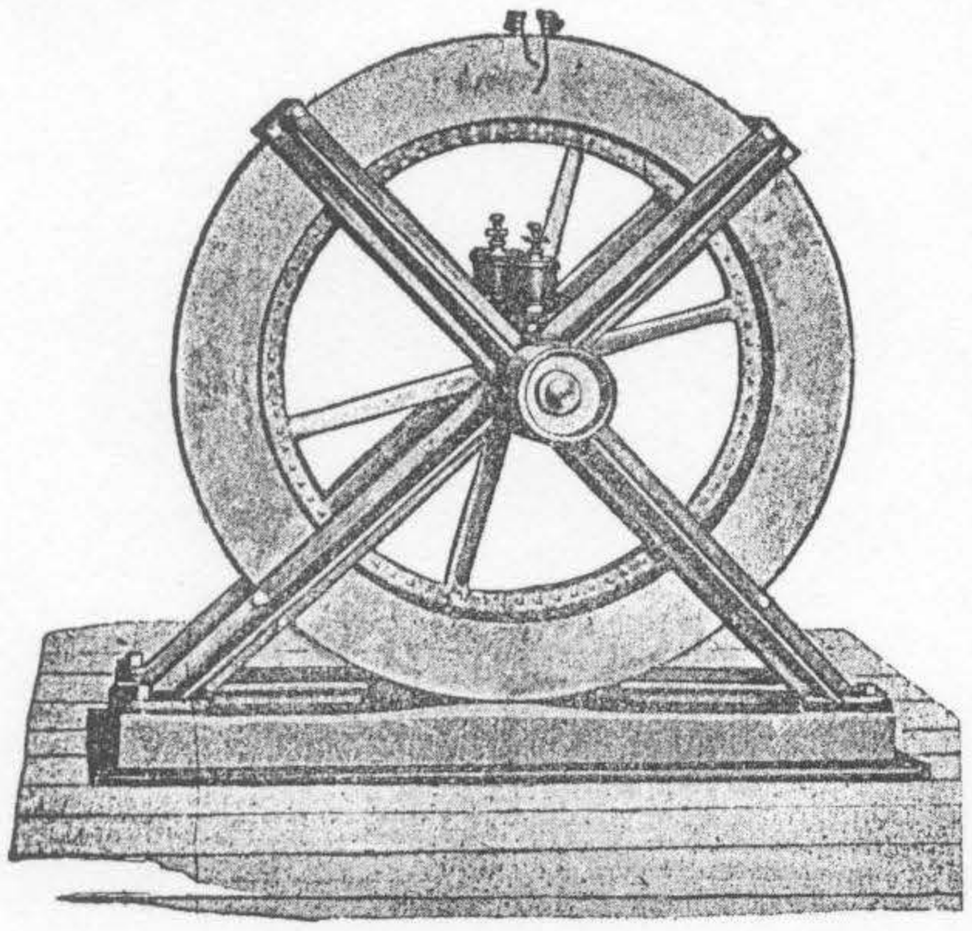


FIG. 2.

projections of one facing those of the other. The armature consists of a wheel of hard bronze, carrying the conductors which revolve between the projections of the field magnet. To wind the armature conductors, I have found it most convenient to proceed in the following manner: I construct a ring of hard bronze of the required size. This ring and the rim of the wheel are provided with the proper number of pins, and both fastened upon a plate. The armature conductors being wound, the pins are cut off and the ends of the conductors fastened by two rings which screw to the bronze ring and the rim of the wheel respectively. The whole may then be taken off and forms a solid structure.

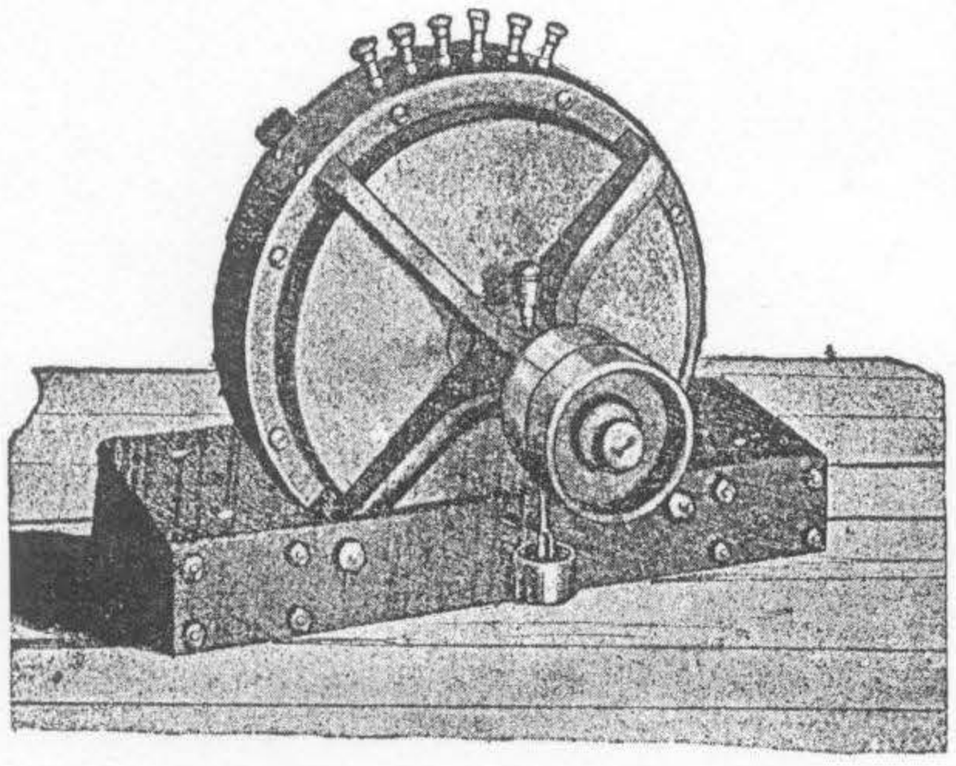


FIG. 3.

The conductors in such a type of machine should consist of sheet copper, the thickness of which, of course, depends on the thickness of the pole projections; or else twisted thin wires should be employed.

Fig. 3 is a smaller machine, in many respects similar to the former, only here the armature conductors and the exciting coil are kept stationary, while only a block of wrought iron is revolved.

It would be uselessly lengthening this description were I to dwell more on the details of construction of these machines. Besides, they have been described somewhat more elaborately in the N.Y. *Electrical Engineer* of March 18, 1891. I deem it well, however, to call the attention of the investigator to two things, the importance of which, though self-evident, he is nevertheless apt to underestimate; namely, to the local action in the conductors, which must be carefully avoided, and to the clearance, which must be small. I may add, that since it is desirable to use very high peripheral speeds, the armature should be of very large diameter in order to avoid impracticable belt speeds. Of the several types of these machines which have been constructed by me, I have found that the type illustrated in Fig. 1 caused me the least trouble in construction, as well as in maintenance, and, on the whole, it has been a good experimental machine.

In operating an induction coil with very rapidly alternating currents, among the first luminous phenomena noticed are naturally those presented by the high-tension

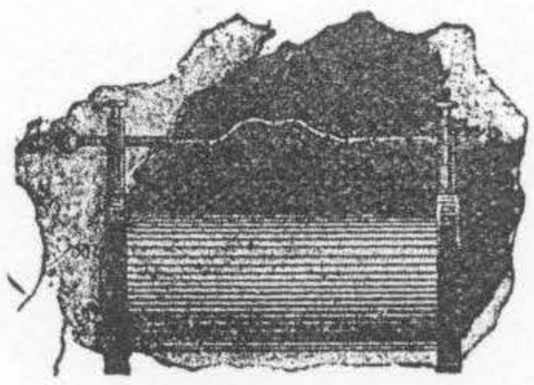


FIG. 4.

discharge. As the number of alternations per second is increased, or as—the number being high—the current through the primary is varied, the discharge gradually changes in appearance. It would be difficult to describe the minor changes which occur, and the conditions which bring them about, but one may note five distinct forms of the discharge.

First, one may observe a weak, sensitive discharge in the form of a thin, feeble coloured thread, Fig. 4. It always occurs when, the number of alternations per second being high, the current through the primary is very small. In spite of the excessively small current, the rate of change is great, and the difference of potential at the terminals of the secondary is therefore considerable, so that the arc is established at great distance; but the quantity of "electricity" set in motion is insignificant, barely sufficient to maintain a thin, threadlike arc. It is excessively sensitive and may be made so to such a degree that the mere act of breathing near the coil will affect it, and unless it is perfectly well protected from currents of air, it wriggles around constantly. Nevertheless, it is in this form excessively persistent, and when the terminals are approached to, say, one-third of the striking distance, it can be blown out only with difficulty. This exceptional persistency, when short,

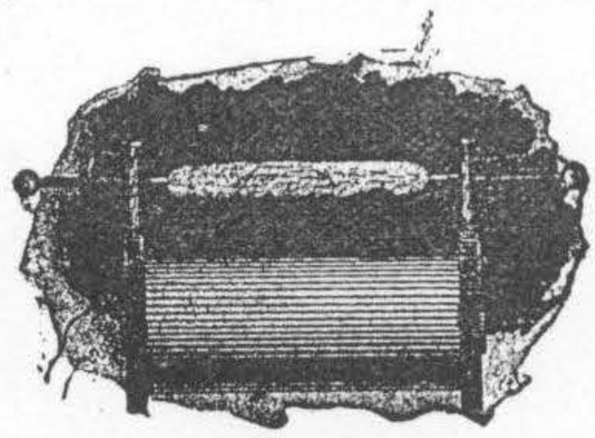


FIG. 5.

is largely due to the arc being excessively thin; presenting, therefore, a very small surface to the blast. Its great sensitiveness, when very long, is probably due to the motion of the particles of dust suspended in the air.

When the current through the primary is increased, the discharge gets broader and stronger, and the effect of the capacity of the coil becomes visible until, finally, under proper conditions, a white flaming arc, Fig. 5, often as thick as one's finger, and striking across the whole coil, is produced. It develops remarkable heat, and may be further characterised by the absence of the high note which accompanies the less powerful discharges. To take a shock from the coil under these conditions would not be advisable, although under different conditions, the potential being much higher, a shock from the coil may be taken with impunity.

(*To be continued.*)

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION.*

BY NIKOLA TESLA.

(Continued from page 83.)

The importance of these elements in an alternate-current circuit is now well known, and, under ordinary conditions, the general rules are applicable. But in an induction coil exceptional conditions prevail. First, the self-induction is of little importance before the arc is established, when it asserts itself; but perhaps never as prominently as in ordinary alternate-current circuits, because capacity is distributed all along the coil, and by reason of the fact that the coil usually discharges through very great resistances; hence the currents are exceptionally small. Secondly, the capacity goes on increasing continually as the potential rises, in consequence of absorption which takes place to a considerable extent. Owing to this there exists no critical relationship between these quantities, and ordinary rules would not seem to be applicable. As the potential is increased either in consequence of the increased frequency or of the increased current through the primary, the amount of the energy stored becomes greater and greater, and the capacity gains more and more in importance. Up to a certain point the capacity is beneficial, but after that it begins to be an enormous drawback. It follows from this that each coil gives the best result with a given frequency and primary current. A very large coil, when operated with currents of very high frequency, may not give as much as $\frac{1}{8}$in. spark. By adding capacity to the terminals the condition may be improved, but what the coil really wants is a lower frequency.

When the flaming discharge occurs, the conditions are evidently such that the greatest current is made to flow through the circuit. These conditions may be attained by varying the frequency within wide limits, but the highest frequency at which the flaming arc can still be produced, determines, for a given primary current, the maximum striking distance of the coil. In the flaming discharge the *éclat* effect of the capacity is not perceptible; the rate at which the energy is being stored then just equals the rate at which it can be disposed of through the circuit. This kind of discharge is the severest test for a coil; the break, when it occurs, is of the nature of that in an overcharged Leyden jar. To give a rough approximation I would state that, with an ordinary coil of, say, 10,000 ohms resistance, the most powerful arc would be produced with about 12,000 alternations per second.

When the frequency is increased beyond that rate, the potential, of course, rises, but the striking distance may, nevertheless, diminish, paradoxical as it may seem. As the potential rises the coil attains more and more the properties of a static machine until, finally, one may observe the beautiful phenomenon of the streaming discharge, Fig. 6, which may be produced across the whole length of the coil. At that stage streams begin to issue freely from all points and projections. These streams will also be seen to pass in abundance in the space between the primary and the insulating tube. When the potential is excessively high they will always appear, even if the frequency be low, and even if the primary be surrounded by as much as an inch of wax, hard rubber, glass, or any other insulating substance. This limits greatly the putput of the coil, but I will later show how I have been able to overcome to a considerable extent this disadvantage in the ordinary coil.

Besides the potential, the intensity of the streams depends on the frequency; but if the coil be very large they show themselves, no matter how low the frequencies used. For instance, in a very large coil of a resistance of 67,000 ohms, constructed by me some time ago, they appear with as low as 100 alternations per second and less, the insulation of the secondary being $\frac{3}{4}$in. of ebonite. When very intense they produce a noise similar to that produced by the charging of a Holtz machine, but much more powerful, and they emit a strong smell of ozone. The lower the frequency, the more apt they are to suddenly injure the coil. With excessively high frequencies they may pass freely without producing any other effect than to heat the insulation slowly and uniformly.

The existence of these streams shows the importance of constructing an expensive coil so as to permit of one's seeing through the tube surrounding the primary, and the latter should be easily exchangeable: or else the space between the primary and secondary should be completely filled up with insulating material so as to exclude all air. The non-observance of this simple rule in the construction of the commercial coils is responsible for the destruction of many an expensive coil.

At the stage when the streaming discharge occurs, or with somewhat higher frequencies, one may, by approaching the terminals considerably and regulating properly the effect of capacity, produce a veritable spray of small silver-white sparks or a bunch of excessively thin silvery threads, Fig. 7, amidst a powerful brush—each spark or thread possibly corresponding to one alternation. This, when produced under proper conditions, is probably the most beautiful discharge, and when an air blast is directed against it, it presents a singular appearance. The spray of sparks, when received through the body, causes some inconvenience, whereas, when the discharge simply streams, nothing at all is likely to be felt if large conducting objects are held in the hands to protect them from receiving small burns.

If the frequency is still more increased, then the coil

* Lecture delivered before the American Institute of Electrical Engineers at Columbia College, New York, May 20.

refuses to give any spark unless at comparatively small distances, and the fifth typical form of discharge may be observed, Fig. 8. The tendency to stream out and dissipate is then so great that when the brush is produced at one terminal no sparking occurs, even if, as I have repeatedly tried, the hand, or any conducting object, is held within the stream; and, what is more singular, the luminous stream is not at all easily deflected by the approach of a conducting body.

At this stage the streams seemingly pass with the greatest freedom through considerable thicknesses of insulators, and it is particularly interesting to study their behaviour. For this purpose it is convenient to connect to the terminals of the coil two metallic spheres which may be placed at any desired distance, Fig. 9. Spheres are preferable to plates, as the discharge can be better observed. By inserting dielectric bodies between the spheres, beautiful discharge phenomena may be observed. If the spheres be quite close and a spark be playing between them, by interposing a thin plate of ebonite between the spheres the spark instantly ceases, and the discharge spreads into an intensely luminous circle several inches in diameter, provided the spheres are sufficiently large. The passage of the streams heats, and after a while softens the rubber so much that two plates may be made to stick together in this manner. If the spheres are so far apart that no spark occurs, even if they are far beyond the striking distance, by inserting a thick plate of glass, the discharge is instantly induced to pass from the spheres to the glass in the form of luminous streams. It appears almost as though these streams pass through the dielectric. In reality this is not the case, as the streams are due to the molecules of the air which are violently agitated in the space between the oppositely charged surfaces of the spheres. When no dielectric other than air is present, the bombardment goes on, but is too weak to be visible. By inserting a dielectric the inductive effect is much increased, and besides, the projected air molecules find an obstacle, and the bombardment becomes so intense that the streams become luminous. If by any mechanical means we could effect such a violent agitation of the molecules we could produce the same phenomenon. A jet of air escaping through a small hole under enormous pressure and striking against an insulating substance, such as glass, may be luminous in the dark, and it might be possible to produce phosphorescence of the glass or other insulators in this manner.

The greater the specific inductive capacity of the interposed dielectric, the more powerful the effect produced. Owing to this, the streams show themselves with excessively high potentials, even if the glass be as much as 1½in. to 2in. thick. But besides the heating due to bombardment, some heating goes on undoubtedly in the dielectric, being apparently greater in glass than in ebonite. I attribute this to the greater specific inductive capacity of the glass, in consequence of which, with the same potential difference, a greater amount of energy is taken up in it than in rubber. It is like connecting to a battery a copper and a brass wire of the same dimensions. The copper wire, though a more perfect conductor, would heat more by reason of its taking more current. Thus what is otherwise considered a virtue of the glass is here a defect. Glass usually gives way much quicker than ebonite; when it is heated to a certain degree, the discharge suddenly breaks through at one point, assuming then the ordinary form of an arc.

The heating effect produced by molecular bombardment of the dielectric would, of course, diminish as the pressure of the air is increased, and at enormous pressures it would be negligible, unless the frequency would increase correspondingly.

It will be often observed in these experiments that when the spheres are beyond the striking distance, the approach of a glass plate, for instance, may induce the spark to jump between the spheres. This occurs when the capacity of the spheres is somewhat below the critical value which gives the greatest difference of potential at the terminals of the coil. By approaching a dielectric, the specific inductive capacity of the space between the spheres is increased, producing the same effect as if the capacity of the spheres were increased. The potential at the terminals may then rise so high that the air space is cracked. The experiment is best performed with a dense glass or mica.

Another interesting observation is that a plate of insulating material, when the discharge is passing through it, is strongly attracted by either of the spheres—that is, by the nearer one, this being obviously due to the smaller mechanical effect of the bombardment on that side, and perhaps also to the greater electrification.

From the behaviour of the dielectrics in these experiments we may conclude, that the best insulator for these rapidly alternating currents would be the one possessing the smallest specific inductive capacity, and at the same time one capable of withstanding the greatest differences of potential; and thus two diametrically opposite ways of securing the required insulation are indicated—namely, to use either a perfect vacuum or a gas under great pressure; but the former would be preferable. Unfortunately neither of these two ways is easily carried out in practice.

It is especially interesting to note the behaviour of an excessively high vacuum in these experiments. If a test tube provided with external electrodes, and exhausted to the highest possible degree, be connected to the terminals of the coil, Fig. 10, the electrodes of the tube are instantly brought to a high temperature, and the glass at each end of the tube is rendered intensely phosphorescent, but the middle appears comparatively dark, and for a while remains cool.

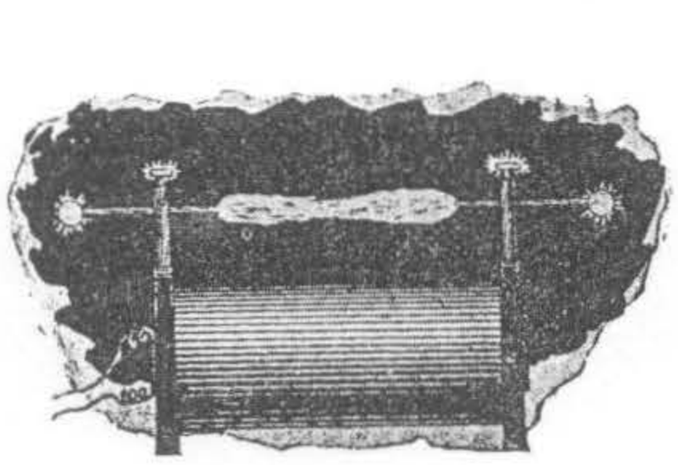


FIG. 6.

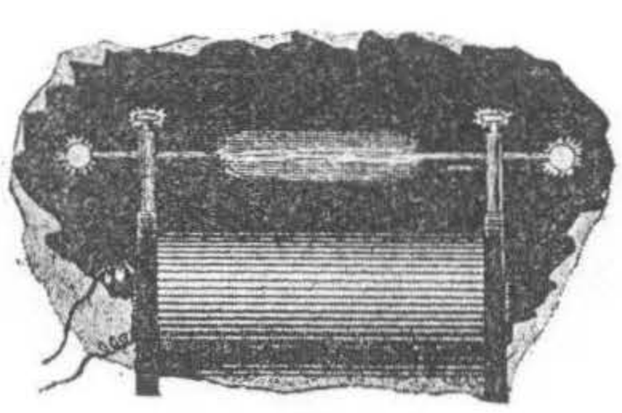


FIG. 7.

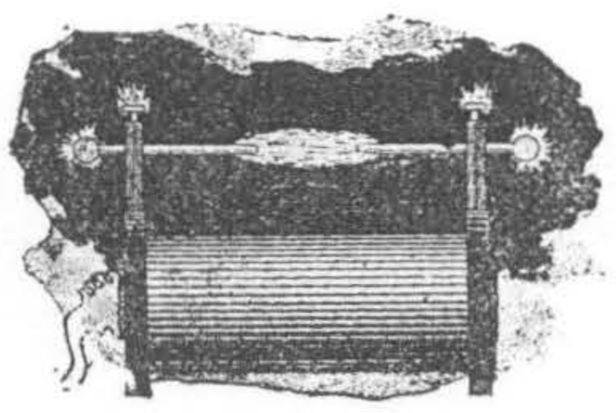


FIG. 8.

When the frequency is so high that the discharge shown in Fig. 8 is observed, considerable dissipation no doubt occurs in the coil. Nevertheless, the coil may be worked for a long time, as the heating is gradual.

In spite of the fact that the difference of potential may be enormous, little is felt when the discharge is passed through the body, provided the hands are armed. This is to some extent due to the higher frequency, but principally to the fact that less energy is available externally, when the difference of potential reaches an enormous value, owing to the circumstance that with the rise of potential, the energy absorbed in the coil increases as the square of the potential. Up to a certain point the energy available externally increases with the rise of potential, then it begins to fall off rapidly. Thus, with the ordinary high-tension induction coil, the curious paradox exists, that while with a given current through the primary the shock might be fatal, with many times that current it might be perfectly harmless, even if the frequency be the same With high frequencies and excessively high potentials when the terminals are not connected to bodies of some size, practically all the energy supplied to the primary is taken up by the coil. There is no breaking through, no local injury, but all the material, insulating and conducting, is uniformly heated.

To avoid misunderstanding in regard to the physiological

effect of alternating currents of very high frequency, I think it necessary to state that, while it is an undeniable fact that they are incomparably less dangerous than currents of low frequencies, yet it should not be thought that they are altogether harmless. What has just been said refers only to currents from an ordinary high-tension induction coil, which currents are necessarily very small; if received directly from a machine or from a secondary of low resistance, they produce more or less powerful effects, and may cause serious injury, especially when used in conjunction with condensers.

The streaming discharge of a high-tension induction coil differs in many respects from that of a powerful static machine. In colour it has neither the violet of the positive, nor the brightness of the negative, static discharge, but lies somewhere between, being, of course, alternatively positive

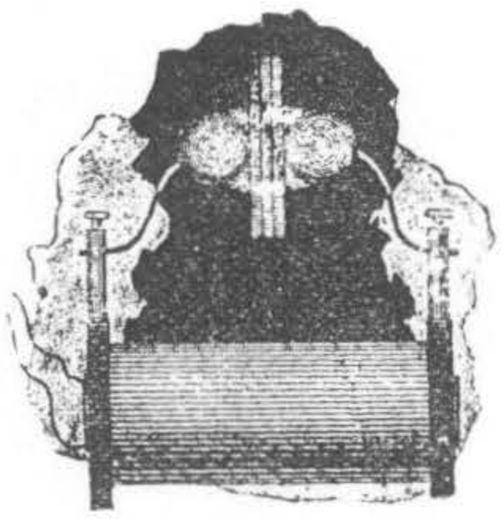


FIG. 9.

and negative. But since the streaming is more powerful when the point or terminal is electrified positively than when electrified negatively, it follows that the point of the brush is more like the positive, and the root more like the negative, static discharge. In the dark, when the brush is very powerful, the root may appear almost white. The wind produced by the escaping streams, though it may be very strong—often indeed to such a degree that it may be felt quite a distance from the coil—is, nevertheless, considering the quantity of the discharge smaller than that produced by the positive brush of a static machine, and it effects the flame much less powerfully. From the nature of the phenomenon we can conclude that the higher the frequency, the smaller must, of course, be the wind produced by the streams, and with sufficiently high frequencies no wind at all would be produced at the ordinary atmospheric pressures. With frequencies obtainable by means of a machine, the mechanical effect is sufficiently great to

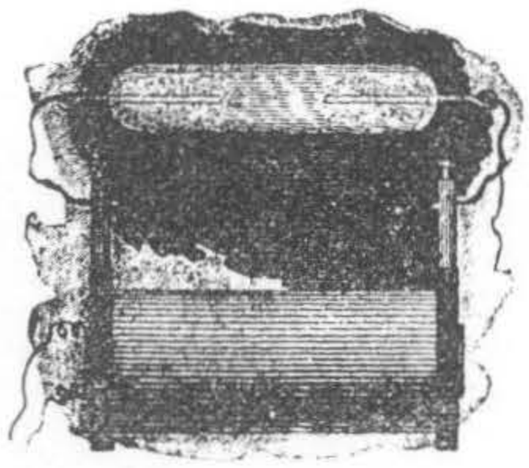


FIG. 10.

revolve, with considerable speed, large pin-wheels, which in the dark present a beautiful appearance owing to the abundance of the streams, Fig. 11.

In general, most of the experiments usually performed with a static machine can be performed with an induction coil when operated with very rapidly alternating currents. The effects produced, however, are much more striking, being of incomparably greater power. When a small length of ordinary cotton-covered wire, Fig. 12, is attached to one terminal of the coil, the streams issuing from all points of the wire may may be so intense as to produce a considerable light effect. When the potentials and frequencies are very high, a wire insulated with guttapercha or rubber and attached to one of the terminals, appears to be covered with a luminous film. A very thin bare wire when attached to a terminal emits powerful streams and vibrates continually to and fro or spins in a circle, producing a singular effect, Fig. 13. Some of these experiments have been described by me in the *Electrical World* (New York) of February 21, 1891.

Another peculiarity of the rapidly alternating discharge of the induction coil is its radically different behaviour with respect to points and rounded surfaces.

If a thick wire, provided with a ball at one end and with a point at the other, be attached to the positive terminal of a static machine, practically all the charge will be lost through the point, on account of the enormously greater tension, dependent on the radius of curvature. But if such a wire is attached to one of the terminals of the induction coil, it will be observed that with very high frequencies streams issue from the ball almost as copiously as from the point, Fig. 14.

It is hardly conceivable that we could produce such a

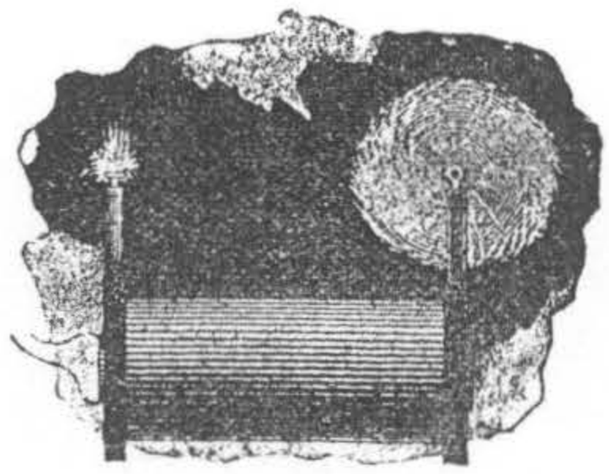


FIG. 11.

condition to an equal degree in a static machine, for the simple reason, that the tension increases as the square of the density, which in turn is proportional to the radius of curvature; hence, with a steady potential an enormous charge would be required to make streams issue from a polished ball while it is connected with a point. But with an induction coil, the discharge of which alternates with great rapidity, it is different. Here we have to deal with two distinct tendencies. First, there is the tendency to escape which exists in a condition of rest, and which depends on the radius of curvature; second, there is the tendency to dissipate into the surrounding air by condenser action, which depends on the surface. When one of these tendencies is a maximum, the other is at a minimum. At the point the luminous stream is principally due to the air molecules coming bodily in contact with the point; they

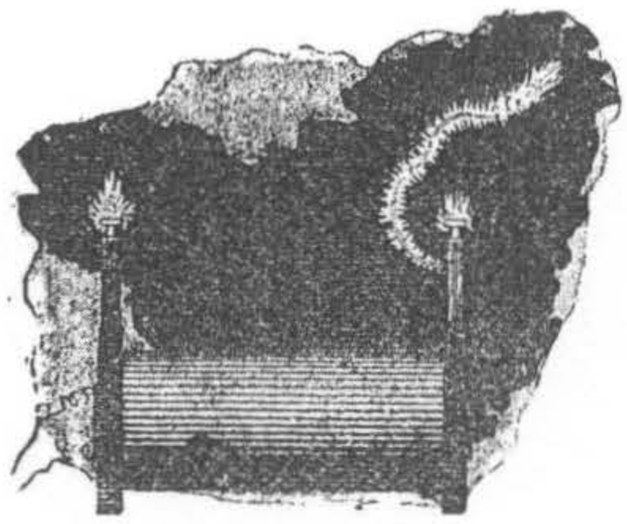


FIG. 12.

are attracted and repelled, charged and discharged, and, their atomic charges being thus disturbed, vibrate and emit light waves. At the ball, on the contrary, there is no doubt that the effect is to a great extent produced inductively, the air molecules not necessarily coming in contact with the ball, though they undoubtedly do so. To convince ourselves of this we only need to exalt the condenser action, for instance, by enveloping the ball, at some distance, by a better conductor than the surrounding medium, the conductor being, of course, insulated; or else by surrounding it with a better dielectric and approaching an insulated conductor; in both cases the streams will break forth more copiously. Also, the larger the ball with a given frequency, or the higher the frequency, the more will the ball have the advantage over the point. But, since a certain intensity of action is required to render the streams visible, it is

obvious that in the experiment described the ball should not be taken too large.

In consequence of this twofold tendency it is possible to produce by means of points effects identical to those produced by capacity. Thus, for instance, by attaching to one terminal of the coil a small length of soiled wire, presenting many points and offering great facility to escape, the potential of the coil may be raised to the same value as by attaching to the terminal a polished ball of a surface many times greater than that of the wire.

An interesting experiment, showing the effect of the points, may be performed in the following manner : Attach to one of the terminals of the coil a cotton-covered wire about 2ft. in length, and adjust the conditions so that streams issue from the wire. In this experiment the primary coil should be preferably placed so that it extends only about half way into the secondary coil. Now touch the free terminal of the secondary with a conducting object held in the hand, or else connect it to an insulated body of some size. In this manner the potential on the wire may be enormously raised. The effect of this will be to either increase, or to diminish, the streams. If they increase, the wire is too short ; if they diminish, it is too long. By adjusting the length of the wire, a point is found where the touching of the other terminal does not at all affect the streams. In this case the rise of potential is exactly counteracted by the drop through the coil. It will be observed that small lengths of wire produce considerable difference in the magnitude and luminosity of the streams. The primary coil is placed sidewise for two reasons : first, to increase the potential at the wire, and, second, to increase the drop through the coil. The sensitiveness is thus augmented.

There is still another and far more striking peculiarity of the brush discharge produced by very rapidly alternating currents. To observe this it is best to replace the usual terminals of the coil by two metal columns insulated with a good thickness of ebonite. It is also well to close all fissures and cracks with wax so that the brushes cannot form anywhere except at the tops of the columns. If the conditions are carefully adjusted—which, of course, must be left to the skill of the experimenter—so that the potential rises to an enormous value, one may produce two powerful brushes several inches long, nearly white at their roots, which in the dark bear a striking resemblance to two flames of a gas escaping under pressure, Fig. 15. But they do not only resemble, they are veritable flames, for they are hot. Certainly they are not as hot as a gas burner, but they would be so if the frequency and the potential would be sufficiently high. Produced with, say, 20,000 alternations per second, the heat is easily perceptible, even if the potential is not excessively high. The heat developed is, of course, due to the impact of the air molecules against the terminals and against each other. As at the ordinary pressures the mean free path is excessively small, it is possible that in spite of the enormous initial speed imparted to each molecule upon coming in contact with the terminal, its progress, by collision with other molecules, is retarded to such an extent that it does not get away far from the terminal, but may strike the same many times in succession. The higher the frequency, the less the molecule is able to get away, and this the more so, as for a given effect the potential required is smaller ; and a frequency is conceivable, perhaps even obtainable, at which practically the same molecules would strike the terminal. Under such conditions the exchange of the molecules would be very slow, and the heat produced at, and very near, the terminal would be excessive. But if the frequency would go on increasing constantly, the heat produced would begin to diminish for obvious reasons. In the positive brush of a static machine the exchange of the molecules is very rapid, the stream is constantly of one direction, and there are fewer collisions, hence the heating effect must be very small. Anything that impairs the facility of exchange tends to increase the local heat produced. Thus, if a bulb be held over the terminal of the coil so as to enclose the brush, the air contained in the bulb is very quickly brought to a high temperature. If a glass tube be held over the brush so as to allow the draught to carry the brush upwards, scorching hot air escapes at the top of the tube. Anything held within the brush is of course rapidly heated, and the possibility of using such heating effects suggests itself.

When contemplating this singular phenomenon of the hot brush, we cannot help being convinced that a similar process must take place in the ordinary flame, and it seems strange that after all these centuries past of familiarity with the flame, now, in this era of electric lighting and heating, we are finally led to recognise that since time immemorial we have, after all, always had "electric light and heat" at our disposal. It is also of no little interest to contemplate that we have a possible way of producing—by other than chemical means—a veritable flame, which would give light and heat without any material being consumed, without any chemical process taking place, and to accomplish this, we only need to perfect methods of producing enormous frequencies and potentials. I have no doubt that if the potential could be made to alternate with sufficient rapidity and power, the brush formed at the end of a wire would lose its electrical characteristics and would become flame-like. The flame must be due to electrostatic molecular action.

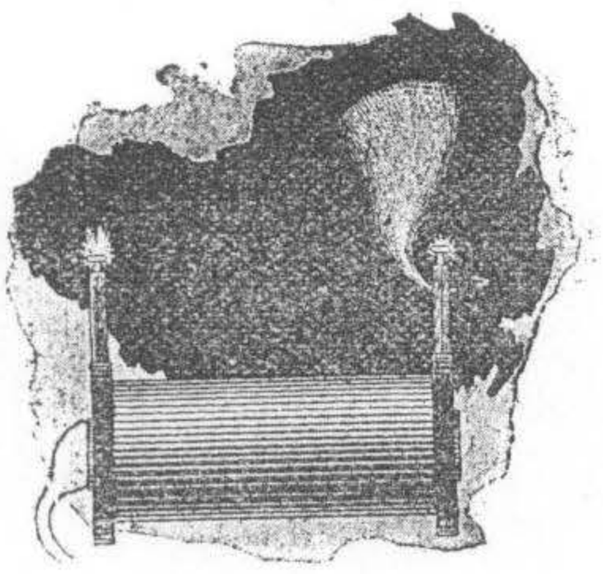


Fig. 13.

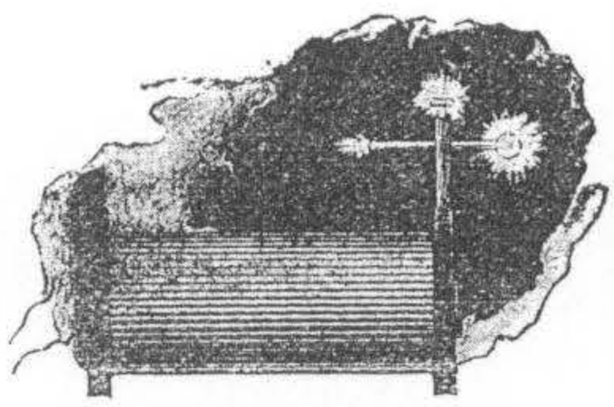


Fig. 14.

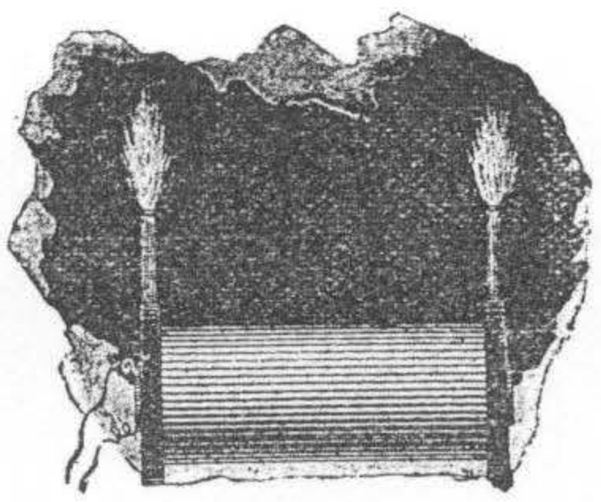


Fig. 15.

This phenomena now explains in a manner which can hardly be doubted the frequent accidents occurring in storms. It is well known that objects are often set on fire without the lightning striking them. We shall presently see how this can happen. On a nail in a roof, for instance, or on a projection of any kind, more or less conducting, or rendered so by dampness, a powerful brush may appear. If the lightning strikes somewhere in the neighbourhood, the enormous potential may be made to alternate or fluctuate perhaps many million times a second. The air molecules are violently attracted and repelled, and by their impact produce such a powerful heating effect that a fire is started. It is conceivable that a ship at sea may, in this manner, catch fire at many points at once. When we consider that even with the comparatively low frequencies obtained from a dynamo machine, and with potentials of no more than 100,000 or 200,000 volts, the heating effects are considerable, we may imagine how much more powerful they must be with frequencies and potentials many times greater, and the above explanation seems, to say the least, very probable. Similar explanations may have been suggested, but I am not aware that, up to present, the heating effects of a brush produced by a rapidly alternating potential have been experimentally demonstrated, at least not to such a remarkable degree.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION.*

BY NIKOLA TESLA.

(Continued from page 113.)

By preventing completely the exchange of the air molecules, the local heating effect may be so exalted as to bring a body to incandescence. Thus, for instance, if a small button, or preferably a very thin wire or filament, be enclosed in an unexhausted globe and connected with the terminal of the coil, it may be rendered incandescent. The phenomenon is made much more interesting by the rapid spinning round in a circle of the top of the filament, thus presenting the appearance of a luminous funnel, Fig. 16, which widens when the potential is increased. When the potential is small the end of the filament may perform irregular motions, suddenly changing from one to the other, or it may describe an ellipse; but when the potential is very high it always spins in a circle; and so does generally

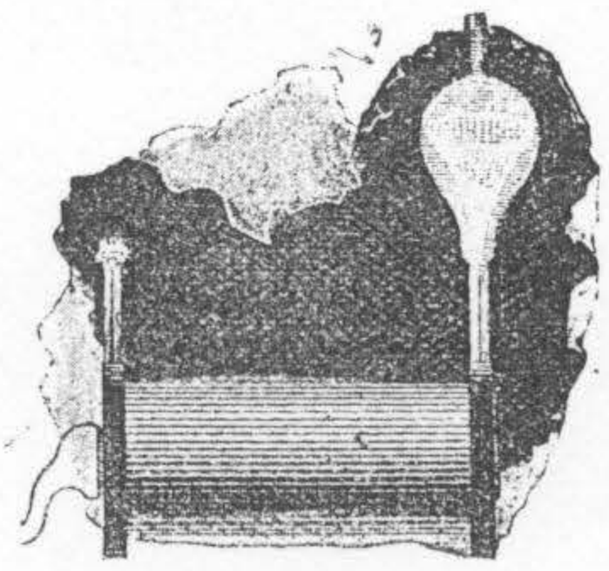


FIG. 16.

a thin straight wire attached freely to the terminal of the coil. These motions are, of course, due to the impact of the molecules, and the irregularity in the distribution of the potential, owing to the roughness and dissymmetry of the wire or filament. With a perfectly symmetrical and polished wire such motions would probably not occur. That the motion is not likely to be due to other causes is evident from the fact that it is not of a definite direction, and that in a very highly-exhausted globe it ceases altogether. The possibility of bringing a body to incandescence in an unexhausted globe, or even when not at all enclosed, would seem to afford a possible way of obtaining light effects, which, in perfecting methods of producing rapidly alternating potentials, might be rendered available for useful purposes.

In employing a commercial coil, the production of very powerful brush effects is attended with considerable difficulties, for when these high frequencies and enormous potentials are used, the best insulation is apt to give way. Usually the coil is insulated well enough to stand the strain from convolution to convolution, since two double silk-covered paraffined wires will withstand a pressure of several thousand volts; the difficulty lies principally in preventing the breaking through from the secondary to the primary, which is greatly facilitated by the streams issuing from the latter. In the coil, of course, the strain is greatest from section to section, but usually in a larger coil there are so many sections that the danger of a sudden giving way is not very great. No difficulty will generally be encountered in that direction, and, besides, the liability of injuring the coil internally is very much reduced by the

* Lecture delivered before the American Institute of Electrical Engineers at Columbia College, New York, May 20.

fact that the effect most likely to be produced is simply a gradual heating, which, when far enough advanced, could not fail to be observed. The principal necessity is then to prevent the streams between the primary and the tube, not only on account of the heating and possible injury, but also because the streams may diminish very considerably the potential difference available at the terminals. A few hints as to how this may be accomplished will probably be found useful in most of these experiments with the ordinary induction coil.

One of the ways is to wind a short primary, Fig. 17A, so that the difference of potential is not at that length great enough to cause the breaking forth of the streams through the insulating tube. The length of the primary should be determined by experiment. Both the ends of the coil should be brought out on one end through a plug of insulating material fitting in the tube as illustrated. In such a disposition one terminal of the secondary is attached to a body the surface of which is determined with the greatest care so as to produce the greatest rise in the potential. At the other terminal a powerful brush appears, which may be experimented upon.

The above plan necessitates the employment of a primary of comparatively small size, and it is apt to heat when powerful effects are desirable for a certain length of time. In such a case it is better to employ a larger coil, Fig. 17B, and introduce it from one side of the tube, until the streams begin to appear. In this case the nearest terminal of the secondary may be connected to the primary or to the ground, which is practically the same thing, if the primary is connected directly to the machine. In the case of ground connections it is well to determine experimentally the frequency which is best suited under the conditions of the test. Another way of obviating the streams, more or less, is to make the primary in sections and supply it from separate well-insulated sources.

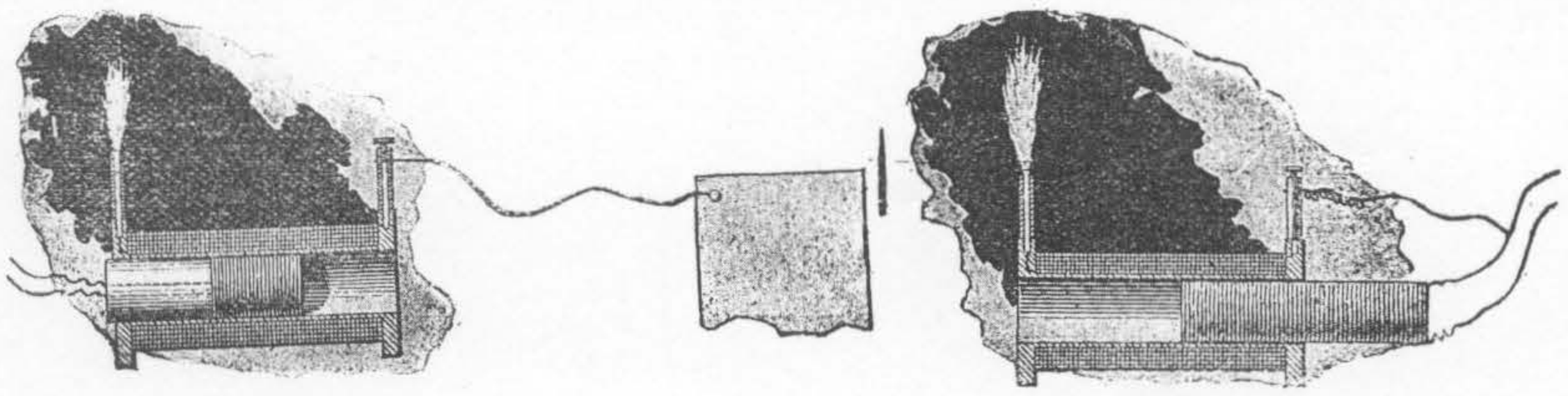


FIG. 17A.

FIG. 17B

In many of these experiments, when powerful effects are wanted for a short time, it is advantageous to use iron cores with the primaries. In such case a very large primary coil may be wound and placed side by side with the secondary, and, the nearest terminal of the latter being connected to the primary, a laminated iron core is introduced through the primary into the secondary as far as the streams will permit. Under these conditions an excessively powerful brush, several inches long, which may be appropriately called "St. Elmo's hot fire," may be caused to appear at the other terminal of the secondary, producing striking effects. It is a most powerful ozoniser, so powerful, indeed, that only a few minutes are sufficient to fill the whole room with the smell of ozone, and it undoubtedly possesses the quality of exciting chemical affinities.

For the production of ozone, alternating currents of very high frequency are eminently suited, not only on account of the advantages they offer in the way of conversion but also because of the fact of the ozonising action of a discharge is dependent on the frequency as well as on the potential, this being undoubtedly confirmed by observation.

In these experiments if an iron core is used it should be carefully watched, as it is apt to get excessively hot in an incredibly short time. To give an idea of the rapidity of the heating, I will state that by passing a powerful current through a coil with many turns, the inserting within the same of a thin iron wire for no more than one second's time is sufficient to heat the wire to something like 100deg. C.

But this rapid heating does not need to discourage us in the use of iron cores in connection with rapidly alternating currents. I have for a long time been convinced that in the industrial distribution by means of transformers, some such plan as the following might be practicable. We may use a comparatively small iron core, subdivided, or perhaps not even subdivided. We may surround this core with a considerable thickness of material which is fireproof and conducts the heat poorly, and on top of that we may place the primary and secondary windings. By using either higher frequencies or greater magnetising forces, we may by hysteresis and eddy currents heat the iron core so far as to bring it nearly to its maximum permeability, which, as Hopkinson has shown, may be as much as 16 times greater than that at ordinary temperatures. If the iron core were perfectly enclosed it would not be deteriorated by the heat, and, if the enclosure of fireproof material would be sufficiently thick, only a limited amount of energy could be radiated in spite of the high temperature. Transformers have been constructed by me on that plan, but for lack of time no thorough tests have as yet been made.

Another way of adapting the iron core to rapid alternations, or, generally speaking, reducing the frictional losses, is to produce by continuous magnetisation a flow of something like 7,000 or 8,000 lines per square centimetre through the core, and then work with weak magnetising forces and preferably high frequencies around the point of greatest permeability. A higher efficiency of conversion and greater output are obtainable in this manner. I have also employed this principle in connection with machines in which there is no reversal of polarity. In these types of machines, as long as there are only few pole projections, there is no great gain, as the maxima and minima of magnetisation are far from the point of maximum permeability; but when the number of the pole projections is very great, the required rate of change may be obtained, without the magnetisation varying so far as to depart greatly from the point of maximum permeability, and the gain is considerable.

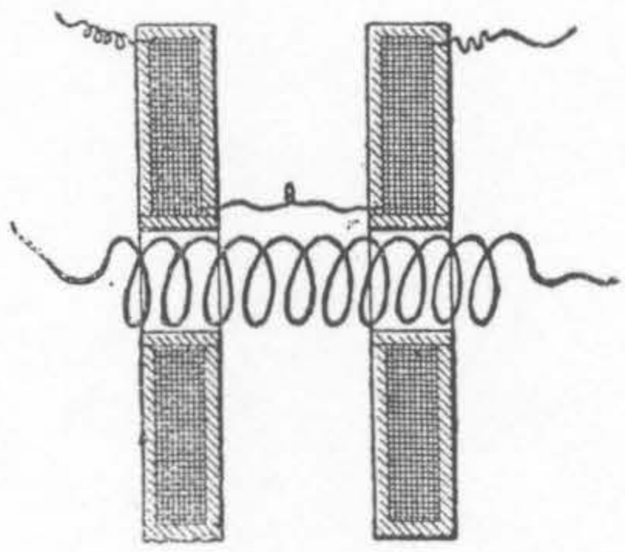


FIG. 18.

The above described arrangements refer only to the use of commercial coils as ordinarily constructed. If it is desired to construct a coil for the express purpose of performing with it such experiments as I have described, or, generally, rendering it capable of withstanding the greatest possible difference of potential, then a construction as indicated in Fig 18 will be found of advantage. The coil in this case is formed of two independent parts which are wound oppositely, the connection between both being made near the primary. The potential in the middle being zero,

there is not much tendency to jump to the primary, and not much insulation is required. In some cases the middle point may, however, be connected to the primary or to the ground. In such a coil the places of greatest difference of potential are far apart and the coil is capable of withstanding an enormous strain. The two parts may be movable so as to allow a slight adjustment of the capacity effect.

As to the manner of insulating the coil, it will be found convenient to proceed in the following way: First, the wire should be boiled in paraffin, until all the air is out; then the coil is wound by running the wire through melted paraffin, merely for the purpose of fixing the wire. The coil is then taken off from the spool, immersed in a cylindrical vessel filled with pure melted wax, and boiled for a long time until the bubbles cease to appear. The whole is then left to cool down thoroughly, and then the mass is taken out of the vessel and turned up in a lathe. A coil made in this manner and with care is capable of withstanding enormous potential differences.

It may be found convenient to immerse the coil in paraffin oil or some other kind of oil; it is a most effective way of insulating, principally on account of the perfect exclusion of air, but it may be found that, after all, a vessel filled with oil is not a very convenient thing to handle in a laboratory. If an ordinary coil can be dismounted, the primary may be taken out of the tube and the latter plugged up on one end, filled with oil, and the primary reinserted. This affords an excellent insulation, and prevents the formation of the streams.

Of all the experiments which may be performed with rapidly alternating currents, the most interesting are those which concern the production of a practical illuminant. It cannot be denied that the present methods, though they were brilliant advances, are very wasteful. Some better methods must be invented, some more pertect apparatus devised. Modern research has opened new possibilities for the production of an efficient source of light, and the attention of all has been turned in the direction indicated by able pioneers. Many have been carried away by the enthusiasm and passion to discover, but in their zeal to reach results, many have been misled. Starting with the idea of producing electromagnetic waves, they turned their attention, perhaps, too much to the study of electromagnetic effects, and neglected the study of electrostatic phenomena. Naturally, nearly every investigator availed himself of an apparatus similar to that used in earlier experiments. But in those forms of apparatus, while the electromagnetic inductive effects are enormous, the electrostatic effects are excessively small.

In the Hertz experiments, for instance, a high-tension induction coil is short-circuited by an arc, the resistance of which is very small, the smaller the more capacity is attached to the terminals; and the difference of potential at these is enormously diminished. On the other hand, when the discharge is not passing between the terminals, the static effects may be considerable, but only qualitatively so, not quantitatively, since their rise and fall is very sudden, and since their frequency is small. In neither case, therefore, are powerful electrostatic effects perceivable. Similar conditions exist when, as in some interesting experiments of Dr. Lodge, Leyden jars are discharged disruptively. It has been thought—and I believe asserted—that in such cases most of the energy is radiated into space. In the light of the experiments which I have described above, it will now not be thought so. I feel safe in asserting that in such cases most of the energy is partly taken up and converted into heat in the arc of the discharge and in the conducting and insulating material of the jar, some energy being, of course, given off by electrification of the air; but the amount of the directly radiated energy is very small.

When a high-tension induction coil, operated by currents alternating only 20,000 times a second, has its terminals closed through even a very small jar, practically all the energy passes through the dielectric of the jar, which is heated, and the electrostatic effects manifest themselves outwardly only to a very weak degree. Now the external circuit of a Leyden jar—that is, the arc and the connections of the coatings—may be looked upon as a circuit generating alternating currents of excessively high frequency and fairly high potential, which is closed through the coatings and the dielectric between them, and from the above it is evident that the external electrostatic effects must be very small, even if a recoil circuit be used. These conditions make it appear that with the apparatus usually at hand the observation of powerful electrostatic effects was impossible, and what experience has been gained in that direction is only due to the great ability of the investigators.

But powerful electrostatic effects are a *sine qua non* of light production on the lines indicated by theory. Electromagnetic effects are primarily unavailable, for the reason that to produce the required effects we would have to pass current impulses through a conductor which, long before the required frequency of the impulses could be reached, would cease to transmit them. On the other hand, electromagnetic waves many times longer than those of light, and producible by sudden discharges of a condenser, could not be utilised, it would seem, except we avail ourselves of their effect upon conductors as in the present methods, which are wasteful. We could not affect by means of such waves the static molecular or atomic charges of a gas, cause them to vibrate and to emit light. Long transverse waves cannot, apparently, produce such effects, since excessively small electromagnetic disturbances may pass readily through miles of air. Such dark waves, unless they are of the length of true light waves, cannot, it would seem, excite luminous radiation in a Geissler tube, and the luminous effects which are producible by induction in a tube devoid of electrodes, I am inclined to consider as being of an electrostatic nature.

To produce such luminous effects, straight electrostatic thrusts are required; these, whatever be their frequency, may disturb the molecular charges and produce light. Since current impulses of the required frequency cannot pass through a conductor of measurable dimensions, we must work with a gas, and then the production of powerful electrostatic effects becomes an imperative necessity.

It has occurred to me, however, that electrostatic effects are in many ways available for the production of light. For instance, we may place a body of some refractory material in a closed, and preferably more or less exhausted, globe, connect it to a source of high, rapidly alternating, potential causing the molecules of the gas to strike it many times a second at enormous speeds, and in this manner, with trillions of invisible hammers, pound it until it gets incandescent; or we may place a body in a very highly-exhausted globe, in a non-striking vacuum, and by employing very high frequencies and potentials transfer sufficient energy from it to other bodies in the vicinity, or in general to the surroundings, to maintain it at any degree of incandescence, or we may, by means of such rapidly alternating high potentials, disturb the ether carried by the molecules of a gas or their static charges, causing them to vibrate and to emit light. But, electrostatic effects being dependent upon the potential and frequency, to produce the most powerful action it is desirable to increase both as far as practicable. It may be possible to obtain quite fair results by keeping either of these factors small, provided the other is sufficiently great; but we are limited in both directions. My experience demonstrates that we cannot go below a certain frequency, for, first, the potential then becomes so great that it is dangerous; and, secondly, the light production is less efficient.

I have found that, by using the ordinary low frequencies, the physiological effect of the current required to maintain at a certain degree of brightness a tube 4ft. long, provided at the ends with outside and inside condenser coatings, is so powerful that, I think, it might produce serious injury to those not accustomed to such shocks; whereas, with 20,000 alternations per second, the tube may be maintained at the same degree of brightness without any effect being felt. This is due principally to the fact that a much smaller potential is required to produce the same light effect, and also to the higher efficiency in the light production. It is evident that the efficiency in such cases is the greater, the higher the frequency, for the quicker the process of charging and discharging the molecules, the less energy will be lost in the form of dark radiation. But, unfortunately, we cannot go beyond a certain frequency on account of the difficulty of producing and conveying the effects.

I have stated above that a body enclosed in an unexhausted bulb may be intensely heated by simply connecting

it with a source of rapidly alternating potential. The heating in such a case is, in all probability, due mostly to the bombardment of the molecules of the gas contained in the bulb. When the bulb is exhausted the heating of the body is much more rapid, and there is no difficulty whatever in bringing a wire or filament to any degree of incandescence by simply connecting it to one terminal of a coil of the proper dimensions. Thus, if the well-known apparatus of Prof. Crookes, consisting of a bent platinum wire with vanes mounted over it, Fig. 19, be connected to one terminal of the coil—either one or both ends of the platinum wire being connected—the wire is rendered almost instantly incandescent, and the mica vanes are rotated as though a current from a battery were used. A thin carbon filament, or preferably a button of some refractory material, Fig. 20, even if it be a comparatively poor conductor, enclosed in an exhausted globe, may be rendered highly incandescent; and in this manner a simple lamp capable of giving any desired candle-power is provided.

The success of lamps of this kind would depend largely on the selection of the light-giving bodies contained within the bulb. Since, under the conditions described, refractory bodies—which are very poor conductors and capable of withstanding for a long time excessively high degrees of temperature—may be used, such illuminating devices may be rendered successful.

It might be thought at first that if the bulb containing the filament or button of refractory material, be perfectly well exhausted—that is, as far as it can be done by the use of the best apparatus—the heating would be much less intense, and that in a perfect vacuum it could not occur at all. This is not confirmed by my experience; quite the contrary, the better the vacuum the more easily the bodies are brought to incandescence. This result is interesting for many reasons.

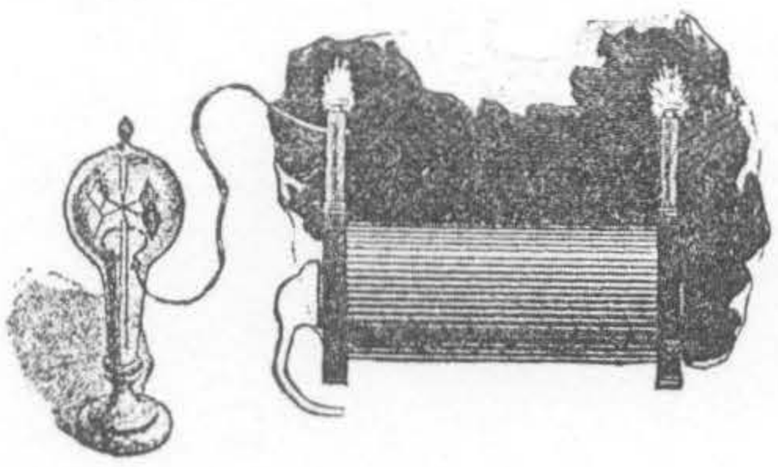


FIG. 19.

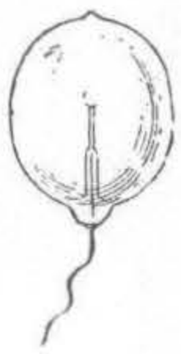


FIG. 20.

At the outset of this work, the idea presented itself to me whether two bodies of refractory material enclosed in a bulb exhausted to such a degree that the discharge of a large induction coil, operated in the usual manner, cannot pass through, could be rendered incandescent by mere condenser action. Obviously, to reach this result, enormous potential differences and very high frequencies are required, as is evident from a simple calculation.

But such a lamp would possess a vast advantage over an ordinary incandescent lamp in regard to efficiency. It is well known that the efficiency of a lamp is to some extent a function of the degree of incandescence, and that, could we but work a filament at many times higher degrees of incandescence, the efficiency would be much greater. In an ordinary lamp this is impracticable on account of the destruction of the filament, and it has been determined by experience how far it is advisable to push the incandescence. It is impossible to tell how much higher efficiency could be obtained if the filament could withstand indefinitely, as the investigation to this end obviously cannot be carried beyond a certain stage; but there are reasons for believing that it would be very considerably higher. An improvement might be made in the ordinary lamp by employing a short and thick carbon; but then the leading-in wires would have to be thick, and, besides, there are many other considerations which render such a modification entirely impracticable. But in a lamp as above described the leading-in wires may be very small, the incandescent refractory material may be in the shape of blocks offering a very small radiating surface, so that less energy would be required to keep them at the desired incandescence; and, in addition to this, the refractory material need not be carbon, but may be manufactured from mixtures of oxides, for instance, with carbon or other material, or may be selected from bodies which are practically non-conductors, and capable of withstanding enormous degrees of temperature.

All this would point to the possibility of obtaining a much higher efficiency with such a lamp than is obtainable in ordinary lamps. In my experience it has been demonstrated that the blocks are brought to high degrees of incandescence with much lower potentials than those determined by calculation, and the blocks may be set at greater distances from each other. We may freely assume, and it is probable, that the molecular bombardment is an important element in the heating, even if the globe be exhausted with the utmost care as I have done; for although the number of the molecules is, comparatively speaking, insignificant, yet on account of the mean free path being very great, there are fewer collisions, and the molecules may reach much higher speeds, so that the heating effect due to this cause may be considerable, as in the Crookes experiments with radiant matter.

But it is likewise possible that we have to deal here with an increased facility of losing the charge in very high vacuum, when the potential is rapidly alternating, in which case most of the heating would be directly due to the surging of the charges in the heated bodies. Or else the observed fact may be largely attributable to the effect of the points which I have mentioned above, in consequence of which the blocks or filaments contained in the vacuum are equivalent to condensers of many times greater surface than that calculated from their geometrical dimensions. Scientific men still differ in opinion as to whether a charge should, or should not, be lost in a perfect vacuum, or, in other words, whether ether is, or is not, a conductor. If the former were the case, then a thin filament enclosed in a perfectly exhausted globe, and connected to a source of enormous, steady potential, would be brought to incandescence.



FIG. 21.



FIG. 22.

Various forms of lamps on the above-described principle, with the refractory bodies in the form of filaments, Fig. 21, or blocks, Fig. 22, have been constructed and operated by me, and investigations are being carried on in this line. There is no difficulty in reaching such high degrees of incandescence that ordinary carbon is to all appearance melted and volatilised. If the vacuum could be made absolutely perfect, such a lamp, although inoperative with apparatus ordinarily used, would, if operated with currents of the required character, afford an illuminant which would never be destroyed, and which would be far more efficient than an ordinary incandescent lamp. This perfection can, of course, never be reached, and a very slow destruction and gradual diminution of the size always occurs, as in incandescent lamps; but there is no possibility of a sudden and premature disabling which occurs in the latter by the breaking of the filament, especially when the incandescent bodies are in the shape of blocks.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION.*

BY NIKOLA TESLA.

(Continued from page 131.)

With these rapidly alternating potentials there is, however, no necessity of enclosing two blocks in a globe, but a single block, as in Fig. 20, or filament, Fig. 23, may be used. The potential in this case must of course be higher, but it is easily obtainable, and besides it is not necessarily dangerous.

The facility with which the button or filament in such a lamp is brought to incandescence, other things being equal,

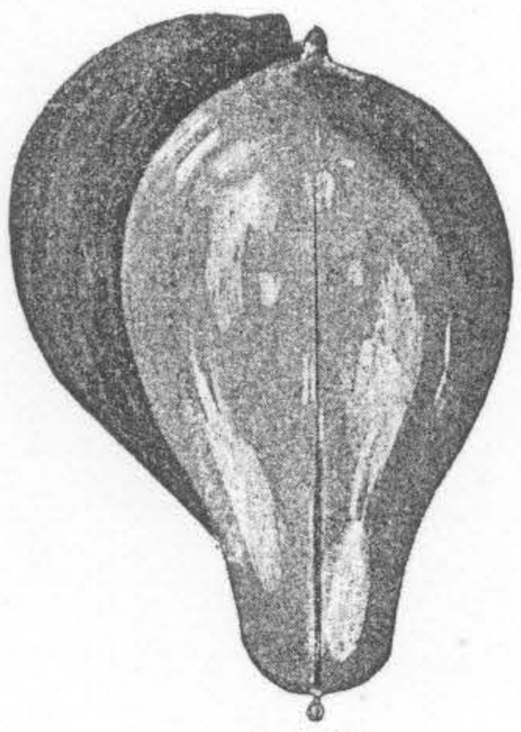


FIG. 23.

depends on the size of the globe. If a perfect vacuum could be obtained, the size of the globe would not be of importance, for then the heating would be wholly due to the surging of the charges, and all the energy would be given off to the surroundings by radiation. But this can never occur in practice. There is always some gas left in the globe, and although the exhaustion may be carried to the highest degree, still the space inside of the bulb must be considered as conducting when such high potentials are used, and I assume that in estimating the energy that may be given off from the filament to the surroundings we may consider the inside surface of the bulb as one coating of a condenser, the air and other objects surrounding the bulb forming the other coating. When the alternations are very low there is no doubt that a considerable portion of the energy is given off by the electrification of the surrounding air.

In order to study this subject better, I carried on some experiments with excessively high potentials and low frequencies. I then observed that when the hand is approached to the bulb—the filament being connected with one terminal of the coil—a powerful vibration is felt, being due to the attraction and repulsion of the molecules of the air which are electrified by induction through the glass. In some cases where the action is very intense I have been able to hear a sound, which must be due to the same cause.

When the alternations are low, one is apt to get an excessively powerful shock from the bulb. In general, when one attaches bulbs or objects of some size to the terminals of the coil, one should look out for the rise of potential, for it may happen that by merely connecting a bulb or plate to the terminal, the potential may rise to many times its original value. When lamps are attached to the terminals, as illustrated in Fig. 24, then the capacity of the bulbs should be such as to give the maximum rise of potential under the existing conditions. In this manner one may obtain the required potential with fewer turns of wire.

The life of such lamps as described above depends, of course, largely on the degree of exhaustion, but to some extent also on the shape of the block of refractory

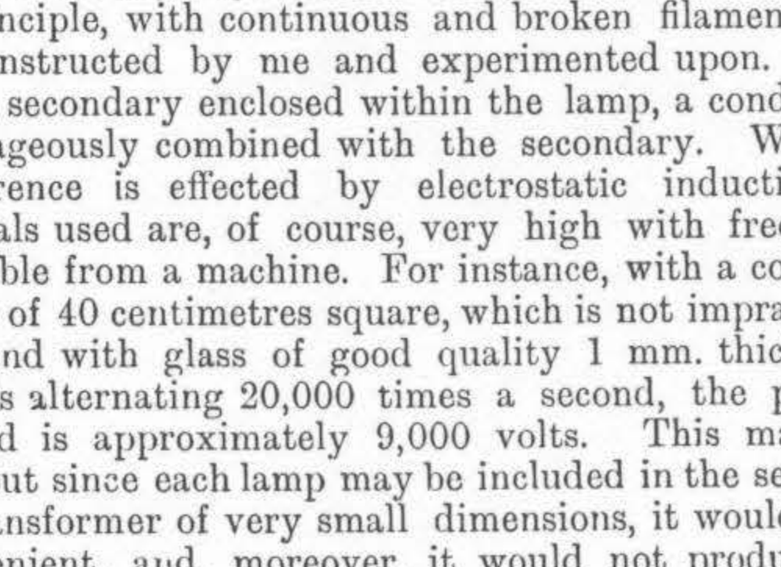


FIG. 24.

material. Theoretically it would seem that a small sphere of carbon enclosed in a sphere of glass would not suffer deterioration from molecular bombardment, for, the matter in the globe being radiant, the molecules would move in straight lines, and would seldom strike the sphere obliquely. An interesting thought in connection with such a lamp is, that in it "electricity" and electrical energy apparently must move in the same lines.

The use of alternating currents of very high frequency makes it possible to transfer, by electrostatic or electromagnetic induction through the glass of a lamp, sufficient energy to keep a filament at incandescence and so do away with the leading-in wires. Such lamps have been proposed, but for want of proper apparatus they have not been successfully operated. Many forms of lamps on this principle, with continuous and broken filaments, have been constructed by me and experimented upon. When using a secondary enclosed within the lamp, a condenser is advantageously combined with the secondary. When the transference is effected by electrostatic induction, the potentials used are, of course, very high with frequencies obtainable from a machine. For instance, with a condenser surface of 40 centimetres square, which is not impracticably large, and with glass of good quality 1 mm. thick, using currents alternating 20,000 times a second, the potential required is approximately 9,000 volts. This may seem large, but since each lamp may be included in the secondary of a transformer of very small dimensions, it would not be inconvenient, and, moreover, it would not produce fatal injury. The transformers would all be preferably in series. The regulation would offer no difficulties, as with currents

* Lecture delivered before the American Institute of Electrical Engineers at Columbia College, New York, May 20.

of such frequencies it is very easy to maintain a constant current.

In the accompanying engravings some of the types of lamps of this kind are shown. Fig. 25 is such a lamp with a broken filament, and Fig. 26A and Fig. 26B one with a single outside and inside coating and a single filament. I have also made lamps with two outside and inside coatings, and a continuous loop connecting the latter. Such lamps have been operated by me with current impulses of the enormous frequencies obtainable by the disruptive discharge of condensers.

The disruptive discharge of a condenser is especially suited for operating such lamps—with no outward electrical connections—by means of electromagnetic induction, the electromagnetic inductive effects being excessively high;

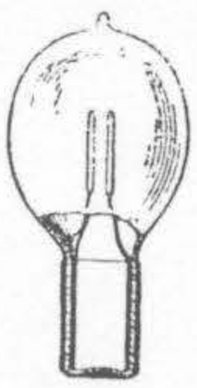


FIG. 25.

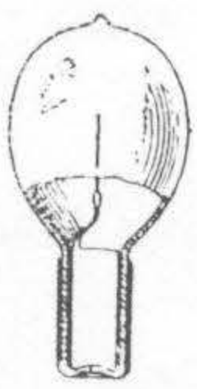


FIG. 26B.

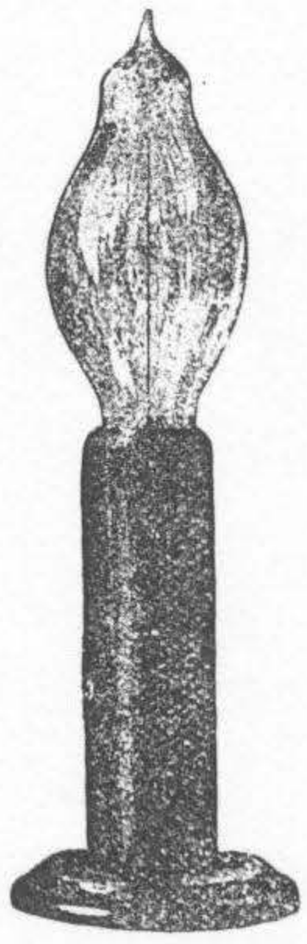


FIG. 26A.

and I have been able to produce the desired incandescence with only a few short turns of wire. Incandescence may also be produced in this manner in a simple closed filament.

Leaving, now, out of consideration the practicability of such lamps, I would only say that they possess a beautiful and desirable feature—namely, that they can be rendered at will more or less brilliant, simply by altering the relative position of the outside and inside condenser coatings, or inducing and induced circuits.

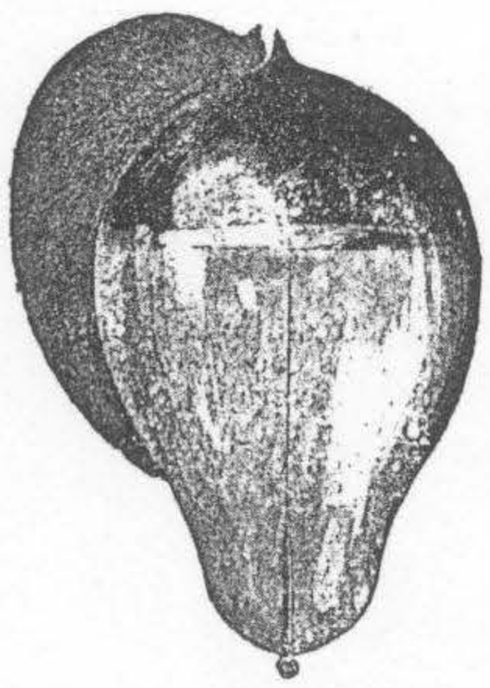


FIG. 27.

When a lamp is lighted by connecting it to one terminal only of the source, this may be facilitated by providing the globe with an outside condenser coating, which serves at the same time as a reflector, and connecting this to an insulated body of some size. Lamps of this kind are illustrated in Fig. 27 and Fig. 28. Fig. 29 shows the plan of connections. The brilliancy of the lamp may in this case be regulated within wide limits by varying the size of the insulated metal plate to which the coating is connected.

It is likewise practicable to light with one leading wire lamps, such as illustrated in Fig. 21 and Fig. 22, by connecting one terminal of the lamp to one terminal of the source, and the other to an insulated body of the required size. In all cases the insulated body serves to give off the energy into the surrounding space, and is equivalent to a return wire. Obviously, in the two last-named cases, instead of connecting the wires to an insulated body, connections may be made to the ground.

The experiments which will prove most suggestive and of most interest to the investigator are propably those performed with exhausted tubes. As might be anticipated, a source of such rapidly alternating potentials is capable of exciting the tubes at a considerable distance, and the light effects produced are remarkable.

During my investigations in this line I endeavoured to excite tubes, devoid of any electrodes, by electromagnetic induction, making the tube the secondary of the induction device, and passing through the primary the discharges of a Leyden jar. These tubes were made of many shapes, and I was able to obtain luminous effects which I then thought were due wholly to electromagnetic induction. But on carefully investigating the phenomena I found that the effects produced were more of an electrostatic nature. It may be attributed to this circumstance that this mode of exciting tubes is very wasteful—namely, the primary circuit being closed, the potential, and consequently the electrostatic inductive effect is much diminished.

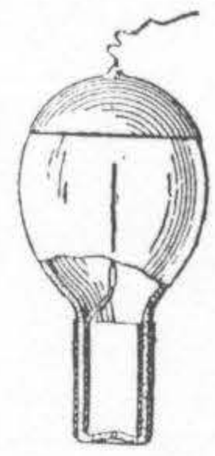


FIG. 28.

When an induction coil, operated as above described, is used, there is no doubt that the tubes are excited by electrostatic induction, and that electromagnetic induction has little, if anything, to do with the phenomena.

This is evident from many experiments. For instance, if a tube be taken in one hand, the observer being near the coil, it is brilliantly lighted and remains so in no matter what position it is held relatively to the observer's body Were the action electromagnetic, the tube could not be lighted when the observer's body is interposed between it and the coil, or at least its luminosity should be considerably diminished. When the tube is held exactly over the centre of the coil—the latter being wound in sections and the primary placed

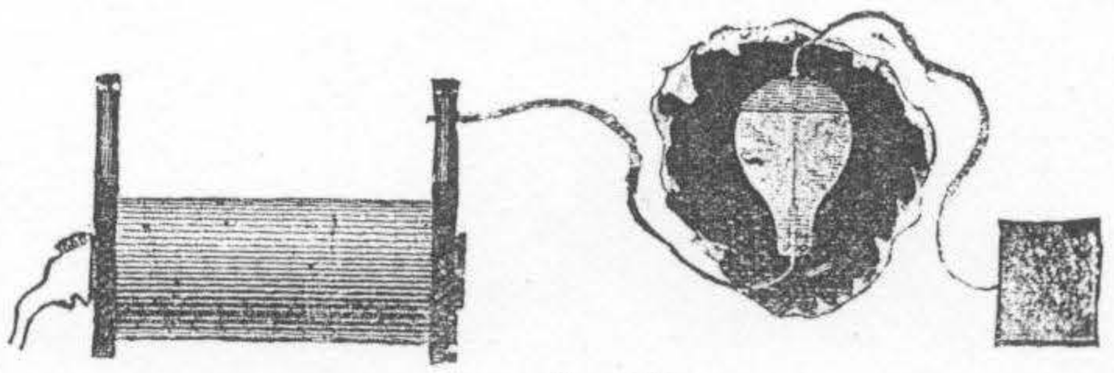


FIG. 29.

symmetrically to the secondary—it may remain completely dark, whereas it is rendered intensely luminous by moving it slightly to the right or left from the centre of the coil. It does not light because in the middle both halves of the coil neutralise each other, and the electric potential is zero. If the action were electromagnetic, the tube should light best in the plane through the centre of the coil, since the electromagnetic effect there should be a maximum. When an arc is established between the terminals, the tubes and lamps in the vicinity of the coil go out, but light up again when the arc is broken, on account of the rise of potential. Yet the electromagnetic effect should be practically the same in both cases.

By placing a tube at some distance from the coil, and nearer to one terminal—preferably at a point on the axis

of the coil—one may light it by touching the remote terminal with an insulated body of some size or with the hand, thereby raising the potential at that terminal nearer to the tube. If the tube is shifted nearer to the coil so that it is lighted by the action of the nearer terminal, it may be made to go out by holding, on an insulated support, the end of a wire connected to the remote terminal, in the vicinity of the nearer terminal, by this means counteracting the action of the latter upon the tube. These effects are evidently electrostatic. Likewise, when a tube is placed at a considerable distance from the coil, the observer may, standing upon an insulated support, between coil and tube, light the latter by approaching the hand to it; or he may even render it luminous by simply stepping between it and the coil. This would be impossible with electromagnetic induction, for the body of the observer would act as a screen.

When the coil is energised by excessively weak currents, the experimenter may, by touching one terminal of the coil with the tube, extinguish the latter, and may again light it by bringing it out of contact with the terminal and allowing a small arc to form. This is clearly due to the respective lowering and raising of the potential at that terminal In the above experiment, when the tube is lighted through a small arc, it may go out when the arc is broken, because the electrostatic inductive effect alone is too weak, though the potential may be much higher; but when the arc is established, the electrification of the end of the tube is much greater, and it consequently lights.

If a tube is lighted by holding it near to the coil, and in the hand which is remote, by grasping the tube anywhere with the other hand, the part between the hands is rendered dark, and the singular effect of wiping out the light of the tube may be produced by passing the hand quickly along the tube and at the same time withdrawing it gently from the coil, judging properly the distance so that the tube remains dark afterwards.

If the primary coil is placed sidewise, as in Fig. 17B for instance, and an exhausted tube be introduced from the other side in the hollow space, the tube is lighted most intensely because of the increased condenser action, and in this position the striæ are most sharply defined. In all these experiments described, and in many others, the action is clearly electrostatic.

The effects of screening also indicate the electrostatic nature of the phenomena and show something of the nature of electrification through the air. For instance, if a tube be placed in the direction of the axis of the coil, and an insulated metal plate be interposed, the tube will generally increase in brilliancy, or if it be too far from the coil to light, it may even be rendered luminous by interposing an insulated metal plate. The magnitude of the effects depends to some extent on the size of the plate. But if the metal plate be connected by a wire to the ground, its interposition will always make the tube go out, even if it be very near the coil. In general, the interposition of a body between the coil and tube, increases or diminishes the brilliancy of the tube, or its facility to light up, according to whether it increases or diminishes the electrification. When experimenting with an insulated plate, the plate should not be taken too large, else it will generally produce a weakening effect by reason of its great facility for giving off energy to the surroundings.

If a tube be lighted at some distance from the coil, and a plate of hard rubber or other insulating substance be interposed, the tube may be made to go out. The interposition of the dielectric in this case only slightly increases the inductive effect, but diminishes considerably the electrification through the air.

In all the cases, then, when we excite luminosity in exhausted tubes by means of such a coil, the effect is due to the rapidly alternating electrostatic potential; and, furthermore, it must be attributed to the harmonic alternation produced directly by the machine, and not to any superimposed vibration which might be thought to exist. Such superimposed vibrations are impossible when we work with an alternate-current machine. If a spring be gradually tightened and released, it does not perform independent vibrations; for this a sudden release is necessary. So with the alternate currents from a dynamo machine: the medium is harmonically strained and released, this giving rise to only one kind of waves; a sudden contact or break, or a sudden giving way of the dielectric, as in the disruptive discharge of a Leyden jar, are essential for the production of superimposed waves.

In all the last described experiments, tubes devoid of any electrodes may be used, and there is no difficulty in producing by their means sufficient light to read by. The light effect is, however, considerably increased by the use of phosphorescent bodies such as yttria, uranium, glass, etc. A difficulty will be found when the phosphorescent material is used, for with these powerful effects it is carried gradually away, and it is preferable to use material in the form of a solid.

Instead of depending on induction at a distance to light the tube, the same may be provided with an external—and, if desired, also with an internal—condenser coating, and it may then be suspended anywhere in the room from a conductor connected to one terminal of the coil, and in this manner a soft illumination may be provided.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION.*

BY NIKOLA TESLA.

(*Concluded from page* 161).

The ideal way of lighting a hall or room, would, however, be to produce such a condition in it that an illuminating device could be moved and put anywhere, and that it is lighted, no matter where it is put, and without being electrically connected to anything. I have been able to produce such a condition by creating in the room a powerful, rapidly alternating electrostatic field. For this purpose I suspend a sheet of metal a distance from the ceiling on insulating cords and connect it to one terminal of the induction coil, the other terminal being preferably connected to the ground. Or else I suspend two sheets as illustrated in Fig. 30, each sheet being connected with one of the terminals of the coil, and their size being carefully determined. An exhausted tube may then be carried in the hand anywhere between the sheets or placed anywhere, even a certain distance beyond them; it remains always luminuous.

In such an electrostatic field interesting phenomena may be observed, especially if the alternations are kept low and the potentials excessively high. In addition to the luminous phenomena mentioned, one may observe that any insulated conductor gives sparks when the hand or another object is approached to it, and the sparks may often be powerful. When a large conducting object is fastened on an insulating support, and the hand approached to it, a vibration, due to the rythmical motion of the air molecules, is felt, and luminous streams may be perceived when the hand is held near a pointed projection. When a telephone receiver is made to touch with one or both of its terminals an insulated conductor of some size, the telephone emits a loud sound; it also emits a sound when a length of wire is attached to one or both terminals, and with very powerful fields a sound may be perceived even without any wire.

How far this principle is capable of practical application the future will tell. It might be thought that electrostatic effects are unsuited for such action at a distance. Electromagnetic inductive effects, if available for the production of light, might be thought better suited. It is true the electrostatic effects diminish nearly with the cube of the distance from the coil, whereas the electromagnetic inductive effects diminish simply with the distance. But when we establish an electrostatic field of force, the condition is very different, for then, instead of the differential effect of both the terminals, we get their cojoint effect. Besides, I would call attention to the fact, that in an alternating electrostatic field, a conductor, such as an exhausted tube for instance, tends to take up most of the energy, whereas, in an an electromagnetic alternating field the conductor tends to take up the least energy, the waves being reflected with but little loss. This is one reason why it is difficult to excite an exhausted tube, at a distance, by electromagnetic induction. I have wound coils of very large diameter and of many turns of wire, and connected a Geissler tube to the ends of the coil with the object of exciting the tube at a distance; but even with the powerful inductive effects producible by Leyden jar discharges, the tube could not be excited unless at a very small distance, although some judgment was used as to the dimensions of the coil. I have also found that even the most powerful Leyden jar discharges are capable of exciting only feeble luminous effects in a closed exhausted tube, and even these effects upon thorough examination I have been forced to consider of an electrostatic nature.

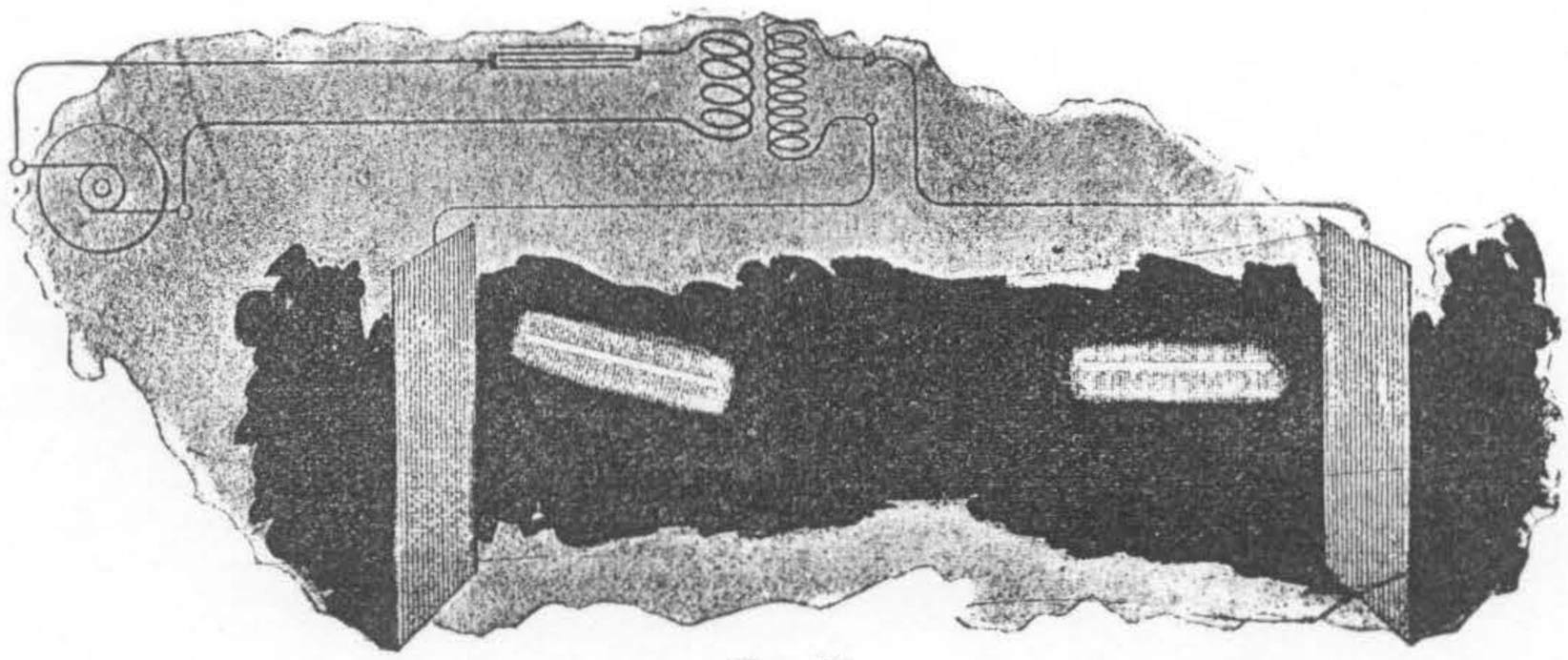


FIG. 30.

How, then, can we hope to produce the required effects at a distance by means of electromagnetic action, when even in the closest proximity to the source of disturbance, under the most advantageous conditions, we can excite but faint luminosity? It is true that when acting at a distance we have the resonance to help us out. We can connect an exhausted tube, or whatever the illuminating device may be, with an insulated system of the proper capacity, and so it may be possible to increase the effect qualitatively, and only qualitatively, for we would not get more energy through the device. So we may by resonance effect obtain the required E.M.F. in an exhausted tube, and excite faint luminous effects, but we cannot get enough energy to render the light practically available, and a simple calculation, based on experimental results, shows that even if all the energy which a tube would receive at a certain distance from the source should be wholly converted into light, it would hardly satisfy the practical requirements. Hence the

* Lecture delivered before the American Institute of Electrical Engineers at Columbia College, New York, May 20.

necessity of directing, by means of a conducting circuit, the energy to the place of transformation. But in so doing we cannot very sensibly depart from present methods, and all we could do would be to improve the apparatus.

From these considerations it would seem that if this ideal way of lighting is to be rendered practicable it will be only by the use of electrostatic effects. In such a case the most powerful electrostatic inductive effects are needed; the apparatus employed must, therefore, be capable of producing high electrostatic potentials changing in value with extreme rapidity. High frequencies are especially wanted, for practical considerations make it desirable to keep down the potential. By the employment of machines, or, generally speaking, of any mechanical apparatus, but low frequencies can be reached; recourse must, therefore, be had to some other means. The discharge of a condenser affords us a means of obtaining frequencies by far higher than are obtainable mechanically, and I have accordingly employed condensers in the experiments to the above end.

When the terminals of a high tension induction coil, Fig. 31, are connected to a Leyden jar, and the latter is discharging disruptively into a circuit, we may look upon the arc playing between the knobs as being a source of alternating, or generally speaking, undulating currents, and then we have to deal with the familiar system of a generator of such currents, a circuit connected to it, and a condenser bridging the circuit. The condenser in such case is a veritable transformer, and since the frequency is excessive, almost any ratio in the strength of the currents in both the branches may be obtained. In reality, the analogy is not quite complete, for in the disruptive discharge we have most generally a fundamental instantaneous variation of comparatively low frequency, and a superimposed harmonic vibration, and the laws governing the flow of currents are not the same for both.

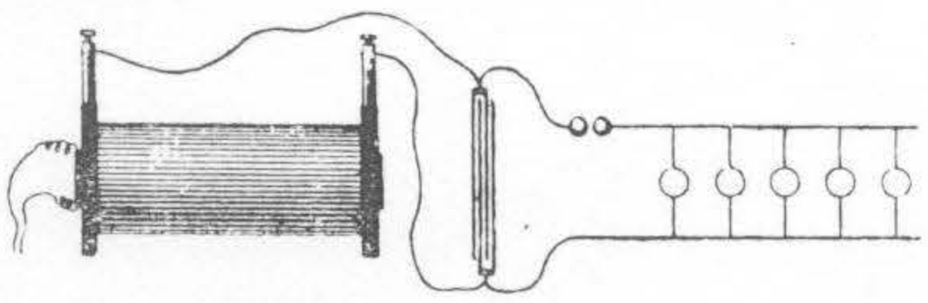


FIG. 31.

In converting in this manner, the ratio of conversion should not be too great, for the loss in the arc between the knobs increases with the square of the current, and if the jar be discharged through very thick and short conductors, with the view of obtaining a very rapid oscillation, a very considerable portion of the energy stored is lost. On the other hand, too small ratios are not practicable for many obvious reasons.

As the converted currents flow in a practically closed circuit, the electrostatic effects are necessarily small, and I therefore convert them into currents or effects of the required character. I have effected such conversions in several ways. The preferred plan of connections is illustrated in Fig. 32. The manner of operating renders it easy to obtain by means of a small and inexpensive apparatus enormous differences of potential which have been usually obtained by means of large and expensive coils. For this it is only necessary to take an ordinary small coil, adjust to it a condenser and discharging circuit, forming the primary of an auxiliary small coil, and convert upward. As the inductive effect of the primary currents is excessively great, the second coil need have comparatively but very few turns. By properly adjusting the elements remarkable results may be secured.

In endeavouring to obtain the required electrostatic effects in this manner, I have, as might be expected, encountered many difficulties which I have been gradually overcoming, but I am not as yet prepared to dwell upon my experiences in this direction.

I believe that the disruptive discharge of a condenser will play an important part in the future, for it offers vast possibilities, not only in the way of producing light in a more efficient manner and in the line indicated by theory, but also in many other respects.

For years the efforts of inventors have been directed towards obtaining electrical energy from heat by means of the thermopile. It might seem invidious to remark that but few know what is the real trouble with the thermopile. It is not the inefficiency or small output—though these are great drawbacks—but the fact that the thermopile has its phylloxera—that is, that by constant use it is deteriorated, which has thus far prevented its introduction on an industrial scale. Now that all modern research seems to point with certainty to the use of electricity of excessively high tension, the question must present itself to many whether it is not possible to obtain in a practicable manner this form of energy from heat. We have been used to look upon an electrostatic machine as a plaything, and somehow we couple with it the idea of the inefficient and impractical. But now we must think differently, for now we know that everywhere we have to deal with the same forces, and that it is a mere question of inventing proper methods or apparatus for rendering them available.

In the present systems of electrical distribution, the employment of the iron with its wonderful magnetic properties allows us to reduce considerably the size of the apparatus; but, in spite of this, it is still very cumbersome. The more we progress in the study of electric and magnetic phenomena, the more we become convinced that the present methods will be short-lived. For the production of light, at least, such heavy machinery would seem to be unnecessary. The energy required is very small, and if light can be obtained as efficiently as, theoretically, it appears possible, the apparatus need have but a very small output. There being a strong probability that the illuminating methods of the future will involve the use of very high potentials, it seems very desirable to perfect a contrivance capable of converting the energy of heat into energy of the requisite form. Nothing to speak of has been done towards this end, for the thought that electricity of some 50,000 or 100,000 volts pressure or more, even if obtained, would be unavailable for practical purposes, has deterred inventors from working in this direction.

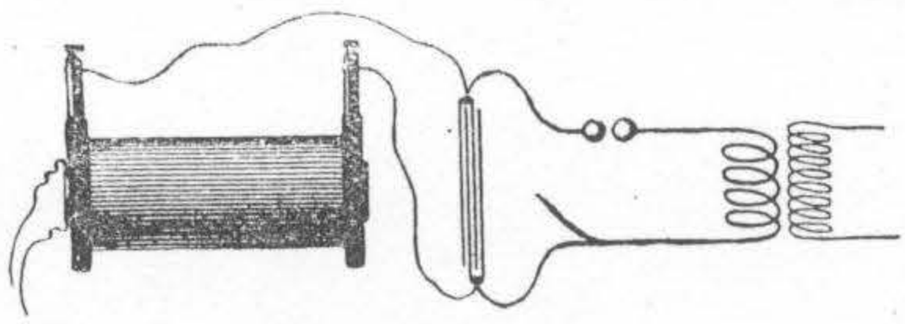


FIG. 32.

In Fig. 31 a plan of connections is shown for converting currents of high, into currents of low, tension by means of the disruptive discharge of a condenser. This plan has been used by me frequently for operating a few incandescent lamps required in the laboratory. Some difficulties have been encountered in the arc of the discharge which I have been able to overcome to a great extent; besides this, and the adjustment necessary for the proper working, no other difficulties have been met with, and it was easy to operate ordinary lamps, and even motors, in this manner. The line being connected to the ground, all the wires could be handled with perfect impunity, no matter how high the potential at the terminals of the condenser. In these experiments a high-tension induction coil, operated from a battery or from an alternate-current machine, was employed to charge the condenser; but the induction coil might be replaced by an apparatus of a different kind, capable of giving electricity of such high tension. In this manner, direct or alternating currents may be converted, and in both cases the current-impulses may be of any desired frequency. When the currents charging the condenser are of the same direction, and it is desired that the converted currents should also be of one direction, the resistance of the discharging circuit should, of course, be so chosen that there are no oscillations.

In operating devices on the above plan, I have observed curious phenomena of impedance which are of interest. For instance, if a thick copper bar be bent, as indicated in

Fig. 33, and shunted by ordinary incandescent lamps, then, by passing the discharge between the knobs, the lamps may be brought to incandescence although they are short-circuited. When a large induction coil is employed it is easy to obtain nodes on the bar, which are rendered evident by the different degree of brilliancy of the lamps, as shown roughly in Fig. 33. The nodes are never clearly defined, but there are simply maxima and minima of potentials along the bar. This is probably due to the irregularity of the arc between the knobs. In general when the above described plan of conversion from high to low tension is used, the behaviour of the disruptive discharge may be closely studied. The nodes may also be investigated by means of an ordinary Cardew voltmeter which should be well insulated. Geissler tubes may also be lighted across the points of the bent bar; in this case, of course, it is better to employ smaller capacities. I have found it practicable to light up in this manner a lamp, and even a Geissler tube, shunted by a short heavy block of metal, and this result seems at first very curious. In fact, the thicker the copper bar in Fig. 33, the better it is for the success of the experiments, as they appear more striking. When lamps with long slender filaments are used it will be often noted that the filaments are from time to time violently vibrated, the vibration being smallest at the nodal points. This vibration seems to be due to an electrostatic action between the filament and the glass of the bulb.

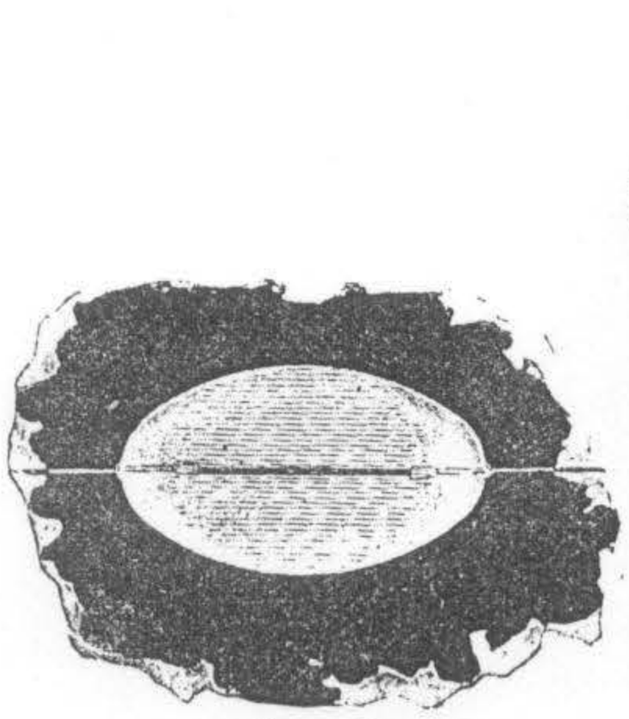


Fig. 34.

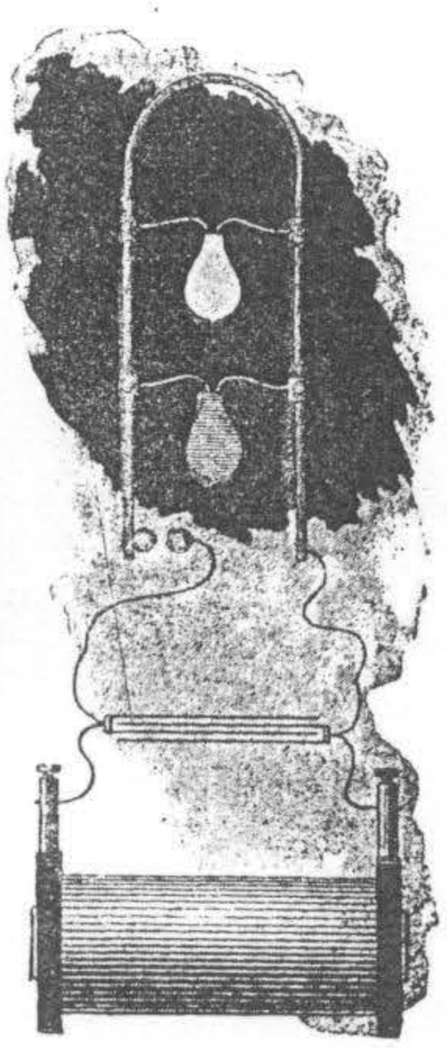


Fig. 33.

In some of the above experiments it is preferable to use special lamps having a straight filament, as shown in Fig 34. When such a lamp is used a still more curious phenomenon than those described may be observed. The lamp may be placed across the copper bar and lighted, and by using somewhat larger capacities, or, in other words, smaller frequencies, or smaller impulsive impedancies, the filament may be brought to any desired degree of incandescence. But when the impedance is increased a point is reached when comparatively little current passes through the carbon, and most of it through the rarified gas; or perhaps it may be more correct to state that the current divides nearly evenly through both, in spite of the enormous difference in the resistance, and this would be true unless the gas and the filament behave differently. It is then noted that the whole bulb is brilliantly illuminated, and the ends of the leading-in wires become incandescent and often throw off sparks in consequence of the violent bombardment, but the carbon filament remains dark. This is illustrated in Fig. 34. Instead of the filament a single wire extending through the the whole bulb may be used, and in this case the phenomenon would seem to be still more interesting.

From the above experiment it will be evident that when ordinary lamps are operated by the converted currents, those should be preferably taken in which the platinum wires are far apart, and the frequencies used should not be too great, else the discharge will occur at the ends of the filament or in the base of the lamp between the leading-in wires, and the lamp might then be damaged.

In presenting to you these results of my investigation on the subject under consideration, I have paid only a passing notice to facts upon which I could have dwelt at length, and among many observations I have selected only those which I thought most likely to interest you. The field is wide and completely unexplored, and at every step a new truth is gleaned, a novel fact observed.

How far the results here borne out are capable of practical applications will be decided in the future. As regards the production of light, some results already reached are encouraging, and make me confident in asserting that the practical solution of the problem lies in the direction I have endeavoured to indicate. Still, whatever may be the immediate outcome of these experiments, I am hopeful that they will only prove a step to further development towards the ideal and final perfection. The possibilities which are opened by modern research are so vast that even the most reserved must feel sanguine of the future. Eminent scientists consider the problem of utilising one kind of radiation without the others a rational one. In an apparatus designed for the production of light by conversion from any form of energy into that of light, such a result can never be reached, for no matter what the process of producing the required vibrations, be it electrical, chemical, or any other, it will not be possible to obtain the higher light vibrations without going through the lower heat vibrations. It is the problem of imparting to a body a certain velocity without passing through all lower velocities. But there is a possibility of obtaining energy not only in the form of light, but motive power, and energy of any other form, in some more direct way from the medium. The time will be when this will be accomplished, and the time has come when one may utter such words before an enlightened audience without being considered a visionary. We are whirling through endless space with an inconceivable speed, all around us everything is spinning, everything is moving, everywhere is energy. There must be some way of availing ourselves of this energy more directly. Then, with the light obtained from the medium, with the power derived from it, with every form of energy obtained without effort, from the store forever inexhaustible, humanity will advance with giant strides. The mere contemplation of these magnificent possibilities expands our minds, strengthens our hopes, and fills our hearts with supreme delight.

TESLA'S SYSTEM OF ELECTRIC LIGHTING WITH CURRENTS OF HIGH FREQUENCY.

IN his lecture delivered before the American Institute of Electrical Engineers,* Mr. Nikola Tesla dwelt at length upon the fact that the direct application of electro-magnetic waves to the production of luminous effects was impracticable and that for this purpose electro-static waves or thrusts must be employed. To make these effects available in practice, however, it is necessary to employ currents of very high frequency and of very high potential.

In a patent just issued to Mr. Tesla on this method of electric illumination, he draws attention to the mechanical difficulty of obtaining the necessary high frequency of alternations, and hence he avails himself of the principle of the disruptive discharge. The current of high frequency is produced by the disruptive discharge of the accumulated energy of a condenser maintained by continuously charging the condenser and discharging it disruptively, in connection with an induction coil which generates the high potentials required.

The accompanying diagram, fig 1, illustrates the method employed by Mr. Tesla, the generator in this case being one delivering alternate currents of comparatively low potential. The potential of the current is raised by means of an induction-coil having a primary, P, and a secondary, S. Then by the current developed in this secondary a condenser, C, is charged, and this condenser discharged into a circuit, A, having an air-gap, *a*. By the means above described, a current of enormous frequency is produced. It is next necessary to convert this into a working circuit of very high potential, for which purpose there is connected up in the circuit, A, the primary, P′, of

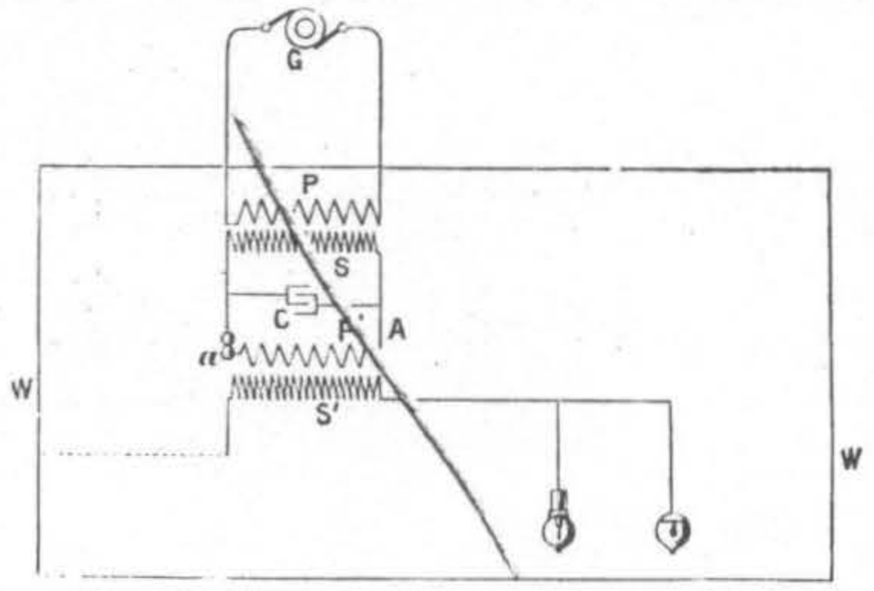
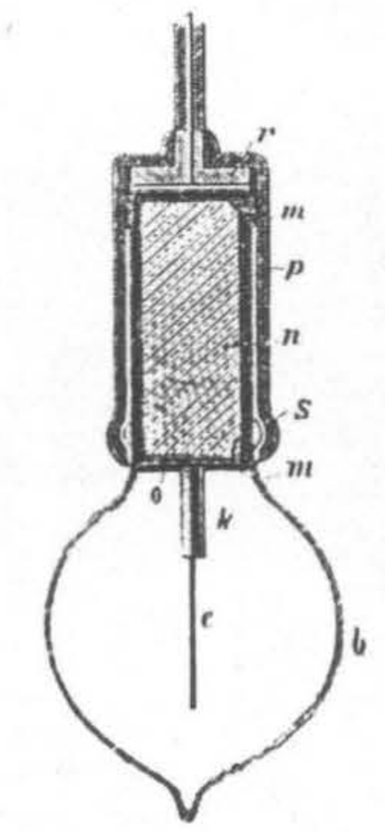


FIG. 1.—TESLA'S NEW SYSTEM OF ELECTRIC LIGHTING.

an induction-coil having a long fine wire secondary, s′. The current in the primary, P′, develops in the secondary, s′, a current or electrical effect of corresponding frequency, but of enormous difference of potential, and the secondary, s′, thus becomes the source of the energy to be applied to the purpose of producing light.

The light-giving devices may be connected to either terminal of the secondary, s′. If desired one terminal may be connected to a conducting-wall, W, of the room to be lighted and the other arranged for connection of the lamps therewith. In such case the walls should be coated with some metallic or conducting substance in order that they may have sufficient conductivity.

Mr. Tesla has devised several forms of lamps to be used in



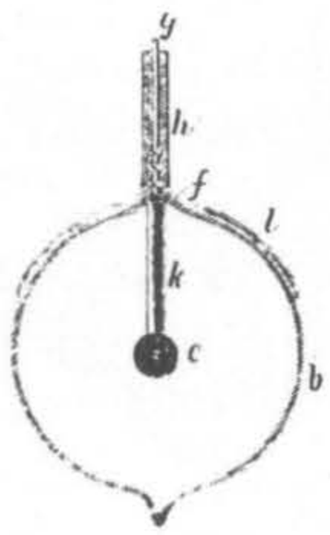


FIG. 2.—TESLA'S LAMP WITH STRAIGHT FILAMENT, ONE INSIDE AND ONE OUTSIDE CONDENSER COATING, AND ONE CONDUCTOR.

FIG. 3.—TESLA'S LAMP WITH INCANDESCENT BALL AND ONE CONDUCTOR.

connection with his system, two forms of which are shown in the engravings figs. 2 and 3. In the former the globe, *b*, is formed with a cylindrical neck, within which is a tube or sheet, *m*, of conducting material on the side and over the end of a cylinder or plug, *n*, of insulating material. The lower edges of this tube are in electrical contact with a metallic plate, *o*,

* *The Electrical Engineer*, May 27th, 1891.

secured to the cylinder, *n*, all the exposed surfaces of the plate and of the other conductors being carefully coated and protected by insulation. The light-giving body, *e*, a straight stem of carbon, is electrically connected with the plate by a conductor, *f*, which is coated with a refractory insulating material, *k*. The neck of the globe fits into a socket composed of an insulating tube or cylinder, *p*, with a more or less complete metallic lining, *s*, electrically connected by a metallic plate, *r*, with a conductor, *y*, that is attached to one pole of the source of current. The metallic lining, *s*, and the sheet, *m*, thus compose the plates of a condenser.

Fig. 3 shows a lamp containing an incandescent body, *e*, which is connected to one pole of the source of current. Outside of the globe the conducting-wires are protected by a coating of insulation, *h*, and inside the globe the supporting-wire is inclosed in and insulated by a coating, *k*, of a refractory insulating substance, such as pipe-clay. A reflecting-plate, *l*, is shown applied to the outside of the globe, *b*. This form of lamp is a type of those designed for direct electrical connection with one terminal of the source of current; but, as in the case of the lamp, fig. 2, there need not be a direct connection, for the carbon or other illuminating body may be rendered luminous by inductive action of the current thereon.

ELECTRIC DISCHARGE IN VACUUM TUBES.

BY NIKOLA TESLA.

IN the *Electrical Engineer* of June 10th, I have noted the description of some experiments of Prof. J. J. Thomson, on the "Electric Discharge in Vacuum Tubes," and in your issue of June 24th, Prof. Elihu Thomson describes an experiment of the same kind. The fundamental idea in these experiments is to set up an electromotive force in a vacuum tube—preferably devoid of any electrodes—by means of electro-magnetic induction, and to excite the tube in this manner.

As I view the subject, I should think that to any experimenter who has carefully studied the problem confronting us and who has attempted to find a solution of it, this idea must present itself as naturally, as, for instance, the idea of replacing the tinfoil coatings of a Leyden jar by rarefied gas and exciting luminosity in the condenser thus obtained by repeatedly charging and discharging it. The idea being obvious, whatever merit there is in this line of investigation must depend upon the completeness of the study of the subject and the correctness of the observations. The following lines are not penned with any desire on my part to put myself on record as one who has performed similar experiments, but with a desire to assist other experimenters by pointing out certain peculiarities of the phenomena observed, which, to all appearances, have not been noted by Prof. J. J. Thomson, who, however, seems to have gone about systematically in his investigations and who has been the first to make his results known. These peculiarities noted by me would seem to be at variance with the views of Prof. J. J. Thomson, and present the phenomena in a different light.

My investigations in this line occupied me principally during the winter and spring of the past year. During this time many different experiments were performed, and in my exchanges of ideas on this subject with Mr. Alfred S. Brown, of the Western Union Telegraph Company, various different dispositions were suggested which were carried out by me in practice. Fig. 1 may serve as an example of one of the many forms of apparatus used. This consisted of a large glass tube sealed at one end and projecting into an ordinary incandescent lamp bulb. The primary, usually consisting of a few turns of thick, well-insulated copper sheet was inserted within the tube, the

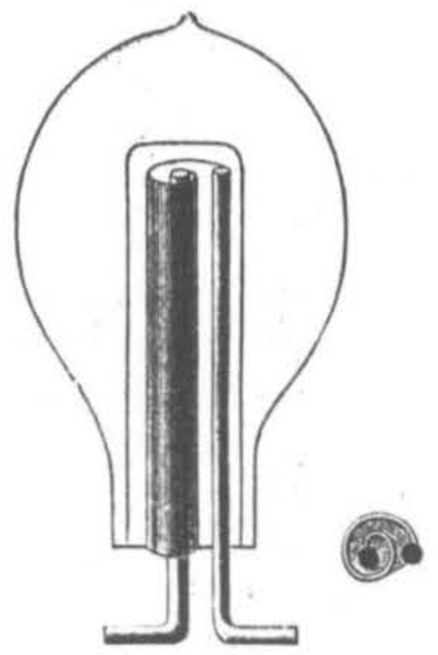
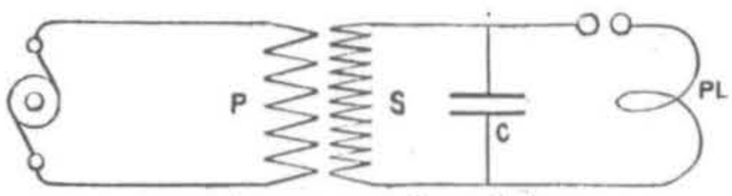


FIG. 1.

inside space of the bulb furnishing the secondary. This form of apparatus was arrived at after some experimenting and was used principally with the view of enabling me to place a polished reflecting surface in the inside of the tube, and for this purpose the last turn of the primary was covered with a thin silver sheet. In all forms of apparatus used there was no special difficulty in exciting a luminous circle or cylinder in proximity to the primary.

As to the number of turns, I cannot quite understand why Prof. J. J. Thomson should think that a few turns were "quite sufficient," but lest I should impute to him an opinion he may not have, I will add that I have gained this impression from the reading of the published abstracts of his lecture. Clearly, the number of turns which gives the best result in any case, is dependent on the dimensions of the apparatus, and, were it not for various considerations, one turn would always give the best result.

I have found that it is preferable to use in these experiments an alternate current machine giving a moderate number of alternations per second to excite the induction coil for charging the Leyden jar which discharges through the primary—shown diagrammatically in fig. 2—as in such case,



C, condenser; P L., primary in lamp

FIG. 2.

before the disruptive discharge takes place the tube or bulb is slightly excited and the formation of the luminous circle is decidedly facilitated. But I have also used a Wimshurst machine is some experiments.

Prof. J. J. Thomson's view of the phenomena under consideration seems to be that they are wholly due to electro-magnetic action. I was, at one time, of the same opinion, but upon carefully investigating the subject I was led to the conviction that they are more of an electrostatic nature. It must be remembered that in these experiments we have to deal with primary currents of an enormous frequency or rate of change and of a high potential, and that the secondary conductor consists of a rarefied gas, and that under such conditions electrostatic effects must play an important part.

In support of my view I will describe a few experiments made by me. To excite luminosity in the tube it is not absolutely necessary that the conductor should be closed. For instance, if an ordinary exhausted tube (preferably of large diameter), be surrounded by a spiral of thick copper wire serving as the primary, a freely luminous spiral may

be induced in the tube, roughly shown in fig. 3. In one of these experiments a curious phenomenon was observed; namely, two intensely luminous circles, each of them close to a turn of the primary spiral, were formed inside of the tube, and I attributed this phenomenon to the existence of nodes on the primary. The circles were connected by a



FIG. 3.

faint luminous spiral parallel to the primary and in close proximity to it. To produce this effect I have found it necessary to strain the jar to the utmost. The turns of the spiral tend to close and form circles, but this, of course, would be expected, and does not necessarily indicate an electro-magnetic effect; whereas the fact that a glow can be produced along the primary in the form of an open spiral argues for an electrostatic effect.

In using Dr. Lodge's recoil circuit, the electrostatic action is likewise apparent. The arrangement is illustrated in fig. 4. In his experiment two hollow exhausted tubes, H H, were

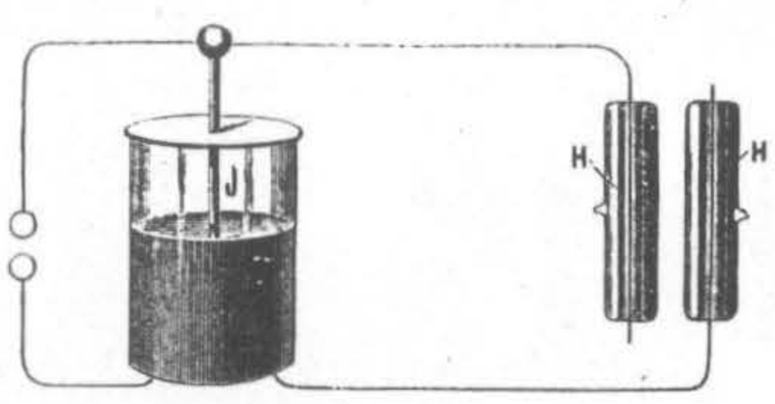


FIG. 4.

slipped over the wires of the recoil circuit and upon discharging the jar in the usual manner, luminosity was excited in the tubes.

Another experiment performed is illustrated in fig. 5. In this case an ordinary lamp bulb was surrounded by one or

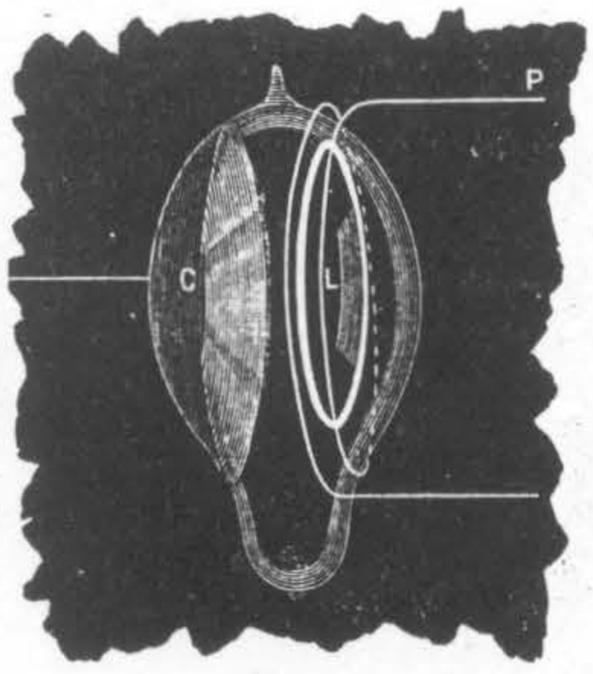


FIG. 5.

two turns of thick copper wire, P, and a luminous circle, L, excited in the bulb by discharging the jar through the primary. The lamp bulb was provided with a tinfoil coating on the side opposite to the primary, and each time the tinfoil coating was connected to the ground or to a large object the luminosity of the circle was considerably increased. This was evidently due to electrostatic action.

In other experiments I have noted that when the primary touches the glass the luminous circle is easier produced and is more sharply defined; but I have not noted that, generally speaking, the circles induced were very sharply defined, as Prof. J. J. Thomson has observed; on the contrary, in my experiments they were broad and often the whole of the bulb or tube was illuminated; and in one case I have observed an intensely purplish glow, to which Prof. J. J. Thomson refers. But the circles were always in close proximity to the primary and were considerably easier produced when the latter was very close to the glass, much more so than would be expected assuming the action to be electro-magnetic and considering the distance; and these facts speak for an electrostatic effect.

Furthermore, I have observed that there is a molecular bombardment in the plane of the luminous circle at right angles to the glass—supposing the circle to be in the plane of the primary—this bombardment being evident from the rapid heating of the glass near the primary. Were the bombardment not at right angles to the glass the heating could not be so rapid. If there is a circumferential movement of the molecules constituting the luminous circle, I have thought that it might be rendered manifest by placing within the tube or bulb, radially to the circle, a thin plate of mica coated with some phosphorescent material, and another such plate tangentially to the circle. If the molecules would move circumferentially, the former plate would be rendered more intensely phosphorescent. For want of time I have, however, not been able to perform the experiment.

Another observation made by me was that when the specific inductive capacity of the medium between the primary and secondary is increased, the inductive effect is augmented. This is roughly illustrated in fig. 6. In this case luminosity

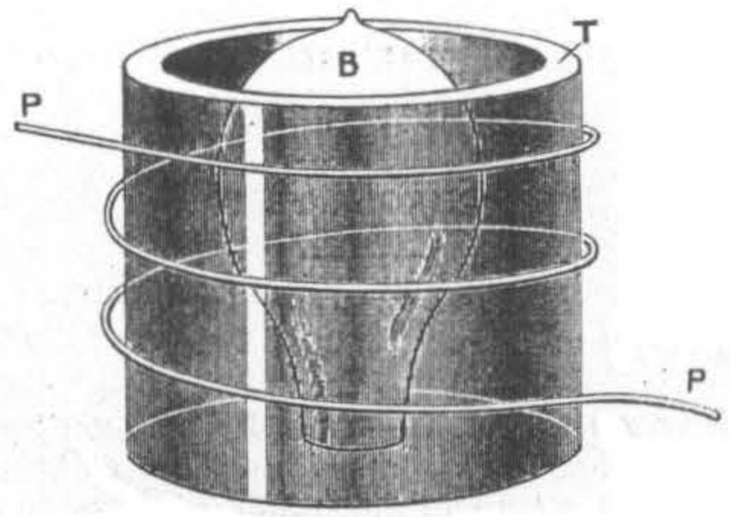


FIG. 6.

was excited in an exhausted tube or bulb, B, and a glass tube, T, slipped between the primary and the bulb, when the effect pointed out was noted. Were the action wholly electro-magnetic no change could possibly have been observed.

I have likewise noted that when a bulb is surrounded by a wire closed upon itself and in the plane of the primary, the formation of the luminous circle within the bulb is not prevented. But if instead of the wire a broad strip of tinfoil is glued upon the bulb, the formation of the luminous band was prevented because then the action was distributed over a greater surface. The effect of the closed tinfoil was no doubt of an electrostatic nature, for it presented a much greater resistance than the closed wire and produced therefore a much smaller electro-magnetic effect

Some of the experiments of Prof. J. J. Thomson also would seem to show some electrostatic action. For instance, in the experiment with the bulb enclosed in a bell jar, I should think that when the latter is exhausted so far that the gas enclosed reaches the maximum conductivity, the formation of the circle in the bulb and jar is prevented because of the space surrounding the primary being highly conducting; when the jar is further exhausted the conductivity of the space around the primary diminishes and the circles appear necessarily first in the bell jar, as the rarefied gas is nearer to the primary. But were the inductive effect very powerful they would probably appear in the bulb also. If, however

the bell jar were exhausted to the highest degree they would very likely show themselves in the bulb only, that is, supposing the vacuous space to be non-conducting. On the assumption that in these phenomena electrostatic actions are concerned we find it easily explicable why the introduction of mercury or the heating of the bulb prevents the formation of the luminous band or shortens the after-glow; and also why in some cases a platinum wire may prevent the excitation of the tube. Nevertheless some of the experiments of Prof. J. J. Thomson would seem to indicate an electromagnetic effect. I may add that in one of my experiments in which a vacuum was produced by the Toricellian method, I was unable to produce the luminous band, but this may have been due to the weak exciting current employed.

My principal argument is the following: I have experimentally proved that if the same discharge which is barely sufficient to excite a luminous band in the bulb when passed through the primary circuit be so directed as to exalt the electrostatic inductive effect—namely, by converting upwards—an exhausted tube, devoid of electrodes, may be excited at a distance of several feet.

EXPERIMENTS ON THE ELECTRIC DISCHARGE IN VACUUM TUBES.

The beautiful and suggestive experiments on the electric discharge in vacuum tubes, shown by Prof. J. J. Thomson on the occasion of the visit of the Physical Society to Cambridge, in May, have excited considerable attention, and the illustrated account of them, which appeared in *The Electrician* of May 22nd, has been widely reproduced both in America and in France. In America the publication of Prof. Thomson's experiments has resulted in some interesting contributions to the *Electrical Engineer* of New York, by Prof. Elihu Thomson and Mr. Nikola Tesla, who appear to have been pursuing the same fruitful line of research. The *raison d'être* and the practical bearing of the phenomena described are not as yet apparent, but they seem to be of the order likely to yield valuable results both to the devotee of pure science and the patentee; indeed, Mr. Nikola Tesla has already brought the results of some of those striking experiments of his recently made public within the cognisance of the American Patent Office. However simple the future explanation, and however far-reaching the possible practical applications of these phenomena may be, they appeal at present mainly to the students of pure science, and to them the following notes by Prof. Elihu Thomson and Mr. Nikola Tesla will be of interest:—

"I have been much interested," says Prof. Elihu Thomson, in the *New York Electrical Engineer* of June 24th, "in the account of novel phenomena given under the title 'Some Experiments on the Electric Discharge in Vacuum Tubes,' by Prof. J. J. Thomson, inasmuch as several months ago I tried the same, or a very similar, experiment. Briefly, my experiment was performed with a closed ring made of a glass tube about one inch in diameter, the external diameter of the ring being about six inches. This was exhausted and laid alongside of a single turn of heavily insulated wire, which formed part of the discharge path from the outside of a Leyden jar, arranged to be charged and discharged rapidly by a Toepler-Holtz machine. It was found that at every discharge of the jar there was a discharge in the tube giving a band of light in the vacuous space. The accompanying engraving (Fig. 1) shows the arrangement of apparatus as just described. Curiously enough, the experiment of Prof. J. J. Thomson, in which a small pellet of mercury in an exhausted tube stopped the discharge, had its counterpart in my own experiments, as follows:—I had constructed a two-way discharge tube (Fig. 2). One branch, *a*, was large in diameter, and the branch *b* was of barometer-tube section. Wires sealed at *c*, *d* enabled a discharge to be passed. A small globule of mercury was placed in the tube, and could be shaken down into the barometer tube

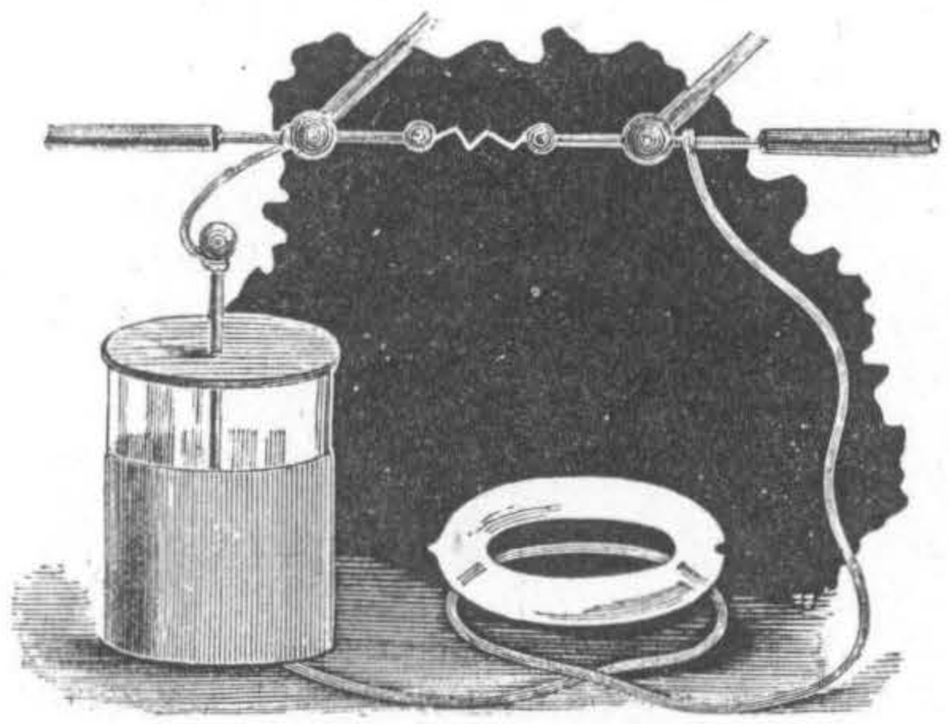


Fig. 1.

and out into the large tube at will. Though the discharge would not always divide and pass through both tubes from *c* to *d*, it sometimes did; but the interposition of the mercury globule in the small tube stopped the discharge through it.

Mr. Nikola Tesla, writing to the same journal (*Electrical Engineer of New York*, July 1), says:—"I have noted the description of some experiments of Prof. J. J. Thomson, on the 'Electric Discharge in Vacuum Tubes,' and in your issue of June 24th, Prof. Elihu Thomson describes an experiment of the same kind. The following lines are not penned with any desire on my part to put myself on record as one who has performed similar experiments, but with a desire to assist other experimenters by pointing out certain peculiarities of the phenomena observed, which, to all appearances, have not been noted by Prof. J. J. Thomson, who, however, seems to have gone about systematically in his investigations, and who has been the first to make his results known. These peculiarities noted by me would seem to be at variance with the views of Prof. J. J. Thomson, and present the phenomena in a different light.

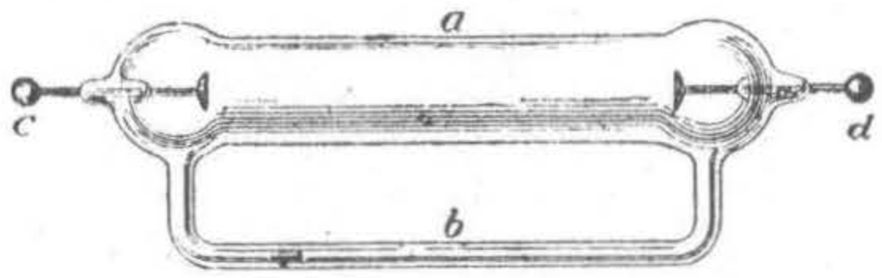


Fig. 2.

"My investigations occupied me principally during the winter and spring of the past year. During this time many different experiments were performed. Fig. 3 may serve as an example of one of the many forms of apparatus used. This consisted of a large glass tube, sealed at one end and projecting into an ordinary incandescent lamp bulb. The primary, usually consisting of a few turns of thick, well-insulated copper sheet, was inserted within the tube, the inside space of the bulb furnishing the secondary. This form of apparatus was arrived at after some experimenting, and was used principally with the view of enabling me to place a polished reflecting surface in the inside of the tube, and for this purpose the last turn of the primary was covered with a thin silver sheet.

"I have found that it is preferable to use in these experiments an alternate current machine, giving a moderate number of alternations per second, to excite the induction coil for charging the Leyden jar which discharges through the primary shown diagrammatically in Fig. 4, as in such case, before the disruptive discharge takes place, the tube or bulb is slightly excited and the formation of the luminous circle is decidedly facilitated. But I have also used a Wimshurst machine in some experiments.

"Prof. J. J. Thomson's view of the phenomena under consideration seems to be that they are wholly due to electro-magnetic action. I was, at one time, of the same opinion, but upon carefully investigating the subject I was led to the conviction that they are more of an electrostatic nature. In support of my view I will describe a few experiments

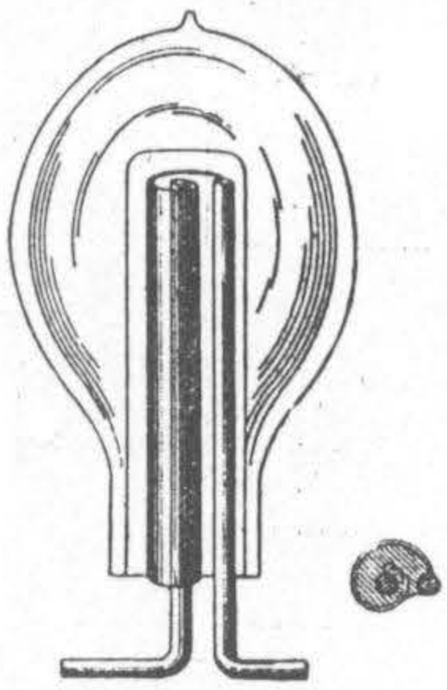


FIG. 3

made by me. To excite luminosity in the tube it is not absolutely necessary that the conductor should be closed. For instance, if an ordinary exhausted tube (preferably of large diameter) be surrounded by a spiral of thick copper wire serving as the primary, a feebly luminous spiral may be induced in the tube, roughly shown in Fig. 5. In one of these experiments a curious phenomenon was observed; namely, two intensely luminous circles, each of them close to a turn of the primary spiral, were formed inside of the tube, and I attributed this phenomenon to the existence of nodes on the primary. The circles were connected by a faint luminous spiral, parallel to the primary and in close proximity to it. To produce this effect I have found it necessary to strain the jar to the utmost. The turns of the spiral tend to close and form circles, but this, of course, would be expected, and does not necessarily indicate an electro-magnetic effect; whereas the fact that a glow can be produced along the primary in the form of an open spiral argues for an electrostatic effect.

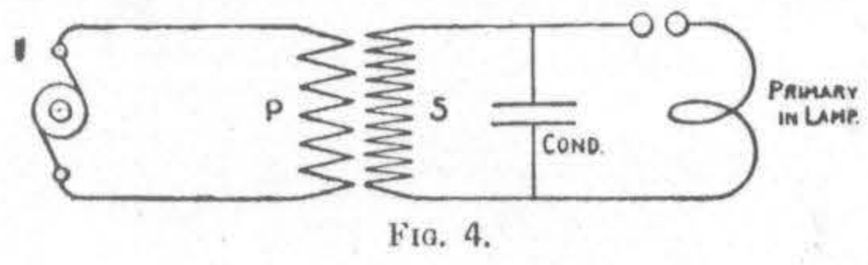


FIG. 4.

"Another experiment performed is illustrated in Fig. 6. In this case an ordinary lamp-bulb was surrounded by one or two turns of thick copper wire, P, and a luminous circle, L, excited in the bulb by discharging the jar through the primary. The lamp-bulb was provided with a tinfoil coating on the side opposite to the primary, and each time the tinfoil coating was connected to the ground, or to a large object, the luminosity of the circle was considerably increased. This was evidently due to electrostatic action.

"In other experiments I have noted that when the primary touches the glass the luminous circle is easier produced and is more sharply defined; but I have not noted that, generally speaking, the circles induced were very sharply defined, as Prof. J. J. Thomson has observed; on the contrary, in my experiments, they were broad, and often the whole of the bulb or tube was illuminated; and in one case I have observed an intensely purplish glow, to which Prof. J. J. Thomson refers. But the circles were always in close proximity to the primary, and were considerably easier produced when the latter was very close to the glass.

"Another observation made by me was that when the specific inductive capacity of the medium between the primary and secondary is increased, the inductive effect is augmented. I have likewise noted that when a bulb is surrounded by a wire closed upon itself and in the plane of the primary, the formation of the luminous circle within the bulb is not prevented. But if, instead of the wire, a broad strip of tinfoil is glued upon the bulb, the formation of the luminous band was prevented.

"Some of the experiments of Prof. J. J. Thomson also would seem to show some electrostatic action. For instance, in the experiment with the bulb enclosed in a bell jar, I should think that when the latter is exhausted so far that the gas enclosed reaches the maximum conductivity, the formation of the circle in the bulb and jar is prevented because of the space surround-

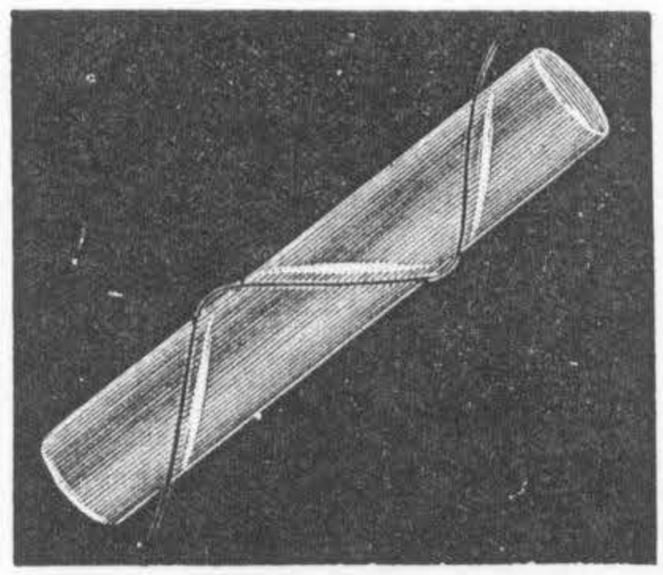


FIG 5

ing the primary being highly conducting; when the jar is further exhausted the conductivity of the space around the primary diminishes, and the circles appear necessarily first in the bell jar as the rarefied gas is nearer to the primary. But were the inductive effect very powerful they would probably appear in the bulb also. If, however, the bell jar were exhausted to the highest degree they would very likely show themselves in the bulb only—that is, supposing the vacuous space to be

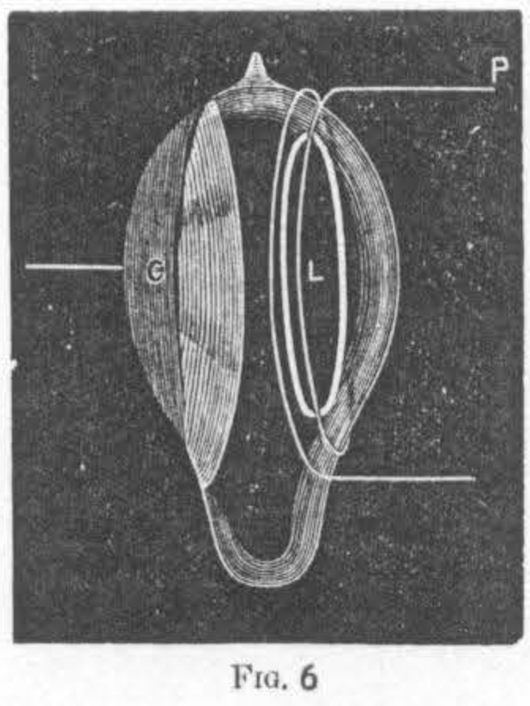


FIG. 6

non-conducting. On the assumption that in these phenomena electrostatic actions are concerned we find it easily explicable why the introduction of mercury or the heating of the bulb prevents the formation of the luminous band or shortens the after-glow; and also why, in some cases, a platinum wire may prevent the excitation of the tube. Nevertheless some of the experiments of Prof. J. J. Thomson would seem to indicate an electro-magnetic effect. I may add that in one of my experiments in which a vacuum was produced in the Toricellian method, I was unable to produce the luminous band, but this may have been due to the weak exciting current employed.

"My principal argument is the following: I have experimentally proved that if the same discharge which is barely sufficient to excite a luminous band in the bulb when passed through the primary circuit be so directed as to exalt the electrostatic inductive effect an exhausted tube, devoid of electrodes, may be excited at a distance of several feet."

Telephonic News

Tesla's Incandescent Lamp.

In the accompanying engravings are illustrated two types of improved lamps invented by Mr. Tesla, and designed for use in his recently patented system of incandescent electric lighting by means of high frequency currents. The lamp shown in Fig. 1 is designed for direct connection with a circuit or source of current; that shown in Fig. 2 is designed for inductive connection with a source of current. In the device illustrated in Fig. 1, A represents a highly vacuous glass globe, in which are sealed conductors, B, C, united with two pieces of carbon G, the joint being surrounded with bronze powder E to effect good connection. The cups surrounding the joint are filled with insulating plugs F of fire-clay. The exhaustion is carried to the highest possible point. Inasmuch as there is a tendency to sparking when the current is turned on before the exhaustion has been carried very high, the ends of the carbon are caused to approach in order that the sparks may leap across between such currents, thus lessening the danger of injury to the carbons. The distance apart of the carbons in the lamp is beyond sparking distance in the vacuum. The system in which this lamp is used, described in a late issue of the REVIEW, consists of disruptively discharging the accumulated energy of a condenser through a primary circuit to produce a current of very high frequency, and then utilizing this primary circuit to induce in a secondary a current of very much higher potential.

In Fig. 2 the carbons are not connected directly to the leading-in circuit, but are inductively connected therewith by a condenser-like arrangement. One form of such a lamp was described in the ELECTRICAL REVIEW. J J are plugs of fire-clay contained in the extensions B, B^1 of the lamp.

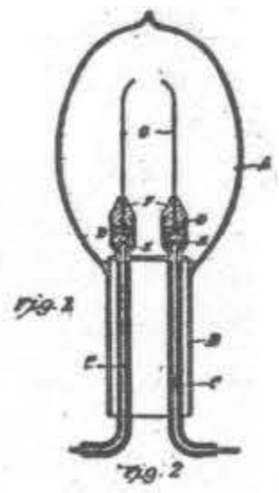
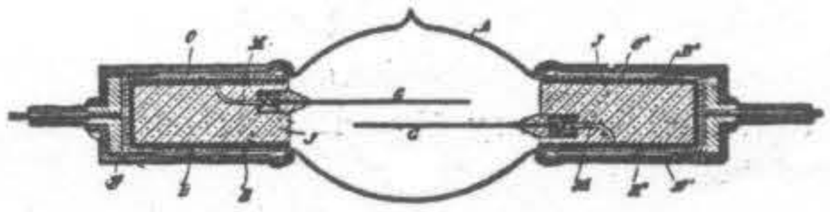


Fig. 2



The conductors G G are supported by these plugs and connected by metallic strips M with the condenser-coatings K K^1. Over the outside of the stems B B^1 are fitted insulating caps N N^1, having metallic linings O O^1, with terminals adapted for connection with the circuit wires. It will thus be seen that the carbons are out of contact with the supply conductors, and can only be acted upon inductively thereby. The incandescence to which the carbons are raised is supposed to be due to the heat developed by the rapid charge and discharge of the condenser.

SCIENCE AND PHILOSOPHY.

WHAT IS ELECTRICITY?

NIKOLA TESLA.

Electrical Review, New York, July 11.

OF all the forms of nature's all-pervading energy, which, ever changing and ever moving, like a soul animates the inert universe, those of electricity and magnetism are perhaps the most fascinating. The effects of gravitation, of heat, and light we observe daily, and soon we get accustomed to them, and soon they lose for us the character of the marvelous and wonderful; but electricity and magnetism, with their singular relationship, with their seemingly dual character, unique among the forces in nature, with their phenomena of attractions, repulsions, and rotations, stimulate and excite the mind to thought and research. We are now confident that electric and magnetic phenomena are attributable to ether; and we are, perhaps, justified in saying that the effects of static electricity are effects of ether under strain, and those of dynamic electricity and electro-magnetism effects of ether in motion. But this still leaves the question, as to what electricity and magnetism are, unanswered. First, we naturally inquire, is there such a thing as electricity? In interpreting electric phenomena, we may speak of electricity or of an electric condition, state, or effect. If we speak of electric effects, we must distinguish two effects opposite in character, and neutralizing each other. In a medium of the properties of ether we cannot exert a strain or produce a displacement or motion of any kind without causing in the surrounding medium an equivalent and opposite effect. But if we speak of electricity, meaning a thing, we must, I think, abandon the idea of two electricities. For how can we imagine that there should be two things, equivalent in amount, alike in their properties, but of opposite character, both clinging to matter, both attracting and completely neutralizing each other? If there is such a thing as electricity, there can be only one such thing, and excess and want of that one thing, possibly, though more probably its condition, determines the positive and negative character. Still, in spite of this, the theory of the two electricities is generally accepted, as it apparently explains electric phenomena in a more satisfactory manner. But a theory which explains better the facts is not necessarily true.

What, of all things, the existence of which we know, have we the best reason to call electricity? We know that it acts like an incompressible fluid; that there must be a constant quantity of it in nature; that it can be neither produced nor destroyed; and that electric and ether phenomena are identical. The idea at once suggests itself, therefore, that electricity might be ether. I must confess that I cannot believe in two electricities, much less in a doubly constituted ether. Electricity cannot be called ether in the broad sense of the term;

but nothing would seem to stand in the way of calling electricity ether associated with matter—bound ether; or, in other words, that the so-called static charge of the molecule is ether associated in some way with the molecule. Looking at it in that light, we would be justified in saying that electricity is concerned in all molecular action. Now, precisely what the ether surrounding the molecules is, wherein it differs from ether in general, can only be conjectured. It cannot differ in density, ether being incompressible; it must, therefore, be under some strain or in motion, and the latter is the more probable. To understand its functions it would be necessary to have an exact idea of the physical construction of matter.

But of all the views of nature the one which assumes one matter and one force, and a perfect uniformity throughout, is the most scientific and the most likely to be true. An infinitesimal world, with the molecules and their atoms spinning and moving in orbits in much the same manner as celestial bodies, carrying with them ether, which is probably spinning with them—in other words, carrying with them static charges—seems to my mind the most probable view; one which in a plausible manner accounts for most of the phenomena observed. The spinning of the molecules and their ether sets up ether tensions or electrostatic strains; the equalization of ether tensions sets up ether motions or electric currents, and the orbital movements produce the effects of electro and permanent magnetism. About fifteen years ago Professor Rowland demonstrated a most interesting and important fact, namely, that a static charge carried around produces the effects of an electric current. We can conceive lines or tubes of force which physically exist, being formed of rows of directed moving molecules; we can see that these lines must be closed; that they must tend to shorten and expand, etc. It likewise explains in a reasonable way the most puzzling phenomenon of all, permanent magnetism, and, in general, has all the beauties of the Ampère theory without possessing the vital defect of the same, namely, the assumption of molecular currents. Without enlarging further upon the subject I would say that I look upon all electrostatic current and magnetic phenomena as being due to electrostatic molecular forces.

We are whirling through the endless space with inconceivable speed; all around us everything is spinning, everything is moving, everywhere is energy. There must be some way of availing ourselves of this energy more directly. Then, with the light obtained from the medium, with the power derived from it, with every form of energy obtained without effort, from the store forever inexhaustible, humanity will advance with giant strides. The mere contemplation of these magnificent possibilities expands our minds, strengthens our hopes, and fills our hearts with supreme delight.

TESLA'S EXPERIMENTS WITH ALTERNATING CURRENTS OF HIGH FREQUENCY.

THE Wednesday evening session of the American Institute of Electrical Engineers was held in Prof. Dwight's room, Columbia College, and will long be remembered by those present, not only on account of the brilliant experiments shown, but also for the many possibilities which it suggested in the development of the artificial illumination of the future. For the purpose of his experiments, Mr. Tesla employed the alternating machine with 384 poles, described in the *Electrical Engineer* of March 18, 1891, which, when run at full speed, permitted him to obtain 20,000 alternations per second. The currents of this machine in all of Mr. Tesla's experiments were first run through a condenser in order to avoid the possibility of injury to the machine. The machine itself was set up in the electrical workshop of the college, and was driven by an electric motor, the speed of which could be varied by a switch on the lecture platform.

Mr. Tesla introduced his subject by the remark that modern science has been able to make rapid strides by the recognition of ether as the medium of transmission of vibrations of various forms which manifest themselves to our senses. We are therefore now able to see things in a different light than was formerly the case, and, being tolerably well able to explain them, the truth cannot be hidden much longer. The answer to the question, "What is electricity?" we were not yet prepared to give. We were justified in assuming, however, that electric phenomena are ether phenomena, and we may consider the phenomena of static electricity as phenomena of ether under strain, and those of dynamic electricity and electro magnetism as phenomena of ether in motion.

Mr. Tesla, while expressing the highest consideration for the work of Dr. Lodge, was not in entire accord with the views advanced by him, which he considered to be more of the nature of ingenious explanations than of a probable theory, Mr. Tesla contending that there can be no two electricities.

Alluding further to the electro magnetic theory of light, and to the Hertz experiments and those of Dr. Lodge and their application to the production of an efficient source of light, Mr. Tesla considered the electro magnetic waves as unavailable for the production of luminous effects, for the reason that long before we could reach the necessary frequency, the conductor would become opaque to the passage of the waves. Mr. Tesla thought that electro magnetic waves, unless they have the frequency of true light waves, cannot produce luminous effects. Not so, however, with the electrostatic waves or thrusts. These, no matter what their frequency, can excite luminous radiation. He

reasoned that the static effects in the Hertz and Lodge experiments were excessively small, due to the fact that they were produced in a practically closed coil, the spark acting as a bridge, making the coil practically continuous and depressing the potential. To obtain the desired difference of potential we must work with an open circuit generator of high potential of high frequency to enhance the electrostatic effects, and it was the recognition of this fact which led Mr. Tesla to the results he showed.

In carrying out this idea of obtaining enormous differences of potential, Mr. Tesla at once encountered the difficulty of obtaining the requisite insulation for the induction coil employed by him. His experience demonstrated that what we consider the best insulators, such as glass and rubber, are inferior to others, not formerly so considered, such as oil and wax. Mr. Tesla then started a spark coil in action, the primary of which was in connection with his alternator, which was speeded to give from 10,000 to 11,000 alternations per second. The coil emitted a clear note, which rose as the number of alternations was increased. As the discharges took place between the terminals of the coil, an exhausted Geissler tube held in proximity to the discharge did not light, but upon blowing out the arc the tube lighted up, which was due to the rise of potential caused by the rupture of the arc. This effect Mr. Tesla considered as purely electrostatic.

Mr. Tesla then showed the influence of insulated bodies having considerable size upon the spark length, demonstrating the effect of capacity upon the nature of the discharge. Thus when we attach an insulated body to the terminal of the coil, the potential may be raised or lowered. He showed this by wrapping an insulated wire of about one foot in length about one terminal of the coil and touching the other terminal with a brass sphere held in the hand; under these conditions streams of light emanated from all sides of the wire. When the sphere was removed, however, the streams disappeared almost entirely. He then cut off the wire in successive lengths, and the stream discharges became more marked and brilliant. He then attached a fine platinum wire to the terminal, which also showed the streams to a remarkable degree, and kept up a continuous vibration to and fro. He also showed a pinwheel effect, the wheel being rapidly rotated, with streams issuing from the two points. Another experiment consisted in attaching two spheres of about four inches diameter to the terminals. The spark passes first between the two points nearest to each other on the spheres, then works up toward their tops, is extinguished and re-established at the first point, this being continuously repeated. The neighboring exhausted tubes and lamps were illuminated and extinguished in unison with the action of the spark between the spheres.

These Mr. Tesla pointed out were not electro magnetic vibrations like the Hertz waves. He showed how by the use of the dielectric the spark is induced to jump between the separated spheres, due to the increase in the specific inductive capacity of the medium, and he also demonstrated that the streaming discharge passed easily through thick glass plates, rubber plates, and a book. Mr. Tesla then showed these static effects in a non-striking vacuum. A tube of this nature when connected to the machine glowed brightly, and the terminals became incandescent. Mr. Tesla then remarked that if, instead of using a filament in a lamp—which necessarily limited us in the degree of incandescence which we could practically employ—we could employ solid blocks of carbon, much higher efficiency could be obtained. Based upon this reasoning, he had constructed a lamp which he showed, containing two blocks of carbon in a non-striking vacuum. When connecting these two carbons to the two terminals of the coil, or one to one terminal and the other to a body of some size, the blocks can be raised to high incandescence.

Mr. Tesla also showed a lamp with but a single rod filament in a non-striking vacuum with no outward connection. The energy is entirely transferred by condenser action through the medium of condenser coatings in the base of the lamp. He also pointed out how the brilliancy of the lamp could be varied by simply altering the relative positions of the condenser coatings. This Mr. Tesla followed by demonstration of the phenomena with an unexhausted globe, and a single filament mounted therein. The filament when connected to one terminal of the coil heats up to bright incandescence and spins around in the globe. He also demonstrated the heating by the use of Crookes' well known apparatus consisting of mica vanes mounted above a platinum wire, which was brought to incandescence by connection with one terminal of the coil, and rotated the mica vanes.

In order to still further verify the conclusions that the electrostatic effects are alone active, Mr. Tesla placed a Geissler tube at right angles to the coil and at its center. In this position the tube did not light up. When placed at the ends, however, the tube lit up brilliantly and gave sufficient light to read by. Mr. Tesla showed both uranium and yttria tubes.

He then showed how exhausted tubes could be made to glow in an electrostatic field. For this purpose two large sheets of zinc were connected to the terminals of the machine at a distance of about 15 feet apart. The tube when placed between these sheets glowed brilliantly and could be moved about freely. Mr. Tesla remarked that, by merely creating such a field in a room, the mere suspension of the tubes in the room would afford the desired illumination.

Coming to the physiological effects, Mr. Tesla adjusted the conditions so that by touching one terminal with a brass sphere he raised the potential of the coil so enormously that a stream of light came out on the other terminal, and he estimated the difference of potential to be nearly 250,000 volts, and then performed the remarkable experiment of receiving the total discharge through his body, protecting his hands from burning by the brass balls held in his hands.

He then lit up lamps by holding them in contact with one terminal or near to the coil.

The lecturer then came to another class of experiments. He stated that he had used a system of conversion from high tension to low with the enormous frequencies of the condenser discharges. Mr. Tesla then showed an interesting experiment, which consisted in passing the converted currents, produced in the manner just described, through a copper bar ⅜ inch in diameter and bent into a loop. Ordinarily such a bar would constitute a short circuit, but Mr. Tesla succeeded in bringing lamps stretched across the parallel sides of the bar to incandescence, demonstrating that the impedance in the loop connecting the two sides was so great as to practically prevent the current from passing through it, and hence acting upon the lamps in the manner described. He also pointed out the existence of modes on the bar. His method consists in continuously charging and disruptively discharging a condenser into the working circuit, the charging of the condenser being effected by a coil operated either by alternating or direct currents. By this means any desired higher frequency may be obtained from any lower frequency.

Mr. Tesla concluded his experiments by exhibiting in action a simple alternate current arc lamp, operated by currents direct from the machine, giving 20,000 alternations per second. The light was beautifully steady and the arc entirely free from the hum accompanying arcs operated with currents of low frequency.

We have given but the merest outline of the many beautiful and highly suggestive experiments made by Mr. Tesla. Notwithstanding the fact that Mr. Tesla excited the intensest interest of his audience for three hours, he was nevertheless unable, for lack of time, to bring before them many experiments, some of which, he said, were even of a more striking nature than those brought out.—*Electrical Engineer.*

TESLA'S ELECTROLYTIC METER.

THE measurement of the quantity of current taken by consumers has given rise to a large variety of meters, one type among these being what are known as electrolytic meters. Probably the best known of this class is the Edison meter in which the quantity or weight of metal deposited from one plate upon another affords a measure of the current passed through the circuit. In other forms the quantity of gas decomposed by the passage of the current gives the desired indication.

In seeking to employ the electrolytic deposition of a metal for this purpose, but to avoid the manipulation required in weighing the plates in order to ascertain the loss in weight, Mr. Nikola Tesla makes use of an electrolytic cell, through which extend two conductors parallel and in close proximity to each other. These conductors are connected in series through a resistance, but in such manner that there is an equal difference of potential between them throughout their entire extent. The terminals of the conductors are connected either in series in the circuit supplying the current to the lamps or other devices, or in parallel to a resistance in the circuit, and in series with the translating devices. Under such circumstances a current passing through the conductors establishes a difference of potential between them which is proportional to the strength of the current, in consequence of which there is a leakage of current from one conductor to the other across the solution. The strength of this leakage current is proportional to the difference of potential, and, therefore, in proportion to the strength of the current passing through the conductors. Moreover, as there is a constant difference of potential between the two conductors throughout the entire extent that is exposed to the solution, the current density through such solution is the same at all corresponding points, and hence the deposit is uniform along the whole of one of the conductors, while the metal is taken away uniformly from the other. The resistance of one conductor is by this means diminished, while that of the other is increased, both in proportion to the strength of the current passing through them. From such variation in the resistance of either or both of the conductors forming the positive and negative electrodes of the cell, the current energy expended may be readily computed.

The accompanying diagrams show the meter in operative relations to a working circuit, and under slightly modified arrangements.

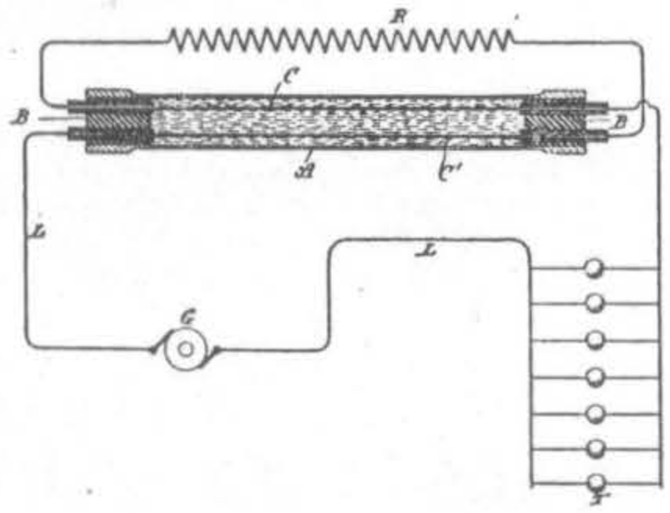


FIG. 1.—TESLA'S ELECTROLYTIC METER.

In Fig. 1, G designates a direct current generator. L L are the conductors of the circuit including lamps or other translating devices T. A is a glass tube, the ends of which are sealed by means of insulating plugs or caps B B. C C′ are two conductors extending through the tube A, their ends passing out through the plugs B to terminals. R is a resistance connected in series with the two conductors C C′, which by their free terminals are connected up in the circuit of one of the conductors L.

The method of using this device, and computing by its means the energy of the current, will be readily understood. First, the resistances of the two conductors C and C′, respectively, are accurately measured and noted. Then a known current is passed through the instrument for a given time, and by a second measurement the increase and diminution of the resistances of the two conductors respectively taken. From these data the constant is obtained, that is to say, for example, the increase of resistance of one conductor or the diminution of the resistance of the other per lamp-hour. These two measurements serve as a check, since the gain of one conductor should equal the loss of the other. A further check is afforded by measuring both wires in series with the resistance, in which case the resistance of the whole should remain constant.

In Fig. 2 the conductors C C′ are connected in parallel,

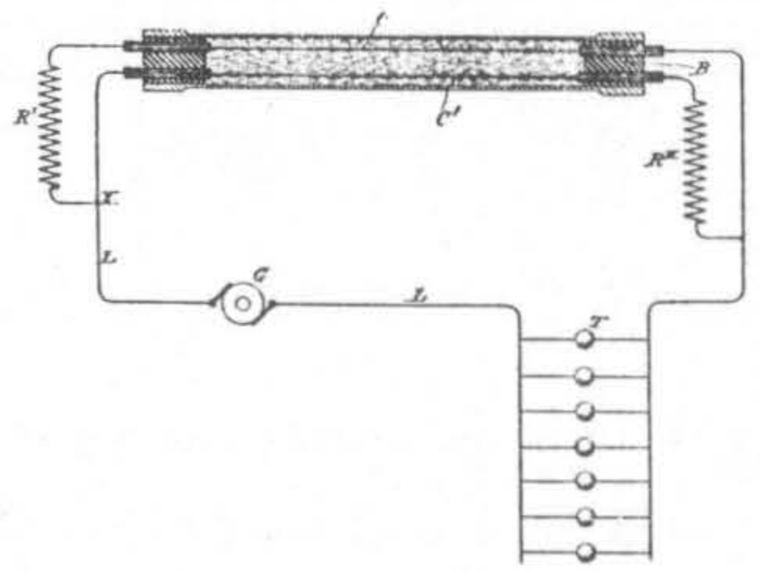


FIG. 2.—TESLA'S ELECTROLYTIC METER.

the current device at X passing in one branch first through a resistance R′ and then through conductor C, while in the other branch it passes first through conductor C′, and then through resistance R″. The resistances R′ R″ are equal, as also are the resistances of the conductors C C′. It will be observed that in the arrangement shown in Fig. 2 there is a constant potential difference between the two conductors C C′ throughout their entire length.

It will be seen that in both cases illustrated, the proportionality of the increase or decrease of resistance to the current strength will always be preserved, for what one conductor gains the other loses, and the resistances of the conductors C C′ are small as compared with the resistances in series with them. After each measurement or registration of a given variation of resistance in one or both conductors, the direction of the current should be changed or the instrument reversed, so that the deposit will be taken from the conductor which has gained and added to that which has lost. By this method it is possible to read off directly the amount of the energy expended by means of a properly-constructed ohm-meter, and without resorting to weighing the deposit; it is not necessary to employ shunts, for the whole of the current to be measured may be passed through the instrument; and the accuracy of the instrument, and correctness of the indications, are but slightly affected by changes in temperature. In addition to these advantages the arrangement possesses the merit of economy of energy, and simplicity in construction.

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TESLA'S EXPERIMENTS.

SINCE the publication of the experiments of Hertz and Lodge, one subject has been prominently brought before the electrical world, and has engaged the serious attention of many men; that is, the question of the production of light without the enormous waste of energy which all methods hitherto used have entailed.

Among those who have been devoting much time and trouble to this subject is Mr. Nikola Tesla, and the full text of his researches is now published, and certainly form the finest contribution to practical electricity that has appeared for some time. In it he points the way to what would seem to be a highly probable solution of the problem under consideration, and has even gone a good way in the actual utilisation of the solution he indicates.

Some electrical engineers have for a considerable time been looking in the direction of greatly increased frequency as a means of much improving our present state of alternate current distribution systems, and in February of the present year, during the discussion on Mr. Swinburne's paper on "Transformer Distribution," at the Institution of Electrical Engineers, Mr. Evershed pointed out that the use of high frequency would enable us to greatly reduce the bulk, and possibly increase the efficiency, of present transformers. It is by the employment of immensely high frequencies, and the almost necessarily following high potentials, that Mr. Tesla has been able to arrive at his wonderful results.

This high frequency he got in two ways. Machines giving as many as 20,000 to 30,000 alternations per second were constructed and used as the source of current, but if higher frequencies were required, a second circuit was taken from a Leyden jar; this was charged from a coil, and the time constant of the second circuit so arranged as to give an oscillating current on discharge; by this means far higher frequencies were obtainable. In this case we have the condenser acting like a frequency-transformer as well as a potential-transformer. Having thus provided his source of current, Mr. Tesla proceeded with the experiments. They are of so interesting and extensive a character, that it is impossible to do more than refer to a few of the more striking. Lamps with a single block of refractory substance were rendered luminous with only one lead to them; and further than this, by exciting a high potential alternating field, it was found possible to light up tubes in a room with *no* leads at all. These effects were found to be all due to electrostatic waves, and not at all to the electro-magnetic ones. A third very beautiful experiment was to excite a stationary vibration in a very thick copper lead, and to light up lamps by joining them across two ventral segments, thus giving a lamp burning brightly though short circuited. The ordinary brush discharge becomes under the conditions of these experiments an actual flame, resembling in all points save the absence of combustion, an ordinary gas flame.

In all the experiments the insulators as well as conductors got considerably heated. It is very probable that this is due to "hysteresis of K."

The practical issues touched on and suggested by Mr. Tesla are also of great importance to both instrument makers and engineers. He shows that the probable cause of the too frequent break-down of high pressure induction coils is due to the molecular impacts of the air layer intervening between primary and secondary, and consequently all such coils should (if possible) be constructed with a continuous insulation; for this purpose oil would seem a very useful body, and the oil induction coil will probably supersede the ordinary one for all purposes other than medical purposes or for very elementary work. He also points the way to the practical use of condensers in engineering. At present the condenser required to pass any considerable amount of energy would in general be rather bulky, but by the use of very high frequencies the size required may be greatly reduced both for transforming and transmitting energy. He also makes the highly ingenious suggestion of allowing the iron core of a transformer to heat itself up by means of Foucault currents and hysteresis losses to the temperature of maximum permeability. Allowing for the increased space required to surround the iron by fire-proof materials, this would itself greatly diminish the section of iron necessary to carry the flow of

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION.*

BY NIKOLA TESLA.

THERE is no subject more captivating, more worthy of study, than nature. To understand this great mechanism, to discover the forces which are active, and the laws which govern them, is the highest aim of the intellect of man.

Nature has stored up in the universe infinite energy. The eternal recipient and transmitter of this infinite energy is the ether. The recognition of the existence of ether, and of the functions it performs, is one of the most important results of modern scientific research. The mere abandoning of the idea of action at a distance, the assumption of a medium pervading all space and connecting all gross matter, has freed the minds of thinkers of an ever-present doubt, and, by opening a new horizon—new and unforeseen possibilities—has given fresh interest to phenomena with which we are familiar of old. It has been a great step towards the understanding of the forces of nature and their multifold manifestations to our senses. It has been for the enlightened student of physics what the understanding of the mechanism of the firearm or of the steam engine was for the barbarian. Phenomena upon which we used to look as wonders baffling explanation, we now see in a different light. The spark of an induction coil, the glow of an incandescent lamp, the manifestations of the mechanical forces of currents and magnets are no longer beyond our grasp; instead of the incomprehensible, as before, their observation suggests now in our minds a simple mechanism, and although as to its precise nature all is still conjecture, yet we know that the truth cannot be much longer hidden, and instinctively we feel that the understanding is dawning upon us. We still admire these beautiful phenomena, these strange forces, but we are helpless no longer; we can in a certain measure explain them, account for them, and we are hopeful of finally succeeding in unravelling the mystery which surrounds them.

In how far we can understand the world around us is the ultimate thought of every student of nature. The coarseness of our senses prevents us from recognising the ulterior construction of matter, and astronomy, this grandest and most positive of natural sciences, can only teach us something that happens, as it were, in our immediate neighbourhood: of the remoter portions of the boundless universe, with its numberless stars and suns, we know nothing. But far beyond the limit of perception of our senses the spirit still can guide us, and so we may hope, that even these unknown worlds—infinitely small and great—may in a measure become known to us. Still, even if this knowledge should reach us, the searching mind will find a barrier, perhaps for ever unsurpassable, to the *true* recognition of that which *seems* to be, the mere *appearance*, of which is the only and slender basis of all our philosophy.

Of all the forms of nature's immeasurable, all-pervading energy, which ever and ever changing and moving, like a soul animates the inert universe, those of electricity and magnetism are perhaps the most fascinating. The effects of gravitation, of heat and light we observe daily, and soon we get accustomed to them, and soon they lose for us the character of the marvellous and wonderful; but electricity and magnetism, with their singular relationship, with their seemingly dual character, unique among the forces in nature, with their phenomena of attractions, repulsions and rotations, strange manifestations of mysterious agents, stimulate and excite the mind to thought and research. What is electricity, and what is magnetism? These questions have been asked again and again. The most able intellects have ceaselessly wrestled with the problem; still the question has not as yet been fully answered. But while we cannot even to-day state what these singular forces are, yet we have made good headway towards the solution of the problem. We are now confident that electric and magnetic phenomena are attributable to ether, and we are perhaps justified in saying that the effects of static electricity are effects of ether under strain, and those of dynamic electricity and electro-magnetism effects of ether in motion. But this still leaves the question, as to what electricity and magnetism are, unanswered.

First, we naturally inquire, What is electricity, and is there such a thing as electricity? In interpreting electric phenomena, we may speak of electricity or of an electric condition, state, or effect. If we speak of electric effects, we must distinguish two such effects, opposite in character and neutralising each other, as observation shows that two such opposite effects exist. This is unavoidable, for in a medium of the properties of ether we cannot possibly exert a strain or produce a displacement or motion of any kind, without causing in the surrounding medium an equivalent and opposite effect. But if we speak of electricity, meaning a *thing*, we must, I think, abandon the idea of two electricities, as the existence of two such things is highly improbable. For how can we imagine that there should be two things, equivalent in amount, alike in their properties, but of opposite character, both clinging to matter, both attracting and completely neutralising each other? Such an assumption, though suggested by many phenomena, though most convenient for explaining them, has little to commend it. If there *is* such a thing as electricity, there can be only *one* such thing, and excess and want of that one thing, possibly; but more probably its condition determines the positive and negative character. The old theory of Franklin, though falling short in some respects, is, from a certain point of view, after all, the most plausible one. Still, in spite of this, the theory of the two electricities is generally accepted, as it apparently explains electric phenomena in a more satisfactory manner. But a theory which better explains the facts is not necessarily true. Ingenious minds will invent theories to suit observation, and almost every independent thinker has his own views on the subject.

It is not with the object of advancing an opinion, but with the desire of acquainting you better with some of the results, which I will describe, to show you the reasoning I have followed, the departures I have made—that I venture to express in a few words the views and convictions which have led me to these results.

I adhere to the idea that there is a thing which we have been in the habit of calling electricity. The question is, What is that thing? or What, of all things, the existence of which we know, have we the best reason to call electricity? We know that it acts like an incompressible fluid; that there must be a constant quantity of it in nature; that it can be neither produced nor destroyed; and, what is more important, the electro-magnetic theory of light and all facts observed teach us that electric and ether phenomena are identical. The idea at once suggests itself, therefore, that electricity might be called ether. In fact, this view has in a certain sense been advanced by Dr. Lodge. His interesting work has been read by everyone, and many have been convinced by his arguments. His great ability and the interesting nature of the subject keep the reader spellbound; but when the impressions fade, one realises that he has to deal only with ingenious explanations. I must confess that I cannot believe in two electricities, much less in a doubly-constituted ether. The puzzling behaviour of the ether as a solid to waves of light and heat, and as a fluid to the motion of bodies through it, is certainly explained in the most natural and satisfactory manner by assuming it to be in motion, as Sir William Thomson has suggested; but regardless of this, there is nothing which would enable us to conclude with certainty that, while a fluid is not capable of transmitting transverse vibrations of a few hundred or thousand per second, it might not be capable of transmitting such vibrations when they range into hundreds of million millions per second. Nor can anyone prove that there are transverse ether waves emitted from an alternate current machine, giving a small number of alternations per second; to such slow disturbances, the ether, if at rest, may behave as a true fluid.

Returning to the subject, and bearing in mind that the existence of two electricities is, to say the least, highly improbable, we must remember that we have no evidence of electricity, nor can we hope to get it, unless gross matter is present. Electricity, therefore, cannot be called ether in the broad sense of the term; but nothing would seem to stand in the way of calling electricity ether associated with matter, or bound ether; or, in other words, that the so-called static

* A lecture delivered before the American Institute of Electrical Engineers, at Columbia College, N.Y., May 20th, 1891.

lines, as the permeability could be increased about sixteen times in this manner, and consequently a considerable reduction in size of all transformers would be effected.

It is impossible to read Mr. Tesla's epoch making paper without admiration at the clearness of view and ingenuity of mind exhibited throughout. It would seem that we are at last fairly progressing towards a means of transforming energy into any form we wish without such a disastrous loss of availability as is now inevitable, and a large measure of the credit must be given to Mr. Tesla for helping so much forward this great end.

charge of the molecule is ether associated in some way with the molecule. Looking at it in that light, we would be justified in saying that electricity is concerned in all molecular actions.

Now, precisely what the ether surrounding the molecules is, wherein it differs from ether in general, can only be conjectured. It cannot differ in density, ether being incompressible; it must, therefore, be under some strain or in motion, and the latter is most probable. To understand its functions, it would be necessary to have an exact idea of the physical construction of matter, of which, of course, we can only form a mental picture.

But of all the views on nature, the one which assumes one matter and one force, and a perfect uniformity throughout, is the most scientific and most likely to be true. An infinitesimal world, with the molecules and their atoms spinning and moving in orbits, in much the same manner as celestial bodies, carrying with them, and probably spinning with them, ether, or, in other words, carrying with them static charges, seems to my mind the most probable view, and one which, in a plausible manner, accounts for most of the phenomena observed. The spinning of the molecules and their ether sets up ether tensions or electrostatic strains; the equalisation of ether tensions sets up ether motions or electric currents, and the orbital movements produced the effects of electro and permanent magnetism.

About 15 years ago, Prof. Rowland demonstrated a most interesting and important fact, namely, that a static charge carried around produces the effects of an electric current. Leaving out of consideration the precise nature of the mechanism, which produces the attraction and repulsion of currents, and conceiving the electrostatically charged molecules in motion, this experimental fact gives us a fair idea of magnetism. We can conceive lines or tubes of force which physically exist being formed of rows of directed moving molecules; we can see that these lines must be closed: that they must tend to shorten and expand, &c. It likewise explains in a reasonable way the most puzzling phenomenon of all, permanent magnetism, and, in general, has all the beauties of the Ampère theory without possessing the vital defect of the same, namely, the assumption of molecular currents. Without enlarging further upon the subject, I would say that I look upon all electrostatic current and magnetic phenomena as being due to electrostatic molecular forces.

The preceding remarks I have deemed necessary to a full understanding of the subject as it presents itself to my mind.

Of all these phenomena the most important to study are the current phenomena, on account of the already extensive and ever-growing use of currents for industrial purposes. It is now a century since the first practical source of current has been produced, and, ever since, the phenomena which accompany the flow of currents have been diligently studied, and through the untiring efforts of scientific men, the simple laws which govern them have been discovered. But these laws were found to hold good only when the currents are of a steady character. When the currents are rapidly varying in strength, quite different phenomena, often unexpected, present themselves, and quite different laws hold good, which even now have not been determined as fully as is desirable, though through the work, principally of English scientists, enough knowledge has been gained on the subject to enable us to treat simple cases which now present themselves in daily practice.

The phenomena which are peculiar to the changing character of the currents are greatly exalted when the rate of change is increased, hence the study of these currents is considerably facilitated by the employment of properly constructed apparatus. It was with this and other objects in view that I constructed alternate current machines capable of giving more than two million reversals of current per minute, and to this circumstance it is principally due that I am able to bring to your attention some of the results thus far reached, which I hope will prove to be a step in advance on account of their direct bearing upon one of the most important problems, namely, the production of a practical and efficient source of light.

The study of such rapidly alternating currents is very interesting. Nearly every experiment discloses something new. Many results may, of course, be predicted, but many more are unforeseen. The experimenter makes many interesting observations. For instance, we take a piece of iron and hold it against a magnet. Starting from low alternations, and running up higher and higher, we feel the impulses succeed each other faster and faster, get weaker and weaker, and finally disappear. We then observe a continuous pull; the pull, of course, is not continuous; it only appears so to us; our sense of touch is imperfect.

We may next establish an arc between the electrodes and observe as the alternations rise, that the note which accompanies alternating arcs gets shriller and shriller, gradually weakens, and finally ceases. The air vibrations, of course, continue, but they are too weak to be perceived; our sense of hearing fails us.

We observe the small physiological effects, the rapid heating of the iron cores and conductors, curious inductive effects, interesting condenser phenomena, and still more interesting light phenomena with a high tension induction coil. All these experiments and observations would be of the greatest interest to the student, but their description would lead me too far from the principal subject. Partly for this reason, and partly on account of the vastly greater importance, I will confine myself to the description of the light effects produced by these currents.

In the experiments to this end a high tension induction coil or equivalent apparatus for converting currents of comparatively low- into currents of high tension is used.

If you will be sufficiently interested in the results I shall describe as to enter into an experimental study of this subject; if you will be convinced of the truth of the arguments I shall advance, your aim will be to produce high frequencies and high potentials; in other words, powerful electrostatic effects. You will then encounter many difficulties, which, if completely overcome, would allow us to produce truly wonderful results.

First will be met the difficulty of obtaining the required frequencies by means of mechanical apparatus, and, if they be obtained otherwise, obstacles of a different nature will present themselves. Next it will be found difficult to provide the requisite insulation without considerably increasing the size of the apparatus, for the potentials required are high, and, owing to the rapidity of the alternations, the insulation presents peculiar difficulties. So, for instance, when a gas is present, the discharge may work, by the molecular bombardment of the gas and consequent heating, through as much as an inch of the best solid insulating material, such as glass, hard rubber, porcelain, sealing wax, &c.; in fact, through any known insulating substance. The chief requisite in the insulation of the apparatus is, therefore, the exclusion of any gaseous matter.

In general my experience tends to show that bodies which possess the highest specific inductive capacity, such as glass, afford a rather inferior insulation to others, which, while they are good insulators, have a much smaller specific inductive capacity, such as oils, for instance, the dielectric losses being no doubt greater in the former. The difficulty of insulating, of course, only exists when the potentials are excessively high, for with potentials such as a few thousand volts there is no particular difficulty encountered in conveying currents from a machine giving, say 20,000 alternations per second, to quite a distance. This number of alternations, however, is by far too small for many purposes, though quite sufficient for some practical applications. This difficulty of insulating is fortunately not a vital drawback; it affects mostly the size of the apparatus, for, when excessively high potentials would be used, the light-giving devices would be located not far from the apparatus, and often they would be quite close to it. As the air bombardment of the insulated wire is dependent on condenser action, the loss may be reduced to a trifle by using excessively thin wires heavily insulated.

Another difficulty will be encountered in the capacity and self-induction necessarily possessed by the coil. If the coil be large, that is, if it contain a great length of wire, it will be generally unsuited for excessively high frequencies; if it be small, it may be well adapted for such frequencies, but the potential might then not be as high as desired. A good insulator, and preferably one possessing a small specific inductive capacity, would afford a two-fold advantage. First, it would enable us to construct a very small coil capable of withstanding enormous differences of potential; and secondly, such a small coil, by reason of its smaller capacity and self-induction, would be capable of a quicker and more vigorous vibration. The problem, then, of constructing a coil or induction apparatus of any kind possessing the requisite qualities I regard as one of no small importance, and it has occupied me for a considerable time.

The investigator who desires to repeat the experiments which I will describe, with an alternate current machine, capable of supplying currents of the desired frequency, and an induction coil, will do well to take the primary coil out and mount the secondary in such a manner as to be able to look through the tube upon which the secondary is wound. He will then be able to observe the streams which pass from the primary to the insulating tube, and from their intensity he will know how far he can strain the coil. Without this precaution he is sure to injure the insulation. This arrangement permits, however, an easy exchange of the primaries, which is desirable in these experiments.

The selection of the type of machine best suited for the purpose must be left to the judgment of the experimenter. There are here illustrated three distinct types of machines, which, besides others, I have used in my experiments.

Fig. 1 represents the machine used in my experiments before this Institute. The field magnet consists of a ring of wrought iron with

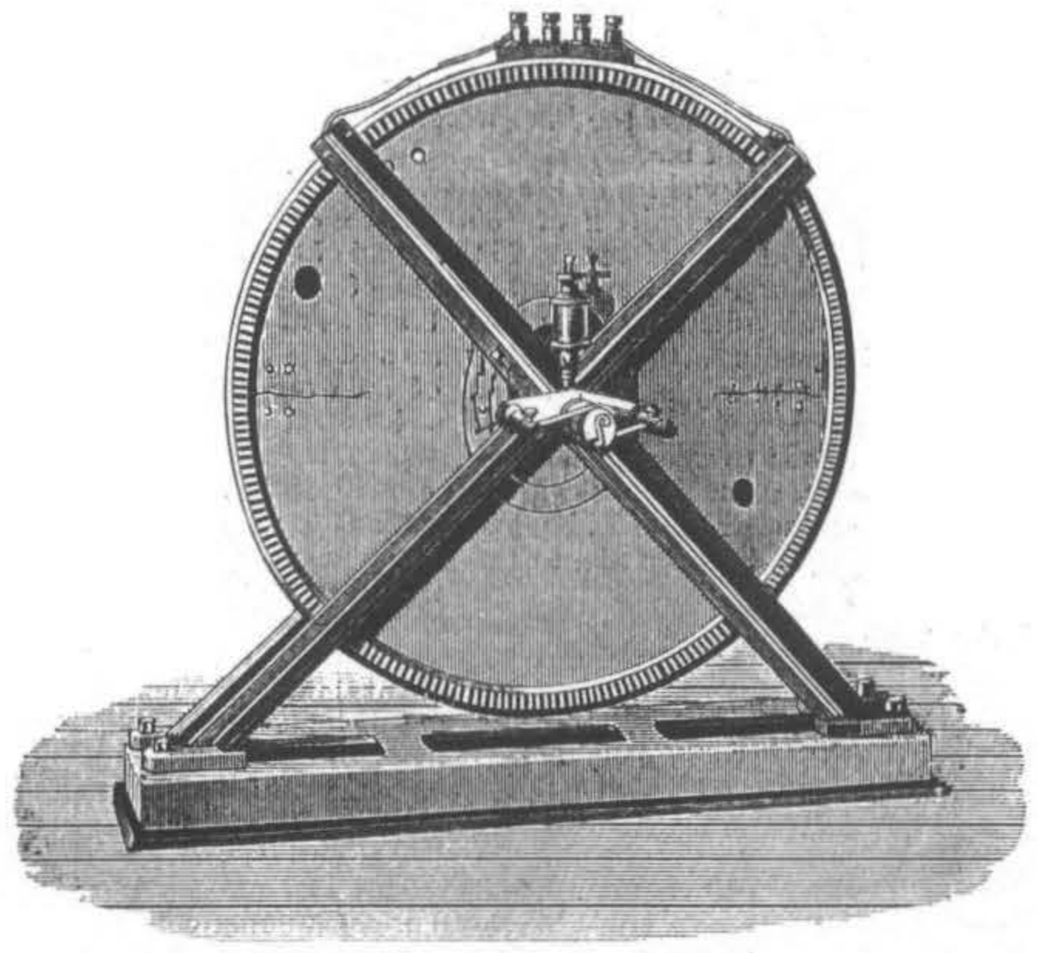


FIG. 1.—HIGH FREQUENCY ALTERNATOR WITH DRUM ARMATURE.

384 pole projections. The armature comprises a steel disc to which is fastened a thin, carefully welded rim of wrought iron. Upon the rim are wound several layers of fine, well-annealed iron wire, which when wound is passed through shellac. The armature wires are wound around brass pins, wrapped with silk thread. The diameter of the armature wire in this type of machine should not be more than

one-sixth of the thickness of the pole projections, else the local action will be considerable.

Fig. 2 represents a larger machine of a different type. The field magnet of this machine consists of two like parts which either enclose an exciting coil, or else are independently wound. Each part has 480 pole projections, the projections of one facing those of the other. The armature consists of a wheel of hard bronze, carrying the conductors which revolve between the projections of the field magnet.

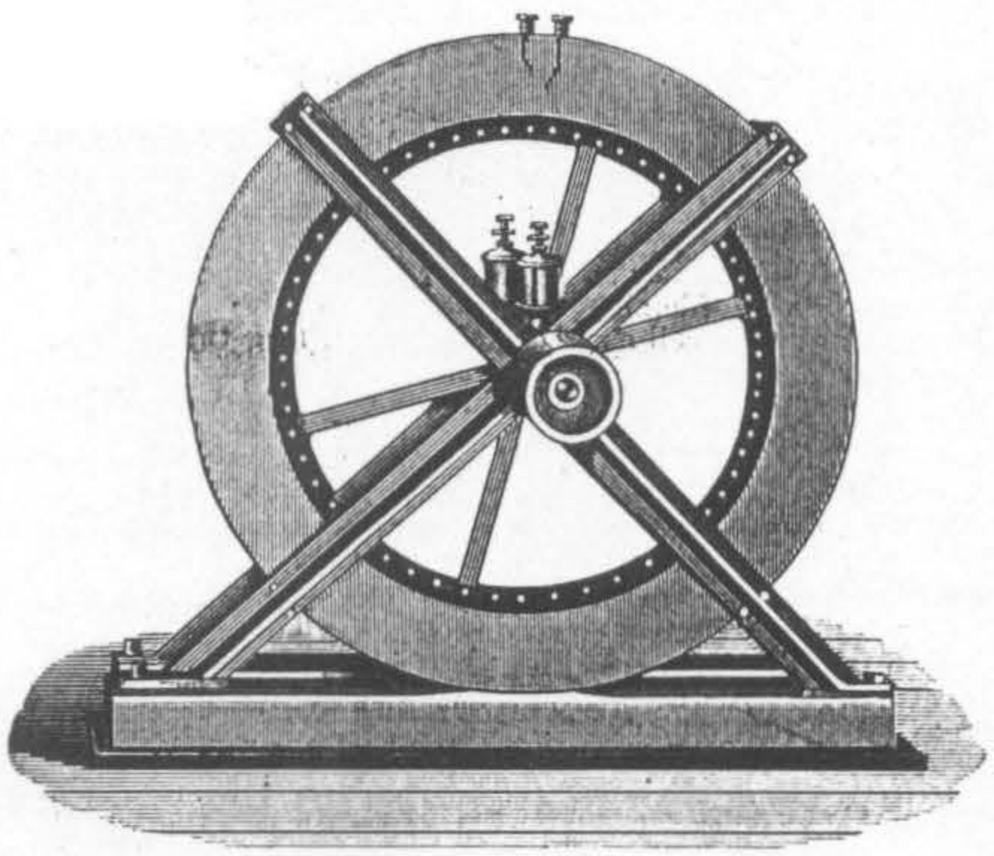


FIG. 2.

HIGH FREQUENCY ALTERNATOR WITH REVOLVING DISC ARMATURE.

To wind the armature conductors, I have found it most convenient to proceed in the following manner: I construct a ring of hard bronze of the required size. This ring and the rim of the wheel are provided with the proper number of pins, and both fastened upon a plate. The armature conductors being wound, the pins are cut off and the ends of the conductors fastened by two rings which screw to the bronze ring and the rim of the wheel respectively. The whole may then be taken off and forms a solid structure. The conductors in such a type of machine should consist of sheet copper, the thickness of which, of course, depends on the thickness of the pole projections; or else twisted thin wires should be employed.

Fig. 3 is a smaller machine, in many respects similar to the former, only here the armature conductors and the exciting coil are kept stationary, while only a block of wrought iron is revolved.

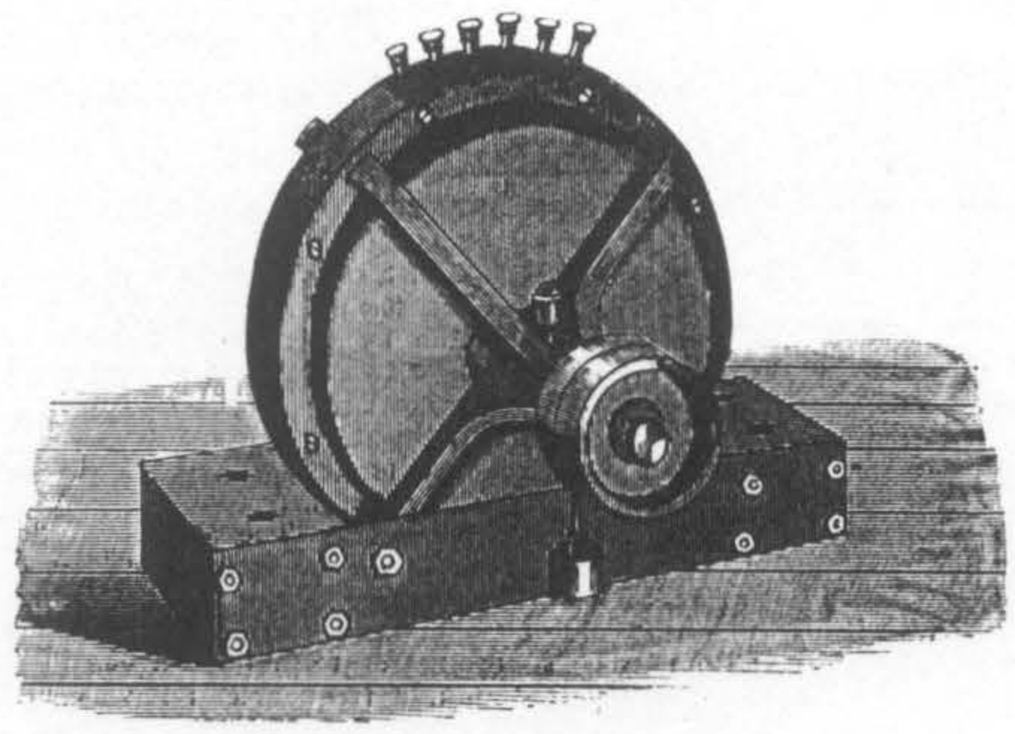


FIG. 3.—HIGH FREQUENCY ALTERNATOR WITH STATIONARY DISC ARMATURE AND STATIONARY EXCITING COIL.

It would be uselessly lengthening this description were I to dwell more on the details of construction of these machines. I deem it well, however, to call the attention of the investigator to two things, the importance of which, though self evident, he is nevertheless apt to underestimate; namely, to the local action in the conductors, which must be carefully avoided, and to the clearance, which must be small. I may add that, since it is desirable to use very high peripheral speeds, the armature should be of very large diameter, in order to avoid impracticable belt speeds. Of the several types of these machines which have been constructed by me, I have found that the type illustrated in fig. 1 caused me the least trouble in construction, as well as in maintenance, and, on the whole, it has been a good experimental machine.

In operating an induction coil with very rapidly alternating currents, among the first luminous phenomena noticed are naturally those presented by the high tension discharge. As the number of alternations per second is increased, or as—the number being high—the current through the primary is varied, the discharge gradually changes in appearance. It would be difficult to describe the minor changes which occur, and the conditions which bring them about, but one may note five distinct forms of the discharge.

First, one may observe a weak, sensitive discharge in the form of a thin, feeble coloured thread (fig. 4). It always occurs when the number of alternations per second being high, the current through the primary is very small. In spite of the excessively small current, the rate of change is great, and the difference of potential at the terminals of the secondary is therefore considerable, so that the arc is established at great distances; but the quantity of "electricity" set in motion is insignificant, barely sufficient to maintain a thin, thread-like arc. It is excessively sensitive, and may be made so to such a degree, that the mere act of breathing near the coil will affect it, and unless it is perfectly well protected from currents of air, it wriggles around constantly. Nevertheless, it is in this form excessively persistent, and when the terminals are approached to, say one-third of the striking distance, it can be blown out only with difficulty. This exceptional persistency, when short, is largely due to the arc being excessively thin, presenting therefore, a very small surface to the blast. Its great sensitiveness, when very long, is probably due to the motion of the particles of dust suspended in the air.

When the current through the primary is increased, the discharge gets broader and stronger, and the effect of the capacity of the coil becomes visible until, finally, under proper conditions, a white flaming arc, fig. 5, often as thick as one's finger, and striking across the whole coil, is produced. It develops remarkable heat, and may be further characterised by the absence of the high note which accompanies the less powerful discharges. To take a shock from the coil under these conditions would not be advisable, although under different conditions the potential being much higher, a shock from the coil may be taken with impunity. To produce this kind of discharge the number of alternations per second must not be too great for the coil used; and, generally speaking, certain relations between capacity, self-induction and frequency must be observed.

The importance of these elements in an alternate current circuit is now well known, and, under ordinary conditions, the general rules are applicable. But in an induction coil exceptional conditions prevail. First, the self-induction is of little importance before the arc is established, when it asserts itself, but perhaps never as prominently as in ordinary alternate current circuits, because capacity is distributed all along the coil, and by reason of the fact that the coil usually discharges through very great resistances; hence the currents are exceptionally small. Secondly, the capacity goes on increasing continually as the potential rises, in consequence of absorption which takes place to a considerable extent. Owing to this there exists no critical relationship between these quantities, and ordinary rules would not seem to be applicable. As the potential is increased either in consequence of the increased frequency, or of the increased current through the primary, the amount of the energy stored becomes greater and greater, and the capacity gains more and more in importance. Up to a certain point the capacity is beneficial, but after that it begins to be an enormous drawback. It follows from this that each coil gives the best result with a given frequency and primary current. A very large coil, when operated with currents of very high efficiency, may not give as much as $\frac{1}{8}$th inch spark. By adding capacity to the terminals, the condition may be improved, but what the coil really wants is a lower frequency.

When the flaming discharge occurs, the conditions are evidently such, that the greatest current is made to flow through the circuit. These conditions may be attained by varying the frequency within wide limits, but the highest frequency at which the flaming arc can still be produced, determines, for a given primary current, the maximum striking distance of the coil. In the flaming discharge the *éclat* effect of the capacity is not perceptible; the rate at which the energy is being stored then just equals the rate at which it can be disposed of through the circuit. This kind of discharge is the severest test for a coil; the break, when it occurs, is of the nature of that in an overcharged Leyden jar. To give a rough approximation, I would state that, with an ordinary coil of, say 10,000 ohms resistance, the most powerful arc would be produced with about 12,000 alternations per second.

When the frequency is increased beyond that rate, the potential, of course, rises, but the striking distance may, nevertheless, diminish, paradoxical as it may seem. As the potential rises the coil attains more and more the properties of a static machine, until, finally, one may observe the beautiful phenomenon of the streaming discharge, fig. 6, which may be produced across the whole length of the coil. At that stage streams begin to issue freely from all points and projections. These streams will also be seen to pass in abundance in the space between the primary and the insulating tube. When the potential is excessively high they will always appear, even if the frequency be low, and even if the primary be surrounded by as much as an inch of wax, hard rubber, glass, or any other insulating substance. This limits greatly the output of the coil, but I will later show how I have been able to overcome to a considerable extent this disadvantage in the ordinary coil.

Besides the potential, the intensity of the streams depends on the frequency; but if the coil be very large they show themselves, no matter how low the frequencies used. For instance, in a very large coil of a resistance of 67,000 ohms, constructed by me some time ago, they appear with as low as 100 alternations per second and less, the insulation of the secondary being $\frac{3}{4}$ inch of ebonite. When very intense they produce a noise similar to that produced by the charging of a Holtz machine, but much more powerful, and they emit a strong smell of ozone. The lower the frequency, the more apt they are to suddenly injure the coil. With excessively high frequencies they

may pass freely without producing any other effect than to heat the insulation slowly and uniformly.

The existence of these streams shows the importance of constructing an expensive coil so as to permit of one's seeing through the tube surrounding the primary, and the latter should be easily exchangeable; or else the space between the primary and secondary should be completely filled up with insulating material so as to exclude all air. The non-observance of this simple rule in the construction of the commercial coils is responsible for the destruction of many an expensive coil.

At the stage when the streaming discharge occurs, or with somewhat higher frequencies, one may, by approaching the terminals considerably and regulating properly the effect of capacity, produce a veritable spray of small silver-white sparks or a bunch of excessively thin silvery threads (fig. 7) amidst a powerful brush—each spark or thread possibly corresponding to one alternation. This, when produced under proper conditions, is probably the most beautiful discharge, and when an air blast is directed against it, it presents a singular appearance. The spray of sparks, when received through the body, causes some inconvenience, whereas, when the discharge simply streams, nothing at all is likely to be felt if large conducting objects are held in the hands to protect them from receiving small burns.

If the frequency is still more increased, then the coil refuses to give any spark unless at comparatively small distances, and the fifth typical form of discharge may be observed (fig. 8). The tendency to stream out and dissipate is then so great that when the brush is produced at one terminal no sparking occurs, even if, as I have repeatedly tried, the hand, or any conducting object, is held within the stream; and, what is more singular, the luminous stream is not at all easily deflected by the approach of a conducting body.

At this stage the streams seemingly pass with the greatest freedom through considerable thicknesses of insulators, and it is particularly interesting to study their behaviour. For this purpose it is convenient to connect to the terminals of the coil two metallic spheres which may be placed at any desired distance (fig. 9). Spheres are preferable to plates, as the discharge can be better observed. By inserting dielectric bodies between the spheres, beautiful discharge phenomena may be observed. If the spheres be quite close and a spark be playing between them, by interposing a thin plate of ebonite between the spheres the spark instantly ceases and the discharge spreads into an intensely luminous circle several inches in diameter, provided the spheres are sufficiently large. The passage of the streams heats, and, after a while, softens the rubber so much that two plates may be made to stick together in this manner. If the spheres are so far apart that no spark occurs, even if they are far beyond the striking distance, by inserting a thick plate of glass the discharge is instantly induced to pass from the spheres to the glass in the form of luminous streams. It appears almost as though these streams pass *through* the dielectric. In reality this is not the case, as the streams are due to the molecules of the air which are violently agitated in the space between the oppositely charged surfaces of the spheres. When no dielectric other than air is present, the bombardment goes on, but is too weak to be visible; by inserting a dielectric the inductive effect is much increased, and besides, the projected air molecules find an obstacle, and the bombardment becomes so intense that the streams become luminous. If by any mechanical means we could effect such a violent agitation of the molecules we could produce the same phenomenon. A jet of air escaping through a small hole under enormous pressure and striking against an insulating substance, such as glass, may be luminous in the dark, and it might be possible to produce phosphorescence of the glass or other insulators in this manner.

The greater the specific inductive capacity of the interposed dielectric, the more powerful the effect produced. Owing to this, the streams show themselves with excessively high potentials even if the glass be as much as 1½ to 2 inches thick. But besides the heating due to bombardment, some heating goes on undoubtedly in the dielectric, being apparently greater in glass than in ebonite. I attribute this to the greater specific inductive capacity of the glass, in consequence of which, with the same potential difference, a greater amount of energy is taken up in it than in rubber. It is like connecting to a battery a copper and a brass wire of the same dimensions. The copper wire, though a more perfect conductor, would heat more by reason of its taking more current. Thus what is otherwise considered a virtue of the glass is here a defect. Glass usually gives way much quicker than ebonite; when it is heated to a certain degree, the discharge suddenly breaks through at one point, assuming then the ordinary form of an arc.

The heating effect produced by molecular bombardment of the dielectric would, of course, diminish as the pressure of the air is increased, and at enormous pressures it would be negligible, unless the frequency would increase correspondingly.

It will be often observed in these experiments that when the spheres are beyond the striking distance, the approach of a glass plate, for instance, may induce the spark to jump between the spheres. This occurs when the capacity of the spheres is somewhat below the critical value which gives the greatest difference of potential at the terminals of the coil. By approaching a dielectric, the specific inductive capacity of the space between the spheres is increased, producing the same effect as if the capacity of the spheres were increased. The potential at the terminals may then rise so high that the air space is cracked. The experiment is best performed with dense glass or mica.

Another interesting observation is that a plate of insulating material, when the discharge is passing through it, is strongly attracted by either of the spheres, that is, by the nearer one, this being obviously due to the smaller mechanical effect of the bombardment on that side, and perhaps also to the greater electrification.

From the behaviour of the dielectrics in these experiments we may conclude, that the best insulator for these rapidly alternating currents would be the one possessing the smallest specific inductive capacity and at the same time one capable of withstanding the greatest differences of potential; and thus two diametrically opposite ways of securing the required insulation are indicated, namely, to use either a perfect vacuum or a gas under great pressure but the former would be preferable. Unfortunately neither of these two ways is easily carried out in practice.

It is especially interesting to note the behaviour of an excessively high vacuum in these experiments. If a test tube, provided with external electrodes and exhausted to the highest possible degree, be connected to the terminals of the coil, fig. 10, the electrodes of the tube are instantly brought to a high temperature and the glass at each end of the tube is rendered intensely phosphorescent, but the middle appears comparatively dark, and for a while remains cool.

When the frequency is so high that the discharge shown in fig. 8 is observed, considerable dissipation no doubt occurs in the coil. Nevertheless the coil may be worked for a long time, as the heating is gradual.

In spite of the fact that the difference of potential may be enormous, little is felt when the discharge is passed through the body, provided the hands are armed. This is to some extent due to the higher frequency, but principally to the fact that less energy is available externally, when the difference of potential reaches an enormous value, owing to the circumstance that, with the rise of potential, the energy absorbed in the coil increases as the square of the potential. Up to a certain point the energy available externally increases with the rise of potential, then it begins to fall off rapidly. Thus, with the ordinary high tension induction coil, the curious paradox exists, that, while with a given current through the primary the shock might be fatal, with many times that current it might be perfectly harmless, even if the frequency be the same. With high frequencies and excessively high potentials when the terminals are not connected to bodies of some size, practically all the energy supplied to the primary is taken up by the coil. There is no breaking through, no local injury, but all the material, insulating and conducting, is uniformly heated.

To avoid misunderstanding in regard to the physiological effect of alternating currents of very high frequency, I think it necessary to state that, while it is an undeniable fact that they are incomparably less dangerous than currents of low frequencies, yet it should not be thought that they are altogether harmless. What has just been said refers only to currents from an ordinary high tension induction coil, which currents are necessarily very small; if received directly from a machine or from a secondary of low resistance, they produce more or less powerful effects, and may cause serious injury, especially when used in conjunction with condensers.

The streaming discharge of a high tension induction coil differs in many respects from that of a powerful static machine. In colour it has neither the violet of the positive, nor the brightness of the negative, static discharge, but lies somewhere between, being of course, alternatively positive and negative. But since the streaming is more powerful when the point or terminal is electrified positively, than when electrified negatively, it follows that the point of the brush is more like the positive, and the root more like the negative static discharge. In the dark, when the brush is very powerful the root may appear almost white. The wind produced by the escaping streams, though it may be very strong—often indeed to such a degree that it may be felt quite a distance from the coil—is, nevertheless, considering the quantity of the discharge, smaller than that produced by the positive brush of a static machine, and it affects the flame much less powerfully. From the nature of the phenomenon we can conclude that the higher the frequency, the smaller must, of course, be the wind produced by the streams, and with sufficiently high frequencies no wind at all would be produced at the ordinary atmospheric pressures. With frequencies obtainable by means of a machine, the mechanical effect is sufficiently great to revolve, with considerable speed, large pin-wheels, which in the dark present a beautiful appearance owing to the abundance of the streams (fig. 11).

In general, most of the experiments usually performed with a static machine can be performed with an induction coil when operated with very rapidly alternating currents. The effects produced, however, are much more striking, being of incomparably greater power. When a small length of ordinary cotton covered wire, fig. 12, is attached to one terminal of the coil, the streams issuing from all points of the wire may be so intense as to produce a considerable light effect. When the potentials and frequencies are very high, a wire insulated with gutta-percha or rubber and attached to one of the terminals, appears to be covered with a luminous film. A very thin bare wire when attached to a terminal emits powerful streams and vibrates continually to and fro or spins in a circle, producing a singular effect (fig. 13).

Another peculiarity of the rapidly alternating discharge of the induction coil is its radically different behaviour with respect to points and rounded surfaces.

If a thick wire, provided with a ball at one end and with a point at the other, be attached to the positive terminal of a static machine, practically all the charge will be lost through the point, on account of the enormously greater tension, dependent on the radius of curvature. But if such a wire is attached to one of the terminals of the induction coil, it will be observed that with very high frequencies streams issue from the ball almost as copiously as from the point (fig. 14).

It is hardly conceivable that we could produce such a condition to an equal degree in a static machine, for the simple reason, that the tension increases as the square of the density, which in turn is proportional to the radius of curvature; hence, with a steady potential an enormous charge would be required to make streams issue from a

polished ball while it is connected with a point. But with an induction coil the discharge of which alternates with great rapidity, it is different. Here we have to deal with two distinct tendencies. First, there is the tendency to escape which exists in a condition of rest, and which depends on the radius of curvature; attracted and repelled, charged and discharged, and their atomic charges being thus disturbed, vibrate and emit light waves. At the ball, on the contrary, there is no doubt that the effect is to a great extent produced inductively, the air molecules not *necessarily* coming in contact with the ball, though they undoubtedly do so. To convince

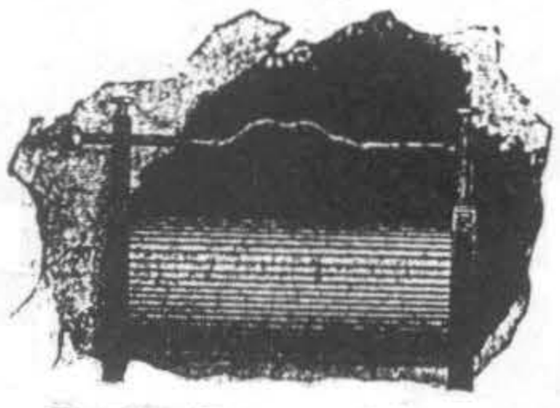


FIG. 4.—SENSITIVE THREAD DISCHARGE.

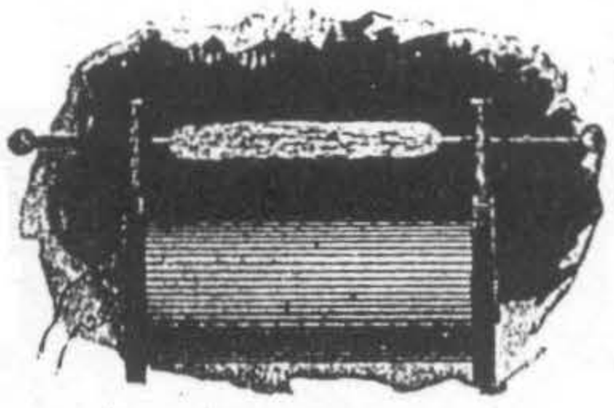


FIG. 5.—FLAMING DISCHARGE.

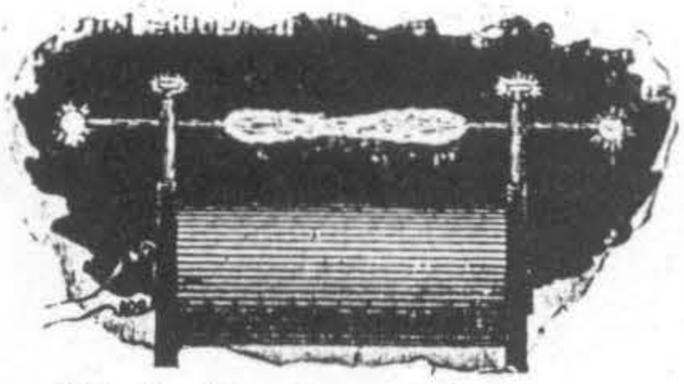


FIG. 6.—STREAMING DISCHARGE.

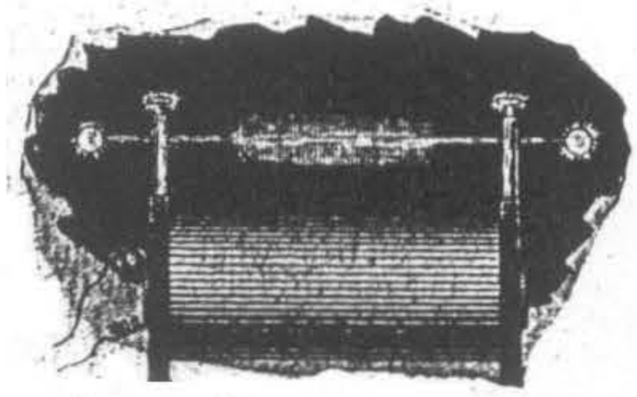


FIG. 7.—BRUSH AND SPRAY DISCHARGE.

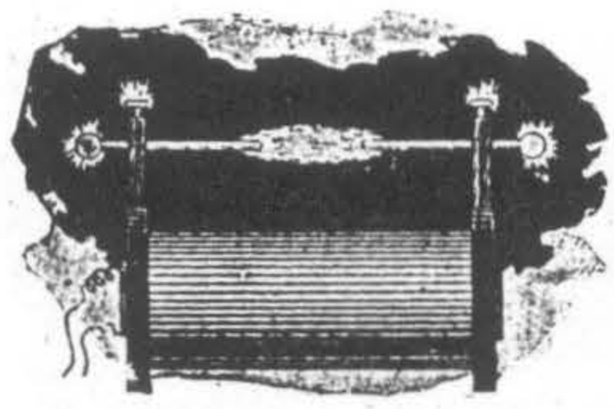


FIG. 8.—FIFTH TYPICAL FORM OF DISCHARGE.



FIG. 9.—LUMINOUS DISCHARGE WITH INTERPOSED INSULATORS.

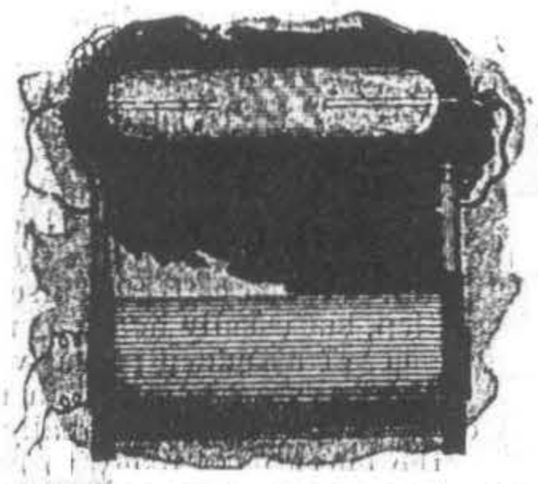


FIG. 10.—DISCHARGE THROUGH HIGHEST VACUUM.

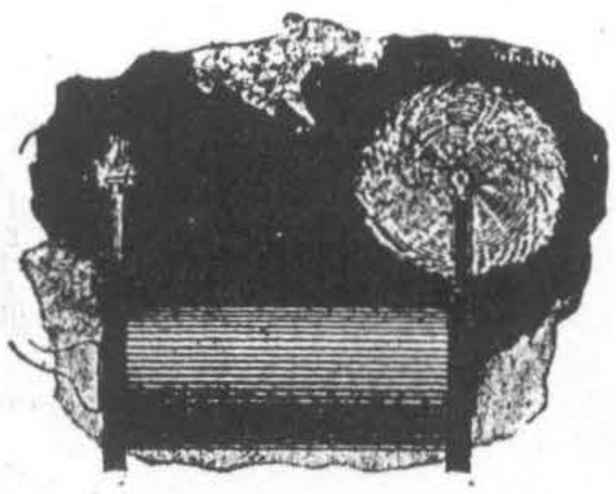


FIG. 11.—PINWHEEL DRIVEN BY A POWERFUL BRUSH.

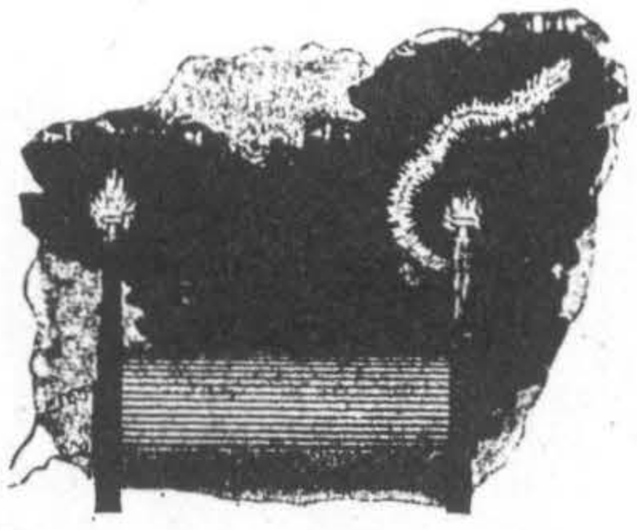


FIG. 12.—LUMINOUS STREAMS ESCAPING FROM A COTTON-COVERED WIRE.

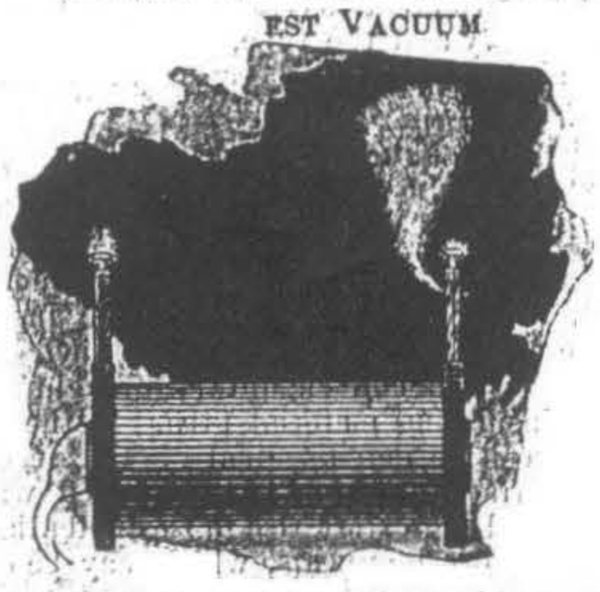


FIG. 13.—ASPECT PRESENTED BY A VERY THIN WIRE ATTACHED TO A TERMINAL OF THE COIL.

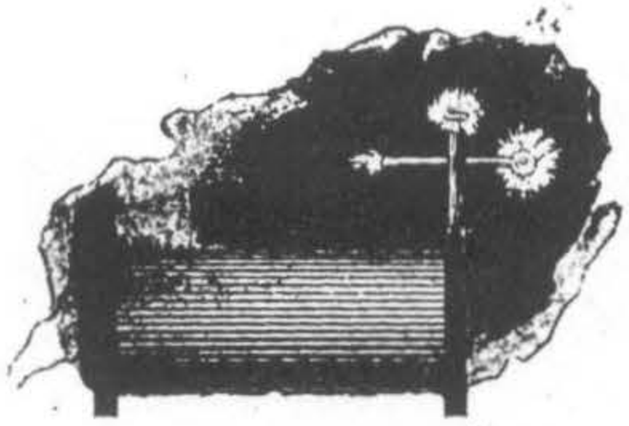


FIG. 14.—EFFECT OF BALL AND POINT.

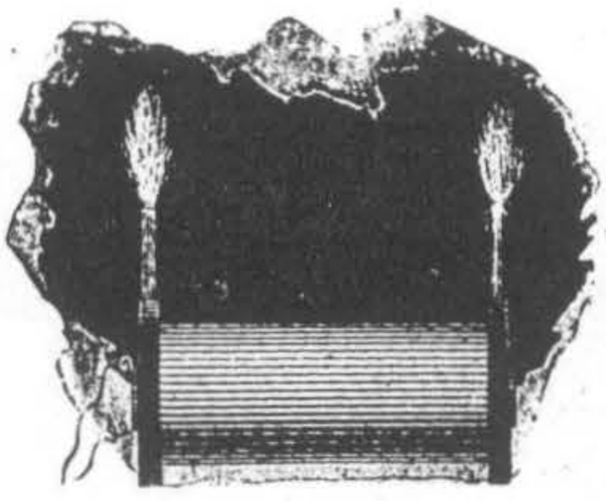


FIG. 15.—ASPECT OF COIL UNDER POWERFUL BRUSH DISCHARGE.

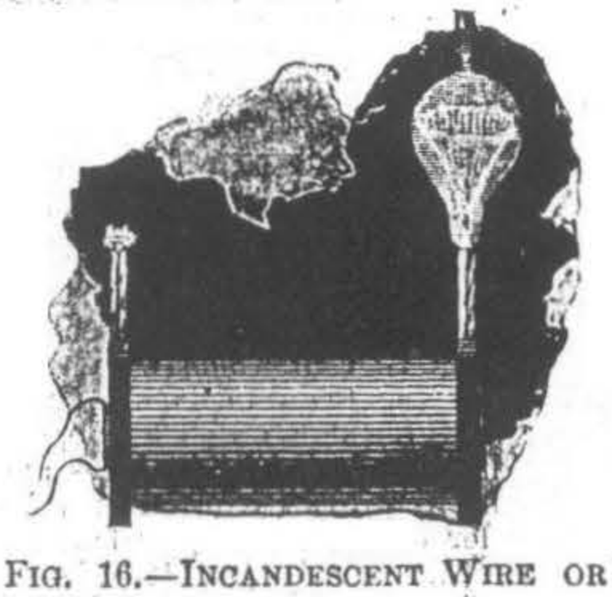


FIG. 16.—INCANDESCENT WIRE OR FILAMENT SPINNING IN AN UNEXHAUSTED GLOBE.

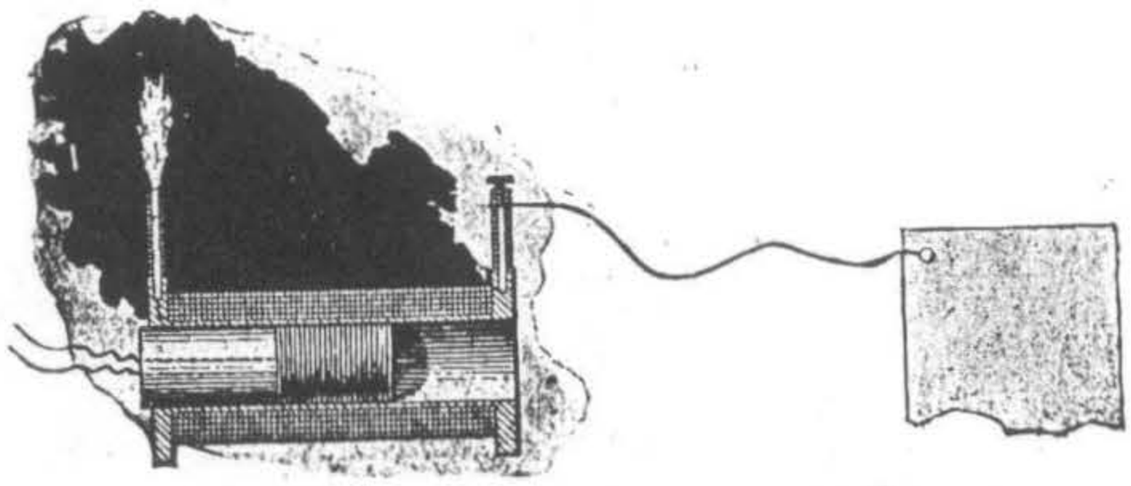


FIG. 17A.—COIL ARRANGED FOR POWERFUL BRUSH EFFECTS.

second, there is the tendency to dissipate into the surrounding air by condenser action, which depends on the surface. When one of these tendencies is a maximum, the other is at a minimum. At the point the luminous stream is principally due to the air molecules coming bodily in contact with the point; they are ourselves of this we only need to exalt the condenser action, for instance, by enveloping the ball, at some distance, by a better conductor, than the surrounding medium, the conductor being, of course, insulated; or else by surrounding it with a better dielectric and approaching an insulated conductor; in both cases the streams will

break forth more copiously. Also, the larger the ball with a given frequency, or the higher the frequency, the more will the ball have the advantage over the point. But since a certain intensity of action is required to render the streams visible, it is obvious that in the experiment described the ball should not be taken too large.

In consequence of this two-fold tendency, it is possible to produce by means of points effects identical to those produced by capacity. Thus, for instance, by attaching to one terminal of the coil a small length of soiled wire, presenting many points and offering great facility to escape, the potential of the coil may be raised to the same value as by attaching to the terminal a polished ball of a surface many times greater than that of the wire.

An interesting experiment, showing the effect of the points, may be performed in the following manner: Attach to one of the terminals of the coil a cotton covered wire about two feet in length, and adjust the conditions so that streams issue from the wire. In this experiment the primary coil should be preferably placed so that it extends only about half way into the secondary coil. Now touch the free terminal of the secondary with a conducting object held in the hand, or else connect it to an insulated body of some size. In this manner the potential on the wire may be enormously raised. The effect of this will be to either increase, or to diminish, the streams. If they increase, the wire is too short; if they diminish, it is too long. By adjusting the length of the wire, a point is found where the touching of the other terminal does not at all affect the streams. In this case the rise of potential is exactly counteracted by the drop through the coil. It will be observed that small lengths of wire produce considerable difference in the magnitude and luminosity of the streams. The primary coil is placed sidewise for two reasons: First, to increase the potential at the wire and, second, to increase the drop through the coil. The sensitiveness is thus augmented.

There is still another and far more striking peculiarity of the brush discharge produced by very rapidly alternating currents. To observe this it is best to replace the usual terminals of the coil by two metal columns insulated with a good thickness of ebonite. It is also well to close all fissures and cracks with wax so that the brushes cannot form anywhere except at the tops of the columns. If the conditions are carefully adjusted—which, of course, must be left to the skill of the experimenter—so that the potential rises to an enormous value, one may produce two powerful brushes several inches long, nearly white at their roots, which in the dark bear a striking resemblance to two flames of a gas escaping under pressure (fig. 15). But they do not only *resemble*, they *are* veritable flames, for they are hot. Certainly they are not as hot as a gas burner, *but they would be so if the frequency and the potential would be sufficiently high*. Produced with, say, twenty thousand alternations per second, the heat is easily perceptible even if the potential is not excessively high. The heat developed is, of course, due to the impact of the air molecules against the terminals and against each other. As, at the ordinary pressures, the mean free path is excessively small, it is possible that in spite of the enormous initial speed imparted to each molecule upon coming in contact with the terminal, its progress—by collision with other molecules—is retarded to such an extent, that it does not get away far from the terminal, but may strike the same many times in succession. The higher the frequency, the less the molecule is able to get away, and this the more so, as for a given effect the potential required is smaller; and a frequency is conceivable—perhaps even obtainable—at which practically the same molecules would strike the terminal. Under such conditions the exchange of the molecules would be very slow, and the heat produced at, and very near, the terminal would be excessive. But if the frequency would go on increasing constantly, the heat produced would begin to diminish for obvious reasons. In the positive brush of a static machine the exchange of the molecules is very rapid, the stream is constantly of one direction, and there are fewer collisions; hence the heating effect must be very small. Anything that impairs the facility of exchange tends to increase the local heat produced. Thus, if a bulb be held over the terminal of the coil so as to enclose the brush, the air contained in the bulb is very quickly brought to a high temperature. If a glass tube be held over the brush so as to allow the draught to carry the brush upwards, scorching hot air escapes at the top of the tube. Anything held within the brush is, of course, rapidly heated, and the possibility of using such heating effects for some purpose or other suggests itself.

When contemplating this singular phenomenon of the hot brush, we cannot help being convinced that a similar process must take place in the ordinary flame, and it seems strange that after all these centuries past of familiarity with the flame, now, in this era of electric lighting and heating, we are finally led to recognise, that since time immemorial we have, after all, always had "electric light and heat" at our disposal. It is also of no little interest to contemplate, that we have a possible way of producing—by other than chemical means—a veritable flame which would give light and heat without any material being consumed, without any chemical process taking place, and to accomplish this, we only need to perfect methods of producing enormous frequencies and potentials. I have no doubt that if the potential could be made to alternate with sufficient rapidity and power, the brush formed at the end of a wire would lose its electrical characteristics and would become flamelike. The flame must be due to electrostatic molecular action.

This phenomenon now explains in a manner which can hardly be doubted the frequent accidents occurring in storms. It is well known that objects are often set on fire without the lightning striking them. We shall presently see how this can happen. On a nail in a roof, for instance, or on a projection of any kind, more or less conducting, or rendered so by dampness, a powerful brush may appear. If the lightning strikes somewhere in the neighbourhood the enormous potential may be made to alternate or fluctuate perhaps many million times a second. The air molecules are violently attracted and repelled, and by their impact produce such a powerful heating effect that a fire is started. It is conceivable that a ship at sea may, in this manner, catch fire at many points at once. When we consider, that even with the comparatively low frequencies obtained from a dynamo machine, and with potentials of no more than one or two hundred thousand volts, the heating effects are considerable, we may imagine how much more powerful they must be with frequencies and potentials many times greater, and the above explanation seems, to say the least, very probable. Similar explanations may have been suggested, but I am not aware that, up to the present, the heating effects of a brush produced by a rapidly alternating potential have been experimentally demonstrated, at least not to such a remarkable degree.

By preventing completely the exchange of the air molecules the local heating effect may be so exalted as to bring a body to incandescence. Thus, for instance, if a small button, or preferably a very thin wire or filament be enclosed in an unexhausted globe and connected with the terminal of the coil, it may be rendered incandescent. The phenomenon is made much more interesting by the rapid spinning round in a circle of the top of the filament, thus presenting the appearance of a luminous funnel, fig. 16, which widens when the potential is increased. When the potential is small the end of the filament may perform irregular motions, suddenly changing from one to the other, or it may describe an ellipse; but when the potential is very high it always spins in a circle; and so does generally a thin straight wire attached freely to the terminal of the coil. These motions are, of course, due to the impact of the molecules, and the irregularity in the distribution of the potential, owing to the roughness and dissymmetry of the wire or filament. With a perfectly symmetrical and polished wire such motions would probably not occur. That the motion is not likely to be due to other causes is evident from the fact that it is not of a definite direction, and that in a very highly exhausted globe it ceases altogether. The possibility of bringing a body to incandescence in an unexhausted globe, or even when not at all enclosed, would seem to afford a possible way of obtaining light effects, which, in perfecting methods of producing rapidly alternating potentials, might be rendered available for useful purposes.

In employing a commercial coil, the production of very powerful brush effects is attended with considerable difficulties, for when these high frequencies and enormous potentials are used, the best insulation is apt to give way. Usually the coil is insulated well enough to stand the strain from convolution to convolution, since two double silk covered paraffined wires will withstand a pressure of several thousand volts; the difficulty lies principally in preventing the breaking through from the secondary to the primary, which is greatly facilitated by the streams issuing from the latter. In the coil, of course, the strain is greatest from section to section, but usually in a larger coil there are so many sections that the danger of a sudden giving way is not very great. No difficulty will generally be encountered in that direction, and besides, the liability of injuring the coil internally is very much reduced by the fact that the effect most likely to be produced is simply a gradual heating, which, when far enough advanced, could not fail to be observed. The principal necessity is then to prevent the streams between the primary and the tube, not only on account of the heating and possible injury, but also because the streams may diminish very considerably the potential difference available at the terminals. A few hints as to how this may be accomplished will probably be found useful in most of these experiments with the ordinary induction coil.

One of the ways is to wind a short primary, fig. 17A, so that the difference of potential is not at that length great enough to cause the breaking forth of the streams through the insulating tube. The length of the primary should be determined by experiment. Both the ends of the coil should be brought out on one end through a plug of insulating material fitting in the tube as illustrated. In such a disposition one terminal of the secondary is attached to a body the surface of which is determined with the greatest care so as to produce the greatest rise in the potential. At the other terminal a powerful brush appears, which may be experimented upon.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY, AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION.*

By NIKOLA TESLA.

(*Continued from page* 108.)

THE above plan necessitates the employment of a primary of comparatively small size, and it is apt to heat when powerful effects are desirable for a certain length of time. In such a case it is better to employ a larger coil, fig. 17B, and introduce it from one side of the tube, until the streams begin to appear. In this case the nearest terminal of the secondary may be connected to the primary or to the ground, which is practically the same thing, if the primary is con-

* A lecture delivered before the American Institute of Electrical Engineers, at Columbia College, N.Y., May 20th, 1891.

nected directly to the machine. In the case of ground connections it is well to determine experimentally the frequency which is best suited under the conditions of the test. Another way of obviating the streams, more or less, is to make the primary in sections and supply it from separate well insulated sources.

In many of these experiments, when powerful effects are wanted for a short time, it is advantageous to use iron cores with the primaries. In such case a very large primary coil may be wound and placed side by side with the secondary, and, the nearest terminal of the latter being connected to the primary, a laminated iron core is introduced through the primary into the secondary as far as the streams will permit. Under these conditions an excessively powerful brush, several inches long, which may be appropriately called "St. Elmo's

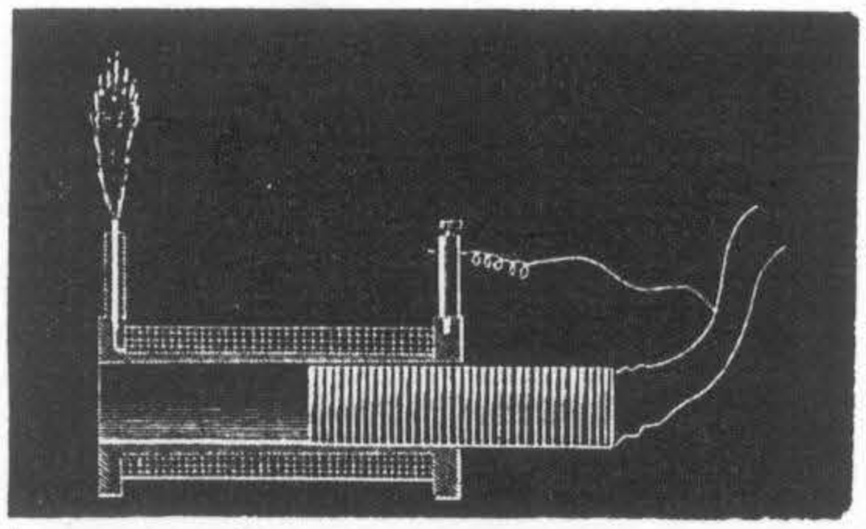


FIG. 17B.—COIL ARRANGED FOR POWERFUL BRUSH EFFECTS.—ST. ELMO'S HOT FIRE.

hot fire," may be caused to appear at the other terminal of the secondary, producing striking effects. It is a most powerful ozoniser, so powerful, indeed, that only a few minutes are sufficient to fill the whole room with the smell of ozone, and it undoubtedly possesses the quality of exciting chemical affinities.

For the production of ozone, alternating currents of very high frequency are eminently suited, not only on account of the advantages they offer in the way of conversion, but also because of the fact, that the ozonising action of a discharge is dependent on the frequency as well as on the potential, this being undoubtedly confirmed by observation.

In these experiments, if an iron core is used it should be carefully watched, as it is apt to get excessively hot in an incredibly short time. To give an idea of the rapidity of the heating, I will state, that by passing a powerful current through a coil with many turns, the inserting within the same of a thin iron wire for no more than one second's time is sufficient to heat the wire to something like 100° C.

But this rapid heating does not need to discourage us in the use of iron cores in connection with rapidly alternating currents. I have for a long time been convinced, that in the industrial distribution by means of transformers, some such plan as the following might be practicable. We may use a comparatively small iron core, subdivided, or perhaps not even subdivided. We may surround this core with a considerable thickness of material which is fireproof and conducts the heat poorly, and on top of that we may place the primary and secondary windings. By using either higher frequencies or greater magnetising forces, we may by hysteresis and eddy currents heat the iron core so far as to bring it nearly to its maximum permeability, which, as Hopkinson has shown, may be as much as sixteen times greater than that at ordinary temperatures. If the iron core were perfectly enclosed it would not be deteriorated by the heat, and, if the enclosure of fireproof material would be sufficiently thick, only a limited amount of energy could be radiated in spite of the high temperature. Transformers have been constructed by me on that plan, but for lack of time no thorough tests have as yet been made.

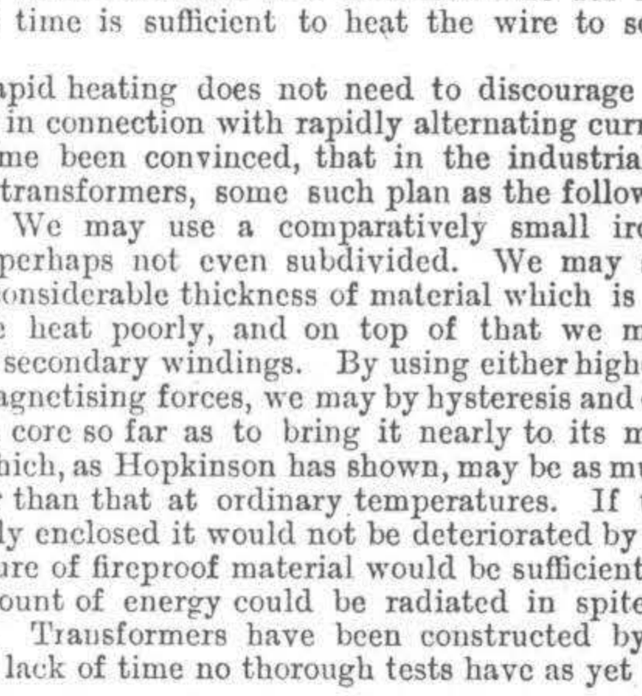


FIG. 18.

COIL FOR PRODUCING VERY HIGH DIFFERENCE OF POTENTIAL.

Another way of adapting the iron core to rapid alternations, or, generally speaking, reducing the frictional losses, is to produce by continuous magnetisation a flow of something like 7,000 or 8,000 lines per square centimetre through the core, and then work with weak magnetising forces and preferably high frequencies around the point of greatest permeability. A higher efficiency of conversion and greater output are obtainable in this manner. I have also employed this principle in connection with machines in which there is no reversal of polarity. In these types of machines, as long as there are only few pole projections, there is no great gain, as the maxima and minima of magnetisation are far from the point of maximum permeability; but when the number of the pole projections is very great, the required rate of change may be obtained, without the magnetisation varying so far as to depart greatly from the point of maximum permeability, and the gain is considerable.

The above described arrangements refer only to the use of commercial coils as ordinarily constructed. If it is desired to construct a coil for the express purpose of performing with it such experiments as I have described, or, generally, rendering it capable of withstanding the greatest possible difference of potential, then a construction as indicated in fig. 18 will be found of advantage. The coil in this case is formed of two independent parts which are wound oppositely, the connection between both being made near the primary. The potential in the middle being zero, there is not much tendency to jump to the primary and not much insulation is required. In some cases, the middle point may, however, be connected to the primary or to the ground. In such a coil the places of greatest difference of potential are far apart and the coil is capable of withstanding an enormous strain. The two parts may be movable so as to allow a slight adjustment of the capacity effect.

As to the manner of insulating the coil, it will be found convenient to proceed in the following way: First, the wire should be boiled in paraffin, until all the air is out; then the coil is wound by running the wire through melted paraffin, merely for the purpose of fixing the wire. The coil is then taken off from the spool, immersed in a cylindrical vessel filled with pure melted wax and boiled for a long time until the bubbles cease to appear. The whole is then left to cool down thoroughly, and then the mass is taken out of the vessel and turned up in a lathe. A coil made in this manner, and with care, is capable of withstanding enormous potential differences.

It may be found convenient to immerse the coil in paraffin oil, or some other kind of oil; it is a most effective way of insulating, principally on account of the perfect exclusion of air, but it may be found that, after all, a vessel filled with oil is not a very convenient thing to handle in a laboratory.

If an ordinary coil can be dismounted, the primary may be taken out of the tube and the latter plugged up on one end, filled with oil, and the primary re-inserted. This affords an excellent insulation, and prevents the formation of the streams.

Of all the experiments which may be formed with rapidly alternating currents, the most interesting are those which concern the production of a practical illuminant. It cannot be denied that the present methods, though they were brilliant advances, are very wasteful. Some better methods must be invented, some more perfect apparatus devised. Modern research has opened new possibilities for the production of an efficient source of light, and the attention of all has been turned in the direction indicated by able pioneers. Many have been carried away by the enthusiasm and passion to discover, but in their zeal to reach results, many have been misled. Starting with the idea of producing electro-magnetic waves, they turned their attention, perhaps too much to the study of electro-magnetic effects, and neglected the study of electrostatic phenomena. Naturally, nearly every investigator availed himself of an apparatus similar to that used in earlier experiments. But in those forms of apparatus, while the electro-magnetic inductive effects are enormous, the electrostatic effects are excessively small.

In the Hertz experiments, for instance, a high tension induction coil is short circuited by an arc, the resistance of which is very small, the smaller the more capacity is attached to the terminals; and the difference of potential at these is enormously diminished. On the other hand, when the discharge is not passing between the terminals, the static effects may be considerable, but only qualitatively so, not quantitatively, since their rise and fall is very sudden, and since their frequency is small. In neither case, therefore, are powerful electrostatic effects perceivable. Similar conditions exist when, as in some interesting experiments of Dr. Lodge, Leyden jars are discharged disruptively. It has been thought—and I believe asserted—that in such cases most of the energy is radiated into space. In the light of the experiments which I have described above, it will now not be thought so. I feel safe in asserting that in such cases most of the energy is partly taken up and converted into heat in the arc of the discharge and in the conducting and insulating material of the jar, some energy being, of course, given off by electrification of the air; but the amount of the directly radiated energy is very small.

When a high tension induction coil, operated by currents alternating only 20,000 times a second, has its terminals closed through even a very small jar, practically all the energy passes through the dielectric of the jar, which is heated, and the electrostatic effects manifest themselves outwardly only to a very weak degree. Now the external circuit of a Leyden jar, that is, the arc and the connections of the coatings, may be looked upon as a circuit generating alternating currents of excessively high frequency and fairly high potential, which is closed through the coatings and the dielectric between them, and from the above it is evident that the external electrostatic effects must be very small, even if a recoil circuit be used. These conditions make it appear that with the apparatus usually at hand, the observation of powerful electrostatic effects was impossible, and what experience has been gained in that direction is only due to the great ability of the investigators.

But powerful electrostatic effects are a *sine qua non* of light production on the lines indicated by theory. Electro-magnetic effects are primarily unavailable, for the reason that to produce the required effects we would have to pass current impulses through a conductor which, long before the required frequency of the impulses could be reached, would cease to transmit them. On the other hand, electro-

magnetic waves many times longer than those of light, and producible by sudden discharges of a condenser, could not be utilised, it would seem, except we avail ourselves of their effect upon conductors as in the present methods, which are wasteful. We could not affect by means of such waves the static molecular or atomic charges of a gas, cause them to vibrate and to emit light. Long transverse waves cannot, apparently, produce such effects, since excessively small electro-magnetic disturbances may pass readily through miles of air. Such dark waves, unless they are of the length of true light waves, cannot, it would seem, excite luminous radiation in a Geissler tube, and the luminous effects, which are producible by induction in a tube devoid of electrodes, I am inclined to consider as being of an electrostatic nature.

To produce such luminous effects, straight electrostatic thrusts are required; these, whatever be their frequency may disturb the molecular charges and produce light. Since current impulses of the required frequency cannot pass through a conductor of measurable dimensions, we must work with a gas, and then the production of powerful electrostatic effects becomes an imperative necessity.

It has occurred to me, however, that electrostatic effects are in many ways available for the production of light. For instance, we may place a body of some refractory material in a closed, and preferably more or less exhausted, globe, connect it to a source of high, rapidly alternating, potential, causing the molecules of the gas to strike it many times a second at enormous speeds, and in this manner, with trillions of invisible hammers, pound it until it gets incandescent; or, we may place a body in a very highly exhausted globe, in a non-striking vacuum, and, by employing very high frequencies and potentials, transfer sufficient energy from it to other bodies in the vicinity, or in general to the surroundings, to maintain it at any degree of incandescence; or, we may, by means of such rapidly alternating high potentials, disturb the ether carried by the molecules of a gas on their static charges, causing them to vibrate and to emit light.

But, electrostatic effects being dependent upon the potential and frequency to produce the most powerful action, it is desirable to increase both as far as practicable. It may be possible to obtain quite fair results by keeping either of these factors small, provided the other is sufficiently great; but we are limited in both directions. My experience demonstrates that we cannot go below a certain frequency, for, first, the potential then becomes so great that it is dangerous; and, secondly, the light production is less efficient.

I have found that, by using the ordinary low frequencies, the physiological effect of the current required to maintain at a certain degree of brightness a tube 4 feet long, provided at the ends with outside and inside condenser coatings, is so powerful that, I think, it might produce serious injury to those not accustomed to such shocks; whereas, with 20,000 alternations per second, the tube may be maintained at the same degree of brightness without any effect being felt. This is due principally to the fact that a much smaller potential is required to produce the same light effect, and also to the higher efficiency in the light production. It is evident that the efficiency in such cases is the greater the higher the frequency, for the quicker the process of charging and discharging the molecules, the less energy will be lost in the form of dark radiation. But, unfortunately, we cannot go beyond a certain frequency on account of the difficulty of producing and conveying the effects.

I have stated above that a body enclosed in an unexhausted bulb may be intensely heated by simply connecting it with a source of rapidly alternating potential. The heating in such a case is, in all probability, due mostly to the bombardment of the molecules of the gas contained in the bulb. When the bulb is exhausted, the heating of the body is much more rapid, and there is no difficulty whatever in bringing a wire or filament to any degree of incandescence by simply connecting it to one terminal of a coil of the proper dimensions. Thus, if the well-known apparatus of Prof. Crookes, consisting of a bent platinum wire with vanes mounted over it (fig. 19), be

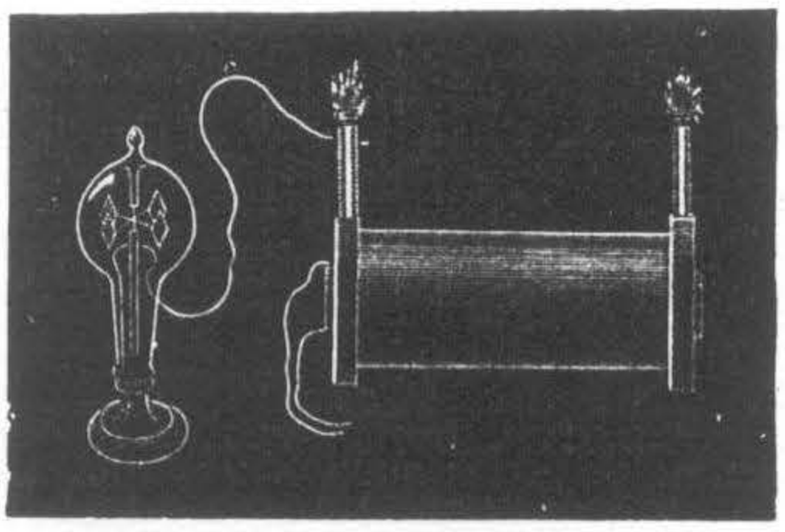


FIG. 19.—THE CROOKES EXPERIMENT ON OPEN CIRCUIT.

connected to one terminal of the coil—either one or both ends of the platinum wire being connected—the wire is rendered almost instantly incandescent, and the mica vanes are rotated as though a current from a battery were used. A thin carbon filament, or, preferably, a button of some refractory material (fig. 20), even if it be a comparatively poor conductor, enclosed in an exhausted globe, may be rendered highly incandescent; and in this manner a simple lamp, capable of giving any desired candle-power, is provided.

The success of lamps of this kind would depend largely on the selection of the light-giving bodies contained within the bulb. Since, under the conditions described, refractory bodies—which are very poor conductors, and capable of withstanding for a long time excessively high degrees of temperature—may be used, such illuminating devices may be rendered successful

It might be thought at first that if the bulb, containing the filament or button of refractory material, be perfectly well exhausted—that is, as far as it can be done by the use of the best apparatus—the heating would be much less intense, and that in a perfect vacuum it could not occur at all. This is not confirmed by my experience; quite the contrary, the better the vacuum the more easily the bodies are brought to incandescence. This result is interesting for many reasons.

At the outset of this work the idea presented itself to me whether two bodies of refractory material enclosed in a bulb exhausted to such a degree that the discharge of a large induction coil, operated in the usual manner, cannot pass through, could be rendered incandescent by mere condenser action. Obviously, to reach this result enormous potential differences and very high frequencies are required, as is evident from a simple calculation.

But such a lamp would possess a vast advantage over an ordinary incandescent lamp in regard to efficiency. It is well known that the efficiency of a lamp is to some extent a function of the degree of incandescence, and that, could we but work a filament at many times higher degrees of incandescence, the efficiency would be much greater. In an ordinary lamp this is impracticable

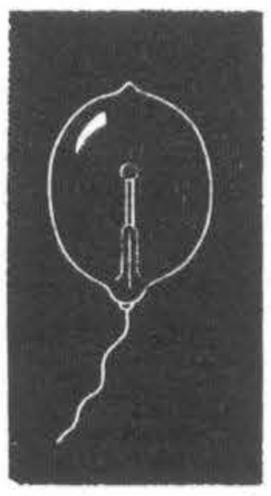


FIG. 20.—LAMP WITH SINGLE BLOCK OF REFRACTORY MATERIAL.

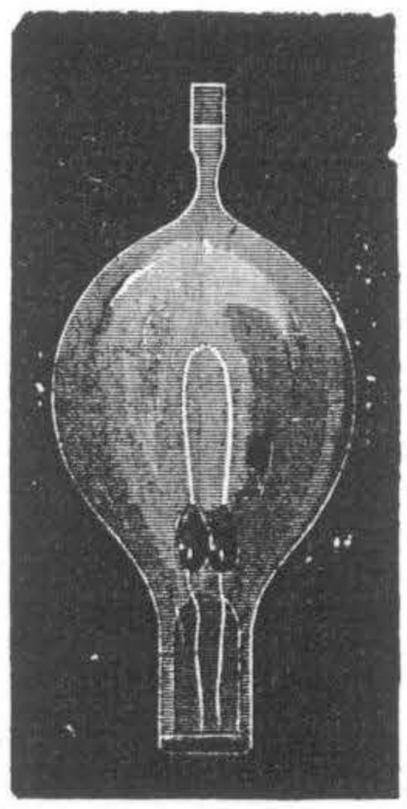


FIG. 21.—LAMP WITH TWO FILAMENTS IN HIGHEST VACUUM WITH LEADING-IN WIRES.

on account of the destruction of the filament, and it has been determined by experience how far it is advisable to push the incandescence. It is impossible to tell how much higher efficiency could be obtained if the filament could withstand indefinitely, as the investigation to this end obviously cannot be carried beyond a certain stage; but there are reasons for believing that it would be very considerably higher. An improvement might be made in the ordinary lamp by employing a short and thick carbon; but then the leading-in wires would have to be thick, and, besides, there are many other considerations which render such a modification entirely impracticable. But in a lamp as above described, the leading-in wires may be very small, the incandescent refractory material may be in the shape of blocks offering a very small radiating surface, so that less energy would be required to keep them at the desired incandescence; and in addition to this, the refractory material need not be carbon, but may be manufactured from mixtures of oxides, for instance, with carbon or other material, or may be selected from bodies which are practically non-conductors, and capable of withstanding enormous degrees of temperature.

All this would point to the possibility of obtaining a much higher efficiency with such a lamp than is obtainable in ordinary lamps. In my experience it has been demonstrated that the blocks are brought to high degrees of incandescence with much lower potentials than those determined by calculation, and the blocks may be set at greater distances from each other. We may freely assume, and it is probable, that the molecular bombardment is an important element in the heating, even if the globe be exhausted with the utmost care, as I have done; for although the number of the molecules is, comparatively speaking, insignificant, yet on account of the mean free path being very great, there are fewer collisions, and the molecules may reach much higher speeds, so that the heating effect due to this cause may be considerable, as in the Crookes experiments with radiant matter.

But it is likewise possible that we have to deal here with an increased facility of losing the charge in very high vacuum, when the potential is rapidly alternating, in which case most of the heating would be directly due to the surging of the charges in the heated bodies. Or else the observed fact may be largely attributable to the effect of the points which I have mentioned above, in consequence of which the blocks or filaments contained in the vacuum are equivalent to condensers of many times greater surface than that calculated from their geometrical dimensions. Scientific men still differ in opinion as to whether a charge should, or should not, be lost in a perfect vacuum, or in other words, whether ether is, or is not, a conductor. If the former were the case, then a thin filament enclosed in a perfectly exhausted globe, and connected to a source of enormous, steady potential, would be brought to incandescence.

Various forms of lamps on the above described principle, with the refractory bodies in the form of filaments, fig. 21, or blocks,

fig. 22, have been constructed and operated by me, and investigations are being carried on in this line. There is no difficulty in reaching such high degrees of incandescence that ordinary carbon is to all appearance melted and volatilised. If the vacuum could be made absolutely perfect, such a lamp, although inoperative with apparatus ordinarily used, would, if operated with currents of the required character, afford an illuminant which would never be destroyed, and which would be far more efficient than an ordinary incandescent lamp. This perfection can, of course, never be reached, and a very slow destruction and gradual diminution of the size always occurs, as in incandescent lamps; but there is no possibility of a sudden and premature disabling which occurs in the latter by the breaking of the filament, especially when the incandescent bodies are n the shape of blocks.

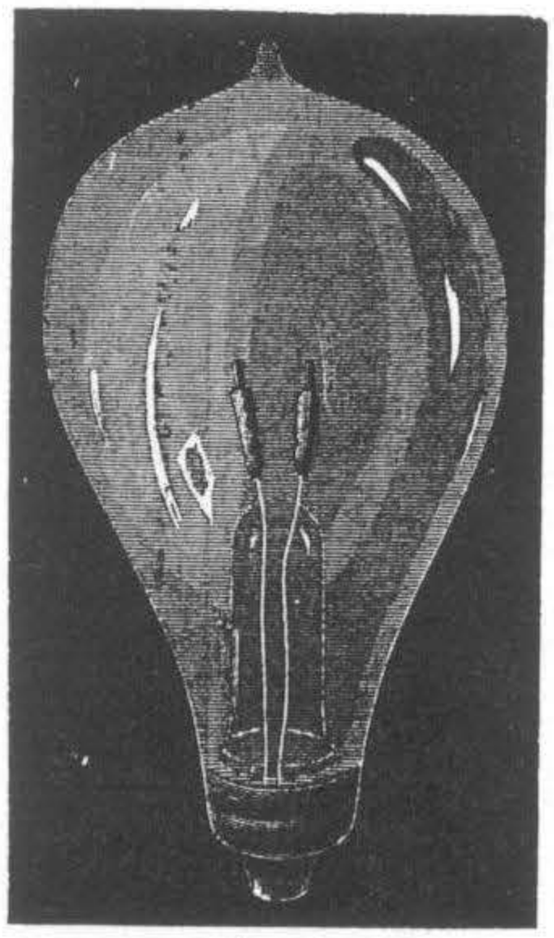


FIG. 22.
LAMP WITH TWO REFRACTORY BLOCKS IN HIGHEST VACUUM.

With these rapidly alternating potentials there is, however, no necessity of enclosing two blocks in a globe, but a single block, as in fig. 20, or filament, fig. 23, may be used. The potential in this case must of course be higher, but it is easily obtainable, and besides it is not necessarily dangerous.

The facility with which the button or filament in such a lamp is brought to incandescence, other things being equal, depends on the size of the globe. If a perfect vacuum could be obtained, the size of the globe would not be of importance, for then the heating would be

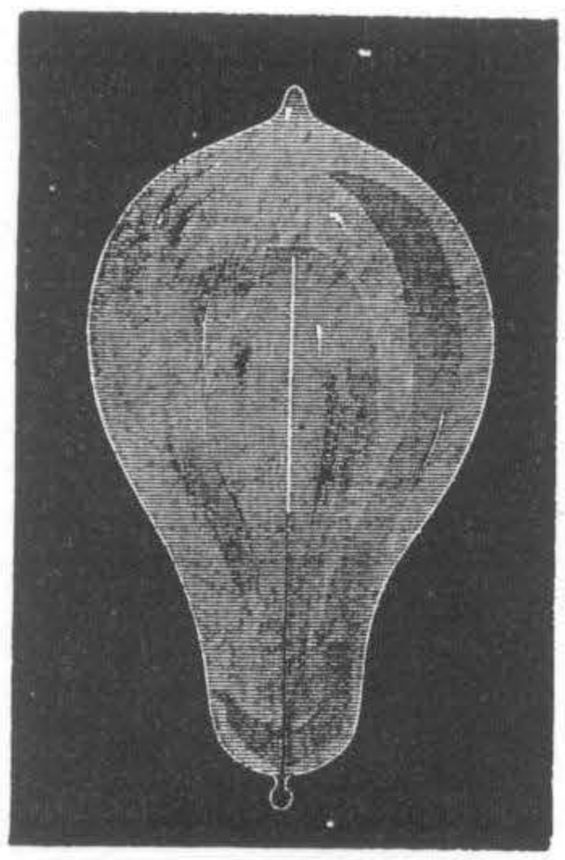


FIG. 23.—LAMP WITH SINGLE STRAIGHT FILAMENT AND ONE LEADING-IN WIRE.

wholly due to the surging of the charges, and all the energy would be given off to the surroundings by radiation. But this can never occur in practice. There is always some gas left in the globe, and although the exhaustion may be carried to the highest degree, still the space inside of the bulb must be considered as conducting when such high potentials are used, and I assume that, in estimating the energy that may be given off from the filament to the surroundings, we may consider the inside surface of the bulb as one coating of a condenser, the air and other objects surrounding the bulb forming the other coating. When the alternations are very low there is no doubt that a considerable portion of the energy is given off by the electrification of the surrounding air.

In order to study this subject better, I carried on some experiments with excessively high potentials and low frequencies. I then observed that when the hand is approached to the bulb—the filament being connected with one terminal of the coil—a powerful vibration is felt, being due to the attraction and repulsion of the molecules of the air which are electrified by induction through the glass. In some cases, when the action is very intense, I have been able to hear a sound, which must be due to the same cause.

When the alternations are low, one is apt to get an excessively powerful shock from the bulb. In general, when one attaches bulbs or objects of some size to the terminals of the coil, one should look out for the rise of potential, for it may happen that by merely connecting a bulb or plate to the terminal, the potential may rise to many times its original value. When lamps are attached to the terminals, as illustrated in fig. 24, then the capacity of the bulbs should be such

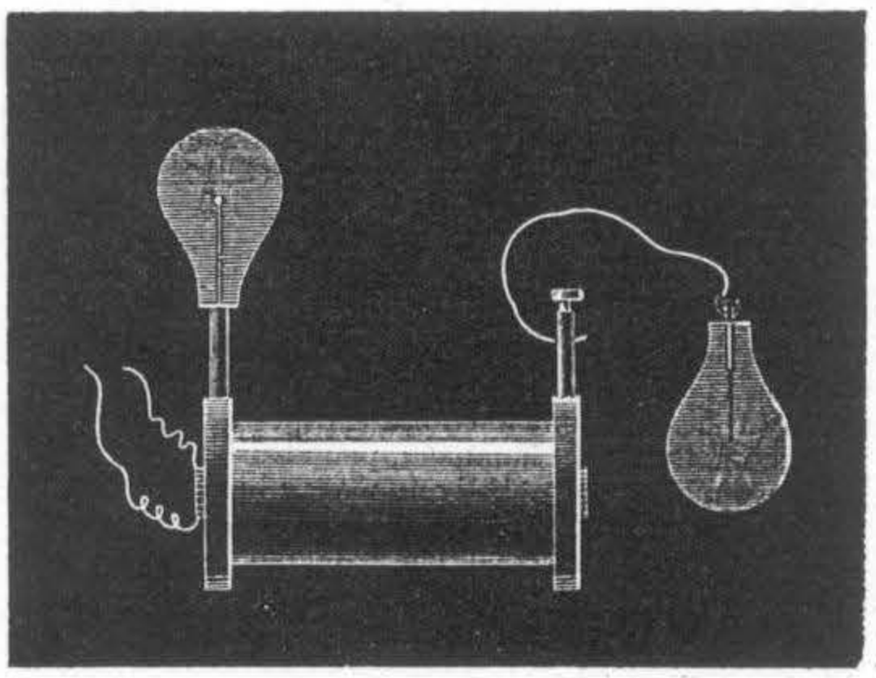


FIG. 24.—LAMPS WITH ONE LEADING-IN WIRE RENDERED INCANDESCENT.

as to give the maximum rise of potential under the existing conditions. In this manner one may obtain the required potential with fewer turns of wire.

The life of such lamps as described above depends, of course, largely on the degree of exhaustion, but to some extent also on the shape of the block of refractory material. Theoretically it would seem that a small sphere of carbon enclosed in a sphere of glass would not suffer deterioration from molecular bombardment, for, the matter in the globe being radiant, the molecules would move in straight lines, and would seldom strike the sphere obliquely. An interesting thought in connection with such a lamp is that in it "electricity" and electrical energy apparently must move in the same lines.

The use of alternating currents of very high frequency makes it possible to transfer, by electrostatic or electro-magnetic induction through the glass of a lamp, sufficient energy to keep a filament at incandescence and so do away with the leading-in wires. Such lamps have been proposed, but for want of proper apparatus they have not been successfully operated. Many forms of lamps on this principle with continuous and broken filaments have been constructed by me and experimented upon. When using a secondary enclosed within the lamp, a condenser is advantageously combined with the secondary. When the transference is effected by electrostatic induction, the potentials used are, of course, very high with frequencies obtainable from a machine. For instance, with a condenser surface of 40 centimetres square, which is not impracticably large, and with glass of good quality 1 mm. thick, using currents alternating 20,000 times a second, the potential required is approximately 9,000 volts. This may seem large, but since each lamp may be included in the secondary of a transformer of very small dimensions, it would not be inconvenient, and, moreover, it would not produce fatal injury. The transformers would all be preferably in series. The regulation would offer no difficulties, as with currents of such frequencies it is very easy to maintain a constant current.

In the accompanying engravings some of the types of lamps of this kind are shown. Fig. 25 is such a lamp with a broken filament, and

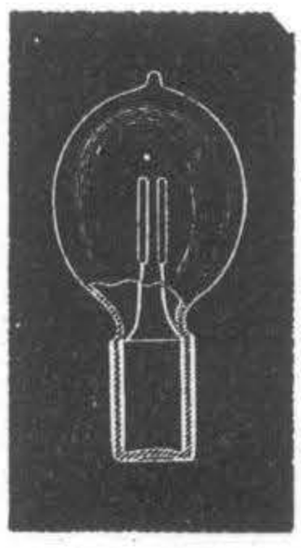


FIG. 25.—LAMP WITH TWO BLOCKS OR FILAMENTS AND A PAIR OF INDEPENDENT INSIDE AND OUTSIDE CONDENSER COATINGS.

fig. 26A and 26B one with a single outside and inside coating and a single filament. I have also made lamps with two outside and inside coatings and a continuous loop connecting the latter. Such lamps have been operated by me with current impulses of the enormous frequencies obtainable by the disruptive discharge of condensers.

The disruptive discharge of a condenser is especially suited for operating such lamps—with no outward electrical connections—by

means of electro-magnetic induction, the electro-magnetic inductive effects being excessively high; and I have been able to produce the desired incandescence with only a few short turns of wire. Incandescence may also be produced in this manner in a simple closed filament.

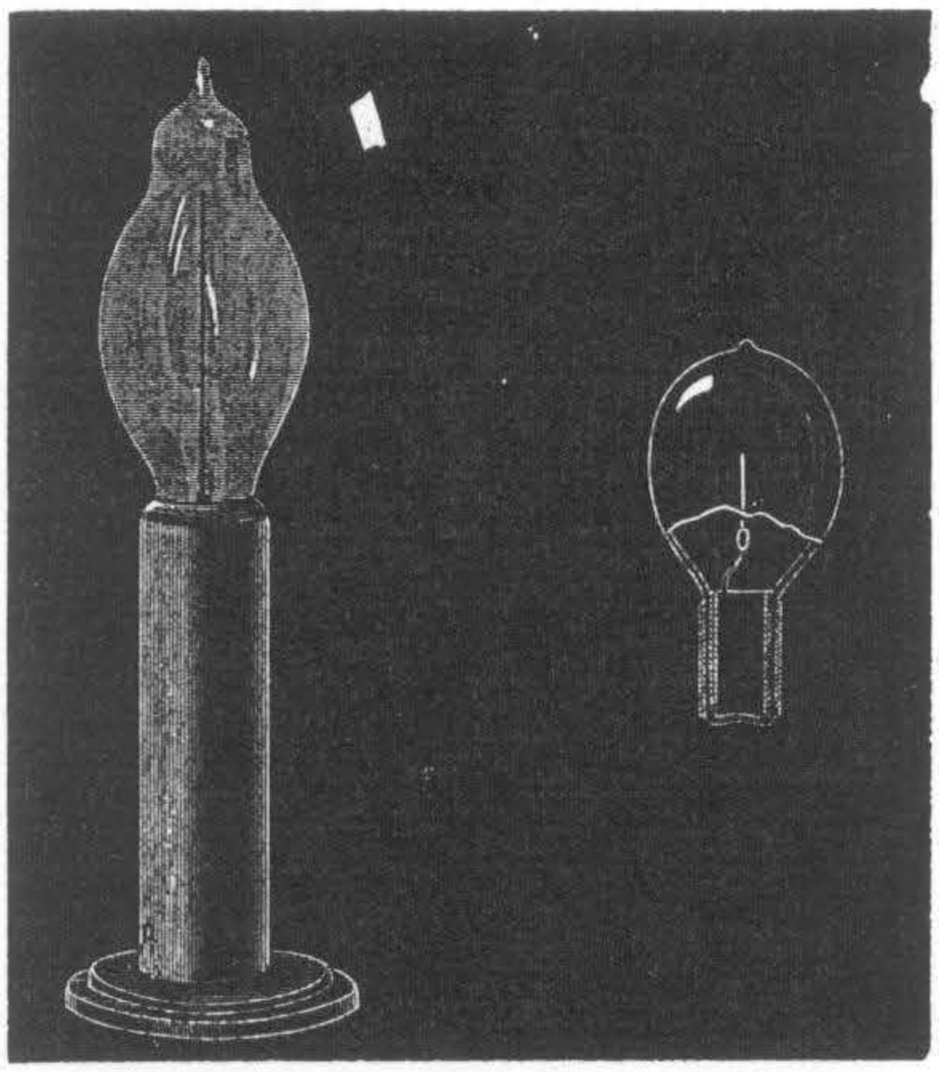


FIG. 26A. FIG. 26B.

LAMP WITH ONE FILAMENT, ONE INSIDE AND ONE OUTSIDE CONDENSER COATING.

Leaving now out of consideration the practicability of such lamps, I would only say that they possess a beautiful and desirable feature, namely, that they can be rendered, at will, more or less brilliant

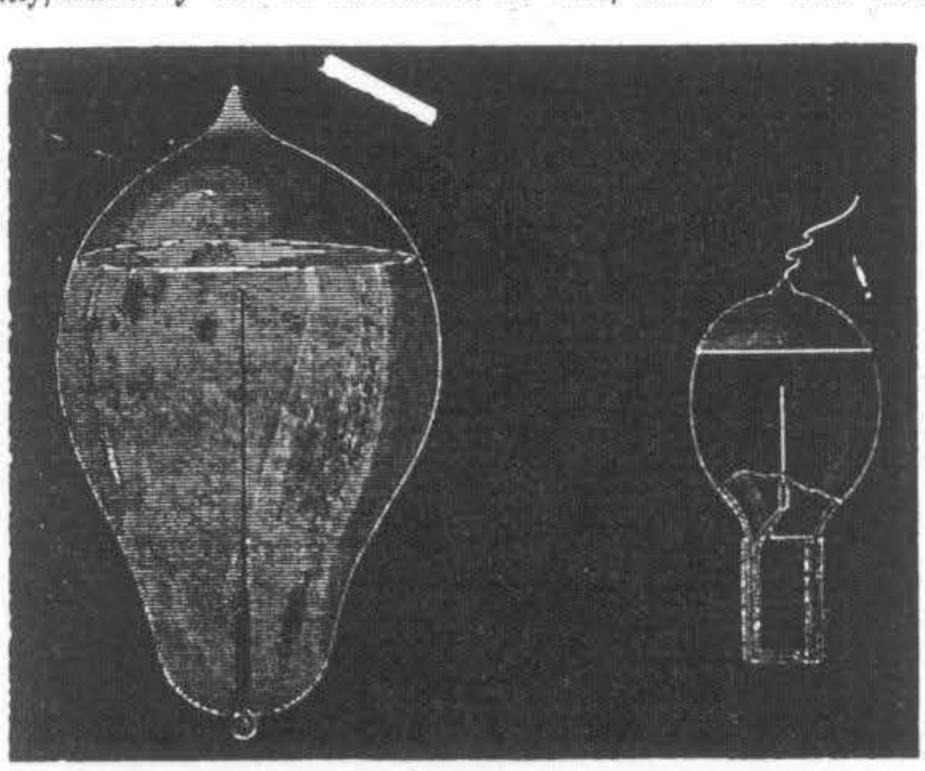


FIG. 27.—LAMP WITH ONE FILAMENT AND LEADING-IN WIRE AND EXTERNAL CONDENSER COATING.

FIG. 28.—LAMP WITH ONE FILAMENT, ONE INSIDE AND ONE OUTSIDE CONDENSER COATING, AND AUXILIARY COATING

simply by altering the relative position of the outside and inside condenser coatings, or inducing and induced circuits.

When a lamp is lighted by connecting it to one terminal only of the source, this may be facilitated by providing the globe with an outside condenser coating, which serves at the same time as a reflector, and connecting this to an insulated body of some size.

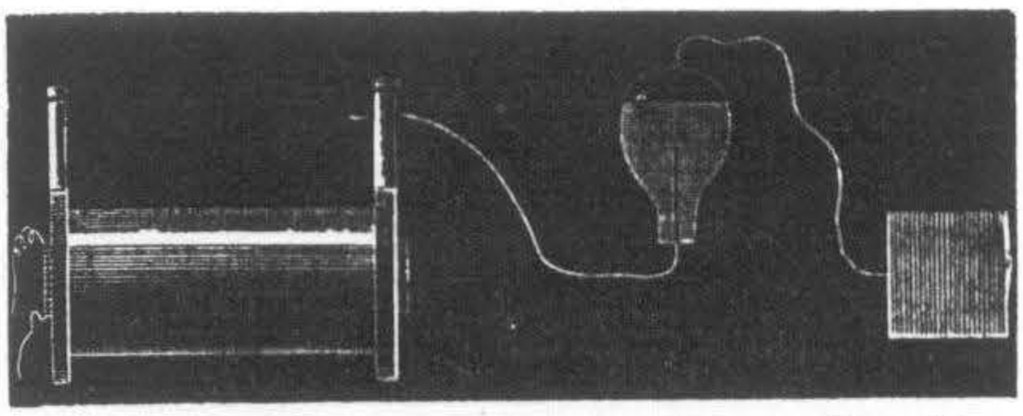


FIG. 29.—INCREASING THE BRILLIANCY OF LAMP ON ONE WIRE.

Lamps of this kind are illustrated in fig. 27 and fig. 28. Fig. 29 shows the plan of connections. The brilliancy of the lamp may, in this case, be regulated within wide limits by varying the size of the insulated metal plate to which the coating is connected.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY, AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION *

BY NIKOLA TESLA.

(*Concluded from page* 151.)

It is likewise practicable to light with one leading wire lamps such as illustrated in fig. 21 and fig. 22, by connecting one terminal of the lamp to one terminal of the source, and the other to an insulated body of the required size. In all cases the insulated body serves to give off the energy into the surrounding space, and is equivalent to a return wire. Obviously, in the two last-named cases, instead of connecting the wires to an insulated body, connections may be made to the ground.

The experiments which will prove most suggestive, and of most interest to the investigator, are probably those performed with exhausted tubes. As might be anticipated, a source of such rapidly alternating potentials is capable of exciting the tubes at a considerable distance, and the light effects produced are remarkable.

During my investigations in this line, I endeavoured to excite tubes, devoid of any electrodes, by electro-magnetic induction, making the tube the secondary of the induction device, and passing through the primary the discharges of a Leyden jar. These tubes were made of many shapes, and I was able to obtain luminous effects which I then thought were due wholly to electro-magnetic induction. But on carefully investigating the phenomena, I found that the effects produced were more of an electrostatic nature. It may be attributed to this circumstance that this mode of exciting tubes is very wasteful, namely, the primary circuit being closed, the potential, and consequently the electrostatic inductive effect, is much diminished.

When an induction coil, operated as above described, is used, there is no doubt that the tubes are excited by electrostatic induction, and that electro-magnetic induction has little, if anything to do with the phenomena.

This is evident from many experiments. For instance, if a tube be taken in one hand, the observer being near the coil, it is brilliantly lighted and remains so, no matter in what position it is held relatively to the observer's body. Were the action electro-magnetic, the tube could not be lighted when the observer's body is interposed between it and the coil, or at least its luminosity should be considerably diminished. When the tube is held exactly over the centre of the coil—the latter being wound in sections, and the primary placed symmetrically to the secondary—it may remain completely dark, whereas it is rendered intensely luminous by moving it slightly to the right or left from the centre of the coil. It does not light, because in the middle both halves of the coil neutralise each other, and the electric potential is zero. If the action were electro-magnetic, the tube should light best in the plane through the centre of the coil, since the electro-magnetic effect there should be a maximum. When an arc is established between the terminals, the tubes and lamps in the vicinity of the coil go out, but light up again when the arc is broken, on account of the rise of potential. Yet the electro-magnetic effect should be practically the same in both cases.

By placing a tube at some distance from the coil, and nearer to one terminal—preferably at a point on the axis of the coil—one may light it by touching the remote terminal with an insulated body of some size or with the hand, thereby raising the potential at that terminal nearer to the tube. If the tube is shifted nearer to the coil so that it is lighted by the action of the nearer terminal, it may be made to go out by holding, on an insulated support, the end of a wire connected to the remote terminal, in the vicinity of the nearer terminal, by this means counteracting the action of the latter upon the tube. These effects are evidently electrostatic. Likewise, when a tube is placed at a considerable distance from the coil, the observer may, standing upon an insulated support, between coil and tube, light the latter by approaching the hand to it; or he may even render it luminous by simply stepping between it and the coil. This would be impossible with electro-magnetic induction, for the body of the observer would act as a screen.

When the coil is energised by excessively weak currents, the experimenter may, by touching one terminal of the coil with the tube, extinguish the latter, and may again light it by bringing it out of contact with the terminal and allowing a small arc to form. This is clearly due to the respective lowering and raising of the potential at that terminal. In the above experiment, when the tube is lighted through a small arc, it may go out when the arc is broken, because the electrostatic inductive effect alone is too weak, though the potential may be much higher; but when the arc is established, the electrification of the end of the tube is much greater, and it consequently lights.

If a tube is lighted by holding it near to the coil, and in the hand which is remote, by grasping the tube anywhere with the other hand, the part between the hands is rendered dark, and the singular effect of wiping out the light of the tube may be produced by passing the hand quickly along the tube, and at the same time withdrawing it gently from the coil, judging properly the distance so that the tube remains dark afterwards.

If the primary coil is placed sidewise, as in fig. 17B for instance, and an exhausted tube be introduced from the other side in the hollow space, the tube is lighted most intensely because of the increased condenser action, and in this position the striæ are most sharply defined. In all these experiments described, and in many others, the action is clearly electrostatic.

The effects of screening also indicate the electrostatic nature of the phenomena, and show something of the nature of electrification through the air. For instance, if a tube be placed in the direction of the axis of the coil, and an insulated metal plate be interposed, the tube will generally increase in brilliancy, or if it be too far from the coil to light, it may even be rendered luminous by interposing an insulated metal plate. The magnitude of the effects depends to some extent on the size of the plate. But if the metal plate be connected by a wire to the ground, its interposition will always make the tube go out, even if it be very near the coil. In general, the interposition of a body between the coil and tube increases or diminishes the brilliancy of the tube, or its facility to light up, according to whether it increases or diminishes the electrification. When experimenting with an insulated plate, the plate should not be taken too large, else it will generally produce a weakening effect by reason of its great facility for giving off energy to the surroundings.

If a tube be lighted at some distance from the coil, and a plate of hard rubber or other insulating substance be interposed, the tube may be made to go out. The interposition of the dielectric in this case only slightly increases the inductive effect, but diminishes considerably the electrification through the air.

In all the cases, then, when we excite luminosity in exhausted tubes by means of such a coil, the effect is due to the rapidly alternating electrostatic potential; and, furthermore, it must be attributed to the harmonic alternation produced directly by the machine, and not to any superimposed vibration which might be thought to exist. Such superimposed vibrations are impossible when we work with an alternate current machine. If a spring be gradually tightened and released, it does not perform independent vibrations; for this a sudden release is necessary. So with the alternate currents from a dynamo machine; the medium is harmonically strained and released, this giving rise to only one kind of waves; a sudden contact or break, or a sudden giving way of the dielectric, as in the disruptive discharge of a Leyden jar, are essential for the production of superimposed waves.

In all the last described experiments, tubes devoid of any electrodes may be used, and there is no difficulty in producing by their means sufficient light to read by. The light effect is, however, considerably increased by the use of phosphorescent bodies such as yttria, uranium glass, &c. A difficulty will be found when the phosphorescent material is used, for with these powerful effects it is carried gradually away, and it is preferable to use material in the form of a solid.

Instead of depending on induction at a distance to light the tube, the same may be provided with an external—and, if desired, also with an internal—condenser coating, and it may then be suspended

* A lecture delivered before the American Institute of Electrical Engineers, at Columbia College, N.Y., May 20th, 1891.

anywhere in the room from a conductor connected to one terminal of the coil, and in this manner a soft illumination may be provided.

The ideal way of lighting a hall or room would, however, be to produce such a condition in it that an illuminating device could be moved and put anywhere, and that it is lighted, no matter where it is put and without being electrically connected to anything. I have been able to produce such a condition by creating in the room a powerful, rapidly alternating electrostatic field. For this purpose I suspend a sheet of metal a distance from the ceiling on insulating cords and connect it to one terminal of the induction coil, the other terminal being preferably connected to the ground. Or else I suspend two sheets as illustrated in fig. 30, each sheet being connected with one of the terminals of the coil, and their size being carefully determined. An exhausted tube may then be carried in the hand anywhere between the sheets or placed anywhere, even a certain distance beyond them; it remains always luminous.

In such an electrostatic field interesting phenomena may be observed, especially if the alternations are kept low and the potentials excessively high. In addition to the luminous phenomena mentioned, one may observe that any insulated conductor gives sparks when the hand or another object is approached to it, and the sparks may often be powerful. When a large conducting object is fastened on an insulating support, and the hand approached to it, a vibration, due to the rythmical motion of the air molecules is felt, and luminous streams may be perceived when the hand is held near a pointed projection. When a telephone receiver is made to touch with one or both of its terminals an insulated conductor of some size, the telephone emits a loud sound; it also emits a sound when a length of wire is attached to one or both terminals, and with very powerful fields a sound may be perceived even without any wire.

How far this principle is capable of practical application, the future will tell. It might be thought that electrostatic effects are unsuited for such action at a distance. Electro-magnetic inductive effects, if available for the production of light, might be thought better suited. It is true the electrostatic effects diminish nearly with the cube of the distance from the coil, whereas the electro-magnetic inductive effects diminish simply with the distance. But when we establish an electrostatic field of force, the condition is very different, for then, instead of the differential effect of both the terminals, we get their conjoint effect. Besides, I would call attention to the fact, that in an alternating electrostatic field, a conductor, such as an exhausted tube, for instance, tends to take up most of the energy, whereas in an electro-magnetic alternating field the conductor tends to take up the least energy, the waves being reflected with but little loss. This is one reason why it is difficult to excite an exhausted tube, at a distance, by electro-magnetic induction. I have wound coils of very large diameter and of many turns of wire, and connected a Geissler tube to the ends of the coil with the object of exciting the tube at a distance; but even with the powerful inductive effects producible by Leyden jar discharges the tube could not be excited unless at a very small distance, although some judgment was used as to the dimensions of the coil. I have also found that even the most powerful Leyden jar discharges are capable of exciting only feeble luminous effects in a closed exhausted tube, and even these effects upon thorough examination I have been forced to consider of an electrostatic nature.

How, then, can we hope to produce the required effects at a distance by means of electro-magnetic action, when even in the closest proximity to the source of disturbance, under the most advantageous conditions, we can excite but faint luminosity? It is true that when acting at a distance we have the resonance to help us out. We can connect an exhausted tube, or whatever the illuminating device may be, with an insulated system of the proper capacity, and so it may be possible to increase the effect qualitatively, and only qualitatively, for we would not get *more* energy through the device. So we may, by resonance effect, obtain the required electromotive force in an exhausted tube, and excite faint luminous effects, but we cannot get enough energy to render the light practically available, and a simple calculation, based on experimental results, shows that even if all the energy which a tube would receive at a certain distance from the source should be wholly converted into light, it would hardly satisfy the practical requirements. Hence the necessity of directing, by means of a conducting circuit, the energy to the place of transformation. But in so doing we cannot very sensibly depart from present methods, and all we could do would be to improve the apparatus.

From these considerations it would seem that if this ideal way of lighting is to be rendered practicable it will be only by the use of electrostatic effects. In such a case the most powerful electrostatic inductive effects are needed; the apparatus employed must, therefore, be capable of producing high electrostatic potentials changing in value with extreme rapidity. High frequencies are especially wanted, for practical considerations make it desirable to keep down the potential. By the employment of machines, or, generally speaking, of any mechanical apparatus, but low frequencies can be reached; recourse must, therefore, be had to some other means. The discharge of a condenser affords us a means of obtaining frequencies by far higher than are obtainable mechanically, and I have accordingly employed condensers in the experiments to the above end.

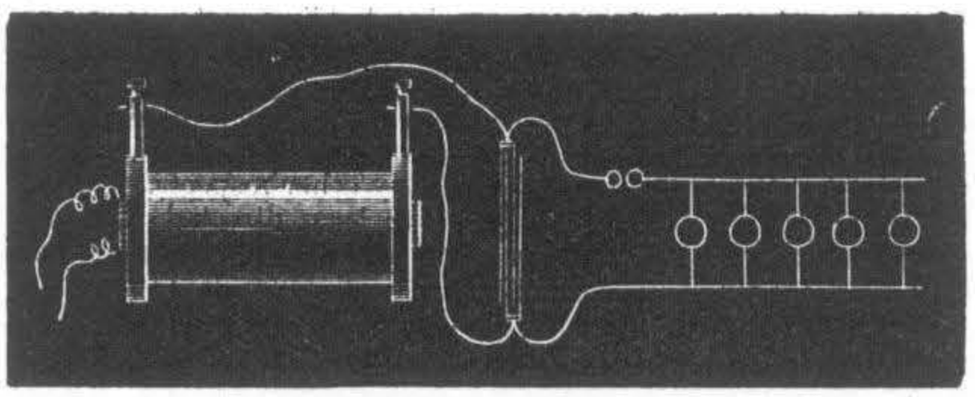


FIG. 31.—DIAGRAM OF CONNECTIONS FOR CONVERTING FROM HIGH TO LOW TENSION BY MEANS OF THE DISRUPTIVE DISCHARGE.

When the terminals of a high tension induction coil, fig. 31, are connected to a Leyden jar, and the latter is discharging disruptively into a circuit, we may look upon the arc playing between the knobs as being a source of alternating, or generally speaking, undulating currents, and then we have to deal with the familiar system of a generator of such currents, a circuit connected to it, and a condenser bridging the circuit. The condenser in such a case is a veritable transformer, and since the frequency is excessive, almost any ratio in the strength of the currents in both the branches may be obtained. In reality the analogy is not quite complete, for in the disruptive discharge we have most generally a fundamental instantaneous variation of comparatively low frequency, and a superimposed harmonic vibration, and the laws governing the flow of currents are not the same for both.

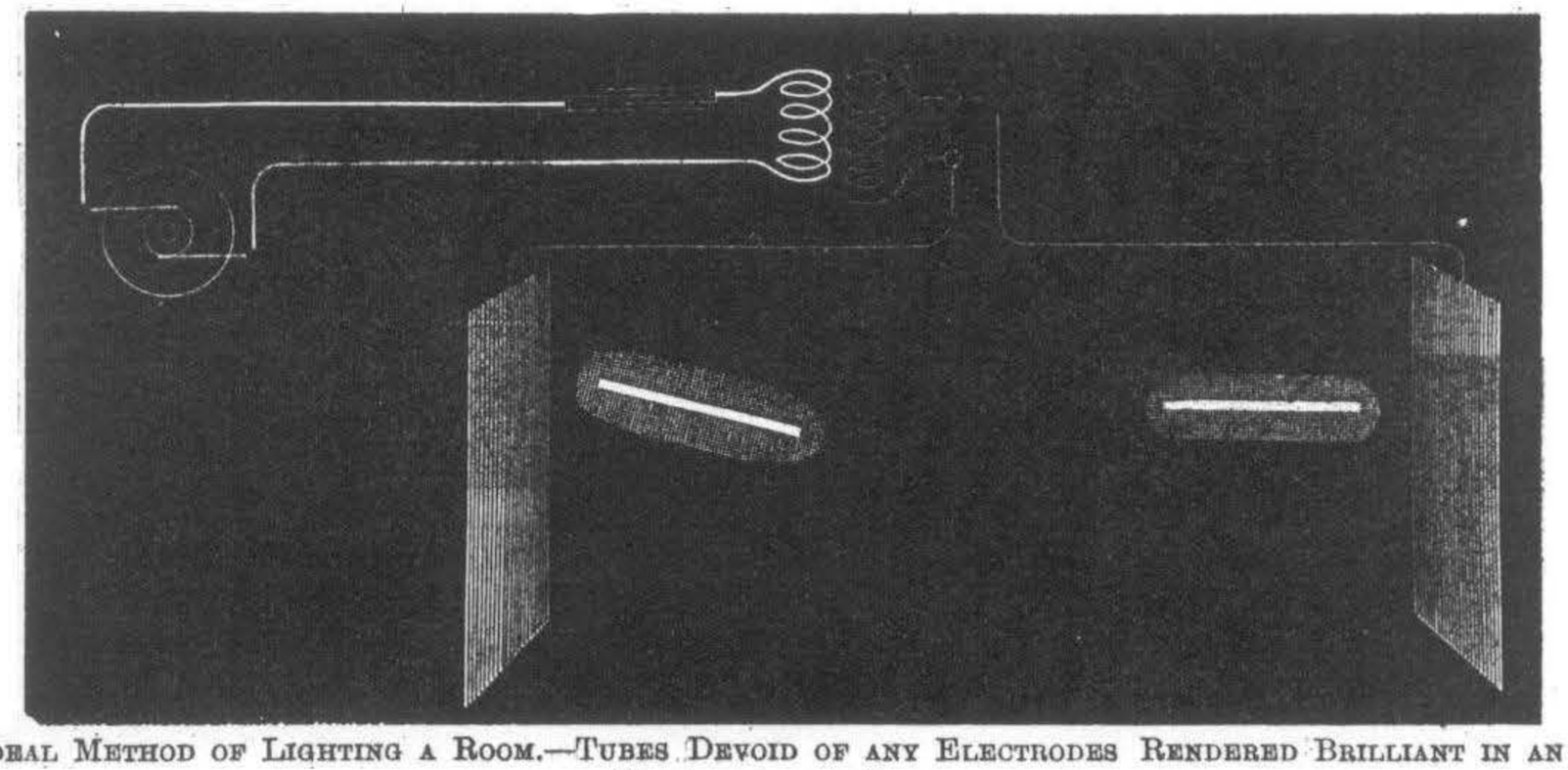


FIG. 30.—IDEAL METHOD OF LIGHTING A ROOM.—TUBES DEVOID OF ANY ELECTRODES RENDERED BRILLIANT IN AN ALTERNATING ELECTROSTATIC FIELD.

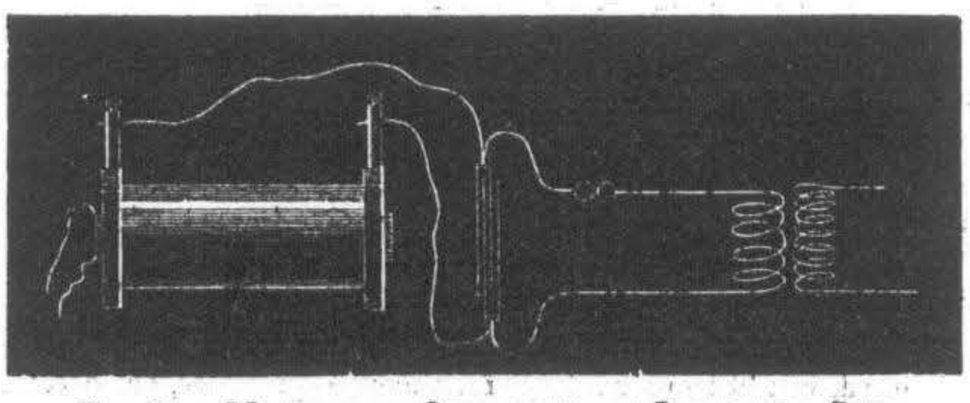


FIG. 32.—MANNER OF OPERATING AN INDUCTION COIL.

In converting in this manner, the ratio of conversion should not be too great, for the loss in the arc between the knobs increases with the square of the current, and if the jar be discharged through very thick and short conductors, with the view of obtaining a very rapid oscillation, a very considerable portion of the energy stored is lost. On the other hand, two small ratios are not practicable for many obvious reasons.

As the converted currents flow in a practically closed circuit, the

electrostatic effects are necessarily small, and I therefore convert them into currents or effects of the required character. I have effected such conversions in several ways. The preferred plan of connections is illustrated in fig. 32. The manner of operating renders it easy to obtain by means of a small and inexpensive apparatus enormous differences of potential which have been usually obtained by means of large and expensive coils. For this it is only necessary to take an ordinary small coil, adjust to it a condenser and discharging circuit, forming the primary of an auxiliary small coil, and convert upward. As the inductive effect of the primary currents is excessively great, the second coil need have comparatively but very few turns. By properly adjusting the elements, remarkable results may be secured.

In endeavouring to obtain the required electrostatic effects in this manner, I have, as might be expected, encountered many difficulties which I have been gradually overcoming, but I am not as yet prepared to dwell upon my experiences in this direction.

I believe that the disruptive discharge of a condenser will play an important part in the future, for it offers vast possibilities, not only in the way of producing light in a more efficient manner and in the line indicated by theory, but also in many other respects.

For years the efforts of inventors have been directed towards obtaining electrical energy from heat by means of the thermopile. It might seem invidious to remark that but few know what is the real trouble with the thermopile. It is not the inefficiency or small output—though these are great drawbacks—but the fact that the thermopile has its phylloxera, that is, that by constant use it is deteriorated, which has thus far prevented its introduction on an industrial scale. Now that all modern research seems to point with certainty to the use of electricity of excessively high tension, the question must present itself to many whether it is not possible to obtain in a practicable manner this form of energy from heat. We have been used to look upon an electrostatic machine as a plaything, and somehow we couple with it the idea of the inefficient and impractical. But now we must think differently, for now we know that everywhere we have to deal with the same forces, and that it is a mere question of inventing proper methods or apparatus for rendering them available.

In the present systems of elcctrical distribution, the employment of the iron with its wonderful magnetic properties allows us to reduce considerably the size of the apparatus; but, in spite of this, it is still very cumbersome. The more we progress in the study of electric and magnetic phenomena, the more we become convinced that the present methods will be short lived. For the production of light, at least, such heavy machinery would seem to be unnecessary. The energy required is very small, and if light can be obtained as efficiently as, theoretically, it appears possible, the apparatus need have but a very small output. There being a strong probability that the

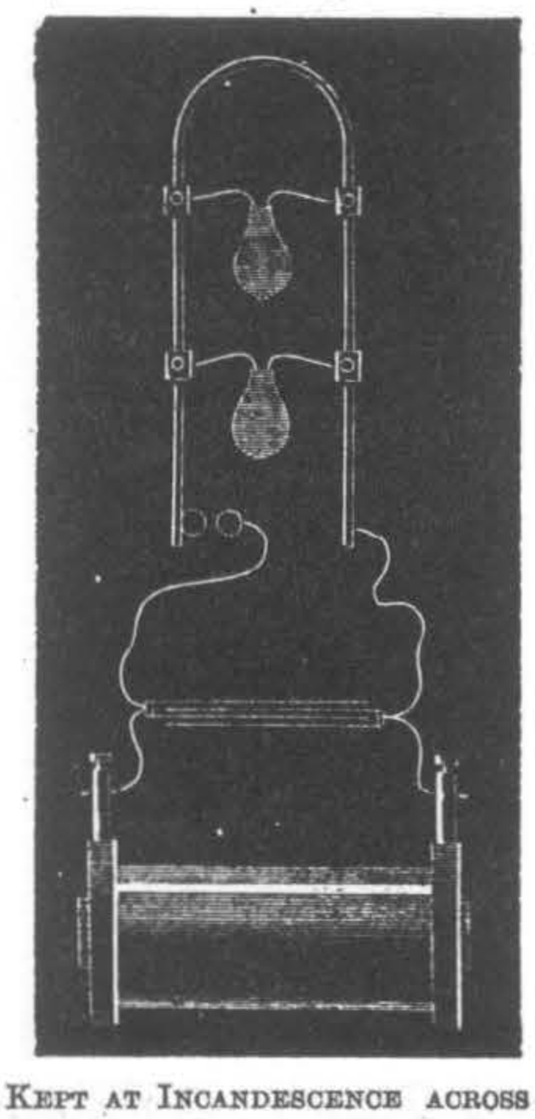


FIG. 33.—LAMP KEPT AT INCANDESCENCE ACROSS A THICK COPPER BAR—SHOWING NODES.

illuminating methods of the future will involve the use of very high potentials, it seems very desirable to perfect a contrivance capable of converting the energy of heat into energy of the requisite form. Nothing to speak of has been done towards this end, for the thought that electricity of some 50,000 or 100,000 volts pressure or more, even if obtained, would be unavailable for practical purposes, has deterred inventors from working in this direction.

In fig. 31 a plan of connections is shown for converting currents of high into currents of low tension, by means of the disruptive discharge of a condenser. This plan has been used by me frequently for operating a few incandescent lamps required in the laboratory. Some difficulties have been encountered in the arc of the discharge, which I have been able to overcome to a great extent; besides this, and the adjustment necessary for the proper working, no other difficulties have been met with, and it was easy to operate ordinary lamps, and even motors, in this manner. The line being connected to the ground, all the wires could be handled with perfect impunity, no matter how high the potential at the terminals of the condenser. In these experiments a high tension induction coil, operated from a battery or from an alternate current machine, was employed to charge the condenser; but the induction coil might be replaced by an apparatus of a different kind, capable of giving electricity of such high tension. In this manner, direct or alternating currents may be converted, and in both cases the current impulses may be of any desired frequency. When the currents charging the condenser are of the same direction, and it is desired that the converted currents should also be of one direction, the resistance of the discharging circuit should, of course, be so chosen that there are no oscillations.

In operating devices on the above plan, I have observed curious phenomena of impedance which are of interest. For instance, if a thick copper bar be bent, as indicated in fig. 33, and shunted by ordinary incandescent lamps, then, by passing the discharge between the knobs, the lamps may be brought to incandescence, although they are short-circuited. When a large induction coil is employed it is easy to obtain nodes on the bar, which are rendered evident by the different degree of brilliancy of the lamps, as shown roughly in fig. 33. The nodes are never clearly defined, but there are simply maxima and minima of potentials along the bar. This is probably due to the irregularity of the arc between the knobs. In general, when the above-described plan of conversion from high to low tension is used, the behaviour of the disruptive discharge may be closely studied. The nodes may also be investigated by means of an ordinary Cardew voltmeter, which should be well insulated. Geissler tubes may also be lighted across the points of the bent bar; in this case, of course, it is better to employ smaller capacities. I have found it practicable to light up in this manner a lamp, and even a Geissler tube, shunted by a short heavy block of metal, and this result seems at first very curious. In fact, the thicker the copper bar in fig. 33, the better it is for the success of the experiments, as they appear more striking. When lamps with long slender filaments are used, it will be often noted that the filaments are from time to time violently vibrated, the vibration being smallest at the nodal points. This vibration seems to be due to an electrostatic action between the filament and the glass of the bulb.

In some of the above experiments, it is preferable to use special lamps having a straight filament, as shown in fig. 34. When such

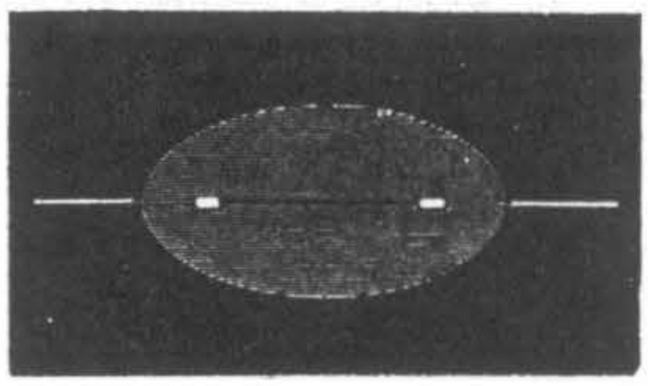


FIG. 34.—PHENOMENON OF IMPEDANCE IN AN INCANDESCENT LAMP.

a lamp is used a still more curious phenomenon than those described may be observed. The lamp may be placed across the copper bar and lighted, and by using somewhat larger capacities, or, in other words, smaller frequencies, or smaller impulsive impedances, the filament may be brought to any desired degree of incandescence. But when the impedance is increased, a point is reached when comparatively little current passes through the carbon, and most of it through the rarefied gas; or perhaps it may be more correct to state that the current divides nearly evenly through both, in spite of the enormous difference in the resistance, and this would be true unless the gas and the filament behave differently. It is then noted that the whole bulb is brilliantly illuminated, and the ends of the leading-in wires become incandescent, and often throw off sparks in consequence of the violent bombardment, but the carbon filament remains dark. This is illustrated in fig. 34. Instead of the filament, a single wire extending through the whole bulb may be used, and in this case the phenomenon would seem to be still more interesting.

From the above experiment it will be evident that, when ordinary lamps are operated by the converted currents, those should be preferably taken in which the platinum wires are far apart, and the frequencies used should not be too great, else the discharge will occur at the ends of the filament or in the base of the lamp between the leading-in wires, and the lamp might then be damaged.

In presenting to you these results of my investigation on the subject under consideration, I have paid only a passing notice to facts upon which I could have dwelt at length, and among many observations I have selected only those which I thought most likely to interest you. The field is wide and completely unexplored, and at every step a new truth is gleaned, a novel fact observed.

How far the results here borne out are capable of practical applications will be decided in the future. As regards the production of light, some results already reached are encouraging, and make me confident in asserting that the practical solution of the problem lies in the direction I have endeavoured to indicate. Still, whatever may be the immediate outcome of these experiments I am hopeful that they will only prove a step to further development towards the ideal and final perfection. The possibilities which are opened by modern research are so vast that even the most reserved must feel sanguine of the future. Eminent scientists consider the problem of utilising one kind of radiation without the others a rational one. In an apparatus designed for the production of light by conversion from any form of energy into that of light, such a result can never be reached, for no matter what the process of producing the required

vibrations, be it electrical, chemical, or any other, it will not be possible to obtain the higher light vibrations without going through the lower heat vibrations. It is the problem of imparting to a body a certain velocity without passing through all lower velocities. But there is a possibility of obtaining energy not only in the form of light, but motive power and energy of any other form, in some more direct way from the medium. The time will be when this will be accomplished, and the time has come when one may utter such words before an enlightened audience without being considered a visionary, We are whirling through endless space with an inconceivable speed, all around us everything is spinning, everything is moving, everywhere is energy. There *must* be some way of availing ourselves of this energy more directly. Then, with the light obtained from the medium, with the power derived from it, with every form of energy obtained without effort, from the store for ever inexhaustible, humanity will advance with giant strides. The mere contemplation of these magnificent possibilities expands our minds, strengthens our hopes, and fills our hearts with supreme delight.

CORRESPONDENCE.

Tesla's Experiments.

I have been much interested in the accounts given by Mr. Nikola Tesla of his experiments with lamps in which illuminations are obtained without the use of the so-called filamentary conductors.

The subject of the patent referred to by you in page 69, July 17th, 1891, is very similar to that of an old patent granted to me in 1882. During the years 1880 to 1882 I went over almost every experiment detailed by Mr. Nikola Tesla in describing his *new* system of electric lighting.

Many forms of lamps are illustrated and described in my patent, No. 4,752, 1882, entitled "Intensifying fluorescent and phosphorescent electric lighting, whereby the same is rendered serviceable for illuminating purposes, and apparatus for effecting the said intensification." These lamps can be worked at high tension and high frequency, but one of my objects at that time was to work these new lamps at safe pressures, and to some extent I accomplished that by placing both conductors inside the bulb, but still the pressure required is very high.

There is every likelihood of this method of lighting being developed into something useful. The luminous effects, and the heating effects of alternating discharges of electricity are not very well understood; text-books of science and teachers usually treat them as pretty tricks only to be stared at, very much in the same way as they treated the induction coil as a funny scientific toy for giving shocks, before it was discovered to be a transformer.

Illumination is so intimately connected with electrical discharges that we cannot but think that a useful method of electric lighting may be worked out on these lines.

My experiments proved the fact that brilliant lights could be so obtained by using high pressures and moderate frequency, and I believe the only direction in which to work for the production of light without any accompanying heat lies in the direction of high pressure alternating electrical discharges.

I have still by me some of my experimental apparatus and all my notes on the subject, so that I shall shortly communicate an article on the whole subject to this journal, so that our editors may print it if it is found of interest.

Rankin Kennedy.

July 17th, 1891.

THE ELECTRICIAN:

A WEEKLY ILLUSTRATED JOURNAL OF

ELECTRICAL ENGINEERING, INDUSTRY AND SCIENCE.

THE ELECTRICIAN, JULY 24, 1891. PRICE FOURPENCE.

NOTES.

THE extracts which we publish this week from Mr. TESLA's lecture on alternating currents of very high frequency will be found instructive reading. The numerous experiments described are of great scientific interest, and in many cases suggest useful applications. The difficulties to be overcome before such currents can be utilised for engineering purposes are far too great to render their introduction on any large scale at all probable; but they may quite possibly be found advantageous for special purposes, such, for instance, as the production of ozone by means of the brush discharge. It is also possible that some of Mr. TESLA's suggested developments with reference to illumination may in the future be profitably carried out, for the efficiency of the best known method of lighting is only a few per cent., and this may be increased in the manner described by Mr. TESLA, if a tolerably cheap converter can be found for transforming the alternating currents supplied to it into other currents of much greater frequency. Mr. TESLA's condenser transformer appears to be an arrangement of this kind, and his experiments, as a whole, form the most practical realisation which has yet appeared of the idea of producing light as the direct result of alternating currents of great frequency. The experiments on the alteration of the character of the brush discharge as the frequency of the alternations was increased are very striking, and are likely to throw light upon the nature of flames. The great importance of displacement currents, and the diminished value of conduction currents, owing to impedance, when the alternations are very frequent, are also clearly brought out in many ways. It is this which explains one of the last experiments described, in which the carbon filament of a glow lamp remains quite dark while the rarefied gas surrounding it is brilliantly illuminated; and the fact that the electric glow is equally intense at the surface, both of sharp points and round knobs, can only be accounted for by assuming that the phenomenon is mainly attributable to condenser action.

MR. TESLA contends that his effects are chiefly electrostatic, but, as Prof. J. J. THOMSON very pertinently remarks in our correspondence columns this week, "it is advisable to have a clear idea of what we mean by electrostatic action" in connection with this subject. The word has, until lately, been confined to phenomena caused by steady electric stresses, and rapidly alternating electromotive forces, such as Mr. TESLA has been dealing with, should not be so referred to. When currents are alternating with great rapidity the electric and magnetic phenomena are so intimately connected that it is next to impossible to separate them, and from a theoretical point of view it is undesirable. In fact the two sets of phenomena cannot exist apart, and Mr. TESLA's effects are "electrostatic" simply because he has only used apparatus which indicates the presence of alternating electromotive forces.

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY, AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION.*

BY NIKOLA TESLA.

The phenomena which are peculiar to the changing character of the currents are greatly exalted when the rate of change is increased, hence the study of these currents is considerably facilitated by the employment of properly constructed apparatus. It was with this and other objects in view that I constructed alternate-current machines capable of giving more than two million reversals of current per minute. The investigator who desires to repeat the experiments which I describe, with an alternate current machine, capable of supplying currents of the desired frequency, and an induction coil, will do well to take the primary coil out and mount the secondary in such a manner as to be able to look through the tube upon which the secondary is wound. He will then be able to observe the streams which pass from the primary to the insulating tube, and from their intensity he will know how far he can strain the coil. The selection of the type of machine best suited for the purpose must be left to the judgment of the experimenter. There are here illustrated three distinct types of machines, which, besides others, I have used in my experiments. Fig. 1 represents the machine used in my experiments before this Institute. It caused me the least trouble in construction as well as in maintenance, and, on the whole, it has been a good experimental machine. The field magnet consists of a ring of wrought iron with 384 pole projections. The armature comprises a steel disc to which is fastened a thin, carefully welded rim of wrought iron. Upon the rim are wound several layers of fine, well annealed iron wire, which, when wound, is passed through shellac. The armature wires are wound around brass pins, wrapped with silk thread. The diameter of the armature wire in this type of machine should not be more than one-sixth of the thickness of the pole projections, else the local action will be considerable. From the behaviour of the dielectrics in these experiments we may conclude that the best insulator for these rapidly alternating currents would be the one possessing the smallest specific inductive capacity, and at the same time one capable of withstanding the greatest differences of potential; and thus two diametrically opposite ways of securing the required insulation are indicated, namely, to use either a perfect vacuum or a gas under great pressure; but the former would be preferable. Unfortunately, neither of these two ways is easily carried out in practice. To avoid misunderstanding in regard to the physiological effect of alternating currents of very high frequency, I think it necessary to state that while it is an undeniable fact that they are incomparably less dangerous than currents of low frequencies, yet it should not be thought that they are altogether harmless.

After referring to the differences which may be observed between the brush discharges obtained by means of a rapidly alternating induction coil, when compared with that obtained from a powerful static machine, Mr. Tesla described the following striking peculiarity of the brush discharge produced by very rapidly alternating currents. To observe this it is best to replace the usual terminals of the coil by two metal columns insulated with a good thickness of ebonite. It is also well to close all fissures and cracks with wax so that the brushes cannot form anywhere except at the tops of the columns. If the conditions are carefully adjusted so that the potential rises to an enormous value, one may produce two powerful brushes several inches long, nearly white at their roots, which, in the dark, bear a striking resemblance to two flames of a gas escaping under pressure (Fig. 2). But they do not only *resemble*, they *are* veritable flames, for they are hot. Certainly they are not as hot as a gas burner, *but they would be so if the frequency and the potential should be sufficiently high.* Produced with, say, 20,000 alternations per second, the heat is easily perceptible even if the potential is not excessively high. If a bulb be held over the terminal of the coil so as to inclose the brush, the air contained in the bulb is very quickly brought to a high temperature. If a glass tube be held over the brush so as to allow the draught to carry the brush upward, scorching hot air escapes at the top of the tube. Anything held within the brush is, of course, rapidly heated, and the possibility of using such heating effects for some purpose or other suggests itself. It is of no little interest to contemplate that we have a possible way of producing—by other than chemcal means—a veritable flame which would give light and heat without any material being consumed, without any chemical process taking place, and to accomplish this we only

* Extracts from a lecture delivered before the American Institute of Electrical Engineers, at Columbia College, May 20, 1891.

need to perfect methods of producing enormous frequencies and potentials. I have no doubt that if the potential could be made to alternate with sufficient rapidity and power, the brush formed at the end of a wire would lose its electrical characteristics, and would become flamelike. The flame must be due to electrostatic molecular action.

By preventing completely the exchange of the air molecules the local heating effect may be so exalted as to bring a body to incan-

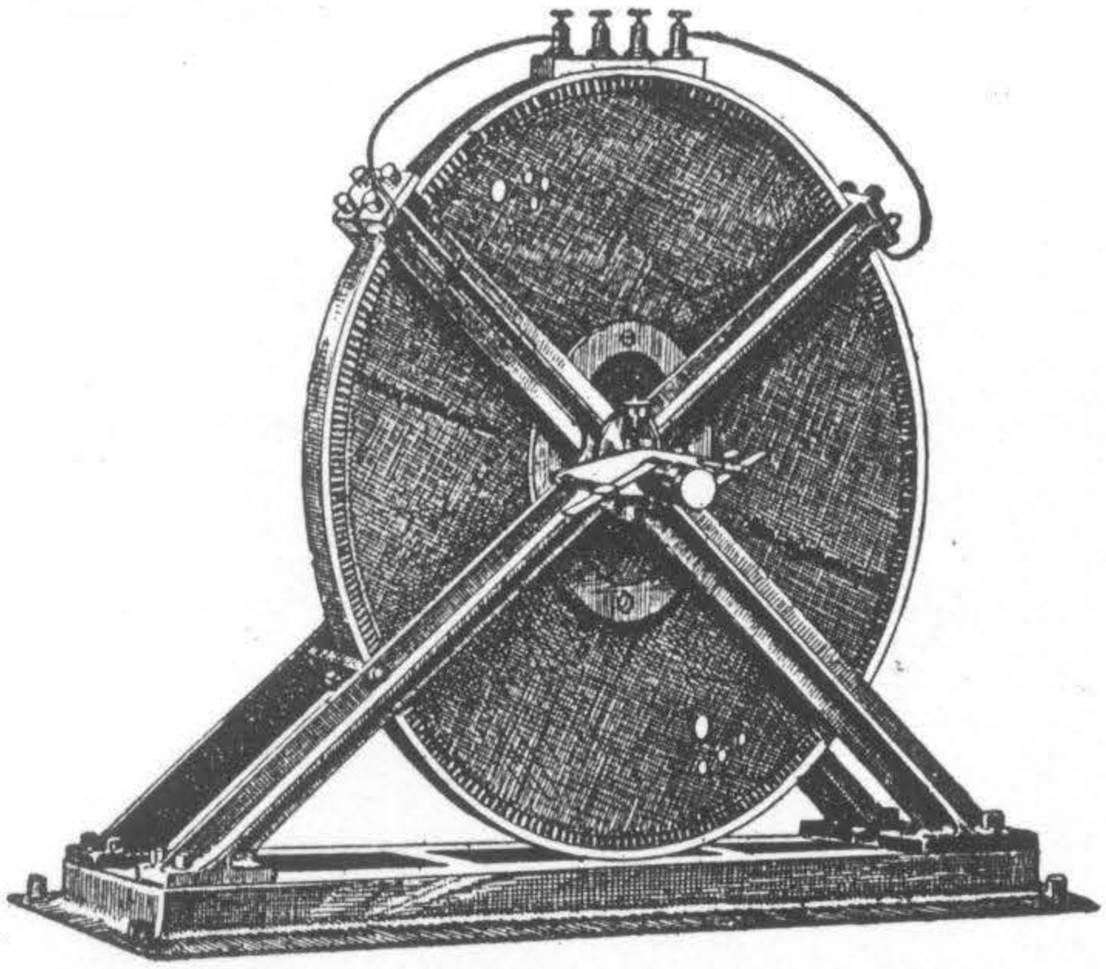


FIG. 1.—High Frequency Alternating-Current Machine with Drum Armature.

descence. Thus, for instance, if a small button, or preferably a very thin wire or filament, be enclosed in an unexhausted globe and connected with the terminal of the coil, it may be rendered incandescent. The phenomenon is made much more interesting by the rapid spinning round in a circle of the top of the filament, thus presenting the appearance of a luminous funnel (Fig. 3), which widens when the potential is increased. When the potential is small the end of the filament may perform irregular motions, suddenly changing from one to the other, or it may describe an ellipse; but when the potential is very high it always spins in a circle; and so does, generally, a thin, straight wire attached freely to the terminal of the coil. These motions are, of course, due to the impact of the molecules and the irregularity in the distribution of the potential, owing to the roughness and dissymmetry of the wire or filament. With a perfectly symmetrical and polished wire such motions would probably not occur. That the motion is not likely

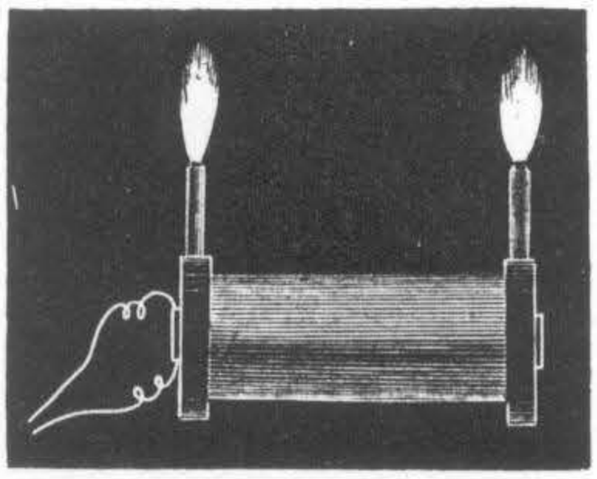


FIG. 2.—Aspect of Coil under powerful Brush Discharge.

to be due to other causes is evident from the fact that it is not of a definite direction, and that in a very highly exhausted globe it ceases altogether. The possibility of bringing a body to incandescence in an unexhausted globe, or even when not at all enclosed, would seem to afford a possible way of obtaining lighting effects, which by perfecting methods of producing rapidly alternating potentials might be rendered available for useful purposes.

Of all the experiments which may be performed with rapidly alternating currents, the most interesting are those which concern the production of a practical illuminant. Modern research has opened new possibilities for the production of an efficient source of light, and the attention of all has been carried in the direction indicated by able pioneers. Many have been carried away by the enthusiasm and passion to discover, but in their zeal to reach results many have been misled. Starting with the idea of producing electro-magnetic waves, they turned their attention, perhaps, too much to the study of electro-magnetic effects and neglected the study of electrostatic phenomena. Naturally, nearly every investigator availed himself of an apparatus similar to that used in earlier experiments. But in those forms of apparatus, while the electromagnetic inductive effects are enormous, the electrostatic effects are excessively small.

It has occurred to me, however, that electrostatic effects are in many ways available for the production of light. The electrostatic effects being dependent upon the potential and frequency, to produce the most powerful action it is desirable to increase both as far as practicable. It may be possible to obtain quite fair results by keeping either of these factors small, provided the other is sufficiently great; but we are limited in both directions. My experience demonstrates that we cannot go below a certain frequency, for, first, the potential then becomes so great that it is dangerous; and, secondly, the light production is less efficient.

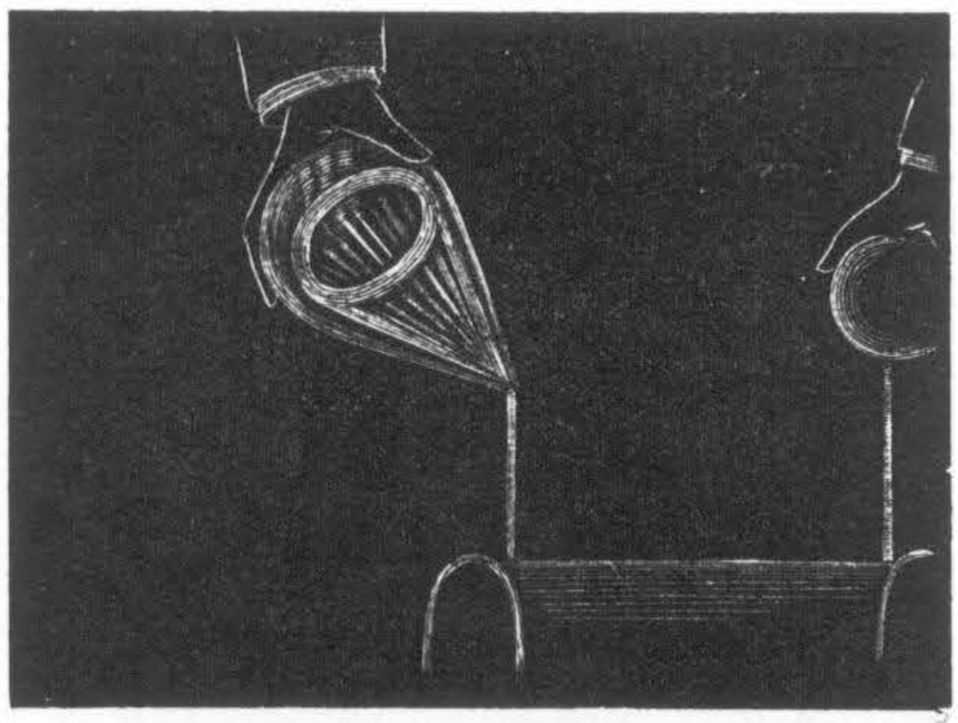


FIG. 3.—Incandescent Wire or Filament spinning in an Exhausted Globe.

I have stated above that a body enclosed in an unexhausted bulb may be intensely heated by simply connecting it with a source of rapidly alternating potential. The success of lamps of this kind would depend largely on the selection of the light-giving bodies contained within the bulb. Since, under the conditions described, refractory bodies—which are very poor conductors and capable of withstanding for a long time excessively high degrees of temperature—may be used, such illuminating devices may be rendered successful. It might be thought at first that if the bulb containing the filament or button of refractory material be perfectly well exhausted—that is, as far as it can be done by the use of the best apparatus—the heating would be much less intense, and that in perfect vacuum it could not occur at all. This is not confirmed by my experience; quite the contrary. The better the vacuum the easier the bodies are brought to incandescence. This result is interesting for many reasons.

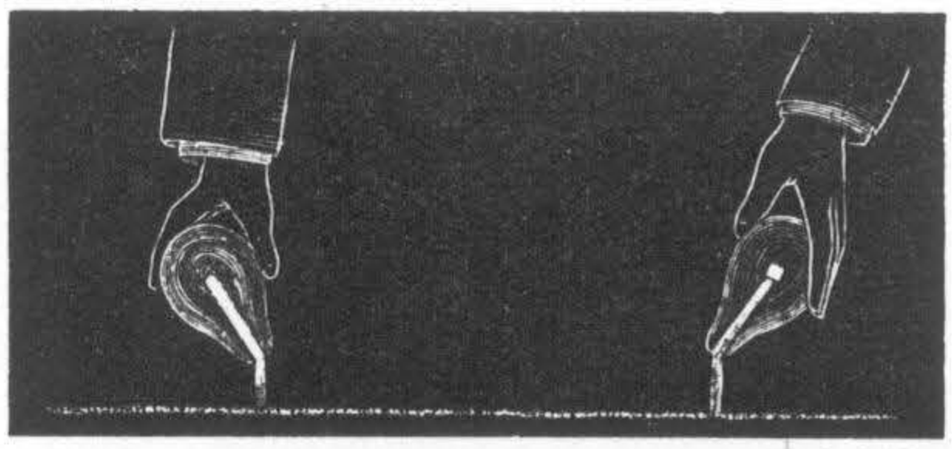


FIG. 4.—Lamp with Single Block of Refractory Material, and Single Filament Lamp.

Various forms of lamps on the above-described principle with the refractory bodies in the form of filaments have been constructed and operated by me, and investigations are being carried on in this line. There is no difficulty in reaching such high degrees of incandescence that ordinary carbon is to all appearance melted and volatilised. If the vacuum could be absolutely perfect such a lamp, although inoperative with apparatus ordinarily used, would, if operated with currents of the required character, afford an illuminant which would never be destroyed, and which would be far more efficient than an ordinary incandescent lamp. This perfection can, of course, never be reached, and a very slow destruction and gradual diminution of the size always occurs, as in incandescent lamps; but there is no possibility of a sudden and premature disabling which occurs in the latter by the breaking of the filament, especially when the incandescent bodies are in the shape of blocks. With these rapidly alternating potentials there is, however, no necessity of enclosing two blocks in a globe, but a single block, as in

Fig. 4, may be used. The potential in this case must, of course, be higher, but it is easily obtainable, and besides it is not necessarily dangerous.

The facility with which the button or filament in such a lamp is brought to incandescence, other things being equal, depends on the size of the globe. The life of such lamps as described above depends, of course, largely on the degree of exhaustion, but to some extent also on the shape of the block of refractory material.

The use of alternating currents of very high frequency makes it possible to transfer, by electrostatic or electro-magnetic induction through the glass of a lamp sufficient energy to keep a filament at incandescence, and so do away with the leading-in wires. Such lamps have been proposed, but for want of proper apparatus they have not been successfully operated. Many forms of lamps on this principle, with continuous and broken filaments, have been constructed by me and experimented upon. When using a secondary enclosed within the lamp, a condenser is advantageously combined with the secondary. When the transference is effected by electrostratic induction, the potentials used are, of course, very high with frequencies obtained from a machine. For instance, with a condenser surface of 40 centimetres square, which is not impracticably large, and with glass of good quality, 1 millimetre thick, using currents alternating 20,000 times a second, the potential required is, approximately, 9,000 volts. This may seem large, but since each lamp may be included in the secondary of a transformer of very small dimensions, it would not be inconvenient, and, moreover, it would not produce fatal injury. The transformers would all be preferably in series. The regulation would offer no difficulties, as with currents of such frequencies it is very easy to maintain a constant current

The experiments which will prove most suggestive and of most interest to the investigator are probably those performed with exhausted tubes. During my investigations in this line I endeavoured to excite tubes, devoid of any electrodes, by electro-magnetic induction, making the tube the secondary of the induction device, and passing through the primary the discharges of a Leyden jar. These tubes were made of many shapes, and I was able to obtain luminous effects which I then thought were due wholly to electro-magnetic induction. But, on carefully investigating the phenomena, I found that the effects produced were more of an electrostatic

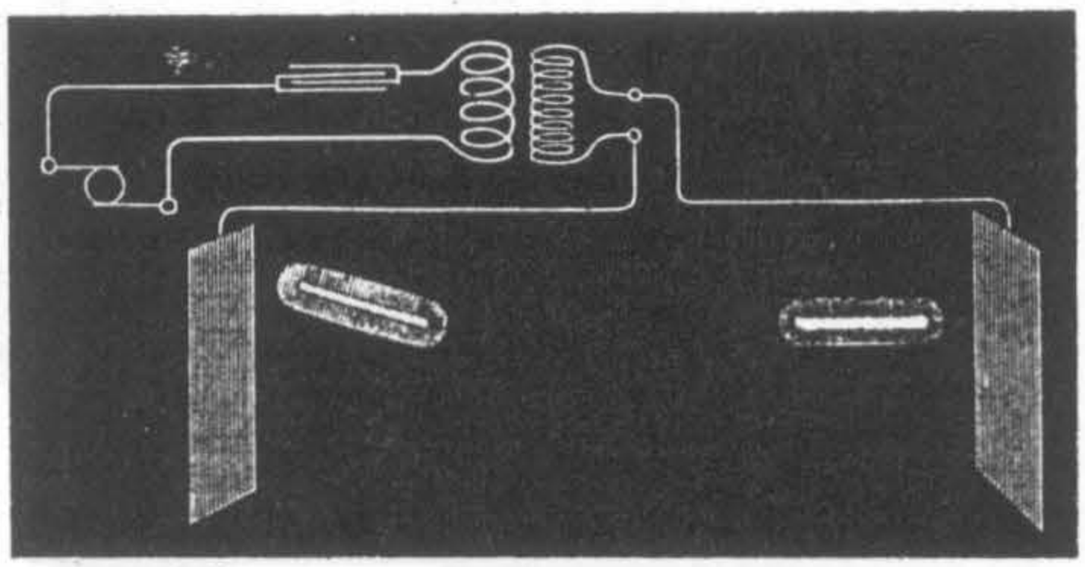


Fig. 5.—Ideal Method of lighting a Room. Tubes devoid of any Electrodes rendered brilliant in an Alternating Electrostatic Field.

nature. It may be attributed to this circumstance that this mode of exciting tubes is very wasteful; namely, the primary circuit being closed, the potential, and consequently the electrostatic inductive effect, is much diminished. When an induction coil, operated as above described, is used, there is no doubt that the tubes are excited by electrostatic induction, and that electro-magnetic induction has little, if anything, to do with the phenomena.

This is evident from many experiments. For instance, if a tube be taken in one hand, the observer being near the coil, it is brilliantly lighted, and remains so, no matter in what position it is held relatively to the observer's body. Were the action electro-magnetic, the tube could not be lighted when the observer's body is interposed between it and the coil, or at least its luminosity should be considerably diminished. When the tube is held exactly over the centre of the coil—the latter being wound in sections, and the primary placed symmetrically to the secondary—it may remain completely dark, whereas it is rendered intensely luminous by moving it slightly to the right or left from the centre of the coil. It does not light because in the middle both halves of the coil neutralise each other, and the electric potential is zero. If the action were electro-magnetic, the tube should light best in the plane through the centre of the coil, since the electro-magnetic effect there should be a maximum. When an arc is established between the terminals, the tubes and lamps in the vicinity of the coil go out, but light up again when the arc is broken, on account of the rise of potential. Yet the electro-magnetic effect should be practically the same in both cases.

By placing a tube at some distance from the coil, and nearer to one terminal—preferably at a point on the axis of the coil—one may light it by touching the remote terminal with an insulated body of some size, or with the hand, thereby raising the potential at that terminal nearer to the tube. If the tube is shifted nearer to the coil, so that it is lighted by the action of the nearer terminal, it may be made to go out by holding, on an insulated support, the end of a wire connected to the remote terminal in the vicinity of the nearer terminal, by this means counteracting the action of the latter upon the tube. These effects are evidently electrostatic. Likewise, when a tube is placed at considerable distance from the coil, the observer may, standing upon an insulated support, between the coil and tube, light the latter by approaching the hand to it; or he may even render it luminous by simply stepping between it and the coil. This would be impossible with electro-magnetic induction, for the body of the observer would act as a screen.

The effects of screening also indicate the electrostatic nature of the phenomena, and show something of the nature of electrification through the air. For instance, if a tube be placed in the direction of the axis of the coil, and an insulated metal plate be interposed, the tube will generally increase in brilliancy, or if it be too far from the coil to light, it may even be rendered luminous by interposing an insulated metal plate. The magnitude of the effects depends to some extent on the size of the plate. But if the metal plate be connected by a wire to the ground, its interposition will always make the tube go out, even if it be very near the coil.

In all the cases, then, when we excite luminosity in exhausted tubes by means of such a coil, the effect is due to the rapidly alternating electrostatic potential; and, furthermore, it must be attributed to the harmonic alternation produced directly by the machine, and not to any superimposed vibration which might be

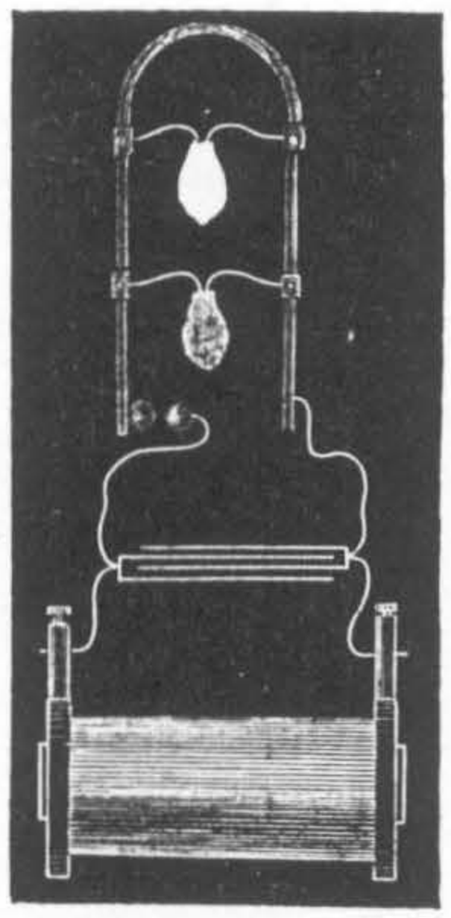


Fig. 6.—Lamp kept at incandescence across a thick Copper Bar, showing nodes.

thought to exist. Such superimposed vibrations are impossible when we work with an alternate current machine. If a spring be gradually tightened and released, it does not perform independent vibrations; for this a sudden release is necessary. So with the alternate currents from a dynamo machine; the medium is harmonically strained and released, this giving rise to only one kind of waves; a sudden contact or break, or a sudden giving way of the dielectric, as in the disruptive discharge of a Leyden jar, are essential for the production of superimposed waves.

In all the last described experiments, tubes devoid of any electrodes may be used, and there is no difficulty in producing by their means sufficient light to read by. The light effect is, however, considerably increased by the use of phosphorescent bodies, such as yttria, uranium glass, &c. A difficulty will be found when the phosphorescent material is used, for with these powerful effects it is carried gradually away, and it is preferable to use material in the form of a solid.

Instead of depending on induction at a distance to light the tube, the same may be provided with an external—and, if desired, also with an internal—condenser coating, and may then be suspended anywhere in the room from a conductor connected to one terminal of the coil, and in this manner a soft illumination may be provided.

The ideal way of lighting a hall or room would, however, be to produce such a condition in it that an illuminating device could be moved and put anywhere, and that it is lighted no matter where it is put, and without being electrically connected to anything. I

have been able to produce such a condition by creating in the room a powerful, rapidly alternating electrostatic field. For this purpose I suspend a sheet of metal at a distance from the ceiling, on insulating cords, and connect it to one terminal of the induction coil, the other terminal being preferably connected to the ground. Or else I suspend two sheets, as illustrated in Fig. 5, each sheet being connected with one of the terminals of the coil, and their size being carefully determined. An exhausted tube may then be carried in the hand anywhere between the sheets or placed anywhere, even a certain distance beyond them ; it remains always luminous.

In operating my devices I have observed curious phenomena of impedance, which are of interest. For instance, if a thick copper bar be bent, as indicated in Fig. 6, and shunted by ordinary incandescent lamps, then, by passing the discharge between the knobs, the lamps may be brought to incandescence although they are short circuited. When a large induction coil is employed it is easy to obtain nodes on the bar which are rendered evident by the different degrees of brilliancy of the lamps. When lamps with long, slender filaments are used it will be often noted that the filaments are from time to time violently vibrated. This vibration seems to be due to an electrostatic action between the filament and the glass of the bulb. In some of the above experiments it is preferable to use special lamps having a straight filament. When such a lamp is used a still more curious phenomenon than those described may be observed. The lamp may be placed across the copper bar and lighted, and by using somewhat larger capacities. or, in other words, smaller frequencies, or smaller impulsive impedances, the filament may be brought to any desired degree of incandescence. But when the impedance is increased, a point is reached when comparatively little current passes through the carbon and most of it through the rarefied gas ; or, perhaps, it may be more correct to state that the current divides nearly evenly through both, in spite of the enormous difference in the resistance, and this would be true unless the gas and the filament behave differently. It is then noted that the whole bulb is brilliantly illuminated, and the ends of the leading-in wires become incandescent, and often throw off sparks in consequence of the violent bombardment ; but the carbon filament remains dark. Instead of the filament a single wire extending through the whole bulb may be used, and in this case the phenomenon would seem to be still more interesting.

In presenting to you these results of my investigation on the subject under consideration I have paid only a passing notice to facts upon which I could have dwelt at length, and among many observations I have selected only those which I thought most likely to interest you. The field is wide and completely unexplored, and at every step a new truth is gleaned, a novel fact observed.

CORRESPONDENCE.

EXPERIMENTS ON THE ELECTRIC DISCHARGE IN VACUUM TUBES.

TO THE EDITOR OF THE ELECTRICIAN.

SIR: In *The Electrician* for July 17th there is a description of some experiments made by Mr. Nikola Tesla, which are somewhat similar in character to those shown by me to the Cambridge Philosophical Society, in February, and to the London Physical Society, on their visit to Cambridge, on May 9th. Mr. Tesla seems to ascribe the effects he observed to electrostatic action, and I have no doubt, from the description he gives of his method of conducting his experiments, that in them electrostatic action plays a very important part. He seems, however, to have misunderstood my position, with respect to the cause of these discharges, which is not, as he implies, that luminosity in tubes without electrodes cannot be produced by electrostatic action, but that it can also be produced when this action is excluded. As a matter of fact, it is very much easier to get the luminosity when these electrostatic effects are operative than when they are not. As an illustration of this I may mention that the first experiment I tried with the discharge of a Leyden jar produced luminosity in the tube, but it was not until after six weeks' continuous experimenting that I was able to get a discharge in the exhausted tube which I was satisfied was due to what is ordinarily called electro-dynamic action. It is advisable to have a clear idea of what we mean by electrostatic action. If, previous to the discharge of the jar, the primary coil is raised to a high potential, it will induce over the glass of the tube a distribution of electricity. When the potential of the primary suddenly falls, this electrification will re-distribute itself, and may pass through the rarefied gas and produce luminosity in doing so. Whilst the discharge of the jar is going on it is difficult, and, from a theoretical point of view, undesirable to separate the effect into two parts, one of which is called electrostatic, the other electro-magnetic; what we can prove is that in this case the discharge is not such as would be produced by electromotive forces derived from a potential function. In my experiments the primary coil was connected to earth, and, as a further precaution, the primary was separated from the discharge tube by a screen of blotting paper, moistened with dilute sulphuric acid and connected to earth. Wet blotting paper is a sufficiently good conductor to screen off a stationary electrostatic effect, though it is not a good enough one to stop waves of alternating electromotive intensity. When showing the experiments to the Physical Society I could not, of course, keep the tubes covered up, but, unless my memory deceives me, I stated the precautions which had been taken against the electrostatic effect. To correct misapprehension I may say that I did not read a formal Paper to the Society, my object being to exhibit a few of the most typical experiments. The account of the experiments in *The Electrician* was from a reporter's note, and was not written or even read by me. I have now almost finished writing out, and hope very shortly to publish, an account of these and a large number of allied experiments, including some analogous to those mentioned by Mr. Tesla on the effect of conductors placed near the discharge tube, which I find, in some cases, to produce a diminution, in others an increase, in the brightness of the discharge, as well as some on the effect of the presence of substances of large specific inductive capacity. These seem to me to admit of a satisfactory explanation, for which, however, I must refer to my Paper. I am glad to be able to take this opportunity of mentioning that I

find that the luminosity produced in a vacuum tube placed near a wire through which a Leyden jar is discharged, was noticed by Hittorf, and described by him in *Weidemann's Annalen*, Vol. XXI., p. 138. As, however, the discharge filled his tube, and did not pass as a ring, I should imagine that the cause of the discharge was primarily electrostatic.—I am, Sir, &c.

J. J. THOMSON.

Cambridge, July 18, 1891.

TESLA'S NEW SYSTEM OF ELECTRIC LIGHTING.

Incandescent Lamps without Return Circuit —Lighting by Condenser Discharge.

WE illustrate herewith an interesting system of electric lighting invented by Mr. Tesla, which is the outgrowth of the striking experiments described by him recently before the Institute of Electrical Engineers. The invention is based upon the discovery that an electric current of an excessively short period and very high potential may be utilised economically and practicably to great advantage for the production of light. As an instance of the lowest practicable limits, fairly good results have been obtained by a frequency as low as 15,000 to 20,000 per second, and a potential of about 20,000 volts. Both frequency and potential may be enormously increased above these figures, the practical limits being determined by the character of the apparatus and its capability of standing the strain.

To produce a current of very high frequency and very high potential, certain well-known devices may be employed. For instance, as the primary source of current or electrical energy a continuous-current generally may be used, the circuit of which may be interrupted with extreme rapidity by mechanical devices, or a magneto-electric machine specially constructed to yield alternating currents of very small period may be used; and in either case, should the potential be too low, an induction coil may be employed to raise it; or, finally, in order to overcome the mechanical difficulties, which in such cases become practically insuperable before the best results are reached, the principle of the disruptive discharge may be utilised. By means of this latter plan a much greater rate of change in the current is produced than by the other means suggested. The current of high frequency is produced by the disruptive discharge of the accumulated energy of a condenser maintained by charging said condenser from a suitable source and discharging it into or through a circuit under proper relations of self-induction, capacity, resistance, and period in well-understood ways. Such a discharge is known to be, under proper conditions, intermittent or oscillating in character, and in this way a current varying in strength at an enormously rapid rate may be produced. Having produced in the above manner a current of excessive frequency, by means of an induction coil, enormously high potentials are obtained—that is to say, in the circuit through which or into which the disruptive discharge of the condenser takes place is included the primary of a suitable induction coil, and by a secondary coil of

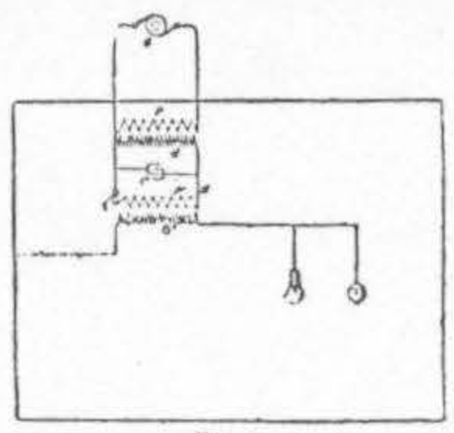


FIG 1

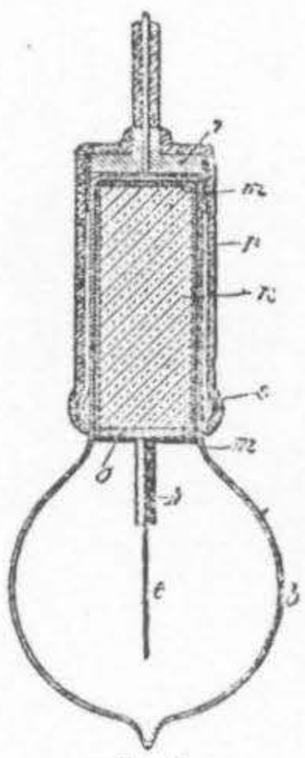


FIG. 2

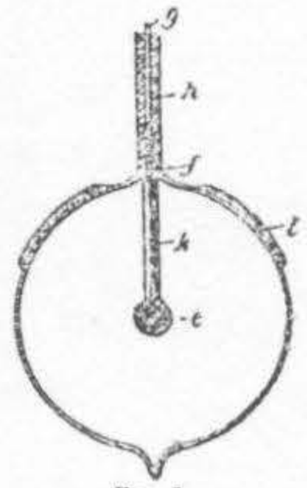


FIG 3

much longer and finer wire is converted to currents of extremely high potential. The differences in the length of the primary and scondary coils in connection with the enormously rapid rate of change in the primary current yield a secondary of enormous frequency and excessively high potential. Such currents are not available for use in the usual ways, but if either of the terminals of the secondary coil is connected to the leading-in wires of an ordinary incandescent lamp, the carbon may be brought to and maintained at incandescence, or a lamp may be rendered luminous by simply being held near the secondary circuit.

The inventor thinks the effects thus produced are attributable to molecular bombardment, condenser action, and electric or etheric disturbances.

In carrying out the invention, care must be taken to reduce to a minimum the opportunity for the dissipation of the energy from the conductors intermediate to the source of current and the light-giving body. For this purpose the conductors should be free from projections and points, and well covered or coated with a good insulator. The body to be rendered incandescent should be selected with a view to its capability of withstanding the action to which it is exposed without being rapidly destroyed, for some conductors will be much more speedily consumed than others.

In the accompanying engravings, which illustrate Mr. Tesla's apparatus, Fig. 1 is a diagram of a system, and Figs. 2 and 3 are vertical sectional views of special forms of light-giving devices.

G is the primary source of current or electrical energy, in the present illustration an alternating current generator of comparatively low electromotive force. The potential of the current is raised by means of an induction coil, having a primary, P and a secondary, S. This secondary charges a condenser, C, and this condenser discharges through or into a circuit, A, having an air-gap, *a*, for maintaining

a disruptive discharge. By the means above described a current of enormous frequency is produced. To convert this into a working current of very high potential, in the circuit A is connected the primary P' of an induction coil having a long fine wire secondary S'. The current in the primary P' develops in the secondary S' a current or electrical effect of corresponding frequency, but of enormous difference of potential, and the secondary S' thus becomes the source of the energy to be applied to the purpose of producing light.

The light-giving devices may be connected to either terminal of the secondary S'. If desired, one terminal may be connected to a conducting wall of a room or space to be lighted, and the other arranged for connection of the lamps therewith. In such case the walls should be coated with some metallic or conducting substance in order that they may have sufficient conductivity. The lamps or light-giving devices may be an ordinary incandescent lamp; specially designed lamps are now preferred, however. This lamp consists of a rarefied or exhausted bulb or globe which incloses a refractory conducting body, as carbon, of comparatively small bulk and any desired shape. This body is to be connected to the secondary by one or more conductors sealed in the glass, as in ordinary lamps, or is arranged to be inductively connected thereto. For this last named purpose the body is in electrical contact with a metallic sheet in the interior of the neck of the globe, and on the outside of said neck is a second sheet which is to be connected with the source of current. Tnese two sheets form the armatures of a condenser, and by them the currents or potentials are developed in the light-giving body. As many lamps of this or other kinds may be connected to the terminal of S', as the energy supplied is capable of maintaining at incandescence.

In Fig. 3, *b* is a rarefied or exhausted glass globe in which is a body of carbon *e*. To this is connected a metallic conductor, *f*, which passes through and is sealed in the glass wall of the globe, outside of which it is united to a copper or other wire, *g*, by means of which it is to be electrically connected to one pole or terminal of the source of current. Outside of the globe the conducting wires are protected by a coating of insulation, *h*, of any suitable kind, and inside the globe the supporting wire is inclosed in and insulated by a tube or coating, *k*, of a refractory insulating substance, such as pipeclay or the like. A reflecting plate, *l*, is shown applied to the outside of the globe *b*. This form of lamp is a type of those designed for direct electrical connection with one terminal of the source of current; but there need not be a direct connection, for the carbon or other illuminating body may be rendered luminous by inductive action of the current thereon, and this may be brought about in several ways. The preferred form of lamp for this purpose is shown in Fig. 2. In this figure the globe *b* is formed with a cylindrical neck, within which is a tube or sheet, *m*, of conducting material on the side and over the end of a cylinder or plug, *n*, of any suitable insulating material. The lower edges of this tube are in electrical contact with a metallic plate, *o*, secured to the cylinder *n*, all the exposed surfaces of such plate and of the other conductors being carefully coated and protected by insulation. The light-giving body *e*, in this case a straight stem of carbon, is electrically connected with the said plate by a wire or conductor similar to the wire *f*, Fig. 3, which is coated in like manner with a refractory insulating material, *k*. The neck of the globe fits into a socket composed of an insulating tube or cylinder, *p*, with a more or less complete metallic lining, *s*, electrically connected by a metallic head or plate, *r*, with a conductor, *g*, that is to be attached to one pole of the source of current. The metallic lining *s* and the sheet *m* thus compose the plates or armatures of a condenser.—*Electrical Review* (N.Y.)

MR. TESLA'S HIGH FREQUENCY EXPERIMENTS.

Some weeks ago we gave a short abstract of a paper read by Mr. Tesla on some very beautiful experiments he has been making. His paper, which is now accessible in full, has deservedly caused no little stir in American electrical circles.

Mr. Tesla has had, or perhaps, we may say, has made for himself, opportunities of experimenting on high alternating pressures and high frequencies, such as have fallen to the lot of no other experimenter. To begin with, he had to design a special dynamo to give the frequencies he required—such, for instance, as 10,000, which is what we think Mr. Tesla means by 20,000 alternations per second. He has designed and made three or four machines specially to give these enormous frequencies, and has then entered on a series of interesting and beautiful experiments. Mr. Tesla is sanguine as to the future of high frequencies, but we are somewhat doubtful. A large number of Mr. Tesla's experiments are old, having been made, perhaps on a somewhat smaller scale, with ordinary Ruhmkorff coils. A Ruhmkorff coil does not, of course, give frequencies of 10,000 a second, but most of the experiments do not really need the high frequencies Mr. Tesla uses.

We are not wanting in appreciation of Mr. Tesla's originality, nor in enthusiasm as to new things, but we must again protest, as we have once before protested, against Mr. Tesla's extraordinary habit of advancing as theories or explanations of phenomena, what are either rational theories rendered unintelligible by being oddly expressed, or mere strings of words without clear-cut definite meaning. Before a man has a right to publish new and unorthodox theories, he should have mastered the old and orthodox explanations of ordinary electrical phenomena. For instance, he states: "I adhere to the idea that there is a thing which we have been in the habit of calling electricity. . . . . The electromagnetic theory of light and all facts observed teach us that electric and ether phenomena are identical. The idea at once suggests itself, therefore, that electricity might be called ether. . . . . We must remember that we have no evidence of electricity, nor can we hope to get it, unless gross matter is present. Electricity cannot therefore be called ether in the broad sense of the term; but nothing would seem to stand in the way of calling electricity ether associated with matter, or bound ether; or, in other words, that the so-called static charge of the molecule is ether associated in some way with the molecule." Then, after some further reasoning, he says, "The spinning of the molecules and their ether sets up ether tensions or electrostatic strains; the equalisation of ether tensions sets up ether motions or electric currents, and the orbital movements produce the effects of electro and permanent magnetism." Elsewhere he says, "Scientific men still differ in opinion as to whether a charge should, or should not, be lost in a perfect vacuum—or, in other words, whether ether is, or is not, a conductor." This may not be so incomprehensible to others as it is to us, and we have a constitutional dislike to the framing of inconceivable theory in regard to subjects which are beyond the experience, and therefore the full conception, of any human being. We cannot even form any sort of working hypothesis from Mr. Tesla's dark sayings. The ultimate constitution of matter has been, and always will be, a subject in which people will delight to speculate in a nebulous and brain-wasting way, and we willingly admit that we can find many more foggy discussions than his nearer home. Moreover, if any part of our mind still remained clear after discussions about ether, we can always have recourse to dissertations on Mind, Right, Chemical Affinity, Duty, Life, or Electrolysis, or we can turn to Dr. Jaeger, and find that, just as ether is indissolubly mixed up with electricity, and is, therefore, the same thing, so disease is the same thing as an uninviting smell.

Passing to less nebulous regions, Mr. Tesla, for instance, inserts a plate of glass between two electrodes, and finds it gets hot. He attributes much of this heating to increased molecular bombardment, and much to the greater specific inductive capacity of the glass, "in consequence of which with the same potential difference a greater amount of energy is taken up in it than in rubber. It is like connecting to a battery a copper and a brass wire of the same dimensions. The wire, though a more perfect conductor, would heat more by reason of its taking more current." Then elsewhere, on the assumption that a high specific inductive capacity of itself means waste of power, he proposes to use, had it been possible, either a great pressure or a vacuum as an insulator, but does not say why their inductive capacities should be low. We do not wish to collect a series of small blemishes from a long and interesting lecture; in fact, the length of our quotations is already great enough to give the reader a falsely unfavourable impression. We think, however, that any one who has read many of Mr. Tesla's articles must have felt difficulty in understanding the frequent vague and idiomatic statements with which they abound. We do not think it too much to ask an electrician occupying such a prominent position as Mr. Tesla has gained for himself in America to omit passages that may detract from his reputation, and to allow us to admire him even more. If Mr. Tesla could keep phantom ideas about the electromagnetic theory of light and Hertz and Dr. Lodge out of his work, we feel sure he would make his interesting experiments more clear. The frequencies he uses are far too low for the velocity of propagation of a disturbance to be sensibly finite in comparison with them, and most of the results have been produced by the host of experimenters on discharges. Such suggestions as that relative to the advantages of high frequencies in making ozone commercially may soon be of enormous importance.

Mr. Tesla may be, and we trust is, on the right track when he suggests that the light of the future may be produced by vacuum tubes; but, on the other hand, the subject has been very patiently investigated already by many inventors without any very promising results.

ELECTRIC LIGHTING.—*N. Tesla, New York.*—This invention has for its object the production of currents of excessively small period and very high potential, and a novel method of an apparatus for utilising the same in the production of light. The rapidity of oscillation of the current produced is far in excess of anything that has heretofore been considered desirable or perhaps possible under practical working conditions and of a potential greater than has ever been applied to any useful purpose. The accompanying figures illustrate the invention, Fig. 1 showing a

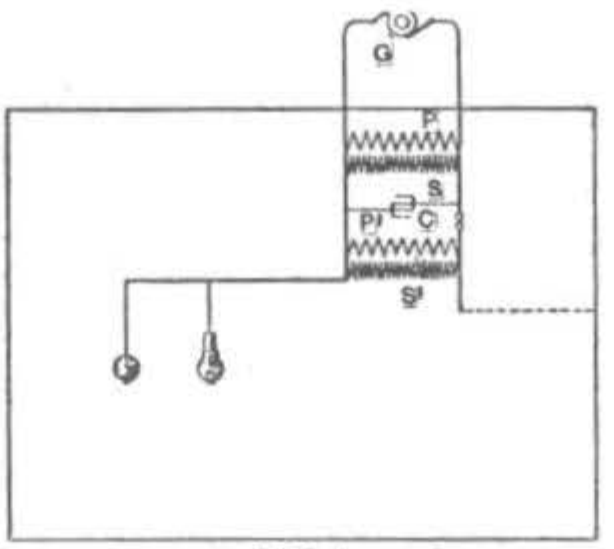


FIG. 1.

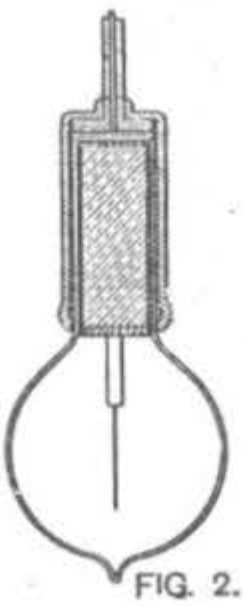


FIG. 2.

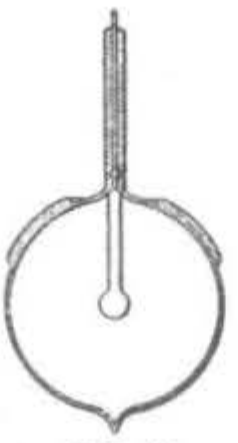


FIG. 3.



FIG. 4.

Industries.

means for producing the current, and Figs. 2, 3, and 4 various types of lamps. Referring to Fig. 1, G is the generator, which is assumed to be an alternating current producer, P S is an induction coil which raises the potential. The current produced in the secondary circuit S is led through a condenser C, which by means provided maintains disruptive discharges into the primary coil P^1 of another induction coil. The secondary coil S^1 has a long fine wire and develops a current of enormous difference of potential. The light-giving devices may be connected to one terminal of this circuit, the other terminal being connected to the wall of a room rendered conductive by being coated with metallic substance. The lamps (see Figs. 2, 3, and 4) consist of exhausted bulbs which enclose refractory conducting bodies of any desired shape. They may be connected directly to one terminal of the circuit as shown in Fig. 3, or they may be arranged to act by inductive action as shown in Fig. 2. In Fig. 4 both terminals are led into the bulb and are both rendered luminous. Claims: The improvements in electric lighting consisting in the production for the operation of the lighting devices of currents of enormous frequency and excessively high potential; the method of producing such a current by charging a condenser and maintaining an intermittent discharge into a primary circuit and producing thereby in a secondary working circuit very high potentials; the method of producing electric lighting by incandescence, by electrically or inductively connecting a conductor enclosed in a rarefied or exhausted receiver to one of the poles of a source of electric energy of a frequency and potential sufficiently high to render the said body incandescent, the other terminal of the source of electric energy being connected to conducting bodies in the vicinity of the said lighting devices.—No. 8575. May 19th, 1891. 8*d*.

The Work of Tesla, Kennedy and Gordon.—Touching the general interest aroused in electrical circles by the results of Mr. Tesla's experiments, it may not be out of place to call attention to the lamp invented by Mr. J. E. Gordon, and described in the REVIEW for December 1st, 1880. Mr. Kennedy briefly alludes to it in his article this week, and we feel sure that but few persons have anything but a faint recollection of Mr. Gordon's work in the direction of producing a workable lamp without a filament.

example, the increase of resistance of one conductor or the diminution of the resistance of the other per lamp-hour. These two measurements serve as a check, since the gain of one conductor should equal the loss of the other. A further check is afforded by measuring both wires in series with the resistance, in which case the resistance of the whole should remain constant.

After each measurement or registration of a given variation of resistance in one or both conductors, the direction of the current is changed or the instrument reversed, so that the deposit will be taken from the conductor which has gained and added to that which has lost. By this method it is possible to read off directly the amount of the energy expended by means of a properly-constructed ohm-meter, and without resorting to weighing the deposit; it is not necessary to employ shunts, for the whole of the current to be measured may be passed through the instrument; and the accuracy of the instrument, and correctness of the indications, are but slightly affected by changes in temperature. In addition to these advantages the arrangement possesses the merit of economy of energy, and simplicity in construction.

TESLA'S ELECTROLYTIC METER.

THIS meter consists of an electrolytic cell, through which extend two conductors parallel and in close proximity to each other. These conductors are connected in series through a resistance, but in such manner that there is an equal difference of potential between them throughout their entire extent. The terminals of the conductors are connected either in series in the circuit supplying the current to the lamps or other devices, or in parallel to a resistance in the circuit, and in series with the translating devices. Under such circumstances a current passing through the conductors establishes a difference of potential between them which is proportional to the strength of the current, in consequence of which there is a leakage of current from one conductor to the other across the solution. The strength of this leakage current is proportional to the difference of potential, and therefore, in proportion to the strength of the current passing through the conductors. Moreover, as there is a constant difference of potential between the two conductors throughout the entire extent that is exposed to the solution, the current density through such solution is the same at all corresponding points, and hence the deposit is uniform along the whole of one of the conductors, while the metal is taken away uniformly from the other. The resistance of one conductor is by this means diminished, while that of the other is increased, both in proportion to the strength of the current passing through them. From such variation in the resistance of either or both of the conductors forming the positive and negative electrodes of the cell, the current energy expended may be readily computed.

The method of using this device, and computing by its means the energy of the current, will be readily understood. First, the resistances of the two conductors, respectively, are accurately measured and noted. Then a known current is passed through the instrument for a given time, and by a second measurement the increase and diminution of the resistances of the two conductors respectively taken. From these data the constant is obtained, that is to say, for

Tesla's "Idiomatic Statements."—We notice *Industries* is protesting against Mr. Tesla's habit of advancing as theories or explanations of phenomena, which are either rational theories made inexplicit by strange expressions or simply lists of words deficient of meaning. We have no desire, says our contemporary, to pick out weak points in such an interesting lecture, but we think that any one who read Mr. Tesla's articles must have had great difficulty in understanding his repeated idiomatic statements. Is it asking Mr. Tesla too much, holding the prominent position he does in the American electrical world, when we say we think if he omitted some of the confusing passages his lectures would be much better understood, and if he would keep ideas anent electro-magnetic theory of light, also Hertz and Dr. Lodge, from his work, his experiments would be clearer as well as more interesting. We hope Mr. Tesla is correct when he surmises that the future light may be produced by vacuum tubes; but we believe the subject has been thoroughly searched out ere this by many inventors without a result which has been very promising.

ELECTRIC DISCHARGE IN VACUUM TUBES.

BY

Nikola Tesla

In The Electrical Engineer of August 12, I find some remarks of Prof. J. J. Thomson, which appeared originally in the London *Electrician* and which have a bearing upon some experiments described by me in your issue of July 1.

I did not, as Prof. J. J. Thomson seems to believe, misunderstand his position in regard to the cause of the phenomena considered, but I thought that in his experiments, as well as in my own, electrostatic effects were of great importance. It did not appear, from the meagre description of his experiments, that all possible precautions had been taken to exclude these effects. I did not doubt that luminosity could be excited in a closed tube when electrostatic action is completely excluded. In fact, at the outset, I myself looked for a purely electrodynamic effect and believed that I had obtained it. But many experiments performed at that time proved to me that the electrostatic effects were generally of far greater importance, and admitted of a more satisfactory explanation of most of the phenomena observed.

In using the term *electrostatic* I had reference rather to the nature of the action than to a stationary condition, which is the usual acceptance of the term. To express myself more clearly, I will suppose that near a closed exhausted tube be placed a small sphere charged to a very high potential. The sphere would act inductively upon the tube, and by distributing electricity over the same, would undoubtedly produce luminosity (if the potential be sufficiently high), until a permanent condition would be reached. Assuming the tube to be perfectly well insulated, there would be only one instantaneous flash during the act of distribution. This would be due to the electrostatic action simply.

But now, suppose the charged sphere to be moved at short intervals with great speed along the exhausted tube. The tube would now be permanently excited, as the moving sphere would cause a constant redistribution of electricity and collisions of the molecules of the rarefied gas. We would still have to deal with an electrostatic effect, and in addition an electrodynamic effect would be observed. But if it were found that, for instance, the effect produced depended more on the specific inductive capacity than on the magnetic permeability of the medium—which would certainly be the case for speeds incomparably lower than that of light—then I believe I would be justified in saying that the effect produced was more of an electrostatic nature. I do not mean to say, however, that any similar condition prevails in the case of the discharge of a Leyden jar through the primary, but I think that such an action would be desirable.

It is in the spirit of the above example that I used the terms "more of an electrostatic nature," and have investigated the influence of bodies of high specific inductive capacity, and observed, for instance, the importance of the quality of glass of which the tube is made. I also endeavored to ascertain the influence of a medium of high permeability by using oxygen. It appeared from rough estimation that an oxygen tube when excited under similar conditions—that is, as far as could be determined—gives more light; but this, of course, may be due to many causes.

Without doubting in the least that, with the care and precautions taken by Prof. J. J. Thomson, the luminosity excited was due solely to electrodynamic action, I would say that in many experiments I have observed curious instances of the ineffectiveness of the screening, and I have also found that the electrification through the air is often of very great importance, and may, in some cases, determine the excitation of the tube.

In his original communication to the *Electrician*, Prof. J. J. Thomson refers to the fact that the luminosity in a tube near a wire through which a Leyden jar was discharged was noted by Hittorf. I think that the feeble luminous effect referred to has been noted by many experimenters, but in my experiments the effects were much more powerful than those usually noted.

NOTES ON A UNIPOLAR DYNAMO.

BY

Nikola Tesla

It is characteristic of fundamental discoveries, of great achievements of intellect, that they retain an undiminished power upon the imagination of the thinker. The memorable experiment of Faraday with a disc rotating between the two poles of a magnet, which has borne such magnificent fruit, has long passed into every-day experience; yet there are certain features about this embryo of the present dynamos and motors which even to-day appear to us striking, and are worthy of the most careful study.

Consider, for instance, the case of a disc of iron or other metal revolving between the two opposite poles of a magnet, and the polar surfaces completely covering both sides of the disc, and assume the current to be taken off or conveyed to the same by contacts uniformly from all points of the periphery of the disc. Take first the case of a motor. In all ordinary motors the operation is dependent upon some shifting or change of the resultant of the magnetic attraction exerted upon the armature, this process being effected either by some mechanical contrivance on the motor or by the action of currents of the proper character. We may explain the operation of such a motor just as we can that of a water-wheel. But in the above example of the disc surrounded completely by the polar surfaces, there is no shifting of the magnetic action, no change whatever, as far as we know, and yet rotation ensues. Here, then, ordinary considerations do not apply; we can not even give a superficial explanation, as in ordinary motors, and the operation will be clear to us only when we shall have recognized the very nature of the forces concerned and fathomed the mystery of the invisible connecting mechanism.

Considered as a dynamo machine, the disc is an equally interesting object of study. In addition to its peculiarity of giving currents of one direction without the employment of commutating devices, such a machine differs from ordinary dynamos in that there is no reaction between armature and field. The armature current tends to set up a magnetization at right angles to that of the field current, but since the current is taken off uniformly from all points of the periphery, and since, to be exact, the external circuit may also be arranged perfectly symmetrical to the field magnet, no reaction can occur. This, however, is true only as long as the magnets are weakly energized, for when the magnets are more or less saturated, both magnetizations at right angles seemingly interfere with each other.

For the above reason alone it would appear that the output of such a machine should, for the same weight, be much greater than that of any other machine in which the armature current tends to demagnetize the field. The extraordinary output of the Forbes unipolar dynamo and the experience of the writer confirm this view.

Again, the facility with which such a machine may be made to excite itself is striking, but this may be due—besides to the absence of armature reaction—to the perfect smoothness of the current and non-existence of self-induction.

If the poles do not cover the disc completely on both sides, then, of course, unless the disc be properly subdivided, the machine will be very inefficient. Again, in this case there are certain points worthy of notice. If the disc be rotated and the field current interrupted, the current through the armature will continue to flow and the field magnets will lose their strength comparatively slowly. The reason of this will at once appear when we consider the direction of the currents set up in the disc.

Referring to diagram in Fig. 1, *d* represents the disc with the sliding contacts B B′ on the shaft and periphery. N and S represent the two poles of a magnet. If the pole N be above, as indicated in the diagram, the disc being supposed to be in the plane of the paper, and rotating in the direction of the arrow D, the current set up in the disc will flow from the centre to the periphery, as indicated by the arrow A. Since the magnetic action is more or less confined to the space between the poles N S, the other portions of the disc may be considered inactive. The current set up will therefore not wholly pass through the external circuit F, but will close through the disc itself, and generally, if the disposition be in any way similar to the one illustrated, by far the greater portion of the current generated will not appear externally, as the circuit F is practically short-circuited by the inactive portions of the disc. The direction of the resulting currents in the latter may be assumed to be as indicated by the dotted lines and arrows *m* and *n*; and the direction of the energizing field current being indicated by the arrows *a b c d*, an inspection of the figure shows that one of the two branches of the eddy current, that is, A B′ *m* B, will tend to demagnetize the field, while the other branch, that is, A B′ *n* B, will have the opposite effect. Therefore the branch A B *m* B that is, the one which is *approaching* the field, will repel the lines of the same, while branch A B′ *n* B, that is, the one *leaving* the field, will gather the lines of force upon itself.

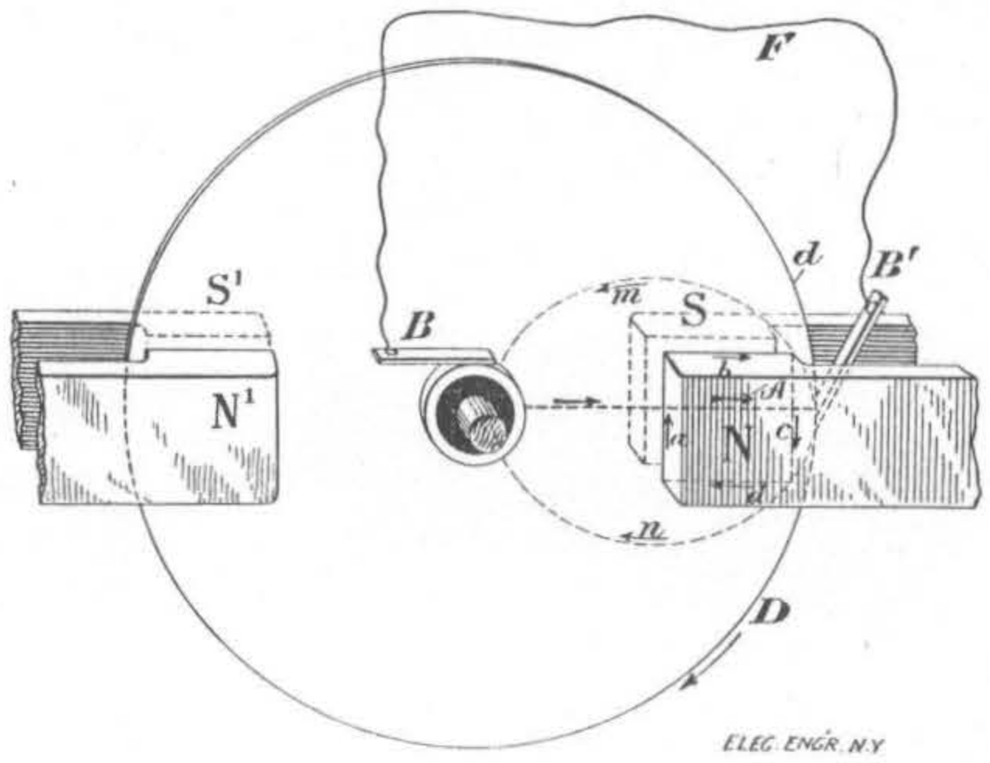
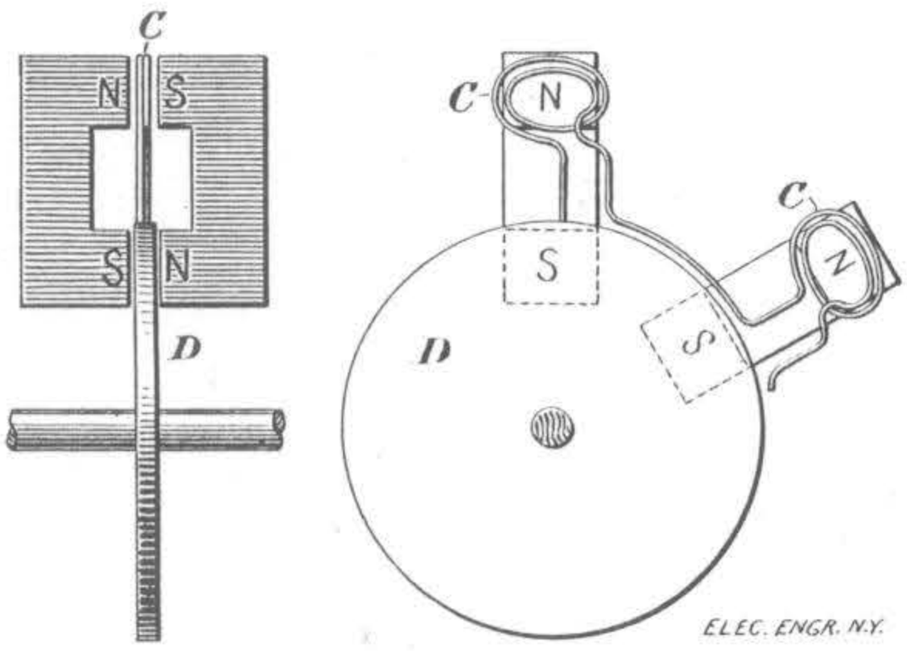


Fig. 1.

In consequence of this there will be a constant tendency to reduce the current flow in the path A B′ *m* B, while on the other hand no such opposition will exist in path A B′ *n* B, and the effect of the latter branch or path will be more or less preponderating over that of the former. The joint effect of both the assumed branch currents might be represented by that of one single current of the same direction as that energizing the field. In other words, the eddy currents circulating in the disc will energize the field magnet. This is a result quite contrary to what we might be led to suppose at first, for we would naturally expect that the resulting effect of the armature currents would be such as to oppose the field current, as generally occurs when a primary and secondary conductor are placed in inductive relations to each other. But it must be remembered that this results from the peculiar disposition in this case, namely, two paths being afforded to the current, and the latter selecting that path which offers the least opposition to its flow. From this we see that the eddy currents flowing in the disc partly energize the field, and for this reason when the field current is interrupted the currents in the disc will continue to flow, and the field magnet will lose its strength with comparative slowness and may even retain a certain strength as long as the rotation of the disc is continued.

The result will, of course, largely depend on the resistance and geometrical dimensions of the path of the result-

ing eddy current and on the speed of rotation; these elements, namely, determine the retardation of this current and its position relative to the field. For a certain speed there would be a maximum energizing action; then at higher speeds, it would gradually fall off to zero and finally reverse, that is, the resultant eddy current effect would be to weaken the field. The reaction would be best demonstrated experimentally by arranging the fields N S, N′ S, freely movable on an axis concentric with the shaft of the disc. If the latter were rotated as before in the direction of the arrow D the field would be dragged in the same direction with a torque, which, up to a certain point,



FIGS. 2 AND 3.

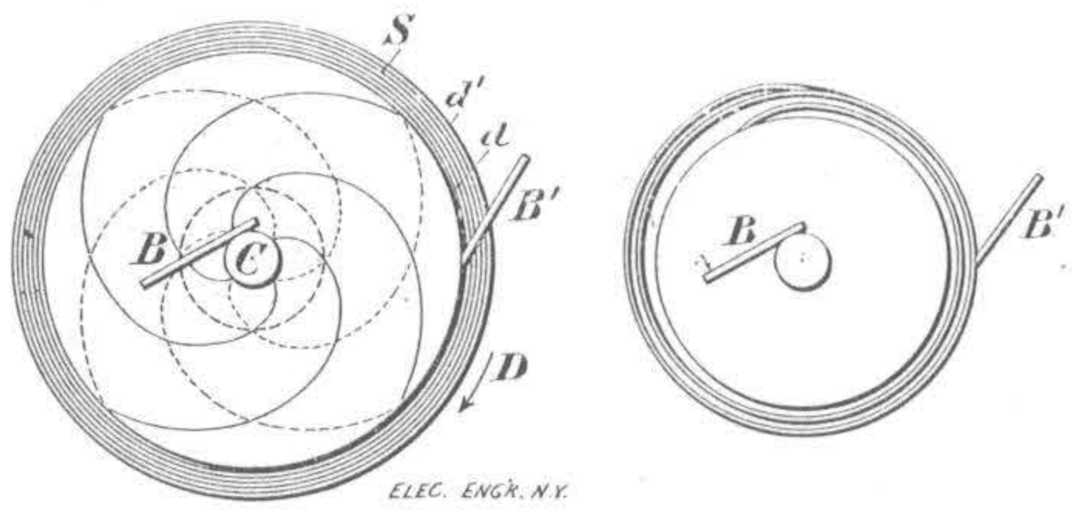
would go on increasing with the speed of rotation, then fall off, and, passing through zero, finally become negative; that is, the field would begin to rotate in opposite direction to the disc. In experiments with alternate current motors in which the field was shifted by currents of differing phase, this interesting result was observed. For very low speeds of rotation of the field the motor would show a torque of 900 lbs. or more, measured on a pulley 12 inches in diameter. When the speed of rotation of the poles was increased the torque would diminish, would finally go down to zero, become negative, and then the armature would begin to rotate in opposite direction to the field.

To return to the principal subject; assume the conditions to be such that the eddy currents generated by the rotation of the disc strengthen the field, and suppose the latter gradually removed while the disc is kept rotating at an increased rate. The current, once started, may then be sufficient to maintain itself and even increase in strength, and then we have the case of Sir William Thomson's "current accumulator." But from the above considerations it would seem that for the success of the experiment the employment of a disc *not subdivided* would be essential, for if there would be a radial subdivision, the eddy currents could not form and the self-exciting action would cease. If such a radially subdivided disc were used it would be necessary to connect the spokes by a conducting rim or in any proper manner so as to form a symmetrical system of closed circuits.

The action of the eddy currents may be utilized to excite a machine of any construction. For instance, in Figs. 2 and 3 an arrangement is shown by which a machine with a disc armature might be excited. Here a number of magnets, N S, N S, are placed radially on each side of a metal disc D carrying on its rim a set of insulated coils, C, C. The magnets form two separate fields, an internal and external one, the solid disc rotating in the field nearest to the axis, and the coils in the field further from it. Assume the magnets slightly energized at the start; they could be strengthened by the action of the eddy currents in the solid disc so as to afford a stronger field for the peripheral coils. Although there is no doubt that under proper conditions a machine might be excited in this or a similar manner, there being sufficient experimental evidence to warrant such an assertion, such a mode of exciting would be wasteful.

But a unipolar dynamo or motor, such as shown in Fig. 1, may be excited in an efficient manner by simply properly subdividing the disc or cylinder in which the currents are set up, and it is practicable to do away with the field coils which are usually employed. Such a plan is illustrated in Fig. 4. The disc or cylinder D is supposed to be arranged to rotate between the two poles N and S of a magnet, which completely cover it on both sides, the contours of the disc and poles being represented by the circles d and d' respectively, the upper pole being omitted for the sake of clearness. The cores of the magnet are supposed to be hollow, the shaft C of the disc passing through them. If the unmarked pole be below, and the disc be rotated screw fashion, the current will be, as before, from the centre to the periphery and may be taken off by suitable sliding contacts, B B′, on the shaft and periphery respectively. In this arrangement the current flowing through the disc and external circuit will have no appreciable effect on the field magnet.

But let us now suppose the disc to be subdivided spirally, as indicated by the full or dotted lines, Fig. 4. The difference of potential between a point on the shaft and a point on the periphery will remain unchanged, in sign as well as in amount. The only difference will be that the resistance of the disc will be augmented and that there will be a greater fall of potential from a point on the shaft to a point on the periphery when the same current is traversing the external circuit. But since the current is forced to follow the lines of subdivision, we see that it will tend either to energize or de-energize the field, and this will depend, other things being equal, upon the direction of the lines of subdivision. If the subdivision be as indicated by the full lines in Fig. 4, it is evident that if the current is of the same direction as before, that is, from centre to periphery, its effect will be to strengthen the field magnet; whereas, if the sub-division be as indicated by the dotted lines, the current generated will tend to weaken the magnets. In the former case the machine will be capable of exciting itself when the disc is rotated in the direction of arrow D; in the latter case the direction of rotation must be reversed. Two



FIGS. 4 AND 5.

such discs may be combined, however, as indicated, the two discs rotating in opposite fields, and in the same or opposite direction.

Similar dispositions may, of course, be made in a type of machine in which, instead of a disc, a cylinder is rotated. In such unipolar machines, in the manner indicated, the usual field coils and poles may be omitted and the machine may be made to consist only of a cylinder or of two discs enveloped by a metal casting.

Instead of subdividing the disc or cylinder spirally, as indicated in Fig. 4, it is more convenient to interpose one or more turns between the disc and the contact ring on the periphery, as illustrated in Fig. 5.

A Forbes dynamo may, for instance, be excited in such a manner. In the experience of the writer it has been found

that instead of taking the current from two such discs by sliding contacts, as usual, a flexible conducting belt may be employed to advantage. The discs are in such case provided with large flanges, affording a very great contact surface. The belt should be made to bear on the flanges with spring pressure to take up the expansion. Several machines with belt contact were constructed by the writer two years ago and worked satisfactorily, but for want of time the work in that direction has been temporarily suspended. A number of features pointed out above have also been used by the writer in connection with some types of alternating current motors.

THE TESLA-FERRARIS CONTROVERSY.

In our issue last week we gave the facts relating to this controversy, stating reasons for our belief that Mr. Tesla is fully entitled to the credit of priority in the discovery and application of the rotating field principle. We are glad to note the following from *Industries* of August 21, that paper having been the first to acquaint the English-speaking world with the work of Prof. Ferraris :

"There has been considerable discussion as to who really invented double and triple current work. The credit seems to lie between Mr. Tesla and Professor Ferraris. The former patented a practical and commercial motor on that principle, and surely he should have the full credit of the invention. We think Mr. Tesla has done far more to make it a practical success than any one, and we hope he will get, not only full credit, but something more substantial than abstract credit as well. At any rate, the invention was not English. Such modifications as using closed coil armatures or triple currents with three wires may be great improvements or not, but they can, in comparison, never rank as original inventions."

Judging from the concluding sentence quoted above, it would seem that our contemporary is still unacquainted with the full scope of Mr. Tesla's work.

PRIORITY IN ALTERNATING-CURRENT MOTORS.

The question of priority in the discovery of the alternating-current motor would seem to need definite settlement, both on account of historical accuracy and the avoidance of acrimonious discussion. It has been usual, in Europe, to ascribe to Prof. Ferraris the priority in the demonstration of the possibility of rotary motion being obtained from alternating currents, and in a recent *résumé* of the subject M. Hospitalier so accorded the credit. The dispute, so far as fundamental principles are concerned, is limited to Prof. Ferraris and Mr. Nikola Tesla; and the New York *Electrical Engineer* this week vigorously asserts the priority for America in the person of Mr. Tesla.

The following are the words of our contemporary: "Prof. Ferraris has been credited with the discovery now in controversy on the strength of his admirable paper, read before an Italian scientific society, in March, 1888, and published in Italian shortly afterwards. But five months before this, in October, 1887, Mr. Tesla had already filed applications for patents embodying the discovery, and several months before that time had so far perfected his invention that a company had been formed to exploit it. Many prominent persons, including several electricians, then saw the Tesla motors at work; and during the winter of 1887-8 one of the best-known scientific men in this country (America) examined and reported favourably upon them. Some time in April, one of the present editors of the New York *Electrical Engineer*, knowing of this new work, saw the motors which had then been running for some time in a temporary laboratory, and induced Mr. Tesla to bring his discovery before the May annual meeting of the American Institute of Electrical Engineers. The motors were actually shown in New York before a large gathering.

"On May 1, 1888—the same year—patents were issued to Mr. Tesla in America as the result of his application in October, and were then accessible at once in every European country. But the work of Prof. Ferraris was not brought to light in English-speaking countries (and others, too, for that matter) until it was given prominence by the publication of it in *Industries*, May 18, 1888. That interesting article was freely copied, as it well deserved, and its publication in this wise created the false idea that Prof. Ferraris's striking work was simultaneous with that of Mr. Tesla, or even prior. But the description of the Tesla invention must have evidently been made public on the patent, in England and other countries, before the date of the *Industries* article, and besides the fact of the issue of the patents there is the fact that a contemporary, the New York *Electrical Review*, had given a short illustrated description of the Tesla motors on May 12.

"More than this, in his essay of March, 1888, Prof. Ferraris expressly denied the practicability of motors that Mr. Tesla already had in successful operation! He hinted at the possibility of using a proper generator for such motors, but no further did he go. Mr. Tesla had already taken coal out of the mine before Prof. Ferraris had made his geological survey of the region. With this admission from Prof. Ferraris, it was not very likely that practical men would recognise the great value of the new principle.

"On examination of Mr. Tesla's now familiar work, we find that he, on the contrary, had not stopped short at a mere rotating field, but dealt broadly with the shifting of the resultant attraction of the magnets; that he had evolved the multiphase system; that he had shown the broad idea of motors employing currents of differing phase in the armature with direct currents in the field; that he had shown both synchronising and torque motors; that he had shown how machines of ordinary construction might be adapted to his system, and had with specific purpose advanced boldly into new territory, of which there was not the slightest hint or suggestion in the work of Prof. Ferraris. In other words, Mr. Tesla not only went to the bottom of the fundamental principles, but tried them in every detail that inventive ingenuity could hit upon. If this is not so, it is time to have the contrary state of affairs proved before Mr. Tesla loses the credit that such work must give him."

The Montreal Meeting of the National Electric Light Association.

Throughout Sunday, Sept. 6, the delegates to the Montreal Convention were gathering from all points of the compass as fast as the railway trains could carry them. The largest contingent, of course, was from New York, and the special train pulled out of the Grand Central station a little late, as special trains generally do, at 9:30. The journey northward was uneventful until when near Manchester, Vt., the engine struck work, perhaps because of the unwonted character of the load it was dragging. One cylinder was disabled, and most of the delegates got out to join the inquest. Mr. J. Carpenter Smith, on the end of a pry bar, rendered so valuable assistance to the engineer that finally the train started ahead with the remaining cylinder, and reached Rutland, where the Boston delegation, about 50 strong, was already waiting, and had been waiting for an hour and a half. The combination train was made up and rushed northward again without further mishap. At St. John the Montreal contingent was waiting to welcome the train, and marched through the cars headed by two bagpipers, who discoursed unearthly sounds until the train got under way. At midnight Montreal was reached, and the assembled crowd proceeded to the Windsor Hotel.

All day Monday arrivals continued. By reason of the multiplicity of entertainments that the hospitality of our Canadian friends had provided but one session was held each day, and the first, which was really a preliminary meeting only, met in Windsor Hall, at three o'clock on Monday afternoon, Sept. 7. President Huntley, of the association, was in the chair, and in a brief speech presented Prof. H. T. Bovey, chairman of the Montreal Citizens' Committee, who spoke a few words of welcome, and then in succession introduced the Hon. James McShane, mayor of Montreal, Sir Donald Smith, Sir William Dawson, Mr. Richard White, and others. All these gentlemen joined in giving the heartiest possible welcome to the Convention. For the United States, President Huntley, U. S. Consul Knapp and Judge Armstrong responded. Following Judge Armstrong, Mr. Erastus Wiman gave a brief address, joining with the gratitude of a member of the association the welcome of a Canadian to the visitors to his native land. Mr. Wiman especially called attention to the splendid work that had been done in the electric transmission of power, and made some interesting applications with reference to the great possibilities of electrical development in the city of Montreal.

President Huntley then read his address, dealing particularly with the modern central station and showing its tendency to develop a zonal system of distribution, employing for the service in each zone that particular class of apparatus best adapted to give good results at that particular distance.

President Huntley then read invitations from McGill University, the Art Association of Montreal, the Harbor Commissioners, and others, and after a vote of thanks had been passed in recognition of these, the meeting adjourned until the next morning, when the business at hand was the reports of the various committees appointed by the association.

The first committee to report was that on the relations between manufacturing companies and central stations, read by Mr. E. R. Weeks, of Kansas City. It was full of excellent suggestions centring around the proposition of an offensive and defensive alliance among central station men. Judge Armstrong, Mr. Wilmerding and Mr. Francisco took part in a vigorous discussion, warmly indorsing the necessity for united action of some sort. Mr. T. Carpenter Smith called attention to the good results that might be obtained by using as far so possible unpatented apparatus, and even making it, when it could be done economically. He felt that in this way the parent companies could be made to feel that the central stations were not entirely dependent on them, and expressed the opinion that there was enough unpatented apparatus to do a very large proportion of central station work if it were only put into use. After further discussion by Judge Armstrong, Mr. Nichols, Mr. Seeley and Mr. Burleigh, the committee, was continued with instructions to formulate a definite plan of campaign.

Mr. H. M. Swetland then presented the report of the Committee of Data. He said that information was very hard to obtain, and really all that it was possible for the committee to do at present was little more than to urge upon the Association the necessity of systematic and regular testing of apparatus, boilers, engines and dynamos. Too much stress, he added, cannot be laid on the need and advantage of just such work, and when careful testing becomes the rule instead of the exception the Committee on Data will be able to secure something in the way of useful information.

There was no report from the committee on the World's Fair, but instead Mr. J. A. Hornsby, secretary of the Electrical Section, reported on the work that had already been done, especially the grand missionary work that has been accomplished in bringing electricity into such an important place in the transmission of power for the exposition. The main building devoted to electricity will certainly be a credit to the country, and although the other electrical exhibits will be somewhat scattered they will be no less imposing. A vigorous effort will be made to hold a great international electrical congress. Suggestions have already been offered to this effect, and informal inquiries have even been made, with the result of receiving many cordial responses from all over the world. The exposition management will do everything in its power to secure an international congress, and it will lay the matter before the United States authorities at an early date. In response to a motion, a new committee on the World's Fair was appointed, consisting of Messrs. Sunny, Coleman, Hart, Royce and Price.

The electric lighting section of the Committee on Data, which was not ready to report at the beginning of the meeting, then read a brief report, dealing particularly with the classification of information which had been received. Apropos of this Mr. E. R. Weeks and Mr. Francisco drew attention to the false impressions produced throughout the country by the difference in cost of electric lighting in various cities. They called special attention to the fact that no notice seemed to be taken of the immense differences in running expenses, but that the public evidently assumed that if light could be furnished very cheaply in one place it could be furnished at an equally low price in all others.

The Committee on Legislation then reported through Judge Armstrong, its chairman, that owing to the lack of co-operation from members in various parts of the country little information could be presented. Messrs. Wilmerding, Francisco, Huntley and Scott gave some detailed account of the legislation that had been going on in their respective States. This topic then gave way to the report of the Committee on Underground Conduits, of which Mr. Francisco is chairman. There was very little to report and at the present time the committee preferred not to attempt any considerable discussion of the matter.

On Wednesday morning the first business taken up was the discussion of an important paper on the management of alternating current stations, read by Mr. T. Carpenter Smith at the previous Convention at Providence. The discussion resolved itself into an experience meeting, and Messrs. Ayer, Blaxter, Smith and Capt. Brophy gave some very interesting bits of practical information for the benefit of the association.

The Committee on Safe Wiring then reported. Judge Armstrong read the somewhat lengthy document that had been prepared. It was of so great importance and so thoroughly worked out that any off-hand discussion was quite out of the question, and the elaborate set of provisional rules that had been brought forward were ordered to be printed, in order that the report might be made a special subject for discussion at the very earliest moment.

At the conclusion of this discussion Mr. Redman's paper on Central Stations Operated by Water Power was read. It dealt mainly with the practical details of the work as carried out in Mr. Redman's station at Rochester, N. Y. Under the conditions there existing the water power installation is a very successful one. On account of the surplus of water the company is able to rent power to several important industries. The paper provoked a lively discussion, which drifted off into all sorts of side issues. Judge Armstrong called attention to the need of impressing on the public mind the occasionally very cheap service that could be obtained by water power. Apropos of this, Mr. Francisco went into the question of meters vs. the contract system of supply. In his own station both power and light were supplied by meter wherever it could be done, at the uniform rate of 25 cents per kilowatt hour. He approved of the meter, as it enabled an equitable adjustment of rates to be had whatever the service to which the meters were put. Messrs. Wilmerding and Ayer took the opposite view, contending that by contract, especially if based on the maximum load, better rates were obtained and more regular receipts. Mr. Scott then put in one of his usual keen inquiries, this time with respect to the actual economy that could be obtained by using water under ordinary circumstances. To this Mr. H. Ward Leonard and Mr. T. Carpenter Smith replied, both taking the view that there were many cases where a good steam plant would be cheaper than water power, even when the latter is available. Mr. Smith went so far as to say that the best use for water in an electric light station was for the purpose of condensation rather than as a source of power.

The next topic to receive consideration was Mr. H. Ward Leonard's proposition for a composite station to use both direct and alternating currents, employing the same network and feeding all or part of it by either system as required. This paper lead to a most interesting and vigorous discussion between the author aud Mr. T. Carpenter Smith, who is an earnest champion of the alternating current system, and although Mr. Leonard expressly disclaimed any intention of advocating the three-wire system as against the alternating, the discussion took an extremely lively turn. Mr. Smith believed that not only was the alternating quite as reliable as the three-wire system of distribution but that it was more efficient and safer, for the danger of a high tension wire crossing the three-wire system and sending its dangerous current directly to the lamps was far greater than breaking the insulation between the primary and secondary coils of converters. He believed that as time went on high tension would be used in connection with transformer sub-stations, and held that the danger from fire in heavy mains of the direct current produced more danger to life than the direct peril of the high tension alternating system. After a prolonged discussion, mainly between the two principals mentioned, the session closed with the reading of Mr. J. J. Burleigh's paper on methods of arranging central station accounts and so classifying them as to lead to the greatest useful result with the minimum of labor.

At the opening of the fourth session, on Thursday morning President Huntley read very pressing invitations from Norfolk, Va., and Augusta, Ga., to hold the next Convention in one of these cities. There was rather a strong feeling in the Convention that the next meeting should be in the West or the South, but the invitations were referred to the executive session.

Captain Eugene Griffin, of the Thomson-Houston Company, then read an interesting paper on the development of the electric railway. He took the view that substantially the modern electric railway was the creation of three years, dating back to 1888, at which time there were 13 small roads of more or less experimental character in operation. On the first of last July there were no less than 354 roads running, the normal growth of a century crowded into a few years. The speaker laid especial stress upon the economic importance of electric rapid transit, and showed that the increase in the average speed of street cars from six to nine miles an hour would more than double the available living area of a city, and in so far would alleviate the condition of the working classes, in addition to rendering useful, suburban portions of the country that otherwise could not well be reached. Captain Griffin said that the dangers of electricity which have been so often overestimated are now gradually becoming to be known at their real value, which is very slight, and the result was shown in the rapid extension of electric systems. A brief discussion followed this paper, in which Mr. Hammer, Judge Armstrong and others took part.

Somewhat of a sensation was created by the Chairman reading a telegram to the effect that the special electrical census reports had been stopped on account of lack of funds. If this stoppage should be permanent the reports are in such an incomplete state that the good results that had already nearly been reached would be irretrievably lost. Even the stoppage of work until the next session of Congress, at which time the topic would be brought up, would be very serious. In response to this Dr. Mason presented the cause of the electrical fraternity in the most effective manner, and finally offered a resolution calling on the Secretary of the Interior to see that the work was continued, requesting the introduction of a proper appropriation bill at the next session of Congress, and endorsing the work that Mr. Foote had already accomplished in the electrical census. Judge Armstrong made a vigorous speech in the same strain and advocated the appointment of a special committee of the association to follow up the resolutions and look after the work in Washington. In response to this the president was authorized to appoint a committee of five to take personal charge of the resolutions and see that something was done in the matter. A resolution was also passed to engage the co-operation of other electrical bodies in attaining the same end of furthering the census work.

After this interpolated business the discussion of the report of the Committee on Safe Wiring, deferred from Tuesday in order to give a chance for the printing of the report, was taken up, after the president had been authorized to appoint a standing committee of five to take charge of further work on wiring rules. The various provisions of the report were then considered seriatim, and, as might have been expected, provoked in the main a lively discussion. Most of them passed without active discussion, but certain topics were vigorously debated, and a considerable number

of minor changes were made. The rules were provisionally adopted and some sections were held for reference to the standing committee just mentioned. Owing to the lateness of the hour the discussion was closed before all the rules had been taken up, and the remainder of the work was left to the committee.

The session terminated with the reading of Mr. C. J. Field's paper on Electric Railway Construction and Operation. This proved to be a most practical paper of great interest to those engaged in electric railway work, and it was most unfortunate that it was read at a time when proper discussion was almost impossible.

On Friday morning the two remaining papers were taken up. The first to be read was Mr. Ayer's very valuable and interesting account of the methods used in the management of the great central station of the Municipal Company in St. Louis. The descriptions of the methods and precautions to be observed in arc lighting was full of practical details that must prove immensely useful to any manager. Two points especially referred to were the necessity of careful testing of apparatus and instruments and the great effect of small changes in the current on the total energy required at the station. Mr. Ayer said on one occasion he had found that a slight accident to an ammeter was increasing the coal bill at the rate of $16 a day, inasmuch as a current only .2 or .3 of an ampère greater than the normal required 20 or 25 per cent. more energy on account of the action of the lamp mechanism upon the electromotive force required. The discussion was comparatively brief, but Messrs. Nicholls, Francisco, Seely and others gave some useful fragments of information from their own experiences, and several minor points were actively discussed.

The final remaining paper, Mr. Warner's practical treatment of the subject of Arc Light Carbons was taken as read, owing to the little time remaining, and after a small amount of casual business had been transacted Sir William Dawson, Mr. F. R. Redpath and Prof. H. T. Bovey were elected honorary members of the association. This terminated the public meetings, and the association then went into executive session. One important item of business transacted at this final meeting was the selection of Buffalo, the home of President Huntley, as the place of the next meeting of the association. The selection was satisfactory to the members, even to those who hoped for the selection of a more Western or Southern point. Three vacancies on the Executive Committee, caused by the expirations of the terms of office of Messrs. J. J. Burleigh, A. M. Robinson and E. W. Rollins, were filled by the election of Messrs. Frederic Nicholls, of Toronto; A. M. Young, of Waterbury, Conn., and M. D. Law, of Schenectady, N. Y.

Resolutions of thanks were then tendered on the part of the association to Lord Stanley, Governor General of Canada; to the City of Montreal; to the Committee on Exhibits, the press, the railway companies, and the management of the Windsor Hotel. The association then adjourned to meet again six months hence in Buffalo.

Electrical Practice in Europe as Seen by an American.—IV.

BY CARL HERING.

The exhibition may now be said to be practically completed, but with the exception, unfortunately, of the one great exhibit, which is attracting so much attention in the electrical fraternity all over the world, namely, the transmission of power from Lauffen. It is unfortunate that there are so many delays; but to one who knows the facts in the case, it is quite comprehensible that such delays occur, and it should be said here that the delays are not due to the company nor the electrical engineers in charge of the works. It will be remembered that the companies whose exhibit this is were under penalty of a heavy fine to be ready to start on August 15th, and as far as they were concerned, all the apparatus was finished and erected, but the postal authorities (German government), who it appears were not under penalty of a fine, were not ready with the line which they had undertaken to construct. This caused a delay of over a week or more, which included some more or less reasonable formalities before it was officially turned over to the exhibitors for use. It was therefore not until a few days ago that the exhibitors could start their trial and experiments.

There are so many novel features about this experiment —for it is in every sense a public experiment, as distinguished from an exhibit of a commercial, model installation—that any engineer who has ever experimented with new apparatus and systems will readily understand that it is quite necessary to proceed carefully and cautiously. The impatient public, however, who are not aware of the difficulties involved, and who do not appreciate the need of proceeding with care, are already drawing unfavorable conclusions, which, however, are not warranted at all, as the writer, who knows the causes of the delays, will vouch for; they are, at least, not warranted at present; what the future will develop we cannot know, nor would we venture to prophesy, except to say that, from what was seen here, the system is no doubt a success, probably a complete success; but whether it will be possible to confine such a high tension current—a truly vicious current—to the line wires is still quite uncertain; if it is possible it is still a question whether it is practicable for commercial purposes. It is to decide this question that this very interesting and costly experiment is being made; and it is only rival companies, and a few pessimistic prophets, who do not wish these bold and enterprising exhibitors success.

The present state of the case is as follows, all other statements to the contrary notwithstanding: As the experiments are made with closed doors, the public have no means of knowing the exact condition of affairs. The writer, however, was one of the few who had the pleasure of witnessing the first arrival of the current from its distant generator. In order to be assured of the proper working of the line, and to see whether it would carry the current at all, which was by no means certain, the secondary current of 12,500 volts was first sent through a bank of lamps at this end, instead of through the motor. This proved a success in apparently every respect; the lamps burned as normally as the calculations intended they should.

The current was then sent through the large and novel motor, which started slowly and gradually under complete control of the engineer, until it reached its predetermined speed, at which it remained running without any adjustments whatsoever, making no more noise than the low humming of any ordinary transformer; it was indeed a novel sight to see such a large motor running without the slightest noise or vibration. It was a triumph of intelligent calculation, as this motor had never been run before, owing to the fact that the generator was built in Zurich and the motor in Berlin, and as it could be run only with this particular three phase-alternating current, it could not be tried until it was mounted here, and received current from its distant mate. Furthermore, it was the first one of that size ever built. The only other one from which experimental data could be obtained was a small one of about one h. p., almost a mere toy in comparison. As it is not a synchronous motor, as other alternating current motors are, the fact that it reached its predetermined speed and remained there, showed, in a measure at least, the correctness of the design. Owing to a hot bearing in the pump the latter could not be run; up to the present, therefore, the motor has not been run loaded, except for a few minutes, too short a time to draw conclusions.

In order to load the transformer fully, as well as to show the public that the current really got here from Lauffen (where the generator is situated), a large bank of lamps encircling a huge sign in front of the exhibit was turned on; they burned brightly, showing that the current not only got here, but that the load was not as great as was expected and prophesied by some. Owing to the breakage of an insulator on the line the current had to be turned off. This last experiment was made yesterday morning and includes the tests made up to the present writing. There were a few delays due to things which are apt to happen in starting any large new installation, but the only evil effect of these is to influence the minds of the impatient public. The interest and impatience are very great, especially as there is at present a municipal congress of the mayors of many German cities here, and it was the intention to start the transmission with great ceremonies during the session of this congress. Possibly it may yet be accomplished.

As soon as it is possible to obtain detailed information the writer will send a full description of this very interesting and novel installation. At present it will suffice to say that the system is designed and invented by M. von Dolivo-Dobrowolsky, a Russian by birth, well known as one of the leading electrical engineers of Germany. He is the electrical engineer of the Allgemeine Elektricitäts Gesellschaft of Berlin, who, together with the firm of Oerlikon (Zurich), are the exhibitors. Whether he is the first inventor need not be discussed here, any more than to say that he was probably not the first to conceive the idea of a rotary current, but that he was probably the first to put it into practice on a large scale and with novel details. The first mentioned firm built the motor, and two of the transformers, all designed by Mr. Dobrowolsky. The firm of Oerlikon built the generator,* which was designed by their engineer, Mr. C. E. L. Brown, who is well known for his very creditable work in dynamo construction. They also built two of the transformers modified in details by Mr. Brown. The line was erected by the government postal authorities, the copper wire being furnished by Hess & Sons, of Heddernheim, near Frankfort.

The three-phase rotary alternating current (drei-Phasiger Drehstrom) consists, as is well known, of three alternating currents differing from each other by one-third of a wave length. Such a current is particularly well suited for motor purposes, as already shown by the well known Tesla motors, in which a similar current is used. The current is transformed from 50 volts at the generator to 12,500 volts by a transformer; at the other end it is transformed back again, and then goes to the motor or lamps as desired. The line has three wires; the generator, motor and transformers have four.

It should be clearly understood that this experiment must not be looked upon as a test to show how much of the actual power of the generator is recovered at the motor. For such a test the line is very poorly proportioned and would give very misleading results. The main questions to be determined are, whether it is at all possible to transmit an alternating current at such high potentials along such an air line on poles; whether the insulation of such a line is possible and practicable; what effect rain has on the insulation, etc.; and if such transmission is at all possible, then to determine by means of tests such figures as are necessary for an engineer to calculate whether an installation of this kind can be made practicable in specific cases, and if so, what the constants are with which he can determine the

*See THE ELECTRICAL WORLD, vol. XVIII., p. 126.

most favorable proportions. It should be regarded, therefore, as an experiment made to obtain the figures for calculating a plant, rather than to determine the actual efficiency of this particular plant, which is of little interest to the intelligent engineer, although the public do not look at it in the same way.

GENERAL EXHIBITION NOTES.

A general tour through the grounds and buildings shows that the progress of electrical engineering here has been a steady and healthy one, and with the exception of the introduction of the rotary alternating current there is no novelty of great importance. There are many modifications of dynamos, systems, etc., showing the natural and steady growth and progress of an important industry in

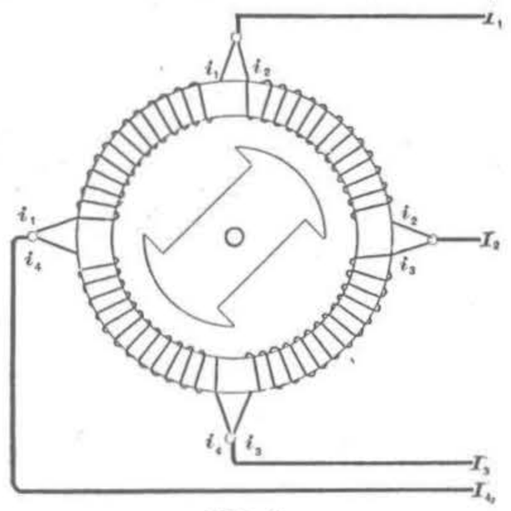


FIG. 1.

which no great monopoly exists in the form of broad fundamental patents, or artificial trusts and combinations, which are such an obstacle to a natural, healthy competition in which the fittest and not the strongest survive. The spirit here appears to be to make the best goods, rather than to pride themselves on their ability to sell something, or to keep others from selling it. The growth of electric lighting and transmission of power is slow here as compared with the United States, but it is steady and sure, and it is not unlikely that the larger European cities will have well planned, regulated and universal electric lighting before the larger American cities. Here the matter of lighting a city is referred to a committee of impartial technical experts, and not to ignorant politicians and contractors; it is

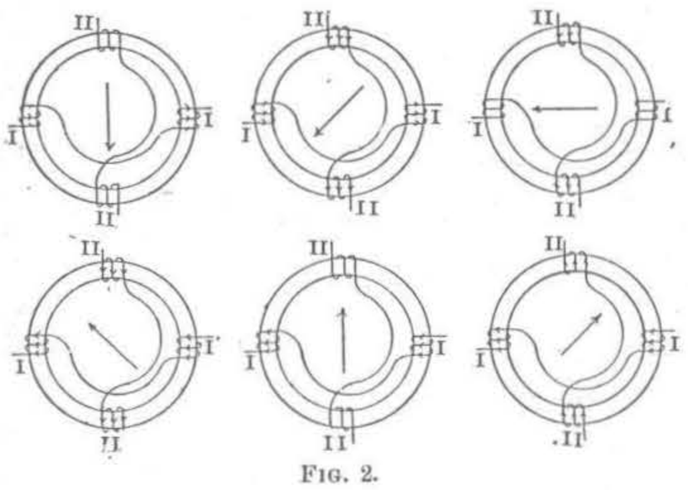


FIG. 2.

not likely either that the "lowest bidder" necessarily is accepted.

In numbers and in varieties of shapes the continuous current dynamos excel, but among the very large machines the alternating current dynamos are about as well represented as their rivals. The direct current systems, however, greatly outnumber the alternating; alternating current transformers are quite rare, while continuous current transformers (double wound dynamos) are comparatively numerous. Judging from the exhibits, transmissions with high tension continuous currents are quite numerous. One very noticeable feature of the exhibits is that the introduction of accumulators for central stations is growing apidly and steadily. The accumulator used in most of

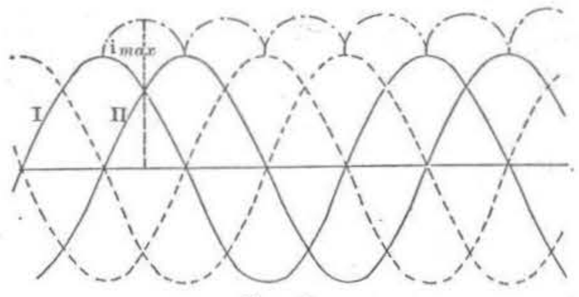


FIG. 3.

them is practically a Planté cell; it was very wisely concluded that for central stations lightness of weight at the expense of durability was poor economy. The present plates are made strong and heavy, and consequently are well able to stand the strains without danger.

Transmission of power by both alternating and continuous currents is one of the principal features of this exhibition. In the former, the tendency is toward multiple phase alternating currents. There is some ill feeling here as to who the inventor of this system is and who has the right to use it, but it is quite likely that it originated in the United States and is public property here. This has reference to what might be called an elementary rotary current of two or three phases. Regarding a new and interesting system of multiple phase currents with numerous phases we will have more to say in subsequent correspondence.

In incandescent lights, a marked improvement is the introduction of 150-volt lamps, and even up to 200 volts. Arc lights here are remarkably steady as compared to our flickering lamps. They are usually run in multiple arc, with incandescent lamps.

The exhibition itself includes many attractions for the public; no trouble has been spared to make it attractive in this respect. A layman can readily find something of interest there, even if he cannot understand it. The illuminated dome of the machinery hall, the colored waterfalls, the large projectors on the towers, with their club-shaped beams of light, all form an interesting sight in the evenings. The attendance, though fair, is not as great as was no doubt expected.

Last week a large party of Austrian and Italian engineers visited the exhibition in a body, and were entertained with

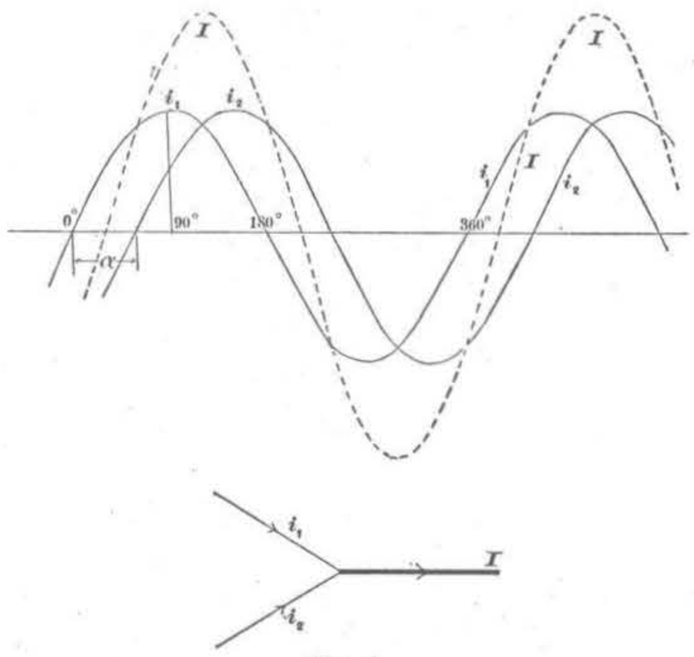


FIG. 4.

ceremonies. At present there is here a congress of cities, composed of the mayors and other municipal officers of about 50 of the most important German cities. They are being entertained as the guests of the city of Frankfort, and are being instructed in the fact that electric lighting for cities is no longer a novel experiment.

THE LAUFFEN-FRANKFORT INSTALLATION.

The occasion of the transmission of power from Lauffen to Frankfort has brought to the notice of the profession more than ever before the two or three phase alternating current system, described as early as 1887-8 by various electricians, among whom are Tesla, Bradley, Haselwander and others. As to who first invented it, we have nothing to say here, but though known for some years it has not until quite recently been of any great importance in practice.

Within the last few years, however, Mr. M. von Dolivo-Dobrowolsky, electrical engineer of the Allgemeine Elektricitäts Gesellschaft, of Berlin, has occupied himself with these currents. His success with motors run with such currents was the origin of the present great transmission of

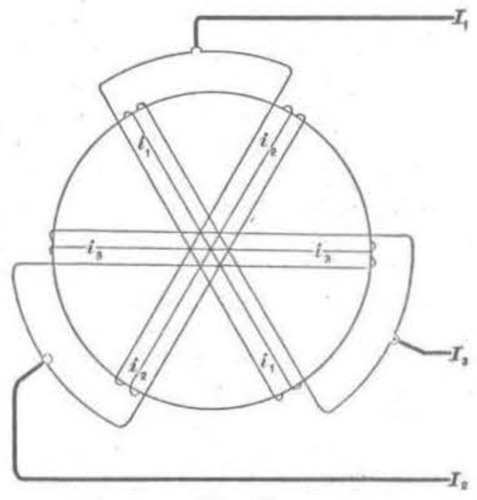


FIG. 5.

power exhibit at Frankfort, the greatest transmission ever attempted. His investigation in this new sphere, and his ability to master the subject from a theoretical or mathematical standpoint, has led him to find the objections, the theoretically best conditions, etc. This, together with his ingenuity, has led him to devise an entirely new and very ingenious modification, which will no doubt have a very great effect on the development of alternating current motors.

It is doubtless well known that if as in Fig. 1 a Gramme ring armature is connected to leads at four points as shown and a magnet is revolved inside of it (or if the ring is revolved in a magnetic field and the current led off by contact rings instead of a commutator) there will be two alternating currents generated, which will differ from each other in their phases only. When one is at a maximum the other is zero. When such a double current is sent into a similarly constructed motor it will produce or generate what might be called a rotary field, which is shown diagrammatically in the six successive positions in Fig. 2. The winding here is slightly different, but it amounts to the same thing as far as we are concerned at present. This is what Mr. Dobrowolsky calls an "elementary" or "simply" rotary current, as used in the Tesla motors. A similar system, but having three different currents instead of two, is the one used in the Lauffen transmission experiment referred to above.

In investigating this subject Mr. Dobrowolsky found that the best theoretical indications for such a system would be a large number of circuits instead of only two or three, each differing from the next one by only a small portion of a wave length; the larger their number the better theoretically. The reason is that with a few currents the resulting magnetism generated in the motor by these currents will pulsate considerably, as shown in Fig. 3, in which the two full lines show the currents differing by 90 degrees. The dotted line above these shows how much the resulting magnetism will pulsate. With two such currents this variation in magnetism will be about 40 degrees above its lowest value. Now, such a variation in the field is undesirable,

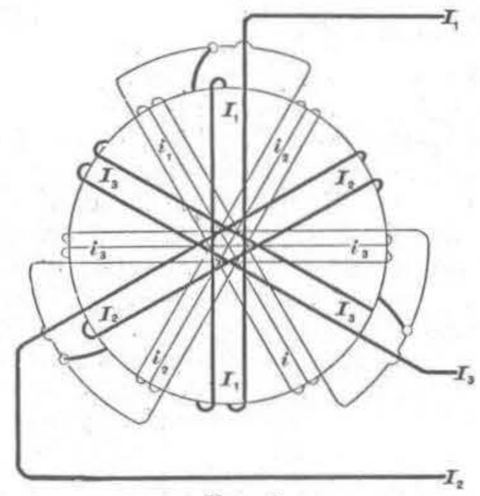


FIG. 6.

as it produces objectionable induction effects, and it has the evil effect of interfering with the starting of the motor loaded, besides affecting the torque considerably if the speed should fall slightly below that for synchronism. A perfect motor should not have these faults, and it is designed to obviate them by striving to obtain a revolving field in which the magnetism is as nearly constant as possible.

If there are two currents differing by 90 degrees, this variation of the magnetism will be about 40 per cent.; with three currents differing 60 degrees, about 14 per cent.; with

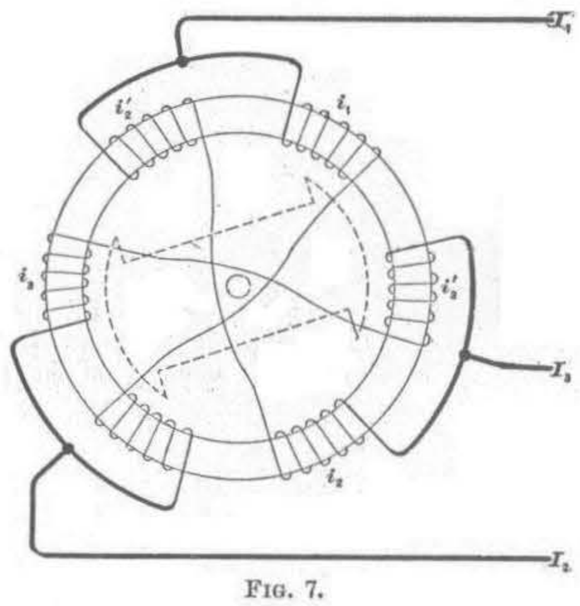


FIG. 7.

6 currents differing 30 degrees it will be only about 4 per cent., and so on. It will be seen, therefore, that by doubling the three-phase system the pulsations are already very greatly reduced. But this would require six wires, while the three-phase system requires only three wires (as each of the three leads can readily be shown to serve as a return lead for the other two in parallel). It is to combine the advantages of both that he designed the following very ingenious system. By this system he can obtain as small a difference of phase as desired, without increasing the num-

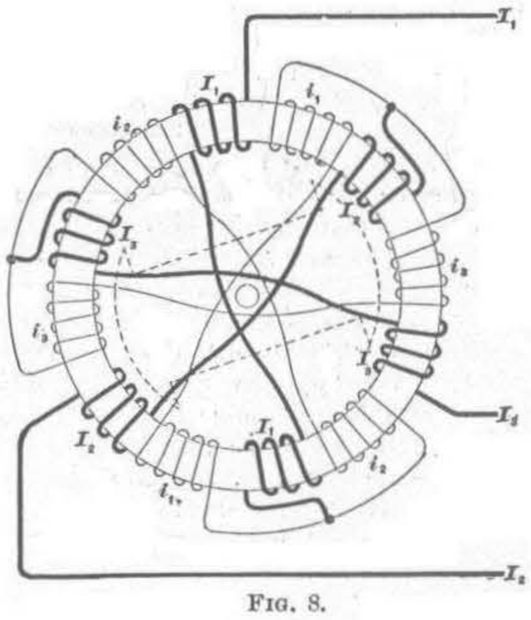


FIG. 8.

ber of wires above three, a statement which might at first seem paradoxical.

Before explaining this ingenious system, it might be well to call attention to a parallel case to the above in continuous current machines and motors. The first dynamos were constructed with two commutator bars. They were soon found to work much better with four, and finally still better as the number of commutator bars (or coils) was increased,

up to a practical limit. Just as the pulsations in the continuous current dynamos were detrimental to proper working, so are these pulsations in few-phased alternating current motors, though the objections manifest themselves in different ways—in the continuous current motors as sparking and in the alternating current motors as detrimental inductive effects.

The underlying principle of this new system may be seen best in Figs. 4, 5, 6, 7 and 8. In Fig. 4 are shown two currents, I_1 and I_2, which differ from each other by an angle D. Suppose these two currents to be any neighboring currents in a simple rotary current system. Now, if these two currents be united into one, as shown in the lower part of the figure, the resulting current I will be about as shown by the dotted line; that is, it will lie between the other two and at its maximum point, and for a difference of phases equal to 90 degrees it will be about 1.4 times as great as the maximum of either of the others; the important feature is that the phase of this current is midway between that of the other two. Fig. 5 shows the winding of a cylinder armature, and Fig. 7 that of a Gramme armature for a simple three-phase current with three leads, with which system we assume that the reader is familiar.

The two figures, 4 and 5 (or 7), correspond with each other in so far as the currents in the three leads, shown in heavy lines, have a phase between those of the two which compose them. Referring now to Fig. 6 (or 8), which is precisely like Fig. 5 (or 7) except that it has an additional winding shown in heavy lines, it will be seen that each of the

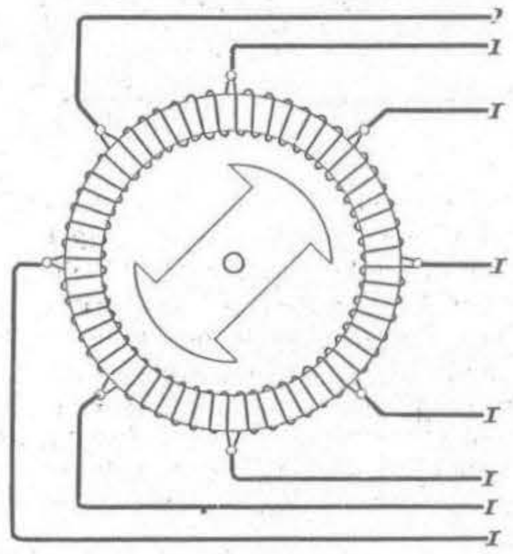


FIG. 9.

three leads, shown in heavy lines, is wound around the armature before leaving it, forming an additional coil lying *between* the two coils with which it is in series. The phase of the heavy line currents was shown in Fig. 4 to lie between the other two, therefore, in the armature in Fig. 6 (or 8) there will be six phases, while in Fig. 5 there are only three, the number of leads (three) remaining the same as before. This is the fundamental principle of this ingenious invention. To have six phases in Fig. 5 would require six leads, but in Fig. 6 precisely the same result is obtained

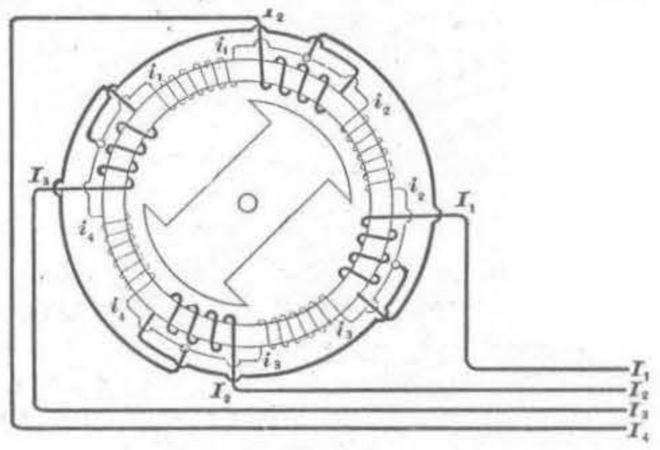


FIG. 10.

with only three leads. In the same way the three leads in Fig. 6 might again be combined and passed around the armature again, and so on forming still more phases, without increasing the number of leads. Figs. 7 and 8 compound with 5 and 6 and show the same system for a Gramme ring instead of a cylinder armature.

As was stated in the early part of this description, the main object in a rotary current motor is to have a magnetic field which is as nearly constant in intensity as possible, and which changes only its position, that is, its axis. But in Fig. 4 it was shown that the current I (in dotted lines) is greater than the others (about as 1.4 to 1 for a phase difference of 90 degrees). If therefore the coils in Fig. 6 or 8 were all alike the magnetism generated by the heavy line coils would be greater than that generated by the others, and would therefore produce very undesirable pulsations in the magnetic fields; but as the magnetism depends on the ampère turns, it is necessary merely to have correspondingly fewer turns on these coils, as compared with the others. This is shown diagrammatically in Figs. 6 and 8, in which the heavy line coils have less windings than the others. In practice it is not always possible to obtain the exact ratio of 1 to 1.4, for instance, but even if this ratio is obtained only approximately, it nevertheless reduces the pulsations very materially below what they would be with half the number of phases. It is therefore not necessary in practice to have more than an approximation to the exact conditions.

Fig. 9 shows a multiple phase armature, having double the number of phases as Fig. 1, and would according to the old system, therefore, require eight leads. Fig. 10 shows the new system with the same number of phases as in Fig. 9, but requiring only four leads instead of eight. Figs. 11 and 12 correspond with Figs. 7 and 8 and show the windings for a multipolar motor in the two systems.

These figures show how a motor may be wound so as to

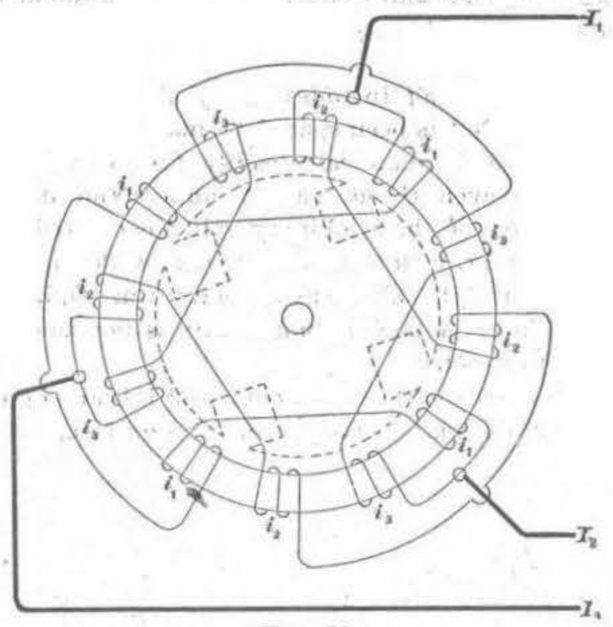


FIG. 11.

be a multiple phase motor, although the current entering the motor is a simple, elementary three or two phase current, which can be transformed by means of a simple three or two phase current transformer, before entering the motor, such transformers as are used at present in the Lauffen-Frankfort transmission. But the same principle as that for the motor may also be applied to transformers themselves, as shown in Figs. 13 and 14. Fig. 13 shows a set of transformers which are fed by a simple three phase current shown in heavy lines, and which gives in its secondary circuit a multiple phase rotary current. The connections for the primary circuit of a transformer with six coils are shown diagrammatically in Fig. 15, the numbers 1 to 6 representing the succession of the phases. Fig. 14 shows

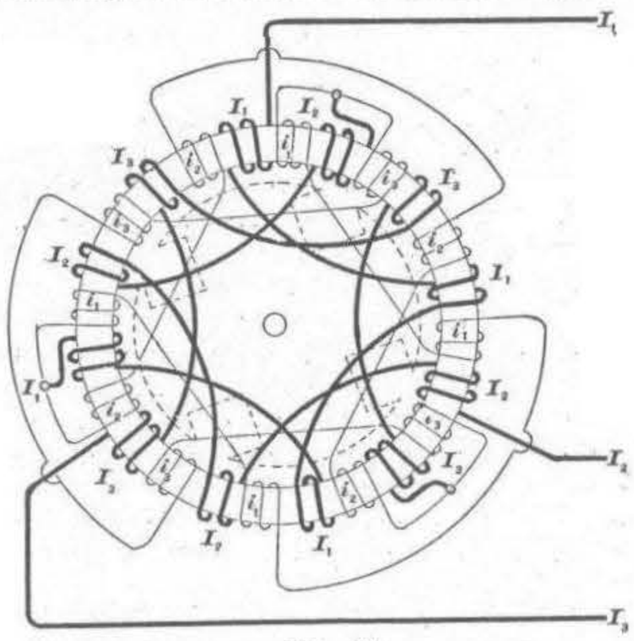


FIG. 12.

a transformer for a two phase current with four leads, transforming into a multiple phase current of 16 leads. The transformer in this figure is a single "interlocked" transformer in which the fields are magnetically connected and not independent of each other as in Fig. 13. This has advantages in the regulation of currents, which do not exist in Fig. 13, but which need not be entered into here. The transformers used in the Lauffen-Frankfort transmission are similar, magnetically, to Fig. 14, only that they are for a simple three phase current in both primary and secondary circuits. Attention is also called to the difference in the connections of secondary circuits in Figs. 13 and 14; in the former they are connected in a closed circuit similarly to an ordinary closed circuit armature, while in Fig. 14 they

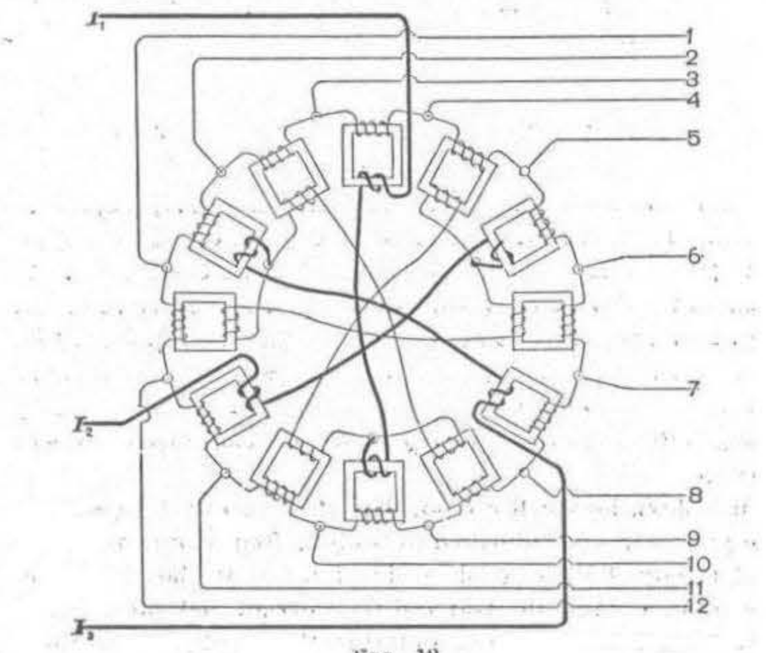


FIG. 13.

are independent as far as the currents themselves are concerned, though magnetically their cores are connected. It is not the intention to enter into a discussion of the relative values of these various connections, but merely to draw attention to the wide range of the number of combinations which this system admits of.

FRANKFORT O. M., Aug. 29, 1891.

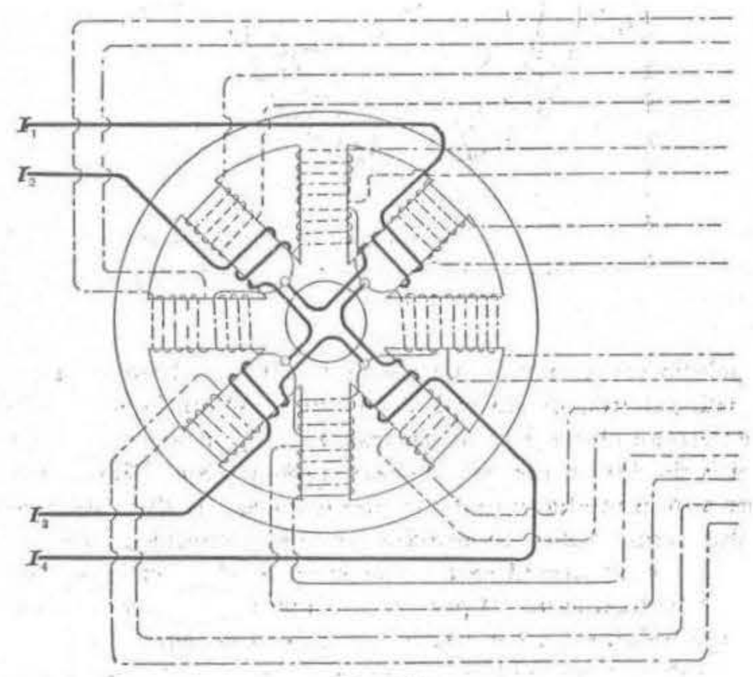


FIG. 14.

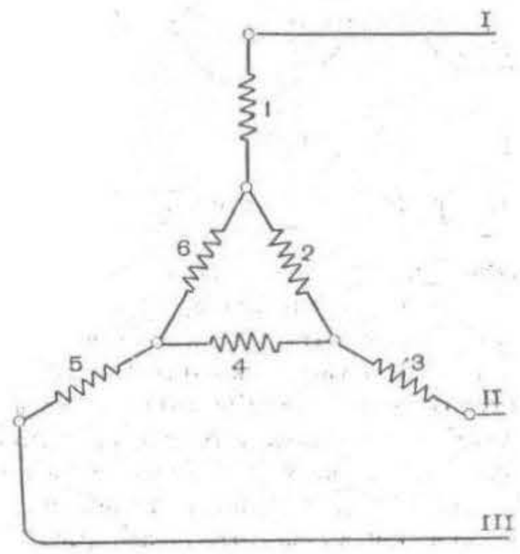


FIG. 15.

American Institute Of Electrical Engineers–Tranactions
September 22, 1891

A paper read at the 59th Meeting of the American Institute of Electrical Engineers, New York, September 22d, 1891. Vice-President Lockwood in the Chair.

ON THE RELATION OF THE AIR GAP AND THE SHAPE OF THE POLES TO THE PERFORMANCE OF DYNAMO-ELECTRIC MACHINERY.

BY HARRIS J. RYAN.

The object of this paper is not to deal with the subject in a new light, but to add to its literature a limited amount of data, the deductions from which go to establish the correctness of the ideas, and the utility of the suggestions put forth in the papers read by Messrs. Swinburne and Esson, at the meetings of the Institution of Electrical Engineers on Feb. 13 and 20, 1890. Up to the time of the publication of these papers, the air gap was usually treated by contributors to electrical literature as an evil in a dynamo, having a necessary existence, and the smaller that it could conveniently be made the better. The shape of the poles had often been spoken of as having a somewhat decided effect on the performance of the dynamo, while but little had been said regarding the cause of such an effect.

There exists some difference of opinion as to what should be known as the number of ampere turns on an armature. For our present purpose we will assume that the

$$\text{Armature ampere turns} = \frac{\left\{\begin{array}{l}\text{The No. of conductors on the surface of}\\ \text{the armature}\end{array}\right\} \times \left\{\begin{array}{l}\text{Strength of current in the armature conductors}\end{array}\right\}}{\text{Number of poles.}}$$

Referring to Fig. 1, it is evident that when we consider the magnetic forces acting in a working dynamo by the route O, I, J, O, that the entire number of ampere turns on the armature are directly opposed in action to the ampere turns on the field. By the route O, M, N, O, all the ampere turns on the armature except those that lie between the double angle of lead G, E, are acting

with the field ampere turns, while those between G, E, are opposed to the same. Therefore by this route, the total number of ampere turns actually aiding the field ampere turns is the total number of armature ampere turns, minus twice the number of ampere turns that lie between the double angle of lead. By the route O, K, L, O, the number of ampere turns acting is the number of ampere turns on the field, minus the number of ampere turns that lie between the double angle of lead. We can then estimate with ample practical accuracy the magnetic density in the air gap at all points, for any given total amount of magnetization through the armature. The

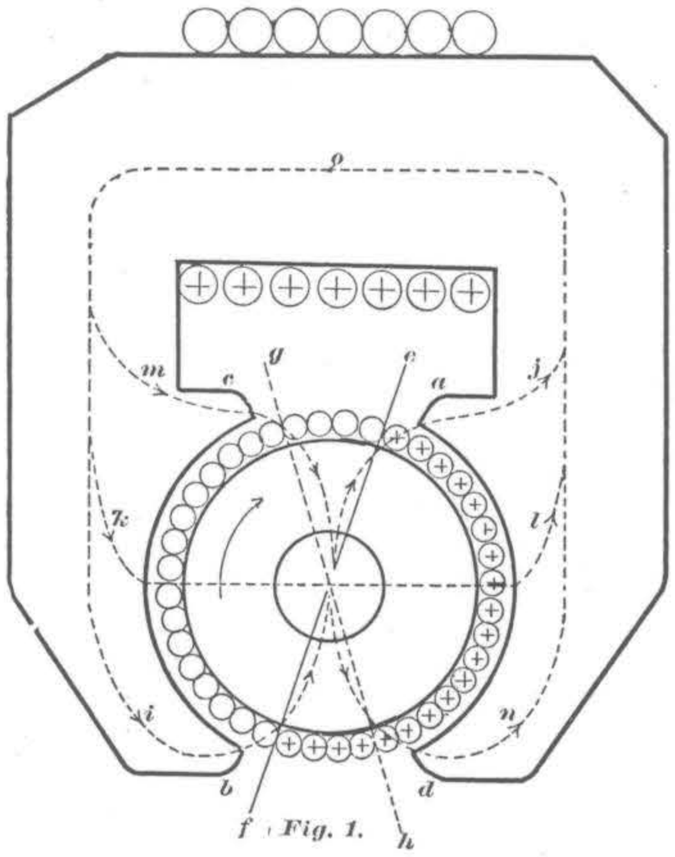


Fig. 1.

ampere turns that lie between the double angle of lead are opposed to the action of the field ampere turns at all points. It is evident that the portion of the armature ampere turns not included between the double angle of lead will increase the magnetization through the air gap by the route O, M, N, O, just as much as they diminish it along the route O, I, J, O, as long as magnetic saturation does not take place in the strengthened pole corners C, D. If the pole corners are thin, as in the types shown in figures 2, 3 and 5, saturation is apt to occur. It is then that the magnetic resistance increases by the route O, M, N, O, and the magnetic

density by this route is no longer increased by the same amount that it is diminished along the route O, I, J, O. On the other hand, when the pole corners are fashioned as seen in figures 4 and 6, so that saturation in the strengthened pole corners can not occur in practice, the current in the armature can produce no modification of the total amount of magnetization through it, other than that which is produced by the action of the ampere turns that lie between the double angle of lead. This action can always be compensated for by putting an equivalent number of series ampere turns on the field acting with the field ampere turns. The double angle of lead can be determined with sufficient accuracy, for with pole corners slightly extended at the centre, see Fig. 11, the diameter of commutation at all loads is very near the weakened

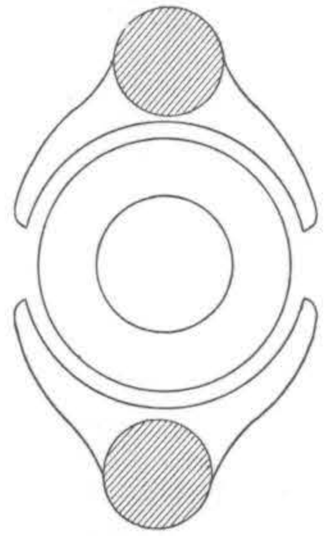


Fig. 2.

pole corners. The pole corners are slightly extended at the centre, so that the coils always enter the field of the weakened pole corners gradually. The E. M. F. developed in the coils as they pass under the poles can never be far different from that actually needed to reverse the current in the coil when passing under the brush. In this way the point of commutation in a dynamo can be kept the same when carbon brushes are used without undue sparking, as long as the armature does not reverse the magnetization under the weakened pole corners.

From the discussion of the magnetic relations of an armature to its field in a dynamo in connection with Fig. 1, it is seen that the magnetization in the air gap under the weakened pole corners becomes zero, when the armature ampere turns are equal to the

ampere turns on the field, whose magnetizing force is impressed between its pole faces through the armature. This impressed magnetizing force is that due to the difference between the total number of ampere turns on the field and the number of ampere turns required to set up the magnetization through the field cores, from pole face to pole face. In order to commutate the current without spark at the commutator, the magnetization in the air gap under the weakened pole corners dare never be allowed to become zero. It follows then that the field ampere turns impressing a magnetizing force between the pole faces must always be somewhat in excess of the maximum number of ampere turns on the armature. The amount of this excess need only be sufficient to insure a positive field at A and B, Fig. 1, strong enough to reverse the current in the coils as they are commutated. When a certain amount of magnetization is to be set up through an armature with the application of the magnetizing force of a given number

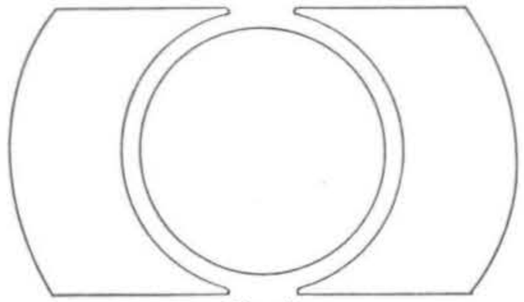


Fig. 3.

of ampere turns impressed between the pole faces, we must provide the requisite amount of magnetic resistance between these pole faces. The value of this resistance will have to be such that the impressed field magnetizing force will establish the desired amount of magnetization. This resistance in most cases is best provided for in a proper length of air gap. In general it is found best to avoid heating in the armature core as far as consistent, by the use of comparatively low magnetic densities for wrought-iron. The magnetic resistance of the armature core under these circumstances is very small and may be neglected.

The magnetic resistance between the pole faces is occasionally provided for largely, either through a saturated core of a ring armature, saturated lugs on armatures where the wires are placed in grooves, or both. This in addition to what air gap may be necessary from a mechanical point of view, go to make up the total amount of magnetic resistance that is provided between the

pole faces. Machines of this order have been developed largely through the old and rather expensive method of experimentation. This method has given us some types in which ordinary results are arrived at, through rather extraordinary means. Take the case of a machine with a ring armature, wires wound in grooves, a very small air gap, and poles shaped somewhat as shown in Fig. 2. Such a machine operated as a dynamo, may require only a quarter of the number of ampere turns that it will have on the armature at full load for field excitation, in order to produce a certain E. M. F. at a given speed. Yet this machine produces a fairly constant potential at the brushes under all variation of load, and without undue sparking at the commutator in the following manner: For the production of a constant E. M. F. at constant speed, the total magnetization through the armature must remain constant. At no load one fourth of the ampere turns needed on

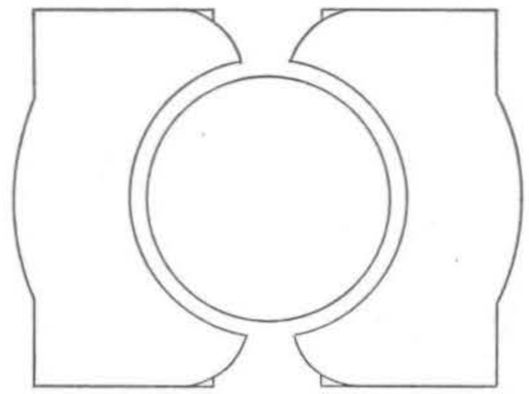


Fig. 4.

the field at full load, are provided by a shunt winding. This shunt winding is sufficient to set up the total amount of magnetization for the production of the normal E. M. F. of the machine when there is no current in the armature. Now in order to take the normal current from the armature without reversing the magnetization under the weakened pole corners, three times as many series ampere turns as there are shunt ampere turns must be added to the field. The addition of these series ampere turns must not increase the total amount of magnetization through the armature, which is accomplished by the thin pole corners. The strong pole corners become saturated when the armature is furnishing even a small amount of the normal current for which it is designed. For most values of the current then, the armature ampere turns, tend to diminish the magnetization under the weakened pole corners, but can not increase it correspondingly

under the saturated pole corners. The action of the series ampere turns on the field prevents the reduction of the magnetization under the weakened pole corners to zero, while the saturated portion of the pole pieces prevents the increase of the total magnetization through the armature, and thus a constant potential is maintained.

The "armature characteristic" IV. plotted in Fig. 7, was taken from the machine of the above sort, built with cast-iron

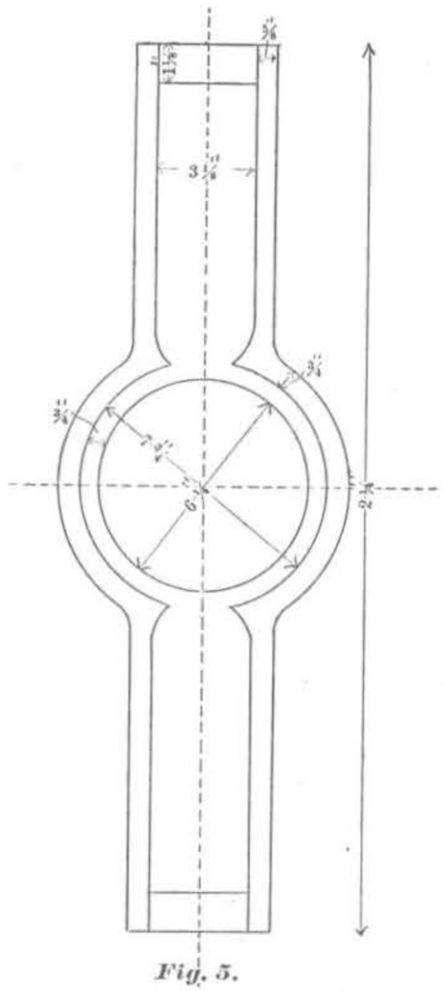


Fig. 5.

fields. The cross-section of the field cores proved on trial to be too small, and became strongly saturated at full load,—while they were quite a little under the point of saturation at no load. This curious result for a constant potential generator was due to the increased magnetic leakage, produced as the series ampere turns on the field came up with the load. Saturation took place as the curve indicates, when the armature furnished a current of about 140 amperes, and no possible compounding could ever make this

generator produce even approximately a constant potential, with variation of load. Steel cores of the same dimensions were substituted for the cast-iron cores. Saturation did not occur in them due to magnetic leakage. The pole corners were very thin, as in Fig. 2, and the "armature characteristic" III. was obtained. The machine was then furnished with a shunt winding that produced a slightly smaller number of initial ampere turns than curve III. indicates as required to produce 125 volts, and with series turns at such a number that the total number of ampere turns on the field for any current developed by the armature is shown by the broken line drawn through curve III. It was under these conditions that the machine performed in the manner described above, and did not vary more than 5 per cent. from the normal E. M. F. on either side, or a total variation of 10 per cent.

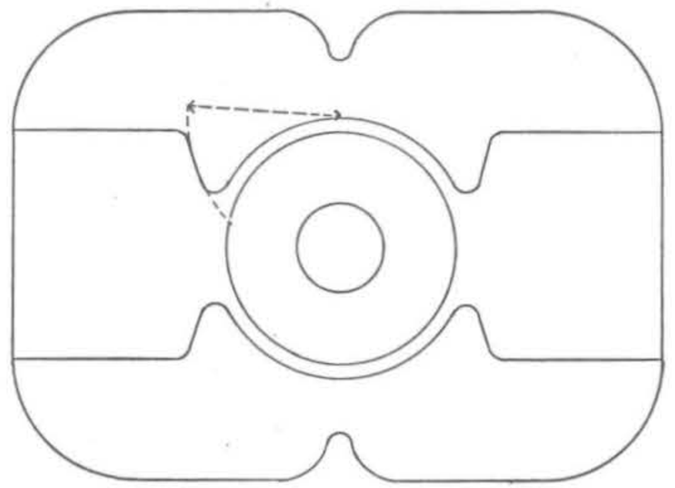


Fig. 6.

It was then almost entirely rebuilt. The armature was provided with a core that was considerably larger in cross-section, and the maximum magnetic density used in it was 11,000 lines per sq. cm. as against 20,000 used before. The lugs on the core were dispensed with, and the wires wound on the surface of the core. The poles were made of cast-iron, and fashioned to accord more nearly with those in Fig. 3. The air gap required ten thousand ampere turns to set up the magnetization through it at no load, while the armature ampere turns were 8,000 at normal output, so that series ampere turns had only to be added to counteract the action of the ampere turns on the armature that lie between the double angle of lead, to increase slightly the E. M. F. by the amount equal to the fall of potential through the armature caused by its resistance, and to compensate for the slight effect of the

pole corners that still became saturated to a limited extent for the higher outputs. It should be remembered that the magnetic leakage that takes place between the adjacent north and south pole corners, one of which is strongly and the other weakly magnetized, plays an important part in saturating thin pole corners. It is evident that unless the "armature characteristic" is a straight line as in curve I., Fig. 7, that the machine can not be made to regulate for constant potential with a high degree of refinement. The poles were again changed and shaped as in Fig. 4, when an "armature characteristic" given in curve I. was

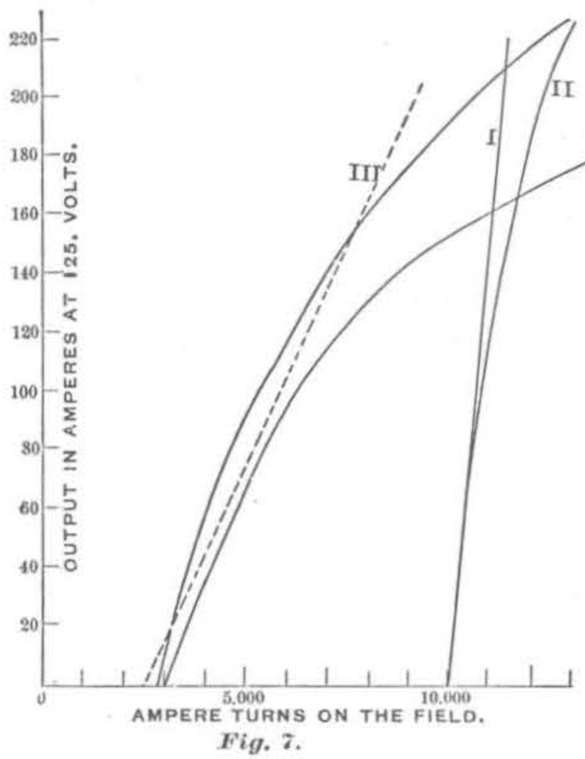


Fig. 7.

obtained, and the proper number of shunt and series ampere turns for a refined degree of regulation were readily decided upon. These experiments confirm what has been said above, and show how useless have been the attempts to diminish the air gap beyond certain limits.

It was shown in the outset how we can calculate the actual magnetic densities in the air gap for any total magnetization through the armature, for any armature current. The results of the following experiments confirm the correctness of these methods. The diagrams in Fig. 8, give the values of the magnetic density at all points of the air gap of a generator producing

125 volts at the brushes and 80 amperes. The following are its dimensions and data:

Diameter of armature core	6.25 in.
Length of armature core	12. in.
Diameter of bore of poles	7.19 in.
Double depth of air gap	.94 in.
Armature sections	50.
Turns per section	2.
Resistance of armature	.06 ohms.
Poles shaped as in Fig. 3,	
Shunt turns on field	6400.
Field current, no load, 125 volts	1.48
Field current, full load, 125 volts	2.10
Speed	1600.

Carbon brushes used without lead.

The "armature characteristic" curved considerably, indicating that the pole corners become saturated. It is evident too that

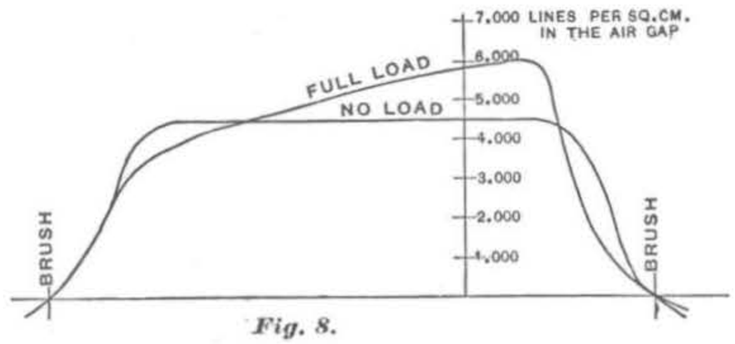


Fig. 8.

the normal magnetization in the pole corners in addition to the magnetic leakage which is greater there than anywhere else, produced saturation in all pole corners, even with no current in the armature. For at full load there were 4,000 ampere turns on the armature, while 4,000 series ampere turns had to be added to the field that produced 125 volts at no load to keep the E. M. F. the same. Therefore at full load we have the same number of ampere turns acting through the weakened pole corners as at no load, and the total amount of magnetization has only been increased 5 per cent., to compensate for the resistance of the armature conductors The conditions, however, are not the same, for there are just 4000 more ampere turns to cause magnetic leakage at the pole corners, so that on the whole the magnetization in them is increased. This increase of magnetic density in them greatly increases their magnetic resistance, for they are saturated to begin with. It is on this account that we find the magnetization under the weakened pole corners diminished, when apparently

the forces acting have not been changed. The magnetization under the strengthened pole corners through the air gap is increased more than it is diminished by the effect of the added magnetic leakage, through the 8000 additional ampere turns that act to produce magnetization by this route through the armature.

In Fig. 9 the diagrams show the magnetic action of the armature of a 10 H. P., 110 volt motor, with poles fashioned as in Fig. 6. Measurements of the magnetic leakage were made on this motor, and the results indicate that the shape given to the pole corners avoided saturation in them even at full load. The double angle of lead was almost 60 degrees. The ampere turns embraced by it on the armature were partially compensated for by 9 series turns on each of the consequent fields. The remainder of the armature ampere turns that lie between the double angle of lead served to weaken the field by just the amount required to produce

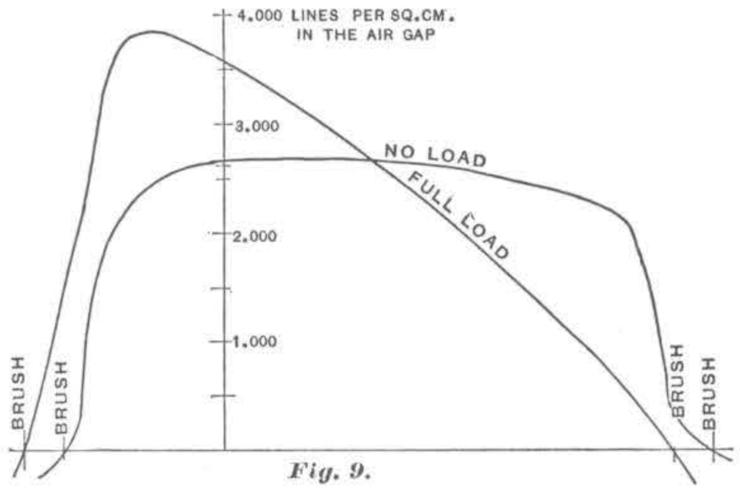


Fig. 9.

a constant speed. The following figures give additional data on this motor:

Diameter of armature core	8.33 in.
Diameter over all	9. in.
Bore of poles,	9.38 in.
Double air gap	1.05 in.
Shunt turns on field	2200.
Shunt current at 110 volts	3.55
Ampere turns on field at 110 volts	7800.
Ampere turns on armature at full load	5750.
Armature sections	48.
Turns per section	3.
Speed	1200.

The ampere turns required to set up 2,600 lines per sq. cm. through a distance of 1.05 in. or 2.64 cms. in open air—

$$\frac{2600\times 2.64}{1.26}=5430.$$

This is the number of field ampere turns that exerted their magnetizing force between the pole faces through the armature. The ampere turns acting through the weakened pole corners are, therefore, very near zero, which is entirely corroborated by the fact that the magnetization was observed to be zero at this point. See full load curve in Fig. 9. Through the strong pole corners the ampere turns acting were the 5430 of the shunt ampere turns, + the 720 of the 9 series turns + the armature ampere turns, 5750—twice the ampere turns between the double angle of lead, 2. [.3×5750], or 3450 = 8550 which will produce a magnetic density through an air gap of 2.64 cms. depth of

$$\frac{8550\times 1.26}{2\,64}=4100.$$

while the actual magnetic density measured at this point was 3950, an agreement within the possible limit of error.

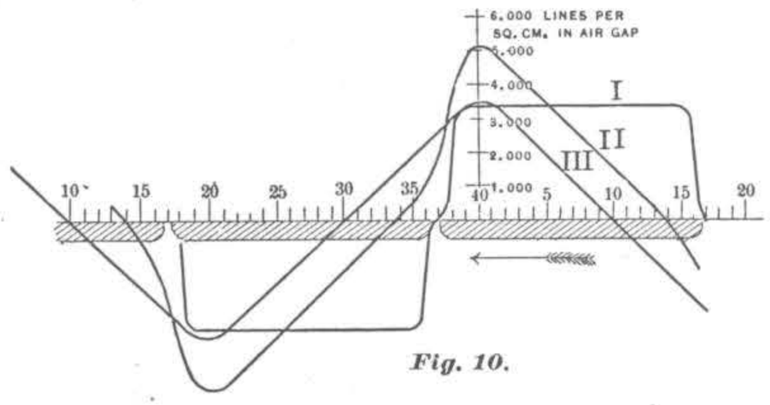


Fig. 10.

In Fig. 10 are given curves showing the magnetic performance of an armature, with its conductors laid in deep narrow grooves, as shown in Fig. 12. The clearance on each side was one-sixteenth of an inch, making the double air gap one-eighth of an inch. Additional dimensions are as follows:

Diameter of the armature core	6. in.
Length of armature core	6. in.
Resistance of armature	.34
Number of sections	64.
Turns per section	3.
Output, amperes	20.
" volts	100.
Speed	1800.

Curve 1, in Fig. 10, shows the distribution of magnetization at 112 volts, no current, a speed of 1800, and a field excitation of 2600 ampere turns. Curve II shows the magnetic distribution for an output of 97 volts and 24 amperes, at a speed of 1800, and a

field excitation of 2600 ampere turns. Curve III shows the magnetic distribution at an output of 40 volts and 20 amperes, at a speed of 1800, with a field excitation of 750 ampere turns. This same excitation when the armature furnished no current, produced an E. M. F. of 48 volts, at a speed of 1800 revolutions. The poles were shaped as in Figs. 11 and 12, but modified as explained below. In making these experiments carbon brushes were used, and their position maintained at the normal diameter of commutation. An average magnetic density in the air gap of 3400 lines per sq. cm. was required to produce an E. M. F. of 112 volts. The grooves on the armature in which the conductors were placed, occupied one-half of the armature surface, so that the actual mag-

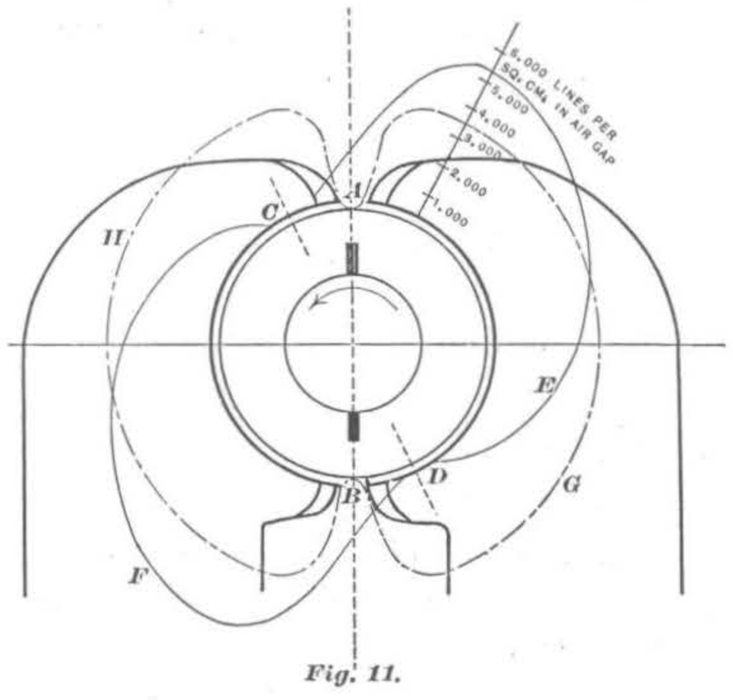


Fig. 11.

netic density in the air gap was 1.8 times this average magnetic density. The ampere turns required to set up this magnetic density in the air gap were

$$\frac{.125 \times 2.54 \times [3400 \times 1.8]}{1.26} = 1520,$$

which is the number of field ampere turns whose magnetizing force is impressed between the pole surfaces through the armature, when it furnishes 112 volts and no current. The ampere turns on the armature at a current of 24 amperes are

$$\frac{2 \times 64 \times 3 \times 12.}{2.} = 2300.$$

as against 1520 impressed by the field. Under these circum-

stances the magnetism under the weakened pole corners is reversed as is also clearly indicated by curve II, in Fig. 10, or the curve C, E, D, F, C, in Fig. 11. This curve also shows that the magnetic density under the strong pole corners was 5,100 lines per sq. cm. Now in building this machine, six longitudinal slots, $1\frac{1}{4}$ inch. deep, were cut in each pole immediately back of the surface, which enables us to be sure of the exact densities in the pole corners for a given distance. For a depth of $1\frac{1}{4}$ inches immediately back of the pole faces, these slots took up one half of the cross-section of the poles. Then a density, therefore, of 5100, really means a density of 10,200 or a strong saturation for a distance of $2\frac{1}{2}$ inches

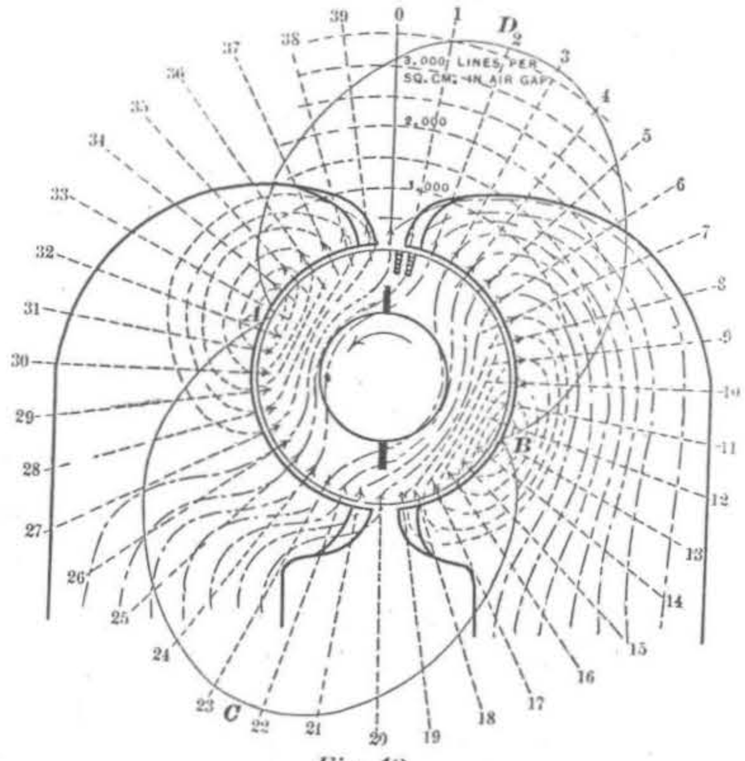


Fig. 12.

in the cast-iron of the poles. The magnetizing force required to produce 10,200 lines per sq. cm. through cast-iron is 200 per centimetre length. Therefore the ampere turns required to establish this density through $2\frac{1}{2}$ inches are

$$\frac{2.5 \times 2.54 \times 200}{1.26} = 1{,}000.$$

The total number of ampere turns acting to produce magnetization through these strong pole corners was the sum of the field ampere turns that impressed magnetizing force from pole face to pole face through the armature, and the ampere turns on the armature covered by the poles. The poles covered approximately 85

per cent. of the armature surface, making this value: $1500 \times [2300 \times .85] = 3400$. Of this number, as was just shown, 1000 were utilized in producing the magnetic density of 5100, through the saturated portion ofthe poles. The remaining 2400 ampere turns exerted their magnetizing force in producing the average magnetic density of 5100 through the air gap, and affords another opportunity of checking these ideas of the action of the armature on the field. For the ampere turns required to set up an average magnetic density of 5100, through the air gap under consideration were:

$$\frac{[1.8 \times 5100] \times .125 \times 2.54}{1.26} = 2300.$$

which checks with the above value as well as could be expected. When the armature furnished 24 amperes, the E. M. F. at the brushes was 97 volts, while with no current it was 112 volts. Of this drop of 15 volts, 8 are accounted for by the resistance of the armature, and the extra seven were caused by the saturated pole corners. By operating this same machine at an E. M. F. at which the pole corners could not saturate with normal output of current, we have demonstrated for us in a very striking manner that the armature ampere turns can not change the total magnetization established through the armature by the field when the pole corners do not saturate. The E. M. F. with the armature current at zero, was brought to 48 volts with a separate field excitation of 750 ampere turns. Then when the armature was allowed to furnish 20 amperes the E. M. F. at the brushes dropped to 40 volts. Of this drop of 8 volts, 7 were produced by the resistance of the armature. Yet the field is powerfully distorted by the armature current, as may be seen by reference to curve III, Fig. 10, or the curve A, D, C, B in Fig 12. Even with this very great rearrangement of the magnetization produced by the armature current, the total magnetization set up by the field is practically unchanged. The difference of potential on the commutator between the points A. B., Fig. 12, was observed to be 72 volts. This excess of E. M. F. over that which was produced at the brushes, the figure shows clearly to be due to the magnetization produced by the armature through itself and the strengthened pole corners. The points where the field is zero are at A, B. They mark the diameter through which the ampere turns encountered on the armature are just equal and opposite in action to the ampere turns of the field that impress a magnetizing force between the pole faces through

the armature. A simple computation will show that this is true. The field ampere turns that impress magnetizing force between the poles when the armature produced an external E. M. F. of 48 volts are

$$\frac{1520 \times 48}{112} = 650.$$

The ampere turns on the armature opposed to the magnetization set up by the route A, B. are $\frac{12}{40}$ of the total number of ampere turns on the armature, [see Fig. 12,] or

$$\frac{12 \times 64 \times 3 \times 20}{40 \times 2} = 576.$$

This is a fair agreement when we consider the accuracy with which the original data may be determined.

Mr. Esson in his valuable paper, above referred to, discussed the requisite features for a generator for constant current, with closed coil armatures, in which regulation is effected by shifting the brushes. He stated that the field should be uniform at all points, under the poles, and that the armature core should be saturated. These statements are a little misleading. The magnetizing force impressed by the field ampere turns must be uniform at all points between the pole faces. This is accomplished by proportioning the poles so that the strongly magnetized pole corners will not become saturated when the brushes have their extreme position for the development of the highest E. M. F. that the machine is to produce. The air gap is made of such a depth that the ampere turns required to set up the magnetization through the armature, without current, and for the production of the highest E. M. F. that the machine will be called on to give, shall be a little more than the armature ampere turns when it furnishes its normal current. Then as long as the brushes are kept under the pole faces, the non-sparking point will be wherever the brushes are placed. This will be the case whether the armature is or is not saturated. A practical demonstration is found in the following experiment: A Siemens and Halske dynamo with magnet and armature cores, whose shape and dimensions are shown in Fig. 5, was used.

Length of armature core	7.25 in.
Number of armature sections	56.
Turns per section	6.
Revolutions	1000.
Output in volts	50.
" " amperes	30.

The field was separately excited with 4000 ampere turns on each of the sets of consequent poles. Regulation could then be effected for a constant current in the armature, of 22 amperes, by shifting the brushes from no E. M. F. to 35 volts without the slightest sparking even when metallic brushes were used. Within this limit the pole corners did not saturate. The field cores were wrought and the yokes cast-iron. When the armature circuit was broken, it was found that the field excitation of 4000 ampere turns produced an E. M. F. of 50 volts. The magnetic density in the field cores, including leakage, was only 11,000 lines per sq. cm. Therefore, of the 4000 ampere turns on the field, not more than 200 were applied in setting up the magnetization from pole face to pole face through the field cores. It is safe to assume, then, that of these 4000 ampere turns, 3800 were active in producing a magnetizing force impressed uniformly over the pole faces through the armature. This same value is obtained by the method adopted in the previous cases. That is by calculating the magnetic density in the air gap when 50 volts were developed, and then deducing the number of ampere turns required to establish such a magnetic density through a $1\frac{1}{2}$ inch air gap. As to the armature, when it produced 22 amperes its ampere turns numbered

$$\frac{2 \times 56 \times 6 \times 11}{2} = 3700$$

or an excess of 100 ampere turns impressed by the field over and above those on the armature. As long as this same number of ampere turns was maintained on the field it was not possible to regulate for a constant current of a lower or a higher strength without sparking. The impressed field ampere turns are in excess of the armature ampere turns by that amount which is just sufficient to produce a weak positive field that will reverse the current in the coil when its terminal bars at the commutator pass under the brush. When regulation is effected by this means it is seen that all pole corners are alike magnetized and at the centre of the pole faces the magnetization is zero when the machine is short-circuited. At full output, at the highest E. M. F., the magnetization under the one set of pole corners is almost zero, and under the other set it is at the maximum value that is ever obtained. In a generator of this type when the poles are made stout enough at all points, the total amount of magnetization through the armature, at all loads, will remain at a constant value.

When used for operating long arc lamps, a "drooping characteristic" can better be obtained by saturated field cores than by saturated pole corners and armature core.

What has been said of dynamos applies equally well to motors. The only difference being that the non-sparking points are on opposite sides of the diameter at which magnetization is zero in the air gap. This is due to a well known cause. In a motor, the armature rotates in an opposite direction when field and armature currents remain the same as in a dynamo. The E. M. F. of self-induction caused by the reversal of the current in a circuit has not changed, while the E. M. F. developed in the coil by the field has changed sign with the change of the direction of rotation. The result is that the reversal of the current in an armature section must take place in a weak field of an opposite sign in a motor from what it does in a dynamo, when sparking is to be avoided entirely.

The action of the current in the armatures of multipolar dynamos and motors will be the same as that found for two pole machines.

Discussion.[1]

The Chairman [Vice-President T. D. Lockwood]:—Gentlemen, you have heard Professor Ryan's paper read, and I am sure you have found it replete with interest and very instructive. Some parts at least, I doubt not, will form a substantial basis for discussion, and the paper is not so long but that we can discuss it fully and freely in the time at our disposal. I see that our worthy Past President, Professor Anthony, is here this evening, and I am sure we should be very glad to hear from him.

Professor Anthony:—Mr. President, as this is the first I have seen of the paper, I hardly feel prepared to enter upon a discussion of it, without having a little more time to think it over. I should like to have had this paper a few days beforehand, in order to feel prepared to enter into a discussion of it. There are a great many new things brought out here—at least they seem new to me. The matter is brought out in a somewhat different light from what I have thought of it before. I should therefore beg to decline to enter into any discussion of it at present.

The Chairman:—As a basis for remarks from some member, I would like to call attention to a point where Professor Ryan seems to differ somewhat from the opinion of Mr. Esson. The author says that "Mr. Esson, in his valuable paper above referred to, discussed the requisite features for a generator for constant current, with closed coil armatures, in which regulation is effected

1. By Messrs. W. A. Anthony, Wolcott, Mailloux, Lockwood and Tesla.

by shifting the brushes. He stated that the field should be uniform at all points, under the poles, and that the armature core should be saturated. These statements are a little misleading. The magnetizing force impressed by the field ampere turns must be uniform at all point between the poles' faces."

It seems to me that there is some foundation for remarks there, from any member who has made that point a study.

Mr. Townsend Wolcott :—It seems to me that Prof. Ryan simply explains what Mr. Esson means there. Mr. Esson says that the field should be uniform at all points, and Prof. Ryan states that that part of the field which is due to the field winding should be constant. That is, it might, indicate total resultant field in the air gap as due to the field, and armature windings—that should not be constant, but the component due to the field windings should be constant. That is what Prof. Ryan means, and I think that is what Mr. Esson meant.

Prof. Anthony :—The difference in that case between Prof Ryan and Mr. Esson seems to be that while Mr. Esson says the armature core should be saturated, Prof. Ryan says this would be true whether the core is saturated or not.

The Chairman :—Mr. Mailloux, will you favor us?

Mr. C. O. Mailloux :—Mr. Chairman, I am somewhat in the same position that Professor Anthony is in, respecting this paper. I do not feel that I understand the paper sufficiently to be able to discuss it intelligently. It contains much matter which requires very careful analysis and digestion to enable it to be discussed properly and intelligently. There are probably some statements to which we might take exception. I think it would be a very much better and more profitable discussion if we had a chance to study the paper, and if Prof. Ryan himself were here to answer questions when the paper is discussed. The whole subject of armature reactions is among the most difficult and puzzling in electrical engineering. There can scarcely be a more perplexing problem, because we have to deal here with the phenomenon of "action at a distance," which has engaged and baffled the efforts of all the great scientific thinkers of the world since the days when Newton pondered over it and made some steps toward a theory which he applied to actions at a distance among the heavenly bodies. During the last few years there has been a great deal written on what might be called the "physics of the air gap" though I believe that the true physical theory of the air gap has yet to be written. Even with all the theory which we have, and while paying proper deference and respect to the very able work of such men as Hopkinson, Swinburne, Esson and others—I can but believe that we have not, after all, much more than working hypotheses; that we have, so to speak, only provisional theories, which are good so far only as they cover the facts now known to us. The truth is, we do not yet know all the facts pertaining to the physics of the air gap, and it will

probably be some time before we understand them all. Though I will not undertake the discussion of this paper, I would refer to one point in connection with what is said near the top of page 454: "When the armature ampere turns are equal to the ampere turns on the field, whose magnetizing force is impressed between its pole faces through the armature." It is quite evident from the sentence which immediately follows that the author wishes to imply what is sometimes spoken of and what is generally understood, as difference of magnetic potential. Mr. Swinburne, I believe, has given it that name, and as we have the exact analogue of it in relation to the electric circuit, I see no reason why we could not use the term in relation to magnetic circuit, and thus express the author's meaning at least as clearly and more succinctly. It is mathematically the line integral of magneto-motive force for that part of the circuit. It means, so to speak, the magneto-motive force lost in the air gap; or the whole magneto-motive force minus the portion that is lost in the field reluctance itself.

The much-mooted question as to the length of the air gap and its relation to the phenomenon of sparking, of course, forms one of the principal subjects that the author has discussed. I have given that subject a great deal of attention in my professional work, and I have taken great care to scan and to canvass the literature on the subject. I find that there is considerable divergence of opinion, and that while theorists are telling us that we should not make the air gap too small, and that we must have a certain minimum of resistance there, yet machines are being made which are very successful, not to say most successful, in which the air gap is exceedingly small. The Oerlikon Dynamo Works, in Switzerland, is perhaps one of the most successful firms building dynamos in the world to-day, and they are noted for the extremely small air gap used in their dynamos, the armature iron being perforated near the edge and the wires passed through the perforations near the periphery of the armature, so that the air gap may be, and is, very small. Mr. Ravenshaw in England has, I believe, cited some experiment with a given machine which he first tried with a very small air gap. He then bored out the field and tried the experiment over again, maintaining the same magnetic density through the entrefer. He found, if I quote him correctly, that it did not make any practical difference so far as the limiting output of the machine within which sparkless running occurs, was concerned. One would conclude from this that it does not make very much difference what is the length of the air gap if certain other apparently equally important factors receive due consideration in the design. Among the factors which a comprehensive theory of armature reactions should include, in my opinion, and which are somewhat neglected by the author, are the number and length of armature reactions, the width of pole pieces, the mode of winding, etc. I regret, indeed, that I

have not had a chance to thoroughly analyze the paper. It certainly discusses one of the most important subjects which could be brought before this Institute, because it relates to a problem of the greatest importance, and regarding which any new knowledge must be of great value to the designer of electrical machinery. It is certainly to be hoped that a good discussion will be had upon it at some future date. I think the paper is well worthy of the attention of the ablest and most competent members in our midst.

PROF. ANTHONY:—Mr. President, I would say one or two words further in regard to this. I feel exactly as Mr. Mailloux does—that we ought to have some opportunity for a discussion of this paper after we have had some time for the study of the paper itself. There are such a multitude of details connected with the action of the armature in a dynamo that it will take very considerable study before we can discuss the paper very intelligently. The length of the air gap, the form of the pole pieces, the form of the pole corners, the relation of the pole cores, of the field cores, the number of ampere turns on the field cores, the winding, and I don't know how many dozen of other things will affect the action of the armature, affect the sparking and the relation of electromotive force, whether constant or not, and all these different things must be considered and their effect taken into account. It seems to me a pretty difficult thing for any one to consider off-hand. I should like to say one word in reference to the width of the air gap here. It was something of a surprise to me to have it implied, as it seems to be in this paper, that the air gap must have somewhat of a magnitude in order to make the dynamo work well. My idea has always been that we must make the air gap as small as possible, and the smaller we could make it the better the dynamo would work. I do not know that I have ever seen anything in my experience that would indicate the necessity of making the air gap any larger than was necessary for getting in the wires and in fact, in a machine that I have recently constructed, we made an armature two feet in diameter for the very purpose of getting the wire in one layer and getting the air gap only one quarter of an inch, with about 100 amperes normal output. When the generator was running street cars, and the current was jumping from 0 to 200 amperes and back continually, it was almost impossible to tell by watching under the brushes when the generator was doing work. The creaking of the engine, etc., indicated it and a man could imagine that he saw a little sparking when he heard the engine working. They were carbon brushes.

MR. MAILLOUX:—I am in accord with Prof. Anthony on the point of the air gap, because I have not only advocated, but I have practised short air gaps for several years.

THE CHAIRMAN:—One moment. By air gap here we understand of course the place between the iron of the armature and the iron of the pole pieces

MR. MAILLOUX:—Yes, sir, which the French call entrefer.

THE CHAIRMAN:—It is not possible that Professor Ryan is speaking of the nearest approach of the two poles.

MR. MAILLOUX:—No, sir, that is called the space between the poles.

THE CHAIRMAN:—I ask because I do not think air gap is the very best term.

MR. MAILLOUX:—I have found practically the same result as found by Prof. Anthony. I have never thought that a short gap necessarily made a sparking machine, if rightly designed. I have in mind now some railway motors which were run with an air gap of scarcely a sixteenth of an inch, and having armature teeth at that; and the machine was quite sparkless at any load for which it was designed. According to theory one would expect such a machine as that to spark very badly. My own experience and the results reported from Europe, particularly from the house that makes the Oerlikon machine in Switzerland have made me less afraid of a small air gap than I used to be.

MR. WOLCOTT:—I would like to ask Mr. Mailloux in regard to that machine, if the teeth were saturated.

MR. MAILLOUX:—No, sir. I examined that point to-day for another purpose. The teeth were not any more saturated than the armature core. The armature core itself had a very low magnetic density. I think that the highest density ever reached through the armature core did not exceed ten thousand lines per square centimetre and that at the normal run it was scarcely six thousand.

MR. WOLCOTT:—It makes it all the worse for the small air gap theory. If the density were very high in the teeth, it might serve the same purpose as the resistance in the air gap, but if the density were low in the teeth it seems to knock the theory all to pieces.

MR. MAILLOUX:—There have been cases where I have been compelled to use high magnetic density in the Pacinotti teeth, so high a density that the permeability fell down to about five; yet I have not noticed that it had any material influence on the sparking.

MR. J. STANFORD BROWN:—The value of the paper has been properly emphasized, likewise the originality of treatment of the subject. As none of us seem particularly prepared to-night to discuss the subject, would it not be well to have it announced that this paper will be more thoroughly discussed at the next, or the following meeting, and would it not be a wise plan, in the case of many of those engaged in designing machinery, and who know more about it than any others, to send this paper to them with the request that, if they can not be present to aid in the discussion, they would be good enough to send in writing so much as they might be willing to add to the subject? This might result in bringing out a great deal of information we can not otherwise get.

THE CHAIRMAN :—It may not be out of order to state that in the card which I received notifying me of this evening's meeting, the subject was mentioned with the intimation if I was particularly interested therein, I could receive a copy by sending for one, but as I supposed there would be a great many here more interested in air gaps than I was, (since my business relates to the very smallest dynamo in the world in which I have always found that the smallest air gap possible was the best for the machine), I did not take the trouble to send for the paper. Perhaps, like other gentlemen, I should therefore plead my inability to discuss the subject on that score. I think we may reasonably regret that Professor Ryan is not here with us this evening to answer questions. I should have wished for myself that the author of the paper had been a little more particular to classify the different machines in question, for while he speaks in a general way at first, and subsequently speaks of a constant potential machine, it is rather difficult to tell what machine he is referring to most of the time, until on the last page but one, where he comes to speak of "Mr. Esson's valuable paper" to which I referred before. He speaks there, of a generator for constant current, by which I suppose he means what we call a series machine with closed coil armatures, by which regulation is achieved by adjusting the brushes. I have a very distinct idea that sparking in dynamos is largely due to a lack of harmony between the short-circuited current, as an individual coil passes under a brush, and the current in that side of the multiple coil armature which the short-circuited coil is approaching. And it has further appeared evident to me, that if we could produce at the moment when the front segment of the commutator leaves the brush—if at that moment we could produce a zero, by opposing the short-circuited current against the current to which the short-circuited coil is about to be introduced, we should have a perfect neutralization, and in consequence, an absence of sparking. I am well aware that there has been a kind of hazy doctrine circulating, or at all events existing among electricians, that the sparking upon a change of current, and when brushes were used to compensate for that change of current, is largely due to the fact that the neutral line had moved forward, and that therefore the brushes would have to be moved forward to catch up to the neutral line, and when the brushes did catch up with the neutral line, the sparking would cease to exist. But when you pursue that theory to its lair you find it is moving in a circle. It may not be out of order to recount an experiment I witnessed showing that in reality as the current in a series machine changed under a difference in load, the neutral line remained stationary as long as the brushes were not moved. For example, suppose a machine was working on a load of forty arc lamps, and some ten of those should be cut out —the load would be very much less, the current would be much stronger—and in a machine furnished with an automatic regulator, the regulator would move forward to cut down the electromotive force developed of course, in bringing the current down to its constant figure once more. It was supposed by many that the neutral line of the machine moved forward when the current changed. That is, when the current increased, the neutral line moved forward. It hardly seemed to me that it was a possible thing, seeing that the current was strengthened not only in the field helices, but also in the armature, the machine being a series machine. A single wire was rigged around the armature. One end was attached to a fixed ring, while the other end was attached to a movable commutator, and the circuit of this wire included a telephone receiver. When the machine was working on a full load we found a place where there was a zero of current. It was absolutely on the neutral line of the machine as it was working then. By the neutral line I mean the moment when a given coil passes over from the influence of the pole upon one side, to the pole upon the other—when it is at the exact point between the two—that is, when it ceases to cross lines of force in one direction and begins to cross them in the other direction. We found that point, and found that the telephone gave forth no sound at all upon changes of resistance and consequent changes of current. Just as long as the brushes were unmoved the telephone gave no sound, no matter how many lamps were put out or how much the current was changed, showing that the neutral line did not move. But when we changed the position of the brushes and moved them forward to compensate for the increased current, we found that there was a change and that the neutral line did not move forward as it was supposed to do, but actually moved backward. Now, that was the result of absolute experiment, and I think when we reflect upon it we will find that experiment is in accord with the best theory, and therefore I think the gap has such a relation to sparking in the constant current machine only in so far as it may modify the form of the pole pieces and, instead of using the phraseology here, I should rather be inclined to use the phraseology that "the requisite feature for a generator for constant current on closed coil armature in which regulation is effected by shifting the brushes, is that the field should be uniform throughout the range of movement of the brushes."

MR. NIKOLA TESLA :—I have had excellent opportunities to study the importance of the air gap, particularly in some types of my motors in which the armature coils are closed. Such a motor is of course a transformer and, following the analogy, the first idea was to secure in it as good a closure of the magnetic circuit as practicable. In the early experiments I constructed motors in which the air gap was often as low as a sixty-fourth of an inch at the start and was gradually increased. This was the result arrived at: Up to a certain point the diminution of the air gap would act very favorably; then the further approach

of iron or the reduction of the air gap would begin to be a great drawback, and it has always been my idea that the real cause of that was the unsymmetrical position of the armature to the field, and the impossibility of making the motor so mechanically perfect that the pull on both sides would be equal. Some time ago I did some work on unipolar dynamos with iron discs and I found that the lateral thrust was very difficult to overcome and it was impracticable to work with very small air gaps, a fact which of course is well known. In the results presented by Professor Ryan there is a point which he has not considered, and which, if I may be permitted to say it, I think ought to have been considered, because it is of enormous importance—so important that it radically changes the whole result, and that is this: In a motor or generator in which the polar faces and the armature core both are smooth, we can reduce the air gap indefinitely, and the smaller it is the better, and in many experiments I have found that we cannot reduce it far enough, disregarding mechanical difficulties. But directly we put projections on the field, as, for instance, Professor Ryan has done (he mentions an experiment in which there were six slots across the field), we cannot work any more with a very small air gap. You see the reason plainly enough. The putting on of these air gaps brings the whole investigation into a different field. If the polar faces be smooth, no matter how close you approach the iron to iron, the armature undergoes a gradual change, but directly you have the grooves, each part of the armature surface has to get out from the very intense field into a weak field and then from the weak into an intense field, and so on repeatedly—six times, as in Professor Ryan's experiments. I have made a great many experiments which confirm that. You can take a smooth field, put a laminated armature without projections in it and work with a certain magnetization, revolving the armature at a given speed. It will not get hot to a high degree. Now put in grooves through the field, and you will find at once that with far less magnetization than before, the armature will get intensely hot. The reason is, that you put each part of the armature through a much more sudden and greater total change, and increase the frictional and current losses. That is the reason also that in the case of the grooves there is a certain increased loss in the voltage, attributed by Professor Ryan wholly to a different cause.

The Chairman's remarks in regard to Mr. Esson's valuable paper, suggest to me a subject in another line of work which I have been pursuing. Mr. Esson pointed out certain requisites of constant current generators with closed coil armatures which practice would not seem to confirm. On this subject I think that I will not risk much in predicting that in a comparatively short time most of the present constant current machines will be replaced by machines of a more modern and improved construction. The old types of these machines have been built by ingeni-

ous men who, rather instinctively, hit upon the right thing—right at that time, but not right now. The main object in these machines is to maintain a constant current in the most efficient and simple manner. Some time ago I had occasion to say a few words—I think in a paper—in regard to this matter. I have constructed such machines in accordance with my view, which is to produce a great rate of change in the current and to replace the ohmic resistance required for steady working, by impedance. In this manner you can construct an arc light machine with only one single layer, no matter how large it is, and you can make it maintain a constant current, within two or three per cent. without any external regulator. One of the ways of obtaining this result is the following: Take, for instance, a two pole machine, selecting a type which allows you to use an armature of the greatest possible diameter. By all means, make the armature as large as possible. Then, instead of making the pole projections of the field smooth, make them with grooves parallel to the armature shaft. The more you make, in fact, the better it is up to a certain point. Then wind the armature symmetrically with reference to the pole projections or grooves, so that you get a great rate of change in the current. Now then, you have a direct current which is commutated just the same as in the Gramme machine, but as to the rate of change it is equivalent to a rapidly alternating current, and of course you increase the impedance through the whole circuit to the extent that you can do away with the great ohmic resistance in the circuit, and you can make the impedance and the armature reaction so great that no matter what the load is, the current is the same. Such a machine has numerous advantages, not the least of which is that it is more efficient, and then again it is so easily repaired, only one layer being required. In all alternating generators, almost without exception, the armatures are built with one single layer of wire The arc light machine must also be built with single layers and the right way to do this is to provide the pole pieces with projections and wind the machine in such a manner that a current of the requisite character is obtained. In regard to the shape of the pole pieces, I had opportunity during the year 1885 to make some observations I then worked at what is called the third brush regulation. It is a principle very interesting, but not very reliable. It may give a wonderful result for a short time, but when you want to show it to the stockholders it cannot do very much. It has been original with me. There have been some other claimants—there are always claimants. But to return to the subject: One of the difficulties encountered in the third brush regulation was the excessive sparking of the third brush. To overcome this, the principal requisite was that the auxiliary brush should not bear on active coils. I then resorted to a means which was obvious. I put under every leading pole piece a good sized groove, which made the coils on each auxiliary brush comparatively inactive, so that

the auxiliary as well as the main brushes would bear upon inactive coils. In this manner I obviated the sparking, but the machine did not look particularly pleasing. Mr. Westinghouse, when he first saw an experimental machine, which later was built at his works, said, looking through the holes, "Mr. Tesla, I like this machine very much. What I like about it best is that one can see through it." Although these machines have not proved a practical success, yet experience with them led to useful results. In the preceding remarks I have not desired to detract in the least from the merit of the opinions expressed by Mr. Esson, nor from those of Professor Ryan, whose investigations are always systematic.

THE CHAIRMAN:—Do you make your suggestion as a motion now, Mr. Brown?

MR. BROWN:—Yes, sir; I make the motion that it be definitely announced that there will be further discussion of this paper at the next meeting or the next following, as may seem best to the Chairman to-night, and that the Secretary be asked to forward copies to such members as he judges are more particularly conversant with the subject, with the request that they send us letters.

THE SECRETARY:—I cannot always tell who are interested. I do my best. But this paper will be published in all the electrical journals at once.

MR. BROWN:—It may not be necessary to send copies. It might be wise to ask for some letters.

MR. MAILLOUX:—I second the motion.

THE CHAIRMAN:—It is moved and seconded that there be further discussion announced upon this paper upon some subsequent meeting.

MR. BIRDSALL:—I think it would be well to endeavor to have Professor Ryan here at the meeting when the paper is discussed.

THE CHAIRMAN:—I do not know how we can get him here.

MR. BIRDSALL:—The Secretary might open correspondence with him. We might have a collation; that generally brings the members.

THE SECRETARY:—I think it is proper to say that Professor Ryan was given charge of installing an underground plant at Cornell, and he said that he could not leave a single day. He was very much disappointed in not being able to attend in person.

THE CHAIRMAN:—Then I will put the motion in this way: It is moved and seconded that further discussion of this paper be postponed until some subsequent meeting to be announced hereafter, when we shall hope to have Professor Ryan with us.

[The motion was carried.]

Mr. Wetzler read some correspondence with respect to proceedings of the Frankfort International Electrical Congress.

THE SECRETARY:—The following is a list of associate members elected by Council since the May meeting.

June 26th, 1891.

Name.	Address.	Endorsed by
BARNARD, JOHN H.	General Manager, Asheville Street Railway Co. and Asheville Light and Power Co., Asheville, N. C.	M. J. Wightmun. H. F. Parshall. J. G. White.
CRAM, HENRY B.	Treasurer, Bernstein Electric Co., 185 Prospect St, Cambridgeport. Mass	Theo. Stebbins. Geo. W. Davenport. S. C. Peck.
DAME, FRANK L.	Superintendent, Vancouver Electric Railway and Light Co., Vancouver, B. C.	J. P. B. Fiske. I. E. Winslow. Chas. R. Cross.
EMERY, CHARLES EDWARD,	Consulting Engineer, 22 Cortlandt St., New York.	Edward Weston. Thomas A. Edison. Frank J. Sprague.
FAY, THOMAS J.	Maine Electric Improvement Co., 136 Liberty St., New York.	Harry Alexander. W. A. Rosenbaum. M. C. Sullivan.
FISH, WALTER C.	Manager, Bernstein Electric Co., 620 Atlantic Ave., Boston, Mass.	Edwd. Blake. Geo. W. Davenport. S. C. Peck.
GANS, JOHN L.	Superintendent and Electrician, The Electric Company, Connellsville, Penn.	J. G. White. R. W. Pope. T. C. Martin.
HADLEY, WARREN B.	Supt. Wiring Dept., Edison Electric Illuminating Co., 431 Fifth Ave., New York.	L. Stieringer. T. C. Martin. S. S. Wheeler.
HEALY, LOUIS W.	The Wightman Electric Co., 1205 Marion St., Scranton, Pa.	M. J. Wightman. E. L. Nichols. Ernest Merritt.
KELLOGG, JAMES W.	Assistant to District Engineer, Edison General Electric Co., 140 E. 27th St., New York.	M. C. Sullivan. T. C. Martin. R. W. Pope.
LUQUEE, THATCHER T. P.	Asst. in Surveying and Practical Mining, and Student in Electrical Engineering, Columbia College, N. Y. and Bedford, N. Y.	M. I. Pupin. F. B. Crocker. W. H. Freedman.
ROSEBRUGH, THOMAS REEVE	Lecturer in Electrical Engineering, School of Practical Science, Toronto, Ont.	T. D. Lockwood. R. W. Pope T. C. Martin
TAINTOR, GILES	Assistant Electrician, N. E. Telephone and Telegraph Co., 7 Walnut St., Boston, Mass.	I. H. Farnham. T. D. Lockwood. Chas. R. Cross.
WIRT, HERBERT C.	Electrician, Marine Dept. Thomson-Houston Electric Co, 12 Millmont St., Roxbury, Mass.	S. C. Peck. Theo. Stebbins. G. W. Davenport.
WOODWARD, FRANCKE L.	Student in Electricity, 49 Grand St., Albany, N. Y.	R. W. Pope. T. C. Martin. Jos. Wetzler.

Total 15.

Council Meeting, Sept. 22d, 1891.

CALDWELL, FORDYCE S.	Proprietor Western Electric Construction Co., 503 Delaware St., Kansas City. Mo., and 151 Henry St., Brooklyn, N. Y.	E. R. Weeks. Maurice E. Bates. J. H. Vail.
CARTWRIGHT, FRED'K G.	Electrical Engineer, and Agent Fort Wayne Electric Co., 35 New Montgomery St., San Francisco, Cal.	Sidney B. Paine. H. L. Lufkin. E. E. Ries.
CHENEY, W. C.	Electrical Engineer, Willamette Falls Electric Co., Portland, Oregon.	O. P. Loomis. P. S. Malcolm. E. F. Peck.
FOOTE, CHARLES W.	Agent, Railway Dept., Thomson-Houston Elec. Co., Society for Savings Bldg., Cleveland, O.	S. D. Nesmith. E. E. Higgins. O. T. Crosby.
HALL, JOHN I..	Manager Western Union Telegraph Co., 300 Market St., Wilmington, Del.	C. R. Van Trump. J W. Lattig. Wm. A. Mosscrop.
HAMILTON, WILLIAM H.	Dealer in Electrical Supplies, 200 State St., Albany, N. Y.	R. J. Pratt. D. H Bates. Wm. C Miller.
HOSFORD, HENRY H.	Electrical Engineer, 1009 Society for Savings Bldg., Cleveland, O.	S. D. Nesmith. E. E. Higgins. O. T. Crosby.
LAND, FRANK	606 Salina St. Syracuse, N. Y.	Harris J. Ryan. Ernest Merritt. Edw. L. Nichols.
MACMULLAN, ROBERT HEATH,	Treasurer and General Manager, Brush Electric Lighting Co., Lafayette, Ind.	Louis Bell. Edward Caldwell. W. J. Johnston.
MARPLE, LUCIUS E.	Electrician, United Electric Railway, Nashville, Tenn., and Wollaston, Mass.	W. H. Blood, Jr. Geo. F. Curtiss. J. P B. Fiske.
MORDEY, WM. MORRIS	Electrician, Brush Electrical Engineering Co., 34 Montserrat Road, Putney, London, Eng.	T. C. Martin. Joseph Wetzler. G. M. Phelps.
MORSS, EVERETT.	Electrician, Simplex Electrical Co. 297 Beacon St., Boston, Mass.	F. A. Pickernell. A. F. Mason. S. C. Peck.
PATTISON, FRANK A.	Firm of Pattison Bros, Consulting and Constructing Electrical Engineers. 135 Broadway, New York City.	J. C. Chamberlain. J. T. Marshall. Wilson S. Howell.
ROGERS, EDWARD H.	Patent Lawyer, firm of Pope and Rogers, 15 Wall St., New York City.	Edward Weston. F. L. Pope. Jos. Wetzler.
RUTHERFORD, W. M.	Electrical Engincer, Thomson-Houston International Electric Co., 620 Atlantic Ave., Boston, Mass.	F. C. Bates. H. G. Reist. Franklin Sheble.
SCHLOSSER, FRED. G.	Superintendent of Electric Dept., Laclede Gas Light Co., 1801 Washington St., St. Louis, Mo.	F. R. Jones. Harris J. Ryan. C. R. Van Trump.
WHITE, GEO. MONTAGU	Agent for West Indies, Thomson-Houston International Electric Co., Kingston, Jamaica, W. I.	G.W. Davenport. T. C. Martin. Joseph Wetzler.

Total, 17.

Transferred from Associate to Full Membership, June 26, 1891.

SMITH, JESSE M.	Consulting Engineer, in Mechanics and Electricity, 36 Moffatt Block, Detroit, Mich.

THE SECRETARY:—The report of the Committee on Units and Standards which, as I understand from Mr. Wetzler, includes a subject brought up before the Frankfort Congress, will probably be submitted to the Institute for discussion either at the October or the November meeting. The report was referred to the Committee on Papers and Meetings, by Council, with the request that it be brought before the Institute for discussion at an early day.

[Adjourned.]

[REPLY TO THE ABOVE DISCUSSION COMMUNICATED BY PROF. HARRIS J. RYAN.]

I have been understood to advocate that the air gap in direct current dynamos should not be made small. I have not desired to advocate either long or short air gaps. I have designed a direct current constant potential dynamo that had the smallest possible air gap that can be provided. The armature conductors were placed under the surface, and the depth of the air gap was just sufficient for mechanical clearance. The magnetic density throughout the armature core was less than 10,000 lines per sq. cm., so that saturation did not take place. When this machine was built and tested, it was found that four times the normal output of the current in the armature did not even distort the field, neither was the neutral point shifted, nor sparking produced. By normal output of current, I mean that current which would not excessively heat the armature on a long run, or a rating of 500 cir. mils per ampere in each conductor. I agree therefore, with the members who said that you may make the air gap as small as you please, if then, you only design the machine right. But most persons who hear this will say: "In what manner do you design the machine right?"

I have examined the complete data and dimensions, together with the corresponding performance of almost every sort of direct current commercial generator or motor, and have not found a set of conditions, where the relations that I have spoken of do not hold true. The point mentioned by Mr. Tesla as being one of such great importance as to change the whole result, is one not at all unknown to me and is one entirely covered in the paper. He said: "In a motor or generator, in which the polar faces and armature core are both smooth, we can reduce the air gap inde-

finitely, and the smaller it is, the better, and in many experiments I found that we can not reduce it far enough, disregarding mechanical difficulties." Now, one of the points I made is that when the poles are so proportioned and used, that saturation does not occur, the armature ampere turns have practically no effect on the total magnetization set up through the armature by the field. This is true no matter how small the air gap may be. If then we use a very small air gap, poles properly proportioned and without too small a space between them, there will be inactive coils in the normal diameter of commutation where the brushes may be placed, and the machine may be operated precisely as Mr. Tesla states. Such a machine, unless it be a very small one, will always have the magnetization reversed to a considerable extent under the pole corners *a*. *b*., Fig. 1. In the larger machines this negative magnetization assumes larger proportions, and the magnetization under the strong pole corners becomes correspondingly large. As a matter of fact, in this line of practice, the manufacturers found it necessary to build up the faces of cast-iron poles with wrought-iron. In this way the strong pole corners are kept from saturation, a condition that was shown to be necessary if the armature current is not to seriously affect the total magnetization especially when small air gaps are used. This type of machinery, performs entirely in accordance with the relations treated of in this paper.

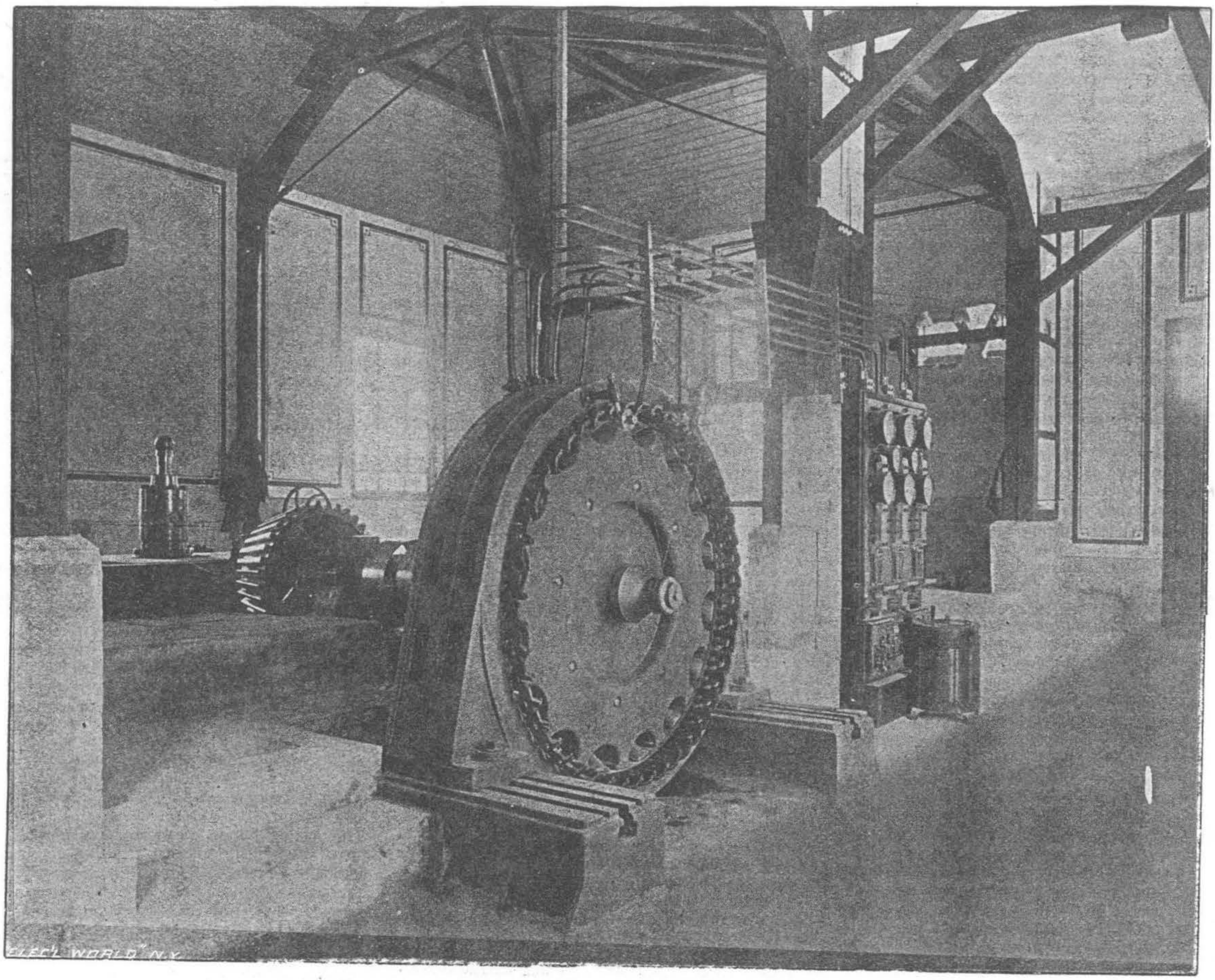
Another point was raised by Mr. Tesla, when he spoke of the effect of the six slots cut in the poles. He misunderstood me. The slots were entirely back of the pole surface. The pole surface was not interfered with by them, that is it was left smooth. All field exploration curves given in this paper are in absolute measure, and were obtained by careful observation from the machines under consideration. The dotted curve, therefore, in Fig. 11, shows the existence of an entirely uniform and unbroken field in the air gap. Therefore, it is seen from actual measurement that the slots did not influence the magnetic distribution in the air gap.

In conclusion I desire to say that the investigations leading to the results established have been prosecuted almost entirely in connection with many classes of well-known modern commercial machinery. For obvious reasons, it has been necessary in this paper to discuss only data and results obtained largely from machinery, that is not at the immediate present, part of the practice of this country.

Priority in Alternating-Current Motors.—The article which we reproduced on September 11th from our New York namesake, discussing the priority of discovery of the alternate-current motor, claimed this priority most emphatically for Mr. Nikola Tesla, who on October 7th, 1887, filed an application for patents in America, having already built and shown his machine in work and formed a company to exploit it some months before this. Mr. Tesla was run very close in claim for priority by Mr. Haselwander, whose machine, built in 1887, is now being shown at work at the Frankfort Exhibition. We have enquired of Messrs. Lahmeyer and Co., of Frankfort, who hold the Haselwander patents, as to the exact dates of the construction of this motor. They state that the first Haselwander rotary-current motor was constructed in the summer of 1887, and was set to work on October 12th, 1887. The first application for a patent for the said motor was made on the 21st July, 1888. As the patents were applied for by Tesla on October 12th, 1887, and were actually issued on May 1st, 1888, 17 days before the publication in England of Prof. Ferraris's Italian paper on "Alternating Motors," and two months and a half before the date of Haselwander's patent, this would seem to settle the question, at any rate with the present data before us, in favour of Mr. Tesla.

Generating Station of the Lauffen-Frankfort Line at Lauffen.

The accompanying illustration gives a view of the interior of the dynamo room at the Lauffen transmission of power plant. The building is at the Wurtembergische Cement Works at Lauffen, that beautiful branch of the Rhine that winds through Wurtemberg along one of the most beautiful river valleys in the world, finally joining the Rhine at Heidelberg. The motive power of the station is a horizontal turbine, having a speed of 50 revolutions and a capacity of 300 h. p., under a head of about 10 feet of water. The transmission to the dynamo is effected by a pair of large beveled gears; the ratio of the dynamo is about three to one, driving the dynamo very nearly 150 revolutions. The dynamo and the electrical part of the plant have already been described in the columns of THE ELECTRICAL WORLD, so that there is comparatively little to say of the electrical details of the station. We have already noted the success of the plant and are sure that our readers will be interested in a glance at the interior of what is really the pioneer station in the new development of electrical art. For particulars we can do no better than to refer to the previous articles we have published on the subject.



GENERATING STATION OF THE LAUFFEN-FRANKFORT LINE AT LAUFFEN.

THE

Electrical Engineer.

VOL. XII. OCTOBER 14, 1891. No. 180.

THE FRANKFORT INTERNATIONAL ELECTRICAL EXHIBITION.—IX.

BY

L. Gutmann

The Lauffen-Frankfort Transmission.

ALL electrical engineers have been interested in the famous transmission of power from Lauffen to Frankfort, and while this is the topic of the day, other transmissions of less gigantic a nature have hitherto been overlooked. The saying is, when the sun shines, the stars are invisible. Before calling your readers' attention to other interesting exhibits, however, it may be said that the current sent from Lauffen has a pressure of 16,000 to 18,000 volts, and 30 to 35 periods of alternation per second. One of the reasons for the reduction in pressure has to be looked for in the fact that the large style or compound insulators of the Johnson & Philipp type, which were to be used, could not be obtained in sufficient number, so that the rest are of the simple type of fluid insulators. Another is the carrying capacity of the conductor, which, with high potential, would cause excessive heating, especially as the oil prevents the radiation, unless choking devices are employed. After the Exhibition is over it is contemplated to raise the pressure to 30,000 volts or more for carrying on the examination of this system by government and other officials.

The Lahmeyer Exhibit.

Pending these experiments, I wish to draw attention to the neat exhibit of Lahmeyer & Co., whose system, as will be seen, is thoroughly worked out. In the Central Machine Hall, shown in Fig. 1 of the accompanying illustrations, there is exhibited in operation a dynamo generating 110 amperes continuous current at a pressure of 660 volts, driven by an engine of the Nurnburger Maschinenbar Aktiengesellschaft, formerly Klett & Co., and another dynamo with the same pressure, but only 70 amperes, driven by a Westinghouse engine of the firm of Garrett, Smith & Co., Magdeburg-Buckau. The general appearance of the compact dynamo is shown in Fig. 1. It is of the four-pole type, the magnets of which project inward towards the armature. The latter is provided with a commutator and but two brushes. In this case the inter-



FIG. 1.—THE LAHMEYER EXHIBIT AT THE FRANKFORT ELECTRICAL EXHIBITION.

nal grouping of the armature winding is not made, as is often done, by cross-connection or coupling in parallel, but the windings or coils having similar positions in the magnetic field, are wound in succession, and therefore are in series with one another. In spite of the pressure, which in these separately-excited dynamos is above the average as regards machines with ordinary commutators, the sparking is quite negligible.

Another dynamo, having a capacity of 150 amperes at 110 volts, is operated by a triple-expansion engine of Gebr. Sachenberg, of Rosslau am E. The current of this dynamo is used for lighting the central station and the surrounding exhibits, and, furthermore, to excite the fields of the two first-named generators, which in turn are connected to bus-bars common to both, energizing a direct current transformer and a motor of 60 h.p., also shown in Fig. 1, which drives a large pump for supplying water from the River Main to the waterfall in the Exhibition grounds. The transformer and motor are of similar construction, with the difference that in the transformer there are wrought iron pole-pieces, which in the motor are of cast iron, and the armature windings are evidently different with regard to length and cross-section, depending on the use to which the device has to be put. In one case all the energy is transformed from high tension to low, while in the other most of the power is used to do mechanical work, and one-seventh or eighth is used for lighting, and at the same time energizing the field magnets. All other arrangements being identical, the transformer may be described by reference to Fig. 1 which shows the motor, the pump in front, and the switchboard to the right.

The transformer has an external appearance similar to the generator with the difference of having two commutators and two sets of brushes. The capacity of the one exhibited is 300 lamps, and the ratio of transformation is 6 : 1. The current with a pressure of 660 volts is transformed to one of 110 volts. Some of the station instrument readings are : Primary, volt, 682, amp. 14.5 ; secondary, volt, 110.5, amp. 72.5; primary, volt, 670, amp. 20; secondary, volt, 108, amp. 10.5; primary, volt, 670, amp. 14 ; secondary, volt, 110, amp. 72. The efficiency of these first machines, as these figures show, is between 81 and 85 per cent. at one-third or one-half load of total capacity of 200 amperes. The armature is provided with two separate sets of windings, one capable of developing or receiving currents under a pressure of 660 volts, while the second produces currents at 110 volts. The field winding consists of four coils, the first layers of which are separable from the rest, and are connected to the terminals of the rheostat, and also to a two-way switch on the switchboard.

This board is clearly shown in detail in Fig. 1. In the upper row are located the line terminals and others for connection behind the switchboard. The two central and circular instruments are the voltmeters for the high and low tension circuits ; to the left is the high-pressure ampere meter, and to the right, one for the low-tension circuit, the indices of which are steadied by moving in mercury. To the right of these is the main primary double pole, double break switch, while to the extreme left is a similar one for the low-tension circuit. The two handles to the left of these main switches are releasing levers for opening the circuits manually, while the relays below the ammeters are for the purpose of effecting this operation automatically in case of abnormal circuit conditions. The device below the voltmeters consists of a rheostat and an electromagnet, whose armature is shown released. The two-way switch at the lower central part of the switchboard is that one to which the extra layers of the field windings are connected for joining them to, or cutting them out of, the low-tension circuit. In the right-hand corner we observe further the main fuses enclosed in glass tubes.

We are now ready to start the operation, and close the high and low pressure circuits while the two-way switch is touching the lower two points, and the resistances of the rheostat are all in the circuit. In this position the transformer acts as a series motor, in which the armature and the separate field winding receive the 660 volt current. The armature begins to turn with very little sparking indeed, increasing in speed as the resistances are gradually cut out. Depending on the load of the circuit, the secondary may be closed after the secondary armature winding has picked up, which takes place in about 10 to 15 seconds. The rheostat lever is turned to the last point, in which position the extra field winding is cut out, and the high pressure current then circulates through only one of the armature windings. Meanwhile, the low-pressure winding has established its current, and supplies or excites its field magnets which are in shunt to the 110 volt brushes. The excitation has reached its normal condition after all resistances are cut out, and by turning the two-way switch into the second position, the extra or separate field winding is placed in series with the other layers.

In constructing this and similar devices, safety in handling was one of the principal objects, and the inventor has therefore decided to have no high-pressure winding on the field at all when the apparatus is in normal working condition. As a further safeguard, an automatic device is mounted on the switchboard, consisting of an electromagnet, situated over a rheostat, by which, when energized by the high-tension circuit, the armature is attracted. The switchboard is now in normal working condition.

The system when explained in detail seems to be rather complicated, but this is by no means the case. After the two main switches are closed, there are but three motions to carry out, viz., cutting out the resistances, grouping the field winding, and placing the armature of the electro-magnet, and it will be attempted to reduce these separate movements into two or one.

The ingenious part in designing these devices is the automatic action and the impossibility of doing harm by wrong connection or failure to turn a switch. The rheostat can be moved only in one direction and not backwards, and the electromagnet above it is in the primary circuit and releases its armature when there is a short circuit or a break on the line. The electromagnet, which in such a case is thrown out of circuit, can no longer hold the heavy iron armature, which drops back and opens the line by removing the rheostat lever from the last contact point, operating at the same time, by means of a special arrangement behind the switchboard, the primary main switch, while the transformer armature gradually comes to rest. It will be noticed that the rheostat contact arm is provided with a metallic sector, which is in the path of the two-way switch, and moves it to its original position. If this operation should not be complete, and the generator were started again at a distant station, after the fault had been removed, the consequence would be evident ; the generator would be short-circuited, as the transformer armature is at rest, and there would be no resistance in circuit. Such a mistake is impossible in this case, because the rheostat switch could not go back to the original position without first changing the position of the two-way switch.

All devices are thoroughly worked out, and the manipulation of the switchboard is as simple as that of any other system. When the transformer is in normal working operation the 660 volt current circulates through the armature only while the field in all all its parts is excited by the second armature winding, whose main current is used for lighting the lamps at a pressure of 110 volts. In the motor the high-tension commutator has a greater prominence than in the transformer, while the one for the low-tension circuit is smaller on account of the reasons given above.

This system of transformation is not the only one shown within the grounds of the Exhibition. Another one especially modified is carried out, bringing the energy from Offenbach to Frankfort, a distance of six miles. In Offenbach a separately excited dynamo produces 22 amperes

under a pressure of 2,000 volts, which tension is kept contant. This current is conducted by means of bare overhead wires supported on fluid insulators, to Frankfort. This type of transformer is self-regulating, that is to say, if the tension of the 2,000 volts current is kept constant in the main station, the transformer maintains the pressure constant in the low-tension circuits at all loads, of course within a certain limit for which it is designed, in spite of increased drop on the line. This result can be obtained by coupling a motor to a compound dynamo which has so many more additional turns as to compensate for the difference of speed of the motor between no load and maximum. In this case there would be constant pressure

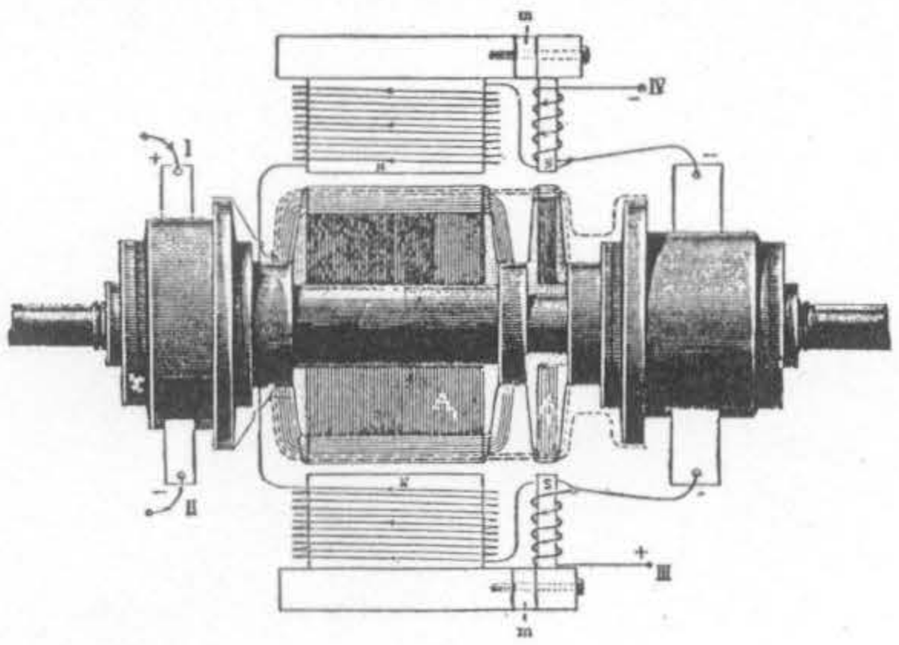


FIG. 2.

in the secondary circuit, but the efficiency of this combination would be less, and the expense of manufacture, and therefore, first cost price greater, than if both could be combined in one machine. If this latter is attempted, it will be found difficult to obtain constant pressure in the secondary circuit. The regulation of the two armature windings cannot be effected by the same means, because at increasing loads and constant speed, the motor winding requires a compensation of opposite character from that of the secondary winding.

Mr. Lahmeyer, however, has solved this question in the following manner: Fig. 2 represents the transformer in diagram. The armature, which is made for larger sizes of the Gramme ring type, is shown in here of the drum type. The high-tension winding is connected to the commutator to the left, on which rest brushes I and II connecting this winding with the high-tension source. These armature coils are wound around the main core, marked A_1. The secondary winding also surrounds the core A_1, but in addition a supplementary core A_2. Its terminals are finally led to the commutator to the right, on which rest brushes III and IV. The main field magnet is energized from brushes III and IV, and forms, therefore, a shunt to the low-pressure winding.

Separated from this field structure by non-magnetic metal *m*, is a small supplementary electro magnet, whose energizing winding takes the full secondary current. The regulation of this machine is similar to a compound wound dynamo, with the difference that the series winding is applied to a separate core and so arranged as not to influence the whole winding. Only the secondary coils are included in this small field. The current in these energizing field coils is proportional to the drop in pressure in the primary circuit, and in the same proportion the pressure is increased in the armature A_2. That is to say, if the pressure is kept constant in the central station, and the transformer is doing a certain amount of work, say for instance, one-half, and suddenly the load is increased to three-quarters, a greater current would be used in the secondary circuit, and a greater current would have to be supplied from the station. The drop on the line would be greater than on half load, and, if there were no compensation, the pressure in the low-tension circuit would drop also, but the supplementary field, carrying a series winding, has now an increased number of ampere turns, and creates a stronger field, while the secondary armature winding cuts a greater number of lines, which enables it to maintain the same pressure as before.

The apparatus is very carefully constructed, compact and well-balanced, and no sparking, or very little indeed, is visible between commutator and brushes on starting or shutting down the machine. Some readings taken on station instruments will give an idea of its efficiency. Primary, volts, 1845, amp. 7.6, secondary volts, 110; amp. 100; primary, volts, 1830, amp. 7.55, secondary volts, 109.5, amp. 100; that is, between 78 and 79 per cent. at half load, the transformer being designed to deliver 200 amperes at 10 volts.

Priority in Alternating Current Motors.

Mr. Nikola Tesla, says the London *Electrical Engineer*, on Oct. 7, 1887, filed an application for patents in America, having already built and shown his machine in work and formed a company to exploit it some months before this. Mr. Tesla was run very close in claim for priority by Mr. Haselwander, whose machine, built in 1887, is now being shown at work at the Frankfort Exhibition. We have inquired of Messrs. Lahmeyer & Co., of Frankfort, who hold the Haselwander patents, as to the exact dates of the construction of this motor. They state that the first Haselwander rotary-current motor was constructed in the summer of 1887, and was set to work on Oct. 12, 1887. The first application for a patent for the said motor was made on July 21, 1888. As the patents were applied for by Tesla on Oct. 12, 1887, and were actually issued on May 1, 1888, 17 days before the publication in England of Prof. Ferraris' Italian paper on "Alternating Motors," and two months and a half before the date of Haselwander's patent, this would seem to settle the question, at any rate with the present data before us, in favor of Mr. Tesla.

The Inventor of the Rotary Field System: Its Present Application and Future.*

BY LUDWIG GUTMANN.

Since the theory of the rotary field system has been argued at length, I wish to take up the practical side of it. I have chosen for my theme, "The Inventor of the Rotary Field System, and Its Present Application and the Future of It;" but I have concluded not to touch here the first part, which involves the question of priority. Later on I shall review the merits of previous inventors in the electrical periodicals.

Before entering upon the subject I should like to mention that I have chosen the expression rotary field and not rotary current, because similar ideas arose also in my mind as have been touched already by Prof. Hospitalier, of Paris, and because the characteristic part of the system is the rotary field. The currents are alternating currents, which are led around a mutual centre in succession, to the apparatus which is to be periodically excited. This mechanical arrangement of conveying power has most likely been the cause for that somewhat obscure expression, "rotary current." The properties attributed to the system are not peculiar to the current; they are peculiar to the rotary field, and these properties can certainly be shown as well on the combined wires as on the apparatus fed by them. Different articles published recently in the "Electrotechnische Zeitschrift," for instance, the one by Von Dolivo-Dobrowolsky (March 20, 1891), in which he says that the experiments made by Schallenberger and Tesla had not led to practical results, are apt to encourage unqualified and incorrect views and conclusions. On the contrary, the motors of Schallenberger are employed in his electric meter, of which at least from 8,000 to 10,000 are in daily use. These numbers alone might well speak against the just mentioned assertion (made by Dobrowolsky), and as to the Tesla motors, they have also come into use in a number of places. The sizes of these motors most employed are 5, 20 and 50 h. p.; they run assynchronously and are modified so that the momentum of rotation is the same in every position of the armature, consequently they are distintinguished by smooth starting and uniform running. The average tension is 400 volts, and the number of periods per second is 60–70. I must remark, however, notwithstanding that, that the rotary field system has not spread in America, and for the following reasons:

At the time when the rotary field system, especially the generators and motors, was perfected, there were in existence in America about 250 central stations for alternating currents; they were partly in practical operation, and partly in process of construction. They worked with alternating current transformers which were fed by currents of 120–133 periods per second. This number of periods is for European ideas a very high one, but allows of the essential advantage of making small and light transformers with little copper and iron and of from 20 to 40 lamps capacity, which are the sizes mostly required in practice.

Let us now consider the commercial sides of the alternating current system and the rotary field system, which is necessary for a practical success. It is evident that the latter system will be more expensive for lighting stations than the former. To prove that, I need only to mention that the two-phase current transformers need two primary coils, of which each must have the same length as the one coil in the ordinary current transformer. In a similar proportion stand transformers which use more than two-phase currents for excitation. From this it is plainly seen that the material used in rotary field transformers produces hardly more than half the result of that used in alternating current transformers. It was simply due to commercial reasons that the rotary field system could not make greater progress in America in comparison with the alternating current system. However, the rotary field motor has received proper recognition. If notwithstanding this, as before mentioned, that motor has not been introduced generally for transmission of power it was for the reason that the motor could not be put on the two-wire circuits of the already existing central stations.

The American electricians always look for the simplest and cheapest system, and that is a two-wire system for alternating currents which can be used without distinction on the same circuit apparatus for lighting and heating purposes as well as for transmission of power. Such a system only will survive in the end, and by its general applicability it will lead to practical and favorable results. Such a system would enable the machines of many stations which are now idle most of the day to be employed, except for a few hours only.

In America the rotary field system has further experienced limitations in the field of transmission of power through the synchronous alternating current motor, but it has come into use in mines and similar places, where a motor with a commutator may cause explosions of gases.

The rotary field system may succeed better in Europe, and especially in Germany, than in America, where there are in existence at present probably over 500 alternating current stations, because it does not there meet its dangerous competitor. There exist in Germany, as far as I am informed, not over six high potential alternating current stations, and the rotary field system is already employed in Germany in the Lauffen-Frankfort plant. In Switzerland there are one or two stations. So much for the present. As we have enjoyed in America several years of experience with this system represented by the Telsa motors, I must oppose the assertion lately made by Herr von Dobrowolsky at a meeting of the Electrotechnische Gesellschaft held here in Frankfort. That gentleman said: "I believe I am able to assert that the motor problem for large and small works has been by this completely solved." This assertion goes most likely too far. The problem was already solved, theoretically and electrically, in 1889, but, as I showed you just now, the practical solution is strongly influenced by conditions of a strictly commercial nature, by competition and by the progress in technics. It must certainly be acknowledged that Herr von Dobrowolsky has done important work in the rotary field system. He has advanced considerably the art of transmitting power from great distances by his special and ingenious motors and construction of transformer. Notwithstanding this technics will not stop but progress steadily and suggest simpler means of accomplishing the result. Already the following competitors present themselves for use in large plants:

1. The synchronous alternating current motor with or without a transformer.

2. The alternating current-continuous current transformer and the continuous current motor.

For use in small works, that is factories and private plants, the motor alone may prove a success, but for central stations transformers will be necessary with the motors. Whether such a central station will pay must be taught by future experience, as a number of transformers will increase the price considerably and as rotary field motors require special stations and circuits without being able also to furnish light. A continuous current station will probably pay better. Outside of that there will be some new competitors (not yet known), which seem predestined for success and which hinder the general introduction of the rotary field system. In general it is a pretty dangerous task to describe the qualities of some not quite perfected machine. However, it is not my intention to describe the motors and work they will do, but I shall indicate here only the direction, the ways which were followed up. These new competitors are a few motor types which require only a two-wire system; they start with a maximal load and are in every respect in a far higher measure assynchronous than the rotary field motors. It is often said in our days that the plain, pure alternating current motor will not have a future because the exciter fields are not constant, and it is pointed out that it was reserved for the rotary field motor to fulfil these principal conditions; but it is not considered that the rotary field motor is a pure alternating current motor too in which a method is employed that gives a constant field in spite of the alternating currents used.

I should like now to make the assertion that if one such method is found several will likely be discovered which have nothing in common in principle.

Unluckily I am not authorized to speak about the construction of such motors, but the independence of the motors from their exciters is shown by the following: A motor was placed in a circuit of 130 periods per second, and its armature started a small dynamo that had a load of 30 lamps and was then running at a speed of 900 revolutions per minute. At a load of 50 lamps the speed of the motor armature dropped to 800 revolutions because it was overloaded. In another instance a motor was placed in a circuit of 70 periods per second; it ran without any load at a speed of about 200 revolutions per minute. Whether and to what extent these alternating current motors will fulfill the expectations entertained must be left to the future. The armatures of the synchronous alternating current motors and rotary field motors are in magnetic equilibrium with their fields, while those of the new motors just mentioned remain in magnetic instability with their exciter field. From these remarks may be concluded that in Europe too, the success of the rotary field system will not depend solely on its own merits; it will—just as in America—be subject to the influence of circumstances and progress, and it may not realize the expected hopes in a few years.

Having now described the rotary field system in accordance with my own views, I will mention that, beside this problem, another one, still more important in my opinion, needs to have our attention here. I refer to the "problem of insulation." After Von Dobrowolsky and Brown have done such valuable work in the successful transmission of power from Lauffen to Frankfort, they would add a new leaf to their laurels, if, in addition, they would also determine the limits of the capacity of insulation on that plant and would communicate to us their results in all details. It seems to me that the ventilation of this question here is well justified, since it has acquired by ready aid on the part of the governments a general and, by calling the congress, an international character.

It would be most valuable to know to what potential the currents can be raised under all conditions of the atmosphere, when the modified form of Johnson Phillipp's insulators is employed, after the projected potential of 30,000 volts has been reached.

In conclusion I would like to add that although the fault I have mentioned arose in my mind regarding the general commercial success of the rotary field system, I willingly concede that Herr von Dobrowolsky alone, and in conjunction with Mr. Brown, of the Oerlikon Gesellschaft, has done most important work; both deserve well the fruits of their labor and I wish these courageous and untiring investigators the greatest success in these experiments, too.

NOTE—To explain my above named views, re Drehfeld, I would say: In Germany there exist three kinds of currents—continuous, alternating and rotary currents. I consider it dangerous to use the name "Drehstrom," or rotary currents; this latter name may be applicable to "eddy currents," and not for three or more separate alternating currents. We know there are in reality continuous, pulsating, alternating, intermittent and other currents which are modifications of the first three, but these would not give us the differences required. The differences are exhibited by the magnetic effects only. Here we must distinguish three totally different kinds—(1) Constant magnetic field, caused by a continuous or practically continuous current; (2) an alternating or intermittent magnetic field, caused by alternating or intermittent currents; and (3) a rotary magnetic field, caused by alternating or intermittent or alternating and intermittent currents applied in cyclical succession through several conductors. A rotary magnetic field can be obtained with two, three and more separate circuits and with as many different kinds of currents, and therefore either all should be called two phase, three or more phase currents, or, as proposed by Mr. Hoopskalter, multiphase currents, or else, if for three wires carrying alternating currents with different phase, a special name would be given. Each of the other forms would be entitled to the same privilege.

* Paper read at the Frankfort Electrical Congress.

Reasons for the Use of the Three-Phase Current in the Lauffen-Frankfort Transmission.

BY C. E. L. BROWN.

The reports of THE ELECTRICAL WORLD upon the transmission of power from Lauffen to Frankfort give the impression that the application of the three-phase current alone renders such an installation possible, and that to its application is due the favorable issue of the experiment.

I wish, however, to call attention to the fact that the principal object of the experiment was to prove the possibility of producing and transmitting high tension currents over long distances by naked wires suspended from poles, and with such a degree of security against danger and such a small amount of loss by leakage as to demonstrate that this mode has commercially a right to exist.

The idea originated with me and was put to the test of experiment at Oerlikon with very encouraging results, which together with the lecture I delivered on the subject at Frankfort on the 9th of. February last, provoked the determination to carry out the Lauffen-Frankfort installation as it now exists.

In that lecture I propounded the view—in opposition to the general opinion at that time—that currents of 20,000 volts or more could be carried by naked wires suspended from poles on suitable insulators without excessive loss by leakage; further, I met all the questions that could arise concerning such an installation as that between Lauffen and Frankfort, and the proof of the correctness of the assertion I then advanced is that the installation in question has been carried out in accordance with my suggestions as given in my lecture referred to.

The adoption of the three-phase current only increased the difficulties to be met, since the generator, the transformer, switches and controlling appliances, as also the conductors—a most important disadvantage—became more complicated than they otherwise would have been had the usual alternating current been chosen. The only reason justifying the choice of the three-phase current was to demonstrate its advantages when applied to several small motors at the same time.

Examining closer into the three-phase current question, the only novelty which the Frankfort exhibition brings to light concerning it are important constructive improvements in its application, and these, almost without exception, I claim as my own, for the first large multiphase generator and transformer, as well as the first practical motor without moving or rubbing contact, were my constructions.

The three-phase current as applied at Frankfort is due to the labors of Mr. Tesla, and will be found clearly specified in his patents.

BADEN, Switzerland, Oct. 12, 1891.

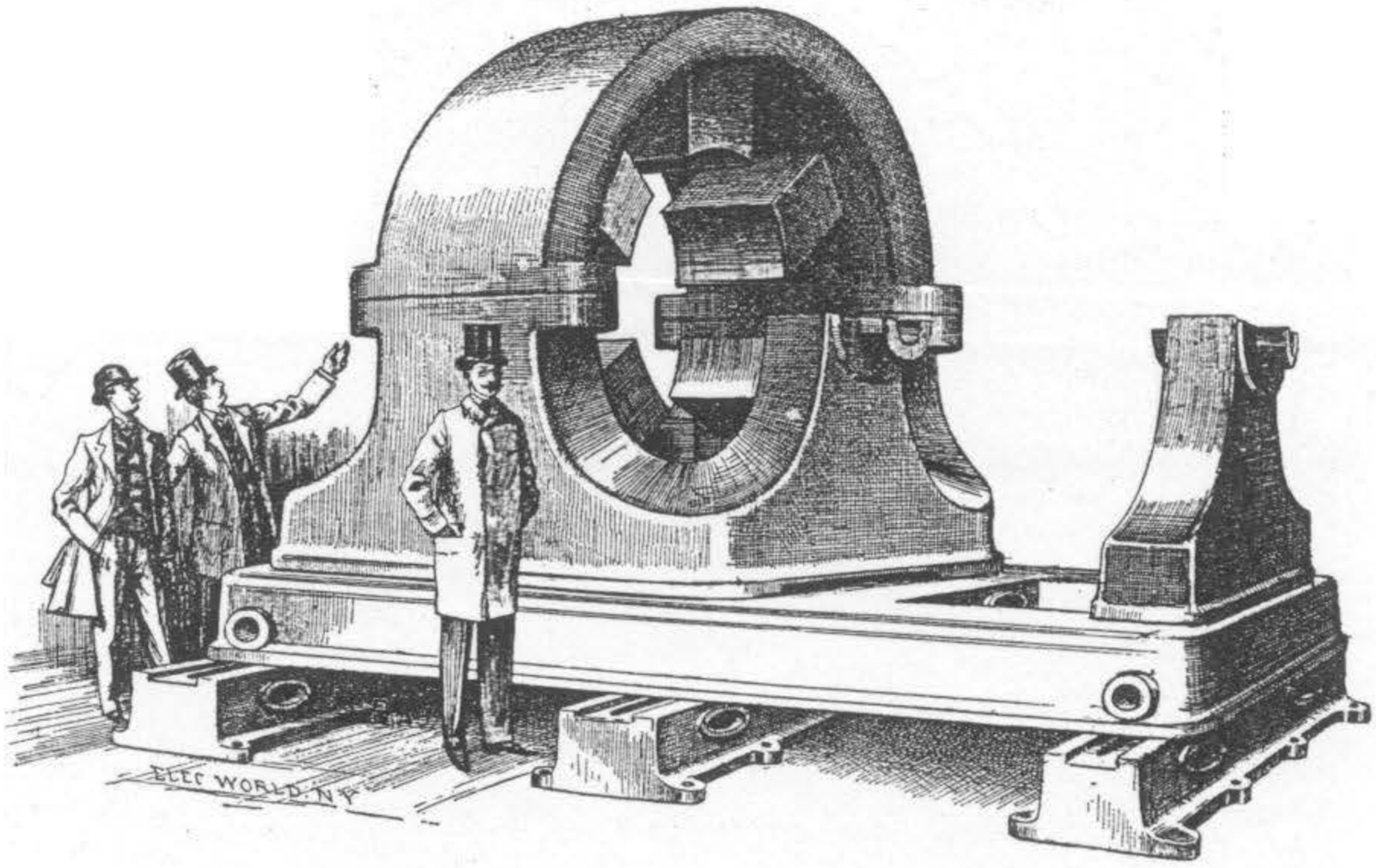
COMMENTS ON MR. BROWN'S LETTER BY CARL HERING.

In regard to the statement made in the beginning of this letter referring to my description of this transmission, I wish to say that I distinctly stated in those descriptions that the chief object of the three-phase currents, *per se*, was to enable alternate current *motors* to be run more readily than by the single phase system. I also stated, and emphasized it by repeating it in several places, that the chief object of the Lauffen-Frankfort experiment was to see whether it was practicable to transmit power on overhead lines by such high tension alternating currents, *per se*, irrespective of whether it was a three or a one phase current, as long as it was an alternating current. Nowhere do I recall having said or inferred that the "three phase current alone renders such an installation possible," except perhaps that I implied that a high tension alternating current transmission, in combination with the three-phase motor, rendered a long distance transmission of power to a *motor, practicable* (not *possible*). I am well aware (which Mr. Brown might have supposed) that it could have been done with an ordinary synchronous alternating current motor, but I said then, and think so still, that the three-phase motor is a more practicable solution. Neither did I say or infer that "to its (three-phase system) application is due the favorable issue of the experiment" except as just explained. It *is* due to the combination of the two that the practical system of a long distance transmission and distribution to a *motor* (as distinguished from lights) by alternate currents was a success. The three-phase system is evidently not essential in a simple high tension transmission of energy. and nowhere did I say this, to my knowledge. What I did say about the high tension transmission portion of this experiment, *per se*, was almost exactly what he states in the second paragraph of this letter.

I would add that I do not think Mr. Brown does proper justice to the real inventor of this modification of the Ferraris-Tesla system, namely, Dobrowolsky, when he claims that "the only novelties which the Frankfort exhibition brings to light concerning it." etc., are all his own (Brown's). It is one thing to make an invention, and it is another thing to carry it out by the best details of construction. In the latter capacity, namely, as a constructor, no one who knows Mr. Brown's works will question his ability as one of the first among electrical engineers of the present time. But without the *invention* of a new principle or a new modification, the ablest constructor would hardly be able to make any very great departures from well known systems. Due credit should therefore be given to the inventors as well as the constructors.

A Colossal Westinghouse Generator.

Among the exhibits of the Westinghouse company at the machine works was a new 500-h. p. six-pole railway generator, shown in the cut on this page. At the time of the convention it was not yet completed, but the massive castings give an excellent idea of its imposing size and solid construction. It is by all odds the largest generator ever manufactured in the Westinghouse works, and a strong candidate for being the largest American



AN IMMENSE WESTINGHOUSE GENERATOR.

built dynamo. The armature conductors in these big machines are laid under the surface of the armature in oval perforations which are afterward milled into deep slots. The commutator is singularly massive, with segments of large cross section and ample bearing surface, a precaution quite important where, as is now the case in most railway generators, carbon brushes are likely to be used.

The machines of the Westinghouse company are singularly beautiful in mechanical design and finish, and the present example partakes of the character of the smaller machines in this as in other respects. It has, however, six poles instead of four, but its electrical properties are quite similar to those of its smaller companions, and if anything can be judged from their performance its operation will be highly satisfactory. The armatures of all these machines are of particularly solid and efficient construction; they run without sparking, are quite indifferent to changes of load, and stand their full output without heating of any moment.

The Westinghouse company was very fully represented at the convention, some of the gentlemen present being Messrs. Samuel Bannister, vice-president; Albert Schmidt, Norman McCarty, E. G. Gray, H. W. Grannis, H. McL. Harding, E. H. Heinrichs and T. W. Burrows, of Pittsburgh; J. A. Rutherford and A. H. Chadbourne, of Philadelphia; J. M. Atkinson and J. L. Barclay, of Chicago; R. S. Brown, of New York, and C. B. Osgood, of Atlanta, Ga.

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The Inventor of the Drehstrom System.

IN another column will be found a letter from Mr. C. E. L. Brown, for some years past the electrician of the Oerlikon Works at Zurich. It is of special interest as bearing on a subject often previously noticed in these columns. Some weeks ago we stated with reference to the long distance transmission of power from Lauffen to Frankfort that the one particular thing undergoing test was not at all the three-phase current system, but the possibility of using enormously high voltages in commercial work. Mr. Brown's letter simply goes to confirm this statement in the most unqualified way, and as the idea of that epoch making experiment originated with him, he certainly is amply qualified to speak with authority on the subject. The final sentence of his letter is one to which we cannot refrain from referring with great satisfaction, as it is an unsolicited and emphatic endorsement of Mr. Nikola Tesla's well founded claims to priority in the use of this particular class of alternating current motors.

TESLA'S ALTERNATING MOTOR OPERATED WITH CONDENSER.

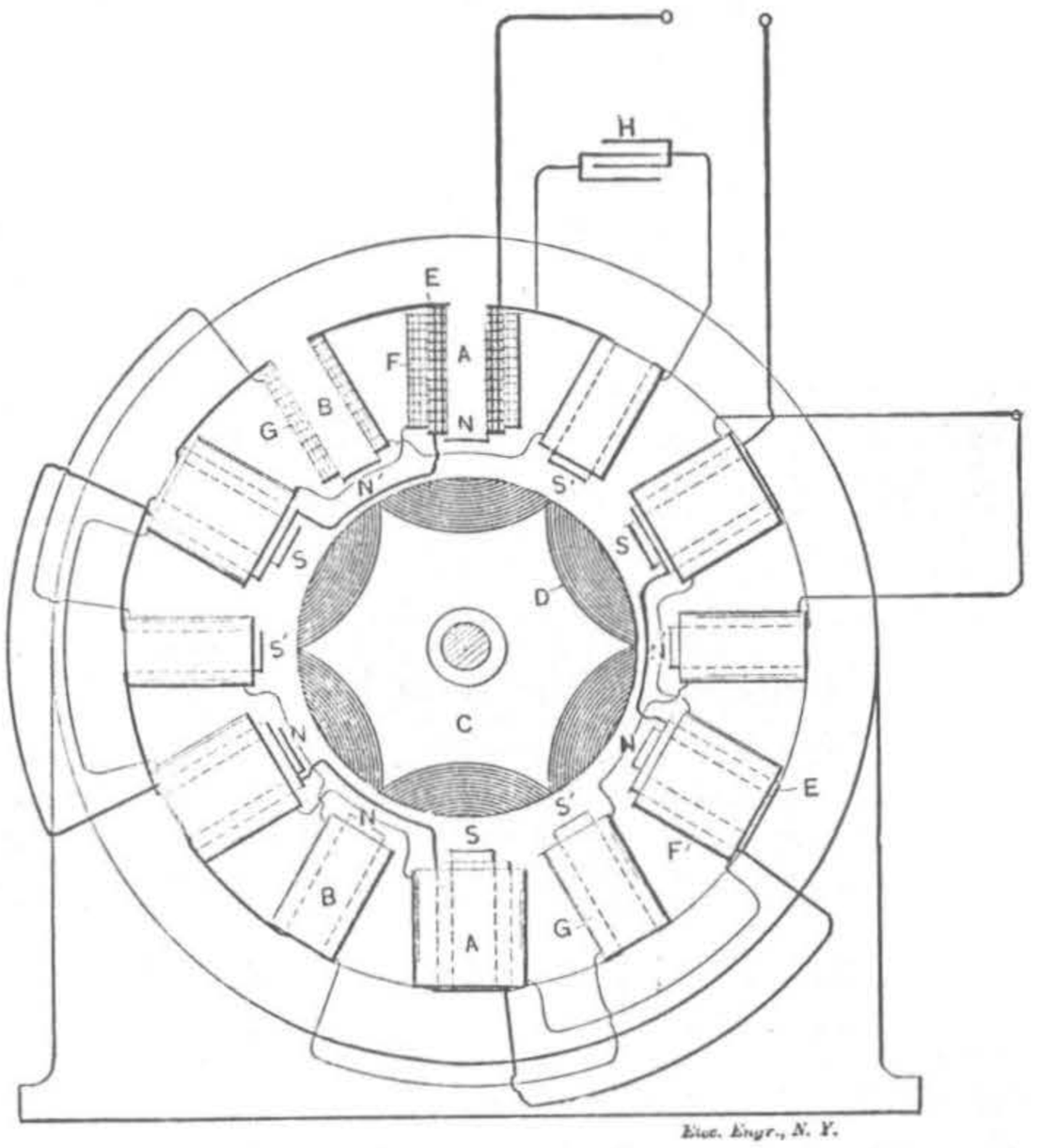
It is a well-known fact that if the field or energizing circuits of a motor, in which the action is dependent upon the inductive influence upon a rotating armature of independent field magnets exerted successively and not simultaneously, be both derived from the same source of alternating currents, and a condenser of proper capacity be included in one of the same, that approximately the desired difference of phase may be obtained between the currents following directly from the source and those flowing through the condenser. The great size and expense of condensers for this purpose that would meet the requirements of the ordinary systems of comparatively low potential, however, are practically prohibitory to their employment in practice.

Another well-known method or plan of securing a difference of phase between the energizing currents of motors of this kind is to induce by the currents in one circuit those in the other circuits, but no means have thus far been proposed that would secure in this way between the phases of the primary or inducing, and the secondary or induced currents, that difference—theoretically, ninety degrees—that, in the type illustrated, is best adapted for practical and economical working.

To accomplish this, Mr. Nikola Tesla has devised a means which renders practicable both the above described methods, and by which he is enabled to obtain an economical and efficient alternating current motor. Mr. Tesla obtains this result by placing a condenser in the secondary or induced circuit of his well-known type of motor, and raising the potential of the secondary currents to such a degree that the capacity of the condenser, which is in part dependent on the potential, need be quite small. The capacity of this condenser is determined, as usual, with reference to the self-induction and other conditions of the circuit so as to cause the currents which pass through it to differ from the primary currents by a quarter phase.

The accompanying diagram illustrates the principle as embodied in a motor in which the inductive relation of the primary and secondary circuits is secured by winding them inside the motor partly upon the same cores. Here A, B, represent the poles of an alternating-current motor, of which C is the armature, wound with coils D, closed upon themselves as is now the general practice in motors of this kind. The poles A which alternate with poles B, are wound with coils of coarse wire E, in such direction as to make them of alternate north and south polarity, as indicated in the diagram by N, S. Over these coils are wound long, fine wire coils F, F, and in the same direction throughout as the coils E. These coils are secondaries in which currents of very high potential are induced. Mr. Tesla, as a rule, connects all the coils E in one series and all the secondaries F in another.

On the intermediate poles B are wound fine wire energizing coils G, which are connected in series with one another and also with the series of secondary coils F, the direction of winding being such that a current impulse induced from the primary coils E imparts the same magnetism to the poles B as that produced in poles A by the primary impulse. This condition is indicated by the letters N′ S′. In the circuit formed by the two sets of coils F and G is introduced a condenser H, the circuit being otherwise closed upon itself, while the free ends of the circuit of coils E are connected to a source of alternating currents.



Tesla Motor With Condenser.

As the condenser capacity which is needed in any particular motor of this kind is dependent upon the rate of alternation or the potential, or both, its size and hence its cost, as before explained, may be brought within economical limits for use with the ordinary circuits. It is evident that by giving to the condenser proper value any desired difference of phase between the primary and secondary energizing circuits may be obtained.

American Institute Of Electrical Engineers-Tranactions
December 16, 1891

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, December 16th, 1891.

The sixty-second meeting of the American Institute of Electrical Engineers was held this date at No. 12 West 31st street. The meeting was called to order by Secretary R. W. Pope.

THE SECRETARY:—Gentlemen, it gives me pleasure to announce that we have with us this evening our esteemed Past President, Professor Elihu Thomson, and in view of the fact that he is not very frequently present, we have induced him to preside over the meeting to-night, but it is understood that he will not refrain from taking part in the discussion should occasion warrant.

THE CHAIRMAN [Prof. Thomson]:—On being asked to preside this evening, I protested that I did not believe I was a Vice-President of the Institute, but the plan seems to be that I shall make up to some extent for my remissness in the past. When I was President of the Institute I did not get down to many meetings, except the annual meetings, and I will take pleasure in doing what I can now to make up for that remissness, if my services are of any use to the Institute.

The proceedings of the evening will commence with the paper "On Polyphasal Generators," by Dr. M. I. Pupin, of Columbia College.

A paper read at the sixty-second meeting of the American Institute of Electrical Engineers, New York, December 16th, 1891. Past-President Thomson in the Chair.

ON POLYPHASAL GENERATORS.

BY M. I. PUPIN, PH. D., COLUMBIA COLLEGE.

Few will deny the importance of the polyphasal current systems; none the fascination of their study. This belief induced me to present the following brief essay before the Institute.

The experimental researches in this new and promising field of electrotechnics are not yet numerous, but still the results already obtained are of so decisive a character as to leave no doubt whatever as to the extremely high practical importance which is attached to electrical generators, motors and transformers constructed according to requirements imposed upon us by this *new method of combining a set of variable electromotive forces.* For who among us does not thoroughly appreciate the beautiful inventions of Nikola Tesla and the completeness of the success which Dobrowolsky and Brown obtained by the practical applications of these inventions?

The exact quantitative relations involved in the polyphasal system of currents are not, I venture to say, quite as well known as its practical results. To give an impulse to further inquiry in that direction is one of the principal aims of this modest investigation. For the present I propose to confine myself to the polyphasal generators in general, and particularly to *polyphasal generators whose system of electromotive forces is capable of producing a rotary magnetic field of constant strength.* The last point seems to me to be one of the vital points in this new method of electrical distribution. It is in this particular point that Mr. Dobrowolsky claims his system to be superior to that of Nikola Tesla.

Let us consider the theoretically simplest form of a polyphasal

generator, as shown in Fig. 1. A non-magnetizable ring with n open equal coils at equal distances from each other rotates uniformly through a perfectly homogeneous magnetic field Let PP′ be the neutral plane of the field. At the instant when coil 1 is at the angular distance θ from the neutral plane PP′ the E. M. F. generated in the various coils will be

$$e_1 = K \sin(\theta + \alpha)$$

$$e_2 = K \sin(\theta + \alpha + \frac{2\pi}{n})$$

. . . . . .

. . . . . .

$$e_n = K \sin\left\{\theta + \alpha + (n-1)\frac{2\pi}{n}\right\}$$

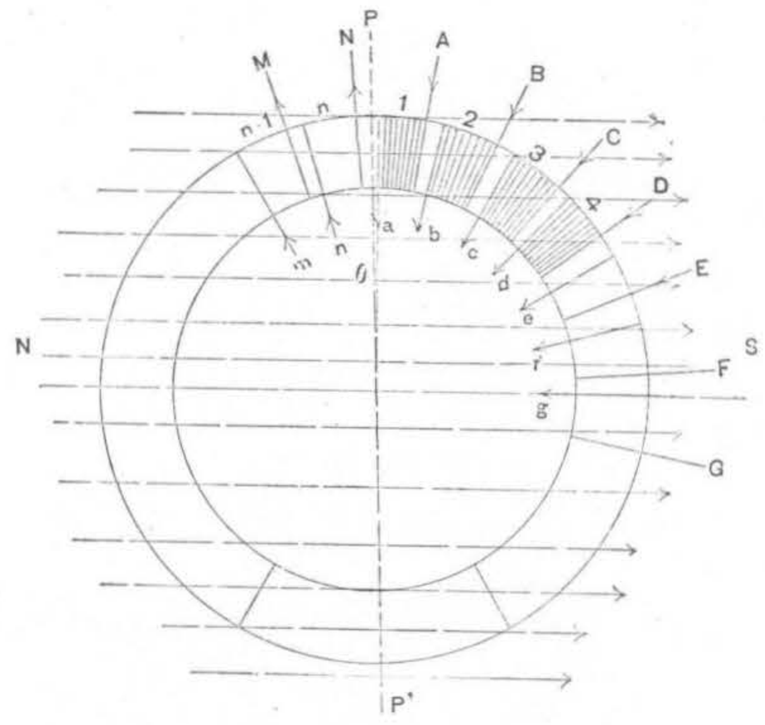


Fig. 1.

Where K is a constant depending, as is well known, on the field intensity, the speed of rotation, the number of turns in the coil and the area of the plane of a turn; α is the angular width of one-half of the coil.

Since

$$\sin(\theta+\alpha)+\sin(\theta+\alpha+\frac{2\pi}{n})+\ldots\ldots+\sin\left\{\theta+\alpha+(n-1)\frac{2\pi}{n}\right\}=0$$

it follows that

$$e_1 + e_2 + e_3 + \ldots\ldots + e_n = 0 \ldots\ldots (1).$$

That is to say, *the sum of electromotive forces generated in the various coils which are on one side of the neutral plane is numerically equal and of opposite sign to that of the coils on the other side of this plane.* This result is well known and self-evident. It is, however, far from self-evident that relation (1), which I shall call the *relation of continuity* for the electromotive forces, will be satisfied by every magnetic field.

Close each coil separately by conductors of equal resistance and self-induction. Let $c_1, c_2 \ldots\ldots c_n$ denote the currents in the n separate circuits. It is evident that

$$c_1 = \frac{K}{I} \sin\ (\theta + \alpha - \varphi)$$

$$c_2 = \frac{K}{I} \sin\ (\theta + \alpha + \frac{2\pi}{n} - \varphi)$$

$$c_3 = \frac{K}{I} \sin\ (\theta + \alpha + 2\,\frac{2\pi}{n} - \varphi)$$

$$c_n = \frac{K}{I} \sin\ \left\{\theta + \alpha + (n-1)\,\frac{2\pi}{n} - \varphi\right\}$$

Where I is the impedance in each circuit and φ the angle of retardation. Hence, we have

$$c_1 + c_2 + c_3 + \ldots\ldots + c_n = 0 \ldots\ldots (2).$$

That is to say, *the relation of continuity is satisfied for the currents also.*

Let the wires $aA, bB, \ldots\ldots nN$ (Fig. 2) represent a part of each of the n conductors of this system. Then, according to relation (2), the sum of the currents in these n linear conductors being always zero, if we joined them all into one conductor there would be no current in this wire, but the currents in the n circuits would circulate exactly the same as before. In fact, the common juncture is useless and can and should be cut out.

The diagram, Fig. 3, represents this method of connecting for a three-phase system. Consider, now, n equal coils distributed at angular distances of $\frac{2\pi}{n}$ over a laminated iron ring B, each coil being a part of the n conductors coming from the generator. Diagram Fig. 4 illustrates this for a three-phase system. Let the n currents be denoted now by $c_1', c_2', \ldots\ldots c_n'$. We shall have, now,

$$c_1' = \frac{K}{I'} \sin\ (\theta + \alpha - \varphi')$$

$$c_2' = \frac{K}{I'} \sin\ (\theta + \alpha + \frac{2\pi}{n} - \varphi')$$

$$c_n' = \frac{K}{I'} \sin\ \left\{\theta + \alpha + (n-1)\,\frac{2\pi}{n} - \varphi'\right\}$$

and therefore

$$c_1' + c_2' + \ldots\ldots + c_n'' = 0 \qquad (3)$$

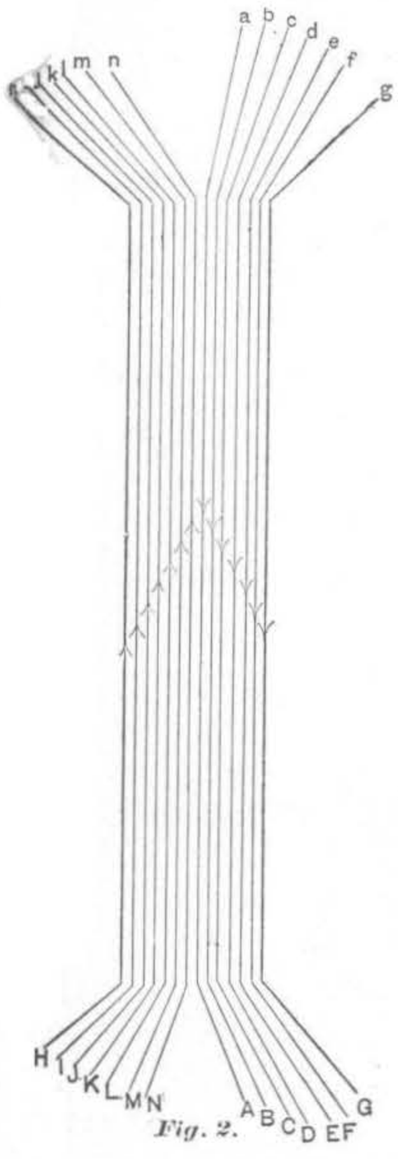


Fig. 2.

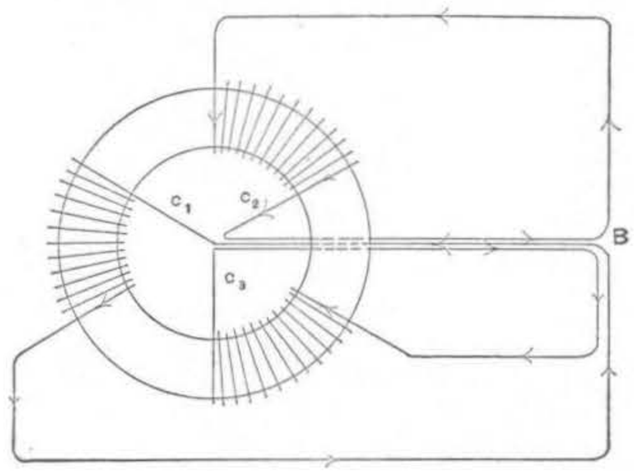


Fig. 3.

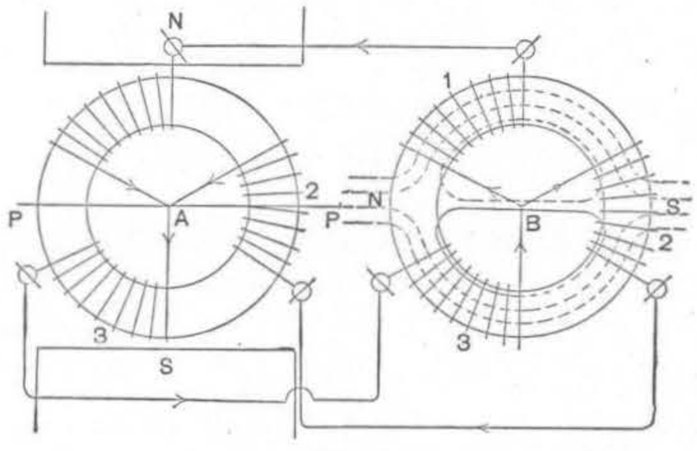


Fig. 4.

The introduction of the iron ring with the n coils into the n phasal system has changed the impedance I, and the angle of retardation φ; but this change is evidently the same for all coils. The correctness of this statement might, perhaps, be questioned, if we supposed that the system of the n variable currents was at

any moment strong enough to saturate the iron ring, I therefore suppose that the intensity of magnetization in the ring is never over 10,000 C. G. S. lines of force. We shall presently see that in the case of a properly built generator the saturation of the iron ring will not vitiate the correctness of the above statement in the slightest.

Let s be the number of turns in each of the n coils. Relation (3) gives

$$4\pi\, s\, c_1' + 4\pi\, s\, c_2' + \ldots\ldots + 4\pi\, s\, c_n' = 0 \qquad (4)$$

That is to say the magneto-motive forces in the n coils of the ring b satisfy the relation of continuity. Relation (4) translated into physical language means that the *magnetization in the iron ring is due to two equal magneto-motive forces working in multiple arc. The magnetic field produced* is *perfectly symmetrical with respect to the ring as indicated by the dotted lines in Fig.* 4.[1]

Consider now n iron ring cores of exactly the same dimensions and made of the same material. Let ρ be the reluctance of each ring. Let each of the n coils be interlinked with one of the iron rings, we shall have n homogeneous magnetic circuits; and as long as the magnetization of these rings is considerably below the saturation point, we shall have

$$\frac{4\pi\, s\, c_1'}{\rho} + \frac{4\pi\, s\, c_2'}{\rho} + \ldots\ldots + \frac{4\pi\, s\, c_n'}{\rho} = 0$$

That is to say the magnetic induction in the n magnetic circuits obeys the same law as the n electric currents; we can therefore employ the method of polyphasal connection for the magnetic circuits also and we obtain what the Germans call a Verkettung der Magnetischen Kreisläufe which may be translated into English by a more accurate expression: *Polyphasal coupling of magnetic circuits.* A transformer constructed on this principle may be called a *coupling transformer*, to distinguish it from the Tesla polyphasal transformer.

A simple consideration will show that the field rotates around the axis of the ring B synchronously with the rotation in the generator which produces the impressed E. M. forces. Consider the armature of the generator. Since the ampere turns on one side of

(1) This will be strictly true when the number of coils over the ring B is even, because then the distribution of the ampere turns over the ring is perfectly symmetrical. It is therefore always strictly true because the number of these coils may be made even in odd number of phases as well as in even number of phases.

the neutral plane is always equal and opposite in sign to the ampere turns on the other side of this plane it is evident that the magnetic field due to the ampere turns in the armature is fixed in space and perfectly symmetrical with respect to the plane of symmetry PP[1]. We can therefore say that this field, though *fixed in space, rotates with respect to the armature* with the *same angular* velocity with which the armature rotates in space. The distribution of the ampere turns over the stationary ring B being at any moment the same as that over the armature ring, it follows that the magnetic field of B also rotates with respect to B synchronously with the rotation in the armature. An inspection of the diagram in Fig. 4 will show that *when the rotation in the generator is reversed the rotation of the field* B *will also be reversed.*

The strength of the rotating magnetic field will vary because the strength of the two equal magneto-motive forces which are working in multiple arc will vary. The following simple consideration will show us the law of this variation. Two cases must be considered separately. First, when n is an odd number; secondly, when n is an even number.

Case 1.

A simple definition will save me tedious repetitions of long sentences. I define the sum of all the electromotive forces generated in all the turns which are at any moment on the same side of the neutral plane of the generator as the *resultant impressed* E. M. F. at that moment. The magneto-motive force of the rotating field will evidently vary according to the same law as the resultant impressed E. M. F. To find the law of variation of the resultant impressed E. M. F., consider the armature of the generator when the angle θ of coil 1 is zero. To make the reasoning shorter, I make now the angular width of each coil equal to $\frac{2\pi}{n}$, so that the n coils completely cover the ring, which makes $\alpha = \frac{\pi}{n}$. If this angular width is smaller, then a simple consideration will show that the law of variation which I am about to deduce will be exactly the same. In the position just mentioned, the coils 1, 2, 3, ... $\frac{n-1}{2}$ will all be on the same

side of the neutral plane, whereas coil $\frac{n+1}{2}$ will be just half on one side and half on the other side of this plane. There is no electromotive force generated in this coil. As the above mentioned angle θ begins to increase from zero, coil $\frac{n+1}{2}$ begins to contribute to the resultant impressed E.M.F., but this contribution is just counterbalanced by the loss due to the entrance of coil n into the opposite region of the neutral plane. The variation in the resultant impressed E. M. F. is therefore due solely to the change of position of the turns in the coils 1, 2, 3, ... $\frac{n-1}{2}$, on one side and the corresponding turns on the other side of the neutral plane. This will be the case until coil $\frac{n+1}{2}$ has completely passed to one side of the neutral plane and coil n is just bisected by it. During this interval θ has increased from zero to $\frac{1}{2}\ \frac{2\pi}{n} = \frac{\pi}{n}$. The value of the resultant impressed E. M. F. at any moment during this interval is easily found. Denote it by E, then

$$E = e_1 + e_2 + \ldots\ldots e_{\frac{n-1}{2}}$$

$$= K\left\{\sin(\theta + \frac{\pi}{n}) + \sin(\theta + \frac{\pi}{n} + \frac{2\pi}{n}) + \ldots\right.$$
$$\left. + \sin\left\{\theta + \frac{\pi}{n} + \left[\frac{(n-1)}{2} - 1\right]\frac{2\pi}{n}\right\}\right.$$

$$= K\left\{\sin(\theta + \frac{\pi}{n}) + \sin(\theta + \frac{\pi}{n} + \frac{2\pi}{n}) + \ldots\ldots\right.$$
$$\left. + \sin\left\{\theta + \frac{\pi}{n} + \left[\frac{n-3}{2}\right]\frac{2\pi}{n}\right\}\right.$$

$$= \left[\frac{K_1 \sin(\theta + \frac{\pi}{n} + \frac{n-3}{4}\frac{2\pi}{n})}{\sin\frac{\pi}{n}}\right] = K_2 \sin\left[\frac{\pi}{2} + \theta - \frac{\pi}{2n}\right)$$

$$= K_2 \cos(\theta - \frac{\pi}{2n})$$

It is evident that the resultant impressed E. M. F. E varies during the interval from $\theta = 0$ to $\theta = \frac{\pi}{n}$ just like $\cos(\theta - \frac{\pi}{2n})$; that is to say, it varies just like a simple harmonic. When $\theta = \frac{\pi}{2n}$, E reaches a maximum which is equal to K_2, it has a minimum both when $\theta = 0$ and when $\theta = \frac{\pi}{n}$, each of these minima equals $K_2 \cos\frac{\pi}{2n}$. The ratio of the minimum to the maximum value equals $\cos\frac{\pi}{2n}$. For a three-phase system this ratio is .866, and it diminishes very rapidly as n increases. It is evident that after θ has reached the value $\frac{\pi}{n}$ the armature is, as far as concerns the resultant impressed E. M. F. in exactly the same position as at the start when $\theta = 0$. We conclude therefore that E has $2n$ equal maxima and $2n$ equal minima during each revolution of the armature. In diagram Fig. 5 these fluctuations of E for a three-phase system are represented graphically.

CASE 2.

Similar relations hold good when n is even. The maxima take place when $\theta = 0, \frac{2\pi}{n}, \frac{4\pi}{n}, \ldots\ldots$ The minima when $\theta = \frac{\pi}{n}, \frac{3\pi}{n}, \frac{5\pi}{n}, \ldots\ldots$ and the ratio of any minimum to any maximum is $\cos\frac{\pi}{n}$. Since the magneto-motive force varies according to the same law as the resultant impressed E. M. F., it follows that the strength of the rotary magnetic field fluctuates periodically, having $2n$ equal maxima and $2n$ equal minima during each revolution and the ratio of any minimum to any maximum equals $\cos\frac{\pi}{2n}$. That is, when n is odd, but when n is even then there are only n maxima and n minima and the ratio of any minimum equals $\cos\frac{\pi}{n}$.

A polyphasal generator of this kind would produce a rotary magnetic field of constant strength only when $n = \infty$. For a three phase system the maximum variation would be nearly 14 per cent. of the maximum value. *This agrees perfectly with Mr. Dobrowolsky's calculations, but I fail to see how these calculations could justify any one to assume that they hold good for all types of polyphasal generators* [2]. The generator which we have considered could be actually constructed but its output would be so small in proportion to its size that we may dismiss it at once as an impracticable machine. We can make it practicable by substituting for the non-magnetizable ring which carries the armature coils a laminated iron ring, and for the uniform magnetic field, the magnetic field of a well made field magnet with its pole pieces placed with respect to the armature coils

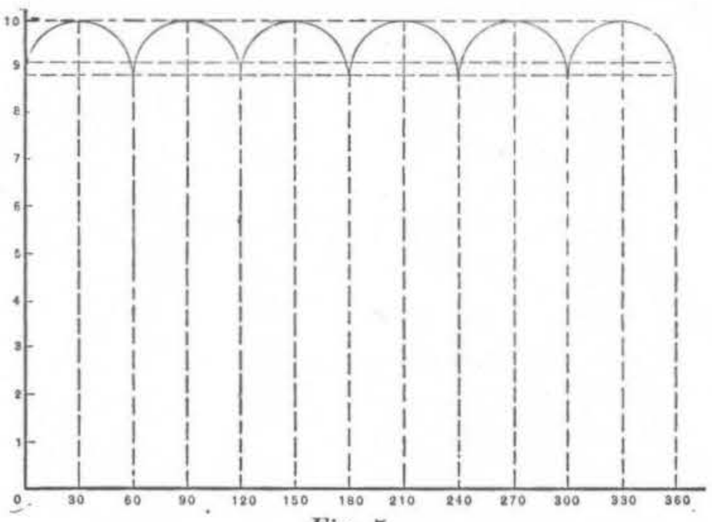


Fig. 5.

in any one of the various ways sanctioned by practical experience. But in a generator of this kind the resultant impressed E. M. F. will no longer vary according to the law which I have pointed out a little while ago. To be sure, we shall still have the same number of maxima and minima, as may be inferred readily from our knowledge of the shape of the E.M.F.curve of a continuous current dynamo. We all know that this curve is not in general a straight line, but a wave line having as many maxima and as many minima as there are sections on the commutator. But the ratio of the maxima to the minima is no longer an a priori calculable quantity. If we knew the mathematical relation between the intensity of the field

(2) M. v. Dolivo-Dobrowolsky : Der Drehstrom und seine Entwickelung; Officielle Austellungs Zeitung, Electricitaet, Heft 12.

at any point of the armature surface and the co-ordinates of this point with respect to the neutral plane then we could calculate that ratio, but the amount of experimental and practical work involved in this problem would be very great. *A much easier and practically much more important problem is to determine the conditions which must be fulfilled in the construction of a polyphasal generator, in order that it may be capable of producing a rotary magnetic field of practically constant intensity in the simplest possible way, that is without the application of brushes and commutators, and also without employing too many phases.* Mr. v. Dolivo-Dobrowolsky seems to think that a three phasal generator is incapable of doing that, for he distinctly says that such a generator necessarily produces a rotary magnetic field whose strength varies 14 per cent. He also states that (evidently to obviate these fluctuations) the Allgemeine Electricitæts Gesellschaft employ a method of transmitting currents of smaller dif-

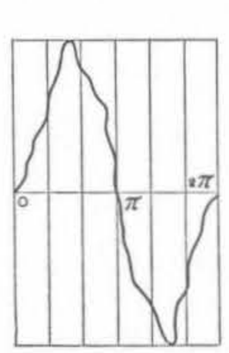


Fig. 6.

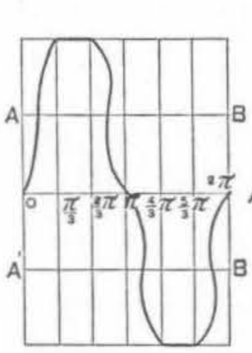


Fig. 7.

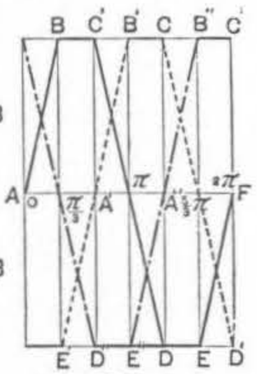


Fig. 8.

ferences of phase than one-third of the period through three wires. In this point they claim to be ahead of Tesla, Bradley, Haselwander and Wenstrom. In fact if one is not exceedingly careful in the perusal of Dobrowolsky's discussions of this subject he will be led to believe that the rotary field in some of Tesla's motors varied as much as 40 per cent. and certainly not less than 14 per cent. I do not think that Mr. Dobrowolsky wishes to be understood as holding that opinion ; for neither he nor anybody else excepting Tesla himself can know what these variations were. The number of phases employed tells us nothing definite about the range of these variations.

A polyphasal dynamo which is capable of producing a rotary magnetic field of constant intensity must be constructed in such a way that its resultant magneto-motive-force must remain constant as long as speed and the magnetic field of the field magnets re-

main constant. As long as the variable electromotive force developed in each coil follows the law of a simple harmonic that result can never be accomplished by a finite number of phases, but it may, perhaps, be accomplished by producing in each coil a variable electromotive force which varies according to some definite complex harmonic law. In a well made commercial machine the electromotive forces developed in the various turns of the armature always vary according to some such a law. The form of this complex harmonic law depends on the form of the magnetic field of the field magnets and also on the distribution of the coils over the armature. The problem that remains to be investigated consists therefore of three parts : 1st. What must be the particular form of the complex harmonic E. M. F. developed in each coil of a polyphasal generator, in order that both the condition of continuity be fulfilled and also that the resultant impressed E .M. F. be continually constant. 2nd. What form of the

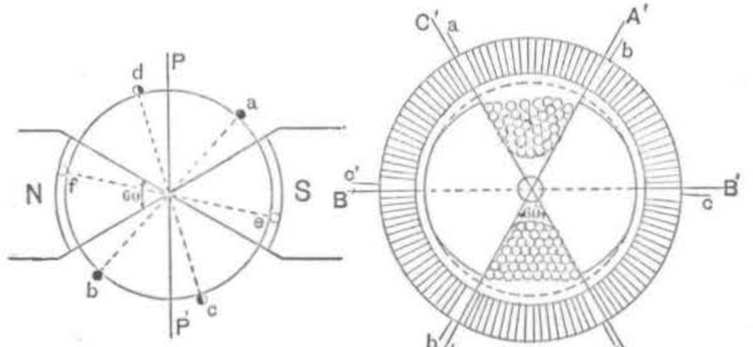


Fig. 9

Fig. 10.

magnetic field of the field magnets will be capable of producing such an E. M. F. 3d. Can a continually constant resultant E. M. F. produce a rotary field of constant strength.

1st. The first part of this problem is purely mathematical. In a paper read before the New York Mathematical Society I indicated a method of discussing this part in a general way, and worked out completely two particular cases, namely the cases of a three and four phasal system. The paper is given in the appendix.

2d. For a three phasal system the form of the complex harmonic E. M. F. given in Fig. 7. will satisfy all the conditions. The form A, B, C, E, F, given in Fig. 8, is only a particular case and ought to be aimed at in the construction of the machine.

When there are only three turns within a space through which the armature moves with respect to the field during the time that corresponds to a complete period as in the case of the Lauffen

generator (see Figs. 11 and 12), then the field of the field-magnets must be constant in intensity during an angle which corresponds to one-sixth of the period. I have indicated that, in the diagram Fig. 9. In the case of bipolar three phasal generators as indicated in the diagram Fig. 10, where we have six coils, the diametrically opposite pairs being connected in series; the pole faces must

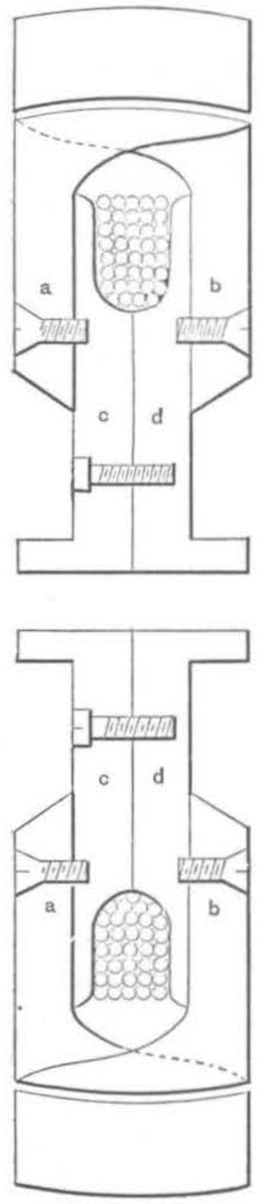


Fig. 11.

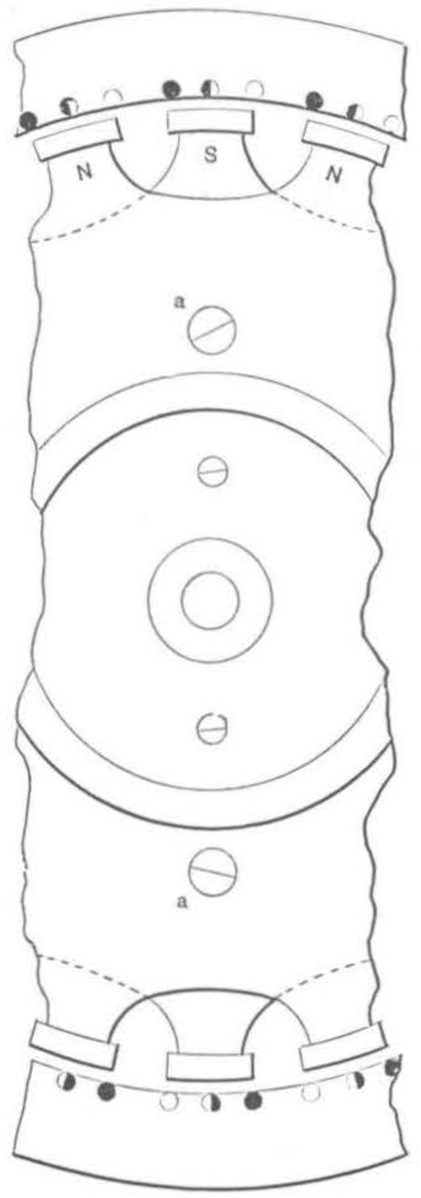


Fig. 12.

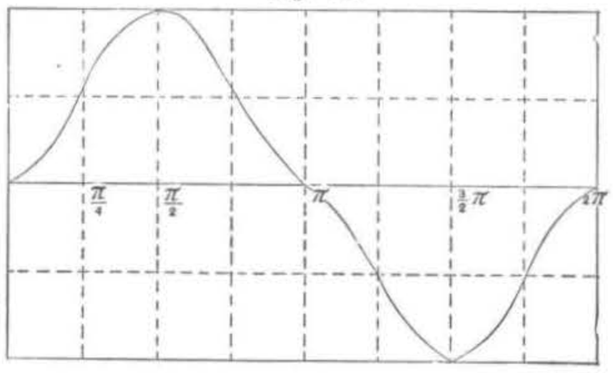
have an angular width of 120 degrees and the field must be constant in intensity within the region bounded at any moment by the armature and the pole faces. This is a practical problem offering no serious difficulties judging from the experimental results obtained by S. Thompson, Isenbeck, Mordey and others,

and also from the experimental results obtained lately by a graduate of our school, Mr. Freedman, John Tyndall Fellow of Columbia College.

The curve of impressed E. M. F, which must be produced in the case of a four phasal generator is given in Fig. 13, and needs no further commentary. Larger number of phases offer no special advantages whereas the disadvantages arising from employing a large number of phases are self-evident.

3d. When a coil, in which a simple harmonic E.M.F.is developed is closed by a resistance, whether self-inductive or non-self-inductive, the current which is set up in the closed circuit will be a simple harmonic, having therefore all the characteristics of the impressed E. M. F. This, however, is not necessarily the case when the impressed E. M. F. is a complex harmonic. A complex harmonic E. M. F. is composed of a large number of simple harmonic E. M. forces of different frequencies, all the higher frequencies being multiples of the fundamental frequency. When, therefore, a coil in which a complex E. M. F. is generated, is closed by a conductor, and the current is started,the current will be also a complex harmonic, each simple harmonic component of the complex harmonic E. M. F. producing its own simple harmonic current which is a component of the resultant complex harmonic current. But since the component simple harmonic E. M. forces have each a different frequency, it follows that they will have a different impedance and the shifting of phase will be also different for each component current, currents of higher frequency having a larger shifting in phase and also the ratio of the amplitude of any one of the component currents to the amplitude of any other component of lower frequency, being smaller than the ratio of the amplitudes of the corresponding component E. M. forces. In this respect the propagation of the complex harmonic

Fig. 13.



current-wave resembles very much the propagation of a complex harmonic sound-wave or a complex harmonic light-wave through an absorptive medium like air. The component simple harmonic waves of light and sound will in general suffer the less through the transmission the longer their wave-length. Just as the sound and light-waves, after such a transmission, lose a great many characteristics of the original vibration which produced them, so an electric wave in its transmission through a conductor possessing ohmic resistance and electro-magnetic, not to speak of the electro-static, inductance will lose a great many characteristics of the impressed E. M. F.

To put this into simple symbolic language of mathematics,

Let L be the coefficient of self-induction of the circuit,

" R be the total resistance,

" $K\sum_{1}^{\infty}{}_{m}\, a_m \sin m\,p\,t$ be the complex harmonic impressed E. M. F. where $p = 2\pi \times$ fundamental frequency,

" x be the value of the current at any moment t.

We shall have, then,

$$L\,\frac{d\,x}{d\,t} + R\,x = K\sum_{1}^{\infty}{}_{m}\, a_m \sin m\,p\,t.$$

The solution of this differential equation gives

$$x = K\sum_{1}^{\infty}{}_{m}\,\frac{a_m}{\sqrt{R^2 + m^2\,p^2\,L^2}}\sin\,(m\,p\,t - \varphi_m)$$

$$\text{where } \tan\varphi_m = \frac{m\,p\,L}{R}$$

The current x is a complex harmonic, its component simple harmonic eurrents being

$$x = x_1 + x_2 + \ldots\ldots + x_m + \ldots\ldots \textit{ad infin.}$$

$$\text{The current } x_\alpha = \frac{K\,a_\alpha}{\sqrt{R^2 + a^2p^2L^2}}\sin\,(a\,p\,t - \varphi_\alpha)$$

$$\tan\varphi_\alpha = \frac{a\,p\,L}{R}$$

Let E be the impressed E. M. F., then

$$E = e_1 + e_2 + e_3 + \ldots\ldots + e_m + \ldots\ldots \textit{ad infin.}$$

The component simple harmonic E. M. F. e_α is given by

$$e_\alpha = a_\alpha \sin \alpha p t$$

These relations give an exact quantitative expression to the preceding physical description.

These considerations made me hesitate at first in taking as granted that a polyphasal generator producing complex E. M. forces, such as I deduced mathematically in the course of my paper, would be capable of producing a rotary magnetic field of constant intensity. But I was glad to find out that my hesitation was groundless, at any rate in certain particular but important cases.

Consider the three-phasal generator whose diagram is given in Fig. 10. Take, now, another *well-laminated* armature wound in a similar way as the armature of the generator. Connect the three pairs of coils of the generator to the three sets of coils in armature 2. We shall have three separate circuits, the ohmic resistance and the self and mutual inductance in each circuit being the same. Denote by E_1 E_2 E_3 the three complex harmonic E. M. forces in the three circuits. Let x, y, z be the currents at any moment. Then we shall have

$$L\frac{dx}{dt} + M\frac{dy}{dt} + M\frac{dz}{dt} + Rx = E_1$$

$$L\frac{dy}{dt} + M\frac{dx}{dt} + M\frac{dz}{dt} + Ry = E_2$$

$$L\frac{dz}{dt} + M\frac{dx}{dt} + M\frac{dy}{dt} + Rz = E_3$$

But since $E_1 + E_2 + E_3 = 0$ for all values of t it follows that

$$L\frac{d}{dt}(x+y+z) + 2M\frac{d}{dt}(x+y+z) + R(x+y+z)$$

$= 0$ for all values of t. This can be true only if

$$x + y + z = 0$$

for all values of t. That is to say, the currents fulfill the condition of continuity. We can therefore employ the method of polyphasal connection. Substitute now in the first of the three differential equations

$$z = -(x+y)$$

and we obtain

$$(L-M)\frac{dx}{dt} + Rx = E_1 = K\sum_1^\infty{}_m a_m \sin m p t$$

The solution of this equation gives

$$x = K\sum_1^\infty{}_m \frac{a_m}{\sqrt{R^2 + m^2 p^2 (L-M)^2}} \sin(m p t - \varphi_m)$$

Similarly

$$y = K\sum_1^\infty{}_m \frac{a_m}{\sqrt{R^2 + m^2 p^2 (L-M)^2}} \sin\left\{m\left(pt + \frac{2\pi}{3}\right) - \varphi_m\right\}$$

$$z = K\sum_1^\infty{}_m \frac{a_m}{\sqrt{R^2 + m^2 p^2 (L-M)^2}} \sin\left\{m\left(pt + \frac{4\pi}{3}\right) - \varphi_m\right\}$$

In the case under consideration both L and M are pretty small when the metallic parts of the magnetic circuits are near the saturation point, so that $L - M$ is small, and $m^2 p^2 (L-M)^2$ may be small in comparison to R^2 even for large values of m, unless the frequency is very high. Also, since

$$\tan \varphi_m = \frac{m p (L-M)}{R}$$

φ_m is exceedingly small unless p is very large, we shall have for moderate frequency generators

$$x = \frac{K}{R}\sum_1^\infty a_m \sin m p t$$

and similarly for y and z. The same method of reasoning may be easily applied to any number of phases. The mathematical operations will be considerably larger, but still the same results will be deduced without much difficulty.

That is to say, the curves for the currents are the same complex harmonics as those of the impressed E. M. F. The currents therefore, produce a rotary magnetic field of constant intensity; this is evidently true even if these currents produce a saturation in the iron part of the magnetic circuits

The resemblance between a polyphasal generator and a continuous current dynamo, which these relations bring into view, is exceedingly striking and instructive.

The advantages gained from a polyphasal generator capable of producing a rotary magnetic field of constant intensity would be very much diminished indeed if it should turn out that it is impossible to devise a simple and efficient method of transformation [3] by means of which the polyphasal system of currents producing a rotary field of constant intensity (a constant rotary field system) can be transformed any number of times without losing its distinguishing characteristic. I intended to discuss this problem also, this evening but having been disappointed by the mechanician who is constructing several pieces of apparatus illustrating this problem I decided to postpone this discussion to some other time.

To sum up:

1st. The consideration of simple harmonic impressed E. M. F's does not tell the whole story of the polyphasal generators.

2nd. The law of variation of the strength of rotary magnetic field which a polyphasal generator can produce is not as simple as Mr. v. D. Dobrowolsky thinks.

3rd. Polyphasal coupling transformers must be worked at low magnetizations and low frequencies, otherwise they will not satisfy the condition of continuity. It follows, therefore, that they will probably be very large for the output which they can give.

4th. It is very probable that nearly constant rotary magnetic fields can be produced in practice by a small number of phases; perhaps not more than three.

(3) Not only transformation of the power supplied by the generator into electrical power of higher or lower potential, but also transformation of this power into mechanical power. This, of course, leads into the discussion of rotary magnetic fields produced under practical conditions.

[PUPIN ON POLYPHASAL GENERATORS.—APPENDIX.]

ON A PECULIAR FAMILY OF COMPLEX HARMONICS.

Read before the New York Mathematical Society, December 5, 1891.

The following investigation was suggested by the practical problem: Can a polyphasal generator be constructed which will be capable of producing a rotary magnetic field of constant intensity? It seems, therefore, sufficient for the present to discuss only those features of the mathematical side of this question which have a direct bearing upon its practical side.

The mathematical theory of polyphasal generators involves a discussion of harmonic functions, or *harmonics*, to use a shorter expression.

A *simple harmonic* is defined by the following expression:—

$$a + b \sin (x + a).$$

This harmonic differs in phase only from the harmonic

$$a + b \sin x.$$

The angle a is called their *difference of phase.*

A *complex harmonic* is defined by the following expression:

$$\sum_{o}^{n} a_{\alpha} \sin a\, x + \sum_{o}^{m} C_{\alpha} \cos a\, x$$

If n and m are infinite the complex harmonic is sometimes called infinitely complex. The multiples a are integral numbers.

Consider a periodic function $f(x)$ whose period is $2\pi = \varphi$. If this function with its differential coefficients is finite, continuous and singly valued for all values of x, with the exception of certain values which are at finite distances from each other, and if in addition

$$f(-x) = -f(x) \text{ and } f(o) = o,$$

then by Fourier's theorem

$$f(x) = a_1 \sin x + a_2 \sin 2x + a_3 \sin 3x + \ldots\ldots + a_m \sin m\, x + ad\ infin.$$

$$\text{where } a_m = \frac{2}{\pi} \int_{o}^{\pi} f(x) \sin m\, x\, dx$$

It is required now that $f(x)$ fulfill the following two conditions :

1st, $f(x)+f(x+\frac{\varphi}{n})+f(x+2\frac{\varphi}{n})+\ldots\ldots$

$$+f[x+(n-1)\frac{\varphi}{n}]=0 \text{ for all values of } x$$

2d, $f(x)+f(x+\frac{\varphi}{n})+f(x+2\frac{\varphi}{n})+\ldots\ldots\ldots$

$$+f(x+\frac{n-1}{2}\frac{\varphi}{n})=\text{const. for all values of } x \text{ betw. } 0$$

and $\frac{\varphi}{2n}$ when n is odd, and

$$f(x)+f(x+\frac{\varphi}{n})+\ldots\ldots+f(x+\frac{n-2}{2}\frac{\varphi}{u})=\text{const.}$$

for all values of x betw. 0 and $\frac{\varphi}{n}$ when n is even.

The coefficients $a_1\ a_2\ \ldots\ldots\ a_m\ \ldots\ldots$ can of course be always so determined as to fulfil not only these two, but also any other number of possible conditions.

The first condition, which I call the *condition of continuity*, can be written

$$a_1\sin x+a_2\sin 2x+\ldots\ldots+a_m\sin mx+\ldots\ldots$$

$$+\ a_1\sin(x+\frac{\varphi}{n})+a_2\sin 2(x+\frac{\varphi}{n})+\ldots\ldots\ldots$$

$$+a_m\sin m(x+\frac{\varphi}{n})+\ldots\ldots$$

$$+\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$+\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$+\ a_1\sin\left\{x+(n-1)\frac{\varphi}{n}\right\}+\ldots\ldots$$

$$+a_m\sin m\left\{x+(n-1)\frac{\varphi}{n}\right\}+\ldots\ldots=0$$

$$\text{or } \sum_1^\infty{}_m\, a_m\frac{\sin m(x+\frac{n-1}{2}\frac{\varphi}{n})\sin\frac{m\varphi}{2}}{\sin\frac{m}{2}\frac{\varphi}{n}}=0\ \ldots\ldots\ (1)$$

This function I call the *resultant of n identical component harmonics* $f(x)$, differing from each other in phase, only, by one nth of the period. It is evident that every term in the resultant vanishes, excepting those terms whose multiple of x is divisible by n. The resultant can therefore be written

$$\sum_1^\infty{}_m\,(-1)^{\alpha(n-1)}\,C_\alpha\sin\alpha n x=F(x)$$

Since

$$C=\frac{4}{\varphi}\int_0^{\frac{\varphi}{2}}F(x)\sin\alpha n x\ dx$$

it follows that if $F(x)=0$ for all values of x betw. $x=0$ and $x=\frac{\varphi}{2}$ then every coefficient C_α is zero. *That is to say,* $f(x)$ *will fulfil the condition of continuity if it contains no terms of the form* $a_m \sin mx$ *where* m *is divisible by* n.

Those acquainted with the theory of dynamo-electric machinery will easily translate this into the following physical language: *The algebraical sum of all the electromotive forces generated at any moment in the various coils of a polyphasal dynamo will not necessarily fulfil the condition of continuity; that is, will not necessarily vanish. The form of the magnetic field must be such that the harmonic electromotive force generated in each coil does not contain in its mathematical expression a multiple of the variable angle which is divisible by the number of the phases.*

The first part of the second condition can be written

$$a_1\sin x+a_2\sin 2x+\ldots\ldots+a_m\sin mx+\ldots\ldots$$

$$+\ a_1\sin(x+\frac{\varphi}{n})+\ldots\ldots+a_m\sin m(x+\frac{\varphi}{n})+\ldots\ldots$$

$$+\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$+\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$+\ a_1\sin(x+\frac{n-1}{2}\frac{\varphi}{n})+\ldots\ldots+a_m\sin m(+x\frac{n-1}{2}\frac{\varphi}{n})$$

$$+\ldots\ldots=\text{const.}$$

$$\text{or } \sum_{1}^{\infty}{}_{m} \; a_m \sin m\left(x + \frac{n-1}{4}\frac{\varphi}{n}\right) \frac{\sin \frac{m(n+1)}{4}\frac{\varphi}{n}}{\sin \frac{m}{2}\frac{\varphi}{n}} = c.$$

for all values of x between $x = 0$ and $x = \frac{1}{2}\frac{\varphi}{n}$

The second part of this condition may be written

$$\sum_{1}^{\infty}{}_{m} \; a_m \frac{\sin m\left(x + \frac{n-2}{4}\frac{\varphi}{n}\right) \sin m \frac{\varphi}{4}}{\sin \frac{m}{2}\frac{\varphi}{n}} = c \quad \ldots \ldots (2)$$

for all values of x betw. $x = 0$ and $x = \frac{\varphi}{n}$

From these two relations, I infer the following physical theorem: *If the terminals of the armature coils of a polyphasal dynamo capable of producing a constant resultant rotary impressed* E. M. F. *be connected to a commutator and the machine be run as a direct current dynamo, it will give an absolutely constant electromotive force, speed and field intensity being maintained constant.*

It must be observed, however, that in the case *when the number of phases is an odd number, then the armature should have twice as many coils as there are phases, and when the machine is run as a polyphasal dynamo, then the diametrically opposed pairs are connected in series.*

Relations (1) and (2) enable us to determine in each case the simplest forms of the component harmonics which will satisfy these two relations. As the simplest forms I define those forms which can be produced in polyphasal generators by the simplest devices of construction.

Particular Cases.

Any further general discussion would have only an indirect bearing upon the practical side of the problem which I propose to discuss at present. I therefore pass to particular cases.

Let $n = 2$.

The above relation gives

$$\sum_{1}^{\infty}{}_{m} \; a_m \sin m x = c$$

for all values of x between $x = 0$ and $x = \pi$.
except when $x = 0$ and $x = \pi$.

This solution has no practical value. I therefore dismiss it.

Let $n = 3$.

The relation given above reduces to

$$\sum_{1}^{\infty}{}_{m} \; a_m \frac{\sin m\left(x + \frac{\pi}{3}\right) \sin m \frac{2\pi}{3}}{\sin \frac{m\pi}{3}}$$

$$\text{or } \sum_{1}^{\infty}{}_{m} \; a_m \; 2 \sin m\left(x + \frac{\pi}{3}\right) \cos \frac{m\pi}{3} = c$$

for all values of x betw. $x = 0$ and $x = \frac{\pi}{3}$.

Since $f(x)$ has only two conditions to fulfil, all the coefficients a_m, where m is an even number, may be suppressed and still leave more than a sufficient number of coefficients, their number being infinity. In that case the last relation reduces to

$$\sum_{1}^{\infty}{}_{m} \; a_m \sin m\left(x + \frac{\pi}{3}\right) = c$$

$$\text{or } \sum_{1}^{\infty}{}_{m} \; a_m \sin m \xi = c$$

for all values of ξ betw. $\xi = \frac{\pi}{3}$ and $\xi = \frac{2\pi}{3}$.

That is to say, the function $f(x)$ itself must be such as to have a constant value between $x = \frac{\pi}{3}$ and $x = \frac{2\pi}{3}$ and, therefore, also between $x = \frac{4}{3}\pi$ and $x = \frac{5}{3}\pi$.

Since $f(x) + f\left(x + \frac{2\pi}{3}\right) = \text{const.}$ for all values of x between $x = 0$ and $x = \frac{\pi}{3}$, I infer that the curve $f(x)$ may have

any one of those forms, one of which is given in Fig. 7 (of the preceding paper). That is, the curve is symmetrical both with respect to the axis of x and also to the bisector $A\ B$ and $A'\ B'$ of the upper and lower maxima.

The curve given in Fig. 8 (of the preceding paper) would perhaps be aimed at in the construction of polyphasal dynamos. Its equation is

$$f(x) = K\ (\sin x - \frac{1}{5^2}\ \sin 5\,x + \frac{1}{7^2}\sin 7\,x - \frac{1}{11^2}\sin 11\,x + \ldots\ldots)$$

Let $n = 4$

Eqnation (2) gives

$$\sum 2\,a_m \sin m\,(x + \frac{\pi}{4})\cos m\,\pi = c$$

and therefore

$$\sum \frac{2\,a_m}{m}\cos m\,(x + \frac{\pi}{4})\cos m\,\frac{\pi}{4} = -\,c\,(x - \frac{\pi}{4})$$

$$= -\,\frac{c}{2}\,x - \frac{c}{2}\,x + \frac{c\,\pi}{4}$$

for all values of x between $x = o$ and $x = \frac{\pi}{2}$

The last equation can also be written

$$\sum \frac{a_m}{m}\cos m\,x - \sum \frac{a_m}{m}\sin m\,\frac{\pi}{2}\sin m\,x$$

$$= -\,\frac{c}{2}\,x - \frac{c}{2}\,(x - \frac{\pi}{2})$$

This relation enables us to determine the form of the component complex harmonic function $f(x)$ which will fulfil all the conditions. It is easily seen that there is in this case just as in the case of three phases an infinitely numerous family of complex harmonics which will fulfil these conditions. The simplest harmonic is obtained by putting

$$\sum \frac{a_m}{m}\cos m\,x = -\,\frac{c}{2}(x - \frac{\pi}{2}.)$$

$$\therefore \frac{a_m}{m}\cdot\frac{\pi}{4} = -\,\frac{c}{2}\int_o^{\frac{\pi}{2}} x\ \cos m\,x\,d\,x + \frac{c\,\pi}{4}\int_o^{\frac{\pi}{2}}\cos m\,x\,d\,x$$

$$= \frac{c}{2\,m^2}$$

and therefore

$$a_m = \frac{2\,c}{m\,\pi}$$

I conclude therefore that the harmonic

$$f(x) = \frac{\sin x}{1^2} - \frac{\sin 3\,x}{3^2} + \frac{\sin 5\,x}{5^2} - \frac{\sin 7\,x}{7^2} + \ldots\ldots ad\ infin.$$

fulfils all the conditions. Its form is given in Fig. 14. (It is only a special case of the curve given in Fig. 13 of the preceding paper.)

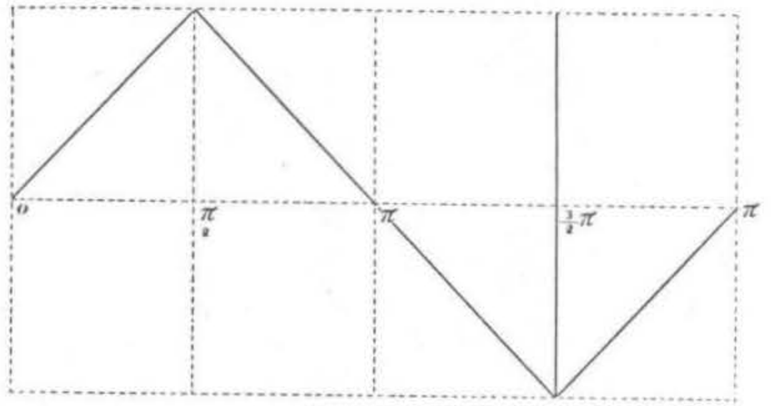


Fig. 14.

The component harmonics fulfilling these conditions may be deduced similarly for any other value of n. But as the problem which I originally proposed to myself does not extend beyond these limits which I have just reached I prefer to postpone further considerations of the subject.

The character of these curves points out clearly the physical fact that it is an easy matter to construct three and four phase generators which will be capable of producing a constant resultant impressed E. M. F. Whether such generators will also be capable of producing a rotary magnetic field of practically constant intensity is a problem which I propose to discuss in a series of papers which will be presented shortly before the American Institute of Electrical Engineers.

Discussion.

The Chairman [Prof. Thomson] :—You have heard the interesting and instructive paper by Dr. Pupin. I would say that it is perhaps the first exposition of some of the principles underlying this system of polyphasal transmission that I have seen, and I hope that the discussion may be indulged in by the members so that we may have some points cleared up by those conversant with the subject. It is now open for discussion.

Mr. Chas. P. Steinmetz :—Having had the pleasure of hearing Prof. Pupin's paper at the New York Mathematical Society some days ago, I might be allowed to make the same remark I made there—that it would be perhaps more advisable to use a shape of the electromotive force similar to Fig. 7, than the shape in Fig. 8, because, as you see, in shape Fig. 8 the curve has a sharp corner, and even if we could produce waves of electromotive force that have sharp corners, it can hardly be expected that

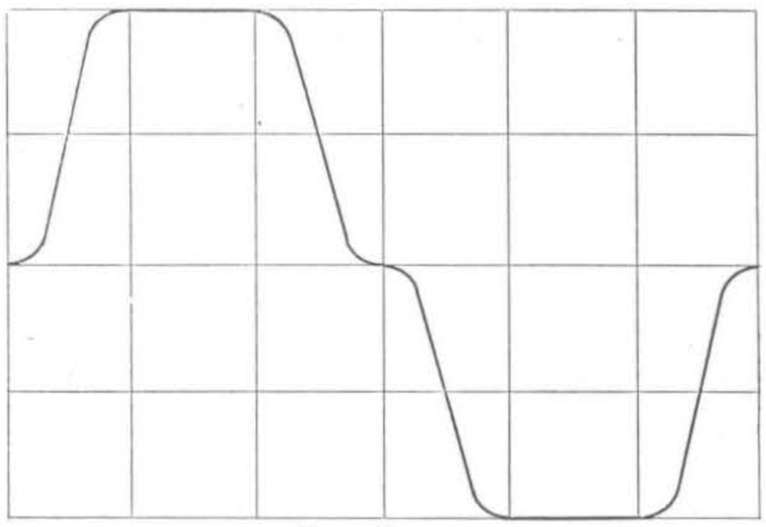


Fig. 15.

we can derive from such a sharp-cornered e. m. f. a current which, after being sent through step-down transformers, over lines of considerable electrostatic capacity, and again through step-down transformers into a motor of high self-induction, would still have retained this sharp-cornered shape. But the theory requires that the electric *current* in the motor has the shape given in Figs. 6 to 8. Even if the e. m. f. had the shape of Fig. 8, the current in such a highly inductive circuit would differ considerably, having lost the sharp corners, etc. Hence Fig. 8 would be less commendable. But the shape of Fig. 7 might easily be chosen, so that there would be no sharp corners, but a steady and continuous variation, as shown in Fig. 15.

Then, with regard to the equations of the currents x, y, z, on page 576, I wish to make a remark. As stated by Dr. Pupin, the complex harmonic of the electromotive force produces a current

which is a complex harmonic too, and it is identically the same complex harmonic as long as the circuit has no self-induction and no capacity or, what amounts to the same, as long as self-induction and capacity have a certain ratio with each other. But as soon as the circuit has self-induction, the complex harmonic of current differs from the complex harmonic of electromotive force, and differs the more, the heavier the self-induction of the circuit is, by the decrease of the higher terms of this infinite series of simple harmonics which constitute the complex harmonic of electromotive force, these having a high self-induction; and therefore if we produce such a type of electromotive force and let it send a current through an inductive circuit, it will probably break to pieces entirely and show a current resembling a simple sine-wave as closely as one egg to another. In the equations for x, y, z, on page 576, as the condition that the shape of the current does not differ from the shape of the electromotive force, was found that the second term, $m^2 p^2 (L - M)^2$, can be neglected against the first term, R^2. This means, in *plain language*, that the shape of the current-wave is the same as that of the e. m. f., if the *self-induction of the circuit is negligible.* For the first term, R, is the *resistance;* the second term, $m p (L - M)$, is the *inductance* of the circuit.

Hence neglecting the second term means neglecting the inductance—that is, it means that the motor circuit has no self-induction. Now, anybody who ever tried to design an alternating motor, has found out to his disgust, generally, that the self-induction of such a motor, even under the most favorable conditions, is anything but negligible. Unfortunately, I could not get any data on these rotary motors, but on some other alternate current motors I can give data. In the Ganz and Company synchronous motor, the plant efficiency is claimed—by the manufacturers—to be 90 per cent. This *unusually* high plant efficiency, this *unusually* low retardation, might be explained by the fact that the motor is synchronous and the field fed by rectified alternate currents, that only the self-induction of the armature is in circuit, and the field adds no self-induction whatever. Furthermore, that the frequency used in those motors, 42 periods per second, is somewhat less than the one-third of the frequency of our American alternators. If this current were a complex harmonic we would have in the main wave 26 degrees retardation and 90 per cent. plant efficiency—that is, the intensity of the current would be 90 per cent. of that value it would have with no self-induction present. The second harmonic has only the plant efficiency of 72 per cent.; the third harmonic of 7, the fourth of 47, the tenth only 20 per cent.—that is, is decreased to 20 per cent., while the first wave is decreased only to 90 per cent. Hence, even in a motor circuit of such unusually low self-induction, if a wave of shape Fig 8 is applied, it will come out entirely broken up, so I do not think that really the self-induction can be neglected. The more, as just

the first term, R, is small, because we do not want to have the resistance of the circuit large, for the resistance determines the loss of power, and we do not want to have so much loss of power. We want to run motors with these currents. Indeed, if we run a motor from this alternating current, we get a counter-electromotive force in the motor, and to make these same equations hold we might represent this counter-electromotive force by apparent resistance. But in such a motor, the counter-electromotive force is not of equal phase with the current, but lags behind the current the more, the lighter the load, and will come nearer in phase to the phase of the current when we increase the load. Hence, the apparent inductance is not even a constant, but a variable of the circuit, and exceedingly variable, too. The inductance is small, almost *nil*, if the motor is at rest under full head of pressure. As soon as the motor starts, its self-induction increases, up to a value which corresponds to the load the motor is carrying, so that if the motor is heavily loaded the inductance is *comparatively* small, though very far from negligible, while, when the motor is running light, its self-induction increases to such a value as to almost entirely shut off the current.

Now I come to the consideration of this quantity $(L - M)$. This quantity is really nothing but, or rather proportional to, that amount of magnetism, or that magnetism which constitutes the rotating magnet poles. So if the motor is at rest, heavy eddies in the short circuit armature-circulating coils, the useful magnetism is almost *nil;* almost no magnetism passes through the armature. Hence L is almost identical with M. The circuit has almost no self-induction. If the motor starts, runs with heavy load, then a certain amount of magnetism passes through the armature. L is different from M. L has increased, and we get a difference of phase of the current and a different shape of the current wave. Now, suppose the motor runs with almost no load, then the self-induction of the motor is very large and we can neglect R, the *first* term, *entirely*.

In this case the original shape of the electromotive force curve is entirely broken up and has changed into a somewhat harmonic shape. So I cannot think there is any hope to transfer any other shape of the curve but a simple harmonic through a circuit of heavy and very variable self-induction. That would be rather disappointing and very disagreeable for the builders of motors if the working of such rotary motors depended upon a certain shape of alternating current waves. Indeed, we all have heard and read half a dozen times—some of us even oftener—how bad and worthless the Tesla motor is, because there the fluctuations of the magnetism amount to, I believe, 41 per cent. and how grand and beautiful the improvements of Mr. Dolivo von Dobrowolsky are, because in his motor the fluctuations amount to only 14 per cent., and if having heard and read something very often proves its truth, then it must certainly be true. At least this statement

about the fluctuations of the intensity of the rotary magnetism seems generally to have been accepted as true. For I never heard any doubt expressed on the correctness of this fluctuation theory. And, nevertheless, in the very first publication of Ferraris on rotating magnet poles, in the very publication which introduced this rotary magnetism to the public years ago, it has been shown that if you sent two alternating currents, one lagging behind the other by one-quarter of a period, through two coils at right angles with each other, those two currents produced in the centre of those coils a magnetic field which revolves with *constant strength* and *constant speed*.

Let A in Fig. 16 represent the one, B the other one, of the two perpendicular coils, which are excited by two alternating currents

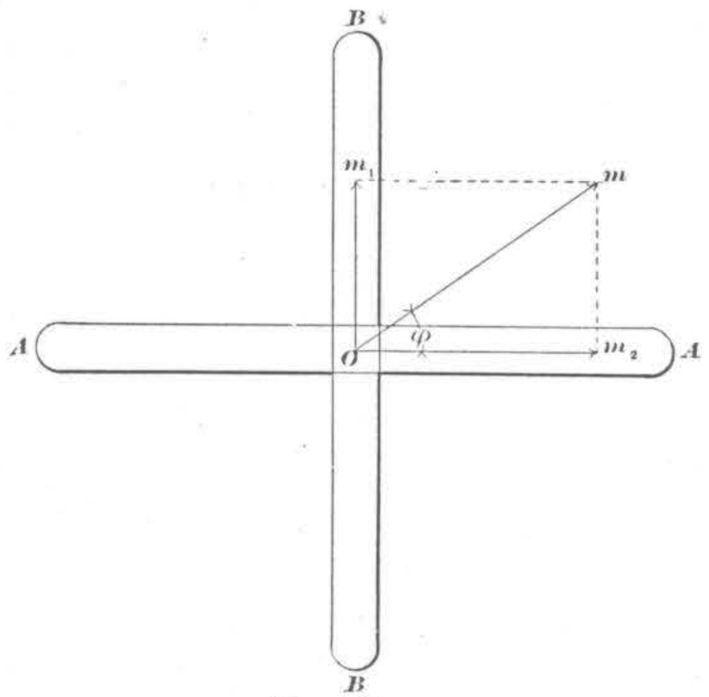


FIG. 16.

of 90 degrees difference of phase. Then the magnetism produced by coil A at any time can be represented by the line,

$$\overline{O\,m_2} = M \sin \varphi$$

The magnetism produced by coil B at the time t is

$$\overline{O\,m_2} = M \cos \varphi$$

where

$$\varphi = \frac{2\pi}{T}\, t$$

T being the time of one complete period.

These two magnetisms, $\overline{O\,m_1}$ and $\overline{O\,m_2}$, combine by the law

of *parallelogram*, which as a consequence of the law of *conservation of energy* holds, to the resulting magnetism:

$$\overline{O\,m} = M$$

of constant strength, at the phase:

$$m_2\, O\, m = \varphi = \frac{2\,\pi}{T}\, t$$

of constant velocity.

That means, the *magnet poles revolve with constant strength and constant velocity, produced by true harmonic or sine-waves.*[1]

Coming, now, to the conclusion, we see

1. It is possible to produce rotary magnetism of constant strength and constant velocity of rotation by means of true sine-waves.

2. It is hopeless to try to produce rotary magnetism of constant strength and velocity by means of a particular shape of the wave of E. M. F., because in a circuit of considerable and variable self-induction the shape of the current wave will differ in a considerable and a variable degree from the shape of the E. M. F. wave for any shape of the E. M. F. but the true harmonic or sine-wave.

3. Hence it is more advisable not to build the *generators* so that they produce that shape of E. M. F. which in a particular type of rotary motors will give magnetism of constant strength and velocity; but to build motors which will give magnetism of constant strength and velocity from true harmonic or sine-waves, as the only waves which can be transformed, transmitted through inductive and other circuits without changing their shape; to build the rotary motors for sine-waves, as the possibility has been shown by Ferraris, and as already in the oldest Tesla motors it evidently has been the aim of the designer. [Applause.]

DR. PUPIN:—Mr. Steinmetz went a little beyond the limits of this paper by talking about the motors. I said at the start that I was going to confine myself to the polyphasal generators and particularly to polyphasal generators which could under certain well defined conditions produce a rotary field of constant strength. I am going to consider in future the question of transformation and the question of rotating field used for driving a motor. Now, in the case that I considered, I simply had an iron ring surrounded by a set of coils and nothing else. I had no motor armature here. In this case, $L - M$ could very easily be made small in comparison to R, the resistance, and therefore may be neglected. But you need not neglect it. If $(L - M)$ is not negligible, then the magneto-motive force will vary, but its variation will be less than 14 per cent. How much less remains to be

1. Kapp: Alternate Current Machinery, page 82.

seen. I don't think that I can show it very well without entering fully into the discussion of the polyphasal motor and transformer. But this subject requires a carefully prepared paper to form a basis on which it can be advantageously discussed. If Mr. Steinmetz will have a little patience, I will promise to give him a chance to discuss these things also.

As far as the Ferraris contrivance is concerned, I never saw that paper to which Mr. Steinmetz refers. There must be a hitch in it, I think. Perhaps Mr. Steinmetz will exactly explain the contrivance, so that we can see the magnetic circuit and see whether his ideas are correct or not. I know a great many mistakes have been made on this very point of the magnetic circuit. Not enough attention was paid as to whether the magneto-motive forces worked in series or multiple arc, nor to the shape and distribution of the magnetic circuits. But still, I would like to know the exact form of the Ferraris motor and the magnetic circuits before I decide to comment upon it.

MR. STEINMETZ:—Ferraris built only a little toy, and his magnetic circuits, so far as I know, were completed in air, not in iron, though that hardly makes any difference. The only possible error there could be is the use of the law of parallelogram in combining M. M. F.'s acting in different directions upon a point, and this law of parallelogram, or polygon, is a consequence of the law of conservation of energy, and therefore its correctness can hardly be questioned. But as soon as you accept that, then the reasoning I have given here must be correct.[1] So there is no possibility of any error if the whole phenomenon takes place in air. Suppose, now, the phenomenon does not take place in air, but in any other medium of constant magnetic conductivity, then you have exactly the same conditions. The air space between armature iron and field iron might introduce some discrepancy, though I hardly think so. But, then, the next problem would simply be how to shape the motor iron, how to distribute the wire coils, to get in the iron circuit separated by the air gap the same magnetic distribution as would take place without any iron in the air.

DR. PUPIN:—As you have heterogeneous media, you cannot have complete homogeneous magnetic circuits, and that is where the difficulty comes in. Your parallelogram of magnetizing forces will not apply here, and you are forced to be satisfied with the application of Ohm's law to magnetic circuits, which will not give you the result you claimed a little while ago.

MR. STEINMETZ:—Consider that wire coils of iron are closely embedded in iron, then there is no question that the same phenomenon takes place in the iron as in Ferraris's experiment in air. So the only problem would be how to shape the iron practically,

1. Exactly the same conclusion I find now given in Kapp, Alternate Current Machinery, page 82.

to get rotary magnetism of constant strength and velocity from sine-waves.

This three-phase current system has been brought up the last time as something entirely new. I cannot agree with that in the least. For already in the old Tesla motor the three phases of current, only that in the three wires that go out from the central station the three currents have not a difference of phase of exactly 120 degrees, but two have a difference of 90 degrees, and either one of these two currents has with the third a difference of phase of 135 degrees. But if now the "Allgemeine Electricitæts Gesellschaft" transmits currents of less than 120 degrees difference of phase—well, then the Dobrowolsky system comes back exactly to the old three-wire system of Tesla, only that the motor is certainly built somewhat differently. But that does not matter. Mechanically, the motor is undoubtedly improved, for there are several years' time between the old Tesla three wire motor and the new German three phaser. Whether the latter shows any improvements in its principles, is a question which is anything but beyond doubt.

But in the new Dolivo von Dobrowolsky system of electric distribution, I really cannot see anything new but the mechanical construction of motors and generators. That it became so famous is, I think, entirely due to the success of the grand transmission of power over such an enormous distance as 116 miles, which cast a halo around everything that was used with this transmission, and so made the rotary motor famous; but, in reality, I think ordinary synchronous motors might just as well have been used, and would have worked just as successfully, so that the choice of the particular motor had nothing to do with the success of the power transmission.

Prof. Thomson:—I should like to make some remarks upon the general subject of the paper. It is a matter to which I have given considerable thought. The subject is somewhat allied to the old Thomson-Houston arc machine. In fact, I remember long ago putting in a patent specification a machine connected so that it had not the three segment commutator but three rings, and it was rejected at the Patent Office on the ground that it was not an invention to put three rings on a three coil armature, any more than it was for any alternating current. But times have changed since then. [Laughter.] It seems to me some light would be thrown on the matter of this discussion by a few simple considerations. We will take the three coil in its simple form—symbols for it, Fig. 17. Now let us lead a wire, *J*, here, which would be a neutral wire. If we wrap that wire around a magnetic core, the effect should of course be the same or it should act the same as though these three wires, *a*, *b*, *c*, were wrapped around the magnetic core. So that if any fluctuations of magnetism were set up in this core by wrapping this neutral wire around the magnetic core, the same effect would be produced by

wrapping these three wires around the magnetic core. That would show that no fluctuation might be expected in such a system. But there is another question that comes in just here. If we look into the manner of generating; if we take our armature and put on three coils, and have a magnetic field which magnetizes this armature core with a constant number of lines, a number of lines which does not change during the rotation—it is evident, then, that whatever actions occur in these coils will be accompanied by no fluctuations of magnetism. You cannot generate in a system of coils any difference of condition which is not expressed by the magnetic field in which it is generated. If the magnetic field is constant, then we have constancy of magnetism in the core. That is, we have no fluctuations. Now, it would

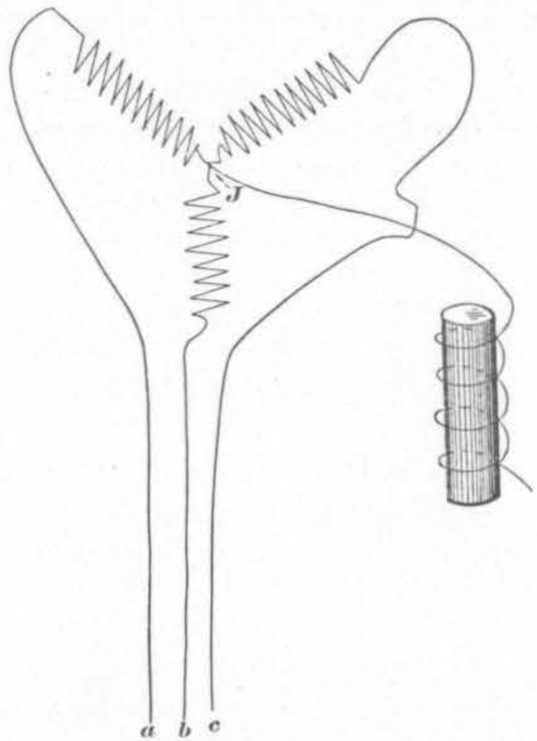


Fig. 17.

seem to me, looking at it from this standpoint, that putting another armature in connection with these corresponding terminals and having a magnetic field for it of constant strength, we would have a rotating field produced in this second armature which would result in the rotation of the armature itself—that is, the tendency to rotate the field would turn the coils backward and this would seem to indicate that under certain conditions we can, with the ordinary arrangements, produce exactly what we want, steady rotative effect without magnetic fluctuations, which would go to bear out the Ferraris idea. Now, how far the production of a rotating magnetic field in the presence of a short circuited armature may modify these conditions, I have not investigated. It does seem to me, however, that in such case the remarks of

Mr. Steinmetz are quite true, that we will have a large self-induction on a light load in such a motor and therefore a waste current, a leakage current corresponding to the leakage current in the transformer. Just how much it will be will of course depend on the general design and the proportions, and of course on the frequency of the alternations. I think the system demands that the frequencies shall be much less than we are accustomed to use in transformers for lighting That the system will have a considerable application, I have not the slightest doubt. It will have a large application. Whether the best form of it is not to place two corresponding armatures in fields, or use synchronizing machines, is a question. I should say, reasoning at the start, that this is probably the chief merit of the system. We have the possibility of getting rid of commutation on high potential transmission of power by making corresponding machines and running corresponding armatures in the fields that are excited. Of course there is a great desire to get a motor which shall enable us to get rid of this constant excitation and which will give us the power of starting under load. The generator reversed and used as a motor, demands that in starting the generator shall also start, that the two machines shall come up together. I have, indeed, taken one Thomson-Houston arc machine and put on three rings and simply delivered the current by three rings to the armature of another machine, and it would start and run up to speed, having no load on it, at least no large load. It would get into synchronous rotation when the power delivered is, after exciting the field fully, considerable. I have constructed some small machines which are almost exactly like Fig. 10. There are six coils on the armature and a field excited separately. The field, by the way, rotates and the angle covered by the field poles is about what is covered there, Fig. 10. I have no indication at all of anything wrong with these machines. They work, we think, perfectly, and so far as the heat generated in the armature goes, it is remarkably small. It is no greater, from actual experiment, than one would expect from an ordinary machine with a commutator. In fact, it is probably less. Probably more fluctuation is introduced into the magnetism by the commutation than there would be in this case by the simple use of three coils without commutation. I would say further that I have never had much confidence in some of the reasoning of Mr. Dobrowolsky in relation to this matter. I have always thought that he was a little out in his argument. He has attempted to show how, by using three phased currents, he could get polyphasal currents from them, by winding the armature in a different way. It strikes me as nothing more than spreading that coil over a certain angle of the armature surface. This, of course, would prevent sudden sharp jumps in the field and might be useful and undoubtedly is useful in the perfection of a motor working upon a closed circuit armature. These matters of discussion would undoubtedly be best

settled by a simple experimentation on the basis of what I indicated a little while ago. It may be that the very fact of the differences of composition of the wave may make a very great difference in the effect. We may not be called upon to reason upon fluctuations of magnetism due to sine curves when those sine curve currents are put in different angular positions. They may act, as in that Ferraris affair, to balance each other and oftentimes these considerations escape us.

I would say that there is another matter which probably ought to be taken into consideration. That is that a mass of iron does not always change its magnetism when you think it ought to. That is, it may hold up by its own inherent property of disregarding reversal—by hysteresis. This would tend, in fact, to hold the magnetism up rather than to allow it to suffer fluctuation. We know that in a closed circuit transformer it is necessary to put energy into the iron to cause it to drop its magnetism. It would tend to remain magnetized if we cut off the current at any portion of a wave, at least up to a certain point, and this would tend to help us out in this very matter of getting rid of fluctuations of magnetism, which of course would be a serious loss of energy in the case of large bodies of iron, the magnetism of which should be allowed to go up and down through large ranges. There is another matter, too, that comes in here. It is whether we get in the motor or in the machine a motion that is equal velocity—that is, whether it is an even pull all the way around, the sum of the magnetic lines being the same, or whether it is a jerky motion, a motion of difference of velocity. Of course, it will naturally be seen at once that unless we get a perfectly uniform flow, our efficiency could not be as high in the case of a fluctuating movement of the lines, and the lines which hesitate and then move forward and then hesitate again and then move forward, that would be only efficient in case the armature was negligible which, of course, could not be the case.

Mr. C. S. Bradley:—Did I understand Prof. Thomson to say that he thought the increase of the phasing by Dobrowolsky's plan was applicable especially to the closed armature?

Prof. Thomson:—No, I made no distinction between the kind of armatures. I simply say that Dobrowolsky's plan of multiplying the coils and connecting them up, did not differ very much, so far as I could see, from simply spreading those coils on the armature.

Mr. Bradley:—I understood you to say at the last that it applied especially to the closed circuit armature.

Prof. Thomson:—You mean by closed circuit armature, closed field and with connections taken out and around?

Mr. Bradley:—Yes.

Prof. Thomson:—No; I did not make such a distinction I should say that the closed circuit here would be just as effective for getting the polyphasal circuit, provided the coils do not cover too large an angle.

MR. BRADLEY:—It is a pretty difficult thing to make a test as to the efficiency of the different armatures. But I have always had an idea that the closed coil armature was exactly adapted to the carrying out of the three phase, because the currents can pass in more directions. There are more subdivisions than there are in the open circuit. With three open coils the position of each would determine its phase. But if it were completely closed and taken out at three points, there is a chance for two wires to operate and leave the third one *nil*, and the current has a chance to pass clear around the armature. That is, it will pass 120 degrees on one side and 240 degrees on the other side, making a multiple arc circuit. In other words, the closed coil armature carries out the plan that Dobrowolsky is trying to carry out, and does exactly what Dobrowolsky is trying to do by placing on the extra coils, without the extra coil.

PROF. THOMSON:—I think that matter is made clear by considering the movement of the armature with respect to the lines. It does not seem to me to make very much difference what the coil is, providing the two armatures—suppose we take that as the typical system—the two machines are connected similarly. The movement of lines in one will be reproduced in the other, provided of course that the order of the connections and the symmetry of the apparatus are preserved.

MR. BRADLEY:—I tested machines running that way. They were direct current machines altered to the three rings. I took them first and ran them as direct current machines. Then I had them changed and put three rings on each one and connected them up, and ran them together with the same power, and took off the same power, and I found the machines ran so nearly alike that I could not detect the difference. By the way, in your speaking of two machines, you have not at any time said motor and dynamo.

PROF. THOMSON:—I, of course, meant motor and dynamo It might interest the members for me to say that at one time, I think it was about 1882, I happened to have a three coil arc machine that had three rings on the shaft, and I discussed with my assistant. Mr. Rice, who is now superintendent of the Thomson-Houston works, this matter of connecting on three rings on two machines, and we found that the machines would work well as a means of transmitting power. But we had not facilities for building such apparatus in any quantity. However, it is an interesting reminiscence, as coming up at this time.

MR. STEINMETZ:—With regard to the spreading out of the coils on the armature, I think this makes very little if any difference in the shape of the wave, because if we had a coil of one single turn we would get a simple harmonic or sine wave where the maximum electromotive force = 1.414, the effective E. M. F. Now, only a few days ago I had occasion to draw the curve of electromotive force under exactly the opposite conditions, the most extreme case of spreading out the coils. A smooth continuous current armature changed into a bipolar alternator by connecting two opposite commutator bars with sliding rings, and I found as ratio between maximum E. M. F. and effective E. M. F.: 1.415; that is, exactly the same value as the sine wave gives. I found a wave somewhat similar to the sine wave, slightly different, with a tendency to the shape that Dr. Pupin showed us here in Fig. 8.

PROF. THOMSON:—In making the remark as to the covering of the coils, I meant a motor with a closed circuit armature—not in relation to the generation of the current.

MR. KENNELLY:—This is a paper which, I think, has to be studied from two points of view. Like all mathematical papers, it presents two different aspects. We are face to face with a condition in the art of electrical distribution which is not only somewhat novel, but is also very intricate, and consequently any assistance, even of the most elementary description, which will enable us to fathom the mysteries of this difficult system of distribution, is one which should be only too gladly welcomed, I think, at the hands of this Institute. We have presented to us in this paper, a mathematical disquisition on the very simplest and most elementary type of the three phase generator, in which it is assumed that there is no armature reaction, no hysteresis and no eddy currents. Under those conditions, just as in the corresponding ideal transformer with constant coefficients, which has been called by some one the "phantom" transformer, that we all aspire so much after but so very seldom see—the fundamental operations of this particular machine are readily capable of being analyzed by the skill that has been presented in this paper. I think that we should be content to take one subject at a time, to consider that we have arrived at a position where modifications which will certainly present themselves by disturbing influences, will ultimately resolve themselves into this fundamental type, as theyare lessened and removed. This is the starting point, so to speak, from which the various roads branch from the theoretical machine to the practical machine. I think, therefore, that while the paper gives us what may be called almost a little discovery, in its way, in practical mathematics, that it should be treated for its own value on the side of a mathematical essay, and not brought into the question of practical and everyday machines. We have the very remarkable fact that although the electromotive force which is capable of being produced by a complex condition of magnetic fields can be a uniform one, and while the currents which are set up by the electromotive force cannot possibly be the prototype of the electromotive force, graphically, when there is any self-induction in the circuit, yet that under the influence of mutual induction, that prototype may be restored. That is a beautiful conception, even although it may not have a very direct bearing on the practical side of the question. It seems to me that

the practical issue of the question is not whether we can produce artificially and with considerable care a constant rotary magnetic field or a constant rotary electromotive force, for by theory we can produce any continuous curve; and any periodic wave can be established as the resultant of a number of simple harmonic waves, it only is a question of how many compounds we want. Sometimes we should want an infinite number. But however interesting that may be from the theoretical point of view, the next step in this difficult pathway which has been outlined here to-night, is not how to produce perfection, but how far differences from perfection will affect the practical result; not how necessary it may be to have a perfectly continuous field, but how far the fluctuations which will almost inevitably present themselves, will affect the efficiency and efficacy of these particular machines. At the same time, while we have to remember that the paper is a theoretical disquisition, it is also the first step towards practice, because theory follows ever slowly in the steps of practice, and it is in the direction of such a theory that we have to hope for the ultimate apprehension of all the difficulties before us.

DR. PUPIN:—The method which I have employed, as Mr. Kennelly remarked, is to go step by step from the ideal to the more and more practical, and see what the real difficulties are. Now, as long as we deal with simple harmonic waves, the question is exceedingly simple and is readily solved. The authorities on theoretical electrical engineering invariably consider the simple sine waves whenever they discuss the subject of periodically varying electric currents. Nobody has ever tackled the problem of complex harmonic waves. We really do not know what a complex harmonic wave will do. We can only guess at it. There are no quantitative relations. Now, I think that I have shown in this paper what a complex harmonic current wave will do in a particular case. I also propose to show before long what it will do in other practically important, but more complicated cases. Mr. Steinmetz points out that a combination of two simple sine waves can produce the same thing which I claim for the complex wave. But the correctness of his statement requires the employment of a homogeneous magnetic medium in which his two coils are to act. I would be very much obliged to him for the proof of the contrary.

The remark of Prof. Thomson with reference to the machine which he put on the blackboard, three coils rotating in a uniform field, has been answered in the very beginning of my paper. They will produce a constant rotary field, although the producing field, the exciting field, is constant. The relation of the coils with respect to the exciting fields, is continually varying, and the electromotive force produced in each one of those is a simple sine wave, and as long as we have simple sine waves and three phases, there will be a maximum variation of fourteen per cent.,

no matter what you do. Now wind the three wires on a piece of iron. The neutral wires will produce no magnetization. The three wires, if they are wound around the same coils in the same way will also produce no magnetization. So I do not think that the experiments suggested by Prof. Thomson could give us any record of any fluctuations in the rotary field. With respect to the production of that particular wave, Mr. Steinmetz remarked that it is impossible to produce anything like it. Of course, in nature there are no discontinuities. Nature hates discontinuity, and there are no absolutely discontinuous functions. Here, you see (Fig. 8), the tangent is continually constant at all points until the corner is reached, when the tangent suddenly becomes zero. This discontinuity is, of course, physically impossible, but in practice we can come as near to it as we choose to do, if we care to take the trouble. Of course, we would employ a practically discontinuous field. That is, you are in a place where there are lines of force, and suddenly you step into a place where there are practically no lines of force. Now, absolutely, that is impossible. But we can come as near as we choose to, by simply shaping the magnetic circuit in such a way that it will be nicely rounded and allow the lines of force of the magnetizing coils to follow it without getting too much out of their way. If you do that, then there will be practical discontinuities. Now, I have an electro-magnet which will do that very nearly, where the lines of force of the magnetizing coils never deviate too suddenly from the magnetic circuit, and therefore there is very little leakage. I hope at some future time to show before the Institute, this electro-magnet. It is a very simple device. I do not say that I can produce that electro-magnet without sacrificing several practical advantages. But if it is only for experimental purposes, I do not care if I do sacrifice them. I dare say I will not rest until I get that electromotive force given in Fig. 8, plotted on paper from experimental results. But it is very difficult to do anything in New York in a hurry, because mechanicians will not attend to their orders when you wish them to, and you have to wait for them. As Mr. Kennelly remarked, I do not think it is time yet to consider what will take place when we apply this rotary field to drive a motor, because I wish to limit the discussion to the limits of the paper.

MR. STEINMETZ:—With regard to this Ferraris scheme, I only wanted to show that under certain conditions a rotary field can be produced by sine waves of electric current. Suppose you have two equal coils at right angles with each other, entirely embedded in iron. The armature of the Pacinotti, or a similar type, with a very small clearance between armature iron and field iron, so small a clearance that the air reluctance can entirely be neglected against the reluctance of the iron—then you have exactly the conditions where you get from two sine waves of 90 degrees difference of phase, a system of magnet poles which revolve with constant intensity and constant velocity.

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THOMPSON, ALEXANDER	Supt. Electrical Dept., and Chief Engineer, Superior Water, Light and Power Co., West Superior, Wis.	April 21, 1891
THOMPSON, WILLIAM GEO. MACNEILL,	Resident Engineer, Sault Ste Marie Canal, Sault Ste. Marie, Ontario.	July 12, 1887
TOBEY, WILLIAM BOARDMAN	Pittsfield Electric Light & Power Co., Pittsfield, Mass.	Sept. 16, 1890
TOTTINGHAM, F. M.	Supt. 2nd. District, Edison Electric Ill. Co., 49 W. 26th St., New York City.	April 21, 1891
TOWNSEND, HENRY C.	(*Manager*). Attorney and Expert in Electrical Cases, 5 Beekman St., New York.	July 10, 1888
TREGONING, JOHN	32 Belmont Ave., Providence, R. I.	April 2, 1889
TROTT, A. H. HARDY	Electrical Expert, with Thomson-Houston Electric Co., Lynn. Mass.	Jan. 20, 1891
TUTTLE, GEORGE W.	Storekeeper, Sawyer-Man Electric Co., 510 West 23d St., New York City.	Mar. 17, 1891
UEBELACKER, CHAS. F.	Brush Electric Co., and 1299 Euclid Ave., Cleveland Ohio.	Feb. 7, 1890
UEHLING, T. A.	Ass't. Supt. and Chemist, U. S. Aluminium Metal Co., Boonton, N. J.	May 19, 1891
UHLENHAUT, FRITZ, JR.	Field Engineering Co., 143 Liberty St., New York.	May 7, 1889
UPTON, FRANCIS R.	(*Manager*). Treasurer and General Manager, Edison Lamp Co., Harrison, N. J. Residence, 107 Day St., Orange, N. J.	May 17, 1887
VAIL, THEO. N.	18 Cortlandt St., New York.	April 15, 1884
VAN BRUNT, WALTER	Manager, Duluth Telephone Co., Duluth, Minn.	Sept. 6, 1887
VANCE, A. ST. CLAIR	General Superintendent, The H. Ward Leonard & Co., 136 Liberty Street, New York City.	April 2, 1889
VANDERGRIFT, JAMES A.	Assistant Supt. and Electrician, Sawyer-Man Electric Co., 534 W. 23d St., New York City.	Nov. 24, 1891
VAN TRUMP, C. REGINALD	Wilmington City Electric Co., Wilmington, Del.	Feb. 5, 1889
VAN VALKENBURGH, F. S.	Central and South American Tel. Co., Tehuantepec, Mexico.	June 5, 1886
VAN VLECK, FRANK	Executive Engineer, Pacific Railway Co., Los Angeles, Cal.	Nov. 16, 1886
VAN WYCK, PHILIP V. R., JR.	36 W. 12th St., New York City.	April 21, 1891
VARLEY, RICHARD, JR.	Electrician, Okonite Insulated Wire Co., Passaic, N. J.	Mar. 18, 1890
VIDUARRE, JOSE	Dealer in Electrical Supplies, Ponce, Porto Rico.	Sept. 6, 1887
WACKER, GEORGE G.	Electric Organs, 3644 Third Ave., New York.	Sept. 6, 1887
WALLACE, WILLIAM	Wire Manufacturer, Ansonia, Conn.	April 15, 1884
WALTER, HENRY E.	3 Princes Mansions, Victoria St., London, Eng.	April 2, 1889

Mr. Tesla's Experiments.—Prof. Crookes, the president of the Institution of Electrical Engineers, when moving the annual report last week, announced that Mr. Nikola Tesla is on his way to England, and had promised to lecture before the Institution in January next, and that the Council would spare no pains to ensure that the lecture should be thoroughly well experimentally illustrated. This meeting is likely, therefore, to prove one of the most noteworthy of the coming session.

"MASSAGE" WITH CURRENTS OF HIGH FREQUENCY.

BY

Nikola Tesla

I TRUST that the present brief communication will not be interpreted by the readers of THE ELECTRICAL ENGINEER as an effort on my part to put myself on record as a "patent medicine" man, for a serious worker cannot despise anything more than the misuse and abuse of electricity which we have frequent occasion to witness. My remarks are elicited by the lively interest which prominent medical practitioners evince at every real advance in electrical investigation. The progress in recent years has been so great that every electrican and electrical engineer is confident that electricity will become the means of accomplishing many things that have been heretofore, with our existing knowledge, deemed impossible. No wonder then that progressive physicians also should expect to find in it a powerful tool and help in new curative processes. Since I had the honor to bring before the American Institute of Electrical Engineers some results in utilizing alternating currents of high tension, I have received many letters from noted physicians inquiring as to the physical effects of such currents of high frequency. It may be remembered that I then demonstrated that a body perfectly well insulated in air can be heated by simply connecting it with a source of rapidly alternating high potential. The heating in this case is due in all probability to the bombardment of the body by air, or possibly by some other medium, which is molecular or atomic in construction, and the presence of which has so far escaped our analysis—for according to my ideas, the true ether radiation with such frequencies as even a few millions per second must be very small. This body may be a good conductor or it may be a very poor conductor of electricity with little change in the result. The human body is, in such a case, a fine conductor, and if a person insulated in a room, or no matter where, is brought into contact with such a source of rapidly alternating high potential, the skin is heated by bombardment. It is a mere question of the dimensions and character of the apparatus to produce any degree of heating desired.

It has occurred to me whether, with such apparatus properly prepared, it would not be possible for a skilled physician, to find in it a means for the effective treatment of various types of disease. The heating will, of course, be superficial, that is, on the skin, and would result, whether the person operated on were in bed or walking around a room, whether dressed in thick clothes or whether reduced to nakedness. In fact, to put it broadly, it is conceivable that a person entirely nude at the North Pole might keep himself comfortably warm in this manner.

Without vouching for all the results, which must of course, be determined by experience and observation, I can at least warrant the fact that heating would occur by the use of this method of subjecting the human body to bombardment by alternating currents of high potential and frequency such as I have long worked with. It is only reasonable to expect that some of the novel effects will be wholly different from those obtainable with the old familiar therapeutic methods generally used. Whether they would all be beneficial or not remains to be proved.

ON POLYPHASAL GENERATORS.[1]

BY M. I. PUPIN, PH. D., COLUMBIA COLLEGE.

FEW will deny the importance of the polyphasal current systems; none the fascination of their study. This belief induced me to present the following brief essay before the Institute.

The experimental researches in this new and promising field of electrotechnics are not yet numerous, but still the results already obtained are of so decisive a character as to leave no doubt whatever as to the extremely high practical importance which is attached to electrical generators, motors and transformers constructed according to requirement imposeds upon us by this new

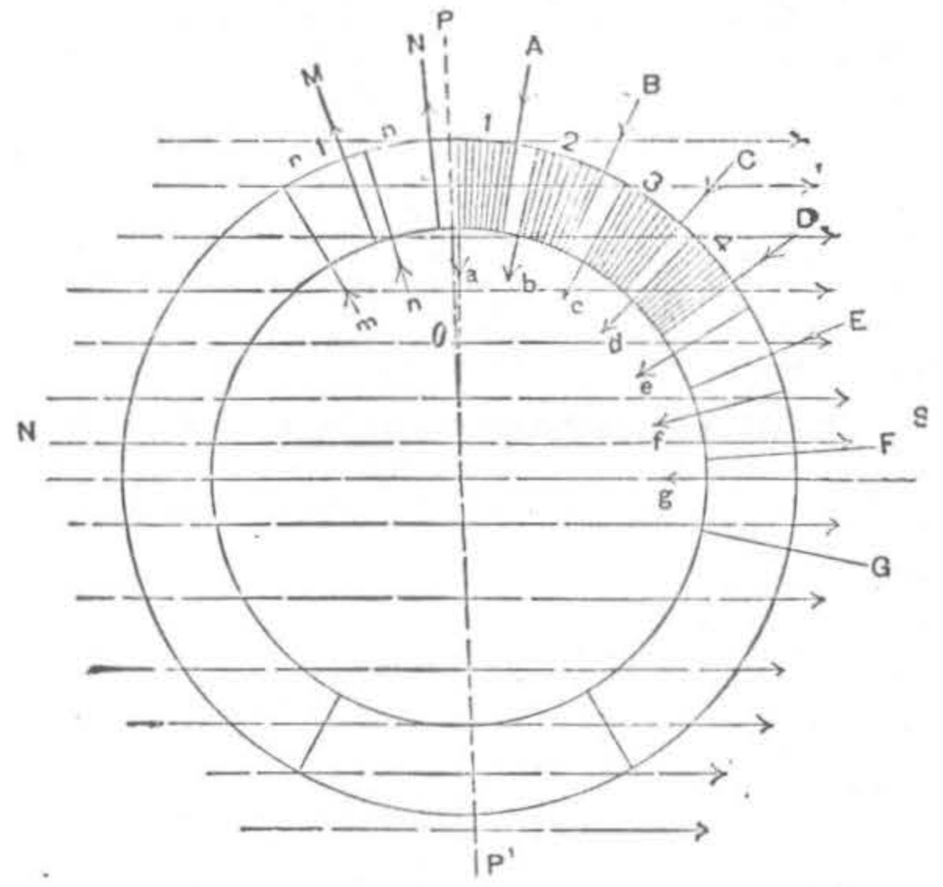

Fig. 1.

method of combining a set of variable electromotive forces. For who among us does not thoroughly appreciate the beautiful inventions of Nikola Tesla and the completeness of the success which Dobrowolsky and Brown obtained by the practical applications of these inventions?

The exact quantitative relations involved in the polyphasal system of currents are not, I venture to say, quite as well known as its practical results. To give an impulse to further inquiry in that direction is one of the principal aims of this modest investigation. For the present I propose to confine myself to the polyphasal generators in general, and particularly to polyphasal generators whose system of electromotive forces is capable of producing a rotary magnetic field of constant strength. The last point seems to me to be one of the vital points in this new method of electrical distribution. It is in this particular point that Mr. Dobrowolsky claims his system to be superior to that of Nikola Tesla.

Let us consider the theoretically simplest form of a polyphasal generator, as shown in Fig. 1. A non-magnetizable ring with n open equal coils at equal distances from each other rotates uniformly through a perfectly homogeneous magnetic field. Let PP' be the neutral plane of the field. At the instant when coil 1 is at the angular distance θ from the neutral plane PP' the E. M. F. generated in the various coils will be

$$e_1 = K \sin (\theta + \alpha)$$

$$e_2 = K \sin (\theta + \alpha + \frac{2\pi}{n})$$

. . . . . .

. . . . . .

1. Read at the sixty-second meeting of the American Institute of Electrica Engineers, New York, December 16th, 1891.

$$e_n = K \sin \left\{ \theta + \alpha + (n-1)\frac{2\pi}{n} \right\}$$

Where K is a constant depending, as is well known, on the field intensity, the speed of rotation, the number of turns in the coil and the area of the plane of a turn; α is the angular width of one-half of the coil.

Since

$$\sin(\theta+\alpha)+\sin\left(\theta+\alpha+\frac{2\pi}{n}+\ldots\ldots+\sin\left\{\theta+\alpha+(n-1)\frac{2\pi}{n}\right\}\right. = 0$$

it follows that

$$e_1 + e_2 + e_3 + \ldots\ldots + e_n = 0 \ldots\ldots (1).$$

That is to say, the sum of electromotive forces generated in the various coils which are on one side of the neutral plane is numerically equal and of opposite sign to that of the coils on the other side of this plane. This result is well known and self-evident. It is, however, far from self-evident that relation (1), which I shall call the *relation of continuity* for the electromotive forces, will be satisfied by every magnetic field.

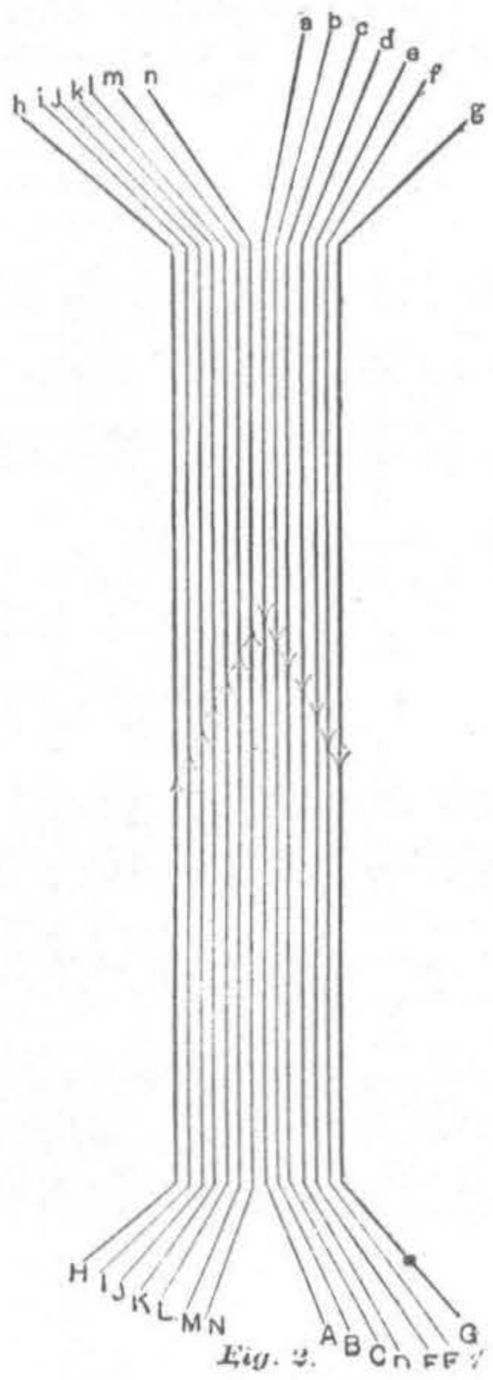

Fig. 2.

Close each coil separately by conductors of equal resistance and self-induction. Let $c_1, c_2 \ldots\ldots c_n$ denote the currents in the n separate circuits. It is evident that

$$c_1 = \frac{K}{I}\sin(\theta+\alpha-\varphi)$$

$$c_2 = \frac{K}{I}\sin\left(\theta+\alpha+\frac{2\pi}{n}-\varphi\right)$$

$$c_3 = \frac{K}{I}\sin\left(\theta+\alpha+2\frac{2\pi}{n}-\varphi\right)$$

$$c_n = \frac{K}{I}\sin\left\{\theta+\alpha+(n-1)\frac{2\pi}{n}-\varphi\right\}$$

Where I is the impedance in each circuit and φ the angle of retardation. Hence, we have

$$c_1 + c_2 + c_3 + \ldots\ldots + c_n = 0 \ldots\ldots (2).$$

That is to say, the relation of continuity is satisfied for the currents also.

Let the wires $a\,A$, $b\,B$, $\ldots\ldots n\,N$ (Fig. 2) represent a part of each of the n conductors of this system. Then, according to relation (2), the sum of the currents in these n linear conductors being always zero, if we join them all into one conductor there would be no current in this wire, but the currents in the n circuits would circulate exactly the same as before. In fact, the common juncture is useless and can and should be cut out.

The diagram, Fig. 3, represents this method of connecting for a three-phase system. Consider, now, n equal coils distributed at angular distances of $\frac{2\pi}{n}$ over a laminated iron ring B, each coil being a part of the n conductors coming from the generator Diagram Fig. 4 illustrates this for a three-phase system. Let the n currents be denoted now by $c_1', c_2', \ldots\ldots c_n'$. We shall have now,

$$c_1' = \frac{K}{I'}\sin(\theta+\alpha-\varphi')$$

$$c_2' = \frac{K}{I'}\sin\left(\theta+\alpha+\frac{2\pi}{n}-\varphi'\right)$$

$$c_n' = \frac{K}{I'}\sin\left\{\Theta+\alpha+(n-1)\frac{2\pi}{n}\varphi'\right\}$$

and therefore

$$c_1' + c_2' + \ldots\ldots + c_n' = 0 \qquad (3)$$

The introduction of the iron ring with the n coils into the n phasal system has changed the impedance I, and the angle of retardation φ; but this change is evidently the same for all coils. The correctness of this statement might, perhaps, be questioned, if we suppose that the system of the n variable currents was at any moment strong enough to saturate the iron ring; I therefore suppose that the intensity of magnetization in the ring is never over 10,000 C. G. S. lines of force. We shall presently see that in the case of a properly built generator the saturation of the iron ring will not vitiate the correctness of the above statement in the slightest.

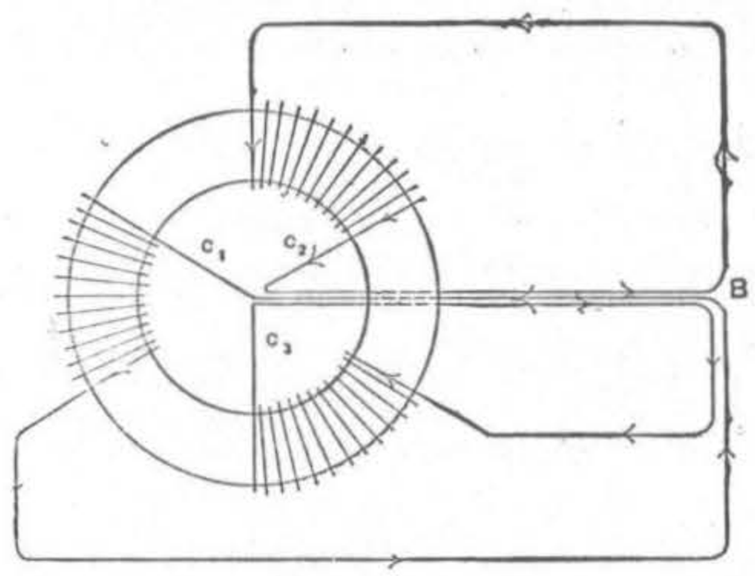

Fig. 3.

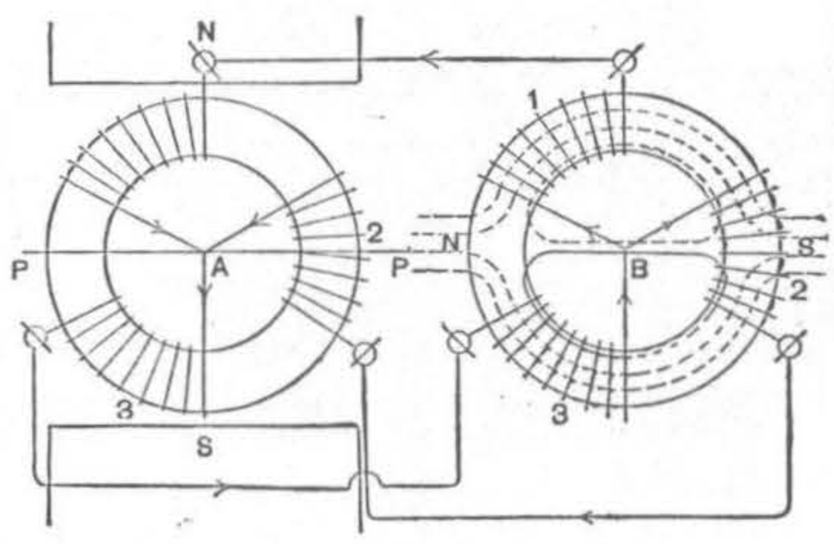

Fig. 4.

Let s be the number of turns in each of the n coils. Relation (3) gives

$$4\pi s c_1' + 4\pi s c_2' + \ldots\ldots + 4\pi s c_n' = 0 \qquad (4)$$

That is to say, the relation of continuity is satisfied by the magneto-motive forces.

Relation (4) translated into physical language means that the magnetization in the iron ring is due to two equal magneto-motive forces working in multiple arc. The magnetic field produced is perfectly symmetrical with respect to the ring as indicated by the dotted lines in Fig. 4.[1]

MR. C. O. HARRIS, formerly of Clower, Harris & Co., Dallas Tex., was in the city last week. Mr. Harris has secured some excellent agencies, and will open an office in Dallas.

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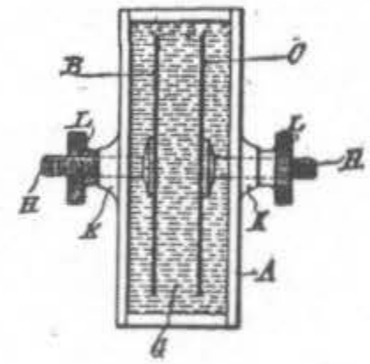
1. This will be always strictly true if we employ an even number of coils, even if the number of phases is odd, because then the distribution of the ampère turns is perfectly symmetrical.

Oil Condenser.

With a view to improving the insulating medium between the plates of a condenser to adapt them more perfectly for use with alternating currents of high frequency, Nikola Tesla proposes to use oil as the insulating material. One form of apparatus is illustrated in the accompanying engraving, wherein is a box provided with condenser plates, B, C, separated by a body of oil contained within the receptacle. The



construction admits of adjusting the distance between the plates, which is of advantage for graduating the condenser to the particular work for which it may be required. The plates are, therefore, mounted upon rods extending through stuffing boxes in the sides of the receptacle, and their distance apart may be graduated by adjusting the thumb screws L on the outside of the receptacle.

On Polyphasal Generators.*

BY M. I. PUPIN, PH. D., COLUMBIA COLLEGE.

Few will deny the importance of the polyphasal current systems: none the fascination of their study. This belief induced me to present the following brief essay before the Institute.

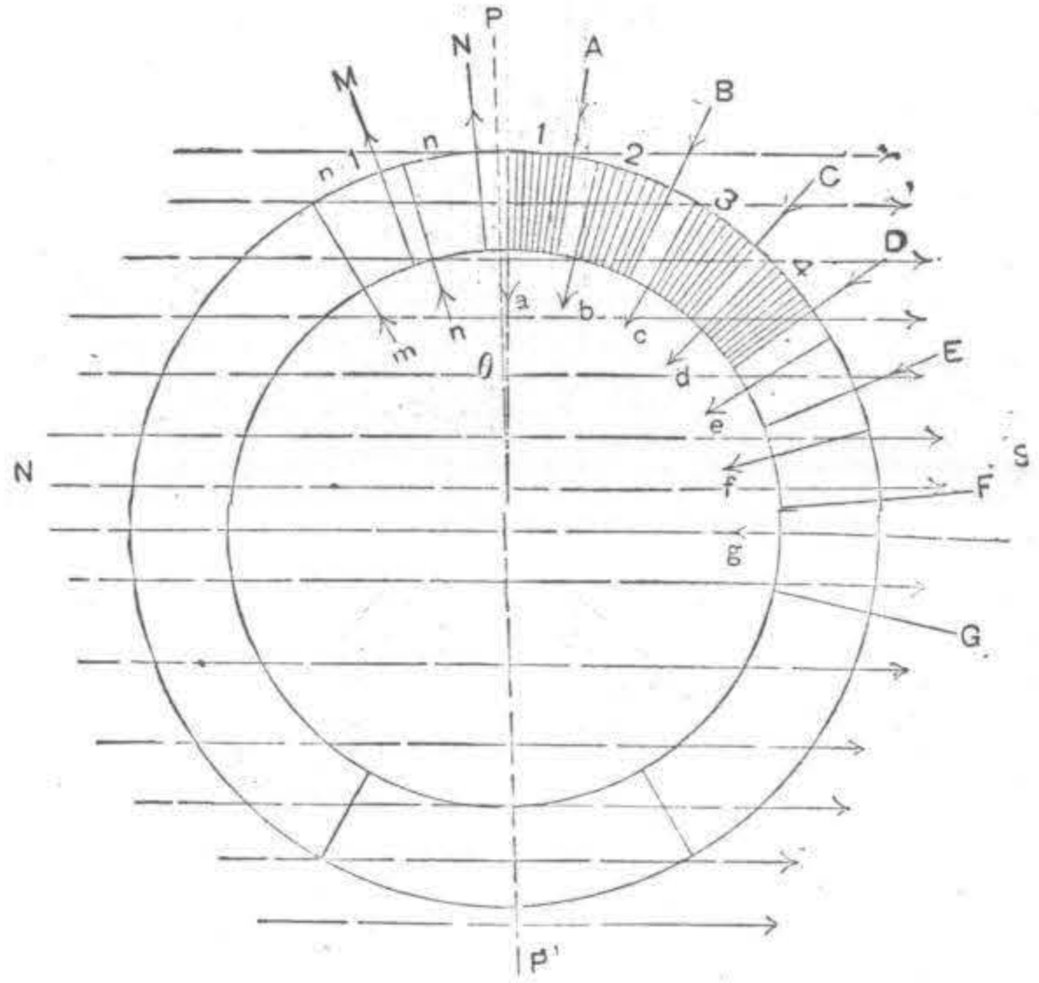


FIG. 1.—POLYPHASAL GENERATORS.

The experimental researches in this new and promising field of electrotechnics are not yet numerous, but still the results already obtained are of so decisive a character as to leave no doubt whatever as to the extremely high practical importance which is attached to electrical generators, motors and transformers constructed according to requirements imposed upon us by this new method of combining a set of variable electromotive forces. For who among us does not thoroughly appreciate the beautiful inventions of Nikola Tesla, and the completeness of the success which Dobrowolsky and Brown obtained by the practical applications of these inventions?

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Let us consider the theoretically simplest form of a polyphasal generator, as shown in Fig. 1. A non-magnetizable ring with n open equal coils at equal distances from each other rotates uniformly through a perfectly homogeneous magnetic field. Let $P\,P'$ be the neutral plane of the field. At the instant when coil 1 is at the angular distance θ from

* A paper read before the American Institute of Electrical Engineers.

the neutral plane $P\,P'$ the E. M. F. generated in the various coils will be

$$e_1 = K \sin (\theta + \alpha)$$
$$e_2 = K \sin (\theta + \alpha + \frac{2\pi}{n}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$e_n = K \sin \left\{ + \alpha + (n-1)\frac{2\pi}{n} \right\}$$

Where K is a constant depending, as is well known, on the field intensity, the speed of rotation, the number of turns in the coil and the area of the plane of a turn; α is the angular width of one-half of the coil.

Since

$$\sin (\theta + \alpha) + \sin \left\{ \theta + \alpha + \frac{2\pi}{n} \right\} + \cdots\cdots + \sin \left\{ \theta + \alpha + (n-1)\frac{2\pi}{n} \right\} = 0,$$

it follows that

$$e_1 + e_2 + e_3 + \cdots\cdots + e_n = 0. \qquad (1)$$

That is to say, the sum of electromotive forces generated in the various coils which are on one side of the neutral plane is numerically equal and of opposite sign to that of the coils on the other side of this plane. This result is well known and self-evident. It is, however, far from self-evident that relation (1), which I shall call the *relation of continuity* for the electromotive forces, will be satisfied by every magnetic field.

Close each coil separately by conductors of equal resist-

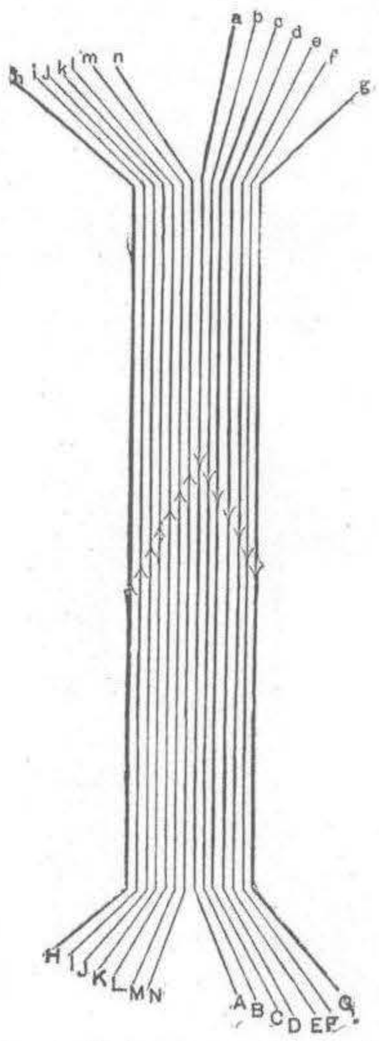

FIG. 2.—POLYPHASAL GENERATORS.

ance and self-induction. Let $c_1, c_2, \ldots\ldots\ldots\ldots c_n$ denote the currents in the n separate circuits. It is evident that

$$c_1 = \frac{K}{I} \sin (\theta + \alpha - \varphi)$$
$$c_2 = \frac{K}{I} \sin (\theta + \alpha + \frac{2\pi}{n} - \varphi)$$
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That is to say, the relation of continuity is satisfied for the currents also.

Let the wires $aA, bB, \ldots\ldots\ldots nN$ (Fig. 2) represent a part of each of the n conductors of this system. Then, according to relation (2), the sum of the currents in these n linear conductors being always zero, if we joined them all into one conductor there would be no current in this wire, but the currents in the n circuits would circulate exactly the same as before. In fact, the common juncture is useless and can and should be cut out.

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$$c_1' = \frac{K}{I} \sin (\theta + \alpha - \varphi')$$
$$c_2' = \frac{K}{I} \sin (\theta + \alpha + \frac{2\pi}{n} - \varphi')$$
$$c_n = \frac{K}{I} \sin \left\{ \theta + \alpha + (n-1)\frac{2\pi}{n} - \varphi' \right\}$$

and, therefore,

$$c_1' + c_2 + \cdots\cdots + c_n'' = 0. \qquad (3)$$

The introduction of the iron ring with the n coils into the n phasal system has changed the impedance I, and the angle of retardation φ; but this change is evidently the same for all coils. The correctness of this statement might perhaps be questioned, if we supposed that the system of the n variable currents was at any moment strong enough to saturate the iron ring, I therefore suppose that the intensity of magnetization in the ring is never over 10,000 C. G. S. lines of force. We shall presently see that in the

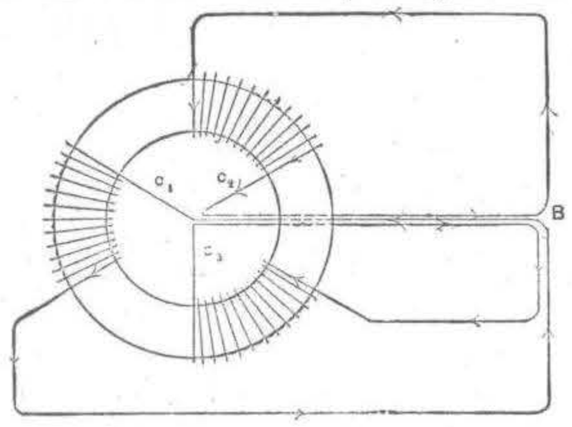


FIG. 3.—POLYPHASAL GENERATORS.

case of a properly built generator the saturation of the iron ring will not vitiate the correctness of the above statement in the slightest.

Let s be the number of turns in each of the n coils. Relation (3) gives

$$4\pi s c_1' + 4\pi s c_2' + \cdots\cdots + 4\pi s c_n' = 0. \qquad (4)$$

That is to say, the relation of continuity is satisfied by the magneto-motive forces.

Relation (4) translated into physical language means that the magnetization in the iron ring is due to two equal magneto-motive forces working in multiple arc. The magnetic field produced is perfectly symmetrical with respect to the ring, as indicated by the dotted lines in Fig 4.*

Consider now n iron ring cores of exactly the same dimensions and made of the same material. Let ρ be the reluctance of each ring. Let each of the n coils be interlinked with one of the iron rings; we shall have n homogeneous magnetic circuits and as long as the magnetization of these rings is considerably below the saturation point we shall have

$$\frac{4\pi s C}{\rho} + \frac{4\pi s C_2}{\rho} + \cdots + \frac{4\pi s C_n'}{\rho} = 0.$$

That is to say the magnetic induction in the n magnetic circuits obeys the same law as the n electric currents; we can therefore employ the method of polyphasal connection for the magnetic circuits also and we obtain what the Germans call a Verkettung der Magnetischen Ströme, which may be translated into English by a more accurate expression: Polyphasal coupling of magnetic circuits. A transformer constructed on this principle may be called a coupled transformer.

A simple consideration will show that the field rotates around the axis of the ring B synchronously with the rotation in the generator which produces the impressed electromotive forces. Consider the armature of the generator. Since the ampère turns on one side of the neutral plane are always equal and opposite in sign to the ampère turns on the other side of this plane it is evident that the magnetic field due to the ampère turns in the armature is fixed in space and perfectly symmetrical with respect to the plane of symmetry $P P^1$. We can therefore say that this field, though *fixed in space, rotates with respect to the armature* with the *same angular* velocity with which the armature rotates in space. The distribution of the ampère turns over the stationary ring B being at any

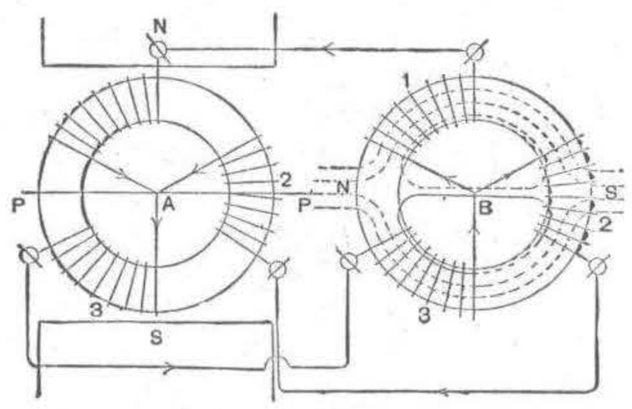


FIG. 4.—POLYPHASAL GENERATORS.

moment the same as that over the armature ring, it follows that the magnetic field of B also rotates with respect to B synchronously with the rotation in the armature. An inspection of the diagram in Fig. 4 will show that when the rotation in the generator is reversed the rotation of the field B will also be reversed.

The strength of the rotating magnetic field will vary because the strength of the two equal magneto-motive forces which are working in multiple arc will vary. The following simple consideration will show us the law of this variation. Two cases must be considered separately: First, when n is an odd number; second, when n is an even number.

*This will be always strictly true if we employ an even number of coils even when the number of phases is odd, because then distribution of the ampère turns is perfectly symmetrical.

CASE ONE.

A simple definition will save me the tedious repetitions of long sentences. I define the sum of all the electromotive forces generated in all the turns which are at any moment on the same side of the neutral plane of the generator as the resultant impressed E. M. F. at that moment. The magneto-motive force of the rotating field will evidently vary according to the same law as the resultant impressed E. M. F. To find the law of variation of the resultant impressed E. M. F. consider the armature of the generator when the angle Θ of coil 1 is zero. To make the reasoning shorter, I make now the angular width of each coil equal to $\frac{2\pi}{n}$, so that the n coils completely cover the ring, which makes $\alpha = \frac{\pi}{n}$. If this angular width is smaller, then a simple consideration will show that the law of variation which I am about to deduce will be exactly the same. In the position just mentioned, the coils 1, 2, 3, $\ldots$ $\frac{n-1}{2}$ will all be on the same side of the neutral plane, whereas coil $\frac{n+1}{2}$ will be just half on one side and half on the other side of this plane. There is no electromotive force generated in this coil. As the above mentioned angle Θ begins to increase from zero, coil $\frac{n+1}{2}$ begins to contribute to the resultant impressed E. M. F., but this contribution is just counterbalanced by the loss due to the entrance of coil n into the opposite region of the neutral plane. The variation in the resultant impressed E. M. F. is therefore due solely to the change of position of the turns in the coils 1, 2, 3, $\ldots$ $\frac{n-1}{2}$, or on one side and the corresponding turns on the other side of the neutral plane. This will be the case until coil $\frac{n+1}{2}$ has completely passed to one side of the neutral plane and coil

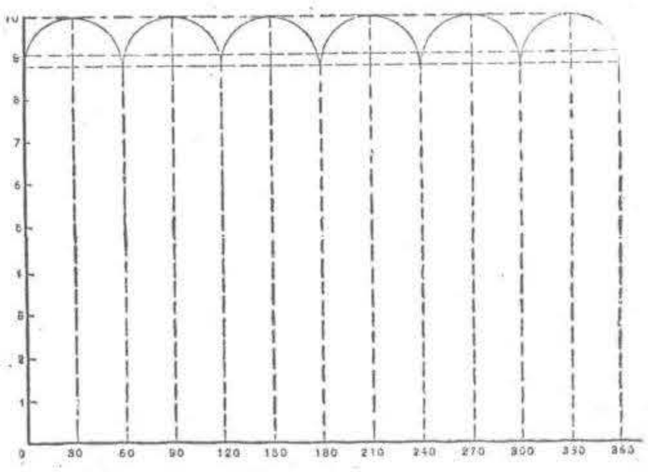


FIG. 5.—POLYPHASAL GENERATORS.

n is just bisected by it. During this interval Θ has increased from zero to $\frac{1}{2}\frac{2\pi}{n} = \frac{\pi}{n}$. The value of the resultant impressed E. M. F. at any moment during this interval is easily found. Denote it by E, then

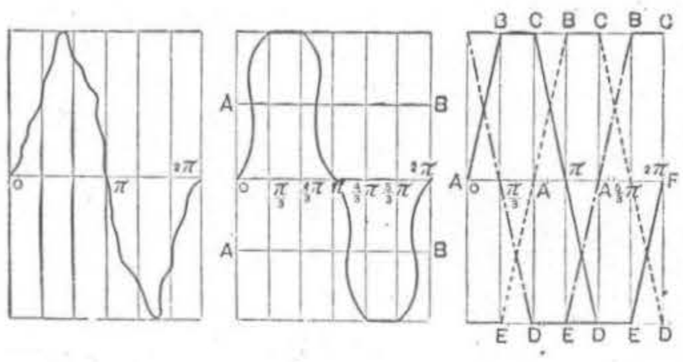
$$E = e_1 + e_2 + \cdots\cdots e_{\frac{n-1}{2}}$$
$$= K \left\{ \sin (\theta + \frac{\pi}{n}) + \sin (\theta + \frac{\pi}{n} + \frac{2\pi}{n}) + \cdots\cdots + \sin \left\{ \theta + \frac{\pi}{n} + \left(\frac{(n-1)}{2} - 1 \right) \frac{2\pi}{n} \right\} \right.$$
$$= K \left\{ \sin (\theta + \frac{\pi}{n}) + \sin (\theta + \frac{\pi}{n} + \frac{2\pi}{n}) + \cdots\cdots + \sin \left\{ \theta + \frac{\pi}{n} + \left(\frac{n-3}{2} \right) \frac{2\pi}{n} \right\} \right.$$
$$= \left\{ \frac{K_1 \sin (\theta + \frac{\pi}{n} + \frac{n-3}{4}\frac{2\pi}{n})}{\sin \frac{\pi}{n}} \right\} = K_2 \sin \left(\frac{\pi}{2} + \theta - \frac{\pi}{2n} \right) = K_2 \cos (\theta - \frac{\pi}{2n})$$

It is evident that the resultant impressed E. M. F. E varies during the interval from $\Theta = 0$ to $\Theta = \frac{\pi}{n}$ just like cos $\left(\Theta - \frac{\pi}{2n} \right)$; that is to say, it varies just like a simple harmonic. When $\Theta = \frac{\pi}{2n}$, E reaches a maximum which is equal to K_2, it has a minimum both when $\Theta = 0$ and when $\Theta = \frac{\pi}{n}$, each of these minima equals $K_2 \cos \frac{\pi}{2n}$. The ratio of the minimum to the maximum value equals cos $\frac{\pi}{2n}$. For a three-phase system this ratio is .866, and it diminishes very rapidly as n increases. It is evident that after Θ has reached the value $\frac{\pi}{n}$ the armature is, as far as concerns the resultant impressed E. M. F., in exactly the same position as at the start when $\Theta = 0$. We conclude, therefore, that E has $2n$ equal maxima and $2n$ equal minima during each revolution of the armature. In diagram Fig. 5 these fluctuations of E for a three-phase system are represented graphically.

CASE TWO.

The same relations hold good when n is even. The maxima take place when $\Theta = 0, \frac{2\pi}{n}, \frac{4\pi}{n}, \ldots\ldots$ The minima when $\Theta = \frac{\pi}{n}, \frac{3\pi}{n}, \frac{5\pi}{n}, \ldots\ldots$ and the ratio of any minimum to any maximum is $\cos \frac{\pi}{n}$. Since the magneto-motive force varies according to the same law as the resultant impressed E. M. F., it follows that the strength of the rotary magnetic field fluctuates periodically, having $2n$ equal maxima and $2n$ equal minima during each revolution, and the ratio of any minimum to any maximum equals $\cos \frac{\pi}{2n}$. That is, when n is odd; but when n is even then there are only n maxima and n minima, and the ratio of any minimum equals $\cos \frac{\pi}{n}$.

A polyphasal generator of this kind would produce a rotary magnetic field of constant strength only when $n = \infty$. For a three-phase system the maximum variation would be nearly 14 per cent. of the maximum value. This agrees perfectly with Mr. Dobrowolsky's calculations, but I fail to see how these calculations could justify any one to assume that they hold good for all types of polyphasal generators.* The generator which we have considered could be actually constructed, but its output would be so small in proportion to its size that we may dismiss it at once as an impracticable machine. We can make it practicable by substituting for the non-magnetizable ring, which carries the armature coils, a laminated iron ring, and for the uniform magnetic field the magnetic field of a well made field magnet, with

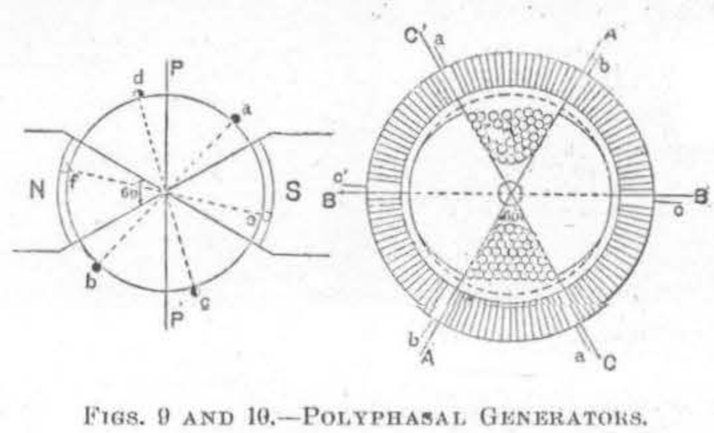


Figs. 6, 7 and 8.—Polyphasal Generators.

its pole pieces placed with respect to the armature coils in any one of the various ways sanctioned by practical experience.

But in a generator of this kind the resultant impressed E. M. F. will no longer vary according to the law which I have pointed out a little while ago. To be sure, we shall still have the same number of maxima and minima, as may be inferred readily from our knowledge of the shape of the E. M. F. curve of a continuous current dynamo. We all know that this curve is not in general a straight line, but a wave line having as many maxima and as many minima as there are sections on the commutator. But the ratio of the maxima to the minima is no longer an *a priori* calculable quantity. If we knew the mathematical relation between the intensity of the field at any point of the armature surface and the co-ordinates of this point with respect to the neutral plane then we could calculate that ratio, but the amount of experimental and practical work involved in this problem would be very great. A much easier and practically much more important problem is to determine the conditions which must be fulfilled in the construction of a polyphasal generator, in order that it may be capable of producing a rotary magnetic field of constant intensity in the simplest possible way, that is without the application of brushes and commutators. Mr. v. Dolivo-Dobrowolsky seems to think that a three-phasal generator is incapable of doing that, for he distinctly says that such a generator necessarily produces a rotary magnetic field whose strength varies 14 per cent. He also states that (evidently to obviate these fluctuations) the Allgemeine Electricitaets Gesellschaft employ a method of transmitting currents of smaller differences of phase than one-third of the period through three wires. In this point they claim to be ahead of Tesla, Bradley, Haselwander and Wenstrom. In fact, if one is not exceedingly careful in the perusal of Dobrowolsky's discussions of this subject he will be led to believe that the rotary field in some of Tesla's motors varied as much as 40 per cent., and certainly not less than 14 per cent. I do not think that Mr. Dobrowolsky wishes to be understood as holding that opinion; for neither he nor anybody else excepting Tesla himself can know what these variations were. The number of phases employed tells us nothing definite about the range of these variations.

A polyphasal dynamo which is capable of producing a rotary magnetic field of constant intensity must be constructed in such a way that its resultant magneto-motive force must remain constant as long as the speed and the magnetic field of the field magnets remain constant. As long as the variable electromotive force developed in each coil follows the law of a simple harmonic that result can never be accomplished by a finite number of phases, but it may, perhaps, be accomplished by producing in each of the generator coils a variable electromotive force which varies according to some definite complex harmonic law. In a well made commercial machine the electromotive forces developed in the various turns of the armature always vary according to some such law. The form of this complex harmonic law depends on the form of the magnetic field of the field magnets, and also on the distribution of the coils over the armature. The problem that remains to be investigated consists, therefore, of three parts: 1st. What must be the particular form of the complex harmonic E. M. F. developed in each coil of a polyphasal generator, in order that both the



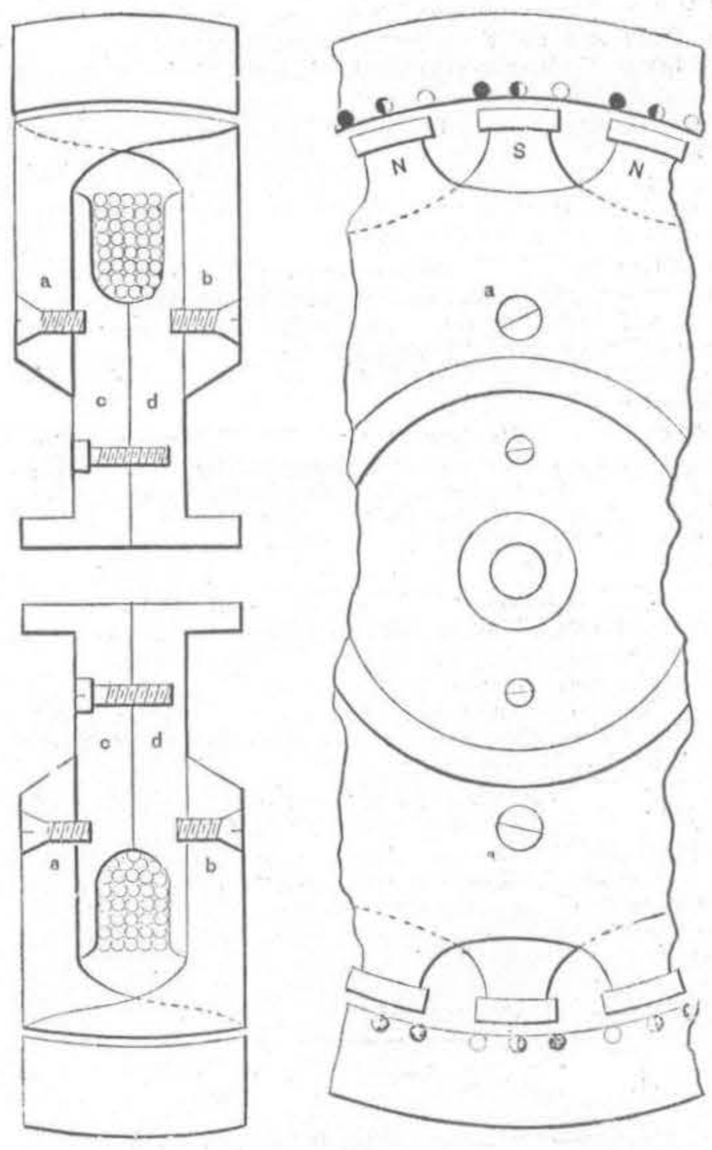
Figs. 9 and 10.—Polyphasal Generators.

condition of continuity be fulfilled, and also that the resultant impressed E. M. F. be continually constant? 2d. What form of the magnetic field of the field magnets will be capable of producing such an E. M F.? 3d. Can a continually constant resultant E. M. F. produce a rotary field of constant strength?

1. The first part of this problem is purely mathematical. In a paper read before the New York Mathematical Society I indicated a method of discussing this part in a general way, and worked out completely two particular cases, namely, the cases of a three and four phasal system. The paper is given in the appendix.

2. For a three-phasal system the form of the complex harmonic E. M. F. given in Fig. 7 will satisfy all the conditions. The form A, B, C, E, F, given in Fig. 8, is only a particular case and ought to be aimed at in the construction of the machine.

When there are only three turns within a space through which the armature moves with respect to the field during the time that corresponds to a complete period as in the case of the Lauffen generator (see Figs. 11 and 12), then the field of the field magnets must be constant in intensity during an angle which corresponds to one-sixth of the period. I have indicated that in the diagram Fig. 9. In the case of bipolar three-phasal generators, as indicated in the diagram Fig. 10, where we have six coils, the diametrically opposite pairs being connected in series; the pole faces must have an angular width of 120 degrees and the field must be constant in intensity within the region



Figs. 11 and 12.—Polyphasal Generators.

bounded at any moment by the armature and the pole faces. This is a practical problem offering no serious difficulties judging from the experimental results obtained by S. Thompson, Isenbeck, Mordey, and others, and also from the experimental results obtained lately by a graduate of our school, Mr. Freedman, John Tyndall Fellow of Columbia College.

The curve of impressed E. M. F. which must be produced in the case of a four-phasal generator is given in Fig. 13, and needs no further commentary. Larger numbers of phases offer no special advantages, whereas the disadvantages arising from employing a large number of phases are self-evident.

3. When a coil in which a simple harmonic E. M. F. is developed is closed by a resistance, whether self-inductive or non-self-inductive, the current which is set up in the circuit closed will be a simple harmonic, having therefore all the characteristics of the impressed E. M. F. This, however, is not necessarily the case when the impressed E. M. F. is a complex harmonic. A complex harmonic E. M. F. is composed of a large number of simple harmonic E. M. Fs. of different frequencies, all the higher frequencies being multiplies of the fundamental frequency. When, therefore, a coil in which a complex E. M. F. is generated is closed by a conductor, and the current is started, the current will be also a complex harmonic, each simple harmonic component of the complex harmonic E. M. F. producing its own simple harmonic current which is a component of the resultant complex harmonic current. But since the component simple harmonic E. M. Fs. have each a different frequency, it follows that they will have a different impedance and the shifting of phase will be also different for each component current, currents of higher frequency having a larger shifting in phase and also the ratio of the amplitude of any one of the component currents to the amplitude of any other component of lower frequency being smaller than the ratio of the amplitudes of the corresponding component E. M. Fs. In this respect the propagation of the complex harmonic current wave resembles very much the propagation of a complex harmonic sound wave or a complex harmonic light wave through an absorptive medium like air. The component simple harmonic

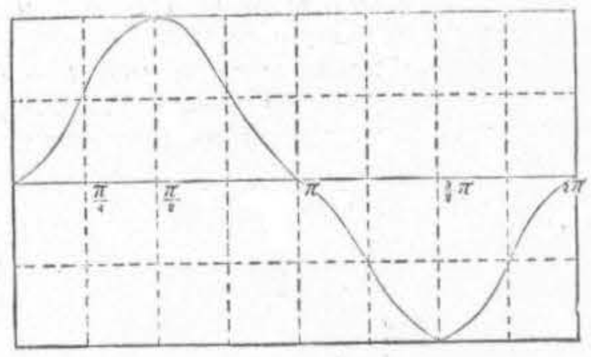


Fig. 13.—Polyphasal Generators.

waves of light and sound will in general suffer the less through the transmission the longer their wave length, just as the sound and light waves, after such a transmission, lose a great many characteristics of the original vibration which produced them, so an electric wave in its transmission through a conductor possessing ohmic resistance and electro-magnetic, not to speak of the electro-static, inductance will lose a great many characteristics of the impressed E. M. F.

To put this into simple symbolic language of mathematics,

Let L be the coefficient of self-induction of the circuit,

" R be the total resistance,

$K \sum_1^\infty{}_m a_m \sin m\,p\,t$ be the complex harmonic impressed E. M. F., where $p = 2\pi \times$ fundamental frequency.

Let x be the value of the current at any moment t. We shall have, then $L \frac{dx}{dt} + R\,x = K \sum_1^\infty{}_m a_m \sin m\,p\,t$.

The solution of this differential equation gives

$$x = K \sum_1^\infty{}_m \frac{a_m}{\sqrt{R^2 + m^2\,p^2\,L^2}} \sin (m\,p\,t - \varphi_m)$$

$$\text{where } \tan \alpha_m = \frac{m\,p\,L}{R}.$$

The current x is a complex harmonic, its component simple harmonic currents being

$$x = x + x_2 + \ldots\ldots + x_m + \ldots\ldots \text{ ad infin.}$$

$$\text{The current } x_\alpha = \frac{K\,a_\alpha}{\sqrt{R^2 + a^2\,p^2\,L^2}} \sin (a\,p\,t - \varphi_\alpha)$$

$$\tan \varphi_\alpha = \frac{a\,p\,L}{R}.$$

Let E be the impressed E. M. F., then

$$E = e_1 + e_2 + e_3 + \ldots\ldots + e_m + \ldots\ldots \text{ ad infin.}$$

The component simple harmonic E. M. F. e_α is given by

$$e_\alpha = a_\alpha \sin a\,p\,t.$$

These relations give an exact quantitative expression to the preceding physical description.

These considerations made me hesitate at first in taking as granted that a polyphasal generator producing complex E. M. Fs., such as I deduced mathematically in the course of my paper, would be capable of producing a rotary magnetic field of constant intensity. But I was glad to find out that my hesitation was groundless, at any rate in certain particular simple cases.

Consider the three-phasal generator whose diagram is given in Fig. 10. Take now another *well-laminated* armature wound in a similar way as the armature of the generator. Connect the three pairs of coils of the generator to the three sets of coils in armature 2. We shall have three separate circuits, the ohmic resistance and the self and mutual inductance in each circuit being the same.

* M. v. Dolivo-Dobrowolsky: Der Drehstrom und seine Entwickelung; Officiele Austellungs Zeitung, Electricitaet, Heft 12.

Denote by $E_1 E_2 F_3$ the three complex harmonic E. M. Fs. in the three circuits. Let x, y, z be the currents at any moment. Then we shall have

$$L\frac{dx}{dt} + M\frac{dy}{dt} + M\frac{dz}{dt} + Rx = E_1$$

$$L\frac{dy}{dt} + M\frac{dx}{dt} + M\frac{dz}{dt} + Ry = E_2$$

$$L\frac{dz}{dt} + M\frac{dx}{dt} + M\frac{dy}{dt} + Rz = E_3$$

But since $E_1 + E_2 + E_3 = 0$ for all values of t it follows that $L\frac{d}{dt}(x + y + z) - 2M\frac{d}{dt}(x + y + z) + R(x + y + z) = 0$ for all values of t. This can be true only if $x + y + z = 0$ for all values of t. That is to say, the currents fulfill the condition of continuity. We can therefore employ the method of polyphasal connection. Substitute now in the first of the three differential equations $z = -(x + y)$ and we obtain $(L - M)\frac{dx}{dt} + Rx =$

$$E_1 = K\sum_{1}^{\infty}{}_{m} a_m \sin m p t.$$

The solution of this equation gives

$$x = K\sum_{1}^{\infty}{}_{m} \frac{a_m}{\sqrt{R^2 + m^2 p^2 (L-M)^2}} \sin (m p t - \varphi_m).$$

Similarly

$$y = K\sum_{1}^{\infty}{}_{m} \frac{a_m}{\sqrt{R^2 + m^2 p^2 (L-M)^2}} \sin\left\{m\left(pt + \frac{2\pi}{3}\right) - \varphi_m\right\}.$$

$$z = K\sum_{1}^{\infty}{}_{m} \frac{a_m}{\sqrt{R^2 + m^2 p^2 (L-M)^2}} \sin\left\{m\left(pt + \frac{4\pi}{3}\right) \varphi_m\right\}.$$

In the case under consideration both L and M are pretty small when the metallic parts of the magnetic circuits are near the saturation point, so that $L - M$ is small, and $m^2 p^2 (L-M)^2$ will be very small in comparison to R^2 even for large values of m, unless the frequency is very high. Also since

$$\tan = \varphi_m \frac{m p (L - M)}{R}$$

φ_m is exceedingly small unless p is very large, we shall have for moderate frequency generators

$$x = \frac{K}{R}\sum_{1}^{\infty}{}_{m} a_m \sin m p t.$$

and similarly for y and z. The same method of reasoning may be easily applied to any number of phases. The mathematical operations will be considerably larger, but still the same results will be deduced without much difficulty.

That is to say, the curves for the currents are the same complex harmonics as those of the impressed E. M. F. The currents, therefore, produce a rotary magnetic field of constant intensity. This is evidently true even if these currents produce a saturation in the iron part of the magnetic circuits.

The resemblance between a polyphasal generator and a continuous current dynamo, which these relations bring into view, is exceedingly striking and instructive.

The advantages gained from a polyphasal generator capable of producing a rotary magnetic field of constant intensity would be very much diminished indeed if it should turn out that it is impossible to devise a simple and efficient method of transformation,* by means of which the polyphasal system of currents producing a rotary field of constant intensity (a constant rotary field system) can be transformed any number of times without losing its distinguishing characteristic. I intended to discuss this problem also this evening, but having been disappointed by the mechanician, who is constructing several pieces of apparatus illustrating this problem, I decided to postpone this discussion to some other time.

To sum up:

1. The consideration of simple harmonic impressed E. M. forces does not tell the whole story of the polyphasal generators.

2. The law of the variation of the strength of the rotary magnetic field which a polyphasal generator can produce is not as simple as Mr. v. D. Dobrowolsky thinks.

3. Polyphasal coupled transformers must be worked at low magnetizations and low frequencies, otherwise they will not satisfy the condition of continuity. It follows, therefore, that they will probably be very large for the output which they can give.

4. It is very probable that nearly constant rotary magnetic fields can be produced in practice by a small number of phases (perhaps not more than three phases) by properly shaping the curve of the impressed E. M. F.

The Westinghouse Reorganization.

The plan of reorganization adopted by the Board of Directors April 14, 1891, and by the stockholders July 15, 1891, has been completed for some time. The stockholders have responded with substantial unanimity to the call for the surrender of forty per cent. of their holdings for the use of the company. Of the stock at the disposal of the company, $4,000,000 has been converted into seven per cent. preferential, cumulative stock and the balance into "assenting stock," entitled after the preferred stock, to a seven per cent. annual preference. Provision has been made for the company's debt and working capital by the sale at par of $3,000,000 of the preferred stock, for which payment in full has been received.

The company have acquired almost all of the stock of the United States Electric Lighting Co. and the Consolidated Electric Light Co. (commonly referred to as the "leased companies"), so that the fixed charges formerly incident to the lessee of those companies are now substantially obliterated, and the consolidation of interests thus effected has rendered possible a great reduction in general expenses. The saving in interest upon debt, rentals and other fixed charges, thus effected by the reorganization, amounts to more than $400,000 per year. All this has been accomplished without increasing the company's capital stock ($10,000,000), of which over $1,000,000, common and preferred, still remains in the treasury for future use. The reorganization has been effected without litigation and without interruption to the business, the three factories having been kept in continuous operation. The company have never been so favorably situated for work as now, and they have every prospect for a large and profitable business.

medicine" man, for a serious worker cannot despise anything more than the misuse and abuse of electricity, which we have frequent occasion to witness. My remarks are elicited by the lively interest which prominent medical practitioners evince at every real advance in electrical investigation. The progress in recent years has been so great, that every electrician and electrical engineer is confident that electricity will become the means of accomplishing many things that have been heretofore, with our existing knowledge, deemed impossible. No wonder then that progressive physicians also should expect to find in it a powerful tool and help in new curative processes.

Since I had the honour to bring before the American Institute of Electrical Engineers some results in utilising alternating currents of high tension, I have received many letters from noted physicians inquiring as to the physical effects of such currents of high frequency. It may be remembered that I then demonstrated that a body perfectly well insulated in air can be heated by simply connecting it with a source of rapidly alternating high potential. The heating in this case is due in all probability to the bombardment of the body by air, or possibly by some other medium, which is molecular or atomic in construction, and the presence of which has so far escaped our analysis—for, according to my ideas, the true ether radiation, with such frequencies as even a few millions per second must be very small. This body may be a good conductor or it may be a very poor conductor of electricity with little change in the result. The human body is, in such a case, a fine conductor, and if a person insulated in a room, or no matter where, is brought into contact with such a source of rapidly alternating high potential, the skin is heated by bombardment. It is a mere question of the dimensions and character of the apparatus to produce any degree of heating desired.

It has occurred to me whether, with such apparatus properly prepared, it would not be possible for a skilled physician to find in it a means for the effective treatment of various types of disease. The heating will, of course, be superficial, that is, on the skin, and would result, whether the person operated on were in bed or walking around a room, whether dressed in thick clothes or whether reduced to nakedness. In fact, to put it broadly, it is conceivable that a person entirely nude at the North Pole might keep himself comfortably warm in this manner.

Without vouching for all the results, which must, of course, be determined by experience and observation, I can at least warrant the fact that heating would occur by the use of this method of subjecting the human body to bombardment by alternating currents of high potential and frequency such as I have long worked with. It is only reasonable to expect that some of the novel effects will be wholly different from those obtainable with the old familiar therapeutic methods generally used. Whether they would all be beneficial or not remains to be proved.

"MASSAGE" WITH CURRENTS OF HIGH FREQUENCY.*

By NIKOLA TESLA.

I TRUST that the present brief communication will not be interpreted by the readers of the *Electrical Engineer* as an effort on my part to put myself on record as a "patent

* *Electrical Engineer*, of New York.

Progress of Mr. Tesla's High Frequency Work.

During the past six months Mr. Nikola Tesla has been steadily at work developing the beautiful principles that he enunciated in his striking lecture before the American Institute of Electrical Engineers. In his skillful hands the experiments have extended far beyond their merely theoretical importance in the direction of important practical applications. Part of the fruits of his industry has already appeared in his method patents on incandescent lighting, another patent on condensers and divers applications that are now in the Patent Office. Many of the practical difficulties that at first appeared have been overcome and we may ere long see the results in commercial work. Meanwhile the transmission of power has not been forgotten, and some interesting improvements in that line may soon be expected, especially as the use of the methods embodied in Mr. Tesla's early patents has recently made such a sensation abroad. About the middle of January Mr. Tesla expects to sail for Europe, to deliver, at the urgent request of his English friends, a lecture on his high frequency researches and to look after his foreign interests generally. The trip will be a flying one of only a couple of months, as the pressure of work at home forbids a long absence. On his return some of the latest commercial developments of his work may be expected to appear as promptly as circumstances will permit. The revolutionary character of his methods will make any extensive application of them of unique interest.

CORRESPONDENCE.

Massage with Currents of High Frequency.

The paper by Mr. Nikola Tesla, which you publish in your last issue, is very interesting, and, doubtless, as it comes from the other side of the water, will attract some attention in English medical circles.

The suggestion set forth is not, however, so entirely new as the author seems to suppose. Raising the temperature of the human body for curative purposes by "connecting it with a source of rapidly alternating high potential" has been practised by myself for some time past, and I believe by others also. I do not say that we have gone so far as to thoroughly warm a nude body with the surrounding air at freezing point, but we have frequently produced a pleasant glow over the whole body, and warmed chill extremities.

As regards the therapeutic value of such treatment, my own experience, gained mainly at the late Institute of Medical Electricity, Limited, leads me to conclude that though this method is valuable to a certain extent, yet it is more useful as an adjunct to, than as a substitute for other forms of treatment. In saying this, I must admit that the method under which I work falls far short of the conditions referred to by Mr. Tesla. I speak of results obtained from the use of an Apps coil, giving a difference of potential of about 10,000 volts, and whose alternations could hardly be called "rapid" in this connection. It is only fair to assume that the effects observed would be much increased by increased rapidity of alternation.

The title Mr. Tesla has chosen for his paper is somewhat misleading, and it is hard to see the connection between the word "massage" and the matter dealt with. I presume he means that the effect produced by electricity thus used is similar to that obtained by massage. If so, the comparison is a very superficial one, for the effects can only be in a small degree similar, though undoubtedly the raising of the surface temperature is an accompaniment of both. I might add that in many cases I find the best effects obtained from the use of massage in addition to or in combination with the high potential coil currents above referred to.

H. Newman Lawrence, M.I.E.E.

Personal.

MR. NIKOLA TESLA left for Europe on the "Umbria" on January 16, to be gone several weeks. He has been invited to lecture before the various electrical and scientific societies of the Old World, and will appear before the English Institution of Electrical Engineers at the end of this month or early in February. While abroad he will seize the opportunity to visit his mother and relatives in Smiljan Lika.

Tesla's Experiments.—During the past six months Mr. Tesla has been hard at work developing the experiments he gave before the American Institute of Electrical Engineers, in the direction of important practical applications. Some of the points of his work are already embodied in patents on incandescent lighting and on condensers. Many of the practical difficulties have already been overcome, and it is hoped that ere long the results may be seen in commercial use.

Progress of Mr. Tesla's High Frequency Work.—The *Electrical World* says: "During the past six months, Mr. Nikola Tesla has been steadily at work developing the beautiful principles that he enunciated in his striking lecture before the American Institute of Electrical Engineers. In his skilful hands the experiments have extended far beyond their merely theoretical importance in the direction of important practical applications. Part of the fruits of his industry has already appeared in his method patents on incandescent lighting, another patent on condensers, and divers applications that are now in the Patent Office. Many of the practical difficulties that at first appeared have been overcome, and we may ere long see the results in commercial work. Meanwhile the transmission of power has not been forgotten, and some interesting improvements in that line may soon be expected, especially as the use of the methods embodied in Mr. Tesla's early patents has recently made such a sensation abroad. About the middle of January, Mr. Tesla expects to sail for Europe to deliver, at the urgent request of his English friends, a lecture on his high frequency researches, and to look after his foreign interests generally. The trip will be a flying one, of only a couple of months, as the pressure of work at home forbids a long absence. On his return, some of the latest commercial developments of his work may be expected to appear as promptly as circumstances will permit. The revolutionary character of his methods will make any extensive application of them of unique interest.

NOTES.

Mr. Tesla's Lecture.—An extraordinary general meeting of the Institution of Electrical Engineers is to be held, by kind permission of the managers, at the Royal Institution, Albemarle-street, on Wednesday, 3rd February, at 8 p.m., when Mr. Nikola Tesla will give his paper upon "Experiments with Alternate Currents of High Potential and High Frequency."

MR. TESLA AND ROTARY CURRENTS.

Mr. Nikola Tesla is now in London, and electrical engineers will be pleased to learn is busy preparing his paper and his apparatus for the promised lecture to the Institution of Electrical Engineers upon alternating currents. This will appropriately take place at the Royal Institution, Albemarle-street, on Wednesday next, by the kind permission of the governors of the celebrated institution which the world-famous experiments of Faraday have rendered such classic ground to all scientific men. The occasion cannot but mark an important era in both theoretical and practical science, for the continuous attention, the experimental skill, and the keen insight of Mr. Tesla into the hitherto little explored ground of rapidly-alternating currents of high potential, with the astonishing results in demonstrating the possibility of lighting incandescent lamps without wires, have raised the expectations of scientific men to a high pitch. Mr. Tesla may well feel a little nervousness in coming before the scientific world in the capacity of apostle of a new and unexplored field, arising out of those opened up by Faraday's immortal experiments themselves; but the extreme beauty of the research, the importance, and apparently unlimited scope of the new experiments fitly carry forward the applications of electrical science whose basis was laid so thoroughly by Faraday in 1831.

For the moment, however, we will leave the fascinating question of high-potential electric illumination, and turn to that field in which Mr. Tesla has done, if possible, even more important work—that of the rotary current. The question of rotary current has taken a very different position in the eyes of English electrical engineers during the past year, due, to a very considerable extent, to the experiment on such a large scale at the recent Frankfort Exhibition, where the transmission of several hundred horse-power over a distance of 110 miles very forcibly brought the attention of the whole world to the importance of the rotary current. Before this time the knowledge upon the question was exceedingly vague, and, curiously enough, a long battle has raged around the very discovery of the rotary magnetic field and the rotary-current motor at a time when, in reality, there seems to have been not even a shadow of a doubt that the credit of the discovery and practical application of the system belonged to Mr. Tesla, who years ago had both patented and shown in working actual motors of the descriptions since shown in various other parts of the world.

The return of Mr. Tesla to Europe, together with the fuller details of his work, which will now be before us, will serve to create an entire revolution in the minds of a great many of those who are at present occupied, tentatively or practically, with this absorbingly interesting problem, and will put the whole question upon its proper basis. Until the publication in our columns a few months ago (September 11th, 1891, p. 246) of details and dates which were authoritatively given in America upon Mr. Tesla's experiments, the European electrical world was in doubt upon the whole question, or more probably gave the credit of the first discovery to Prof. Ferraris—whose work in this field certainly deserves the highest recognition—and the credit of the construction of the rotary-current motor, either singly or conjointly, to Herr Dobrowolsky, Herr Haselwander, or others.



NIKOLA TESLA.

It may be well to recall the dates given in the article above-mentioned. Prof. Ferraris's paper was given in March, 1888, and published shortly afterwards. Five months before this Mr. Tesla had filed his patents, and motors were run experimentally. On May 1, 1888, the patents were issued, and in the same month these motors were shown before the American Institute of Electrical Engineers, while it was not till May 18th that the work of Prof. Ferraris was published in England. As mentioned in our article on July 31st, 1891, it appears that Haselwander's rotary-current dynamo was constructed in the summer of 1889, and first set to work on 12th October of the same year; on July, 21, 1888, Haselwander applied for his German patents, which were accepted in 1890, and issued in June, 1890. Prof. Ferraris's experiments were undertaken in 1885, but Mr. Tesla claims to have been earlier afield. It seems, however, perfectly clear that men in widely separate localities were working independently, though contemporaneously, in the same direction and for similar objects.

On hearing that Mr. Tesla had arrived in London, we thought it well to take an early opportunity of calling upon him to obtain from him some particulars of the progress of the application of the rotary current in America, and to hear his views upon the question.

In the first place, it is interesting to learn that Mr. Tesla's discovery was due originally, not to direct experiment, but to abstract reasoning and mathematical calculation. A native of Montenegro, Mr. Tesla later came to Paris, and in the course of his lectures and study

was more particularly interested in the fascinating study of mathematical maxima and minima. Watching the action of the reversed dynamo running as a motor with segmented commutator, he suggested the desirability and the possibility of constructing a motor without commutator, which suggestion was scouted at the time. The march of his ideas, however, may be gauged from the mention of the maxima and minima theorem. Granted a rising and falling of E.M.F. in the commutator of a dynamo due to revolving position of the coils as now run, it was easy to jump to the conclusion that if waxing and waning currents could be sent into the coils in proper order, rotation should be at once obtained. Mr. Tesla is one of those gifted men who have that remarkable property, present in all men of high talent or genius, of an extraordinarily strong imaginative or conceptive faculty, by which material combinations are represented in the mind before they are constructed either on paper or in material substances. His motor was constructed and the results deliberately worked out in his mind before ever experiments were made; and he knew absolutely both that his motor would run, and which way it would run upon joining up the wires, and the result accrued exactly as expected. Unable to obtain sufficient

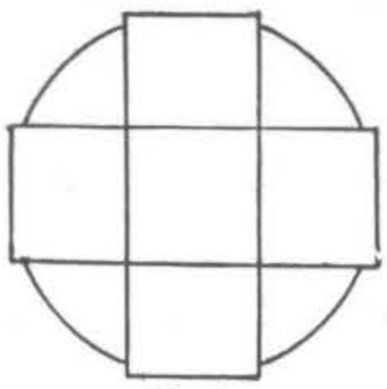


Fig. 1

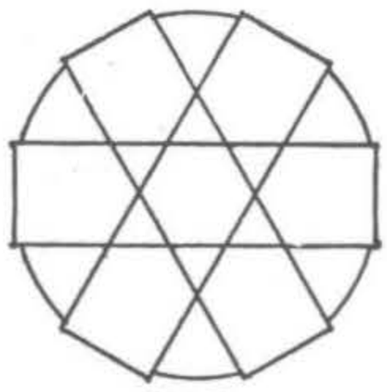


Fig 2

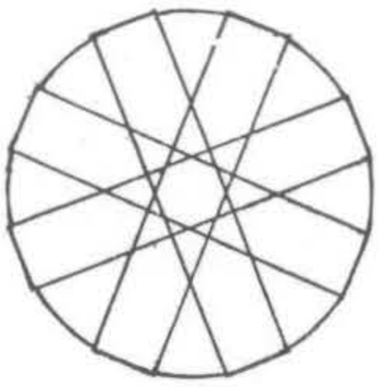


Fig 3

support in Europe, Mr. Tesla went to America, and there constructed and patented his motors. He constructed motors with the simple two-phase mentioned by Ferraris, in which the armature is wound at right angles, as indicated in Fig. 1. He constructed the three-phase motor since rendered famous as "Drehstrom" in Germany, in which the coils are distributed at an angle of 180deg. round the armature, as indicated in Fig. 2. He, further, long and exhaustively experimented with multiphase currents, both with split coils and with numerous separate currents, up to a dozen or more currents. The split multiphase current indicated in Fig. 3 is a simple modification of Fig. 2, by merely winding the three coils each in two coils disposed at a little distance from each other, thus producing a multiphase field; and he arrived conclusively at this result, that for practical purposes there is little to be gained in efficiency from the use of greatly-divided fields—not more, he finds, than of the nature of $\frac{1}{2}$ per cent. gain. Motors were constructed, tested, and shown at the dates already mentioned, with efficiencies of over 90 per cent., and of great capacity for the weight—for instance, a 10-h.p. motor of 90 per cent. efficiency weighing only 850lb., half the weight of any of the same power since constructed in Europe. Results so promising, not to say revolutionary, could not but receive support, but his financial partners advised against publication of the full details and results, or European engineers would have long been in possession of the facts of the case. Mr Tesla's inventions, after being broadly protected in America, England, and Germany, amongst other countries, were taken up by Mr. Westinghouse, who proposed at once to put down large works capable of turning out 1,000 motors a week. Unfortunately, just at this moment occurred the financial panic which, it will be remembered, was suffered by the Westinghouse companies, and the matter had to be left. However, this has now been got over, and the motors are being made, and applied as fast as made. Mr. Tesla informs us—a fact that will astonish European electrical engineers considerably—that before he left he had seen running a 1,000 h.p. Tesla alternate-current motor, one of a number now being constructed at the Westinghouse Works in Pittsburgh for transmission of power. These are motors with revolving armature and three collector rings. Large numbers of the smaller motors have been in application for some time principally for mining purposes at high efficiencies and without needing repair. These motors start under load with strong torque: as an illustration, one experiment, with a small motor, was tried with a fixed rope over a 12in. pulley on the axle of the motor—the rope being previously tested to withstand 1,000lb. pull. On starting from rest the rope snapped immediately—a tangible demonstration of the strength of torque. Mr. Tesla states that his system of winding the alternate-current motors has now been brought to such a state of perfection, that for a three-wire circuit he can guarantee to build motors of large size to give 1 h.p. for every 20lb. of weight of an efficiency of $97\frac{1}{2}$ per cent. What result better than this could be desired it is certainly difficult to imagine. It is evident, as we have said, that Mr. Tesla's appearance upon the scene will change the attitude of scientific men and engineers very considerably, both as regards the utilisation of rotary-current motors and as to the credit which should be given to this most interesting discovery.

Mr. Tesla's Lecture to the Institution of Electrical Engineers.—On the occasion of Mr. Tesla's lecture on alternating currents of high potential next Wednesday, the members will meet at the Royal Institution, Albemarle Street.

The Electro-Harmonic Society.—Members will doubtless be glad to meet again on Friday evening next, for the interval since the last concert has been a lengthy one. The programme is of a lighter order than usual so far as the part singing is concerned, there being several items calculated to produce merriment. Professor Ayrton, F.R.S., President of the Institute Electrical Engineers, has kindly consented to take the chair, and we believe that Mr. Nikola Tesla will accompany him, so everybody ought to be at high tension on the evening in question.

SOME POSSIBILITIES OF ELECTRICITY.

We know little as yet concerning the mighty agency we call electricity. "Substantialists" tell us it is a kind of matter. Others view it, not as matter, but as a form of energy. Others, again, reject both these views. Professor Lodge considers it "a form, or rather a mode of manifestation of the ether." Professor Nikola Tesla demurs to the view of Professor Lodge, but thinks that "nothing would seem to stand in the way of calling electricity ether associated with matter, or bound ether." High authorities cannot yet even agree whether we have one electricity or two opposite electricities. The only way to tackle the difficulty is to persevere in experiment and observation. If we never learn what electricity is; if, like life or like matter, it should always remain an unknown quantity, we shall assuredly discover more about its attributes and functions.

The light which the study of electricity throws upon a variety of chemical phenomena—witnessed alike in our little laboratories and in the vast laboratories of the earth and sun—cannot be overlooked. Without going into transcendental speculations as to the origin of all things, it may be mentioned that the theory which now meets with most favour as best representing the genesis of the chemical elements is, that at the time each element was differentiated from the all-pervading *protyl*, it took to itself definite quantities of electricity, and upon these quantities the atomicity of the element depends. Professor Oliver Lodge expresses this when he says, "Every monad atom has associated with it a certain definite quantity of electricity; every dyad has twice this quantity associated with it; every triad three times as much, and so on."[1] Helmholtz considers it to be probable that electricity is as atomic as matter, and that an electrical atom is as definite a quantity as a chemical atom. This, however, must not yet be regarded as a certainty, for it is possible that all the facts at present known may be explicable in another way. If an atom of matter is endowed with the property of taking to itself one, two, three, or more units of electricity, it does not follow that electricity is atomic. Imagine the atoms of matter to act like so many bottles, capable of holding one, two, three, or more pints. Imagine electricity to be like water in the ocean, which for the purposes of this argument may be considered inexhaustible and structureless. One of the atomic "bottle" elements dipped into the ocean would certainly take to itself one, two, three, or more pints

(1) "On Electrolysis," Britis Association Reports, 1885.

of water, but it would by no means follow that the ocean was atomic in that it was capable of being divided up into an infinite number of little parcels, each holding a pint or its multiple.

For this and other reasons I think we must accept the hypothesis of the atomic character of electricity as not yet definitely proved, although it is not improbable.

I have spoken of the "ether"—an impalpable, invisible entity, by which all space is supposed to be filled. By means of the ether theory we can explain electrical phenomena, as well as those appertaining to the phenomena of light.

Until quite recently we have been acquainted with only a very narrow range of ethereal vibrations, from the extreme red of the solar spectrum on the one side to the ultra-violet on the other—say, from three ten-millionths of a millimetre to eight ten-millionths of a millimetre. Within this comparatively limited range of ethereal vibrations and the equally narrow range of sound-vibrations all our knowledge has been hitherto confined.

Whether vibrations of the ether, longer than those which affect us as light, may not be constantly at work around us, we have, until lately, never seriously enquired. But the researches of Lodge in England and of Hertz in Germany give us an almost infinite range of ethereal vibrations or electrical rays, from wave-lengths of thousands of miles down to a few feet. Here is unfolded to us a new and astonishing world—one which it is hard to conceive should contain no possibilities of transmitting and receiving intelligence.

Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog. But the electrical vibrations of a yard or more in wave-length of which I have spoken will easily pierce such mediums, which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possibile fulfilment. At the present time experimentalists are able to generate electrical waves of any desired wave-length from a few feet upwards, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably-shaped bodies acting as lenses, and so direct a sheaf of rays in any given direction; enormous lens-shaped masses of pitch and similar bodies have been used for this purpose. Also an experimentalist at a distance can receive some, if not all, of these rays on a properly-constituted instrument, and by concerted signals messages in the Morse code can thus pass from one operator to another. What, therefore, remains to be discovered is—firstly, simpler and more certain means of generating electrical rays of any desired wave-length, from the

shortest, say of a few feet in length, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers which will respond to wave-lengths between certain defined limits and be silent to all others; thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space in all directions, and fading away according to the law of inverse squares.

Any two friends living within the radius of sensibility of their receiving instruments, having first decided on their special wave-length and attuned their respective instruments to mutual receptivity, could thus communicate as long and as often as they pleased by timing the impulses to produce long and short intervals on the ordinary Morse code. At first sight an objection to this plan would be its want of secrecy. Assuming that the correspondents were a mile apart, the transmitter would send out the waves in all directions, filling a sphere a mile in radius, and it would therefore be possible for any one living within a mile of the sender to receive the communication. This could be got over in two ways. If the exact position of both sending and receiving instruments were accurately known, the rays could be concentrated with more or less exactness on the receiver. If, however, the sender and receiver were moving about, so that the lens device could not be adopted, the correspondents must attune their instruments to a definite wave-length, say, for example, fifty yards. I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw or altering the length of a wire, so as to become receptive of wave-lengths of any preconcerted length. Thus, when adjusted to fifty yards, the transmitter might emit, and the receiver respond to, rays varying between forty-five and fifty-five yards, and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy; for curiosity the most inveterate would surely recoil from the task of passing in review all the millions of possible wave-lengths on the remote chance of ultimately hitting on the particular wave-length employed by his friends whose correspondence he wished to tap. By "coding" the message even this remote chance of surreptitious straying could be obviated.

This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in

the path of researches which are now being actively prosecuted in every capital of Europe that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. Even now, indeed, telegraphing without wires is possible within a restricted radius of a few hundred yards, and some years ago I assisted at experiments where messages were transmitted from one part of a house to another without an intervening wire by almost the identical means here described.

The discovery of a receiver sensitive to one set of wave-lengths and silent to others is even now partially accomplished. The human eye is an instance supplied by nature of one which responds to the narrow range of electro-magnetic impulses between the three ten-millionths of a millimetre and the eight ten-millionths of a millimetre. It is not improbable that other sentient beings have organs of sense which do not respond to some or any of the rays to which our eyes are sensitive, but are able to appreciate other vibrations to which we are blind. Such beings would practically be living in a different world to our own. Imagine, for instance, what idea we should form of surrounding objects were we endowed with eyes not sensitive to the ordinary rays of light but sensitive to the vibrations concerned in electric and magnetic phenomena. Glass and crystal would be among the most opaque of bodies. Metals would be more or less transparent, and a telegraph wire through the air would look like a long narrow hole drilled through an impervious solid body. A dynamo in active work would resemble a conflagration, whilst a permanent magnet would realise the dream of mediæval mystics and become an everlasting lamp with no expenditure of energy or consumption of fuel.

In some parts of the human brain may lurk an organ capable of transmitting and receiving other electrical rays of wave-lengths hitherto undetected by instrumental means. These may be instrumental in transmitting thought from one brain to another. In such a way the recognised cases of thought transference, and the many instances of "coincidence" would be explicable. I will not speculate on the result were we eventually to catch and harness these "brain-waves."

Whatever be the length of the electric wave, the velocity with which it travels is constant, and is equal to the velocity of light, or about one hundred and eighty thousand miles a second. Professor Oliver Lodge, who has worked for some years on these subjects, gives[1] formulæ for calculating the frequency of vibration and the wave-length of the electrical rays given by the discharge of Leyden jars of different capacities. The bigger the jar and the greater the size of the circuit the longer will be the waves. Thus, a pint jar discharging through a two-yard circuit will give waves of a length

(1) *Modern Views of Electricity*, pp. 246-7.

of fifteen or twenty metres, and they will follow each other at the rate of ten millions a second. A jar the size of a thimble will give waves only about two or three feet long, and they will succeed one another at the rate of two hundred and fifty or three hundred millions a second. With every diminution in size of the apparatus the wave-lengths get shorter, and could we construct Leyden jars of molecular dimensions, Professor Lodge considers the rays might fall within the narrow limits of visibility. We do not know the intimate structure of a molecule sufficiently to understand how it could act as a Leyden jar; yet it is not improbable that the discontinuous phosphorescent light emitted from certain of the rare earths, when excited by a high tension current of elecricity in a good vacuum, is really an artificial production of these electric waves, sufficiently short to affect our organs of vision. If such a light could be produced more easily and more regularly, it would be far more economical than light from a flame or from the arc or incandescent lamp, as very little of the energy is expended in the form of heat rays. Of such production of light Nature supplies us with examples in the glow-worm and the fire-flies, whose light, though sufficiently energetic to be seen at a considerable distance, is accompanied by no liberation of heat capable of detection by our most delicate instruments.

By means of currents alternating with very high frequency, Professor Nikola Tesla has succeeded in passing by induction, through the glass of a lamp, energy sufficient to keep a filament in a state of incandescence without the use of connecting wires. These lamps possess one interesting feature; they can be rendered at will more or less brilliant by simply altering the relative position of the outside and inside condenser coatings. If exhausted glass tubes are used as the source of light, very beautiful effects are produced. The electric generator is capable of exciting the tubes at a considerable distance, and the luminous effects are very striking. For instance, if a tube be taken in one hand, the observer being near the generator, it will be brilliantly lighted, and will remain so, no matter in what position it is held relatively to the observer's body. Even with tubes having no electrodes there is no difficulty in producing by this means sufficient light to read by, and the light will be considerably increased by the use of phosphorescent materials, such as yttria, uranium-glass, &c.

The ideal way of lighting a room would be by creating in it a powerful, rapidly-alternating electrostatic field, in which a vacuum tube could be moved and put anywhere, and lighted without being metallically connected with anything. Professor Tesla has obtained such a condition by suspending, some distance apart, two sheets of metal, each connected with one of the terminals of the induction

coil. If an exhausted tube is carried anywhere between these plates it remains always luminous. In such a room, in addition to the luminous phenomena mentioned, it is observed that any insulated conductor gives sparks when the hand or any other object is approached to it, and the sparks may often be powerful.

Alternating currents have at best a somewhat doubtful reputation; but it follows from Tesla's researches that, as the rapidity of the alternation increases, they become incomparably less dangerous. It further appears that a true flame can now be produced without chemical aid—a flame which yields light and heat without the consumption of material and without any chemical process. To this end we require improved methods for producing excessively frequent alternations and enormous potentials. The energy required is very small, and if light can be obtained as efficiently as, theoretically, it appears possible, the apparatus need have but a very small output. For the production of light at least, the heavy machinery at present in use would seem to be unnecessary. There being a strong probability that the illuminating methods of the future will involve the use of very high potentials, one of the problems in the near future will be to perfect a contrivance capable of converting the energy of heat into energy of the required form. The extent to which this new method of illumination may be practically available experiment alone can decide. In any case our insight into the possibilities of static electricity have been extended, and the ordinary electrostatic machine will cease to be regarded as a mere toy.

Another tempting field of research, scarcely yet attacked by pioneers, awaits exploration. I allude to the mutual action of electricity and life. No sound man of science endorses the assertion that "electricity is life;" nor can we ever venture to speak of life as one of the varieties or manifestations of energy. Nevertheless, electricity has an important influence upon vital phenomena, and is in turn set in action by the living being, animal or vegetable. We have electric fishes—one of them the prototype of the torpedo of modern warfare. There is the electric slug, which is reported to have been met with in gardens and roads about Hornsey Rise, and which, if touched, occasioned a momentary numbness of the finger-tip. There is also an electrical centipede. In the study of such facts and such relations the scientific electrician has before him an almost infinite field of inquiry.

If we take a bird's-eye view of the solid work that lies ahead, the first requisite is certainly a source of electricity cheaper and more universally applicable than the tedious conversion of chemical energy into heat, of heat again into mechanical power, and of such power into electric current. It is depressing to reflect that this roundabout process, with losses at every step, is still our best

means of obtaining a supply of electricity. Until this is accomplished, we are still haunted by the steam-engine with its clouds of smoke and its heaps of cinders and ashes. Water power to set dynamos in action is only available in exceptional cases, and very rarely indeed in our country. Whilst we are seeking for cheaper sources of electricity, no endeavour must be spared to tame the fierceness of those powerful alternating currents now so largely used. Too many clever electricians have shared the fate of Tullus Hostilius, who, according to the Roman myth, incurred the wrath of Jove for practising magical arts, and was struck dead with a thunderbolt. In modern language, he was simply working with a high tension current, and, inadvertently touching a live wire, got a fatal shock.

We know that the rays of the arc light, allowed to act judiciously on plants, may, to a more or less extent, compensate for lack of solar heat and light; but so long as electric energy is so costly, we cannot bring this interesting fact into industrial practice. In respect to vegetation, it is still uncertain whether electrical currents exercise any decided or uniform influence upon growing crops of grain or fruit; or whether such influence would be favourable or the reverse. Experiments tried by the late Sir W. Siemens lead to the opinion that electricity may induce earlier and better harvests; but much further study is here needed. Nor have we yet solved the equally important and closely connected question, whether we may by electrical action rout the parasitical insects and fungi which in some seasons rob us of no less than the tenth of our crops. A moderate estimate puts the mean loss in the home kingdoms at £12,000,000 per annum. In India and some of the colonies, a number of destroyers, which it is not my business to specify, are less easily contented. Like Falstaff, in the words of Dame Quickly, they seek to take, "not some, but all." The attacks of the phylloxera have cost our French neighbours more than did the Franco-Prussian war.

It has been found in not a few experiments that electric currents not only give increased vigour to the life of the higher plants, but tend to paralyse the baneful activity of parasites, animal and vegetable. Here, then, is unlimited scope for practical research, in which the electrical engineer must join forces with the farmer, the gardener, and the vegetable physiologist. We have definitely to decide whether, and under what circumstance, electricity is beneficial to our crops; and whether, and under what conditions, it is deadly to parasitic pests.

With regard to the possible applications of electricity to agriculture, I may mention that the total amount of *vis viva* which the sun pours out yearly upon every acre of the earth's surface, chiefly in the form of heat, is 800,000 horse-power.[1] Of this mighty

(1) *The Perplexed Farmer*, by George Ville. English Edition, by W. Crookes.

supply of energy a flourishing crop utilizes only 3,200 horse-power, so that the energy wasted per acre of land is 796,800 horse-power. We talk loudly of the importance of utilizing the refuse of our manufactures; but what is the value of alkali waste, of furnace slags, of coal tar, or of all of them together, compared to the loss of 796,800 horse-power per acre?

The application of electricity to sanitary improvements is another possibility, turning again mainly on a cheap supply of current. The electrical treatment and purification of sewage and industrial waste waters is a demonstrated reality which merely requires a reduction in the cost of the agent employed.

The sterilization, *i.e.*, the destruction of disease germs by electrical means, of the water supply of cities has been proposed and discussed. Theoretically, it is possible, but the practical difficulty of dealing with the vast volumes of water required for the daily consumption of London is prodigious. But, "a difficulty," said Lord Lyndhurst, "is a thing to be overcome." There is a still more important consideration; the living organisms in water are by no means all pathogenic—many are demonstratively harmless, and others are probably beneficial. Pasteur proposed to bring up young animals on sterilized food and drink with a view to determine whether their health and development would be affected for the better or for the worse. Decisive results are not yet forthcoming. Before the sterilization of our water sources can be prudently undertaken, this great question must be first decided by experimental biologists.

Another point at which the practical electrician should aim is nothing less than the control of the weather. We are told that these islands have no climate—merely samples—that an English summer consists of three fine days and a thunderstorm, and that the only fruit that ripens with us is a baked apple. There is more than a grain of truth in this sarcasm. The great evil of a thunderstorm in this country is not that the lightning may kill a man or a cow, or set barns or stacks on fire. The real calamity consists in the weather being upset. The storm is followed by a fall of temperature; and a fit of rain, clouds and wind, which rarely lasts less than a week, sadly interferes with the growth and ripening of grain and fruits. The question is, Cannot the accumulations of electric energy in the atmosphere be thwarted, dispersed, or turned to practical use? In like manner we may hope to abate the terrible fog nuisance, which is now in point of time no longer confined to the month of November, and by no means limits its attacks to London. It has been shown that during a genuine London fog the air is decidedly electro-positive. What the effect would be of neutralizing it would not be very difficult to show.

We hear of attempts at rain-making said to have been more or less successful. Shall we ever be able, not to reduce our rainfall in quantity, but to concentrate it on a smaller number of days, so as to be freed from a perennial drizzle?

I shall, perhaps, be styled a dreamer, or something worse, if I remotely hint at still further amending the ways of Nature. We all know, too well, that cloudiness and rainfall occur chiefly by day, and clear skies at night. This is precisely the opposite distribution to that which our crops require. We need clear heavens by day, that the supply of sunshine may not be interfered with, and we want clouds at night to prevent the earth losing by radiation the heat which it has gained in the day. As we have just seen, Nature supplies energy amply sufficient. How is this enormous quantity of power to be made available? These are problems which may safely be left to the devices and the inspirations of our electrical engineers.

I have thus glanced at some of the intricate electrical problems to be solved—some of the enormous difficulties to be surmounted. Progress, a word now in the mouth of everyone, may—as Dean Swift observed—be too fast for endurance. Sufficient for this generation are the wonders thereof!

WILLIAM CROOKES.

JOURNAL

OF THE

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An Extraordinary General Meeting of the Institution was held at the Royal Institution, Albemarle Street, on Wednesday evening, February 3rd—Professor W. E. AYRTON, F.R.S., President, in the Chair.

The following lecture was delivered by NIKOLA TESLA, Foreign Member, on

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.

Ladies and Gentlemen,—I cannot find words to express how deeply I feel the honour of addressing some of the foremost thinkers of the present times, and so many able scientific men, engineers and electricians, of the country greatest in scientific achievements.

The results which I have the honour to present before *such* gathering I cannot call my own. There are among you not a few who can lay better claim than myself on any feature of merit which this work may contain. I need not mention many names which are world-known—names of those among you who are recognised as the leaders in this enchanting science; but *one*, at least, I must mention—a name which could not be omitted in a demonstration of this kind. It is a name associated with the most beautiful invention ever made: it is Crookes!

When I was at college, a good time ago, I read, in a translation (for then I was not familiar with your magnificent language), the description of his experiments on radiant matter. I read it only *once* in my life—*that* time—yet every detail about that charming work I can remember this day. Few are the books, let me say, which can make such an impression upon the mind of a student.

But if on the present occasion I mention this name, as one of many your Institution can boast of, it is because I have more than one reason to do so. For what I have to tell you and to show you this evening concerns in a large measure that same vague world which Professor Crookes has so ably explored; and, more than this, when I trace back the mental process which led me to these advances—which even by myself cannot be considered trifling, since they are so appreciated by you—I believe that their real origin, that which started me to work in this direction, and brought me to them after a long period of constant thought, was that fascinating little book which I read many years ago.

And now that I have made a feeble effort to express my homage and acknowledge my indebtedness to him and others among you, I will make a second effort, which I hope you will not find so feeble as the first, to entertain you.

Give me leave to introduce the subject in a few words.

A short time ago I had the honour to bring before our American Institute of Electrical Engineers some results then arrived at by me in a novel line of work. I need not assure you that the many evidences which I have received that English scientific men and engineers were interested in this work, have been for me a great reward and encouragement. I will not dwell upon the experiments already described, except with the view of completing, or more clearly expressing, some ideas advanced by me before, and also with the view of rendering the study here presented self-contained, and my remarks on the subject of this evening's lecture consistent.

This investigation, then, it goes without saying, deals with alternating currents, and, to be more precise, with alternating currents of high potential and high frequency. Just in how much a very high frequency is essential for the production of the results presented, is a question which, even with my present experience, would embarrass me to answer. Some of the experiments may be performed with low frequencies; but very high frequencies are desirable, not only on account of the many effects secured by their use, but also as a convenient means of obtaining, in the induction apparatus employed, the high potentials which, in their turn, are necessary to the demonstration of most of the experiments here contemplated.

Of the various branches of electrical investigation, perhaps the most interesting and immediately the most promising is that dealing with alternating currents. The progress in this branch of applied science has been so great in recent years that it justifies the most sanguine hopes. Hardly have we become familiar with one fact, when novel experiences are made, and new avenues of research are opened. Even at this hour possibilities not dreamt of before are, by the use of these currents, partly realised. As in Nature all is ebb and tide, all is wave motion, so it seems that in all branches of industry alternating currents—electric wave motion—will have the sway.

One reason, perhaps, why this branch of science is being so rapidly developed is to be found in the interest which is attached to its experimental study. We wind a simple ring of iron with coils; we establish the connections to the generator, and with wonder and delight we note the effects of strange forces which we bring into play, which allow us to transform, to transmit and direct energy at will. We arrange the circuits properly, and we see the mass of iron and wires behave as though it were endowed with life, spinning a heavy armature, through invisible connections, with great speed and power—with the energy possibly conveyed from a great distance. We observe how the energy of an alternating current traversing the wire manifests itself—not so much in the wire as in the surrounding space—in the most surprising manner, taking the forms of heat, light, mechanical energy, and, most surprising of all, even chemical affinity. All these observations fascinate us, and fill us with an intense desire to know more about the nature of these phenomena. Each day

we go to our work in the hope of discovering,—in the hope that some one, no matter who, may find a solution of one of the pending great problems,—and each succeeding day we return to our task with renewed ardour; and even if we *are* unsuccessful, our work has not been in vain, for in these strivings, in these efforts, we have found hours of untold pleasure, and we have directed our energies to the benefit of mankind.

We may take—at random, if you choose—any of the many experiments which may be performed with alternating currents; a few of which only, and by no means the most striking, form the subject of this evening's demonstration: they are all equally interesting, equally inciting to thought.

Here is a simple glass tube from which the air has been partially exhausted. I take hold of it; I bring my body in contact with a wire conveying alternating currents of high potential, and the tube in my hand is brilliantly lighted. In whatever position I may put it, wherever I may move it in space, as far as I can reach, its soft, pleasing light persists with undiminished brightness.

Here is an exhausted bulb suspended from a single wire. Standing on an insulated support, I grasp it, and a platinum button mounted in it is brought to vivid incandescence.

Here, attached to a leading wire, is another bulb, which, as I touch its metallic socket, is filled with magnificent colours of phosphorescent light.

Here still another, which by my fingers' touch casts a shadow—the Crookes shadow of the stem inside of it.

Here, again, insulated as I stand on this platform, I bring my body in contact with one of the terminals of the secondary of this induction coil—with the end of a wire many miles long—and you see streams of light break forth from its distant end, which is set in violent vibration.

Here, once more, I attach these two plates of wire gauze to the terminals of the coil, I set them a distance apart, and I set the coil to work. You may see a small spark pass between the plates. I insert a thick plate of one of the best dielectrics between them, and instead of rendering altogether

impossible, as we are used to expect, I *aid* the passage of the discharge, which, as I insert the plate, merely changes in appearance and assumes the form of luminous streams.

Is there, I ask, can there be, a more interesting study than that of alternating currents?

In all these investigations, ladies and gentlemen, in all these experiments, which are so very, very interesting, for many years past—ever since the greatest experimenter who lectured in this hall discovered its principle—we have had a steady companion, an appliance familiar to everyone, a plaything *once*, a thing of momentous importance *now*—the induction coil. There is no dearer appliance to the electrician. From the ablest among you, I dare say, down to the inexperienced student, to your lecturer, we all have passed many delightful hours in experimenting with the induction coil. We have watched its play, and thought and pondered over the beautiful phenomena which it disclosed to our ravished eyes. So well known is this apparatus, so familiar are these phenomena to everyone, that my courage nearly fails me when I think that I have ventured to address so able an audience, that I have hazarded to entertain you with that same old subject. Here in reality is the same apparatus, and here are the same phenomena, only the apparatus is operated somewhat differently, the phenomena are presented in a different aspect. Some of the results we find as expected, others surprise us, but all captivate our attention, for in scientific investigation each novel result achieved may be the centre of a new departure, each novel fact learned may lead to important developments.

Usually in operating an induction coil we have set up a vibration of moderate frequency in the primary, either by means of an interruptor or break, or by the use of an alternator. Earlier English investigators, to mention only Spottiswoode and J. E. H. Gordon, have used a rapid break in connection with the coil. Our knowledge and experience of to-day enables us to see clearly why these coils under the conditions of the tests did not disclose any remarkable phenomena, and why able experimenters failed to perceive many of the curious effects which have since been observed.

In the experiments such as performed this evening, we operate the coil either from a specially constructed alternator capable of giving many thousands of reversals of current per second, or, by disruptively discharging a condenser through the primary, we set up a vibration in the secondary circuit of a frequency of many hundred thousands or millions per second, if we so desire; and in using either of these means we enter a field as yet unexplored.

It is impossible to pursue an investigation in any novel line without finally making some interesting observation or learning some useful fact. That this statement is applicable to the subject of this lecture the many curious and unexpected phenomena which we observe afford a convincing proof. By way of illustration take, for instance, the most obvious phenomena, those of the discharge of the induction coil.

Here is a coil which is operated by currents vibrating with extreme rapidity, obtained by disruptively discharging a Leyden jar. It would not surprise a student were the lecturer to say that the secondary of this coil consists of a small length of comparatively stout wire; it would not surprise him were the lecturer to state that, in spite of this, the coil is capable of giving any potential which the best insulation of the turns is able to withstand; but although he may be prepared, and even indifferent as to the anticipated result, yet the aspect of the discharge of the coil will surprise and interest him. Everyone is familiar with the discharge of an ordinary coil; it need not be reproduced here. But, by way of contrast, here is a form of discharge of a coil the primary current of which is vibrating several hundred thousand times per second. The discharge of an ordinary coil appears as a simple line or band of light. The discharge of this coil appears in the form of powerful brushes and luminous streams issuing from all points of the two straight wires attached to the terminals of the secondary.

Now compare this phenomenon which you have just witnessed with the discharge of a Holtz or Wimshurst machine—that other interesting appliance so dear to the experimenter. What a difference there is between both these phenomena! And yet, had I made the necessary arrangements—which could have been made

easily, were it not that they would interfere with other experiments—I could have produced with this coil sparks which, had I the coil hidden from your view and only two knobs exposed, even the keenest observer among you would find it difficult, if not

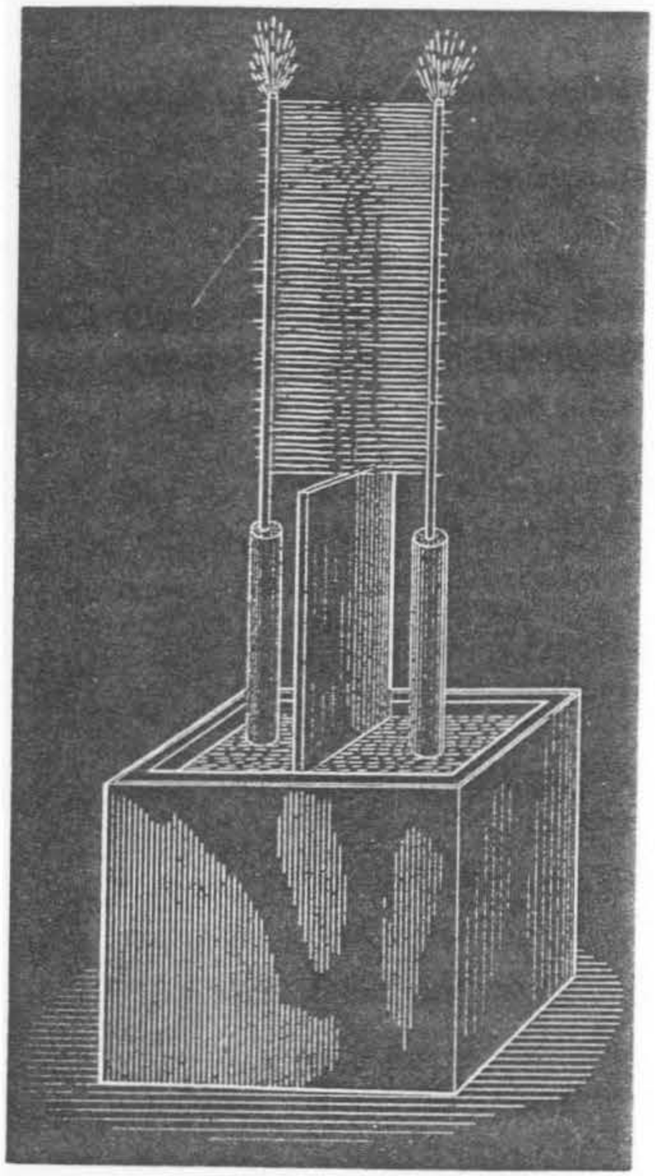

FIG. 1.—Discharge between Two Wires with Frequencies of a Few Hundred Thousands per Second.

impossible, to distinguish from those of an influence or friction machine. This may be done in many ways—for instance, by operating the induction coil which charges the condenser from an alternating-current machine of very low frequency, and preferably adjusting the discharge circuit so that there are no

oscillations set up in it. We then obtain in the secondary circuit, if the knobs are of the required size and properly set, a more or less rapid succession of sparks of great intensity and small quantity, which possess the same brilliancy, and are accompanied by the same sharp crackling sound, as those obtained from a friction or influence machine.

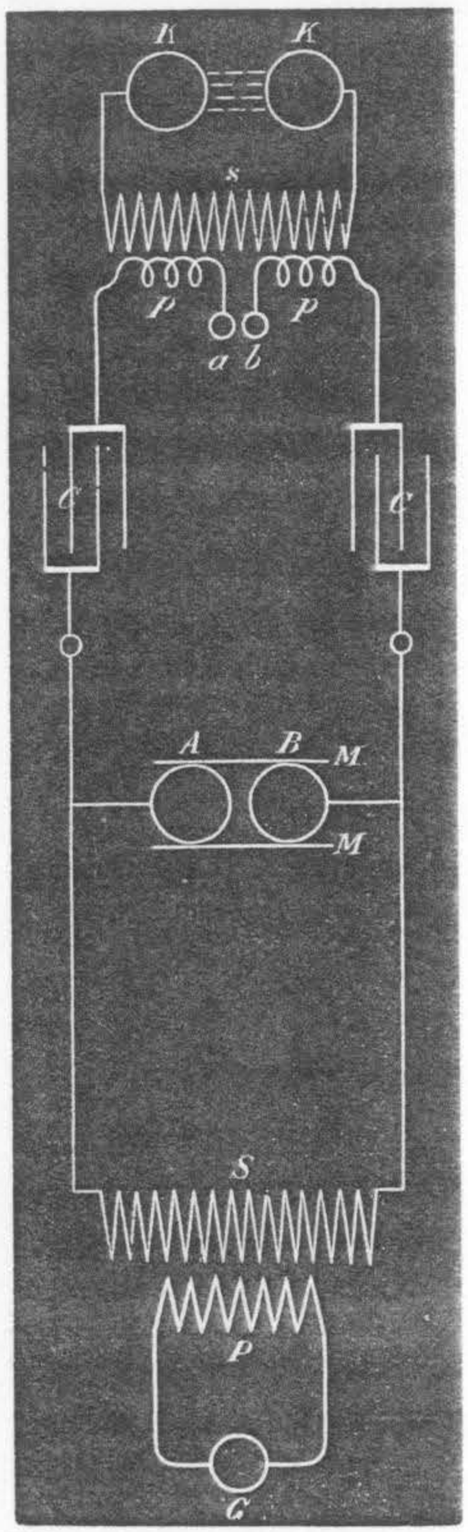

FIG. 2.—Imitating the Spark of a Holtz Machine.

Another way is to pass through two primary circuits, having a common secondary, two currents of a slightly different period, which produce in the secondary circuit sparks occurring at comparatively long intervals. But, even with the means at hand this evening, I may succeed in imitating the spark of a Holtz machine. For this purpose I establish between the terminals of the coil which charges the condenser a long, unsteady arc, which is periodically interrupted by the upward current of air produced by it. To increase the current of air I place on each side of the arc, and close to it, a large plate of mica. The condenser charged from this coil discharges into the primary circuit of a second coil through a small air gap, which is necessary to produce a sudden rush of current through the primary. The scheme of connections in the present experiment is indicated in Fig. 2.

G is an ordinarily constructed alternator, supplying the

primary, P, of an induction coil, the secondary, S, of which charges the condensers, or jars, C C. The terminals of the secondary are connected to the inside coatings of the jars, the outer coatings being connected to the ends of the primary, p p, of a second induction coil. This primary p p has a small air gap, a b.

The secondary, s, of this coil is provided with knobs, or spheres, K K, of the proper size, and set at a distance suitable for the experiment.

A long arc is established between the terminals, A B, of the first induction coil. M M are the mica plates.

Each time the arc is broken between A and B the jars are quickly charged and discharged through the primary p p, producing a snapping spark between the knobs K K. Upon the arc forming between A and B the potential falls, and the jars cannot be charged to such high potential as to break through the air gap a b until the arc is again broken by the draught.

In this manner sudden impulses, at long intervals, are produced in the primary p p, which in the secondary s give a corresponding number of impulses of great intensity. If the secondary knobs, or spheres, K K, are of the proper size, the sparks show much resemblance to those of a Holtz machine.

But these two effects, which to the eye appear so very different, are only two of the many discharge phenomena. We only need to change the conditions of the test, and again we make other observations of interest.

When, instead of operating the induction coil as in the two last experiments, we operate it from a high-frequency alternator, as in the next experiment, a systematic study of the phenomena is rendered much more easy. In such case, in varying the strength and frequency of the currents through the primary, we may observe five distinct forms of discharge, which I have described in my former paper on this subject before the American Institute of Electrical Engineers, May 20th, 1891.

It would take too much time, and it would lead us too far from the subject presented this evening, to reproduce all these forms, but it seems to me desirable to show you one of them.

It is a brush discharge, which is interesting in more than one respect. Viewed from a near position, it resembles much a jet of gas escaping under great pressure. We know that the phenomenon is due to the agitation of the molecules near the terminal, and we anticipate that some heat must be developed by the impact of the molecules against the terminal or against each other. Indeed, we find that the brush is hot, and only a little thought leads us to the conclusion that, could we but reach sufficiently high frequencies, we could produce a brush which would give intense light and heat, and which would resemble in every particular an ordinary flame, save, perhaps, that both phenomena might not be due to the same agent,—save, perhaps, that chemical affinity might not be *electrical* in its nature.

As the production of heat and light is here due to the impact of the molecules, or atoms, of air, or of something else besides, and as we can augment the energy simply by raising the potential, we might, even with frequencies obtained from a dynamo machine, intensify the action to such a degree as to bring the terminal to melting heat. But with such low frequencies we would have to deal always with something of the nature of an electric current. If I approach a conducting object to the brush, a thinny little spark passes, yet, even with the frequencies used this evening, the tendency to spark is not very great. So, for instance, if I hold a metallic sphere at some distance above the terminal, you may see the whole space between the terminal and sphere illuminated by the streams without the spark passing; and with the much higher frequencies obtainable by the disruptive discharge of a condenser, were it not for the sudden impulses, which are comparatively few in number, sparking would not occur even at very small distances. However, with incomparably higher frequencies, which we may yet find means to produce efficiently, and provided that electric impulses of such high frequencies could be transmitted through a conductor, the electrical characteristics of the brush discharge would completely vanish—no spark would pass, no shock would be felt—yet we would still have to deal with an *electric* phenomenon, but in the broad,

modern interpretation of the word. In my first paper before referred to, I have pointed out the curious properties of the brush, and described the best manner of producing it, but I have thought it worth while to endeavour to express myself more clearly in regard to this phenomenon, because of its absorbing interest.

When a coil is operated with currents of very high frequency, beautiful brush effects may be produced, even if the coil be of comparatively small dimensions. The experimenter may vary them in many ways, and, if it were nothing else, they afford a pleasing sight. What adds to their interest is that they may be produced with one single terminal as well as with two—in fact, often better with one than with two.

But of all the discharge phenomena observed, the most pleasing to the eye, and the most instructive, are those observed with a coil which is operated by means of the disruptive discharge of a condenser. The power of the brushes, the abundance of the sparks, when the conditions are patiently adjusted, is often amazing. With even a very small coil, if it be so well insulated as to stand a difference of potential of several thousand volts per turn, the sparks may be so abundant that the whole coil may appear a complete mass of fire.

Curiously enough, the sparks, when the terminals of the coil are set at a considerable distance, seem to dart in every possible direction, as though the terminals were perfectly independent of each other. As the sparks would soon destroy the insulation, it is necessary to prevent them. This is best done by immersing the coil in a good liquid insulator, such as boiled-out oil. Immersion in a liquid may be considered almost an absolute necessity for the continued and successful working of such a coil.

It is of course out of question, in an experimental lecture, with only a few minutes at disposal for the performance of each experiment, to show these discharge phenomena to advantage, as to produce each phenomenon at its best a very careful adjustment is required. But even if imperfectly produced, as they are likely to be this evening, they are sufficiently striking to interest an intelligent audience.

Before showing some of these curious effects I must, for the sake of completeness, give a short description of the coil and other apparatus used in the experiments with the disruptive discharge this evening.

It is contained in a box, B (Fig. 3), of thick boards of hard

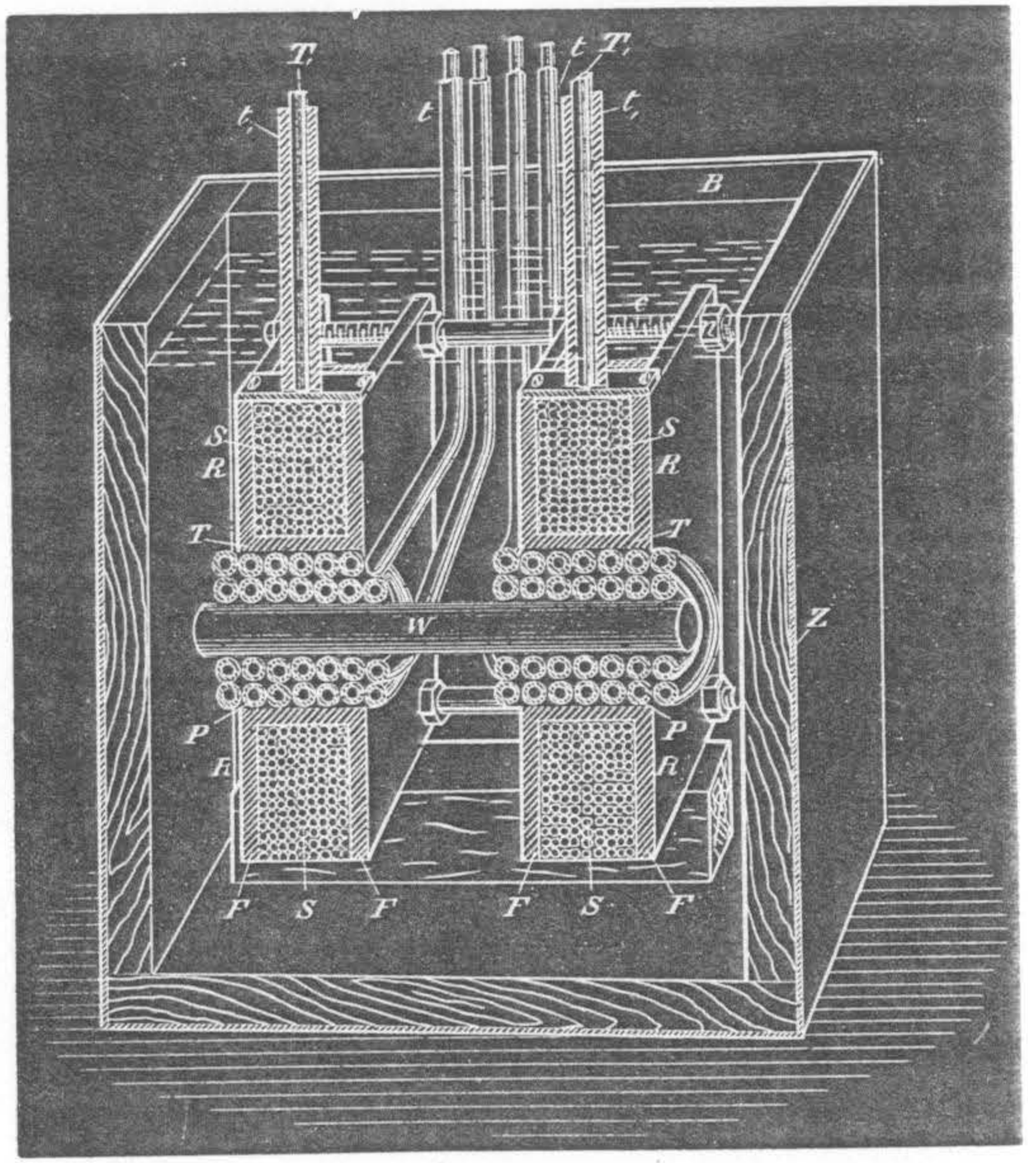

FIG. 3.—Disruptive Discharge Coil.

wood, covered on the outside with zinc sheet, Z, which is carefully soldered all around. It might be advisable, in a strictly scientific investigation, when accuracy is of great importance, to do away with the metal cover, as it might introduce many errors, principally on account of its complex action upon the coil, as a

condenser of very small capacity, and as an electrostatic and electro-magnetic screen. When the coil is used for such experiments as are here contemplated, the employment of the metal cover offers some practical advantages, but these are of not sufficient importance to be dwelt upon.

The coil should be placed symmetrically to the metal cover, and the space between should of course not be too small—certainly not less than, say, 5 centimetres, but much more if possible; especially the two sides of the zinc box, which are at right angles to the axis of the coil, should be sufficiently remote from the latter, as otherwise they might impair its action and be a source of loss.

The coil consists of two spools of hard rubber, R R, held apart at a distance of 10 centimetres by bolts, c, and nuts, n, likewise of hard rubber. Each spool comprises a tube, T, of approximately 8 centimetres inside diameter and 3 millimetres thick, upon which are screwed two flanges, F F, 24 centimetres square, the space between the flanges being about 3 centimetres. The secondary, S S, of the best gutta-percha-covered wire, has 26 layers, 10 turns in each, giving for each half a total of 260 turns. The two halves are wound oppositely and connected in series, the connection between both being made over the primary. This disposition, besides being convenient, has the advantage that when the coil is well balanced—that is, when both of its terminals, T_1 T_1, are connected to bodies or devices of equal capacity—there is not much danger of breaking through to the primary, and the insulation between the primary and the secondary need not be thick. In using the coil it is advisable to attach to *both* terminals devices of nearly equal capacity, as, when the capacity of the terminals is not equal, sparks will be apt to pass to the primary. To avoid this, the middle point of the secondary may be connected to the primary, but this is not always practicable.

The primary, P P, is wound in two parts, and oppositely, upon a wooden spool, W, and the four ends are led out of the oil through hard rubber tubes, t t. The ends of the secondary, T_1 T_1, are also led out of the oil through rubber tubes, t_1 t_1, of great thickness. The primary and secondary layers are insulated by

cotton cloth, the thickness of the insulation, of course, bearing some proportion to the difference of potential between the turns of the different layers. Each half of the primary has four layers, 24 turns in each, this giving a total of 96 turns. When both the parts are connected in series, this gives a ratio of conversion of about 1 : 2·7, and with the primaries in multiple, 1 : 5·4; but in operating with very rapidly alternating currents this ratio does not convey even an approximate idea of the ratio of the E.M.F.'s in the primary and secondary circuits. The coil is held in position in the oil on wooden supports, there being about 5 centimetres thickness of oil all around. Where the oil is not specially needed, the space is filled with pieces of wood, and for this purpose principally the wooden box B surrounding the whole is used.

The construction here shown is of course not the best on general principles, but I believe it is a good and convenient one for the production of effects in which an excessive potential and a very small current is needed.

In connection with the coil, I use either the ordinary form of discharger or a modified form. In the former I have introduced two changes which secure some advantages, and which are obvious. If they are mentioned, it is only in the hope that some experimenter may find them of use.

One of the changes is that the adjustable knobs, A and B (Fig. 4), of the discharger are held in jaws, $J\,J$, of brass by spring pressure, this allowing to turn them successively in different positions and so do away with the tedious process of frequent polishing up.

The other change consists in the employment of a strong electro-magnet, $N\,S$, which is placed with its axis at right angles to the line joining the knobs A and B, and produces a strong magnetic field between them. The pole-pieces of the magnet are movable, and properly formed so as to protrude between the brass knobs, in order to make the field as intense as possible; but to prevent the discharge from jumping to the magnet, the pole-pieces are protected by a layer of mica, $M\,M$, of sufficient thickness. $s_1\,s_1$ and $s_2\,s_2$ are screws for fastening the wires. On each side one

of the screws is for large and the other for small wires. $L\,L$ are screws for fixing in position the rods, $R\,R$, which support the knobs.

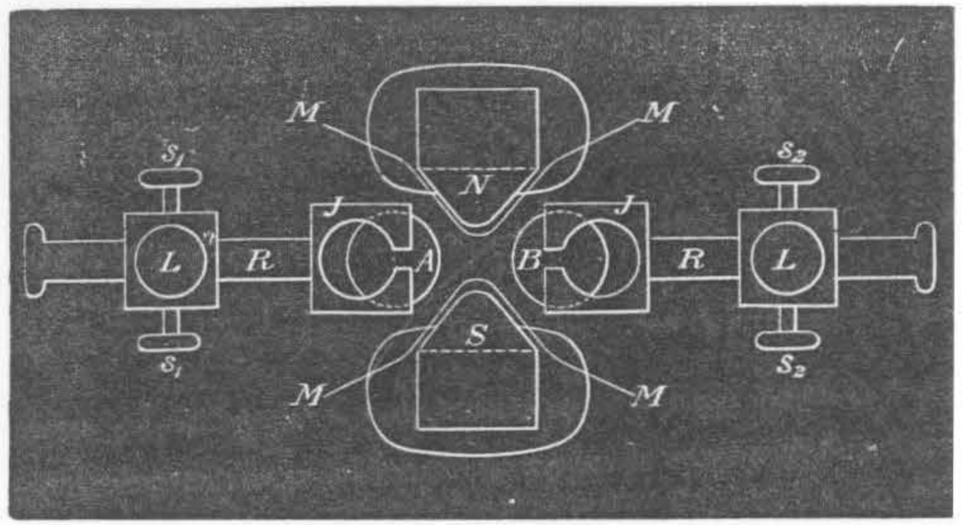

FIG. 4.—Arrangement of Improved Discharger and Magnet.

In another arrangement with the magnet I take the discharge between the rounded pole-pieces themselves, which in such case are insulated and preferably provided with polished brass caps.

The employment of an intense magnetic field is of advantage principally when the induction coil or transformer which charges the condenser is operated by currents of very low frequency. In such a case the number of the fundamental discharges between the knobs may be so small as to render the currents produced in the secondary unsuitable for many experiments. The intense magnetic field then serves to blow out the arc between the knobs as soon as it is formed, and the fundamental discharges occur in quicker succession.

Instead of the magnet, a draught or blast of air may be employed with some advantage. In this case the arc is preferably established between the knobs $A\,B$, in Fig. 2 (the knobs $a\,b$ being generally joined, or entirely done away with), as in this disposition the arc is long and unsteady, and is easily affected by the draught.

When a magnet is employed to break the arc, it is better to choose the connection indicated schematically in Fig. 5, as in this

case the currents forming the arc are much more powerful, and the magnetic field exercises a greater influence. The use of the

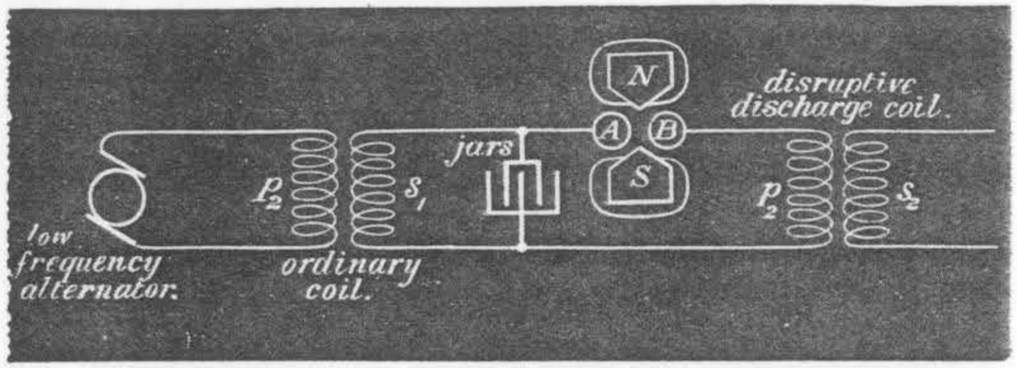

FIG. 5.—Arrangement with Low-Frequency Alternator and Improved Discharger.

magnet permits, however, of the arc being replaced by a vacuum tube, but I have encountered great difficulties in working with an exhausted tube.

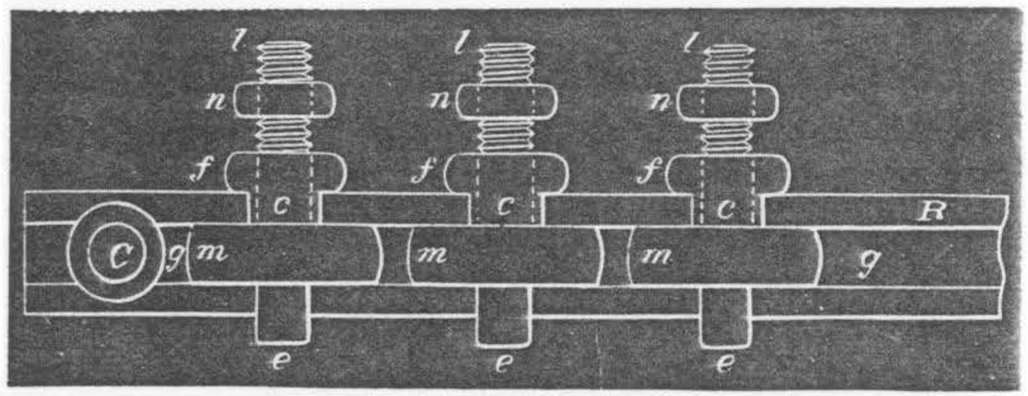

FIG. 6.

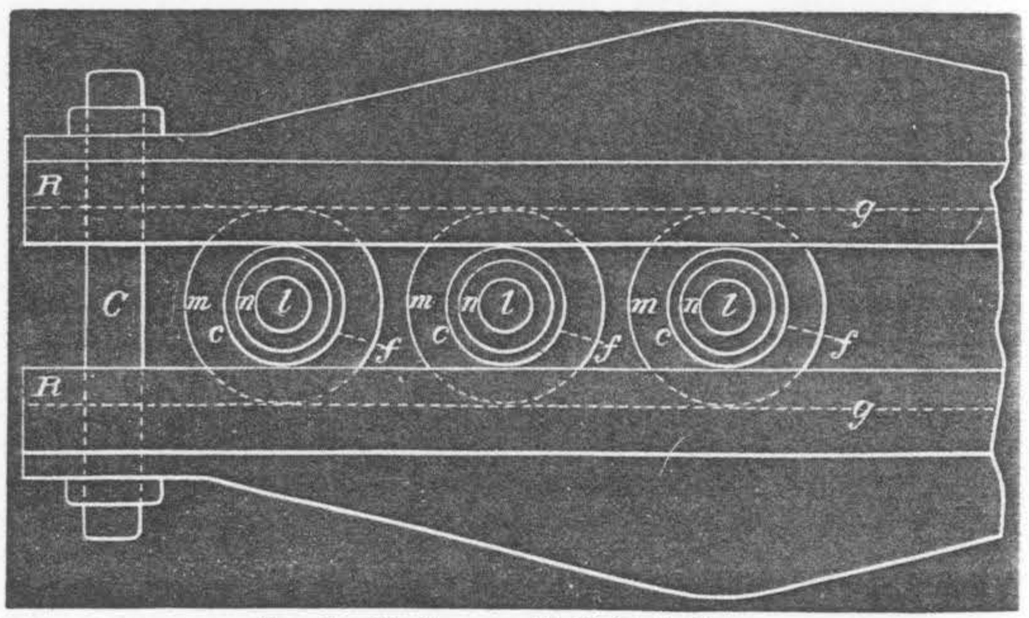

FIG. 7.—Discharger with Multiple Gaps.

The other form of discharger used in these and similar experiments is indicated in Figs. 6 and 7. It consists of a number of brass pieces, *c c* (Fig. 6), each of which comprises a spherical middle portion, *m*, with an extension, *e*, below—which is merely used to fasten the piece in a lathe when polishing up the discharging surface—and a column above, which consists of a knurled flange, *f*, surmounted by a threaded stem, *l*, carrying a nut, *n*, by means of which a wire is fastened to the column. The flange *f* conveniently serves for holding the brass piece when fastening the wire, and also for turning it in any position when it becomes necessary to present a fresh discharging surface. Two stout strips of hard rubber, *R R*, with planed grooves, *g g* (Fig. 7), to fit the middle portion of the pieces *c c*, serve to clamp the latter and hold them firmly in position by means of two bolts, *C C* (of which only one is shown), passing through the ends of the strips.

In the use of this kind of discharger I have found three principal advantages over the ordinary form. Firstly, the dielectric strength of a given total width of air space is greater when a great many small air gaps are used instead of one, which permits of working with a smaller length of air gap, and that means smaller loss and less deterioration of the metal; secondly, by reason of splitting the arc up into smaller arcs, the polished surfaces are made to last much longer; and thirdly, the apparatus affords some gauge in the experiments. I usually set the pieces, by putting between them sheets of uniform thickness, at a certain very small distance which is known from the experiments of Sir William Thomson to require a certain electro-motive force to be bridged by the spark. It should, of course, be remembered that the sparking distance is much diminished as the frequency is increased. By taking any number of spaces the experimenter has a rough idea of the electro-motive force, and he finds it also easier to repeat an experiment, as he has not the trouble of setting the knobs again and again. With this kind of discharger I have been able to maintain an oscillating motion without any spark being visible with the naked eye between the knobs, and they would not show a very appreciable

rise in temperature. This form of discharger also lends itself to many arrangements of condensers and circuits which are often very convenient and time-saving. I have used it preferably in a disposition similar to that indicated in Fig. 2, when the currents forming the arc are small.

I may here mention that I have also used dischargers with single or multiple air gaps, in which the discharge surfaces were rotated with great speed. No particular advantage was, however, gained by this method, except in cases where the currents from the condenser were large and the keeping cool of the surfaces was necessary, and in cases when, the discharge not being oscillating of itself, the arc as soon as established was broken by the air current, thus starting the vibration at intervals in rapid succession. I have also used mechanical interruptors in many ways. To avoid the difficulties with frictional contacts, the preferred plan adopted was to establish the arc and rotate through it at great speed a rim of mica provided with many holes, and fastened to a steel plate. It is understood, of course, that the employment of a magnet, air current, or other interruptor, produces no effect worth noticing, unless the self-induction, capacity, and resistance are so related that there are oscillations set up upon each interruption.

I will now endeavour to show you some of the most noteworthy of these discharge phenomena.

I have stretched across the room two ordinary cotton-covered wires, each about 7 metres in length. They are supported on insulating cords at a distance of about 30 centimetres. I attach now to each of the terminals of the coil one of the wires, and set the coil in action. Upon turning the lights off in the room you see the wires strongly illuminated by the streams issuing abundantly from their whole surface in spi of the cotton covering, which may even be very thick. When the experiment is performed under good conditions, the light from the wires is sufficiently intense to allow distinguishing the objects in a room. To produce the best result it is, of course, necessary to adjust arefully the capacity of the jars, the arc between the knobs, the length of the wires. My experience is that calculation

of the length of the wires leads in such case to no result whatever. The experimenter will do best to take the wires at the start very long, and then adjust by cutting off first long pieces, and then smaller and smaller ones as he approaches the right length.

A convenient way is to use an oil condenser of very small capacity, consisting of two small adjustable metal plates, in connection with this and similar experiments. In such case I take wires rather short, and set at the beginning the condenser plates at maximum distance. If the streams from the wires increase by approach of the plates, the length of the wires is about right; if they diminish, the wires are too long for that frequency and potential. When a condenser is used in connection with experiments with such a coil, it should be an oil condenser by all means, as in using an air condenser considerable energy might be wasted. The wires leading to the plates in the oil should be very thin, heavily coated with some insulating compound, and provided with a conducting covering—this preferably extending under the surface of the oil. The conducting cover should not be too near the terminals, or ends, of the wire, as a spark would be apt to jump from the wire to it. The conducting coating is used to diminish the air losses, in virtue of its action as an electrostatic screen. As to the size of the vessel containing the oil, and the size of the plates, the experimenter gains at once an idea from a rough trial. The size of the plates *in oil* is, however, calculable, as the dielectric losses are very small.

In the preceding experiment it is of considerable interest to know what relation the quantity of the light emitted bears to the frequency and potential of the electric impulses. My opinion is that the heat as well as light effects produced should be proportionate, under otherwise equal conditions of test, to the product of frequency and square of potential, but the experimental verification of the law, whatever it may be, would be exceedingly difficult. One thing is certain, at any rate, and that is, that in augmenting the potential and frequency we rapidly intensify the streams; and, though it may be very sanguine, it is

surely not altogether hopeless to expect that we may succeed in producing a practical illuminant on these lines. We would then be simply using burners or flames, in which there would be no chemical process, no consumption of material, but merely a transfer of energy, and which would in all probability emit more light and less heat than ordinary flames.

The luminous intensity of the streams is, of course, considerably increased when they are focused upon a small surface. This may be shown by the following experiment.

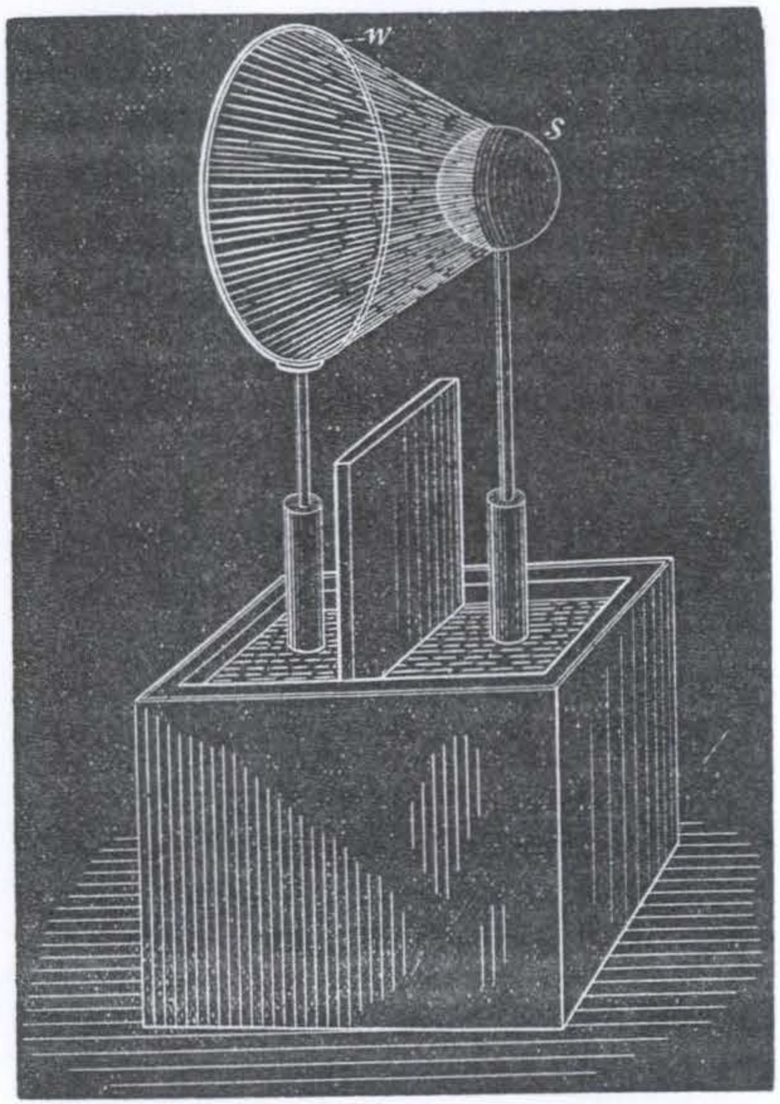

Fig. 8.—Effect produced by Concentrating Streams.

I attach to one of the terminals of the coil a wire, w (Fig. 8), bent in a circle of about 30 centimetres in diameter, and to the

other terminal I fasten a small brass sphere, s; the surface of the wire being preferably equal to the surface of the sphere, and the centre of the latter being in a line at right angles to the plane of the wire circle and passing through its centre. When the discharge is established under proper conditions, a luminous hollow cone is formed, and in the dark one half of the brass sphere is strongly illuminated, as shown in the cut.

By some artifice or other it is easy to concentrate the streams upon small surfaces and to produce very strong light effects. Two thin wires may thus be rendered intensely luminous.

In order to intensify the streams the wires should be very thin and short; but as in this case their capacity would be generally too small for the coil, at least for such a one as the present, it is necessary to augment the capacity to the required value, while, at the same time, the surface of the wires remains very small. This may be done in many ways.

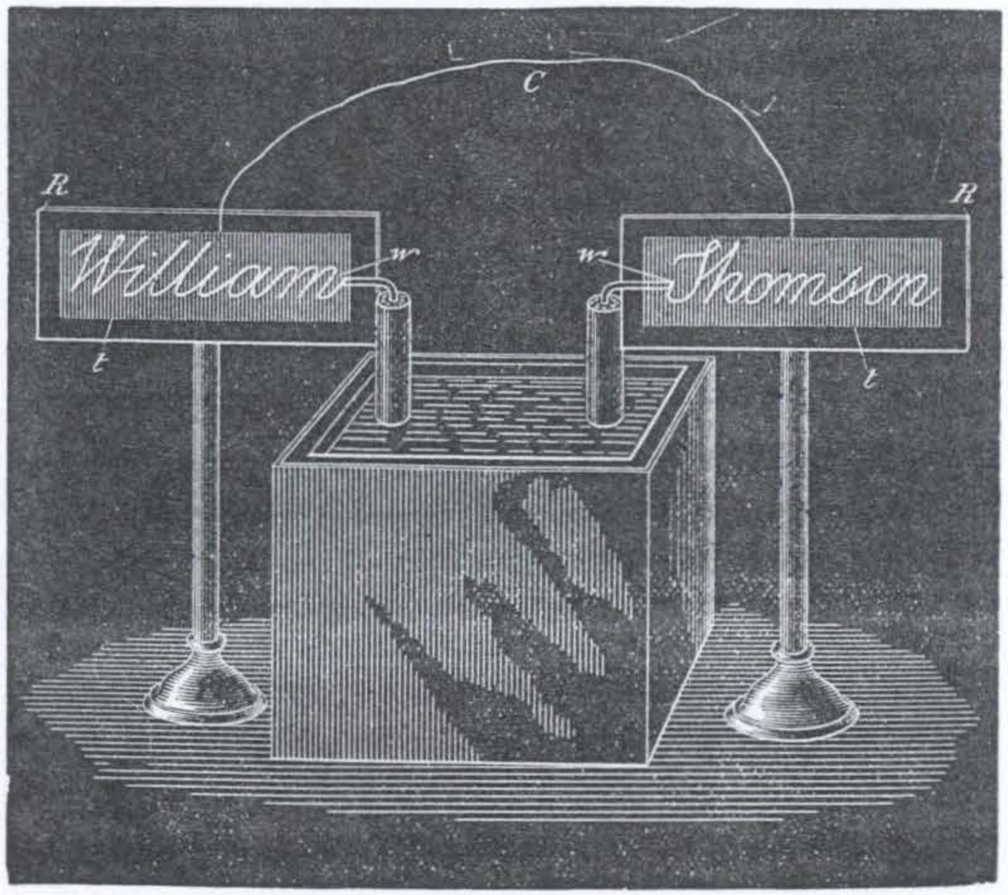

Fig. 9.—Wires rendered intensely Luminous.

Here, for instance, I have two plates, *R R*, of hard rubber (Fig 9), upon which I have glued two very thin wires, *w w*, so as to form a name. The wires may be bare or covered with the best insulation—it is immaterial for the success of the experiment. Well, insulated wires, if anything, are preferable. On the back of each plate, indicated by the shaded portion, is a tinfoil coating *t t*. The plates are placed in line at a sufficient distance to prevent a spark passing from one to the other wire. The two tinfoil coatings I have joined by a conductor, *C*, and the two wires I presently connect to the terminals of the coil. It is now easy, by varying the strength and frequency of the currents through the primary, to find a point at which the capacity of the system is best suited to the conditions, and the wires become so strongly luminous that, when the light in the room is turned off, the name formed by them appears in brilliant letters.

It is perhaps preferable to perform this experiment with a coil operated from an alternator of high frequency, as then, owing to the harmonic rise and fall, the streams are very uniform, though they are less abundant than when produced with such a coil as the present. This experiment, however, may be performed with low frequencies, but much less satisfactorily.

When two wires, attached to the terminals of the coil, are set at the proper distance, the streams between them may be so intense as to produce a continuous luminous sheet. To show this phenomenon I have here two circles, *C* and *c* (Fig. of 10), of rather stout wire, one being about 80 centimetres and the other 30 centimetres in diameter. To each of the terminals of the coil I attach one of the circles. The supporting wires are so bent that the circles may be placed in the same plane, coinciding as nearly as possible. When the light in the room is turned off and the coil set to work, you see the whole space between the wires uniformly filled with streams, forming a luminous disc, which could be seen from a considerable distance, such is the intensity of the streams. The outer circle could have been much larger than the present one; in fact, with this coil I have used much larger circles, and I have been able to produce a strongly luminous sheet, covering an area of more than 1 square metre, which is a

remarkable effect with this very small coil. To avoid uncertainty, the circle has been taken smaller, and the area is now about 0·43 square metre.

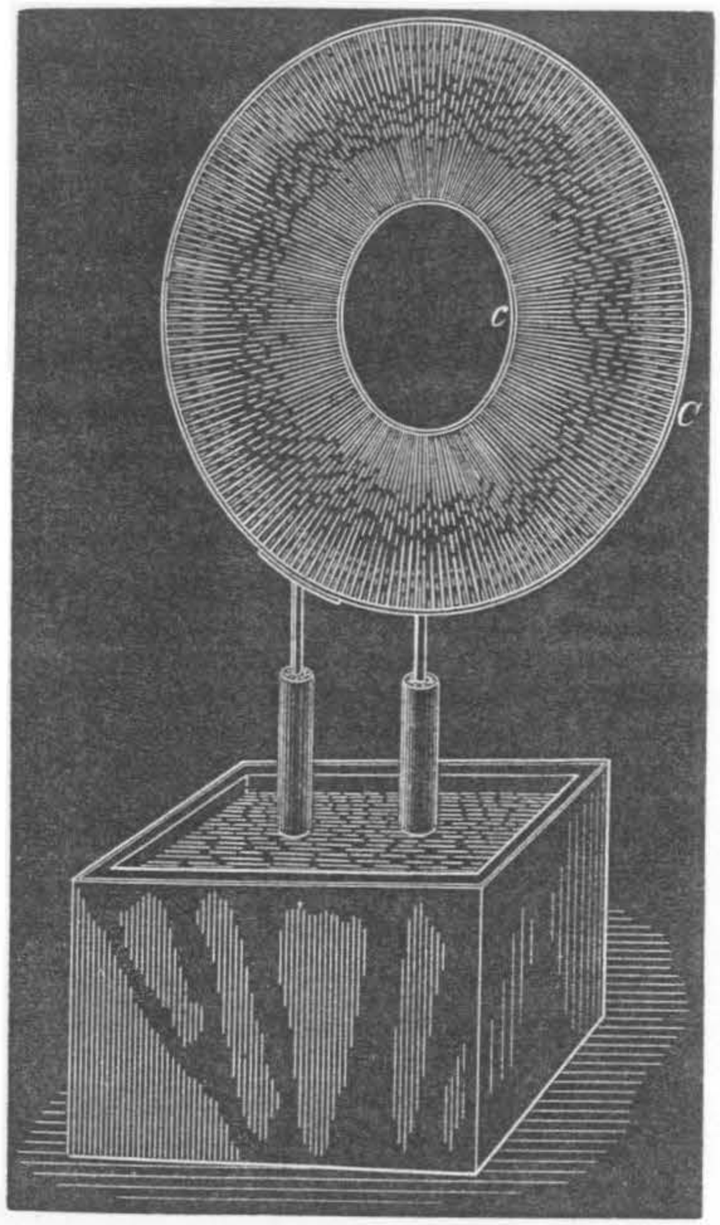

Fig. 10.—Luminous Discs.

The frequency of the vibration, and the quickness of succession of the sparks between the knobs, affect to a marked degree the appearance of the streams. When the frequency is very low, the air gives way in more or less the same manner, as by a steady difference of potential, and the streams consist of distinct threads, generally mingled with thin sparks, which probably correspond

to the successive discharges occurring between the knobs. But when the frequency is extremely high, and the arc of the discharge produces a very *loud* but *smooth* sound—showing both that oscillation takes place and that the sparks succeed each other with great rapidity—then the luminous streams formed are perfectly uniform. To reach this result very small coils and jars of small capacity should be used. I take two tubes of thick Bohemian glass, about 5 centimetres in diameter and 20 centimetres long. In each of the tubes I slip a primary of very thick copper wire. On the top of each tube I wind a secondary of much thinner gutta-percha-covered wire. The two secondaries I connect in series, the primaries preferably in multiple arc. The tubes are then placed in a large glass vessel, at a distance of 10 to 15 centimetres from each other, on insulating supports, and the vessel is filled with boiled-out oil, the oil reaching about an inch above the tubes. The free ends of the secondary are lifted out of the oil and placed parallel to each other at a distance of about 10 centimetres. The ends which are scraped should be dipped in the oil. Two four-pint jars joined in series may be used to discharge through the primary. When the necessary adjustments in the length and distance of the wires above the oil and in the arc of discharge are made, a luminous sheet is produced between the wires which is perfectly smooth and textureless, like the ordinary discharge through a moderately exhausted tube.

I have purposely dwelt upon this apparently insignificant experiment. In trials of this kind the experimenter arrives at the startling conclusion that, to pass ordinary luminous discharges through gases, no particular degree of exhaustion is needed, but that the gas may be at ordinary or even greater pressure. To accomplish this, a very high frequency is essential; a high potential is likewise required, but this is a merely incidental necessity. These experiments teach us that, in endeavouring to discover novel methods of producing light by the agitation of atoms, or molecules, of a gas, we need not limit our research to the vacuum tube, but may look forward quite seriously to the possibility of obtaining the light effects without the use of any vessel whatever, with air at ordinary pressure.

Such discharges of very high frequency, which render luminous the air at ordinary pressures, we have probably often occasion to witness in Nature. I have no doubt that if—as many believe—the *Aurora borealis* is produced by sudden cosmic disturbances, such as eruptions at the sun's surface, which set the electrostatic charge of the earth in an extremely rapid vibration, the red glow observed is not confined to the upper rarefied strata of the air, but the discharge traverses, by reason of its very high frequency, also the dense atmosphere in the form of a *glow*, such as we ordinarily produce in a slightly exhausted tube. If the frequency were very low, or even more so, if the charge were not at all vibrating, the dense air would break down as in a lightning discharge. Indications of such breaking down of the lower dense strata of the air have been repeatedly observed at the occurrence of this marvellous phenomenon; but if it does occur, it can only be attributed to the fundamental disturbances, which are few in number, for the vibration produced by them would be far too rapid to allow a disruptive break. It is the original and irregular impulses which affect the instruments; the superimposed vibrations probably pass unnoticed.

When an ordinary low-frequency discharge is passed through moderately rarefied air, the air assumes a purplish hue. If by some means or other we increase the intensity of the molecular, or atomic, vibration, the gas changes to a white colour. A similar change occurs at ordinary pressures with electric impulses of very high frequency. If the molecules of the air around a wire are moderately agitated, the brush formed is reddish or violet; if the vibration is rendered sufficiently intense, the streams become white. We may accomplish this in various ways. In the experiment before shown with the two wires across the room, I have endeavoured to secure the result by pushing to a high value both the frequency and potential; in the experiment with the thin wires glued on the rubber plate, I have concentrated the action upon a very small surface—in other words, I have worked with a great electric density.

A most curious form of discharge is observed with such

a coil when the frequency and potential are pushed to the extreme limit. To perform the experiment, every part of the coil should be heavily insulated, and only two small spheres — or, better still, two sharp-edged metal discs (*d d*, Fig. 11) of no more than a few centimetres in diameter—

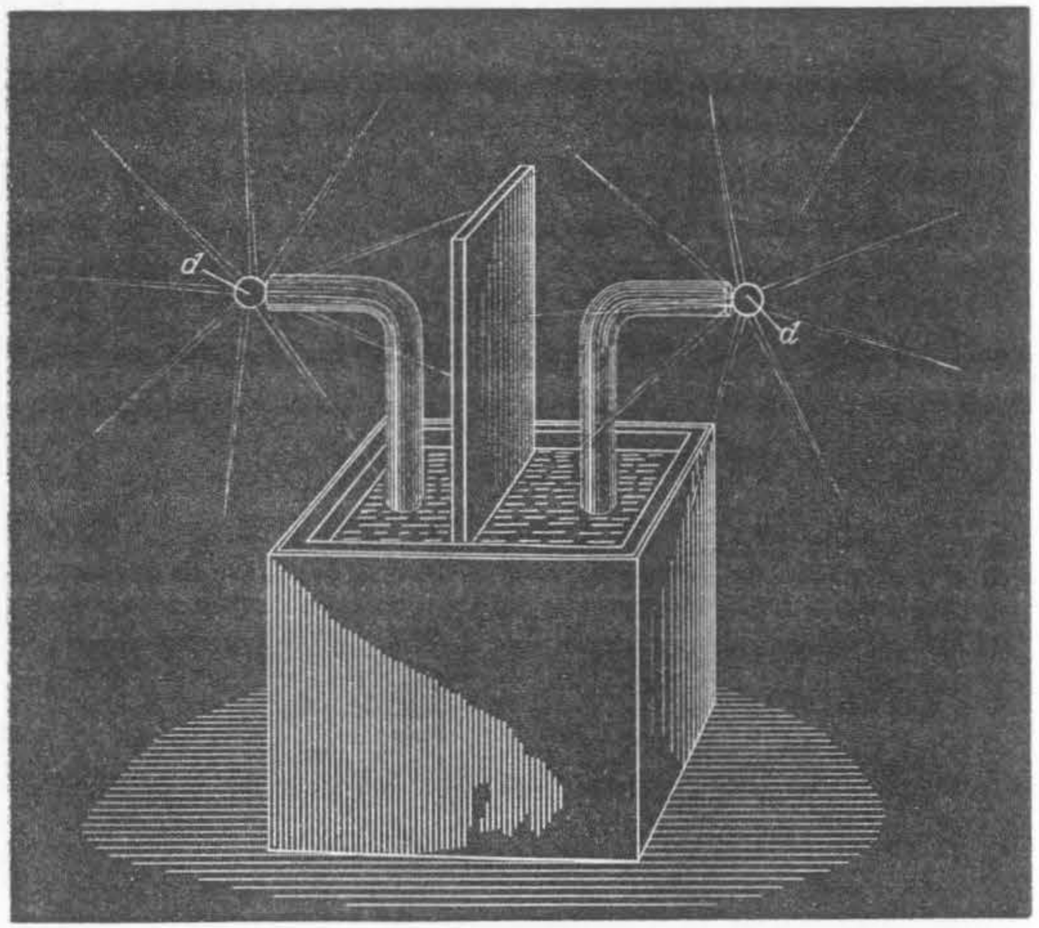

FIG. 11.—Phantom Streams.

should be exposed to the air. The coil here used is immersed in oil, and the ends of the secondary reaching out of the oil are covered with an air-tight cover of hard rubber of great thickness. All cracks, if there are any, should be carefully stopped up, so that the brush discharge cannot form anywhere except on the small spheres or plates which are exposed to the air. In this case, since there are no large plates or other bodies of capacity attached to the terminals, the coil is capable of an extremely rapid vibration. The potential may be raised by increasing, as far as the experimenter judges proper, the rate of change of the primary current. With a coil not widely

differing from the present, it is best to connect the two primaries in multiple arc; but if the secondary should have a much greater number of turns, the primaries should preferably be used in series, as otherwise the vibration might be too fast for the secondary. It occurs under these conditions that misty white streams break forth from the edges of the discs and spread out phantom-like into space. With this coil, when fairly well produced, they are about 25 to 30 centimetres long. When the hand is held against them, no sensation is produced, and a spark, causing a shock, jumps from the terminal only upon the hand being brought much nearer. If the oscillation of the primary current is rendered intermittent by some means or other, there is a corresponding throbbing of the streams, and now the hand or other conducting object may be brought in still greater proximity to the terminal without a spark being caused to jump.

Among the many beautiful phenomena which may be produced with such a coil, I have here selected only those which appear to possess some features of novelty, and lead us to some conclusions of interest. One will not find it at all difficult to produce in the laboratory, by means of it, many other phenomena which appeal to the eye even more than these here shown, but present no particular feature of novelty.

Early experimenters describe the display of sparks produced by an ordinary large induction coil upon an insulating plate separating the terminals. Quite recently Siemens performed some experiments in which fine effects were obtained, which were seen by many with interest. No doubt large coils, even if operated with currents of low frequencies, are capable of producing beautiful effects. But the largest coil ever made could not, by far, equal the magnificent display of streams and sparks obtained from such a disruptive discharge coil when properly adjusted. To give an idea, a coil such as the present one will cover easily a plate of 1 metre in diameter completely with the streams. The best way to perform such experiments is to take a very thin rubber or a glass plate and glue on one side of it a narrow ring of tinfoil of very large diameter, and on the other a circular washer, the centre of the latter coinciding with

that of the ring, and the surfaces of both being preferably equal, so as to keep the coil well balanced. The washer and ring should be connected to the terminals by heavily insulated thin wires. It is easy in observing the effect of the capacity to produce a sheet of uniform streams, or a fine network of thin silvery threads, or a mass of loud brilliant sparks, which cover completely the plate.

Since I have advanced the idea of the conversion by means of the disruptive discharge, in my paper before the American Institute of Electrical Engineers at the beginning of the past year, the interest excited in it has been considerable. It affords us a means for producing any potentials by the aid of inexpensive coils operated from ordinary systems of distribution, and —what is perhaps more appreciated—it enables us to convert currents of any frequency into currents of any other lower or higher frequency. But its chief value will perhaps be found in the help which it will afford us in the investigations of the phenomena of phosphorescence, which a disruptive discharge coil is capable of exciting in innumerable cases where ordinary coils, even the largest, would utterly fail.

Considering its probable uses for many practical purposes, and its possible introduction into laboratories for scientific research, a few additional remarks as to the construction of such a coil will perhaps not be found superfluous.

It is, of course, absolutely necessary to employ in such a coil wires provided with the best insulation.

Good coils may be produced by employing wires covered with several layers of cotton, boiling the coil a long time in pure wax, and cooling under moderate pressure. The advantage of such a coil is that it can be easily handled, but it cannot probably give as satisfactory results as a coil immersed in pure oil. Besides, it seems that the presence of a large body of wax affects the coil disadvantageously, whereas this does not seem to be the case with oil. Perhaps it is because the dielectric losses in the liquid are smaller.

I have tried at first silk- and cotton-covered wires with oil immersion, but I have been gradually led to use gutta-percha-

covered wires, which proved most satisfactory. Gutta-percha insulation adds, of course, to the capacity of the coil, and this, especially if the coil be large, is a great disadvantage when extreme frequencies are desired; but, on the other hand, gutta-percha will withstand much more than an equal thickness of oil, and this advantage should be secured at any price. Once the coil has been immersed, it should never be taken out of the oil for more than a few hours, else the gutta-percha will crack up and the coil will not be worth half as much as before. Gutta-percha is probably slowly attacked by the oil, but after an immersion of eight to nine months I have found no ill effects.

I have obtained in commerce two kinds of gutta-percha wire: in one the insulation sticks tightly to the metal, in the other it does not. Unless a special method is followed to expel all air, it is much safer to use the first kind. I wind the coil within an oil tank so that all interstices are filled up with the oil. Between the layers I use cloth boiled out thoroughly in oil, calculating the thickness according to the difference of potential between the turns. There seems not to be a very great difference whatever kind of oil is used; I use paraffin or linseed oil.

To exclude more perfectly the air, an excellent way to proceed, and easily practicable with small coils, is the following:—Construct a box of hard wood of very thick boards which have been for a long time boiled in oil. The boards should be so joined as to safely withstand the external air pressure. The coil being placed and fastened in position within the box, the latter is closed with a strong lid, and covered with closely fitting metal sheet, the joints of which are soldered very carefully. On the top two small holes are drilled, passing through the metal sheet and the wood, and in these holes two small glass tubes are inserted and the joints made air-tight. One of the tubes is connected to a vacuum pump, and the other with a vessel containing a sufficient quantity of boiled-out oil. The latter tube has a very small hole at the bottom, and is provided with a stop-cock. When a fairly good vacuum has been obtained, the stop-cock is opened and the oil slowly fed in. Proceeding in this manner, it is impossible that any big bubbles, which are the principal danger, should remain between the turns.

The air is most completely excluded, probably better than by boiling out, which, however, when gutta-percha-coated wires are used, is not practicable.

For the primaries I use ordinary line wire with a thick cotton coating. Strands of very thin insulated wires properly interlaced would, of course, be the best to employ for the primaries, but they are not to be had.

In an experimental coil the size of the wires is not of great importance. In the coil here used the primary is No. 12, and the secondary No. 24 Brown and Sharpe W.G. wire; but the sections may be varied considerably: it would only imply different adjustments, the results aimed at would not be materially affected.

I have dwelt at some length upon the various forms of brush discharge because, in studying them, we not only observe phenomena which please our eye, but also afford us food for thought, and lead us to conclusions of practical importance. In the use of alternating currents of very high tension, not too much precaution can be taken to prevent the brush discharge. In a main conveying such currents, in an induction coil or transformer, or in a condenser, the brush discharge is a source of great danger to the insulation. In a condenser especially the gaseous matter must be most carefully expelled, for in it the charged surfaces are near each other, and if the potentials are high, just as sure as a weight will fall if let go, so the insulation will give way if a single gaseous bubble of some size be present, whereas, if all gaseous matter were carefully excluded, the condenser would safely withstand a much higher difference of potential. A main conveying alternating currents of very high tension may be injured merely by a blow-hole or small crack in the insulation, the more so as a blow-hole is apt to contain gas at low pressure; and as it appears almost impossible to completely obviate such little imperfections, I am led to believe that in our future distributions of electrical energy by currents of very high tension, liquid insulation will be used. The cost is a great drawback, but if we employ an oil as an insulator, the distributions of electrical energy with something like 100,000 volts, and even more, become, at least with higher

frequencies, so easy that they could be hardly called engineering feats. With oil insulation and alternate-current motors transmissions of power can be effected with safety, and upon an industrial basis, at distances of as much as a thousand miles.

A peculiar property of oils, and liquid insulation in general, when subjected to rapidly changing electric stresses, is to disperse any gaseous bubbles which may be present, and diffuse them through its mass, generally long before any injurious break can occur. This feature may be easily observed with an ordinary induction coil by taking the primary out, plugging up the end of the tube upon which the secondary is wound, and filling it with some fairly transparent iusulator, such as paraffin oil. A primary of a diameter something like 6 mm. smaller than the inside of the tube may be inserted in the oil. When the coil is set to work, one may see, looking from the top through the oil, many luminous points—air bubbles which are caught by inserting the primary, and which are rendered luminous in consequence of the violent bombardment. The occluded air, by its impact against the oil, heats it; the oil begins to circulate, carrying some of the air along with it, until the bubbles are dispersed and the luminous points disappear. In this manner, unless large bubbles are occluded in such way that circulation is rendered impossible, a damaging break is averted, the only effect being a moderate warming up of the oil. If, instead of the liquid, a solid insulation, no matter how thick, were used, a breaking through and injury of the apparatus would be inevitable.

The exclusion of gaseous matter from any apparatus in which the dielectric is subjected to more or less rapidly changing electric forces is, however, not only desirable in order to avoid a possible injury of the apparatus, but also on account of economy. In a condenser, for instance, as long as only a solid or only a liquid dielectric is used, the loss is small; but if a gas under ordinary or small pressure be present the loss may be very great. Whatever the nature of the force acting in the dielectric may be, it seems that in a solid or liquid the molecular displacement produced by the force is small: hence the product of force and displacement is insignificant, unless the force be very great; but

in a gas the displacement, and therefore this product, is considerable: the molecules are free to move, they reach high speeds, and the energy of their impact is lost in heat or otherwise. If the gas be strongly compressed, the displacement due to the force is made smaller, and the losses are reduced.

In most of the succeeding experiments I prefer, chiefly on account of the regular and positive action, to employ the alternator before referred to. This is one of the several machines constructed by me for the purposes of these investigations. It has 384 pole projections, and is capable of giving currents of a frequency of about 10,000 per second. This machine has been illustrated and briefly described in my first paper before the American Institute of Electrical Engineers, May 20th, 1891, to which I have already referred. A more detailed description, sufficient to enable any engineer to build a similar machine, will be found in several electrical journals of that period.

The induction coils operated from the machine are rather small, containing from 5,000 to 15,000 turns in the secondary. They are immersed in boiled-out linseed oil, contained in wooden boxes covered with zinc sheet.

I have found it advantageous to reverse the usual position of the wires, and to wind, in these coils, the primaries on the top; this allowing the use of a much bigger primary, which, of course, reduces the danger of overheating, and increases the output of the coil. I make the primary on each side at least 1 centimetre shorter than the secondary, to prevent the breaking through on the ends, which would surely occur unless the insulation on the top of the secondary be very thick, and this, of course, would be disadvantageous.

When the primary is made movable, which is necessary in some experiments, and many times convenient for the purposes of adjustment, I cover the secondary with wax, and turn it off in a lathe to a diameter slightly smaller than the inside of the primary coil. The latter I provide with a handle reaching out of the oil, which serves to shift it in any position along the secondary.

I will now venture to make, in regard to the general manipulation of induction coils, a few observations bearing upon points which have not been fully appreciated in earlier experiments with such coils, and are even now often overlooked.

The secondary of the coil possesses usually such a high self-induction that the current through the wire is inappreciable, and may be so even when the terminals are joined by a conductor of small resistance. If capacity is added to the terminals, the self-induction is counteracted, and a stronger current is made to flow through the secondary, though its terminals are insulated from each other. To one entirely unacquainted with the properties of alternating currents nothing will look more puzzling. This feature was illustrated in the experiment performed at the beginning with the top plates of wire gauze attached to the terminals and the rubber plate. When the plates of wire gauze were close together, and a small arc passed between them, the arc *prevented* a strong current to pass through the secondary, because it did away with the capacity on the terminals; when the rubber plate was inserted between, the capacity of the condenser formed counteracted the self-induction of the secondary, a stronger current passed now, the coil performed more work, and the discharge was by far more powerful.

The first thing, then, in operating the induction coil is to combine capacity with the secondary, to overcome the self-induction. If the frequencies and potentials are very high, gaseous matter should be carefully kept away from the charged surfaces. If Leyden jars are used, they should be immersed in oil, as otherwise considerable dissipation may occur if the jars are greatly strained. When high frequencies are used, it is of equal importance to combine a condenser with the primary. One may use a condenser connected to the ends of the primary or to the terminals of the alternator, but the latter is not to be recommended, as the machine might be injured. The best way is, undoubtedly, to use the condenser in series with the primary and with the alternator, and to adjust its capacity so as to annul the self-induction of both the latter. The condenser should be adjustable by very small steps, and for a finer adjustment

a small oil condenser with movable plates may be used conveniently.

I think it best at this juncture to bring before you a phenomenon, observed by me some time ago, which to the purely scientific investigator may perhaps appear more interesting than any of the results which I have the privilege to present to you this evening.

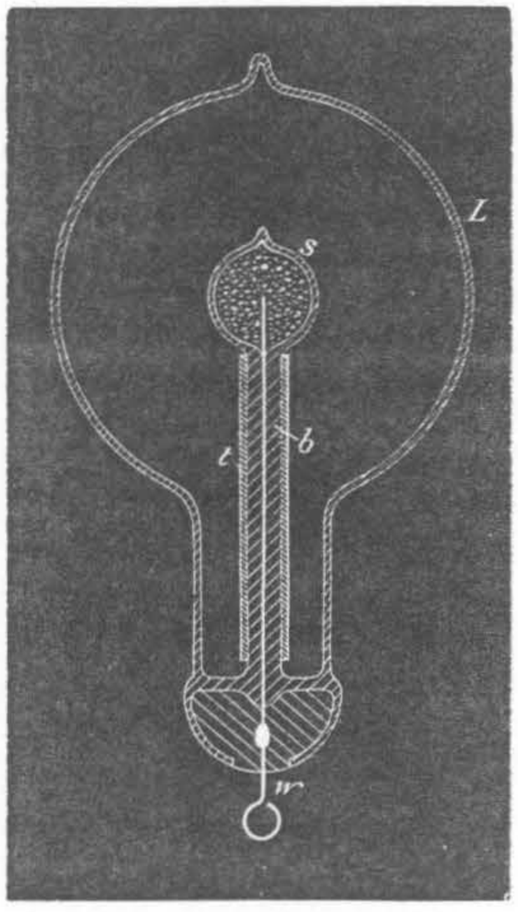

FIG. 12.

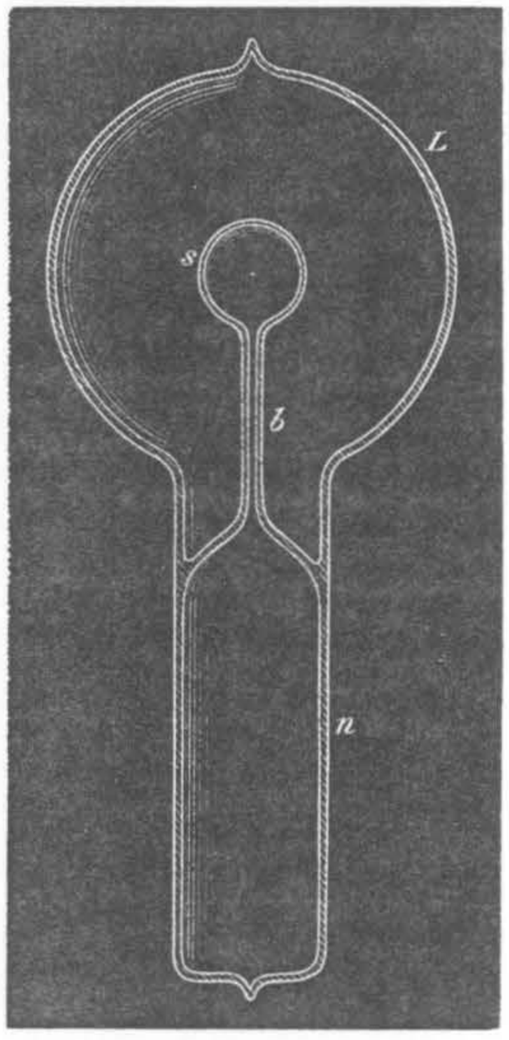

FIG. 13.

Bulbs for producing Rotating Brush.

It may be quite properly ranked among the brush phenomena —in fact, it is a brush, formed at, or near, a single terminal in high vacuum.

In bulbs provided with a conducting terminal, though it be of aluminium, the brush has but an ephemeral existence, and cannot, unfortunately, be indefinitely preserved in its most sensitive

state, even in a bulb devoid of any conducting electrode. In studying the phenomenon, by all means a bulb having no leading-in wire should be used. I have found it best to use bulbs constructed as indicated in Figs. 12 and 13.

In Fig. 12 the bulb comprises an incandescent lamp globe, *L*, in the neck of which is sealed a barometer tube, *b*, the end of which is blown out to form a small sphere, *s*. This sphere should be sealed as closely as possible in the centre of the large globe. Before sealing, a thin tube, *t*, of aluminium sheet may be slipped in the barometer tube, but it is not important to employ it.

The small hollow sphere *s* is filled with some conducting powder, and a wire, *w*, is cemented in the neck for the purpose of connecting the conducting powder with the generator.

The construction shown in Fig. 13 was chosen in order to remove from the brush any conducting body which might possibly affect it. The bulb consists in this case of a lamp globe, *L*, which has a neck, *n*, provided with a tube, *b*, and small sphere, *s*, sealed to it, so that two entirely independent compartments are formed, as indicated in the drawing. When the bulb is in use, the neck *n* is provided with a tinfoil coating, which is connected to the generator, and acts inductively upon the moderately rarefied and highly conducting gas enclosed in the neck. From there the current passes through the tube *b* into the small sphere *s*, to act by induction upon the gas contained in the globe *L*.

It is of advantage to make the tube *t* very thick, the hole through it very small, and to blow the sphere *s* very thin. It is of the greatest importance that the sphere *s* be placed in the centre of the globe *L*.

Figs. 14, 15, and 16 indicate different forms, or stages, of the brush. Fig. 14 shows the brush as it first appears in a bulb provided with a conducting terminal; but, as in such a bulb it very soon disappears—often after a few minutes—I will confine myself to the description of the phenomenon as seen in a bulb without conducting electrode. It is observed under the following conditions:—

When the globe *L* (Figs. 12 and 13) is exhausted to

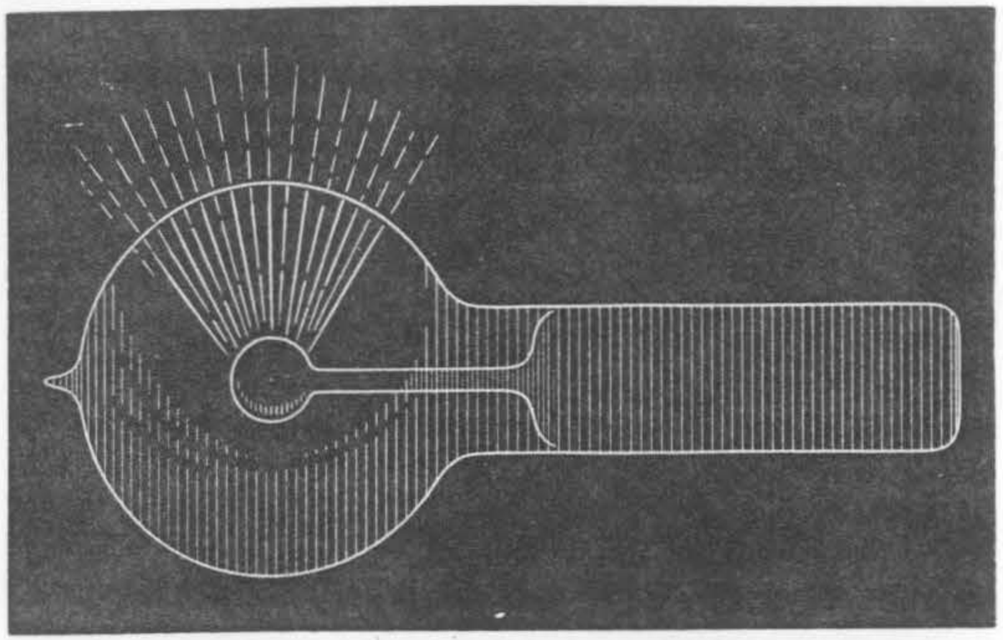

Fig. 16.

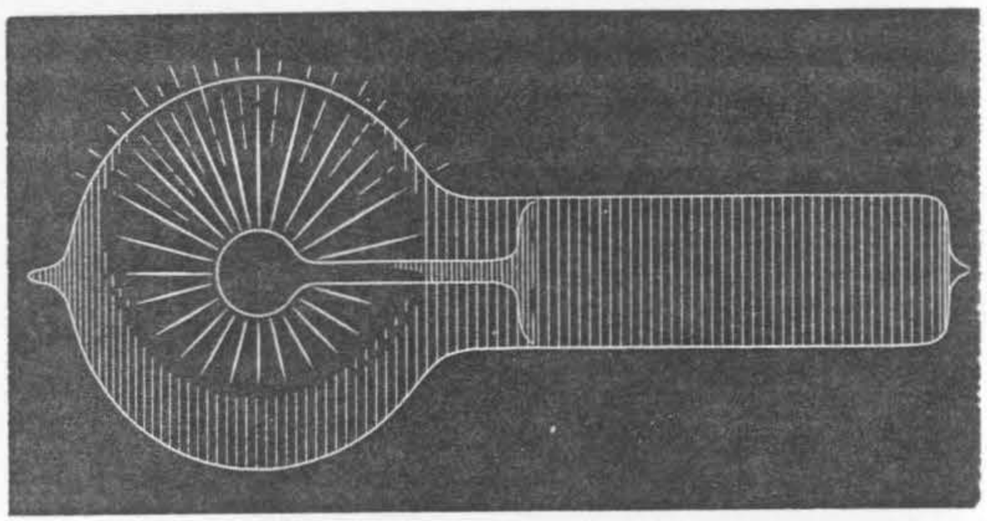

Fig. 15. Forms and Phases of the Rotating Brush.

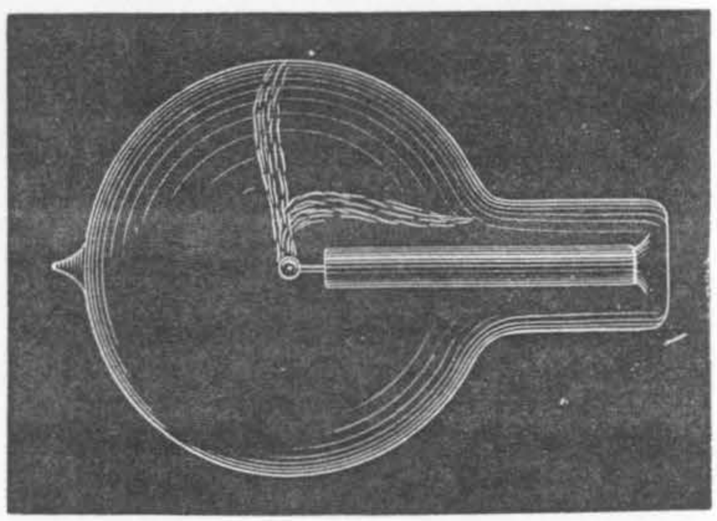

Fig. 14.

a very high degree, generally the bulb is not excited upon connecting the wire w (Fig. 12) or the tinfoil coating of the bulb (Fig. 13) to the terminal of the induction coil. To excite it, it is usually sufficient to grasp the globe L with the hand. An intense phosphorescence then spreads at first over the globe, but soon gives place to a white, misty light. Shortly afterwards one may notice that the luminosity is unevenly distributed in the globe, and after passing the current for some time the bulb appears as in Fig. 15. From this stage the phenomenon will gradually pass to that indicated in Fig. 16, after some minutes, hours, days, or weeks, according how the bulb is worked. Warming the bulb or increasing the potential hastens the transit.

When the brush assumes the form indicated in Fig. 16, it may be brought to a state of extreme sensitiveness to electrostatic and magnetic influence. The bulb hanging straight down from a wire, and all objects being remote from it, the approach of the observer at a few paces from the bulb will cause the brush to fly to the opposite side, and if he walks around the bulb it will always keep on the opposite side. It may begin to spin around the terminal long before it reaches that sensitive stage. When it begins to turn around principally, but also before, it is affected by a magnet, and at a certain stage it is susceptible to magnetic influence to an astonishing degree. A small permanent magnet, with its poles at a distance of no more than 2 centimetres, will affect it visibly at a distance of 2 metres, slowing down or accelerating the rotation according to how it is held relatively to the brush. I think I have observed that at the stage when it is most sensitive to magnetic, it is not most sensitive to electrostatic influence. My explanation is, that the electrostatic attraction between the brush and the glass of the bulb, which retards the rotation, grows much quicker than the magnetic influence when the intensity of the stream is increased.

When the bulb hangs with the globe L down, the rotation is always clockwise. In the Southern Hemisphere it would occur in the opposite direction, and on the Equator the brush should not turn at all. The rotation may be reversed by a magnet kept

at some distance. The brush rotates, seemingly, best when it is at right angles to the lines of force of the earth. It very likely rotates, when at its maximum speed, in synchronism with the alternations, say 10,000 times a second. The rotation can be slowed down or accelerated by the approach or receding of the observer, or any conducting body, but it cannot be reversed by putting the bulb in any position. When it is in the state of the highest sensitiveness, and the potential or frequency be varied, the sensitiveness is rapidly diminished. Changing either of these but little will generally stop the rotation. The sensitiveness is likewise affected by the variations of temperature. To attain great sensitiveness it is necessary to have the small sphere s in the centre of the globe L, as otherwise the electrostatic action of the glass of the globe will tend to stop the rotation. The sphere s should be small and of uniform thickness: any dissymmetry of course has the effect to diminish the sensitiveness.

The fact that the brush rotates in a definite direction in a permanent magnetic field seems to show that in alternating currents of very high frequency the positive and negative impulses are not equal, but that one always preponderates over the other.

Of course, this rotation in one direction may be due to the action of two elements of the same current upon each other, or to the action of the field produced by one of the elements upon the other, as in a series motor, without necessarily one impulse being stronger than the other. The fact that the brush turns, as far as I could observe, in any position, would speak for this view. In such case it would turn at any point of the earth's surface. But, on the other hand, it is then hard to explain why a permanent magnet should reverse the rotation, and one must assume the preponderation of impulses of one kind.

As to the causes of the formation of the brush or stream, I think it is due to the electrostatic action of the globe and the dissymmetry of the parts. If the small bulb s and the globe L were perfect concentric spheres, and the glass throughout of the same thickness and quality, I think the brush would not form, as the tendency to pass would be equal on all sides. That the

formation of the stream is due to an irregularity is apparent from the fact that it has the tendency to remain in one position, and rotation occurs most generally only when it is brought out of this position by electrostatie or magnetic influence. When in an extremely sensitive state it rests in one position, most curious experiments may be performed with it. For instance, the experimenter may, by selecting a proper position, approach the hand at a certain considerable distance to the bulb, and he may cause the brush to pass off by merely stiffening the muscles of the arm. When it begins to rotate slowly, and the hands are held at a proper distance, it is impossible to make even the slightest motion without producing a visible effect upon the brush. A metal plate connected to the other terminal of the coil affects it at great distance, slowing down the rotation often to one turn a second.

I am firmly convinced that such a brush, when we learn how to produce it properly, will prove a valuable aid in the investigation of the nature of the forces acting in an electrostatic or magnetic field. If there is any motion which is measurable going on in the space, such a brush ought to reveal it. It is, so to speak, a beam of light, frictionless, devoid of inertia.

I think that it may find practical applications in telegraphy. With such a brush it would be possible to send despatches across the Atalantic, for instance, with any speed, since its sensitiveness may be so great that the slightest changes will affect it. If it were possible to make the stream more intense and very narrow, its deflections could be easily photographed.

I have been interested to find whether there is a rotation of the stream itself, or whether there is simply a stress travelling around in the bulb. For this purpose I mounted a light mica fan so that its vanes were in the path of the brush. If the stream itself was rotating, the fan would be spun around. I could produce no distinct rotation of the fan, although I tried the experiment repeatedly; but as the fan exerted a noticeable influence on the stream, and the apparent rotation of the latter was in this case never quite satisfactory, the experiment did not appear to be conclusive.

I have been unable to produce the phenomenon with the

disruptive discharge coil, although every other of these phenomena can be well produced by it—many, in fact, much better than with coils operated from an alternator.

It may be possible to produce the brush by impulses of one direction, or even by a steady potential, in which case it would be still more sensitive to magnetic influence.

In operating an induction coil with rapidly alternating currents, we realise with astonishment, for the first time, the great importance of the relation of capacity, self-induction, and frequency as regards the general result. The effects of capacity are the most striking, for in these experiments, since the self-induction and frequency both are high, the critical capacity is very small, and need be but slightly varied to produce a very considerable change. The experimenter may bring his body in contact with the terminals of the secondary of the coil, or attach to one or both terminals insulated bodies of very small bulk, such as bulbs, and he may produce a considerable rise or fall of potential. and greatly affect the flow of the current through the primary. In the experiment before shown, in which a brush appears at a wire attached to one terminal, and the wire is vibrated when the experimenter brings his insulated body in contact with the other terminal of the coil, the sudden rise of potential was made evident.

I may show you the behaviour of the coil in another manner which possesses a feature of some interest. I have here a little light fan of aluminum sheet, fastened to a needle and arranged to rotate freely in a metal piece screwed to one of the terminals of the coil. When the coil is set to work, the molecules of the air are rhythmically attracted and repelled. As the force with which they are repelled is greater than that with which they are attracted, it results that there is a repulsion exerted on the surfaces of the fan. If the fan were made simply of a metal sheet, the repulsion would be equal on the opposite sides, and would produce no effect. But if one of the opposing surfaces is screened, or if, generally speaking, the bombardment on this side is weakened in some way or other, there remains the repulsion exerted upon the other, and the fan is set in rotation. The

screening is best effected by fastening upon one of the opposing sides of the fan insulated conducting coatings, or, if the fan is made in the shape of an ordinary propeller screw, by fastening on one side, and close to it, an insulated metal plate. The static screen may, however, be omitted, and simply a thickness of insulating material fastened to one of the sides of the fan.

To show the behaviour of the coil, the fan may be placed upon the terminal and it will readily rotate when the coil is operated by currents of very high frequency. With a steady potential, of course, and even with alternating currents of very low frequency, it would not turn, because of the very slow exchange of air and, consequently, smaller bombardment; but in the latter case it might turn if the potential were excessive. With a pin wheel, quite the opposite rule holds good: it rotates best with a steady potential, and the effort is the smaller the higher the frequency. Now it is very easy to adjust the conditions so that the potential is normally not sufficient to turn the fan, but that by connecting the other terminal of the coil with an insulated body it rises to a much greater value, so as to rotate the fan, and it is likewise possible to stop the rotation by connecting to the terminal a body of different size, thereby diminishing the potential.

Instead of using the fan in this experiment, we may use the "electric" radiometer with similar effect. But in this case it will be found that the vanes will rotate only at high exhaustion or at ordinary pressures; they will not rotate at moderate pressures, when the air is highly conducting. This curious observation was made conjointly by Professor Crookes and myself. I attribute the result to the high conductivity of the air, the molecules of which then do not act as independent carriers of electric charges, but act all together as a single conducting body. In such case, of course, if there is any repulsion at all of the molecules from the vanes, it must be very small. It is possible, however, that the result is in part due to the fact that the greater part of the discharge passes from the leading-in wire through the highly conducting gas, instead of passing off from the conducting vanes.

In trying the preceding experiment with the electric radio-

meter the potential should not exceed a certain limit, as then the electrostatic attraction between the vanes and the glass of the bulb may be so great as to stop the rotation.

A most curious feature of alternate currents of high frequencies and potentials is that they enable us to perform many experiments by the use of one wire only. In many respects this feature is of great interest.

In a type of alternate-current motor invented by me some years ago, I produced rotation by inducing, by means of a single alternating current passed through a motor circuit, in the mass or other circuits of the motor, secondary currents, which, jointly with the primary or inducing current, created a moving field of force. A simple but crude form of such a motor is obtained by winding upon an iron core a primary, and close to it a secondary coil, joining the ends of the latter and placing a freely movable metal disc within the influence of the field produced by both. The iron core is employed for obvious reasons, but it is not essential to the operation. To improve the motor, the iron core is made to encircle the armature. Again to improve, the secondary coil is made to overlap partly the primary, so that it cannot free itself from a strong inductive action of the latter, repel it its lines as it may. Once more to improve, the proper difference of phase is obtained between the primary and secondary currents by a condenser, self-induction, resistance, or equivalent windings.

I had discovered, however, that rotation is produced by means of a single coil and core; my explanation of the phenomenon, and leading thought in trying the experiment, being that there must be a true time lag in the magnetisation of the core. I remember the pleasure I had when, in the writings of Professor Ayrton, which came later to my hand, I found the idea of the time lag advocated. Whether there is a true time lag, or whether the retardation is due to eddy-currents circulating in minute paths, must remain an open question, but the fact is that a coil wound upon an iron core and traversed by an alternating current creates a moving field of force, capable of setting an armature in rotation. It is of some interest, in conjunction with the historical Arago experiment, to mention that in lag, or phase, motors I have produced rotation in opposite direction to the moving field, which means that in that experiment the magnet may not rotate, or may even rotate in opposite direction to the moving disc. Here, then, is a motor (schematically illustrated in Fig. 17), comprising a coil and iron core, and a freely movable copper disc in proximity to the latter.

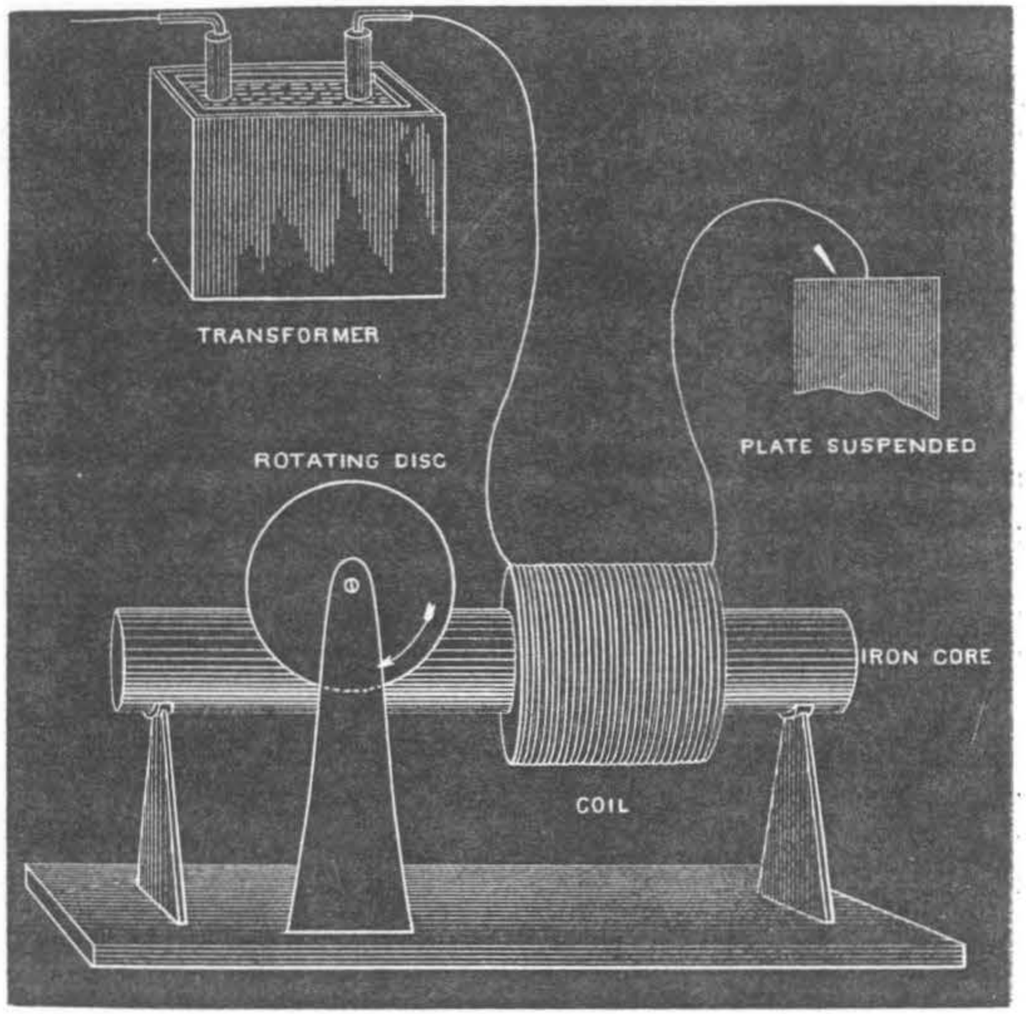

FIG. 17.—Single-Wire and "No-Wire" Motor.

To demonstrate a novel and interesting feature, I have, for a reason which I will explain, selected this type of motor. When the ends of the coil are connected to the terminals of an alternator, the disc is set in rotation. But it is not *this* experiment, now well known, which I desire to perform. What I wish to show you is that this motor rotates with *one single* connection between it and the generator; that is to say, one terminal of

the motor is connected to one terminal of the generator—in this case the secondary of a high-tension induction coil—the other terminals of motor and generator being insulated in space. To produce rotation it is generally (but not absolutely) necessary to connect the free end of the motor coil to an insulated body of some size. The experimenter's body is more than sufficing. If he touches the free terminal with an object held in the hand, a current passes through the coil and the copper disc is set in rotation. If an exhausted tube is put in series with the coil, the tube lights brilliantly, showing the passage of a strong current. Instead of the experimenter's body, a small metal sheet suspended on a cord may be used with the same result. In this case the plate acts as a condenser in series with the coil. It counteracts the self-induction of the latter and allows a strong current to pass. In such a combination, the greater the self-induction of the coil the smaller need be the plate, and this means that a lower frequency, or eventually a lower potential, is required to operate the motor. A single coil wound upon a core has a high self-induction: for this reason principally, this type of motor was chosen to perform the experiment. Were a secondary closed coil wound upon the core, it would tend to diminish the self-induction, and then it would be necessary to employ a much higher frequency and potential. Neither would be advisable, for a higher potential would endanger the insulation of the small primary coil, and a higher frequency would result in a materially diminished torque.

It should be remarked that when such a motor with a closed secondary is used, it is not at all easy to obtain rotation with excessive frequencies, as the secondary cuts off almost completely the lines of the primary—and this, of course, the more, the higher the frequency—and allows the passage of but a minute current. In such a case, unless the secondary is closed through a condenser, it is almost essential, in order to produce rotation, to make the primary and secondary coils overlap each other more or less.

But there is an additional feature of interest about this motor. It is, namely, not necessary to have even a single connection

between the motor and generator, except, perhaps, through the ground; for not only is an insulated plate capable of giving off energy into space, but it is likewise capable of deriving it from an alternating electrostatic field, though in the latter case the available energy is much smaller. In this instance one of the motor terminals is connected to the insulated plate or body located within the alternating electrostatic field, and the other terminal preferably to the ground.

It is quite possible, however, that such "no-wire" motors, as they might be called, could be operated by conduction through the rarefied air at considerable distances. Alternate currents, especially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. The upper strata of the air are rarefied. To reach a number of miles out into space requires the overcoming of difficulties of a merely mechanical nature. There is no doubt that with the enormous potentials obtainable by the use of high frequencies and oil insulation luminous discharges might be passed through many miles of rarefied air, and that, by thus directing the energy of many hundreds or thousands of horse-power, motors or lamps might be operated at considerable distances from stationary sources. But such schemes are mentioned merely as possibilities. We shall have no need to transmit power in this way. We shall have no need to *transmit* power at all. Ere many generations pass, our machinery will be driven by a power obtainable at any point of the universe. This idea is not novel. Men have been led to it long ago by instinct or reason. It has been expressed in many ways, and in many places, in the history of old and new. We find it in the delightful myth of Antheus, who derives power from the earth; we find it among the subtile speculations of one of your splendid mathematicians, and in many hints and statements of thinkers of the present time. Throughout space there is energy. Is this energy static or kinetic? If static, our hopes are in vain; if kinetic—and this we know it is, for certain—then it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of Nature. Of all, living or dead, Crookes came nearest to doing it. His radiometer will turn in the light of day and in the darkness

of the night; it will turn everywhere where there is heat, and heat is everywhere. But, unfortunately, this beautiful little machine, while it goes down to posterity as the most interesting, must likewise be put on record as the most inefficient machine ever invented!

The preceding experiment is only one of many equally interesting experiments which may be performed by the use of only one wire with alternate currents of high potential and frequency. We may connect an insulated line to a source of such currents, we may pass an inappreciable current over the line, and on any point of the same we are able to obtain a heavy current, capable of fusing a thick copper wire. Or we may, by the help of some artifice, decompose a solution in an electrolytic cell by connecting only one pole of the cell to the line or source of energy. Or we may, by attaching to the line, or only bringing into its vicinity, light up an incandescent lamp, an exhausted tube, or a phosphorescent bulb.

However impracticable this plan of working may appear in many cases, it certainly seems practicable, and even recommendable, in the production of light. A perfected lamp would require but little energy, and if wires are used at all, we ought to be able to supply that energy without a return wire.

It is now a fact that a body may be rendered incandescent or phosphorescent by bringing it either in single contact or merely in the vicinity of a source of electric impulses of the proper character, and that in this manner a quantity of light sufficient to afford a practical illuminant may be produced. It is, therefore, to say the least, worth while to attempt to determine the best conditions and to invent the best appliances for attaining this object.

Some experiences have already been gained in this direction, and I will dwell on them briefly, in the hope that they might prove useful.

The heating of a conducting body enclosed in a bulb, and connected to a source of rapidly alternating electric impulses, is dependent on so many things of a different nature, that it would be difficult to give a generally applicable rule under which the

maximum heating occurs. As regards the size of the vessel, I have lately found that at ordinary or only slightly differing atmospheric pressures, when air is a good insulator, and hence practically the same amount of energy by a certain potential and frequency is given off from the body, whether the bulb be small or large, the body is brought to a higher temperature if enclosed in a small bulb, because of the better confinement of heat in this case.

At lower pressures, when air becomes more or less conducting, or if the air be sufficiently warmed as to become conducting, the body is rendered more intensely incandescent in a large bulb, obviously because, under otherwise equal conditions of test, more energy may be given off from the body when the bulb is large.

At very high degrees of exhaustion, when the matter in the bulb becomes "radiant," a large bulb has still an advantage, but a comparatively slight one, over the small bulb.

Finally, at excessively high degrees of exhaustion, which cannot be reached except by the employment of special means, there seems to be, beyond a certain and rather small size of vessel, no perceptible difference in the heating.

These observations were the result of a number of experiments, of which one, showing the effect of the size of the bulb at a high degree of exhaustion, may be described and shown here, as it presents a feature of interest. Three spherical bulbs of 2 inches, 3 inches, and 4 inches diameter were taken, and in the centre of each was mounted an equal length of an ordinary incandescent lamp filament of uniform thickness. In each bulb the piece of filament was fastened to the leading-in wire of platinum, contained in a glass stem sealed in the bulb; care being taken, of course, to make everything as nearly alike as possible. On each glass stem in the inside of the bulb was slipped a highly polished tube made of aluminum sheet, which fitted the stem and was held on it by spring pressure. The function of this aluminum tube will be explained subsequently. In each bulb an equal length of filament protruded above the metal tube. It is sufficient to say now that under these conditions equal lengths of filament of the same thickness—in other words, bodies of equal bulk—were brought to

incandescence. The three bulbs were sealed to a glass tube, which was connected to a Sprengel pump. When a high vacuum had been reached, the glass tube carrying the bulbs was sealed off. A current was then turned on successively on each bulb, and it was found that the filaments came to about the same brightness, and, if anything, the smallest bulb, which was placed midway between the two larger ones, may have been slightly brighter. This result was expected, for when either of the bulbs was connected to the coil the luminosity spread through the other two, hence the three bulbs constituted really one vessel. When all the three bulbs were connected in multiple arc to the coil, in the largest of them the filament glowed brightest, in the next smaller it was a little less bright, and in the smallest it only came to redness. The bulbs were then sealed off and separately tried. The brightness of the filaments was now such as would have been expected on the supposition that the energy given off was proportionate to the surface of the bulb, this surface in each case representing one of the coatings of a condenser. Accordingly, there was less difference between the largest and the middle-sized than between the latter and the smallest bulb.

An interesting observation was made in this experiment. The three bulbs were suspended from a straight bare wire connected to a terminal of the coil, the largest bulb being placed at the end of the wire, at some distance from it the smallest bulb, and an equal distance from the latter the middle-sized one. The carbons glowed then in both the larger bulbs about as expected, but the smallest did not get its share by far. This observation led me to exchange the positions of the bulbs, and I then observed that whichever of the bulbs was in the middle it was by far less bright than it was in any other position. This mystifying result was, of course, found to be due to the elctrostatic action between the bulbs. When they were placed at considerable distance, or when they were attached to the corners of an equilateral triangle of copper wire, they glowed about in the order determined by their surfaces.

As to the shape of the vessel, it is also of some importance, especially at high degrees of exhaustion. Of all the possible

constructions, it seems that a spherical globe with the refractory body mounted in its centre is the best to employ. In experience it has been demonstrated that in such a globe a refractory body of a given bulk is more easily brought to incandescence than when otherwise shaped bulbs are used. There is also an advantage in giving to the incandescent body the shape of a sphere, for self-evident reasons. In any case, the body should be mounted in the centre, where the atoms rebounding from the glass collide. This object is best attained in the spherical bulb; but it is also attained in a cylindrical vessel with one or two straight filaments coinciding with its axis, and possibly also in parabolical or spherical bulbs with the refractory body or bodies placed in the focus or foci of the same, though the latter is not probable, as the electrified atoms should in all cases rebound normally from the surface they strike, unless the speed were excessive, in which case they *would* probably follow the general law of reflection No matter what shape the vessel may have, if the exhaustion be low, a filament mounted in the globe is brought to the same degree of incandescence in all parts; but if the exhaustion be high, and the bulb be spherical or pear-shaped, as usual, focal points form, and the filament is heated to a higher degree at or near such points.

To illustrate the effect, I have here two small bulbs which are alike, only one is exhausted to a low and the other to a very high degree. When connected to the coil, the filament in the former glows uniformly throughout all its length; whereas in the latter, that portion of the filament which is in the centre of the bulb glows far more intensely than the rest. A curious point is that the phenomenon occurs even if two filaments are mounted in a bulb, each being connected to one terminal of the coil, and, what is still more curious, if they be very near together, provided the vacuum be very high. I noted in experiments with such bulbs that the filaments would give way usually at a certain point, and in the first trials I attributed it to a defect in the carbon. But when the phenomenon occurred many times in succession I recognised its real cause.

In order to bring a refractory body enclosed in a bulb to

incandescence, it is desirable, on account of economy, that all the energy supplied to the bulb from the source should reach without loss the body to be heated: from there, and from nowhere else, it should be radiated. It is, of course, out of the question to reach this theoretical result, but it is possible by a proper construction of the illuminating device to approximate it more or less.

For many reasons, the refractory body is placed in the centre of the bulb, and it is usually supported on a glass stem containing the leading-in wire. As the potential of this wire is alternated, the rarefied gas surrounding the stem is acted upon inductively, and the glass stem is violently bombarded and heated. In this manner by far the greater portion of the energy supplied to the bulb—especially when exceedingly high frequencies are used—may be lost for the purpose contemplated. To obviate this loss, or at least to reduce it to a minimum, I usually screen the rarefied gas surrounding the stem from the inductive action of the leading-in wire by providing the stem with a tube or coating of conducting material. It seems beyond doubt that the best among metals to employ for this purpose is aluminum, on account of its many remarkable properties. Its only fault is that it is easily fusible, and therefore its distance from the incandescing body should be properly estimated. Usually, a thin tube, of a diameter somewhat smaller than that of the glass stem, is made of the finest aluminum sheet, and slipped on the stem. The tube is conveniently prepared by wrapping around a rod fastened in a lathe a piece of aluminum sheet of the proper size, grasping the sheet firmly with clean chamois leather or blotting paper, and spinning the rod very fast. The sheet is wound tightly around the rod, and a highly polished tube of two or three layers of the sheet is obtained. When slipped on the stem, the pressure is generally sufficient to prevent it from slipping off, but, for safety, the lower edge of the sheet may be turned inside. The upper inside corner of the sheet—that is, the one which is nearest to the refractory incandescent body—should be cut out diagonally, as it often happens that, in consequence of the intense heat, this corner turns towards the inside and comes very near

to, or in contact with, the wire, or filament, supporting the refractory body. The greater part of the energy supplied to the bulb is then used up in heating the metal tube, and the bulb is rendered useless for the purpose. The aluminum sheet should project above the glass stem more or less—1 inch or so—or else, if the glass be too close to the incandescing body, it may be strongly heated, and become more or less conducting, whereupon it may be ruptured, or may, by its conductivity, establish a good electrical connection between the metal tube and the leading-in wire, in which case, of course, again, most of the energy will be lost in heating the former. Perhaps the best way is to make the top of the glass tube, for about an inch, of a much smaller diameter. To still further reduce the danger arising from the heating of the glass stem, and also with the view of preventing an electrical connection between the metal tube and the electrode, I preferably wrap the stem with several layers of thin mica, which extends at least as far as the metal tube. In some bulbs I have also used an outside insulating cover.

The preceding remarks are only made to aid the experimenter in the first trials, for the difficulties which he encounters he may soon find means to overcome in his own way.

To illustrate the effect of the screen, and the advantage of using it, I have here two bulbs of the same size, with their stems, leading-in wires, and incandescent lamp filaments tied to the latter, as nearly alike as possible. The stem of one bulb is provided with an aluminum tube, the stem of the other has none. Originally the two bulbs were joined by a tube which was connected to a Sprengel pump. When a high vacuum had been reached, first the connecting tube, and then the bulbs, were sealed off; they are therefore of the same degree of exhaustion. When they are separately connected to the coil giving a certain potential, the carbon filament in the bulb provided with the aluminum screen is rendered highly incandescent, while the filament in the other bulb may, with the same potential, not even come to redness, although in reality the latter bulb takes generally more energy than the former. When they are both connected together to the terminal, the difference is even more

apparent, showing the importance of the screening. The metal tube placed on the stem containing the leading-in wire performs really two distinct functions: first, it acts more or less as an electrostatic screen, thus economising the energy supplied to the bulb; and, second, to whatever extent it may fail to act electrostatically, it acts mechanically, preventing the bombardment, and consequently intense heating and possible deterioration, of the slender support of the refractory incandescent body, or of the glass stem containing the leading-in wire. I say *slender* support, for it is evident that in order to confine the heat more completely to the incandescing body its support should be very thin, so as to carry away the smallest possible amount of heat by conduction. Of all the supports used I have found an ordinary incandescent lamp filament to be the best, principally because, among conductors, it can withstand the highest degrees of heat.

The effectiveness of the metal tube as an electrostatic screen depends largely on the degree of exhaustion.

At excessively high degrees of exhaustion—which are reached by using great care and special means in connection with the Sprengel pump—when the matter in the globe is in the ultra-radiant state, it acts most perfectly. The shadow of the upper edge of the tube is then sharply defined upon the bulb.

At a somewhat lower degree of exhaustion, which is about the ordinary "non-striking" vacuum, and generally as long as the matter moves predominantly in straight lines, the screen still does well. In elucidation of the preceding remark it is necessary to state that what is a "non-striking" vacuum for a coil operated, as ordinarily, by impulses, or currents, of low frequency, is not, by far, so when the coil is operated by currents of very high frequency. In such case the discharge may pass with great freedom through the rarefied gas through which a low-frequency discharge may not pass, even though the potential be much higher. At ordinary atmospheric pressures just the reverse rule holds good: the higher the frequency, the less the spark discharge is able to jump between the terminals, especially if they are knobs or spheres of some size.

Finally, at very low degrees of exhaustion, when the gas is

well conducting, the metal tube not only does not act as an electrostatic screen, but even is a drawback, aiding to a considerable extent the dissipation of the energy laterally from the leading-in wire. This, of course, is to be expected. In this case, namely, the metal tube is in good electrical connection with the leading-in wire, and most of the bombardment is directed upon the tube. As long as the electrical connection is not good, the conducting tube is always of some advantage, for although it may not greatly economise energy, still it protects the support of the refractory button, and is a means for concentrating more energy upon the same.

To whatever extent the aluminum tube performs the function of a screen, its usefulness is therefore limited to very high degrees of exhaustion when it is insulated from the electrode—that is, when the gas as a whole is non-conducting, and the molecules, or atoms, act as independent carriers of electric charges.

In addition to acting as a more or less effective screen, in the true meaning of the word, the conducting tube or coating may also act, by reason of its conductivity, as a sort of equaliser or dampener of the bombardment against the stem. To be explicit, I assume the action as follows:—Suppose a rhythmical bombardment to occur against the conducting tube by reason of its imperfect action as a screen, it certainly must happen that some molecules, or atoms, strike the tube sooner than others. Those which come first in contact with it give up their superfluous charge, and the tube is electrified, the electrification instantly spreading over its surface. But this must diminish the energy lost in the bombardment, for two reasons: firstly, the charge given up by the atoms spreads over a great area, and hence the electric density at any point is small, and the atoms are repelled with less energy than they would be if they would strike against a good insulator; secondly, as the tube is electrified by the atoms which first come in contact with it, the progress of the following atoms against the tube is more or less checked by the repulsion which the electrified tube must exert upon the similarly electrified atoms. This repulsion may perhaps be sufficient to prevent a large portion of the atoms from striking the tube, but at any rate it must diminish

the energy of their impact. It is clear that when the exhaustion is very low, and the rarefied gas well conducting, neither of the above effects can occur, and, on the other hand, the fewer the atoms, with the greater freedom they move; in other words, the higher the degree of exhaustion, up to a limit, the more telling will be both the effects.

What I have just said may afford an explanation of the phenomenon observed by Professor Crookes, namely, that a discharge through a bulb is established with much greater facility when an insulator than when a conductor is present in the same. In my opinion, the conductor acts as a dampener of the motion of the atoms in the two ways pointed out; hence, to cause a visible discharge to pass through the bulb, a much higher potential is needed if a conductor, especially of much surface, be present.

For the sake of clearness of some of the remarks before made, I must now refer to Figs. 18, 19, and 20, which illustrate various arrangements with a type of bulb most generally used.

Fig. 18 is a section through a spherical bulb, L, with the glass stem, s, containing the leading-in wire, w, which has a lamp filament, l, fastened to it, serving to support the refractory button, m, in the centre. M is a sheet of thin mica wound in several layers around the stem s, and a is the aluminum tube.

Fig. 19 illustrates such a bulb in a somewhat more advanced stage of perfection. A metallic tube, S, is fastened by means of some cement to the neck of the tube. In the tube is screwed a plug, P, of insulating material, in the centre of which is fastened a metallic terminal, t, for the connection to the leading-in wire, w. This terminal must be well insulated from the metal tube S, therefore, if the cement used is conducting—and most generally it is sufficiently so—the space between the plug P and the neck of the bulb should be filled with some good insulating material, as mica powder.

Fig. 20 shows a bulb made for experimental purposes. In this bulb the aluminum tube is provided with an external connection, which serves to investigate the effect of the tube under various conditions. It is referred to chiefly to suggest a line of experiment followed.

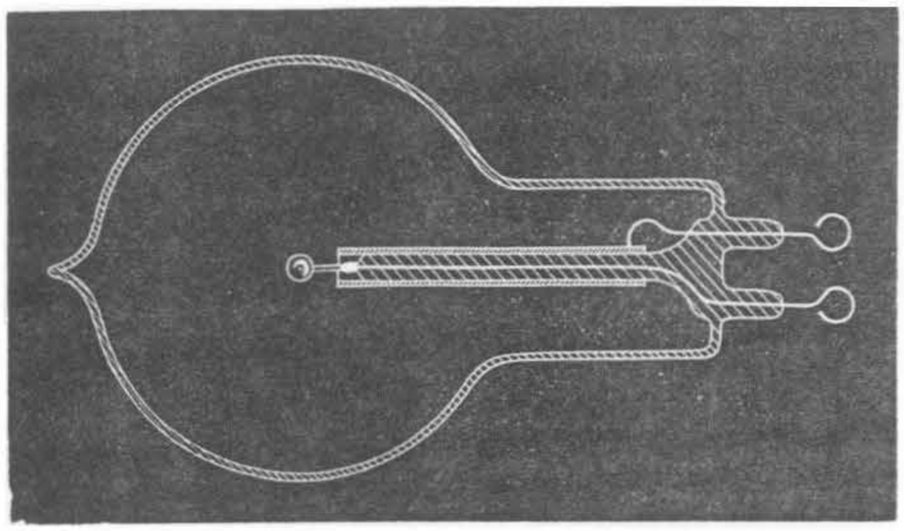

Fig. 20.—Bulb for Experiments with Conducting Tube.

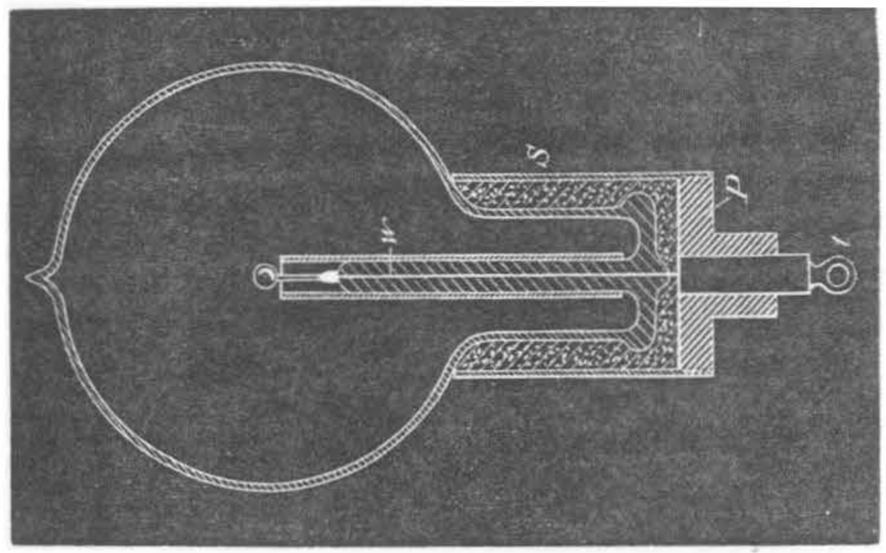

Fig. 19.—Improved Bulb with Socket and Screen.

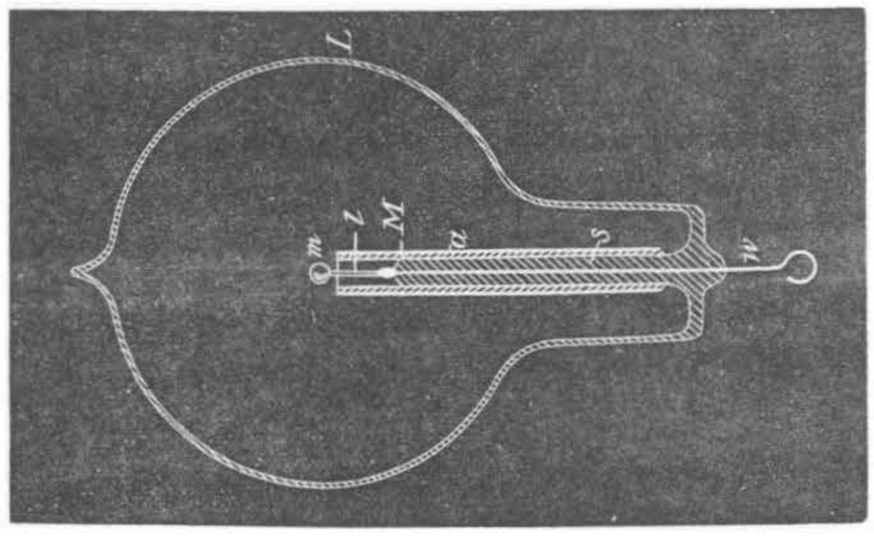

Fig. 18.—Bulb with Mica Tube and Aluminum Screen.

Since the bombardment against the stem containing the leading-in wire is due to the inductive action of the latter upon the rarefied gas, it is of advantage to reduce this action as far as practicable by employing a very thin wire, surrounded by a very thick insulation of glass or other material, and by making the wire passing through the rarefied gas as short as practicable. To combine these features I employ a large tube, T (Fig. 21), which

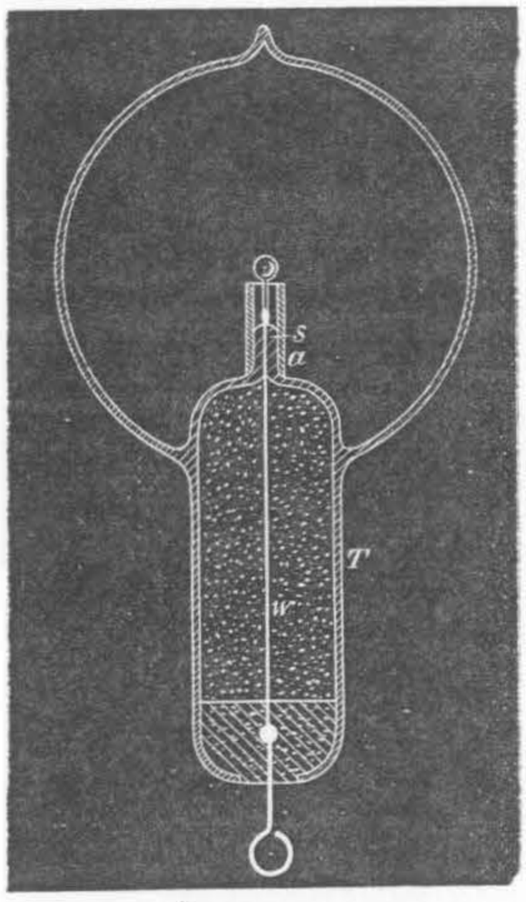

FIG. 21.—Iproved Bulb with Non-conducting Button.

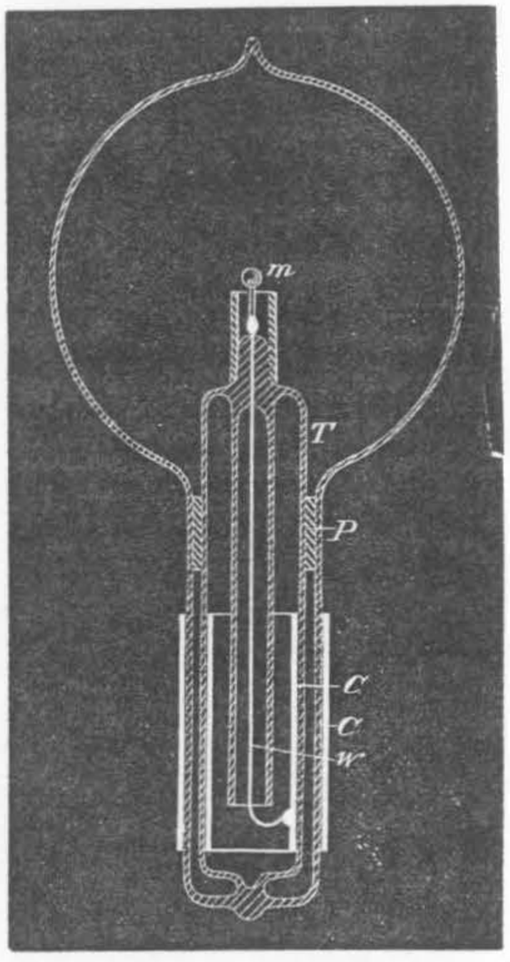

FIG. 22.—Type of Bulb without Leading-in Wire

protrudes into the bulb to some distance, and carries on the top a very short glass stem, s, into which is sealed the leading-in wire, w, and I protect the top of the glass stem against the heat by a small aluminum tube, a, and a layer of mica underneath the same, as usual. The wire w, passing through the large tube to the outside of the bulb, should be well insulated—with a glass tube,

for instance—and the space between ought to be filled out with some excellent insulator. Among many insulating powders I have tried, I have found that mica powder is the best to employ. If this precaution is not taken, the tube T, protruding into the bulb, will surely be cracked in consequence of the heating by the brushes, which are apt to form in the upper part of the tube, near the exhausted globe, especially if the vacuum be excellent, and therefore the potential necessary to operate the lamp very high.

Fig. 22 illustrates a similar arrangement, with a large tube, T, protruding into the part of the bulb containing the refractory button, m. In this case the wire leading from the outside into the bulb is omitted, the energy required being supplied through condenser coatings, $C\,C$. The insulating packing, P, should in this construction be tightly fitting to the glass, and rather wide, or otherwise the discharge might avoid passing through the wire, w, which connects the inside condenser coating to the incandescent button, m.

The molecular bombardment against the glass stem in the bulb is a source of great trouble. As illustration I will cite a phenomenon only too frequently and unwillingly observed. A bulb, preferably a large one, may be taken, and a good conducting body, such as a piece of carbon, may be mounted in it upon a platinum wire sealed in the glass stem. The bulb may be exhausted to a fairly high degree, nearly to the point when phosphorescence begins to appear. When the bulb is connected with the coil, the piece of carbon, if small, may become highly incandescent at first, but its brightness immediately diminishes, and then the discharge may break through the glass somewhere in the middle of the stem, in the form of bright sparks, in spite of the fact that the platinum wire is in good electrical connection with the rarefied gas through the piece of carbon or metal at the top. The first sparks are singularly bright, recalling those drawn from a clear surface of mercury. But, as they heat the glass rapidly, they of course lose tnen brightness, and cease when the glass at the ruptured place becomes incandescent, or generally sufficiently hot to conduct. When observed for the first time the phenomenon must appear very curious, and shows in a striking manner

how radically different alternate currents, or impulses, of high frequency behave, as compared with steady currents, or currents of low frequency. With such currents—namely, the latter—the phenomenon would of course not occur. When frequencies such as are obtained by mechanical means are used, I think that the rupture of the glass is more or less the consequence of the bombardment, which warms it up and impairs its insulating power; but with frequencies obtainable with condensers, I have no doubt that the glass may give way without previous heating. Although this appears most singular at first, it is in reality what we might expect to occur. The energy supplied to the wire leading into the bulb is given off partly by direct action through the carbon button, and partly by inductive action through the glass surrounding the wire. The case is thus analogous to that in which a condenser shunted by a conductor of low resistance is connected to a source of alternating currents. As long as the frequencies are low, the conductor gets the most, and the condenser is perfectly safe; but when the frequency becomes excessive, the *rôle* of the conductor may become quite insignificant. In the latter case the difference of potential at the terminals of the condenser may become so great as to rupture the dielectric, notwithstanding the fact that the terminals are joined by a conductor of low resistance.

It is, of course, not necessary, when it is desired to produce the incandescence of a body enclosed in a bulb by means of these currents, that the body should be a conductor, for even a perfect non-conductor may be quite as readily heated. For this purpose it is sufficient to surround a conducting electrode with the non-conducting material, as, for instance, in the bulb described before in Fig. 21, in which a thin incandescent lamp filament is coated with a non-conductor, and supports a button of the same material on the top. At the start the bombardment goes on by inductive action through the non-conductor, until the same is sufficiently heated to become conducting, when the bombardment continues in the ordinary way.

A different arrangement used in some of the bulbs constructed is illustrated in Fig. 23. In this instance a non-

conductor, m, is mounted in a piece of common arc light carbon so as to project some small distance above the latter.

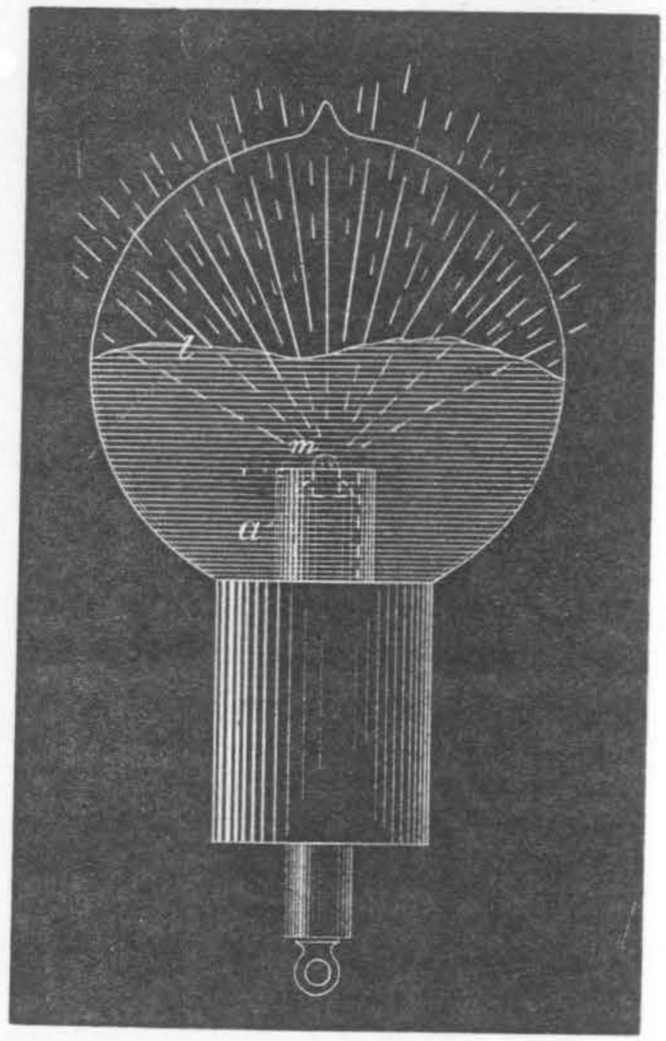

FIG. 23.—Effect produced by a Ruby Drop.

The carbon piece is connected to the leading-in wire passing through a glass stem, which is wrapped with several layers of mica. An aluminum tube, a, is employed, as usual for screening. It is so arranged that it reaches very nearly as high as the carbon, and only the non-conductor, m, projects a little above it. The bombardment goes at first against the upper surface of carbon, the lower parts being protected by the aluminum tube. As soon, however, as the non-conductor, m, is heated, it is rendered good conducting, and then it becomes the centre of the bombardment, being most exposed to the same.

I have also constructed during these experiences many such single-wire bulbs with or without internal electrode, in which the radiant matter was projected against, or focused upon, the body to be rendered incandescent. Fig. 24 illustrates one of the

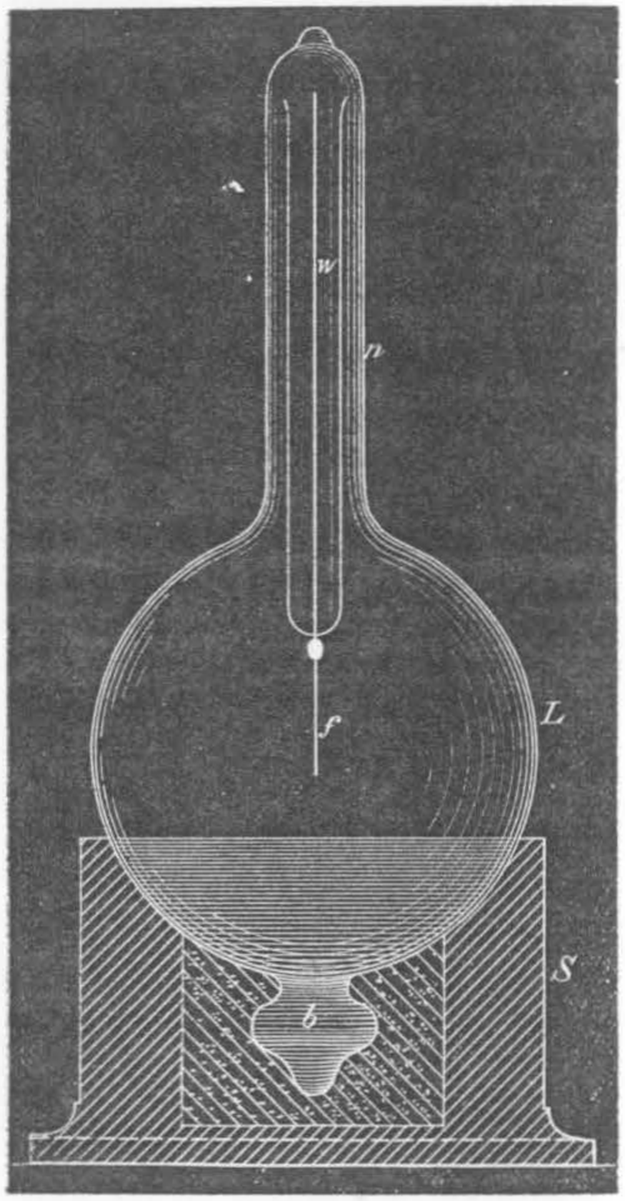

FIG. 24.—Bulb without Leading-in Wire, showing Effect of Projected Matter.

bulbs used. It consists of a spherical globe, L, provided with a long neck, n, on the top, for increasing the action in some cases by the application of an external conducting coating. The globe L is blown out on the bottom into a very small bulb, b, which

serves to hold it firmly in a socket, S, of insulating material into which it is cemented. A fine lamp filament, f, supported on a wire, w, passes through the centre of the globe L. The filament is rendered incandescent in the middle portion, where the bombardment proceeding from the lower inside surface of the globe is most intense. The lower portion of the globe, as far as the socket S reaches, is rendered conducting, either by a tinfoil coating or otherwise, and the external electrode is connected to a terminal of the coil.

The arrangement diagramatically indicated in Fig. 24 was found to be an inferior one when it was desired to render incandescent a filament or button supported in the centre of the globe, but it was convenient when the object was to excite phosphorescence.

In many experiments in which bodies of a different kind were mounted in the bulb as, for instance, indicated in Fig. 23, some observations of interest were made.

It was found, among other things, that in such cases, no matter where the bombardment began, just as soon as a high temperature was reached there was generally one of the bodies which seemed to take most of the bombardment upon itself, the other, or others, being thereby relieved. This quality appeared to depend principally on the point of fusion, and on the facility with which the body was "evaporated," or, generally speaking, disintegrated—meaning by the latter term not only the throwing off of atoms, but likewise of larger lumps. The observation made was in accordance with generally accepted notions. In a highly exhausted bulb electricity is carried off from the electrode by independent carriers, which are partly the atoms, or molecules, of the residual atmosphere, and partly the atoms, molecules, or lumps thrown off from the electrode. If the electrode is composed of bodies of different character, and if one of these is more easily disintegrated than the others, most of the electricity supplied is carried off from that body, which is then brought to a higher temperature than the others, and this the more, as upon an increase of the temperature the body is still more easily disintegrated.

It seems to me quite probable that a similar process takes place in the bulb even with a homogeneous electrode, and I think it to be the principal cause of the disintegration. There is bound to be some irregularity, even if the surface is highly polished, which, of course, is impossible with most of the refractory bodies employed as electrodes. Assume a point of the electrode gets hotter, instantly most of the discharge passes through that point, and a minute patch is probably fused and evaporated. It is now possible that in consequence of the violent disintegration the spot attacked sinks in temperature, or that a counter-force is created, as in an arc; at any rate, the local tearing-off meets with the limitations incident to the experiment, whereupon the same process occurs on another place. To the eye the electrode appears uniformly brilliant, but there are upon it points, constantly shifting and wandering around, of a temperature far above the mean, and this materially hastens the process of deterioration. That some such thing occurs, at least when the electrode is at a lower temperature, sufficient experimental evidence can be obtained in the following manner:—Exhaust a bulb to a very high degree, so that with a fairly high potential the discharge cannot pass—that is, not a *luminous* one, for a weak invisible discharge occurs always. in all probability. Now raise slowly and carefully the potential, leaving the primary current on no more than for an instant. At a certain point, two, three, or half a dozen phosphorescent spots will appear on the globe. These places of the glass are evidently more violently bombarded than others, this being due to the unevenly distributed electric density, necessitated, of course, by sharp projections, or, generally speaking, irregularities of the electrode. But the luminous patches are constantly changing in position, which is especially well observable if one manages to produce very few, and this indicates that the configuration of the electrode is rapidly changing.

From experiences of this kind I am led to infer that, in order to be most durable, the refractory button in the bulb should be in the form of a sphere, with a highly polished surface. Such a small sphere could be manufactured from a diamond or some other crystal, but a better way would be to fuse, by the employment of extreme degrees of temperature, some oxide—as, for instance, zirconia—into a small drop, and then keep it in the bulb at a temperature somewhat below its point of fusion.

Interesting and useful results can no doubt be reached in the direction of extreme degrees of heat. How can such high temperatures be arrived at? How are the highest degrees of heat reached in Nature? By the impact of stars, by high speeds and collisions. In a collision any rate of heat generation may be attained. In a chemical process we are limited. When oxygen and hydrogen combine, they fall, metaphorically speaking, from a definite height. We cannot go very far with a blast, nor by confining heat in a furnace, but in an exhausted bulb we can concentrate any amount of energy upon a minute button. Leaving practicability out of consideration, this, then, would be the means which, in my opinion, would enable us to reach the highest temperature. But a great difficulty, when proceeding in this way, is encountered: namely, in most cases the body is carried off before it can fuse and form a drop. This difficulty exists principally with an oxide such as zirconia, because it cannot be compressed in so hard a cake that it would not be carried off quickly. I endeavoured repeatedly to fuse zirconia, placing it in a cup or arc light carbon as indicated in Fig. 23. It glowed with a most intense light, and the stream of the particles projected out of the carbon cup was of a vivid white; but, whether it was compressed in a cake or made into a paste with carbon, it was carried off before it could be fused. The carbon cup containing the zirconia had to be mounted very low in the neck of a large bulb, as the heating of the glass by the projected particles of the oxide was so rapid that in the first trial the bulb was cracked almost in an instant when the current was turned on. The heating of the glass by the projected particles was found to be always greater when the carbon cup contained a body which was rapidly carried off—I presume because in such cases, with the same potential, higher speeds were reached, and also because, per unit of time, more matter was projected—that is, more particles would strike the glass.

The before-mentioned difficulty did not exist, however, when the body mounted in the carbon cup offered great resistance to deterioration. For instance, when an oxide was first fused in an oxygen blast and then mounted in the bulb, it melted very readily into a drop.

Generally during the process of fusion magnificent light effects were noted, of which it would be difficult to give an adequate idea. Fig. 23 is intended to illustrate the effect observed with a ruby drop. At first one may see a narrow funnel of white light projected against the top of the globe, where it produces an irregularly outlined phosphorescent patch. When the point of the ruby fuses the phosphorescence becomes very powerful; but as the atoms are projected with much greater speed from the surface of the drop, soon the glass gets hot and "tired," and now only the outer edge of the patch glows. In this manner an intensely phosphorescent, sharply defined line, *l*, corresponding to the outline of the drop, is produced, which spreads slowly over the globe as the drop gets larger. When the mass begins to boil, small bubbles and cavities are formed, which cause dark-coloured spots to sweep across the globe. The bulb may be turned downwards without fear of the drop falling off, as the mass possesses considerable viscosity.

I may mention here another feature of some interest, which I believe to have noted in the course of these experiments, though the observations do not amount to a certitude. It *appeared* that under the molecular impact caused by the rapidly alternating potential the body was fused, and maintained in that state at a lower temperature in a highly exhausted bulb than was the case at normal pressure and application of heat in the ordinary ways—that is, at least, judging from the quantity of the light emitted. One of the experiments performed may be mentioned here by way of illustration. A small piece of pumice-stone was stuck on a platinum wire, and first melted to it in a gas burner. The wire was next placed between two pieces of charcoal and a burner applied so as to produce an intense heat, sufficient to melt down the pumice-stone into a small glass-like button. The platinum wire had to be taken of sufficient thickness to prevent

its melting in the fire. While in the charcoal fire, or when held in a burner to gain a better idea of the degree of heat, the button glowed with great brilliancy. The wire with the button was then mounted in a bulb, and upon exhausting the same to a high degree the current was turned on slowly so as to prevent the cracking of the button. The button was heated to the point of fusion, and when it melted it did not, apparently, glow with the same brilliancy as before; and this would indicate a lower temperature. Leaving out of consideration the observer's possible, and even probable, error, the question is, can a body under these conditions be brought from a solid to a liquid state with evolution of *less* light?

When the potential of a body is rapidly alternated it is certain that the structure is jarred. When the potential is very high, although the vibrations may be few—say 20,000 per second—the effect upon the structure may be considerable. Suppose, for example, that a ruby is melted into a drop by a steady application of energy. When it forms a drop, it will emit visible and invisible waves, which will be in a definite ratio, and to the eye the drop will appear to be of a certain brilliancy. Next, suppose we diminish to any degree we choose the energy steadily supplied, and, instead, supply energy which rises and falls according to a certain law. Now, when the drop is formed, there will be emitted from it three different kinds of vibrations—the ordinary visible, and two kinds of invisible waves: that is, the ordinary dark waves of all lengths, and, in addition, waves of a well-defined character. The latter would not exist by a steady supply of the energy, still they help to jar and loosen the structure. If this really be the case, then the ruby drop will emit relatively less visible and more invisible waves than before. Thus it would seem that when a platinum wire, for instance, is fused by currents alternating with extreme rapidity, it emits at the point of fusion less light and more invisible radiation than it does when melted by a steady current, though the total energy used up in the process of fusion is the same in both cases. Or, to cite another example, a lamp filament is not capable of withstanding as long with currents of extreme frequency as it does with steady currents,

assuming that it be worked at the same luminous intensity. This means that for rapidly alternating currents the filament should be shorter and thicker. The higher the frequency—that is, the greater the departure from the steady flow—the worse it would be for the filament. But if the truth of this remark were demonstrated, it would be erroneous to conclude that such a refractory button as used in these bulbs would be deteriorated quicker by currents of extremely high frequency than by steady or low-frequency currents. From experience I may say that just the opposite holds good: the button withstands the bombardment better with currents of very high frequency. But this is due to the fact that a high-frequency discharge passes through a rarefied gas with much greater freedom than a steady or low-frequency discharge, and this will say that with the former we can work with a lower potential or with a less violent impact. As long, then, as the gas is of no consequence, a steady or low-frequency current is better; but as soon as the action of the gas is desired and important, high frequencies are preferable.

In the course of these experiences great many trials were made with all kinds of carbon buttons. Electrodes made of ordinary carbon buttons were decidedly more durable when the buttons were obtained by the application of enormous pressure. Electrodes prepared by depositing carbon in well-known ways did not show up well: they blackened the globe very quickly. From many experiences I conclude that lamp filaments obtained in this manner can be advantageously used only with low potentials and low-frequency currents. Some kinds of carbon withstand so well that, in order to bring them to the point of fusion, it is necessary to employ very small buttons. In this case the observation is rendered very difficult, on account of the intense light produced. Nevertheless, there can be no doubt that all kinds of carbon are fused under the molecular bombardment, but the liquid state must be one of great instability. Of all the bodies tried, there were two which withstood best—diamond and carborundum. These two showed up about equally, but the latter was preferable, for many reasons. As it is more than likely that this body is not yet generally known, I will venture to call your attention to it.

It has been recently produced by Mr. E. G. Acheson, of Monongahela City, Pennsylvania, U.S.A. It is intended to replace ordinary diamond powder for polishing precious stones, &c., and I have been informed that it accomplishes this object quite successfully. I do not know why the name "carborundum" has been given to it, unless there is something in the process of its manufacture which justifies this selection. Through the kindness of the inventor, I obtained a short while ago some samples which I desired to test in regard to their qualities of phosphorescence and capability of withstanding high degrees of heat.

Carborundum can be obtained in two forms—in the form of "crystals" and of powder. The former appear to the naked eye dark-coloured, but are very brilliant; the latter is of nearly the same colour as ordinary diamond powder, but very much finer. When viewed under a microscope, the samples of crystals given to me did not appear to have any definite form, but rather resembled pieces of broken-up egg coal of fine quality. The majority were opaque, but there were some which were transparent and coloured. The crystals are a kind of carbon containing some impurities; they are extremely hard, and withstand for a long time even an oxygen blast. When the blast is directed against them, they at first form a cake of some compactness, probably in consequence of the fusion of impurities they contain. The mass withstands for a very long time the blast without further fusion; but a slow carrying off, or burning, occurs, and finally a small quantity of a glass-like residue is left, which, I suppose, is melted alumina. When compressed strongly they conduct very well, but not as well as ordinary carbon. The powder, which is obtained from the crystals in some way, is practically non-conducting. It affords a magnificent polishing material for stones.

The time has been too short to make a satisfactory study of the properties of this product, but enough experience has been gained in a few weeks I have experimented upon it to say that it does possess some remarkable properties in many respects. It withstands excessively high degrees of heat, it is little deteriorated

by molecular bombardment, and it does not blacken the globe as ordinary carbon does. The only difficulty which I have found in its use in connection with these experiments was to find some binding material which would resist the heat and the effect of the bombardment as successfully as carborundum itself does.

I have here a number of bulbs which I have provided with buttons of carborundum. To make such a button of carborundum crystals I proceed in the following manner:—I take an ordinary lamp filament and dip its point in tar, or some other thick substance or paint which may be readily carbonised. I next pass the point of the filament through the crystals, and then hold it vertically over a hot plate. The tar softens and forms a drop on the point of the filament, the crystals adhering to the surface of the drop. By regulating the distance from the plate the tar is slowly dried out and the button becomes solid. I then once more dip the button in tar and hold it again over a plate until the tar is evaporated, leaving only a hard mass which firmly binds the crystals. When a larger button is required, I repeat the process several times, and I generally also cover the filament a certain distance below the button with crystals. The button being mounted in a bulb, when a good vacuum has been reached, first a weak, and then a strong discharge is passed through the bulb to carbonise the tar and expel all gases, and later it is brought to a very intense incandescence.

When the powder is used I have found it best to proceed as follows:—I make a thick paint of carborundum and tar, and pass a lamp filament through the paint. Taking then most of the paint off by rubbing the filament against a piece of chamois leather, I hold it over a hot plate until the tar evaporates and the coating becomes firm. I repeat this process as many times as it is necessary to obtain a certain thickness of coating. On the point of the coated filament I form a button in the same manner.

There is no doubt that such a button—properly prepared under great pressure—of carborundum, especially of powder of the best quality, will withstand the effect of the bombardment fully as good as anything we know. The difficulty is that the binding material gives way, and the carborundum is slowly thrown off

after some time. As it does not seem to blacken the globe in the least, it might be found useful for coating the filaments of ordinary incandescent lamps, and I think that it is even possible to produce thin threads or sticks of carborundum which will replace the ordinary filaments in an incandescent lamp. A carborundum coating seems to be more durable than other coatings, not only because the carborundum can withstand high degrees of heat, but also because it seems to unite with the carbon better than any other material I have tried. A coating of zirconia or any other oxide, for instance, is far more quickly destroyed. I prepared buttons of diamond dust in the same manner as of carborundum, and these came in durability nearest to those prepared of carborundum, but the binding paste gave way much more quickly in the diamond buttons: this, however, I attributed to the size and irregularity of the grains of the diamond.

It was of interest to find whether carborundum possesses the quality of phosphorescence. One is, of course, prepared to encounter two difficulties: first, as regards the rough product, the "crystals," they are good conducting, and it is a fact that conductors do not phosphoresce; second, the powder, being exceedingly fine, would not be apt to exhibit very prominently this quality, since we know that when crystals, even such as diamond or ruby, are finely powdered they lose the property of phosphorescence to a considerable degree.

The question presents itself here, Can a conductor phosphoresce? What is there in such a body as a metal, for instance, that would deprive it of the quality of phosphorescence, unless it is that property which characterises it as a conductor? for it is a fact that most of the phosphorescent bodies lose that quality when they are sufficiently heated to become more or less conducting. Then, if a metal be in a large measure, or perhaps entirely, deprived of that property, it should be capable of phosphorescence. Therefore it is quite possible that at some extremely high frequency, when behaving practically as a non-conductor, a metal or any other conductor might exhibit the quality of phosphorescence, even though it be entirely incapable of phosphorescing under the impact of a low-frequency discharge. There is,

however, another possible way how a conductor might at least *appear* to phosphoresce.

Considerable doubt still exists as to what really is phosphorescence, and as to whether the various phenomena comprised under this head are due to the same causes. Suppose that in an exhausted bulb, under the molecular impact, the surface of a piece of metal or other conductor is rendered strongly luminous, but at the same time it is found that it remains comparatively cool, would not this luminosity be called phosphorescence? Now such a result, theoretically at least, is possible, for it is a mere question of potential, or speed. Assume the potential of the electrode, and consequently the speed of the projected atoms, to be sufficiently high, the surface of the metal piece against which the atoms are projected would be rendered highly incandescent, since the process of heat generation would be incomparably faster than that of radiating or conducting away from the surface of the collision. In the eye of the observer, a single impact of the atoms would cause an instantaneous flash; but if the impacts were repeated with sufficient rapidity, they would produce a continuous impression upon his retina. To him then the surface of the metal would appear continuously incandescent and of constant luminous intensity, while in reality the light would be either intermittent or at least changing periodically in intensity. The metal piece would rise in temperature until equilibrium was attained—that is, until the energy continuously radiated would equal that intermittently supplied. But the supplied energy might under such conditions not be sufficient to bring the body to any more than a very moderate mean temperature, especially if the frequency of the atomic impacts be very low—just enough that the fluctuation of the intensity of the light emitted could not be detected by the eye. The body would now, owing to the manner in which the energy is supplied, emit a strong light, and yet be at a comparatively very low mean temperature. How could the observer call the luminosity thus produced? Even if the analysis of the light would teach him something definite, still he would probably rank it under the phenomena of phosphorescence. It is conceivable that in such a way both conducting and non-conducting bodies may be maintained at a certain luminous intensity, but the energy required would very greatly vary with the nature and properties of the bodies.

These and some foregoing remarks of a speculative nature were made merely to bring out curious features of alternate currents or electric impulses. By their help we may cause a body to emit *more* light, while at a certain mean temperature, than it would emit if brought to that temperature by a steady supply; and, again, we may bring a body to the point of fusion, and cause it to emit *less* light than when fused by the application of energy in ordinary ways. It all depends on how we supply the energy, and what kind of vibrations we set up: in one case the vibrations are more, in the other less, adapted to affect our sense of vision.

Some effects, which I had not observed before, obtained with carborundum in the first trials, I attributed to phosphorescence, but in subsequent experiments it appeared that it was devoid of that quality. The crystals possess a noteworthy feature. In a bulb provided with a single electrode in the shape of a small circular metal disc, for instance, at a certain degree of exhaustion the electrode is covered with a milky film, which is separated by a dark space from the glow filling the bulb. When the metal disc is covered with carborundum crystals, the film is far more intense, and snow-white. This I found later to be merely an effect of the bright surface of the crystals, for when an aluminum electrode was highly polished it exhibited more or less the same phenomenon. I made a number of experiments with the samples of crystals obtained, principally because it would have been of special interest to find that they are capable of phosphorescence, on account of their being conducting. I could not produce phosphorescence distinctly, but I must remark that a decisive opinion cannot be formed until other experimenters have gone over the same ground.

The powder behaved in some experiments as though it contained alumina, but it did not exhibit with sufficient distinctness the red of the latter. Its dead colour brightens considerably under the molecular impact, but I am now convinced it does not

phosphoresce. Still, the tests with the powder are not conclusive, because powdered carborundum probably does not behave like a phosphorescent sulphide, for example, which could be finely powdered without impairing the phosphorescence, but rather like powdered ruby or diamond, and therefore it would be necessary, in order to make a decisive test, to obtain it in a large lump and polish up the surface.

If the carborundum proves useful in connection with these and similar experiments, its chief value will be found in the production of coatings, thin conductors, buttons, or other electrodes capable of withstanding extremely high degrees of heat.

The production of a small electrode capable of withstanding enormous temperatures I regard as of the greatest importance in the manufacture of light. It would enable us to obtain, by means of currents of very high frequencies, certainly twenty times, if not more, the quantity of light which is obtained in the present incandescent lamp by the same expenditure of energy. This estimate may appear to many exaggerated, but in reality I think it is far from being so. As this statement might be misunderstood, I think it necessary to expose clearly the problem with which in this line of work we are confronted, and the manner in which, in my opinion, a solution will be arrived at.

Anyone who begins a study of the problem will be apt to think that what is wanted in a lamp with an electrode is a very high degree of incandescence of the electrode. There he will be mistaken. The high incandescence of the button is a necessary evil, but what is really wanted is the high incandescence of the gas surrounding the button. In other words, the problem in such a lamp is to bring a mass of gas to the highest possible incandescence. The higher the incandescence, the quicker the mean vibration, the greater is the economy of the light production. But to maintain a mass of gas at a high degree of incandescence in a glass vessel, it will always be necessary to keep the incandescent mass away from the glass—that is, to confine it as much as possible to the central portion of the globe.

In one of the experiments this evening a brush was produced at the end of a wire. This brush was a flame, a source of heat

and light. It did not emit much perceptible heat, nor did it glow with an intense light; but is it the less a flame because it does not scorch my hand? is it the less a flame because it does not hurt my eye by its brilliancy? The problem is precisely to produce in the bulb such a flame, much smaller in size, but incomparably more powerful. Were there means at hand for producing electric impulses of a sufficiently high frequency, and for transmitting them, the bulb could be done away with, unless it were used to protect the electrode, or to economise the energy by confining the heat. But as such means are not at disposal, it becomes necessary to place the terminal in a bulb and rarefy the air in the same. This is done merely to enable the apparatus to perform the work which it is not capable of performing at ordinary air pressure. In the bulb we are able to intensify the action to any degree—so far that the brush emits a powerful light. The intensity of the light emitted depends principally on the frequency and potential of the impulses, and on the electric density on the surface of the electrode. It is of the greatest importance to employ the smallest possible button, in order to push the density very far. Under the violent impact of the molecules of the gas surrounding it, the small electrode is of course brought to an extremely high temperature, but around it is a mass of highly incandescent gas, a flame or photosphere, many hundred times the volume of the electrode. With a diamond, carborundum, or zirconia button the photosphere can be as much as one thousand times the volume of the button. Without much reflecting one would think that in pushing so far the incandescence of the electrode it would be instantly volatilised. But after a careful consideration he would find that, theoretically, it should not occur, and in this fact—which, however, is experimentally demonstrated—lies principally the future value of such a lamp.

At first, when the bombardment begins, most of the work is performed on the surface of the button, but when a highly conducting photosphere is formed the button is comparatively relieved. The higher the incandescence of the photosphere, the more it approaches in conductivity to that of the electrode, and

the more, therefore, the solid and the gas form one conducting body. The consequence is that, the further is forced the incandescence, the more work, comparatively, is performed on the gas, and the less on the electrode. The formation of a powerful photosphere is consequently the very means for protecting the electrode. This protection, of course, is a relative one, and it should not be thought that by pushing the incandescence higher the electrode is actually less deteriorated. Still, theoretically, with extreme frequencies, this result must be reached, but probably at a temperature too high for most of the refractory bodies known. Given, then, an electrode which can withstand to a certain very high limit the effect of the bombardment and outward strain, it would be safe no matter how much it is forced beyond that limit. In an incandescent lamp quite different considerations apply. There the gas is not at all concerned: the whole of the work is performed on the filament; and the life of the lamp diminishes so rapidly with the increase of the degree of incandescence, that economical reasons compel us to work it at a low incandescence. But if an incandescent lamp is operated with currents of very high frequency, the action of the gas cannot be neglected, and the rules for the most economical working must be considerably modified.

In order to bring such a lamp with one or two electrodes to a great perfection, it is necessary to employ impulses of very high frequency. The high frequency secures, among others, two chief advantages, which have a most important bearing upon the economy of the light production. Firstly, the deterioration of the electrode is reduced by reason of the fact that we employ a great many small impacts, instead of few violent ones, which shatter quickly the structure; secondly, the formation of a large photosphere is facilitated.

In order to reduce the deterioration of the electrode to the minimum, it is desirable that the vibration be harmonic, for any suddenness hastens the process of destruction. An electrode lasts much longer when kept at incandescence by currents, or impulses, obtained from a high-frequency alternator, which rise and fall more or less harmonically, than by impulses obtained

from a disruptive discharge coil. In the latter case there is no doubt that most of the damage is done by the fundamental sudden discharges.

One of the elements of loss in such a lamp is the bombardment of the globe. As the potential is very high, the molecules are projected with great speed; they strike the glass, and usually excite a strong phosphorescence. The effect produced is very pretty, but for economical reasons it would be perhaps preferable to prevent, or at least reduce to the minimum, the bombardment against the globe, as in such case it is, as a rule, not the object to excite phosphorescence, and as some loss of energy results from the bombardment. This loss in the bulb is principally dependent on the potential of the impulses, and on the electric density on the surface of the electrode. In employing very high frequencies the loss of energy by the bombardment is greatly reduced, for, firstly, the potential needed to perform a given amount of work is much smaller, and, secondly, by producing a highly conducting photosphere around the electrode, the same result is obtained as though the electrode were much larger, which is equivalent to a smaller electric density. But be it by the diminution of the maximum potential or of the density, the gain is effected in the same manner, namely, by avoiding violent shocks, which strain the glass much beyond its limit of elasticity. If the frequency could be brought high enough, the loss due to the imperfect elasticity of the glass would be entirely negligible. The loss due to bombardment of the globe may, however, be reduced by using two electrodes instead of one. In such case each of the electrodes may be connected to one of the terminals; or else, if it is preferable to use only one wire, one electrode may be connected to one terminal, and the other to the ground or to an insulated body of some surface, as, for instance, a shade on the lamp. In the latter case, unless some judgment is used, one of the electrodes might glow more intensely than the other.

But, on the whole, I find it preferable when using such high frequencies to employ only one electrode and one connecting wire. I am convinced that the illuminating device of the near

future will not require for its operation more than one lead, and, at any rate, it will have no leading-in wire, since the energy required can be as well transmitted through the glass. In experimental bulbs the leading-in wire is most generally used on account of convenience, as in employing condenser coatings in the manner indicated in Fig. 22, for example, there is some difficulty in fitting the parts, but these difficulties would not exist if a great many bulbs were manufactured; otherwise the energy can be conveyed through the glass as well as through a wire, and with these high frequencies the losses are very small. Such illuminating devices will necessarily involve the use of very high potentials, and this, in the eyes of practical men, might be an objectionable feature. Yet, in reality, high potentials are not objectionable—certainly not in the least as far as the safety of the devices is concerned.

There are two ways of rendering an electric appliance safe. One is to use low potentials, the other is to determine the dimensions of the apparatus so that it is safe no matter how high a potential is used. Of the two, the latter seems to me the better way, for then the safety is absolute, unaffected by any possible combination of circumstances, which might render even a low-potential appliance dangerous to life and property. But the practical conditions require not only the judicious determination of the dimensions of the apparatus; they likewise necessitate the employment of energy of the proper kind. It is easy, for instance, to construct a transformer capable of giving, when operated from an ordinary alternate-current machine of low tension, say 50,000 volts, which might be required to light a highly exhausted phosphorescent tube, so that, in spite of the high potential, it is perfectly safe, the shock from it producing no inconvenience. Still, such a transformer would be expensive, and in itself inefficient; and, besides, what energy was obtained from it would not be economically used for the production of light. The economy demands the employment of energy in the form of extremely rapid vibrations. The problem of producing light has been likened to that of maintaining a certain high-pitch note by means of a bell. It should be said a *barely*

audible note; and even these words would not express it, so wonderful is the sensitiveness of the eye. We may deliver powerful blows at long intervals, waste a good deal of energy, and still not get what we want; or we may keep up the note by delivering frequent gentle taps, and get nearer to the object sought by the expenditure of much less energy. In the production of light, as far as the illuminating device is concerned, there can be only one rule—that is, to use as high frequencies as can be obtained; but the means for the production and conveyance of impulses of such character impose, at present at least, great limitations. Once it is decided to use very high frequencies, the return wire becomes unnecessary, and all the appliances are simplified. By the use of obvious means the same result is obtained as though the return wire were used. It is sufficient for this purpose to bring in contact with the bulb, or merely in the vicinity of the same, an insulated body of some surface. This surface need, of course, be the smaller, the higher the frequency and potential used, and necessarily, also, the higher the economy of the lamp or other device.

This plan of working has been resorted to on several occasions this evening. So, for instance, when the incandescence of a button was produced by grasping the bulb with the hand, the body of the experimenter merely served to intensify the action. The bulb used was similar to that illustrated in Fig. 19, and the coil was excited to a small potential, not sufficient to bring the button to incandescence when the bulb was hanging from the wire; and incidentally, in order to perform the experiment in a more suitable manner, the button was taken so large that a perceptible time had to elapse before, upon grasping the bulb, it could be rendered incandescent. The contact with the bulb was of course quite unnecessary. It is easy, by using a rather large bulb with an exceedingly small electrode, to adjust the conditions so that the latter is brought to bright incandescence by the mere approach of the experimenter within a few feet of the bulb, and that the incandescence subsides upon his receding.

In another experiment, when phosphorescence was excited, a similar bulb was used. Here again, originally, the potential

was not sufficient to excite phosphorescence until the action was intensified—in this case, however, to present a different feature, by touching the socket with a metallic object held in the hand. The electrode in the bulb was a carbon button so large that it could not be brought to incandescence and thereby spoil the effect produced by phosphorescence.

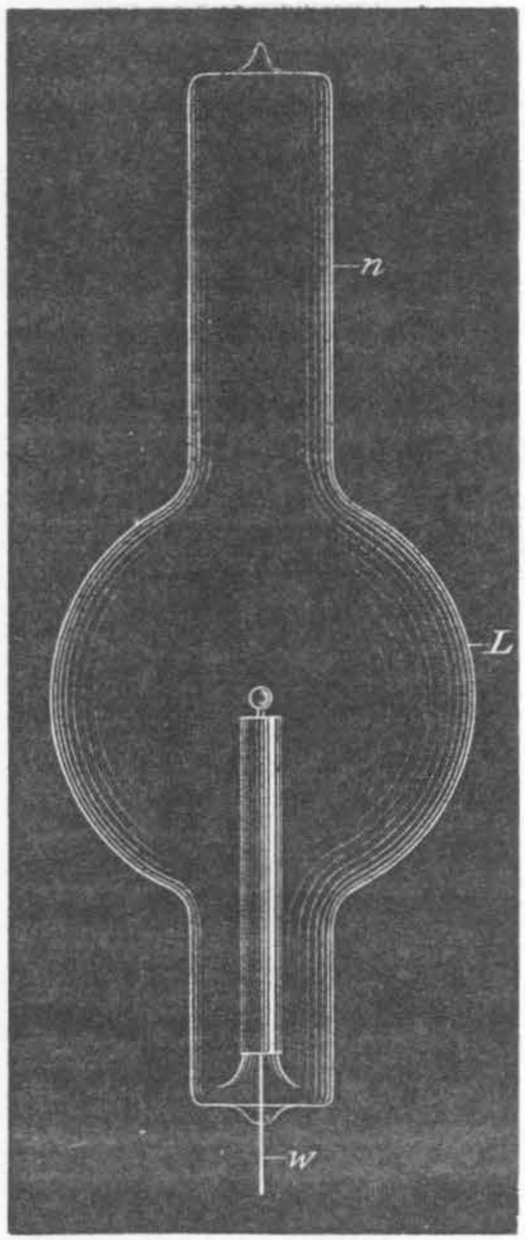

FIG. 25.—Improved Experimental Bulb.

Again, in another of the early experiments, a bulb was used as illustrated in Fig. 12. In this instance, by touching the bulb with one or two fingers, one or two shadows of the stem inside

were projected against the glass, the touch of the finger producing the same result as the application of an external negative electrode under ordinary circumstances.

In all these experiments the action was intensified by augmenting the capacity at the end of the lead connected to the terminal. As a rule, it is not necessary to resort to such means, and would be quite unnecessary with still higher frequencies, but when it *is* desired, the bulb or tube can be easily adapted to the purpose.

In Fig. 25, for example, an experimental bulb, L, is shown, which is provided with a neck, n, on the top for the application of an external tinfoil coating, which may be connected to a body of

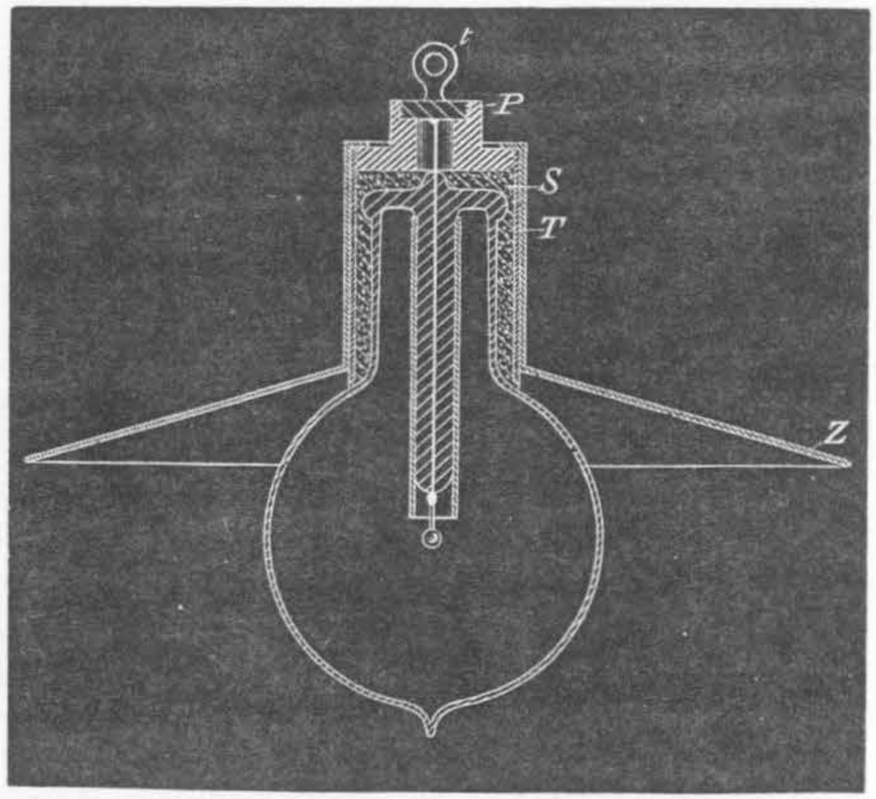

FIG. 26.—Improved Bulb with Intensifying Reflector.

larger surface. Such a lamp as illustrated in Fig. 25 may also be lighted by connecting the tinfoil coating on the neck n to the terminal, and the leading-in wire, w, to an insulated plate. If the bulb stands in a socket upright, as shown in the cut, a shade of conducting material may be slipped in the neck n, and the action thus magnified.

A more perfected arrangement used in some of these bulbs is illustrated in Fig. 26. In this case the construction of the bulb is as shown and described before, when reference was made to Fig. 19. A zinc sheet, Z, with a tubular extension, T, is slipped over the metallic socket, S. The bulb hangs downwards from the terminal, t, the zinc sheet Z performing the double office of intensifier and reflector. The reflector is separated from the terminal t by an extension of the insulating plug, P.

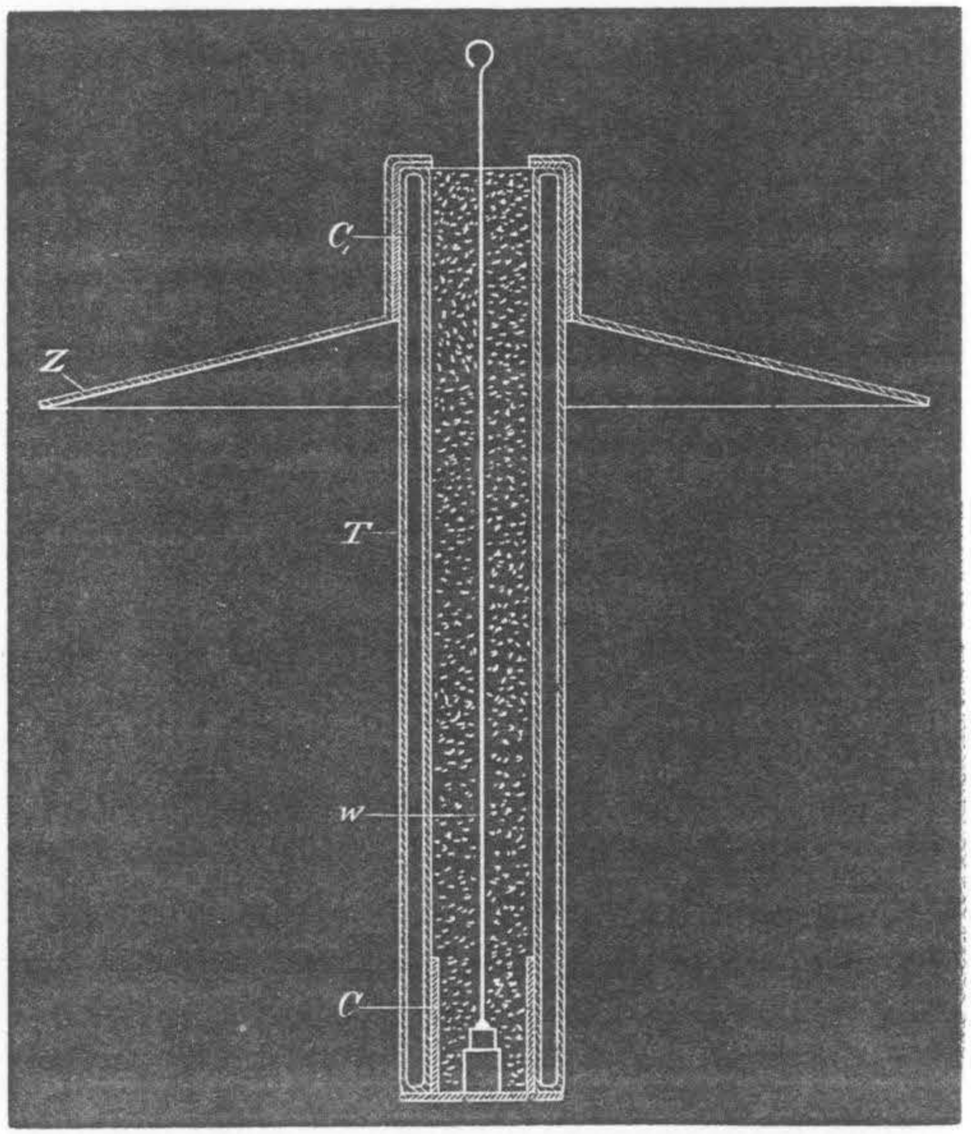

FIG. 27.—Phosphorescent Tube with Intensifying Reflector.

A similar disposition with a phosphorescent tube is illustrated in Fig. 27. The tube, T, is prepared from two short tubes of a different diameter, which are sealed on the ends. On the lower

end is placed an outside conducting coating, C, which connects to the wire, w. The wire has a hook on the upper end for suspension, and passes through the centre of the inside tube, which is filled with some good and tightly packed insulator. On the outside of the upper end of the tube T is another conducting coating, C_1, upon which is slipped a metallic reflector, Z, which should be separated by a thick insulation from the end of wire w.

The economical use of such a reflector or intensifier would require that all energy supplied to an air condenser should be recoverable, or, in other words, that there should not be any losses, neither in the gaseous medium nor through its action elsewhere. This is far from being so, but, fortunately, the losses may be reduced to anything desired. A few remarks are necessary on this subject, in order to make the experiences gathered in the course of these investigations perfectly clear.

Suppose a small helix with many well-insulated turns, as in experiment Fig. 17, has one of its ends connected to one of the terminals of the induction coil, and the other to a metal plate, or, for the sake of simplicity, a sphere, insulated in space. When the coil is set to work, the potential of the sphere is alternated, and the small helix now behaves as though its free end were connected to the other terminal of the induction coil. If an iron rod be held within the small helix, it is quickly brought to a high temperature, indicating the passage of a strong current through the helix. How does the insulated sphere act in this case? It can be a condenser, storing and returning the energy supplied to it, or it can be a mere sink of energy, and the conditions of the experiment determine whether it is more one or the other. The sphere being charged to a high potential, it acts inductively upon the surrounding air, or whatever gaseous medium there might be. The molecules, or atoms, which are near the sphere are of course more attracted, and move through a greater distance than the farther ones. When the nearest molecules strike the sphere they are repelled, and collisions occur at all distances within the inductive action of the sphere. It is now clear that, if the potential be steady, but little loss of energy can be caused in this way, for the molecules which are nearest

to the sphere, having had an additional charge imparted to them by contact, are not attracted until they have parted, if not with all, so with most of the additional charge, which can be accomplished only after a great many collisions. From the fact that with a steady potential there is but little loss in dry air, one must come to such a conclusion. When the potential of the sphere, instead of being steady, is alternating, the conditions are entirely different. In this case a rhythmical bombardment occurs, no matter whether the molecules after coming in contact with the sphere lose the imparted charge or not; what is more, if the charge is not lost, the impacts are only the more violent. Still, if the frequency of the impulses be very small, the loss caused by the impacts and collisions would not be serious unless the potential were excessive. But when extremely high frequencies and more or less high potentials are used, the loss may be very great. The total energy lost per unit of time is proportionate to the product of the number of impacts per second, or the frequency, and the energy lost in each impact. But the energy of an impact must be proportionate to the square of the electric density of the sphere, since the charge imparted to the molecule is proportionate to that density. I conclude from this that the total energy lost must be proportionate to the product of the frequency and the square of the electric density; but this law needs experimental confirmation. Assuming the preceding considerations to be true, then, by rapidly alternating the potential of a body immersed in an insulating gaseous medium, any amount of energy may be dissipated into space. Most of that energy, then, I believe, is not dissipated in the form of long ether waves, propagated to considerable distance, as is thought most generally, but is consumed—in the case of an insulated sphere, for example—in impact and collisional losses—that is, heat vibrations—on the surface and in the vicinity of the sphere. To reduce the dissipation it is necessary to work with a small electric density—the smaller, the higher the frequency.

But since, on the assumption before made, the loss is diminished with the square of the density, and since currents of very high frequencies involve considerable waste when transmitted through

conductors, it follows that, on the whole, it is better to employ one wire than two. Therefore, if motors, lamps, or devices of any kind are perfected, capable of being advantageously operated by currents of extremely high frequency, economical reasons will make it advisable to use only one wire, especially if the distances are great.

When energy is absorbed in a condenser, the same behaves as though its capacity were increased. Absorption exists more or less always, but generally it is small and of no consequence as long as the frequencies are not very great. In using extremely high frequencies, and, necessarily, in such case also high potentials, the absorption—or, what is here meant more particularly by this term, the loss of energy due to the presence of a gaseous medium—is an important factor to be considered, as the energy absorbed in the air condenser may be any fraction of the supplied energy. This would seem to make it very difficult to tell from the measured or computed capacity of an air condenser its actual capacity or vibration period, especially if the condenser is of very small surface and is charged to a very high potential. As many important results are dependent upon the correctness of the estimation of the vibration period, this subject demands the most careful scrutiny of other investigators. To reduce the probable error as much as possible in experiments of the kind alluded to, it is advisable to use spheres or plates of large surface, so as to make the density exceedingly small. Otherwise, when it is practicable, an oil condenser should be used in preference. In oil or other liquid dielectrics there are seemingly no such losses as in gaseous media. It being impossible to exclude entirely the gas in condensers with solid dielectrics, such condensers should be immersed in oil, for economical reasons if nothing else: they can then be strained to the utmost and will remain cool. In Leyden jars the loss due to air is comparatively small, as the tinfoil coatings are large, close together, and the charged surfaces not directly exposed; but when the potentials are very high, the loss may be more or less considerable at, or near, the upper edge of the foil, where the air is principally acted upon. If the jar be immersed in boiled-out

oil, it will be capable of performing four times the amount of work which it can for any length of time when used in the ordinary way, and the loss will be inappreciable.

It should not be thought that the loss in heat in an air condenser is necessarily associated with the formation of *visible* streams, or brushes. If a small electrode, enclosed in an unexhausted bulb, is connected to one of the terminals of the coil, streams can be seen to issue from the electrode, and the air in the bulb is heated; if, instead of a small electrode, a large sphere is enclosed in the bulb, no streams are observed, still the air is heated.

Nor should it be thought that the temperature of an air condenser would give even an approximate idea of the loss in heat incurred, as in such case heat must be given off much more quickly, since there is, in addition to the ordinary radiation, a very active carrying away of heat by independent carriers going on, and since not only the apparatus, but the air at some distance from it, is heated in consequence of the collisions which must occur.

Owing to this, in experiments with such a coil, a rise of temperature can be distinctly observed only when the body connected to the coil is very small. But with apparatus on a larger scale, even a body of considerable bulk would be heated, as, for instance, the body of a person; and I think that skilled physicians might make observations of utility in such experiments, which, if the apparatus were judiciously designed, would not present the slightest danger.

A question of some interest, principally to meteorologists, presents itself here. How does the earth behave? The earth is an air condenser, but is it a perfect or a very imperfect one—a mere sink of energy? There can be little doubt that to any small disturbance, as might be caused in an experiment, the earth behaves as an almost perfect condenser. But it might be different when its charge is set in vibration by some sudden disturbance occurring in the heavens. In such case, as before stated, probably only little of the energy of the vibrations set up would be lost into space in form of long ether radiations;

but most of the energy, I think, would spend itself in molecular impacts and collisions, and pass off into space in the form of short heat, and possibly light, waves. As both the frequency of the vibrations of the charge and the potential are in all probability excessive, the energy converted into heat may be considerable. Since the density must be unevenly distributed, either in consequence of the irregularity of the earth's surface, or on account of the condition of the atmosphere on various places, the effect produced would accordingly vary from place to place. Considerable variations in the temperature and pressure of the atmosphere may in this manner be caused at any point of the surface of the earth. The variations may be gradual or very sudden, according to the nature of the original disturbance, and may produce rain and storms, or locally modify the weather in any way.

From the remarks before made one may see what an important factor of loss the air in the neighbourhood of a charged surface becomes when the electric density is great and the frequency of the impulses excessive. But the action as explained implies that the air is insulating—that is, that it is composed of independent carriers immersed in an insulating medium. This is the case only when the air is at something like ordinary or greater, or at extremely small, pressure. When the air is slightly rarefied and conducting, then true conduction losses occur also. In such case, of course, considerable energy may be dissipated into space even with a steady potential, or with impulses of low frequency, if the density is very great.

When the gas is at very low pressure, an electrode is heated more because higher speeds can be reached. If the gas around the electrode is strongly compressed, the displacements, and consequently the speeds, are very small, and the heating is insignificant. But if in such case the frequency could be sufficiently increased, the electrode would be brought to a high temperature as well as if the gas were at very low pressure; in fact, exhausting the bulb is only necessary because we cannot produce (and possibly not convey) currents of the required frequency.

Returning to the subject of electrode lamps, it is obviously of advantage in such a lamp to confine as much as possible the heat to the electrode by preventing the circulation of the gas in the bulb. If a very small bulb be taken, it would confine the heat better than a large one, but it might not be of sufficient capacity to be operated from the coil, or, if so, the glass might get too hot. A simple way to improve in this direction is to employ a globe of the required size, but to place a small bulb, the diameter of which is properly estimated, over the refractory button contained in the globe. This arrangement is illustrated in Fig. 28.

The globe, L, has in this case a large neck, n, allowing the small bulb, b, to slip through. Otherwise the construction is the same as shown in Fig. 18, for example. The small bulb is conveniently supported upon the stem, s, carrying the refractory button, m. It is separated from the aluminum tube, a, by several layers of mica, M, in order to prevent the cracking of the neck by the rapid heating of the aluminum tube upon a sudden turning on of the current. The inside bulb should be as small as possible when it is desired to obtain light only by incandescence of the electrode. If it is desired to produce phosphorescence, the bulb should be larger, else it would be apt to get too hot, and the phosphorescence would cease. In this arrangement usually only the small bulb shows phosphorescence, as there is practically no bombardment against the outer globe. In some of these bulbs constructed as illustrated in Fig. 28 the small tube was coated with phosphorescent paint, and beautiful effects were obtained. Instead of taking the inside bulb large, in order to avoid undue heating, it answers the purpose to make the electrode m larger. In this case the bombardment is weakened by reason of the smaller electric density.

Many bulbs were constructed on the plan illustrated in Fig. 29. Here a small bulb, b, containing the refractory button, m, upon being exhausted to a very high degree, was sealed in a large globe, L, which was then moderately exhausted and sealed off. The principal advantage of this construction was that it allowed to reach extremely high vacua, and, at the same time-

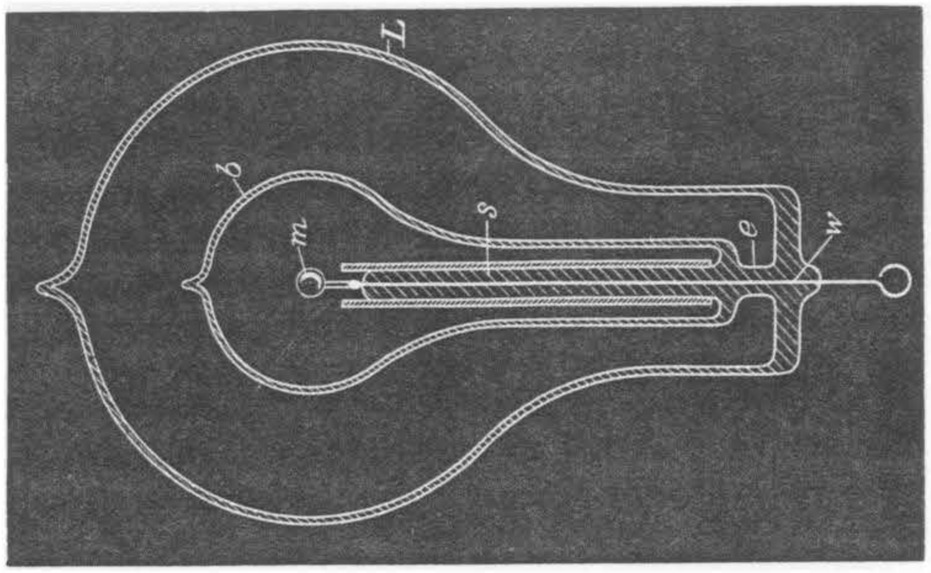

Fig. 29.—Lamp with Independent Auxiliary Bulb.

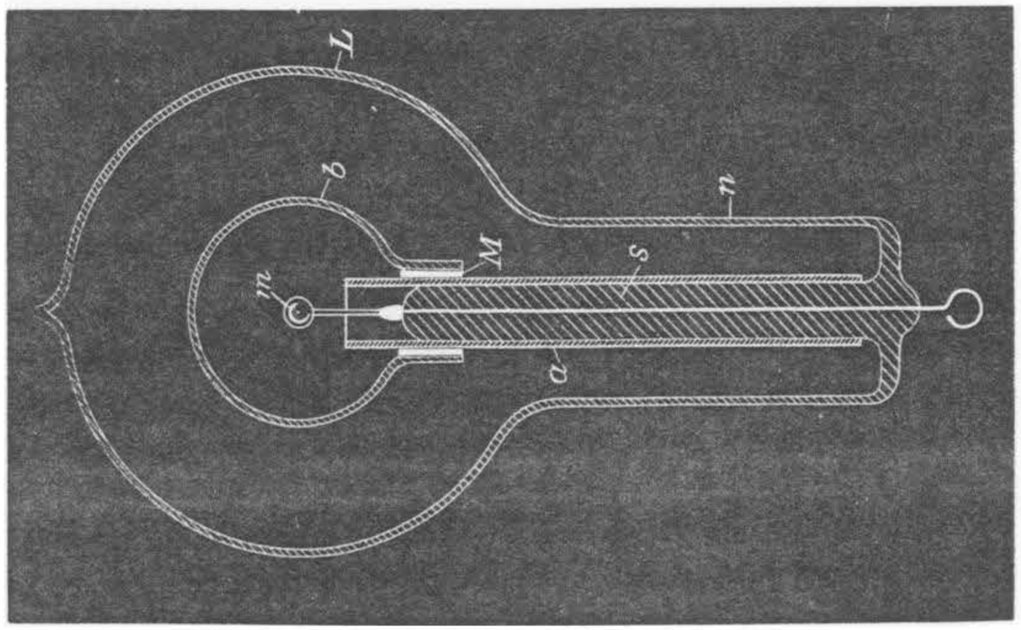

Fig. 28.—Lamp with Auxiliary Bulb for Confining the Action to the Centre.

use a large bulb. It was found, in the course of experiences with bulbs such as illustrated in Fig. 29, that it was well to make the stem, *s*, near the seal at *e* very thick, and the leading-in wire, *w*, thin, as it occurred sometimes that the stem at *e* was heated and the bulb was cracked. Often the outer globe *L* was exhausted only just enough to allow the discharge to pass through, and the space between the bulbs appeared crimson, producing a curious effect. In some cases, when the exhaustion in globe *L* was very low, and the air good conducting, it was found necessary, in order to bring the button *m* to high incandescence, to place, preferably on the upper part of the neck of the globe, a tinfoil coating which was connected to an insulated body to the ground, or to the other terminal of the coil, as the highly conducting air weakened the effect somewhat, probably by being acted upon inductively from the wire *w* where it entered the bulb at *e*. Another difficulty—which, however, is always present when the refractory button is mounted in a very small bulb—existed in the construction illustrated in Fig. 29, namely, the vacuum in the bulb *b* would be impaired in a comparatively short time.

The chief idea in the two last described constructions was to confine the heat to the central portion of the globe by preventing the exchange of air. An advantage is secured, but owing to the heating of the inside bulb, and slow evaporation of the glass, the vacuum is hard to maintain, even if the construction illustrated in Fig. 28 be chosen, in which both bulbs communicate.

But by far the better way—the ideal way—would be to reach sufficiently high frequencies. The higher the frequency, the slower would be the exchange of the air, and I think that a frequency may be reached at which there would be no exchange whatever of the air molecules around the terminal. We would then produce a flame in which there would be no carrying away of material, and a queer flame it would be, for it would be rigid! With such high frequencies the inertia of the particles would come into play. As the brush, or flame, would gain rigidity in virtue of the inertia of the particles, the exchange of the latter would be prevented. This would necessarily occur, for, the number of the impulses being augmented, the potential energy

of each would diminish, so that finally only atomic vibrations could be set up, and the motion of translation through measurable space would cease. Thus an ordinary gas burner connected to a source of rapidly alternating potential might have its efficiency augmented to a certain limit, and this for two reasons—because of the additional vibration imparted, and because of a slowing down of the process of carrying off. But the renewal being rendered difficult, and renewal being necessary to maintain the *burner*, a continued increase of the frequency of the impulses, assuming they could be transmitted to and impressed upon the flame, would result in the "extinction" of the latter, meaning by this term only the cessation of the chemical process.

I think, however, that in the case of an electrode immersed in a fluid insulating medium, and surrounded by independent carriers of electric charges, which can be acted upon inductively, a sufficiently high frequency of the impulses would probably result in a gravitation of the gas all around towards the electrode. For this it would be only necessary to assume that the independent bodies are irregularly shaped: they would then turn towards the electrode their side of the greatest electric density, and this would be a position in which the fluid resistance to approach would be smaller than that offered to the receding.

The general opinion, I do not doubt, is that it is out of question to reach any such frequencies as might—assuming some of the views before expressed to be true—produce any of the results which I have pointed out as mere possibilities. This may be so, but in the course of these investigations, from the observation of many phenomena I have gained the conviction that these frequencies would be much lower than one is apt to estimate at first. In a flame we set up light vibrations by causing molecules, or atoms, to collide. But what is the ratio of the frequency of the collisions and that of the vibrations set up? Certainly it must be incomparably smaller than that of the knocks of the bell and the sound vibrations, or that of the discharges and the oscillations of the condenser. We may cause the molecules of the gas to collide by the use of alternate electric impulses of high frequency, and so we may imitate the process in a flame; and from experi-

ments with frequencies which we are now able to obtain, I think that the result is producible with impulses which are transmissible through a conductor.

In connection with thoughts of a similar nature, it appeared to me of great interest to demonstrate the rigidity of a vibrating gaseous column. Although with such low frequencies as, say 10,000 per second, which I was able to obtain without difficulty from a specially constructed alternator, the task looked discouraging at first, I made a series of experiments. The trials with air at ordinary pressure led to no result, but with air moderately rarefied I obtained what I think to be an unmistakable experimental evidence of the property sought for. As a result of this kind might lead able investigators to conclusions of importance, I will describe one of the experiments performed.

It is well known that when a tube is slightly exhausted the discharge may be passed through it in form of a thin luminous thread. When produced with currents of low freqnency, obtained from a coil operated as usual, this thread is inert. If a magnet be approached to it, the part near the same is attracted or repelled, according to the direction of the lines of force of the magnet. It occurred to me that if such a thread would be produced with currents of very high frequency, it should be more or less rigid, and as it was visible it could be easily studied. Accordingly I prepared a tube about 1 inch in diameter and 1 metre long, with outside coating at each end. The tube was exhausted to a point at which by a little working the thread discharge could be obtained. It must be remarked here that the general aspect of the tube, and the degree of exhaustion, are quite different than when ordinary low-frequency currents are used. As it was found preferable to work with one terminal, the tube prepared was suspended from the end of a wire connected to the terminal, the tinfoil coating being connected to the wire, and to the lower coating sometimes a small insulated plate was attached. When the thread was formed it extended through the upper part of the tube and lost itself in the lower end. If it possessed rigidity it resembled, not exactly an elastic cord stretched tight between two supports, but a cord suspended from a height

with a small weight attached on the end. When the finger or a magnet was approached to the upper end of the luminous thread, it could be brought locally out of position by electrostatic or magnetic action; and when the disturbing object was very quickly removed, an analogous result was produced, as though a suspended cord would be displaced and quickly released near the point of suspension. In doing this the luminous thread was set in vibration, and two very sharply marked nodes, and a third indistinct one, were formed. The vibration, once set up, continued for fully eight minutes, dying gradually out. The speed of the vibration often varied perceptibly, and it could be observed that the electrostatic attraction of the glass affected the vibrating thread; but it was clear that the electrostatic action was not the cause of the vibration, for the thread was most generally stationary, and could always be set in vibration by passing the finger quickly near the upper part of the tube. With a magnet the thread could be split in two and both parts vibrated. By approaching the hand to the lower coating of the tube, or insulated plate if attached, the vibration was quickened; also, as far as I could see, by raising the potential or frequency. Thus, either increasing the frequency or passing a stronger discharge of the same frequency corresponded to a tightening of the cord. I did not obtain any experimental evidence with condenser discharges. A luminous band excited in a bulb by repeated discharges of a Leyden jar must possess rigidity, and if deformed and suddenly released should vibrate. But probably the amount of vibrating matter is so small that in spite of the extreme speed the inertia cannot prominently assert itself. Besides, the observation in such a case is rendered extremely difficult on account of the fundamental vibration.

The demonstration of the fact—which still needs better experimental confirmation—that a vibrating gaseous column possesses rigidity, might greatly modify the views of thinkers. When with low frequencies and insignificant potentials indications of that property may be noted, how must a gaseous medium behave under the influence of enormous electrostatic stresses which may be active in the interstellar space, and which may

alternate with inconceivable rapidity? The existence of such an electrostatic, rhythmically throbbing force—of a vibrating electrostatic field—would show a possible way how solids might have formed from the ultra-gaseous uterus, and how transverse and all kinds of vibrations may be transmitted through a gaseous medium filling all space. Then, ether might be a true fluid, devoid of rigidity, and at rest, it being merely necessary as a connecting link to enable interaction. What determines the rigidity of a body? It must be the speed and the amount of moving matter. In a gas the speed may be considerable, but the density is exceedingly small; in a liquid the speed would be likely to be small, though the density may be considerable; and in both cases the inertia resistance offered to displacement is practically *nil*. But place a gaseous (or liquid) column in an intense, rapidly alternating electrostatic field, set the particles vibrating with enormous speeds, then the inertia resistance asserts itself. A body might move with more or less freedom through the vibrating mass, but as a whole it would be rigid.

There is a subject which I must mention in connection with these experiments: it is that of high vacua. This is a subject the study of which is not only interesting, but useful, for it may lead to results of great practical importance. In commercial apparatus, such as incandescent lamps, operated from ordinary systems of distribution, a much higher vacuum than presently obtained would not secure a very great advantage. In such a case the work is performed on the filament and the gas is little concerned; the improvement, therefore, would be but trifling. But when we begin to use very high frequencies and potentials, the action of the gas becomes all-important, and the degree of exhaustion materially modifies the results. As long as ordinary coils, even very large ones, were used, the study of the subject was limited, because just at a point when it became most interesting it had to be interrupted on account of the "non-striking" vacuum being reached. But presently we are able to obtain from a small disruptive discharge coil potentials much higher than even the largest coil was capable of giving, and, what is more, we can make the potential alternate with great rapidity. Both of these results

enable us now to pass a luminous discharge through most any vacua obtainable, and the field of our investigations is greatly extended. Think we as we may, of all the possible directions to develop a practical illuminant, the line of high vacua seems to be the most promising at present. But to reach extreme vacua the appliances must be much more improved, and ultimate perfection will not be attained until we shall have discarded the mechanical and perfected an *electrical* vacuum pump. Molecules and atoms can be thrown out of a bulb under the action of an enormous potential: *this* will be the principle of the vacuum pump of the future. For the present we must secure the best results we can with mechanical appliances. In this respect it might not be out of the way to say a few words about the method of, and apparatus for, producing excessively high degrees of exhaustion of which I have availed myself in the course of these investigations. It is very probable that other experimenters have used similar arrangements; but as it is possible that there may be an item of interest in their description, a few remarks which will render this investigation more complete might be permitted.

The apparatus is illustrated in a drawing shown in Fig. 30. S represents a Sprengel pump, which has been specially constructed to better suit the work required. The stop-cock which is usually employed has been omitted, and instead of it a hollow stopper, s, has been fitted in the neck of the reservoir, R. This stopper has a small hole, h, through which the mercury descends; the size of the outlet, o, being properly determined with respect to the section of the fall tube, t, which is sealed to the reservoir instead of being connected to it in the usual manner. This arrangement overcomes the imperfections and troubles which often arise from the use of the stop-cock on the reservoir and the connection of the latter with the fall tube.

The pump is connected through a U-shaped tube, t, to a very large reservoir, R_1. Especial care was taken in fitting the grinding surfaces of the stoppers, p and p_1, and both of these and the mercury caps above them were made exceptionally long. After the U-shaped tube was fitted and put in place, it was heated, so

as to soften and take off the strain resulting from imperfect fitting. The U-shaped tube was provided with a stop-cock, C, and two ground connections, g and g_1—one for a small bulb, b, usually containing caustic potash, and the other for the receiver, r, to be exhausted.

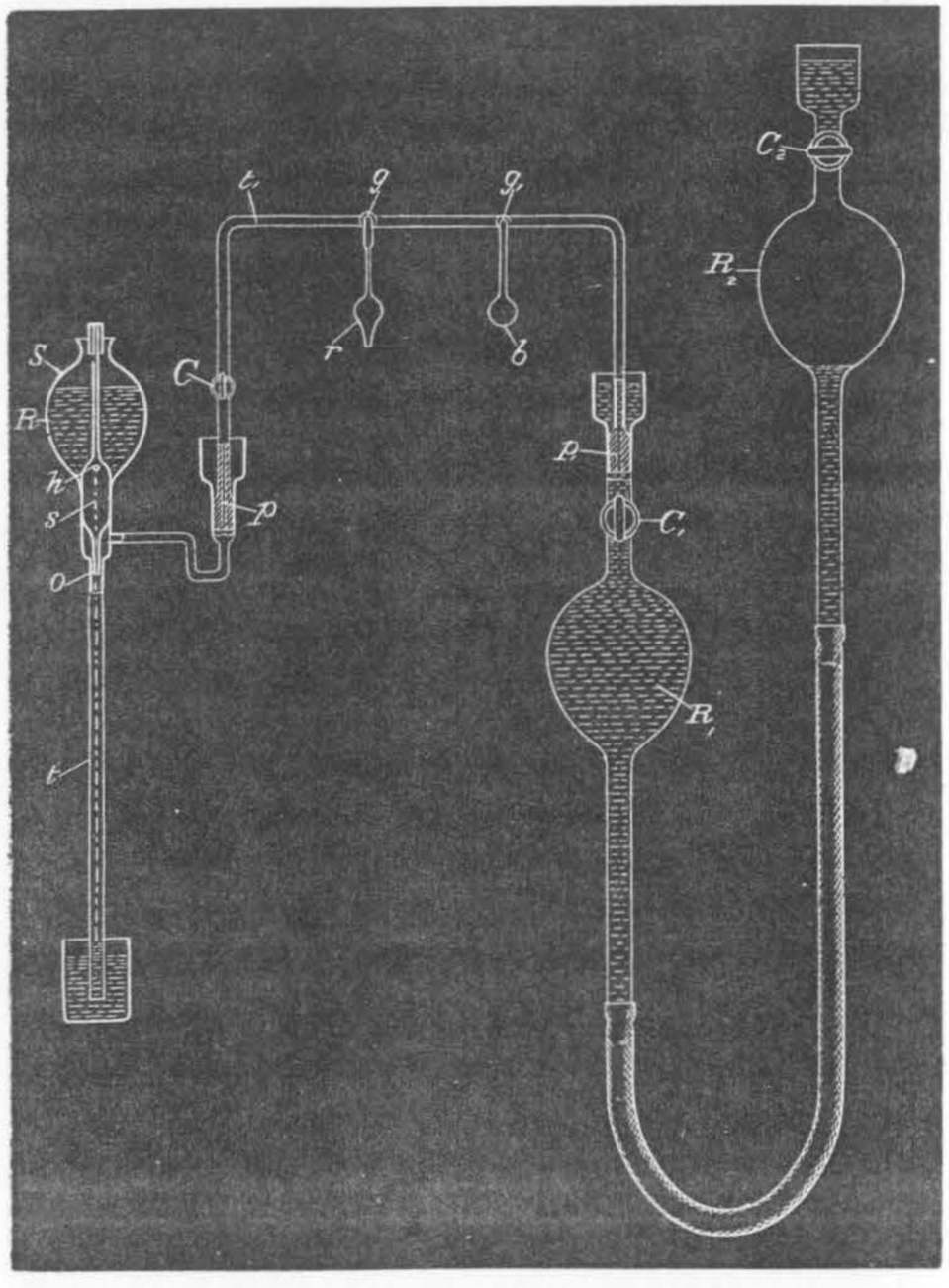

FIG. 30.—Apparatus Used for Obtaining High Degrees of Exhaustion.

The reservoir R_1 was connected by means of a rubber tube to a slightly larger reservoir, R_2, each of the two reservoirs being

provided with a stop-cock, C_1 and C_2, respectively. The reservoir R_2 could be raised and lowered by a wheel and rack, and the range of its motion was so determined that when it was filled with mercury and the stop-cock C_2 closed, so as to form a Torricellian vacuum in it when raised, it could be lifted so high that the mercury in reservoir R_1 would stand a little above stop-cock C_1; and when this stop-cock was closed and the reservoir R_2 descended, so as to form a Torricellian vacuum in reservoir R_1, it could be lowered so far as to completely empty the latter, the mercury filling the reservoir R_2 up to a little above stop-cock C_2.

The capacity of the pump and of the connections was taken as small as possible relatively to the volume of reservoir R_1, since, of course, the degree of exhaustion depended upon the ratio of these quantities.

With this apparatus I combined the usual means indicated by former experimenters for the production of very high vacua. In most of the experiments it was convenient to use caustic potash. I may venture to say, in regard to its use, that much time is saved and a more perfect action of the pump ensured by fusing and boiling the potash as soon as, or even before, the pump settles down. If this course is not followed, the sticks, as ordinarily employed, may give moisture off at a certain very slow rate, and the pump may work for many hours without reaching a very high vacuum. The potash was heated either by a spirit lamp, or by passing a discharge through it, or by passing a current through a wire contained in it. The advantage in the latter case was that the heating could be more rapidly repeated.

Generally the process of exhaustion was the following:—At the start, the stop-cocks C and C_1 being open, and all other connections closed, the reservoir R_2 was raised so far that the mercury filled the reservoir R_1 and a part of the narrow connecting U-shaped tube. When the pump was set to work, the mercury would, of course, quickly rise in the tube, and reservoir R_2 was lowered, the experimenter keeping the mercury at about the same level. The reservoir R_2 was balanced by a long spring which facilitated the operation, and the friction of the parts was

generally sufficient to keep it almost in any position. When the Sprengel pump had done its work, the reservoir R_2 was further lowered and the mercury descended in R_1 and filled R_2, whereupon stop-cock C_2 was closed. The air adhering to the walls of R_1 and that absorbed by the mercury was carried off, and to free the mercury of all air the reservoir R_2 was for a long time worked up and down. During this process some air, which would gather below stop-cock C_2, was expelled from R_2 by lowering it far enough and opening the stop-cock, closing the latter again before raising the reservoir. When all the air had been expelled from the mercury, and no air would gather in R_2 when it was lowered, the caustic potash was resorted to. The reservoir R_2 was now again raised until the mercury in R_1 stood above stop-cock C_1. The caustic potash was fused and boiled, and the moisture partly carried off by the pump and partly re-absorbed; and this process of heating and cooling was repeated many times, and each time, upon the moisture being absorbed or carried off, the reservoir R_2 was for a long time raised and lowered. In this manner all the moisture was carried off from the mercury, and both the reservoirs were in proper condition to be used. The reservoir R_2 was then again raised to the top, and the pump was kept working for a long time. When the highest vacuum obtainable with the pump had been reached, the potash bulb was usually wrapped with cotton which was sprinkled with ether so as to keep the potash at a very low temperature, then the reservoir R_2 was lowered, and upon reservoir R_1 being emptied the receiver r was quickly sealed up.

When a new bulb was put on, the mercury was always raised above stop-cock C_1, which was closed, so as to always keep the mercury and both the reservoirs in fine condition, and the mercury was never withdrawn from R_1 except when the pump had reached the highest degree of exhaustion. It is necessary to observe this rule if it is desired to use the apparatus to advantage.

By means of this arrangement I was able to proceed very quickly, and when the apparatus was in perfect order it was possible to reach the phosphorescent stage in a small bulb in less than 15 minutes, which is certainly very quick work for a small

laboratory arrangement requiring all in all about 100 pounds of mercury. With ordinary small bulbs the ratio of the capacity of the pump, receiver, and connections, and that of reservoir R was about 1-20, and the degrees of exhaustion reached were necessarily very high, though I am unable to make a precise and reliable statement how far the exhaustion was carried.

What impresses the investigator most in the course of these experiences is the behaviour of gases when subjected to great rapidly alternating electrostatic stresses. But he must remain in doubt as to whether the effects observed are due wholly to the molecules, or atoms, of the gas which chemical analysis discloses to us, or whether there enters into play another medium of a gaseous nature, comprising atoms, or molecules, immersed in a fluid pervading the space. Such a medium surely must exist, and I am convinced that, for instance, even if air were absent, the surface and neighbourhood of a body in space would be heated by rapidly alternating the potential of the body; but no such heating of the surface or neighbourhood could occur if all free atoms were removed and only a homogeneous, incompressible, and elastic fluid—such as ether is supposed to be—would remain, for then there would be no impacts, no collisions. In such a case, as far as the body itself is concerned, only frictional losses in the inside could occur.

It is a striking fact that the discharge through a gas is established with ever-increasing freedom as the frequency of the impulses is augmented. It behaves in this respect quite contrarily to a metallic conductor. In the latter the impedance enters prominently into play as the frequency is increased, but the gas acts much like a series of condensers would: the facility with which the discharge passes through seems to depend on the rate of change of potential. If it act so, then in a vacuum tube even of great length, and no matter how strong the current, self-induction could not assert itself to any appreciable degree. We have, then, as far as we can now see, in the gas a conductor which is capable of transmitting electric impulses of any frequency which we may be able to produce. Could the frequency be brought high enough, then a queer system of electric distribution, which

would be likely to interest gas companies, might be realised: metal pipes filled with gas—the metal being the insulator, the gas the conductor—supplying phosphorescent bulbs, or perhaps devices as yet uninvented. It is certainly possible to take a hollow tore of copper, rarefy the gas in the same, and by passing impulses of sufficiently high frequency through a circuit around it, bring the gas inside to a high degree of incandescence; but as to the nature of the forces there would be considerable uncertainty, for it would be doubtful whether with such impulses the copper tore would act as a static screen. Such paradoxes and apparent impossibilities we encounter at every step in this line of work, and therein lies, to a great extent, the charm of the study.

I have here a short and wide tube which is exhausted to a high degree and covered with a substantial coating of bronze, the coating allowing barely the light to shine through. A metallic clasp, with a hook for suspending the tube, is fastened around the middle portion of the latter, the clasp being in contact with the bronze coating. I now want to light the gas inside by suspending the tube on a wire connected to the coil. Anyone who would try the experiment for the first time, not having any previous experience, would probably take care to be quite alone when making the trial, for fear that he might become the joke of his assistants. Still, the bulb lights in spite of the metal coating, and the light can be distinctly perceived through the latter. A long tube covered with aluminum bronze lights when held in one hand—the other touching the terminal of the coil—quite powerfully. It might be objected that the coatings are not sufficiently conducting; still, even if they were highly resistant, they ought to screen the gas. They certainly screen it perfectly in a condition of rest, but not by far perfectly when the charge is surging in the coating. But the loss of energy which occurs within the tube, notwithstanding the screen, is occasioned principally by the presence of the gas. Were we to take a large hollow metallic sphere and fill it with a perfect incompressible fluid dielectric, there would be no loss inside of the sphere, and consequently the inside might be considered as perfectly screened, though the potential be very rapidly alternating. Even were the sphere

filled with oil, the loss would be incomparably smaller than when the fluid is replaced by a gas, for in the latter case the force produces displacements: that means impact and collisions in the inside.

No matter what the pressure of the gas may be, it becomes an important factor in the heating of a conductor when the electric density is great and the frequency very high. That in the heating of conductors by lightning discharges air is an element of great importance, is almost as certain as an experimental fact. I may illustrate the action of the air by the following experiment:—I take a short tube which is exhausted to a moderate degree and has a platinum wire running through the middle from one end to the other. I pass a steady or low-frequency current through the wire, and it is heated uniformly in all parts. The heating here is due to conduction, or frictional losses, and the gas around the wire has—as far as we can see—no function to perform. But now let me pass sudden discharges, or a high-frequency current, through the wire. Again the wire is heated, this time principally on the ends and least in the middle portion; and if the frequency of the impulses, or the rate of change, is high enough, the wire might as well be cut in the middle as not, for practically all the heating is due to the rarefied gas. Here the gas might only act as a conductor of no impedance diverting the current from the wire as the impedance of the latter is enormously increased, and merely heating the ends of the wire by reason of their resistance to the passage of the discharge. But it is not at all necessary that the gas in the tube should be conducting; it might be at an extremely low pressure, still the ends of the wire would be heated—as, however, is ascertained by experience—only the two ends would in such case not be electrically connected through the gaseous medium. Now what with these frequencies and potentials occurs in an exhausted tube occurs in the lightning discharges at ordinary pressure. We only need remember one of the facts arrived at in the course of these investigations, namely, that to impulses of very high frequency the gas at ordinary pressure behaves much in the same manner as though it were at moderately low pressure. I think that in

lightning discharges frequently wires or conducting objects are volatilised merely because air is present, and that, were the conductor immersed in an insulating liquid, it would be safe, for then the energy would have to spend itself somewhere else. From the behaviour of gases to sudden impulses of high potential I am led to conclude that there can be no surer way of diverting a lightning discharge than by affording it a passage through a volume of gas, if such a thing can be done in a practical manner.

There are two more features upon which I think it necessary to dwell in connection with these experiments—the "radiant "state" and the "non-striking vacuum."

Anyone who has studied Crookes's work must have received the impression that the "radiant state" is a property of the gas inseparably connected with an extremely high degree of exhaustion. But it should be remembered that the phenomena observed in an exhausted vessel are limited to the character and capacity of the apparatus which is made use of. I think that in a bulb a molecule, or atom, does not precisely move in a straight line because it meets no obstacle, but because the velocity imparted to it is sufficient to propel it in a sensibly straight line. The mean free path is one thing, but the velocity—the energy associated with the moving body—is another, and under ordinary circumstances I believe that it is a mere question of potential, or speed. A disruptive discharge coil, when the potential is pushed very far, excites phosphorescence and projects shadows, at comparatively low degrees of exhaustion. In a lightning discharge, matter moves in straight lines at ordinary pressure when the mean free path is exceedingly small, and frequently images of wires or other metallic objects have been produced by the particles thrown off in straight lines.

I have prepared a bulb to illustrate by an experiment the correctness of these assertions. In a globe, L (Fig. 31), I have mounted upon a lamp filament, f, a piece of lime, l. The lamp filament is connected with a wire which leads into the bulb, and the general construction of the latter is as indicated in Fig. 19, before described. The bulb being suspended from a wire connected to the terminal of the coil, and the latter being set to

work, the lime piece l and the projecting parts of the filament f are bombarded. The degree of exhaustion is just such that with the potential the coil is capable of giving phosphorescence of the glass is produced, but disappears as soon as the vacuum is impaired. The lime containing moisture, and moisture being given off as soon as heating occurs, the phosphorescence lasts only for a few moments. When the lime has been sufficiently

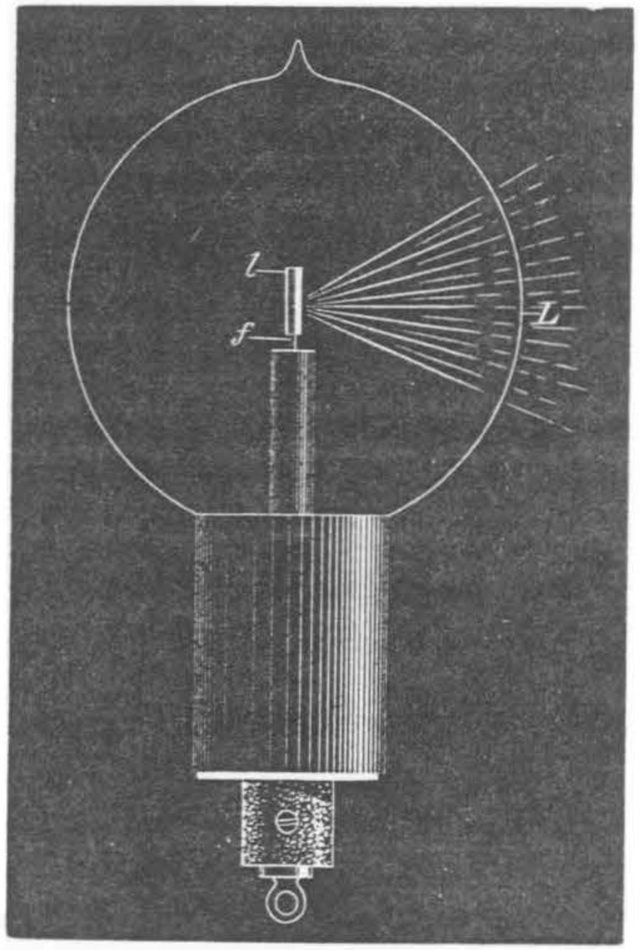

FIG. 31.—Bulb showing Radiant Lime Stream at Low Exhaustion.

heated, enough moisture has been given off to impair materially the vacuum of the bulb. As the bombardment goes on, one point of the lime piece is more heated than other points, and the result is that finally practically all the discharge passes through that point which is intensely heated, and a white stream of lime particles (Fig. 31) then breaks forth from that point. This stream is composed of "radiant" matter, yet the degree of

exhaustion is low. But the particles move in straight lines because the velocity imparted to them is great, and this is due to three causes—to the great electric density, the high temperature of the small point, and the fact that the particles of the lime are easily torn and thrown off—far more easily than those of carbon. With frequencies such as we are able to obtain, the particles are bodily thrown off and projected to a considerable distance; but with sufficiently high frequencies no such thing would occur: in such case only a stress would spread or a vibration would be propagated through the bulb. It would be out of question to reach any such frequency on the assumption that the atoms move with the speed of light; but I believe that such a thing is impossible: for this an enormous potential would be required. With potentials which we are able to obtain, even with a disruptive discharge coil, the speed must be quite insignificant.

As to the "non-striking vacuum," the point to be noted is that it can occur only with low-frequency impulses, and it is necessitated by the impossibility of carrying off enough energy with such impulses in high vacuum, since the few atoms which are around the terminal, upon coming in contact with the same are repelled and kept at a distance for a comparatively long period of time, and not enough work can be performed as to render the effect perceptible to the eye. If the difference of potential between the terminals is raised, the dielectric breaks down. But with very high frequency impulses there is no necessity for such breaking down, since any amount of work can be performed by continually agitating the atoms in the exhausted vessel, provided the frequency is high enough. It is easy to reach—even with frequencies obtained from an alternator as here used—a stage at which the discharge does not pass between two electrodes in a narrow tube, each of these being connected to one of the terminals of the coil, but it is difficult to reach a point at which a luminous discharge would not occur around each electrode.

A thought which naturally presents itself in connection with high-frequency currents is, to make use of their powerful electro-dynamic inductive action to produce light effects in a sealed glass globe. The leading-in wire is one of the defects of the present

incandescent lamp, and if no other improvement were made, that imperfection at least should be done away with. Following this thought, I have carried on experiments in various directions, of which some were indicated in my former paper. I may here mention one or two more lines of experiment which have been followed up.

Many bulbs were constructed as shown in Fig. 32 and Fig. 33.

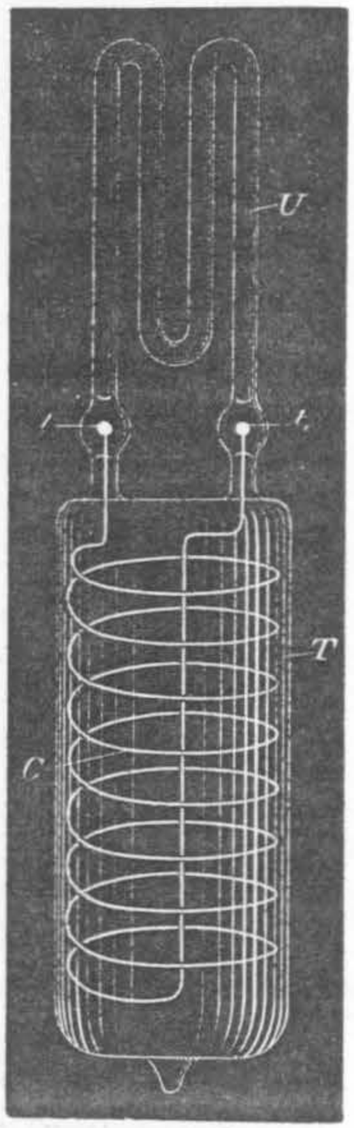

FIG. 32.—Electro-dynamic Induction Tube.

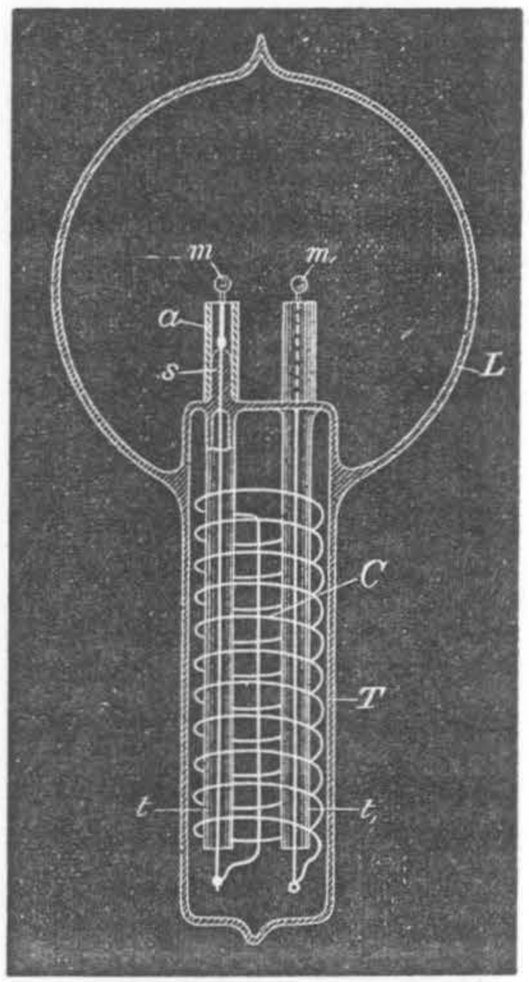

FIG. 33.—Electro-dynamic Induction Lamp.

In Fig. 32 a wide tube, T, was sealed to a smaller W-shaped tube, U, of phosphorescent glass. In the tube T was placed a coil, C, of aluminum wire, the ends of which were provided with

small spheres, t and t_1, of aluminum, and reached into the U tube. The tube T was slipped into a socket containing a primary coil through which usually the discharges of Leyden jars were directed, and the rarefied gas in the small U tube was excited to strong luminosity by the high-tension currents induced in the coil C. When Leyden jar discharges were used to induce currents in the coil C, it was found necessary to pack the tube T tightly with insulating powder, as a discharge would occur frequently between the turns of the coil, especially when the primary was thick and the air gap, through which the jars discharged, large, and no little trouble was experienced in this way.

In Fig. 33 is illustrated another form of the bulb constructed. In this case a tube, T, is sealed to a globe, L. The tube contains a coil, C, the ends of which pass through two small glass tubes, t and t_1, which are sealed to the tube T. Two refractory buttons, m and m_1, are mounted on lamp filaments which are fastened to the ends of the wires passing through the glass tubes t and t_1. Generally in bulbs made on this plan the globe L communicated with the tube T. For this purpose the ends of the small tubes t and t_1 were just a trifle heated in the burner, merely to hold the wires, but not to interfere with the communication. The tube T, with the small tubes, wires through the same, and the refractory buttons m and m_1, was first prepared, and then sealed to globe L, whereupon the coil C was slipped in and the connections made to its ends. The tube was then packed with insulating powder, jamming the latter as tight as possible up to very nearly the end, then it was closed and only a small hole left through which the remainder of the powder was introduced, and finally the end of the tube was closed. Usually in bulbs constructed as shown in Fig. 33 an aluminum tube, a, was fastened to the upper end, s, of each of the tubes t and t_1, in order to protect that end against the heat. The buttons m and m_1 could be brought to any degree of incandescence by passing the discharges of Leyden jars around the coil C. In such bulbs with two buttons a very curious effect is produced by the formation of the shadows of each of the two buttons.

Another line of experiment, which has been assiduously followed, was to induce by electro-dynamic induction a current or luminous discharge in an exhausted tube or bulb. This matter has received such an able treatment at the hands of Professor J. J. Thomson, that I could add but little to what he has made known, even had I made it the special subject of this lecture. Still, since experiences in this line have gradually led me to the present views and results, a few words must be devoted here to this subject.

It has occurred, no doubt, to many, that as a vacuum tube is made longer the electro-motive force per unit length of the tube, necessary to pass a luminous discharge through the latter, gets continually smaller; therefore, if the exhausted tube be made long enough, even with low frequencies a luminous discharge could be induced in such a tube closed upon itself. Such a tube might be placed around a hall or on a ceiling, and at once a simple appliance capable of giving considerable light would be obtained. But this would be an appliance hard to manufacture and extremely unmanageable. It would not do to make the tube up of small lengths, because there would be with ordinary frequencies considerable loss in the coatings, and besides, if coatings were used, it would be better to supply the current directly to the tube by connecting the coatings to a transformer. But even if all objections of such nature were removed, still, with low frequencies the light conversion itself would be inefficient, as I have before stated. In using extremely high frequencies the length of the secondary—in other words, the size of the vessel—can be reduced as far as desired, and the efficiency of the light conversion is increased, provided that means are invented for efficiently obtaining such high frequencies. Thus one is led, from theoretical and practical considerations, to the use of high frequencies, and this means high electro-motive forces and small currents in the primary. When he works with condenser charges —and these are the only means up to the present known for reaching these extreme frequencies—he gets to electro-motive forces of several thousands of volts per turn of the primary. He cannot multiply the electro-dynamic inductive effect by taking

more turns in the primary, for he arrives at the conclusion that the best way is to work with one single turn—though he must sometimes depart from this rule—and he must get along with whatever inductive effect he can obtain with one turn. But before he has long experimented with the extreme frequencies required to set up in a small bulb an electro-motive force of several thousands of volts, he realises the great importance of electrostatic effects, and these effects grow relatively to the electro-dynamic in significance as the frequency is increased.

Now, if anything is desirable in this case, it is to increase the frequency, and this would make it still worse for the electro-dynamic effects. On the other hand, it is easy to exalt the electrostatic action as far as one likes by taking more turns on the secondary, or combining self-induction and capacity to raise the potential. It should also be remembered that, in reducing the current to the smallest value and increasing the potential, the electric impulses of high frequency can be more easily transmitted through a conductor.

These and similar thoughts determined me to devote more attention to the electrostatic phenomena, and to endeavour to produce potentials as high as possible, and alternating as fast as they could be made to alternate. I then found that I could excite vacuum tubes at considerable distance from a conductor connected to a properly constructed coil, and that I could, by converting the oscillatory current of a condenser to a higher potential, establish electrostatic alternating fields which acted through the whole extent of a room, lighting up a tube no matter where it was held in space. I thought to recognise that I had made a step in advance, and I have persevered in this line; but I wish to say that I share with all lovers of science and progress the one and only desire—to reach a result of utility to men in any direction to which thought or experiment may lead me. I think that this departure is the right one, for I cannot see, from the observation of the phenomena which manifest themselves as the frequency is increased, what there would remain to act between two circuits conveying, for instance, impulses of several hundred millions per second, except electrostatic forces.

Even with such trifling frequencies the energy would be practically all potential, and my conviction has grown strong that, to whatever kind of motion light may be due, it is produced by tremendous electrostatic stresses vibrating with extreme rapidity.

Of all these phenomena observed with currents, or electric impulses, of high frequency, the most fascinating for an audience are certainly those which are noted in an electrostatic field acting through considerable distance, and the best an unskilled lecturer can do is to begin and finish with the exhibition of these singular effects. I take a tube in the hand and move it about, and it is lighted wherever I may hold it; throughout space the invisible forces act. But I may take another tube and it might not light, the vacuum being very high. I excite it by means of a disruptive discharge coil, and now it will light in the electrostatic field. I may put it away for a few weeks or months, still it retains the faculty of being excited. What change have I produced in the tube in the act of exciting it? If a motion imparted to the atoms, it is difficult to perceive how it can persist so long without being arrested by frictional losses; and if a strain exerted in the dielectric, such as a simple electrification would produce, it is easy to see how it may persist indefinitely, but very difficult to understand why such a condition should aid the excitation when we have to deal with potentials which are rapidly alternating.

Since I have exhibited these phenomena for the first time, I have obtained some other interesting effects. For instance, I have produced the incandescence of a button, filament, or wire enclosed in a tube. To get to this result it was necessary to economise the energy which is obtained from the field and direct most of it on the small body to be rendered incandescent. At the beginning the task appeared difficult, but the experiences gathered permitted to reach the result easily. In Fig. 34 and Fig. 35 two such tubes are illustrated which are prepared for the occasion. In Fig. 34 a short tube, T_1, sealed to another long tube, T, is provided with a stem, s, with a platinum wire sealed in the latter. A very thin lamp filament, l, is fastened to this wire, and connection to the outside is made through a thin copper wire, w. The tube is provided with outside and inside coatings, C and C_1 respectively,

and is filled as far as the coatings reach with conducting, and the space above with insulating powder. These coatings are merely

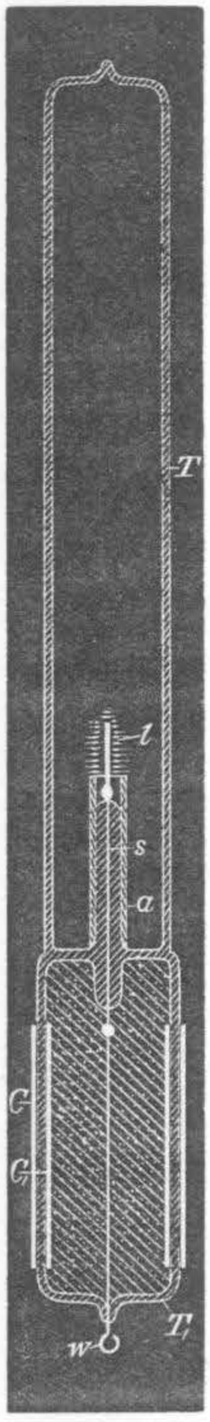

Fig. 34.—Tube with Filament rendered Incandescent in an Electrostatic Field.

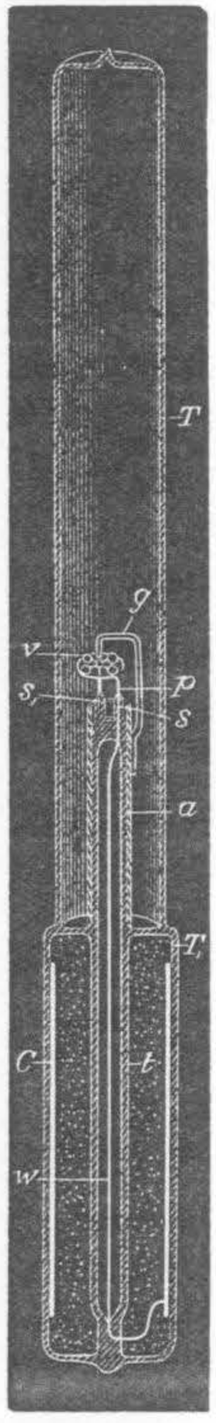

Fig. 35.—Crookes Experiment in Electrostatic Field.

used to enable to perform two experiments with the tube—namely, to produce the effect desired either by a direct connection of the body of the experimenter or of another body to the wire w, or by acting inductively through the glass. The stem s is provided with

an aluminum tube, a, for purposes before explained, and only a small part of the filament reaches out of this tube. By holding the tube T_1 anywhere in the electrostatic field the filament is rendered incandescent.

A more interesting piece of apparatus is illustrated in Fig. 35. The construction is the same as before, only instead of the lamp filament a small platinum wire, p, sealed in a stem, s, and bent above it in a circle, is connected to the copper wire w, which is joined to an inside coating, C. A small stem, s_1, is provided with a needle, on the point of which is arranged to rotate very freely a very light fan of mica, v. To prevent the fan from falling out, a thin stem of glass, g, is bent properly and fastened to the aluminum tube. When the glass tube is held anywhere in the electrostatic field the platinum wire becomes incandescent, and the mica vanes are rotated very fast.

Intense phosphorescence may be excited in a bulb by merely connecting it to a plate within the field, and the plate need not be any larger than an ordinary lamp shade. The phosphorescence excited with these currents is incomparably more powerful than with ordinary apparatus. A small phosphorescent bulb, when attached to a wire connected to a coil, emits sufficient light to allow reading ordinary print at a distance of 5 to 6 paces. It was of interest to see how some of the phosphorescent bulbs of Professor Crookes would behave with these currents, and he has had the kindness to lend me a few for the occasion. The effects produced are magnificent, especially by the sulphide of calcium and sulphide of zinc. From the disruptive discharge coil they glow intensely merely by holding them in the hand and connecting the body to the terminal of the coil.

To whatever results investigations of this kind may lead, their chief interest lies for the present in the possibilities they offer for the production of an efficient illuminating device. In no branch of electric industry is an advance more desired than in the manufacture of light. Every thinker, when considering the barbarous methods employed, the deplorable losses incurred in our best systems of light production, must have asked himself, What is likely to be the light of the future? Is it to be an

incandescent solid, as in the present lamp, or an incandescent gas, or a phosphorescent body, or something like a burner, but incomparably more efficient?

There is little chance to perfect a gas burner; not perhaps, because human ingenuity has been bent upon that problem for centuries, without a radical departure having been made—though this argument is not devoid of force—but because in a burner the higher vibrations can never be reached except by passing through all the low ones. For how is a flame produced unless by a fall of lifted weights? Such process cannot be maintained without renewal, and renewal is repeated passing from low to high vibrations. One way only seems to be open to improve a burner, and that is by trying to reach higher degrees of incandescence. Higher incandescence is equivalent to a quicker vibration: that means more light from the same material; and that, again, means more economy. In this direction some improvements have been made, but the progress is hampered by many limitations. Discarding, then, the burner, there remains the three ways first mentioned, which are essentially electrical.

Suppose the light of the immediate future to be a solid rendered incandescent by electricity. Would it not seem that it is better to employ a small button than a frail filament? From many considerations it certainly must be concluded that a button is capable of a higher economy, assuming, of course, the difficulties connected with the operation of such a lamp to be effectively overcome. But to light such a lamp we require a high potential; and to get this economically we must use high frequencies.

Such considerations apply even more to the production of light by the incandescence of a gas, or by phosphorescence. In all cases we require high frequencies and high potentials. These thoughts occurred to me a long time ago.

Incidentally we gain, by the use of very high frequencies, many advantages, such as a higher economy in the light production, the possibility of working with one lead, the possibility of doing away with the leading-in wire, &c.

The question is, How far can we go with frequencies? Ordinary conductors rapidly lose the facility of transmitting electric

impulses when the frequency is greatly increased. Assume the means for the production of impulses of very great frequency brought to the utmost perfection, everyone will naturally ask how to transmit them when the necessity arises. In transmitting such impulses through conductors we must remember that we have to deal with *pressure* and *flow*, in the ordinary interpretation of these terms. Let the pressure increase to an enormous value, and let the flow correspondingly diminish, then such impulses—variations merely of pressure, as it were—can no doubt be transmitted through a wire even if their frequency be many hundreds of millions per second. It would, of course, be out of question to transmit such impulses through a wire immersed in a gaseous medium, even if the wire were provided with a thick and excellent insulation, for most of the energy would be lost in molecular bombardment and consequent heating. The end of the wire connected to the source would be heated, and the remote end would receive but a trifling part of the energy supplied. The prime necessity, then, if such electric impulses are to be used, is to find means to reduce as much as possible the dissipation.

The first thought is, employ the thinnest possible wire surrounded by the thickest practicable insulation. The next thought is, to employ electrostatic screens. The insulation of the wire may be covered with a thin conducting coating, and the latter connected to the ground. But this would not do, as then all the energy would pass through the conducting coating to the ground, and nothing would get to the end of the wire. If a ground connection is made, it can only be made through a conductor offering an enormous impedance, or through a condenser of extremely small capacity. This, however, does not do away with other difficulties.

If the wave length of the impulses is much smaller than the length of the wire, then corresponding short waves will be set up in the conducting coating, and it will be more or less the same as though the coating were directly connected to earth. It is therefore necessary to cut up the coating in sections much shorter than the wave length. Such an arrangement does not still afford a perfect screen, but it is ten thousand times better

than none. I think it preferable to cut up the conducting coating in small sections, even if the current-waves be much longer than the coating.

If a wire were provided with a perfect electrostatic screen, it would be the same as though all objects were removed from it at infinite distance. The capacity would then be reduced to the capacity of the wire itself, which would be very small. It would then be possible to send over the wire current-vibrations of very high frequencies at enormous distances without affecting greatly the character of the vibrations. A perfect screen is of course out of question, but I believe that with a screen such as I have just described telephony could be rendered practicable across the Atlantic. According to my ideas, the gutta-percha-covered wire should be provided with a thin conducting coating sub-divided in sections. On the top of this should be again placed a layer of gutta-percha and other insulation, and on the top of the whole the armour. But such cables will not be constructed, for ere long intelligence—transmitted without wires—will throb through the earth like a pulse through a living organism. The wonder is that, with the present state of knowledge and the experiences gained, no attempt is being made to disturb the electrostatic or magnetic condition of the earth, and transmit, if nothing else, intelligence.

It has been my chief aim in presenting these results to point out phenomena or features of novelty, and to advance ideas which I am hopeful will serve as starting-points of new departures. It has been my chief desire this evening to entertain you with some novel experiments. Your applause, so frequently and generously accorded, has told me that I have succeeded.

In conclusion, let me thank you most heartily for your kindness and attention, and assure you that the honour I have had in addressing such a distinguished audience, the pleasure I have had in presenting these results to a gathering of so many able men—and among them also some of those in whose work for many years past I have found enlightenment and constant pleasure—I shall never forget.

The PRESIDENT: It is my most pleasing duty to propose a very

hearty vote of thanks to our lecturer, who has entertained us, it is true, for two hours; but we would willingly wait for another hour's similar entertainment. I venture to suggest that those of us who have time at our disposal should regard this as but Act I., and persuade the lecturer to continue—after an interval for refreshment, of course—to give us Act II. No words of mine, obviously, are necessary to make you appreciate the magnificent results you have seen. To have shared with Professor Galileo Ferraris the invention of the principle of the rotary magnetic field, and its application to practical alternate-current motors on a large scale, would have been quite sufficient to have made our distinguished lecturer to-night honoured among us; but in these magnificent experiments we have seen on electrostatic electric lamps he has really surpassed himself, and I therefore propose a hearty vote of thanks for the delightful lecture we have had this evening.

As we are guests here to-night, we must not separate without offering our thanks to the managers of the Royal Institution for having so kindly given us the use of this theatre.

One other vote of thanks we must not forget—to Mr. Siemens, for having placed the resources of his firm at the disposal of Mr. Tesla for preparing these experiments.

The several resolutions were carried by acclamation.

The meeting then adjourned.

The Two Hundred and Thirtieth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday evening, February 11th, 1892—Professor W. E. AYRTON, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on January 28th, 1892, were read and approved.

The names of new candidates for election into the Institution were announced and ordered to be suspended.

Donations to the Library were announced as having been received since the last meeting from Mr. John Aylmer, Professor A. B. W. Kennedy, and Mr. Stuart A. Russell, Members; and Mr. J. Louis Balbi, Associate; to whom the thanks of the meeting were duly accorded.

The PRESIDENT: Mr. Siemens, I am sorry to say, like our Secretary, is suffering from illness, and unable to come to the meeting this evening; but Mr. G. P. Simpson will officiate in his place, and I now ask him to read Mr. Siemens's paper.

The following paper was then read:—

SOME EXPERIMENTAL INVESTIGATIONS OF ALTERNATE CURRENTS.

By ALEXANDER SIEMENS, Vice-President.

Most of the papers read before this Institution on the subject of alternate electric currents, and on apparatus employed for utilising them, have dealt principally with the theoretical side of the question, and undoubtedly have been extremely useful to constructors of alternate-current apparatus. Nevertheless, certain gaps in our knowledge obtruded themselves in practice, and the investigations and experiments which are described in the present communication were undertaken, not so much to verify any particular theory, as to increase our knowledge of useful facts.

For convenience of reference, these experiments are not described in chronological order, but they have been grouped

together according to the subjects which they are intended to elucidate. Foremost among these is the loss of energy through the heating of iron by induction where alternate electric currents are employed—a subject which engaged the attention of Prof. Ewing and of Dr. J. Hopkinson six years ago, whose researches pointed out the direction in which further experiments should be made. It is well known that this loss is caused by the so-called Foucault currents and by hysteresis. The effect of the former is counteracted by laminating the core of a magnet either by building it up with wires of small diameter or with thin discs, according to the direction of the lines of induction.

A short consideration will show that the heat produced by Foucault currents can be calculated beforehand for a core of known construction and dimensions.

Take the case of an iron wire, 1 cm. long, subjected to an induction parallel to its axis of B lines per 1 square cm. of its section.

Let r be the radius of the wire, and ρ the radius of a ring, of the width $d\rho$, concentric with the wire. In this ring currents will be produced in the same manner as in the secondary circuit of a transformer.

The maximum induction passing through this ring is $N = \rho^2 \pi . B.$ Hence the electro-motive force generated is $E = 4 n N \times 10^{-8} = 4 n \rho^2 \pi B 10^{-8}$ volts.

If c is the conductivity of the iron employed, the resistance of the ring is $R = \frac{1}{c} \times \frac{2\pi\rho}{d\rho}$; consequently the waste of energy in this ring, expressed in watts, is

$$d W = \frac{E^2}{R} = 8 c \pi n^2 B^2 \rho^3 d\rho . 10^{-16}.$$

The total energy wasted in 1 cm. length of the wire is therefore

$$W = 2 c . \pi . n^2 . B^2 . r^4 . 10^{-16} \text{ watts.}$$

From this formula a table has been calculated to indicate the waste of energy by Foucault currents in 1 cwt. of iron of the conductivity $c = 0{\cdot}102 \times 10^6$, when an alternate current of the frequency $n = 100 \sim$ per second was employed.

Induction. B	Diameter of Wire. ½ mm.	1 mm.	2 mm.	3 mm.
1,000	0·8 watts	3·3 watts	13·3 watts	29·9 watts.
2,000	3·3 „	13·3 „	53·3 „	119·9 „
3,000	7·4 „	29·9 „	119·9 „	269·8 „
4,000	13·4 „	53·3 „	213·3 „	479·8 „
5,000	20·8 „	83·3 „	333·2 „	749·7 „
6,000	29·9 „	119·9 „	479·8 „	1,079·4 „

In order to determine the total loss of energy caused by the heating of the iron, experiments were made with a specially constructed "cable transformer."

This mode of constructing transformers has been foreshadowed by Dr. Werner von Siemens, who proposed in his patent No. 42 of 1886 to surround the primary and secondary circuits of a transformer with iron wire, but his experiments gave no satisfactory results.

The subject was recently taken up again, and the present form of these transformers was suggested by Mr. Dieselhorst and Dr. Baur.

The principal advantage which is claimed for this form of transformer is that it can be made by machinery, in the same way as a submarine cable is made, the employment of manual labour in putting it together being entirely avoided.

A special machine has been designed and erected for completing such transformers in one operation, after the iron core has been prepared on an ordinary rope stranding machine.

Besides offering these facilities for manufacture, the peculiar shape of the cable transformer lends itself to a variety of useful applications.

For instance, at the Crystal Palace Exhibition one of these transformers connects an alternate-current machine to a high-voltage transformer some distance away, raising the potential of the current at the same time from 80 volts to 2,500 volts.

The transformer used for the experiments has a core of 900 soft iron wires, each 1 mm. in diameter by 6 metres long, twisted up in the form of a rope, and surrounded by two windings of copper wire, properly insulated, the one for high voltage and the other for low voltage.

From the fact that the diameter of the transformer is very small compared to its length, it follows that the magnetic field, and consequently the induction in the iron core, is uniformly distributed, with the exception of a slight drop at either end.

The mean induction produced by passing an alternate current through the low-voltage circuit was measured by the difference of potential obtained in the high-voltage circuit while no current was passing through the latter.

The temperature of the iron core was ascertained by measuring the increase in the electrical resistance of one of its wires, which had been insulated from the rest by a cotton covering.

By actual comparison it was found that one of the wires near the periphery gave, within the limits of errors of observation, the same results as the central wire, so that the exact position of this "test wire" has no influence on the result; the heating of the cotton insulation can be neglected, as its mass is so very small compared with that of the iron.

Separate tests were made to determine the specific heat of the iron, which was found to be = 0·112, and the temperature coefficient for the electrical resistance of the test wire, which was equal to 0·0054.

The current was kept on for a short time only, as it was desired in the first instance to determine the rate at which energy is converted into heat in such a transformer, and the rise in temperature after keeping the current on for s seconds can be calculated from the formula,

$$t_s = \frac{R_s - R_0}{\cdot 0054 \,.\, R_0}$$

R_0 = electrical resistance before starting the current; R_s = electrical resistance after keeping the current on for s seconds.

During the time that the current passes, the test-wire will lose a certain amount of heat by radiation and convection, although it is surrounded by all the other iron wires, which are heated in a similar manner. This loss can, however, easily be allowed for by plotting a "cooling curve" after the passage of the current has been stopped, with times as abscissæ and temperatures as ordinates.

In this way the rise of temperature of the iron core per second was observed with an alternate current of 100 $\sim$ per second, varying in strength so as to produce a different induction for each observation.

Considering that the loss of energy caused by the heating of the iron is proportionate to its mass, to its specific heat, and to its rise of temperature per second, it was possible to plot a curve in which the maximum number of C.G.S. lines per square cm. are the abscissæ, and the losses of energy are represented as ordinates calculated for the mass of 1 cwt. of soft iron wires 1 mm. in diameter.

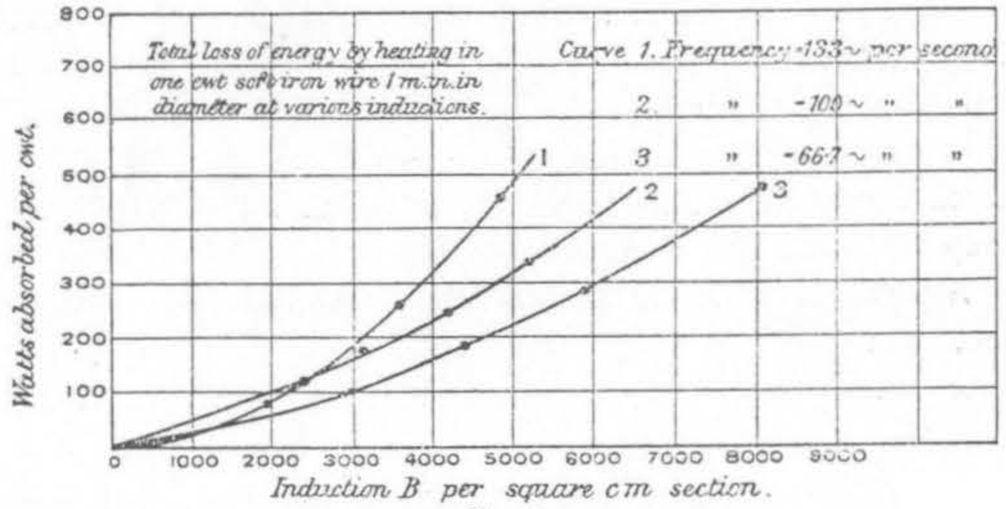

FIG. 1.

It should be added that the abscissæ of Curve 2, Diagram I., which embodies the results obtained, have been calculated from the measured volts, instead of from the calculated mean volts, which in sinoidal waves are = 0·9 measured volts.

This was done as Curve 2 was to be used for designing transformers where the measured volts only are used for calculation.

As this curve gives the losses caused by hysteresis and by Foucault currents, while the formula given above enables us to calculate the losses caused by the Foucault currents alone, we can determine the loss by hysteresis alone by a simple subtraction.

All these results, it must be remembered, refer to 1 cwt. of soft iron, subdivided into wires of 1 mm. diameter, on which

an alternate current is acting of a frequency of 100 $\sim$ per second, the type of apparatus used being a cable transformer.

The following table shows the results :—

Induction. B =	Losses of Energy. Curve 2.	Foucault Currents.	Hysteresis.
1,000	43·2 watts	3·3 watts	39·9 watts.
2,000	96·2 „	13·3 „	82·9 „
3,000	158·0 „	29·9 „	128·1 „
4,000	231·2 „	53·3 „	177·9 „
5,000	309·5 „	83·3 „	226·2 „
6,000	390·1 „	119·9 „	270·2 „

The losses caused by hysteresis are independent of the dimensions of the iron; this table enables us, therefore, together with the formula for the losses caused by Foucault currents, to predetermine the rate of the loss of energy in iron wire of any weight or dimensions when acted upon by an alternate current of a frequency equal to 100 $\sim$ per second.

Similar experiments were made with alternate currents of a frequency of 66·6 $\sim$ per second, and of a frequency of 133·3 $\sim$ per second, and the curves embodying the results are also shown on Diagram I.

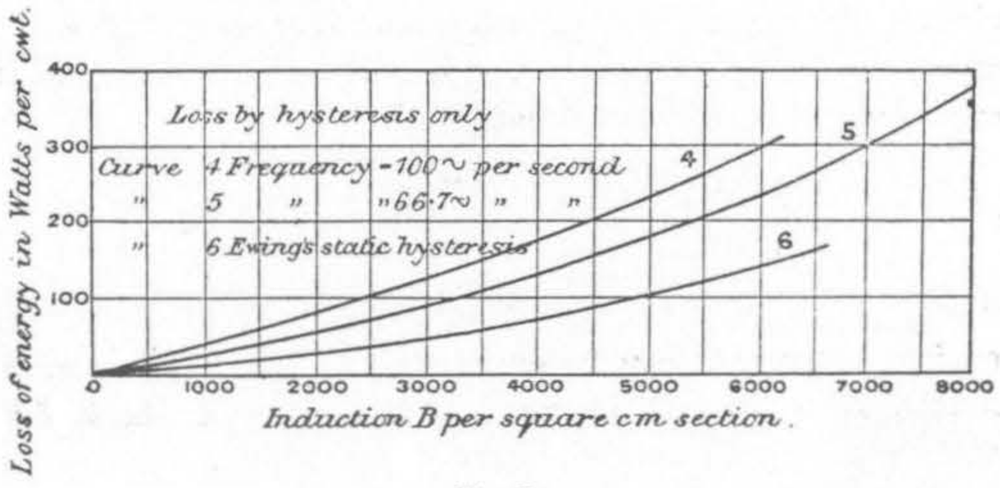

FIG. 2.

It should be observed that the currents of 66·6 and of 100 $\sim$ were obtained from the same alternate-current machine (type W_i), which has a high self-induction in the armature, and of which it has been ascertained experimentally that the waves of its current are sinoidal.

The currents of 133 ∩∪ per second were produced by another type of machine (W_{II}) with a low self-induction and a very narrow field.

On Diagram II. the losses by hysteresis alone have been shown, derived from the curves of Diagram I. by deducting the losses caused by Foucault currents according to calculation. By way of comparison, Professor Ewing's curve of losses caused by static hysteresis has been added. In this table the results obtained with alternate currents of 133·3 ∩∪ per second have been been left out of consideration, on account of their being made with a different machine, as just explained.

The next point to be investigated is the change which an alteration of the frequency of the current will involve in the case of a transformer designed for a given voltage in its secondary circuit. If it is borne in mind that this voltage, apart from the constant factors, depends on the product n N (n denoting the frequency, and N the maximum number of lines of induction), it follows at once that in order to produce the same E.M.F. with a lower frequency the number of lines of induction has to be increased in proportion, and *vice versa*. In other words, if the same E.M.F. is to be produced in the secondary circuit of a given transformer, the product n N must be constant. This result can at once be applied to the formula, which gives the losses of energy caused by Foucault currents—

$$W = 2\,c\,\pi\,n^2\,B^2\,r^4\,10^{-16};$$

and as $N = r^2 \,.\, \pi \,.\, B$, the formula can be expressed—

$$W = \frac{2\,c}{\pi}(n\,N)^2\,10^{-16};$$

or, in other words, these losses are constant for the same transformer, whatever the frequency may be, as long as the E.M.F. of the secondary circuit remains the same.

A comparison of the curves for a frequency of 66·7 and of 100 ∩∪ per second on Diagram I. shows that the losses of energy for the same induction are practically proportional to the frequencies. The same curves show that this loss increases more rapidly than the number of lines of induction.

From this consideration it follows that a transformer which has been designed to produce a certain E.M.F. in its secondary circuit with a given frequency cannot produce the same E.M.F. with a lower frequency without over-heating, while it remains cooler when it is worked with a higher frequency. In other words, transformers built for low frequency require much material.

An experiment was made to ascertain the final temperatures of a 50-H.P. transformer worked with different frequencies, and after 10 hours' working the maximum temperature was found to be—For a frequency of 100 ∩∪ per second, 53° C. in the core, and 46° C. on the outside; for a frequency of 66 ∩∪ per second, 69° C. in the core, and 57° C. on the outside—a result which appears to bear out the above consideration.

What frequency is most advantageous can, however, not be settled by taking into account nothing but the heating of the transformers: it is quite evident that the construction of suitable generating apparatus plays as important a part; and the problem resolves itself into the commercial one, Which combination of apparatus can be constructed most cheaply?

The question, What induction should be settled upon in designing a transformer? is rather a complex one, and it can only be solved by taking into consideration—

1st. The amount of material, iron and copper.

2nd. The drop of potential difference in the secondary circuit from no load to full load.

3rd. The efficiency of the apparatus.

4th. The heating of the apparatus.

In order to facilitate the investigations a series of transformers is compared which all have the same length of iron core, and the same number of turns of copper wire of the same diameter.

It is assumed that one of these transformers is designed for an induction B = 5,000, and that its output is such that the weights of the iron and of the copper used in its construction are equal to each other and to 1 cwt.; this may be called the normal transformer.

If, now, another transformer of the same series, but with a lower induction, is to produce the same voltage, the section of the

iron has to be increased proportionately: for instance, in the case of B = 2,500 it has to be doubled.

The weight of the iron employed varies, in fact, inversely as the induction, and their relation can be represented by a rectangular hyperbola (Curve 7).

As we have assumed that the thickness of the copper wire and the number of its turns are to be the same in all these transformers, the weight of the copper will vary directly with the length of wire wound on the iron core, and this can be determined if the relationship between the length of periphery and the section of the iron core is known.

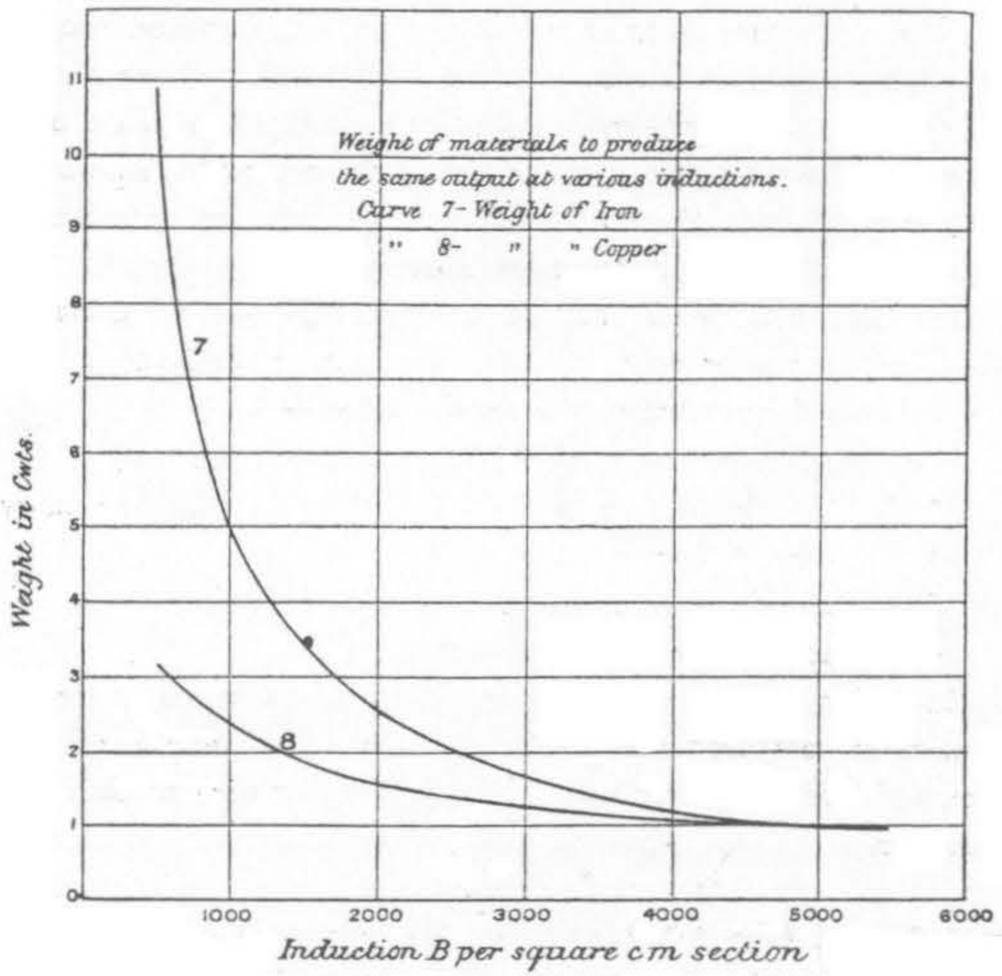

FIG. 3.

In the case of the sections of the cores being circles or squares or rectangles, with the same ratio between their length and width, the length of periphery varies as the square root of

the section. As transformers are generally designed with cores of this kind, it may be accepted that the periphery of the iron core, and, consequently, the weight of copper to be employed, varies as the square root of the section of the iron core.

The weight of copper in the series of transformers under contemplation can therefore be represented by a curve (8) the ordinates of which are the square root of the ordinates of the curve giving the weight of iron for the corresponding inductions. From these two curves it appears that the weight of the iron increases very rapidly with decreasing induction, while the weight of copper increases at a slower rate.

As materials are important items in the cost of a transformer, the consideration of the first point shows the desirability of employing a strong induction. A similar conclusion will be drawn from the investigation of the relation between the induction and the drop of difference of potential in the secondary circuit of the series of transformers. As they are all supposed to give the same current, the drop from no load to full load will be in proportion to the resistance of the circuit. This resistance is in proportion to the weight of copper employed, as all the transformers are assumed to be wound with wire of the same diameter. The curve (8) giving the weight of copper at different inductions will therefore also indicate, in comparison with the normal transformer, the variation in the drop of potential between no load and full load under the same circumstances.

In order to determine the variation of the efficiency of the transformers under investigation, it is necessary to treat separately the losses in the iron and in the copper. The former can be found by the aid of the curves on Diagram I., in combination with the curve giving the weight of iron necessary at the various inductions.

An example will best illustrate how this loss is ascertained in a case where the total mass of the iron is worked at the same induction, produced by a current of a frequency equal to 100 ∿ per second, the iron mass being composed of 1 mm. wires. The loss in the normal transformer working with an induction B = 5,000, and with a weight of iron = 1 cwt., is 309·6 watts,

according to Diagram I. For another transformer working with an induction B = 2,500, the weight of iron, as shown by the curve (7), has to be increased to 2 cwt.; at the same time the loss per cwt. is reduced to 126·8 watts, or the total loss is reduced to 253·6 watts.

In a similar manner the losses for the different inductions have been calculated, and the results are embodied in a curve (9) which indicates that the loss of energy in the cores of transformers increases with the strength of induction, at first rapidly, but after the induction has reached a value of B = 1,000 the increase is very slow. As far as the loss of energy in the iron goes, it is, therefore, of not much consequence what induction between 1,000 and 5,000 lines per square cm. is used. The influence of the strength of induction on the loss of energy in the copper can be shown in the simplest manner by comparing this loss in the normal transformers designed for 5,000 lines with the loss in the other transformers of the series.

There are evidently three possible cases for the normal transformer: the loss in the copper may be equal to the loss in the iron, or it may be greater, or it may be less. For each of these cases a curve can be plotted showing the sum of the losses in the iron and in the copper at the corresponding induction.

If we take, for instance, the case that the losses in copper and in iron are equal, the total loss in the transformer having an induction B = 5,000, is $2 \times 309{\cdot}6$ watts.

For the transformer having an induction B = 2,500 the loss in the iron is given in our Curve 9, and the loss in the copper is in proportion to its weight, which varies in accordance with Curve 8, or, in this particular case, the loss is $= \sqrt{2} \times 309{\cdot}6$ watts. In this way Curve 11 has been plotted for the case of the losses being equal, Curve 10 represents the case where the loss in the copper is equal to two-thirds of the loss in the iron, and Curve 12 where the loss in the copper is 50 per cent. greater than the loss in the iron.

Taking these curves to represent generally the variation of the total loss at the various inductions, it appears that, when keeping the loss in copper small in comparison with the loss in

iron, it is quite possible to obtain about the same efficiency with any induction between 2,000 and 5,000 lines per square cm., but if a lower induction is used the efficiency, even on full load, decreases very rapidly.

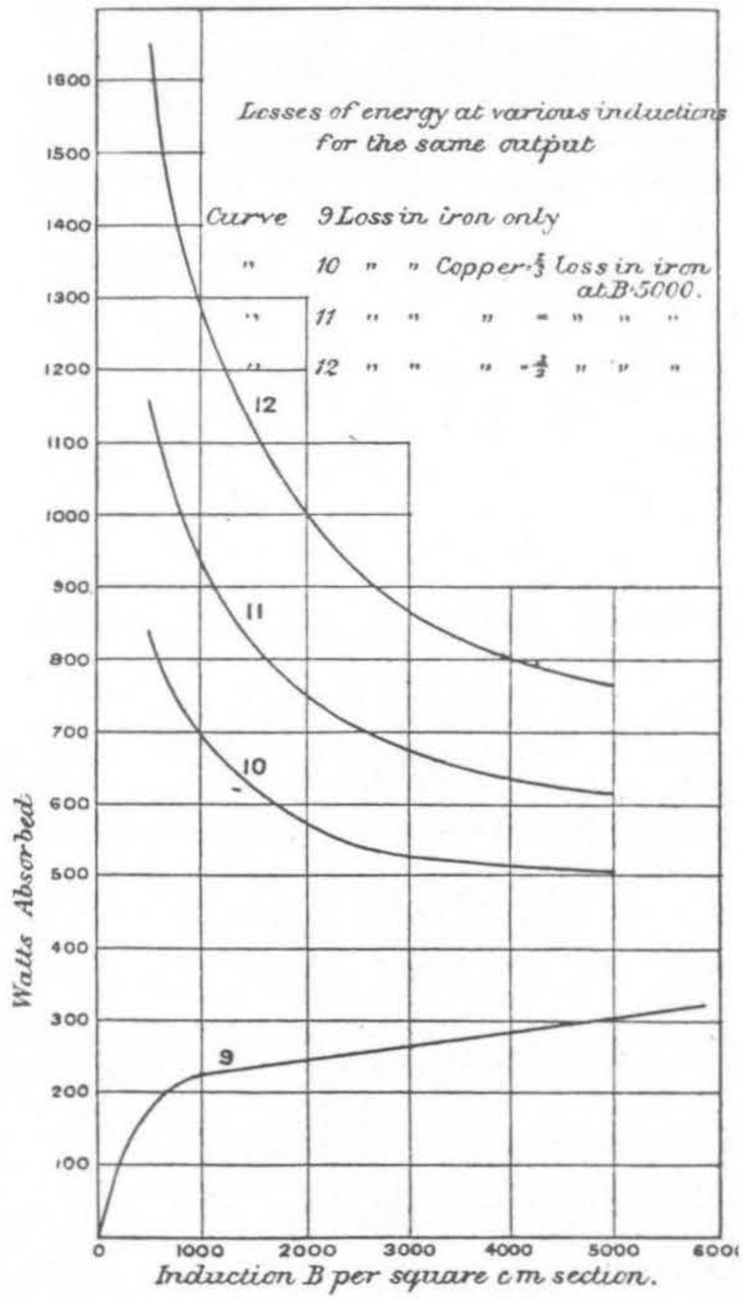

FIG. 4.

From the consideration of efficiency it is, therefore, desirable to work the transformer with a high induction, and it is only the question of the heating of the apparatus which imposes restric-

tions on the use of high inductions, to avoid the destruction of the insulating material. In other words, the problem was to find the maximum internal temperature of a body of known dimensions, when the rate at which its mass is heated has been determined.

In order to obtain some data towards the solution of this problem, a solenoid was constructed by winding 18 lbs. of insulated iron wire, 2·4 mm. in diameter, on a brass tube 300 mm. long, 8 mm. internal diameter, and provided with flanges at the ends each 100 mm. diameter.

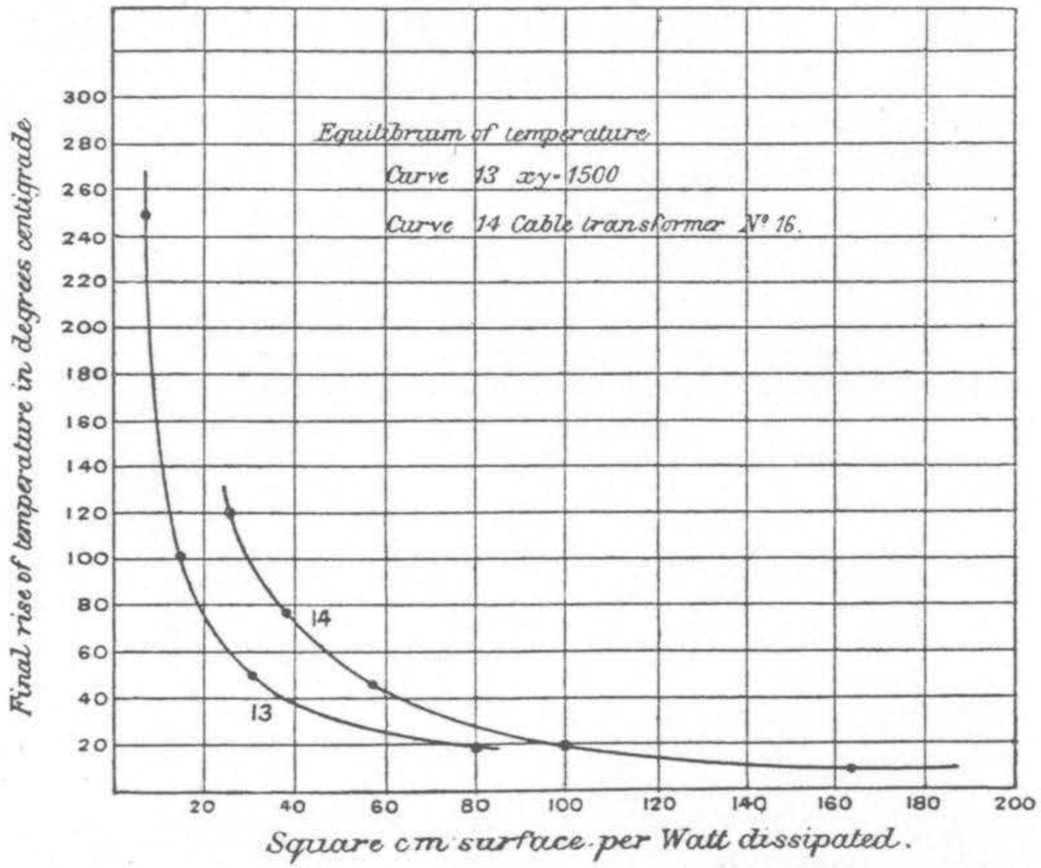

FIG. 5.

The internal temperature was measured by means of a thermometer just fitting the brass tube, and due care was taken to keep the temperature of the surrounding air constant during the experiments.

A constant direct current was sent through the coil, and a reading of the thermometer was taken after it had ceased rising. The rate at which energy was supplied to the coil was determined by the product of the square of the current into the resistance of the coil, measured when the equilibrium of temperature had been attained.

By varying the current the internal temperature could be varied, and the results were plotted in Curve 13, the abscissæ of which represent the cooling surface in square centimetres per watt dissipated, and the ordinates indicate the excess of the internal temperature of the coil over the temperature of the surrounding air in degrees centigrade, after the equilibrium between the supply and the dissipation of energy had been established in each case.

This curve is a rectangular hyperbola of the equation, $x\,y = 1{,}500$, and it shows that if the temperature of such a coil is to be kept at 100° C. the cooling surface should be 15 square cm. for each watt converted into heat in the coil.

It is self-evident that this curve (13) relates only to the coil by the aid of which it was constructed, and that it can only serve as a guide under strictly similar circumstances. By way of comparison a set of experiments were made on the same lines with a cable transformer, hung up in air, 6 metres long and 9·5 cm. in diameter, the internal temperature of which was determined by means of a test wire, as described above.

This curve (14) shows that for an internal temperature of 100° C. a cooling surface of about 28 square cm. has to be provided per watt of energy converted into heat in the transformer.

Before it is possible to draw general conclusions as to the connection between the internal temperature of transformers and their cooling surface, it is obviously necessary to make a good many more experiments in the direction indicated by the two curves just described.

Last year Dr. Fleming read a paper before this Institution, "On some Effects of Alternating-Current Flow in Circuits "having Capacity and Self-Induction" (*Journal of the Institution of Electrical Engineers*, vol. xx., No. 94, p. 374); it is, therefore, not necessary to repeat here the results of some experiments which were brought to the notice of the Institution at that time.

A very important factor in the construction of alternate-

current apparatus is the striking distance of these currents in various materials, as this determines, in the case of high-voltage currents, the thickness of the insulating material with which the conductors have to be surrounded, the ohmic resistance being no guide.

The first set of these experiments referred to the striking distance in air. In all the experiments made the frequency of the alternate current was 100 $\sim$ per second, except where another frequency is specially mentioned, and the voltage was produced by means of an alternate-current machine and a transformer, and it was measured by one of Sir William Thomson's static voltmeters.

The electrodes were re-polished each time a spark had passed between them; one of them was fixed horizontally during the experiments, while the other could be advanced towards it from above by means of a micrometer screw which allowed of reading to a hundredth of a millemetre.

The experiments were made in the following manner:—After connecting the electrodes of the spark micrometer to the terminals of the transformer, a certain voltage was put on and accurately measured; the distance between the electrodes was then slowly diminished until sparking occurred. Each experiment was repeated at least three times. Various electrodes were experimented with, the first pair being two plane parallel surfaces. In this case the fixed horizontal electrode consisted of a polished brass disc about 100 mm. in diameter, while the movable electrode was also formed by a brass disc, but only 37 mm. in diameter. To prevent the action of sharp edges, the edges of the discs were rounded off. The temperature of the surrounding air during these experiments was 14·75° C.

The results obtained are as follows:—

Difference of Potential.	Striking Distance.	Difference of Potential.	Striking Distance.
2,000 volts ...	0·67 mm.	10,000 volts ...	4·80 mm.
4,000 „ ...	1·59 „	12,000 „ ...	6·46 „
6,000 „ ...	2·53 „	15,000 „ ...	10·23 „
8,000 „ ...	3·60 „		

The last reading, giving the striking distance for 15,000 volts,

cannot be correct, as the sparks started from the upper edge of the smaller disc, and not from the nearest points between the two discs, the smaller disc being placed above the fixed one.

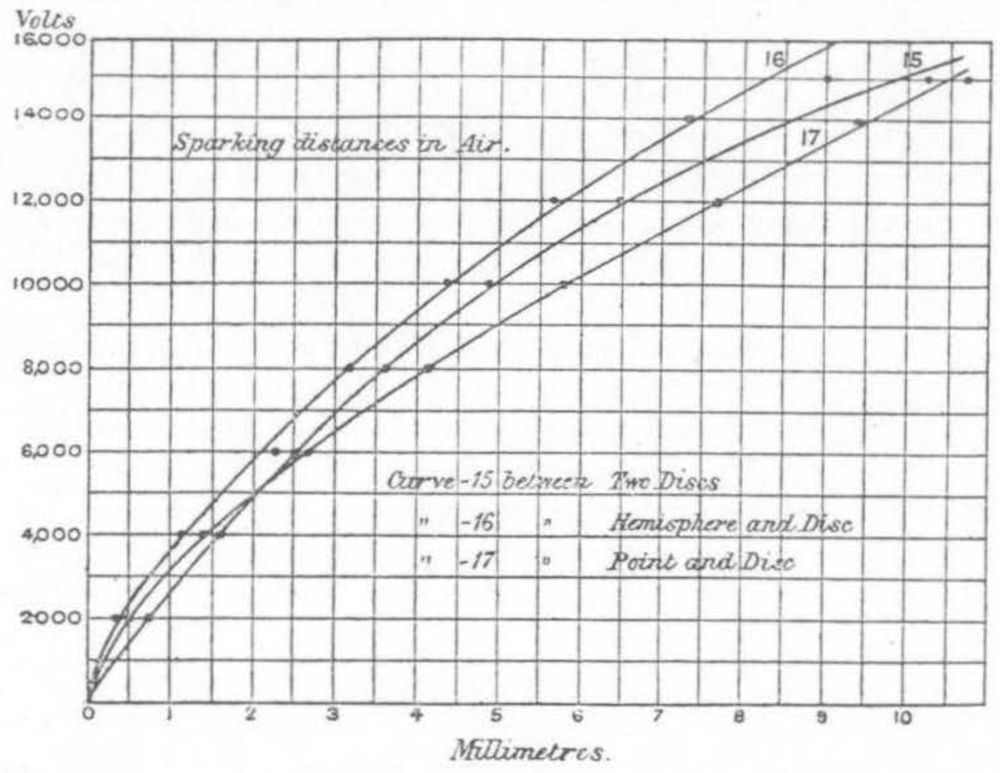

FIG. 6.

Curve 15 is the graphic representation of the above table.

For the next series the arrangements were the same as before, with the exception that the smaller movable disc was replaced by a half-sphere of 10 mm. diameter. The temperature of the air during these experiments was from 16° to 17° C., and its humidity 80 per cent.

Difference of Potential.	Striking Distance.	Difference of Potential.	Striking Distance.
2,000 volts ...	0·45 mm.	10,000 volts ...	4·37 mm.
4,000 „ ...	1·40 „	12,000 „ ...	5·65 „
6,000 „ ...	2·30 „	14,000 „ ...	7·32 „
8,000 „ ...	3·25 „	15,000 „ ...	9·02 „

These results are plotted in Curve 16.

After this the movable electrode of the spark micrometer was replaced by a steel point of an angle of 60°, its section

being an equilateral triangle of 5 mm. sides. This point was also re-polished after each spark; the spark, however, did not always start from the point. During these experiments the temperature of the air was 12° C., and its humidity about 50 per cent.

Difference of Potential.	Striking Distance.	Difference of Potential.	Striking Distance.
2,000 volts ...	0·40 mm.	10,000 volts ...	5·78 mm.
4,000 „ ...	1·26 „	12,000 „ ...	7·60 „
6,000 „ ...	2·66 „	14,000 „ ...	2·37 „
8,000 „ ...	4·08 „	15,000 „ ...	10·70 „

Curve 17 embodies this table.

After this the influence of an alteration in the frequency was tried by lowering this to 80 ∿ per second, and repeating some of the first experiments with disc electrodes. The striking distances for 4,000 volts and for 6,000 volts under these circumstances were found to be 1·47 mm. and 2·30 mm., or only slightly different from those produced by a frequency of 100 ∿ per second. From theoretical considerations it might have been expected that the distances would vary directly as the frequencies.

In order to investigate the influence of capacity, one or more coils of gutta-percha-covered wire were connected to the circuit of the transformer in parallel with the spark micrometer. The first experiments were made with a frequency of 100 ∿ per second, the two disc electrodes, and a capacity of 0·113 microfarads. The temperature of the air was 16·5° C., and its humidity 79 per cent.

Potential Difference.	Sparking Distance. With Capacity.	Without Capacity.
4,000 volts ...	1·53 mm. ...	1·59 mm.
6,000 „ ...	2·21 „ ...	2·53 „
10,000 „ ...	4·17 „ ...	4·50 „

A further experiment under similar conditions, but with a capacity of 0·28 microfarads in circuit, showed that the sparking distance at 10,000 volts was further reduced to 3·94 mm.

These tests were repeated with other electrodes, viz., the spherical surface and the disc.

At a difference of potential of 10,000 volts the sparking distance turned out to be—

1. With 0·14 M.F. capacity in circuit ... 4·08 mm.
2. Without any „ „ ... 4·50 „
3. With 0·14 M.F. „ „ ... 4·06 „

After that the steel point and the disc were used as electrodes, a capacity of 0·14 M.F. being connected to the circuit, and the results were —

Difference of Pot ntial.	Sparking Distance. Without.	With Capacity.
4,000 volts ...	1·26 mm. ...	1·14 mm.
10,000 „ ...	5·78 „ ...	4·83 „

All these experiments point to the fact that the sparking distances in air are diminished to a slight extent when capacity comes into play.

With a view of ascertaining how the voltage is propagated along a circuit, the position of the micrometer relatively to the cable was varied.

The experiments detailed above were made with the spark micrometer connected to the beginning of the cable; they were afterwards repeated after inserting the spark micrometer in the middle of the cable, and again after it had been connected to the end of the cable. In all three positions the same striking distance was observed under similar circumstances, which tends to prove that the voltage is propagated uniformly over the whole length of conductor, even if there is capacity in some parts of the circuit.

As stated above, the voltage experimented with was measured by means of Sir William Thomson's static voltmeters; but it is undoubtedly the highest ordinate of the wave which causes the spark. This "real" voltage can be found, if sine waves are assumed, by multiplying the measured volts by $\sqrt{2}$, and these new figures should be applicable to constant continuous currents.

In this way the results of Curve 15 were corrected, and compared with some results published by Warren de la Rue in *Nature* on the 12th September, 1878. Assuming that the E.M.F. of his

cells was equal to 1·03 volts, and reducing his results to volts and millimetres, they compare as follows :—

Difference of Potential.	Striking Distance. Warren de la Rue.	Siemens.
2,000 volts ...	0·45 mm. ...	0·25 mm.
4,000 „ ...	0·95 „ ...	0·80 „
6,000 „ ...	1·55 „ ...	1·45 „
8,000 „ ...	2·15 „ ...	2·15 „
10,000 „ ...	2·85 „ ...	2·85 „

On referring to the other curves published at the same time, it will be seen that Warren de la Rue found the sparking distances between two plain surfaces and between two spherical surfaces not to differ very much from each other. It may, therefore, be allowable to compare the mean values of these two curves of his with Curve 16 for the sparking distance between a hemisphere and a plain surface after the values of the volts have been multiplied with $\sqrt{2}$.

Difference of Potential.	Striking Distance. Warren de la Rue.	Siemens.
2,000 volts ...	0·36 mm. ...	0·25 mm.
4,000 „ ...	0·87 „ ...	0·80 „
6,000 „ ...	1·50 „ ...	1·45 „
8,000 „ ...	2·10 „ ...	2·16 „
10,000 „ ...	2·75 „ ...	2·85 „

Both these tables show that the results are practically identical, and consequently it may be concluded that the secondary current of the transformer used for the experiments is really a sine function.

Some further experiments were made with the same alternate-current machine and transformer, and a frequency of 100 $\sim$ per second, to determine the striking distance in various insulating materials. The differences of potential were again measured by Sir William Thomson's static voltmeter, or, in the case of the higher ones, by his volt balance.

One series of experiments, represented by Curve 18, was made by connecting the terminals of the transformer to the inner and outer conductor of concentric cables the insulation of which

consisted of impregnated fibrous material. The difference of potential was then gradually and slowly raised until the insulation gave way.

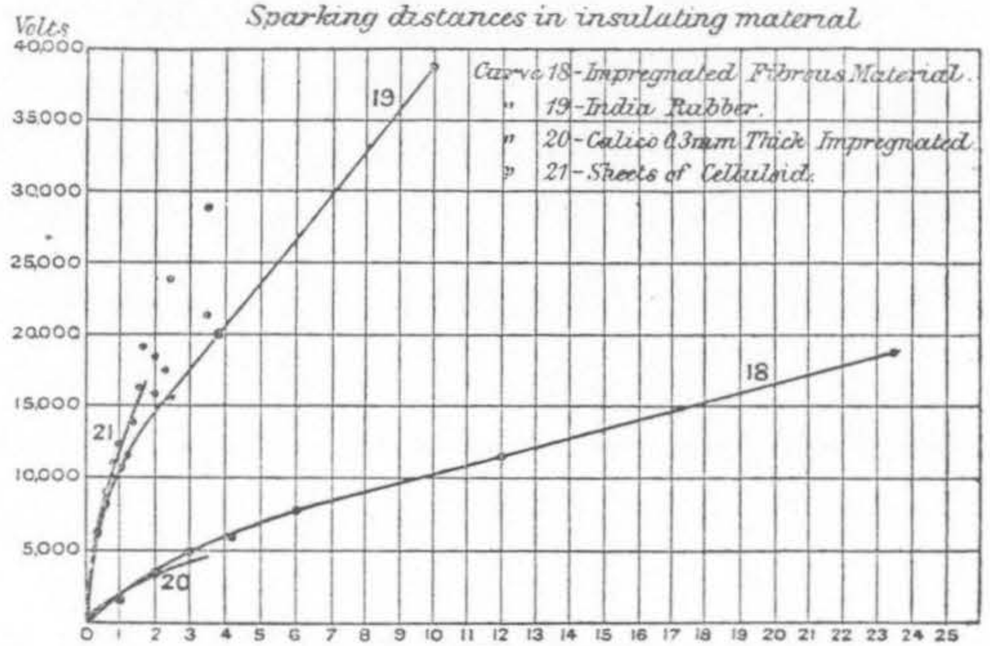

FIG. 7.

Curve 18 really consists of two parts, the lower of which was obtained by breaking 35 short samples of cable, made with various thicknesses of the insulating material; the upper part, above 7,000 volts, was determined by breaking actual cables, not less than 50 yards in length, specially manufactured for these experiments.

The next series of experiments dealt with india-rubber insulation, but results proved to be extremely irregular, although a curve (19) has been plotted which gives the minimum voltage at which sparking occurred at the various thicknesses.

The following table gives the details of the samples tested, and under what voltage they broke down :—

No.		Thickness of India-Rubber.	
1.	40 in. of 880 H wire ...	3·5 mm., broke with	21,500 volts.
2.	10 yds. of experimental core,	3·8 mm. „ „	20,000 „
3.	1½ „ „ „	2·5 mm. „ „	16,000 „
4.	1 „ concentric cable.	3·5 mm. „ „	28,000 „
5.	90 „ No. 504 core ...	1·2 mm. „ „	12,000 „
6.	46 „ „ 505 „ ...	2·0 mm. „ „	16,500 „
7.	50 „ „ 507 „ ...	1·8 mm. „ „	18,200 „
8.	48 „ „ 508 „ ...	2·3 mm. „ „	16,800 „
9.	5 „ „ 200 H wire	2·3 mm. „ „	28,000 „
10.	1 „ concentric cable	2·0 mm. „ „	17,500 „
11.	India-rubber sheet, ...	0·5 mm. „ „	7,500 „
12.	„ „ ...	1·0 mm. „ „	10,500 „
13.	Experimental piece of core,	10·0 mm. „ „	38,000 „

The concentric cables were tested by connecting the transformer to the two conductors; the sheets were placed between the disc and the spherical electrode. The core, when in short lengths, was covered with tinfoil; when long, it was immersed in water; and the terminals of the transformer were connected, the one to the insulated conductor, the other to the water or the tinfoil respectively.

Another set of tests were made by placing calico on the disc of the spark micrometer, and by connecting the other pole to a copper brush, such as are used in dynamo machines, resting on the calico.

Several samples of calico were tried—

(*a*) Thin calico, 0·12 mm. thick, not impregnated.

(*b*) Silesia calico, 0·15 mm. thick, not impregnated.

(*c*) Thick calico, 0·30 mm. thick, not impregnated.

(*d*) Thick calico, 0·30 mm. thick, impregnated.

All four samples required the same lowest difference of potential—about 700 volts—for a breakdown. Different spots of the same sheet behaved very differently, some not breaking with even 1,000 volts; but at least one spot could always be found which broke down with 700 volts.

Curve 20 gives the results obtained with several layers of the impregnated thick calico. The layers were tightly pressed together before being tested, and the points of the curve give the minimum value of the voltage which broke them down.

The last curve (21) records the sparking distance through celluloid, which was tested in sheets placed between the two discs of the spark micrometer.

A good many of the high-tension experiments were made with a specially constructed powerful transformer, capable of giving at its secondary terminals a current of 2 amperes under a pressure of about 50,000 volts. This is now on view at the Crystal Palace Electrical Exhibition, and various experiments are shown to exhibit its qualities. Unfortunately, it is too heavy to be shown in this Institution.

In conclusion, it should be mentioned that all the experiments described in this communication were carried out at Woolwich, at the works of Messrs. Siemens Brothers & Co., mostly under the immediate care of Dr. Baur, who was freely assisted by the heads of the various departments whenever he encountered difficulties in the course of his work.

Mr. PREECE: When reference was made two or three times this evening to the fact that I read a paper *last year*, I became for the first time conscious that since that paper was read so many striking phenomena have been brought before us that I had almost forgotten many points involved in that paper, and I wanted before the discussion commenced not only to refresh my own memory, but also to point out to you two or three additions I have made. But first I want to express my great regret that the paper in its complete state has not been already in the hands of every member of this Institution. This is due, unfortunately, to a circumstance which we regret very much indeed —the illness of Mr. Webb. Had he been well enough, I have no doubt we should all have had copies, but perhaps before we next meet you all may have them. I have added several tests that have been kindly given to me, so as to make the paper more complete; and I have added a section that I think has a very important bearing on the whole subject, and I will, with your permission, read it to you. It bears on the durability of india-rubber. Mr. Preece

Mr. Preece.

Now I want to lay great stress on the effect of age on india-rubber. It is all very well for us to see pretty figures like this on the board showing how much a specially prepared rubber will resist high pressures under fresh and peculiar circumstances; but we want to know what will be the effect of high pressures when they have been acting on conductors for more than twelve months. Now, on the next occasion when we meet here, I hope to have displayed on the table samples of india-rubber in all stages of manufacture, both for wire and for other purposes, which have been subjected to this particular test—a test which I have introduced into our specifications for india-rubber wire, and which I hope to have printed with the paper. On that occasion Mr. Roberts, who has had more experience in testing than most people, will himself explain how this test is conducted, and show results. Another point to which I should like to refer is this—that although I was very kindly assisted in the preparation of my paper by all the manufacturers with whom I placed myself in communication, there were one or two, unfortunately, with whom I had not communicated, viz.: Messrs. Hooper & Co., the Telegraph Manufacturing Company of Helsby, and the Okonite Company of Manchester. Naturally you may assume the result. Letters, rather severe in tone, implied neglect. I hope I have satisfied everybody that it was only an offence of omission and not of commission. This pretty book is, I think, to a certain extent the result of my omission. It is a book—a price-list—issued by a company with which I had had no acquaintance; it is called the "International Okonite Company, Limited." But the result of the omission has been, in the first place, to have myself supplied with several samples of this wire, which have given very high figures and very good results; but more, it has had the result of bringing out a price-book that in method and order and classification is worthy the study of every manufacturer present. It has also taught me a fact; and in giving you this fact, although the clock has struck half-past nine, I am sure you will excuse me for one moment in being a little frivolous. Now there is a story told about Artemus Ward that, in exhibiting one of his panoramas, there was a terrific blotch on it, and he said one day: "Ladies and

"gentlemen, that blotch is a cow. For ten years I have shown that Mr. Preece.
"panorama, and I did not know what that blotch was; but this
"morning the artist told me it was a cow, and I am bound now to
"tell you that that is a cow." Now the reference is this: What is the meaning of "okonite"? I never knew until to-day what "okonite" meant. I do not know now what the substance okonite is. The samples shown to me were vulcanised india-rubber, and very good vulcanised india-rubber too. Okonite has yet to appear upon this hemisphere. But this was how the matter was explained to me: "Nearly all good insulators end in 'onite.'
"You only have to put 'O K'—'all correct'—before it, and there
"you have 'okonite.'"

Another regret I have to admit to you, and that is, I have not been able in my paper to make any reference to oil as an insulator. We heard a very high testimonial paid to oil by Tesla the other day. We know that oil has been used much in this country, and it is now in the hands of Messrs. Johnson & Phillips, and especially in the hands of Mr. Phillips, who has promised that I should have all the particulars relating to oil, but unfortunately he also is ill. But I want to mention another point in connection with oil as an insulator, and it is the fact that the use of oil as an insulator is, I believe, the invention of Professor Hughes. In the year 1858, before many of you were born, Professor Hughes read a paper at the Society of Arts on, I think it was called a viscous insulator—[Prof. HUGHES: A semi-fluid insulator]—a semi-fluid insulator. He showed that if you took a submarine cable and coated it first with a thin layer of gutta-percha, and put a loose gutta-percha pipe outside it, and filled the interstice with the semi-fluid material, you had an insulator which, by its mobility, recovered itself. He stuck a knife through. there was dead earth for a moment, but in another moment the insulation was restored. This first oil insulation is, I am afraid, forgotten. It was brought out again by Mr. David Brooks about ten years ago, and for quite eight years we had a line of pipes all the way from Vauxhall to Clapham Junction where the wires were insulated with oil. I think oil is destined to perform a very important function in future. Another point. At the next

Mr. Preece.

meeting Major Cardew will probably commence the discussion with a description of a new method he has devised, and a paper upon which he read before the Royal Society a fortnight ago, showing how with a differential method and with a quadrant electrometer he is able to measure insulators far beyond anything on that board, showing visibly before us how you can measure 250,000 megohms with quite as much ease as we measure an ohm or half an ohm. Now I asked Mr. Simpson not to rub out those figures he had on the board. I am particularly interested in those figures, because those figures of De la Rue were the results of experiments he did for me in his laboratory in the year 1878, to determine the striking distance across air, with a view to forming lightning protectors, so that we may ensure that the surfaces of the lightning protector should be as near as possible without being struck by working currents—that is, that the distance between the earth plate and the line plate should be somewhere about the distance across which 700 volts would strike. The figures given by Mr. Siemens in his paper are the exact figures we found then. They are the figures that I have worked upon ever since, and the reason why I did not want them rubbed out was this—because, if you will remember, that in the earlier and smaller voltages there was always a considerable difference between the striking distance for direct currents and the striking distance for alternating currents. In the higher E.M.F. they equalised exactly; but when you come to 4,000 volts and under, then you found, at 2,000 volts, while the striking distance by De la Rue was 0·45, by Siemens it was 0·36; and so throughout till you get to 6,000 volts, the alternating currents always being smaller than the continuous. Now the reason why I have taken in my paper, and also why the Board of Trade has taken, a lower figure – that is, a striking distance of 2,000 volts across the tenth of an inch—is because we have to anticipate what may take place when cracks and fissures occur in insulating media, and where you have not to deal with a bright surface cleaned between each experiment; you have to deal with the dirty and damp surfaces. Every engineer will take a factor

of safety of 1 in 4 or 1 in 5, and so I select 500 volts per millimetre; and that is why I in my paper, and Major Cardew in the Board of Trade rules, have taken 2,000 volts per 1-10th inch as the minimum. In this proportion of striking distance I have never yet found two men agree. Mr. Ferranti brought down the striking distance with a transformer of high frequency as low as 620 volts per millimetre. What Mr. Tesla has done I do not know. I am very sorry he is not here, as we might have got from him some interesting facts bearing on this subject. Mr. Preece.

The discussion on Mr. Preece's paper and Mr. Siemens's paper was postponed until the next meeting.

The PRESIDENT announced that, as the result of the ballot for new members, the following candidates were elected:—

Foreign Member:

William Stanley, jun.

Associates:

John William Forster Ashwin.
William Joseph Bamber.
Lieut. W. P. Brett, R.E.
George Henry Cottam.
J. A. Dawson.
Maynard Dodd.
Claud Edward G. Gilbert.
John Derby Hyde.
James Hardie McLean.
G. A. Nussbaum.
Thomas Henry Palgham.
James Edward Pearce.
Maurice Pitman.
Thomas Henry Smith.

Paul Winsloe-Phillipps.

Students:

Percival C. Austwick.
Walter James Bache.
Alfred H. Bayes.
William W. Borman.
Robert Frederick Botting.
Frank C. Briggs.
Henry Ridley Burnett.
H. J. Cash.
Herbert George Crabb.
V. J. Delebecque.
John Fowler.
Qliver Freeman.
Arnold Hartley.
Walter Hawkings.
Fred. N. Haward.
Leopold William Heath.
John George Maxwell Hilton.
F. O. Hunt.
Alfred Claude Ivimy.
John Acheson Traill Marsh.

THE

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TESLA.

Although Prof. Ayrton in his presidential address has raised many points suitable for discussion, and although many questions of a practical character arise out of the meetings of the City and South London and the Central London Railway Companies, not to speak of those concerning the exhibition at the Crystal Palace, it is inevitable that we give the place of honour to our guest from across the Atlantic. Till a short time ago, Tesla was a name almost unknown to English ears. A few men had watched the announcements of his work in America, and Prof. S. P. Thompson, if we remember aright, introduced the name of the worker and his work in the borderland of science to the English public. But the man himself is now amongst us, and after his brilliant experimental lecture in the theatre of the Royal Institution on Wednesday the name will become as familiar as a household word. Geissler tubes have long been shown in the laboratory and the lecture-room, and many men have thought that in the dim and distant future something practical might arise from that root. De la Rue made many investigations; Spottiswoode, as will be remembered from his paper at the York meeting of the British Association, carried on the work; but perhaps above all others Crookes delved most deeply into this borderland of science. Now we have Mr. Tesla going many steps beyond his predecessors, mainly because he has called to his aid far greater "frequencies." The field of investigation has other explorers in Lodge, Hertz, J. J. Thomson, and we believe that the work done by Willoughby Smith ought not to be lost to view.

It was an excellent suggestion of the Institution to obtain the consent of the Royal Institution so that Mr. Tesla might expound his discoveries and show his experiments upon the spot which the immortal Faraday has made sacred to science. Hence it was that on Wednesday a brilliant gathering of members of the Institution met in the historic theatre to listen to the most recent and most wonderful discoveries in electrical science, and to witness experiments which to many of the audience undoubtedly came as one of the greatest surprises of the century. Mr. Tesla commenced his lecture by acknowledging his great indebtedness to Prof. Crookes, whose work first led him to undertake investigation into what at first sight seems a field rather barren of practical results. Perhaps, however, we are sometimes too anxious to see the end before the beginning is rightly grasped; still, we agree with those who consider blind experiment a waste of time. That is, the experimenter who, Micawber like, waits to see what will turn up, cannot be placed upon an equality with the one who has an object to gain and an end in view. It would be futile to attempt to describe Mr. Tesla's lecture or to discuss his investigations. That can only be done in a lengthy illustrated article, which no doubt will be duly forthcoming. It was perfectly evident, however, that Mr. Tesla's object is to obtain light, to supersede the present form of incandescent lamp by another form, to supersede the existing dynamo by another type. This is a very definite object, one that

deserves success, and one which, if it succeeds, will create a revolution in the industry. The scientific questions involved are of great interest, and will no doubt receive careful attention. Mr. Tesla kept his audience spellbound for two hours, and at the end of that time explained he had only performed about ne-third of the experiments he wished to show. We trust that after all these years during which, as the lecturer said, the apparatus used has been common property, some practical development will be found to prove its utility.

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NOTES.

To say that a large audience was enchanted by the long-expected lecture of Mr. Nikola Tesla on Wednesday night is no exaggeration; for as soon as he grasped his long glass tubes they glowed with softened splendour, as, magician-like, he waved them over his head, and little bulbs of glass with phosphorescing powder gleamed with a weird, if not ghastly, radiance when merely hung on his finger tip. Vainly did the unscientific members of the audience whisper to their neighbours, "How is it done?" And in his enthusiasm the lecturer, who seemed to love his wonderful lamps and globes, forgot to give an explanation. The more initiated flinched at the ominous crackle of the high-pressure discharges, and looked with some apprehension at a wooden box in which a magnetic interrupter was enclosed, and from which flames rose when the current was turned on. But the flames were shut down with an ordinary wooden lid, and the spluttering terminals shot out angry discharges at an iron clamp which the lecturer presented to it when he wished to convey a few hundred thousand volts through his body to a vacuum tube.

The apparatus used by Mr. Nikola Tesla is of the simplest description, but the arrangement of the subsidiary parts is complicated, and the adjustments are numerous and difficult to make. The high-frequency dynamo, which was placed in the dynamo-room of the Royal Institution, is most remarkable for its unsophisticated and plain design. It consists of a stationary armature, about 30 inches diameter, with 380 inwardly projecting coils, like those of a Parker alternator. A thin iron disc, like a fine-pitch gear wheel, is provided with 380 tiny magnets connected-up in series, runs with very small clearance, and generates a current with some 13,000 periods per second. This dynamo and several of the more characteristic experiments were described and illustrated in *The Electrician*, Vol. XXVII., p. 332. But no illustrations can convey an idea of the beautiful effects to those who have not seen them; and no report of the lecture can give to those who were not present, such an insight into Mr. Nikola Tesla's attractive personality as it was the privilege of his audience to enjoy.

The audience which gathers at the meetings of the Institution of Electrical Engineers is, probably, the most youthful of any scientific society; but several of the well-known men who often attend and take part in the proceedings are not members of the Institution. The Institution of Civil Engineers not only offers admirable accommodation, but provides a few members who contribute very usefully to the discussions. Some of these have been startled to find that their prerogative as members of the older Institution was of no avail for gaining admission to Mr. Nikola Tesla's lecture, and had to beg for tickets from members of the Institution of Electrical Engineers. That these tickets could be used for admitting strangers to the theatre of the Royal Institution came as a surprise when announcement was made to this effect after Prof. Ayrton's address; but this hope was rudely shattered by a circular, dated February 1st, which withdrew this privilege. As a last resource, several country members were appealed to by telegraph, and were good enough to send their post cards to their more fortunate London friends. By a fortunate combination of circumstances the theatre was just full, and no one was turned away. We understand that the Institution of Civil Engineers can accommodate only 400, and that the audience on Wednesday numbered about 800.

ENGINEERING.

FRIDAY, FEBRUARY 5, 1892.

ALTERNATE CURRENTS OF HIGH FREQUENCY.

WEDNESDAY evening saw another of those successful meetings for which the Royal Institution is famed. This time, however, the audience were not able to congratulate themselves that they were the first to view in public the striking experiments which were performed before them, as it is the custom of Royal Institution audiences to do, for on one occasion before, in America, Mr. Tesla, the lecturer of the evening, had been over the same ground.* This was probably no disadvantage either to him or to the numerous members and associates of the Institution of Electrical Engineers who crowded to hear him, for the fame of his researches had had time to spread, and their significance to become more or less appreciated. Not that Mr. Tesla needed this to render him welcome in this country, for the man who shares with Professor Ferraris the honour of having invented the self-starting alternate current motor, requires no introduction in England, nor, indeed, in any country where scientific ability is appreciated.

Our account of the previous lecture will have rendered our readers familiar with the line of Mr. Tesla's researches. We may, however, briefly state that he has devoted himself for the last year or two to the investigation of the effects attending the use of alternate currents of very high frequency and of high potential. This matter of the frequency of alternation seems to have been neglected by former experimenters with vacuum tubes. They took great pains to get immense potentials, but paid little attention to the rate at which the current vibrated to and fro. It now appears, however, that the rate of alternation is as important as potential in evolving certain phenomena, and by increasing it to a very great extent perfectly new and unexpected results can be obtained. This can be done in various ways, of which Mr. Tesla employs two. He has an alternate current dynamo, the armature of which consists of a steel disc, having arrayed on its rim 380 poles. This runs within a ring of magnets of corresponding number, and with the machine rotating at 2000 revolutions, gives 13,000 complete alternations per second. The current thus produced is sent through the primary wire of an induction coil, and its potential raised from 50,000 volts to more than a million, although, of course, the exact amount is a matter of conjecture. In another method of obtaining currents of high frequency there was employed an alternator lent by Messrs. Siemens Brothers. The current was sent through the primary of a large induction coil, in the circuit of which a special break was interposed. This consisted of two balls, between which the current sparked, and two powerful magnet poles, which blew out the spark as fast as it was formed, and thus greatly multiplied the effect. The current from the secondary coil was then sent through the primary coil of one of Mr. Tesla's oil insulated induction coils; in the circuit of the secondary coil there was interposed a battery of Leyden jars, which was constantly charged and discharged, the discharge being of an alternating character with a frequency of immense rapidity.

Mr. Tesla's coils are of peculiar form. The primary coil is on the outside, and is separated from the secondary by some little space. The whole is immersed in oil, and the inventor insists most strongly that a solid dielectric can never be used successfully in this position. If this be damaged it is spoiled irretrievably, while the oil may be struck through time after time, and instantly repairs itself. Any bubbles of air that the oil may contain are soon warmed and rise, and thus the defects are rapidly expelled, an event which cannot occur in a solid substance, in which defects tend to aggravate, and not to eliminate themselves.

Mr. Tesla began his lecture with a tribute to the work of Professor Crookes, which, he said, had fired his imagination when at college, and had given a bent to his studies. He then turned to his own researches, and in a second revealed to his audience the immense distance which separates himself from his predecessors, by taking in one hand an exhausted tube, 4 ft. long, while the other hand was connected to one terminal of a coil. Instantly the tube glowed with a brilliant lambent flame from end to end, and recalled to every one the idea of the magician's enchanted wand. When the gas was turned out, the light was sufficient to reveal the lecturer and his assistants, and would have been enough to enable him to read newspaper print. It was a most striking experiment; the old ideas of electric circuits, metallic electrodes, and all the rest of time-honoured notions, seemed to be flatly contradicted. From a single terminal of the coil the electro-magnetic radiations were conducted through the body of the lecturer to the tube, and entering through the glass, they put the few molecules of air that it contained into such active oscillation that they glowed in their mutual bombardment.

It was a breach of the dramatic canons to begin with an experiment of such brilliancy, and then to descend to others of less importance, but it was an indication of the power of the lecturer, and

* See ENGINEERING, vol. li., page 710.

evoked rounds of applause. Indeed, the reception accorded to Mr. Tesla was one that must have raised feelings of pride in any breast. Both seats and standing room were filled, and on the front benches were to be seen most of our leading electricians and electrical engineers. All through the evening there was rapt attention, which never flagged even during the less striking experiments.

Putting down the tube, Mr. Tesla attached an exhausted bulb to one terminal of a coil, and showed that phosphorescence was immediately set up in it. When he placed his hand near to it this phosphorescence was immensely increased, and the lamp filled with a vivid glow. This was repeated in other ways with different bulbs, and then two plates were attached to the terminals of a coil, with a sheet of vulcanite between them. The current then endeavoured to spark across, and beat itself in purple rays on the sheet, branching out in streaming brushes to make its way round the edges of the plate. Turning to his audience, Mr. Tesla exclaimed: "Is there anything more fascinating than the study of alternating currents?" It was evident to all in the room that use had not rendered the lecturer insusceptible to the beauties of the experiments that he showed, and that his mind was as completely filled with wonder and enthusiasm as that of the merest novice present, and probably far more so, as he saw further into the inner nature of the phenomena which he displayed, and grasped more of their significance.

The next experiment was the passage of sparks between two balls, to simulate the discharge from a Wimshurst machine. This was done most successfully, and it was difficult to believe that the well-known discs were not being turned in the anteroom. At first a 2-in. spark was shown, and then one of 6 in., the balls being changed, for the size of the balls appears to have a distinct effect on the appearance of the arc set up between them. Next came another of those brilliant sights which are always so effective with an audience, especially when it is in a cordial mood. Two wires were stretched across the well of the theatre, about a foot apart, and were connected to the poles of a coil. When the current was turned on they glowed for their entire length with a blue light, which streamed from one to the other, and was of sufficient intensity to reveal the faces of the audience. Here there was no case of exhausted globes; the light was given off in the open air, and if not enough for the ordinary domestic purposes, was at any rate of very appreciable intensity. In this case the alternations were obtained by aid of the Leyden jars. The same idea was developed in another way in the next experiment. A wire ring, 3 ft. in diameter, was connected to one terminal of a coil, and a second ring, 6 in. in diameter, was connected to the other, the two being concentric. The light streamed radially from one to the other, making a palpitating purple disc of great beauty.

Speaking on the subject of phosphorescence, Mr. Tesla stated his belief that it could be excited in all substances, if currents of sufficient frequency and potential were employed. He was also of opinion that exhaustion of the air was not necessary. Hitherto it has not been possible to drive the molecules on to the substance unless a fairly clear road were prepared for them, by removing all but an infinitesimal number. They could not get through the *mêlée*. But with sufficient initial velocity they will be able to proceed in straight lines, just as a cannon shot will pierce a crowd that would stop or deflect a cricket ball. All that is wanted is that the atoms shall fly fast enough and often enough to raise the surface, even of metal, to the phosphorescing, or at least to the glowing stage. With extremely rapid alternation, also, the molecules never get far away from the substance they bombard, and so their heat is not diffused. Crookes' phosphorescent tubes give a magnificent glow if only held in the hand, while the other hand is applied to a coil working with sufficient frequency and potential.

Visible light and heat are not necessary to prove the existence of the electric radiation, and Crookes' radiometer placed near a ball connected to one pole of a coil, rotates very briskly—curiously, however, in the opposite direction to that which it follows under the influence of light. This is explained as being due to the streams from the glass. In a second instance an unexhausted radiometer was made to rotate; the fans were covered on one side with mica, and the spindle was connected to the coil. The effect of the mica was to prevent the molecules heating one side of the vanes. As the current was increased the speed diminished on account of the electrostatic action between the mica and the glass.

In a certain sense the most interesting part of the lecture was that dealing with lamps, because here we seem to get nearer to some practical result. Mr. Tesla's lamps mostly consist of a bulb inclosing a button of carbon resting on the end of a wire or a filament. This wire is screened by being surrounded by a tube of aluminium, which forces the radiation to follow it to the button, and not stream off sideways. When the single conductor, which this lamp contains, is connected to one terminal of a coil, the carbon glows with a light the intensity of which varies with the character of the current. On Wednesday the light seemed to be about equal to 5 candle-power. When a metal screen was put over the lamp, and the radiations that fell on it were deflected back on to the sphere, the light was doubled, and reached a perfectly useful limit. Wonderful as this was, a greater marvel appeared when two zinc plates, one at a height of 10 ft. and one on the floor, were connected respectively to the poles of the coil. Then it only needed that a lamp of this construction should be brought into the intervening space to glow brilliantly without any electrical connection whatever. The radiation between plate and plate was so active that in passing through the attenuated atmosphere in the globe, it evolved the molecular bombardment which made the carbon glow.

The practical man asked as the lecturer finished, "What is the use of it all?" Nearly fifty years ago he was present when Faraday explained the laws of electro-magnetic induction, and then he also asked the same question. It was not till the Paris Exhibition of 1878 that he got his answer, but we shall be much mistaken if he has to wait so long this time. Wait he must, and in the mean time he cannot do better than join in honouring such men as Mr. Tesla who engage in researches which promise no immediate pecuniary benefit. He must, however, be dull if he cannot discern in the few experiments we have described, out of the many shown to the audience, a clue tending towards a great discovery that would entirely revolutionise our methods of artificial illumination. If a space measuring several feet in each direction can be brought into such a condition that an attenuated atmosphere introduced into it instantly becomes self-luminous, it does not call for any great stretch of imagination to see the whole of the atmosphere of our rooms in the same condition, and filled with the same clear light which bathes our planetary system. Just as the sun puts the ether into vibration of the kind revealed to our senses as light, so does electric energy also put it into vibration of the same kind, but of a different degree. Wednesday's lecture marks one step in the progress toward luminous electric radiations; possibly some of us may live to see the remaining stages covered.

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Power Transmission by Alternating Currents.

THE brief paper by William Stanley, Jr., which we publish elsewhere, gives an interesting view of the alternating current phase of power transmission. It is specially important as bringing to public notice again the very ingenious motor devised by Messrs. Stanley and Kelly, to which reference has several times been made in our columns. One very pretty feature of this machine is the ingenious method for neutralizing lag between field and armature circuits. This question of a practical alternating motor for general use is one of the greatest importance since on the existence of each machine depends the availability of the alternating current in the general transmission of power. In cases where the electromotive force of transmission must be higher than that of utilization, the high efficiency of the alternate current transformer is of no avail unless convenient and efficient motors can be employed in connection with it.

Mr. Tesla and the Drehstrom Sytems.

IN another column will be found a few remarks of Mr. Carl Hering concerning Mr. Tesla's position with reference to the invention of the rotary field motor, written a month ago, but unpublished until now, for the reasons that are made evident to the reader here. It is in final response to communications sent by Mr. C. E. L. Brown to this and other journals ostentatiously upholding Mr. Tesla's rights in the matter. We desire to state right here that THE ELECTRICAL WORLD has over and over put itself on record as upholding Mr. Tesla's priority in the enunciation of the principles of multiphase motors. We have taken this position in the editorial columns several times already, and have had, at no time, any desire to recede from it. The question between Mr. Brown and Mr. Hering as to Dobrowolsky's work in this direction has been discussed quite long enough, and we here take the opportunity of bringing the matter to a close, as it is neither necessary nor interesting. There exists between the two foreign engineers concerned a keen professional rivalry, and THE ELECTRICAL WORLD does not propose to be used as a cat's paw to pull Mr. Brown's chestnuts out of the fire. Both of these engineers are possessed of undoubted ability, which we have always taken pleasure in recognizing, but we do not think that any question as to the merits of their work should be conducted through an American journal and over the shoulders of Mr. Hering, who is the gentleman apparently attacked.

Latest Foreign Electrical News.

(By Cable from Our Own Correspondent.)

LONDON, Feb. 1, 1892.—Mr. Nikola Tesla's lecture on his high frequency work, which has been long promised, will be given before the Institution of Electrical Engineers on Wednesday next at the rooms of the Royal Institution. It has been anticipated with the greatest interest by every one, as Mr. Tesla's previous work shows the importance of the subject.

Mr. Tesla and the Drehstrom System.

BY CARL HERING.

As Mr. C. E. L. Brown, in communications to THE ELECTRICAL WORLD and other journals, seems determined to insist that I have neglected the work of Mr. Tesla on rotary current, I wish here to state that there is no one more ready than myself to give Mr. Tesla due credit for his work, and I have always considered him to be an original inventor of the rotary field system and the first to reduce it to practice, and I believe I so stated it in my articles. If I have at any time failed to give him credit for the extent to which he developed it, it has been because Mr. Tesla has been too modest (or perhaps prudent) to let the world know what he had accomplished, and we ought therefore not to be blamed if we do not always know what he has done. When the articles which have caused this discussion were being written, Mr. Tesla's patents were not accessible to me. Just where Mr. Dobrowolsky's improvements begin I have not yet been able to ascertain.

The fact that I have personally tried to persuade Mr. Tesla to write a paper on his work in this field will show that I am very anxious myself to know just how far he carried his work, and why it was not continued. In justice to Mr. Dobrowolsky, it ought to be said that if Tesla did not publish his researches other than his patents, Dobrowolsky ought to have the credit at least for what he did that was not included in Tesla's patents. Dobrowolsky, though he may have been an independent inventor, admits that Tesla's work is prior to his, but he claims to have made

improvements. In my articles I distinctly stated that I did not wish to enter into a discussion of the subject of priority. Dobrowolsky's system has proved itself to be a success; it was natural to assume that he had made some improvements. It must be left to a discussion between Tesla and Dobrowolsky, and not to others, to determine, if necessary, just where the one left off and the other began. The modesty of both of these gentlemen would, I feel sure, lead to a clear understanding.

Regarding the subject of priority, it may be of interest here to say that in a conversation with Prof. Ferraris, last summer, that gentleman told me with very becoming modesty that, although he had experimented with the rotary field several years before Tesla's work was published, he did not think it was possible that Tesla could have known of his work, and he therefore believed that Tesla invented it entirely independently. He also stated that Tesla developed it much farther than he (Ferraris) did.

ELECTRIC LIGHT AND ELECTRIC FORCE.

IF the beautiful experiments exhibited at the Royal Institution by Mr. Tesla, the able lieutenant of Mr. Edison, are of practical value, and not the mere playthings of the lecture-room, we may be on the eve of some of the greatest discoveries that the world has ever seen. What mankind want during the waking hours of the night is not a glow in the darkness, however intense, but a suffusing, pervading illumination. They want, in fact, sunshine at night. But this, it seems, is what Mr. Tesla is on the eve of offering to us. At his lectures at the Royal Institution, the following striking experiment was shown. It consisted "in joining two sheets of tinfoil, one over the lecturer's head, the other on the table, to the poles of his generator. The space between these two sheets immediately became electrified, and a long vacuum-tube waved about in it, without attachment to any conductor whatever, glowed in the darkness like a flaming sword. This experiment was intended to illustrate the possibility of rendering an entire room so electric, by plates in the ceiling or under the floor, that vacuum-bulbs placed anywhere within it would yield a light." In other words, we shall be able to fill our rooms with the potentiality of light, and then be able, by the simple introduction of vacuum-tubes, to obtain any quantity of light. Those who want real daylight, and daylight, be it remembered, without heat, will be able to run a vacuum-tube round the whole length of the cornice, and so obtain a diffused illumination of almost any brilliancy. The relief to our eyes, were such a condition of things rendered practical for ordinary houses, would be immense. There is no greater mistake than to suppose that a strong light is bad for the eyes. Staring at a bright jet of flame point-blank is bad, just as staring at the sun is hurtful to the eyes; but in practice no light that falls on the book can be too strong for healthy eyes. The proof of this is simple enough. Every one admits that it is better to read and work by daylight than by artificial light; but whoever got artificial light of anything like the strength of daylight? Read by the most powerful of lamps in a darkened room, and then let the shutters be opened, and you will find that the light on your book, though you may be sitting close to your lamp, is at once greatly intensified. If, then, we fill our rooms with electricity, and draw off a daylight supply in our vacuum-tubes, we shall be saving, not injuring our eyes. It will be said, perhaps, that if the electricians perfect their appliances, and make electric lighting cheap, easy, and some twenty times more effectual than it is at present, the world will still be the loser, and for this reason. The presence of darkness compels a cessation of human labour, and so imposes a certain amount of rest on the poorest of mankind. But if night can be turned into day, men will be tempted to forego their rest, and thus the new discovery will only bind men more closely than ever to the chariot-wheels of toil. Possibly this argument may have had something in it when it was first used by a protesting and primitive philanthropist disgusted to find that an enterprising brother-troglodyte had sat up to finish his canoe by the flickering and precarious light of a resinous pine-branch. The friend of cave-man doubtless pointed out that from this small beginning would flow endless toil and misery to the sons of men; and in the instinctive horror of night-work possessed by all unsophisticated persons, we can catch an echo of that primordial sermon. It was of little avail, however, and the more man progresses in civilisation, the more he insists on stealing life from the hours of darkness. The argument that electric daylight might prove a curse instead of a blessing, comes too late. Men have already insisted on working at night; and therefore the better the light, the better they will bear the burden of their toil. No one who has seen a couple of village carpenters working late to finish a coffin by one dip-candle can doubt that good, cheap light would enormously decrease the physical hardships of the poor. If factories and workshops could be made as light as day by electricity, not a few of the physical ills from which our operatives suffer would be put an end to. While dealing with Mr. Tesla's experiments, we must not forget to notice the very curious facts connected with his generation of light in a vacuum-tube without the use of connecting-wires. The lecturer stands in "an electrostatic field" capable of illuminating a lamp without wires, and feels nothing. Nay, more, he holds a vacuum-tube in one hand, and touches "a terminal" with the other, a process which makes him "the channel for a current at something like fifty thousand volts," and yet does not receive the slightest injury. Yet, strangely enough, a current of one-five-hundredth of this intensity would be enough to destroy him altogether. For some incomprehensible reason, the greater the "pace" of the electricity, the less its effect on the human organism.

If the electricians give us sunshine at night, they will have bestowed on mortals a godlike gift. We want, however, something else from the electricians even more than that. It is a something they have often tried to give, but have never yet succeeded in bestowing on us,—a practical electric motor. In the first place, we want a motor which will supersede horses for the traction of light vehicles. Imagine the convenience of electric cabs and omnibuses! At present, not only five million inhabitants have in London to be fed and watered and provided with air and light and room, but half-a-million horses. If these could be dispensed with, the saving would be enormous. Nor would the saving in keep be the only convenience. Carriages and carts without horses would take just half the room now occupied. Electrical traction would therefore put an end to the congestion of traffic which is so serious in many thoroughfares. Instead of a cab, we should have a light arm-chair on wheels, with a seat in front for the driver, which would carry us in safety at eight miles an hour. Quite as great is the need for a good electric motor for house-work. It is no good to talk about setting up in our houses neat little dynamos that a housemaid could learn how to work in a few hours. The housemaids never would learn, and we should soon find the neat little dynamo standing rusty and dust-grimed in the area, forgotten of man and maid. If electricity is to be any good in the house, it must come in ready in a box,—potted energy which can be applied, like grease, wherever it is wanted. In this shape it may have a hundred uses. The footman, instead of turning the knife-machine, will connect it with the electrical motor, the cook will use it to turn the handle of the egg-whisk, the coffee-roaster, and the coffee-grinder, and to turn the meat. In the laundry it will do our mangling and ironing. In the stable it will clip the horses, and in the gardener's department pump the water and cut the lawn. Everything, in fact, that now revolves by the exertion of muscular effort, will be arranged to turn by electricity. When the electricians have given us the household motor, and not till then, shall we be able to say that man has chained the thunderbolt, and made it an obedient slave.

MR. TESLA BEFORE THE LONDON INSTITUTION OF ELECTRICAL ENGINEERS—AND THE ROYAL INSTITUTION.

(*Special Cablegram to* THE ELECTRICAL ENGINEER.)

ON the evening of February 3, Mr. Nikola Tesla, by special invitation, delivered a lecture on the results of his latest investigations before the London Institution of Electrical Engineers.

After a short introductory as to the theory which led him up to his new line of work, involving the application of enormously high potentials and frequencies far exceeding those heretofore employed, Mr. Tesla began his experimental demonstrations with the exhibition of various forms of discharges. He showed first an induction coil operated by condenser discharge. With this coil he produced various remarkable discharge phenomena. Among others he imitated the spark of a Holtz machine and showed a brush discharge covering an area of something like 4 or 5 square feet, and also a luminous wire outlining the name of William Thomson. Mr. Tesla then took up some very novel and exceedingly interesting phenomena discovered by him some time ago consisting of a brush rotating in an exhausted globe. He showed that the brush was affected electrostatically, magnetically (even by the earth's magnetism), and that the study of these phenomena might lead to important discoveries as to the nature of electrostatic or electromagnetic fields.

Mr. Tesla showed how Crookes' well-known radiometer is set in motion *at ordinary atmospheric* pressures with alternating high potentials, thus affording another link in the chain of evidence which is gradually establishing the truth of modern views.

The subject of obtaining motive power was next taken up by Mr. Tesla, who exhibited a motor running on one wire and also without any connection with the generator, and the lecturer also dwelt on the possibility of running motors without wires.

Mr. Tesla next spoke of the construction of light-giving bulbs and the manner in which the dissipation of the energy supplied is prevented in the bulb by screening and allowing it to be dissipated only from the point at which it is wanted. In this connection he brought before his audience the results obtained with "carborundum," the new diamond-like substance recently produced by Mr. E. G. Acheson, of Monongahela, Pa.

Mr. Tesla then proceeded to show an interesting experiment which consisted in bringing a button to incandescence in a tube, holding the latter in the hand, and with another tube he repeated the experiment of Prof. Crookes by bringing a small platinum wire in the tube to incandescence and rotating a small fan.

Mr. Tesla also dwelt on phosphorescence and concluded his address with a demonstration of the luminous effects produced upon tubes in an electrostatic field.

On the following evening Mr. Tesla repeated his lecture before the Royal Institution by invitation.

Some idea of the interest aroused by Mr. Tesla's lecture may be formed from the fact that the London *Times* went to the unusual length of devoting a column editorial to it and publishing a very full report of it, with a description of his more striking demonstrations.

MR. TESLA'S LECTURES ON ALTERNATE CURRENTS OF HIGH POTENTIAL AND FREQUENCY.

IT is not often that the outward and visible signs of a great scientific success are so prominent as they were last week at the Royal Institution. The reports which have reached this country of the work of Mr. Nikola Tesla have made his name known to those who are watching or aiding the progress of electrical science. He was recently invited by the Institute of Electrical Engineers to lecture before it, and the interest which his coming excited spread in widening circles as the day on which he was to exhibit his experiments drew near.

It was evident that the ordinary meeting-room of the Institute would be too small, and the Managers of the Royal Institution placed their theatre at its disposal. Members of the Royal Institution, were, however, anxious to hear and see for themselves; and finally Mr. Tesla consented to lecture on two consecutive nights to the Institute and the Institution respectively.

On both occasions the room was full; on the first it was overflowing. Gathered round the lecture table was a crowd of those whose business it is, either as theorists or as practical men, to keep abreast of the wave of scientific advance; but as the youthful lecturer —who looks even younger than his years—with a modesty and charm of manner which were altogether irresistible, showed wonder after wonder, the interest of this critical audience deepened into enthusiasm. The speaker's broken English and imperfect explanations did not detract from his success. His marvellous skill as an experimentalist was evident and unmistakable, and his hearers left the room convinced, not only that another step forward has been taken, but also that in Mr. Tesla we have a scientific explorer, who, if health and life be granted him, will travel fast and far.

Briefly, Mr. Tesla has done much to attain the continuous stream of electrical oscillations which Prof. Fitzgerald, at a recent meeting of the Physical Society, compared to a continuous whistle. The oscillations which Hertz studied die out almost instantaneously. Could they be maintained, a practically new weapon would be placed in our hands. Tesla does not, indeed, maintain them, but he renews them many times per second, and the results are marvellous.

Though the potential is enormous, the electrode of the apparatus can be safely handled. If a person in conducting communication with it touches a vacuum bulb or tube it glows, and if the tube is brought near to others it sets them a-glowing too. No return is needed, the current is completed through surrounding space. The phosphorescent materials in some of the beautiful tubes lent by Mr. Crookes shone brightly when one electrode only was connected with the coil. If the terminal is surrounded by an aluminium tube, the glow is notably increased. The experiment of making a vacuum-tube luminous by simply holding it in an oscillating field was successfully performed, and the lecturer himself received with impunity a crackling discharge, some six or eight inches in length, by holding his hand at that distance from the terminal of his coil.

All these things are not merely wonders. Mr. Tesla is working with an object. He is one of those who hold that a phosphorescent glow is the light of the future. He hints at artificial auroræ spreading from the summits of towers of hitherto undreamt-of height, and he has at all events got as far as producing in air at atmospheric pressure a glowing plane bounded by two rings about a foot and thirty inches in diameter respectively. Whether his visions will all be realized may be doubtful. There is is no doubt that they are guiding him aright. As Lord Rayleigh said in moving the vote of thanks, a door has been opened into a new region of inquiry, into which Mr. Crookes and Mr. Tesla have entered almost alone.

Those who some fifteen months ago heard Prof. Hertz acknowledge in terms of genuine emotion that he had built upon a foundation laid by Englishmen, that Englishmen had first recognized the importance of his work, and that from England its first reward had come, must have listened with pleasure when the part that this country has taken in the development of electrical science was referred to in a like appreciative tone by Mr. Tesla. It is not indeed that the achievements of our great electricians are bettered or rendered more important by acknowledgment, but it is pleasant to note how cosmopolitan science is becoming, and that among scientific workers the feeling of fellowship is overcoming that of rivalry. For the rest we can only congratulate Mr. Tesla alike upon his work and his reception, and the scientific world on the exhibition of a number of beautiful experiments which will afford food for useful reflection to theorist and experimenter alike.

A. W. R.

The announcement of Mr. Nikola Tesla's lecture to the Institution of Electrical Engineers excited widespread interest among all in the least degree interested in electrical science. The succession of almost marvellous experiments in which in great measure it consisted must have gone far beyond the anticipations of the most sanguine of those of the audience who had had no previous account of the nature and results of his work. It is not too much to say that the Royal Institution lectures mark a distinct epoch in the progress of theoretical and applied electricity. While, on the one hand, the experiments which the lecturer showed seemed to point to a possible revolution of our methods of electric lighting, on the other hand they must have suggested, if not for the first

time, in a new and forcible way, important questions of electrical theory, and the physiological effects of rapidly alternating currents. That he should have been able unharmed to place himself in the space between two tinfoil plates connected to the terminals of his rapidly alternating machine, was to the ordinary observer in itself sufficiently startling; but that he should have been able to present a piece of iron to one of the poles of the machine, drawing a spark of several inches in length with impunity, and thereby to interpose his body as a connecting link between the machine and a long vacuum tube which glowed like a flaming sword, must have appeared to many of those most conversant with electrical phenomena truly astonishing.

Hitherto, alternating machines of great frequency and high potential have been deemed peculiarly dangerous, and not without reason. But it did not follow, of course, that with a sufficient increase of the frequency of alternation, the danger might not completely disappear. It will be of great importance to inquire in what way the immunity of the experimenter from injury is brought about. Are impulses of 20,000 reversals per second and upwards without serious effect on the nervous system of the human body, so that conduction takes place through it without any disagreeable consequences? or is the conduction effected without the nervous system being concerned at all?

The delicate network of nerves in the eye is sensitive to a certain range of frequency of electrical vibrations, and perfectly insensitive to vibrations which lie outside that range in frequency. In the same way the insensitiveness of the general nerve-system of the human body interposed between a glowing vacuum tube and the terminal of a rapidly alternating machine or transformer may begin and end at much lower limits. There is also, of course, the interesting question of the distribution of these rapidly alternating currents in the somewhat complicated conductor formed by the human body, which may have a great deal to do with the result.

It ought to be recalled here that Prof. J. J. Thomson has been working in the same field, and has obtained somewhat similar results. These were made the subject of a very interesting demonstration to the members of the Physical Society on the occasion of their visit to Cambridge in May of last year. For a long time Prof. Thomson has investigated this subject both theoretically and experimentally, and his researches have thrown much light on the *rationale* of the very striking results obtained by Mr. Tesla and himself in their closely allied but independently carried out series of experiments.

The admirable experiments of Mr. Tesla are only another instance of the way in which practical applications of science promote its progress, by enabling apparatus to be constructed on an engineering scale, and with all the security for effective action which the constructive art of the engineer furnishes so well. His simple alternating machine, running with very little clearance at a speed of about 2000 revolutions per minute, is itself a triumph of skill in design and construction, and well illustrates how desirable and even necessary it is to take advantage of all the aids to exactness, and they are many, which can be obtained from the refined machine tools and truth of design which characterize the engineering workshop of to-day. The ordinary optician of twenty years ago, with his imperfect lathes, and general utter want of power-driven appliances, his continual hand-fitting and shaping, and the absolute non-interchangeability of the parts of his instruments, has almost passed away; and even the physical laboratory has become in great measure an engineering workshop, in which are to be found Whitworth lathes and end-measuring machines adapted for the most exact work.

One point in this connection is worthy of notice. Mr. Tesla insists strongly on the essentially electrostatic nature of the phenomena illustrated by his lectures; while, on the other hand, *one* object aimed at in Prof. Thomson's experiments was to show that in a tube without electrodes luminosity could be produced by electrodynamic action alone—that is to say, in a field of electric force which is not electrostatic in the sense of admitting of the derivation of its intensity at each point from a potential function.

The changes produced in the distribution of electricity on neighbouring conductors will cause glow in a vacuum tube when a Holtz machine or Leyden jar is discharged; and this will in general be more or less operative. But it is not in general possible to separate the electromotive forces due to this cause from those due to electromagnetic action. Prof. Thomson has succeeded in some cases in screening off these electrostatic effects, and in producing a glow discharge in which electrostatic action could have little or no share.

The glow or flame discharges from the terminals of his induction coils, the glow discharge from the long wires stretched from the induction coil towards the roof of the hall, the glowing vacuous bulbs and phosphorescent tubes placed in the field between the parallel tin-foil plates attached to the transformer terminals are all phenomena of the highest importance; though, of course, they are only exceedingly striking and effective illustrations of experimental results already arrived at by the lecturer himself and others, and communicated in a more or less complete manner to the electrical world. The application of these, which Mr. Tesla suggests as a possible one in the future, would bring about an ideal form of electric lighting, which would transcend in luxury and convenience our present system of electric lighting by incandescent lamps as far as the latter transcends the oil lamps and tallow dips used by our near ancestors. Every drawing-room would become an electric field in a continual state of rapidly alternating stress, in which the occupants would live, experiencing no unpleasant effects whatever, while vacuous bulbs or phosphorescent globes and tubes, without care or attention, would shed a soft diffused light, of colour and intensity arranged to suit the most luxurious fancy. It would be interesting also to know whether, after all, habitual dwelling in a region of electric stress rapidly changed from one extreme of high intensity to the opposite, produced very slow physiological effects which could be traced in the improved health and longevity of the persons so dwelling, or the reverse. If such applications are made (and there does not seem to be any sufficient reason why they should not come to pass), the magnificent researches of Mr Crookes, as well as those of other investigators to whom the lecturer justly and generously acknowledged his indebtedness, will bear some practical fruit in an almost totally unexpected manner, by becoming at once available in connection with a new and beautiful development of what is at present the most progressive of the physical sciences.

It does seem that we are on the point of farther great advance into the undiscovered domain of electrical science, and it is significant that it is likely to lie along one of the routes made clearer to us by the discovery and verification of the great theory of electrical radiation. Who knows what further discoveries may be obtained before the present century has come to an end? We are advancing so rapidly that no one can declare that the record of discovery of the nineteenth century has nearly closed. One important means of further investigating electrical radiation will be that which Prof. Fitzgerald made an attempt to find—a means of maintaining for any required length of time electrical vibrations of sufficiently high frequency. Mr. Tesla's results seem to promise that this problem may perhaps be solved before very long, and many outstanding questions of the electromagnetic theory of light thereby set at rest. In many other ways his researches are certain to promote scientific discovery. To quote his own words: "The field is wide and completely unexplored, and at every step a new truth is gleaned, a novel fact observed." G.

MR. TESLA AND VIBRATORY CURRENTS.

The lecture given by Mr. Tesla on Wednesday last week before the Institution of Electrical Engineers, and repeated on the Thursday before the Royal Institution, will live long in the imagination of every person in the brilliant scientific audiences that heard him, opening as it did, to many of them for the first time, apparently limitless possibilities in the applications and control of electricity. Seldom has there been such a gathering of all the foremost electrical authorities of the day, on the tiptoe of expectation to witness the experiments, details of some of which had already been given to us from the other side of the Atlantic, but of which no written account could convey the true significance and beauty. Long before the hour of meeting the hall was crowded, and Mr. Tesla was watched throughout with the keenest interest as he adjusted his apparatus quivering with lightning-like discharges, and now lighted a vacuum tube by grasping it in his hand, now brought to incandescence the filament of an ordinary lamp attached by a single wire, there rendering the air in the interior of a large ring luminous with flame, or sending streams of light from wires stretched over the audience, and, most fascinating of all, after electrifying the whole space of air between his table and an iron plate above him, waving a luminous tube in his hand totally unconnected to any wire whatever. It was, indeed, curious to see the most prominent and noted electricians of the day as interested in Mr. Tesla and his experiments as any child with the first friction machine, asking whether it was safe to do this or that, to touch the wires, and whether they might be allowed to try. For full two hours Mr. Tesla kept his audience spellbound, with easy confidence and the most modest manner possible displaying his experiments, and suggesting, one after another, outlooks for the practical application of his researches; and it was difficult to realise that this memorable lecture was the second only that he had ever delivered. Even at the end Mr. Tesla tantalisingly informed his listeners that he had shown them but one-third of what he was prepared to do, and the whole audience, after Prof. Ayrton had proposed the vote of congratulation and declared the meeting over, yet remained in their seats unwilling to disperse, insisting upon more, and Mr. Tesla had to deliver a supplementary lecture.

It is not for us here to describe the lecture in its details, as a full and illustrated report, revised by Mr. Tesla, is being prepared for the *Journal* of the Institution of Electrical Engineers, which will appear in due time, and containing much even that could only be glanced at in the lecture itself, and this will be the proper material for electrical engineers to fully discuss. But it may be allowed us to dwell a little upon the scientific *modus operandi*, and give certain particulars which our readers, no doubt, are looking for with interest.

In the first place, it may be stated, as Mr. Tesla mentioned, but which hardly seems to be realised, that practically the whole of the experiments shown were new, and had never been shown before, and were not merely a repetition of those given in his lecture in America. That of lighting tubes in an electrostatic field and of bringing filaments to incandescence on a single wire were shown before, and being of the most importance, naturally were not left out. But all the other experiments, together with most of the apparatus itself, was novel, and was supplementary to that of his American lecture.

In the next place, it is important to understand—as also stated by Mr. Tesla at the time, but hardly, perhaps, yet

realised—that nearly the whole of his experiments and effects were produced by means of an ordinary alternating current from an ordinary commercial alternating-current dynamo—such, in fact, as can, in many places, be obtained from a central supply company's mains. These effects can be, and were, brought about also by means of the currents from his special alternator, but the chief benefit of the use of this alternator is in being able to obtain perfectly harmonious currents of a known number of alternations per second, and in research work this knowledge is evidently of immense value.

Without going deeply into the detail or the theory of the working of the apparatus used, it is seen, therefore, that the effects are produced by using an alternating current, either generated direct at high potential and with high frequency of reversal per second, or ordinary currents converted into such currents. Mr. Tesla termed these currents "alternating currents of high potential and high frequency," but in the same way that the term rotary current (first proposed, we believe, in these columns) has now gained acceptance to indicate alternating currents varying in phase for producing a rotating magnetic field, so we may, perhaps, venture to use the term "vibratory currents" for those of high potential and high frequency. To generate vibratory currents from an ordinary alternating-current circuit, Mr. Tesla uses first an ordinary transformer in oil to transform upwards; the secondary current from this he passes into a second transformer having in its circuit a magnetic spark interrupter, and from the secondary circuit of this second transformer (which it may be noted is of comparatively thick short wire) he obtains discharges in all respects similar to those of the great induction coils, but of very high frequency. Connecting this circuit to a properly-adjusted condenser, in his case a set of Leyden jars, a surging effect is produced on the currents, which raises the frequency of vibrations from 25,000 or so per second to some millions per second, and the potential to some hundreds of thousands, or even, perhaps, millions of volts. The frequency in the case of the use of the Tesla dynamo can of course be accurately determined. The potential, it seems, cannot be accurately arrived at by calculation, or, rather, the calculation does not give an accurate result correspondent with the actualities achieved in these effects—a fact, as we shall see, that may have very important theoretical results upon the wave theory of electricity.

Having at command a vibratory current of this nature, the results shown by Mr. Tesla were the first outcome of continued and careful experiments. Not only does the molecular bombardment of the molecules of highly-exhausted gases in vacuum tubes show phosphorescence, but gases at low states of exhaustion do the same, and even ordinary air at ordinary temperature, as Mr. Tesla showed at his lecture, where the space between two concentric rings glowed with discharge like a vacuum tube itself, while the vacuum tube glowed when at some considerable distance from the plates to which the two poles were connected. In this manner, by vibrating the air molecules at speed correspondent to that of the vibration of light, phosphorescent effects could be shown with ease. Phosphorescence, Mr. Tesla explained, he regarded as incandescence in another form. Ordinary incandescence accrues after the filament has passed interiorly from the state of cold to that of intense heat; while if we regard a bombardment of molecules with sufficient intensity upon the surface of a material, we may conceive an infinitesimal film of that material rendered continuously incandescencent without the trouble of heating the whole—in a word, we obtain the light vibrations without passing through the whole gamut of heat vibrations—which has long been the electrical engineer's most ardent desire. To obtain a concrete idea of the difference between the ordinary alternating current and the vibratory current, we might imagine the first as a large ordinary steam engine reciprocating at 100 revolutions, while the second becomes a smaller and smaller material engine as its reciprocations mount from hundreds to thousands, or hundreds of thousands, in the same unit of time. In the latter we have the greatest efficiency with the smallest of first outlay.

We need not go further into the detail of the experiments shown by Mr. Tesla based upon these considerations, as they will be given, as we have said, fully in his paper. We merely mention here that Mr. Tesla hinted at illumination of houses without wires, transmission of light and power to a distance without wires, the synchronising of various wave-lengths for multiplex telegraphy without wires, the use of motors with but one wire, or even possibly without any, and the recovery of the solar energy radiated around us direct—"gearing," as he said, "our motors to Nature's wheels."

He demonstrated that our ideas upon dielectrics required modification, and that it was a mere question of potential to make every material or gas a conductor. It was shown that the interposition of a plate of ebonite, in fact, facilitated, rather than otherwise, the discharge. He showed that the vanes of the Crookes radiometer would rotate under the influence of his vibratory current, a rotation, curiously enough, the reverse way to that induced by light. We believe a similar result was first pointed out in a paper read before the Institution at Edinburgh by Mr. A. R. Bennett.

Mr. Tesla incidentally showed that the glow discharge in a tube under certain conditions would revolve and then become extremely susceptible to the feeblest magnetism, and he hinted that possibly by this means the rapidity of transmission of telegrams through submarine cables might be greatly increased.

A word remains about one or two personal and scientific problems. In the first place, it will be interesting to know Mr. Tesla's own ideas as to the future practicability of his researches—ideas which, of course, will have to await their fulfilment for some time for actual application in practice. The question naturally arises, How can the vibratory current be applied to lighting? Should we expect to have incandescent or phosphorescent lamps of a pattern similar to those we know in the Edison-Swan lamps or the Geissler tubes, or should we expect rather to discover a practical means for rendering the whole mass of the air in a room softly and beautifully phosphorescent? Both, Mr. Tesla thinks, if we understand him aright, may occur, but he looks certainly to the possibility of the last and most fascinating project. Further, many of those who witnessed his experiments must have asked themselves a question as to the danger of the vibratory currents, which Mr. Tesla handled so unconcernedly. We took an opportunity of enquiring of Mr. Tesla with reference to this point, how, indeed, he came to dare to take the current through his body? It was the result of a long debate in his mind, it appears, that caused him to attempt the experiment. Reason and calculation showed him that such currents ought not to be dangerous to life any more than the vibrations of light are dangerous. The self-induction and frequency of alternation should be too great for any current to pass, and for a current to be dangerous a certain quantity must pass. Conceive a thin diaphragm in a water-pipe, with to and fro piston-strokes of considerable amplitude the diaphragm will be ruptured at once. With reduced strokes of the same total energy the diaphragm will be less liable to rupture, until with a vibratory impulse of many thousands per second no actual current flows, and the diaphragm is in no danger of rupture. So with the vibratory current—yet in spite of reason and analogy it was with the feelings of a man about to plunge from Brooklyn Bridge (as one might well believe) that Mr. Tesla took his first shock from his apparatus. The result justified his daring, and he suffered no more than a slight shaking in the arms. A spark, of course, passes and this punctures the skin and causes a slight burn, but that is all. This can easily be avoided by holding a conductor of suitable size in the hand and receiving the shock upon that.

There lurks in one sentence of Mr. Tesla's lecture a statement which will cause much discussion in high scientific circles. We shall not further refer to it here than to say, that if the voltage obtained is not exactly calculable from the data laid down of the condenser and the frequencies—if, in a word, the result is not approximately that calculated, but considerably lower, then this would certainly seem to show that Hertz's experiments and results are not final, and the

way is open to further experiments and research in this direction.

From the way in which Mr. Tesla alluded feelingly to the impulse in research given to himself from perusal of Crookes's experiments in high vacuum, the effect upon students and scientific men generally of the publication of his own promising researches must be great. We can only hope that others, now that the way has been shown, will take up the work, and before many years have passed produce for the world at large the thoroughly practical outcome hinted at in the "wonder-full" lecture by Mr. Tesla at the Royal Institution, on Wednesday, the 3rd of February, 1892.

NIKOLA TESLA.

IT was not to be expected that in the short evening at his disposal, and with such a host of experiments to be performed, Mr. Nikola Tesla could do more than indicate, merely, the kind of way in which the remarkable results of his untiring labours were obtained. So various were the phenomena, that even the lecturer was from time to time in doubt as to the best way of presenting the delectable feast to his guests; and so incomprehensible were the effects that he confessed, "I cannot see the forest on account of the trees."

Already the work of Mr. Tesla, with regard to currents of high frequency and high potential, had been received and appreciated in this country, as far as printed descriptions could make it plain to us. But something more was needed to impress us with the true sense of its importance. We wanted to see the phenomena themselves, and to have before us the man who had deciphered them from Nature's infinite book of mysteries.

The lecture given before the Electrical Engineers at the Royal Institution last Wednesday, was only the second which Mr. Tesla had ever given in public. At the invitation of the managers of the Royal Institution, the lecture was repeated on Thursday to its own members. There were large and distinguished audiences upon both occasions, which were enlivened, on Thursday especially, by the presence of ladies.

The first lecture which Mr. Tesla delivered on the subject of high frequencies and high potentials, was given before the American Institute of Electrical Engineers, at Columbia College, N.Y., in May, 1891. It is reported upon in our columns for July and August of that year.

With researches on high rates of discharge we naturally connect the names of such men as Crookes, Rayleigh, Spottiswoode, and De la Rue. It would appear, also, that Mr. Rankin Kennedy had already demonstrated the possibility of lighting by the means which Mr. Tesla has followed, when in 1882 Mr. Kennedy patented (No. 4,752) a method for "Intensifying fluorescent and phosphorescent electric lighting, whereby the same is rendered serviceable for illuminating purposes, and apparatus for effecting the said intensification."

Throughout his lectures, Mr. Tesla has shown a deep sense of his appreciation for those who have been before him in the field, and everywhere he has specially acknowledged his indebtedness to Mr. Crookes, whose fascinating little book he declares gave him the initiative to labour in the direction of electrical discharge. To all who would claim priority in this or any research, we recommend a careful reading of the eloquent little speech with which Mr. Tesla replied to the vote of thanks on Thursday at the Royal Institution. For this purpose we have printed it in our columns.

Mr. Tesla has many more things in view, than those he introduced to us last week. Not a third of the experiments he had prepared were actually shown, on account of the limits of time. It will be well, therefore, to reserve any criticism or discussion of the results, until Mr. Tesla has had the opportunity of describing them in detail; this, we believe, he intends to do through the press, at an early date.

It may be observed that the high frequency and high potential are obtained from an induction coil of a special form, and receiving in its primary, a special oscillatory current. Mr. Tesla sends the current from an alternating dynamo into the primary of a transformer, the secondary being connected through a magneto-static interrupter to two brass knobs, between which a series of discharges takes place. From these knobs are taken leads to the primary terminals of an induction coil, not directly, however, but through a capacity formed by Leyden jars. It is thus seen that when a spark occurs at the brass knobs, an oscillatory discharge surges through the added capacity, and the primary of the induction coil. The rate of these oscillations is about one million per second. The effect of the passage of this current, through the primary, is to produce at the secondary terminals a current, not only of high frequency, but of high potential.

When phenomena, such as those developed by Mr. Tesla, are brought before us, it is usual to seek out, on the principle of reversibility, the complimentary set of facts, advancing from where they stop, to find a return path with new beauties. In this case the result of such a line of thought leads us to the endeavours of Becquerel and Minchin to obtain currents and E.M.Fs. from electrodes, when acted upon by solar rays. In the *Philosophical Magazine* for March, 1891, Prof. Minchin writes: "It is conceivable that a photo-electric battery may yet be found which will simply act as a transformer of the energy it receives from the sun, while its own materials, being merely the implements used in the process, may be almost wholly unmodified."

The latest experiments with photo-electric cells have established the remarkable fact that when a suitable capacity is connected to them, they can be changed from an insensitive to a sensitive state by the action of a Hertz oscillator at a distance of many feet. How is this? Another analogy lies in the fact that of the liquids used in connection with the original experiments with silver plates, those which were fluorescent, such as cocine, sulphate of quinine, and fluorescine, seemed to suggest a connection between fluorescence and the electrical effect. In would be a revelation, indeed, if the light of Mr. Tesla's experiments could be found to illuminate the mysteries of those of Prof. Minchin, and *vice versâ*.

The idea of using electric lamps, without the intervention of leads, will remind some of our readers of the extraordinary telephonic experiments of Prof. Dolbear, when he delighted his audience by removing the wires connected to his receiver, and fixing the instrument some yards away from the terminals, invited those that had ears to, hear. There is, of course, a great distinction to be drawn between these results and those of Mr. Tesla. The nature of the undulations in the two cases are probably widely different.

If to the genius and imaginative mind of Mr. Tesla the number and complexity of ideas revealed by his experiments are so great that he owns himself lost in them as in a forest of thoughts, to others the darkness must be deeper still. Yet, though we cannot see even the trees, we are grateful to our distinguished visitor, for cutting us a little path, leading us a little way, and refreshing us with his great enthusiasm.

MR. TESLA'S LECTURE.

AT the close of the lecture by Mr. Tesla, on Thursday, last week, the vote of thanks of the members of the Royal Institution was proposed by Lord Rayleigh, and put to the meeting by Sir Frederick Bramwell, as follows :—

Lord RAYLEIGH : Sir Frederick Bramwell, ladies and gentlemen,—Although it is not our custom here to follow the lecture with remarks from anyone else, I think you will agree with me that this is no ordinary occasion. At the request of the managers of the Institution, and for the delectation of its members, Mr. Tesla consented to repeat the labours of last night, labours which, though small to him, would have completely exhausted anyone else.

I wish our great electrician, whose name appeared before us in letters of fire, in one of Mr. Tesla's experiments, were here to propose this motion. There is only one respect in which I have any qualification to speak, and that is that I have made attempts myself to experiment with currents of a high degree of frequency. I was tolerably satisfied when I had a discharge rate of 2,000 per second, but we have had to-night ten or twenty thousand per second. My apparatus was on a very small scale indeed. Mr. Tesla has taken us into some of the dark—metaphorically dark—places in nature. These fields have been but little trodden, Mr. Crookes and Mr. Tesla alone have had the *entrée*. In what has been put before us to-night, there has been matter which will afford food for intellectual contemplation for a long time to come. I think, at the same time, it will be obvious to you that Mr. Tesla has not worked blindly or at random, but has been guided by the proper use of a scientific imagination. Without the use of such a guide we can scarcely hope to do anything of real service. I do not think there is anything I need add ; it does not require any great capacity to see that Mr. Tesla has the genius of a discoverer, and we may look forward to a long career of discovery for him. His labours will be followed with admiration by all men of science of England, and especially by those in this Institution to whom he has done the favour of lecturing to-night. I thank Mr. Tesla for his lecture.

Sir FREDERICK BRAMWELL : Ladies and gentlemen,—I believe it is usual to second the vote of thanks. I, for one, should be very glad for Lord Rayleigh to put the motion to you. It is the duty of myself, however, to second this vote, which I do most heartily. Our treasurer is not here to-night ; he foresees as the result of the lecture, that the whole of our apparatus, in this line of study, is antiquated, and we shall have to begin afresh. This has evidently been too much for our treasurer, and he has consequently stayed away. In my own province of mechanical engineering, there was a time when we were content to have boilers which would be ridiculed now ; and turning from mechanical engineering to electrical science, we have seen to-night the same development from the slow-going, old-fashioned style of phenomena, as that which I have referred to in the case of the steam boiler. I can only regret that Mr. Tesla has kept within the limits of time, and has had to refrain from giving us that which we so much liked. I wish he could give us another evening, and show us more of the experiments. I put the vote to the meeting.

Mr. TESLA : It would be difficult for me to find words to express the thoughts I feel ; I have been so kindly received and generously treated. Whatever I have shown you here is not my own, it is the outcome of the work of English scientific men, whose names we delight to hear, and whom everyone loves and admires. To-night my aspirations are fulfilled in having my labours appreciated by some of the foremost men in the world, and I cannot tell you how highly I esteem your thanks, and how much it will encourage me to further work. There is one thing I desire to tell you—I am not a speaker, nor did I prepare to speak at all, and these two considerations should disqualify me at once—but this I want to say : We have worked before with the problems that are at hand until they have been perfected. The water wheel, the gas engine, the steam engine, thanks to the great spirits which your country has produced, are brought to a high state of efficiency. In these departures we have come, so to speak, to the limit. We have now a possibility opened to us of accomplishing things we never dreamed of before, and in this lies the whole aspiration of scientific investigators. These contrivances are but in an imperfect state ; they have consumed many years of my incessant thought, some other experimenter will start where I have stopped, and so the world goes on ; but the same advantage which another will have from my work, I have already had myself, from those who have gone before. The foremost scientific men of this country agree that there is a way of producing the electric light by fluorescence as the result of oscillations of a certain frequency. I will not dare to speak of what they have achieved in this direction, for if I do, my discourse would be the praise of their work ; it is, therefore, out of place. You will believe that these words are sincere, even if they are not put forth in the expressions of a good orator. We have a start. We can set up in a room the oscillations, and the only difficulty with which we are confronted is the perfecting of the apparatus. Thus we can have a light which will not need any leading wires, which will be a good luminant, and will never be destroyed—it will last for any length of time. This will be a great advancement over present methods. These difficulties are nothing compared to the problems English scientific men have opened up before. For instance, in the production of power. We are able to produce power at any point in the universe, and when this great work is finished, what an effect it will have upon the whole human race ! I wish to say that the results I have shown you to-night are the outcome of the work of others, and I do not want to impress you as though I was displaying any discovery of my own. If anyone can reap the benefit of it, my desire is fulfilled. I am only paying a duty which any lover of science must pay to those who have been before in the field. Others have arrived at results. We are younger, and we go on from them, climbing the stairs ; or, rather, we younger ones are taking the "lift"—we are using the "elevator." The older ones were content with the stairs! I thank you most heartily, and express the hope that I may be able to bring before you some better work than I have shown you to-night.

THE INVENTOR OF THE THREE-PHASE ALTERNATING MOTOR SYSTEM.*

IN a communication which appeared in one of our contemporaries a short while ago, Mr. C. E. L. Brown, the well-known Swiss electrical engineer, in referring to the transmission of power between Lauffen and Frankfort, sought to correct the erroneous impression that the three-phase system was the salient feature of this installation, and pointed out that the principal object of the experiment was to prove the possibility of producing and transmitting high-tension currents over long distances by naked wires suspended from poles, and with such a degree of security against danger and such a small amount of leakage as to demonstrate that this method has a right to commercial existence. The adoption of the three-phase current, according to Mr. Brown, only increased the difficulties to be met, since nearly all the apparatus thereby became more complicated, and the only reason justifying the adoption of the three-phase current was to demonstrate its advantages when applied to several small motors at the same time. The only novelty in the system

* New York *Electrical Engineer*.

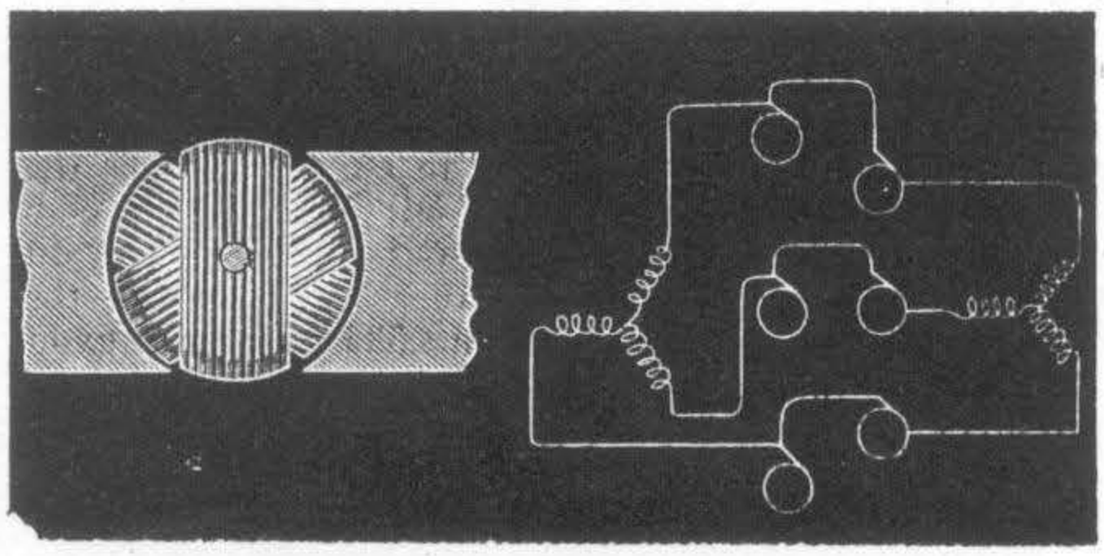
shown at Frankfort were important constructive improvements in its application which Mr. Brown, almost without exception, claimed as his own. Mr. Brown concluded by asserting that the three-phase current as applied at Frankfort was "due to the labours of Mr. Tesla, and will be found clearly specified in his patents."

In reply to the above, Mr. Carl Hering thought that Mr. Brown had not done proper justice to the real inventor of this modification of the Ferraris-Tesla system, namely, Dobrowolsky. Without the *invention* of a new principle or a new modification, the ablest constructor would hardly be able to make any very great departures from well-known systems. Due credit should therefore be given to the inventors as well as the constructors.

In support of the claims made in the concluding paragraph of Mr. Brown's communication, quoted above, that gentleman has asked us to publish the following letter, which explains itself :—

I should like to make a few remarks on Mr. Carl Hering's comments on my letter of the 12th October last.

I would first draw his attention to the concluding paragraph of that letter; and secondly refer him to Mr. Tesla's patents for the three-phase current filed October 12th, 1887, Nos. 381,968 and 382,280, and his further patent No. 390,414, filed April 23rd of the



following year, of the existence of which patents Mr. Hering seems to be ignorant. For his further edification I enclose sketches which are *fac-simile* copies of drawings in the patents above referred to.

I think that he should then see that I have done full justice to the true inventor of the three-phase current system.

C. E. L. BROWN.

Baden, Switzerland, *Jan. 6th*, 1892.

THE ELECTRICIAN:

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NOTES.

If we do not look to the columns of the *Referee* for useful suggestions in electric engineering and apt explanation of scientific phenomena, the fault rests entirely with ourselves. Commenting, as nearly every journal has done, upon Nikola Tesla's experiments, and alluding to the manufacture of light, Lamb's Chinaman who burned down his house in order to provide roast pork is used as an excellent illustration of the

wastefulness of our present methods of producing light. The commercial value of the vacuum tube illumination is dwelt upon; and the science of the paragraphs, except those which are based on the leading article in *The Times*, is singularly correct for a non-scientific, we will not say non-technical, paper.

The various ideas which some of the audience carried away from Mr. Tesla's lecture, and which have appeared in the daily papers, are rather strange. One account is that he has discovered what electricity really is, and that he can manufacture a new kind which gives a very pretty light, that he has "invented" vacuum tubes which need no wires; but there is still some doubt as to whether, if we wish to use these for domestic purposes, we must make ourselves "a channel for a current at something like 50,000 volts." The leading article in *The Times*, from which this expression is quoted, is another example of unusually accurate newspaper science. The "at" instead of "of" just avoids the confusion between current and volts, which is so common. But the article goes on to say—"The vacuum tube glows like the gates of sunrise, but the lecturer feels nothing, though a current of one five-hundredths of the intensity might easily terminate his career." Never was that foreign word "intensity" more vaguely used; we owe a serious grudge to the French nation for it.

Mr. Tesla himself is, we understand, not quite prepared to admit that the current which passes through the body is the only element of danger to be considered; but it is difficult to see what other factor than current enters into the question, unless it be that of frequency. Two or three milliamperes at ordinary frequencies can be taken without much discomfort; and with such pressures as 100,000 volts, which Messrs. Swinburne and Co. often experiment with, it would be very easy, though very foolish, to run a quarter-horse power motor, using the body as part of the circuit.

TESLA'S EXPERIMENTS IN ELECTRIC LIGHTING.

THE remarkable experiments in a new system of electric lighting shown by Mr. Nikola Tesla at the Royal Institution last week seem to have astonished those who do not keep themselves abreast of the progress of the science of electricity. Mr. Tesla performed some of his more interesting experiments before the Institute of Electrical Engineers in New York some months ago, and the news of his achievements led to a pressing invitation being sent to him from this country. Our readers will remember that on July 24 last we gave an illustrated description of Mr. Tesla's system, which gives incandescent lamps without return current and light by condenser discharge. The chronological order of development, omitting details, may be stated to be Geissler tubes, Crookes's "bombardment," and Tesla's remarkable discovery of the effects to be produced by a very high potential and excessively short period.

In commencing his lecture, Mr. Tesla referred to the work of Mr. Crookes, which he said had given a bent to his studies while at college, and induced him during the last two or three years to make those researches which have so far led to discoveries which are obviously of the greatest importance. In his investigations, Mr. Tesla found that a frequency as low as 15,000 to 20,000 per second, and a potential of 20,000 volts would give some remarkable results; but he also found that both frequency and potential may be enormously increased,—the practical limits being determined by the character of the apparatus, and its capability of standing the strain. Mr. Tesla's alternating generator consists of a stationary armature, about 30in. in diameter, having 380 coils projecting inwards. A thin disc of iron, with 380 little magnets connected in series, driven by a motor at about 2,000 revolutions, generates a current of 13,000, or more, periods per second,—indeed, more are needed for the production of some of the phenomena. The current obtained is sent through the primary of an induction coil of peculiar form, the primary being outside the secondary and insulated by oil. The potential is by this means raised to something estimated at about a million volts. In the circuit of the secondary coil there is also a battery of Leyden jars, which produce a frequency of almost inconceivable rapidity. The use of oil is necessary, as Mr. Tesla is convinced that a solid dielectric cannot be used, and the most perfect insulation is an absolute necessity. With the aid of the article above referred to a sufficient idea of the apparatus can be obtained, but the experiments must be seen to be appreciated. For instance, taking in one hand an exhausted tube 4ft. long, and connecting the other hand with one terminal of a coil, the tube immediately glowed with a brilliant luminosity, the light being sufficient to enable the spectators to see the experimenter and his assistants when the gas was turned down. It must be understood that there was no metallic circuit, but the few particles of air left in the exhausted tube glowed by the effects of the molecular bombardment. The theory is at present that in consequence of the enormously high frequency, together with the very high potential, the "current" can pass through the human frame without injuring the tissues. Another remarkable experiment consists in joining two sheets of tinfoil, one over the lecturer's head the other on the table, to the poles of his generator. The space between these two sheets immediately became electrified, and a long vacuum tube waved about in it, without attachment to any conductor whatever, glowed in the darkness like a flaming sword. This experiment was intended to illustrate the possibility of rendering an entire room so electric, by plates in the ceiling or under the floor, that vacuum bulbs placed anywhere within it would yield a light. The experiment was modified by placing a large zinc plate about 10ft. from the floor, and another on the floor, and connecting them respectively to the terminals or poles of the coil. The whole air between them became apparently intensely electrified, and an exhausted tube passed between the plates became luminous, and the vacuum lamps of Mr. Tesla's design, which contain a button of

carbon attached to a wire (see July 24, 1891), glowed brilliantly without having any connection of a metallic or other substance. In another experiment, Mr. Tesla connected a variety of vacuum tubes containing small discs of metal, and even non-conductors, such as aluminium, lime, or carbon, to one pole of the coil, and produced some beautiful effects. In the midst of a luminous haze, due to the residual gas in the tube, the disc of solid matter became brightly incandescent, and yielded a comparatively powerful light, which became brighter when he brought his bare hand close to the bulb, and brighter still when he placed over the bulb an ordinary shade of metal. Extremely beautiful effects of phosphorescence were also produced by touching one wire from the generator and holding a bulb containing the phosphorescent material, such as yttrium, sulphate of zinc, and artificial diamond. The sulphate of zinc in particular gave a magnificent green glow altogether surpassing the phosphorescence phenomena producible in the ordinary way. But experiments must be seen to be appreciated, and though the effects produced by Mr. Tesla have occupied the attention of electricians for some months both in America and this country, they have not yet been explained. It is evident that an important discovery has been made, and numerous workers will investigate the phenomena wherever suitable appliances are available.

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A Brilliant Lecture from Mr. Tesla.

WE are pleased to note in the cable dispatch this week the cordial reception of Mr. Tesla in England, and the widespread interest attracted by his extraordinary experiments shown in the lecture at the Royal Institution. Our readers will remember the excitement caused by the first exhibition of his remarkable work before the American Institute of Electrical Engineers, as well as the preliminary account of his wonderful experiments that was published in THE ELECTRICAL WORLD very nearly a year ago. Mr. Tesla has opened a new field of electrical research, one which promises both important theoretical and practical results. Sensational as some of the experiments appear, Mr. Tesla is persistently working in the direction of their practical application, never losing sight, in the brilliancy of the theoretical possibilities, of the application of the principle involved to the service of mankind. It is difficult now to estimate the value of his researches, for as yet much of his most important work has not been made public, but his friends know and appreciate the intensely practical turn that his later work has taken. Mr. Tesla has for some years worked very quietly and unostentatiously, and it is only recently that the world has waked up to the importance of what he has accomplished.

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Mr. Nikola Tesla's reception in London has partaken of the nature of an ovation, and the English electrical press is filled with enthusiastic comments upon his lecture at the Institution of Civil Engineers. All the praise showered upon him is well deserved and must be most gratifying after his many hours of patient toil and research.

Tesla Experiments and What They May Lead To.

The work done by Mr. Nikola Tesla, whose lecture at Columbia College is well remembered by American electricians, and who last Wednesday delivered a lecture at the rooms of the Royal Institution in London, as mentioned in the cable dispatch in this week's issue of THE ELECTRICAL WORLD, has naturally attracted much attention on both sides of the Atlantic. Mr. J. J. Carty, electrician of the Metropolitan Telephone and Telegraph Company of this city, talking with a reporter, suggests that by the use of a dynamo of sufficient capacity a current might be sent from the shore to a war vessel that would disable her crew and possibly even her machinery. "As a result of his experiments," added Mr. Carty, "Tesla thinks that there is a possibility of a man visiting the North Pole in perfect comfort and standing there without any clothing on, being warmed by this current of electricity. Now, it does not require any great stretch of the imagination to suppose that this heating influence could be increased so as to produce the most disastrous effects upon the crew of a war ship.

"I sometimes give myself up to the imagination of what the Ericsson monitor of the future may be in the case of a great naval war. If the suggestions which have come to me from the Tesla experiment are developed into practical value as an energy of war, it is possible to conceive of a float constructed with a large plate and a dynamo carried out into the stream or bay or ocean, guided from shore, and waiting for a war ship. When the war ship comes and presents its sides, perhaps a mile or more away, a current is established between the armor and the plate on the float."

"These waves will pass through fog, or even through a brick wall, and this fact alone would revolutionize the ordinary means of defense. I can give you a simple illustration. These electric waves will go through solid matter without injury, exactly as light goes through a window pane. You know that Prof. Bell sent a current of electricity over a wave of light which carried a telephonic message for a short distance, but the wave that he generated would be useless in case of a fog. In this case a fog or a stone wall would offer no resistance.

"Now, leaving the matter of war out of the consideration, it seems to me that these experiments may develop something of the highest value in the arts of peace. For instance, it would be perfectly feasible to generate a current of electricity which would penetrate a fog, and would be received by an apparatus on a steamship or vessel, and devices might be invented by which the wave would be enabled to communicate intelligence. The enormous factors contained in these suggestions are less appalling than would have been the idea of the construction of the steamship 'City of Paris' to ocean navigators and marine architects of the day of Columbus. There is, therefore, every reason to expect that in the future, and perhaps in the very near future, steamships will be provided with these apparatuses, and will be able to communicate with comparative ease at sea and through a fog. Some of the bottom principles in this suggestion have, in fact, already been made the subject of patents.

"Then again, a besieged garrison might be able to communicate with its army, using the earth as a medium for the electric wave. There is no doubt whatever of the feasibility of this. I can demonstrate it any day. I can give an illustration of something that happened to me in Buffalo which proves it. I was talking over a long distance telephone wire to friends in Cambridge, Mass., and I could hear with perfect distinctness the starting and stopping of the electric railway cars running through the streets of Cambridge. Perhaps a more remarkable illustration occurred in Paris, when certain noises produced in the electric light station in London were heard at the telephone in Paris, having been carried over a circuit through the earth."

MR. TESLA'S LATEST WORK.

THOSE who had the good fortune to attend Mr. Tesla's famous lecture at Columbia College last May, will probably have evinced no surprise on reading the account of his lecture delivered in London, as given in our cablegram last week. It must indeed have been apparent to even the most casual observer that Mr. Tesla's researches had extended much further than the limits of a single evening would permit him to touch upon, while, on the other hand, it was but natural to expect that so skillful an experimenter as Mr. Tesla would make considerable progress during the time intervening between his first lecture and the one just delivered. The latter, is, if anything, even more striking in its results and in its possibilities than that of last May, which came as a revelation to electrical engineers. In it Mr. Tesla has demonstrated not only a number of facts of the highest importance as bearing upon the modern views of the nature of electricity, but has actually shown how to apply some of his results in actual practice. Thus, the operation of a motor running on one wire and even without any connection with the generator would alone have sufficed to make the occasion a memorable one; but the numerous other beautiful experiments performed confirm the opinion, already well grounded, that Mr. Tesla has opened up a new and vast field not only of research but of practical applications. The London Institution of Electrical Engineers and the Royal Institution are to be congratulated on having had Mr. Tesla's latest results first brought out before them, and it is understood that the American Institute of Electrical Engineers will be similarly favored by Mr. Tesla on his return.

MR. TESLA AND THE DREHSTROM-SYSTEM.*

By CARL HERING.

As Mr. C. E. L. Brown, in communications to the *Electrical World* and other journals, seems determined to insist that I have neglected the work of Mr. Tesla on rotary current, I wish here to state that there is no one more ready than myself to give Mr. Tesla due credit for his work, and I have always considered him to be an original inventor of the rotary field system, and the first to reduce it to practice, and I believe I so stated it in my articles. If I have at any time failed to give him credit for the extent to which he developed it, it has been because Mr. Tesla has been too modest (or perhaps prudent) to let the world know what he had accomplished, and we ought, therefore, not to be blamed if we do not always know what he has done. When the articles which have caused this discussion were being written, Mr. Tesla's patents were not accessible to me. Just where Mr. Dobrowolsky's improvements begin I have not yet been able to ascertain.

The fact that I have personally tried to persuade Mr. Tesla to write a paper on his work in this field, will show that I am very anxious myself to know just how far he carried his work, and why it was not continued. In justice to Mr. Dobrowolsky, it ought to be said that if Tesla did not publish his researches other than his patents, Dobrowolsky ought to have the credit at least for what he did that was not included in Tesla's patents. Dobrowolsky, though he may have been an independent inventor, admits that Tesla's work is prior to his, but he claims to have made improvements. In my articles I distinctly stated that I did not wish to enter into a discussion of the subject of priority. Dobrowolsky's system has proved itself to be a success; it was natural to assume that he had made some improvements. It must be left to a discussion between Tesla and Dobrowolsky, and not to others, to determine, if necessary, just where the one left off and the other began. The modesty of both of these gentlemen would, I feel sure, lead to a clear understanding.

Regarding the subject of priority, it may be of interest here to say that in a conversation with Prof. Ferraris, last summer, that gentleman told me with very becoming modesty that, although he had experimented with the rotary field several years before Tesla's work was published, he did not think it was possible that Tesla could have known of his work, and he, therefore, believed that Tesla invented it entirely independently. He also stated that Tesla developed it much farther than he (Ferraris) did.

CORRESPONDENCE.

Mr. Tesla's Experiments.

While impressions of Mr. Tesla's experiments are still fresh in the minds of those present at the Royal Institution, I ask permission to call attention to one or two points that may refer to the nature of electricity and magnetism.

An insulated conductor was suspended from above the head of the lecturer to the front of the gallery and back again, in two lines slightly converging towards the gallery. When this conductor was placed in the electric circuit, and the room darkened, its whole length glowed with a beautiful violet haze, appearing equally vivid at all parts of the conductor. The haze surrounding the conductor in that space we find imbued with magnetism, when current is passing. Mr. Tesla also connected up two bare wires of circular form, and different diameters, placed concentrically and in the same plane. These, likewise, showed the same violet haze, but directed (like the streamers of the Aurora Borealis) towards each other. In this last experiment the haze seemed less vivid than in the former one, and I should like to know if this is the opinion of others who were present. Of course, the frequency, or potential, may have been changed; or the relative position of the conductors may affect the haze; but,

as we found that a dielectric placed between two sparking terminals facilitated the discharge, it may be that the haze was increased by the use of insulation. If this be so, it is important to know under what change of conditions insulation would cease to facilitate discharge, or vary the magnetic haze, as it might then be used as a test of the quality of insulating material.

My next point is that the violet or magnetic haze would imprint an image on a sensitised photographic plate probably without the aid of a lens, or other light than its own. We know how sensitive such plates are to blue and violet rays of the spectrum; and we know that stars—never seen by man—appear on plates after a lengthened exposure. By calling in, therefore, the aid of another branch of science, we may yet be able to see the exact image of varying electrical or magnetic conditions permanently recorded, and comparable at sight. And we may also hope to acquire further knowledge of these subtle forms of energy.

J. Sinclair Fairfax.

February 15*th*, 1892.

In reference to your article in last week's issue *re* high tension work, I notice that our names (Pyke and Harris) as having been workers in this field have been omitted, due probably to not having courted publicity in the matter. I enclose copies of our patents for the insulation and cooling of electrical inductoria, and also that regarding vacuum tubes, condensers, &c. The method will work economically and brilliantly with the ordinary tensions and alternation speeds in use for lighting and is a practical and brilliant method of illumination. I am aware of what has been done by others in this field and believe that our patent in regard to transformers is a master one and shows clearly the essential points in the design of high tension transformers for continuous use, transforming a really *considerable* quantity of energy.

Mr. Tesla's experiments, exceedingly interesting and valuable as they are, as pure research, have no commercial value, as induction and retardation with these very high tensions and rapid alternation speeds cause great loss, so that probably any approach to a small percentage of efficiency is absolutely impossible.

L. Pyke.

February 15*th*, 1892.

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NOTES.

Like many of those who were present at Mr. Tesla's lectures, a correspondent who writes to us this week has been led to imagine that certain of his striking experiments are altogether new, while they really consist in repetitions of well-known effects on a large scale; and no one is better aware of this than Mr. Tesla himself. The glowing wires which excited so much interest were a reproduction, in a more brilliant style, of the experiment which was shown by Dr. Oliver Lodge at the Physical Society on June 12th last, and which was described on p. 200 of our last volume. Dr. Lodge's wire did not glow so brightly, it is true. He had a single wire about 60ft. long, and nothing more than a couple of Leyden jars and a Wimshurst machine were used. The length of the wire had been arranged to be in resonance, or syntony, with the jar, and thus distinct stationary waves were set up, part of the wire being dark and part bright. We are not aware whether Mr. Tesla has attempted to reproduce this interesting effect. The experiment with the concentric rings appeared to be more of the nature of a brush discharge. Our correspondent assumes that some appreciable current was passing, and that the space surrounding the conductor was "imbued with magnetism." It is doubtful whether in the majority of the experiments a single milliampere was used; and though Mr. Tesla has not yet proved that Prof. J. J. Thomson's experiments are not electro-magnetic, he seems justified, in the sense in which he uses the expression, in contending that all his own results are purely electrostatic.

It is as impossible to separate electro-magnetic phenomena from electrostatic, as to draw a line between kinetic and potential forms of energy. When the currents and potentials under investigation are steady, it is comparatively easy to distinguish between the electric and magnetic parts of the phenomena; but in electrical oscillations, such as Hertz, Tesla, and Thomson have worked with, the currents and potentials are constantly changing, and theory indicates that each electro-magnetic disturbance must then be accompanied by a corresponding electrostatic one at right angles to it, and *vice versa*. Since both kinds of disturbance must exist together with rapid oscillations, it is necessary, before any phenomenon can be called electrostatic, to know what is meant by the electrostatic effects being more important than the electro-magnetic ones. As far as we are aware, no one has yet clearly pointed this out.

Men of Ability and Genius in the Electric Lighting Field.

In the portrait gallery presented in this issue of the REVIEW will be seen the faces of three men whose names are imperishable in the records of electrical invention. These names are Edison, Thomson and Brush. The first the most versatile of inventors, the other two possessing the inventive quality in a very large degree and at all times careful and clean cut in their work, so that when it was presented to the public for adoption or rejection it immediately found an abiding place in the industrial progress of the time.

It is nothing to the discredit of these three gentlemen that, while they have worked so earnestly and triumphantly, they have been appreciated in a commercial way, and a comfortable fortune belongs to each.

Our picture gallery also contains the countenances of Nikola Tesla, the brilliant young inventor; of Mr. J. J. Wood, one of the earliest workers in arc lighting, and whose dynamo machine ranks among the very first in the field; Mr. R. T. McDonald, one of the most energetic and successful of electric light manufacturers and organizers.

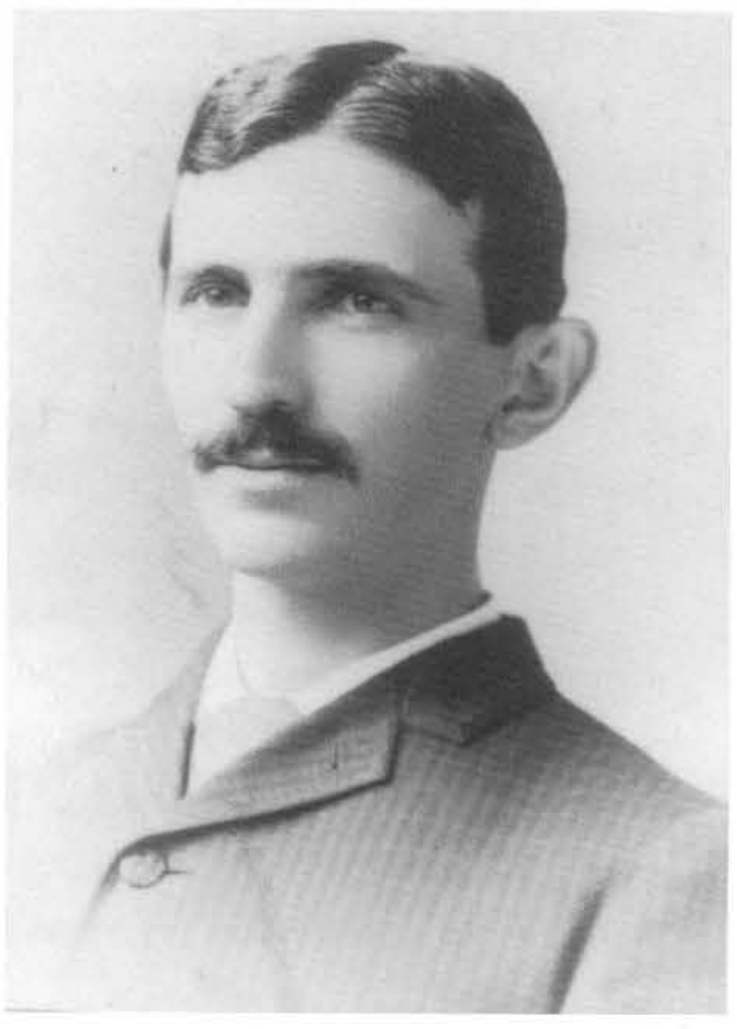
There are many other names indentified with the wonderful development, both technical and commercial, that has brought the electrical industry so rapidly to the front. The list of names identified with the electric lighting and electric power industry is a long one. It should include Charles A. Coffin, of Boston, and his associates, E. 1. Garfield, S. A. Barton and others; George Westinghouse, Jr., of Pittsburgh; Edward Weston, Edward H. Johnson, Frank J. Sprague, S. Insull and Stephen D. Field, of New York; W. Stanley, Jr., Pittsfield, Mass.; O. Shallenberger, of Pittsburgh; M. M. M. Slattery, of Fort Wayne; Capt. Eugene Griffin and O. T. Crosby, of Boston; Charles E. Dustin, of Hartford, Conn.; Prof. William A. Anthony, of Manchester, Conn.; Frank A. Perret, S. S. Wheeler, and scores of other bright and enthusiastic young and active men, who, one and all, add their share to advancing the interests of the electrical industry, and particularly the branch devoted to lighting and the transmission of power.



THOMAS A. EDISON, ORANGE, N. J.



CHARLES F. BRUSH, CLEVELAND.



NIKOLA TESLA, NEW YORK.



PROF. ELIHU THOMSON, LYNN, MASS.

NOTES.

Tesla's Experiments.—Mr. J. E. H. Gordon will contribute an article on Mr. Tesla's experiments to the March number of the *Nineteenth Century*.

NOTES.

Mr. Tesla in a New Guise.—*Church Bells*, a weekly paper for Church folk, speaks of Mr. Nikola Tesla as Edison's right-hand man.

Mr. Nikola Tesla.—On Friday last, says our Paris Correspondent, Mr. Nikola Tesla repeated his magnificent experiments with alternating currents of high frequency before the Société Française de Physique and the Société Internationale des Électriciens. Unfortunately, Mr. Tesla confined himself to demonstrating by a series of very beautiful experiments (which it is unnecessary to describe, since they have all been published some time ago in the English technical journals) the numerous phenomena to which these currents may give rise, without either alluding to his methods of obtaining these high frequencies, or giving the audience the benefit of his own personal explanation of the phenomena. An exchange of ideas on the question would, however, have been much appreciated. Mr. Tesla was, nevertheless, warmly congratulated on his experimental skill.

Latest Foreign Electrical News.

(By Cable from Our Own Correspondent.)

LONDON, Feb. 19, 1891.—The commissioners having the matter in charge have just issued a set of what are regarded as very stringent regulations governing the installation of electric lighting plants in theatres. The regulations apply especially to the provision of safe and reliable wiring.

The lecture recently delivered by Mr. Nikola Tesla before the Institution of Electrical Engineers on his very elaborate experimental investigation of the phenomena accompanying currents of high frequency still continues to be the subject of much discussion by both the scientific and daily press of England. It is probable that no American scientific lecturer ever created more interest in any subject or drew out more comments from the scientific men of England than Mr. Tesla has done by a single lecture. He left England a day or two ago, going to France, and it is announced that he will lecture to-day in Paris on the subject mentioned above, which has already gained for him a wide reputation in European countries, especially in France, Italy and Germany.

Tesla's Wonderful Electrical Experiments.

Mr. Nicolas Tesla, of New York, has lately repeated in London, at the Royal Institution, the remarkable electrical experiments first shown in this city. The lecturer was received with great enthusiasm in London. The proceedings are described by *Engineering* as follows: Wednesday, Feb. 3, saw another of those successful meetings for which the Royal Institution is famed. This time, however, the audience were not able to congratulate themselves that they were the first to view in public the striking experiments which were performed before them, as it is the custom of Royal Institution audiences to do, for on one occasion before, in America, Mr. Tesla, the lecturer of the evening, had been over the same ground. This was probably no disadvantage either to him or to the numerous members and associates of the Institution of Electrical Engineers who crowded to hear him, for the fame of his researches had had time to spread, and their significance to become more or less appreciated. Not that Mr. Tesla needed this to render him welcome in this country, for the man who shares with Professor Ferraris the honor of having invented the self-starting alternate current motor requires no introduction in England, nor, indeed, in any country where scientific ability is appreciated.

Our account of the previous lecture will have rendered our readers familiar with the line of Mr. Tesla's researches. We may, however, briefly state that he has devoted himself for the last year or two to the investigation of the effects attending the use of alternate currents of very high frequency and of high potential. This matter of the frequency of alternation seems to have been neglected by former experimenters with vacuum tubes. They took great pains to get immense potentials, but paid little attention to the rate at which the current vibrated to and fro. It now appears, however, that the rate of alternation is as important as potential in evolving certain phenomena, and by increasing it to a very great extent perfectly new and unexpected results can be obtained. This can be done in various ways, of which Mr. Tesla employs two. He has an alternate current dynamo, the armature of which consists of a steel disk, having arrayed on its rim 380 poles. This runs within a ring of magnets of corresponding number, and with the machine rotating at 2,000 revolutions, gives 13,000 complete alternations per second. The current thus produced is sent through the primary wire of an induction coil, and its potential raised from 50,000 volts to more than a million, although, of course, the exact amount is a matter of conjecture. In another method of obtaining currents of high frequency there was employed an alternator lent by Messrs. Siemens Brothers. The current was sent through the primary of a large induction coil, in the circuit of which a special break was interposed. This consisted of two balls, between which the current sparked, and two powerful magnet poles, which blew out the spark as fast as it was formed, and thus greatly multiplied the effect. The current from the secondary coil was then sent through the primary coil of one of Mr. Tesla's oil-insulated induction coils; in the circuit of the secondary coil there was interposed a battery of Leyden jars, which was constantly charged and discharged, the discharge being of an alternating character, with a frequency of immense rapidity.

Mr. Tesla's coils are of peculiar form. The primary coil is on the outside, and is separated from the secondary by some little space. The whole is immersed in oil, and the inventor insists most strongly that a solid dielectric can never be used successfully in this position. If this be damaged, it is spoiled irretrievably, while the oil may be struck through time after time, and instantly repairs itself. Any bubbles of air that the oil may contain are soon warmed and rise, and thus the defects are rapidly expelled—an event which cannot occur in a solid substance, in which defects tend to aggravate and not to eliminate themselves.

Mr. Tesla began his lecture with a tribute to the work of Professor Crookes, which, he said, had fired his imagination when at college, and had given a bent to his studies. He then turned to his own researches, and in a second revealed to his audience the immense distance which separates himself from his predecessors, by taking in one hand an exhausted tube, 4 ft. long, while the other hand was connected to one terminal of a coil. Instantly the tube glowed with a brilliant lambent flame from end to end, and recalled to every one the idea of the magician's enchanted wand. When the gas was turned out, the light was sufficient to reveal the lecturer and his assistants, and would have been enough to enable him to read newspaper print. It was a most striking experiment; the old ideas of electric circuits, metallic electrodes, and all the rest of time-honored notions, seemed to be flatly contradicted. From a single terminal of the coil the electro-magnetic radiations were conducted through the body of the lecturer to the tube, and entering through the glass, they put the few molecules of air that it contained into such active oscillation that they glowed in their mutual bombardment.

It was a breach of the dramatic canons to begin with an experiment of such brilliancy, and then to descend to others of less importance, but it was an indication of the power of the lecturer, and evoked rounds of applause. Indeed, the reception accorded to Mr. Tesla was one that must have raised feelings of pride in any breast. Both seats and standing room were filled, and on the front benches were to be seen most of our leading electricians and electrical engineers. All through the evening there was rapt attention, which never flagged, even during the less striking experiments.

Putting down the tube, Mr. Tesla attached an exhausted bulb to one terminal of a coil, and showed that phosphorescence was immediately set up in it. When he placed his hand near to it this phosphorescence was immensely increased, and the lamp filled with a vivid glow. This was repeated in other ways with different bulbs, and then two plates were attached to the terminals of a coil, with a sheet of vulcanite between them. The current then endeavored to spark across, and beat itself in purple rays on the sheet, branching out in streaming brushes to make its way round the edges of the plate. Turning to his audience, Mr. Tesla exclaimed: "Is there anything more fascinating than the study of alternating currents?" It was evident to all in the room that use had not rendered the lecturer insusceptible to the beauties of the experiments that he showed, and that his mind was as completely filled with wonder and enthusiasm as that of the merest novice present, and probably far more so, as he saw further into the inner nature of the phenomena which he displayed, and grasped more of their significance.

The next experiment was the passage of sparks between two balls, to simulate the discharge from a Wimshurst machine. This was done most successfully, and it was difficult to believe that the well known disks were not being turned in the ante-room. At first a 2 inch spark was shown, and then one of 6 inches, the balls being changed, for the size of the balls appears to have a distinct effect on the appearance of the arc set up between them. Next came another of those brilliant sights which are always so effective with an audience, especially when it is in a cordial mood. Two wires were stretched across the wall of the theater, about a foot apart, and were connected to the poles of a coil. When the current was turned on they glowed for their entire length with a blue light, which streamed from one to the other, and was of sufficient intensity to reveal the faces of the audience. Here there was no case of exhausted globes; the light was given off in the open air, and if not enough for the ordinary domestic purposes, was at any rate of very appreciable intensity. In this case the alternations were obtained by aid of the Leyden jars. The same idea was developed in another way in the next experiment. A wire ring, 3 feet in diameter, was connected to one terminal of a coil, and a second ring, 6 inches in diameter, was connected to the other, the two being concentric. The light streamed radially from one to the other, making a palpitating purple disk of great beauty.

Speaking on this subject of phosphorescence, Mr. Tesla stated his belief that it could be excited in all substances, if currents of sufficient frequency and potential were employed. He was also of opinion that exhaustion of the air was not necessary. Hitherto it has not been possible to drive the molecules on to the substance unless a fairly clear road were prepared for them, by removing all but an infinitesimal number. They could not get through the *melee*. But with sufficient initial velocity they will be able to proceed in straight lines, just as a cannon shot will pierce a crowd that would stop or deflect a cricket ball. All that is wanted is that the atoms shall fly fast enough and often enough to raise the surface, even of metal, to the phosphorescing or at least to the glowing stage. With extremely rapid alternation, also, the molecules never get far away from the substance they bombard, and so their heat is not diffused. Crookes' phosphorescent tubes give a magnificent glow if only held in the hand, while the other hand is applied to a coil working with sufficient frequency and potential.

Visible light and heat are not necessary to prove the existence of the electric radiation, and Crookes' radiometer placed near a ball connected to one pole of a coil rotates very briskly—curiously, however, in the opposite direction to that which it follows under the influence of light. This is explained as being due to the streams from the glass. In a second instance an unexhausted radiometer was made to rotate; the fans were covered on one side with mica, and the spindle was connected to the coil. The effect of the mica was to prevent the molecules heating one side of the vanes. As the current was increased, the speed diminished on account of the electrostatic action between the mica and the glass.

In a certain sense the most interesting part of the lecture was that dealing with lamps, because here we seem to get nearer to some practical result. Mr. Tesla's lamps mostly consist of a bulb inclosing a button of carbon resting on the end of a wire or a filament. This wire is screened by being surrounded by a tube of aluminum, which forces the radiation to follow it to the button, and not stream off sideways. When the single conductor, which this lamp contains, is connected to one terminal of a coil, the carbon glows with a light the intensity of which varies with the character of the current. On Wednesday the light seemed to be about equal to 5 candle power. When a metal screen was put over the lamp, and the radiations that fell on it were deflected back on to the sphere, the light was doubled, and reached a perfectly useful limit. Wonderful as this was, a greater marvel appeared when two zinc plates, one at a height of 10 feet and one on the floor, were connected respectively to the poles of the coil. Then it only needed that a lamp of this construction should be brought into the intervening space to glow brilliantly without any electrical connection whatever. The radiation between plate and plate was so active that, in passing through the attenuated atmosphere in the globe, it evolved the molecular bombardment which made the carbon glow.

The practical man asked as the lecturer finished, "What is the use of it all?" Nearly fifty years ago he was present when Faraday explained the laws of electro-magnetic induction, and then he also asked the same question. It was not till the Paris Exhibition of 1878 that he got his answer, but we shall be much mistaken if he has to wait so long this time. Wait he must, and in the mean time he cannot do better than join in honoring such men as Mr. Tesla, who engage in researches which promise no immediate pecuniary benefit. He must, however, be dull if he cannot discern in the few experiments we have described, out of the many shown to the audience, a clew tending toward a great discovery that would entirely revolutionize our methods of artificial illumination. If a space measuring several feet in each direction can be brought into such a condition that an attenuated atmosphere introduced into it instantly becomes self-luminous, it does not call for any great stretch of imagination to see the whole of the atmosphere of our rooms in the same condition, and filled with the same clear light which bathes our planetary system. Just as the sun puts the ether into vibration of the kind revealed to our senses as light, so does electric energy also put it into vibration of the same kind, but of a different degree. Wednesday's lecture marks one step in the progress toward luminous electric radiations; possibly some of us may live to see the remaining stages covered.

Tesla's London Lecture.

Replying to a correspondent, the London *Electrician* says the Tesla experiments "really consist in repetitions of "well known effects on a large scale, and no one is bet- "ter aware of this than Mr. Tesla himself. The glow- "ing wires which excited so much interest were a "reproduction, in a more brilliant style, of the experi- "ment which was shown by Dr. Oliver Lodge, at the "Physical Society, on June 12th last." This is very true, yet it should not be forgotten that Mr. Tesla's experiments in alternations of high frequency were first publicly shown May 20th last, before the American Institute of Electrical Engineers, in this city, since which nearly a year has elapsed. Of course, Mr. Tesla well knows, and has so stated publicly in England, that he is merely developing the earlier researches of British scientists. But his work is largely original, in spite of his modesty.

THE LATEST ELECTRICAL DISCOVERY

On Wednesday, the 3rd of February, the Royal Institution was crowded with one of the most critical scientific audiences in the world, who were held spellbound for more than two hours while Mr. Tesla gave an account of his discoveries. Mr. Tesla is a young electrician born at Rieka, on the border of Montenegro, and now domiciled in America. The interest of the lecture lay not in the beautiful experiments with which it was illustrated, nor in the actual facts put forward, but in the hope which it held out that we may now draw back a little farther the veil which hides one of the most fascinating mysteries of nature, namely the relations between light and electricity, and between matter and motion.

The tendency of modern science is to remove day by day the barriers between its different branches. Our views of the phenomena of light and heat, of electricity and magnetism, and even of matter and motion, are rapidly merging into one general theory of molecular physics, which is perhaps best expressed by the vortex theory of Sir William Thomson.

According to this theory the whole of every part of space is filled with a fluid called ether, almost infinitely thin, and almost infinitely elastic. The historic experiments of Faraday interpreted by the mathematical researches of Clerk Maxwell have demonstrated almost beyond doubt that the same ether whose waves carry light and heat from the sun and stars to the earth, also carries the waves of electric and magnetic induction which, as the daily experiments at Kew Observatory show, follow each outburst of solar activity.

Sir William Thomson holds that all that which we know as matter consists of vortices or whirlpools of this ether, which, from their rapid rotating motion, resist displacement, and therefore show the common properties of hardness and strength in the same way as a spinning top or gyroscope tends to keep its axis in a fixed direction. But whether the molecules or particles of what we know as matter are independent matter, or whether they are ether whirlpools, we know that they keep up an incessant hammering one on another, and thus on everything in space.

Professor Crookes has shown that the forces contained in this

bombardment are immensely greater than any forces we have yet handled, many millions of horse power being contained in an ordinary room. Owing, however, to the forces being in every possible direction they neutralise each other, and no result of them is perceivable to our senses; but if ever we discover how to so direct their courses as to send the majority of them in the same direction, we shall have at our disposal forces as much exceeding any we are now acquainted with as the blow struck by a bullet exceeds the force required to pull the trigger of a gun. In fact, as Mr. Tesla put it in his lecture, 'We shall then hook our machinery on to the machinery of Nature.' It is because they hold out to us a hope, however distant, of some day so guiding the ether storm, that the experiments of Nikola Tesla are of such transcendent interest and importance.

Professor Crookes, in his experiments on 'radiant matter,' has given us the first hint of a method of directing what, for want of more exact knowledge, we will call the molecules of matter. With the appliances at his command, however, he was unable to impart any great change of direction, but he succeeded in making that change manifest by reducing the disturbing forces acting against his directing force. In other words, he pumped out from glass bulbs and tubes nearly all the air or other gas that they contained, and the comparatively few particles left were then free to travel in any course imparted to them without much change caused by collision with others. This special direction was imparted by means of electricity, and gave us the beautiful phenomena of phosphorescence and radiant matter which are now so well known in these experiments.

By means of suitably shaped terminals a stream of molecules is focussed on a given point. If a piece of carbon or platinum is placed at that point it becomes white hot under the bombardment, from identically the same cause which causes a sheet of flame to appear when a cannon shot strikes an iron target. If a ruby or other phosphorescent material is placed there it glows with its characteristic colour, and if a little delicately balanced vane or windmill is placed so that the stream is directed on one side of its fans it rapidly revolves. The forces available in these experiments were, however, almost indefinitely small, being as it were merely flying spray from the great torrent into which we have not yet been able to penetrate.

We now come to the advances made by Mr. Tesla.

In all the above experiments the electricity by which the directing force was imparted to the molecules was electricity of a comparatively slow alternation period, namely, electric currents oscillating about 80 to 100 times per second. It was as if we had tried to ventilate a room by causing a man to walk slowly through it with an umbrella. He would undoubtedly move the air, but would move it so slowly that ordinary methods would be insufficient to enable us to perceive its motion. In order to cause a rush of air we must put up

a rapidly moving fan or other suitable machinery. Mr. Tesla, seeing this, abandoned the ordinary dynamo, which, as we have already noted, gives about 80 alternations per second, and the ordinary induction coil, which gives about the same number, and boldly constructed a dynamo which gives 20,000 alternations per second, and by connecting this to suitable condensers he multiplied its alternations until they reached 1,000,000 or 1,500,000 per second.

Then at once an entire set of new phenomena appeared, and the experimenter entered a region of mystery and hope. One of the first things noticed was, that either because these vibrations are too rapid to excite corresponding vibrations in the nerves of the body, or from some other cause, no shock is felt from the current; and that though an ordinary current at 2,000 volts will kill, yet this current at 50,000 volts cannot be felt at all.

It was also found that the vibrations keep time in some unknown way with the vibrations of solid matter. Vulcanite is one of the best insulators known, and will entirely stop any ordinary current or discharge, but the stream of sparks between two poles with this current pours through a thick sheet of vulcanite as easily or even with greater ease than through air. It does not perforate it in any way, but passes through it as light passes through glass.

All the 'Crookes' phenomena of radiant matter are almost indefinitely increased; it is the blow of mitrailleuse bullets compared to the blow of an air-ball thrown against the wind. The forces can be directed for a considerable distance through space without the aid of wires. Electric lamps light easily when attached to one single wire, and require no return conductor; and, more wonderful still, if metal plates are fixed on the roof and walls of a room and connected to the terminals, the whole atmosphere of that room, whether it be ether or whether it be particles of common matter, is thrown into a state of storm and agitation which can be at once made perceptible by bringing into the space tubes or globes from which the air has been partially exhausted. Such tubes though without any metallic connections yet glow and throb as if powerful currents of electricity were being sent through them from an ordinary induction coil.

A 'Crookes' radiometer placed near a metal conductor from which neither spark nor glow is perceptible yet rotates as if it were placed near a lamp or heated body, but rotates in the wrong direction, and, last of all, a true flame burns in which nothing is consumed.

When the discharge issues from a suitable terminal it has the appearance and roaring sound of a gas flame burning under too high a pressure, and gives off a considerable heat; to use Mr. Tesla's words again: 'This is not unexpected, as all the force and heat in the universe is due to the falling together of lifted weights, and the same result is produced whether these weights have been lifted apart by chemical energy, and rest in the form of oxygen and hydrogen ready

to combine chemically, or in the form of mechanical energy of moving molecules directed by the electric current.'

On the same table, on which Mr. Tesla's experiments were shown a few days ago, there swung, in the year 1834, a delicately balanced galvanometer needle, under the influence of the first induction current, produced by the genius of Faraday. The force available to move it was very small, probably not greater than the forces lighting Mr. Tesla's tubes, yet that force has now developed one of the greatest industries of the world. It lights millions of lamps in London and elsewhere, in America it drives cars on thousands of miles of railways, and will soon distribute the power of Niagara Falls to the inhabitants of the neighbouring States. May we not hope for some such development of the new discovery, and that we shall some day harness to our machinery the natural forces, which from the beginning of time have literally been slipping through our fingers?

Should the application of Mr. Tesla's results ever fulfil the bold dreams of scientific imagination, we shall see a social and political change at least as important as that caused by the railway system or the electric telegraph.

Most manual labour will become unnecessary, as unlimited power will be available at every man's hand. Engineering works will be able to be carried out on a far greater scale than has yet been even contemplated, and doubtless a corresponding era of material prosperity will set in; but, whether these dreams are ever fulfilled or not, few who attended Mr. Tesla's lecture will forget the possibilities which seemed to open to their minds when they saw a living man standing in the midst of the electric storm, receiving unharmed in his hands flashes of veritable lightning, and waving above his head a tube, through which the very life blood of creation pulsed, in waves of purple fire.

J. E. H. GORDON.

Tesla Apparatus.—Our readers will be interested to learn that a Tesla experimental apparatus is being con-

structed for lecture purposes at the Finsbury Technical College. The students will be very much on the *qui vive* the first time Dr. Thompson ventures to take the million-volt shock into his body. Some one must evidently follow suit to Mr. Tesla, but we have heard the opinion expressed by several engineers that they would hardly like to build and test such an apparatus with a trust in its harmlessness merely from abstract or mathematical reasoning without trying it, say, on a calf first. Mr. Tesla has a splendidly-equipped laboratory in New York, and the experiments he showed at the Royal Institution are by no means all he had to produce, given more accurately determined conditions. With the experimental skill of Finsbury also turned on to this new branch of electricity—the "vibratory current" system—we may soon see electric lamps without wires—primitive, no doubt, but yet alight—amongst the regular course of lecture demonstrations at technical colleges.

THE

Electrical Engineer.

VOL. XIII. MARCH 9, 1892. No. 201.

THE TESLA MULTIPHASE CURRENT MOTORS.

BY



THE prominence which has been given to power transmission by multiphase currents in the experiments between Frankfort and Lauffen, seems to have led to the impression, even among those otherwise well informed, that this was the first example of this method of transmission. It may therefore be well to put on record the fact that in this country multiphase motors manufactured by the Westinghouse Co. have been in successful commercial operation for several years, and a three phase power plant has been in daily service in the shops of the Westinghouse Co. at Pittsburgh for some time past, driving the shafting and machinery of the winding department.

As is well known, Mr. Nikola Tesla is the inventor of the multiphase motor, and his patents in this country are controlled by the Westinghouse Electric & Manufacturing Company, who have been quietly standardizing the different sizes and have, within the last year or two, placed a large number of them in service.

The generators for these motors are of the Westinghouse multipolar type with toothed, drum armatures wound to give currents of sixty or ninety degrees difference of phase. These machines, one type of which is shown in Fig. 1, are built either entirely self-exciting and self-regulating or separately-exciting and self-regulating. The machine shown is designed for 60 kilowatt capacity.

The motors are constructed with internal poles and grooved armatures. The larger motors have armatures with three collecting rings, and the fields are excited with direct current. The smaller ones have armatures wound with coils closed upon themselves, doing away with all collecting rings and commutators. The engraving Fig. 2, shows a 10 h. p. Tesla motor and Fig. 3 exhibits the armature removed from the enclosing field magnets. These multiphase motors are built in sizes of from 1 to 1,000 h. p.

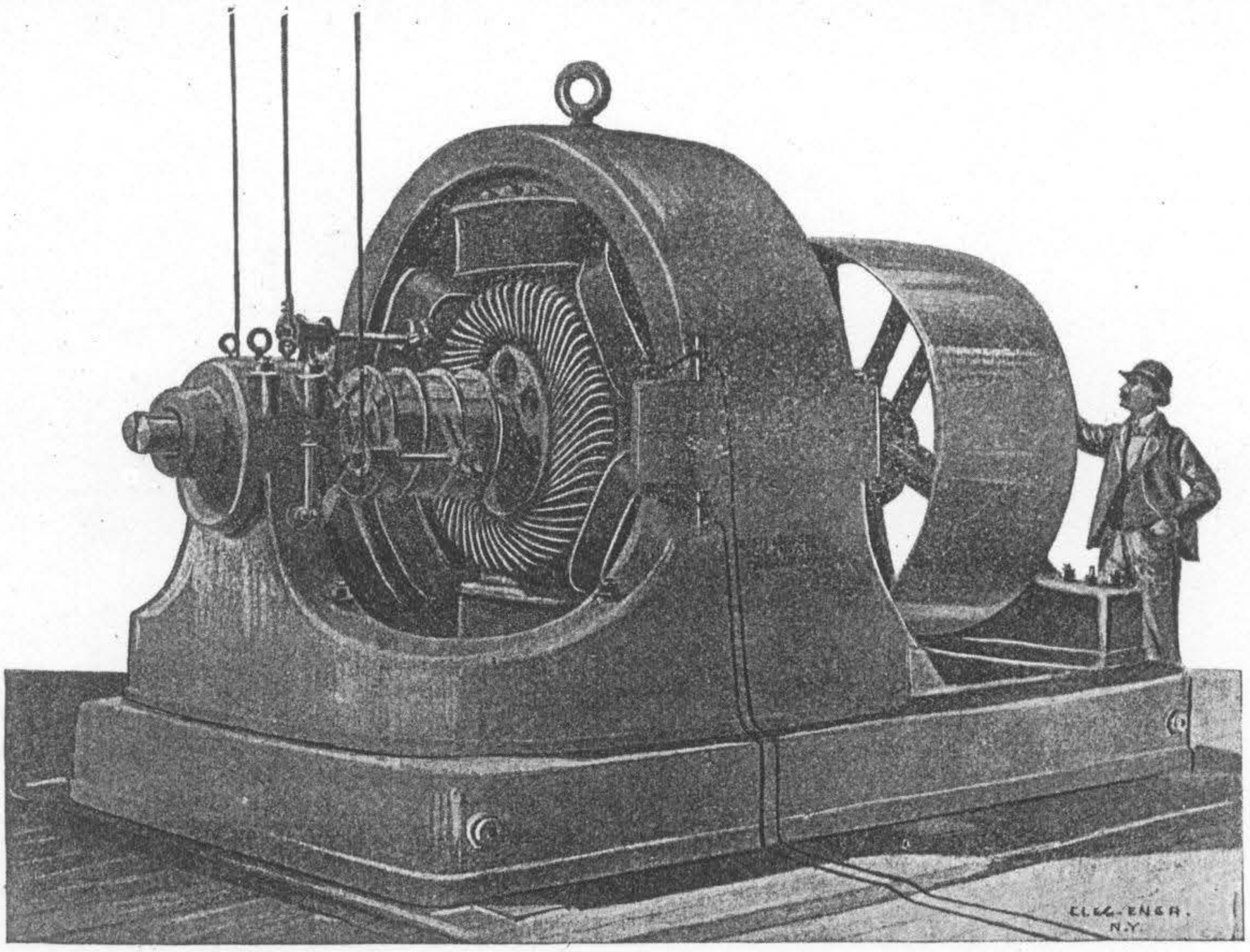


FIG. 4.—THREE-PHASE 1,000 H. P. TESLA ALTERNATING MOTOR.

A 1,000 h. p. three-phase generator or motor, for the same machine can be made either as a motor or generator, is shown in the engraving Fig. 4 and when run as a generator will give 150 amperes at 5,000 volts. In mechanical design this machine is similar to the multipolar direct current railway generators built by the Westinghouse Company. The armature is of the drum type with slots for the wire and is without bands.

With the Tesla multiphase system the power can be subdivided to any extent for motor or lighting purposes, and high pressures may be employed which can be reduced to whatever voltage is desired. The multiphase motors

start under load, and run at constant speed. The smaller ones are made entirely alternating, and the larger ones are self-exciting after reaching synchronism.

As the starting torque with the Tesla multiphase motors is comparable with shunt wound direct current machines,

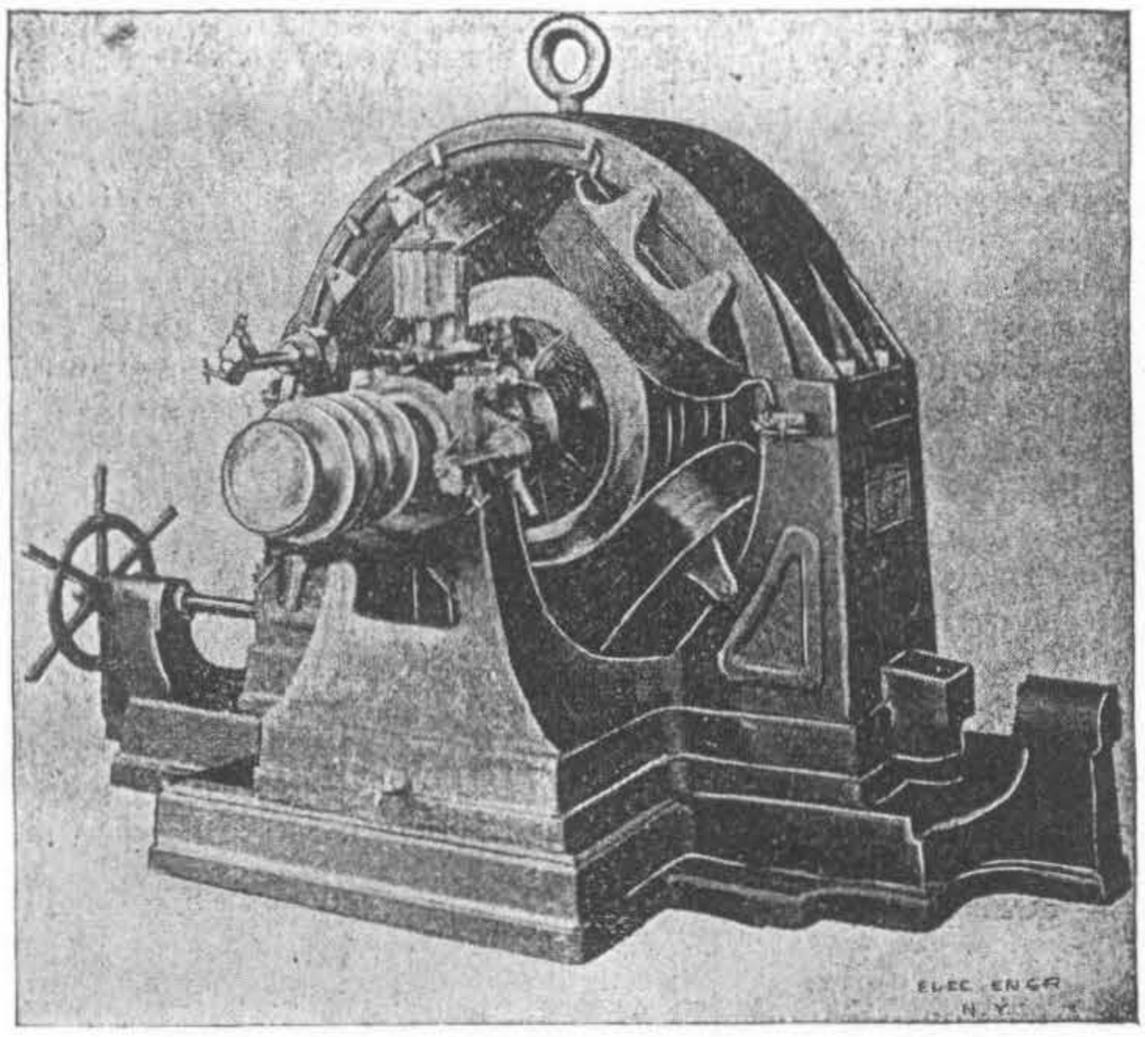
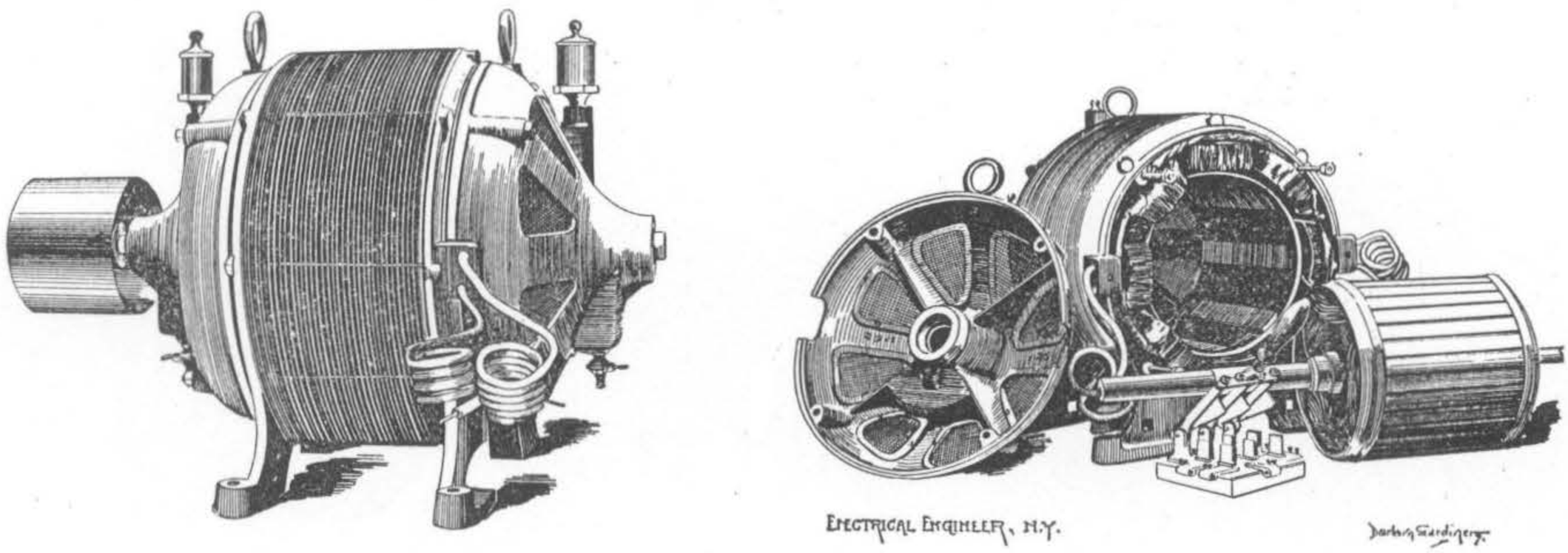


FIG. 1.—GENERATOR FOR OPERATING TESLA ALTERNATING MOTOR.

they may be applied in every case where direct current shunt wound motors can be used. At starting, the direct current motors require dead resistance in series, which means considerable loss, but the alternating current motor has inductive resistance, and therefore the loss at starting is much less. Multiphase motors can be used for operating mines, factories, and street railways, and the generating station may be located wherever most convenient for obtaining the best results, and if the pressure is not over 5,000 volts, the motors may be supplied direct from the mains. The Tesla motor has a great advantage over other types of



FIGS. 2 AND 3.—10 H. P. TESLA ALTERNATING MOTOR.

motors in that it requires no commutator, and consequently is sparkless. The motor may be boxed up, and kept free from dust and grit, and high pressures can be employed successfully. No starting resistance is required and the motor is small and compact, and requires no attention. Tests made at the Westinghouse Co.'s works demonstrate that the Tesla motors are fully as efficient as the best direct current motors.

Tesla's Experiments.—The French papers this week are full of Mr. Tesla and his brilliant experiments. No man in our age has achieved such a universal scientific reputation in a single stride as this gifted young electrical engineer. The *Nineteenth Century* contains an article by Mr. J. E. H. Gordon, introducing the subject to the literary world in admirable and brilliant style reflecting both the scientific depth and the coruscations of the original experiments.

Tesla at the Royal Institution.

So great was the interest and enthusiasm with which Mr. Tesla's first lecture and experiments were received at the Royal Institution that he complied with the urgent request to repeat the same, and at the close of the second meeting Lord Rayleigh arose and spoke as follows: Sir Frederick Bramwell, ladies and gentlemen—Although it is not our custom here to follow the lecture with remarks from any one else, I think you will agree with me that this is no ordinary occasion. At the request of the managers of the institution, and for the delectation of its members, Mr. Tesla consented to repeat the labors of last night, labors which, though small to him, would have completely exhausted any one else.

I wish our great electrician, whose name appeared before us in letters of fire, in one of Mr. Tesla's experiments, were here to propose this motion. There is only one respect in which I have any qualification to speak, and that is that I have made attempts myself to experiment with currents of a high degree of frequency. I was tolerably satisfied when I had a discharge rate of 2,000 per second, but we have had to-night ten or twenty thousand per second. My apparatus was on a very small scale indeed. Mr. Tesla has taken us into some of the dark—metaphorically dark—places in nature. These fields have been but little trodden. Mr. Crookes and Mr. Tesla alone have had the *entree*. In what has been put before us to-night, there has been matter which will afford food for intellectual contemplation for a long time to come. I think, at the same time, it will be obvious to you that Mr. Tesla has not worked blindly or at random, but has been guided by the proper use of a scientific imagination. Without the use of such a guide, we can scarcely hope to do anything of real service. I do not think there is anything I need add; it does not require any great capacity to see that Mr. Tesla has the genius of a discoverer, and we may look forward to a long career of discovery for him. His labors will be followed with admiration by all men of science of England, and especially by those in this institution to whom he has done the favor of lecturing to-night. I thank Mr. Tesla for his lecture.

Sir Frederick Bramwell: Ladies and gentlemen—I believe it is usual to second the vote of thanks. I, for one, should be very glad for Lord Rayleigh to put the motion to you. It is the duty of myself, however, to second this vote, which I do most heartily. Our treasurer is not here to-night; he foresees, as the result of the lecture, that the whole of our apparatus, in this line of study, is antiquated, and we shall have to begin afresh. This has evidently been too much for our treasurer, and he has consequently stayed away. In my own province of mechanical engineering, there was a time when we were content to have boilers which would be ridiculed now; and turning from mechanical engineering to electrical science, we have seen to-night the same development from the slow-going, old-fashioned style of phenomena, as that which I have referred to in the case of the steam boiler. I can only regret that Mr. Tesla has kept within the limits of time, and has had to refrain from giving us that which we so much liked. I wish he could give us another evening, and show us more of the experiments. I put the vote to the meeting.

Mr. Tesla: It would be difficult for me to find words to express the thoughts I feel; I have been so kindly received and generously treated. Whatever I have shown you here is not my own; it is the outcome of the work of English scientific men, whose names we delight to hear, and whom every one loves and admires. To-night my aspirations are fulfilled in having my labors appreciated by some of the foremost men in the world, and I cannot tell you how highly I esteem your thanks, and how much it will encourage me to further work. There is one thing I desire to tell you—I am not a speaker, nor did I prepare to speak at all, and these two considerations should disqualify me at once—but this I want to say:

We have worked before with the problems that are at hand until they have been perfected. The water wheel, the gas engine, the steam engine, thanks to the great spirits which your country has produced, are brought to a high state of efficiency. In these departures we have come, so to speak, to the limit. We have now a possibility opened to us of accomplishing things we never dreamed of before, and in this lies the whole aspiration of scientific investigators. These contrivances are but in an imperfect state; they have consumed many years of my incessant thought; some other experimenter will start where I have stopped, and so the world goes on; but the same advantage which another will have from my work, I have already had myself from those who have gone before. The foremost scientific men of this country agree that there is a way of producing the electric light by fluorescence as the result of oscillations of a certain frequency. I will not dare to speak of what they have achieved in this direction, for if I do my discourse would be the praise of their work; it is, therefore, out of place. You will believe that these words are sincere, even if they are not put forth in the expressions of a good orator. We have a start. We can set up in a room the oscillations, and the only difficulty with which we are confronted is the perfecting of the apparatus. Thus we can have a light which will not need any leading wires, which will be a good luminant, and will never be destroyed—it will last for any length of time. This will be a great advancement over present methods. These difficulties are nothing compared to the problems English scientific men have opened up before. For instance, in the production of power. We are able to produce power at any point in the universe, and when this great work is finished, what an effect it will have upon the whole human race! I wish to say that the results I have shown you to-night are the outcome of the work of others, and I do not want to impress you as though I was displaying any discovery of my own. If any one can reap the benefit of it, my desire is fulfilled. I am only paying a duty which any lover of science must pay to those who have been before in the field. Others have arrived at results. We are younger, and we go on from them, climbing the stairs; or, rather, we younger ones are taking the "lift"—we are using the "elevator." The older ones were content with the stairs. I thank you most heartily, and express the hope that I may be able to bring before you some better work than I have shown you to-night.

For the purpose of the experiments, says the *Practical Engineer*, Mr. Tesla employed an alternating current dynamo of special construction, and capable of producing alternations amounting, it was said, to as many as 20,000 in a single second.

The current was controlled by a switch on the lecture table, and the first experiment consisted in holding an exhausted glass tube, 3 feet long, in one hand, while the other was placed upon the terminal of the transformer; the tube then appeared lighted throughout its length with a brilliant blue light. The lecturer then showed a glass bulb lighted in a similar way when attached to one wire only, and also showed the phenomenon of a Crookes' shadow. On attaching a copper plate to each terminal of the transformer, an arc being formed between them, and upon the insertion of a plate of ebonite, the arc gave place to a blue light over the faces of the opposing plate.

When suitable terminals were attached to the transformer, lines of light 7 inches long were readily obtained through air, and when balls of brass 4 inches in diameter were attached, sparks were obtained over a distance of 1¼ inches. Under favorable conditions, Mr. Tesla said, this discharge appeared exactly similar to that of the Wimshurst influence machine. Another beautiful experiment was made with two thin wires about 10 feet long stretched from the lecture table to the gallery, at a distance of about 9 inches apart. These, on the extinction of the gas, were seen to glow with a blue phosphorescent light.

Some Geissler tubes, provided by Professor Crookes, were then exhibited; one of these contained yttria and another sulphate of calcium. Attaching a wire to one of these, Mr. Tesla held it in his hand, while touching the terminal of the transformer with the other. The glass vessel was then seen to be filled with the characteristic colored phosphorescence, and the material continued to phosphoresce after the current had ceased to flow.

Referring to the difficulties found in obtaining good insulating media, Mr. Tesla said the transformer used by him was provided with oil insulation, the exterior of the primary coil being about one-quarter inch less in diameter than that of the internal diameter of the tube upon which the secondary was wound, and the annular space filled with oil. With currents of such high tension and frequency, solid insulation, according to Mr. Tesla, is quite useless, and is absolutely certain to break down after working for a short time, a fact he adduced as the reason why the costly induction coils now made often become useless after a short period. His transformer had, he said, sometimes broken down twelve times a day, yet, owing to the fluid insulation, it was never permanently injured. For the production of the effects shown with yttria and sulphate of calcium tubes, alternations amounting to the almost inconceivable number of 100,000 per second are, according to Mr. Tesla, essential. One of the most remarkable effects observed in connection with these currents of high frequency is, that no matter how great their intensity, they have no effect on the animal system, and thus appear to be perfectly safe. As an illustration of this, he took an iron bar in one hand and a vacuum tube in the other. On making his body a portion of the circuit by placing the point of the bar upon a terminal, emitting sparks several inches long, the vacuum tube glowed brilliantly, while the lecturer remained wholly unaffected.

The most striking experiment, however, was one designed to show the possibility of illuminating a room by making the space itself electric. Above the head of the lecturer was hung a plate of zinc about 8 feet long by 1 foot wide, a similar plate being hung upon the wall at a distance of about 10 feet, and parallel to the first. Between these two plates an intense electrical field was then produced, and exhausted glass tubes placed anywhere in the field at once glowed with phosphorescent light. The lecturer took in his hand a glass wand, 3 feet long, and, with no special connection of any sort to his body or to the glass, when waved in the magnet field it shone like a flaming sword. If such an electric field were produced in a room, it is manifest that it could be illuminated by merely hanging suitable glass globes without connection of any kind.

We have not been able to more than faintly describe a portion of Mr. Tesla's experiments, but it will be evident that the phenomena disclosed were of no ordinary kind. On the possibilities of their immediate application it would be almost rash to speculate, and we shall look forward with excited curiosity to the further experiments and lectures which we understand Mr. Tesla has promised to give on the subject.

USEFUL AND SCIENTIFIC NOTES.

THE total make of open-hearth steel ingots in the United Kingdom last year was 1,514,538 tons, or a decrease on the previous year of 49,662 tons. Of this 100,486 tons were made on the basic system.

Tesla's Experiments.—In an article on Tesla's recent experiments, the *Electrical Engineer* says:—"Reason and calculation showed him that such currents ought not to be dangerous to life any more than the vibrations of light are dangerous. The self-induction and frequency of alternation should be too great for any current to pass, and for a current to be dangerous a certain quantity must pass. Conceive a thin diaphragm in a water-pipe, with to and fro piston-strokes of consid erable amplitude, the diaphragm will be ruptur ed at once. With reduced strokes of the same total energy the diaphragm will be less liable to rupture, until with a vibratory impulse of many thousan ds per second no actual current flows, and the diaphragm is in no danger of rupture. So with the vibratory current—yet in spite of reason and analogy it was with the feelings of a man about to plunge from Brooklyn Bridge—as one might well believe—that Mr. Tesla took his first shock from his apparatus. The result justified his daring, and he suffered no more than a slight shaking in the arms. A spark, of course, passes, and this punctures the skin and causes a slight burn, but that is all. This can easily be avoided by holding a conductor of suitable size in the hand and receiving the shock upon that."

Mr. Tesla Before the Royal Institution, London.

Although the official report of Nikola Tesla's lecture before the Royal Institution, London, recently, has not yet been published, our readers would not find a *resumé* uninteresting and we publish an article of this character taken from our esteemed contemporary the *Electrical Engineer*, of London, of a recent issue. Mr. Tesla is the lion in electrical circles without doubt and deserves every honor given him.

The lecture given by Mr. Tesla on Wednesday last week before the Institution of Electrical Engineers, and repeated on Thursday before the Royal Institution, will live long in the imagination of every person in the brilliant scientific audiences that heard him, opening, as it did, to many of them, for the first time, apparently limitless possibilities in the applications and control of electricity. Seldom has there been such a gathering of all the foremost electrical authorities of the day, on the tiptoe of expectation to witness the experiments, details of some of which had already been given to us from the other side of the Atlantic, but of which no written account could convey the true significance and beauty. Long before the hour of meeting the hall was crowded, and Mr. Tesla was watched throughout with the keenest interest as he adjusted his apparatus, quivering with lightning-like discharges, and now lighted a vacuum tube by grasping it in his hand, now brought to incandescence the filament of an ordinary lamp attached by a single wire, there rendering the air in the interior of a large ring luminous with flame, or sending streams of light from wires stretched over the audience, and, most fascinating of all, after electrifying the whole space of air between his table and an iron plate above him, waving a luminous tube in his hand totally unconnected to any wire whatever. It was, indeed, curious to see the most prominent and noted electricians of the day as interested in Mr. Tesla and his experiments as any child with the first friction machine, asking whether it was safe to do this or that, to touch the wires, and whether they might be allowed to try. For full two hours Mr. Tesla kept his audience spellbound, with easy confidence and the most modest manner possible displaying his experiments, and suggesting, one after another, outlooks for the practical application of his researches; and it was difficult to realize that this memorable lecture was the second only that he had ever delivered. Even at the end Mr. Tesla tantalizingly informed his listeners that he had shown them but one-third of what he was prepared to do, and the whole audience, after Professor Ayrton had proposed the vote of congratulation and declared the meeting over, yet remained in their seats, unwilling to disperse, insisting upon more, and Mr. Tesla had to deliver a supplementary lecture.

In the first place, it may be stated, as Mr. Tesla mentioned, but which hardly seems to be realized, that practically the whole of the experiments shown were new, and had never been shown before, and were not merely a repetition of those given in his lecture in America. That of lighting tubes in an electrostatic field and of bringing filaments to incandescence on a single wire were shown before, and being of the most importance, naturally, were not left out. But all the other experiments, together with most of the apparatus itself, was novel, and was supplementary to that of his American lecture.

In the next place, it is important to understand—as also stated by Mr. Tesla at the time, but hardly, perhaps, yet realized—that nearly the whole of his experiments and effects were produced by means of an ordinary alternating current from an ordinary commercial alternating current dynamo—such, in fact, as can, in many places, be obtained from a central supply company's mains. These effects can be, and were, brought about also by means of the currents from his special alternator, but the chief benefit of the use of this alternator is in being able to obtain perfectly harmonious currents of a known number of alternations per second, and in research work this knowledge is evidently of immense value.

Without going deeply into the detail or the theory of the working of the apparatus used, it is seen, therefore, that the effects are produced by using an alternating current, either generated direct at high potential and with high frequency of reversal per second, or ordinary currents converted into such currents. Mr. Tesla termed these currents "alternating currents of high potential and high frequency," but in the same way that the term rotary current (first proposed, we believe, in these columns) has now gained acceptance to indicate alternating currents varying in phase for producing a rotating magnetic field, so we may, perhaps, venture to use the term "vibratory currents" for those of high potential and high frequency. To generate vibratory currents from an ordinary alternating current circuit, Mr. Tesla uses, first, an ordinary transformer in oil to transform upwards; the secondary current from this he passes into a second transformer having in its circuit a magnetic spark interrupter, and from the secondary circuit of this second transformer (which, it may be noted, is of comparatively thick short wire) he obtains discharges in all respects similar to those of the great induction coils, but of very high frequency. Connecting this circuit to a properly adjusted condenser, in his case a set of Leyden jars, a surging effect is produced on the currents, which raises the frequency of vibrations from 25,000 or so per second to some millions per second, and the potential to some hundreds of thousands, or even, perhaps, millions of volts. The frequency in the case of the use of the Tesla dynamo can, of course, be accurately determined. The potential, it seems, cannot be accurately arrived at by calculation, or, rather, the calculation does not give an accurate result correspondent with the actualities achieved in these effects—a fact, as we shall see, that may have very important theoretical results upon the wave theory of electricity.

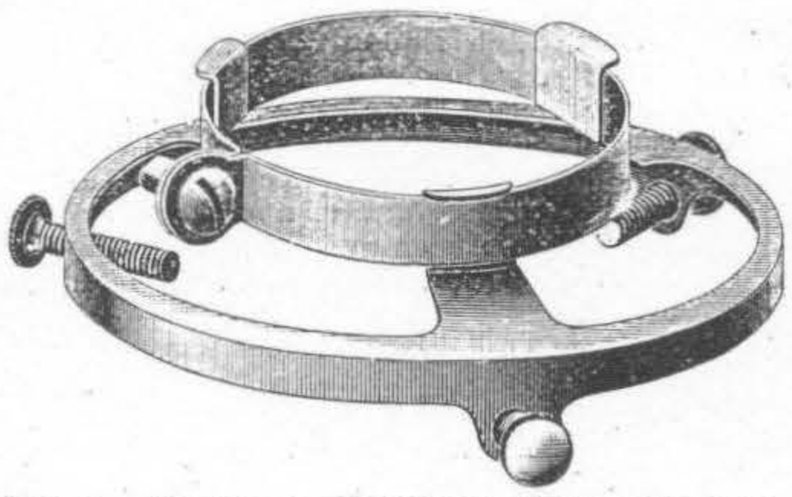


FIG. 1.—GERMANIA UNIVERSAL SHADE-HOLDER.

Having at command a vibratory current of this nature, the results shown by Mr. Tesla were the first outcome of continued and careful experiments. Not only does the molecular bombardment of the molecules of highly-exhausted gases in vacuum tubes show phosphorescence, but gases at low states of exhaustion do the same, and even ordinary air at ordinary temperature, as Mr. Tesla showed at his lecture, where the space between two concentric rings glowed with discharge like a vacuum tube itself, while the vacuum tube glowed when at some considerable distance from the plates to which the two poles were connected. In this manner, by vibrating the air molecules at speed correspondent to that of the vibration of light, phosphorescent effects could be shown with ease. Phosphorescence, Mr. Tesla explained, be regarded as incandescence in another form. Ordinary incandescence accrues after the filament has passed interiorly from the state of cold to that of intense heat; while, if we regard a bombardment of molecules with sufficient intensity upon the surface of a material, we may conceive an infinitesimal film of that material rendered continuously incandescent without the trouble of heating the whole—in a word, we obtain the light vibrations without passing through the whole gamut of heat vibrations—which has long been the electrical engineer's most ardent desire. To obtain a concrete idea of the difference between the ordinary alternating current and the vibratory current, we might imagine the first as a large ordinary steam engine reciprocating at 100 revolutions, while the second becomes a smaller and smaller material engine as its reciprocations mount from hundreds to thousands, or hundreds of thousands, in the same unit of time. In the latter we have the greatest efficiency with the smallest of first outlay.



FIG. 2.—GERMANIA UNIVERSAL SHADE-HOLDER.

Mr. Tesla incidentally showed that the glow discharge in a tube, under certain conditions, would revolve and then become extremely susceptible to the feeblest magnetism, and he hinted that possibly by this means the rapidity of transmission of telegrams through submarine cables might be greatly increased.

A word remains about one or two personal and scientific problems. In the first place, it will be interesting to know Mr. Tesla's own ideas as to the future practicability of his researches—ideas which, of course, will have to await their fulfillment for some time for actual application in practice. The question naturally arises: How can the vibratory current be applied to lighting? Should we expect to have incandescent or phosphorescent lamps of a pattern similar to those we know in the Edison-Swan lamps or the Geissler tubes, or should we expect rather to discover a practical means for rendering the whole mass of the air in a room softly and beautifully phosphorescent? Both, Mr. Tesla thinks, if we understand him aright, may occur, but he looks certainly to the possibility of the last and most fascinating project.

Further, many of those who witnessed his experiments must have asked themselves a question as to the danger of the vibratory currents, which Mr. Tesla handled so unconcernedly. We took an opportunity of enquiring of Mr. Tesla, with reference to this point, how, indeed, he came to dare to take the current through his body? It was the result of a long debate in his mind, it appears, that caused him to attempt the experiment. Reason and calculation showed him that such currents ought not to be dangerous to life any more than the vibrations of light are dangerous. The self-induction and frequency of alternation should be too great for any current to pass, and for a current to be dangerous a certain quantity must pass. Conceive a thin diaphragm in a water-pipe; with to and fro piston-strokes of considerable amplitude the diaphragm will be ruptured at once. With reduced strokes of the same total energy the diaphragm will be less liable to rupture, until, with a vibratory impulse of many thousands per second, no actual current flows, and the diaphragm is in no danger of rupture. So with the vibratory current—yet in spite of reason and analogy it was with the feelings of a man about to plunge from Brooklyn Bridge (as one might well believe) that Mr. Tesla took his first shock from his apparatus. The result justified his daring, and he suffered no more than a slight shaking in the arms. A spark, of course, passes and this punctures the skin and causes a slight burn, but that is all. This can easily be avoided by holding a conductor of suitable size in the hand and receiving the shock upon that.

There lurks in one sentence of Mr. Tesla's lecture a statement which will cause much discussion in high scientific circles. We shall not further refer to it here than to say, that if the voltage obtained is not exactly calculable from the data laid down of the condenser and the frequencies—if, in a word, the result is not approximately that calculated, but considerably lower, then this would certainly seem to show that Hertz's experiments and results are not final, and the way is open to further experiments and research in this direction.

From the way in which Mr. Tesla alluded feelingly to the impulse in research given to himself from perusal of Crookes' experiments in high vacuum, the effect upon students and scientific men generally of the publication of his own promising researches must be great. We can only hope that others, now that the way has been shown, will take up the work, and before many years have passed produce for the world at large the thoroughly practical outcome hinted at in the "wonderful" lecture by Mr. Tesla at the Royal Institution, on Wednesday, February 3, 1892.

LITTLE men may say what they please, and folk are not much the worse or much the better. Except for the "little drops of water" teaching of our infancy, we should say they were none at all. But when a man of light and leading takes in hand to instruct the public, his teaching should be accurate as well as interesting, because the public learns its lessons by heart and picks out misstatements for choice.

"It is not too late in the day," says the *City Leader*, "to refer to the admirable article from the pen of Professor Crookes, which appeared in the *Fortnightly Review* last month." And it does so at some length, dwelling upon the marvellous methods of ethereal communication and transmission of power which Mr. Tesla has made so popular.

"Professor Crookes," it says, "regards it as extremely probable that before long we shall be able to converse with each other at a distance of a mile or more, with no other medium of communication than the air. It must not be supposed, though, that such a feat will be possible without the aid of mechanical and electrical appliances." Then the "appliances" follow:—"*Electrical waves, electrical rays, sending and receiving instruments, and other paraphernalia with which the lay mind is not familiar.*"

I acquit Professor Crookes of this combination. It is obviously the work of a classical brain, and is based on the Thucydidean idiom of "horses, cows, pigs, sheep, and other donkeys."

Then, however, follows a statement for which Professor Crookes *is* responsible. I pointed it out before, and knew it was bound to be quoted. "The total amount of power which the sun pours out every year upon every acre of the earth's surface is 800,000 horse-power. Of this a flourishing crop only utilises about 3,200 horse power, so that 796,000 horse power is wasted. What a great thing to utilise some of this enormous energy!"

What a still greater thing it would be to understand what is meant by 800,000 horse-power poured out every year!

One of these days Kant will come true, and the only facts that really exist will be the things that we believe to be facts. And then quantity of work and rate of work will get mixed up in space, and nature will have to violate her own laws or come to a full stop, and we shall collide with the moon and be utterly burnt up. And Professor Crookes will be responsible.

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A Fundamental Patent for Alternating Currents.

IT would be interesting to know who makes the most money from United States patents, the inventors or the lawyers. It seems sometimes as if our patent office methods were arranged for the benefit of the lawyers rather than for the inventors. A patent has just been issued which appears to claim broadly the transmission of electricity by means of high tension alternating currents, which are transformed at the distant station to low tension currents by means of some induction apparatus. As this appears to cover a broad field, embracing practically all the already existing alternating current installations, and will include many similar installations of the future, it appears to be a matter of importance. The greater part of the text and claims are given in another column. Being issued, it carries with it the indorsement of the patent office that the matter is patentable. As it was patented in France by the same parties as early as 1881, or 11 years ago, it cannot run very much longer in this country, but if it can be sustained it will play an important part in the alternating current industry of this country even for the short remaining period of its life. Deprez, the patentee, was one of the earliest workers in this field, and it can be assumed that he has furnished good proof of priority to the patent office. The immediate effect will probably be litigation, and there will be much of it, too, if there is any chance of its being sustained. That such an occurrence is possible in our patent office is unfortunate, and cannot fail to have a very bad effect on the investments in patented articles in this country. As it is, any one who wishes to start the introduction of some article, patented or not, will never know if there is not some fundamental patent lying dormant in the patent office to be thrust upon him unexpectedly at some future date, after he is well established in an honest business. Such a law is like some others in this country, for the benefit and profit of lawyers rather than for the good of the people. Let us hope the patent will prove to be a dead letter rather than a legal monopoly or even only a scarecrow.

Tesla's Lecture in Paris.

IT appears sometimes as though there was an opinion abroad that Americans, though practical, are not patient, scientific investigators. It is true we do not spend our time with such matters as calculating π to 300 decimal places, a thing which we understand one of our European cousins has accomplished, and if he expects praise from us he will be disappointed, as we can admire nothing but his patience. Nor do we spend our time in working out with great care abstruse matters that do not promise some useful results. There is generally to be seen in the work of our investigators the desire to get at some practical result which can be turned to use in the industries, and it is therefore probably often the case that such investigations are not made public until some practically useful results have been arrived at. Mr. Tesla's researches are a good illustration of the nature of the work done by one of our investigators, and they certainly may be classed with the most useful and novel researches made abroad. Judging from the great interest which they have awakened abroad, they are regarded there also as among the most novel, interesting and promising of all recent investigations. They differ from many European researches in that they open up a new field in which it certainly looks as if some highly useful and practical results could be attained. There are difficulties in the way, but, though great, they are apparently not regarded as discouraging to this indefatigable investigator. That our present method of generating light is even less economical than the generation of power by means of the steam engine is well known to those who have studied the efficiencies of our light-producing devices. The arc light is at present the most economical method known, of those commercially in use, but even this leaves a tempting field for the investigator to discover improvements. The firefly and other organic generators of the "ideal" light have shown us that there is a way of generating light economically and without the accompaniment of useless and expensive heat. Mr. Tesla's researches appear to point out the direction in which we may approach this ideal; he has, in fact, already produced a bright light by a new method. How efficient it is does not seem to have been determined yet, but as it appears to approach the ideal "cold light," it probably will prove to be much more economical than the forms used at present. It remains, still, to make it practically applicable. Let us hope he will soon accomplish this also.

Tesla's Experiments with Alternating Currents of High Frequency.*

BY E. RAVEROT.

The phenomena produced by alternating currents of great frequency and very high potentials were exhibited in public for the first time in France, on Friday, Feb. 19, by the discoverer. The event was one of great importance, as the first experimental presentation before the physicists and electricians of France of an entirely new field of research. Physics, after having created the scientific industries, now receives from them in return very valuable means of investigation which assure the investigator a rich harvest of discoveries. When we consider the researches of Planté with the secondary battery, and witness the discoveries of Tesla with his powerful induction coils, the proof of this assertion becomes evident, and the field of future developments in store for experimental physics grows brighter.

In the light of the experiments of Mr. Tesla we can understand more clearly many of the mysterious phenomena of the radiant state of matter pointed out by Prof. Crookes, of phosphorescence and the molecular bombardment; they lead us to clearer ideas of several contested points in the theory of electricity.

The limited time did not permit Mr. Tesla to dwell as much as he would have wished upon the theory and the arrangements of the experiments, and we must content ourselves here with giving simply the personal impressions

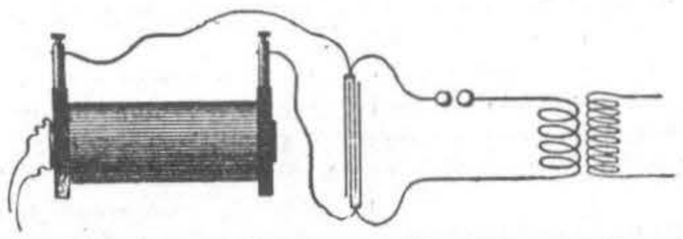


FIG. 1.—DISRUPTIVE DISCHARGE THROUGH THE PRIMARY OF A TRANSFORMER.

of a charmed listener who will endeavor to state what he saw or what he believed he saw.

In order to produce the currents of the very great frequency and very high potential necessary for the experiments, recourse was had to two methods. In the one he employs a multipolar alternator of his own design, giving directly a frequency of 15,000 to 25,000 alternations per second. In this machine (which is the same as that used in his lecture in New York†) the field magnets are fixed and consist of a forged iron ring 81 centimetres in outside diameter and about 2½ centimetres in breadth, having 384 polar projections, between which are wound in a zigzag form two wires, to constitute the exciting circuit for the magnets. The inside diameter of this stationary field is about 76 centimetres. The movable armature is made of a disc, on the surface of which are located the windings, attached laterally by strong pins. The speed of the machine varies between 2,000 and 3,000 revolutions per minute; it can generate as much as 10 ampères. The potential of the machine is regulated by means of a condenser. The current from it supplies the primary circuit of an induction

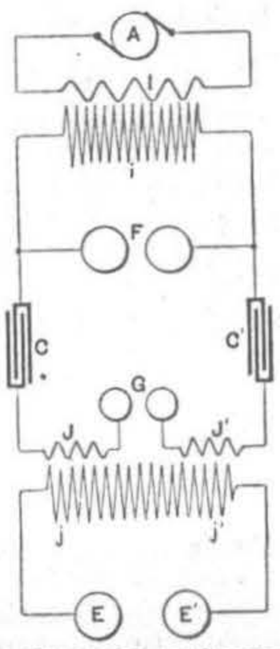


FIG. 2.—DIAGRAM OF CONNECTIONS.

coil of special construction, of which we will speak later on.

The other method used by Mr. Tesla to obtain the enormous frequencies of 300,000 to 400,000 alternations per second and the exceedingly high potentials of over half a million volts, is based on the employment of the disruptive discharge of a condenser in combination with induction coils of peculiar construction. Fig. 1 shows this arrangement of apparatus, which was already described in his former papers. Fig. 2 shows a diagram of the disposition of the apparatus and connections which, however, Mr. Tesla did not stop to describe; we give it here as we remember it, and if there are any errors they are on our part. From the connections shown it seems to us to represent the general disposition of the apparatus used in the experiments which we witnessed.

On this diagram, *A* represents a Siemens alternator which generated the initial energy of the primary circuit *I* of the first induction coil of the transformers. In the secondary circuit *i* of this transformer are connected symmetrically condensers *C* and *C*¹, the disruptive discharge of which passes with the desired frequency through the primary circuit *J J*¹ of the second transformer, the secondary circuit of which terminates at the poles *E* and *E*¹, where the currents of high frequency and enormous potentials may then be led off. *G* and *F* are discharge knobs intended, apparently, to regulate the frequency of the disruptive discharges. We call attention to the function of these adding, however, that our impressions as to their function were obtained by a single inspection of the diagram and connections, but that we do not guarantee that our views are correct. The same is said with regard to Fig. 3, which shows the transformer used by Mr. Tesla, which was drawn from memory. Regarding this transformer Mr. Tesla stated that the length of its secondary wire is only

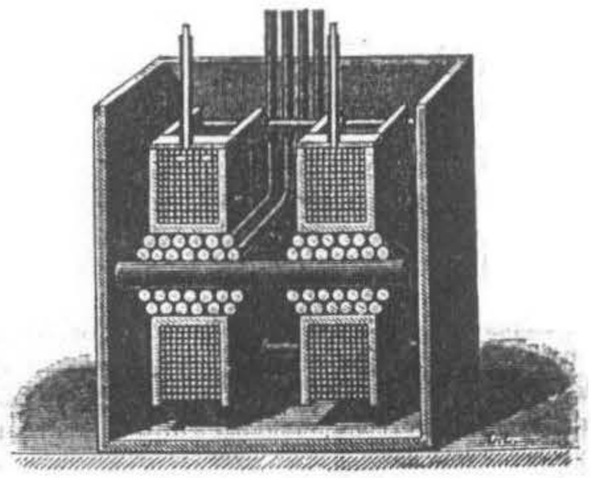


FIG. 3.—HIGH FREQUENCY TRANSFORMER.

from 60 to 100 metres. It gives as high as half a million volts when its primary circuit is excited by the disruptive discharge of the condensers, with a frequency of 300,000 to 400,000 alterations per second. The transformer ratio is one to six and the number of windings of the primary coil is 300. The entire coils are placed in a tank filled with oil. This is indispensable under the condition of such high voltages and such great frequencies.*

The principle of this method is based on the phenomenon of resonance which requires very delicate and laborious regulation and adjustment. Mr. Tesla dwelt repeatedly on this difficulty, and illustrated the same with experiments, which could have been shown also by calculation; the chief obstacle in this is the uncertain knowledge of the



FIG. 4.—UNIPOLAR LAMP.

effective capacity of bodies separated by air, that is, the effect of convection or of absorption.

The second method shows the important part which condensers take in all the experiments of Mr. Tesla, the electrostatic function of which shows clearly the nature of the observed phenomena.

Mr. Tesla also pointed out the analogy of the effects produced by his induction coils for high frequency with those produced by the Wimshurst machine. He can produce phenomena and sparks with his apparatus absolutely identical with those which are ordinarily observed with such influence machines. In seems, in fact, that many of the experiments shown ought to succeed equally well under similar conditions with the discharges from his coils and with

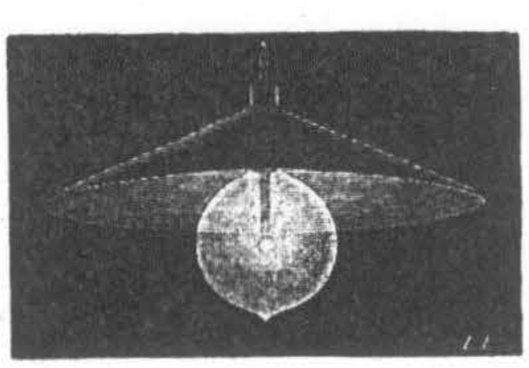


FIG. 5.—LAMP WITH A SHADE AS A CONDENSER PLATE.

those from an electrostatic machine. If, for instance, one pole of a small radiometer of Crookes be connected, the radiometer is put in motion, at least when the conditions of resonance of the circuit are favorable. At the lecture the radiometer, when attached by only one pole, was at first immovable, but started to move when a plate of a certain capacity was connected to the second electrode of the radiometer bulb.

The operation of the radiometer of Crookes, attributed to the unequal molecular bombardment produced on the two different surfaces of the fans, is analogous to the unipolar effects produced at each one of the two poles of the high tension transformer of Mr. Tesla. One can understand now the statement of Mr. Tesla in his former publications, that he utilizes in his experiments the "molecular bombardment" and "the condensing action." We recall also a statement of Mr. Tesla in his former publications that "every body, whether a conductor or susceptible of conducting a current of high tension, can, if it be inclosed in a properly exhausted tube, become luminous or incandescent when it is connected directly to the pole of a secondary circuit of the source of energy excited by induction."

Such are in effect the conditions of operation of Mr. Tesla's unipolar incandescent lamp. At the end of the conducting wire is placed a knob of conducting matter which

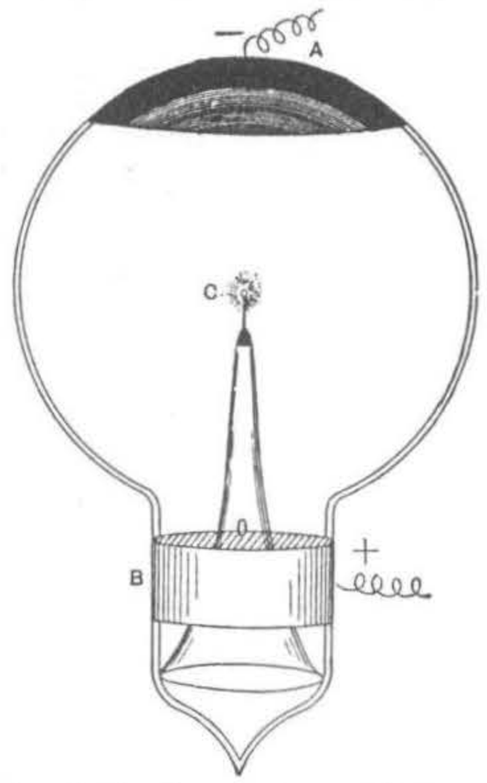


FIG. 6.—AN EXPERIMENT OF CROOKES.

is placed in a bulb from which the air is exhausted, like in the ordinary incandescent lamp; this knob becomes illuminated with a brilliant light when the wire is connected to one pole of the high frequency transformer. The lamp is shown in Fig. 4. The knob is subjected to the molecular bombardment of a rapidly varying electrostatic field. The nature of the phenomenon is made evident when the intensity of this field is increased by the operator bringing his hand near the bulb, his body communicating through the ground with the other pole of the transformer. Another remarkable and very useful quality of the unipolar lamp of this inventor is that of being able to vary the amount of light at will by simply changing the electrostatic capacity of the system. Mr. Tesla utilizes this property in a curious manner by employing as a plate condenser a lamp shade in the form of a reflector as shown in Fig. 5.

This recalls us to the experiment of Prof. Crookes* shown in the course of his researches, of the passage of an electric discharge in a high vacuum. A small piece of char-

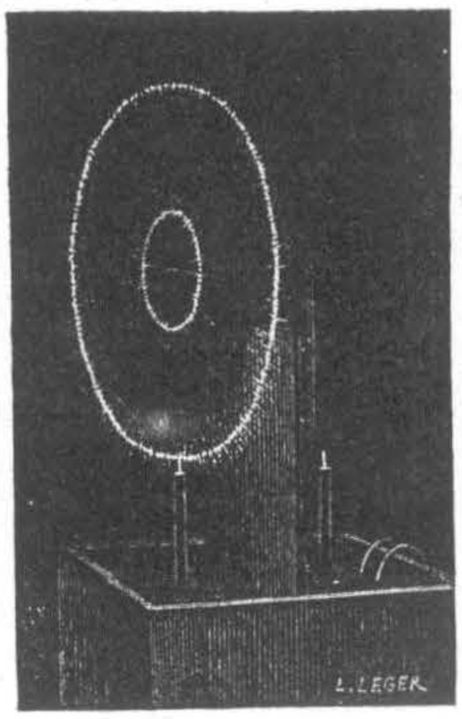


FIG. 7.—INCANDESCENCE OF WIRES BY MOLECULAR BOMBARDMENT.

coal placed at *C* (Fig. 6) in a bulb exhausted to the extreme vacuum of one ten-millionth part of an atmosphere is brought to incandescence under the influence of molecular currents.

In the course of his investigations Mr. Tesla has varied the dimensions of the bulbs of the lamps between great extremes. The relative size of the incandescent knob, and the degree of rarefaction in the bulb, are conditions which require very careful examination and determination. He presented to the audience numerous facts showing the complexity of his investigations and the great amount of patience which is required.

Not being able to go at greater length into this subject we must content ourselves with pointing out merely the chief experiments by which he showed the very great influence of the relative proportions of the parts and their relation to the high frequency transformer. In connecting the poles to bare wires or even to wires covered with an insulating substance, and interposing a plate of very high in-

* *La Lumière Electrique.*
† See THE ELECTRICAL WORLD, July 11, 1891.

*This reminds us of the first great induction coil of M. Jean, which was insulated with the essence of turpentine. (Du Moncel, "Notice sur la Bobine d'Induction," p. 40.

* "L'Electricité et son Trajet," par William Crookes. *La Lumière Electrique*, vol. XXXIX., p. 337.

sulating material (in order to avoid direct discharges), the wires will be seen to become radiant along their entire length, with a small crackling light, resulting from the direct or outside bombardment on the whole surface of the wire. Fig. 9 shows the appearance of two concentric circles showing this phenomenon in one of its finest forms. Another similar phenomenon is shown in Fig. 8, in which a very fine wire, invisible by itself, radiates brilliantly when connected to the high frequency transformer.

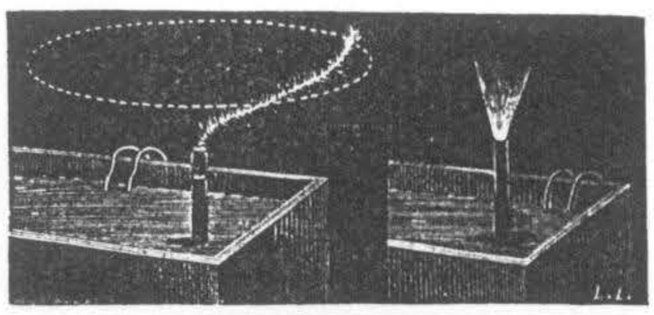


FIG. 8.—INCANDESCENCE AND MOVEMENT OF A FINE WIRE.

FIG. 9.—UNIPOLAR FLAME FROM A TRANSFORMER.

Under slightly different conditions a conductor of a certain capacity in the form of a metallic plate was connected to one pole, and there then appeared on the other pole a true flame, as shown in Fig. 9. This experiment suggested to Mr. Tesla some very original thoughts on the constitution of ordinary flames, the nature of which might be connected in some way with the phenomenon of molecular bombardment produced by the rapid variations of chemical energy and the equalization of the affinities.

The discharge in the form of a flame is one of the five typical forms of the illuminating discharges which Mr. Tesla brought out in his orignal paper.

The discharges vary in form, depending on the frequency, the capacity and the potential; if, for instance, the poles of the high frequency transformer terminate in two poles, the discharge takes the form of a spark depending on the dimensions of the electrodes of the exciter. In this connection one of the most curious experiments shown is that indicated

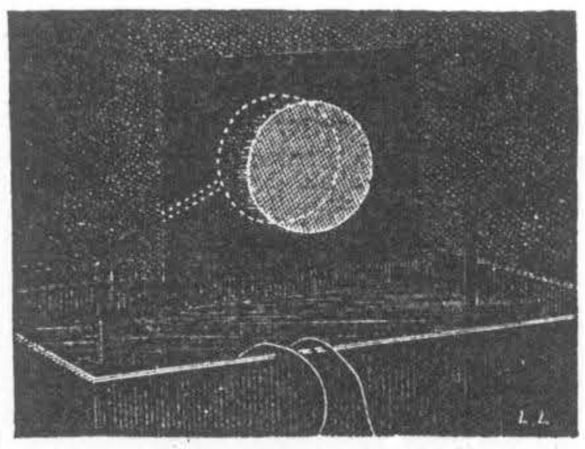


FIG. 10.—HEATING OF AN EBONITE PLATE BY HIGH FREQUENCY DISCHARGE.

in Fig. 10. The discharge passes at first in the form of a simple spark or of an arc between two discs, one of which is made of metallic cloth. The interposition between these of an insulated plate of ebonite, instead of simply obstructing the passage of the arc, increases the condensing action and substitutes for the arc a form of discharge which fills all the space between the discs; the heating action on the ebonite manifests itself to a great degree.

During the lecture Mr. Tesla took a ball of copper in each hand, and by means of them touched the two poles of the high frequency transformer; he then received through his body the full potential of 70,000 volts developed in this transformer of 9,000 ohms. It certainly is not one of the least curious effects of enormous frequency that it renders harmless to the human body currents the danger of which is only too well known when the frequency is low. The investigator remarked to the audience that when he first

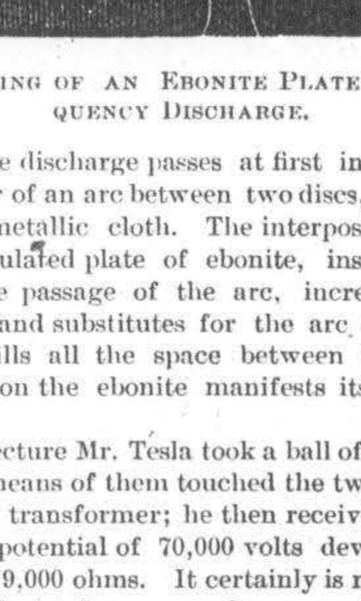


FIG. 11.—UNIPOLAR ILLUMINATION OF AN EXHAUSTED TUBE.

tried this experiment he felt like a man about to jump from the Brooklyn Bridge. In the whole course of his experiments Mr. Tesla was not afraid to hold in his hands the lighting apparatus and to use his body as a conductor. The action of the body is due as much to its induction effects resulting from the approach of a conducting surface as to its conductivity. The discharges of excessive frequencies do not, in fact, require two-wire conductors for their transmission. If, for instance, one pole is connected to one end of the exhausted tube shown in Fig. 11 the tube will be illuminated, but it will be brighter at that end to which the wire is connected, and will gradually grow less bright toward the other end. It suffices, however, merely to connect to the other end of the tube a conducting or semiconducting body having a sufficiently good conducting surface, in order to make the illumination equal throughout the whole tube. The body which is connected acts as a real diffuser through which the discharge is disseminated into the surrounding air, which therefore replaces the return conductor. The same effect is produced with a lamp having two carbons instead of one, as shown in Fig. 12. If one pole only is connected to one terminal of the transformer, it becomes highly incandescent while the second one is only slightly illuminated. An interesting feature to be noted here is the shadow thrown in the bulb by the second carbon and its support. It suffices, however, merely to connect to the second carbon a body having the proper capacity, in order that both may burn equally bright. This experiment was one of those in which the light produced was of the greatest intensity; it was like



FIG. 12.—UNIPOLAR INCANDESCENCE OF A LAMP WITH TWO CARBONS.

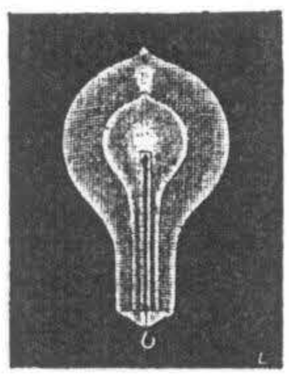
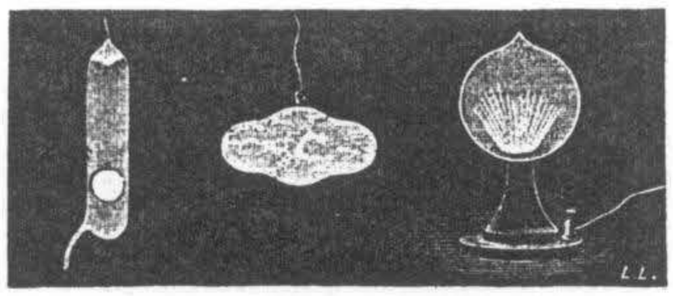


FIG. 13.—LAMP WITH DOUBLE BULB.

that of one of the ordinary incandescent lamps with carbon filaments when forced to a very high candle power. Mr Tesla furthermore pointed out that the carbon knobs of these lamps can also be illuminated entirely by induction a phenomenon which he pointed out in his earlier papers. They are in this case furnished with condensing armatures placed on the outside and inside of the bulb. Such an arrangement obviates the necessity of introducing wires through the bulbs and therefore permits them to be hermetically sealed without a break in the continuity of the bulb. The energy is transmitted entirely in this case through the glass. The induction is, perhaps, in this case the cause of the lowering of the efficiency of these lamps, which otherwise ought to be very high. Fig. 13 shows an arrangement of two concentric bulbs as made by Mr. Tesla in order to diminish the action of the air in contact with the bulb. The space intermediate between the two bulbs is exhausted to a less degree than that in the inner bulb and appears to act like an interposed conductor. This arrangement, however, increases the temperature of the interior bulb.

The question of the life of the substances subjected to



FIGS. 14, 15, 16.—PHOSPHORESCENCE FROM A HIGH FREQUENCY DISCHARGE.

the molecular bombardment in the bulbs is one of the features which require very careful investigation in order to render such lamps practical. In the beginning of his researches Mr. Tesla used for the incandescent knobs carbon prepared like that for the filaments of the ordinary incandescent lamps, and treated with hydrocarbons. He obtains more satisfactory results now with a variety of pure carbon prepared by Mr. Atchison and known by the name of *carburendum*, as nearly as we can remember from the pronunciation.

In the course of his investigations he was led to the very interesting and particularly fascinating study of phosphorescent bodies. With his high frequencies and exceedingly high potentials the phosphorescence in the path of the discharge acquires a degree heretofore unknown. Figs. 14, 15 and 16 give but a poor idea of the fine appearance of some Crookes tubes containing calcium sulphide (bright yellow), yttria (green) and rubies (red), resembling strawberries, etc. Mr. Tesla also showed numerous glass tubes having their internal surface covered with phosphorescent matter. In the latter, the phosphorescence of the glass adds its light to that of the matter in the tube; in a large number of cases the action is particularly intense at the equator of the bulb, as shown in Fig. 17. We call attention to the illumination of the glass tube, in spite of the thin layer of metal deposited on its surface, which, as might at first appear, ought to obscure the light.

The great variety and number of experiments shown and mentioned by Mr. Tesla showed the activity with which he has pursued this captivating problem of alternating currents of very high frequency. He is now studying the question as to how far such effects may be utilized and conducted to a distance. The great difficulty which the insulation of such conductors presents is evident; their surface, whether

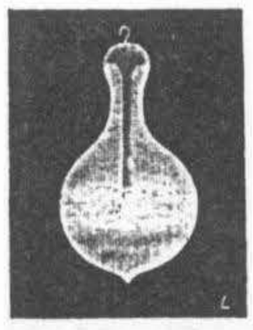


FIG. 17.—EQUATORIAL PHOSPHORESCENCE OF GLOBES.

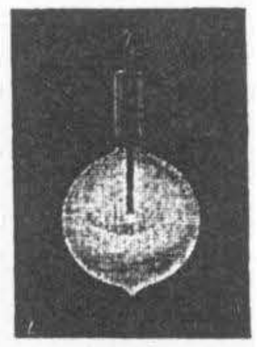


FIG. 19.—SENSITIVE UNIPOLAR DISCHARGES.

bare or covered with any insulation whatsoever, remains exposed to the molecular bombardment. He spoke of a wire having the ordinary protection of a continuous insulating covering which is surrounded by an armature, which acts as a condenser. A unipolar lamp will burn with a different intensity when it is connected to the conductor itself or to the exterior metallic cover. Mr. Tesla expects to get good results from a system of static screens formed by a metallic protection in short lengths around the wire.

In this connection he made an allusion to some hopes he had regarding the possibility of transatlantic telephony, which, however, we did not quite understand. As to the transportation of energy to a distance, by currents of such great frequency, he says that there will be no necessity felt for such a transportation, as one would then know how to obtain the energy and motive force in any point or place in the universe. To illustrate this he mentioned that the radiometer of Crookes operates anywhere, in the light as well as in invisible heat, and according to his views this machine is one of the most inefficient known. Under the

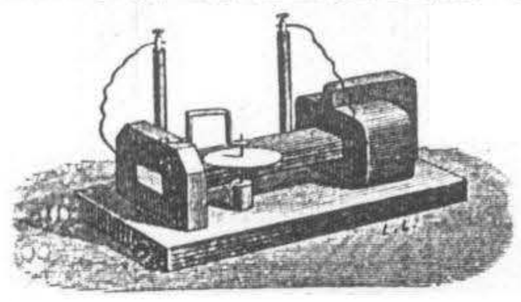


FIG. 18.—MOTOR WORKING WITH ALTERNATING CURRENTS OF HIGH FREQUENCY.

conditions in which these unipolar lamps are lighted, there is nothing to hinder one from gathering the energy in a form suitable to drive a motor. Fig. 18 shows such an apparatus in the form of a motor turning from the impulses of discharges of high frequency traversing a solenoid wound around the ends of a bundle of iron wires. The movable part is a copper disc unsymmetrically situated relatively to the bundle of wires. The general analogy of the form of this with the gyroscopic apparatus of Messrs. de Fonvielle and Lontin (and others) appears very curious. Does it not indicate the identity of the action of currents whose frequencies are very different from each other? As an incidental experiment the rapid heating of a piece of iron subjected to the action of the discharge currents was pointed out.

Mr. Tesla furthermore described a phenomenon capable of application to submarine telegraphy, by showing the extreme sensitiveness of the directing action of a magnet (even if very long and very weak) on the discharge in a unipolar lamp as shown in Fig. 19, the electrical processes presenting the subject of the light of the future in

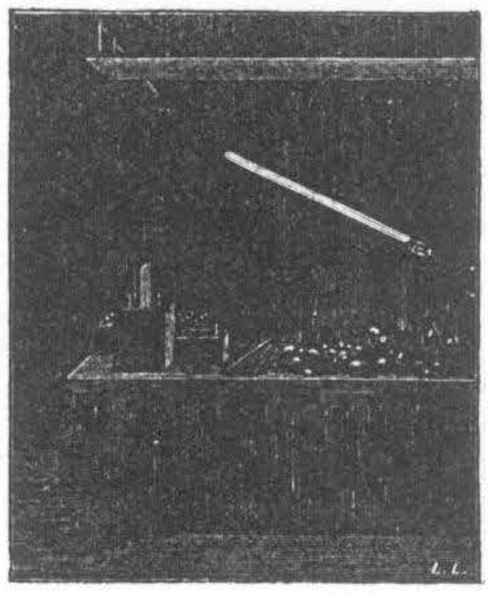


FIG. 20.—ILLUMINATION OF RAREFIED TUBES IN THE ELECTROSTATIC FIELD.

quite a different aspect than the chemical processes, and Mr. Tesla showed on several occasions the striking experiment which in his opinion shows the ideal method of lighting. His experiment showed that the energy of the electrostatic field produced by the rapid and powerful alternations of a

high tension transformer is capable of being utilized. This is, so to speak, his typical experiment. A metallic plate about three metres in length and one-third of a metre in breadth was suspended about two and one-half metres above the lecturer's platform, as shown in Fig. 20. The electrostatic field was generated in the space in which the lecturer stood, between the plates and the floor, which were respectively connected to the two poles of the transformer. Exhausted tubes of glass more than a metre long, held in the hand of Mr. Tesla in this field, were brilliantly illuminated throughout their entire length as shown in the figure. The light was intense, being almost vivid, and resembling in its tint the light from the moon. One might say it appeared like a luminous sword in the hand of an archangel representing justice. The appearance was very fine and the effect very grand.

But the experiments of Mr. Tesla have, in our opinion, quite a different bearing, as we are tempted to see equally well in the phenomena of the electrostatic field as in the illumination of the unipolar suns of the inventor the experimental confirmation of our own views on the electrostatic nature of light.*

One sees from this lecture the deep interest which the works and discoveries of Mr. Tesla have inspired among physicists since the first appearance of his publication, and it is with great satisfaction that we are able to express the feeling of admiration which his experiments have inspired in us.

MR. TESLA'S EXPERIMENTS ON ALTERNATING CURRENTS OF GREAT FREQUENCY.

Mr. Nikola Tesla, to whom the English and French scientific public has just accorded a very warm reception, is a pioneer in electric science, and one of those who will have influenced future progress through an almost radical transformation of the old processes and old methods.

Some day we shall have occasion to describe the two alternating current motors devised by Mr. Tesla as long ago as 1888. At present, we shall content ourselves with recurring to his magnificent experiments on high potentials and alternating currents of great frequency, of which we have already given a complete idea in summarizing the communication made by the author on the 20th of May, 1891, before the American Institute of Electrical Engineers.

In the train of this communication, which made a very great sensation in the scientific world, Mr. Tesla, acceding to the pressing solicitations of his friends and admirers, came to Europe and performed at London on February 3d, and at Paris on the 19th of the same month, before the French Society of Physics and the International Society of Electricians, assembled in the hall of the Society of Encouragement, the remarkable experiments of which we were witness and of which we propose to give an idea, despite the dryness of the subject, its very special character, and our inability to make a clear exposition of it.

Mr. Tesla did not content himself with a simple repetition of the experiments made in America, but he extended them and rendered them complete, and the communications made in Europe may be considered as the second part of a long and remarkable study of which the first part was presented in the New World last year.

In the first place, let us briefly recall the processes employed by Mr. Tesla for the production of alternating currents of great frequency. The simplest consists in the use of an alternator of special form, which is represented herewith in Fig. 2. This consists of a steel disk 30 inches in diameter, upon which are mounted 384 small bobbins, or, more accurately, 384 small zigzag windings. This disk revolves in the interior of a fixed ring carrying 384 inductor poles. The result is that the frequency of the alternating currents engendered by the revolution of the armature before the inductors produces 192 periods per revolution, and that at the normal maximum velocity of 3,000 revolutions per minute, or 30 per second, a frequency of 9,600 periods per second is obtained, instead of the hundred solely that ordinary alternators give. The alternating current thus engendered is collected through the aid of two rings against which two brushes rub, as in all alternators with movable armature. A separate excitation permits of varying at will the alternator's electro-motive force, which, under full excitation, may reach 200 volts. In the second process employed by Mr. Tesla for obtaining much greater frequencies, which may reach and even exceed a million per second, he utilizes an ordinary alternator. In the experiments of February 19, he employed a Siemens alternator, whose frequency did not exceed fifty periods per second.

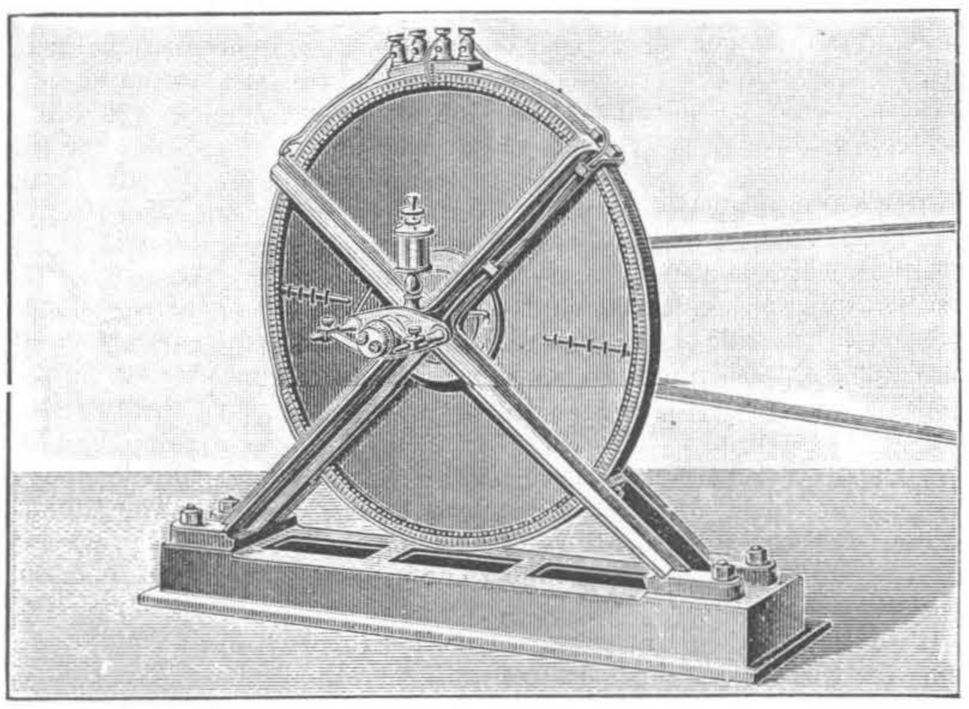


Fig. 2.—TESLA'S RAPID ALTERNATOR.

The alternating current thus produced is sent to an induction coil by establishing in derivation, upon the primary circuit, a disruptive discharge apparatus formed of a condenser and two polished bars whose distance apart may be varied. This spacing regulates the frequency of the discharges, and, consequently, the frequency of the currents traversing the inductor of the bobbin. The sparks of the disruptive discharges burst forth in a powerful magnetic field which facilitates their rapid production, as well as the cooling of the space wherein they are produced with so great a rapidity. Whatever be the process employed for obtaining great frequencies, the potential is always inadequate, and it is increased by transforming the alternating current by the aid of a suitable bobbin. This latter consists of an internal inductor winding and an external armature winding, formed of relatively coarse wire, and of a number of quite small spirals; for it must not be lost sight of that, seeing the great frequency of the currents, the electromotive force developed for a given length of wire is incomparably higher than with ordinary bobbins. These bobbins have no iron core, and are completely submerged in boiled linseed oil; the object of which is to secure perfect insulation and to prevent the presence of air, which, in this particular case, would be very prejudicial through the considerable heating that it would produce under the action of the enormous and frequently reversed electrostatic tensions to which it would be submitted.

In order to obtain powerful effects, Mr. Tesla overcomes the prejudicial effects of self-induction by utilizing the properties of condensers properly interposed in the circuit of the alternator or in derivation upon the terminals of the disruptive discharge apparatus.

A certain number of the experiments made by Mr. Tesla on Feb. 19 were merely a reproduction of those that we have spoken of before. We shall therefore not reproduce them, but shall dwell more especially upon those that present a character of novelty.

The first experiments were made with the disruptive discharge apparatus, that which gives the greatest frequencies at present obtainable by the means at our disposal. In these conditions, the electrostatic discharges traverse the air under the form of luminous discharges, as if the air were rarefied. On interposing an ebonite plate, the electrostatic capacity of the system formed by the two balls between which the discharge takes place and the ebonite plate is increased by the interposition of a dielectric whose specific inductive capacity is greater than that of the air, and the brightness of the discharges is thereby intensified. These discharges easily traverse long tubes containing rarefied gases, which they illuminate with a bright light, each rarefied gas giving to the light its own distinctive color. The discharges occur likewise between two cotton-covered wires insulated from each other and put in connection with the two terminals of the bobbin. These wires emit a violet light throughout their entire length, and even render luminous the space comprised between them.

All the other experiments were made with the alternator shown in Fig. 2, which gives from 9,000 to 10,000 periods per second. Mr. Tesla first showed the discharges in the form of a flame.

In order to prove that these discharges of high potential and great frequency are not dangerous, he was able, on taking in his hands two metallic balls designed to prevent his being burned by the spark, to receive the entire discharge from the bobbin, the discharge passing through his body interposed between the two balls. Mr. Tesla afterward showed that the return wire is absolutely useless for making the discharge current pass. The latter may be established by the air, and pass more easily if care be taken to connect one of the extremities of the wire of the bobbin with a conducting plate insulated in space. The molecular bombardment heats the part which presents but little sur-

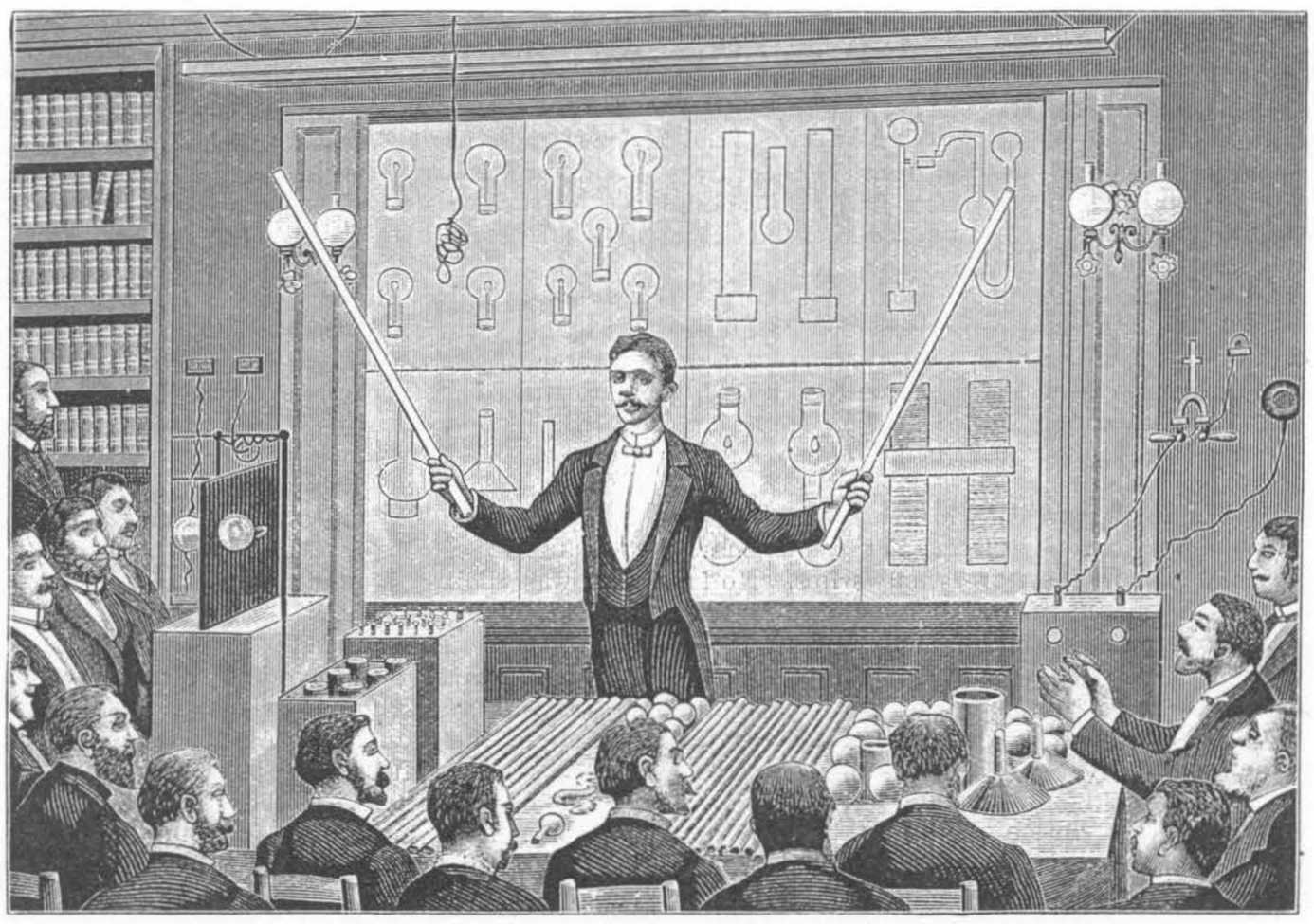


Fig. 1.—PARIS—MR. TESLA LECTURING BEFORE THE FRENCH PHYSICAL SOCIETY AND THE INTERNATIONAL SOCIETY OF ELECTRICIANS.

face put in communication with the second pole of the bobbin, and it was thus that Mr. Tesla showed us the incandescence of a thin platinum wire or of a carbon filament inclosed in a globe of rarefied air.

Every increase in the capacity of the system increases the discharge current, and, consequently, the incandescence. It suffices, for example, to bring the hand near the globe containing the incandescent body, and to place a metallic shade above the latter, or even (an effect paradoxical in appearance) to place the shade alongside of the globe, to produce an increase of brightness resulting from the increase of the electrostatic capacity.

The wire to which the filament is attached is connected, as we have said, with the secondary wire of the bobbin, whose other wire communicates with an insulated metallic plate. Such metallic communication is not indispensable. In fact, if the wire is covered with lead, a layer of gutta percha entirely insulating the copper wire and the leaden tube that envelops it, the lamp with a single filament becomes lighted as brilliantly when it is put in communication with the copper wire or the leaden tube.

Mr. Tesla thus actuated a Crookes electric radiator, and even a special single wire motor, to describe which would lead us too far. He afterward illuminated certain bodies that are but mediocre conductors, such as alumina, carbon, lime, "carborundum," and a few phosphorescent bodies, such as sulphide of calcium, yttria, sulphide of zinc, and the ruby, the marvelous effects of which several times gained the unanimous applause of the spectators. Mr. Tesla finally terminated with a few experiments in the illumination of tubes of rarefied gases without wires or electrodes, the tubes being simply placed in the periodical electrostatic field produced between one of the insulated poles of the bobbin on the one hand and an insulated metallic plate placed above the experimenter and communicating with the other pole of the bobbin on the other hand.

Fig. 1 shows one of these experiments, in which Mr. Tesla is producing the illumination of two tubes at once. In order to effect the extinction of one of these tubes, it suffices to interpose a middlingly conductive screen in the electrostatic field, or to place the tube in a direction sensibly perpendicular to the flux of induction of the field. The same tube remains dark in all positions if it is held by its two extremities at once, the body forming a screen. On sliding the hand along the tube, it is possible to render one of its extremities luminous. Nothing is more curious than to see the light produced by this process thus extinguished and relighted at will.

Such are, very briefly described, the principal experiments which, for more than two hours, deeply interested the members of the two societies mentioned above, who had the good fortune to be present at Mr. Tesla's lecture.

It would be difficult as yet to say what future is in store for them from the standpoint of an industrial, utilitarian and practical new mode of production of light. The more so as the dream of the inventor is broader and his views more exalted than the experiments that he presented to us allow to be seen. His final ambition appears to be to transform the energy of the medium that environs us, and which is very evident by its numerous manifestations, into light, or at least to obtain therefrom radiations of the same wave length and same frequency as those that produce luminous sensations. Crookes' radiometer has already proved that it is possible to convert the radiant energy of a medium directly into mechanical energy, and although, from the standpoint of rendering, this radiometer is the most detestable of all transformation apparatus, it is none the less the most admirable, by the fact that it affords us a tangible demonstration of the possibility of such transformation.

On the other hand, Mr. Tesla, in his memorable experiments, has shown us that, on periodically varying, with very great frequency, an electrostatic field, it is possible to place apparatus of great simplicity therein, such as tubes of rarefied gases, which collect a portion of such energy and render it luminous. To the philosopher and savant nothing more is necessary to establish the possibility, if not the probability, of the realization of Mr. Tesla's final views. To him the light of the future resides in the incandescence of solids, gases, and phosphorescent bodies excited (if we may use a somewhat vague expression) by high potentials varying with very great frequency.

The young scientist is convinced of this as a precursor, and almost as a prophet. He introduces so much warmth and sincerity into his explanations and experiments that faith wins us, and, despite ourselves, we believe that we are witnesses of the dawn of a nearby revolution in the present processes of illumination. —*E. Hospitalier, in La Nature.*

DISTINGUISHED ELECTRICIANS.

The portraits here presented represent men who, while they have achieved notability in the electric world, have, in so doing, shown that they possessed the requisites for success in any branch of work. Untiring industry, great ingenuity, and a belief in themselves would have made them great in any of the executive departments of life. Thomas Alva Edison's story has been told so often that it cannot but be a trite one. He was born on the 11th of February, 1847, at Milan, Ohio. He began life at the age of twelve as a train boy, soon advancing to be a news dealer with four young assistants. He then began practicing telegraphy, and at last obtained a position in Port Huron. He soon began to invent, and in 1864 he moved to Memphis and had one of his inventions, an automatic repeater, put into service. He struggled along, inventing, working at his profession, and experimenting, until he went to Boston in 1868, where he was able to open a workshop for developing his inventions. Shortly afterward he was retained by the Western Union Telegraph Company, and started an electrical laboratory at Newark, where he employed 300 men. In 1876 he moved to Menlo Park, New Jersey, and in 1887 left Menlo Park and erected in Orange, New Jersey, what is supposed to be the largest experimental laboratory of its kind in the world. His inventions, which are numbered by hundreds, center largely on electricity, although one of the most wonderful of his achievements, the phonograph, is not an electrical invention at all.



THOMAS A. EDISON, ORANGE, N. J.

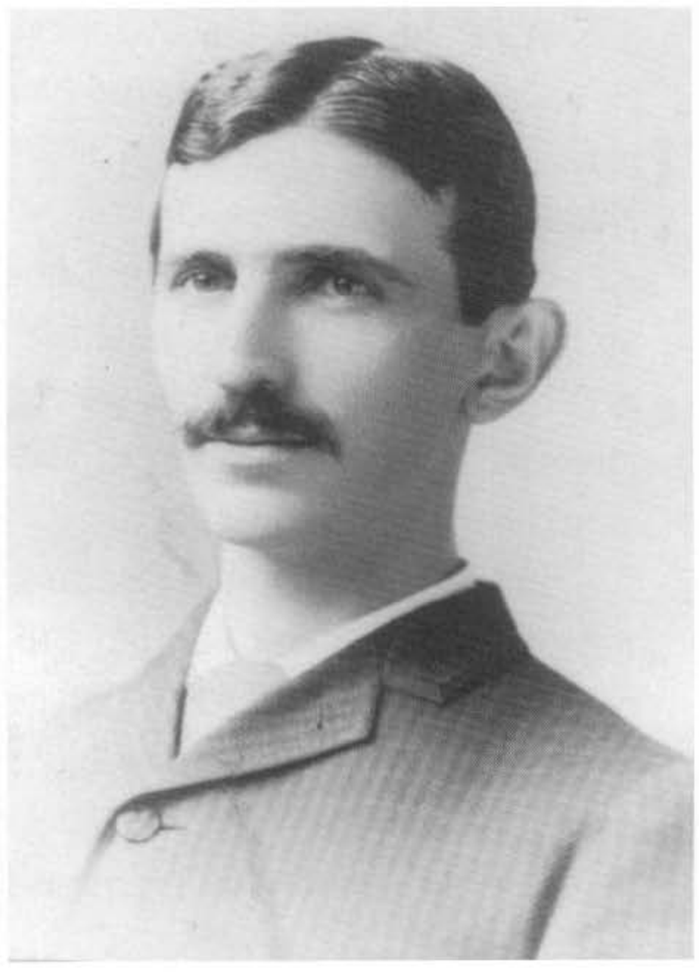


PROF. ALEXANDER GRAHAM BELL, WASHINGTON.

Alexander Graham Bell was born in Edinburgh, Scotland, March 3, 1847, being therefore almost exactly the same age as Edison. His father and grandfather were both language teachers, and the young Bell's attention was directed to language by the course of studies prescribed by his father. The synthesis of artificial speech, by Helmholtz's method, is said to have early engaged his attention, and he resolved to pursue one of the outcomes of his studies, multiple telegraphy,



PROF. ELIHU THOMSON, LYNN, MASS.



NIKOLA TESLA, NEW YORK.

to a practical conclusion. It has been said that all this time the idea of speech transmission was an undercurrent of thought with him, and he has testified that, before 1870, he avowed his belief that we would one day speak by telegraph. Going through all sorts of experiments, he succeeded in inventing the telephone. He lectured on it before the Society of Arts, in Boston, May 25, 1876, exhibited it at the Centennial in Philadelphia, and in August of the same year speech, it was said, was transmitted over a telegraph line. He has received numerous honors, and has written numbers of papers on his other scientific work, such as the photophone. He has also, for years, studied the subject of speech for the deaf and dumb.

Elihu Thomson was born in Manchester, England, 1853, and at the age of 5 came to this country with his parents, who settled in Philadelphia, where he was educated, graduating from the Central High School in 1870. He experimented a great deal during his boyhood in electricity and chemistry, photography and similar subjects. Graduating at the age of 17, he spent six months as an analytical chemist in a laboratory, and was then appointed Assistant Professor of Chemistry and Physics in the High School, and was promoted to the chair of Professor of Chemistry and Mechanics in 1876. He frequently lectured and continually experimented during this period, in the Artisans' Night Schools, Franklin Institute and elsewhere. He was associated with Prof. Edwin J. Houston in some patents relating to dynamos, and upon these and other inventions based the American Electric Company, since called the Thomson-Houston Electric Company, organized in 1880, and became chief electrician of the company. His invention of electric welding and brazing has been fully described in the columns of the SCIENTIFIC AMERICAN and SUPPLEMENT. His very remarkable experiments in alternating current induction have done much to win for him an international renown. The air blast applied to switches and commutators for blowing away destructive arcs is a type of his practical way of reaching results. Like Edison, he holds a great number of patents.

Nikola Tesla was born at Smiljan, a small place on the Austrian border, and is now 35 years of age. His education was received at Carlstadt in Croatia; he too showed the experimental bent and eventually entered the polytechnic school in Gratz, Austria. Here he studied engineering and devoted his spare time to studying electricity; on graduation he entered the engineering department of the telegraph at Buda-Pesth, and in 1881 took up the electric light and the construction of dynamo machines as his especial work. He is said to have been greatly impressed by the drawbacks incident to the employment of the commutator and collecting brushes on dynamos and motors. But his recent work and that which has brought his name more prominently before the world than ever before has been with alternating currents. Employing a dynamo giving 20,000 alternations in a single second, he has produced what may be properly termed the most remarkable experimental results recently attained by electricity. With these alternations used in the production of the most beautiful lighting effects, he succeeded in showing or at least in indicating the possibility of producing electric light without any conductors whatever. Two very striking points brought out were the construction of his apparatus. In his transformer he employs a liquid insulator, the point being that the perforations of its material naturally do no harm, as they instantly close up again. Another point was that these currents of high frequency have no effect on the animal system, being apparently perfectly safe, however great their intensity or high the potential difference developed in their circuit.

NIKOLA TESLA.

IT was not to be expected that in the short evening at his disposal, and with such a host of experiments to be performed, Mr. Nikola Tesla could do more than indicate, merely, the kind of way in which the remarkable results of his untiring labors were obtained. So various were the phenomena, that even the lecturer was from time to time in doubt as to the best way of presenting the delectable feast to his guests; and so incomprehensible were the effects that he confessed, "I cannot see the forest on account of the trees."

Already the work of Mr. Tesla, with regard to currents of high frequency and high potential, had been received and appreciated in this country, as far as printed descriptions could make it plain to us. But something more was needed to impress us with the true sense of its importance. We wanted to see the phenomena themselves, and to have before us the man who had deciphered them from nature's infinite book of mysteries.

The lecture given before the electrical engineers at the Royal Institution, Feb. 10, was only the second which Mr. Tesla had ever given in public. At the invitation of the managers of the Royal Institution, the lecture was repeated the next day to its own members. There were large and distinguished audiences upon both occasions, which were enlivened, on Feb. 11 especially, by the presence of ladies.

The first lecture which Mr. Tesla delivered on the subject of high frequencies and high potentials was given before the American Institute of Electrical Engineers, at Columbia College, N. Y., in May, 1891. It is reported upon in our columns for July and August of that year.

With researches on high rates of discharge we naturally connect the names of such men as Crookes, Rayleigh, Spottiswoode, and De la Rue. It would appear, also, that Mr. Rankin Kennedy had already demonstrated the possibility of lighting by the means which Mr. Tesla has followed, when, in 1882, Mr. Kennedy patented (No. 4,752) a methed for "Intensifying fluorescent and phosphorescent electric lighting, whereby the same is rendered serviceable for illuminating purposes, and apparatus for effecting the said intensification."

Throughout his lectures, Mr. Tesla has shown a deep sense of his appreciation for those who have been before him in the field, and everywhere he has specially acknowledged his indebtedness to Mr. Crookes, whose fascinating little book he declares gave him the initiative to labor in the direction of electrical discharge. To all who would claim priority in this or any research, we recommend a careful reading of the eloquent little speech with which Mr. Tesla replied to the vote of thanks on Feb. 11 at the Royal Institution. For this purpose we have printed it in our columns.

Mr. Tesla has many more things in view than those he introduced to us recently. Not a third of the experiments he had prepared were actually shown, on account of the limits of time. It will be well, therefore, to reserve any criticism or discussion of the results until Mr. Tesla has had the opportunity of describing them in detail; this, we believe, he intends to do through the press at an early date.

It may be observed that the high frequency and high potential are obtained from an induction coil of a special form, and receiving in its primary a special oscillatory current. Mr. Tesla sends the current from an alternating dynamo into the primary of a transformer, the secondary being connected through a magnetostatic interrupter to two brass knobs, between which a series of discharges takes place. From these knobs are taken leads to the primary terminals of an induction coil, not directly, however, but through a capacity formed by Leyden jars. It is thus seen that when a spark occurs at the brass knobs, an oscillatory discharge surges through the added capacity and the primary of the induction coil. The rate of these oscillations is about one million per second. The effect of the passage of this current, through the primary, is to produce at the secondary terminals a current, not only of high frequency, but of high potential.

When phenomena such as those developed by Mr. Tesla are brought before us, it is usual to seek out, on the principle of reversibility, the complementary set of facts, advancing from where they stop, to find a return path with new beauties. In this case the result of such a line of thought leads us to the endeavors of Becquerel and Minchin to obtain currents and E.M.Fs. from electrodes, when acted upon by solar rays. In the *Philosophical Magazine* for March, 1891, Professor Minchin writes: "It is conceivable that a photo-electric battery may yet be found which will simply act as a transformer of the energy it receives from the sun, while its own materials, being merely the implements used in the process, may be almost wholly unmodified."

The latest experiments with photo-electric cells have established the remarkable fact that when a suitable capacity is connected to them, they can be changed from an insensitive to a sensitive state by the action of a Hertz oscillator at a distance of many feet. How is this? Another analogy lies in the fact that of the liquids used in connection with the original experiments with silver plates, those which were fluorescent, such as eosine, sulphate of quinine, and fluorescine, seemed to suggest a connection between fluorescence and the electrical effect. It would be a revelation, indeed, if the light of Mr. Tesla's experiments could be found to illuminate the mysteries of those of Professor Minchin, and *vice versa*.

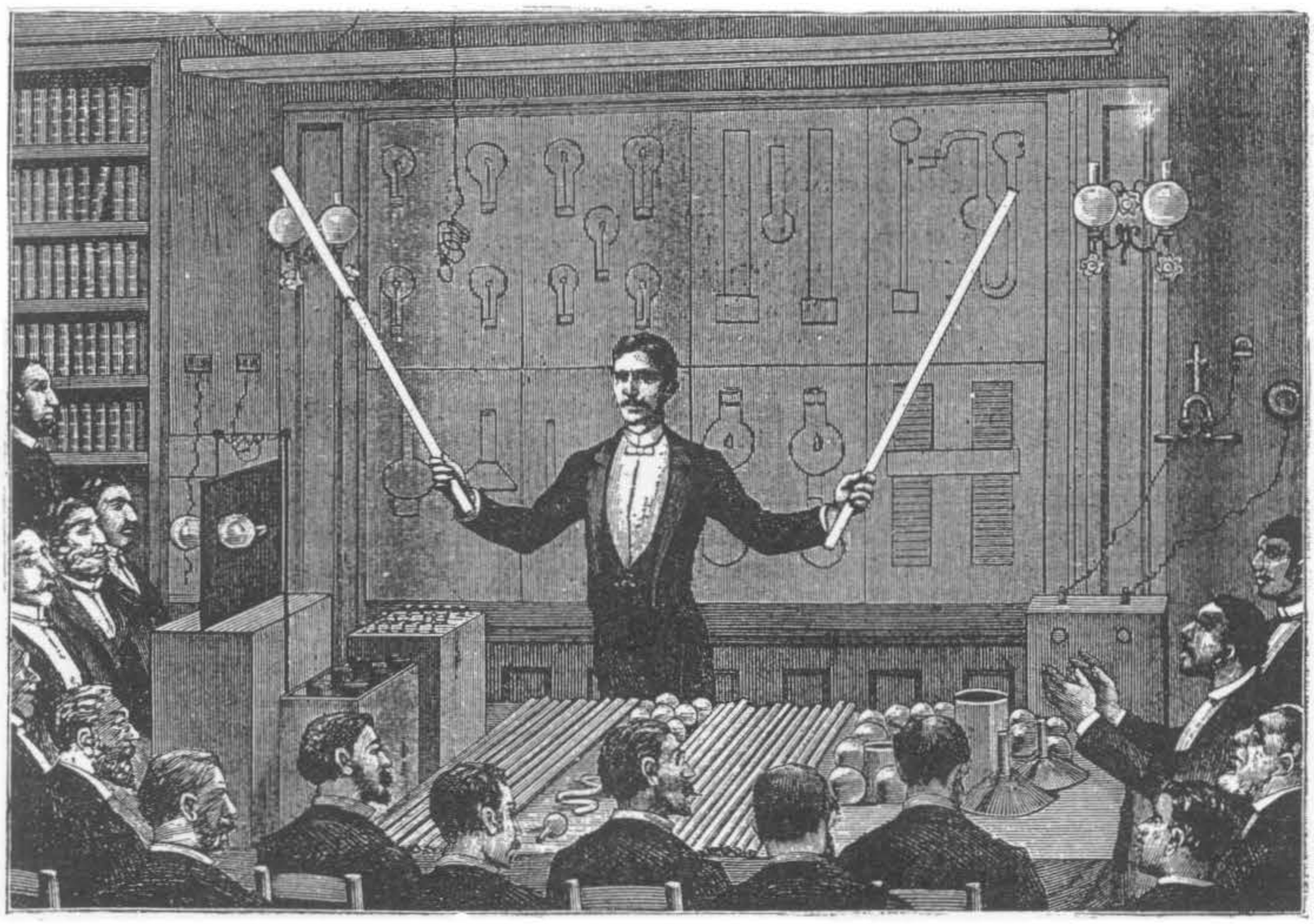
The idea of using electric lamps, without the intervention of leads, will remind some of our readers of the extraordinary telephonic experiments of Professor Dolbear, when he delighted his audience by removing the wires connected to his receiver, and fixing the instrument some yards away from the terminals, invited those that had ears, to hear. There is, of course, a great distinction to be drawn between these results and those of Mr. Tesla. The nature of the undulations in the two cases is probably widely different.

If to the genius and imaginative mind of Mr. Tesla the number and complexity of ideas revealed by his experiments are so great that he owns himself lost in them as in a forest of thoughts, to others the darkness must be deeper still. Yet, though we cannot even see the trees, we are grateful to our distinguished visitor for cutting us a little path, leading us a little way, and refreshing us with his great enthusiasm.—*The Electrical Review, London.*

Mr. Tesla in France.

Nikola Tesla has made a profound impression abroad, and the lectures which he delivered in England and France last month were received with positive enthusiasm. In the latter country the reception was naturally of a more demonstrative character, and one of the French scientific journals in a frontispiece fairly represents Mr. Tesla as a prestidigitateur. The illustration is presented herewith. The engraving is supposed to illustrate the joint meeting of the Société de Physique and the Société Intenationale des Electriciens, which was held on February 20th. To quote from the journal in question, "The young savant is as thoroughly convinced as a forerunner, almost, we might say, as an apostle. There is so much enthusiasm and sincerity in his explanations and experiments, that faith is born within one, and he believes he is present at the dawn of a revolution in artificial means of illumination. * * * The warm plaudits that his lectures have received in England and France prove that he has excited the enthusiasm, if not the conviction of those men who are most capable to appreciate the grandeur and importance of his work. For the skillful experimenter we wish all success in the new field in which he is engaged. We trust that when next he comes to Europe the light of the future will have become the light of the present."

When his work excites such rapturous comments as this,



MR. TESLA IN FRANCE.

and when he is regarded almost as a magician, Mr. Tesla must regard his trip abroad as decidedly successful.

While Americans do not perhaps indulge in such high-sounding phrases, they none the less appreciate the marvelous work that Mr. Tesla has accomplished, and are no less ready to give him the hearty and enthusiastic praise that he deserves. His lectures abroad are not merely repetitions of his paper before the American Institute of Electrical Engineers, but are important developments of that remarkable production,

TESLA APPARATUS.

A TESLA experimental apparatus is being constructed for lecture purposes at the Finsbury Technical College, says the London *Electrical Engineer*. The students will be very much on the *qui vive* the first time Dr. Thompson ventures to take the million-volt shock into his body. Some one must evidently follow suit to Mr. Tesla, but we have heard the opinion expressed by several engineers that they would hardly like to build and test such an apparatus with a trust in its harmlessness merely from abstract or mathematical reasoning without trying it, say, on a calf first. Mr. Tesla has a splendidly-equipped laboratory in New York, and the experiments he showed at the Royal Institution are by no means all he had to produce, given more accurately determined conditions.

[76897.]—**Tesla's High-Voltage Generator.**—"Dynamotor" is too ambitious. That apparatus is not going to be driven by gut or clock-work, nor is it going to be done on a small scale. The current may be small, but the energy involved is enormous, and though M. Tesla finds it not dangerous, I fear some of his imitators, when they do imitate him, will come to grief. At any rate, the non-danger point cannot be passed except by great power, perfect appliances, and thorough knowledge.

SIGMA.

MR. TESLA'S EXPERIMENTS.

"THE French papers this week are full," says the *London Electrical Engineer*, "of Mr. Tesla and his brilliant experiments. No man in our age has achieved such a universal scientific reputation in a single stride as this gifted young electrical engineer."

THE TESLA MULTIPHASE CURRENT MOTORS.*

By ALBERT SCHMID.

The prominence which has been given to power transmission by multiphase currents in the experiments between Frankfort and Lauffen, seems to have led to the impression, even among those otherwise well-informed, that this was the first example of this method of transmission. It may therefore be well to put on record the fact that in this country multiphase motors manufactured by the Westinghouse Company have been in successful commercial operation for several years, and a three-phase power plant has been in daily service in the shops of the Westinghouse Company at Pittsburgh for some time past, driving the shafting and machinery of the winding department.

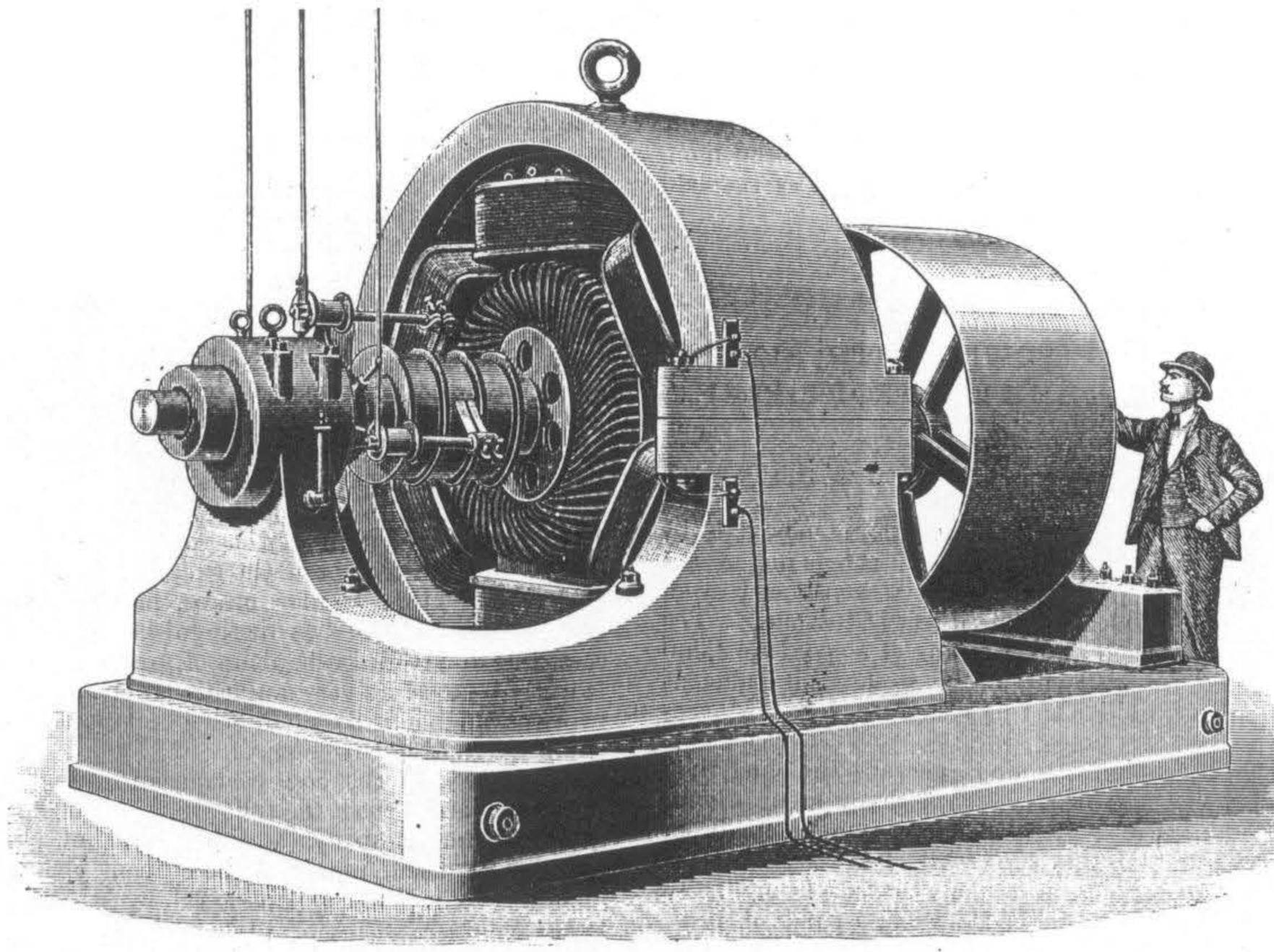


Fig. 1.—Three-Phase 1,000 H.P. Tesla Alternating Motor.

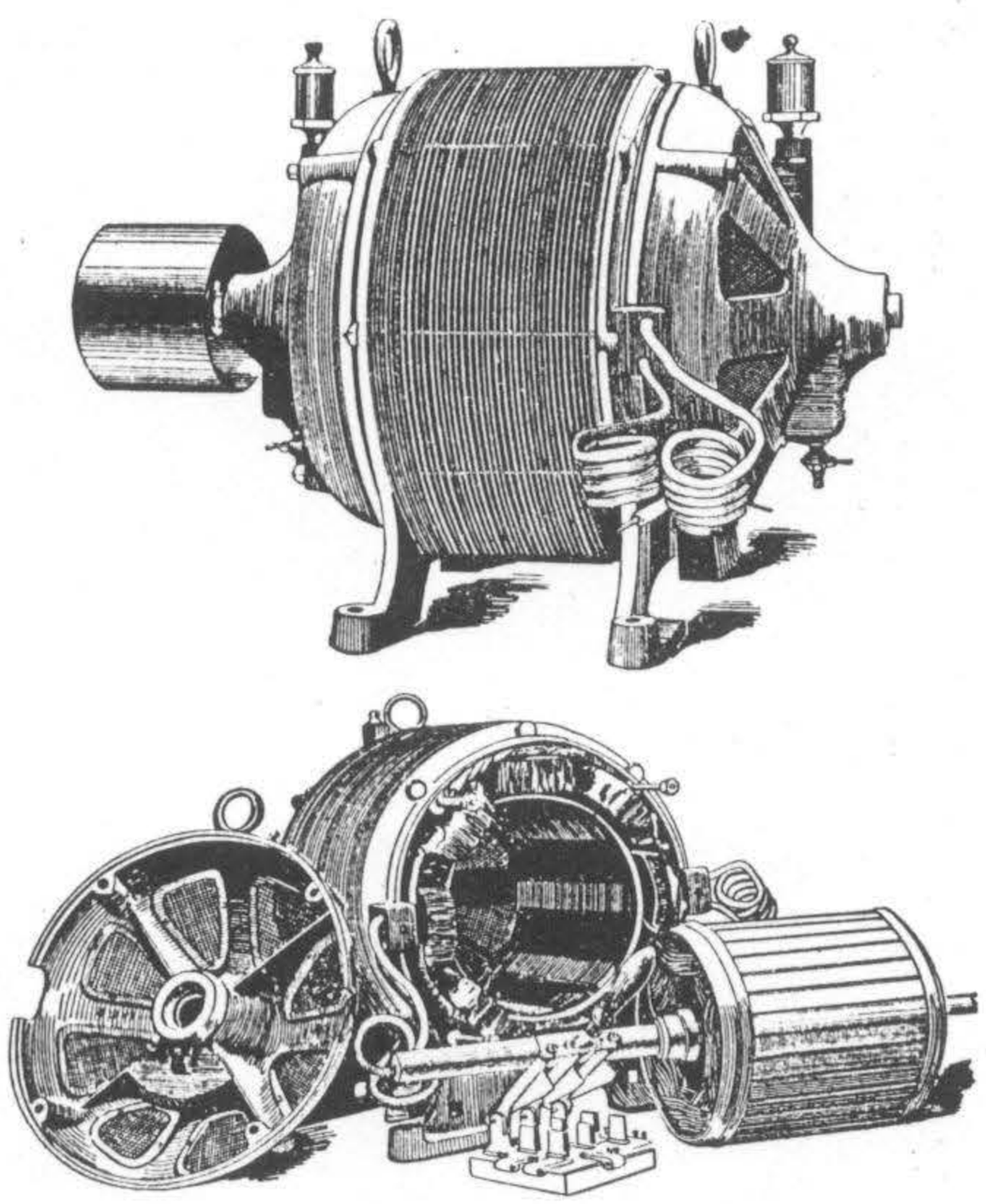
As is well known, Mr. Nikola Tesla is the inventor of the multiphase motor, and his patents in this country are controlled by the Westinghouse Electric and Manufacturing Company, who have been quietly standardising the different sizes and have, within the last year or two, placed a large number of them in service.

The generators for these motors are of the Westinghouse multipolar type, with toothed drum armatures wound to give currents of 60 or 90 degrees difference of phase. These machines are built either entirely self-exciting and self-regulating, or separately exciting and self-regulating. The machine shown is designed for 60 kilowatt capacity.

The motors are constructed with internal poles and grooved armatures. The larger motors have armatures with three collecting rings, and the fields are excited with direct current. The smaller ones have armatures wound with coils closed upon themselves, doing away with all collecting rings and commutators. The engraving, fig. 2, shows a 10 H.P. Tesla motor and fig. 3 exhibits the armature removed from the enclosing field magnets. These multiphase motors are built in sizes of from 1 to 1,000 H.P.

A 1,000 H.P. three-phase generator or motor, for the same machine can be made either as a motor or generator, is shown in the engraving fig. 1, and when run as a generator will give 150 ampères at 5,000 volts. In mechanical design this machine is similar to the multipolar direct current railway generators built by the Westinghouse Company. The armature is of the drum type with slots for the wire and is without bands.

With the Tesla multiphase system the power can be subdivided to any extent for motor or lighting purposes, and high pressures may be employed which can be reduced to whatever voltage is desired. The multiphase motors start under load, and run at constant speed. The smaller ones are made entirely alternating, and the larger ones are self-exciting after reaching synchronism.



Figs. 2 and 3.—10 H.P. Tesla Alternating Motor.

As the starting torque with the Tesla multiphase motors is comparable with shunt wound direct current machines, they may be applied in every case where direct current

* *Electrical Engineer*, New York.

shunt wound motors can be used. At starting, the direct current motors require dead resistance in series, which means considerable loss, but the alternating current motor has inductive resistance, and therefore the loss at starting is much less. Multiphase motors can be used for operating mines, factories, and street railways, and the generating station may be located wherever most convenient for obtaining the best results, and if the pressure is not over 5,000 volts, the motors may be supplied direct from the mains. The Tesla motor has a great advantage over other types of motors in that it requires no commutator, and consequently is sparkless. The motor may be boxed up, and kept free from dust and grit, and high pressures can be employed successfully. No starting resistance is required and the motor is small and compact, and requires no attention. Tests made at the Westinghouse Company's works demonstrate that the Tesla motors are fully as efficient as the best direct current motors.

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Tesla's Experiments.

[*From London Electrical Engineer.*]

The French papers this week are full of Mr. Tesla and his brilliant experiments. No man in our age has achieved such a universal scientific reputation in a single stride as this gifted young electrical engineer. The *Nineteenth Century* contains an article by Mr. J. E. H. Gordon, introducing the subject to the literary world in admirable and brilliant style, reflecting both the scientific depth and the coruscations of the original experiments.

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

BY NIKOLA TESLA.

I cannot find words to express how deeply I feel the honour of addressing some of the foremost thinkers of the present times, and so many able scientific men, engineers, and electricians, of the country greatest in scientific achievements. The results which I have the honour to present before such gathering I cannot call my own. There are among you not a few who can lay better claim than myself on any feature of merit which this work may contain. I need not mention many names which are world-known—names of those among you who are recognised as the leaders in this enchanting science; but one, at least, I must mention—a name which could not be omitted in a demonstration of this kind. It is a name associated with the most beautiful invention ever made: it is Crookes!

When I was at college, a good time ago, I read, in a translation (for then I was not familiar with your magnificent language), the description of his experiments on radiant matter. I read it only once in my life—that time—yet every detail about that charming work I can remember this day. Few are the books, let me say, which can make such an impression upon the mind of a student. But if on the present occasion I mention this name, as one of many your Institution can boast of, it is because I have more than one reason to do so. For what I have to tell you and to show you this evening concerns in a large measure that same vague world which Prof. Crookes has so ably explored; and, more than this, when I trace back the mental process which led me to these advances—which even by myself cannot be considered trifling, since they are so appreciated by you—I believe that their real origin, that which started me to work in this direction, and brought me to them after a long period of constant thought, was that fascinating little book which I read many years ago.

And now that I have made a feeble effort to express my homage and acknowledge my indebtedness to him and others among you, I will make a second effort, which I hope you will not find so feeble as the first, to entertain you. Give me leave to introduce the subject in a few words. A short time ago I had the honour to bring before our American Institute of Electrical Engineers some results then arrived at by me in a novel line of work. I need not assure you that the many evidences which I have received that English scientific men and engineers were interested in this work, have been for me a great reward and encouragement. I will not dwell upon the experiments already described, except with the view of completing, or more clearly expressing, some ideas advanced by me before, and also with the view of rendering the study here presented self-contained, and my remarks on the subject of this evening's lecture consistent. This investigation, then, it goes without saying, deals with alternating currents, and, to be more precise, with alternating currents of high potential and high frequency. Just in how much a very high frequency is essential for the production of the results presented, is a question which, even with my present experience, would embarrass me to answer. Some of the experiments may be performed with low frequencies, but very high frequencies are desirable, not only on account of the many effects secured by their use, but also as a convenient means of obtaining, in the induction apparatus employed, the high potentials which, in their turn, are necessary to the demonstration of most of the experiments here contemplated.

Of the various branches of electrical investigation, perhaps the most interesting and immediately the most promising is that dealing with alternating currents. The progress in this branch of applied science has been so great in recent years that it justifies the most sanguine hopes. Hardly have we become familiar with one fact when novel experiences are made, and new avenues of research are opened. Even at this hour possibilities not dreamt of before are, by the use of these currents, partly realised. As in Nature all is ebb and tide, all is wave motion, so it seems that in all branches of industry alternating currents—electric wave motion—will have the sway. One reason, perhaps, why this branch of science is being so rapidly developed is to be found in the interest which is attached to its experimental study. We wind a simple ring of iron with coils; we establish the connections to the generator, and with wonder and delight we note the effects of strange forces which we bring into play, which allow us to transform, to transmit and direct energy at will. We arrange the circuits properly, and we see the mass of iron and wires behave as though it were endowed with life, spinning a heavy armature, through invisible connections, with great speed and power—with the energy possibly conveyed from a great distance. We observe how the energy of an alternating current traversing the wire manifests itself—not so much in the wire as in the surrounding space—in the most surprising manner, taking the forms of heat, light, mechanical energy, and, most surprising of all, even chemical affinity. All these observations fascinate us, and fill us with an intense desire to know more about the nature of these phenomena. Each day we go to our work in the hope of discovering—in the hope that someone, no matter who, may find a solution of one of the pending great problems—and each succeeding day we return to our task with renewed ardour; and even if we are unsuccessful, our work has not been in vain, for in these strivings, in these efforts, we have found hours of untold pleasure, and we have directed our energies to the benefit of mankind.

* Lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the *Journal* of the Institution of Electrical Engineers.

We may take—at random, if you choose, any of the many experiments which may be performed with alternating currents; a few of which only, and by no means the most striking, form the subject of this evening's demonstration; they are all equally interesting, equally inciting to thought. Here is a simple glass tube from which the air has been partially exhausted. I take hold of it; I bring my body in contact with a wire conveying alternating currents of high potential, and the tube in my hand is brilliantly lighted. In whatever position I may put it, wherever I may move it in space, as far as I can reach, its soft, pleasing light persists with undiminished brightness. Here is an exhausted bulb suspended from a single wire. Standing on an insulated support, I grasp it, and a platinum button mounted in it is brought to vivid incandescence. Here, attached to a leading wire, is another bulb, which, as I touch its metallic socket, is filled with magnificent colours of phosphorescent light. Here still another, which by my fingers' touch casts a shadow—the Crookes shadow of the stem inside of it. Here, again, insulated as I stand on this platform, I bring my body in contact with one of the terminals of the secondary of this induction coil—with the end of a wire many miles along—and you see streams of light break forth from its distant end, which is set in violent vibration. Here, once more, I attach these two plates of wire gauze to the terminals of the coil, I set them a distance apart, and I set the coil to work. You may see a small spark pass between the plates. I insert a thick plate of one of the best dielectrics between them, and instead of rendering altogether impossible, as we are used to expect, I aid the passage of the discharge, which, as I insert the plate, merely changes in appearance and assumes the form of luminous streams. Is there, I ask, can there be, a more interesting study than that of alternating currents?

In all these investigations, ladies and gentlemen, in all these experiments, which are so very, very interesting, for many years past—ever since the greatest experimenter who lectured in this hall discovered its principle—we have had a steady companion, an appliance familiar to everyone, a plaything once, a thing of momentous importance now—the induction coil. There is no dearer appliance to the electrician. From the ablest among you, I dare say, down to the inexperienced student, to your lecturer, we all have passed many delightful hours in experimenting with the induction coil. We have watched its play, and thought and pondered over the beautiful phenomena which it disclosed to our ravished eyes. So well known is this apparatus, so familiar are these phenomena to everyone, that my courage nearly fails me when I think that I have ventured to address so able an audience, that I have hazarded to entertain you with that same old subject. Here in reality is the same apparatus, and here are the same phenomena, only the apparatus is operated somewhat differently, the phenomena are presented in a different aspect. Some of the results we find as expected, others surprise us, but all captivate our attention, for in scientific investigation each novel result achieved may be the centre of a new departure, each novel fact learned may lead to important developments. Usually in operating an induction coil we have set up a vibration of moderate frequency in the primary, either by means of an interruptor or break, or by the use of an alternator. Earlier English investigators, to mention only Spottiswoode and J. E. H. Gordon, have used a rapid break in connection with the coil. Our knowledge and experience of to-day enables us to see clearly why these coils, under the conditions of the tests, did not disclose any remarkable phenomena, and why able experimenters failed to perceive many of the curious effects which have since been observed. In the experiments such as performed this evening, we operate the coil either from a specially-constructed alternator capable of giving many thousands of reversals of current per second, or, by disruptively discharging a condenser through the primary, we set up a vibration in the secondary circuit of a frequency of many hundred thousands or millions per second, if we so desire; and in using either of these means we enter a field as yet unexplored.

It is impossible to pursue an investigation in any novel line without finally making some interesting observation or learning some useful fact. That this statement is applicable to the subject of this lecture the many curious and unexpected phenomena which we observe afford a convincing proof. By way of illustration take, for instance, the most obvious phenomena, those of the discharge of the induction coil. Here is a coil which is operated by currents vibrating with extreme rapidity, obtained by disruptively discharging a Leyden jar. It would not surprise a student were the lecturer to say that the secondary of this coil consists of a small length of comparatively stout wire; it would not surprise him were the lecturer to state that, in spite of this, the coil is capable of giving any potential which the best insulation of the turns is able to withstand; but although he may be prepared, and even indifferent as to the anticipated result, yet the aspect of the discharge of the coil will surprise and interest him. Everyone is familiar with the discharge of an ordinary coil; it need not be reproduced here. But, by way of contrast, here is a form of discharge of a coil the primary current of which is vibrating several hundred thousand times per second. The discharge of an ordinary coil appears as a simple line or band of light. The discharge of this coil appears in the form of powerful brushes and luminous streams issuing from all points of the two straight wires attached to the terminals of the secondary. Now compare this phenomenon which you have just witnessed with the discharge of a Holtz or Wimshurst machine—that other interesting appliance so dear to the experimenter. What a difference there is between both these phenomena! And yet, had I made the necessary arrangements—which could have been made easily, were it not that they would interfere with other experiments, I could have produced with this coil sparks which, had I the coil hidden from your view and only two knobs exposed, even

the keenest observer among you would find it difficult, if not impossible, to distinguish from those of an influence or friction machine. This may be done in many ways—for instance, by operating the induction coil which charges the condenser from an alternating-current machine of very low frequency, and preferably adjusting the discharge circuit so that there are no oscillations set up in it. We then obtain in the secondary circuit, if the knobs are of the required size and properly set, a more or less rapid succession of sparks of great intensity and small quantity, which possess the same brilliancy, and are accompanied by the same sharp crackling sound as those obtained from a friction or influence machine.

Another way is to pass through two primary circuits, having a common secondary, two currents of a slightly different period, which produce in the secondary circuit sparks occurring at comparatively long intervals. But, even with the means at hand this evening, I may succeed in imitating the spark of a Holtz machine. For this purpose I establish between the terminals of the coil which charges the condenser a long unsteady arc, which is periodically interrupted by the upward current of air produced by it. To increase the current of air I place on each side of the arc, and close to it, a large plate of mica. The condenser charged from this coil discharges into the primary circuit of a second coil through a small air gap, which is necessary to produce a sudden rush of current through the primary. The scheme of connections in the present experiment is indicated in

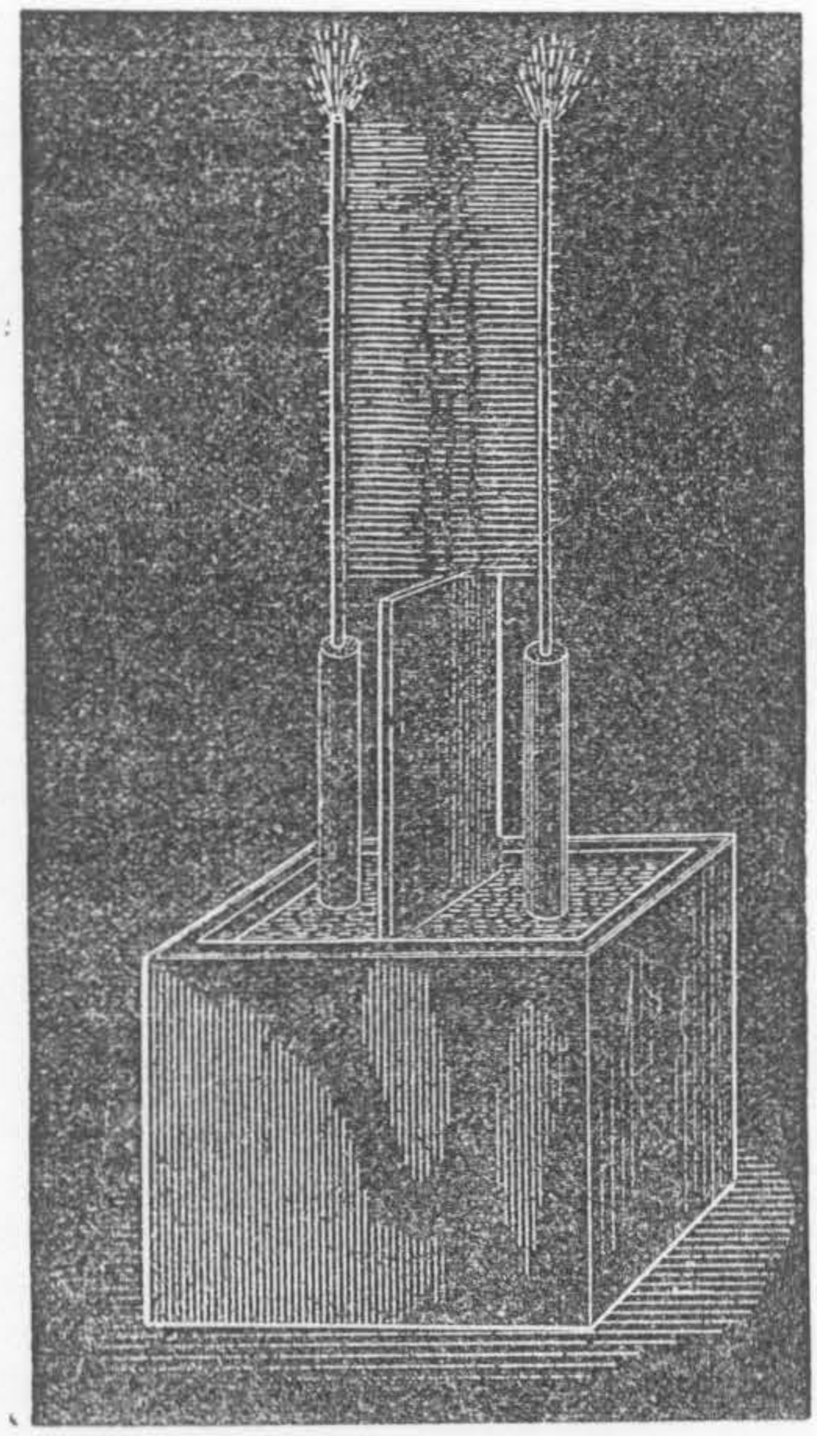


FIG. 1.—Discharge between Two Wires with Frequencies of a Few Hundred Thousands per Second.

Fig. 2 G is an ordinarily constructed alternator supplying the primary, P, of an induction coil, the secondary, S, of which charges the condensers, or jars, C C. The terminals of the secondary are connected to the inside coatings of the jars, the outer coatings being connected to the ends of the primary, *p p*, of a second induction coil. This primary, *p p*, has a small air gap, *a b*. The secondary, *s*, of this coil is provided with knobs, or spheres, K K, of the proper size, and set at a distance suitable for the experiment. A long arc is established between the terminals, A B, of the first induction coil. M M are the mica plates. Each time the arc is broken between A and B the jars are quickly charged and discharged through the primary, *p p*, producing a snapping spark between the knobs, K K. Upon the arc forming between A and B the potential falls, and the jars cannot be charged to such high potential as to break through the air gap, *a b*, until the arc is again broken by the draught. In this manner sudden impulses at long intervals are produced in the primary, *p p*, which in the secondary, *s*, give a corresponding number of impulses of great intensity. If the secondary knobs, or spheres, K K, are of the proper size, the sparks show much resemblance to those of a Holtz machine.

But these two effects, which to the eye appear so very different, are only two of the many discharge phenomena. We only need to change the conditions of the test, and again we make other observations of interest. When, instead of operating the induction coil as in the two last experiments, we operate it from a high-frequency alternator, as in the next experiment, a systematic study of the phenomena is rendered much more easy. In such case, in varying the strength and frequency of the currents through the primary, we may observe five distinct forms of discharge, which I have described in my former paper on this subject before the American Institute of Electrical Engineers, May 20, 1891.

It would take too much time, and it would lead us too far from the subject presented this evening, to reproduce all these forms, but it seems to me desirable to show you one of them. It is a brush discharge, which is interesting in more than one respect. Viewed from a near position, it resembles much a jet of gas escaping under great pressure. We know that the phenomenon is due to the agitation of the molecules near the terminal, and we anticipate that some heat must be developed by the impact of the molecules against the terminal or against each other. Indeed, we find that the brush is hot, and only a little thought leads us to the conclusion that, could we but reach sufficiently high frequencies, we could produce a brush which would give intense light and heat, and which would resemble in every particular an ordinary flame, save, perhaps, that both phenomena might not be due to the same agent—save, perhaps, that chemical affinity might not be electrical in its nature. As the production of heat and light is here due to the impact of the molecules, or atoms, of air or of something else besides, and as we can augment the energy simply by raising the potential, we might, even with frequencies obtained from a dynamo machine, intensify the action to such a degree as to bring the terminal to melting heat. But with such low frequencies we would have to deal always with something of the nature of an electric current. If I approach a conducting object to the brush a thinny little spark passes, yet even with the frequencies used this evening the tendency to spark is not very great. So, for instance, if I hold a metallic sphere at some distance above the terminal, you may see the whole space between the terminal and

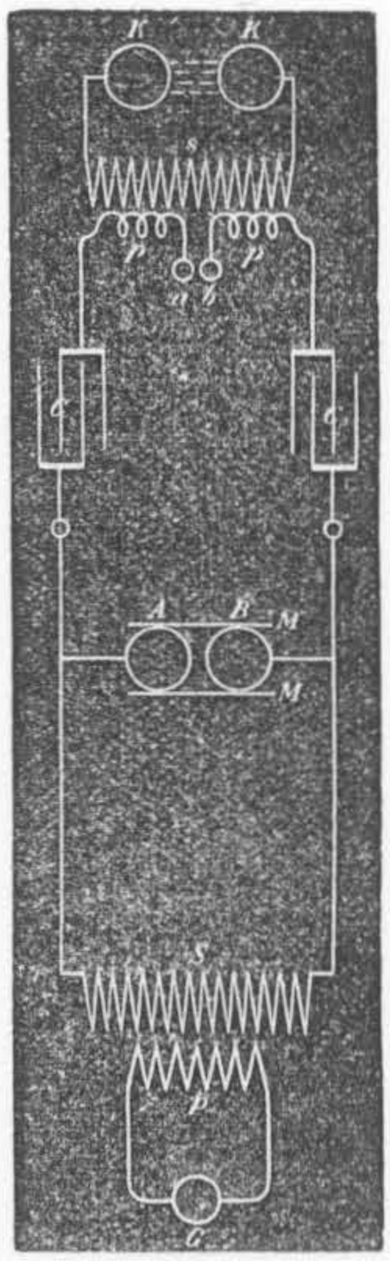


FIG. 2.—Imitating the Spark of a Holtz Machine.

sphere illuminated by the streams without the spark passing; and with the much higher frequencies obtainable by the disruptive discharge of a condenser, were it not for the sudden impulses, which are comparatively few in number, sparking would not occur even at very small distances. However, with incomparably higher frequencies, which we may yet find means to produce efficiently, and provided that electric impulses of such high frequencies could be transmitted through a conductor, the electrical characteristics of the brush discharge would completely vanish—no spark would pass, no shock would be felt—yet we would still have to deal with an electric phenomenon, but in the broad, modern interpretation of the word. In my first paper before referred to, I have pointed out the curious properties of the brush, and described the best manner of producing it, but I have thought it worth while to endeavour to express myself more clearly in regard to this phenomenon, because of its absorbing interest. When a coil is operated with currents of very high frequency, beautiful brush effects may be produced, even if the coil be of comparatively small dimensions. The experimenter may vary them in many ways, and, if it were nothing else, they afford a pleasing sight. What adds to their interest is that they may be produced with one single terminal as well as with two; in fact, often better with one than with two.

But of all the discharge phenomena observed, the most pleasing to the eye, and the most instructive, are those observed with a coil which is operated by means of the disruptive discharge of a condenser. The power of the brushes, the abundance of the sparks, when the conditions are patiently adjusted, is often

amazing. With even a very small coil, if it be so well insulated as to stand a difference of potential of several thousand volts per turn, the sparks may be so abundant that the whole coil may appear a complete mass of fire. Curiously enough, the sparks, when the terminals of the coil are set at a considerable distance, seem to dart in every possible direction, as though the terminals were perfectly independent of each other. As the sparks would soon destroy the insulation, it is necessary to prevent them. This is best done by immersing the coil in a good liquid insulator, such as boiled-out oil. Immersion in a liquid may be considered almost an absolute necessity for the continued and successful working of such a coil.

It is, of course, out of question, in an experimental lecture, with only a few minutes at disposal for the performance of each experiment, to show these discharge phenomena to advantage, as to produce each phenomenon at its best a very careful adjustment is required. But even if imperfectly produced, as they are likely to be this evening, they are sufficiently striking to interest an intelligent audience. Before showing some of these curious effects I must, for the sake of completeness, give a short description of the coil and other apparatus used in the experiments with the disruptive discharge this evening. It is contained in a box, B, Fig. 3, of thick boards

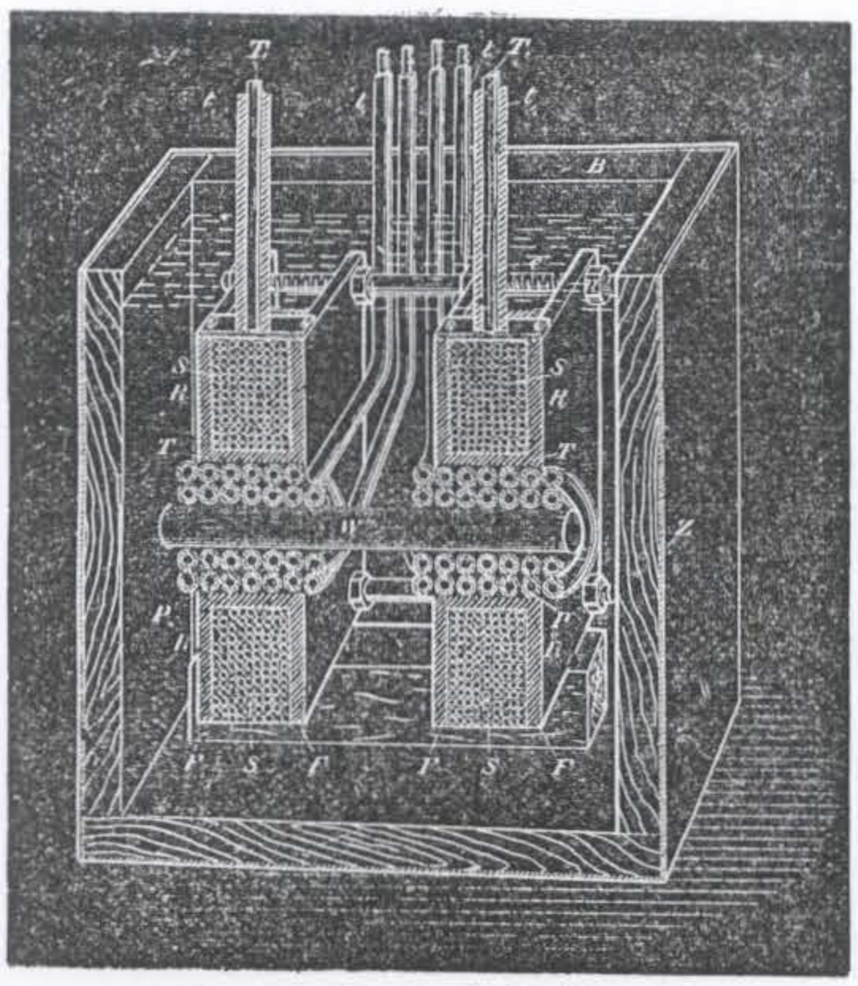


FIG. 3.—Disruptive Discharge Coil.

of hard wood, covered on the outside with zinc sheet, Z, which is carefully soldered all round. It might be advisable, in a strictly scientific investigation, when accuracy is of great importance, to do away with the metal cover, as it might introduce many errors, principally on account of its complex action upon the coil, as a condenser of very small capacity, and as an electrostatic and electromagnetic screen. When the coil is used for such experiments as are here contemplated, the employment of the metal cover offers some practical advantages, but these are of not sufficient importance to be dwelt upon. The coil should be placed symmetrically to the metal cover, and the space between should, of course, not be too small—certainly not less than, say, five centimetres, but much more if possible; especially the two sides of the zinc box, which are at right angles to the axis of the coil, should be sufficiently remote from the latter, as otherwise they might impair its action and be a source of loss. The coil consists of two spools of hard rubber, R R, held apart at a distance of 10 centimetres by bolts, *c*, and nuts, *n*, likewise of hard rubber. Each spool comprises a tube, T, of approximately eight centimetres inside diameter and three millimetres thick, upon which are screwed two flanges, F F, 24 centimetres square, the space between the flanges being about three centimetres. The secondary, S S, of the best guttapercha-covered wire, has 26 layers, 10 turns in each, giving for each half a total of 260 turns. The two halves are wound oppositely and connected in series, the connection between both being made over the primary. This disposition, besides being convenient, has the advantage that when the coil is well balanced—that is, when both of its terminals, T_1 T_1, are connected to bodies or devices of equal capacity—there is not much danger of breaking through to the primary, and the insulation between the primary and the secondary need not be thick. In using the coil it is advisable to attach to both terminals devices of nearly equal capacity, as, when the capacity of the terminals is not equal, sparks will be apt to pass to the primary. To avoid this, the middle point of the secondary may be connected to the primary, but this is not always practicable. The primary, P P, is wound in two parts, and oppositely, upon a wooden spool, W, and the four ends are led out of the oil through hard rubber tubes, *t t*. The ends of the secondary, T_1 T_1, are also led out of the oil through rubber tubes, t_1 t_1, of great thickness. The primary and secondary layers are insulated by cotton cloth, the thickness of the insulation, of course, bearing some proportion to the difference of potential between the turns of the different layers. Each half of the primary has four layers, 24 turns in each, this giving a total of 96 turns. When both the parts are connected in series, this gives a ratio of conversion of about 1 : 2·7, and with the primaries in multiple, 1 : 5·4; but in operating with very rapidly-alternating currents this ratio does not convey even an approximate idea of the ratio of the E.M.F.'s in the primary and secondary circuits. The coil is held in position in the oil on wooden supports, there being about five centimetres thickness of oil all around. Where the oil is not specially needed, the space is filled with pieces of wood, and for this purpose principally the wooden box, B, surrounding the whole is used. The construction here shown is, of course, not the best on general principles, but I believe it is a good and convenient one for the production of effects in which an excessive potential and a very small current is needed. In connection with the coil, I use either the ordinary form of discharger or a modified form. In the former I have introduced two changes which secure some advantages, and which are obvious. If they are mentioned, it is only in the hope that some experimenter may find them of use. One of the changes is that the adjustable knobs, A and B (Fig. 4), of the discharger are held in jaws, J J, of brass by spring pressure, this allowing to turn them successively in different positions and so do away with the tedious process of frequent polishing up. The other change consists in the employment of a strong electromagnet, N S, which is placed with its axis at right angles to the line joining the knobs A and B, and produces a strong magnetic field between them. The pole-pieces of the magnet are movable, and properly formed so as to protrude between the brass knobs, in order to make the field as intense as possible; but to prevent the discharge from jumping to the magnet, the pole-pieces are protected by a layer of mica, M M, of sufficient thickness; s_1 s_1 and s_2 s_2 are screws for fastening the wires. On each side one of the screws is for large and the other for small wires. L L are screws for fixing in position the rods, R R, which support the knobs. In another arrangement with the

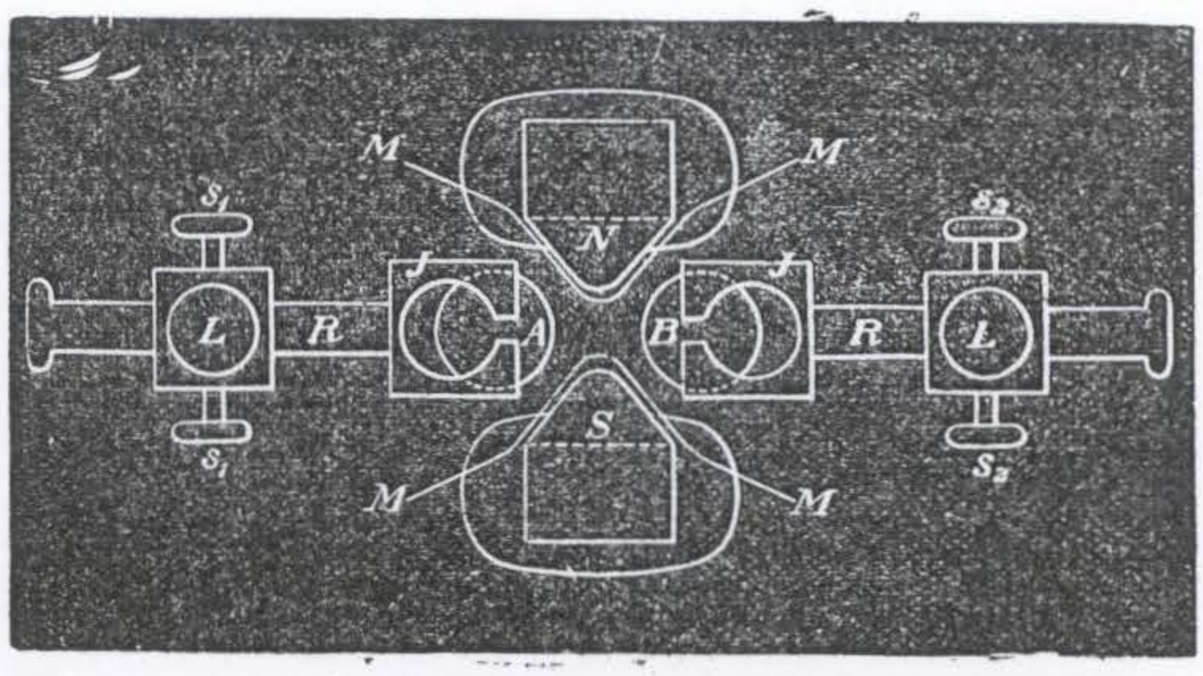


FIG. 4.—Arrangement of Improved Discharger and Magnet.

magnet I take the discharge between the rounded pole-pieces themselves, which in such case are insulated and preferably provided with polished brass caps.

The employment of an intense magnetic field is of advantage principally when the induction coil or transformer which charges the condenser is operated by currents of very low frequency. In such a case the number of the fundamental discharges between the knobs may be so small as to render the currents produced in the secondary unsuitable for many experiments. The intense magnetic field then serves to blow out the arc between the knobs as soon as it is formed, and the fundamental discharges occur in quicker succession. Instead of the magnet, a draught or blast of air may be employed with some advantage. In this case the arc is preferably established between the knobs, A B, in Fig 2 (the knobs *a b* being generally joined, or entirely done away with), as in this disposition the arc is long and unsteady, and is easily affected by the draught. When a magnet is employed to break the arc, it is better to choose the connection indicated schematically in Fig. 5, as in this case the currents forming the arc are much more powerful, and the magnetic field exercises a greater influence.

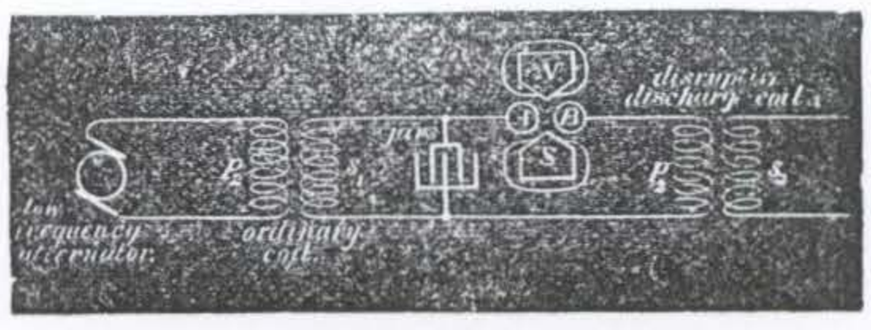


FIG. 5.—Arrangement with Low-Frequency Alternator and Improved Discharger.

The use of the magnet permits, however, of the arc being replaced by a vacuum tube, but I have encountered great difficulties in working with an exhausted tube.

The other form of discharger used in these and similar experiments is indicated in Figs. 6 and 7. It consists of a number of brass pieces, *c c* (Fig. 6), each of which comprises a spherical middle portion, *m*, with an extension, *e*, below—which is merely used to fasten the piece in a lathe when polishing up the discharging surface—and a column above, which consists of a knurled flange, *f*, surmounted by a threaded stem, *l*, carrying a nut, *n*, by means of which a wire is fastened to the column. The

flange, *f*, conveniently serves for holding the brass piece when fastening the wire, and also for turning it in any position when it becomes necessary to present a fresh discharging surface. Two stout strips of hard rubber, R R, with planed grooves, *g g* (Fig. 7), to fit the middle portion of the pieces, *c c*, serve to clamp the latter and hold them firmly in position by means of two bolts, C C (of which only one is shown), passing through the ends of the strips. In the use of this kind of discharger I have found three principal advantages over the ordinary form. Firstly, the dielectric strength of a given total width of air space is greater when a great many small air gaps are used instead of one, which permits of working with a smaller length of air gap, and that means smaller loss and less deterioration of the metal; secondly, by reason of splitting the arc up into smaller arcs, the polished surfaces are made to last much longer; and thirdly, the apparatus affords some gauge in the experiments. I usually set the pieces, by putting between them sheets of uniform thickness, at a certain very small distance which is known from the experiments of Sir William Thomson to require a certain E.M.F. to be bridged by the spark. It should, of course, be remembered that the sparking distance is much diminished as the frequency is increased. By taking any number of spaces the experimenter has a rough idea of

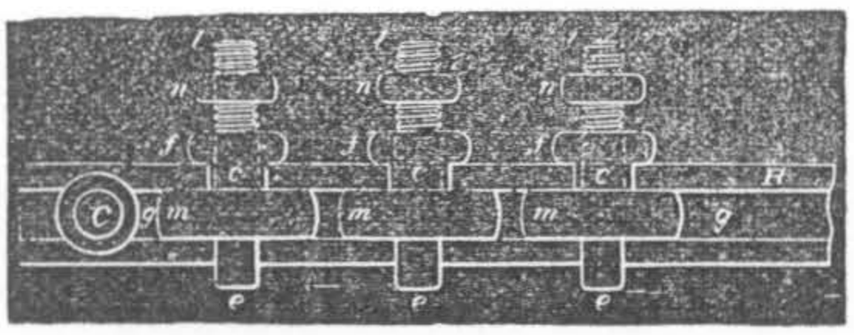


FIG. 6.

the E.M.F., and he finds it also easier to repeat an experiment, as he has not the trouble of setting the knobs again and again. With this kind of discharger I have been able to maintain an oscillating motion without any spark being visible with the naked eye between the knobs, and they would not show a very appreciable rise in temperature. This form of discharger also lends itself to many arrangements of condensers and circuits which are often very convenient and time-saving. I have used it preferably in a disposition similar to that indicated in Fig. 2, when the currents forming the arc are small.

I may here mention that I have also used dischargers with single or multiple air gaps, in which the discharge surfaces were rotated with great speed. No particular advantage was, however, gained by this method, except in cases where the currents from the condenser were large and the keeping cool of the surfaces was necessary, and in cases when, the discharge not being oscillating of itself, the arc as soon as established was broken by the air current, thus starting the vibration at intervals in rapid succession. I have also used mechanical interrupters in many ways. To avoid the difficulties with frictional contacts, the preferred plan adopted was to establish the arc and rotate through it at great speed a rim of mica provided with many holes, and fastened to a steel plate. It is understood, of course, that the employment of a magnet, air current, or other interrupter, produces no effect worth noticing, unless the self-induction, capacity, and resistance are so related that there are oscillations set up upon each interruption.

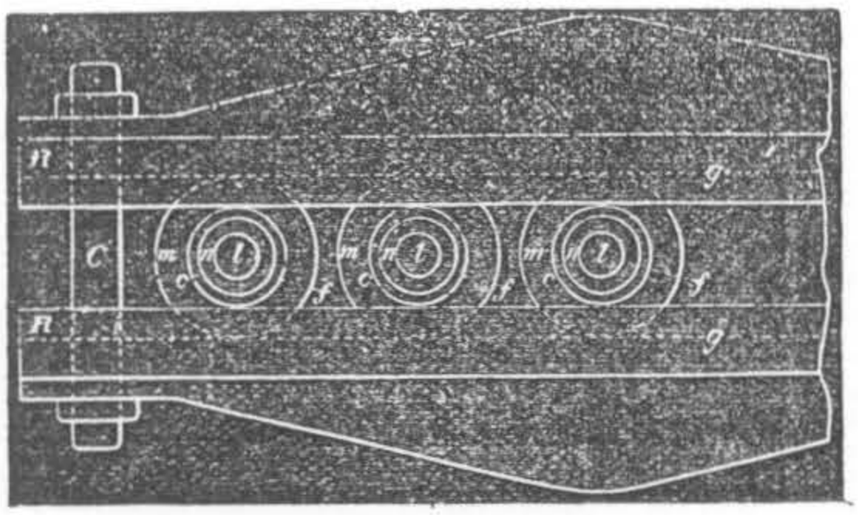


FIG. 7.—Discharger with Multiple Gaps.

I will now endeavour to show you some of the most noteworthy of these discharge phenomena. I have stretched across the room two ordinary cotton-covered wires, each about seven metres in length. They are supported on insulating cords at a distance of about 30 centimetres. I attach now to each of the terminals of the coil one of the wires, and set the coil in action. Upon turning the lights off in the room you see the wires strongly illuminated by the streams issuing abundantly from their whole surface in spite of the cotton covering, which may even be very thick. When the experiment is performed under good conditions, the light from the wires is sufficiently intense to allow distinguishing the objects in a room. To produce the best result it is, of course, necessary to adjust carefully the capacity of the jars, the arc between the knobs, and the length of the wires. My experience is that calculation of the length of the wires leads in such case to no result whatever. The experimenter will do best to take the wires at the start very long, and then adjust by cutting off first long pieces, and then smaller and smaller ones as he approaches the right length. A convenient way is to use an oil condenser of very small capacity, consisting of two small adjustable metal plates, in connection with this and similar experiments. In such case I take wires rather short, and set at the beginning the condenser plates at maximum distance. If the streams from the wires increase by approach of the plates, the length of the wires is

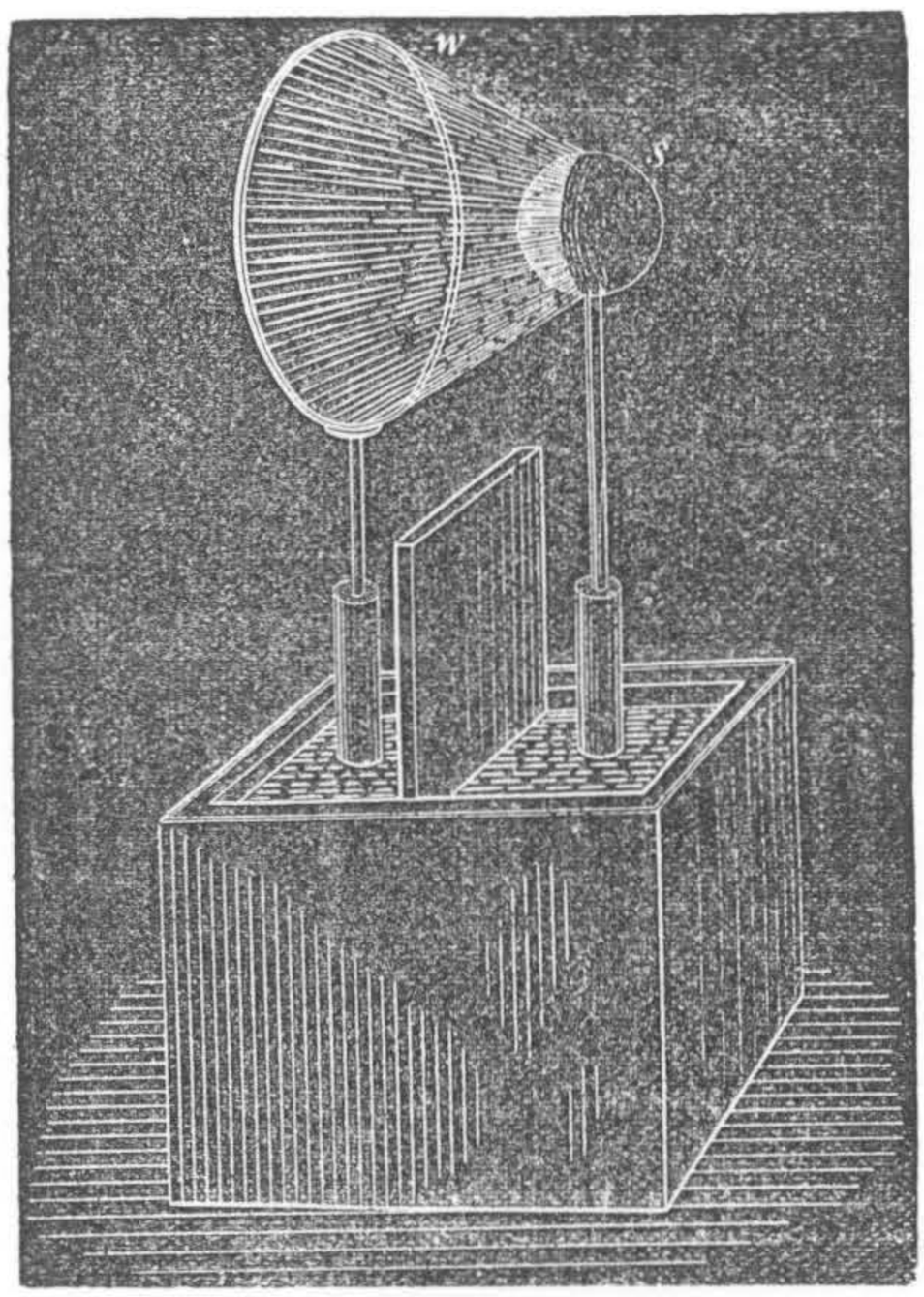


FIG. 8.—Effect produced by Concentrating Streams.

about right; if they diminish, the wires are too long for that frequency and potential. When a condenser is used in connection with experiments with such a coil, it should be an oil condenser by all means, as in using an air condenser considerable energy might be wasted. The wires leading to the plates in the oil should be very thin, heavily coated with some insulating

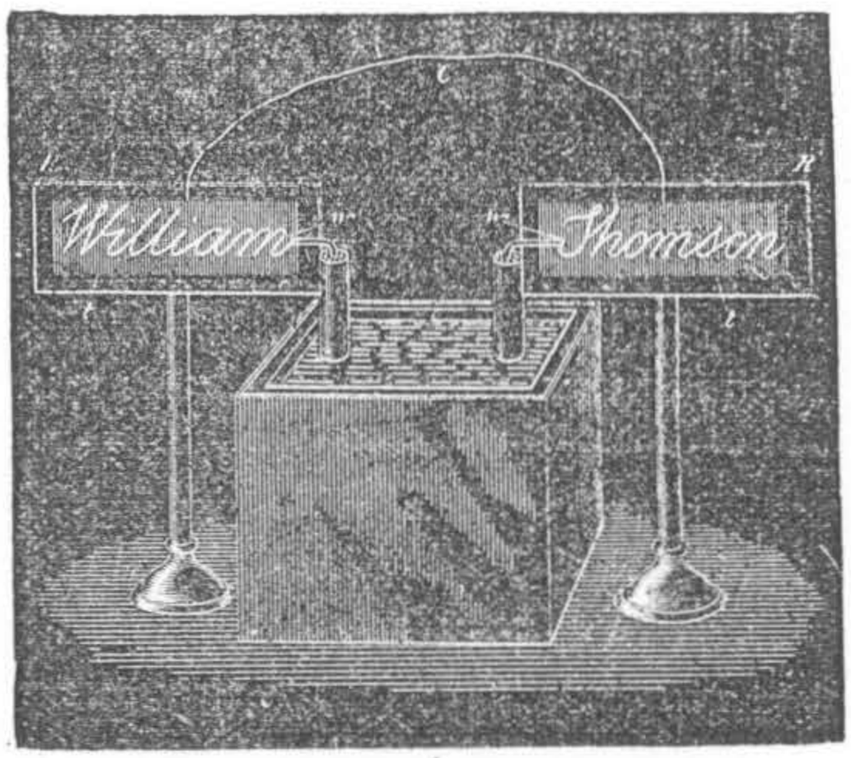


FIG. 9.—Wires Rendered Intensely Luminous.

compound, and provided with a conducting covering—this preferably extending under the surface of the oil. The conducting cover should not be too near the terminals, or ends, of the wire, as a spark would be apt to jump from the wire to it. The conducting coating is used to diminish the air losses, in virtue of its action as an electrostatic screen. As to the size of the vessel containing the oil, and the size of the plates, the experimenter gains at once an idea from a rough trial. The size of the plates in oil is, however, calculable, as the dielectric losses are very small. In the preceding experiment it is of considerable interest to know what relation the quantity of the light emitted bears to the frequency and potential of the electric impulses. My opinion is that the heat as well as light effects produced should be proportionate, under otherwise equal conditions of test, to the product of frequency and square of potential, but the experimental verification of the law, whatever it may be, would be exceedingly difficult. One thing is certain, at any rate, and that is, that in augmenting the potential and frequency we

rapidly intensify the streams; and, though it may be very sanguine, it is surely not altogether hopeless to expect that we may succeed in producing a practical illuminant on these lines. We would then be simply using burners or flames, in which there would be no chemical process, no consumption of material, but merely a transfer of energy, and which would in all probability emit more light and less heat than ordinary flames. The luminous intensity of the stream is, of course, considerably increased when they are focused upon a small surface. This may be shown by the following experiment. I attach to one of the terminals of the coil a wire, *w* (Fig. 8), bent in a circle of about 30 centimetres in diameter, and to the other terminal I fasten a small brass sphere, *s*; the surface of the wire being preferably equal to the surface of the sphere, and the centre of the latter being in a line at right angles to the plane of the wire circle and passing through its centre. When the discharge is established under proper conditions, a luminous hollow cone is formed, and in the dark one half of the brass sphere is strongly illuminated, as shown in the cut. By some artifice or other it is easy to concentrate the streams upon small surfaces and to produce very strong light effects. Two thin wires may thus be rendered intensely luminous. In order to intensify the streams the wires should be very thin and short; but as in this case their capacity would be generally too small for the coil, at least for such a one as the present, it is necessary to augment the capacity to the required value, while, at the same time, the surface of the wires remains very small. This may be done in many ways. Here, for instance, I have two plates, R R, of hard rubber, Fig. 9, upon which I have glued two very thin wires, *w w*, so as to form a name. The wires may be bare or covered with the best insulation—it is immaterial for the success of the experiment. Well, insulated wires, if anything, are preferable. On the back of each plate, indicated by the shaded portion, is a tinfoil coating, *t t*. The plates are placed in line at a sufficient distance to prevent a spark passing from one to the other wire. The two tinfoil coatings I have joined by a conductor, C, and the two wires I presently connect to the terminals of the coil. It is now easy, by varying the strength and frequency of the currents through the primary, to find a point at which the capacity of the system is best suited to the conditions, and the wires become so strongly luminous that when the light in the room is turned off, the name formed by them appears in brilliant letters. It is perhaps preferable to perform this experiment with a coil operated from an alternator of high frequency, as then, owing to the harmonic rise and fall, the streams are very uniform, though they are less abundant than when produced with such a coil as the present. This experiment, however, may be performed with low frequencies, but much less satisfactorily.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

BY NIKOLA TESLA.

(*Continued from page 405.*)

When two wires, attached to the terminals of the coil, are set at the proper distance, the streams between them may be so intense as to produce a continuous luminous sheet. To show this phenomenon I have here two circles, C and *c* (Fig. 10), of rather stout wire, one being about 80 centimetres and the other 30 centimetres in diameter. To each of the terminals of the coil I attach one of the circles. The supporting wires are so bent that the circles may be placed on the same plane, coinciding as nearly as possible. When the light in the room is turned off and the coil set to work, you see the whole space between the wires uniformly filled with streams, forming a luminous disc, which could be seen from a considerable distance, such is the intensity of the streams. The outer circle could have been much larger than the present one; in fact, with this coil I have used much larger circles, and I have been able to produce a strongly luminous sheet, covering an area of more than one square metre, which is a remarkable effect with this very small coil. To avoid uncertainty, the circle has been taken

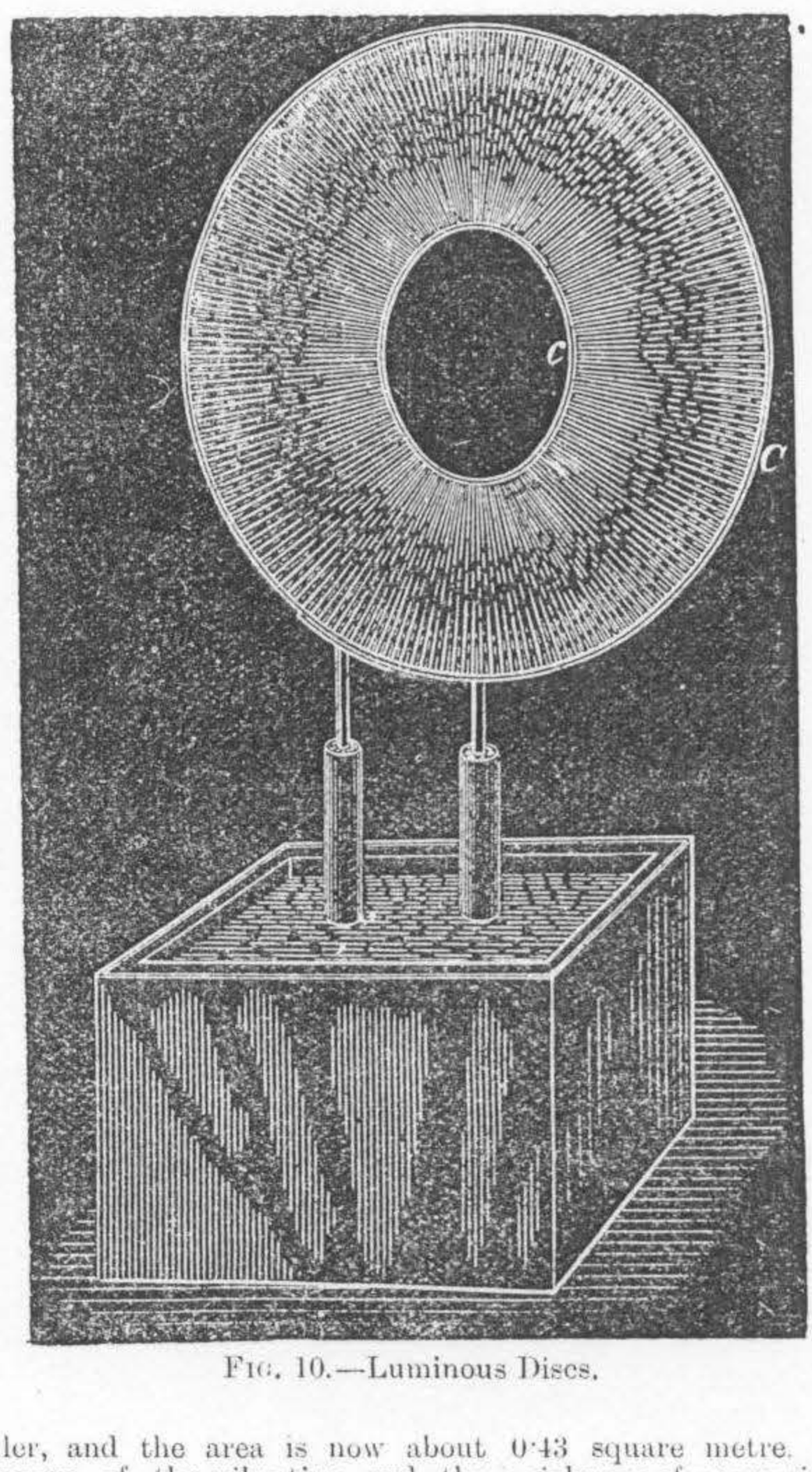


FIG. 10.—Luminous Discs.

smaller, and the area is now about 0·43 square metre. The frequency of the vibration and the quickness of succession of the sparks between the knobs affect to a marked degree the appearance of the streams. When the frequency is very low the air gives way in more or less the same manner as by a steady difference of potential, and the streams consists of distinct threads generally mingled with thin sparks, which probably correspond to the successive discharges occurring between the knobs. But when the frequency is extremely high, and the arc of the discharge produces a very loud but smooth sound—showing both that oscillation takes place and that the sparks succeed each other with great rapidity—then the luminous streams formed are perfectly uniform. To reach this result very small coils and jars of small capacity should be used. I take two tubes of thick Bohemian glass, about five centimetres in diameter and 20 centimetres long. In each of the tubes I slip a primary of very thick copper wire. On the top of each tube I wind a secondary of much thinner gutta-percha-covered wire. The two secondaries I connect in series, the primaries preferably in multiple arc. The tubes are then placed in a large glass vessel, at a distance of 10 to 15 centimetres from each other, on insulating supports, and the vessel is filled with boiled-out oil, the oil reaching about an inch above the tubes.

* Lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the *Journal* of the Institution of Electrical Engineers.

The free ends of the secondary are lifted out of the oil and placed parallel to each other at a distance of about 10 centimetres. The ends which are scraped should be dipped in the oil. Two four-pint jars joined in series may be used to discharge through the primary. When the necessary adjustments in the length and distance of the wires above the oil and in the arc of discharge are made, a luminous sheet is produced between the wires which is perfectly smooth and textureless, like the ordinary discharge through a moderately exhausted tube.

I have purposely dwelt upon this apparently insignificant experiment. In trials of this kind the experimenter arrives at the startling conclusion that to pass ordinary luminous discharges through gases no particular degree of exhaustion is needed, but that the gas may be at ordinary or even greater pressure. To accomplish this a very high frequency is essential; a high potential is likewise required, but this is a merely incidental necessity. These experiments teach us that in endeavouring to discover novel methods of producing light by the agitation of atoms, or molecules of a gas, we need not limit our research to the vacuum tube, but may look forward quite seriously to the possibility of obtaining the light effects without the use of any vessel whatever with air at ordinary pressure. Such discharges of very high frequency, which render luminous the air at ordinary pressures, we have probably often occasion to witness in nature. I have no doubt that if, as many believe, the aurora borealis is produced by sudden cosmic disturbances, such as eruptions at the sun's surface, which set the electrostatic charge of the earth in an extremely rapid vibration, the red glow observed is not confined to the upper rarefied strata of the air, but the discharge traverses, by reason of its very high frequency, also the

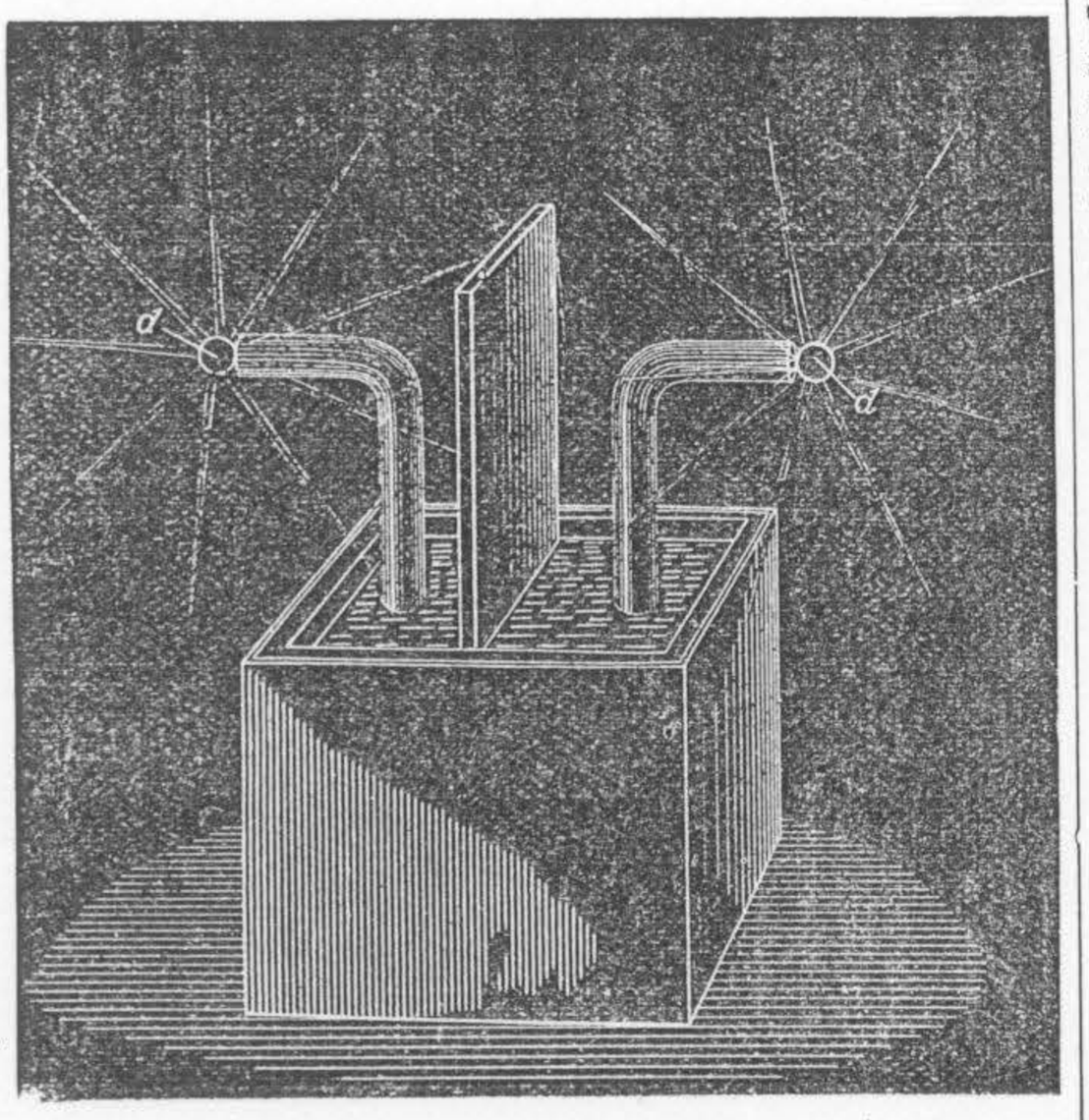


FIG. 11.—Phantom Streams.

dense atmosphere in the form of a glow, such as we ordinarily produce in a slightly exhausted tube. If the frequency were very low, or even more so, if the charge were not at all vibrating, the dense air would break down as in a lightning discharge. Indications of such breaking down of the lower dense strata of the air have been repeatedly observed at the occurrence of this marvellous phenomenon; but if it does occur, it can only be attributed to the fundamental disturbances, which are few in number, for the vibration produced by them would be far too rapid to allow a disruptive break. It is the original and irregular impulses which affect the instruments. The superimposed vibrations probably pass unnoticed. When an ordinary low-frequency discharge is passed through moderately rarefied air, the air assumes a purplish hue. If by some means or other we increase the intensity of the molecular, or atomic, vibration, the gas changes to a white colour. A similar change occurs at ordinary pressures with electric impulses of very high frequency. If the molecules of the air around a wire are moderately agitated, the brush formed is reddish or violet; if the vibration is rendered sufficiently intense, the streams become white. We may accomplish this in various ways. In the experiment before shown with the two wires across the room, I have endeavoured to secure the result by pushing to a high value both the frequency and potential; in the experiment with the thin wires glued on the rubber plate, I have concentrated the action upon a very small surface—in other words, I have worked with a great electric density.

A most curious form of discharge is observed with such a coil when the frequency and potential are pushed to the extreme limit. To perform the experiment, every part of the coil should be heavily insulated, and only two small spheres—or better still, two sharp-edged metal discs (*d d*, Fig. 11) of no more than a few centimetres in diameter—should be exposed to the air. The coil here used is immersed in oil, and the ends of the secondary reaching out of the oil are covered with an air-tight cover of hard rubber of great thickness. All cracks, if there are any, should be carefully stopped up, so that the brush discharge cannot form anywhere except on the small spheres or plates which are exposed to the air. In this case, since there are no large plates or other bodies of capacity attached to the terminals, the coil is capable of an extremely rapid vibration. The potential may be raised by increasing, as far as the experimenter judges proper, the rate of change of the primary current. With a coil not widely differing from the present, it is best to connect the two primaries in multiple arc; but if the secondary should have a much greater number of turns, the primaries should preferably be used in series, as otherwise the vibration might be too fast for the secondary. It occurs under these conditions that misty white streams break forth from the edges of the disc and spread out phantomlike into space. With this coil, when fairly well produced, they are about 25 to 30 centimetres long. When the hand is held against them, no sensation is produced, and a spark, causing a shock, jumps from the terminal only upon the hand being brought much nearer. If the oscillation of the primary current is rendered intermittent by some means or other, there is a corresponding throbbing of the streams, and now the hand or other conducting object may be brought in still greater proximity to the terminal without a spark being caused to jump. Among the many beautiful phenomena which may be produced with such a coil, I have here selected only those which appear to possess some features of novelty, and lead us to some conclusions of interest. One will not find it at all difficult to produce in the laboratory by means of it many other phenomena which appeal to the eye even more than these here shown, but present no particular feature of novelty.

Early experimenters describe the display of sparks produced by an ordinary large induction coil upon an insulating plate separating the terminals. Quite recently Siemens performed some experiments in which fine effects were obtained, which were seen by many with interest. No doubt large coils, even if operated with currents of low frequencies, are capable of producing beautiful effects. But the largest coil ever made could not, by far, equal the magnificent display of streams and sparks obtained from such a disruptive discharge coil when properly adjusted. To give an idea, a coil such as the present one will cover easily a plate of one metre in diameter completely with the streams. The best way to perform such experiments is to take a very thin rubber or a glass plate and glue on one side of it a narrow ring of tinfoil of very large diameter, and on the other a circular washer, the centre of the latter coinciding with that of the ring, and the surfaces of both being preferably equal, so as to keep the coil well balanced. The washer and ring should be connected to the terminals by heavily insulated thin wires. It is easy in observing the effect of the capacity to produce a sheet of uniform streams, or a fine network of thin silvery threads, or a mass of loud brilliant sparks, which cover completely the plate.

Since I have advanced the idea of the conversion by means of the disruptive discharge, in my paper before the American Institute of Electrical Engineers at the beginning of the past year, the interest excited in it has been considerable. It affords us a means for producing any potentials by the aid of inexpensive coils operated from ordinary systems of distribution, and—what is perhaps more appreciated—it enables us to convert currents of any frequency into currents of any other lower or higher frequency. But its chief value will perhaps be found in the help which it will afford us in the investigations of the phenomena of phosphorescence, which a disruptive discharge coil is capable of exciting in innumerable cases where ordinary coils, even the largest, would utterly fail. Considering its probable uses for many practical purposes, and its possible introduction into laboratories for scientific research, a few additional remarks as to the construction of such a coil will, perhaps, not be found superfluous. It is, of course, absolutely necessary to employ in such a coil wires provided with the best insulation. Good coils may be produced by employing wires covered with several layers of cotton, boiling the coil a long time in pure wax, and cooling under moderate pressure. The advantage of such a coil is that it can be easily handled, but it cannot probably give as satisfactory results as a coil immersed in pure oil. Besides, it seems that the presence of a large body of wax affects the coil disadvantageously, whereas this does not seem to be the case with oil. Perhaps it is because the dielectric losses in the liquid are smaller. I have tried at first silk-covered and cotton-covered wires with oil immersion, but I have been gradually led to use guttapercha-covered wires, which proved most satisfactory. Guttapercha insulation adds, of course, to the capacity of the coil, and this, especially if the coil be large, is a great disadvantage when extreme frequencies are desired; but, on the other hand, guttapercha will withstand much more than an equal thickness of oil, and this advantage should be secured at any price. Once the coil has been immersed, it should never be taken out of the oil for more than a few hours, else the guttapercha will crack up and the coil will not be worth half as much as before. Guttapercha is probably slowly attacked by the oil, but after an immersion of eight to nine months I have found no ill-effects. I have obtained in commerce two kinds of guttapercha wire: in one the insulation sticks tightly to the metal, in the other it does not. Unless a special method is followed to expel all air, it is much safer to use the first kind. I wind the coil within an oil tank so that all interstices are filled up with the oil. Between the layers I use cloth boiled out thoroughly in oil, calculating the thickness according to the difference of potential between the turns. There seems not to be a very great difference whatever kind of oil is used; I use paraffin or linseed oil.

To exclude more perfectly the air, an excellent way to proceed, and easily practicable with small coils, is the following : Construct a box of hard wood of very thick boards which have been for a long time boiled in oil. The boards should be so joined as to safely withstand the external air pressure. The coil being placed and fastened in position within the box, the latter is closed with a strong lid, and covered with closely-fitting metal sheet, the joints of which are soldered very carefully. On the top two small holes are drilled, passing through the metal sheet and the wood, and in these holes two small glass tubes are inserted and the joints made air-tight. One of the tubes is connected to a vacuum pump, and the other with a vessel containing a sufficient quantity of boiled-out oil. The latter tube has a very small hole at the bottom, and is provided with a stop-cock. When a fairly good vacuum has been obtained, the stop-cock is opened and the oil slowly fed in. Proceeding in this manner, it is impossible that any big bubbles, which are the principal danger, should remain between the turns. The air is most completely excluded, probably better than by boiling out, which, however, when guttapercha-coated wires are used, is not practicable. For the primaries I use ordinary line wire with a thick cotton coating. Strands of very thin insulated wires properly interlaced would, of course, be the best to employ for the primaries, but they are not to be had. In an experimental coil the size of the wires is not of great importance. In the coil here used the primary is No. 12, and the secondary No. 24 Brown and Sharpe W.G. wire ; but the sections may be varied considerably ; it would only imply different adjustments, the results aimed at would not be materially affected.

I have dwelt at some length upon the various forms of brush discharge because, in studying them, we not only observe phenomena which please our eye, but also afford us food for thought, and lead us to conclusions of practical importance. In the use of alternating currents of very high tension, not too much precaution can be taken to prevent the brush discharge. In a main conveying such currents, in an induction coil or transformer, or in a condenser, the brush discharge is a source of great danger to the insulation. In a condenser especially the gaseous matter must be most carefully expelled, for in it the charged surfaces are near each other, and if the potentials are high, just as sure as a weight will fall if let go, so the insulation will give way if a single gaseous bubble of some size be present, whereas, if all gaseous matter were carefully excluded, the condenser would safely withstand a much higher difference of potential. A main conveying alternating currents of very high tension may be injured merely by a blow-hole or small crack in the insulation, the more so as a blow-hole is apt to contain gas at low pressure ; and as it appears almost impossible to completely obviate such little imperfections, I am led to believe that in our future distributions of electrical energy by currents of very high tension, liquid insulation will be used. The cost is a great drawback, but if we employ an oil as an insulator, the distributions of electrical energy with something like 100,000 volts, and even more, become, at least with higher frequencies, so easy that they could be hardly called engineering feats. With oil insulation and alternate-current motors transmissions of power can be effected with safety, and upon an industrial basis, at distances of as much as a thousand miles.

A peculiar property of oils, and liquid insulation in general, when subjected to rapidly changing electric stresses, is to disperse any gaseous bubbles which may be present, and diffuse them through its mass, generally long before any injurious break can occur. This feature may be easily observed with an ordinary induction coil by taking the primary out, plugging up the end of the tube upon which the secondary is wound, and filling it with some fairly transparent insulator, such as paraffin oil. A primary of a diameter something like six millimetres smaller than the inside of the tube may be inserted in the oil. When the coil is set to work, one may see, looking from the top through the oil, many luminous points—air bubbles which are caught by inserting the primary, and which are rendered luminous in consequence of the violent bombardment. The occluded air, by its impact against the oil, heats it ; the oil begins to circulate, carrying some of the air along with it, until the bubbles are dispersed and the luminous points disappear. In this manner, unless large bubbles are occluded in such way that circulation is rendered impossible, a damaging break is averted, the only effect being a moderate warming up of the oil. If, instead of the liquid, a solid insulation, no matter how thick, were used, a breaking through and injury of the apparatus would be inevitable.

The exclusion of gaseous matter from any apparatus in which the dielectric is subjected to more or less rapidly changing electric forces is, however, not only desirable in order to avoid a possible injury of the apparatus, but also on account of economy. In a condenser, for instance, as long as only a solid or only a liquid dielectric is used, the loss is small ; but if a gas under ordinary or small pressure be present the loss may be very great. Whatever the nature of the force acting in the dielectric may be, it seems that in a solid or liquid the molecular displacement produced by the force is small : hence the product of force and displacement is insignificant, unless the force be very great ; but in a gas the displacement, and therefore this product, is considerable ; the molecules are free to move, they reach high speeds, and the energy of their impact is lost in heat or otherwise. If the gas be strongly compressed, the displacement due to the force is made smaller, and the losses are reduced.

In most of the succeeding experiments I prefer, chiefly on account of the regular and positive action, to employ the alternator before referred to. This is one of the several machines constructed by me for the purposes of these investigations. It has 384 pole projections, and is capable of giving currents of a frequency of about 10,000 per second. This machine has been illustrated and briefly described in my first paper before the American Institute of Electrical Engineers, May 20th, 1891, to which I have already referred. A more detailed description, sufficient to enable any engineer to build a similar machine, will be found in several electrical journals of that period. The induction coils operated from the machine are rather small, containing from 5,000 to 15,000 turns in the secondary. They are immersed in boiled-out linseed oil, contained in wooden boxes covered with zinc sheet. I have found it advantageous to reverse the usual position of the wires, and to wind, in these coils, the primaries on the top ; this allowing the use of a much bigger primary, which, of course, reduces the danger of overheating, and increases the output of the coil. I make the primary on each side at least one centimetre shorter than the secondary, to prevent the breaking through on the ends, which would surely occur unless the insulation on the top of the secondary be very thick, and this, of course, would be disadvantageous. When the primary is made movable, which is necessary in some experiments, and many times convenient for the purposes of adjustment, I cover the secondary with wax, and turn it off in a lathe to a diameter slightly smaller than the inside of the primary coil. The latter I provide with a handle reaching out of the oil, which serves to shift it in any position along the secondary.

I will now venture to make, in regard to the general manipulation of induction coils, a few observations bearing upon points which have not been fully appreciated in earlier experiments with such coils, and are even now often overlooked. The secondary of the coil possesses usually such a high self-induction that the current through the wire is inappreciable, and may be so even when the terminals are joined by a conductor of small resistance. If capacity is added to the terminals, the self-induction is counteracted, and a stronger current is made to flow through the secondary, though its terminals are insulated from each other. To one entirely unacquainted with the properties of alternating currents nothing will look more puzzling. This feature was illustrated in the experiment performed at the beginning with the top plates of wire gauze attached to the terminals and the rubber plate. When the plates of wire gauze were close together, and a small arc passed between them, the arc prevented a strong current to pass through the secondary, because it did away with the capacity on the terminals ; when the rubber plate was inserted between, the capacity of the condenser formed counteracted the self-induction of the secondary, a stronger current passed now, the coil performed more work, and the discharge was by far more powerful. The first thing, then, in operating the induction coil is to combine capacity with the secondary, to overcome the self-induction. If the frequency and potentials are very high, gaseous matter should be carefully kept away from the charged surfaces. If Leyden jars are used, they should be immersed in oil, as otherwise considerable dissipation may occur if the jars are greatly strained. When high frequencies are used, it is of equal importance to combine a condenser with the primary. One may use a condenser connected to the ends of the primary or to the terminals of the alternator, but the latter is not to be recommended, as the machine might be injured. The best way is, undoubtedly, to use the condenser in series with the primary and with the alternator, and to adjust its capacity so as to annul the self-induction of both the latter. The condenser should be adjustable by very small steps, and for a finer adjustment a small oil condenser with movable plates may be used conveniently.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

BY NIKOLA TESLA.

(Continued from page 429.)

I think it best at this juncture to bring before you a phenomenon, observed by me some time ago, which to the purely

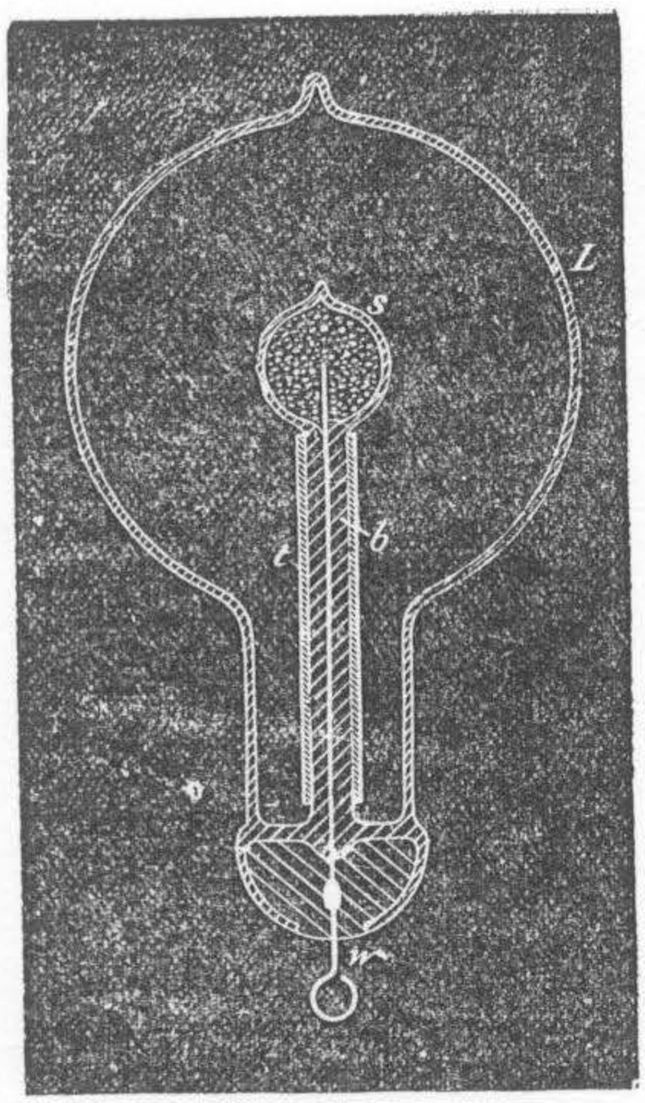


FIG. 12.—Bulb for Producing Rotating Brush.

scientific investigator may perhaps appear more interesting than any of the results which I have the privilege to present to you this evening. It may be quite properly ranked among the brush

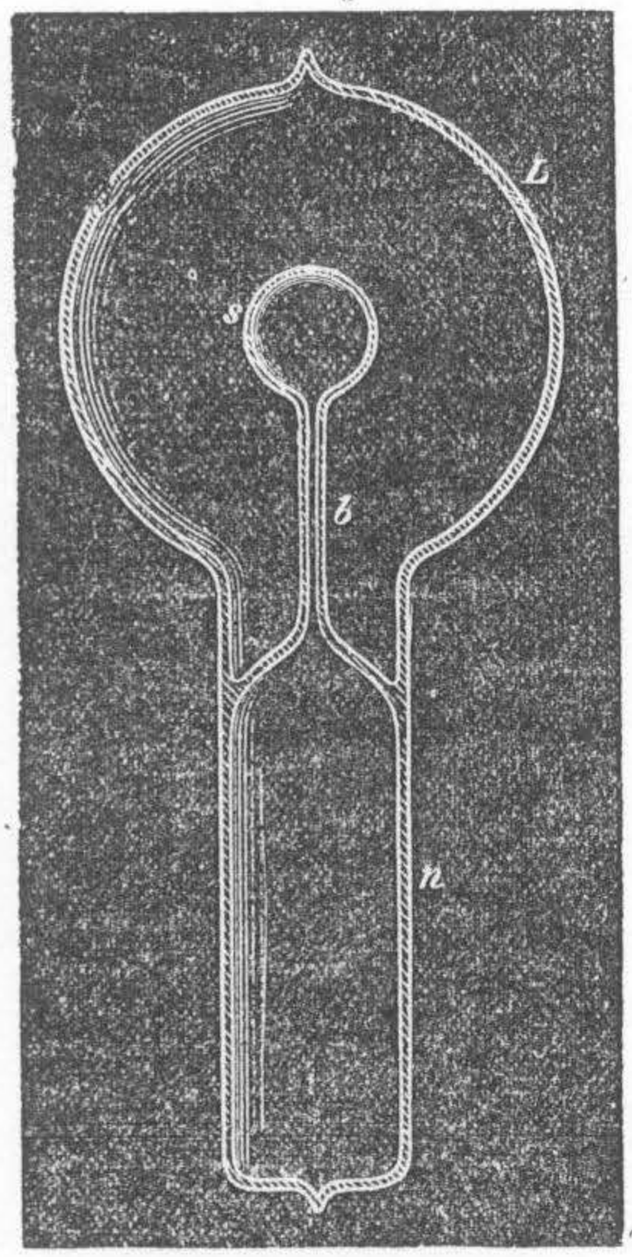
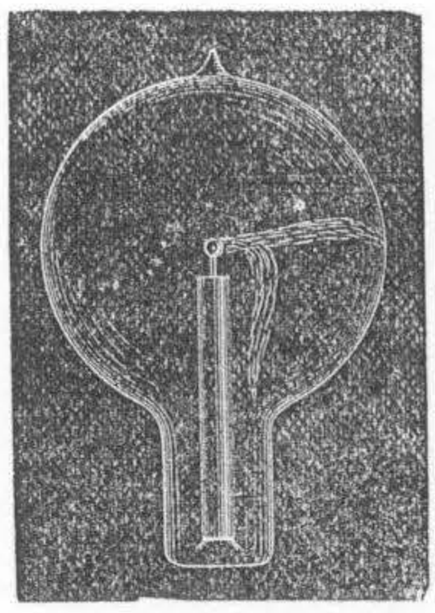
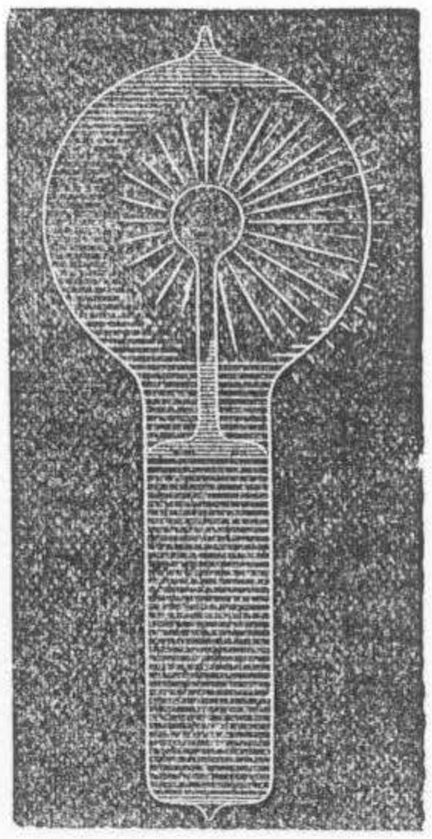


FIG. 13.—Bulb for Producing Rotating Brush.

phenomena—in fact, it is a brush formed at, or near, a single terminal in high vacuum. In bulbs provided with a conducting terminal, though it be of aluminium, the brush has but an ephemeral existence, and cannot, unfortunately, be indefinitely preserved in its most sensitive state, even in a bulb devoid of any conducting electrode. In studying the phenomenon, by all means a bulb having no leading-in wire should be used. I have found it best to use bulbs constructed as indicated in Figs. 12 and 13. In Fig. 12 the bulb comprises an incandescent lamp globe, L, in the neck of which is sealed a barometer tube, *b*, the end of which is blown out to form a small sphere, *s*. This sphere should be sealed as closely as possible in the centre of the large globe. Before sealing, a thin tube, *t*, of aluminium sheet may be slipped in the barometer tube, but it is not important to employ it. The small hollow sphere, *s*, is filled with some conducting powder, and a wire, *w*, is cemented in the neck for the purpose of connecting the conducting powder with the generator. The construction shown in Fig. 13 was chosen in order to remove from the brush any conducting body which might possibly affect it. The bulb consists in this case of a lamp globe, L, which has a neck, *n*, provided with a tube, *b*, and small sphere,





FIGS. 14 AND 15.—Forms and Phases of the Rotating Brush.

s, sealed to it, so that two entirely independent compartments are formed, as indicated in the drawing. When the bulb is in use, the neck, *n*, is provided with a tinfoil coating, which is connected to the generator, and acts inductively upon the moderately rarefied and highly conducting gas enclosed in the neck. From there the current passes through the tube, *b*, into the small sphere, *s*, to act by induction upon the gas contained in the globe, L. It is of advantage to make the tube, *t*, very thick, the hole through it very small, and to blow the sphere, *s*, very thin. It is of the greatest importance that the sphere, *s*, be placed in the centre of the globe, L. Figs. 14, 15, and 16 indicate different forms or stages of the brush. Fig. 14 shows the brush as it first appears in a bulb provided with a conducting terminal; but as in such a bulb it very soon disappears—often in a few minutes— I will confine myself to the description of the phenomenon as seen in a bulb with-

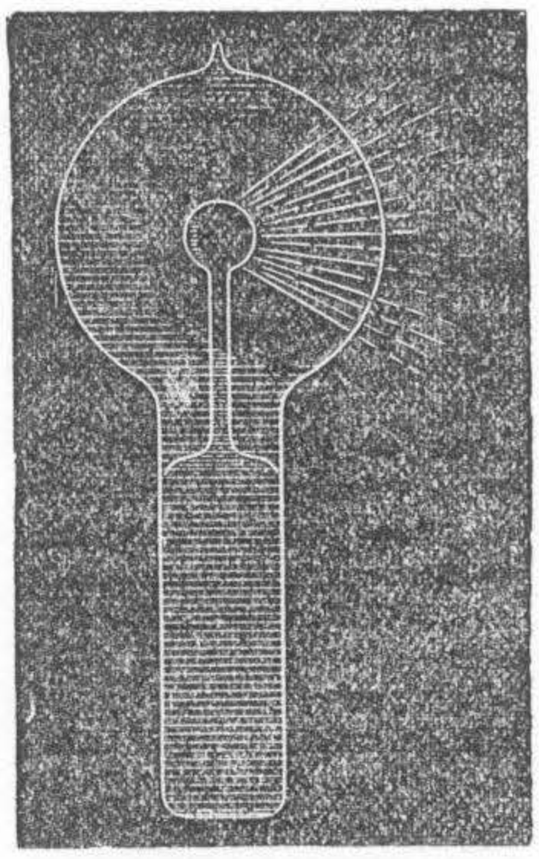


FIG. 16.—Form and Phase of the Rotating Brush.

out conducting electrode. It is observed under the following conditions: When the globe, L (Figs. 12 and 13), is exhausted to a very high degree, generally the bulb is not excited upon connecting the wire, *w* (Fig. 12), or the tinfoil coating of the bulb, Fig. 13, to the terminal of the induction coil. To excite it, is is usually sufficient to grasp the globe, L, with the hand. An intense phosphorescence then spreads at first over the globe, but soon gives place to a white misty light. Shortly after-

* Lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the *Journal* of the Institution of Electrical Engineers.

wards one may notice that the luminosity is unevenly distributed in the globe, and after passing the current for some time the bulb appears as in Fig. 15. From this stage the phenomenon will gradually pass to that indicated in Fig. 16, after some minutes, hours, days, or weeks, according how the bulb is worked. Warming the bulb or increasing the potential hastens the transit. When the brush assumes the form indicated in Fig. 16, it may be brought to a state of extreme sensitiveness to electrostatic and magnetic influence. The bulb hanging straight down from a wire, and all objects being remote from it, the approach of the observer at a few paces from the bulb will cause the brush to fly to the opposite side, and if he walks around the bulb it will always keep on the opposite side. It may begin to spin around the terminal long before it reaches that sensitive stage. When it begins to turn around principally, but also before, it is affected by a magnet, and a certain stage it is susceptible to magnetic influence to an astonishing degree. A small permanent magnet, with its poles at a distance of no more than two centimetres, will affect it visibly at a distance of two metres, slowing down or accelerating the rotation according to how it is held relatively to the brush. I think I have observed that at the stage when it is most sensitive to magnetic, it is not most sensitive to electrostatic influence. My explanation is, that the electrostatic attraction between the brush and the glass of the bulb, which retards the rotation, grows much quicker than the magnetic influence when the intensity of the stream is increased. When the bulb hangs with the globe, L, down, the rotation is always clockwise. In the southern hemisphere it would occur in the opposite direction, and on the equator the brush should not turn at all. The rotation may be reversed by a magnet kept at some distance. The brush rotates, seemingly, best when it is at right angles to the lines of force of the earth. It very likely rotates, when at its maximum speed, in synchronism with the alternations, say 10,000 times a second. The rotation can be slowed down or accelerated by the approach or receding of the observer, or any conducting body, but it cannot be reversed by putting the bulb in any position. When it is in the state of the highest sensitiveness, and the potential or frequency be varied, the sensitiveness is rapidly diminished. Changing either of these but little will generally stop the rotation. The sensitiveness is likewise affected by the variations of temperature. To attain great sensitiveness it is necessary to have the small sphere, *s*, in the centre of the globe, L, as otherwise the electrostatic action of the glass of the globe will tend to stop the rotation. The sphere, *s*, should be small and of uniform thickness: any dissymmetry, of course, has the effect to diminish the sensitiveness. The fact that the brush rotates in a definite direction in a permanent magnetic field seems to show that in alternating currents of very high frequency the positive and negative impulses are not equal, but that one always preponderates over the other. Of course this rotation in one direction may be due to the action of two elements of the same current upon each other, or to the action of the field produced by one of the elements upon the other, as in a series motor, without necessarily one impulse being stronger than the other. The fact that the brush turns, as far as I could observe, in any position, would speak for this view. In such case it would turn at any point of the earth's surface. But, on the other hand, it is then hard to explain why a permanent magnet should reverse the rotation, and one must assume the preponderance of impulses of one kind.

As to the causes of the formation of the brush or stream, I think it is due to the electrostatic action of the globe and the dissymmetry of the parts. If the small bulb, *s*, and the globe, L, were perfect concentric spheres, and the glass throughout of the same thickness and quality, I think the brush would not form, as the tendency to pass would be equal on all sides. That the formation of the stream is due to an irregularity is apparent from the fact that it has the tendency to remain in one position, and rotation occurs most generally only when it is brought out of this position by electrostatic or magnetic influence. When in an extremely sensitive state it rests in one position, most curious experiments may be performed with it. For instance, the experimenter may, by selecting a proper position, approach the hand at a certain considerable distance to the bulb, and he may cause the brush to pass off by merely stiffening the muscles of the arm. When it begins to rotate slowly, and the hands are held at a proper distance, it is impossible to make even the slightest motion without producing a visible effect upon the brush. A metal plate connected to the other terminal of the coil affects it at great distance, slowing down the rotation often to one turn a second. I am firmly convinced that such a brush, when we learn how to produce it properly, will prove a valuable aid in the investigation of the nature of the forces acting in an electrostatic or magnetic field. If there is any motion which is measurable going on in the space, such a brush ought to reveal it. It is, so to speak, a beam of light, frictionless, devoid of inertia. I think that it may find practical applications in telegraphy. With such a brush it would be possible to send despatches across the Atlantic, for instance, with any speed, since its sensitiveness may be so great that the slightest changes will affect it. If it were possible to make the stream more intense and very narrow, its deflections could be easily photographed. I have been interested to find whether there is a rotation of the stream itself, or whether there is simply a stress travelling around in the bulb. For this purpose I mounted a light mica fan so that its vanes were in the path of the brush. If the stream itself was rotating, the fan would be spun around. I could produce no distinct rotation of the fan, although I tried the experiment repeatedly; but as the fan exerted a noticeable influence on the stream, and the apparent rotation of the latter was in this case never quite satisfactory, the experiment did not appear to be conclusive. I have been unable to produce the phenomenon with the disruptive discharge coil, although every other of these phenomena can be well produced by it—many, in fact, much better than with coils operated from an alternator. It may be possible to produce the brush by impulses of one direction, or even by a steady potential, in which case it would be still more sensitive to magnetic influence.

In operating an induction coil with rapidly alternating currents, we realise with astonishment, for the first time, the great importance of the relation of capacity, self-induction, and frequency as regards the general result. The effects of capacity are the most striking, for in these experiments, since the self-induction and frequency both are high, the critical capacity is very small, and need be but slightly varied to produce a very considerable change. The experimenter may bring his body in contact with the terminals of the secondary of the coil, or attach to one or both terminals insulated bodies of very small bulk, such as bulbs, and he may produce a considerable rise or fall of potential, and greatly affect the flow of the current through the primary. In the experiment before shown, in which a brush appears at a wire attached to one terminal, and the wire is vibrated when the experimenter brings his insulated body in contact with the other terminal of the coil, the sudden rise of potential was made evident.

I may show you the behaviour of the coil in another manner which possesses a feature of some interest. I have here a little light fan of aluminium sheet, fastened to a needle and arranged to rotate freely in a metal piece screwed to one of the terminals of the coil. When the coil is set to work, the molecules of the air are rhythmically attracted and repelled. As the force with which they are repelled is greater than that with which they are attracted, it results that there is a repulsion exerted on the surfaces of the fan. If the fan were made simply of a metal sheet, the repulsion would be equal on the opposite sides, and would produce no effect. But if one of the opposing surfaces is screened, or if, generally speaking, the bombardment on this side is weakened in some way or other, there remains the repulsion exerted upon the other, and the fan is set in rotation. The screening is best effected by fastening upon one of the opposing sides of the fan insulated conducting coatings, or, if the fan is made in the shape of an ordinary propeller screw, by fastening on one side, and close to it, an insulated metal plate. The static screen may, however, be omitted, and simply a thickness of insulating material fastened to one of the sides of the fan. To show the behaviour of the coil, the fan may be placed upon the terminal and it will readily rotate when the coil is operated by currents of very high frequency. With a steady potential, of course, and even with alternating currents of very low frequency, it would not turn, because of the very slow exchange of air, and consequently smaller bombardment; but in the latter case it might turn if the potential were excessive. With a pin wheel, quite the opposite rule holds good; it rotates best with a steady potential, and the effort is the smaller the higher the frequency. Now it is very easy to adjust the conditions so that the potential is normally not sufficient to turn the fan, but that by connecting the other terminal of the coil with an insulated body it rises to a much greater value, so as to rotate the fan, and it is likewise possible to stop the rotation by connecting to the terminal a body of different size, thereby diminishing the potential. Instead of using the fan in this experiment, we may use the "electric" radiometer with similar effect. But in this case it will be found that the vanes will rotate only at high exhaustion or at ordinary pressures; they will not rotate at moderate pressures, when the air is highly conducting. This curious observation was made conjointly by Prof. Crookes and myself. I attribute the result to the high conductivity of the air, the molecules of which then do not act as independent carriers of electric charges, but act all together as a single conducting body. In such case, of course, if there is any repulsion at all of the molecules from the vanes, it must be very small. It is possible, however, that the result is in part due to the fact that the greater part of the discharge passes from the leading-in wire through the highly-conducting gas, instead of passing off from the conducting vanes. In trying the preceding experiment with the electric radiometer the potential should not exceed a certain limit, as then the electrostatic attraction between the vanes and the glass of the bulb may be so great as to stop the rotation.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

BY NIKOLA TESLA.

(*Continued from page 449.*)

A most curious feature of alternate currents of high frequencies and potentials is that they enable us to perform many experiments by the use of one wire only. In many respects this feature is of great interest. In a type of alternate-current motor invented by me some years ago, I produced rotation by inducing, by means of a single alternating current passed through a motor circuit, in the mass or other circuits of the motor, secondary currents, which, jointly with the primary or inducing current, created a moving field of force. A simple but crude form of such a motor is obtained by winding upon an iron core a primary, and close to it a secondary coil, joining the ends of the latter and placing a freely movable metal disc within the influence of the field produced by

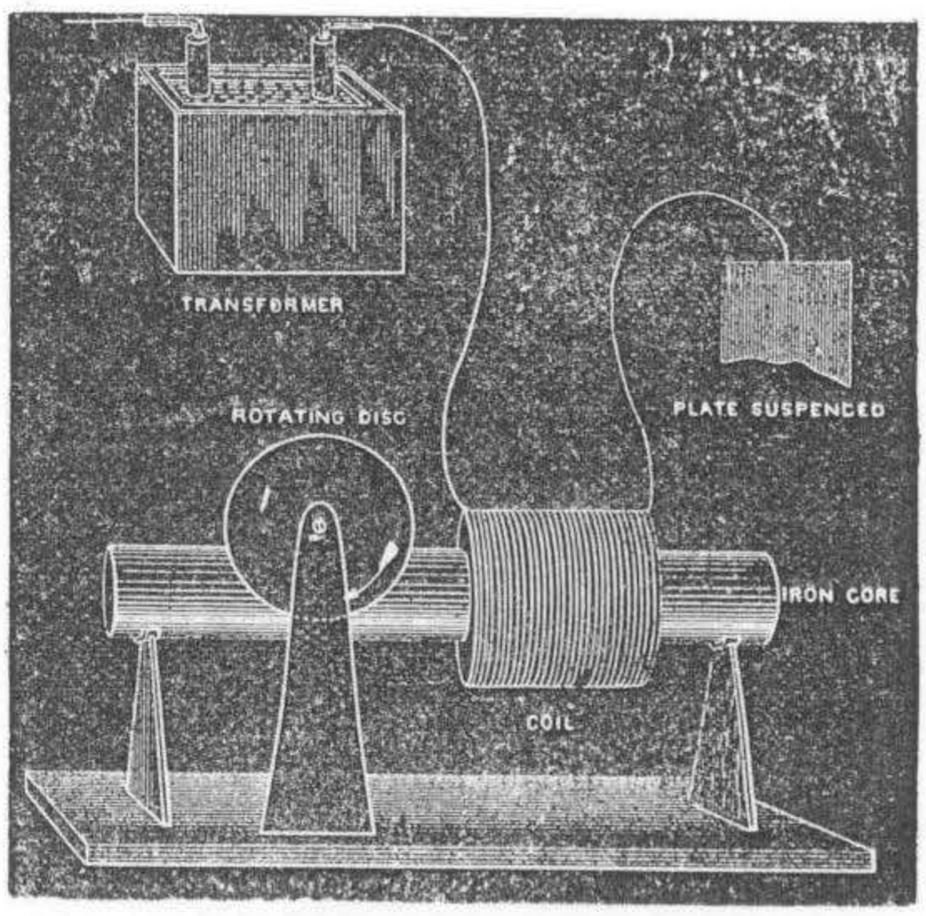


FIG. 17.—Single-Wire and "No-Wire" Motor.

both. The iron core is employed for obvious reasons, but it is not essential to the operation. To improve the motor, the iron core is made to encircle the armature. Again to improve, the secondary coil is made to overlap partly the primary, so that it cannot free itself from a strong inductive action of the latter, repel it its lines as it may. Once more to improve, the proper difference of phase is obtained between the primary and secondary currents by a condenser, self-induction, resistance, or equivalent windings. I had discovered, however, that rotation is produced by means of a single coil and core; my explanation of the phenomenon, and leading thought in trying the experiment, being that there must be a true time lag in the magnetisation of the core. I remember the pleasure I had when, in the writings of Prof. Ayrton, which came later to my hand, I found the idea of the time lag advocated. Whether there is a true time lag, or whether the retardation is due to eddy-currents circulating in minute paths, must remain an open question; but the fact is that a coil wound upon an iron core and traversed by an alternating current creates a moving field of force, capable of setting an armature in rotation. It is of some interest, in conjunction with the historical Arago experiment, to mention that in lag, or phase, motors I have produced rotation in opposite direction to the moving field, which means that in that experiment the magnet may not rotate, or may even rotate in opposite direction to the moving disc. Here, then, is a motor (schematically illustrated in Fig. 17), comprising a coil and iron core, and a freely movable copper disc in proximity to the latter. To demonstrate a novel and interesting feature, I have, for a reason which I will explain, selected this type of motor. When the ends of the coil are connected to the terminals of an alternator, the disc is set in rotation. But it is not this experiment, now well known, which I desire to perform. What I wish to

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show you is that this motor rotates with one single connection between it and the generator; that is to say, one terminal of the motor is connected to one terminal of the generator—in this case the secondary of a high-tension induction coil—the other terminals of motor and generator being insulated in space. To produce rotation it is generally (but not absolutely) necessary to connect the free end of the motor coil to an insulated body of some size. The experimenter's body is more than sufficing. If he touches the free terminal with an object held in the hand, a current passes through the coil and the copper disc is set in rotation. If an exhausted tube is put in series with the coil, the tube lights brilliantly, showing the passage of a strong current. Instead of the experimenter's body, a small metal sheet suspended on a cord may be used with the same result. In this case the plate acts as a condenser in series with the coil. It counteracts the self-induction of the latter and allows a strong current to pass. In such a combination, the greater the self-induction of the coil the smaller need be the plate, and this means that a lower frequency, or eventually a lower potential, is required to operate the motor. A single coil wound upon a core has a high self-induction; for this reason principally, this type of motor was chosen to perform the experiment. Were a secondary closed coil wound upon the core, it would tend to diminish the self-induction, and then it would be necessary to employ a much higher frequency and potential. Neither would be advisable, for a higher potential would endanger the insulation of the small primary coil, and a higher frequency would result in a materially diminished torque.

It should be remarked than when such a motor with a closed secondary is used, it is not at all easy to obtain rotation with excessive frequencies, as the secondary cuts off almost completely the lines of the primary—and this, of course, the more the higher the frequency—and allows the passage of but a minute current. In such a case, unless the secondary is closed through a condenser, it is almost essential, in order to produce rotation, to make the primary and secondary coils overlap each other more or less. But there is an additional feature of interest about this motor. It is, namely, not necessary to have even a single connection between the motor and generator, except, perhaps, through the ground; for not only is an insulated plate capable of giving off energy into space, but it is likewise capable of deriving it from an alternating electrostatic field, though in the latter case the available energy is much smaller. In this instance one of the motor terminals is connected to the insulated plate or body located within the alternating electrostatic field, and the other terminal preferably to the ground. It is quite possible, however, that such "no-wire" motors, as they might be called, could be operated by conduction through the rarefied air at considerable distances. Alternate currents, especially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. The upper strata of the air are rarefied. To reach a number of miles out into space requires the overcoming of difficulties of a merely mechanical nature. There is no doubt that with the enormous potentials obtainable by the use of high frequencies and oil insulation luminous discharges might be passed through many miles of rarefied air, and that, by thus directing the energy of many hundreds or thousands of horse-power, motors or lamps might be operated at considerable distances from stationary sources. But such schemes are mentioned merely as possibilities. We shall have no need to transmit power in this way. We shall have no need to transmit power at all. Ere many generations pass, our machinery will be driven by a power obtainable at any point of the universe.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

BY NIKOLA TESLA.

(Continued from page 471.)

This idea is not novel. Men have been led to it long ago by instinct or reason. It has been expressed in many ways, and in many places, in the history of old and new. We find it in the delightful myth of Antheus, who derives power from the earth; we find it among the subtle speculations of one of your splendid mathematicians, and in many hints and statements of thinkers of the present time. Throughout space there is energy. Is this energy static or kinetic? If static, our hopes are in vain; if kinetic—and this we know it is for certain—then it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature. Of all, living or dead, Crookes came nearest to doing it. His radiometer will turn in the light of day and in the darkness of the night; it will turn everywhere where there is heat, and heat is everywhere. But, unfortunately, this beautiful little machine, while it goes down to posterity as the most interesting, must likewise be put on record as the most inefficient machine ever invented!

The preceding experiment is only one of many equally interesting experiments which may be performed by the use of only one wire with alternate currents of high potential and frequency. We may connect an insulated line to a source of such currents, we may pass an inappreciable current over the line, and on any point of the same we are able to obtain a heavy current, capable of fusing a thick copper wire. Or we may, by the help of some artifice, decompose a solution in an electrolytic cell by connecting only one pole of the cell to the line or source of energy. Or we may, by attaching to the line, or only bringing into its vicinity, light up an incandescent lamp, an exhausted tube, or a phosphorescent bulb. However impracticable this plan of working may appear in many cases, it certainly seems practicable, and even recommendable, in the production of light. A perfected lamp would require but little energy, and if wires are used at all, we ought to be able to supply that energy without a return wire. It is now a fact that a body may be rendered incandescent or phosphorescent by bringing it either in single contact or merely in the vicinity of a source of electric impulses of the proper character, and that in this manner a quantity of light sufficient to afford a practical illuminant may be produced. It is, therefore, to say the least, worth while to attempt to determine the best conditions and to invent the best appliances for attaining this object. Some experiences have already been gained in this direction, and I will dwell on them briefly, in the hope that they might prove useful. The heating of a conducting body enclosed in a bulb, and connected to a source of rapidly-alternating electric impulses, is dependent on so many things of a different nature, that it would be difficult to give a generally applicable rule under which the maximum heating occurs. As regards the size of the vessel, I have lately found that at ordinary or only slightly differing atmospheric pressures, when air is a good insulator, and hence practically the same amount of energy by a certain potential and frequency is given off from the body, whether the bulb be small or large, the body is brought to a higher temperature if enclosed in a small bulb, because of the better confinement of heat in this case. At lower pressures, when air becomes more or less conducting, or if the air be sufficiently warmed as to become conducting, the body is rendered more intensely incandescent in a large bulb, obviously because, under otherwise equal conditions of tests, more energy may be given off from the body when the bulb is large. At very high degrees of exhaustion, when the matter in the bulb becomes "radiant," a large bulb has still an advantage, but a comparatively slight one, over the small bulb. Finally, at excessively high degrees of exhaustion, which cannot be reached except by the employment of special means, there seems to be, beyond a certain and rather small size of vessel, no perceptible difference in the heating.

These observations were the result of a number of experiments, of which one, showing the effect of the size of the bulb at a high degree of exhaustion, may be described and shown here, as it presents a feature of interest. Three spherical bulbs of 2in., 3in., and 4in. diameter were taken, and in the centre of each was mounted an equal length of an ordinary incandescent lamp filament of uniform thickness. In each bulb the piece of filament was fastened to the leading-in wire of platinum, contained in a glass stem sealed in the bulb; care being taken, of course, to make everything as nearly alike as possible. On each glass stem in the inside of the bulb was slipped a highly-polished tube made of aluminium sheet, which fitted the stem and was held on it by spring pressure. The function of this aluminium tube will be explained subsequently. In each bulb an equal length of filament protruded above the metal tube. It is sufficient to say now that under these conditions equal lengths of filament of the same thickness—in other words, bodies of equal bulk—were brought to incandescence. The three bulbs were sealed to a glass tube, which was connected to a Sprengel pump. When a high vacuum had been reached, the glass tube carrying the bulbs was sealed off. A current was then turned on successively on each bulb, and it was found that the filaments came to about the same brightness, and, if anything, the smallest bulb, which was placed midway between the two larger ones, may have been slightly brighter. This result was expected, for when either of the bulbs was connected to the coil luminosity spread through the other two, hence the three bulbs constituted really one vessel. When all the three bulbs were connected in multiple arc to the coil, in the largest of them the filament glowed brightest, in the next smaller it was a little less bright, and in the smallest it only came to redness. The bulbs were then sealed off and separately tried. The brightness of the filaments was now such as would have been expected on the supposition that the energy given off was proportionate to the surface of the bulb, this surface in each case representing one of the coatings of a condenser. Accordingly, there was less difference between the largest and the middle-sized than between the latter and the s r allest bulb.

An interesting observation was made in this experiment. The three bulbs were suspended from a straight bare wire connected to a terminal of the coil, the largest bulb being placed at the end of the wire, at some distance from it the smallest bulb, and an equal distance from the latter the middle-sized one. The carbons glowed then in both the larger bulbs about as expected, but the smallest did not get its share by far. This observation led me to exchange the positions of the bulbs, and I then observed that whichever of the bulbs was in the middle it was by far less bright than it was in any other position. This mystifying result was, of course, found to be due to electrostatic action between the bulbs. When they were placed at considerable distance, or when they were attached to the corners of an equilateral triangle of copper wire, they glowed about in the order determined by their surfaces. As to the shape of the vessel, it is also of some importance, especially at high degrees of exhaustion. Of all the possible constructions, it seems that a spherical globe with the refractory body mounted in its centre is the best to employ. In experience it has been demonstrated that in such a globe a refractory body of a given bulk is more easily brought to incandescence than when otherwise shaped bulbs are used. There is also an advantage in giving to the incandescent body the shape of a sphere, for self-evident reasons. In any case the body should be mounted in the centre, where the atoms rebounding from the glass collide. This object is best attained in the spherical bulb, but it is also attained in a cylindrical vessel with one or two straight filaments coinciding with its axis, and possibly also in parabolical or spherical bulbs with the refractory body or bodies placed in the focus or foci of the same, though the latter is not probable, as the electrified atoms should in all cases rebound normally from the surface they strike, unless the speed were excessive, in which case they would probably follow the general law of reflection. No matter what shape the vessel may have, if the exhaustion be low, a filament mounted in the globe is brought to the same degree of incandescence in all parts; but if the exhaustion be high, and the bulb be spherical or pear-shaped, as usual, focal points form, and the filament is heated to a higher degree at or near such points. To illustrate the effect, I have here two small bulbs which are alike, only one is exhausted to a low and the other to a very high degree. When connected to the coil, the filament in the former glows uniformly throughout all its length; whereas in the latter, that portion of the filament which is in the centre of the bulb glows far more intensely than the rest. A curious point is that the phenomenon occurs even if two filaments are mounted in a bulb, each being connected to one terminal of the coil, and, what is still more curious, if they be very near together, provided the vacuum be very high. I noted in experiments with such bulbs that the filaments would give way usually at a certain point, and in the first trials I attributed it to a defect in the carbon. But when the phenomenon occurred many times in succession I recognised its real cause.

In order to bring a refractory body enclosed in a bulb to incandescence, it is desirable, on account of economy, that all the energy supplied to the bulb from the source should reach without loss the body to be heated; from there, and from nowhere else, it should be radiated. It is, of course, out of the question to reach this theoretical result, but it is possible by a proper construction of the illuminating device to approximate more or less to it. For many reasons, the refractory body is placed in the centre of the bulb, and it is usually supported on a glass stem containing the leading-in wire. As the potential of this wire is alternated, the rarefied gas surrounding the stem is acted upon inductively, and the glass stem is violently bombarded and heated. In this manner by far the greater portion of the energy supplied to the bulb—especially when exceedingly high frequencies are used—may be lost for the purpose contemplated. To obviate this loss, or at least to reduce it to a minimum, I usually screen the rarefied gas surrounding the stem from the inductive action of the leading-in wire by providing the stem with a tube or coating of conducting

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material. It seems beyond doubt that the best among metals to employ for this purpose is aluminium, on account of its many remarkable properties. Its only fault is that it is easily fusible, and therefore its distance from the incandescing body should be properly estimated. Usually, a thin tube, of a diameter somewhat smaller than that of the glass stem, is made of the finest aluminium sheet, and slipped on the stem. The tube is conveniently prepared by wrapping around a rod fastened in a lathe a piece of aluminium sheet of the proper size, grasping the sheet firmly with clean chamois leather or blotting-paper, and spinning the rod very fast. The sheet is wound tightly around the rod, and a highly-polished tube of two or three layers of the sheet is obtained. When slipped on the stem, the pressure is generally sufficient to prevent it from slipping off, but, for safety, the lower edge of the sheet may be turned inside. The upper inside corner of the sheet—that is, the one which is nearest to the refractory incandescent body—should be cut out diagonally, as it often happens that, in consequence of the intense heat, this corner turns towards the inside and comes very near to, or in contact with, the wire, or filament, supporting the refractory body. The greater part of the energy supplied to the bulb is then used up in heating the metal tube, and the bulb is rendered useless for the purpose. The aluminium sheet should project above the glass stem more or less—1in. or so—or else, if the glass be too close to the incandescing body, it may be strongly heated, and become more or less conducting, whereupon it may be ruptured, or may, by its conductivity, establish a good electrical connection between the metal tube and the leading-in wire, in which case, of course, again, most of the energy will be lost in heating the former. Perhaps the best way is to make the top of the glass tube, for about an inch, of a much smaller diameter. To still further reduce the danger arising from the heating of the glass stem, and also with the view of preventing an electrical connection between the metal tube and the electrode, I preferably wrap the stem with several layers of thin mica, which extends at least as far as the metal tube. In some bulbs I have also used an outside insulating cover.

The preceding remarks are only made to aid the experimenter in the first trials, for the difficulties which he encounters he may soon find means to overcome in his own way. To illustrate the effect of the screen, and the advantage of using it, I have here two bulbs of the same size, with their stems, leading-in wires, and incandescent lamp filaments tied to the latter, as nearly alike as possible. The stem of one bulb is provided with an aluminium tube, the stem of the other has none. Originally the two bulbs were joined by a tube which was connected to a Sprengel pump. When a high vacuum had been reached, first the connecting tube and then the bulbs were sealed off; they are therefore of the same degree of exhaustion. When they are separately connected to the coil giving a certain potential, the carbon filament in the bulb provided with the aluminium screen is rendered highly incandescent, while the filament in the other bulb may, with the same potential, not even come to redness, although in reality the latter bulb takes generally more energy than the former. When they are both connected together to the terminal, the difference is even more apparent, showing the importance of the screening. The metal tube placed on the stem containing the leading-in wire performs really two distinct functions: First, it acts more or less as an electrostatic screen, thus economising the energy supplied to the bulb; and, second, to whatever extent it may fail to act electrostatically, it acts mechanically, preventing the bombardment, and consequently intense heating and possible deterioration, of the slender support of the refractory incandescent body, or of the glass stem containing the leading-in wire. I say slender support, for it is evident that in order to confine the heat more completely to the incandescing body its support should be very thin, so as to carry away the smallest possible amount of heat by conduction. Of all the supports used I have found an ordinary incandescent lamp filament to be the best, principally because, among conductors, it can withstand the highest degrees of heat.

The effectiveness of the metal tube as an electrostatic screen depends largely on the degree of exhaustion. At excessively high degrees of exhaustion—which are reached by using great care and special means in connection with the Sprengel pump—when the matter in the globe is in the ultra-radiant state, it acts most perfectly. The shadow of the upper edge of the tube is then sharply defined upon the bulb. At a somewhat lower degree of exhaustion, which is about the ordinary "non-striking" vacuum, and generally as long as the matter moves predominantly in straight lines, the screen still does well. In elucidation of the preceding remark it is necessary to state what is a "non-striking" vacuum for a coil operated, as ordinarily, by impulses, or currents, of low frequency is not, by far, so when the coil is operated by currents of very high frequency. In such case the discharge may pass with great freedom through the rarefied gas through which a low-frequency discharge may not pass, even though the potential be much higher. At ordinary atmospheric pressures just the reverse rule holds good; the higher the frequency, the less the spark discharge is able to jump between the terminals, especially if they are knobs or spheres of some size. Finally, at very low degrees of exhaustion, when the gas is well conducting, the metal tube not only does not act as an electrostatic screen, but even is a drawback, aiding to a considerable extent the dissipation of the energy laterally from the leading-in wire. This, of course, is to be expected. In this case—namely, the metal tube is in good electrical connection with the leading-in wire, and most of the bombardment is directed upon the tube. As long as the electrical connection is not good, the conducting tube is always of some advantage, for although it may not greatly economise energy, still it protects the support of the refractory button, and is a means for concentrating more energy upon the same.

To whatever extent the aluminum tube performs the function of a screen, its usefulness is therefore limited to very high degrees of exhaustion when it is insulated from the electrode—that is, when the gas as a whole is non-conducting, and the molecules, or atoms, act as independent carriers of electric charges. In addition to acting as a more or less effective screen, in the true meaning of the word, the conducting tube or coating may also act, by reason of its conductivity, as a sort of equaliser or dampener of the bombardment against the stem. To be explicit, I assume the action as follows: Suppose a rhythmical bombardment to occur against the conducting tube by reason of its imperfect action as a screen, it certainly must happen that some molecules, or atoms, strike the tube sooner than others. Those which come first in contact with it give up their superfluous charge, and the tube is electrified, the electrification instantly spreading over its surface. But this must diminish the energy lost in the bombardment, for two reasons: firstly, the charge given up by the atoms spreads over a great area, and hence the electric density at any point is small, and the atoms are repelled with less energy than they would be if they would strike against a good insulator; secondly, as the tube is electrified by the atoms which first come in contact with it, the progress of the following atoms against the tube is more or less checked by the repulsion which the electrified tube must exert upon the similarly electrified atoms. This repulsion may perhaps be sufficient to prevent a large portion of the atoms from striking the tube, but at any rate it must diminish the energy of their impact. It is clear that when the exhaustion is very low, and the rarefied gas well conducting, neither of the above effects can occur, and, on the other hand, the fewer the atoms, with the greater freedom they move; in other words, the higher the degree of exhaustion, up to a limit, the more telling will be both the effects.

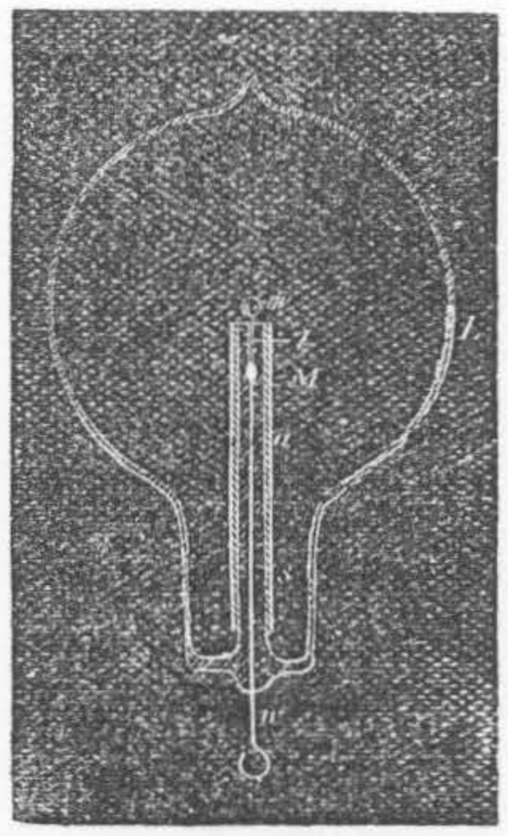

FIG. 18.—Bulb with Mica Tube with Aluminium Screen.

What I have just said may afford an explanation of the phenomenon observed by Prof. Crookes—namely, that a discharge through a bulb is established with much greater facility when an insulator than when a conductor is present in the same. In my opinion, the conductor acts as a dampener of the motion of the atoms in two ways pointed out; hence, to cause a visible discharge to pass through the bulb, a much higher potential is needed if a conductor, especially of much surface, be present. For the sake of clearness of some of the remarks before made, I must now refer to Figs. 18, 19, and 20, which illustrate various arrangements with a type or bulb most generally used, Fig. 18 is a section through a spherical bulb, L, with the glass stem, *s*, containing the leading-in wire, *w*, which has a lamp filament, *l*, fastened to it, serving to support the refractory button, *m*, in the centre. M is a sheet of thin mica wound in several layers around stem, s, and *a* is the aluminium tube. Fig. 19 illustrates such a bulb in a somewhat more advanced stage of perfection. A metallic tube, S, is fastened by means of some cement to the neck of the tube. In the tube is screwed a plug, P, of insulating material, in the centre of which is fastened a metallic terminal, *t*, for the connection to the leading-in wire, *w*. This terminal must be well insulated from the metal tube, S, therefore, if the cement used is conducting—and most generally it is sufficiently so—the space between the plug, P, and the neck of the bulb should be filled with some good insulating material, as mica powder. Fig. 20 shows a bulb made for experimental purposes. In this bulb the aluminium tube is provided with an external connection, which serves to investigate the effect of the tube under various conditions. It is referred to chiefly to suggest a line of experiment followed.

Since the bombardment against the stem containing the leading-in wire is due to the inductive action of the latter upon the rarefied gas, it is of advantage to reduce this action as far as practicable by employing a very thin wire, surrounded by a very thick insulation of glass or other material, and by making the wire passing through the rarefied gas as short as practicable. To combine these features I employ a large tube, T (Fig. 21), which protrudes into the bulb to some distance, and carries on the top a very short

glass stem, *s*, into which is sealed the leading-in wire, *w*, and I protect the top of the glass stem against the heat by a small aluminium tube, *a*, and a layer of mica underneath the same, as usual. The wire, *w*, passing through the large tube to the outside of the bulb, should be well insulated—with a glass tube, for instance—and the space between ought to be filled out with some excellent insulator. Among many insulating powders I have tried, I have found that mica powder is the best to employ. If this precaution is not taken, the tube, T, protruding into the bulb will surely be cracked in consequence of the heating by the brushes, which are apt to form in the upper part of the tube, near the exhausted

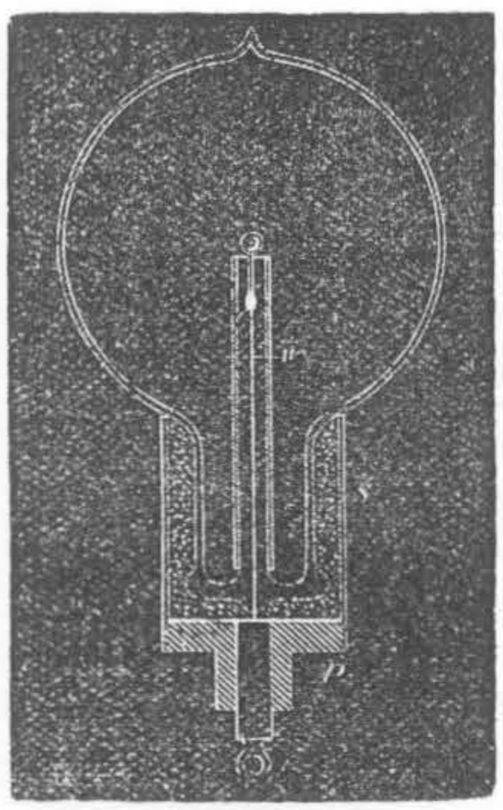

FIG. 19.—Improved Bulb with Socket and Screen.

globe, especially if the vacuum be excellent, and therefore the potential necessary to operate the lamp very high. Fig. 22 illustrates a similar arrangement, with a large tube, T, protruding into the part of the bulb containing the refractory button, *m*. In this case the wire leading from the outside into the bulb is omitted, the energy required being supplied through condenser coatings, C C. The insulating packing, P, should in this construction be tightly fitting to the glass, and rather wide, or otherwise the discharge might avoid passing through the wire, *w*, which connects the inside condenser coating to the incandescent button, *m*.

The molecular bombardment against the glass stem in the bulb is a source of great trouble. As illustration I will cite a phenomenon only too frequently and unwillingly observed. A bulb, preferably a large one, may be taken, and a good conducting body, such as a piece of carbon, may be mounted in it upon a platinum wire sealed in the glass stem. The bulb may be exhausted to a fairly high degree, nearly to the point when phosphorescence begins to appear. When the bulb is connected with the coil, the piece of

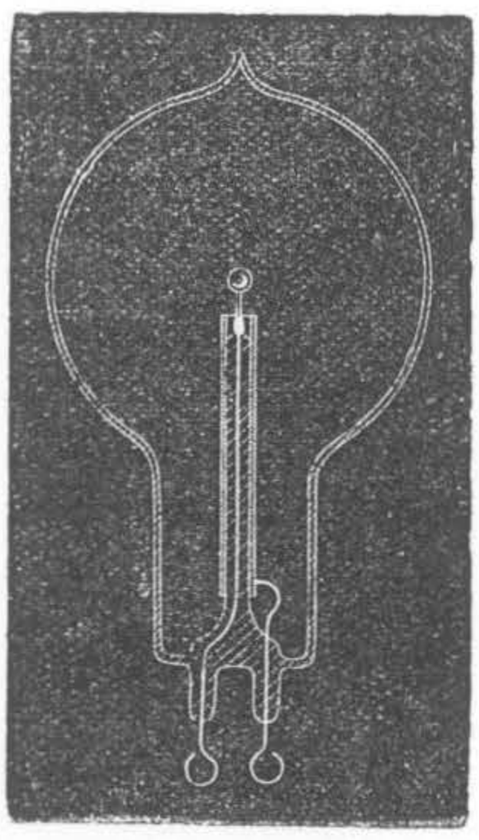

FIG. 20.—Bulb for Experiments with Conducting Tube.

carbon, if small, may become highly incandescent at first, but its brightness immediately diminishes, and then the discharge may break through the glass somewhere in the middle of the stem, in the form of bright sparks, in spite of the fact that the platinum wire is in good electrical connection with the rarefied gas through the piece of carbon or metal at the top. The first sparks are singularly bright, recalling those drawn from a clear surface of mercury. But as they heat the glass rapidly they of course lose their brightness, and cease when the glass at the ruptured place becomes incandescent, or generally sufficiently hot to conduct. When observed for the first time the phenomenon must appear very curious, and shows in a striking manner how radically different alternate currents, or impulses, of high frequency behave, as compared with steady currents, or currents of low frequency. With such currents—namely, the latter—the phenomenon would, of course, not occur. When frequencies such as are obtained by mechanical means are used, I think that the rupture of the glass is more or less the consequence of the bombardment, which warms it up and impairs its insulating power; but with frequencies obtainable with condensers, I have no doubt that the glass may give way without previous heating.

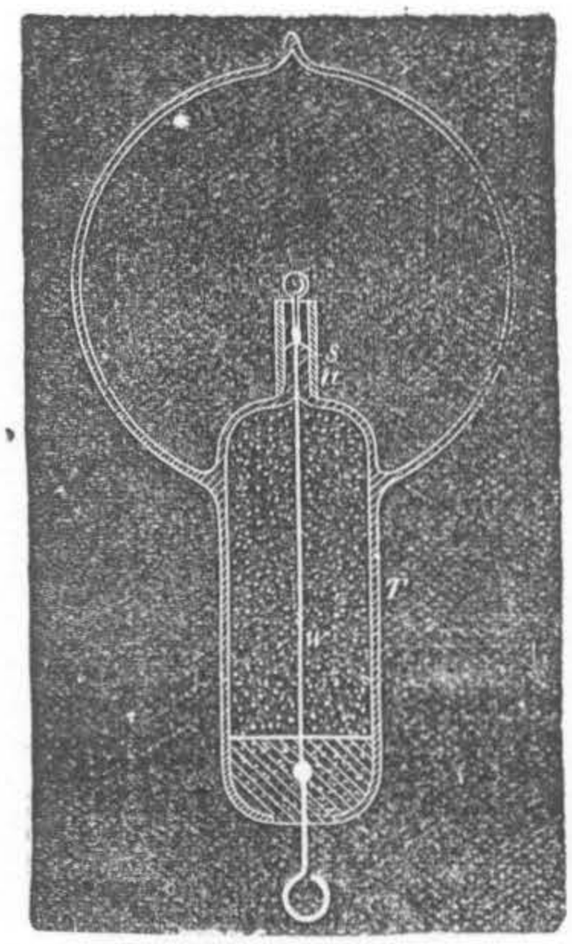

FIG. 21.—Improved Bulb with Non-conducting Button.

Although this appears most singular at first, it is in reality what we might expect to occur. The energy supplied to the wire leading into the bulb is given off partly by direct action through the carbon button, and partly by inductive action through the glass surrounding the wire. The case is thus analogous to that in which a condenser shunted by a conductor of low resistance is connected to a source of alternating currents. As long as the frequencies are low, the conductor gets the most, and the condenser is perfectly safe; but when the frequency becomes excessive the *rôle* of the conductor may become quite insignificant. In the latter case the difference of potential at the terminals of the condenser may become so great as to rupture the dielectric, notwithstanding the fact that the terminals are joined by a conductor

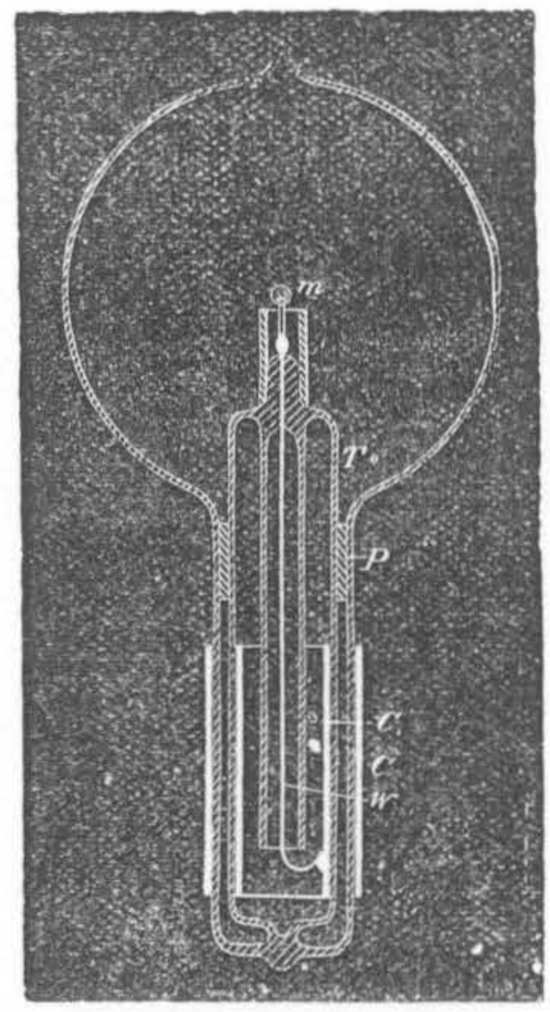

FIG. 22.—Type of Bulb without Leading-in Wire.

of low resistance. It is, of course, not necessary, when it is desired to produce the incandescence of a body enclosed in a bulb by means of these currents, that the body should be a conductor, for even a perfect non-conductor may be quite as readily heated. For this purpose it is sufficient to surround a conducting electrode with the non-conducting material, as, for instance, in the bulb described before in Fig. 21, in which a thin incandescent lamp filament is coated with a non-conductor, and supports a button of the same material on the top. At the start the bombardment goes on by inductive action through the non-conductor until the same is sufficiently heated to become conducting, when the bombardment continues in the ordinary way.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

BY NIKOLA TESLA.

(Continued from page 520.)

One of the experiments performed may be mentioned here by way of illustration. A small piece of pumice-stone was stuck on a platinum wire, and first melted to it in a gas burner. The wire was next placed between two pieces of charcoal and a burner applied so as to produce an intense heat, sufficient to melt down the pumice-stone into a small glass-like button. The platinum wire had to be taken of sufficient thickness to prevent its melting in the fire. While in the charcoal fire, or when held in a burner to gain a better idea of the degree of heat, the button glowed with great brilliancy. The wire with the button was then mounted in a bulb, and upon exhausting the same to a high degree the current was turned on slowly so as to prevent the cracking of the button. The button was heated to the point of fusion, and when it melted it did not, apparently, glow with the same brilliancy as before; and this would indicate a lower temperature. Leaving out of consideration the observer's possible, and even probable, error, the question is, can a body under these conditions be brought from a solid to a liquid state with evolution of less light? When the potential of a body is rapidly alternated it is certain that the structure is jarred. When the potential is very high, although the vibrations may be few—say, 20,000 per second—the effect upon the structure may be considerable. Suppose, for example, that a ruby is melted into a drop by a steady application of energy. When it forms a drop, it will emit visible and invisible waves, which will be in a definite ratio, and to the eye the drop will appear to be of a certain brilliancy. Next, suppose we diminish to any degree we choose the energy steadily supplied, and, instead, supply energy which rises and falls according to a certain law. Now, when the drop is formed, there will be emitted from it three different kinds of vibrations—the ordinary visible, and two kinds of invisible waves: that is, the ordinary dark waves of all lengths, and, in addition, waves of a well-defined character. The latter would not exist by a steady supply of energy, still they help to jar and loosen the structure. If this really be the case, then the ruby drop will emit relatively less visible and more invisible waves than before. Thus it would seem that when a platinum wire, for instance, is fused by currents alternating with extreme rapidity, it emits at the point of fusion less light and more invisible radiation than it does when melted by a steady current, though the total energy used up in the process of fusion is the same in both cases. Or, to cite another example, a lamp filament is not capable of withstanding as long with currents of extreme frequency as it does with steady currents, assuming that it be worked at the same luminous intensity. This means that for rapidly-alternating currents the filament should be shorter and thicker. The higher the frequency—that is, the greater the departure from the steady flow—the worse it would be for the filament. But if the truth of this remark were demonstrated, it would be erroneous to conclude that such a refractory button as used in these bulbs would be deteriorated quicker by currents of extremely high frequency than by steady or low-frequency currents. From experience I may say that just the opposite holds good: the button withstands the bombardment better with currents of very high frequency. But this is due to the fact that a high-frequency discharge passes through a rarefied gas with much greater freedom than a steady or low-frequency discharge, and this will say that with the former we can work with a lower potential or with a less violent impact. As long, then, as the gas is of no consequence, a steady or low-frequency current is better, but as soon as the action of the gas is desired and important, high frequencies are preferable.

In the course of these experiences great many trials were made with all kinds of carbon buttons. Electrodes made of ordinary carbon buttons were decidedly more durable when the buttons were obtained by the application of enormous pressure. Electrodes prepared by depositing carbon in well-known ways did not show up well; they blackened the globe very quickly. From many experiences I conclude that lamp filaments obtained in this manner can be advantageously used only with low potentials and low-frequency currents. Some kinds of carbon withstand so well that, in order to bring them to the point of fusion, it is necessary to employ very small buttons. In this case the observation is rendered very difficult, on account of the intense light produced. Nevertheless, there can be no doubt that all kinds of carbon are fused under the molecular bombardment, but the liquid state must be one of great instability. Of all the bodies tried, there were two which withstood best—diamond and carborundum. These two showed up about equally, but the latter was preferable, for many reasons. As it is more than likely that this body is not yet generally known, I will venture to call your attention to it. It has been recently produced by Mr. E. G. Acheson, of Monongahela City, Pennsylvania, U.S.A. It is intended to replace ordinary diamond powder for polishing precious stones, etc., and I have been informed that it accomplishes this object quite successfully. I do not know why the name "carborundum" has been given to it, unless there is something in the process of its manufacture which justifies this selection. Through the kindness of the inventor, I obtained a short while ago some samples which I desired to test in regard to their qualities of phosphorescence and capability of withstanding high degrees of heat. Carborundum can be obtained in two forms—in the form of "crystals" and of powder. The former appear to the naked eye dark-coloured, but are very brilliant; the latter is of nearly the same colour as ordinary diamond powder, but very much finer. When viewed under a microscope, the samples of crystals given to me did not appear to have any definite form, but rather resembled pieces of broken-up egg coal of fine quality. The majority were opaque, but there were some which were transparent and coloured. The crystals are a kind of carbon containing some impurities; they are extremely hard, and withstand for a long time even an oxygen blast. When the blast is directed against them, they at first form a cake of some compactness, probably in consequence of the fusion of impurities they contain. The mass withstands for a very long time the blast without further fusion; but a slow carrying off or burning occurs, and finally a small quantity of a glass-like residue is left, which, I suppose, is melted alumina. When compressed strongly they conduct very well, but not as well as ordinary carbon. The powder, which is obtained from the crystals in some way, is practically non-conducting. It affords a magnificent polishing material for stones. The time has been too short to make a satisfactory study of the properties of this product, but enough experience has been gained in the few weeks I have experimented upon it to say that it does possess some remarkable properties in many repects. It withstands excessively high degrees of heat, it is little deteriorated by molecular bombardment, and it does not blacken the globe as ordinary carbon does. The only difficulty which I have found in its use in connection with these experiments was to find some binding material which would resist the heat and the effect of the bombardment as successfully as carborundum itself does. I have here a number of bulbs which I have provided with buttons of carborundum. To make such a button of carborundum crystals I proceed in the following manner: I take an ordinary lamp filament and dip its point in tar, or some other thick substance or paint which may be readily carbonised. I next pass the point of the filament through the crystals, and then hold it vertically over a hot plate. The tar softens and forms a drop on the point of the filament, the crystals adhering to the surface of the drop. By regulating the distance from the plate the tar is slowly dried out and the button becomes solid. I then once more dip the button in tar and hold it again over a plate until the tar

* Lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the *Journal* of the Institution of Electrical Engineers.

is evaporated, leaving only a hard mass which firmly binds the crystals. When a larger button is required, I repeat the process several times, and I generally also cover the filament a certain distance below the button with crystals. The button being mounted in a bulb, when a good vacuum has been reached, first a weak, and then a strong discharge is passed through the bulb to carbonise the tar and expel all gases, and later it is brought to a very intense incandescence. When the powder is used I have found it best to proceed as follows: I make a thick paint of carborundum and tar, and pass a lamp filament through the paint. Taking then most of the paint off by rubbing the filament against a piece of chamois leather, I hold it over a hot plate until the tar evaporates and the coating becomes firm. I repeat this process as many times as it is necessary to obtain a certain thickness of coating. On the point of the coated filament I form a button in the same manner. There is no doubt that such a button—properly prepared under great pressure—of carborundum, especially of powder of the best quality, will withstand the effect of the bombardment fully as good as anything we know. The difficulty is that the binding material gives way, and the carborundum is slowly thrown off after some time. As it does not seem to blacken the globe in the least, it might be found useful for coating the filaments of ordinary incandescent lamps, and I think that it is even possible to produce thin threads or sticks of carborundum which will replace the ordinary filament in an incandescent lamp. A carborundum coating seems to be more durable than other coatings, not only because the carborundum can withstand high degrees of heat, but also because it seems to unite with the carbon better than any other material I have tried. A coating of zirconia or any other oxide, for instance, is far more quickly destroyed. I prepared buttons of diamond dust in the same manner as of carborundum, and these came in durability nearest to those prepared of carborundum, but the binding paste gave way much more quickly in the diamond buttons; this, however, I attributed to the size and irregularity of the grains of the diamond It was of interest to find whether carborundum possesses the quality of phosphorescence. One is, of course, prepared to encounter two difficulties: first, as regards the rough product, the "crystals," they are good conducting, and it is a fact that conductors do not phosphoresce; second, the powder, being exceedingly fine, would not be apt to exhibit very prominently this quality, since we know that when crystals, even such as diamond or ruby, are finely powdered they lose the property of phosphorescence to a considerable degree.

The question presents itself here, Can a conductor phosphoresce? What is there in such a body as a metal, for instance, that would deprive it of the quality of phosphorescence, unless it is that property which characterises it as a conductor? for it is a fact that most of the phosphorescent bodies lose that quality when they are sufficiently heated to become more or less conducting. Then, if a metal be in a large measure, or perhaps entirely, deprived of that property, it should be capable of phosphorescence. Therefore it is quite possible that at some extremely high frequency, when behaving practically as a non-conductor, a metal or any other conductor might exhibit the quality of phosphorescence, even though it be entirely incapable of phosphorescing under the impact of a low-frequency discharge. There is, however, another possible way how a conductor might at least appear to phosphoresce. Considerable doubt still exists as to what really is phosphorescence, and as to whether the various phenomena comprised under this head are due to the same causes. Suppose that in an exhausted bulb, under the molecular impact, the surface of a piece of metal or other conductor is rendered strongly luminous, but at the same time it is found that it remains comparatively cool, would not this luminosity be called phosphorescence? Now such a result, theoretically at least, is possible, for it is a mere question of potential, or speed. Assume the potential of the electrode, and consequently the speed of the projected atoms, to be sufficiently high, the surface of the metal piece against which the atoms are projected would be rendered highly incandescent, since the process of heat generation would be incomparably faster than that of radiating or conducting away from the surface of the collision. In the eye of the observer, a single impact of the atoms would cause an instantaneous flash; but if the impacts were repeated with sufficient rapidity, they would produce a continuous impression upon his retina. To him then the surface of the metal would appear continuously incandescent and of constant luminous intensity, while in reality the light would be either intermittent or at least changing periodically in intensity. The metal piece would rise in temperature until equilibrium was attained—that is, until the energy continuously radiated would equal that intermittently supplied. But the supplied energy might under such conditions not be sufficient to bring the body to any more than a very moderate mean temperature, especially if the frequency of the atomic impacts be very low—just enough that the fluctuation of the intensity of the light emitted could not be detected by the eye. The body would now, owing to the manner in which the energy is supplied, emit a strong light, and yet be a comparatively very low mean temperature. How could the observer call the luminosity thus produced? Even if the analysis of the light would teach him something definite, still he would probably rank it under the phenomena of phosphorescence. It is conceivable that in such a way both conducting and non-conducting bodies may be maintained at a certain luminous intensity, but the energy required would very greatly vary with the nature and properties of the bodies. These and some foregoing remarks of a speculative nature were made merely to bring out curious features of alternate currents or electric impulses. By their help we may cause a body to emit more light, while at a certain mean temperature, than it would emit if brought to that temperature by a steady supply; and, again, we may bring a body to the point of fusion and cause it to emit less light than when fused by the application of energy in ordinary ways. It all depends on how we supply the energy, and what kind of vibrations we set up. In one case the vibrations are more, in the other less, adapted to affect our sense of vision.

Some effects, which I had not observed before, obtained with carborundum in the first trials I attributed to phosphorescence, but in subsequent experiments it appeared that it was devoid of that quality. The crystals possess a noteworthy feature. In a bulb provided with a single electrode in the shape of a small circular metal disc, for instance, at a certain degree of exhaustion the electrode is covered with a milky film, which is separated by a dark space from the glow filling the bulb. When the metal disc is covered with carborundum crystals, the film is far more intense, and snow-white. This I found later to be merely an effect of the bright surface of the crystals, for when an aluminium electrode was highly polished it exhibited more or less the same phenomenon. I made a number of experiments with the samples of crystals obtained, principally because it would have been of special interest to find that they are capable of phosphorescence, on account of their being conducting. I could not produce phosphorescence distinctly, but I must remark that a decisive opinion cannot be formed until other experimenters have gone over the same ground. The powder behaved in some experiments as though it contained alumina, but it did not exhibit with sufficient distinctness the red of the latter. Its dead colour brightens considerably under the molecular impact, but I am now convinced it does not phosphoresce. Still, the tests with the powder are not conclusive, because powdered carborundum probably does not behave like a phosphorescent sulphide, for example, which could be finely powdered without impairing the phosphorescence, but rather like powdered ruby or diamond, and therefore it would be necessary, in order to make a decisive test, to obtain it in a large lump and polish up the surface. If the carborundum proves useful in connection with these and similar experiments, its chief value will be found in the production of coatings, thin conductors, buttons, or other electrodes capable of withstanding extremely high degrees of heat.

The production of a small electrode capable of withstanding enormous temperatures I regard as of the greatest importance in the manufacture of light. It would enable us to obtain, by means of currents of very high frequencies, certainly twenty times, if not more, the quantity of light which is obtained in the present incandescent lamp by the same expenditure of energy. This estimate may appear to many exaggerated, but in reality I think it is far from being so. As this statement might be misunderstood, I think it necessary to expose clearly the problem with which in this line of work we are confronted, and the manner in which, in my opinion, a solution will be arrived at. Anyone who begins a study of the problem will be apt to think that what is wanted in a lamp with an electrode is a very high degree of incandescence of the electrode. There he will be mistaken. The high incandescence of the button is a necessary evil, but what is really wanted is the high incandescence of the gas surrounding the button. In other words, the problem in such a lamp is to bring a mass of gas to the highest possible incandescence. The higher the incandescence, the quicker the mean vibration, the greater is the economy of the light production. But to maintain a mass of gas at a high degree of incandescence in a glass vessel, it will always be necessary to keep the incandescent mass away from the glass—that is, to confine it as much as possible to the central portion of the globe. In one of the experiments this evening a brush was produced at the end of a wire. This brush was a flame, a source of heat and light. It did not emit much perceptible heat, nor did it glow with an intense light; but is it the less a flame because it does not scorch my hand? Is it the less a flame because it does not hurt my eye by its brilliancy? The problem is precisely to produce in the bulb such a flame, much smaller in size, but imcomparably more powerful. Were there means at hand producing electric impulses of a sufficiently high frequency, and for transmitting them, the bulb could be done away with, unless it were used to protect the electrode, or to economise the energy by confining the heat. But as such means are not at disposal, it becomes necessary to place the terminal in a bulb and rarefy the air in the same. This is done merely to enable the apparatus to perform the work which it is not capable of performing at ordinary air pressure. In the bulb we are able to intensify the action to any degree—so far that the brush emits a powerful light. The intensity of the light emitted depends principally on the frequency and potential of the impulses, and on the electric density of the surface of the electrode. It is of the greatest importance to employ the smallest possible button, in order to push the density very far. Under the violent impact of the molecules of the gas surrounding it, the small electrode is of course brought to an extremely high temperature, but around it is a mass of highly incandescent gas, a flame or photosphere, many hundred times the volume of the electrode. With a diamond, carborundum, or zirconia button the photosphere can be as much as one thousand times the volume of the button. Without much reflecting one would think that in pushing so far the incandescence of the electrode it would be instantly volatilised. But after a careful consideration he would find that, theoretically, it should not occur, and in this fact—which, however, is experimentally demonstrated—lies principally the future value of such a lamp. At first, when the bombardment begins, most of the work is performed on the surface of the button, but when a highly-conducting photosphere is formed the button is comparatively relieved. The higher the incandescence of the photosphere the more it approaches in conductivity to that of the electrode, and

the more, therefore, the solid and the gas form one conducting body. The consequence is that, the further is forced the incandescence the more work, comparatively, is performed on the gas, and the less on the electrode. The formation of a powerful photosphere is consequently the very means for protecting the electrode. This protection, of course, is a relative one, and it should not be thought that by pushing the incandescence higher the electrode is actually less deteriorated. Still, theoretically, with extreme frequencies, this result must be reached, but probably at a temperature too high for most of the refractory bodies known. Given, then, an electrode which can withstand to a certain very high limit the effect of the bombardment and outward strain, it would be safe no matter how much it is forced beyond that limit. In an incandescent lamp quite different considerations apply. There the gas is not at all concerned ; the whole of the work is performed on the filament, and the life of the lamp diminishes so rapidly with the increase of the degree of incandescence, that economical reasons compel us to work it at a low incandescence. But if an incandescent lamp is operated with currents of very high frequency, the action of the gas cannot be neglected, and the rules for the most economical working must be considerably modified.

In order to bring such a lamp with one or two electrodes to great perfection, it is necessary to employ impulses of very high frequency. The high frequency secures, among others, two chief advantages, which have a most important bearing upon the economy of the light production. Firstly, the deterioration of the electrode is reduced by reason of the fact that we employ a great many small impacts, instead of few violent ones, which shatter quickly the structure ; secondly, the formation of a large photosphere is facilitated In order to reduce the deterioration of the electrode to the minimum, it is desirable that the vibration be harmonic, for any suddenness hastens the process of destruction. An electrode lasts much longer when kept at incandescence by currents, or impulses, obtained from a high-frequency alternator, which rise and fall more or less harmonically, than by impulses obtained from a disruptive discharge coil. In the latter case there is no doubt that most of the damage is done by the fundamental sudden discharges. One of the elements of loss in such a lamp is the bombardment of the globe. As the potential is very high, the molecules are projected with great speed ; they strike the glass, and usually excite a strong phosphorescence. The effect produced is very pretty, but for economical reasons it would be perhaps preferable to prevent, or at least reduce to the minimum, the bombardment against the globe, as in such case it is, as a rule, not the object to excite phosphorescence, and as some loss of energy results from the bombardment. This loss in the bulb is principally dependent on the potential of the impulses, and on the electric density on the surface of the electrode. In employing very high frequencies the loss of energy by the bombardment is greatly reduced, for, firstly, the potential needed to perform a given amount of work is much smaller, and, secondly, by producing a highly-conducting photosphere around the electrode, the same result is obtained as though the electrode were much larger, which is equivalent to a smaller electric density. But be it by the diminution of the maximum potential or of the density, the gain is effected in the same manner—namely, by avoiding violent shocks, which strain the glass much beyond its limit of elasticity. If the frequency could be brought high enough, the loss due to the imperfect elasticity of the glass would be entirely negligible. The loss due to bombardment of the globe may, however, be reduced by using two electrodes instead of one. In such case each of the electrodes may be connected to one of the terminals ; or else, if it is preferable to use only one wire, one electrode may be connected to one terminal, and the other to the ground or to an insulated body of some surface, as, for instance, a shade on the lamp. In the latter case, unless some judgment is used, one of the electrodes might glow more intensely than the other. But, on the whole, I find it preferable when using such high frequencies to employ only one electrode and one connecting wire. I am convinced that the illuminating device of the near future will not require for its operation more than one lead, and, at any rate, it will have no leading-in wire, since the energy required can be as well transmitted through the glass. In experimental bulbs the leading-in wire is most generally used on account of convenience, as in employing condenser coatings in the manner indicated in Fig. 22, for example, there is some difficulty in fitting the parts, but these difficulties would not exist if a great many bulbs were manufactured ; otherwise the energy can be conveyed through the glass as well as through a wire, and with these high frequencies the losses are very small. Such illuminating devices will necessarily involve the use of very high potentials, and this, in the eyes of practical men, might be an objectionable feature. Yet, in reality, high potentials are not objectionable—certainly not in the least as far as the safety of the devices is concerned.

There are two ways of rendering an electric appliance safe. One is to use low potentials, the other is to determine the dimensions of the apparatus so that it is safe no matter how high a potential is used. Of the two, the latter seems to me the better way, for then the safety is absolute, unaffected by any possible combination of circumstances which might render even a low-potential appliance dangerous to life and property. But the practical conditions require not only the judicious determination of the dimensions of the apparatus ; they likewise necessitate the employment of energy of the proper kind. It is easy, for instance, to construct a transformer capable of giving, when operated from an ordinary alternate-current machine of low tension—say, 50,000 volts—which might be required to light a highly-exhausted phosphorescent tube, so that, in spite of the high potential, it is perfectly safe, the shock from it producing no inconvenience. Still, such a transformer would be expensive, and in itself inefficient ; and, besides, what energy was obtained from it would not be economically used for the production of light. The economy demands the employment of energy in the form of extremely rapid vibrations. The problem of producing light has been likened to that of maintaining a certain high-pitched note by means of a bell. It should be said a barely audible note ; and even these words would not express it, so wonderful is the sensitiveness of the eye. We may deliver powerful blows at long intervals, waste a good deal of energy, and still not get what we want ; or we may keep up the note by delivering frequent gentle taps, and get nearer to the object sought by the expenditure of much less energy. In the production of light, so far as the illuminating device is concerned, there can be only one rule—that is, to use as high frequencies as can be obtained ; but the means for the production and conveyance of impulses of such character impose, at present at least, great limitations. Once it is decided to use very high frequencies, the return wire becomes unnecessary, and all the appliances are simplified. By the use of obvious means the same result is obtained as though the return wire were used. It is sufficient for this purpose to bring in contact with the bulb, or merely in the vicinity of the same, an insulated body of some surface. This surface need, of course, be the smaller the higher the frequency and potential used, and necessarily, also, the higher the economy of the lamp or other device. This plan of working has been resorted to on several occasions this evening. So, for instance, when the incandescence of a button was produced by grasping the bulb with the hand, the body of the experimenter merely served to intensify the action. The bulb used was similar to that illustrated in Fig. 19, and the coil was excited to a small potential, not sufficient to bring the button to incandescence when the bulb was hanging from the wire ; and incidentally, in order to perform the experiment in a more suitable manner, the button was taken so large that a perceptible time had to elapse before, upon grasping the bulb, it could be rendered incandescent. The contact with the bulb was, of course, quite unnecessary. It is easy, by using a rather large bulb with an exceedingly small electrode, to adjust the conditions so that the latter is brought to bright incandescence by the mere approach of the experimenter within a few feet of the bulb, and that the incandescence subsides upon his receding.

In another experiment, when phosphorescence was excited, a similar bulb was used. Here again, originally, the potential was not sufficient to excite phosphorescence until the action was intensified—in this case, however, to present a different feature, by touching the socket with a metallic object held in the hand. The electrode in the bulb was a carbon button so large that it could not be brought to incandescence and thereby spoil the effect produced by phosphorescence. Again, in another of the early experiments, a bulb was used as illustrated in Fig. 12. In this instance, by touching the bulb with one or two fingers, one or two shadows of the stem inside were projected against the glass, the touch of the finger producing the same result as the application of an external negative electrode under ordinary circumstances.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

BY NIKOLA TESLA.

(Continued from page 545.)

In all these experiments the action was intensified by augmenting the capacity at the end of the lead connected to the terminal. As a rule, it is not necessary to resort to such means, and would be quite unnecessary with still higher frequencies, but when it is desired, the bulb or tube can be easily adapted to the purpose. In Fig. 25, for example, an experimental bulb, L, is shown, which is provided with a neck, *n*, on the top for the application of an external tinfoil coating, which may be connected to a body of larger surface. Such a lamp as illustrated in Fig. 25 may also be lighted by connecting the tinfoil coating on the neck, *n*, to the terminal, and the leading-in wire, *w*, to an insulated plate. If the bulb stands in a socket upright, as shown in the cut, a shade of conducting material may be slipped in the neck, *n*, and the action thus magnified. A more perfected arrangement used in some of these bulbs is illustrated in Fig. 26. In this case the construction of the bulb is as shown and described before, when reference was made to Fig. 19. A zinc sheet, Z, with a tubular extension, T, is slipped over the metallic socket, S. The bulb hangs downwards from the terminal, *t*, the zinc sheet, Z, performing the double office of intensifier and reflector. The reflector is separated from the terminal, *t*, by an extension of the insulating plug, P. A similar disposition with a phosphorescent tube is illustrated in Fig. 27. The tube, T, is prepared from two short tubes of a different diameter, which are sealed on the ends. On the lower end is placed an outside conducting coating, C, which connects to the wire, *w*. The wire has a hook on the upper end for suspension, and passes through the centre of the inside tube, which is filled with some good and tightly-packed insulator. On the outside of the upper end of the tube, T, is another conducting coating, C_1, upon which is slipped a metallic reflector, Z, which should be separated by a thick insulation from the end of wire, *w*.

The economical use of such a reflector or intensifier would require that all energy supplied to an air condenser should be recoverable, or, in other words, that there should not be any losses, neither in the gaseous medium nor through its action elsewhere. This is far from being so, but, fortunately, the losses may be reduced to anything desired. A few remarks are necessary on this subject, in order to make the experiences gathered in the course of these investigations perfectly clear. Suppose a small helix with many well-insulated turns, as in experiment Fig. 17, has one of its ends connected to one of the terminals of the induction coil, and the other to a metal plate, or, for the sake of simplicity, a sphere, insulated in space. When the coil is set to work, the potential of the sphere is alternated, and the small helix now behaves as though its free end were connected to the other terminal of the induction coil. If an iron rod be held within the small helix, it is quickly brought to a high temperature, indicating the passage of a strong current through the helix. How

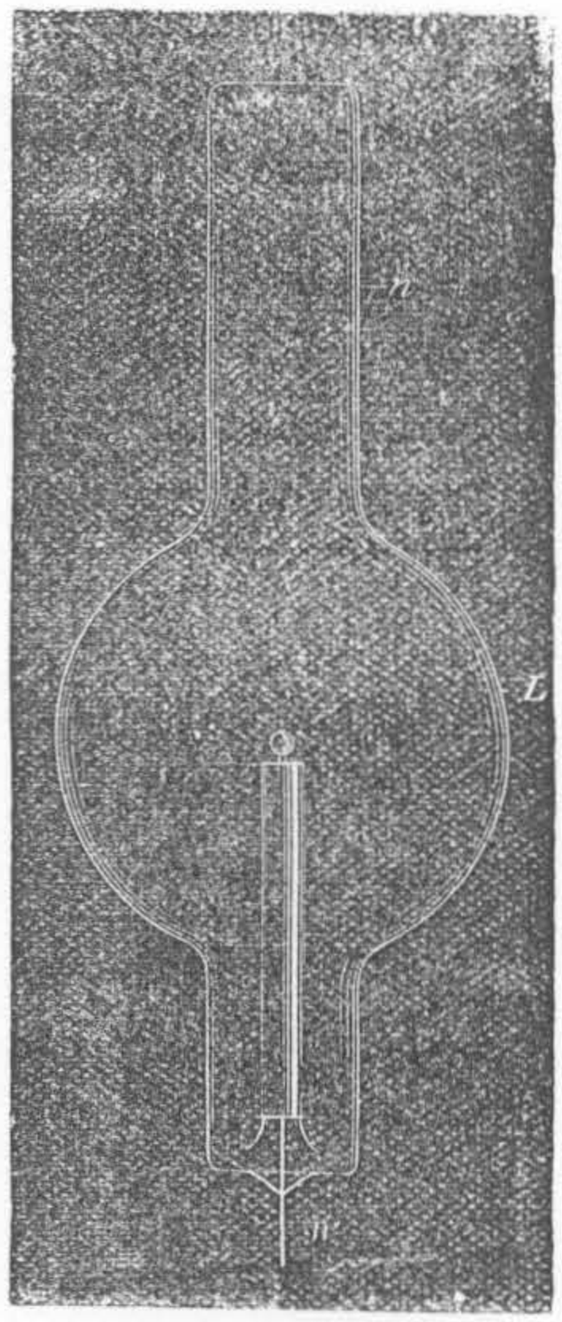

FIG. 25.—Improved Experimental Bulb.

does the insulated sphere act in this case? It can be a condenser, storing and returning the energy supplied to it, or it can be a mere sink of energy, and the conditions of the experiment determine whether it is more one or the other. The sphere being charged to a high potential, it acts inductively upon the surrounding air, or whatever gaseous medium there might be. The molecules, or atoms, which are near the sphere are of course more attracted, and move through a greater distance than the farther ones. When the nearest molecules strike the sphere they are repelled, and collisions occur

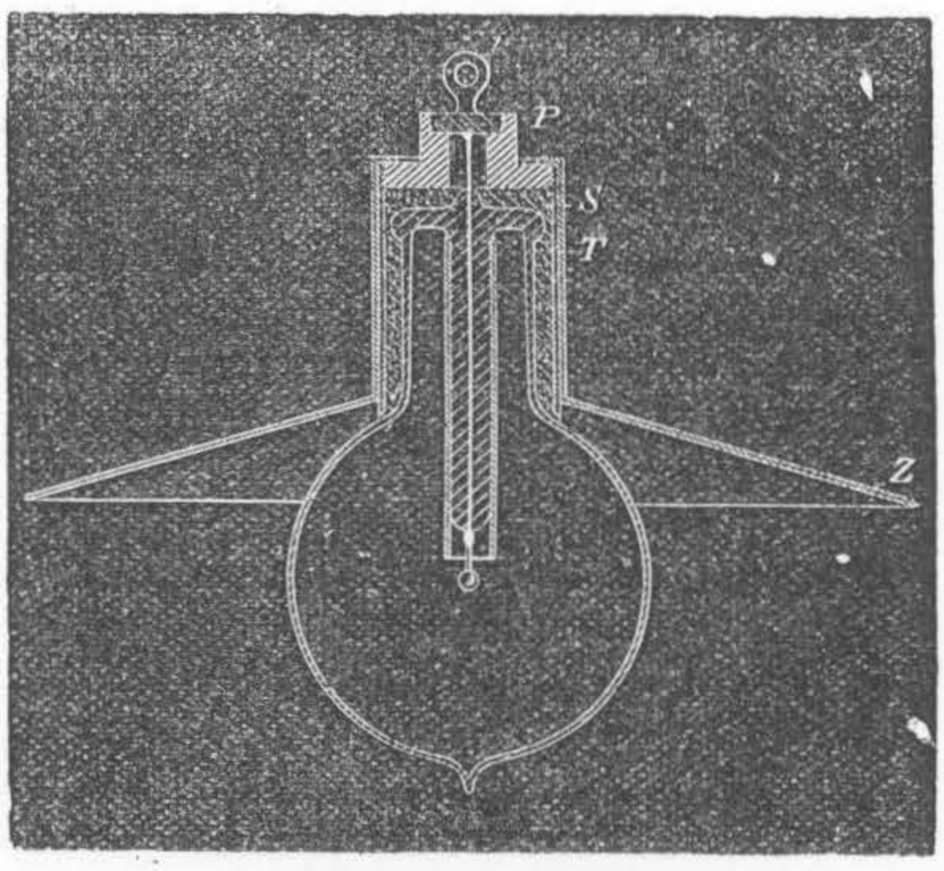

FIG. 26.—Improved Bulb with Intensifying Reflector.

a all distances within the inductive action of the sphere. It is now clear that, if the potential be steady, but little loss of energy can be caused in this way, for the molecules which are nearest to the sphere, having had an additional charge imparted to them by contact, are not attracted until they have parted, if not with all, so with most of the additional charge, which can be accomplished only after a great many collisions. From the fact that with a steady potential there is but little loss in dry air, one must come to such a conclusion. When the potential of the sphere, instead of being steady, is alternating, the conditions are entirely different. In this case a rhythmical bombardment

* Lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the *Journal* of the Institution of Electrical Engineers.

occurs, no matter whether the molecules after coming in contact with the sphere lose the imparted charge or not; what is more, if the charge is not lost, the impacts are only the more violent. Still, if the frequency of the impulses be very small, the loss caused by the impacts and collisions would not be serious unless the potential were excessive. But when extremely high frequencies and more or less high potentials are used, the loss may be very great. The total energy lost per unit of time is proportionate to the product of the number of impacts per second, or the frequency, and the energy lost in each impact. But the energy of an impact must be proportionate to the square of the electric density of the sphere, since the charge imparted to the molecule is proportionate to that density. I conclude from this that the total energy lost must be proportionate to the product of the frequency and the square of the electric density; but this law needs experimental confirmation. Assuming the preceding considerations to be true, then, by rapidly alternating the potential of a body immersed in an insulating gaseous medium, any amount of energy may be dissipated into space. Most of that energy, then, I believe, is not dissipated in the form of long ether waves, propagated to considerable distance, as is thought most generally, but is consumed—in the case of an insulated sphere, for example—in impact and collisional losses—that is, heat vibrations—on the surface and in the vicinity of the sphere. To reduce the dissipation, it is necessary to work with a small electric density—the smaller, the higher the frequency. But since, on the assumption before made, the loss is diminished with the square of the density, and since currents of very high frequencies involve considerable waste when transmitted through conductors, it follows that, on the whole, it is better to employ one wire than two. Therefore, if motors, lamps, or devices of any kind are perfected, capable of being advantageously operated by currents of extremely high frequency, economical reasons will make it advisable to use only one wire, especially if the distances are great.

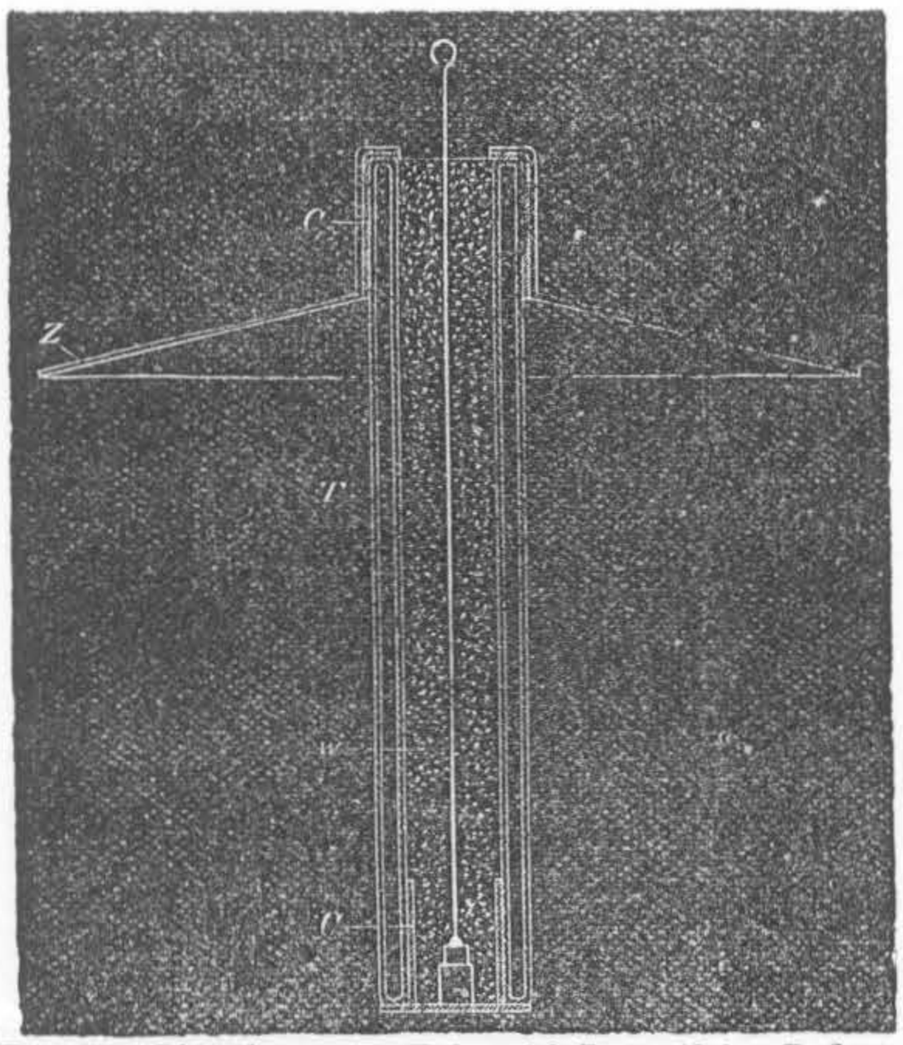

FIG. 27.—Phosphorescent Tube with Intensifying Reflector.

When energy is absorbed in a condenser, the same behaves as though its capacity were increased. Absorption exists more or less always, but generally it is small and of no consequence as long as the frequencies are not very great. In using extremely high frequencies, and, necessarily, in such case also high potentials, the absorption—or what is here meant more particularly by this term, the loss of energy due to the presence of a gaseous medium—is an important factor to be considered, as the energy absorbed in the air condenser may be any fraction of the supplied energy. This would seem to make it very difficult to tell from the measured or computed capacity of an air condenser its actual capacity or vibration period, especially if the condenser is of very small surface and is charged to a very high potential. As many important results are dependent upon the correctness of the estimation of the vibration period, this subject demands the most careful scrutiny of other investigators. To reduce the probable error as much as possible in experiments of the kind alluded to, it is advisable to use spheres or plates of large surface, so as to make the density exceedingly small. Otherwise, when it is practicable, an oil condenser should be used in preference. In oil or other liquid dielectries there are seemingly no such losses as in gaseous media. It being impossible to exclude entirely the gas in condensers with solid dielectrics, such condensers should be immersed in oil, for economical reasons if nothing else: they can then be strained to the utmost and will remain cool. In Leyden jars the loss due to air is comparatively small, as the tinfoil coatings are large, close together, and the charged surfaces not directly exposed; but when the potentials are very high, the loss may be more or less considerable at, or near, the upper edge of the foil, where the air is principally acted upon. If the jar be immersed in boiled-out oil, it will be capable of performing four times the amount of work which it can for any length of time when used in the ordinary way, and the loss will be inappreciable.

It should not be thought that the loss in heat in an air condenser is necessarily associated with the formation of visible streams or brushes. If a small electrode, enclosed in an unexhausted bulb, is connected to one of the terminals of the coil, streams can be seen to issue from the electrode, and the air in the bulb is heated; if, instead of a small electrode, a large sphere is enclosed in the bulb, no streams are observed, still the air is heated. Nor should it be thought that the temperature of an air condenser would give even an approximate idea of the loss in heat incurred, as in such case heat must be given off much more quickly since there is, in addition to the ordinary radiation, a very active carrying away of heat by independent carriers going on, and since not only the apparatus, but the air at some distance from it, is heated in consequence of the collisions which must occur. Owing to this, in experiments with such a coil, a rise of temperature can be distinctly observed only when the body connected to the coil is very small. But with apparatus on a large scale, even a body of considerable bulk would be heated, as, for instance, the body of a person; and I think that skilled physicians might make observations of utility in such experiments, which, if the apparatus were judiciously designed, would not present the slightest danger.

A question of some interest, principally to meteorologists, presents itself here. How does the earth behave? The earth is an air condenser, but is it a perfect or a very imperfect one—a mere sink of energy? There can be little doubt that to any small disturbance, as might be caused in an experiment, the earth behaves as an almost perfect condenser. But it might be different when its charge is set in vibration by some sudden disturbance occurring in the heavens. In such case, as before stated, probably

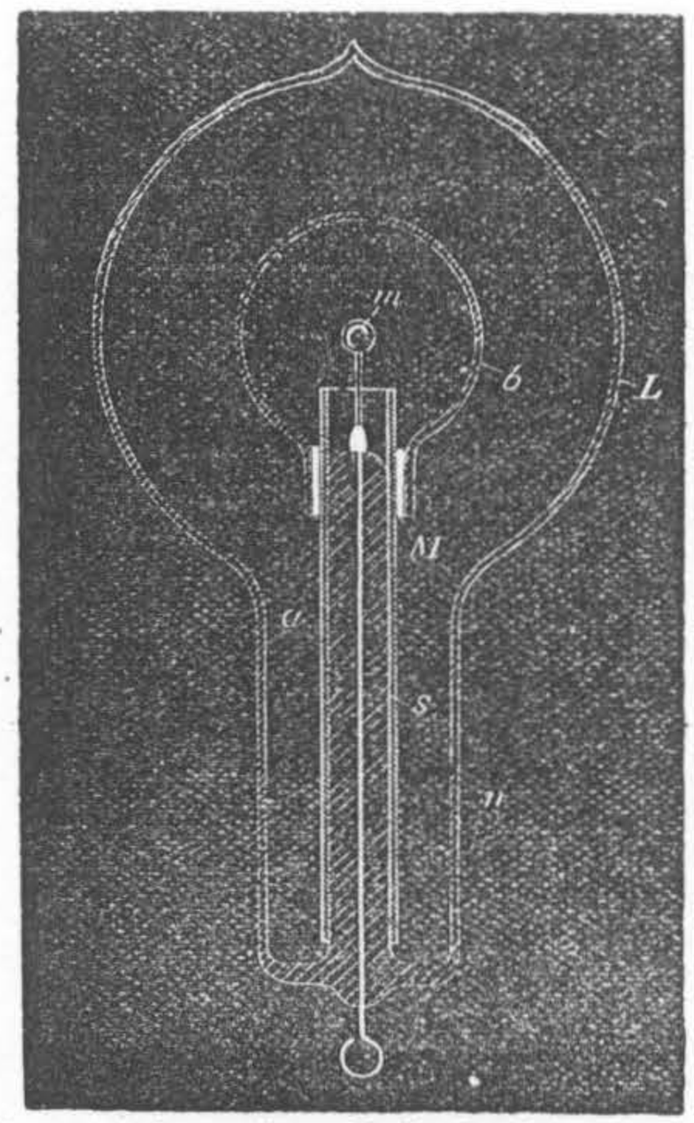

FIG. 28.—Lamp with Auxiliary Bulb, Confining Action to Centre.

only little of the energy of the vibrations set up would be lost into space in form of long ether radiations; but most of the energy, I think, would spend itself in molecular impacts and collisions, and pass off into space in the form of short heat, and possibly light, waves. As both the frequency of the vibration of the charge and the potential are in all probability excessive, the energy converted into heat may be considerable. Since the density must be unevenly distributed, either in consequence of the irregularity of the earth's surface, or on account of the condition of the atmosphere on various places, the effect produced would accordingly vary from place to place. Considerable variations in the temperature and pressure of the atmosphere may in this manner be caused at any point of the surface of the earth. The variations may be gradual or very sudden, according to the nature of the original disturbance, and may produce rain and storms, or locally modify the weather in any way.

From the remarks before made one may see what an important factor of loss the air in the neighbourhood of a charged surface becomes when the electric density is great and the frequency of the impulses excessive. But the action as explained implies that the air is insulating—that is, that it is composed of independent carriers immersed in an insulating medium. This is the case only when the air is at something like ordinary or greater, or at extremely small, pressure. When the air is slightly rarefied and conducting, then true conduction losses occur also. In such case, of course, considerable energy may be dissipated into space even with a steady potential, or with impulses of low frequency, if the density is very great. When the gas is at very low pressure, an electrode is heated more, because higher speeds can be reached. If the gas around the electrode is strongly compressed, the displacements, and consequently the speeds, are very small, and the heating is insignificant. But if in such case the frequency could

be sufficiently increased, the electrode would be brought to a high temperature as well as if the gas were at very low pressure; in fact, exhausting the bulb is only necessary because we cannot produce (and possibly not convey) currents of the required frequency.

Returning to the subject of electrode lamps, it is obviously of advantage in such a lamp to confine as much as possible the heat to the electrode by preventing the circulation of the gas in the bulb. If a very small bulb be taken, it would confine the heat better than a large one, but it might not be of sufficient capacity to be operated from the coil, or, if so, the glass might get too hot. A simple way to improve in this direction is to employ a globe of the required size, but to place a small bulb, the diameter of which is properly estimated, over the refractory button contained in the globe. This arrangement is illustrated in Fig. 28. The globe, L, has in this case a large neck, *n*, allowing the small bulb, *b*, to slip through. Otherwise the construction is the same as shown in Fig. 18, for example. The small bulb is conveniently supported upon the stem, *s*, carrying the refractory button, *m*. It is separated from the aluminium tube, *a*, by several layers of mica, M, in order to prevent the cracking of the neck by the rapid heating of the aluminium tube upon a sudden turning on of the current. The inside bulb should be as small as possible when it is desired to obtain light only by incandescence of the electrode. If it is desired to produce phosphorescence, the bulb should be larger, else it would be apt to get too hot, and the phosphorescence would cease. In this arrangement usually only the small bulb shows phosphoresence, as there is practically no bombardment against the outer globe. In some of these bulbs constructed as illustrated in Fig. 28, the small tube was coated with phosphorescent paint, and beautiful effects were obtained. Instead of taking the inside bulb large, in order to avoid undue heating, it answers the purpose to make the electrode, *m*, larger. In this case the bombardment is weakened by reason of the smaller electric density

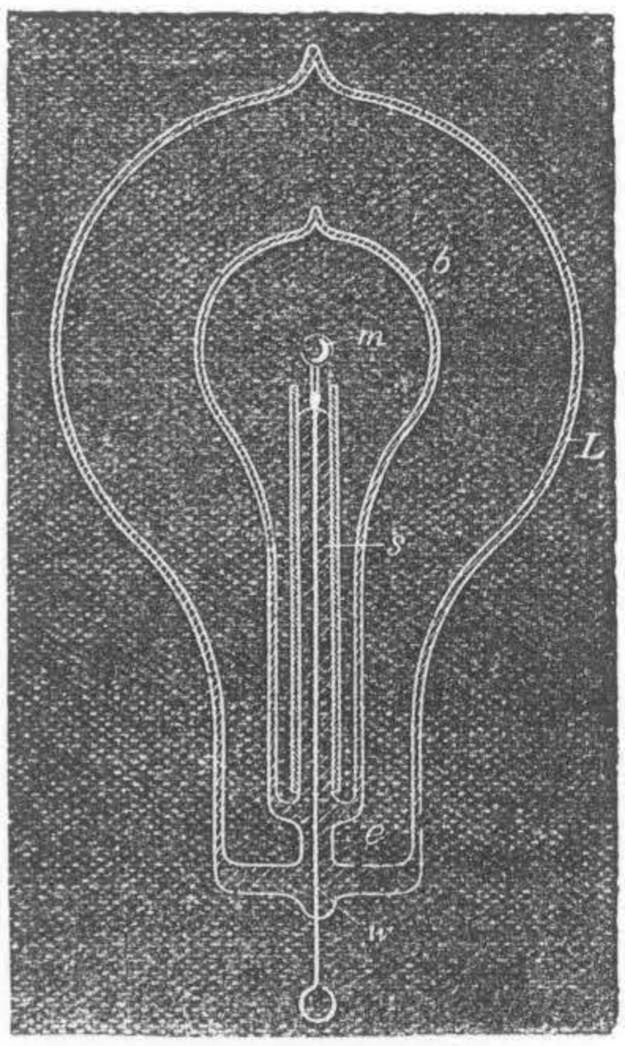

FIG. 29.—Lamp with Independent Auxiliary Bulb.

Many bulbs were constructed on the plan illustrated in Fig. 29. Here a small bulb, *b*, containing the refractory button, *m*, upon being exhausted to a very high degree, was sealed in a large globe, L, which was then moderately exhausted and sealed off. The principal advantage of this construction was that it allowed to reach extremely high vacua, and, at the same time use a large bulb. It was found, in the course of experiences with bulbs such as illustrated in Fig. 29, that it was well to make the stem, *s*, near the seal at *e* very thick, and the leading-in wire, *w*, thin, as it occurred sometimes that the stem at *e* was heated and the bulb was cracked. Often the outer globe, L, was exhausted only just enough to allow the discharge to pass through, and the space between the bulbs appeared crimson, producing a curious effect. In some cases, when the exhaustion in globe, L, was very low, and the air good conducting, it was found necessary, in order to bring the button, *m*, to high incandescence, to place, preferably on the upper part of the neck of the globe, a tinfoil coating which was connected to an insulated body to the ground, or to the other terminal of the coil, as the highly-conducting air weakened the effect somewhat, probably by being acted upon inductively from the wire, *w*, where it entered the bulb at *e*. Another difficulty—which, however, is always present when the refractory button is mounted in a very small bulb—existed in the construction illustrated in Fig. 29—namely, the vacuum in the bulb, *b*, would be impaired in a comparatively short time. The chief idea in the two last-described constructions was to confine the heat to the central portion of the globe by preventing the exchange of air. An advantage is secured, but owing to the heating of the inside bulb, and slow evaporation of the glass, the vacuum is hard to maintain, even if the construction illustrated in Fig. 28 be chosen, in which both bulbs communicate.

But by far the better way—the ideal way—would be to reach sufficiently high frequencies. The higher the frequency the slower would be the exchange of the air, and I think that a frequency may be reached at which there would be no exchange whatever of the air molecules around the terminal. We would then produce a flame in which there would be no carrying away of material, and a queer flame it would be, for it would be rigid! With such high frequencies the inertia of the particles would come into play. As the brush, or flame, would gain rigidity in virtue of the inertia of the particles, the exchange of the latter would be prevented. This would necessarily occur, for, the number of impulses being augmented, the potential energy of each would diminish, so that finally only atomic vibrations could be set up, and the motion of translation through measurable space would cease. Thus an ordinary gas burner connected to a source of rapidly alternating potential might have its efficiency augmented to a certain limit, and this for two reasons—because of the additional vibration imparted, and because of a slowing down of the process of carrying off. But the renewal being rendered difficult, and renewal being necessary to maintain the burner, a continued increase of the frequency of the impulses, assuming they could be transmitted to and impressed upon the flame, would result in the "extinction" of the latter, meaning by this term only the cessation of the chemical process. I think, however, that in the case of an electrode immersed in a fluid insulating medium, and surrounded by independent carriers of electric charges, which can be acted upon inductively, a sufficiently high frequency of the impulses would probably result in a gravitation of the gas all around towards the electrode. For this it would be only necessary to assume that the independent bodies are irregularly shaped. They would then turn towards the electrode their side of the greatest electric density, and this would be a position in which the fluid resistance to approach would be smaller than that offered to the receding.

The general opinion, I do not doubt, is that it is out of question to reach any such frequencies as might—assuming some of the views before expressed to be true—produce any of the results which I have pointed out as mere possibilities. This may be so, but in the course of these investigations, from the observation of many phenomena I have gained the conviction that these frequencies would be much lower than one is apt to estimate at first. In a flame we set up light-vibrations by causing molecules, or atoms, to collide. But what is the ratio of the frequency of the collisions and that of the vibrations set up? Certainly it must be incomparably smaller than that of the knocks of the bell and the sound-vibrations, or that of the discharges and the oscillations of the condenser. We may cause the molecules of the gas to collide by the use of alternate electric impulses of high frequency, and so we may imitate the process in a flame; and from experiments with frequencies which we are now able to obtain, I think that the result is producible with impulses which are transmissible through a conductor. In connection with thoughts of a similar nature, it appeared to me of great interest to demonstrate the rigidity of a vibrating gaseous column. Although with such low frequencies as, say, 10,000 per second, which I was able to obtain without difficulty from a specially constructed alternator, the task looked discouraging at first, I made a series of experiments. The trials with air at ordinary pressure led to no result, but with air moderately rarefied I obtained what I think to be an umistakable experimental evidence of the property sought for. As a result of this kind might lead able investigators to conclusions of importance, I will describe one of the experiments performed. It is well known that when a tube is slightly exhausted the discharge may be passed through it in form of a thin luminous thread. When produced with currents of low frequency, obtained from a coil operated as usual, this thread is inert. If a magnet be approached to it, the part near the same is attracted or repelled, according to the direction of the lines of force of the magnet. It occurred to me that if such a thread would be produced with currents of very high frequency, it should be more or less rigid, and as it was visible it could be easily studied. Accordingly, I prepared a tube about 1in. in diameter and one metre long, with outside coating at each end. The tube was exhausted to a point at which by a little working the thread discharge could be obtained. It must be remarked here that the general aspect of the tube, and the degree of exhaustion, are quite different than when ordinary low-frequency currents are used. As it was found preferable to work with one terminal, the tube prepared was suspended from the end of a wire connected to the terminal, the tinfoil coating being connected to the wire, and to the lower coating sometimes a small insulated plate was attached. When the thread was formed it extended through the upper part of the tube and lost itself in the lower end. If it possessed rigidity it resembled, not exactly an elastic cord stretched tight between two supports, but a cord suspended from a height with a small weight attached on the end. When the finger or a magnet was approached to the upper end of the luminous thread, it could be brought locally out of position by electrostatic or magnetic action, and when the disturbing object was very quickly removed an analogous result was produced, as though a suspended cord would be displaced and quickly released near the point of suspension. In doing this the luminous thread was set in vibration, and two very sharply marked nodes, and a third indistinct one, were formed. The vibration, once set up, continued for fully eight minutes, dying gradually out. The speed of the vibration often varied perceptibly, and it could be observed that the electrostatic attraction of the glass affected the vibrating thread; but it was clear that the electrostatic action was not the cause of the vibration, for the thread was most generally stationary, and could always be set in vibration by passing the finger quickly near the upper part of the tube. With a magnet the thread could be split in two and both

parts vibrated. By approaching the hand to the lower coating of the tube, or insulated plate, if attached, the vibration was quickened; also, as far as I could see, by raising the potential or frequency. Thus, either increasing the frequency or passing a stronger discharge of the same frequency corresponded to a tightening of the cord. I did not obtain any experimental evidence with condenser discharges. A luminous band excited in a bulb by repeated discharges of a Leyden jar must possess rigidity, and if deformed and suddenly released should vibrate. But probably the amount of vibrating matter is so small that in spite of the extreme speed the inertia cannot prominently assert itself. Besides, the observation in such a case is rendered extremely difficult on account of the fundamental vibration.

The demonstration of the fact—which still needs better experimental confirmation—that a vibrating gaseous column possesses rigidity, might greatly modify the views of thinkers. When with low frequencies and insignificant potentials indications of that property may be noted, how must a gaseous medium behave under the influence of enormous electrostatic stresses which may be active in the interstellar space, and which may alternate with inconceivable rapidity? The existence of such an electrostatic, rhythmically throbbing force—of a vibrating electrostatic field—would show a possible way how solids might have formed from the ultra-gaseous uterus, and how transverse and all kinds of vibrations may be transmitted through a gaseous medium filling all space. Then ether might be a true fluid, devoid of rigidity, and at rest, it being merely necessary as a connecting link to enable interaction. What determines the rigidity of a body? It must be the speed and the amount of moving matter.

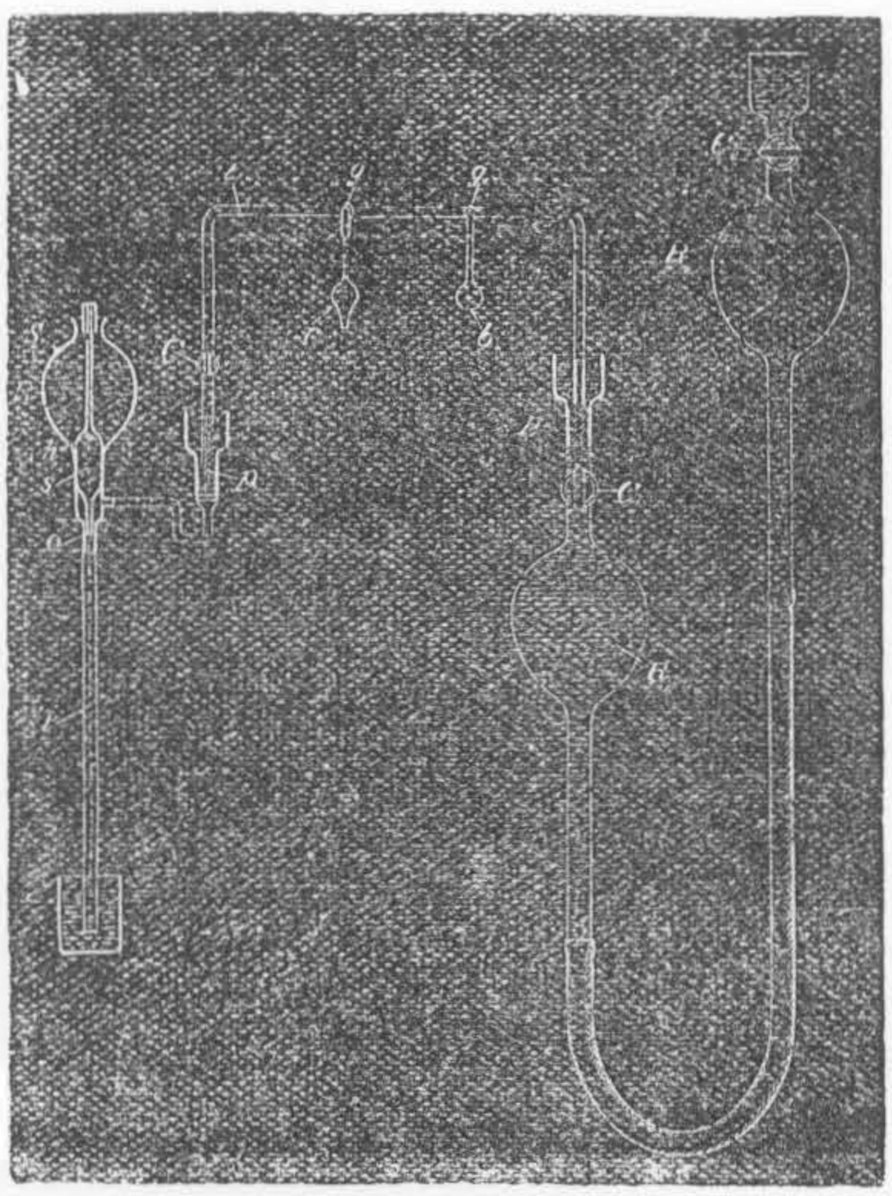

FIG. 30.—Apparatus Used for Obtaining High Degrees of Exhaustion.

In a gas the speed may be considerable, but the density is exceedingly small: in a liquid the speed would be likely to be small, though the density may be considerable; and in both cases the inertia resistance offered to displacement is practically *nil*. But place a gaseous (or liquid) column in an intense, rapidly-alternating electrostatic field, set the particles vibrating with enormous speeds, then the inertia resistance asserts itself. A body might move with more or less freedom through the vibrating mass, but as a whole it would be rigid.

There is a subject which I must mention in connection with these experiments: it is that of high vacua. This is a subject the study of which is not only interesting, but useful, for it may lead to results of great practical importance. In commercial apparatus, such as incandescent lamps, operated from ordinary systems of distribution, a much higher vacuum than presently obtained would not secure a very great advantage. In such a case the work is performed on the filament and the gas is little concerned; the improvement, therefore, would be but trifling. But when we begin to use very high frequencies and potentials, the action of the gas becomes all-important, and the degree of exhaustion materially modifies the results. As long as ordinary coils, even very large ones, were used, the study of the subject was limited, because just at a point when it became most interesting it had to be interrupted on account of the "non-striking" vacuum being reached. But presently we are able to obtain from a small disruptive discharge coil potentials much higher than even the largest coil was capable of giving, and, what is more, we can make the potential alternate with great rapidity. Both of these results enable us now to pass a luminous discharge through most any vacua obtainable, and the field of our investigations is greatly extended. Think we as we may of all the possible directions to develop a practical illuminant, the line of high vacua seems to be the most promising at present. But to reach extreme vacua the appliances must be much more improved, and ultimate perfection will not be attained until we shall have discarded the mechanical and perfected an electrical vacuum pump. Molecules and atoms can be thrown out of a bulb under the action of an enormous potential; this will be the principle of the vacuum pump of the future. For the present we must secure the best results we can with mechanical appliances. In this respect it might not be out of the way to say a few words about the method of, and apparatus for, producing excessively high degrees of exhaustion, of which I have availed myself in the course of these investigations. It is very probable that other experimenters have used similar arrangements; but as it is possible that there may be an item of interest in their description, a few remarks which will render this investigation more complete might be permitted. The apparatus is illustrated in a drawing show in Fig. 30. S represents a Sprengel pump, which has been specially constructed to better suit the work required. The stop-cock which is usually employed has been omitted, and instead of it a hollow stopper, s, has been fitted in the neck of the reservoir, R. This stopper has a small hole, h, through which the mercury descends; the size of the outlet, o, being properly determined with respect to the section of the fall tube, t, which is sealed to the reservoir instead of being connected to it in the usual manner. This arrangement overcomes the imperfections and troubles which often arise from the use of the stop-cock on the reservoir and the connection of the latter with the fall tube. The pump is connected through a U-shaped tube, t, to a very large reservoir, R_1. Especial care was taken in fitting the grinding surfaces of the stoppers, p and p_1, and both of these and the mercury caps above them were made exceptionally long. After the U-shaped tube was fitted and put in place, it was heated, so as to soften and take off the strain resulting from imperfect fitting. The U-shaped tube was provided with a stop-cock, C, and two ground connections, g and g_1—one for a small bulb, b, usually containing caustic potash, and the other for the receiver, r, to be exhausted. The reservoir R_1 was connected by means of a rubber tube to a slightly larger reservoir, R_2, each of the two reservoirs being provided with a stop-cock, C_1 and C_2, respectively. The reservoir R_2 could be raised and lowered by a wheel and rack, and the range of its motion was so determined that when it was filled with mercury and the stop-cock C_2 closed, so as to form a Torricellian vacuum in it when raised, it could be lifted so high that the mercury in reservoir R_1 would stand a little above stop-cock C_1; and when this stop-cock was closed and the reservoir R_2 descended, so as to form a Torricellian vacuum in reservoir R_1, it could be lowered so far as to completely empty the latter, the mercury filling the reservoir R_2 up to a little above stop-cock C_2. The capacity of the pump and of the connections was taken as small as possible relatively to the volume of reservoir R_1, since, of course, the degree of exhaustion depended upon the ratio of these quantities.

With this apparatus I combined the usual means indicated by former experimenters for the production of very high vacua. In most of the experiments it was convenient to use caustic potash. I may venture to say, in regard to its use, that much time is saved and a more perfect action of the pump ensured by fusing and boiling the potash as soon as, or even before, the pump settles down. If this course is not followed, the sticks, as ordinarily employed, may give moisture off at a certain very low rate, and the pump may work for many hours without reaching a very high vacuum. The potash was heated either by a spirit lamp, or by passing a discharge through it, or by passing a current through a wire contained in it. The advantage in the latter case was that the heating could be more rapidly repeated. Generally the process of exhaustion was the following: At the start, the stop-cocks, C and C_1, being open, and all other connections closed, the reservoir R_2 was raised so far that the mercury filled the reservoir R_1, and a part of the narrow connecting U-shaped tube. When the pump was set to work the mercury would, of course, quickly rise in the tube, and reservoir R_2 was lowered, the experimenter keeping the mercury at about the same level. The reservoir R_2 was balanced by a long spring which facilitated the operation, and the friction of the parts was generally sufficient to keep it almost in any position. When the Sprengel pump had done its work, the reservoir R_2 was further lowered and the mercury descended in R_1 and filled R_2, whereupon stop-cock C_2 was closed. The air adhering to the walls of R_1 and that absorbed by the mercury was carried off, and to free the mercury of all air the reservoir R_2 was for a long time worked up and down. During this process some air, which would gather below stop-cock C_2, was expelled from R_2 by lowering it far enough and opening the stop-cock, closing the latter again before raising the reservoir. When all the air had been expelled from the mercury, and no air would gather in R_2 when it was lowered, the caustic potash was resorted to. The reservoir R_2 was now again raised until the mercury in R_1 stood above stop-cock C_1. The caustic potash was fused and boiled, and the moisture partly carried off by the pump and partly reabsorbed; and this process of heating and cooling was repeated many times, and each time, upon the moisture being absorbed or carried off, the reservoir R_2 was for a long time raised and lowered. In this manner all the moisture was carried off from the mercury, and both the reservoirs were in proper condition to be used. The reservoir R_2 was then again raised to the top, and the pump was kept working for a long time.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

BY NIKOLA TESLA.

(Continued from page 569.)

When the highest vacuum obtainable with the pump had been reached, the potash bulb was usually wrapped with cotton which was sprinkled with ether so as to keep the potash at a very low temperature, then the reservoir R_2 was lowered, and upon reservoir R_1 being emptied the receiver, r, was quickly sealed up. When a new bulb was put on, the mercury was always raised above stop-cock C_1, which was closed, so as to always keep the mercury and both the reservoirs in fine condition, and the mercury was never withdrawn from R_1 except when the pump had reached the highest degree of exhaustion. It is necessary to observe this rule if it is desired to use the apparatus to advantage. By means of this arrangement I was able to proceed very quickly, and when the apparatus was in perfect order it was possible to reach the phosphorescent stage in a small bulb in less than 15 minutes, which is certainly very quick work for a small laboratory arrangement requiring in all about 100lb. of mercury. With ordinary small bulbs the ratio of the capacity of the pump, receiver, and connections, and that of reservoir, R, was about 1 : 20, and the degrees of exhaustion reached were necessarily very high, though I am unable to make a precise and reliable statement how far the exhaustion was carried.

What impresses the investigator most in the course of these experiences is the behaviour of gases when subjected to great rapidly-alternating electrostatic stresses. But he must remain in doubt as to whether the effects observed are due wholly to the molecules, or atoms, of the gas which chemical analysis discloses to us, or whether there enters into play another medium of a gaseous nature, comprising atoms, or molecules, immersed in a fluid pervading the space. Such a medium surely must exist, and I am convinced that, for instance, even if air were absent, the surface and neighbourhood of a body in space would be heated by rapidly alternating the potential of the body; but no such heating of the surface or neighbourhood could occur if all free atoms were removed and only a homogeneous, incompressible, and elastic fluid—such as ether is supposed to be—would remain, for then there would be no impacts, no collisions. In such a case, as far as the body itself is concerned, only frictional losses in the inside could occur.

It is a striking fact that the discharge through a gas is established with ever-increasing freedom as the frequency of the impulses is augmented. It behaves in this respect quite contrarily to a metallic conductor. In the latter the impedance enters prominently into play as the frequency is increased, but the gas acts much like a series of condensers would; the facility with which the discharge passes through seem to depend on the rate of change of potential. If it act so, then in a vacuum tube even of great length, and no matter how strong the current, self-induction could not assert itself to any appreciable degree. We have, then, as far as we can now see, in the gas a conductor which is capable of transmitting electric impulses of any frequency which we may be able to produce. Could the frequency be brought high enough, then a queer system of electric distribution which would be likely to interest gas companies, might be realised; metal pipes filled with gas—the metal being the insulator, the gas the conductor—supplying phosphorescent bulbs, or, perhaps, devices as yet uninvented. It is certainly possible to take a hollow tore of copper, rarefy the gas in the same, and by passing impulses of sufficiently high frequency through a circuit around it, bring the gas inside to a high degree of incandescence; but as to the nature of the forces there would be considerable uncertainty, for it would be doubtful whether with such impulses the copper tore would act as a static screen. Such paradoxes and apparent impossibilities we encounter at every step in this line of work, and therein lies, to a great extent, the charm of the study.

I have here a short and wide tube which is exhausted to a high degree and covered with a substantial coating of bronze, the

* Lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the *Journal* of the Institution of Electrical Engineers.

coating allowing barely the light to shine through. A metallic clasp, with a hook for suspending the tube, is fastened around the middle portion of the latter, the clasp being in contact with the bronze coating. I now want to light the gas inside by suspending the tube on a wire connected to the coil. Anyone who would try the experiment for the first time, not having any previous experience, would probably take care to be quite alone when making the trial, for fear that he might become the joke of his assistants. Still, the bulb lights in spite of the metal coating, and the light can be distinctly perceived through the latter. A long tube covered with aluminium bronze lights when held in one hand—the other touching the terminal of the coil—quite powerfully. It might be objected that the coatings are not sufficiently conducting; still, even if they were highly resistant, they ought to screen the gas. They certainly screen it perfectly in a condition of rest, but not by far perfectly when the charge is surging in the coating. But the loss of energy which occurs within the tube, notwithstanding the screen, is occasioned principally by the presence of the gas. Were we to take a large hollow metallic sphere and fill it with a perfect incompressible fluid dielectric, there would be no loss inside of the sphere, and consequently the inside might be considered as perfectly screened, though the potential be very rapidly alternating. Even were the sphere filled with oil, the loss would be imcomparably smaller than when the fluid is replaced by a gas, for in the latter case the force produces displacements: that means impact and collisions in the inside.

No matter what the pressure of the gas may be, it becomes an important factor in the heating of a conductor when the electric density is great and the frequency very high. That in the heating of conductors by lightning discharges air is an element of great importance, is almost as certain as an experimental fact. I may illustrate the action of the air by the

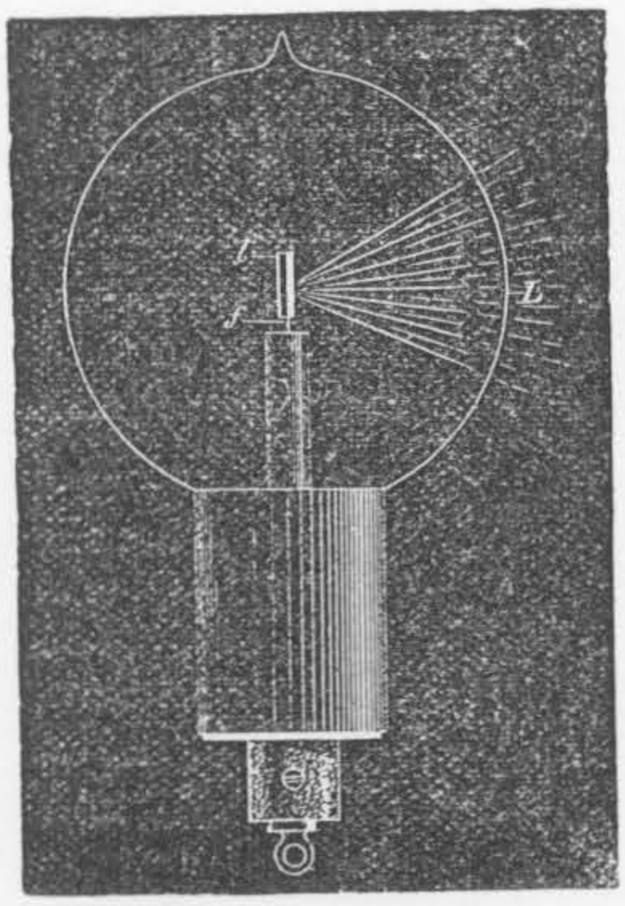

FIG. 31.—Bulb showing Radiant Lime Stream at Low Exhaustion.

following experiment: I take a short tube which is exhausted to a moderate degree, and has a platinum wire running through the middle from one end to the other. I pass a steady or low-frequency current through the wire, and it is heated uniformly in all parts. The heating here is due to conduction, or frictional losses, and the gas around the wire has, as far as we can see, no function to perform. But now let me pass sudden discharges, or a high-frequency current, through the wire. Again the wire is heated, this time principally on the ends and least in the middle portion; and if the frequency of the impulses, or the rate of change, is high enough, the wire might as well be cut in the middle as not, for practically all the heating is due to the rarefied gas. Here the gas might only act as a conductor of no impedance diverting the current from the wire as the impedance of the latter is enormously increased, and merely heating the ends of the wire by reason of their resistance to the passage of the discharge. But it is not at all necessary that the gas in the tube should be conducting; it might be at an extremely low pressure, still the ends of the wires would be heated—as, however, is ascertained by experience—only the two ends would in such case not be electrically connected through the gaseous medium. Now what with these frequencies and potentials occurs in an exhausted tube occurs in the lightning discharges at ordinary pressure. We only need remember one of the facts arrived at in the course of these investigations—namely, that to impulses of very high frequency the gas at ordinary pressure behaves in much the same manner as though it were at moderately low pressure. I think that in lightning discharges frequently wires or conducting objects are volatilised merely because air is present, and that, were the conductor immersed in an insulating liquid, it would be safe, for then the energy would have to spend itself somewhere else. From the behaviour of gases to sudden impulses of high potential, I am led to conclude that there can be no surer way of diverting a lightning discharge than by affording it a passage through a volume of gas, if such a thing can be done in a practical manner.

There are two more features upon which I think it necessary to dwell in connection with these experiments—the "radiant state" and the "non-striking vacuum." Anyone who has studied Crooke's work must have received the impression that the "radiant state" is a property of the gas inseparably connected with an extremely high degree of exhaustion. But it should be remembered that the phenomena observed in an exhausted vessel are limited to the character and capacity of the apparatus which is made use of. I think that in a bulb a molecule, or atom, does not precisely move in a straight line because it meets no obstacle, but because the velocity imparted to it is sufficient to propel it in a sensibly straight line. The mean free path is one thing, but the velocity—the energy associated with the moving body—is another, and under ordinary circumstances I believe that it is a mere question of potential, or speed. A disruptive discharge coil, when the potential is pushed very far, excites phosphorescence and projects shadows, at comparatively low degrees of exhaustion. In a lightning discharge matter moves in straight lines at ordinary pressure when the free mean path is exceedingly small, and frequently images of wires or other metallic objects have been produced by the particles thrown off in straight lines. I have prepared a bulb to illustrate by an experiment the correctness of these assertions. In a globe, L, Fig. 31, I have mounted upon a lamp filament, *f*, a piece of lime, *l*. The lamp filament is connected with a wire which leads into the bulb, and the general construction of the latter is as indicated in Fig. 19, before described.

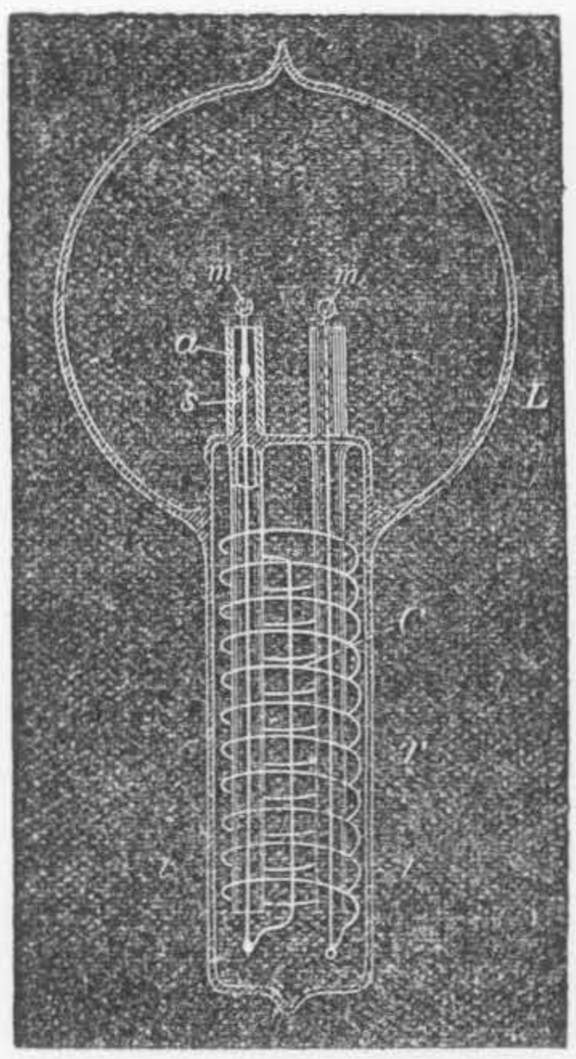

FIG. 32.—Electro-dynamic Induction Lamp.

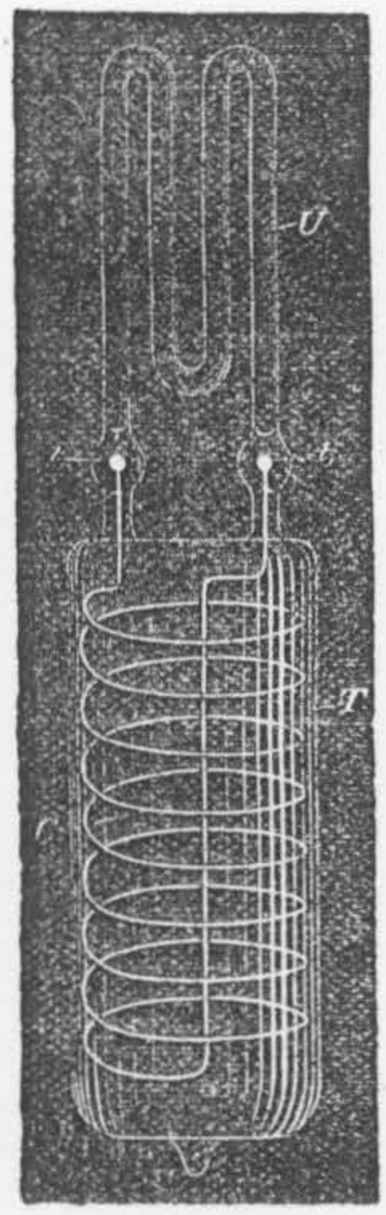

FIG. 33.—Electro-dynamic Induction Tube.

The bulb being suspended from a wire connected to the terminal of the coil, and the latter being set to work, the lime piece, *l*, and the projecting parts of the filament, *f*, are bombarded. The degree of exhaustion is just such that with the potential the coil is capable of giving phosphorescence of the glass is produced, but disappears as soon as the vacuum is impaired. The lime containing moisture, and moisture being given off as soon as heating occurs, the phosphorescence lasts only for a few moments. When the lime has been sufficiently heated, enough moisture has been given off to impair materially the vacuum of the bulb. As the bombardment goes on, one point of the lime piece is more heated than other points, and the result is that finally practically all the discharge passes through that point which is intensely heated, and a white stream of lime particles, Fig. 31, then breaks forth from that point. This stream is composed of "radiant" matter, yet the degree of exhaustion is low. But the particles move in straight lines, because the velocity imparted to them is great, and this is due to three causes—to the great electric density, the high temperature of the small point, and the fact that the particles of the lime are easily torn and thrown off—far more easily than those of carbon. With frequencies such as we are able to obtain, the particles are bodily thrown off and projected to a considerable distance; but with sufficiently high frequencies no such thing would occur. In such case only a stress would spread, or a vibration would be propagated through the bulb. It would be out of question to reach any such frequency on the assumption that the atoms move with the speed of light; but I believe that such a thing is impossible. For this an enormous potential would be required. With potentials which we are able to obtain, even with a disruptive discharge coil, the speed must be quite insignificant.

As to the "non-striking vacuum," the point to be noted is that it can occur only with low-frequency impulses, and it is necessitated by the impossibility of carrying off enough energy with such impulses in high vacuum, since the few atoms which are around the terminal, upon coming in contact with the same are repelled and kept at a distance for a comparatively long period

of time, and not enough work can be performed as to render the effect perceptible to the eye. If the difference of potential between the terminals is raised, the dielectric breaks down. But with very high frequency impulses there is no necessity for such breaking down, since any amount of work can be performed by continually agitating the atoms in the exhausted vessel, provided the frequency is high enough. It is easy to reach—even with frequencies obtained from an alternator as here used—a stage at which the discharge does not pass between two electrodes in a narrow tube, each of these being connected to one of the terminals of the coil, but it is difficult to reach a point at which a luminous discharge would not occur around each electrode.

A thought which naturally presents itself in connection with high-frequency currents is, to make use of their powerful electrodynamic inductive action to produce light effects in a sealed glass globe. The leading-in wire is one of the defects of the present incandescent lamp, and if no other improvement were made, that imperfection at least should be done away with. Following this thought, I have carried on experiments in various directions, of which some were indicated in my former paper. I may here mention one or two more lines of experiment which have been followed up. Many bulbs were constructed, as shown in Fig. 32 and Fig. 33. In Fig. 32 a wide tube, T, was sealed to a smaller W-shaped tube, U, of phosphorescent glass. In the tube T was placed a coil, C, of aluminium wire, the ends of which were provided with small spheres, t and t_1, of aluminium, and reached into the U-tube. The tube T was slipped into a socket containing a primary coil through which usually the discharges of Leyden jars were directed, and the rarefied gas in the small U-tube was excited to strong luminosity by the high-tension currents induced in the coil C. When Leyden jar discharges were used to induce currents in the coil C, it was found necessary to pack the tube T tightly with insulating powder, as a discharge would occur frequently between the turns of the coil, especially when the primary was thick and the air gap, through which the jars discharged, large, and no little trouble was experienced in this way. In Fig. 33 is illustrated another form of the bulb constructed. In this case a tube, T, is sealed to a globe, L. The tube contains a coil, C, the ends of which pass through two small glass tubes, t and t_1, which are sealed to the tube T. Two refractory buttons, m and m_1, are mounted on lamp filaments which are fastened to the ends of the wires passing through the glass tubes t and t_1. Generally in bulbs made on this plan the globe L communicated with the tube T. For this purpose the ends of the small tubes, t and t_1, were just a trifle heated in the burner, merely to hold the wires, but not to interfere with the communication. The tube T, with the small tubes, wires through the same, and the refractory buttons, m and m_1, was first prepared, and then sealed to globe L, whereupon the coil C was slipped in and the connections made to its ends. The tube was then packed with insulating powder, jamming the latter as tight as possible up to very nearly the end, then it was closed and only a small hole left through which the remainder of the powder was introduced, and finally the end of the tube was closed. Usually in bulbs constructed as shown in Fig. 33, an aluminium tube, a, was fastened to the upper end, s, of each of the tubes t and t_1, in order to protect that end against the heat. The buttons, m and m_1, could be brought to any degree of incandescence by passing the discharges of Leyden jars around the coil C. In such bulbs with two buttons a very curious effect is produced by the formation of the shadows of each of the two buttons.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

BY NIKOLA TESLA.

(Concluded from page 595.)

Another line of experiment, which has been assiduously followed, was to induce by electro-dynamic induction a current or luminous discharge in an exhausted tube or bulb. This matter has received such an able treatment at the hands of Prof. J. J. Thomson that I could add but little to what he has made known, even had I made it the special subject of this lecture. Still, since experiences in this line have gradually led me to the present views and results, a few words must be devoted here to this subject. It has occurred, no doubt, to many, that as a vacuum tube is made longer the E.M.F. per unit length of the tube necessary to pass a luminous discharge through the latter, gets continually smaller: therefore, if the exhausted tube be made long enough, even with low frequencies a luminous discharge could be induced in such a tube closed upon itself. Such a tube might be placed around a hall or on a ceiling, and at once a simple appliance capable of giving considerable light would be obtained. But this would be an appliance hard to manufacture and extremely unmanageable. It would not do to make the tube up of small lengths, because there would be with ordinary frequencies considerable loss in the coatings, and, besides, if coatings were used it would be better to supply the current directly to the tube by connecting the coatings to a transformer. But even if all objections of such nature were removed, still, with low frequencies the light conversion itself would be inefficient, as I have before stated. In using extremely high frequencies the length of the secondary—in other words, the size of the vessel—can be reduced as far as desired, and the efficiency of the light conversion is increased, provided that means are invented for efficiently obtaining such high frequencies.

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Thus one is led, from theoretical and practical considerations, to the use of high frequencies, and this means high E.M.F.'s and small currents in the primary. When he works with condenser charges—and these are the only means up to the present known for reaching these extreme frequencies—he gets to E.M.F.'s of several thousands of volts per turn of the primary. He cannot multiply the electro-dynamic inductive effect by taking more turns in the primary, for he arrives at the conclusion that the best way is to work with one single turn—though he must sometimes depart from this rule—and he must get along with whatever inductive effect he can obtain with one turn. But before he has long experimented with the extreme frequencies required to set up in a small bulb an E.M.F. of several thousands of volts, he realises the great importance of electrostatic effects, and these effects grow relatively to the electro-dynamic in significance as the frequency is increased. Now, if anything is desirable in this case, it is to increase the frequency, and this would make it still worse for the electro-dynamic effects. On the other hand, it is easy to exalt the electrostatic action as far as one likes by taking more turns on the secondary, or combining self-induction and capacity to raise the potential. It should also be remembered that, in reducing the current to the smallest value and increasing the potential, the electric impulses of high frequency can be more easily transmitted through a conductor.

These and similar thoughts determined me to devote more attention to the electrostatic phenomena, and to endeavour to produce potentials as high as possible, and alternating as fast as they could be made to alternate. I then found that I could excite vacuum tubes at considerable distance from a conductor connected to a properly constructed coil, and that I could, by converting the oscillatory current of a condenser to a higher potential, establish electrostatic alternating fields which acted through the whole extent of a room, lighting up a tube, no matter where it was held in space. I thought to recognise that I had made a step in advance, and I have persevered in this line; but I wish to say that I share with all lovers of science and progress the one and only desire—to reach a result of utility to men in any direction to which thought or experiment may lead me. I think that this departure is the right one, for I cannot see, from the observation of the phenomena which manifest themselves as the frequency is increased, what there would remain to act between two circuits conveying, for instance, impulses of several hundred millions per second, except electrostatic forces. Even with such trifling frequencies the energy would be practically all potential, and my conviction has grown strong that, to whatever kind of motion light may be due, it is produced by tremendous electrostatic stresses vibrating with extreme rapidity. Of all these phenomena observed with currents, or electric impulses, of high frequency, the most fascinating for an audience are certainly those which are noted in an electrostatic field acting through considerable distance, and the best an unskilled lecturer can do is to begin and finish with the exhibition of these singular effects. I take a tube in the hand and move it about, and it is lighted wherever I may hold it; throughout space the invisible forces act. But I may take another tube and it might not light, the vacuum being very high. I excite it by means of a disruptive discharge coil, and now it will light in the electrostatic field. I may put it away for a few weeks or months, still it retains the faculty of being excited. What change have I produced in the tube in the act of exciting it? If a motion imparted to the atoms, it is difficult to perceive how it can persist so long without being arrested by frictional losses, and if a strain exerted in the dielectric, such as a simple electrification would produce, it is easy to see how it may persist indefinitely, but very difficult to understand why such a condition should aid the excitation when we have to deal with potentials which are rapidly alternating.

Since I have exhibited these phenomena for the first time, I have obtained some other interesting effects. For instance, I have produced the incandescence of a button, filament, or wire enclosed in a tube. To get to this result it was necessary to economise the energy which is obtained from the field and direct most of it on the small body to be rendered incandescent. At the beginning the task appeared difficult, but the experiences gathered permitted to reach the result easily. In Fig. 34 and Fig. 35 two such tubes are illustrated which are prepared for the occasion. In Fig. 34 a short tube, T_1, sealed to another long tube, T, is provided with a stem, s, with a platinum wire sealed in the latter. A very thin lamp filament, l, is fastened to this wire, and connection to the outside is made through a thin copper wire, w. The tube is provided with outside and inside coatings, C and C_1 respectively, and is filled as far as the coatings reach with conducting, and the space above with insulating powder. These coatings are merely used to enable to perform two experiments with the tube—namely, to produce the effect desired either by a direct connection of the body of the experimenter or of another body to the wire, w, or by acting inductively through the glass. The stem, s, is provided with an aluminium tube, a, for purposes before explained, and only a small part of the filament reaches out of this tube. By holding the tube T_1 anywhere in the electrostatic field the filament is rendered incandescent. A more interesting piece of apparatus is illustrated in Fig. 35. The construction is the same as before, only instead of the lamp filament a small platinum wire, p, sealed in a stem, s, and bent above it in a circle, is connected to the copper wire w, which is joined to an inside coating, C. A small stem, s_1, is provided with a needle, on the point of which is arranged to rotate very freely a very light fan of mica, r. To prevent the fan from falling out, a thin stem of glass, g, is bent properly and fastened to the aluminium tube. When the glass tube is held anywhere in the electrostatic field the platinum wire becomes incandescent, and the mica vanes are rotated very fast.

Intense phosphorescence may be excited in a bulb by merely connecting it to a plate within the field, and the plate need not be any larger than an ordinary lamp shade. The phosphorescence excited with these currents is incomparably more powerful than with ordinary apparatus. A small phosphorescent bulb, when attached to a wire connected to a coil, emits sufficient light to allow reading ordinary print at a distance of five to six paces. It was of interest to see how some of the phosphorescent bulbs of Prof. Crookes would behave with these currents, and he has had the kindness to lend me a few for the occasion. The effects produced are magnificent, especially by the sulphide of calcium and sulphide of zinc. From the disruptive discharge coil they glow intensely merely by holding them in the hand and connecting the body to the terminal of the coil.

To whatever results investigations of this kind may lead, their chief interest lies for the present in the possibilities they offer for the production of an efficient illuminating device. In no branch of electric industry is an advance more desired than in the manufacture of light. Every thinker, when considering the barbarous methods employed, the deplorable losses incurred in our best systems of light production, must have asked himself, What is likely to be the light of the future? Is it to be an incandescent solid, as in the present lamp, or an incandescent gas, or a phosphorescent body, or something like a burner, but incomparably more efficient? There is little chance to perfect a gas burner; not perhaps, because human ingenuity has been bent upon that problem for centuries without a radical departure having been made—though this argument is not devoid of force—but because in a



FIG. 34.—Tube with Filament Rendered Incandescent in an Electrostatic Field.



FIG. 35.—Crookes Experiment in Electrostatic Field.

burner the higher vibrations can never be reached except by passing through all the low ones. For how is a flame produced unless by a fall of lifted weights? Such process cannot be maintained without renewal, and renewal is repeated passing from low to high vibrations. One way only seems to be open to improve a burner, and that is by trying to reach higher degrees of incandescence. Higher incandescence is equivalent to a quicker vibration: that means more light from the same material; and that, again, means more economy. In this direction some improvements have been made, but the progress is hampered by many limitations. Discarding, then, the burner, there remains the three ways first mentioned, which are essentially electrical. Suppose the light of the immediate future to be a solid rendered incandescent by electricity. Would it not seem that it is better to employ a small button than a frail filament? From many considerations it certainly must be concluded that a button is capable of higher economy, assuming, of course, the difficulties connected with the operation of such a lamp to be effectively overcome. But to light such a lamp we require a high potential; and to get this economically we must use high frequencies. Such considerations apply even more to the production of light by the incandescence of a gas, or by phosphorescence. In all cases we require high frequencies and high potentials. These thoughts occurred to me a long time ago.

Incidentally we gain, by the use of very high frequencies, many advantages, such as a higher economy in the light production, the possibility of working with one lead, the possibility of doing away with the leading-in wire, etc. The question is, How far can we go with frequencies? Ordinary conductors rapidly lose the facility of transmitting electric impulses when the frequency is greatly increased. Assume the means for the production of impulses of very great frequency brought to the utmost perfection, everyone will naturally ask how to transmit them when the necessity arises. In transmitting such impulses through conductors, we must remember that we have to deal with pressure and flow, in the ordinary interpretation of these terms. Let the pressure increase to an enormous value, and let the flow correspondingly diminish, then such impulses—variations merely of pressure, as it were—can no doubt be transmitted through a wire even if their frequency be many hundreds of millions per second. It would, of course, be out of question to transmit such impulses through a wire immersed in a gaseous medium, even if the wire were provided with a thick and excellent insulation, for most of the energy would be lost in molecular bombardment and consequent heating. The end of the wire connected to the source would be heated, and the remote end would receive but a trifling part of the energy supplied. The prime necessity, then, if such electric impulses are to be used, is to find means to reduce as much as possible the dissipation. The first thought is, employ the thinnest possible wire surrounded by the thickest practicable insulation. The next thought is, to employ electrostatic screens. The insulation of the wire may be covered with a thin conducting coating, and the latter connected to the ground. But this would not do, as then all the energy would pass through the conducting coating to the ground, and nothing would get to the end of the wire. If a ground connection is made, it can only be made through a conductor offering an enormous impedance, or through a condenser of extremely small capacity. This, however, does not do away with other difficulties. If the wave-length of the impulses is much smaller than the length of the wire, then corresponding short waves will be set up in the conducting coating, and it will be more or less the same as though the coating were directly connected to earth. It is, therefore, necessary to cut up the coating in sections much shorter than the wave-length. Such an arrangement does not still afford a perfect screen, but it is ten thousand times better than none. I think it preferable to cut up the conducting coating in small sections, even if the current-waves be much longer than the coating. If a wire were provided with a perfect electrostatic screen, it would be the same as though all objects were removed from it at infinite distance. The capacity would then be reduced to the capacity of the wire itself, which would be very small. It would then be possible to send over the wire current-vibrations of very high frequencies at enormous distances without affecting greatly the character of the vibrations. A perfect screen is of course out of question, but I believe that with a screen such as I have just described telephony could be rendered practicable across the Atlantic. According to my ideas, the guttapercha-covered wire should be provided with a thin conducting coating subdivided in sections. On the top of this should be again placed a layer of guttapercha and other insulation, and on the top of the whole the armour. But such cables will not be constructed, for ere long intelligence—transmitted without wires—will throb through the earth like a pulse through a living organism. The wonder is that, with the present state of knowledge and the experiences gained, no attempt is being made to disturb the electrostatic or magnetic condition of the earth, and transmit, if nothing else, intelligence. It has been my chief aim in presenting these results to point out phenomena or features of novelty, and to advance ideas which I am hopeful will serve as starting points of new departures. It has been my chief desire this evening to entertain you with some novel experiments. Your applause, so frequently and generously accorded, has told me that I have succeeded.

In conclusion, let me thank you most heartily for your kindness and attention, and assure you that the honour I have had in addressing such a distinguished audience, the pleasure I have had in presenting these results to a gathering of so many able men—and among them also some of those in whose work for many years past I have found enlightenment and constant pleasure—I shall never forget.

NIKOLA TESLA AND HIS BUSINESS.

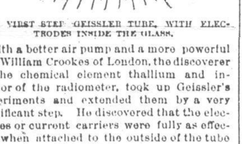
Light Without Heat His Aim—The Aurora Brought Down to Us from the Sky—The Dawn of Manifold Possibilities Revealed.

Nikola Tesla's production of an aurora, in the lecture rooms of New York, London, and Paris, comes as a sequel to experiments that reach back all the way to the famous kite-flying of Franklin. How readily electricity glides into light everybody knows who has walked along a fleecy carpet and applied his finger-tip to a bell wire or a water pipe. Indeed, so readily do sparks stream from electrical machinery that such machinery has to be excluded from mines and other places where a spark might cause an explosion. To bring the electric spark to magnitude and continuity has been a



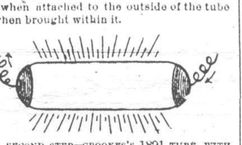
NIKOLA TESLA.

task which these many years has occupied an army of inventors. In their progressive steps these inventors have been greatly indebted to the induction coil, especially as improved by Ruhmkorff. His apparatus consists, essentially, of a coil of ordinary wire encircling a second coil formed of extremely fine wire. When a momentary current from a battery or a dynamo is sent through the first coil it induces in the second a current so highly intensified as to flash forth as lightning. In an apparatus of large dimensions this discharge can be thirty inches in length. Developed in form, the induction coil has been indispensable in Tesla's experiments. His work has distinctly diverged from the line of investigation which has given us light as an incident of the intense heat of carbon threads and pencils. He has sought to obtain light directly from electricity, avoiding costly and useless partnership with heat. On this particular track Dr. H. Geissler of Bonn labored long ago. In the tubes known by his name he produced a luminous glow of great beauty, sending through highly rarified gases the pulsations from an induction coil.



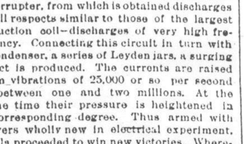
THE FIRST STEP—GEISSLER TUBE, WITH ELECTRODES INSIDE THE GLASS.

With a better air pump and a more powerful coil William Crookes of London, the discoverer of the chemical element thallium and inventor of the radiometer, took up Geissler's experiments and extended them by a very significant step. He discovered that the electrodes or current carriers were fully as effective when attached to the outside of the tube as when brought within it.



THE SECOND STEP—CROOKES'S 1801 TUBE, WITH ELECTRODES ON THE EXTERIOR OF THE GLASS.

It was at this interesting and suggestive stage of development that Tesla began to solve the problem of how electricity might best be changed into light. He had been engaged in perfecting a generator of alternating currents, a machine of novel and excellent pattern. It occurred to him that these currents gave him a means of experimenting on lines wholly new: for an alternating current differs from a continuous one as puffs of air, now from north, now from south, differ from a constant breeze in either direction. What might he not do were he able to charge electricity from a stream to vibrations approaching in period those of light? In the apparatus he used in his lecture at Columbia College last year Tesla departed very far from the ordinary alternator with but a dozen poles in its circle. On the rim of his rotating disk he had no less than 384 poles, which gave 16,000 alternations per second instead of 300, a customary number. In his later work Tesla adopts the current as delivered by the common alternator used in electric lighting. For increasing the frequency of its reversals he employs a condenser and converter such as he had at Columbia College, but now much developed in form. This contrivance consists of a transformer, of the type familiar to consumers of electric light, with a second transformer having in its circuit a magnetic spark interrupter, from which is obtained discharges in all respects similar to those of the largest induction coil—discharges of very high frequency. Connecting this circuit in turn with a condenser, a series of Leyden jars, a surging effect is produced. The currents are raised from vibrations of 25,000 or so per second to between one and two millions. At the same time their pressure is heightened in a corresponding degree. Thus armed with powers wholly new in electrical experiment, Tesla proceeded to win new victories. Where as Crookes found it enough that his electrodes merely touched the outside of the tube which he was to set aglow, Tesla produces the same luminosity by entirely detaching his electrodes from the tube and retiring them to a distance of several feet.



THE THIRD STEP—TESLA 1892 EFFECT, WITH DISTANT EXTERIOR ELECTRODES.

In the intervening space, with no wires or connections of any kind, he places glass tubes, or globes, which shine as if auroral beams from the northern sky were entrapped in them. The light here is due, so to speak, to molecular bombardment, to the particles of imprisoned gas striking one another with a velocity so tremendous as to glow visibly. We have a familiar illustration of the same kind of fact when a nail is violently and repeatedly struck by a hammer on an anvil until it reaches glowing heat. But resuming the path of his main purpose, the setting light unaccompanied by heat, Tesla has arrived at results more remarkable still. As fast as he was able to increase the frequency of electric alternations he tried a variety of experiments. Among these was the admitting of more and more air into the exhausted tubes placed in the excited electric field. He found to his great delight that the luminous effect persisted, and this to the point when a tube was exhausted in no degree whatever. He was now led to the culmination of his work—the dispensing with tubes altogether, the production of light by agitations of the light-bearing ether so rapid as to provoke vision. In his latest experiments Tesla suspends from the walls of a room two metallic plates, attaches them to the poles of his condenser, and in the intervening space, without tubes, globes, or other objects, creates a soft and diffused glow. The light is fainter, however, than that which shines in a tube or globe brought into the same field space.

Without any mechanism whatever in view, and from precisely such an alternating current as that led to are and incandescent lamps, an effect without example in the art of lighting is made available for the drawing room, the theatre, and the picture gallery. In a scheme devised by Mr. John Van Vleck, an electrical engineer of New York, the ordinary current as delivered to a consumer can serve to actuate a motor, can be turned into lamps, or applied to producing the Tesla effect.

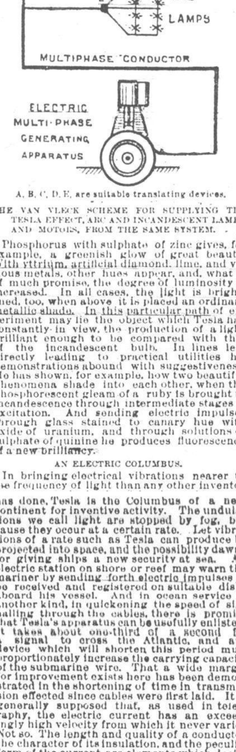
Tesla is busily engaged in perfecting his results by successive improvements in the appliances for their production. As his light seems to be unalloyed with heat, and its user is free from the cost and care of lamps, its further development is awaited with the keenest interest. Yet, even in its present state, the



TESLA'S LATEST EFFECT—A LUMINOUS CLOUD BETWEEN TWO ELECTRODES.

Tesla apparatus must rank with Franklin's kite, which showed electricity and lightning to be one; with Bell's disks, which either electricity or light can arouse to speech; and with Hertz's resonator, which proves to the eye what so long was but an unfulfilled anticipation, that, after all, light is only a particular effect of electro-magnetism.

Indeed, Tesla's experiments make clear that every common flame is but a brilliant manifestation of electro-magnetic energy. Attached to a pole of his condenser, a thread of cotton streams forth with a flame like that of Moses's bush, which burned but was not consumed. From the two terminals of his apparatus are emitted brushlike electric discharges that not only resemble, but are veritable flames. Let the current mount still higher in its pressure, beating still faster, and to touch as well as to sight the identity would instantly become evident. By varying the substances which he exposes to his currents, Tesla produces exquisite effects in color.



A, B, C, D, E, are suitable translating devices.

THE VAN VLECK SCHEME FOR SUPPLYING THE TESLA EFFECT, ARC AND INCANDESCENT LAMPS, AND MOTORS, FROM THE SAME SYSTEM.

Phosphorus with sulphate of zinc gives, for example, a greenish glow of great beauty. With yttrium, artificial diamond, lime, and various metals, other hues appear, and, what is of much promise, the degree of luminosity is increased. In all cases, the light is brightened, too, when above it is placed an ordinary metallic shade. In this particular path of experiment may lie the object which Tesla has constantly in view, the production of a light brilliant enough to be compared with that of the incandescent bulb. In lines less directly leading to practical utilities his demonstrations abound with suggestiveness. He has shown, for example, how two beautiful phenomena shade into each other, when the phosphorescent gleam of a ruby is brought to incandescence through intermediate stages of excitation. And sending electric impulses through glass stained to canary hue with oxide of uranium, and through solutions of sulphate of quinine he produces fluorescence of a new brilliancy.

AN ELECTRIC COLUMBUS.

In bringing electrical vibrations nearer to the frequency of light than any other inventor has done, Tesla is the Columbus of a new continent for inventive activity. The undulations we call light are stopped by fog, because they occur at a certain rate. Let vibrations of a rate such as Tesla can produce be projected into space, and the possibility dawns for giving ships a new security at sea. An electric station on shore or reef may warn the mariner by sending forth electric impulses to be received and registered on suitable disks aboard his vessel. And in ocean service of another kind, in quickening the speed of signalling through the cables, there is promise that Tesla's apparatus can be usefully enlisted. It takes about one-third of a second for a signal to cross the Atlantic, and any device which will shorten this period must proportionately increase the carrying capacity of the submarine wire. That a wide margin for improvement exists here has been demonstrated in the shortening of time in transmission effected since cables were first laid. It is generally supposed that, as used in telegraphy, the electric current has an exceedingly high velocity from which it never varies. Not so. The length and density of the conductor, the character of its insulation, and the peculiar form of the current, are elements which decide the rate of propagation.

In bridging part of the wide interval between the comparatively slow waves which excite the sensation of sound and the vastly swifter ones which awaken vision, Tesla opens the door to an illimitable realm of experiment. To waves of a new order the old methods of arrest and transmission will not apply. Alexander Graham Bell, in his experiments with the photophone, found that an invisible beam of light easily passed through a sheet of hard rubber; Tesla in the same way finds that insulation is a relative term. Substances that keep ordinary currents strictly to their path are easily pierced by the throbs which he employs. Oil, which closes over an electric wound, has therefore to replace cotton, silk, and rubber. It would seem, in truth, as if the electrician will soon be able to choose the special vibration suited to traverse any medium whatever, gaseous, liquid, or solid; that he will encounter no obstacle which he cannot render as it were transparent.

WHO NIKOLA TESLA IS.

Who is this man who has done so much and initiated so much more, before whom the Nestors of European science sit entranced as he brings before them marvel after marvel? Whence does he come? What country gave him birth only to surrender him to America?

On the southern confines of the empire of Austria-Hungary, Croatia comes to the Adriatic Sea. Here is a land of mixed races, of a history so troubled that it has language to hold a hundred words for knife and but one for mercy. Here in the hamlet of Smiljan Nikola Tesla was born thirty-five years ago. At Carlstadt, in Croatia, and at the polytechnic school in Gratz, Austria, he received his education. As a student of engineering the subject of electricity strongly attracted him, and he devoted his spare time to electrical experiment. On graduating in 1881 he entered the telegraph service at Buda-Pesth, taking up the electric light and the construction of dynamo machines as his special work. About five years ago he came to the United States. During part of this time he was in the employ of the Westinghouse Company, where he earned the highest esteem as an electrician and as a man. Latterly he has pursued an independent course of experiment, with results briefly touched upon in this article.

In person Tesla might pass for an Italian. He has an Italian sensitiveness of temperament, as well as an Italian excitability. His command of English is capital, and as he unfolds his results to an audience with exquisite dexterity his enthusiasm is contagious. With inborn resources of the rarest, with excellent education and practical training, with the opportunities of the world focused around him what of achievement may not the future hold for Nikola Tesla?

GEORGE ILES.

Personal.

MR. NIKOLA TESLA.

THE many friends of Mr. Tesla will be grieved to learn that he has just sustained a severe bereavement in the death of his mother, with the intention of seeing whom he made his recent trip to Europe. Owing to this loss, Mr. Tesla has been detained in Gospic, Lika, and he will not return to this country as soon as he intended when he left here. It is believed that he will return early next month.

ROYAL SOCIETY CONVERSAZIONE.

THE first of the two annual conversaziones given by the Royal Society, that is the one from which ladies are excluded, was held last Wednesday evening in Burlington House, and was attended by some four hundred guests. The exhibition of novel scientific apparatus was not large, and with some notable exceptions, it was not of high interest.

Electrical matters are now always very much to the front at such exhibitions. Professor Crookes repeated some of Mr. Tesla's experiments, but with simpler apparatus. He used an induction coil, giving twenty complete alternations per second and 467,000 volts, to charge a battery of Leyden jars. The discharges from the battery were sent round the primary wire of an induction coil immersed in oil, while the discharge from the secondary was used to produce the various effects. The vibratory current of the spark of the Leyden jar raised the number of alternations in the final current to one million, it was stated, while the volts were 116,000. The visitors were greatly interested in taking the discharge through their bodies, in confirmation of Tesla's contention that currents of high frequency are not dangerous. Mr. Crookes showed all the usual phenomena of stream and brush discharges, the lighting of vacuum tubes without conductors, phosporescence of air, and the like. Professor Oliver Lodge had a number of experiments to demonstrate the behaviour of the electric spark under various conditions. He discharged through air to water, showing how it spread out over the surface seeking for a path, and then he made the discharge take place under water, the result being an exceedingly loud crack and a greatly increased illumination. A shower, with too great a spark length for a strong discharge, excited much admiration, the air being filled with a multitude of violet streams, recalling vividly some photographs of lighting.

Mr. James Wimshurst always prepares some novelty for the Royal Society. This time he had a number of Leyden jars with removable coatings, both inner and outer, made of convolutions of insulated copper wires. The ends of the wire were brought near together, and armed with balls, and it was curious to see the effect of the surging of the charge in the wire. Each time the jar discharged there was an additional discharge in each of the coatings. By combining several jars, very pretty and erratic effects could be obtained.

Of all the apparatus to be seen in the room, nothing exceeded in practical interest the new optical pyrometer invented by Professor H. le Chatelier, and shown by Professor W. C. Roberts-Austen. If the promise of this instrument is fulfilled, and we see no reason why it should not, it will be possible to read the temperature of a furnace or a piece of glowing metal, by merely looking at it through a telescope. The principle of the apparatus is very simple. The light from a standard naphtha lamp is reflected to the eye through a piece of red glass. At the same time the light of the glowing body reaches the eye through another part of the same glass. The aperture through which it comes can be expanded and contracted by means of sliding V-shaped shutters until a uniform illumination of the two parts of the field of vision is attained. Connected with the shutters is an arm moving over a scale. This scale is graduated empirically, either by means of platinum-rhodium thermo-junction pyrometer, or by other means. Of course the new instrument is not available for temperatures below the glowing point.

On the next stand came an exceedingly ingenious and workmanlike chronograph, exhibited by the Rev. Frederick J. Smith. The records are made by means of styli operated by electro-magnets on a vertical smoked paper, which is attached to a carriage running on rails. The time is measured by means of a tuning-fork, which draws a wavy line on the paper. The fork is set in action and the carriage released to make its travel under the influence of a weight. The commencement of the period to be measured is marked by the breaking of an electric circuit, and the drawing of a line on the paper; the end of the period is marked by a second circuit being broken, and another line drawn. The distance between these lines can then be measured by means of a micrometer apparatus, and the time estimated by reference to the known period of the tuning-fork. Mr. Smith had a steel bar a few feet in length, and at intervals during the evening he measured the speed of sound through it. He is also able to measure the modulus of elasticity of metals without mechanical experiments, since the modulus is a function of the velocity of propagation of sound in the metal. The instrument is also furnished with continuous contact breakers to enable photographs to be taken in rapid succession by means of electric sparks, of moving objects, such as falling drops of water, the wings of insects, and the like.

Another chronographic instrument was shown by Captain Holden, R.A. It consisted of a high-speed chronographic pen, with an automatic resetting attachment. The object of this instrument is to take a number of successive records of short intervals of time, on a revolving drum or moving surface, under as nearly as possible the same conditions. The pen is automatically reset after making each record, and the condition of the various circuits in connection with it may be made absolutely identical, and thus the small time error in the working of the apparatus entirely eliminated.

The committee of Kew Observatory have undertaken the examination of photographic lenses, and they showed Major Darwin's apparatus which has been constructed for the purpose. In bright weather the lens is mounted in a frame, and a picture of a distant object is thrown on a ground-glass screen. The lens is then rotated to a definite angle first to right and then to left, and the focal length is deduced from the measured movements of the object on the screen. At the same time it is noted if the movement of the object is exactly horizontal, and if not its divergence is measured. To try the figure of the lens it is focussed to the edge of a fine ribbon of steel, and the steel is gradually turned towards a flatwise position until it becomes visible. The sooner it is perceived the better the lens. If there is any distortion it is immediately shown in the fine black line in the field of view. The points referred to in the certificate given are principal focal length and of back focus; centering in mount; effective operation of different stops; angle of field of view; curvature of field; definition. When the weather is obscure a collimater is substituted for the distant object.

The new form of eudiometer exhibited by Dr. W. Marcet, is an exceedingly convenient one, especially devised for the rapid and accurate demonstration of the quantity of oxygen contained in air. It consists of a U-tube, the leg in which the mixture of air and hydrogen is exploded being surrounded by a water jacket to maintain the gases at a constant temperature. In using the instrument it is filled with mercury, and a charge of hydrogen is then admitted through a cock at the top of the exploding limb, all the conections being first exhausted of air, and further "washed out" by blowing a current of hydrogen through them into an exhausted india-rubber bag, before the cock on the eudiometer is opened. The connections are next made to the apparatus for supplying the air to be tested under slight pressure, and all traces of hydrogen being driven out of the connecting tubes, &c., a measured quantity of air is admitted to the endiometer. This air and the hydrogen are then mixed in the usual way by producing oscillations in the mercury column and finally exploded by an electric spark. The details of the apparatus have been well worked out to secure handiness of manipulation and accuracy.

Professor Frank Clowes showed a convenient mode of obtaining in an ordinary miner's safety lamp a very delicate flame, suitable for testing the presence of minute quantities of firedamp or other inflammable vapour in air. When a lamp is burnt in air containing such admixture there is formed above the flame proper a luminous "cap," the height of which increases in a certain proportion as the percentage of inflammable gas or vapour in the air increases. When small percentages only of such inflammable gas are present, the "cap" is not readily observable or measurable, unless the flame over which it is formed is of very low luminosity, and such a flame it is the object of Professor Clowes' device to supply. For this purpose he fits an ordinary miner's safety lamp with a very small tube which extends from the side of the wick to an external connection on the lamp case, where it can be coupled by a flexible tube to a light steel bottle containing compressed hydrogen. When the atmosphere in which the lamp is burning is to be tested, the hydrogen is turned on and of course ignites from the lamp flame, forming a small jet by the side of the latter. The lamp wick is then turned down until the lamp flame proper is extinguished, leaving the small hydrogen jet alone burning. This hydrogen flame is then adjusted to a standard height, and the luminous "cap" formed over it is measured. The hydrogen flame having a very low luminosity, this "cap" can be observed readily. When the desired measurement has been made the lamp-wick is turned up again, when it reignites from the hydrogen flame, and the supply of hydrogen can then be disconnected, and the lamp restored to its normal condition. By the use of this pale hydrogen flame the presence of percentages of firedamp as low as 0.25 or 0.3 can be detected and estimated, while the ordinary flame of the lamp, when carefully adjusted, will only serve to indicate percentages above 3. The application of this mode of testing was shown by a lamp burning in a suitable small testing chamber containing air with which a small percentage of gas had been mixed, the "cap" on the flame being seen through a window in the side of the testing chamber.

Messrs. Pyke and Harris showed an alternate current dynamo in which there were no sliding electric contacts. Both the field and the armature coils are stationary. The variations of the magnetic circuit are obtained by means of revolving magnetic inductors which move between two sets of stationary poles wound with coils. The field is produced by a single coil surrounded by magnetic material both on its inner and outer circumference and on one face. Its poles are formed as laminated rings with projecting pole pieces, the two rings being concentric with the poles projecting towards each other. On these poles are placed coils, and between them the inductors pass. An even number of polar projections are employed, and the revolving inductors are arranged so, that in proportion as one pole is being demagnetised, the magnetism of the other poles increases, and *vice versâ*, thus the total magnetic effect being always approximately constant. The induced current conductor is so arranged that the polar projections which are being magnetised, and those which are being demagnetised, have a similar inducing action upon it, the magnetising of one set of polar projections thus increasing the effect produced on the same wire by the demagnetisation of the other set of polar projections. The machine can be constructed for single or many phase alternating currents.

Mr. Cecil Carus-Wilson showed samples of musical sands from New Zealand, and also of some artificial musical sands which he had succeeded in producing. Some of the latter had been "killed" by constant exhibition, and gave only a dull sound in place of the musical note.

There were two very popular exhibits downstairs. Professor C. V. Boys showed on the screen photographs of flying bullets. These are obtained by throwing the shadow of the bullets, obtained by an electric spark, on to a sensitised plate. The bullet in its course completes a circuit between a lead and a copper wire and effects the discharge of a small Leyden jar. This brings about the discharge of a larger jar, and gives the spark which produces the photograph. The pictures were most interesting, indeed they surpassed anything of the kind ever yet shown. In front of the bullet there was a wave of compressed air, and behind it another, each clearly indicated in the photographs. The bullet also left a wake behind it, caused by the efforts of the air to fill the space in its rear. The pictures of bullets passing through sheets of glass were much appreciated. At the rear of the pane the particles were flying off as if by the result of an explosion, while in the front the disturbance was much less. The air waves caused by the vibration of the glass could be seen running down in front of it, and changing from compression to rarefaction as the nodes occurred in the glass. One picture represented an aluminium bullet fired by smokeless powder from a magazine rifle with a speed of 3000 ft. per second. It had pierced a sheet of paper, and was followed by the scraps which it had cut out. Each of these was surrounded by its own compression waves of air, and it was noticeable that where these met they did not cross like sound waves, but united and flowed away at their mean angle. One of the bullets had a number of holes pierced through it at right angles to its axis, and through one of these the light could be seen, demonstrating that the photograph had been taken in one two-hundred-thousandth of a second. The marvellous powers of the photographic plate were signally shown by this exhibit, which was intensely interesting.

At eleven o'clock there was a demonstration of composite heliochromy by Mr. F. E. Ives, of Philadelphia. Three photographs are simultaneously taken by one camera on one plate. By means of light filters one of the negatives is made by such light rays only as excite the fundamental red sensation, and in due proportion; another by light rays as they excite the fundamental green sensation, and another by light rays as they excite the fundamental blue-violet sensation. These three pictures are all reproduced through coloured glasses and superposed on the screen, giving a coloured representation of the original object which is wonderfully natural. The same result can also be obtained by means of a device the size of stereoscope, being three optical systems with red, green, and blue glasses. The three images being exactly superposed appear as one only, in which the natural colours are reproduced, together with the light and shade. The effect is exceedingly good, and the process seems full of promise.

Among the minor exhibits was a lecture-room apparatus by Professor T. E. Thorpe to show the phenomena of dust explosion; vacuum tubes without electrodes by Dr. J. T. Bottomley; an apparatus for testing for incompleteness of colour vision by Mr. R. Brudenell Carter; and photographs of stellar spectra by Professor J. Norman Lockyer. There were also some very interesting archæological remains from Mashonaland, but they do not fall within the scope of this article.

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Tesla's London Lecture.

AT last the much talked of lecture of Mr. Tesla, held in London in February, has reached this side. In order to give Americans the benefit of it, we print it in full in this issue. It forms a very interesting addition to his first paper, read in New York a year ago, and also printed in full in THE ELECTRICAL WORLD, July 11, 1891. To comment on it here would be quite impossible for any one who has not himself worked in this new and strange field which Mr. Tesla was unquestionably the first to enter and is at present still the sole explorer. We can only read with silent admiration the descriptions of his very interesting experiments and of his strange, dream-like prophecies of the future which his researches lead him to predict and which, coming from any one less distinguished, would doubtless be laughed at as wild speculations. One cannot help admiring his courage, modesty, clear-sightedness and persistency in working as he does in this strange field, in which it seems as though the obstacles were almost insurmountable. The fact that these currents defy the resistance of almost all our known methods of insulation would in itself seem sufficient to discourage most experimenters. Being sure of the correctness of one of his chief objects, namely, that there must be some way of artificially producing cheap and economic light by methods radically different from the present, he proceeded first to find it, then to overcome the difficulties encountered and to make it practical. In general his lecture is of scientific interest, but much of it can be read with interest by any electrician, and will give him a good idea of the nature of this new field of research. This present lecture is more in the nature of a continuation of his first one, rather than a repetition, as he appears to assume a knowledge of the former paper, although this assumption is not essential. A large portion is devoted to a detailed description of his experiments and of his apparatus, intended more particularly for those who wish to reproduce them; other portions, to some of the more or less definite conclusions which he has arrived at; still others, to interesting predictions which his researches justify him to make. He credits Crookes with having given him his first idea, and throughout his whole lecture, with becoming modesty, he appears to forget Tesla, in his interest in the experiments. The interesting nature of this field and of his predictions will be seen from the following extracts: He speaks of the possibility of obtaining light effects without the use of any vessel whatsoever, with air at ordinary pressure; he advocates oil as one of the best insulators, and speaks of distribution at 100,000 volts as "an easy matter," and practicable to even 1,000 miles; with his sensitive rotating brush discharge he thinks that transatlantic telegraphy will be possible at any speed; he speaks of 20,000 vibrations per second as "few," and of air as being "highly conducting" in this new field; of running lamps and motors, not only with one wire, but also with no wire at all, and at considerable distances; this he follows by predicting that we shall have no need to transmit power at all, and it is only a question of time when we will be able to obtain it, extract it, as it were, from any point in the universe; he believes it quite possible to obtain at least twenty times the efficiency of our present incandescent lamp, and shows the importan of the incandescence of the gas surrounding the button in his lamp, the button itself being merely a "necessary evil. High potentials such as he uses he does not consider dangerous. He speaks of a system in which the metal pipes are the insulators and the gas in them the conductors. He describes a cable with which telephoning across the Atlantic may become possible, but adds that it will not be required, as ere long "intelligence will be transmitted without wires through the earth." He has been led to believe that light and heat effects in his experiments are proportional to the product of the frequency and the square of the potential, and suggests the possibility of using frequencies of several millions per second!

Experiments with Alternate Currents of High Potential and High Frequency.*

BY NIKOLA TESLA.

I cannot find words to express how deeply I feel the honor of addressing some of the foremost thinkers of the present time, and so many able scientific men, engineers and electricians, of the country greatest in scientific achievements.



NIKOLA TESLA.

The results which I have the honor to present before such a gathering I cannot call my own. There are among you not a few who can lay better claim than myself on any feature of merit which this work may contain. I need not mention many names which are world-known—names of those among you who are recognized as the leaders in this enchanting science; but one, at least, I must mention—a name which could not be omitted in a demonstration of this kind. It is a name associated with the most beautiful invention ever made: it is Crookes!

When I was at college, a good time ago, I read, in a translation (for then I was not familiar with your magnificent language), the description of his experiments on radiant matter. I read it only once in my life—that time—yet every detail about that charming work I can remember this day. Few are the books, let me say, which can make such an impression upon the mind of a student.

But if, on the present occasion, I mention this name as one of many your institution can boast of, it is because I have more than one reason to do so. For what I have to tell you and to show you this evening concerns, in a large measure, that same vague world which Professor Crookes has so ably explored; and, more than this, when I trace back the mental process which led me to these advances—which even by myself cannot be considered trifling, since they are so appreciated by you—I believe that their real origin, that which started me to work in this direction, and brought me to them, after a long period of constant thought, was that fascinating little book which I read many years ago.

And now that I have made a feeble effort to express my homage and acknowledge my indebtedness to him and others among you, I will make a second effort, which I hope you will not find so feeble as the first, to entertain you.

Give me leave to introduce the subject in a few words.

A short time ago I had the honor to bring before our American Institute of Electrical Engineers† some results then arrived at by me in a novel line of work. I need not assure you that the many evidences which I have received that English scientific men and engineers were interested in this work have been for me a great reward and encouragement. I will not dwell upon the experiments already described, except with the view of completing, or more clearly expressing, some ideas advanced by me before, and also with the view of rendering the study here presented self-contained, and my remarks on the subject of this evening's lecture consistent.

This investigation, then, it goes without saying, deals with alternating currents, and, to be more precise, with alternating currents of high potential and high frequency. Just in how much a very high frequency is essential for the production of the results presented is a question which, even with my present experience, would embarrass me to answer. Some of the experiments may be performed with low frequencies; but very high frequencies are desirable, not only on account of the many effects secured by their use, but also as a convenient means of obtaining, in the induction apparatus employed, the high potentials, which in their turn are necessary to the demonstration of most of the experiments here contemplated.

Of the various branches of electrical investigation, perhaps the most interesting and immediately the most promising is that dealing with alternating currents. The progress in this branch of applied science has been so great in recent years that it justifies the most sanguine hopes. Hardly have we become familiar with one fact, when novel experiences are met with and new avenues of research are opened. Even at this hour possibilities not dreamed of before are, by the use of these currents, partly realized. As in nature all is ebb and tide, all is wave motion, so it seems that in all branches of industry alternating currents—electric wave motion—will have the sway.

One reason, perhaps, why this branch of science is being so rapidly developed is to be found in the interest which is attached to its experimental study. We wind a simple ring of iron with coils; we establish the connections to the generator, and with wonder and delight we note the effects of strange forces which we bring into play, which allow us to transform, to transmit and direct energy at will. We arrange the circuits properly, and we see the mass of iron and wires behave as though it were endowed with life, spinning a heavy armature, through invisible connections, with great speed and power—with the energy possibly conveyed from a great distance. We observe how the energy of an alternating current traversing the wire manifests itself—not so much in the wire as in the surrounding space—in the most surprising manner, taking the forms of heat, light, mechanical energy, and, most surprising of all, even chemical affinity. All these observations fascinate us, and fill us with an intense desire to know more about the nature of these phenomena. Each day we go to our work in the hope of discovering,—in the hope that some one, no matter who, may find a solution of one of the pending great problems,—and each succeeding day we return to our task with renewed ardor; and even if we *are* unsuccessful, our work has not been in vain, for in these strivings, in these efforts, we have found hours of untold pleasure, and we have directed our energies to the benefit of mankind.

We may take—at random, if you choose—any of the many experiments which may be performed with alternating currents; a few of which only, and by no means the most striking, form the subject of this evening's demonstration; they are all equally interesting, equally inciting to thought.

Here is a simple glass tube from which the air has been partially exhausted. I take hold of it; I bring my body in contact with a wire conveying alternating currents of high potential, and the tube in my hand is brilliantly lighted. In whatever position I may put it, wherever I may move it in space, as far as I can reach, its soft, pleasing light persists with undiminished brightness.

Here is an exhausted bulb suspended from a single wire. Standing on an insulated support, I grasp it, and a platinum button mounted in it is brought to vivid incandescence.

Here, attached to a leading wire, is another bulb, which, as I touch its metallic socket, is filled with magnificent colors of phosphorescent light.

Here still another, which by my fingers' touch casts a shadow—the Crookes shadow, of the stem inside of it.

Here, again, insulated as I stand on this platform, I bring my body in contact with one of the terminals of the secondary of this induction coil—with the end of a wire many miles long—and you see streams of light break forth from its distant end, which is set in violent vibration.

Here, once more, I attach these two plates of wire gauze to the terminals of the coil, I set them a distance apart, and I set the coil to work. You may see a small spark pass between the plates. I insert a thick plate of one of the best dielectrics between them, and instead of rendering altogether impossible, as we are used to expect, I *aid* the passage of the discharge, which, as I insert the plate, merely changes in appearance and assumes the form of luminous streams.

Is there, I ask, can there be, a more interesting study than that of alternating currents?

In all these investigations, in all these experiments, which are so very, very interesting, for many years past—ever since the greatest experimenter who lectured in this hall discovered its principle—we have had a steady companion, an appliance familiar to every one, a plaything once, a thing of momentous importance now—the induction coil. There is no dearer appliance to the electrician. From the ablest among you, I dare say, down to the inexperienced student, to your lecturer, we all have passed many delightful hours in experimenting with the induction coil. We have watched its play, and thought and pondered over the beautiful phenomena which it disclosed to our ravished eyes. So well known is this apparatus, so familiar are these phenomena to every one, that my courage nearly fails me when I think that I have ventured to address so able an audience, that I have ventured to entertain you with that same old subject. Here in reality is the same apparatus, and here are the same phenomena, only the apparatus is operated somewhat differently, the phenomena are presented in a different aspect. Some of the results we find as expected, others surprise us, but

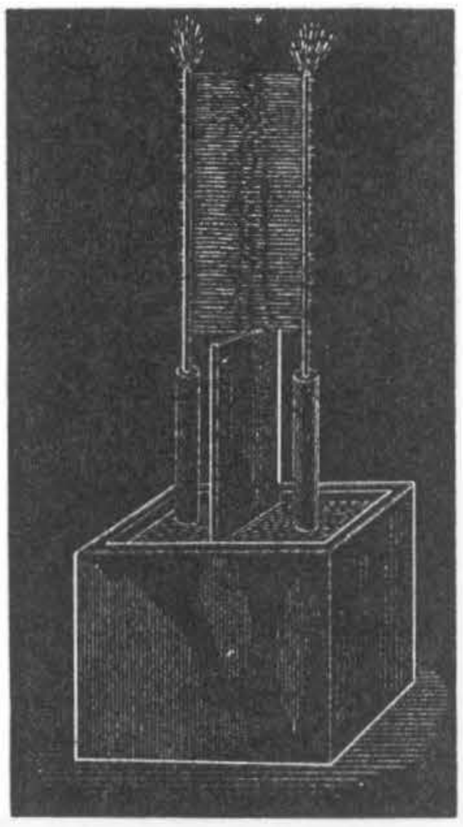

FIG. 1.—DISCHARGE BETWEEN TWO WIRES WITH FREQUENCIES OF A FEW HUNDRED THOUSAND PER SECOND.

all captivate our attention, for in scientific investigation each novel result achieved may be the centre of a new departure, each novel fact learned may lead to important developments.

Usually in operating an induction coil we have set up a vibration of moderate frequency in the primary, either by means of an interrupter or break, or by the use of an alternator. Earlier English investigators, to mention only Spottiswoode and J. E. H. Gordon, have used a rapid break in connection with the coil. Our knowledge and experience of to-day enables us to see clearly why these coils under the conditions of the tests did not disclose any remarkable phenomena, and why able experimenters failed to preceive many of the curious effects which have since been observed.

In the experiments such as performed this evening, we operate the coil either from a specially constructed alternator capable of giving many thousands of reversals of current per second, or, by disruptively discharging a condenser through the primary, we set up a vibration in the secondary circuit of a frequency of many hundred thousand or millions per second, if we so desire; and in using either of these means we enter a field as yet unexplored.

It is impossible to pursue an investigation in any novel line without finally making some interesting observation or learning some useful fact. That this statement is applicable to the subject of this lecture the many curious and unexpected phenomena which we observe afford a convincing proof. By way of illustration, take for instance the most obvious phenomena, those of the discharge of the induction coil.

Here is a coil which is operated by currents vibrating with extreme rapidity, obtained by disruptively discharging a Leyden jar. It would not surprise a student were the lecturer to say that the secondary of this coil consists of a small length of comparatively stout wire; it would not surprise him were the lecturer to state that, in spite of this, the coil is capable of giving any potential which the best insulation of the turns is able to withstand; but although he may be prepared, and even be indifferent as to the anticipated result, yet the aspect of the discharge of the coil will surprise and interest him. Every one is familiar with the discharge of an ordinary coil; it need not be reproduced here. But, by way of contrast, here is a form of discharge of a coil, the primary current of which is vibrating several hundred thousand times per second. The discharge of an ordinary coil appears as a simple line or band of light. The discharge of this coil appears in the form of powerful brushes and luminous streams issuing from all points of the two straight wires attached to the terminals of the secondary.

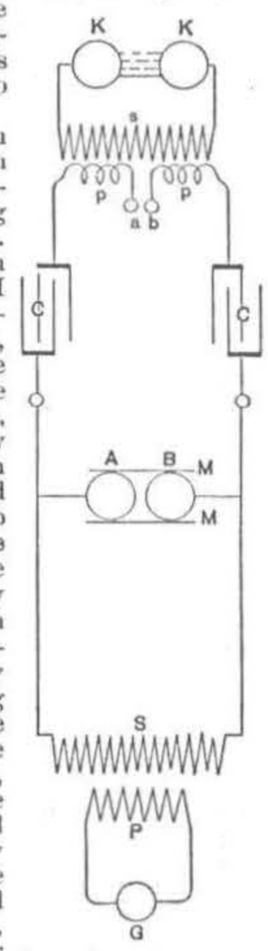

FIG. 2.—IMITATING THE SPARK OF A HOLTZ MACHINE

Now compare this phenomenon which you have just witnessed with the discharge of a Holtz or Wimshurst machine—that other interesting appliance so dear to the experimenter. What a difference there is between these phenomena! And yet, had I made the necessary arrangements—which could have been made easily, were it not that they would interfere with other experiments—I could have produced with this coil sparks which, had I the coil hidden from your view and only two knobs exposed, even the keenest observer among you would find it difficult, if not impossible, to distinguish from those of an influence or friction machine. This may be done in many ways—for instance, by operating the induction coil which charges the condenser from an alternating-current machine of very low frequency, and preferably adjusting the discharge circuit so that there are no oscillations set up in it. We then obtain in the secondary circuit, if the knobs are of the required size and properly set, a more or less rapid succession of sparks of great intensity and small quantity, which possess the same brilliancy, and are accompanied by the same sharp crackling sound, as those obtained from a friction or influence machine.

Another way is to pass through two primary circuits, having a common secondary, two currents of a slightly different period, which produce in the secondary circuit sparks occurring at comparatively long intervals. But, even with the means at hand this evening, I may succeed in imitating the spark of a Holtz machine. For this purpose I establish between the terminals of the coil which charges the condenser a long, unsteady arc, which is periodically interrupted by the upward current of air produced by it. To increase the current of air I place on each side of the arc, and close to it, a large plate of mica. The condenser charged from this coil discharges into the primary circuit of a second coil through a small air gap, which is necessary to produce a sudden rush of current through the primary. The scheme of connections in the present experiment is indicated in Fig. 2.

G is an ordinarily constructed alternator, supplying the primary *P* of an induction coil, the secondary *S* of which charges the condensers or jars *C C*. The terminals of the secondary are connected to the inside coatings of the jars, the outer coatings being connected to the ends of the primary *p p* of a second induction coil. This primary *p p* has a small air gap *a b*.

The secondary *s* of this coil is provided with knobs or spheres *K K* of the proper size and set at a distance suitable for the experiment.

A long arc is established between the terminals *A B* of the first induction coil. *M M* are the mica plates.

Each time the arc is broken between *A* and *B* the jars are quickly charged and discharged through the primary *p p*, producing a snapping spark between the knobs *K K*. Upon the arc forming between *A* and *B* the potential falls, and the jars cannot be charged to such high potential as to break through the air gap *a b* until the arc is again broken by the draught.

In this manner sudden impulses, at long intervals, are produced in the primary *p p*, which in the secondary *s* give a corresponding number of impulses of great intensity. If the secondary knobs or spheres, *K K*, are of the proper size, the sparks show much resemblance to those of a Holtz machine.

But these two effects, which to the eye appear so very different, are only two of the many discharge phenomena. We only need to change the conditions of the test, and again we make other observations of interest.

When, instead of operating the induction coil as in the two last experiments, we operate it from a high frequency alternator, as in the next experiment, a systematic study of the phenomena is rendered much more easy. In such case, in varying the strength and frequency of the currents through the primary, we may observe five distinct forms of discharge, which I have described in my former paper on the subject* before the American Institute of Electrical Engineers, May 20, 1891.

It would take too much time, and it would lead us too far from the subject presented this evening, to reproduce all these forms, but it seems to me desirable to show you one of them. It is a brush discharge, which is interesting in more than one respect. Viewed from a near position it resembles much a jet of gas escaping under great pressure. We know that the phenomenon is due to the agitation of the molecules near the terminal, and we anticipate that some heat must be developed by the impact of the molecules against the terminal or against each other. Indeed, we find that the brush is hot, and only a little thought leads us to the conclusion that, could we but reach sufficiently high frequencies, we could produce a brush which would give intense light and heat, and which would resemble in every particular an ordinary flame, save, perhaps, that both phenomena might not be due to the same agent—save, perhaps, that chemical affinity might not be *electrical* in its nature.

As the production of heat and light is here due to the impact of the molecules, or atoms of air, or something else besides, and, as we can augment the energy simply by raising the potential, we might, even with frequencies obtained from a dynamo machine, intensify the action to such a degree as to bring the terminal to melting heat. But with such low frequencies we would have to deal always with something of the nature of an electric current. If I approach a conducting object to the brush, a thin little spark passes, yet, even with the frequencies used this

*A lecture delivered before the Institution of Electrical Engineers (London) Feb. 3, 1892.

†For Mr. Tesla's American lecture on this subject see THE ELECTRICAL WORLD of July 11, 1891, and for a report of his French lecture see THE ELECTRICAL WORLD of March 26, 1892.

*See THE ELECTRICAL WORLD, July 11, 1891

evening, the tendency to spark is not very great. So, for instance, if I hold a metallic sphere at some distance above the terminal you may see the whole space between the terminal and sphere illuminated by the streams without the spark passing; and with the much higher frequencies obtainable by the disruptive discharge of a condenser, were it not for the sudden impulses, which are comparatively few in number, sparking would not occur even at very small distances. However, with incomparably higher frequencies, which we may yet find means to produce efficiently, and provided that electric impulses of such high frequencies could be transmitted through a conductor, the electrical characteristics of the brush discharge would completely vanish—no spark would pass, no shock would be felt—yet we would still have to deal with an *electric* phenomenon, but in the broad, modern interpretation of the word. In my first paper before referred to I have pointed out the curious properties of the brush, and described the best manner of producing it, but I have thought it worth while to endeavor to express myself more clearly in regard to this phenomenon, because of its absorbing interest.

When a coil is operated with currents of very high frequency, beautiful brush effects may be produced, even if the coil be of comparatively small dimensions. The experimenter may vary them in many ways, and, if it were nothing else, they afford a pleasing sight. What adds to their interest is that they may be produced with one single terminal as well as with two—in fact, often better with one than with two.

But of all the discharge phenomena observed, the most pleasing to the eye, and the most instructive, are those observed with a coil which is operated by means of the disruptive discharge of a condenser. The power of the brushes, the abundance of the sparks, when the conditions are patiently adjusted, is often amazing. With even a very small coil, if it be so well insulated as to stand a difference of potential of several thousand volts per turn, the sparks may be so abundant that the whole coil may appear a complete mass of fire.

Curiously enough the sparks, when the terminals of the coil are set at a considerable distance, seem to dart in every possible direction as though the terminals were perfectly independent of each other. As the sparks would soon destroy the insulation it is necessary to prevent them. This is best done by immersing the coil in a good liquid insulator, such as boiled-out oil. Immersion in a liquid may be considered almost an absolute necessity for the continued and successful working of such a coil.

It is of course out of the question, in an experimental lecture, with only a few minutes at disposal for the performance of each experiment, to show these discharge phenomena to advantage, as to produce each phenomenon at its best a very careful adjustment is required. But even if imperfectly produced, as they are likely to be this evening, they are sufficiently striking to interest an intelligent audience.

Before showing some of these curious effects I must, for the sake of completeness, give a short description of the coil and other apparatus used in the experiments with the disruptive discharge this evening.

It is contained in a box B (Fig. 3) of thick boards of hard wood, covered on the outside with zinc sheet Z, which is carefully soldered all around. It might be advisable, in a strictly scientific investigation, when accuracy is of great importance, to do away with the metal cover, as it might introduce many errors, principally on account of its complex action upon the coil, as a condenser of very small capacity and as an electrostatic and electromagnetic screen. When the coil is used for such experiments as are here contemplated, the employment of the metal cover offers some practical advantages, but these are not of sufficient importance to be dwelt upon.

The coil should be placed symmetrically to the metal

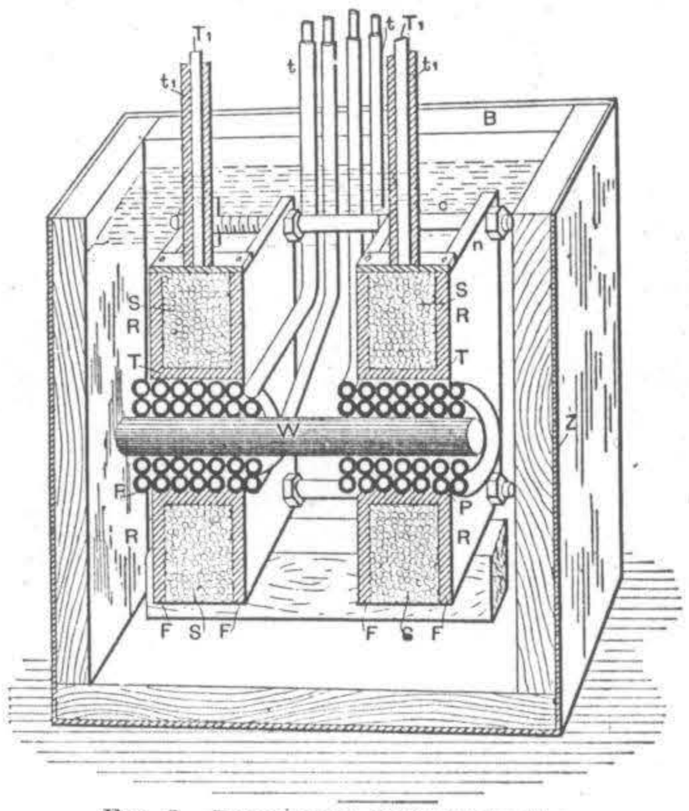

FIG. 3.—DISRUPTIVE DISCHARGE COIL.

cover, and the space between should, of course, not be too small, certainly not less than, say, five centimetres, but much more if possible; especially the two sides of the zinc box, which are at right angles to the axis of the coil, should be sufficiently remote from the latter, as otherwise they might impair its action and be a source of loss.

The coil consists of two spools of hard rubber R R, held apart at a distance of 10 centimetres by bolts c and nuts n, likewise of hard rubber. Each spool comprises a tube T of approximately 8 centimetres inside diameter, and 3 millimetres thick, upon which are screwed two flanges F F, 24 centimetres square, the space between the flanges being about 3 centimetres. The secondary, S S, of the best gutta percha-covered wire, has 26 layers, 10 turns in each, giving for each half a total of 260 turns. The two halves are wound oppositely and connected in series, the connection between both being made over the primary. This disposition, besides being convenient, has the advantage that when the coil is well balanced—that is, when both of its terminals T_1 T_1 are connected to bodies or devices of equal capacity—there is not much danger of breaking through to the primary, and the insulation between the primary and the secondary need not be thick. In using the coil it is advisable to attach to *both* terminals devices of nearly equal capacity, as, when the capacity of the terminals is not equal, sparks will be apt to pass to the primary. To avoid this, the middle point of the secondary may be connected to the primary, but this is not always practicable.

The primary P P is wound in two parts, and oppositely, upon a wooden spool W, and the four ends are led out of the oil through hard rubber tubes t t. The ends of the secondary T_1 T_1 are also led out of the oil through rubber tubes t_1 t_1 of great thickness. The primary and secondary layers are insulated by cotton cloth, the thickness of the insulation, of course, bearing some proportion to the difference of potential between the turns of the different layers. Each half of the primary has four layers, 24 turns in each, this giving a total of 96 turns. When both the parts are connected in series, this gives a ratio of conversion of about 1 : 2.7, and with the primaries in multiple, 1 : 5.4; but in operating with very rapidly alternating currents this ratio does not convey even an approximate idea of the ratio of the E. M. Fs. in the primary and secondary circuits. The coil is held in position in the oil on wooden supports, there being about 5 centimetres thickness of oil all round. Where the oil is not specially needed, the space is filled with pieces of wood, and for this purpose principally the wooden box B surrounding the whole is used.

The construction here shown is, of course, not the best on general principles, but I believe it is a good and convenient one for the production of effects in which an excessive potential and a very small current are needed.

In connection with the coil I use either the ordinary form of discharger or a modified form. In the former I have introduced two changes which secure some advantages, and which are obvious. If they are mentioned, it is only in the hope that some experimenter may find them of use.

One of the changes is that the adjustable knobs A and B

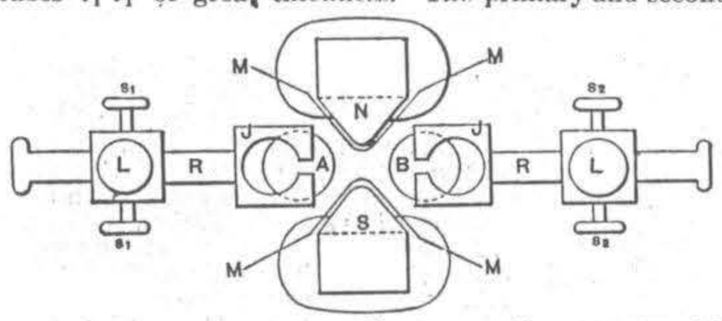

FIG. 4.—ARRANGEMENT OF IMPROVED DISCHARGER AND MAGNET.

(Fig. 4), of the discharger are held in jaws of brass, J J, by spring pressure, this allowing of turning them successively into different positions, and so doing away with the tedious process of frequent polishing up.

The other change consists in the employment of a strong electromagnet N S, which is placed with its axis at right angles to the line joining the knobs A and B, and produces a strong magnetic field between them. The pole pieces of the magnet are movable and properly formed so as to protrude between the brass knobs, in order to make the field as intense as possible; but to prevent the discharge from jumping to the magnet the pole pieces are protected by a layer of mica, M M, of sufficient thickness. s_1 s_1 and s_2 s_2 are screws for fastening the wires. On each side one of the screws is for large and the other for small wires. L L are screws for fixing in position the rods R R, which support the knobs.

In another arrangement with the magnet I take the discharge between the rounded pole pieces themselves, which in such case are insulated and preferably provided with polished brass caps.

The employment of an intense magnetic field is of advantage principally when the induction coil or transformer which charges the condenser is operated by currents of very low frequency. In such a case the number of the fundamental discharges between the knobs may be so small as to render the currents produced in the secondary unsuitable for many experiments. The intense magnetic field then serves to blow out the arc between the knobs as soon as it is formed, and the fundamental discharges occur in quicker succession.

Instead of the magnet, a draught or blast of air may be employed with some advantage. In this case the arc is preferably established between the knobs A B, in Fig. 2 (the knobs a b being generally joined, or entirely done away with), as in this disposition the arc is long and unsteady, and is easily affected by the draught.

When a magnet is employed to break the arc, it is better to choose the connection indicated diagrammatically in Fig. 5, as in this case the currents forming the arc are much more powerful, and the magnetic field exercises a greater influence. The use of the magnet permits, however, of the arc being replaced by a vacuum tube, but I have encountered great difficulties in working with an exhausted tube.

The other form of discharger used in these and similar experiments is indicated in Figs. 6 and 7. It consists of a number of brass pieces c c (Fig. 6), each of which comprises a spherical middle portion m with an extension e below—

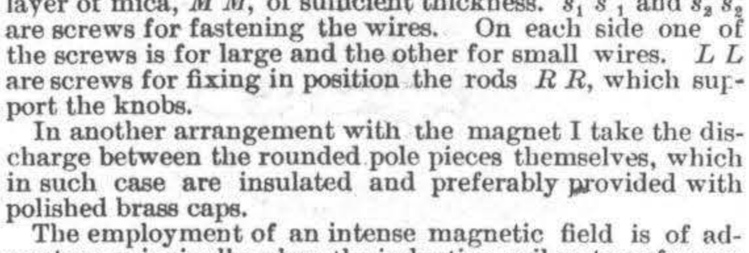

FIG. 5.—ARRANGEMENT WITH LOW-FREQUENCY ALTERNATOR AND IMPROVED DISCHARGER.

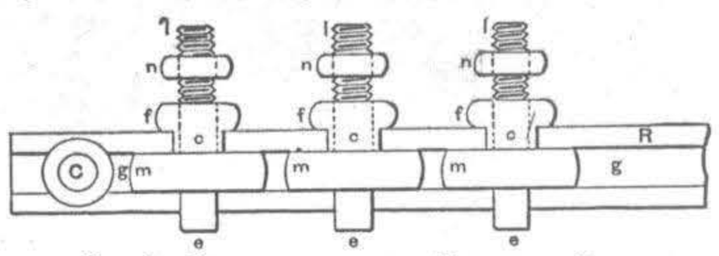

FIG. 6.—DISCHARGER WITH MULTIPLE GAPS.

which is merely used to fasten the piece in a lathe when polishing up the discharging surface—and a column above, which consists of a knurled flange f surmounted by a threaded stem l carrying a nut n; by means of which a wire is fastened to the column. The flange f conveniently serves for holding the brass piece when fastening the wire, and also for turning it in any position when it becomes necessary to present a fresh disharging surface. Two stout strips of hard rubber R R, with planed grooves g g (Fig. 7) to fit the middle portion of the pieces c c, serve to clamp the latter and hold them firmly in position by means of two bolts C C (of which only one is shown) passing through the ends of the strips.

In the use of this kind of discharger I have found three principal advantages over the ordinary form. First, the dielectric strength of a given total width of air space is greater when a great many small air gaps are used instead of one, which permits of working with a smaller length of air gap, and that means smaller loss and less deterioration of the metal; secondly by reason of splitting the arc up into smaller arcs, the polished surfaces are made to last much longer; and, thirdly, the apparatus affords some gauge in the experiments. I usually set the pieces by putting between them sheets of uniform thickness at a certain very small distance which is known from the experiments of Sir William Thomson to require a certain electromotive force to be bridged by the spark.

It should, of course, be remembered that the sparking distance is much diminished as the frequency is increased. By taking any number of spaces the experimenter has a rough idea of the electromotive force, and he finds it easier to repeat an experiment, as he has not the trouble of setting the knobs again and again. With this kind of discharger I have been able to maintain an oscillating motion without any spark being visible with the naked eye between the knobs, and they would not show a very appreciable rise in temperature. This form of discharge also lends itself to many arrangements of condensers and circuits which are often very convenient and time-saving. I have used it preferably in a disposition similar to that indicated in Fig. 2, when the currents forming the arc are small.

I may here mention that I have also used dischargers with single or multiple air gaps, in which the discharge surfaces were rotated with great speed. No particular advantage was, however, gained by this method, except in cases where the currents from the condenser were large and the keeping cool of the surfaces was necessary, and in cases when, the discharge not being oscillating of itself, the arc as soon as established was broken by the air current, thus starting the vibration at intervals in rapid succession. I have also used mechanical interrupters in many ways. To avoid the difficulties with frictional contacts, the preferred plan adopted was to establish the arc and rotate through it at great speed a rim of mica provided with many holes and fastened to a steel plate. It is understood, of course, that the employment of a magnet, air current, or other interrupter, produces an effect worth noticing, unless the self-induction, capacity and resistance are so related that there are oscillations set up upon each interruption.

I will now endeavor to show you some of the most noteworthy of these discharge phenomena.

I have stretched across the room two ordinary cotton covered wires, each about 7 metres in length. They are supported on insulating cords at a distance of about 30 centimetres. I attach now to each of the terminals of the coil one of the wires and set the coil in action. Upon turning the lights off in the room you see the wires strongly illuminated by the streams issuing abundantly from their whole surface in spite of the cotton covering, which may even be very thick. When the experiment is performed under good conditions, the light from the wires is sufficiently intense to allow distinguishing the objects in a room. To produce the best result it is, of course, necessary to adjust carefully the capacity of the jars, the arc between the knobs and the length of the wires. My experience is that calculation of the length of the wires leads, in such case, to no result whatever. The experimenter will do best to take the wires at the start very long, and then adjust by cutting off first long pieces, and then smaller and smaller ones as he approaches the right length.

A convenient way is to use an oil condenser of very small capacity, consisting of two small adjustable metal plates, in connection with this and similar experiments. In such case I take wires rather short and set at the beginning the condenser plates at maximum distance. If the streams for the wires increase by approach of the

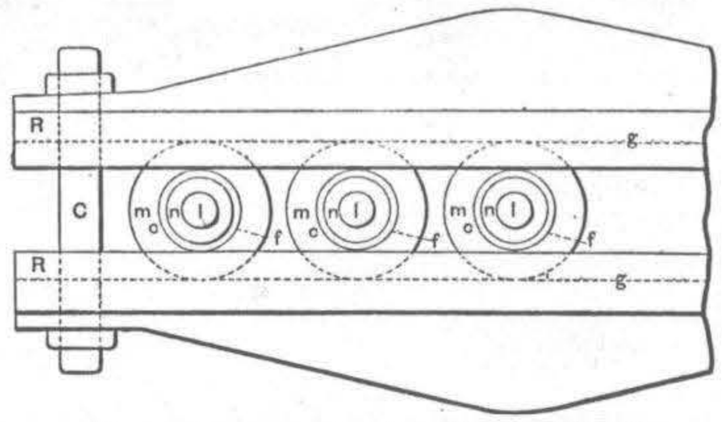

FIG. 7.—DISCHARGER WITH MULTIPLE GAPS.

plates, the length of the wires is about right; if they diminish the wires are too long for that frequency and potential. When a condenser is used in connection with experiments with such a coil, it should be an oil condenser by all means, as in using an air condenser considerable energy might be wasted. The wires leading to the plates in the oil should be very thin, heavily coated with some insulating compound, and provided with a conducting covering—this preferably extending under the surface of the oil. The conducting cover should not be too near the terminals, or ends, of the wire, as a park would be apt to jump from the wire to it. The conducting coating is used to diminish the air losses, in virtue of its action as an electrostatic screen. As to the size of the vessel containing the oil, and the size of the plates, the experimenter gains at once an idea from a rough trial. The size of the plates *in oil* is, however, calculable, as the dielectric losses are very small.

In the preceding experiment it is of considerable interest to know what relation the quantity of the light emitted bears to the frequency and potential of the electric impulses. My opinion is that the heat as well as light effects produced should be proportionate, under otherwise equal conditions of test, to the product of frequency and square of potential, but the experimental verification of the law, whatever it may be, would be exceedingly difficult. One thing is certain, at any rate, and that is, that in augmenting the potential and frequency we rapidly intensify the streams; and, though it may be very sanguine, it is surely not altogether hopeless to expect that we may succeed in producing a practical illuminant on these lines. We would

then be simply using burners or flames, in which there would be no chemical process, no consumption of material, but merely a transfer of energy, and which would, in all probability emit more light and less heat than ordinary flames.

The luminous intensity of the streams is, of course, considerably increased when they are focused upon a small surface. This may be shown by the following experiment:

I attach to one of the terminals of the coil a wire *w* (Fig. 8), bent in a circle of about 30 centimetres in diameter, and to the other terminal I fasten a small brass sphere *s*, the surface of the wire being preferably equal to the surface of the sphere, and the centre of the latter being in a line at right angles to the plane of the wire circle and passing through its centre. When the discharge is established under proper conditions, a luminous hollow cone is formed, and in the dark one-half of the brass sphere is strongly illuminated, as shown in the cut.

By some artifice or other, it is easy to concentrate the streams upon small surfaces and to produce very strong light effects. Two thin wires may thus be rendered intensely luminous.

In order to intensify the streams the wires should be very thin and short; but as in this case their capacity would be generally too small for the coil—at least, for such a one as the present—it is necessary to augment the capacity to the required value, while, at the same time, the surface of the wires remains very small. This may be done in many ways.

Here, for instance, I have two plates, *R R*, of hard rubber (Fig. 9), upon which I have glued two very thin wires *w w*, so as to form a name. The wires may be bare or covered with the best insulation—it is immaterial for the success of the experiment. Well insulated wires, if anything, are preferable. On the back of each plate, indicated by the shaded portion, is a tinfoil coating *t t*. The plates are placed in line at a sufficient distance to prevent a spark passing from one to the other wire. The two tinfoil coatings I have joined by a conductor *C*, and the two wires I presently connect to the terminals of the coil. It is now easy, by varying the strength and frequency of the currents through the primary, to find a point at which the capacity of the system is best suited to the conditions, and the wires become so strongly luminous that, when the light in the room is turned off the name formed by them appears in brilliant letters.

It is perhaps preferable to perform this experiment with a coil operated from an alternator of high frequency, as then, owing to the harmonic rise and fall, the streams are very uniform, though they are less abundant than when produced with such a coil as the present. This experiment, however, may be performed with low frequencies, but much less satisfactorily.

When two wires, attached to the terminals of the coil,

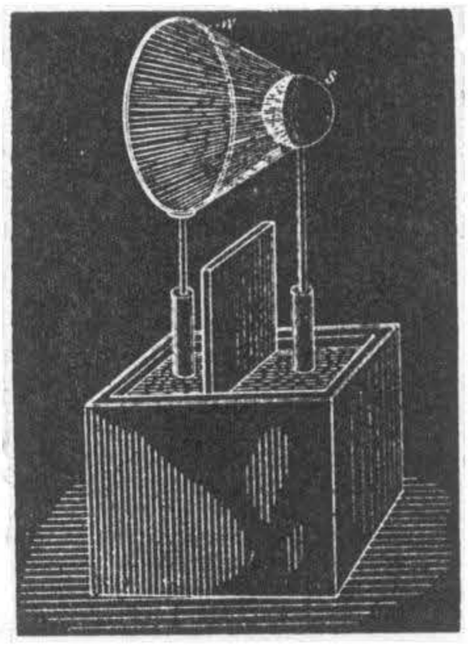

FIG. 8.—EFFECT PRODUCED BY CONCENTRATING STREAMS.

are set at the proper distance, the streams between them may be so intense as to produce a continuous luminous sheet. To show this phenomenon I have here two circles, *C* and *c* (Fig. 10), of rather stout wire, one being about 80 centimetres and the other 30 centimetres in diameter. To each of the terminals of the coil I attach one of the circles. The supporting wires are so bent that the circles may be placed in the same plane, coinciding as nearly as possible. When the light in the room is turned off and the coil set to work, you see the whole space between the wires uniformly filled with streams, forming a luminous disc, which could be seen from a considerable distance, such is the intensity of the streams. The outer circle could have been much larger than the present one; in fact, with this coil I have used much larger circles, and I have been able to produce a strongly luminous sheet, covering an area of more than one square metre, which is a remarkable effect with this very small coil. To avoid uncertainty, the circle has been taken smaller, and the area is now about 0.43 square metre.

The frequency of the vibration, and the quickness of succession of the sparks between the knobs, affect to a marked degree the appearance of the streams. When the frequency is very low, the air gives way in more or less the same manner, as by a steady difference of potential, and the streams consist of distinct threads, generally mingled with thin sparks, which probably correspond to the successive discharges occurring between the knobs. But when the frequency is extremely high, and the arc of the discharge produces a very *loud* but *smooth* sound—showing both that oscillation takes place and that the sparks succeed each other with great rapidity—then the luminous streams formed are perfectly uniform. To reach this result very small coils and jars of small capacity should be used. I take two tubes of thick Bohemian glass, about 5 centimetres in diameter and 20 centimetres long. In each of the tubes I slip a primary of very thick copper wire. On the top of each tube I wind a secondary of much thinner gutta-percha covered wire. The two secondaries I connect in series, the primaries preferably in multiple arc. The tubes are then placed in a large glass vessel, at a distance of 10 to 15 centimetres from each other, on insulating supports, and the vessel is filled with boiled-out oil, the oil reaching about an inch above the tubes. The free ends of the secondary are lifted out of the oil and placed parallel to each other at a distance of about 10 centimetres. The ends which are scraped should be dipped in the oil. Two four-pint jars joined in series may be used to discharge through the primary. When the necessary adjustments in the length and distance of the wires above the oil and in the arc of discharge are made, a luminous sheet is produced between the wires which is perfectly smooth and textureless, like the ordinary discharge through a moderately exhausted tube.

I have purposely dwelt upon this apparently insignificant experiment. In trials of this kind the experimenter arrives at the startling conclusion that, to pass ordinary luminous discharges through gases, no particular degree of exhaustion is needed, but that the gas may be at ordinary or even greater pressure. To accomplish this, a very high fre-

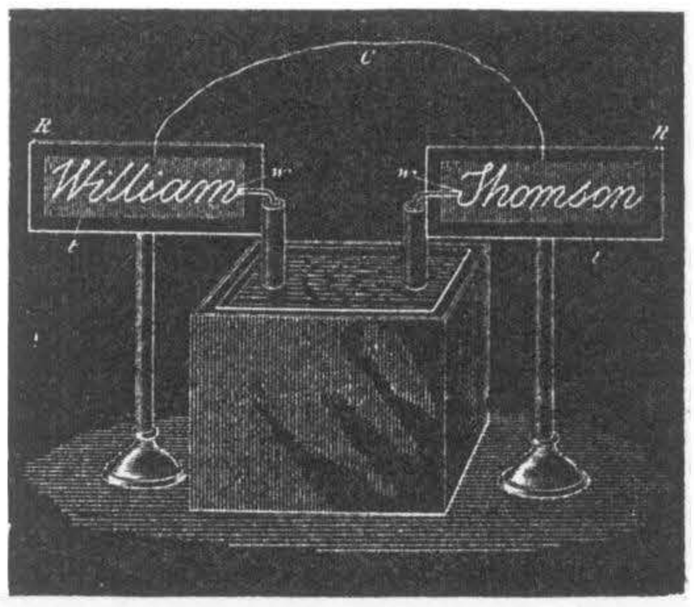

FIG. 9.—WIRES RENDERED INTENSELY LUMINOUS.

quency is essential; a high potential is likewise required, but this is a merely incidental necessity. These experiments teach us that, in endeavoring to discover novel methods of producing light by the agitation of atoms, or molecules, of a gas, we need not limit our research to the vacuum tube, but may look forward quite seriously to the possibility of obtaining the light effects without the use of any vessel whatever, with air at ordinary pressure.

Such discharges of very high frequency, which render luminous the air at ordinary pressures, we have probably often occasion to witness in Nature. I have no doubt that if, as many believe, the aurora borealis is produced by sudden cosmic disturbances, such as eruptions at the sun's surface, which set the electrostatic charge of the earth in an extremely rapid vibration, the red glow observed is not confined to the upper rarefied strata of the air, but the discharge traverses, by reason of its very high frequency, also the dense atmosphere in the form of a *glow*, such as we ordinarily produce in a slightly exhausted tube. If the frequency were very low, or even more so, if the charge were not at all vibrating, the dense air would break down as in a lightning discharge. Indications of such breaking down of the lower dense strata of the air have been repeatedly observed at the occurrence of this marvelous phenomenon; but if it does occur, it can only be attributed to the fundamental disturbances, which are few in number, for the vibration produced by them would be far too rapid to allow a disruptive break. It is the original and irregular impulses which affect the instruments; the superimposed vibrations probably pass unnoticed.

When an ordinary low frequency discharge is passed through moderately rarefied air, the air assumes a purplish hue. If by some means or other we increase the intensity of the molecular, or atomic, vibration, the gas changes to a white color. A similar change occurs at ordinary pressures with electric impulses of very high frequency. If the molecules of the air around a wire are moderately agitated, the brush formed is reddish or violet; if the vibration is rendered sufficiently intense, the streams become white. We may accomplish this in various ways. In the experiment before shown with the two wires across the room, I have endeavored to secure the result by pushing to a high value both the frequency and potential; in the experiment with the thin wires glued on the rubber plate I have concentrated the action upon a very small surface—in other words, I have worked with a great electric density.

A most curious form of discharge is observed with such a coil when the frequency and potential are pushed to the extreme limit. To perform the experiment, every part of the coil should be heavily insulated, and only two small spheres—or, better still, two sharp-edged metal discs (*d d*, Fig. 11) of no more than a few centimetres in diameter—

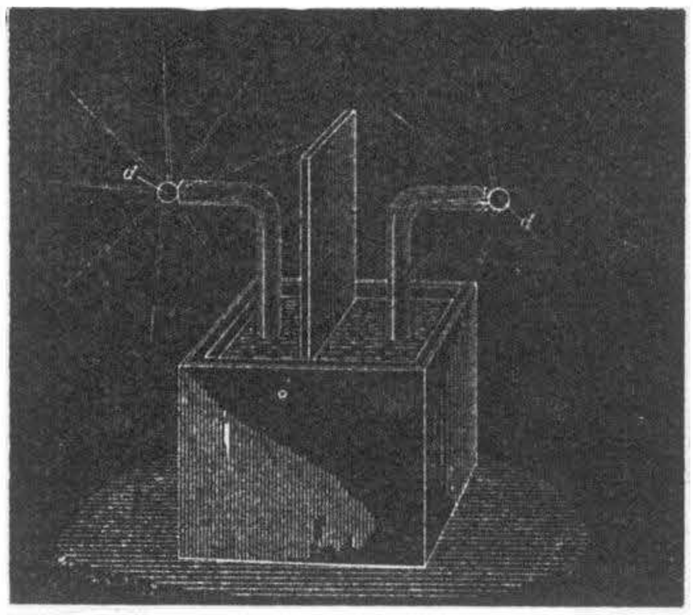

FIG. 11.—PHANTOM STREAMS.

should be exposed to the air. The coil here used is immersed in oil, and the ends of the secondary reaching out of the oil are covered with an air-tight cover of hard rubber of great thickness. All cracks, if there are any, should be carefully stopped up, so that the brush discharge cannot form anywhere except on the small spheres or plates which are exposed to the air. In this case, since there are no large plates or other bodies of capacity attached to the terminals, the coil is capable of an extremely rapid vibration. The potential may be raised by increasing, as far as the experimenter judges proper, the rate of change of the primary current. With a coil not widely differing from the present, it is best to connect the two primaries in multiple arc; but if the secondary should have a much greater number of turns the primaries should preferably be used in series, as otherwise the vibration might be too fast for the secondary. It occurs under these conditions that misty white streams break forth from the edges of the discs and spread out phantom-like into space. With this coil, when fairly well produced, they are about 25 to 30 centimetres long. When the hand is held against them no sensation is produced, and a spark, causing a shock, jumps from the terminal only upon the hand being brought much nearer. If the oscillation of the primary current is rendered intermittent by some means or other, there is a corresponding throbbing of the streams, and now the hand or other conducting object may be brought in still greater proximity to the terminal without a spark being caused to jump.

Among the many beautiful phenomena which may be produced with such a coil I have here selected only those which appear to possess some features of novelty, and lead us to some conclusions of interest. One will not find it at all difficult to produce in the laboratory, by means of it, many other phenomena which appeal to the eye even more than these here shown, but present no particular feature of novelty.

Early experimenters describe the display of sparks produced by an ordinary large induction coil upon an insulating plate separating the terminals. Quite recently Siemens performed some experiments in which fine effects were obtained, which were seen by many with interest. No doubt large coils, even if operated with currents of low frequencies, are capable of producing beautiful effects. But the largest coil ever made could not, by far, equal the magnificent display of streams and sparks obtained from such a disruptive discharge coil when properly adjusted. To give an idea, a coil such as the present one will cover easily a plate of 1 metre in diameter completely with the streams. The best way to perform such experiments is to take a very thin rubber or a glass plate and glue on one side of it a narrow ring of tinfoil of very large diameter, and on the other a circular washer, the centre of the latter coinciding with that of the ring, and the surfaces of both being preferably equal, so as to keep the coil well balanced. The washer and ring should be connected to the terminals by heavily insulated thin wires. It is easy in observing the effect of the capacity to produce a sheet of uniform streams, or a fine network of thin silvery threads, or a mass of loud brilliant sparks, which completely cover the plate.

Since I have advanced the idea of the conversion by

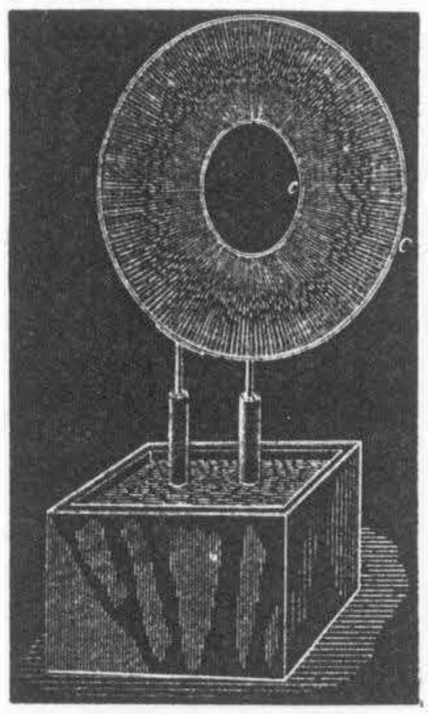

FIG. 10.—LUMINOUS DISCS.

means of the disruptive discharge, in my paper before the American Institute of Electrical Engineers at the beginning of the past year, the interest excited in it has been considerable. It affords us a means for producing any potentials by the aid of inexpensive coils operated from ordinary systems of distribution, and—what is perhaps more appreciated—it enables us to convert currents of any frequency into currents of any other lower or higher frequency. But its chief value will perhaps be found in the help which it will afford us in the investigations of the phenomena of phosphorescence, which a disruptive discharge coil is capable of exciting in innumerable cases where ordinary coils, even the largest, would utterly fail.

Considering its probable uses for many practical purposes, and its possible introduction into laboratories for scientific research, a few additional remarks as to the construction of such a coil will perhaps not be found superfluous.

It is, of course, absolutely necessary to employ in such a coil wires provided with the best insulation.

Good coils may be produced by employing wires covered with several layers of cotton, boiling the coil a long time in pure wax, and cooling under moderate pressure. The advantage of such a coil is that it can be easily handled, but it cannot probably give as satisfactory results as a coil immersed in pure oil. Besides, it seems that the presence of a large body of wax affects the coil disadvantageously, whereas this does not seem to be the case with oil. Perhaps it is because the dielectric losses in the liquid are smaller.

I have tried at first silk and cotton covered wires with oil immersion, but I have been gradually led to use gutta-percha covered wires, which proved most satisfactory. Gutta-percha insulation adds, of course, to the capacity of the coil, and this, especially if the coil be large, is a great disadvantage when extreme frequencies are desired; but, on the other hand, gutta-percha will withstand much more than an equal thickness of oil, and this advantage should be secured at any price. Once the coil has been immersed, it should never be taken out of the oil for more than a few hours, else the gutta-percha will crack up and the coil will not be worth half as much as before. Gutta-percha is probably slowly attacked by the oil, but after an immersion of eight to nine months I have found no ill effects.

I have obtained in commerce two kinds of gutta-percha wire: in one the insulation sticks tightly to the metal, in the other it does not. Unless a special method is followed to expel all air, it is much safer to use the first kind. I

wind the coil within an oil tank so that all interstices are filled up with the oil. Between the layers I use cloth boiled out thoroughly in oil, calculating the thickness according to the difference of potential between the turns. There seems not to be a very great difference whatever kind of oil is used; I use paraffine or linseed oil.

To exclude more perfectly the air, an excellent way to proceed, and easily practicable with small coils, is the following: Construct a box of hard wood of very thick boards which have been for a long time boiled in oil. The boards should be so joined as to safely withstand the external air pressure. The coil being placed and fastened in position within the box, the latter is closed with a strong lid, and covered with closely fitting metal sheets, the joints of which are soldered very carefully. On the top two small holes are drilled, passing through the metal sheet and the wood, and in these holes two small glass tubes are inserted and the joints made air-tight. One of the tubes is connected to a vacuum pump, and the other with a vessel containing a sufficient quantity of boiled-out oil. The latter tube has a very small hole at the bottom, and is provided with a stopcock. When a fairly good vacuum has been obtained, the stopcock is opened and the oil slowly fed in. Proceeding in this manner, it is impossible that any big bubbles, which are the principal danger, should remain between the turns. The air is most completely excluded, probably better than by boiling out, which, however, when gutta-percha coated wires are used, is not practicable.

For the primaries I use ordinary line wire with a thick cotton coating. Strands of very thin insulated wires

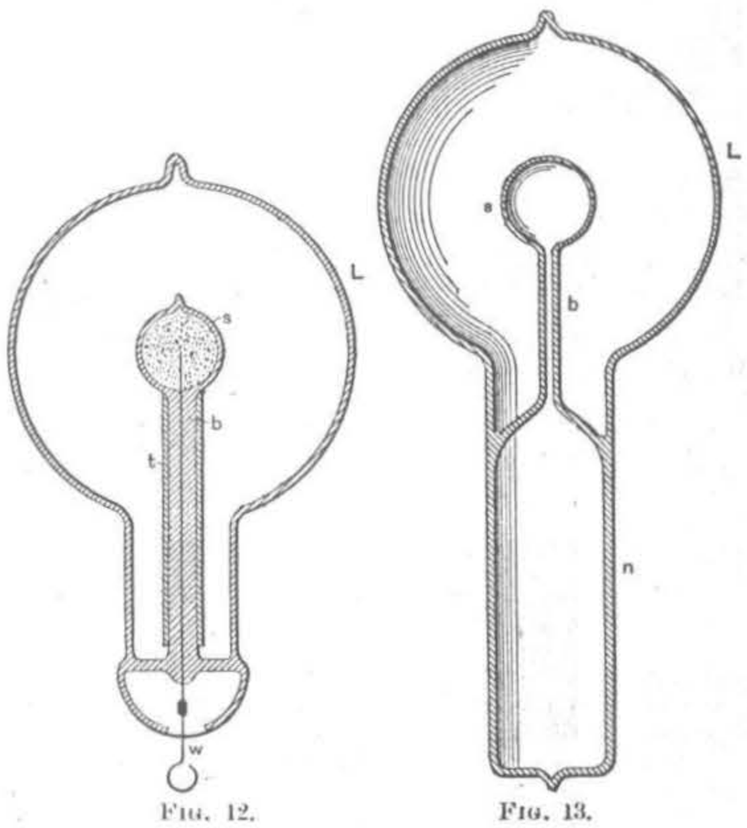

Fig. 12. Fig. 13.

Bulbs for Producing Rotating Brush.

properly interlaced would, of course, be the best to employ for the primaries, but they are not to be had.

In an experimental coil the size of the wires is not of great importance. In the coil here used the primary is No. 12 and the secondary No. 24 Brown & Sharpe gauge wire; but the sections may be varied considerably. It would only imply different adjustments; the results aimed at would not be materially affected.

I have dwelt at some length upon the various forms of brush discharge because, in studying them, we not only observe phenomena which please our eye, but also afford us food for thought, and lead us to conclusions of practical importance. In the use of alternating currents of very high tension, too much precaution cannot be taken to prevent the brush discharge. In a main conveying such currents, in an induction coil or transformer, or in a condenser, the brush discharge is a source of great danger to the insulation. In a condenser especially the gaseous matter must be most carefully expelled, for in it the charged surfaces are near each other, and if the potentials are high, just as sure as a weight will fall if let go, so the insulation will give way if a single gaseous bubble of some size be present, whereas, if all gaseous matter were carefully excluded, the condenser would safely withstand a much higher difference of potential. A main conveying alternating currents of very high tension may be injured merely by a blowhole or small crack in the insulation, the more so as a blowhole is apt to contain gas at low pressure; and as it appears almost impossible to completely obviate such little imperfections, I am led to believe that in our future distribution of electrical energy by currents of very high tension liquid insulation will be used. The cost is a great drawback, but if we employ an oil as an insulator the distribution of electrical energy with something like 100,000 volts, and even more, become, at least with higher frequencies, so easy that they could be hardly called engineering feats. With oil insulation and alternate current motors transmissions of power can be effected with safety and upon an industrial basis at distances of as much as a thousand miles.

A peculiar property of oils, and liquid insulation in general, when subjected to rapidly changing electric stresses, is to disperse any gaseous bubbles which may be present, and diffuse them through its mass, generally long before any injurious break can occur. This feature may be easily observed with an ordinary induction coil by taking the primary out, plugging up the end of the tube upon which the secondary is wound, and filling it with some fairly transparent insulator, such as paraffine oil. A primary of a diameter something like six millimetres smaller than the inside of the tube may be inserted in the oil. When the coil is set to work one may see, looking from the top through the oil, many luminous points—air bubbles which are caught by inserting the primary, and which are rendered luminous in consequence of the violent bombardment. The occluded air, by its impact against the oil, heats it; the oil begins to circulate, carrying some of the air along with it, until the bubbles are dispersed and the luminous points disappear. In this manner, unless large bubbles are occluded in such way that circulation is rendered impossible, a damaging break is averted, the only effect being a moderate warming up of the oil. If, instead of the liquid, a solid insulation, no matter how thick, were used, a breaking through and injury of the apparatus would be inevitable.

The exclusion of gaseous matter from any apparatus in which the dielectric is subjected to more or less rapidly changing electric forces is, however, not only desirable in order to avoid a possible injury of the apparatus, but also on account of economy. In a condenser, for instance, as long as only a solid or only a liquid dielectric is used, the loss is small; but if a gas under ordinary or small pressure be present the loss may be very great. Whatever the nature of the force acting in the dielectric may be, it seems that in a solid or liquid the molecular displacement produced by the force is small: hence the product of force and displacement is insignificant, unless the force be very great; but in a gas the displacement, and therefore this product, is considerable; the molecules are free to move, they reach high speeds, and the energy of their impact is lost in heat or otherwise. If the gas be strongly compressed, the displacement due to the force is made smaller, and the losses are reduced.

In most of the succeeding experiments I prefer, chiefly on account of the regular and positive action, to employ the alternator before referred to. This is one of the several machines constructed by me for the purposes of these investigations. It has 384 pole projections, and is capable of giving currents of a frequency of about 10,000 per second. This machine has been illustrated and briefly described in my first paper before the American Institute of Electrical Engineers, May 20, 1891, to which I have already referred. A more detailed description, sufficient to enable any engineer to build a similar machine, will be found in several electrical journals of that period.

The induction coils operated from the machine are rather small, containing from 5,000 to 15,000 turns in the secondary. They are immersed in boiled-out linseed oil, contained in wooden boxes covered with zinc sheet.

I have found it advantageous to reverse the usual position of the wires, and to wind, in these coils, the primaries on the top; this allowing the use of a much bigger primary, which, of course, reduces the danger of overheating and increases the output of the coil. I make the primary on each side at least one centimetre shorter than the secondary, to prevent the breaking through on the ends, which would surely occur unless the insulation on the top of the secondary be very thick, and this, of course, would be disadvantageous.

When the primary is made movable, which is necessary in some experiments, and many times convenient for the purposes of adjustment, I cover the secondary with wax, and turn it off in a lathe to a diameter slightly smaller than the inside of the primary coil. The latter I provide with a handle reaching out of the oil, which serves to shift it in any position along the secondary.

I will now venture to make, in regard to the general manipulation of induction coils, a few observations bearing upon points which have not been fully appreciated in earlier experiments with such coils, and are even now often overlooked.

The secondary of the coil possesses usually such a high self-induction that the current through the wire is inappreciable, and may be so even when the terminals are joined by a conductor of small resistance. If capacity is added to the terminals, the self-induction is counteracted, and a stronger current is made to flow through the secondary, though its terminals are insulated from each other. To one entirely unacquainted with the properties of alternating currents nothing will look more puzzling. This feature was illustrated in the experiment performed at the beginning with the top plates of wire gauze attached to the terminals and the rubber plate. When the plates of wire gauze were close together, and a small arc passed between them, the arc *prevented* a strong current from passing through the secondary, because it did away with the capacity on the terminals; when the rubber plate was inserted between, the capacity of the condenser formed counteracted the self-induction of the secondary, a stronger current passed now, the coil performed more work, and the discharge was by far more powerful.

The first thing, then, in operating the induction coil is to combine capacity with the secondary to overcome the self-induction. If the frequencies and potentials are very high gaseous matter should be carefully kept away from the charged surfaces. If Leyden jars are used, they should be immersed in oil, as otherwise considerable dissipation may occur if the jars are greatly strained. When high

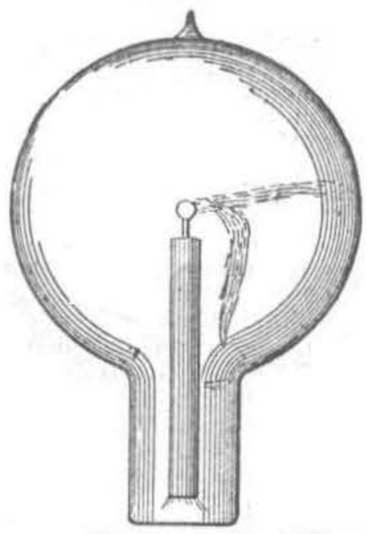

Fig. 14.—Forms and Phases of the Rotating Brush.

frequencies are used, it is of equal importance to combine a condenser with the primary. One may use a condenser connected to the ends of the primary or to the terminals of the alternator, but the latter is not to be recommended, as the machine might be injured. The best way is undoubtedly to use the condenser in series with the primary and with the alternator, and to adjust its capacity so as to annul the self-induction of both the latter. The condenser should be adjustable by very small steps, and for a finer adjustment a small oil condenser with movable plates may be used conveniently.

I think it best at this juncture to bring before you a phenomenon, observed by me some time ago, which to the purely scientific investigator may perhaps appear more interesting than any of the results which I have the privilege to present to you this evening.

It may be quite properly ranked among the brush phenomena—in fact, it is a brush, formed at, or near, a single terminal in high vacuum.

In bulbs provided with a conducting terminal, though it be of aluminium, the brush has but an ephemeral existence, and cannot, unfortunately, be indefinitely preserved in its most sensitive state, even in a bulb devoid of any conducting electrode. In studying the phenomenon, by all means a bulb having no leading-in wire should be used. I have found it best to use bulbs constructed as indicated in Figs. 12 and 13.

In Fig. 12 the bulb comprises an incandescent lamp globe L, in the neck of which is sealed a barometer tube b, the end of which is blown out to form a small sphere s. This sphere should be sealed as closely as possible in the centre of the large globe. Before sealing, a thin tube t, of aluminium sheet, may be slipped in the barometer tube, but it is not important to employ it.

The small hollow sphere s is filled with some conducting powder, and a wire w is cemented in the neck for the purpose of connecting the conducting powder with the generator.

The construction shown in Fig. 13 was chosen in order to remove from the brush any conducting body which might possibly affect it. The bulb consists in this case of a lamp globe L, which has a neck n, provided with a tube b and small sphere s, sealed to it, so that two entirely independent compartments are formed, as indicated in the drawing. When the bulb is in use, the neck n is provided with a tinfoil coating, which is connected to the generator and acts inductively upon the moderately rarefied and highly conducting gas inclosed in the neck. From there the current passes through the tube b into the small sphere s, to act by induction upon the gas contained in the globe L.

It is of advantage to make the tube t very thick, the hole through it very small, and to blow the sphere s very thin. It is of the greatest importance that the sphere s be placed in the centre of the globe L.

Figs. 14, 15 and 16 indicate different forms, or stages, of

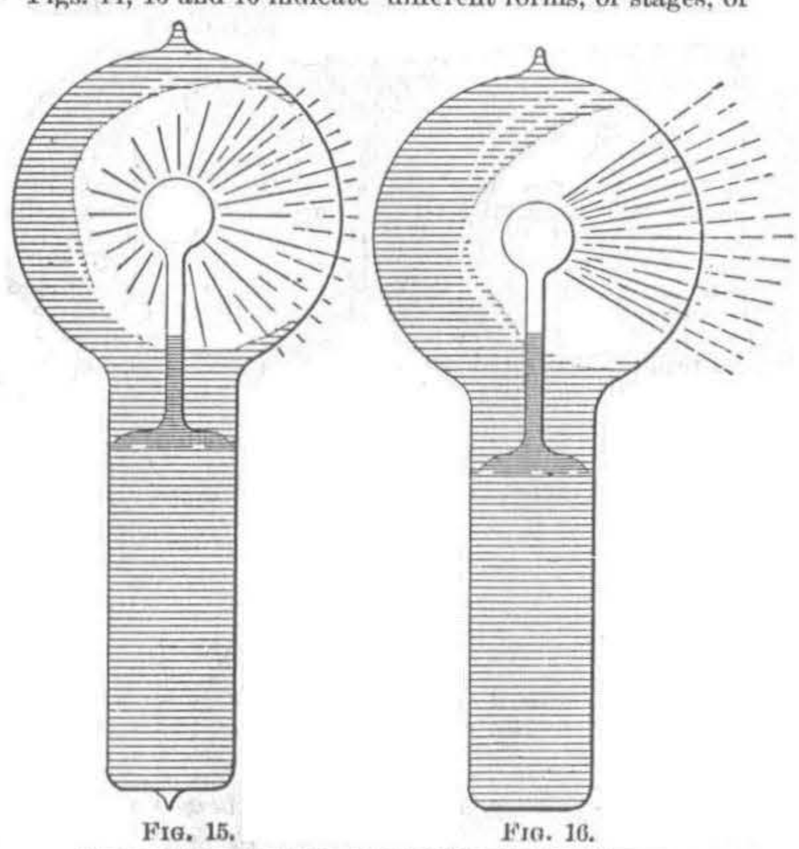

Fig. 15. Fig. 16.

Forms and Phases of the Rotating Brush.

the brush. Fig. 14 shows the brush as it first appears in a bulb provided with a conducting terminal; but, as in such a bulb it very soon disappears—often after a few minutes—I will confine myself to the description of the phenomenon as seen in a bulb without conducting electrode. It is observed under the following conditions:

When the globe L (Figs. 12 and 13) is exhausted to a very high degree, generally the bulb is not excited upon connecting the wire w (Fig. 12) or the tinfoil coating of the bulb (Fig. 13) to the terminal of the induction coil. To excite it, it is usually sufficient to grasp the globe L with the hand. An intense phosphorescence then spreads at first over the globe, but soon gives place to a white, misty light. Shortly afterward one may notice that the luminosity is unevenly distributed in the globe, and after passing the current for some time the bulb appears as in Fig. 15. From this stage the phenomenon will gradually pass to that indicated in Fig. 16, after some minutes, hours, days or weeks, according as the bulb is worked. Warming the bulb or increasing the potential hastens the transit.

When the brush assumes the form indicated in Fig. 16, it may be brought to a state of extreme sensitiveness to electrostatic and magnetic influence. The bulb hanging straight down from a wire, and all objects being remote from it, the approach of the observer at a few paces from the bulb will cause the brush to fly to the opposite side, and if he walks around the bulb it will always keep on the opposite side. It may begin to spin around the terminal long before it reaches that sensitive stage. When it begins to turn around principally, but also before, it is affected by a magnet, and at a certain stage it is susceptible to magnetic influence to an astonishing degree. A small permanent magnet, with its poles at a distance of no more than two centimetres, will affect it visibly at a distance of two metres, slowing down or accelerating the rotation according to how it is held relatively to the brush. I think I have observed that at the stage when it is most sensitive to magnetic, it is not most sensitive to electrostatic, influence. My explanation is, that the electrostatic attraction between the brush and the glass of the bulb, which retards the rotation, grows much quicker than the magnetic influence when the intensity of the stream is increased.

When the bulb hangs with the globe L down, the rotation is always clockwise. In the southern hemisphere it would occur in the opposite direction and on the equator the brush should not turn at all. The rotation may be reversed by a magnet kept at some distance. The brush rotates best, seemingly, when it is at right angles to the lines of force of the earth. It very likely rotates, when at its maximum speed, in synchronism with the alternations, say 10,000 times a second. The rotation can be slowed down or accelerated by the approach or receding of the observer, or any conducting body, but it cannot be reversed by putting the bulb in any position. When it is in the state of the highest sensitiveness and the potential or frequency be varied the sensitiveness is rapidly diminished. Changing either of these but little will generally stop the rotation. The sensitiveness is likewise affected by the variations of temperature. To attain great sensitiveness it is necessary to have the small sphere s in the centre of the globe L, as otherwise the electrostatic action of the glass of the globe will tend to stop the rotation. The sphere s should be small and of uniform thickness; any dissymmetry of course has the effect to diminish the sensitiveness.

The fact that the brush rotates in a definite direction in

a permanent magnetic field seems to show that in alternating currents of very high frequency the positive and negative impulses are not equal, but that one always preponderates over the other.

Of course, this rotation in one direction may be due to the action of two elements of the same current upon each other, or to the action of the field produced by one of the elements upon the other, as in a series motor, without necessarily one impulse being stronger than the other. The fact that the brush turns, as far as I could observe, in any position, would speak for this view. In such case it would turn at any point of the earth's surface. But, on the other hand, it is then hard to explain why a permanent magnet should reverse the rotation, and one must assume the preponderance of impulses of one kind.

As to the causes of the formation of the brush or stream, I think it is due to the electrostatic action of the globe and the dissymmetry of the parts. If the small bulb *s* and the globe *L* were perfect concentric spheres, and the glass throughout of the same thickness and quality, I think the brush would not form, as the tendency to pass would be equal on all sides. That the formation of the stream is due to an irregularity is apparent from the fact that it has the tendency to remain in one position, and rotation occurs most generally only when it is brought out of this position by electrostatic or magnetic influence. When in an extremely sensitive state it rests in one position, most curious experiments may be performed with it. For instance, the experimenter may, by selecting a proper position, approach the hand at a certain considerable distance to the bulb, and he may cause the brush to pass off by merely stiffening the muscles of the arm. When it begins to rotate slowly, and the hands are held at a proper distance, it is impossible to make even the slightest motion without producing a visible effect upon the brush. A metal plate connected to the other terminal of the coil affects it at a great distance, slowing down the rotation often to one turn a second.

I am firmly convinced that such a brush, when we learn how to produce it properly, will prove a valuable aid in the investigation of the nature of the forces acting in an electrostatic or magnetic field. If there is any motion which is measurable going on in the space, such a brush ought to reveal it. It is, so to speak, a beam of light, frictionless, devoid of inertia.

I think that it may find practical applications in telegraphy. With such a brush it would be possible to send dispatches across the Atlantic, for instance, with any speed, since its sensitiveness may be so great that the slightest changes will affect it. If it were possible to make the stream more intense and very narrow, its deflections could be easily photographed.

I have been interested to find whether there is a rotation of the stream itself, or whether there is simply a stress traveling around in the bulb. For this purpose I mounted a light mica fan so that its vanes were in the path of the brush. If the stream itself was rotating the fan would be spun around. I could produce no distinct rotation of the fan, although I tried the experiment repeatedly; but as the fan exerted a noticeable influence on the stream, and the apparent rotation of the latter was, in this case, never quite satisfactory, the experiment did not appear to be conclusive.

I have been unable to produce the phenomenon with the disruptive discharge coil, although every other of these phenomena can be well produced by it—many, in fact, much better than with coils operated from an alternator.

It may be possible to produce the brush by impulses of one direction, or even by a steady potential, in which case it would be still more sensitive to magnetic influence.

In operating an induction coil with rapidly alternating currents, we realize with astonishment, for the first time, the great importance of the relation of capacity, self-induction and frequency as regards the general result. The effects of capacity are the most striking, for in these experiments, since the self-induction and frequency both are high, the critical capacity is very small, and need be but slightly varied to produce a very considerable change. The experimenter may bring his body in contact with the terminals of the secondary of the coil, or attach to one or both terminals insulated bodies of very small bulk, such as bulbs, and he may produce a considerable rise or fall of potential, and greatly affect the flow of the current through the primary. In the experiment before shown, in which a brush appears at a wire attached to one terminal, and the wire is vibrated when the experimenter brings his insulated body in contact with the other terminal of the coil, the sudden rise of potential was made evident.

I may show you the behavior of the coil in another manner which possesses a feature of some interest. I have here a little light fan of aluminium sheet, fastened to a needle and arranged to rotate freely in a metal piece screwed to one of the terminals of the coil. When the coil is set to work, the molecules of the air are rhythmically attracted and repelled. As the force with which they are repelled is greater than that with which they are attracted, it results that there is a repulsion exerted on the surfaces of the fan. If the fan were made simply of a metal sheet, the repulsion would be equal on the opposite sides, and would produce no effect. But if one of the opposing surfaces is screened, or if, generally speaking, the bombardment on this side is weakened in some way or other, there remains the repulsion exerted upon the other, and the fan is set in rotation. The screening is best effected by fastening upon one of the opposing sides of the fan insulated conducting coatings, or, if the fan is made in the shape of an ordinary propeller screw, by fastening on one side, and close to it, an insulated metal plate. The static screen may, however, be omitted, and simply a thickness of insulating material fastened to one of the sides of the fan.

To show the behavior of the coil, the fan may be placed upon the terminal and it will readily rotate when the coil is operated by currents of very high frequency. With a steady potential, of course, and even with alternating currents of very low frequency, it would not turn, because of the very slow exchange of air and, consequently, smaller bombardment; but in the latter case it might turn if the potential were excessive. With a pin wheel, quite the opposite rule holds good; it rotates best with a steady potential, and the effort is the smaller the higher the frequency. Now, it is very easy to adjust the conditions so that the potential is normally not sufficient to turn the fan, but that by connecting the other terminal of the coil with an insulated body it rises to a much greater value, so as to rotate the fan, and it is likewise possible to stop the rotation by connecting to the terminal a body of different size, thereby diminishing the potential.

Instead of using the fan in this experiment, we may use the "electric" radiometer with similar effect. But in this case it will be found that the vanes will rotate only at high exhaustion or at ordinary pressures; they will not rotate at moderate pressures, when the air is highly conducting. This curious observation was made conjointly by Professor Crookes and myself. I attribute the result to the high conductivity of the air, the molecules of which then do not act as independent carriers of electric charges, but act all together as a single conducting body. In such case, of course, if there is any repulsion at all of the molecules from the vanes, it must be very small. It is possible, however, that the result is in part due to the fact that the greater part of the discharge passes from the leading-in wire through the highly conducting gas, instead of passing off from the conducting vanes.

In trying the preceding experiment with the electric radiometer the potential should not exceed a certain limit, as then the electrostatic attraction between the vanes and the glass of the bulb may be so great as to stop the rotation.

A most curious feature of alternate currents of high frequencies and potentials is that they enable us to perform many experiments by the use of one wire only. In many respects this feature is of great interest.

In a type of alternate current motor invented by me some years ago I produced rotation by inducing, by means of a single alternating current passed through a motor circuit, in the mass or other circuits of the motor, secondary currents, which, jointly with the primary or inducing current, created a moving field of force. A simple but crude form of such a motor is obtained by winding upon an iron core a primary, and close to it a secondary coil, joining the ends of the latter and placing a freely movable metal disc within the influence of the field produced by both. The iron core is employed for obvious reasons, but it is not essential to the operation. To improve the motor, the iron core is made to encircle the armature. Again to improve, the secondary coil is made to overlap partly the primary, so that it cannot free itself from a strong inductive action of the latter, repel its lines as it may. Once more to improve, the proper difference of phase is obtained between the primary and secondary currents by a condenser, self-induction, resistance or equivalent windings.

I had discovered, however, that rotation is produced by means of a single coil and core; my explanation of the phenomenon, and leading thought in trying the experiment, being that there must be a true time lag in the magnetization of the core. I remember the pleasure I had when, in the writings of Professor Ayrton, which came later to my hand, I found the idea of the time lag advocated. Whether there is a true time lag, or whether the retardation is due to eddy currents circulating in minute paths, must remain an open question, but the fact is that a coil wound upon an iron core and traversed by an alternating

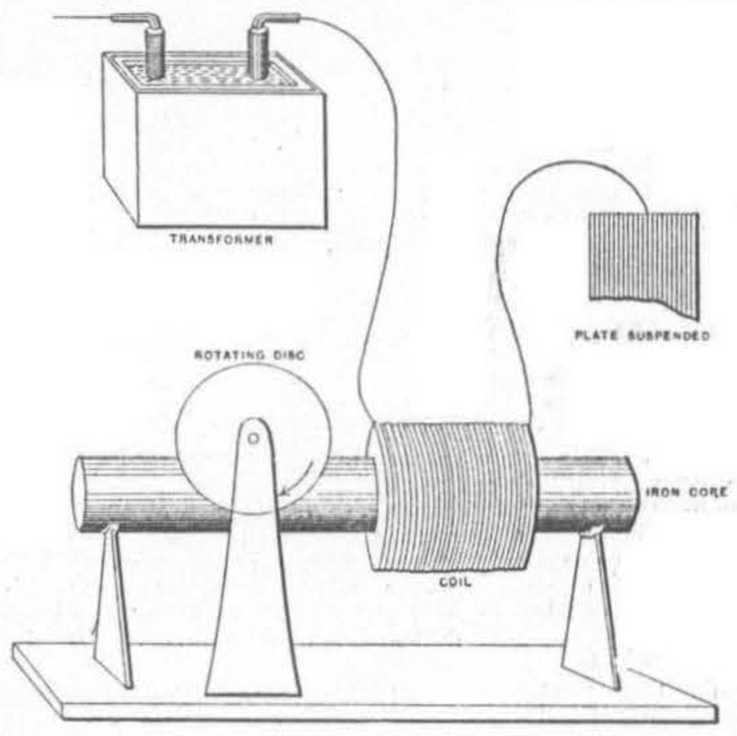

FIG. 17.—SINGLE WIRE AND "NO-WIRE" MOTOR.

current creates a moving field of force, capable of setting an armature in rotation. It is of some interest, in conjunction with the historical Arago experiment, to mention that in lag or phase motors I have produced rotation in the opposite direction to the moving field, which means that in that experiment the magnet may not rotate, or may even rotate in the opposite direction to the moving disc. Here, then, is a motor (diagrammatically illustrated in Fig. 17), comprising a coil and iron core, and a freely movable copper disc in proximity to the latter.

To demonstrate a novel and interesting feature, I have, for a reason which I will explain, selected this type of motor. When the ends of the coil are connected to the terminals of an alternator the disc is set in rotation. But it is not this experiment, now well known, which I desire to perform. What I wish to show you is that this motor rotates with *one single* connection between it and the generator; that is to say, one terminal of the motor is connected to one terminal of the generator—in this case the secondary of a high-tension induction coil—the other terminals of motor and generator being insulated in space. To produce rotation it is generally (but not absolutely) necessary to connect the free end of the motor coil to an insulated body of some size. The experimenter's body is more than sufficient. If he touches the free terminal with an object held in the hand, a current passes through the coil and the copper disc is set in rotation. If an exhausted tube is put in series with the coil, the tube lights brilliantly, showing the passage of a strong current. Instead of the experimenter's body, a small metal sheet suspended on a cord may be used with the same result. In this case the plate acts as a condenser in series with the coil. It counteracts the self-induction of the latter and allows a strong current to pass. In such a combination, the greater the self-induction of the coil the smaller need be the plate, and this means that a lower frequency, or eventually a lower potential, is required to operate the motor. A single coil wound upon a core has a high self-induction; for this reason principally, this type of motor was chosen to perform the experiment. Were a secondary closed coil wound upon the core, it would tend to diminish the self-induction, and then it would be necessary to employ a much higher frequency and potential. Neither would be advisable, for a higher potential would endanger the insulation of the small primary coil, and a higher frequency would result in a materially diminished torque.

It should be remarked that when such a motor with a closed secondary is used, it is not at all easy to obtain rotation with excessive frequencies, as the secondary cuts off almost completely the lines of the primary—and this, of course, the more, the higher the frequency—and allows the passage of but a minute current. In such a case, unless the secondary is closed through a condenser, it is almost essential, in order to produce rotation, to make the primary and secondary coils overlap each other more or less.

But there is an additional feature of interest about this motor, namely, it is, not necessary to have even a single connection between the motor and generator, except, perhaps, through the ground; for not only is an insulated plate capable of giving off energy into space, but it is likewise capable of deriving it from an alternating electrostatic field, though in the latter case the available energy is much smaller. In this instance one of the motor terminals is connected to the insulated plate or body located within the alternating electrostatic field, and the other terminal preferably to the ground.

It is quite possible, however, that such "no-wire" motors, as they might be called, could be operated by conduction through the rarefied air at considerable distances. Alternate currents, especially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. The upper strata of the air are rarefied. To reach a number of miles out into space requires the overcoming of difficulties of a merely mechanical nature. There is no doubt that with the enormous potentials obtainable by the use of high frequencies and oil insulation luminous discharges might be passed through many miles of rarefied air, and that, by thus directing the energy of many hundreds or thousands of horse-power, motors or lamps might be operated at considerable distances from stationary sources. But such schemes are mentioned merely as possibilities. We shall have no need to transmit power in this way. We shall have no need to *transmit* power at all. Ere many generations pass, our machinery will be driven by a power obtainable at any point of the universe. This idea is not novel. Men have been led to it long ago by instinct or reason. It has been expressed in many ways, and in many places, in the history of old and new. We find it in the delightful myth of Antheus, who derives power from the earth; we find it among the subtile speculations of one of your splendid mathematicians, and in many hints and statements of thinkers of the present time. Throughout space there is energy. Is this energy static or kinetic? If static our hopes are in vain; if kinetic—and this we know it is, for certain—then it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature. Of all, living or dead, Crookes came nearest to doing it. His radiometer will turn in the light of day and in the darkness of the night; it will turn everywhere where there is heat, and heat is everywhere. But, unfortunately, this beautiful little machine, while it goes down to posterity as the most interesting, must likewise be put on record as the most inefficient machine ever invented!

The preceding experiment is only one of many equally interesting experiments which may be performed by the use of only one wire with alternate currents of high potential and frequency. We may connect an insulated line to a source of such currents, we may pass an inappreciable current over the line, and on any point of the same we are able to obtain a heavy current, capable of fusing a thick copper wire. Or we may, by the help of some artifice, decompose a solution in any electrolytic cell by connecting only one pole of the cell to the line or source of energy. Or we may, by attaching to the line, or only bringing into its vicinity, light up an incandescent lamp, an exhausted tube, or a phosphorescent bulb.

However impracticable this plan of working may appear in many cases, it certainly seems practicable, and even recommendable, in the production of light. A perfected lamp would require but little energy, and if wires were used at all we ought to be able to supply that energy without a return wire.

It is now a fact that a body may be rendered incandescent or phosphorescent by bringing it either in single contact or merely in the vicinity of a source of electric impulses of the proper character, and that in this manner a quantity of light sufficient to afford a practical illuminant may be produced. It is, therefore, to say the least, worth while to attempt to determine the best conditions and to invent the best appliances for attaining this object.

Some experiences have already been gained in this direction, and I will dwell on them briefly, in the hope that they might prove useful.

The heating of a conducting body inclosed in a bulb, and connected to a source of rapidly alternating electric impulses, is dependent on so many things of a different nature, that it would be difficult to give a generally applicable rule under which the maximum heating occurs. As regards the size of the vessel, I have lately found that at ordinary or only slightly differing atmospheric pressures, when air is a good insulator, and hence practically the same amount of energy by a certain potential and frequency is given off from the body, whether the bulb be small or large, the body is brought to a higher temperature if inclosed in a small bulb, because of the better confinement of heat in this case.

At lower pressures, when air becomes more or less conducting, or if the air be sufficiently warmed as to become conducting, the body is rendered more intensely incandescent in a large bulb, obviously because, under otherwise equal conditions of test, more energy may be given off from the body when the bulb is large.

At very high degrees of exhaustion, when the matter in the bulb becomes "radiant," a large bulb has still an advantage, but a comparatively slight one, over the small bulb.

Finally, at excessively high degrees of exhaustion, which cannot be reached except by the employment of special means, there seems to be, beyond a certain and rather small size of vessel, no perceptible difference in the heating.

These observations were the result of a number of experiments, of which one, showing the effect of the size of the bulb at a high degree of exhaustion, may be described and shown here, as it presents a feature of interest. Three spherical bulbs of 2 inches, 3 inches and 4 inches diameter were taken, and in the centre of each was mounted an equal length of an ordinary incandescent lamp filament of uniform thickness. In each bulb the piece of filament was fastened to the leading-in wire of platinum, contained in a glass stem sealed in the bulb; care being taken, of course, to make everything as nearly alike as possible. On each glass stem in the inside of the bulb was slipped a highly polished tube made of aluminium sheet, which fitted the stem and was held on it by spring pressure. The function of this aluminium tube will be explained subsequently. In each bulb an equal length of filament protruded above the metal tube. It is sufficient to say now that under these conditions equal lengths of filament of the same thick-

ness—in other words, bodies of equal bulk—were brought to incandescence. The three bulbs were sealed to a glass tube, which was connected to a Sprengel pump. When a high vacuum had been reached, the glass tube carrying the bulbs was sealed off. A current was then turned on successively on each bulb, and it was found that the filaments came to about the same brightness, and, if anything, the smallest bulb, which was placed midway between the two larger ones, may have been slightly brighter. This result was expected, for when either of the bulbs was connected to the coil the luminosity spread through the other two, hence the three bulbs constituted really one vessel. When all the three bulbs were connected in multiple arc to the coil, in the largest of them the filament glowed brightest, in the next smaller it was a little less bright, and in the smallest it only came to redness. The bulbs were then sealed off and separately tried. The brightness of the filaments was now such as would have been expected on the supposition that the energy given off was proportionate to the surface of the bulb, this surface in each case representing one of the coatings of a condenser. Accordingly, there was less difference between the largest and the middle sized than between the latter and the smallest bulb.

An interesting observation was made in this experiment. The three bulbs were suspended from a straight bare wire connected to a terminal of the coil, the largest bulb being placed at the end of the wire, at some distance from it the smallest bulb, and an equal distance from the latter the middle-sized one. The carbons glowed then in both the larger bulbs about as expected, but the smallest did not get its share by far. This observation led me to exchange the position of the bulbs, and I then observed that whichever of the bulbs was in the middle it was by far less bright than it was in any other position. This mystifying result was, of course, found to be due to the electrostatic action between the bulbs. When they were placed at a considerable distance, or when they were attached to the corners of an equilateral triangle of copper wire, they glowed about in the order determined by their surfaces.

As to the shape of the vessel, it is also of some importance, especially at high degrees of exhaustion. Of all the possible constructions, it seems that a spherical globe with the refractory body mounted in its centre is the best to employ. In experience it has been demonstrated that in such a globe a refractory body of a given bulk is more easily brought to incandescence than when otherwise shaped bulbs are used. There is also an advantage in giving to the incandescent body the shape of a sphere, for self-evident reasons. In any case the body should be mounted in the centre, where the atoms rebounding from the glass collide. This object is best attained in the spherical bulb; but it is also attained in a cylindrical vessel with one or two straight filaments coinciding with its axis, and possibly also in parabolical or spherical bulbs with the refractory body or bodies placed in the focus or foci of the same; though the latter is not probable, as the electrified atoms should in all cases rebound normally from the surface they strike, unless the speed were excessive, in which case they *would* probably follow the general law of reflection. No matter what shape the vessel may have, if the exhaustion be low, a filament mounted in the globe is brought to the same degree of incandescence in all parts; but if the exhaustion be high and the bulb be spherical or pear-shaped, as usual, focal points form and the filament is heated to a higher degree at or near such points.

To illustrate the effect, I have here two small bulbs which are alike, only one is exhausted to a low and the other to a very high degree. When connected to the coil, the filament in the former glows uniformly throughout all its length; whereas in the latter, that portion of the filament which is in the centre of the bulb glows far more intensely than the rest. A curious point is that the phenomenon occurs even if two filaments are mounted in a bulb, each being connected to one terminal of the coil, and, what is still more curious, if they be very near together, provided the vacuum be very high. I noted in experiments with such bulbs that the filaments would give way usually at a certain point, and in the first trials I attributed it to a defect in the carbon. But when the phenomenon occurred many times in succession I recognized its real cause.

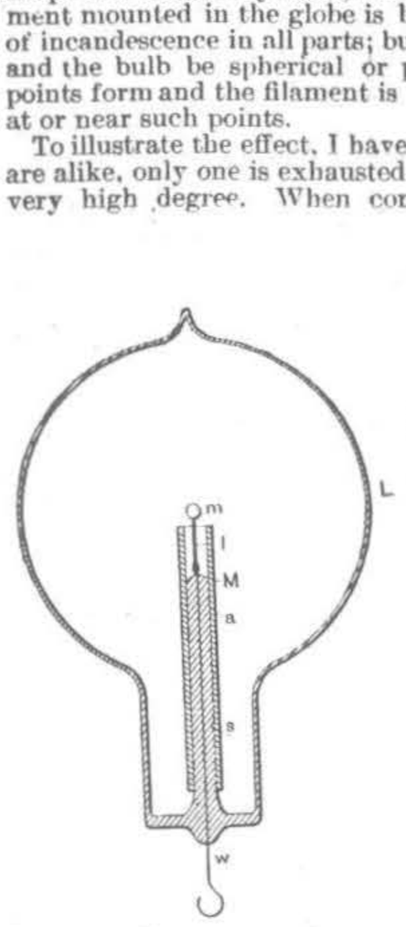

Fig. 18.—Bulb with Mica Tube and Aluminium Screen.

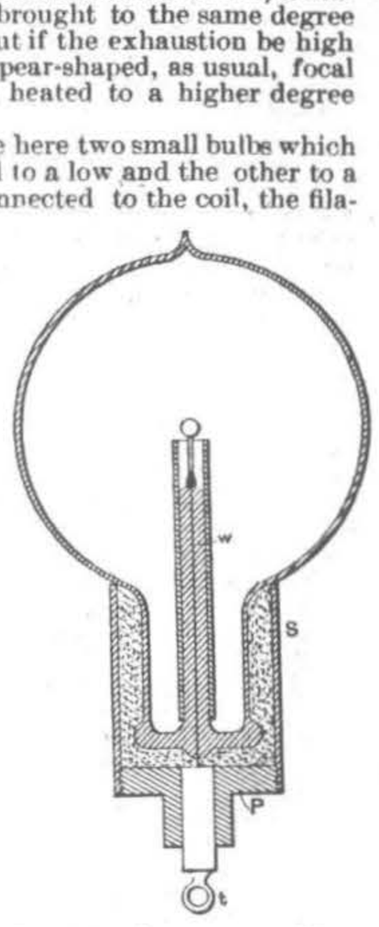

Fig. 19.—Improved Bulb with Socket and Screen.

In order to bring a refractory body inclosed in a bulb to incandescence, it is desirable, on account of economy, that all the energy supplied to the bulb from the source should reach without loss the body to be heated; from there, and from nowhere else, it should be radiated. It is, of course, out of the question to reach this theoretical result, but it is possible by a proper construction of the illuminating device to approximate it more or less.

For many reasons, the refractory body is placed in the centre of the bulb, and it is usually supported on a glass stem containing the leading-in wire. As the potential of this wire is alternated, the rarefied gas surrounding the stem is acted upon inductively, and the glass stem is violently bombarded and heated. In this manner by far the greater portion of the energy supplied to the bulb—especially when exceedingly high frequencies are used—may be lost for the purpose contemplated. To obviate this loss, or at least to reduce it to a minimum, I usually screen the rarefied gas surrounding the stem from the inductive action of the leading-in wire by providing the stem with a tube or coating of conducting material. It seems beyond doubt that the best among metals to employ for this purpose is aluminium, on account of its many remarkable properties. Its only fault is that it is easily fusible, and, therefore, its distance from the incandescing body should be properly estimated. Usually, a thin tube, of a diameter somewhat smaller than that of the glass stem, is made of the finest aluminium sheet, and slipped on the stem. The tube is conveniently prepared by wrapping around a rod fastened in a lathe a piece of aluminium sheet of the proper size, grasping the sheet firmly with clean chamois leather or blotting paper, and spinning the rod very fast. The sheet is wound tightly around the rod, and a highly polished tube of one or three layers of the

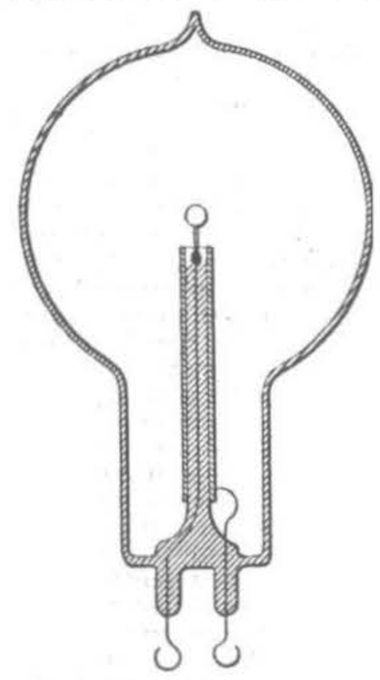

Fig. 20.—Bulb for Experiments with Conducting Tube.

sheet is obtained. When slipped on the stem, the pressure is generally sufficient to prevent it from slipping off, but, for safety, the lower edge of the sheet may be turned inside. The upper inside corner of the sheet—that is, the one which is nearest to the refractory incandescent body—should be cut out diagonally, as it often happens that, in consequence of the intense heat, this corner turns toward the inside and comes very near to, or in contact with, the wire, or filament, supporting the refractory body. The greater part of the energy supplied to the bulb is then used up in heating the metal tube, and the bulb is rendered useless for the purpose. The aluminium sheet should project above the glass stem more or less—one inch or so—or else, if the glass be too close to the incandescing body, it may be strongly heated and become more or less conducting, whereupon it may be ruptured, or may, by its conductivity, establish a good electrical connection between the metal tube and the leading-in wire, in which case, again, most of the energy will be lost in heating the former. Perhaps the best way is to make the top of the glass tube, for about an inch, of a much smaller diameter. To still further reduce the danger arising from the heating of the glass stem, and also with the view of preventing an electrical connection between the metal tube and the electrode, I preferably wrap the stem with several layers of thin mica, which extends at least as far as the metal tube. In some bulbs I have also used an outside insulating cover.

The preceding remarks are only made to aid the experimenter in the first trials, for the difficulties which he encounters he may soon find means to overcome in his own way.

To illustrate the effect of the screen, and the advantage of using it, I have here two bulbs of the same size, with their stems, leading-in wires and incandescent lamp filaments tied to the latter, as nearly alike as possible. The stem of one bulb is provided with an aluminium tube, the stem of the other has none. Originally the two bulbs were joined by a tube which was connected to a Sprengel pump. When a high vacuum had been reached, first the connecting tube, and then the bulbs, were sealed off; they are therefore of the same degree of exhaustion. When they are separately connected to the coil giving a certain potential, the carbon filament in the bulb provided with the aluminium screen is rendered highly incandescent, while the filament in the other bulb may, with the same potential, not even come to redness, although in reality the latter bulb takes generally more energy than the former. When they are both connected together to the terminal, the difference is even more apparent, showing the importance of the screening. The metal tube placed on the stem containing the leading-in wire performs really two distinct functions: First; it acts more or less as an electrostatic screen, thus economizing the energy supplied to the bulb; and, second, to whatever extent it may fail to act electrostatically, it acts mechanically, preventing the bombardment, and consequently intense heating and possible deterioration of the slender support of the refractory incandescent body, or of the glass stem containing the leading-in wire. I say *slender* support, for it is evident that in order to confine the heat more completely to the incandescing body its support should be very thin, so as to carry away the smallest possible amount of heat by conduction. Of all the supports used I have found an ordinary incandescent lamp filament to be the best, principally because among conductors it can withstand the highest degrees of heat.

The effectiveness of the metal tube as an electrostatic screen depends largely on the degree of exhaustion.

At excessively high degrees of exhaustion—which are reached by using great care and special means in connection with the Sprengel pump—when the matter in the globe is in the ultra-radiant state, it acts most perfectly. The shadow of the upper edge of the tube is then sharply defined upon the bulb.

At a somewhat lower degree of exhaustion, which is about the ordinary "non-striking" vacuum, and generally as long as the matter moves predominantly in straight lines, the screen still does well. In elucidation of the preceding remark it is necessary to state that what is a "non-striking" vacuum for a coil operated, as ordinarily, by impulses, or currents, of low frequency, is not, by far, so when the coil is operated by currents of very high frequency. In such case the discharge may pass with great freedom through the rarefied gas through which a low-frequency discharge may not pass, even though the potential be much higher. At ordinary atmospheric pressures just the reverse rule holds good: the higher the frequency, the less the spark discharge is able to jump between the terminals, especially if they are knobs or spheres of some size.

Finally, at very low degrees of exhaustion, when the gas is well conducting, the metal tube not only does not act as an electrostatic screen, but even is a drawback, aiding to a considerable extent the dissipation of the energy laterally from the leading-in wire. This, of course, is to be expected. In this case, namely, the metal tube is in good electrical connection with the leading-in wire, and most of the bombardment is directed upon the tube. As long as the electrical connection is not good, the conducting tube is always of some advantage, for although it may not greatly economize energy, still it protects the support of the refractory button, and is a means for concentrating more energy upon the same.

To whatever extent the aluminium tube performs the function of a screen, its usefulness is therefore limited to very high degrees of exhaustion when it is insulated from the electrode—that is, when the gas as a whole is non-conducting, and the molecules, or atoms, act as independent carriers of electric charges.

In addition to acting as a more or less effective screen, in the true meaning of the word, the conducting tube or coating may also act, by reason of its conductivity, as a sort of equalizer or dampener of the bombardment against the stem. To be explicit, I assume the action as follows: Suppose a rhythmical bombardment to occur against the conducting tube by reason of its imperfect action as a screen, it certainly must happen that some molecules, or atoms, strike the tube sooner than others. Those which come first in contact with it give up their superfluous charge, and the tube is electrified, the electrification instantly spreading over its surface. But this must diminish the energy lost in the bombardment for two reasons: first, the charge given up by the atoms spreads over a great area, and hence the electric density at any point is small, and the atoms are repelled with less energy than they would be if they would strike against a good insulator; secondly, as the tube is electrified by the atoms which first come in contact with it, the progress of the following atoms against the tube is more or less checked by the repulsion which the electrified tube must exert upon the similarly electrified atoms. This repulsion may perhaps be sufficient to prevent a large portion of the atoms from striking the tube, but at any rate it must diminish the energy of their impact. It is clear that when the exhaustion is very low, and the rarefied gas well conducting, neither of the above effects can occur, and, on the other hand, the fewer the atoms, with the greater freedom they move; in other words, the higher the degree of exhaustion, up to a limit, the more telling will be both the effects.

What I have just said may afford an explanation of the phenomenon observed by Prof. Crookes, namely, that a discharge through a bulb is established with much greater facility when an insulator than when a conductor is present in the same. In my opinion, the conductor acts as a dampener of the motion of the atoms in the two ways pointed out; hence, to cause a visible discharge to pass through the bulb, a much higher potential is needed if a conductor, especially of much surface, be present.

For the sake of clearness of some of the remarks before made, I must now refer to Figs. 18, 19 and 20, which illustrate various arrangements with a type of bulb most generally used.

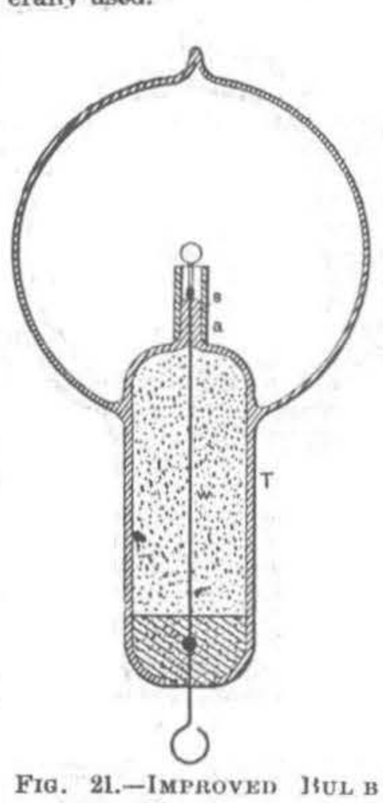

Fig. 21.—Improved Bulb with Non-Conducting Button.

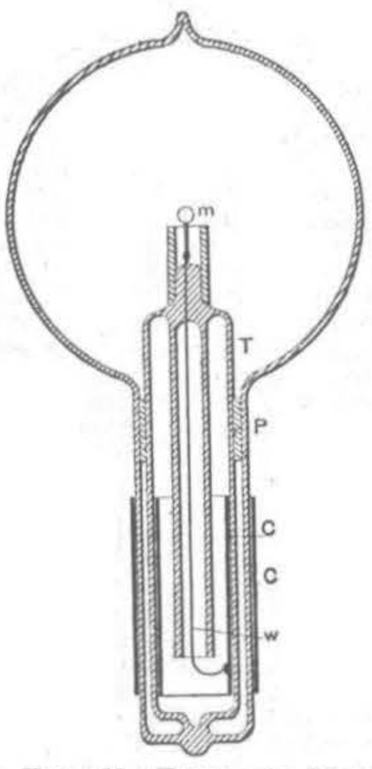

Fig. 22.—Type of Bulb without Leading-in Wire.

Fig. 18 is a section through a spherical bulb L, with the glass stem s, containing the leading-in wire w, which has a lamp filament l fastened to it, serving to support the refractory button m in the centre. M is a sheet of thin mica wound in several layers around the stem s, and a is the aluminium tube.

Fig. 19 illustrates such a bulb in a somewhat more advanced stage of perfection. A metallic tube S is fastened by means of some cement to the neck of the tube. In the tube is screwed a plug P, of insulating material, in the centre of which is fastened a metallic terminal t, for the connection to the leading-in wire w. This terminal must be well insulated from the metal tube S, therefore, if the cement used is conducting—and most generally it is sufficiently so—the space between the plug P and the neck of the bulb should be filled with some good insulating material, as mica powder.

Fig. 20 shows a bulb made for experimental purposes. In this bulb the aluminium tube is provided with an external connection, which serves to investigate the effect of the tube under various conditions. It is referred to chiefly to suggest a line of experiment followed.

Since the bombardment against the stem containing the leading-in wire is due to the inductive action of the latter upon the rarefied gas, it is of advantage to reduce this action as far as practicable by employing a very thin wire, surrounded by a very thick insulation of glass or other material, and by making the wire passing through the rarefied gas as short as practicable. To combine these features I employ a large tube T (Fig. 21), which protrudes into the bulb to some distance, and carries on the top a very short

glass stem *s*, into which is sealed the leading-in wire *w*, and I protect the top of the glass stem against the heat by a small aluminium tube *a* and a layer of mica underneath the same, as usual. The wire *w*, passing through the large tube to the outside of the bulb, should be well insulated—with a glass tube, for instance—and the space between ought to be filled out with some excellent insulator. Among many insulating powders I have tried, I have found that mica powder is the best to employ. If this precaution is not taken, the tube *T*, protruding into the bulb, will surely be cracked in consequence of the heating by the brushes which are apt to form in the upper part of the tube, near the exhausted globe, especially if the vacuum be excellent, and therefore the potential necessary to operate the lamp very high.

Fig. 22 illustrates a similar arrangement, with a large tube *T* protruding into the part of the bulb containing the refractory button *m*. In this case the wire leading from the outside into the bulb is omitted, the energy required being supplied through condenser coatings *C C*. The insulating packing *P* should in this construction be tightly fitting to the glass, and rather wide, or otherwise the discharge might avoid passing through the wire *w*, which connects the inside condenser coating to the incandescent button *m*.

The molecular bombardment against the glass stem in the bulb is a source of great trouble. As illustration I will cite a phenomenon only too frequently and unwillingly observed. A bulb, preferably a large one, may be taken, and a good conducting body, such as a piece of carbon, may be mounted in it upon a platinum wire sealed in the glass stem. The bulb may be exhausted to a fairly high degree, nearly to the point when phosphorescence begins to appear. When the bulb is connected with the coil, the piece of carbon, if small, may become highly incandescent at first, but its brightness immediately diminishes, and then the discharge may break through the glass somewhere in the middle of the stem, in the form of bright sparks, in spite of the fact that the platinum wire is in good electrical connection with the rarefied gas through the piece of carbon or metal at the top. The first sparks are singularly bright, recalling those drawn from a clear surface of mercury. But, as they heat the glass rapidly, they, of course, lose their brightness, and cease when the glass at the ruptured place becomes incandescent, or generally sufficiently hot to conduct. When observed for the first time the phenomenon must appear very curious, and shows in a striking manner how radically different alternate currents, or impulses, of high frequency behave, as compared with steady currents, or currents of low frequency. With such currents—namely the latter—the phenomenon would of course not occur. When frequencies such as are obtained by mechanical means are used, I think that the rupture of the glass is more or less the consequence of the bombardment, which warms it up and impairs its insulating power; but with frequencies obtainable with condensers I have no doubt that the glass may give way without previous heating. Although this appears most singular at first, it is in reality what we might expect to occur. The energy supplied to the wire leading into the bulb is given off partly by direct action through the carbon button, and partly by inductive action through the glass surrounding the wire. The case is thus analogous to that in which a condenser shunted by a conductor of low resistance is connected to a source of alternating currents. As long as the frequencies are low, the conductor gets the most, and the condenser is perfectly safe; but when the frequency becomes excessive, the *rôle* of the conductor may become quite insignificant. In the latter case the difference of potential at the terminals of the condenser may become so great as to rupture the dielectric, notwithstanding the fact that the terminals are joined by a conductor of low resistance.

It is, of course, not necessary, when it is desired to produce the incandescence of a body inclosed in a bulb by means of these currents, that the body should be a conductor, for even a perfect non-conductor may be quite as readily heated. For this purpose it is sufficient to surround a conducting electrode with a non-conducting material, as, for instance, in the bulb described before in Fig. 21, in which a thin incandescent lamp filament is coated with a non-conductor, and supports a button of the same material on the top. At the start the bombardment goes on by inductive action through the non-conductor, until the same is sufficiently heated to become conducting, when the bombardment continues in the ordinary way.

A different arrangement used in some of the bulbs constructed is illustrated in Fig. 23. In this instance a non-conductor *m* is mounted in a piece of common arc light carbon so as to project some small distance above the latter. The carbon piece is connected to the leading-in wire passing through a glass stem, which is wrapped with several layers of mica. An aluminium tube *a* is employed as usual for screening. It is so arranged that it reaches very nearly as high as the carbon and only the non-conductor *m* projects a little above it. The bombardment goes at first against the upper surface of carbon, the lower parts being protected by the aluminium tube. As soon, however, as the non-conductor *m* is heated it is rendered good conducting, and then it becomes the centre of the bombardment, being most exposed to the same.

I have also constructed during these experiments many such single-wire bulbs with or without internal electrode, in which the radiant matter was projected against, or focused upon, the body to be rendered incandescent. Fig. 24 illustrates one of the bulbs used. It consists of a spherical globe *L*, provided with a long neck *n*, on the top, for increasing the action in some cases by the application of an external conducting coating. The globe *L* is blown out on the bottom into a very small bulb *b*, which serves to hold it firmly in a socket *S* of insulating material into which it is cemented. A fine lamp filament *f*, supported on a wire *w*, passes through the centre of the globe *L*. The filament is rendered incandescent in the middle portion, where the bombardment proceeding from the lower inside surface of the globe is most intense. The lower portion of the globe, as far as the socket *S* reaches, is rendered conducting, either by a tinfoil coating or otherwise, and the external electrode is connected to a terminal of the coil.

The arrangement diagramatically indicated in Fig. 24 was found to be an inferior one when it was desired to render incandescent a filament or button supported in the centre of the globe, but it was convenient when the object was to excite phosphorescence.

In many experiments in which bodies of a different kind were mounted in the bulb as, for instance, indicated in Fig. 23, some observations of interest were made.

It was found, among other things, that in such cases, no matter where the bombardment began, just as soon as a high temperature was reached there was generally one of the bodies which seemed to take most of the bombardment upon itself, the other, or others, being thereby relieved. This quality appeared to depend principally on the point of fusion, and on the facility with which the body was "evaporated," or, generally speaking, disintegrated—meaning by the latter term not only the throwing off of atoms, but likewise of larger lumps. The observation made was in accordance with generally accepted notions. In a highly exhausted bulb electricity is carried off from the electrode by independent carriers, which are partly the atoms, or molecules, of the residual atmosphere, and partly the atoms, molecules, or lumps thrown off from the electrode. If the electrode is composed of bodies of different character, and if one of these is more easily disintegrated than the others, most of the electricity supplied is carried off from that body, which is then brought to a higher temperature than the others, and this the more, as upon an increase of the temperature the body is still more easily disintegrated.

It seems to me quite probable that a similar process takes place in the bulb even with a homogeneous electrode, and I think it to be the principal cause of the disintegration. There is bound to be some irregularity, even if the surface is highly polished, which, of course, is impossible with most of the refractory bodies employed as electrodes. Assume that a point of the electrode gets hotter, instantly most of the discharge passes through that point, and a minute patch is probably fused and evaporated. It is now possible that in consequence of the violent disintegration the spot attacked sinks in temperature, or that a counter force is created, as in an arc; at any rate, the local tearing off meets with the limitations incident to the experiment, whereupon the same process occurs on another place. To the eye the electrode appears uniformly brilliant, but there are upon it points constantly shifting and wandering around, of a temperature far above the mean, and this materially hastens the process of deterioration. That some such thing occurs, at least when the electrode is at a lower temperature, sufficient experimental evidence can be obtained in the following manner: Exhaust a bulb to a very high degree, so that with a fairly high potential the discharge cannot pass—that is, not a *luminous* one, for a weak invisible discharge occurs always, in all probability. Now raise slowly and carefully the potential, leaving the primary current on no more than for an instant. At a certain point, two, three, or half a dozen phosphorescent spots will appear on the globe. These places of the glass are evidently more violently bombarded than others, this being due to the unevenly distributed electric density, necessitated, of course, by sharp projections, or, generally speaking, irregularities of the electrode. But the luminous patches are constantly changing in position, which is especially well observable if one manages to produce very few, and this indicates that the configuration of the electrode is rapidly changing.

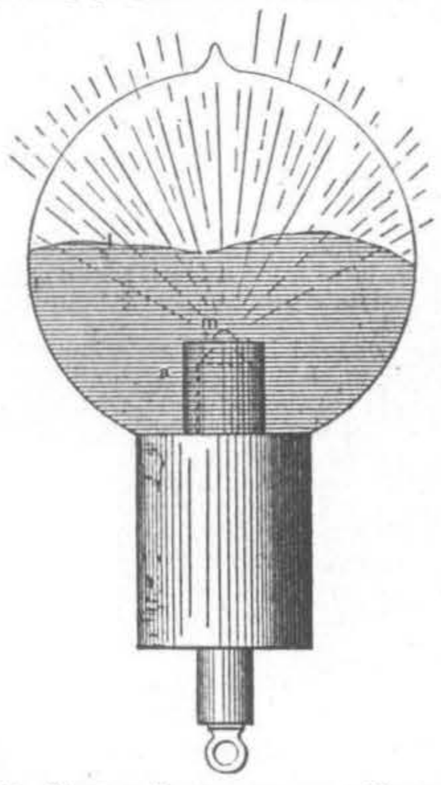

FIG. 23.—EFFECT PRODUCED BY A RUBY DROP.

From experiences of this kind I am led to infer that, in order to be most durable, the refractory button in the bulb should be in the form of a sphere with a highly polished surface. Such a small sphere could be manufactured from a diamond or some other crystal, but a better way would be to fuse, by the employment of extreme degrees of temperature, some oxide—as, for instance, zirconia—into a small drop, and then keep it in the bulb at a temperature somewhat below its point of fusion.

Interesting and useful results can no doubt be reached in the direction of extreme degrees of heat. How can such high temperatures be arrived at? How are the highest degrees of heat reached in nature? By the impact of stars, by high speeds and collisions. In a collision any rate of heat generation may be attained. In a chemical process we are limited. When oxygen and hydrogen combine, they fall, metaphorically speaking, from a definite height. We cannot go very far with a blast, nor by confining heat in a furnace, but in an exhausted bulb we can concentrate any amount of energy upon a minute button. Leaving practicability out of consideration, this, then, would be the means which, in my opinion, would enable us to reach the highest temperature. But a great difficulty when proceeding in this way is encountered, namely, in most cases the body is carried off before it can fuse and form a drop. This difficulty exists principally with an oxide such as zirconia, because it cannot be compressed in so hard a cake that it would not be carried off quickly. I endeavored repeatedly to fuse zirconia, placing it in a cup or arc light carbon as indicated in Fig. 23. It glowed with a most intense light, and the stream of the particles projected out of the carbon cup was of a vivid white; but whether it was compressed in a cake or made into a paste with carbon, it was carried off before it could be fused. The carbon cup containing the zirconia had to be mounted very low in the neck of a large bulb, as the heating of the glass by the projected particles of the oxide was so rapid that in the first trial the bulb was cracked almost in an instant when the current was turned on. The heating of the glass by the projected particles was found to be always greater when the carbon cup contained a body which was rapidly carried off—I presume because in such cases, with the same potential, higher speeds were reached, and also because, per unit of time, more matter was projected—that is, more particles would strike the glass.

The before-mentioned difficulty did not exist, however, when the body mounted in the carbon cup offered great resistance to deterioration. For instance, when an oxide was first fused in an oxygen blast and then mounted in the bulb, it melted very readily into a drop.

Generally during the process of fusion magnificent light effects were noted, of which it would be difficult to give an adequate idea. Fig. 23 is intended to illustrate the effect observed with a ruby drop. At first one may see a narrow funnel of white light projected against the top of the globe, where it produces an irregularly outlined phosphorescent patch. When the point of the ruby fuses the phosphorescence becomes very powerful; but as the atoms are projected with much greater speed from the surface of the drop, soon the glass gets hot and "tired," and now only the outer edge of the patch glows. In this manner an intensely phosphorescent, sharply defined line, *l*, corresponding to the outline of the drop, is produced, which spreads slowly over the globe as the drop gets larger. When the mass begins to boil, small bubbles and cavities are formed, which cause dark colored spots to sweep across the globe. The bulb may be turned downward without fear of the drop falling off, as the mass possesses considerable viscosity.

I may mention here another feature of some interest, which I believe to have noted in the course of these experiments, though the observations do not amount to a certitude. It *appeared* that under the molecular impact caused by the rapidly alternating potential the body was fused and maintained in that state at a lower temperature in a highly exhausted bulb than was the case at normal pressure and application of heat in the ordinary way—that is, at least, judging from the quantity of the light emitted. One of the experiments performed may be mentioned here by way of illustration. A small piece of pumice stone was stuck on a platinum wire, and first melted to it in a gas burner. The wire was next placed between two pieces of charcoal and a burner applied so as to produce an intense heat, sufficient to melt down the pumice stone into a small glass-like button. The platinum wire had to be taken of sufficient thickness to prevent its melting in the fire. While in the charcoal fire, or when held in a burner to get a better idea of the degree of heat, the button glowed with great brilliancy. The wire with the button was then mounted in a bulb, and upon exhausting the same to a high degree, the current was turned on slowly so as to prevent the cracking of the button. The button was heated to the point of fusion, and when it melted it did not, apparently, glow with the same brilliancy as before, and this would indicate a lower temperature. Leaving out of consideration the observer's possible, and even probable, error, the question is, can a body under these conditions be brought from a solid to a liquid state with evolution of *less* light?

When the potential of a body is rapidly alternated it is certain that the structure is jarred. When the potential is very high, although the vibrations may be few—say 20,000 per second—the effect upon the structure may be considerable. Suppose, for example, that a ruby is melted into a drop by a steady application of energy. When it forms a drop it will emit visible and invisible waves, which will be in a definite ratio, and to the eye the drop will appear to be of a certain brilliancy. Next, suppose we diminish to any degree we choose the energy steadily supplied, and, instead, supply energy which rises and falls according to a certain law. Now, when the drop is formed, there will be emitted from it three different kinds of vibrations—the ordinary visible, and two kinds of invisible waves: that is, the ordinary dark waves of all lengths, and, in addition, waves of a well defined character. The latter would not exist by a steady supply of the energy; still they help to jar and loosen the structure. If this really be the case, then the ruby drop will emit relatively less visible and more invisible waves than before. Thus it would seem that when a platinum wire, for instance, is fused by currents alternating with extreme rapidity, it emits at the point of fusion less light and more invisible radiation than it does when melted by a steady current, though the total energy used up in the process of fusion is the same in both cases. Or, to cite another example, a lamp filament is not capable of withstanding as long with currents of extreme frequency as it does with steady currents, assuming that it be worked at the same luminous intensity. This means that for rapidly alternating currents the filament should be shorter and thicker. The higher the frequency—that is, the greater the departure from the steady flow—the worse it would be for the filament. But if the truth of this remark were demonstrated, it would be erroneous to conclude that such a refractory button as used in these bulbs would be deteriorated quicker by currents of extremely high frequency than by steady or low frequency currents. From experience I may say that just the opposite holds good: the button withstands the bombardment better with currents of very high frequency. But this is due to the fact that a high frequency discharge passes through a rarefied gas with much greater freedom than a steady or low frequency discharge, and this will say that with the former we can work with a lower potential or with a less violent impact. As long, then, as the gas is of no consequence, a steady or low frequency current is better; but as soon as the action of the gas is desired and important, high frequencies are preferable.

In the course of these experiments a great many trials were made with all kinds of carbon buttons. Electrodes made of ordinary carbon buttons were decidedly more durable when the buttons were obtained by the application of enormous pressure. Electrodes prepared by depositing carbon in well known ways did not show up well; they blackened the globe very quickly. From many experiences I conclude that lamp filaments obtained in this manner can be advantageously used only with low potentials and low frequency currents. Some kinds of carbon withstand so well that, in order to bring them to the point of fusion, it is necessary to employ very small buttons. In this case the observation is rendered very difficult on account of the intense heat produced. Nevertheless there can be no doubt that all kinds of carbon are fused under the molecular bombardment, but the liquid state must be one of great instability. Of all the bodies tried there were two which withstood best—diamond and carborundum. These two showed up about equally, but the latter was preferable, for many reasons. As it is more than likely that this body is not yet generally known, I will venture to call your attention to it.

It has been recently produced by Mr. E. G. Acheson, of Monongahela City, Pa., U. S. A. It is intended to replace ordinary diamond powder for polishing precious stones, etc., and I have been informed that it accomplishes this object quite successfully. I do not know why the name "carborundum" has been given to it, unless there is something in the process of its manufacture which justifies

this selection. Through the kindness of the inventor, I obtained a short while ago some samples which I desired to test in regard to their qualities of phosphorescence and capability of withstanding high degrees of heat.

Carborundum can be obtained in two forms—in the form of "crystals" and of powder. The former appear to the naked eye dark colored, but are very brilliant; the latter is of nearly the same color as ordinary diamond powder, but very much finer. When viewed under a microscope the samples of crystals given to me did not appear to have any definite form, but rather resembled pieces of broken up egg coal of fine quality. The majority were opaque, but there were some which were transparent and colored. The crystals are a kind of carbon containing some impurities; they are extremely hard, and withstand for a long time even an oxygen blast. When the blast is directed against them they at first form a cake of some compactness, probably in consequence of the fusion of impurities they contain. The mass withstands for a very long time the blast without further fusion; but a slow carrying off, or burning, occurs, and, finally, a small quantity of a glass-like residue is left, which, I suppose, is melted alumina. When compressed strongly they conduct very well, but not as well as ordinary carbon. The powder, which is obtained from the crystals in some way, is practically non-conducting. It affords a magnificent polishing material for stones.

The time has been too short to make a satisfactory study of the properties of this product, but enough experience has been gained in a few weeks I have experimented upon it to say that it does possess some remarkable properties in many respects. It withstands excessively high degrees of heat, it is little deteriorated by molecular bombardment, and it does not blacken the globe as ordinary carbon does. The only difficulty which I have found in its use in connection with these experiments was to find some binding material which would resist the heat and the effect of the bombardment as successfully as carborundum itself does.

I have here a number of bulbs which I have provided with buttons of carborundum. To make such a button of carborundum crystals I proceed in the following manner: I take an ordinary lamp filament and dip its point in tar, or some other thick substance or paint which may be readily carbonized. I next pass the point of the filament through the crystals, and then hold it vertically over a hot plate. The tar softens and forms a drop on the point of the filament, the crystals adhering to the surface of the drop. By regulating the distance from the plate the tar is slowly dried out and the button becomes solid. I then once more dip the button in tar and hold it again over a plate until the tar is evaporated, leaving only a hard mass which firmly binds the crystals. When a larger button is required I repeat the process several times, and I generally also cover the filament a certain distance below the button with crystals. The button being mounted in a bulb, when a good vacuum has been reached, first a weak and then a strong discharge is passed through the bulb to carbonize the tar and expel all gases, and later it is brought to a very intense incandescence.

When the powder is used I have found it best to proceed as follows: I make a thick paint of carborundum and tar, and pass a lamp filament through the paint. Taking then most of the paint off by rubbing the filament against a piece of chamois leather, I hold it over a hot plate until the tar evaporates and the coating becomes firm. I repeat this process as many times as it is necessary to obtain a certain thickness of coating. On the point of the coated filament I form a button in the same manner.

There is no doubt that such a button—properly prepared under great pressure—of carborundum, especially of powder of the best quality, will withstand the effect of the bombardment fully as well as anything we know. The difficulty is that the binding material gives way, and the carborundum is slowly thrown off after some time. As it does not seem to blacken the globe in the least, it might be found useful for coating the filaments of ordinary incandescent lamps, and I think that it is even possible to produce thin threads or sticks of carborundum which will replace the ordinary filaments in an incandescent lamp. A carborundum coating seems to be more durable than other coatings, not only because the carborundum can withstand high degrees of heat, but also because it seems to unite with the carbon better than any other material I have tried. A coating of zirconia or any other oxide, for instance, is far more quickly destroyed. I prepared buttons of diamond dust in the same manner as of carborundum, and these came in durability nearest to those prepared of carborundum, but the binding paste gave way much more quickly in the diamond buttons: this, however, I attributed to the size and irregularity of the grains of the diamond.

It was of interest to find whether carborundum possesses the quality of phosphorescence. One is, of course, prepared to encounter two difficulties: first, as regards the rough product, the "crystals," they are good conducting, and it is a fact that conductors do not phosphoresce; second, the powder, being exceedingly fine, would not be apt to exhibit very prominently this quality, since we know that when crystals, even such as diamond or ruby, are finely powdered, they lose the property of phosphorescence to a considerable degree.

The question presents itself here, can a conductor phosphoresce? What is there in such a body as a metal, for instance, that would deprive it of the quality of phosphorescence, unless it is that property which characterizes it at a conductor? for it is a fact that most of the phosphorescent bodies lose that quality when they are sufficiently heated to become more or less conducting. Then, if a metal be in a large measure, or perhaps entirely, deprived of that property, it should be capable of phosphorescence. Therefore it is quite possible that at some extremely high frequency, when behaving practically as a non-conductor, a metal or any other conductor might exhibit the quality of phosphorescence, even though it be entirely incapable of phosphorescing under the impact of a low-frequency discharge. There is, however, another possible way how a conductor might at least *appear* to phosphoresce.

Considerable doubt still exists as to what really is phosphorescence, and as to whether the various phenomena comprised under this head are due to the same causes. Suppose that in an exhausted bulb, under the molecular impact, the surface of a piece of metal or other conductor is rendered strongly luminous, but at the same time it is found that it remains comparatively cool, would not this luminosity be called phosphorescence? Now such a result, theoretically at least, is possible, for it is a mere question of potential or speed. Assume the potential of the electrode, and consequently the speed of the projected atoms, to be sufficiently high, the surface of the metal piece against which the atoms are projected would be rendered highly incandescent, since the process of heat generation would be incomparably faster than that of radiating or conducting away from the surface of the collision. In the eye of the observer a single impact of the atoms would cause an instantaneous flash, but if the impacts were repeated with sufficient rapidity they would produce a continuous impression upon his retina. To him then the surface of the metal would appear continuously incandescent and of constant luminous intensity, while in reality the light would be either intermittent or at least changing periodically in intensity. The metal piece would rise in temperature until equilibrium was attained—that is, until the energy continuously radiated would equal that intermittently supplied. But the supplied energy might under such conditions not be sufficient to bring the body to any more than a very moderate mean temperature, especially if the frequency of the atomic impacts be very low—just enough that the fluctuation of the intensity of the light emitted could not be detected by the eye. The body would now, owing to the manner in which the energy is supplied, emit a strong light, and yet be at a comparatively very low mean temperature. How could the observer call the luminosity thus produced? Even if the analysis of the light would teach him something definite, still he would probably rank it under the phenomena of phosphorescence. It is conceivable that in such a way both conducting and non-conducting bodies may be maintained at a certain luminous intensity, but the energy required would very greatly vary with the nature and properties of the bodies.

These and some foregoing remarks of a speculative nature were made merely to bring out curious features of alternate currents or electric impulses. By their help we may cause a body to emit *more* light, while at a certain mean temperature, than it would emit if brought to that temperature by a steady supply; and, again, we may bring a body to the point of fusion, and cause it to emit *less* light than when fused by the application of energy in ordinary ways. It all depends on how we supply the energy, and what kind of vibrations we set up: in one case the vibrations are more, in the other less, adapted to affect our sense of vision.

Some effects, which I had not observed before, obtained with carborundum in the first trials, I attributed to phosphorescence, but in subsequent experiments it appeared that it was devoid of that quality. The crystals possess a noteworthy feature. In a bulb provided with a single electrode in the shape of a small circular metal disc, for instance, at a certain degree of exhaustion the electrode is covered with a milky film, which is separated by a dark space from the glow filling the bulb. When the metal disc is covered with carborundum crystals, the film is far more intense, and snow-white. This I found later to be merely an effect of the bright surface of the crystals, for when an aluminium electrode was highly polished it exhibited more or less the same phenomenon. I made a number of experiments with the samples of crystals obtained, principally because it would have been of special interest to find that they are capable of phosphorescence, on account of their being conducting. I could not produce phosphorescence distinctly, but I must remark that a decisive opinion cannot be formed until other experimenters have gone over the same ground.

The powder behaved in some experiments as though it contained alumina, but it did not exhibit with sufficient distinctness the red of the latter. Its dead color brightens considerably under the molecular impact, but I am now convinced it does not phosphoresce. Still, the tests with the powder are not conclusive, because powdered carborundum probably does not behave like a phosphorescent sulphide, for example, which could be finely powdered without impairing the phosphorescence, but rather like powdered ruby or diamond, and therefore it would be necessary, in order to make a decisive test, to obtain it in a large lump and polish up the surface.

If the carborundum proves useful in connection with these and similar experiments, its chief value will be found in the production of coatings, thin conductors, buttons, or other electrodes capable of withstanding extremely high degrees of heat.

The production of a small electrode capable of withstanding enormous temperatures I regard as of the greatest importance in the manufacture of light. It would enable us to obtain, by means of currents of very high frequencies, certainly 20 times, if not more, the quantity of light which is obtained in the present incandescent lamp by the same expenditure of energy. This estimate may appear to many exaggerated, but in reality I think it is far from being so. As this statement might be misunderstood I think it necessary to expose clearly the problem with which in this line of work we are confronted, and the manner in which, in my opinion, a solution will be arrived at.

Any one who begins a study of the problem will be apt to think that what is wanted in a lamp with an electrode is a very high degree of incandescence of the electrode. There he will be mistaken. The high incandescence of the button is a necessary evil, but what is really wanted is the high incandescence of the gas surrounding the button. In other words, the problem in such a lamp is to bring a mass of gas to the highest possible incandescence. The higher the incandescence, the quicker the mean vibration, the greater is the economy of the light production. But to maintain a mass of gas at a high degree of incandescence in a glass vessel, it will always be necessary to keep the incandescent mass away from the glass; that is, to confine it as much as possible to the central portion of the globe.

In one of the experiments this evening a brush was produced at the end of a wire. This brush was a flame, a source of heat and light. It did not emit much perceptible heat, nor did it glow with an intense light; but is it the less a flame because it does not scorch my hand? Is it the less a flame because it does not hurt my eye by its brilliancy? The problem is precisely to produce in the bulb such a flame, much smaller in size, but incomparably more powerful. Were there means at hand for producing electric impulses of a sufficiently high frequency, and for transmitting them, the bulb could be done away with, unless it were used to protect the electrode, or to economize the energy by confining the heat. But as such means are not at disposal, it becomes necessary to place the terminal in a bulb and rarefy the air in the same. This is done merely to enable the apparatus to perform the work which it is not capable of performing at ordinary air pressure. In the bulb we are able to intensify the action to any degree—so far that the brush emits a powerful light.

The intensity of the light emitted depends principally on the frequency and potential of the impulses, and on the electric density on the surface of the electrode. It is of the greatest importance to employ the smallest possible button, in order to push the density very far. Under the violent impact of the molecules of the gas surrounding it, the small electrode is of course brought to an extremely high temperature, but around it is a mass of highly incandescent gas, a flame photosphere, many hundred times the volume of the electrode. With a diamond, carborundum or zirconia button the photosphere can be as much as one thousand times the volume of the button. Without much reflecting one would think that in pushing so far the incandescence of the electrode it would be instantly volatilized. But after a careful consideration he would find that, theoretically, it should not occur, and in this fact—which, however, is experimentally demonstrated—lies principally the future value of such a lamp.

At first, when the bombardment begins, most of the work is performed on the surface of the button, but when a highly conducting photosphere is formed the button is comparatively relieved. The higher the incandescence of the photosphere the more it approaches in conductivity to that of the electrode, and the more, therefore, the solid and the gas form one conducting body. The consequence is that the further is forced the incandescence the more work, comparatively, is performed on the gas, and the less on the electrode. The formation of a powerful photosphere is consequently the very means for protecting the electrode. This protection, of course, is a relative one, and it should not be thought that by pushing the incandescence higher the electrode is actually less deteriorated, Still, theoretically, with extreme frequencies, this result must be reached, but probably at a temperature too high for most of the refractory bodies known. Given, then, an electrode which can withstand to a very high limit the effect of the bombardment and outward strain, it would be safe no matter how much it is forced beyond that limit. In an incandescent lamp quite different considerations apply. There the gas is not at all concerned: the whole of the work is performed on the filament; and the life of the lamp diminishes so rapidly with the increase of the degree of incandescence that economical reasons compel us to work it at a low incandescence. But if an incandescent lamp is operated with currents of very high frequency, the action of the gas cannot be neglected, and the rules for the most economical working must be considerably modified.

In order to bring such a lamp with one or two electrodes to a great perfection, it is necessary to employ impulses of very high frequency. The high frequency secures, among others, two chief advantages, which have a most important bearing upon the economy of the light production. First, the deterioration of the electrode is reduced by reason of the fact that we employ a great many small impacts, instead of a few violent ones, which shatter quickly the structure; secondly, the formation of a large photosphere is facilitated.

In order to reduce the deterioration of the electrode to the minimum, it is desirable that the vibration be harmonic, for any suddenness hastens the process of destruction. An electrode lasts much longer when kept at incandescence by currents, or impulses, obtained from a high-frequency alternator, which rise and fall more or less harmonically, than by impulses obtained from a disruptive discharge coil. In the latter case there is no doubt that most of the damage is done by the fundamental sudden discharges.

One of the elements of loss in such a lamp is the bombardment of the globe. As the potential is very high, the molecules are projected with great speed; they strike the glass, and usually excite a strong phosphorescence. The effect produced is very pretty, but for economical reasons it would be perhaps preferable to prevent, or at least reduce to the minimum, the bombardment against the globe, as in such case it is, as a rule, not the object to excite phosphorescence, and as some loss of energy results from the bombardment. This loss in the bulb is principally dependent on the potential of the impulses and on the electric density on the surface of the electrode. In employing very high frequencies the loss of energy by the bombardment is greatly reduced, for, first, the potential needed to perform a given amount of work is much smaller; and, secondly, by producing a highly conducting photosphere around the electrode, the same result is obtained as though the electrode were much larger, which is equivalent to a smaller electric density. But be it by the diminution of the maximum potential or of the density, the gain is effected in the same manner, namely, by avoiding violent shocks, which strain the glass much beyond its limit of elasticity. If the frequency could be brought high enough, the loss due to the imperfect elasticity of the glass would be entirely negligible. The loss due to bombardment of the globe may, however, be reduced by using two electrodes instead of one. In such case each of the electrodes may be connected to one of the terminals; or else, if it is preferable to use only one wire, one electrode may be connected to one terminal and the other to the ground or to an insulated body of some surface, as, for instance, a shade on the lamp. In the latter case, unless some judgment is used, one of the electrodes might glow more intensely than the other.

But on the whole I find it preferable when using such high frequencies to employ only one electrode and one connecting wire. I am convinced that the illuminating device of the near future will not require for its operation more than one lead, and, at any rate, it will have no leading-in wire, since the energy required can be as well transmitted through the glass. In experimental bulbs the leading-in wire is most generally used on account of convenience, as in employing condenser coatings in the manner indicated in Fig. 22, for example, there is some difficulty in fitting the parts, but these difficulties would not exist if a great many bulbs were manufactured; otherwise the energy can be conveyed through the glass as well as through a wire, and with these high frequencies the losses are very small. Such illuminating devices will necessarily involve the use of very high potentials, and this, in the eyes of practical men, might be an objectionable feature. Yet, in reality, high potentials are not objectionable—certainly not in the least as far as the safety of the devices is concerned.

There are two ways of rendering an electric appliance safe. One is to use low potentials, the other is to determine the dimensions of the apparatus so that it is safe no matter how high a potential is used. Of the two the latter seems to me the better way, for then the safety is absolute, unaffected by any possible combination of circumstances which might render even a low-potential appliance dangerous to life and property. But the practical conditions require not only the judicious determination of the dimensions of the apparatus; they likewise necessitate the employment of energy of the proper kind. It is easy, for instance, to construct a transformer capable of giving, when operated from an ordinary alternate current machine of low tension, say 50,000 volts, which might be required to light a highly exhausted phosphorescent tube, so that, in spite of the high

potential, it is perfectly safe, the shock from it producing no inconvenience. Still, such a transformer would be expensive, and in itself inefficient; and, besides, what energy was obtained from it would not be economically used for the production of light. The economy demands the employment of energy in the form of extremely rapid vibrations. The problem of producing light has been likened to that of maintaining a certain high-pitch note by means of a bell. It should be said a *barely audible* note; and even these words would not express it, so wonderful is the sensitiveness of the eye. We may deliver powerful blows at long intervals, waste a good deal of energy, and still not get what we want; or we may keep up the note by delivering frequent gentle taps, and get nearer to the object sought by the expenditure of much less energy. In the production of light, as far as the illuminating device is concerned, there can be only one rule—that is, to use as high frequencies as can be obtained; but the means for the production and conveyance of impulses of such character impose, at present at least, great limitations. Once it is decided to use very high frequencies, the return wire becomes unnecessary, and all the appliances are simplified. By the use of obvious means the same result is obtained as though the return wire were used. It is sufficient for this purpose to bring in contact with the bulb, or merely in the vicinity of the same, an insulated body of some surface. The surface need, of course, be the smaller, the higher the frequency and potential used, and necessarily, also, the higher the economy of the lamp or other device.

This plan of working has been resorted to on several occasions this evening. So, for instance, when the incandescence of a button was produced by grasping the bulb with the hand, the body of the experimenter merely served to intensify the action. The bulb used was similar to that illustrated in Fig. 19, and the coil was excited to a small potential, not sufficient to bring the button to incandescence when the bulb was hanging from the wire; and incidentally, in order to perform the experiment in a more suitable manner, the button was taken so large that a perceptible time had to elapse before, upon grasping the bulb, it could be rendered incandescent. The contact with the bulb was, of course, quite unnecessary. It is easy, by using a rather large bulb with an exceedingly small electrode, to adjust the conditions so that the latter is brought to bright incandescence by the mere approach of the experimenter within a few feet of the bulb, and that the incandescence subsides upon his receding.

In another experiment, when phosphorescence was excited, a similar bulb was used. Here again, originally, the potential was not sufficient to excite phosphorescence until the action was intensified—in this case, however, to present a different feature, by touching the socket with a metallic object held in the hand. The electrode in the bulb was a carbon button so large that it could not be brought to incandescence, and thereby spoil the effect produced by phosphorescence.

Again, in another of the early experiments, a bulb was used as illustrated in Fig. 13. In this instance, by touching the bulb with one or two fingers, one or two shadows of the stem inside were projected against the glass, the touch of the finger producing the same result as the application of an external negative electrode under ordinary circumstances.

In all these experiments the action was intensified by augmenting the capacity at the end of the lead connected to the terminal. As a rule, it is not necessary to resort to

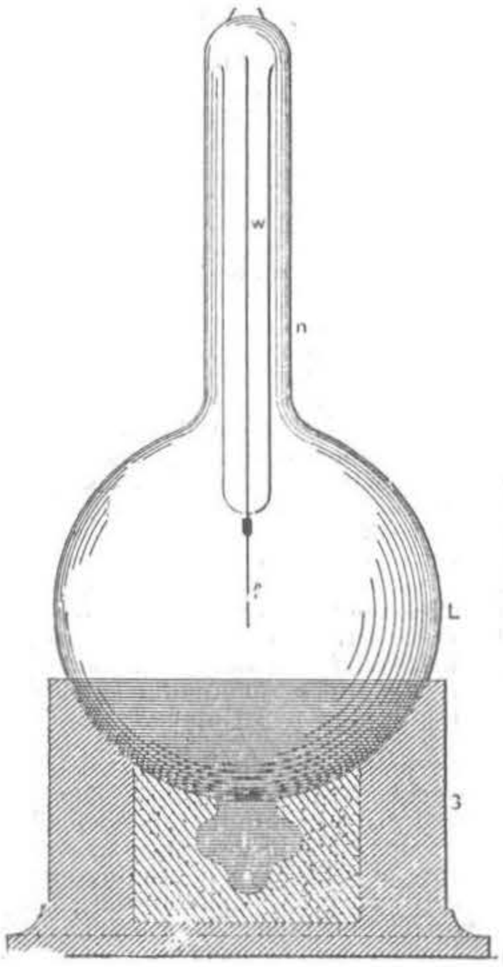

FIG. 24.—BULB WITHOUT LEADING-IN WIRE, SHOWING EFFECT OF PROJECTED MATTER.

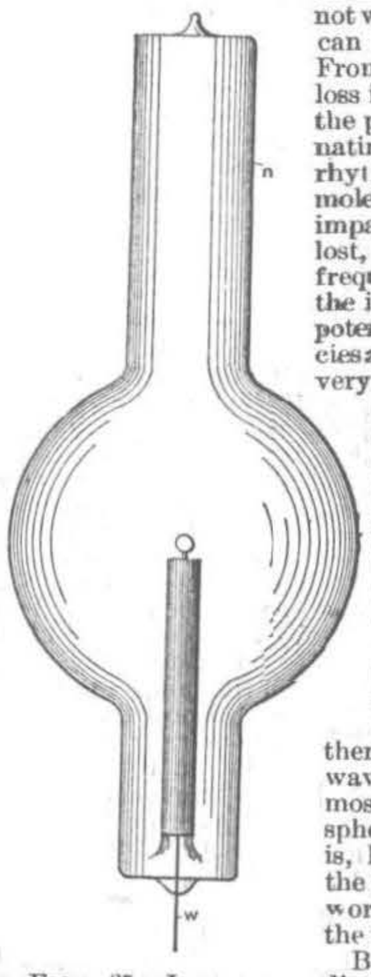

FIG. 25.—IMPROVED EXPERIMENTAL BULB.

such means, and would be quite unnecessary with still higher frequencies; but when it *is* desired, the bulb, or tube, can be easily adapted to the purpose.

In Fig. 24, for example, an experimental bulb L is shown, which is provided with a neck n on the top for the application of an external tinfoil coating, which may be connected to a body of larger surface. Such a lamp as illustrated in Fig. 25 may also be lighted by connecting the tinfoil coating on the neck n to the terminal, and the leading-in wire w to an insulated plate. If the bulb stands in a socket upright, as shown in the cut, a shade of conducting material may be slipped in the neck n, and the action thus magnified.

A more perfected arrangement used in some of these bulbs is illustrated in Fig. 26. In this case the construction of the bulb is as shown and described before, when reference was made to Fig. 19. A zinc sheet Z, with a tubular extension T, is slipped over the metallic socket S. The bulb hangs downward from the terminal t, the zinc sheet Z, performing the double office of intensifier and reflector. The reflector is separated from the terminal t by an extension of the insulating plug P.

A similar disposition with a phosphorescent tube is illustrated in Fig. 27. The tube T is prepared from two short tubes of a different diameter, which are sealed on the ends. On the lower end is placed an outside conducting coating C, which connects to the wire w. The wire has a hook on the upper end for suspension, and passes through the centre of the inside tube, which is filled with some good and tightly packed insulator. On the outside of the upper end of the tube T is another conducting coating C_1, upon which is slipped a metallic reflector Z, which should be separated by a thick insulation from the end of wire w.

The economical use of such a reflector or intensifier would require that all energy supplied to an air condenser should be recoverable, or, in other words, that there should not be any losses, neither in the gaseous medium nor through its action elsewhere. This is far from being so, but, fortunately, the losses may be reduced to anything desired. A few remarks are necessary on this subject, in order to make the experiences gathered in the course of these investigations perfectly clear.

Suppose a small helix with many well insulated turns, as in experiment Fig. 17, has one of its ends connected to one

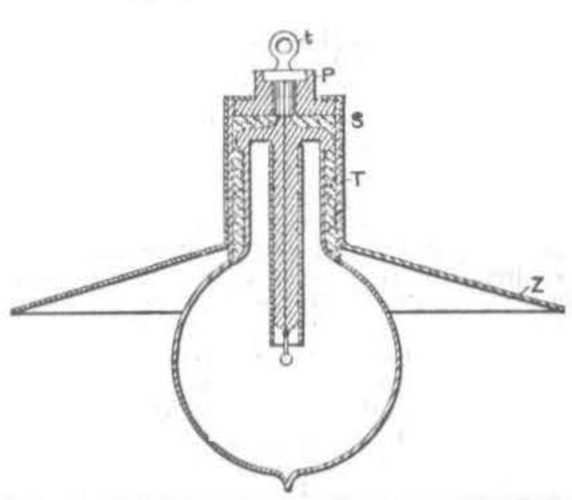

FIG. 26.—IMPROVED BULB WITH INTENSIFYING REFLECTOR.

of the terminals of the induction coil, and the other to a metal plate, or, for the sake of simplicity, a sphere, insulated in space. When the coil is set to work, the potential of the sphere is alternated, and the small helix now behaves as though its free end were connected to the other terminal of the induction coil. If an iron rod be held within the small helix it is quickly brought to a high temperature, indicating the passage of a strong current through the helix. How does the insulated sphere act in this case? It can be a condenser, storing and returning the energy supplied to it, or it can be a mere sink of energy, and the conditions of the experiment determine whether it is more one or the other. The sphere being charged to a high potential, it acts inductively upon the surrounding air, or whatever gaseous medium there might be. The molecules, or atoms, which are near the sphere are of course more attracted, and move through a greater distance than the farther ones. When the nearest molecules strike the sphere they are repelled, and collisions occur at all distances within the inductive action of the sphere. It is now clear that, if the potential be steady, but little loss of energy can be caused in this way, for the molecules which are nearest to the sphere, having had an additional charge imparted to them by contact, are not attracted until they have parted, if not with all, at least with most of the additional charge, which can be accomplished only after a great many collisions. From the fact that with a steady potential there is but little loss in dry air, one must come to such a conclusion. When the potential of the sphere, instead of being steady, is alternating, the conditions are entirely different. In this case a rhythmical bombardment occurs, no matter whether the molecules after coming in contact with the sphere lose the imparted charge or not; what is more, if the charge is not lost, the impacts are only the more violent. Still if the frequency of the impulses be very small, the loss caused by the impacts and collisions would not be serious unless the potential were excessive. But when extremely high frequencies and more or less high potentials are used, the loss may be very great. The total energy lost per unit of time is proportionate to the product of the number of impacts per second, or the frequency and the energy lost in each impact. But the energy of an impact must be proportionate to the square of the electric density of the sphere, since the charge imparted to the molecule is proportionate to that density. I conclude from this that the total energy lost must be proportionate to the product of the frequency and the square of the electric density; but this law needs experimental confirmation. Assuming the preceding considerations to be true, then, by rapidly alternating the potential of a body immersed in an insulating gaseous medium, any amount of energy may be dissipated into space. Most of that energy then, I believe, is not dissipated in the form of long ether waves, propagated to considerable distance, as is thought most generally, but is consumed—in the case of an insulated sphere, for example—in impact and collisional losses—that is, heat vibrations—on the surface and in the vicinity of the sphere. To reduce the dissipation it is necessary to work with a small electric density—the smaller the higher the frequency.

But since, on the assumption before made, the loss is diminished with the square of the density, and since currents of very high frequencies involve considerable waste when transmitted through conductors, it follows that, on the whole, it is better to employ one wire than two. Therefore, if motors, lamps, or devices of any kind are perfected, capable of being advantageously operated by currents of extremely high frequency, economical reasons will make it advisable to use only one wire, especially if the distances are great.

When energy is absorbed in a condenser the same behaves as though its capacity were increased. Absorption always exists more or less, but generally it is small and of no consequence as long as the frequencies are not very great. In using extremely high frequencies, and, necessarily in such case, also high potentials, the absorption—or, what is here meant more particularly by this term, the loss of energy due to the presence of a gaseous medium—is an important factor to be considered, as the energy absorbed in the air condenser may be any fraction of the supplied energy. This would seem to make it very difficult to tell from the measured or computed capacity of an air condenser its actual capacity or vibration period, especially if the condenser is of very small surface and is charged to a very high potential. As many important results are dependent upon the correctness of the estimation of the vibration period, this subject demands the most careful scrutiny of other investigators. To reduce the probable error as much as possible in experiments of the kind alluded to, it is advisable to use spheres or plates of large surface, so as to make the density exceedingly small. Otherwise, when it is practicable, an oil condenser should be used in preference. In oil or other liquid dielectrics there are seemingly no such losses as in gaseous media. It being impossible to exclude entirely the gas in condensers with solid dielectrics, such condensers should be immersed in oil, for economical reasons if nothing else; they can then be strained to the utmost and will remain cool. In Leyden jars the loss due to air is comparatively small, as the tinfoil coatings are large, close together, and the charged surfaces not directly exposed; but when the potentials are very high, the loss may be more or less considerable at, or near, the upper edge of the foil, where the air is principally acted upon. If the jar be immersed in boiled-out oil, it will be capable of performing four times the amount of work which it can for any length of time when used in the ordinary way, and the loss will be inappreciable.

It should not be thought that the loss in heat in an air condenser is necessarily associated with the formation of *visible* streams or brushes. If a small electrode, inclosed in an unexhausted bulb, is connected to one of the terminals of the coil, streams can be seen to issue from the electrode and the air in the bulb is heated; if, instead of a small electrode, a large sphere is inclosed in the bulb, no streams are observed, still the air is heated.

Nor should it be thought that the temperature of an air condenser would give even an approximate idea of the loss in heat incurred, as in such case heat must be given off much more quickly, since there is, in addition to the ordinary radiation, a very active carrying away of heat by independent carriers going on, and since not only the apparatus, but the air at some distance from it is heated in consequence of the collisions which must occur.

Owing to this, in experiments with such a coil, a rise of temperature can be distinctly observed only when the body connected to the coil is very small. But with apparatus on a larger scale, even a body of considerable bulk would be heated, as, for instance, the body of a person; and I think that skilled physicians might make observations of utility in such experiments, which, if the apparatus were judiciously designed, would not present the slightest danger.

A question of some interest, principally to meteorologists, presents itself here. How does the earth behave? The earth is an air condenser, but it is a perfect or a very imperfect one—a mere sink of energy? There can be little doubt that to such small disturbance as might be caused in an experiment the earth behaves as an almost perfect condenser. But it might be different when its charge is set in vibration by some sudden disturbance occurring in the heavens. In such case, as before stated, probably only little of the energy of the vibrations set up would be lost into space in the form of long ether radiations, but most of the energy, I think, would spend itself in molecular impacts and collisions, and pass off into space in the form of short heat, and possibly light, waves. As both the frequency of the vibrations of the charge and the potential are in all probability excessive, the energy converted into heat may be considerable. Since the density must be unevenly distributed, either in consequence of the irregularity of the earth's surface, or on account of the condition of the atmosphere in various places, the effect produced would accordingly vary from place to place. Considerable variations in the temperature and pressure of the atmosphere may in this manner be caused at any point of the surface of the earth. The variations may be gradual or very sud-

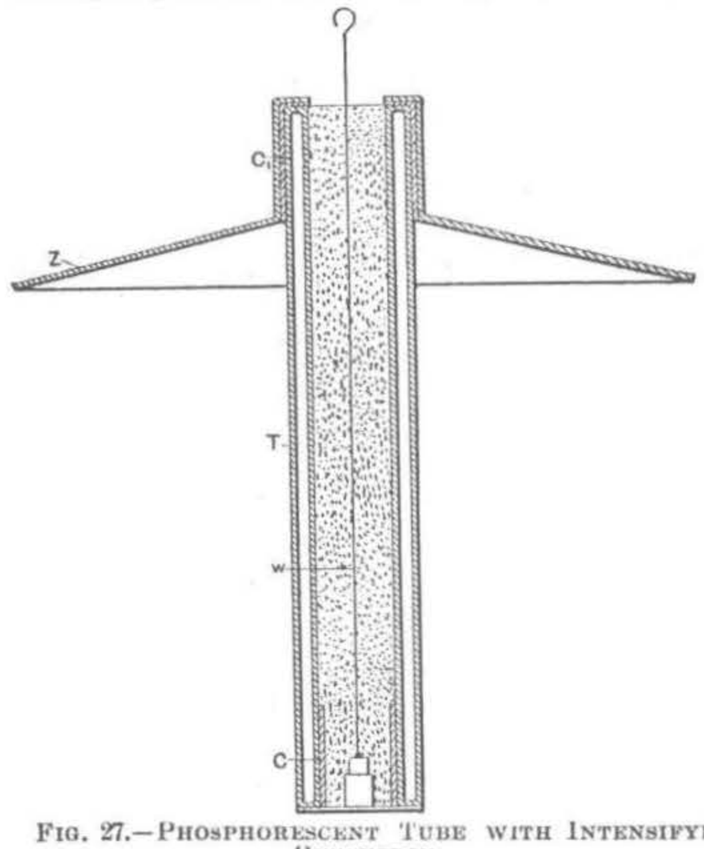

FIG. 27.—PHOSPHORESCENT TUBE WITH INTENSIFYING REFLECTOR.

den, according to the nature of the general disturbance, and may produce rain and storms, or locally modify the weather in any way.

From the remarks before made one may see what an important factor of loss the air in the neighborhood of a charged surface becomes when the electric density is great and the frequency of the impulses excessive. But the action as explained implies that the air is insulating—that is, that it is composed of independent carriers immersed in an insulating medium. This is the case only when the air is at something like ordinary or greater, or at extremely small, pressure. When the air is slightly rarefied and conducting, then true conduction losses occur also. In such case, of course, considerable energy may be dissipated into space even with a steady potential, or with impulses of low frequency, if the density is very great.

When the gas is at very low pressure, an electrode is heated more because higher speeds can be reached. If the gas around the electrode is strongly compressed, the displacements, and consequently the speeds, are very small, and the heating is insignificant. But if in such case the frequency could be sufficiently increased, the electrode would be brought to a high temperature as well as if the gas were at very low pressure; in fact, exhausting the bulb is only necessary because we cannot produce (and possibly not convey) currents of the required frequency.

Returning to the subject of electrode lamps, it is obviously of advantage in such a lamp to confine as much as possible the heat to the electrode by preventing the circula-

tion of the gas in the bulb. If a very small bulb be taken, it would confine the heat better than a large one, but it might not be of sufficient capacity to be operated from the coil, or, if so, the glass might get too hot. A simple way to improve in this direction is to employ a globe of the required size, but to place a small bulb, the diameter of which is properly estimated, over the refractory button contained in the globe. This arrangement is illustrated in Fig. 28.

The globe L has in this case a large neck n, allowing the small bulb b to slip through. Otherwise the construction is the same as shown in Fig. 18, for example. The small bulb is conveniently supported upon the stem s, carrying the refractory button m. It is separated from the aluminium tube a by several layers of mica M, in order to prevent the cracking of the neck by the rapid heating of the aluminium tube upon a sudden turning on of the current. The inside bulb should be as small as possible when it is desired to obtain light only by incandescence of the electrode. If it is desired to produce phosphorescence, the bulb should be larger, else it would be apt to get too hot, and the phosphorescence would cease. In this arrangement usually only the small bulb shows phosphorescence, as there is practically no bombardment against the outer globe. In some of these bulbs constructed as illustrated in Fig. 28 the small tube was coated with phosphorescent paint, and beautiful effects were obtained. Instead of making the inside bulb large, in order to avoid undue heating, it answers the purpose to make the electrode m larger. In this case the bombardment is weakened by reason of the smaller electric density.

Many bulbs were constructed on the plan illustrated in Fig. 29. Here a small bulb b, containing the refractory button m, upon being exhausted to a very high degree was sealed in a large globe L, which was then moderately exhausted and sealed off. The principal advantage of this construction was that it allowed of reaching extremely high vacua, and, at the same time use a large bulb. It was found, in the course of experiences with bulbs such as illustrated in Fig. 29, that it was well to make the stem s near the seal at e very thick, and the leading-in wire w thin, as it occurred sometimes that the stem at e was heated and the bulb was cracked. Often the outer globe L was exhausted only just enough to allow the discharge to pass through, and the space between the bulbs appeared crimson, producing a curious effect. In some cases, when the exhaustion in globe L was very low, and the air good conducting, it was found necessary, in order to bring the button m to high incandescence, to place, preferably on the upper part of the neck of the globe, a tinfoil coating which was connected to an insulated body, to the ground, or to the other terminal of the coil, as the highly conducting air weakened the effect somewhat, probably by being acted upon inductively from the wire w, where it entered the bulb at e. Another difficulty—which, however, is always present when the refractory button is mounted in a very small bulb—existed in the construction illustrated in Fig. 29, namely, the vacuum in the bulb b would be impaired in a comparatively short time.

The chief idea in the two last described constructions was to confine the heat to the central portion of the globe by preventing the exchange of air. An advantage is secured, but owing to the heating of the inside bulb and slow evaporation of the glass the vacuum is hard to maintain, even if the construction illustrated in Fig. 28 be chosen, in which both bulbs communicate.

But by far the better way—the ideal way—would be to reach sufficiently high frequencies. The higher the frequency the slower would be the exchange of the air, and I think that a frequency may be reached at which there would be no exchange whatever of the air molecules around the terminal. We would then produce a flame in which there would be no carrying away of material, and a queer flame it would be, for it would be rigid! With such high frequencies the inertia of the particles would come into play. As the brush, or flame, would gain rigidity in virtue of the inertia of the particles, the exchange of the latter would be prevented. This would necessarily occur, for, the number of the impulses being augmented, the potential energy of each would diminish, so that finally only atomic vibrations could be set up, and the motion of translation through measurable space would cease. Thus an ordinary gas burner connected to a source of rapidly alternating potential might have its efficiency augmented to a certain limit, and this for two reasons—because of the additional vibration imparted, and because of a slowing down of the process of carrying off. But the renewal being rendered difficult, and renewal being necessary to maintain the *burner*, a continued increase of the frequency of the impulses, assuming they could be transmitted to and impressed upon the flame, would result in the "extinction" of the latter, meaning by this term only the cessation of the chemical process.

I think, however, that in the case of an electrode immersed in a fluid insulating medium, and surrounded by independent carriers of electric charges, which can be acted upon inductively, a sufficiently high frequency of the impulses would probably result in a gravitation of the gas all around toward the electrode. For this it would be only necessary to assume that the independent bodies are irregularly shaped; they would then turn toward the electrode their side of the greatest electric density, and this would be a position in which the fluid resistance to approach would be smaller than that offered to the receding.

The general opinion, I do not doubt, is that it is out of the question to reach any such frequencies as might—assuming some of the views before expressed to be true—produce any of the results which I have pointed out as mere possibilities. This may be so, but in the course of these investigations, from the observation of many phenomena I have gained the conviction that these frequencies would be much lower than one is apt to estimate at first. In a flame we set up light vibrations by causing molecules, or atoms, to collide. But what is the ratio of the frequency of the collisions and that of the vibrations set up? Certainly it must be incomparably smaller than that of the knocks of the bell and the sound vibrations, or that of the discharges and the oscillations of the condenser. We may cause the molecules of the gas to collide by the use of alternate electric impulses of high frequency, and so we may imitate the process in a flame; and from experiments with frequencies which we are now able to obtain, I think tha, the result is producible with impulses which are transmissible through a conductor.

In connection with thoughts of a similar nature, it appeared to me of great interest to demonstrate the rigidity of a vibrating gaseous column. Although with such low frequencies as, say 10,000 per second, which I was able to obtain without difficulty from a specially constructed alternator, the task looked discouraging at first, I made a series of experiments. The trials with air at ordinary pressure led to no result, but with air moderately rarefied I obtain what I think to be an unmistakable experimental evidence of the property sought for. As a result of this kind might lead able investigators to conclusions of importance I will describe one of the experiments performed.

It is well known that when a tube is slightly exhausted the discharge may be passed through it in the form of a thin luminous thread. When produced with currents of low frequency, obtained from a coil operated as usual, this thread is inert. If a magnet be approached to it, the part near the same is attracted or repelled, according to the direction of the lines of force of the magnet. It occurred to me that if such a thread would be produced with currents of very high frequency, it should be more or less rigid, and as it was visible it could be easily studied. Accordingly I prepared a tube about 1 inch in diameter and 1 metre long, with outside coating at each end. The tube was exhausted to a point at which by a little working the thread discharge could be obtained. It must be remarked here that the general aspect of the tube, and the degree of exhaustion, are quite different than when ordinary low frequency currents are used. As it was found preferable to work with one terminal, the tube prepared was suspended from the end of a wire connected to the terminal, the tinfoil coating being connected to the wire, and to the lower coating sometimes a small insulated plate was attached. When the thread was formed it extended through the upper part of the tube and lost itself in the lower end. If it possessed rigidity it resembled, not exactly an elastic cord stretched tight between two supports, but a cord suspended from a height with a small weight attached at the end. When the finger or a magnet was approached to the upper end of the luminous thread, it could be brought locally out of position by electrostatic or magnetic action; and when the disturbing object was very quickly removed, an analogous result was produced, as though a suspended cord would be displaced and quickly released near the point of suspension. In doing this the luminous thread was set in vibration, and two very sharply marked nodes, and a third indistinct one, were formed. The vibration, once set up, continued for fully eight minutes, dying gradually out. The speed of the vibration often varied perceptibly, and it could be observed that the electrostatic attraction of the glass affected the vibrating thread; but it was clear that the electrostatic action was not the cause of the vibration, for the thread was most generally stationary, and could always be set in vibration by passing the finger quickly near the upper part of the tube. With a magnet the thread could be split in two and both parts vibrated. By approaching the hand to the lower coating of the tube, or insulated plate if attached, the vibration was quickened; also, as far as I could see, by raising the potential or frequency. Thus, either increasing the frequency or passing a stronger discharge of the same frequency corresponded to a tightening of the cord. I did not obtain any experimental evidence with condenser discharges. A luminous band excited in a bulb by repeated discharges of a Leyden jar must possess rigidity, and if deformed and suddenly release should vibrate. But probably the amount of vibrating matter is so small that in spite of the extreme speed the inertia cannot prominently assert itself. Besides, the observation in such a case is rendered extremely difficult on account of the fundamental vibration.

The demonstration of the fact—which still needs better experimental confirmation—that a vibrating gaseous column possesses rigidity, might greatly modify the views of thinkers. When with low frequencies and insignificant potentials indications of that property may be noted, how must a gaseous medium behave under the influence of enormous electrostatic stresses which may be active in the interstellar space, and which may alternate with inconceivable rapidity? The existence of such an electrostatic, rhythmically throbbing force—of a vibrating electrostatic field—would show a possible way how solids might have formed from the ultra-gaseous uterus, and how transverse and all kinds of vibrations may be transmitted through a gaseous medium filling all space. Then, ether might be a true fluid, devoid of rigidity, and at rest, it being merely necessary as a connecting link to enable interaction. What determines the rigidity of a body? It must be the speed and the amount of moving matter. In a gas the speed may be considerable, but the density is exceedingly small; in a liquid the speed would be likely to be small, though the density may be considerable; and in both cases the inertia resistance offered to displacement is practically *nil*. But place a gaseous (or liquid) column in an intense, rapidly alternating electrostatic field, set the particles vibrating with enormous speeds, then the inertia resistance asserts itself. A body might move with more or less freedom through the vibrating mass, but as a whole it would be rigid.

There is a subject which I must mention in connection with these experiments: it is that of high vacua. This is a subject the study of which is not only interesting, but useful, for it may lead to results of great practical importance. In commercial apparatus, such as incandescent lamps, operated from ordinary systems of distribution, a much higher vacuum than obtained at present would not secure a very great advantage. In such a case the work is performed on the filament and the gas is little concerned; the improvement, therefore, would be but trifling. But when we begin to use very high frequencies and potentials, the action of the gas becomes all important, and the degree of exhaustion materially modifies the results. As long as ordinary coils, even very large ones, were used, the study of the subject was limited, because just at a point when it became most interesting it had to be interrupted on account of the "non-striking" vacuum being reached. But presently we are able to obtain from a small disruptive discharge coil potentials much higher than even the largest coil was capable of giving, and, what is more, we can make the potential alternate with great rapidity. Both of these results enable us now to pass a luminous discharge through almost any vacua obtainable, and the field of our investigations is greatly extended. Think we as we may, of all the possible directions to develop a practical illuminant, the line of high vacua seems to be the most promising at present. But to reach extreme vacua the appliances must be much more improved, and ultimate perfection will not be attained until we shall have discarded the mechanical and perfected an *electrical* vacuum pump. Molecules and atoms can be thrown out of a bulb under the action of an enormous potential: *this* will be the principle of the vacuum pump of the future. For the present, we must secure the best results we can with mechanical appliances. In this respect, it might not be out of the way to say a few words about the method of, and apparatus for, producing excessively high degrees of exhaustion of which I have availed myself in the course of these investigations. It is very probable that other experimenters have used similar arrangements; but as it is possible that there may be an item of interest in their description, a few remarks, which will render this investigation more complete, might be permitted.

The apparatus is illustrated in a drawing shown in Fig. 30. S represents a Sprengel pump, which has been specially constructed to better suit the work required. The stop-cock which is usually employed has been omitted, and instead of it a hollow stopper s has been fitted in the neck of the reservoir R. This stopper has a small hole h, through which the mercury descends; the size of the outlet o being properly determined with respect to the section of the fall tube t, which is sealed to the reservoir instead of being connected to it in the usual manner. This arrangement overcomes the imperfections and troubles which often arise from the use of the stopcock on the reservoir and the connection of the latter with the fall tube.

The pump is connected through a U-shaped tube t to a very large reservoir R_1. Especial care was taken in fitting the grinding surfaces of the stoppers p and p_1, and both of these and the mercury caps above them were made exceptionally long. After the U-shaped tube was fitted and put in place, it was heated, so as to soften and take off the strain resulting from imperfect fitting. The U-shaped tube was provided with a stopcock C, and two ground connections g and g_1—one for a small bulb b, usually containing caustic potash, and the other for the receiver r, to be exhausted.

The reservoir R_1 was connected by means of a rubber tube to a slightly larger reservoir R_2, each of the two reservoirs being provided with a stopcock C_1 and C_2, respectively. The reservoir R_2 could be raised and lowered by a wheel and rack, and the range of its motion was so determined that when it was filled with mercury and the stopcock C_2 closed, so as to form a Torricellian vacuum in it when raised, it could be lifted so high that the mercury in reservoir R_1 would stand a little above stopcock C_1; and when this stopcock was closed and the reservoir R_2 descended, so as to form a Torricellian vacuum in reservoir R_1, it could be lowered so far as to completely empty the latter, the mercury filling the reservoir R_2 up to a little above stopcock C_2.

The capacity of the pump and of the connections was taken as small as possible relatively to the volume of reservoir, R_1, since, of course, the degree of exhaustion depended upon the ratio of these quantities.

With this apparatus I combined the usual means indicated by former experiments for the production of very high vacua. In most of the experiments it was convenient to use caustic potash. I may venture to say, in regard to its use, that much time is saved and a more perfect action of the pump insured by fusing and boiling the potash as soon as, or even before, the pump settles down. If this course is not followed the sticks, as ordinarily employed, may give moisture off at a certain very slow rate, and the pump may work for many hours without reaching a very high vacuum. The potash was heated either by a spirit lamp or by passing a discharge through it, or by passing a

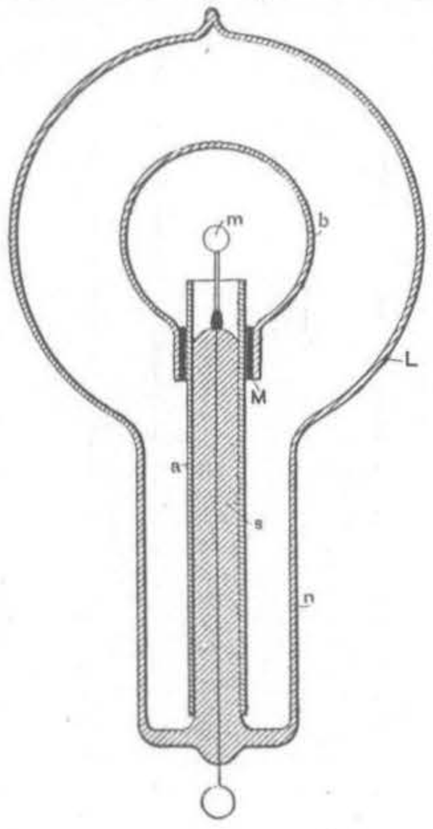

Fig. 28.—Lamp with Auxiliary Bulb for Confining the Action to the Centre.

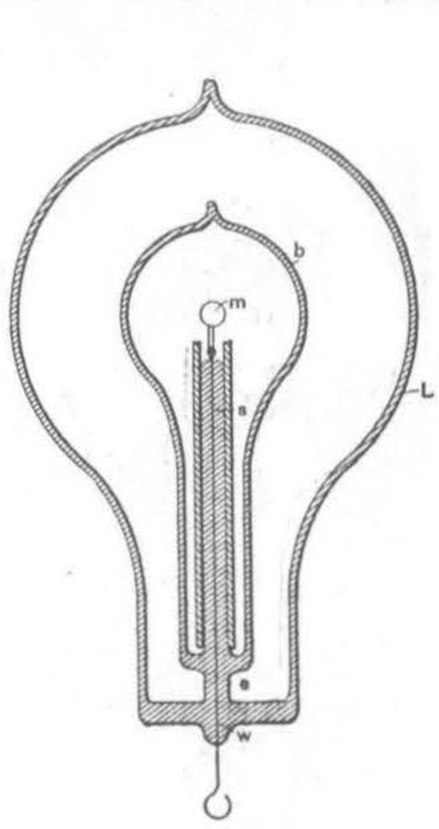

Fig. 29.—Lamp with Independent Auxiliary Bulb.

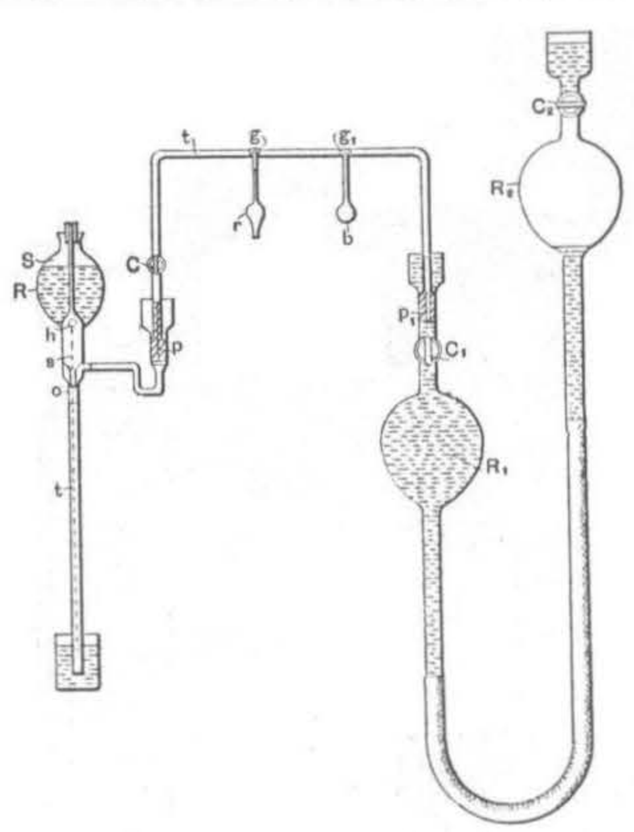

Fig. 30.—Apparatus Used for Obtaining High Degrees of Exhaustion.

current through a wire contained in it. The advantage in the latter case was that the heating could be more rapidly repeated.

Generally the process of exhaustion was the following:—At the start, the stop-cocks C and C_1 being open, and all other connections closed, the reservoir R_2 was raised so far that the mercury filled the reservoir R_1 and a part of the narrow connecting U-shaped tube. When the pump was set to work, the mercury would, of course, quickly rise in the tube, and reservoir R_2 was lowered, the experimenter keeping the mercury at about the same level. The reservoir R_2 was balanced by a long spring which facilitated the operation, and the friction of the parts was generally sufficient to keep it almost in any position. When the Sprengel pump had done its work, the reservoir R_2 was further lowered and the mercury descended in R_1 and filled R_2, whereupon stopcock C_2 was closed. The air adhering to the walls of R_1 and that absorbed by the mercury was carried off, and to free the mercury of all air the reservoir R_2 was for a long time worked up and down. During this process some air, which would gather below stopcock C_2, was expelled from R_2 by lowering it far enough and opening the stopcock, closing the latter again before raising the reservoir. When all the air had been expelled from the mercury, and no air would gather in R_2 when it was lowered, the caustic potash was resorted to. The reservoir R_2 was now again raised until the mercury in R_1 stood above stopcock C_1. The caustic potash was fused and boiled, and the moisture partly carried off by the pump and partly re-absorbed; and this process of heating and cooling was repeated many times, and each time, upon the moisture being absorbed or carried off, the reservoir R_2 was for a long time raised and lowered. In this manner all the moisture was carried off from the mercury, and both the reservoirs were in proper condition to be used. The reservoir R_2 was then again raised to the top, and the pump was kept working for a long time. When the highest vacuum obtainable with the pump had been reached the potash bulb was usually wrapped with cotton which was sprinkled with ether so as to keep the potash at a very low temperature, then the reservoir R_2 was lowered, and upon reservoir R_1 being emptied the receiver r was quickly sealed up.

When a new bulb was put on, the mercury was always raised above stopcock C_1, which was closed, so as to always keep the mercury and both the reservoirs in fine condition, and the mercury was never withdrawn from R_1 except when the pump had reached the highest degree of exhaustion. It is necessary to observe this rule if it is desired to use the apparatus to advantage.

By means of this arrangement I was able to proceed very quickly, and when the apparatus was in perfect order it was possible to reach the phosphorescent stage in a small bulb in less than 15 minutes, which is certainly very quick work for a small laboratory arrangement requiring all in all about 100 pounds of mercury. With ordinary small bulbs the ratio of the capacity of the pump, receiver, and connections, and

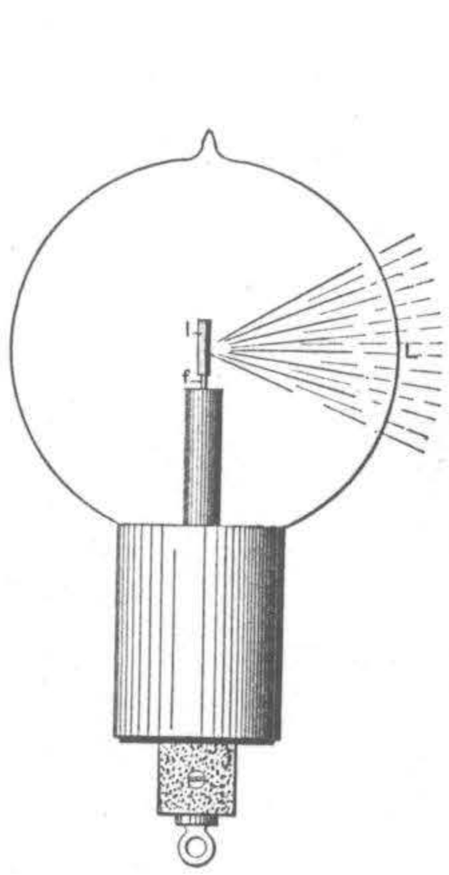

FIG. 31.—BULB SHOWING RADIANT LIME STREAM AT LOW EXHAUSTION.

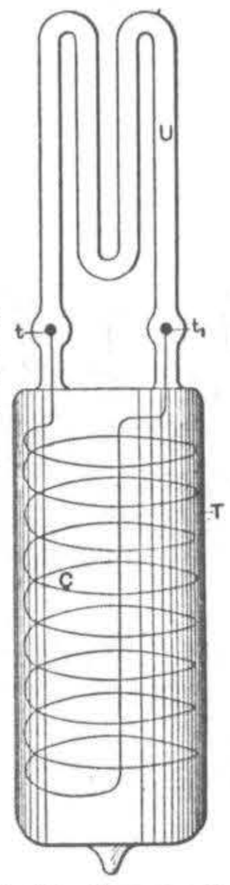

FIG. 32.—ELECTRO-DYNAMIC INDUCTION TUBE.

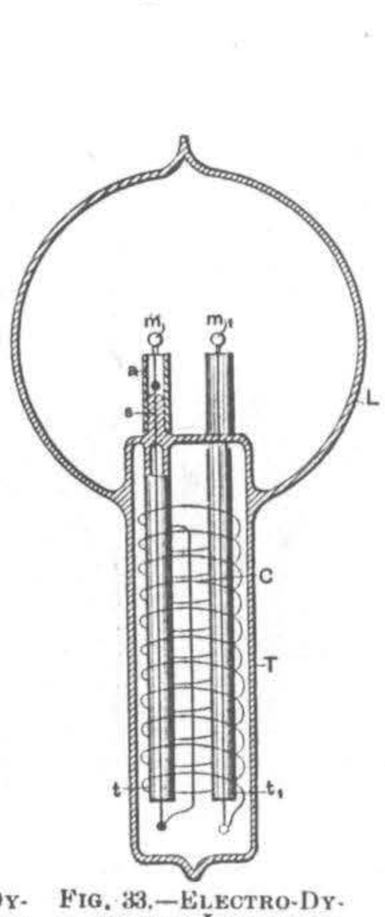

FIG. 33.—ELECTRO-DYNAMIC INDUCTION LAMP.

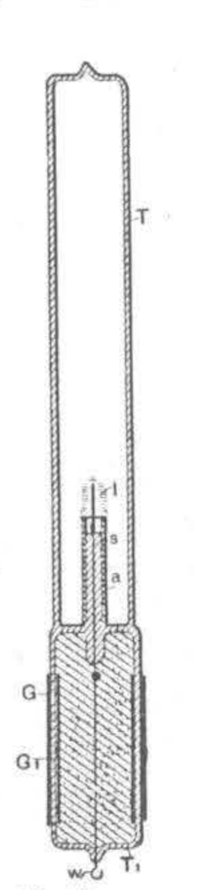

FIG. 34.—TUBE WITH FILAMENT RENDERED INCANDESCENT.

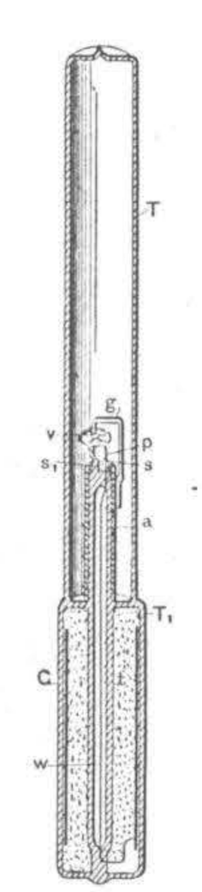

FIG. 35. — EXPERIMENT IN ELECTROSTATIC FIELD.

that of reservoir R was about 1-20, and the degrees of exhaustion reached were necessarily very high, though I am unable to make a precise and reliable statement how far the exhaustion was carried.

What impresses the investigator most in the course of these experiences is the behavior of gases when subjected to great rapidly alternating electrostatic stresses. But he must remain in doubt as to whether the effects observed are due wholly to the molecules, or atoms, of the gas which chemical analysis discloses to us, or whether there enters into play another medium of a gaseous nature, comprising atoms, or molecules, immersed in a fluid pervading the space. Such a medium surely must exist, and I am convinced that, for instance, even if air were absent, the surface and neighborhood of a body in space would be heated by rapidly alternating the potential of the body; but no such heating of the surface or neighborhood could occur if all free atoms were removed and only a homogeneous, incompressible, and elastic fluid—such as ether is supposed to be—would remain, for then there would be no impacts, no collisions. In such a case, as far as the body itself is concerned, only frictional losses in the inside could occur.

It is a striking fact that the discharge through a gas is established with ever increasing freedom as the frequency of the impulses is augmented. It behaves in this respect quite contrarily to a metallic conductor. In the latter the impedance enters prominently into play as the frequency is increased, but the gas acts much as a series of condensers would; the facility with which the discharge passes through seems to depend on the rate of change of potential. If it act so, then in a vacuum tube even of great length, and no matter how strong the current, self-induction could not assert itself to any appreciable degree. We have, then, as far as we can now see, in the gas a conductor which is capable of transmitting electric impulses of any frequency which we may be able to produce. Could the frequency be brought high enough, then a queer system of electric distribution, which would be likely to interest gas companies, might be realized: metal pipes filled with gas—the metal being the insulator, the gas the conductor—supplying phosphorescent bulbs, or perhaps devices as yet uninvented. It is certainly possible to take a hollow core of copper, rarefy the gas in the same, and by passing impulses of sufficiently high frequency through a circuit around it, bring the gas inside to a high degree of incandescence; but as to the nature of the forces there would be considerable uncertainty, for it would be doubtful whether with such impulses the copper core would act as a static screen. Such paradoxes and apparent impossibilities we encounter at every step in this line of work, and therein lies, to a great extent, the charm of the study.

I have here a short and wide tube which is exhausted to a high degree and covered with a substantial coating of bronze, the coating allowing barely the light to shine through. A metallic clasp, with a hook for suspending the tube, is fastened around the middle portion of the latter, the clasp being in contact with the bronze coating. I now want to light the gas inside by suspending the tube on a wire connected to the coil. Any one who would try the experiment for the first time, not having any previous experience, would probably take care to be quite alone when making the trial, for fear that he might become the joke of his assistants. Still, the bulb lights in spite of the metal coating, and the light can be distinctly perceived through the latter. A long tube covered with aluminium bronze lights when held in one hand—the other touching the terminal of the coil—quite powerfully. It might be objected that the coatings are not sufficiently conducting; still, even if they were highly resistant, they ought to screen the gas. They certainly screen it perfectly in a condition of rest, but not by far perfectly when the charge is surging in the coating. But the loss of energy which occurs within the tube, notwithstanding the screen, is occasioned principally by the presence of the gas. Were we to take a large hollow metallic sphere and fill it with a perfect incompressible fluid dielectric, there would be no loss inside of the sphere, and consequently the inside might be considered as perfectly screened, though the potential be very rapidly alternating. Even were th sphere filled with oil, the loss would be incomparably smaller than when the fluid is replaced by a gas, for in the latter case the force produces displacements; that means impact and collisions in the inside.

No matter what the pressure of the gas may be, it becomes an important factor in the heating of a conductor when the electric density is great and the frequency very high. That in the heating of conductors by lightning discharges air is an element of great importance, is almost as certain as an experimental fact. I may illustrate the action of the air by the following experiment: I take a short tube which is exhausted to a moderate degree and has a platinum wire running through the middle from one end to the other. I pass a steady or low frequency current through the wire, and it is heated uniformly in all parts. The heating here is due to conduction, or frictional losses, and the gas around the wire has—as far as we can see—no function to perform. But now let me pass sudden discharges, or a high frequency current, through the wire. Again the wire is heated, this time principally on the ends and least in the middle portion; and if the frequency of the impulses, or the rate of change, is high enough, the wire might as well be cut in the middle as not, for practically all the heating is due to the rarefied gas. Here the gas might only act as a conductor of no impedance diverting the current from the wire as the impedance of the latter is enormously increased, and merely heating the ends of the wire by reason of their resistance to the passage of the discharge. But it is not at all necessary that the gas in the tube should be conducting; it might be at an extremely low pressure, still the ends of the wire would be heated—as, however, is ascertained by experience—only the two ends would in such case not be electrically connected through the gaseous medium. Now what with these frequencies and potentials occurs in an exhausted tube occurs in the lightning discharges at ordinary pressure. We only need remember one of the facts arrived at in the course of these investigations, namely, that to impulses of very high frequency the gas at ordinary pressure behaves much in the same manner as though it were at moderately low pressure. I think that in lightning discharges frequently wires or conducting objects are volatilized merely because air is present, and that, were the conductor immersed in an insulating liquid, it would be safe, for then the energy would have to spend itself somewhere else. From the behavior of gases to sudden impulses of high potential I am led to conclude that there can be no surer way of diverting a lightning discharge than by affording it a passage through a volume of gas, if such a thing can be done in a practical manner.

There are two more features upon which I think it necessary to dwell in connection with these experiments—the "radiant state" and the "non-striking vacuum."

Any one who has studied Crookes' work must have received the impression that the "radiant state" is a property of the gas inseparably connected with an extremely high degree of exhaustion. But it should be remembered that the phenomena observed in an exhausted vessel are limited to the character and capacity of the apparatus which is made use of. I think that in a bulb a molecule, or atom, does not precisely move in a straight line because it meets no obstacle, but because the velocity imparted to it is sufficient to propel it in a sensibly straight line. The mean free path is one thing, but the velocity—the energy associated with the moving body—is another, and under ordinary circumstances I believe that it is a mere question of potential or speed. A disruptive discharge coil, when the potential is pushed very far, excites phosphorescence and projects shadows, at comparatively low degrees of exhaustion. In a lightning discharge, matter moves in straight lines at ordinary pressure when the mean free path is exceedingly small, and frequently images of wires or other metallic objects have been produced by the particles thrown off in straight lines.

I have prepared a bulb to illustrate by an experiment the correctness of these assertions. In a globe L (Fig. 31) I have mounted upon a lamp filament f a piece of lime l. The lamp filament is connected with a wire which leads into the bulb, and the general construction of the latter is as indicated in Fig. 19, before described. The bulb being suspended from a wire connected to the terminal of the coil, and the latter being set to work, the lime piece l and the projecting parts of the filament f are bombarded. The degree of exhaustion is just such that with the potential the coil is capable of giving phosphorescence of the glass is produced, but disappears as soon as the vacuum is impaired. The lime containing moisture, and moisture being given off as soon as heating occurs, the phosphorescence lasts only for a few moments. When the lime has been sufficiently heated, enough moisture has been given off to impair materially the vacuum of the bulb. As the bombardment goes on, one point of the lime piece is more heated than other points, and the result is that finally practically all the discharge passes through that point which is intensely heated, and a white stream of lime particles (Fig. 31) then breaks forth from that point. This stream is composed of "radiant" matter, yet the degree of exhaustion is low. But the particles move in straight lines because the velocity imparted to them is great, and this is due to three causes—to the great electric density, the high temperature of the small point, and the fact that the particles of the lime are easily torn and thrown off—far more easily than those of carbon. With frequencies such as we are able to obtain, the particles are bodily thrown off and projected to a considerable distance; but with sufficiently high frequencies no such thing would occur: in such case only a stress would spread or a vibration would be propagated through the bulb. It would be out of the question to reach any such frequency on the assumption that the atoms move with the speed of light; but I believe that such a thing is impossible; for this an enormous potential would be required. With potentials which we are able to obtain, even with a disruptive discharge coil, the speed must be quite insignificant.

As to the "non-striking vacuum," the point to be noted is that it can occur only with low frequency impulses, and it is necessitated by the impossibility of carrying off enough energy with such impulses in high vacuum since the few atoms which are around the terminal upon coming in contact with the same are repelled and kept at a distance for a comparatively long period of time, and not enough work can be performed to render the effect perceptible to the eye. If the difference of potential between the terminals is raised, the dielectric breaks down. But with very high frequency impulses there is no necessity for such breaking down, since any amount of work can be performed by continually agitating the atoms in the exhausted vessel, provided the frequency is high enough. It is easy to reach—even with frequencies obtained from an alternator as here used—a stage at which the discharge does not pass between two electrodes in a narrow tube, each of these being connected to one of the terminals of the coil, but it is difficult to reach a point at which a luminous discharge would not occur around each electrode.

A thought which naturally presents itself in connection with high frequency currents, is to make use of their powerful electro-dynamic inductive action to produce light effects in a sealed glass globe. The leading-in wire is one of the defects of the present incandescent lamp, and if no other improvement were made, that imperfection at least should be done away with. Following this thought, I have carried on experiments in various directions, of which some were indicated in my former paper. I may here mention one or two more lines of experiment which have been followed up.

Many bulbs were constructed as shown in Fig. 32 and Fig. 33.

In Fig. 32 a wide tube T was sealed to a smaller W-shaped tube U, of phosphorescent glass. In the tube T was placed a coil C of aluminium wire, the ends of which were provided with small spheres t and t_1 of aluminium, and reached into the U tube. The tube T was slipped into a socket containing a primary coil through which usually the discharges of Leyden jars were directed, and the rarefied gas in the small U tube was excited to strong luminosity by the high-tension currents induced in the coil C. When Leyden jar discharges were used to induce currents in the coil C, it was found necessary to pack the tube T tightly with insulating powder, as a discharge would occur frequently between the turns of the coil, especially when the primary was thick and the air gap, through which the jars discharged, large, and no little trouble was experienced in this way.

In Fig. 33 is illustrated another form of the bulb constructed. In this case a tube T is sealed to a globe L. The tube contains a coil C, the ends of which pass through two small glass tubes t and t_1, which are sealed to the tube T. Two refractory buttons m and m_1 are mounted on lamp filaments which are fastened to the ends of the wires passing through the glass tubes t and t_1. Generally in bulbs made on this plan the globe L communicated with the tube T. For this purpose the ends of the small tubes t and t_1 were just a trifle heated in the burner, merely to hold the wires, but not to interfere with the communication. The tube T, with the small tubes, wires through the same, and the refractory buttons m and m_1, was first prepared, and then sealed to globe L, whereupon the coil C was slipped in and the connections made to its ends. The

tube was then packed with insulating powder, jamming the latter as tight as possible up to very nearly the end, then it was closed and only a small hole left through which the remainder of the powder was introduced, and finally the end of the tube was closed. Usually in bulbs constructed as shown in Fig. 33 an aluminium tube a was fastened to the upper end s of each of the tubes t and t_1, in order to protect that end against the heat. The buttons m and m_1 could be brought to any degree of incandescence by passing the discharges of Leyden jars around the coil C. In such bulbs with two buttons a very curious effect is produced by the formation of the shadows of each of the two buttons.

Another line of experiment, which has been assiduously followed, was to induce by electro-dynamic induction a current or luminous discharge in an exhausted tube or bulb. This matter has received such able treatment at the hands of Prof. J. J. Thomson that I could add but little to what he has made known, even had I made it the special subject of this lecture. Still, since experiences in this line have gradually led me to the present views and results, a few words must be devoted here to this subject.

It has occurred, no doubt, to many that as a vacuum tube is made longer the electromotive force per unit length of the tube, necessary to pass a luminous discharge through the latter, gets continually smaller; therefore, if the exhausted tube be made long enough, even with low frequencies a luminous discharge could be induced in such a tube closed upon itself. Such a tube might be placed around a hall or on a ceiling, and at once a simple appliance capable of giving considerable light would be obtained. But this would be an appliance hard to manufacture and extremely unmanageable. It would not do to make the tube up of small lengths, because there would be with ordinary frequencies considerable loss in the coatings, and besides, if coatings were used, it would be better to supply the current directly to the tube by connecting the coatings to a transformer. But even if all objections of such nature were removed, still, with low frequencies the light conversion itself would be inefficient, as I have before stated. In using extremely high frequencies the length of the secondary—in other words, the size of the vessel—can be reduced as far as desired, and the efficiency of the light conversion is increased, provided that means are invented for efficiently obtaining such high frequencies. Thus one is led, from theoretical and practical considerations, to the use of high frequencies, and this means high electromotive forces and small currents in the primary. When he works with condenser charges—and they are the only means up to the present known for reaching these extreme frequencies—he gets to electromotive forces of several thousands of volts per turn of the primary. He cannot multiply the electro-dynamic inductive effect by taking more turns in the primary, for he arrives at the conclusion that the best way is to work with one single turn—though he must sometimes depart from this rule—and he must get along with whatever inductive effect he can obtain with one turn. But before he has long experimented with the extreme frequencies required to set up in a small bulb an electromotive force of several thousands of volts he realizes the great importance of electrostatic effects, and these effects grow relatively to the electro-dynamic in significance as the frequency is increased.

Now, if anything is desirable in this case, it is to increase the frequency, and this would make it still worse for the electro-dynamic effects. On the other hand, it is easy to exalt the electrostatic action as far as one likes by taking more turns on the secondary, or combining self-induction and capacity to raise the potential. It should also be remembered that, in reducing the current to the smallest value and increasing the potential, the electric impulses of high frequency can be more easily transmitted through a conductor.

These and similar thoughts determined me to devote more attention to the electrostatic phenomena, and to endeavor to produce potentials as high as possible, and alternating as fast as they could be made to alternate. I then found that I could excite vacuum tubes at considerable distance from a conductor connected to a properly constructed coil, and that I could, by converting the oscillatory current of a condenser to a higher potential, establish electrostatic alternating fields which acted through the whole extent of a room, lighting up a tube no matter where it was held in space. I thought I recognized that I had made a step in advance, and I have persevered in this line; but I wish to say that I share with all lovers of science and progress the one and only desire—to reach a result of utility to men in any direction to which thought or experiment may lead me. I think that this departure is the right one, for I cannot see, from the observation of the phenomena which manifest themselves as the frequency is increased, what there would remain to act between two circuits conveying, for instance, impulses of several hundred millions per second, except electrostatic forces. Even with such trifling frequencies the energy would be practically all potential, and my conviction has grown strong that, to whatever kind of motion light may be due, it is produced by tremendous electrostatic stresses vibrating with extreme rapidity.

Of all these phenomena observed with currents, or electric impulses, of high frequency, the most fascinating for an audience are certainly those which are noted in an electrostatic field acting through considerable distance, and the best an unskilled lecturer can do is to begin and finish with the exhibition of these singular effects. I take a tube in the hand and move it about, and it is lighted wherever I may hold it; throughout space the invisible forces act. But I may take another tube and it might not light, the vacuum being very high. I excite it by means of a disruptive discharge coil, and now it will light in the electrostatic field. I may put it away for a few weeks or months, still it retains the faculty of being excited. What change have I produced in the tube in the act of exciting it? If a motion imparted to the atoms, it is difficult to perceive how it can persist so long without being arrested by frictional losses; and if a strain exerted in the dielectric, such as a simple electrification would produce, it is easy to see how it may persist indefinitely, but very difficult to understand why such a condition should aid the excitation when we have to deal with potentials which are rapidly alternating.

Since I have exhibited these phenomena for the first time, I have obtained some other interesting effects. For instance, I have produced the incandescence of a button, filament, or wire enclosed in a tube. To get to this result it was necessary to economize the energy which is obtained from the field and direct most of it on the small body to be rendered incandescent. At the beginning the task appeared difficult, but the experiences gathered permitted me to reach the result easily. In Fig. 34 and Fig. 35 two such tubes are illustrated which are prepared for the occasion. In Fig. 34 a short tube T_1, sealed to another long tube T, is provided with a stem s, with a platinum wire sealed in the latter. A very thin lamp filament l is fastened to this wire, and connection to the outside is made through a thin copper wire w. The tube is provided with outside and inside coatings, C and C_1 respectively, and is filled as far as the coatings reach with conducting, and the space above with insulating powder. These coatings are merely used to enable me to perform two experiments with the tube—namely, to produce the effect desired either by direct connection of the body of the experimenter or of another body to the wire w, or by acting inductively through the glass. The stem s is provided with an aluminium tube a, for purposes before explained, and only a small part of the filament reaches out of this tube. By holding the tube T_1 anywhere in the electrostatic field the filament is rendered incandescent.

A more interesting piece of apparatus is illustrated in Fig. 35. The construction is the same as before, only instead of the lamp filament a small platinum wire p, sealed in a stem s, and bent above it in a circle, is connected to the copper wire w, which is joined to an inside coating C. A small stem s_1 is provided with a needle, on the point of which is arranged to rotate very freely a very light fan of mica v. To prevent the fan from falling out, a thin stem of glass g is bent properly and fastened to the aluminium tube. When the glass tube is held anywhere in the electrostatic field the platinum wire becomes incandescent, and the mica vanes are rotated very fast.

Intense phosphorescence may be excited in a bulb by merely connecting it to a plate within the field, and the plate need not be any larger than an ordinary lamp shade. The phosphorescence excited with these currents is incomparably more powerful than with ordinary apparatus. A small phosphorescent bulb, when attached to a wire connected to a coil, emits sufficient light to allow reading ordinary print at a distance of five to six paces. It was of interest to see how some of the phosphorescent bulbs of Professor Crookes would behave with these currents, and he has had the kindness to lend me a few for the occasion. The effects produced are magnificent, especially by the sulphide of calcium and sulphide of zinc. From the disruptive discharge coil they glow intensely merely by holding them in the hand and connecting the body to the terminal of the coil.

To whatever results investigations of this kind may lead, their chief interest lies for the present in the possibilities they offer for the production of an efficient illuminating device. In no branch of electric industry is an advance more desired than in the manufacture of light. Every thinker, when considering the barbarous methods employed, the deplorable losses incurred in our best systems of light production, must have asked himself, What is likely to be the light of the future? Is it to be an incandescent solid, as in the present lamp, or an incandescent gas, or a phosphorescent body, or something like a burner, but incomparably more efficient?

There is little chance to perfect a gas burner; not, perhaps, because human ingenuity has been bent upon that problem for centuries without a radical departure having been made—though this argument is not devoid of force—but because in a burner the higher vibrations can never be reached except by passing through all the low ones. For how is a flame produced unless by a fall of lifted weights? Such process cannot be maintained without renewal, and renewal is repeated passing from low to high vibrations. One way only seems to be open to improve a burner, and that is by trying to reach higher degrees of incandescence. Higher incandescence is equivalent to a quicker vibration; that means more light from the same material, and that, again, means more economy. In this direction some improvements have been made, but the progress is hampered by many limitations. Discarding, then, the burner, there remain the three ways first mentioned, which are essentially electrical.

Suppose the light of the immediate future to be a solid rendered incandescent by electricity. Would it not seem that it is better to employ a small button than a frail filament? From many considerations it certainly must be concluded that a button is capable of a higher economy, assuming, of course, the difficulties connected with the operation of such a lamp to be effectively overcome. But to light such a lamp we require a high potential; and to get this economically we must use high frequencies.

Such considerations apply even more to the production of light by the incandescence of a gas, or by phosphorence. In all cases we require high frequencies and high potentials. These thoughts occurred to me a long time ago.

Incidentally we gain, by the use of very high frequencies, many advantages, such as a higher economy in the light production, the possibility of working with one lead, the possibility of doing away with the leading-in wire, etc.

The question is, how far can we go with frequencies? Ordinary conductors rapidly lose the facility of transmitting electric impulses when the frequency is greatly increased. Assume the means for the production of impulses of very great frequency brought to the utmost perfection, every one will naturally ask how to transmit them when the necessity arises. In transmitting such impulses through conductors we must remember that we have to deal with *pressure* and *flow*, in the ordinary interpretation of these terms. Let the pressure increase to an enormous value, and let the flow correspondingly diminish, then such impulses—variations merely of pressure, as it were—can no doubt be transmitted through a wire even if their frequency be many hundreds of millions per second. It would, of course, be out of question to transmit such impulses through a wire immersed in a gaseous medium, even if the wire were provided with a thick and excellent insulation, for most of the energy would be lost in molecular bombardment and consequent heating. The end of the wire connected to the source would be heated, and the remote end would receive but a trifling part of the energy supplied. The prime necessity, then, if such electric impulses are to be used, is to find means to reduce as much as possible the dissipation.

The first thought is, employ the thinnest possible wire surrounded by the thickest practicable insulation. The next thought is to employ electrostatic screens. The insulation of the wire may be covered with a thin conducting coating and the latter connected to the ground. But this would not do, as then all the energy would pass through the conducting coating to the ground and nothing would get to the end of the wire. If a ground connection is made it can only be made through a conductor offering an enormous impedance, or though a condenser of extremely small capacity. This, however, does not do away with other difficulties.

If the wave length of the impulses is much smaller than the length of the wire, then corresponding short waves will be sent up in the conducting coating, and it will be more or less the same as though the coating were directly connected to earth. It is therefore necessary to cut up the coating in sections much shorter than the wave length. Such an arrangement does not still afford a perfect screen, but it is ten thousand times better than none. I think it preferable to cut up the conducting coating in small sections, even if the current waves be much longer than the coating.

If a wire were provided with a perfect electrostatic screen, it would be the same as though all objects were removed from it at infinite distance. The capacity would then be reduced to the capacity of the wire itself, which would be very small. It would then be possible to send over the wire current vibrations of very high frequencies at enormous distance without affecting greatly the character of the vibrations. A perfect screen is of course out of the question, but I believe that with a screen such as I have just described telephony could be rendered practicable across the Atlantic. According to my ideas, the gutta-percha covered wire should be provided with a third conducting coating subdivided in sections. On the top of this should be again placed a layer of gutta-percha and other insulation, and on the top of the whole the armor. But such cables will not be constructed, for ere long intelligence—transmitted without wires—will throb through the earth like a pulse through a living organism. The wonder is that, with the present state of knowledge and the experiences gained, no attempt is being made to disturb the electrostatic or magnetic condition of the earth, and transmit, if nothing else, intelligence.

It has been my chief aim in presenting these results to point out phenomena or features of novelty, and to advance ideas which I am hopeful will serve as starting points of new departures. It has been my chief desire this evening to entertain you with some novel experiments. Your applause, so frequently and generously accorded, has told me that I have succeeded.

In conclusion, let me thank you most heartily for your kindness and attention, and assure you that the honor I have had in addressing such a distinguished audience, the pleasure I have had in presenting these results to a gathering of so many able men—and among them also some of those in whose work for many years past I have found enlightenment and constant pleasure—I shall never forget.

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

BY NIKOLA TESLA.

I cannot find words to express how deeply I feel the honor of addressing some of the foremost thinkers of the present times, and so many able scientific men, engineers, and electricians, of the country greatest in scientific achievements. The results which I have the honor to present before such a gathering I cannot call my own. There are among you not a few who can lay better claim than myself on any feature of merit which this work may contain. I need not mention many names which are world-known—names of those among you who are recognized as the leaders in this enchanting science; but one, at least, I must mention—a name which could not be omitted in a demonstration of this kind. It is a name associated with the most beautiful invention ever made: it is Crookes!

When I was at college, a good time ago, I read, in a translation (for then I was not familiar with your magnificent language), the description of his experiments on radiant matter. I read it only once in my life—that time—yet every detail about that charming work I can remember this day. Few are the books, let me say, which can make such an impression upon the mind of a student. But if on the present occasion I mention this name, as one of many your Institution can boast of, it is because I have more than one reason to do so. For what I have to tell you and to show you this evening, concerns in a large measure that same vague world which Prof. Crookes has so ably explored; and, more than this, when I trace back the mental process which led me to these advances—which even by myself cannot be considered trifling, since they are so appreciated by you—I believe that their real origin, that which started me to work in this direction, and brought me to them after a long period of constant thought, was that fascinating little book which I read many years ago.

And now that I have made a feeble effort to express my homage and acknowledge my indebtedness to him and others among you, I will make a second effort, which I hope you will not find so feeble as the first, to entertain you. Give me leave to introduce the subject in a few words. A short time ago I had the honor to bring before our American Institute of Electrical Engineers some results then arrived at by me in a novel line of work. I need not assure you that the many evidences which I have received that English scientific men and engineers were interested in this work, have been for me a great reward and encouragement. I will not dwell upon the experiments already described, except with the view of completing, or more clearly expressing, some ideas advanced by me before, and also with the view of rendering the study here presented, self-contained, and my remarks on the subject of this evening's lecture consistent. This investigation, then, it goes without saying, deals with alternating currents, and, to be more precise, with alternating currents of high potential and high frequency. Just in how much a very high frequency is essential for the production of the results presented, is a question which, even with my present experience, would embarrass me to answer. Some of the experiments may be performed with low frequencies, but very high frequencies are desirable, not only on account of the many effects secured by their use, but also as a convenient means of obtaining, in the induction apparatus employed, the high potentials which, in their turn, are necessary to the demonstration of most of the experiments here contemplated.

Of the various branches of electrical investigation, perhaps the most interesting and immediately the most promising, is that dealing with alternating currents. The progress in this branch of applied science has been so great in recent years that it justifies the most sanguine hopes. Hardly have we become familiar with one fact when novel experiences are made, and new avenues of research are opened. Even at this hour possibilities not dreamt of before are, by the use of these currents, partly realized. As in Nature all is ebb and tide, all is wave motion, so it seems that in all branches of industry alternating currents—electric wave motion—will have the sway. One reason, perhaps, why this branch of science is being so rapidly developed, is to be found in the interest which is attached to its experimental study. We wind a simple ring of iron with coils; we establish the connections to the generator, and with wonder and delight we note the effects of strange forces which we bring into play, which allow us to transform, to transmit and direct energy at will. We arrange the circuits properly and we see the mass of iron and wires behave as though it were endowed with life, spinning a heavy armature, through invisible connections, with great speed and power—with the energy possibly conveyed from a great distance. We observe how the energy of an alternating current traversing the wire manifests itself—not so much in the wire as in the surrounding space—in the most surprising manner, taking the forms of heat, light, mechanical energy, and, most surprising of all, even chemical affinity. All these observations fascinate us, and fill us with an intense desire to know more about the nature of these phenomena. Each day we do our work in the hope of discovering—in the hope that some one, no matter who, may find a solution of one of the pending great problems—and each succeeding day we return to our task with renewed ardor; and even if we are unsuccesseful, our work has not been in vain, for in these strivings, in these efforts, we have found hours of untold pleasure, and we have directed our energies to the benefit of mankind.

We may take—at random, if you choose, any of the many experiments which may be performed with alternating currents; a few of which only, and by no means the most striking, form the subject of this evening's demonstration; they are all equally interesting, equally inciting to thought. Here is a simple glass tube from which the air has been partially exhausted. I take hold of it; I bring my body in contact with a wire conveying alternating currents of high potential, and the tube in my hand is brilliantly lighted. In whatever position I may put it, wherever I may move it in space, as far as I can reach, its soft, pleasing light persists with undiminished brightness. Here is an exhausted bulb suspended from a single wire. Standing on an insulated support, I grasp it, and a platinum mounted in it is brought to vivid incandescence. Here, attached to a leading wire, is another bulb, which, as I touch its metallic socket, is filled with magnificent colors of phosphorescent light. Here still another, which by my fingers' touch casts a shadow—the Crookes shadow of the stem inside of it. Here, again, insulated as I stand on this platform, I bring my body in contact with one of the terminals of the secondary of this induction coil—with the end of a wire many miles long—and you see streams of light break forth from its distant end, which is set in violent vibration. Here, once more, I attach these two plates of wire gauze to the terminals of the coil, I set them a distance apart, and I set the coil to work. You may see a small spark pass between the plates. I insert a thick plate of one of the best dielectrics between them, and instead of rendering altogether im-

* Abstract of a lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the Journal of the Institution.

possible, as we are used to expect, I aid the passage of the dischage, which, as I insert the plate, merely changes in appearance, and assumes the form of luminous streams. Is there, I ask, can there be, a more interesting study than that of alternating currents?

In all these investigations, ladies and gentlemen, in all these experiments, which are so very, very interesting, for many years past—ever since the greatest experimenter who lectured in this hall discovered its principle—we have had a steady companion, an appliance familiar to everyone, a plaything once, a thing of momentous importance now—the induction coil. There is no dearer appliance to the electrician. From the ablest among you, I dare say, down to the inexperienced student, to your lecturer, we have all passed many delightful hours in experimenting with the induction coil. We have watched its play, and thought and pondered over the beautiful phenomena which is disclosed to our ravished eyes. So well known is this apparatus, so familiar are these phenomena to everyone, that my courage nearly fails me when I think that I have ventured to address so able an audieuce, that I have hazarded to entertain you with that same old subject. Here in reality is the same apparatus, and here are the same phenenomena, only the apparatus is operated somewhat differently, the phenomena are presented in a different aspect. Some of the results we find as expected, others surprise us, but all captivate our attention, for in scientific investigation each novel result achieved may be the centre of a new departure, each novel fact learned may lead to important developments. Usually in operating an induction coil we have set up a vibration of moderate frequency in the primary, either by means of an interruptor or break, or by the use of an alternator. Earlier English investigators, to mention only Spottiswoode and J. E. H. Gordon, have used a rapid break in connection with the coil. Our knowledge and experience of to-day enables us to see clearly why these coils, under the conditions of the tests, did not disclose any remarkable phenomena, and why able experimenters failed to perceive many of the curious effects which have since been observed. In the experiments such as performed this evening, we operate the coil either from a specially-constructed alternator capable of giving many thousands of reversals of current per second, or, by disruptively discharging a condenser through the primary, we set up a vibration in the secondary circuit of a frequency of many hundred thousands or millions per second, if we so desire; and in using either of these means we enter a field as yet unexplored.

It is impossible to pursue an investigation in any novel line without finally making some interesting observation, or learning some useful fact. That this statement is applicable to the subject of this lecture, the many curious and unexpected phenomena which we observe afford a convincing proof. By way of illustration take, for instance, the most obvious phenomena, those of the discharge of the induction coil. Here is a coil which is operated by currents vibrating with extreme rapidity, obtained by disruptively discharging a Leyden jar. It would not surprise a student were the lecturer to say that the secondary of this coil consists of a small length of comparatively stout wire; it would not surprise him were the lecturer to state that, in spite of this, the coil is capable of giving any potential which the best insulation of the turns is able to withstand; but although he may be prepared, and even indifferent as to the anticipated result, yet the aspect of the discharge of the coil will surprise and interest him. Everyone is familiar with the discharge of an ordinary coil; it need not be reproduced here. But, by way of contrast, here is a form of discharge of a coil the primary current of which is vibrating several hundred thousand times per second. The discharge of an ordinary coil appears as a simple line or band of light. The discharge of this coil appears in the form of powerful brushes and luminous streams issuing from all points of the two straight wires attached to the terminals of the secondary. Now compare this phenomenon which you have just witnessed with the discharge of a Holtz or Wimshurst machine—that other interesting appliance so dear to the experimenter. What a difference there is between both these phenomena! And yet, had I made the necessary arrangements—which could have been made easily, were it not that they would interfere with other experimenters; I could have produced with this coil sparks which, had I the coil hidden from your view and only two knobs exposed, even the keenest observer among you would find it difficult, if not impossible, to distinguish from those of an influence or friction machine. This may be done in many ways—for instance, by operating the induction coil which charges the condenser from an alternating-current machine of very low frequency, and preferably adjusting the discharge circuit so that there are no oscillations set up in it. We then obtain in the secondary circuit, if the knobs are of the required size and properly set, a more or less rapid succession of sparks of great intensity and small quantity, which possess the same brilliancy, and are accompanied by the same sharp crackling sound as those obtained from a friction or influence machine.

Another way is to pass through two primary circuits, having a common secondary, two currents of a slightly different period, which produce in the secondary circuit sparks occurring at comparatively long intervals. But, even with the means at hand this evening, I may succeed in imitating the spark of a Holtz machine. For this purpose I establish between the terminals of the coil which charges the condenser, a long unsteady arc, which is periodically interrupted by upward current of air produced by it. To increase the current of air I place on each side of the arc, and close to it, a large plate of mica. The condenser charged from this coil discharges into the primary circuit of a second coil through a small air gap, which is necessary to produce a sudden rush of current through the primary.

When, instead of operating the induction coil as in the two last experiments, we operate it from a high-frequency alternator, as in the next experiment, a systematic study of the phenomena is rendered much more easy. In such case, in varying the strength and frequency of the currents through the primary, we may observe five distinct forms of discharge, which I have described in my former paper on this subject before the American Institute of Electrical Engineers, May 20, 1891.

It would take too much time, and it would lead us too far from the subject presented this evenin, to reproduce all these forms, but it seems to me desirable to show you one of them. It is a brush discharge, which is interesting in more than one respect. Viewed from a near position, it resembles much, a jet of gas escaping under great pressure. We know that the phenomenon is due to the agitation of the molecules near the terminal, and we anticipate that some heat must be developed by the impact of the molecules against the terminal or against each other. Indeed, we find that the brush is hot, and only a little thought leads us to the conclusion that, could we but reach sufficiently high frequencies, we could produce a brush which would give intense light and heat, and which would resemble in every particular an ordinary flame, save, perhaps, that both phenomena might not be due to the same agent—save, perhaps, that chemical affinity might not be electrical in its nature. As the production of heat and light is here due to the impact of the molecules, or atoms, of air or of something else besides, and as we can augment the energy simply by raising the potential, we might, even with frequencies obtained from a dynamo machine, intensify the action to such a degree as to bring the terminal to melting heat. But with such low frequencies we would have to deal always with something of the nature of an electric current. If I approach a conducting object to the brush, a little spark passes, yet even with the frequencies used this evening the tendency to spark is not very great. So, for instance, if I hold a metallic sphere at some distance above the terminal, you may see the whole space between the terminal and sphere illuminated by the streams without the spark passing; and with the much higher frequencies obtainable by the disruptive discharge of a condenser, were it not for the sudden impulses, which are comparatively few in number, sparking would not occur even at very small distances. However, with incomparably higher frequencies, which we may yet find

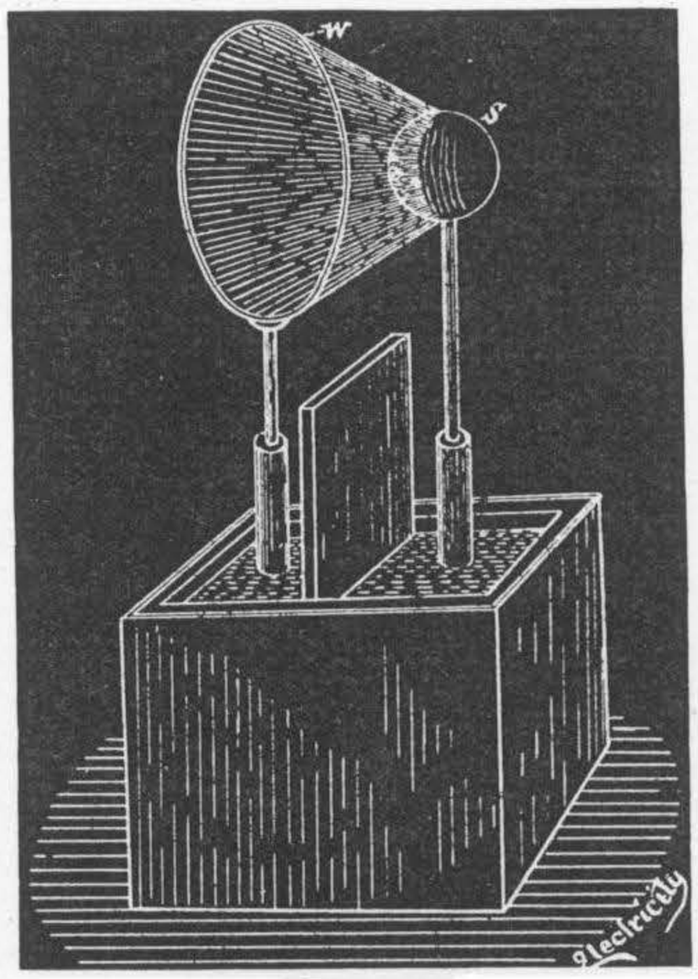

FIG. 1.

means to produce efficiently, and provided that electric impulses of such high frequencies could be transmitted through a conductor, the electrical characteristics of the brush discharge would completely vanish—no spark would pass, no shock would be felt—yet we would still have to deal with an electric phenomenon, but in the broad, modern interpretation of the word. In my first paper before referred to, I have pointed out the curious properties of the brush, and described the best manner of producing it, but I have thought it worth while to endeavor to express myself more clearly in regard to this phenomenon, because of its absorbing interest. When a coil is operated with currents of very high frequency, beautiful brush effects may be produced, even if the coil be of comparatively small dimensions. The experimenter may vary them in many ways, and if it were nothing else, they afford a pleasing sight. What adds to their interest is that they may be produced with one single terminal as well as with two; in fact, often better with one than with two.

But of all the discharge phenomena observed, the most pleasing to the eye, and the most instructive, are those observed with a coil which is operated by means of the disruptive discharge of a condenser. The power of the brushes, the abundance of the sparks, when the conditions are patiently adjusted, is often amazing. With even a very small coil, if it be so well insulated, as to

stand a difference of potential of several thousand volts per turn, the sparks may be so abundant that the whole coil may apper a complete mass of fire. Curiously enough, the sparks, when the terminals of the coil are set at a considerable distance, seem to dart in every possible direction, as though the terminals were perfectly independent of each other. As the sparks would soon destroy the insulation, it is necessary to prevent them. This is best done by immersing the coil in a good liquid insulator, such as boiled-out oil. Immersion in a liquid may be considered almost an absolute necessity for the continued and successful working of such a coil.

The employment of an intense magnetic field is of advantage principally when the induction coil or transformer which charges the condenser is operated by currents of very low frequency. In such a case, the number of the fundamental discharges between the knobs may be so small as to render the currents produced in the, secondary unsuitable for many experiments. The intense magnetic field then serves to blow out the arc between the knobs as soon as it is formed, and the fundamental discharges occur in quicker succession. Instead of the magnet, a draught or blast of air may be used with some advantage.

I will now endeavor to show you some of the most noteworthy of these discharge phenomena. I have stretched across the room two ordinary cotton-covered wires, each about seven metres in length. They are supported on insulating cords at a distance of about 30 centimetres. I attach now to each of the terminals of the coil one of the

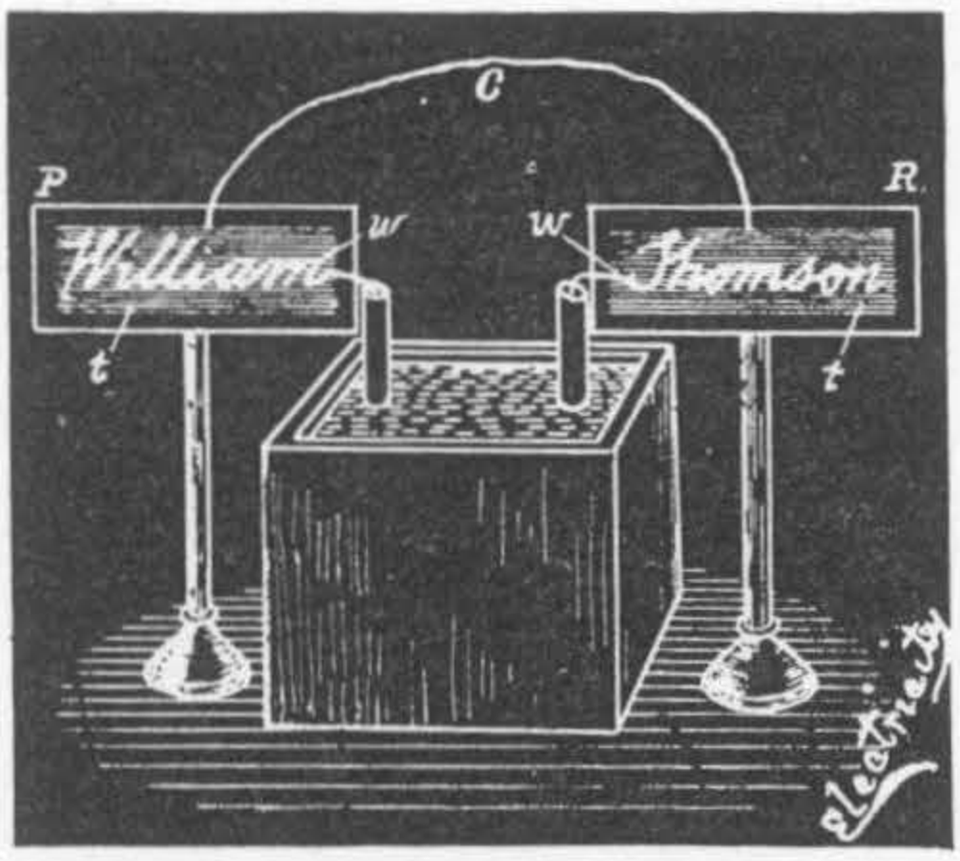

FIG. 2.

wires, and set the coil in action. Upon turning the lights off in the room you see the wires strongly illuminated by the streams issuing abundantly from their whole surface in spite of the cotton covering, which may even be very thick. When the experiment is performed under good conditions, the light from the wires is sufficiently intense to allow distinguishing the objects in a room. To produce the best results, it is of course necessary to adjust carefully the capacity of the jars, the arc between the knobs, and the length of the wires. My experience is, that calculation of the length of the wires leads in such case to no result whatever.

In the preceding experiment it is of considerable interest to know what relation the quantity of the light emitted bears to the frequency, and potential of the electric impulses. My opinion is, that the heat as well as light effects produced should be proportionate, under otherwise equal conditions of test, to the product of frequency and square of potential, but the experimental verification of the law, whatever it may be, would be exceedingly difficult. One thing is certain, at any rate, and that is, that in augumenting the potential and frequency, we rapidly intensify the streams; and, though it may be very sanguine, it is surely not altogether hopeless, to expect that we may succeed in producing a practical illuminant on these lines. We would then be simply using burners or flames, in which there would be no chemical process, no consumption of material, but merely a transfer of energy, which would, in all probability, emit more light and less heat than ordinary flames. The luminous intensity of the stream is, of course, considerably increased when they are focused upon a small surface. This may be shown by the following experiment. I attach to one of the terminals of the coil a wire, *w* (Fig. 1) bent in a circle of about 30 centimetres in diameter, and to the other terminal I fasten a small brass sphere, *s*; the surface of the wire being preferably equal to the surface of the sphere, and the centre of the latter being in a line at right angles to the plane of the wire circle and passing through its centre. When the discharge is established under proper conditions, a luminous hollow cone is formed, and in the dark, one half of the brass sphere is strongly illuminated, as shown in the cut. By some artifice or other, it is easy to concentrate the streams upon small surfaces and to produce very strong light effects. Two thin wires may thus be rendered intensely luminous. In order to intensify the streams, the wires should be very thin and short; but as in this case their capacity would be generally too small for the coil, at least for such a one as the present, it is necessary to augument the capacity to the required value, while, at the same time, the surface of the wires remains very small. This may be done in many ways. Here, for instance, I have two plates, P R, of hard rubber, (Fig. 2) upon which I have glued two very thin wires, *w w*, so as to form a name. The wires may be bare or covered with best insulation—it is immaterial for the success of the experiment. Well insulated wires, if anything, are preferable. On the back of each plate, indicated by the shaded portion, is a tinfoil coating, *t t*. The plates are placed in a line at a sufficient distance to prevent a spark passing from one to the other wire. The two tinfoil coatings I have joined by a conductor, C, and the two wires I presently connect to the terminals of the coil. It is now easy, by varying the strength and frequency of the currents through the primary, to find a point at which the capacity of the system is best suited to the conditions, and the wires become so strongly luminous that when the light in the room is turned off, the name formed by them appears in brilliant letters. It is perhaps preferable to perform this experiment with a coil operated from an alternator of high frequency, as then, owing to the harmonic rise and fall, the streams are very uniform, though they are less abundant than when produced with such a coil as the present. This experiment, however, may be performed with low frequencies, but much less satisfactorily.

(To be Continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

PART II.

BY NIKOLA TESLA.

When two wires, attached to the terminals of the coil, are set at the proper distance, the streams between them may be so intense as to produce a continuous luminious sheet. To show this phenomenon, I have here two circles, *C* and *c* (Fig. 3), of rather stout wire, one being about 32 inches and the other 8 inches in diameter. To each of the terminals of the coil I attach one of the circles. The supporting wires are so bent that the circles may be placed in the same plane, coinciding as nearly as possible. When the light in the room is turned off and the coil set to work, you see the whole space between the wires uniformly filled with streams, forming a luminous disc, which could be seen from a considerable distance, such is the intensity of the streams. The outer circle could have been much larger than the present one; in fact, with this coil I have

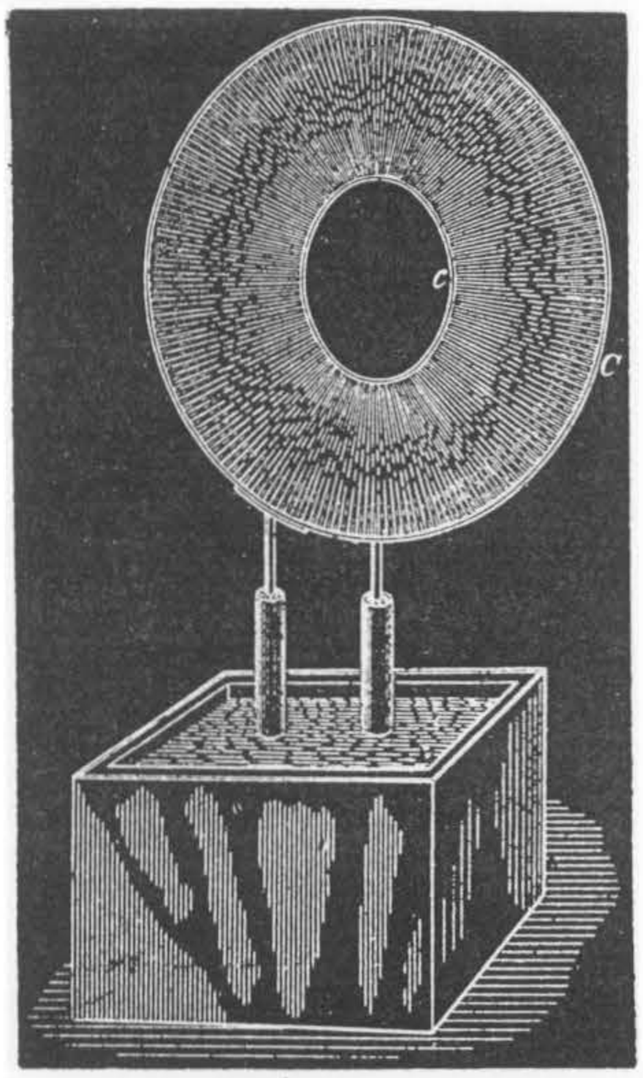

FIG. 3.

used much larger circles, and I have been able to produce a strongly luminious sheet, covering an area of more than 10 square feet, which is a remarkable effect with this very small coil. To avoid uncertainty, the circle has been taken smaller, and the area is now about 5.7 square feet.

The frequency of the vibration, and the quickness of the succession of the sparks between the knobs, affect to a marked degree the appearance of the streams. When the frequency is very low, the air gives way in more or less the same manner, as by a steady difference of potential, and the streams consist of distinct threads, generally mingled with thin sparks, which probably corresponds to the successive discharges occuring between the knobs. But, when the frequency is extremely high, and the arc of the discharge produces a very *loud* but *smooth* sound—showing both that oscilation takes place and that the sparks succeed each other with great rapidity—then the luminous streams formed are perfectly uniform. To reach this result very small coils and jars of small capacity should be used. I take two tubes of thick Bohemian glass, about 2 inches in diameter and 8 inches long. In each of the tubes I slip a primary of very thick copper wire. On the top of each tube I wind a secondary of much thinner gutta-percha covered wire. The two secondaries I connect in series, the primaries preferably in multiple arc. The tubes are then placed in a large glass vessel, at a distance of 4 to 6 inches from each other, on insulating supports, and the vessel is filled with boiled-out oil, the oil reaching about an inch above the tubes. The free ends of the secondary are lifted out of the oil and placed parallel to each other at a distance of about 4 inches. The ends which are scraped should be dipped in the oil. Two four-pint jars joined in series may be used to discharge through the primary. When the necessary adjustments in the length and distance of the wires above the oil and in the arc of discharge are made, a luminous sheet is produced between the wires which is perfectly smooth and textureless, like the ordinary discharge through a moderately exhausted tube.

I have purposely dwelt upon this apparently insignificant experiment. In trials of this kind the experimenter arrives at the startling conclusion that, to pass ordinary luminous discharges through gases, no particular degree of exhaustion is needed, but that the gas may be at ordinary or even greater pressure. To accomplish this, a very high frequency is essential; a high potential is likewise required, but this is a merely incidental necessity. These experiments teach us that, in endeavoring to discover novel methods of producing light by the agitation of atoms, or molecules, of a gas, we need not limit our research to the vacuum tube, but may look forward quite seriously to the possibility of obtaining the light effects without the use of any vessel whatever, with air at ordinary pressure.

Such discharges of very high frequency, which render luminous the air at ordinary pressure, we probably often liave occasion to witness in Nature. I have no doubt that if, as many believe, the aurora borealis is produced by sudden cosmic disturbances such as eruptions at the sun's surface, which sets the electrostatic charge of the earth in an extremely rapid vibration, the red glow observed is not confined to the upper rarefied strata of the air, but the discharge traverses, by reason of its very high frequency, also the dense atmosphere in the form of a *glow*, such as we ordinarily produce in a slightly exhausted tube. If the frequency were very low, or even more so, if the charge were not at all vibrating, the dense air would break down as in a lightning discharge. Indications of such breaking down of the lower dense strata of the air have been repeatedly observed at the occurance of this marvelous phenomenon; but if it does not occur, it can only be attributed to the fundamental disturbances, which are few in number, for the vibration produced by them would be far too rapid to allow a disruptive break. It is the original and irregular impulses which affect the instruments; the superimposed vibrations probably pass unnoticed.

When an ordinary low frequency discharge is passed through moderately rarefied air, the air assumes a purplish hue. If by some means or other we increase the intensity of the molecular, or atomic, vibration, the gas changes to a white color. A similar change occurs at ordinary pressures with electric impulses of very high frequency. If the brush formed is reddish or violet, if the vibration is rendered sufficiently intense, the streams become white. We may accomplish this in various ways. In the experiment before shown with the two wires across the room, I have endeavored to secure the result by pushing to a high value both the frequency and potential; in the experiment with the thin wires glued on the rubber plate I have concentrated the action upon a very small surface—in other words, I have worked with a great electric density.

A most curious form of discharge is observed with such a coil when the frequency and potential are pushed to the extreme limit. To perform the experiment, every part of the coil should be heavily insulated, and only two small spheres—or, better still, two sharp-edged metal discs (see Fig. 4) of no more than a few centimetres in diameter—should be exposed to the air. The coil here is immersed in oil, and the ends of the secondary reaching out of the oil are covered with an air-tight cover of hard rubber of great thickness. All cracks, if there are any, should be carefully stopped up so that the brush discharge cannot form anywhere except on the small spheres or plates which are exposed to the air. In this case, as there are no large plates or other bodies of capacity attached to the terminals, the coil is capable of an extremely rapid vibration. The potential may be raised by increasing as far as the experimenter judges proper, the rate of change of the primary current. With a coil not widely differing from the present, it is best to connect the two primaries in multiple arc; but if the secondary should have a much greater number of turns the primaries should preferably be used in series, as otherwise the vibration might be too fast for the secondary. It occurs under these conditions that misty white streams break

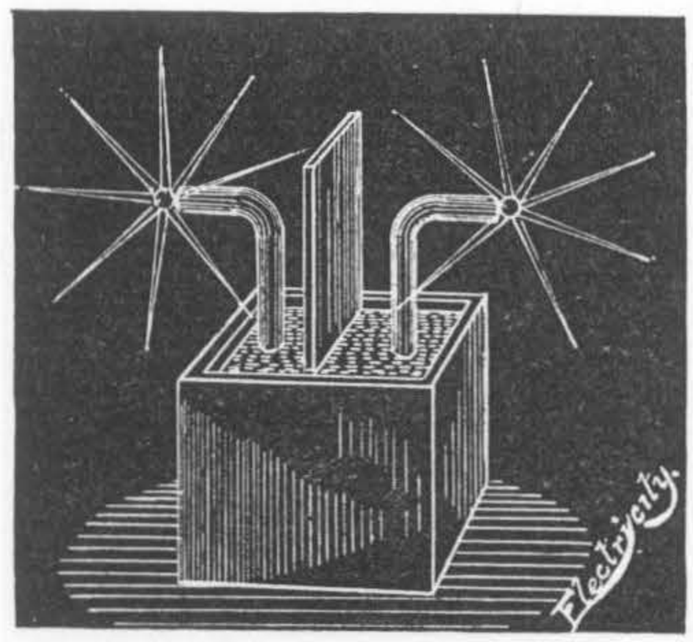

FIG. 4.

forth from the edges of the discs and spread out phantom-like into space. With this coil, when fairly well produced, they are about 10 to 12 inches long. When the hand is held against them no sensation is produced, and a spark, causing a shock, jumps from the terminal only upon the hand being much nearer. If the oscillation of the primary current is rendered intermittent by some means or other, there is a corresponding throbbing of the streams, and now the hand or other conducting object may be brought in still greater proximity to the terminal without a spark being caused to jump.

Among the many beautiful phenomena which may be produced with such a coil I have here selected only those which appear to possess some features of novelty, and lead us to some conclusions of interest. One will not find it at all difficult to produce in the laboratory, by means of it, many other phenomena which appeal to the eye even more than these here shown, but which present no particular feature of novelty.

Early experimenters describe the display of sparks produced by an ordinary large induction coil upon an insulating plate separating the terminals. Quite recently Siemens performed some experiments in which fine effects were obtained, which were seen by many with interest. No doubt large coils, even if operated with currents of low frequencies, are capable of producing beautiful effects. But the largest coil ever made could not, by far, equal the magnificent display of streams and sparks obtained from such a disruptive discharge coil when properly adjusted. To give an idea, a coil such as the present one will cover easily a plate of $3\frac{1}{8}$ feet in diameter

* Abstract of a lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the Journal of the Institution.

completely with the streams. The best way to perform such experiments is to take a very thin rubber or a glass plate and glue on one side of it a narrow ring of tinfoil of very large diameter, and on the other a circular washer, the centre of the latter coinciding with that of the ring, and the surfaces of both being preferably equal, so as to keep the coil well balanced. The washer and ring should be connected to the terminals by heavily insulated thin wire. It is easy in observing the effect of the capacity to produce a sheet of uniform streams, or a fine network of thin silvery threads, or a mass of loud brilliant sparks, which completely cover the plate.

Since I have advanced the idea of the conversion by means of the disruptive discharge, in my paper before the American Institute of Electrical Engineers at the beginning of the past year, the interest excited in it has been considerable. It affords us a means for producing any potentials by the aid of inexpensive coils operated from ordinary systems of distribution, and—what is perhaps more appreciated—it enables us to convert currents of any frequency into currents of any other lower or higher frequency. But its chief value will perhaps be found in the help which it will afford us in the investigations of the phenomena of phosphorescence, which a disruptive discharge coil is capable of exciting in innumerable cases where ordinary coils, even the largest, would utterly fail.

I have dwelt at some length upon the various forms of brush discharge because, in studying them, we not only observe phenomena which please our eye, but also afford us food for thought, and lead us to conclusions of practical importance. In the use of alternating currents of very high tension, too much precaution cannot be taken to prevent the brush discharge. In a main conveying such currents, in an induction coil or transformer, or in a condenser, the brush discharge is a source of great danger to the insulation. In a condenser especially, the gaseous matter must be most carefully expelled, for in it the charged surfaces are near each other, and if the potentials are high, just as sure as a weight will fall if let go, the insulation will give way if a single gaseous bubble of some size be present, whereas, if all gaseous matter were carefully excluded, the condenser would safely withstand a much higher difference of potential. A main conveying alternating currents of very high tension may be injured merely by a blowhole or small crack in the insulation, the more so as a blowhole is apt to contain gas at low pressure; and as it appears almost impossible to completely obviate such little imperfections, I am led to believe that in our future distribution of electrical energy by currents of very high tension, liquid insulation will be used. The cost is a great drawback, but if we employ an oil as an insulator the distribution of electrical energy with something like 100,000 volts, and even more, becomes, at least with higher frequencies, so easy that it could be hardly called an engineering feat. With oil insulation and alternate current motors, transmissions of power can be effected with safety and upon an industrial basis at distances of as much as a thousand miles.

A peculiar property of oils and liquid insulation in general, when subjected to rapidly changing electric stresses, is to disperse any gaseous bubbles which may be present, and diffuse them through its mass, generally long before any injurious break can occur. This feature may be easily observed with an ordinary induction coil by taking the primary out, plugging up the end of the tube upon which the secondary is wound, and filling it with some fairly transparent insulator, such as paraffine oil. A primary of a diameter something like $\frac{1}{40}$ inch smaller than the inside of the tube may be inserted in the oil. When the coil is set to work one may see, looking from the top through the oil, many luminous points—air bubbles which are caught by inserting the primary, and which are rendered luminous in consequence of the violent bombardment. The occluded air, by its impact against the oil, heats it; the oil begins to circulate, carrying some of the air along with it, until the bubbles are dispersed and the luminous points disappear. In this manner, unless large bubbles are occluded in such way that circulation is rendered impossible, a damaging break is averted, the only effect being a moderate warming up of the oil. If instead of the liquid, a solid insulation, no matter how thick, were used, a breaking through and injury of the apparatus would be inevitable.

The exclusion of gaseous matter from any apparatus in which the dielectric is subjected to more or less rapidly changing electric forces is, however, not only desirable in order to avoid a possible injury of the apparatus, but also on account of economy. In a condenser, for instance, as long as only a solid or only a liquid dielectric is used, the loss is small; but if a gas under ordinary or small pressure be present the loss may be very great. Whatever the nature of the force acting in the dielectric may be, it seems that in a solid or liquid the molecular displacement produced by the force is small: hence the product of force and displacement is insignificant, unless the force be very great; but in a gas the displacement, and therefore this product, is considerable; the molecules are free to move, they reach high speeds, and the energy of their impact is lost in heat or otherwise. If the gas be strongly compressed, the displacement due to the force is made smaller, and the losses are reduced.

In most of the succeeding experiments I prefer, chiefly on account of the regular and positive action, to employ the alternator before referred to. This is one of the several machines constructed by me for the purposes of these investigations. It has 384 pole projections, and is capable of giving currents of a frequency of about 10,000 per second. This machine has been illustrated and briefly described in my first paper before the American Institute of Electrical Engeneers, May 20, 1891, to which I have already referred. A more detailed description, sufficient to enable any engineer to build a similar machine, will be found in several electrical journals of that period.

The induction coils operated from the machine are rather small, containing from 5,000 to 15,000 turns in the secondary. They are immersed in boiled-out linseed oil, contained in wooden boxes covered with zinc sheet.

I have found it advantageous to reverse the usual position of the wire, and to wind in these coils, the primaries on the top; this allowing the use of a much bigger primary, which, of course, reduces the danger of overheating and increases the output of the coil. I make the primary on each side at least $\frac{3}{8}$ inch shorter than the secondary, to prevent the breaking through at the ends, which would surely occur unless the insulation on the top of the secondary be very thick, and this, of course, would be disadvantageous.

When the primary is made movable, which is necessary in some experiments, and many times convenient for the purposes of adjustment, I cover the secondary with wax, and turn if off in a lathe to a diameter slightly smaller than the inside of the primary coil. The latter I provide with a handle reaching out of the coil, which serves to shift it in any position along the secondary.

I will now venture to make, in regard to the general manipulation of inducton coils, a few observations bearing upon points which have not been fully appreciated in earlier experiments with such coils, and are even now often overlooked.

The secondary of the coil possesses usually such a high self-induction that the current through the wire is inappreciable, and may be so even when the terminals are joined by a conductor of small resistance. If capacity is added to the terminals, the self-induction is counteracted, and a stronger current is made to flow through the secondary, though its terminals are insulated from each other. To one entirely unacquainted with the properties of alternating currents nothing will look more puzzling. This feature was illustrated in the experiment performed at the beginning with the top plates of wire guaze attached to the terminals and the rubber plate. When the plates of wire gauze were close together, and a small arc passed between them, the arc *prevented* a strong current from passing through the secondary, because it did away with the capacity on the terminals; when the rubber plate was inserted between, the capacity of the condenser formed counteracted the self-induction of the secondary, a stronger current passed now, the coil performed more work, and the discharge was by far more powerful.

The first thing, then, in operating the induction coil is to combine capacity with the secondary to overcome the self-induction. If the frequencies and potentials are very high, gaseous matter should be carefully kept away from the charged surfaces. If Leyden jars are used, they should be immersed in oil, as otherwise considerable dissipation may occur if the jars are greatly strained. When high frequencies are used, it is of equal importance to combine a condenser with the primary. One may use a condenser connected to the ends of the primary or to the terminals of the alternator, but the latter is not to be recommended, as the machine might be injured. The best way is undoubtedly to use the condenser in series with the primary and with the alternator, and to adjust its capacity so as to annul the self-induction of both the latter. The condenser should be adjustable by very small steps, and for a fine adjustment a small oil condenser with movable plates may be used conveniently.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

PART II.

BY NIKOLA TESLA.

I think it best at this juncture to bring before you a phenomenon observed by me some time ago, which to the purely scientific investigator may perhaps appear more interesting than any of the results which I have the privilege to present to you this evening.

It may be quite properly ranked among the brush phenomena—in fact, it is a brush, formed at, or near a single terminal in high vacuum.

In bulbs provided with a conducting terminal, though it be of aluminum, the brush has but an ephemeral existence, and cannot, unfortunately, be indefinitely preserved in its most sensitive state, even in a bulb devoid of any conducting electrode. In studying the phenomenon, by all means a bulb having no leading-in wire should be used. I have found it best to use bulbs constructed as indicated in Figs. 5 and 6.

In Fig. 5 the bulb comprises an incandescent lamp globe L, in the neck of which is sealed a barometer tube b, the end of which is blown out to form a small sphere s. This sphere should be sealed as closely as possible in the centre of the large globe. Before sealing, a thin tube t, of aluminum sheet, may be slipped in the barometer tube, but it is not important to employ it.

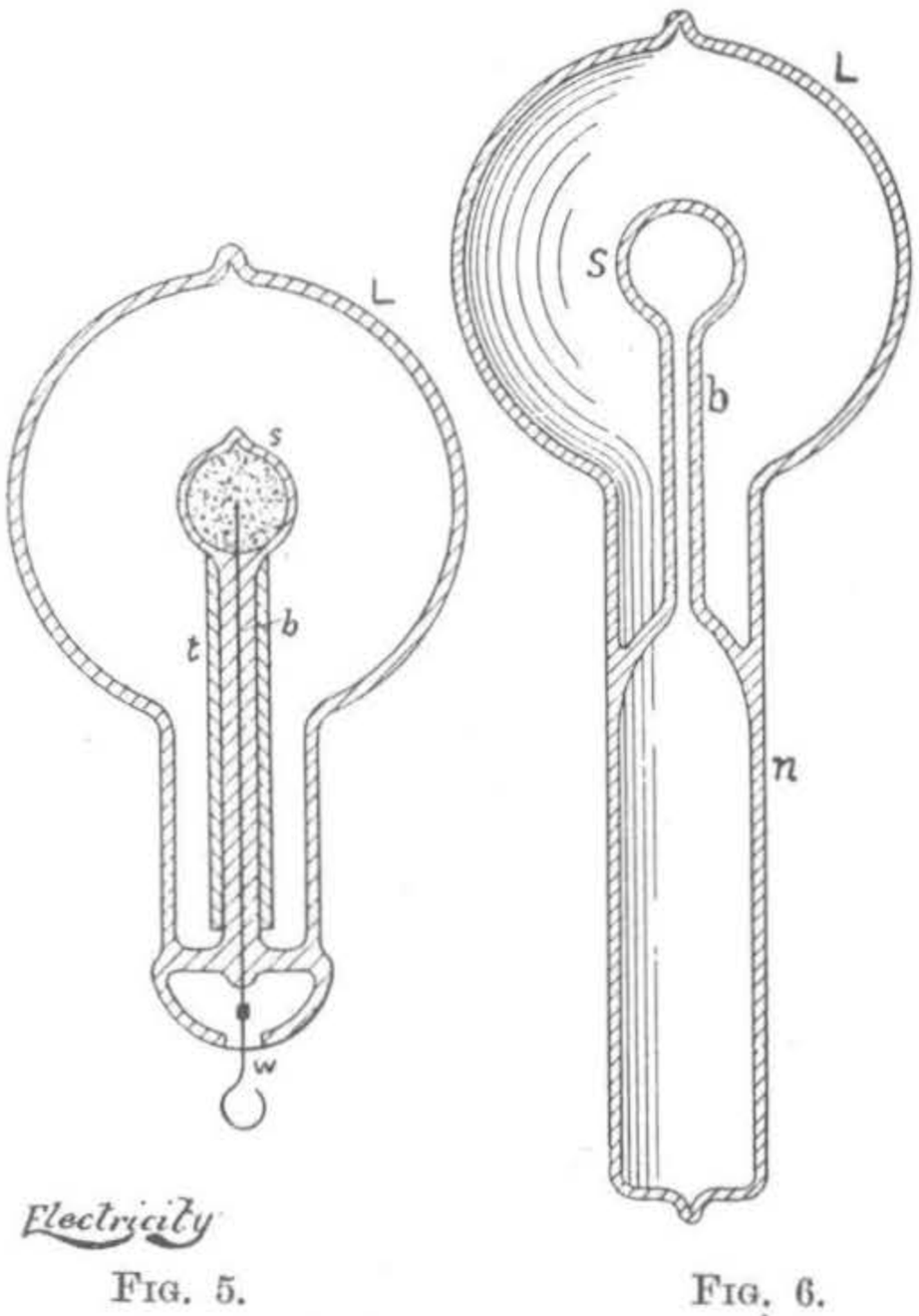

FIG. 5.

FIG. 6.

The small hollow sphere s is filled with some conducting powder, and a wire w is cemented in the neck for the purpose of connecting the conducting powder with the generator.

The construction shown in Fig. 6 was chosen in order to remove from the brush any conducting body which might possibly affect it. The bulb consists in this case of a lamp globe L, which has a neck n, provided with a tube b and small sphere s, sealed to it, so that two entirely independent compartments are formed, as indicated in the drawing. When the bulb is in use, the neck n is provided with a tin-foil coating, which is connected to the generator and acts inductively upon the moderately rarefied and highly conducting gas inclosed in the neck. From there the current passes through the tube b into the small sphere s, to act by induction upon the gas contained in the globe L.

It is of advantage to make the tube b very thick, the hole through it very small, and to blow the sphere s very thin. It is of the greatest importance that the sphere s be placed in the centre of the globe L.

Figs. 7, 8 and 9 indicate different forms, or states, of the brush. Fig. 7 shows the brush as it first appears in a bulb provided with a conducting terminal; but, as in such a bulb it very soon disappears—often after a few minutes—I will confine myself to the description of the phenomenon

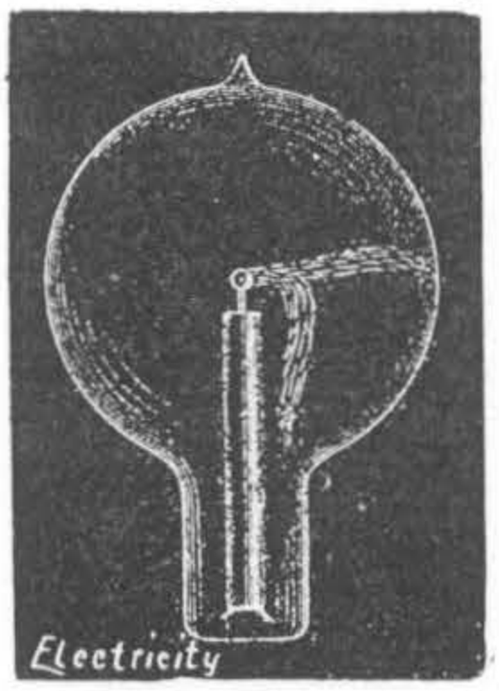

FIG. 7.

as seen in a bulb without conducting electrode. It is observed under the following conditions:

When the globe L (Figs. 5 and 6) is exhausted to a very high degree, generally the bulb is not excited upon connecting the wire w (Fig. 5), or the tinfoil coating of the bulb (Fig. 6) to the terminals of the induction coil. To excite it, it is usually sufficient to grasp the globe L with the hand. An intense phosphorescence then spreads at first over the globe, but soon gives place to a white, misty light. Shortly afterward one may notice that the luminosity is unevenly distributed in the globe, and after passing the current for some time the bulb appears as in Fig. 8. From this stage the phenomenon will gradually pass to that indicated in Fig. 9, after some minutes, hour, days, or weeks, according as the bulb is worked. Warming the bulb or increasing the potential hastens the transit.

When the brush assumes the form indicated in Fig. 9, it may be brought to a state of extreme sensitiveness to electrostatic and magnetic influence. The bulb hanging straight down from the wire, and all objects being remote from it, the approach of the observer at a few paces from the bulb will cause the brush to fly to the opposite side, and if he walks around the bulb it will always keep on the opposite side. It may begin to spin around the terminal long before it reaches the sensitive stage. When it begins to turn around principally, but also before, it is affected by a magnet, and at a certain stage it is susceptible to magnetic influence to an astonishing degree. A small permanent magnet, with its poles at a distance of no more than 1 inch, will affect it visibly at a distance of 7 feet, slowing down or accelerat-

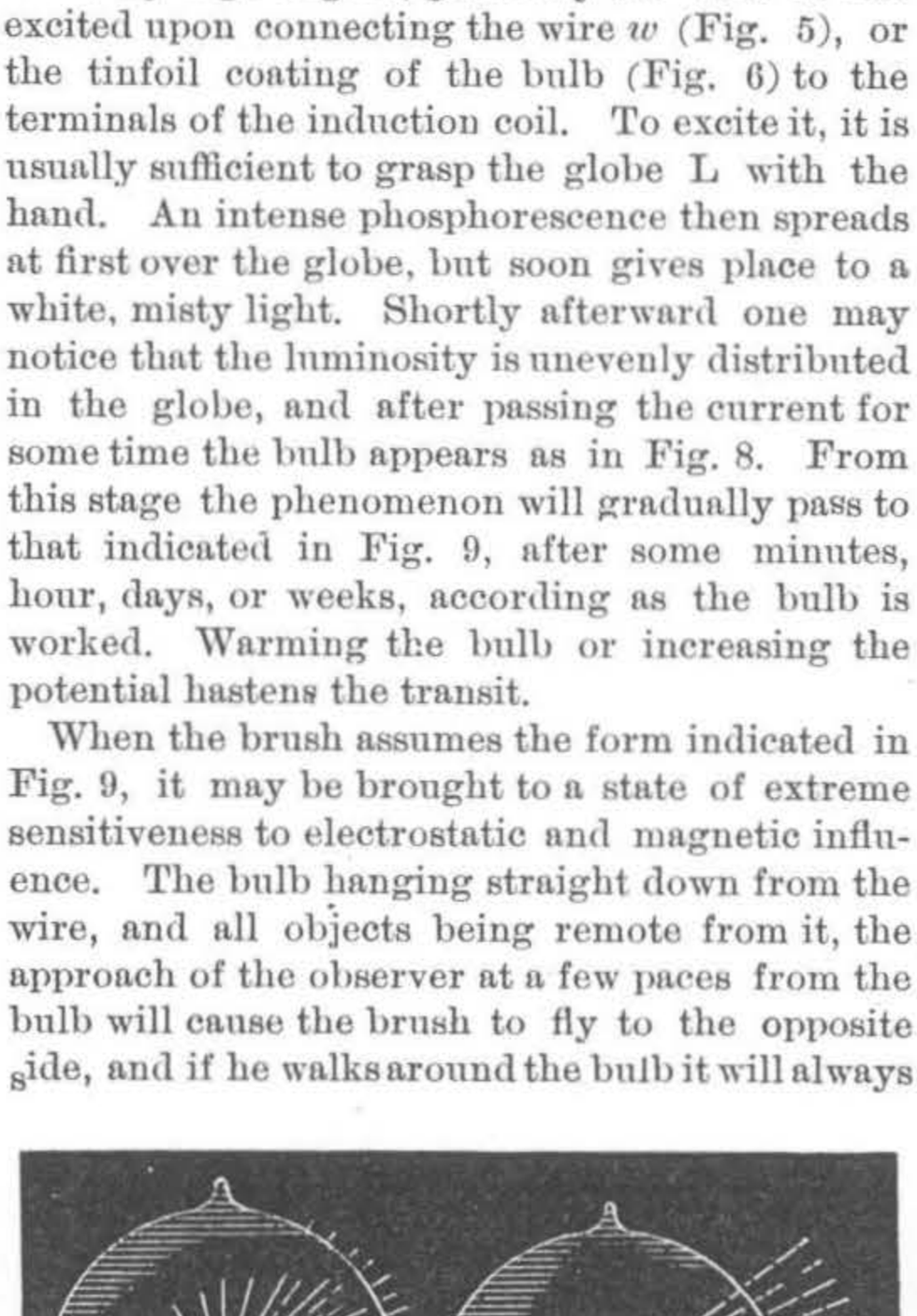

FIG. 8. FIG. 9.

* Abstract of a lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the Journal of the Institution.

ing the rotation according to how it is held relatively to the brush. I think I have observed that at the stage when it is most sensitive to magnetic, it is not most sensitive to electrostatic influence. My explanation is that the electrostatic attraction between the brush and the glass of the bulb, which retards the rotation, grows much quicker than the magnetic influence when the intensity of the stream is increased.

When the bulb hangs with the globe L down, the rotation is always clockwise. In the southern hemisphere it would occur in the opposite direction, and on the equator the brush would not turn at all. The rotation may be reversed by a magnet kept at some distance. The brush rotates best, seemingly, when it is at right angles to the lines of force of the earth. It very likely rotates, when at its maximum speed, in synchronism with the alterations, say 10,000 times a second. The rotation can be slowed down or accelerated by the approach or receding of the observer or any conducting body, but it cannot be reversed by putting the bulb in any position. When it is in the state of the highest sensitiveness and the potential or frequency is varied, the sensitiveness is rapidly diminished. Changing either of these but little will generally stop the rotation. The sensitiveness is likewise affected by the variations of the temperature. To attain great sensitiveness it is necessary to have the small sphere s in the centre of the globe L, as otherwise the electrostatic action of the glass of the globe will tend to stop the rotation. The sphere s should be small and of uniform thickness; any dissymmetry of course has the effect of diminishing the sensitiveness.

The fact that the brush rotates in a definite direction in a permanent magnetic field seems to show that in alternating currents of very high frequency the positive and negative impulses are not equal, but that one always preponderates over the other.

Of course, this rotation in one direction may be due to the action of two elements of the same current upon each other, or to the action of the field produced by one of the elements upon the other, as in a series motor, without necessarily one impulse being stronger than the other. The fact that the brush turns, as far as I could observe, in any position, would speak for this view. In such case it would turn at any point of the earth's surface. But, on the other hand, it is then hard to explain why a permanent magnet should reverse the rotation, and one must assume the preponderance of impulses of one kind.

As to the causes of the formation of the brush or stream, I think it is due to the electrostatic action of the globe and the dissymmetry of the parts. If the small bulb s and the globe L were perfect concentric spheres, and the glass throughout of the same thickness and quality, I think the brush would not form, as the tendency to pass would be equal on all sides. That the formation of the stream is due to an irregularity is apparent from the fact that it has the tendency to remain in one position, and rotation occurs most generally only when it is brought out of this position by electrostatic or magnetic influence. When in an extremely sensitive state it rests in one position, most curious experiments may be performed with it. For instance, the experimenter may, by selecting a proper position, approach the hand at a certain considerable distance to the bulb, and he may cause the brush to pass off by merely stiffening the muscles of the arm. When it begins to rotate slowly, and the hands are held at a proper distance, it is impossible to make even the slightest motion without producting a visible effect upon the brush. A metal plate connected to the other terminal of the coil affects it at a great distance, slowing down the rotation often to one turn a second.

I am firmly convinced that such a brush, when we learn how to produce it properly, will prove a valuable aid in the investigation of the nature of the forces acting in an electrostatic or magnetic field. If there is any motion which is measurable going on in the space, such a brush ought to reveal it. It is, so to speak, a beam of light, frictionless, devoid of inertia.

I think that it may find practical application in telegraphy. With such a brush it would be possible to send dispatches across the Atlantic, for instance, with any speed, since its sensitiveness may be so great that the slightest changes will affect it. If it were possible to make the stream more intense and very narrow, its deflections could be easily photographed.

I have been interested to find whether there is a rotation of the stream itself, or whether there is simply a stress traveling around in the bulb. For this purpose I mounted a light mica fan so that its vanes were in the path of the brush. If the stream itself was rotating, the fan would be spun around. I could produce no distinct rotation of the fan, although I tried the experiment repeatedly; but as the fan exerted a noticeable influence on the stream, and the apparent rotation of the latter was, in this case, never quite satisfactory, the experiments did not appear to be conclusive.

I have been unable to produce the phenomenon with the disruptive discharge coil, although every other of these phenomena can be well produced by it—many, in fact, much better than with coils operated from an alternator.

It may be possible to produce the brush by impulses of one direction, or even by a steady potential, in which case it would be still more sensitive to magnetic influence.

In operating an induction coil with rapidly alternating currents, we realize with astonishment, for the first time, the great importance of the relation of capacity, self-induction and frequency as regards the general result. The effects of capacity are the most striking, for in these experiments, since the self-induction and frequency both are high, the critical capacity is very small and need be but slightly varied to produce a very considerable change. The experimenter may bring his body in contract with the terminals of the secondary of the coil, or attach to one or both terminals insulated bodies of very small bulk, such as bulbs, and he may produce a considerable rise or fall of potential, and greatly affect the flow of the current through the primary. In the experiment before shown, in which a brush appears at a wire attached to one terminal, and the wire is vibrated when the experimenter brings his insulated body in contact with the other terminal of the coil, the sudden rise of potential was made evident.

I may show you the behavior of the coil in another manner which possesses a feature of some interest. I have here a little light fan of aluminum sheet, fastened to a needle and arranged to rotate freely in a metal piece screwed to one of the terminals of the coil. When the coil is set to work, the molecules of the air are rhythmically attracted and repelled. As the force with which they are repelled is greater than that with which they are attracted, it results that there is a repulsion exerted on the surfaces of the fan. If the fan were made simply of a metal sheet, the repulsion would be equal on the opposite sides, and would produce no effect. But, if one of the opposing surfaces is screened, or if, generally speaking, the bombardment on this side is weakened in some way or other, there remains the repulsion exerted upon the other, and the fan is set in rotation. The screening is best effected by fastening upon one of the opposing sides of the fan an insulated conducting coating, or, if the fan is made in the shape of an ordinary propeller screw, by fastening on one side, and close to it, an insulated metal plate. The static screen may, however, be omitted, and simply a thickness of insulating material fastened to one of the sides of the fan.

To show the behavior of the coil, the fan may be placed upon the terminal and it will readily rotate when the coil is operated by currents of very high frequency. With a steady potential of course, and even with alternating currents of very low frequency, it would not turn, because of the very slow exchange of air and, consequently, smaller bombandment; but in the latter case it might turn if the potential were excessive. With a pin wheel, quite the opposite rule holds good; it rotates best with a steady potential, and the effort is the smaller the higher the frequency. Now, it is very easy to adjust the conditions so that the potential is normally not sufficient to turn the fan, but that by connecting the other terminal of the coil with an insulated body it rises to a much greater value, so as to rotate the fan, and it is likewise possible to stop the rotation by connecting to the terminal a body of different size, thereby diminishing the potential.

Instead of using the fan in this experiment, we may use the "electric" radiometer with similar effect. But in this case it will be found that the vanes will rotate only at high exhaustion or at ordinary pressures; they will not rotate at moderate pressures, when the air is highly conducting. This curious observation was made conjointly by Professor Crookes and myself. I attribute the result to the high conductivity of the air, the molecules of which then do not act as independent carriers of electric charges, but act all together as a single conducting body. In such case, of course, if there is any repulsion at all of the molecules from the vanes, it must be very small. It is possible, however, that the result is in part due to the fact that the greater part of the discharge passes from the leading-in wire through the highly conducting gas, instead of passing off from the conducting vanes.

In trying the preceding experiment with the electric radiometer, the potential should not exceed a certain limit, as the electrostatic attraction between the vanes and the glass of the bulb may be so great as to stop the rotation.

A most curious feature of alternate currents of high frequencies and potential is that they enable us to perform many experiments by the use of one wire only. In many respects this feature is of great interest.

In a type of alternate current motor invented by me some years ago I produced rotation by inducing, by means of a single alternating current passed through a motor circuit, in the mass or other circuits of the motor, secondary currents, which, jointly with the primary or inducing current created a moving field of force. A simple but crude form of such a motor is obtained by winding upon an iron core a primary, and close to it a secondary coil joining the ends of the latter and placing a freely movable metal disc within the influence of the field produced by both. The iron core is employed for obvious reasons, but it is not essential to the operation. To improve the motor, the iron core is made to encircle the armature. Again to improve, the secondary coil is made to overlap partly the primary, so that it cannot free itself from a strong inductive action of the latter, repel its lines as it may. Once more to improve, the proper difference of phase is obtained between the primary and secondary currents by a condenser, self-induction, resistance or equivalent windings.

To be continued.

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

PART III.

BY NIKOLA TESLA.

I had discovered, however, that rotation is produced by means of a single coil and core; my explanation of the phenomenon, and leading thought in trying the experiment, being that there must be a true time lag in the magnetization of the core. I remember the pleasure I had when, in the writings of Professor Ayrton, which came later to my hand I found the idea of the time lag advocated. Whether there is a true time lag, or whether the retardation is due to eddy currents circulating in minute paths, must remain an open question, but the fact is that a coil wound upon an iron core and traversed by an alternating current creates a moving field of force, capable of setting an armature in rotation. It is of some interest, in conjunction with the historical Arago experiment, to mention that in lag or phase motors I have produced rotation in the opposite direction to the moving field, which means that in that experiment the magnet may not rotate, or may even rotate in the opposite direction to the moving disc. Here, then, is a motor (diagrammatically illustrated in Fig. 10), comprising a coil and iron core and a freely movable copper disc in proximity to the latter.

To demonstrate a novel and interesting feature, I have, for a reason which I will explain, selected this type of motor. When the ends of the coil are connected to the terminals of an alternator the disc is set in rotation. But it is not this experiment, now well known, which I desire to perform. What I wish to show you is that this motor rotates with *one single* connection between it and the generator; that is to say, one terminal of the motor is connected to one terminal of the generator—in this case the secondary of a high-tension induction coil—the other terminals of motor and generator being insulated in space. To produce rotation it is generally (but not absolutely) necessary to connect the free end of the motor coil to an insulated body of some size. The experimenter's body is more than sufficient. If he touches the free terminal with an object held in the hand, a current passes through the coil and the copper disc is set in rotation. If an exhausted tube is put in series with the coil, the tube lights brilliantly, showing the passage of a strong current. Instead of the experimenter's body, a small metal sheet suspended on a cord may be used with the same result. In this case the plate acts as a condenser in series with the coils. It counteracts the self-induction of the latter, and allows a strong current to pass. In such a combination, the greater the self-induction of the coil the smaller need be the plate, and this means that a lower frequency, or eventually a lower potential, is required to operate the motor. A single coil wound upon a core has a high self-inducton; for this reason principally, this type of motor was chosen to perform the experiment. Were a secondary closed coil wound upon the core, it would tend to diminish the self-induction, and then it would be necessary to employ a much higher frequency and potential. Neither would be advisable, for a higher potential would endanger the insulation of the small primary coil, and a higher frequency would result in a materially diminished torque.

It should be remarked that when such a motor with a closed secondary is used, it is not at all easy to obtain rotation with excessive frequencies, as the secondary cuts off almost completely

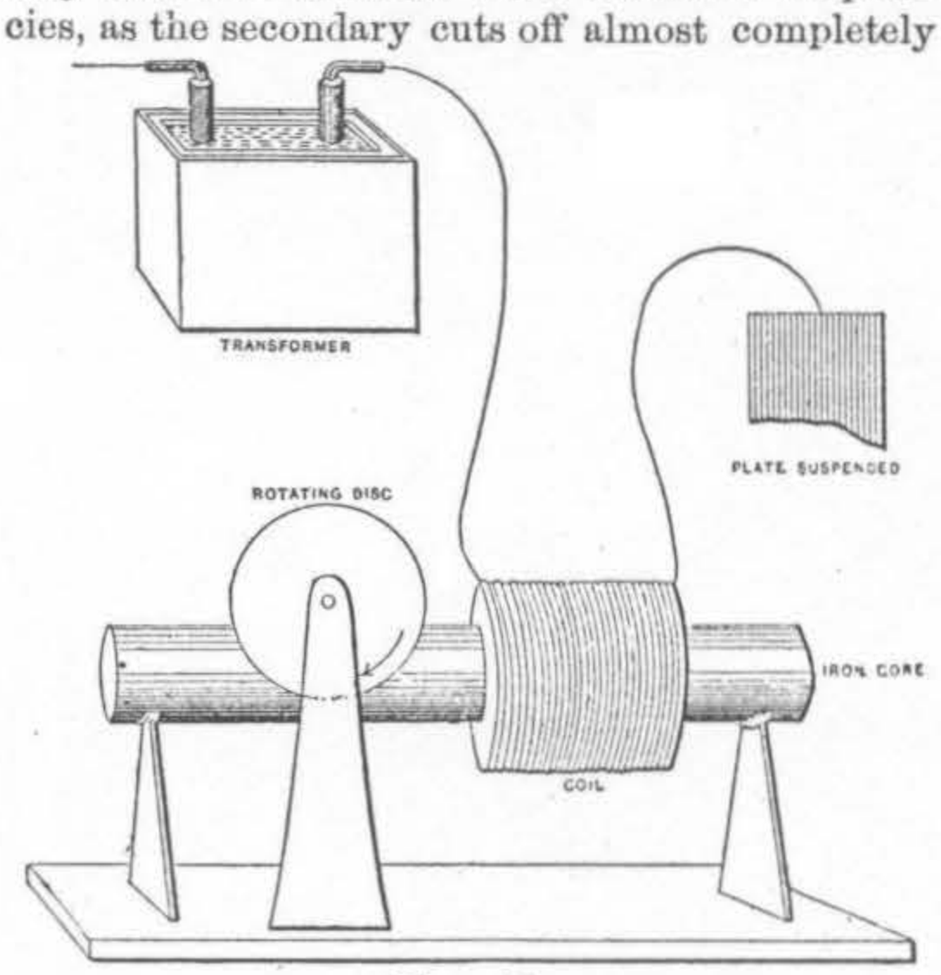

FIG. 10.

the lines of the primary—and this, of course, the more, the higher the frequency—and allows the passage of but a minute current. In such a case, unless the secondary is closed through a condenser, it is almost essential, in order to produce rotation, to make the primary and secondary coils overlap each other more or less.

But there is an additional *feature of interest* about this motor, namely, it is not necessary to have even a single connection between the motor and generator, except, perhaps, through the ground; for not only is an insulated plate capable of giving off energy into space, but it is likewise capable of deriving it from an alternating electrostatic field, though in the latter case the available energy is much smaller. In this instance one of the motor terminals is connected to the insulated plate or body located within the alternating electrostatic field, and the other terminal preferably to the ground.

It is quite possible, however, that such "no-wire" motors, as they might be called, could be operated by conduction through the rarefied air at considerable distances. Alternate currents, es-

* Abstract of a lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the Journal of the Institution.

pecially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. The upper strata of the air are rarefied. To reach a number of miles out into space requires the overcoming of difficulties of a merely mechanical nature. There is no doubt that with the enormous potentials obtainable by the use of high frequencies and oil insulation, luminous discharges might be passed through many miles of rarefied air, and that, by thus directing the energy of many hundreds or thousands of horse-power, motors or lamps might be operated at considerable distances from stationary sources. But such schemes are mentioned merely as possibilities. We shall have no need to transmit power in this way. We shall have no need to *transmit* power at all. Ere many generations pass, our machinery will be driven by a power obtainable at any point of the universe. This idea is not novel. Men have been led to it long ago by instinct or reason. It has been expressed in many ways, and in many places, in history old and new. We find it in the delightful myth of Antheus, who derives power from the earth; we find it among the subtle speculations of one of your splendid mathematicians, and in many hints and statements of thinkers of the present time. Throughout space there is energy. Is this energy static or kinetic? If static our hopes are in vain; if kinetic—and this we know it is, for certain—then it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature. Of all, living or dead, Crookes came nearest to doing it. His radiometer will turn in the light of day and in the darkness of the night; it will turn everywhere where there is heat, and heat is everywhere. But, unfortunately, this beautiful little machine, while it goes down to posterity as the most interesting, must likewise be put on record as the most inefficient machine ever invented!

The preceding experiment is only one of many equally interesting experiments which may be performed by the use of only one wire with alternate currents of high potential and frequency. We may connect an insulated line to a source of such currents, we may pass an inappreciable current over the line, and on any point of the same we are able to obtain a heavy current, capable of fusing a thick copper wire. Or we may, by the help of some artifice, decompose a solution in any electrolytic cell by connecting only one pole of the cell to the line or source of energy. Or we may, by attaching it to the line, or only bringing it into its vicinity, light up an incandescent lamp, an exhausted tube, or a phosphorescent bulb.

However impracticable this plan of working may appear in many cases, it certainly seems practicable, and even recommendable, in the production of light. A perfected lamp would require but little energy, and if wires were used at all we ought to be able to supply that energy without a return wire.

It is now a fact that a body may be rendered incandescent or phosphorescent by bringing it either in single contact or merely in the vicinity of a source of electric impulses of the proper character, and that in this manner a quantity of light sufficient to afford a practical illuminant may be produced. It is, therefore, to say the least, worth while to attempt to determine the best conditions, and to invent the best appliances for attaining this object.

Some experiences have already been gained in this direction, and I will dwell on them briefly, in the hope that they may prove useful.

The heating of a conducting body inclosed in a bulb, and connected to a source of rapidly alternating electric impulses, is dependent on so many things of a different nature, that it would be difficult to give a generally applicable rule under which the maximum heating occurs. As regards the size of the vessel, I have lately found that at ordinary or only slightly differing atmospheric pressures, when air is a good insulator, and hence practically the same amount of energy by a certain potential and frequency is given off from the body, whether the bulb be small or large, the body is brought to a higher temperature if inclosed in a small bulb, because of the better confinement of heat in this case,

At lower pressures, when air becomes more or less conducting, or if the air be sufficiently warmed as to become conducting, the body is rendered more intensely incandescent in a large bulb, obviously because, under otherwise equal conditions of test, more energy may be given off from the body when the bulb is large.

At very high degrees of exhaustion, when the matter in the bulb becomes "radiant," a large bulb has still an advantage, but a comparatively slight one, over the small bulb.

Interesting and useful results can no doubt be reached in the direction of extreme degrees of heat. How can such high temperatures be arrived at? How are the highest degrees of heat reached in nature? By the impact of stars, by high speeds and collisions. In a collision any rate of heat generation may be attained. In a chemical process we are limited. When oxygen and hydrogen combine, they fall, metaphorically speaking, from a definite height. We cannot go very far with a blast, nor by confining heat in a furnace, but in an exhausted bulb we can concentrate any amount of energy upon a minute button. Leaving practicability out of consideration, this, then, would be the means which, in my opinion, would enable us to reach the highest temperature. But a great difficulty when proceeding in this way is encountered; namely, in most cases the body is carried off before it can fuse and form a drop. This difficulty exists principally with an oxide such as zirconia, because it cannot be compressed in so hard a cake that it would not be carried off quickly. I endeavored repeatedly to fuse zirconia, placing it in a cup of arc light carbon as indicated in Fig. II. It glowed with a most intense light, and the stream of the particles projected out of the carbon cup was of a vivid white; but whether it was compressed in a cake or made into a paste with carbon, it was carried off before it could be fused. The carbon cup containing the zirconia had to be mounted very low in the neck of a large bulb, as the heating of the glass by the projected particles of the oxide was so rapid that in the first trial the bulb was cracked almost in an instant when the current was turned on. The heating of the glass by the projected particles was found to be always greater when the carbon cup contained a body which was rapidly carried off—I presume because in such cases, with the same potential, higher speeds were reached, and also because, per unit of time, more matter was projected; that is, more particles would strike the glass.

The before mentioned difficulty did not exist, however, when the body mounted in the carbon cup offered great resistance to deterioration. For instance, when an oxide was first used in an oxygen blast and then mounted in the bulb, it melted very readily into a drop.

Generally during the process of fusion magnificent light effects were noted, of which it would be difficult to give an adequate idea. Fig. II is intended to illustrate the effects observed with the ruby drop. At first one may see a narrow funnel of white light projected against the top of the globe, where it produces an irregularly outlined phosphorescent patch. When the point of the ruby fuses, the phosphorescence becomes very powerful; but as the atoms are projected with much greater speed from the surface of the drop, soon the glass gets hot and "tired," and now only the outer edge of the patch glows. In this manner an intensely phosphorescent, sharply defined line *l*, corresponding to the outline of the drop, is produced, which spreads slowly over the globe as the drop gets larger. When the mass begins to boil, small bubbles and cavities are formed, which cause dark colored spots to sweep across the globe. The bulb may be turned downward without fear of the drop falling off, as the mass possesses considerable viscosity.

I may mention here another feature of some interest, which I believe to have noticed in the course of these experiments, though the observations do not amount to a certitude. It *appeared* that under the molecular impact caused by the rapidly alternating potential the body was fused and maintained in that state at a lower temperature in a highly exhausted bulb than was the case at normal pressure and application of heat in the ordinary way; that is, at least, judging from the quantity of the light emitted. One of the experiments performed may be mentioned here by way of illustration. A small piece of pumice stone was stuck on a platinum wire, and first melted to it in a gas burner. The wire was next placed between two pieces of charcoal and a burner applied so as to produce an intense heat, sufficient to melt down the pumice stone into a small glass-like button. The platinum wire had to be taken of sufficient thickness to prevent its melting in the fire. While in the charcoal fire, or when held in a burner to get a better idea of the degree of heat, the button glowed with great brilliancy. The wire with the button was then mounted in a bulb, and upon exhausting the same to a high degree, the current was turned on slowly so as to prevent the cracking of the button. The button was heated to the point of fusion, and when it melted it did not, apparently, glow with the same brilliancy as before, and this would indicate a lower temperature. Leaving out of consideration the observer's possible, and even probable error, the question is, can a body under these conditions be brought from a solid to a liquid state with evolution of *less* light?

When the potential of a body is rapidly alternated, it is certain that the structure is jarred. When the potential is very high, although the vibrations may be few—say 20,000 per second—the effect upon the structure may be considerable. Suppose, for example, that a ruby is melted into a drop by a steady application of energy. When it forms a drop it will emit visible and invisible waves, which will be in a definite ratio, and to the eye the drop will appear to be of a certain brilliancy. Next, suppose we diminish to any degree we choose the energy steadily supplied, and instead, supply energy which rises and falls according to a certain law. Now, when the drop is formed, there will be emitted from it three different kinds of vibrations—the ordinary visible, and two kinds of invisible waves; that is, the ordinary dark waves of all lengths and in addition, waves of a well defined character. The latter would not exist by a steady supply of the energy; still they help to jar and loosen the structure. If this really be the case, then the ruby drop will emit relatively less visible and more invisible waves than before. Then it would seem that when a platinum wire, for instance, is fused by currents alternating with extreme rapidity, it emits at the point of fusion less light and more invisible radiation than it does when melted by a steady current, though the total energy used up in the process of fusion is the same in both cases. Or, to cite another example, a lamp filament is not capable of withstanding as long with currents of extreme frequency as it does with steady currents, assuming that it be worked at the same luminous intensity. This means that for rapidly alternating currents the filament should be shorter and thicker. The

higher the frequency—that is, the greater the departure from the steady flow—the worse it would be for the filament. But if the truth of this remark were demonstrated, it would be erroneous to conclude that such a refractory button as used in these bulbs would be deteriorated quicker by currents of extremely high frequency than by steady or low frequency currents. From experience I may say that just the opposite holds good:

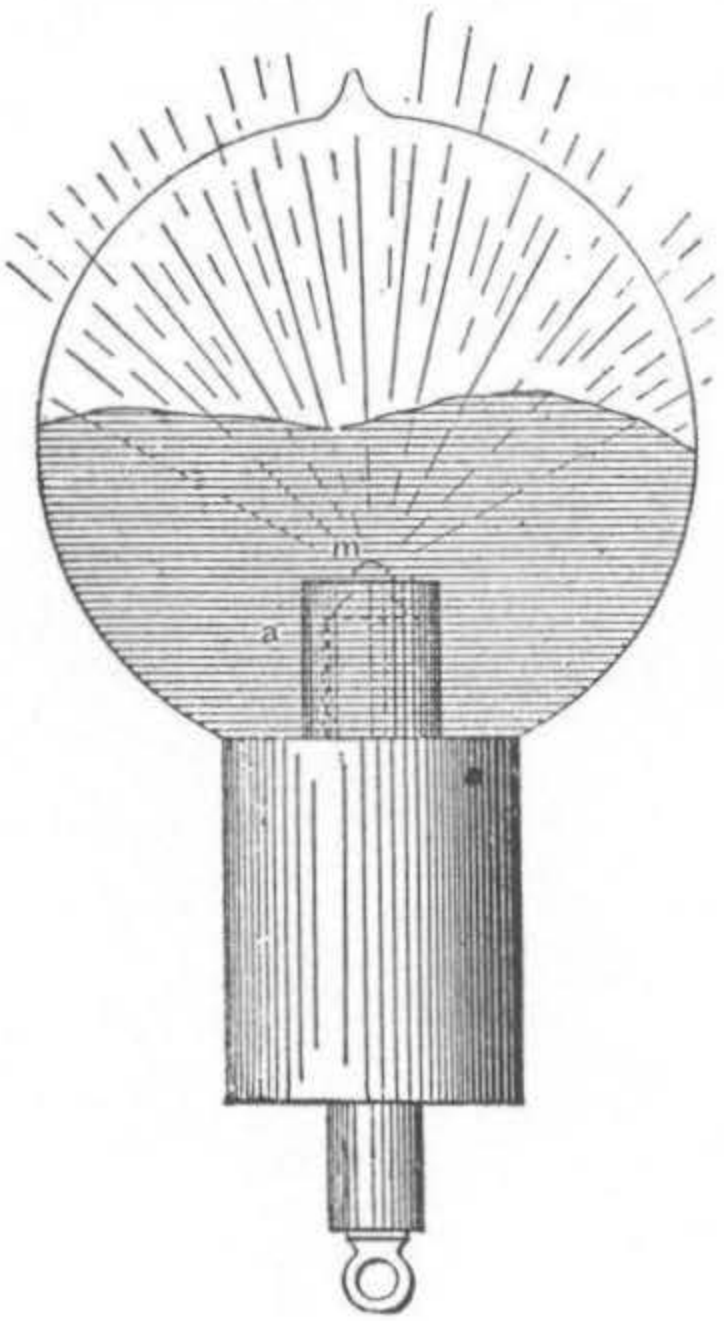

FIG. 11.

the button withstands the bombardment better with currents of very high frequency. But this is due to the fact that a high frequency discharge passes through a rarefied gas with much greater freedom than a steady or low frequency discharge, and this will say that with the former we can work with a lower potential or with a less violent impact. As long, then, as the gas is of no consequence, a steady or low frequency current is better; but as soon as the action of the gas is desired and important, high frequencies are preferable.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

PART V.

BY NIKOLA TESLA.

In the course of these experiments a great many trials were made with all kinds of carbon buttons. Electrodes made of ordinary carbon buttons were decidedly more durable when the buttons were obtained by the application of enormous pressure. Electrodes prepared by depositing carbon in well known ways did not show up well; they blackened the globe very quickly. From many experiences I conclude that lamp filaments obtained in this manner can be advantageously used only with low potentials and low frequency currents. Some kinds of carbon withstand so well that, in order to bring them to the point of fusion, it is necessary to employ very small buttons. In this case the observation is rendered very difficult on account of the intense heat produced. Nevertheless there can be no doubt that all kinds of carbon are fused under the molecular bombardment, but the liquid state must be one of great instability. Of all the bodies tried there were two which withstood best—diamond and carborundum.

There is no doubt that such a button—properly prepared under great pressure—of carborundum, especially of powder of the best quality, will withstand the effect of the bombardment fully as well as anything we know. The difficulty is that the binding material gives way, and the carborundum is slowly thrown off after some time. As it does not seem to blacken the globe in the least, it might be found useful for coating the filaments of ordinary incandescent lamps, and I think that it is even possible to produce thin threads or sticks of carborundum which will replace the ordinary filaments in an incandescent lamp. A carborundum coating seems to be more durable than other coatings, not only because the carborundum can withstand high degrees of heat, but also because it seems to unite with the carbon better than any other material I have tried. A coating of zirconia or any other oxide, for instance, is far more quickly destroyed. I prepared buttons of diamond dust in the same manner as of carborundum, and these came in durability nearest to those prepared of carborundum, but the binding paste gave way much more quickly in the diamond buttons; this, however, I attributed to the size and irregularity of the grains of the diamond.

If the carborundum proves useful in connection with these and similar experiments, its chief value will be found in the production of coatings, thin conductors, buttons, or other electrodes capable of withstanding extremely high degrees of heat.

The production of a small electrode capable of withstanding enormous temperatures I regard as of the greatest importance in the manufacture of light. It would enable us to obtain, by means of very high frequencies, certainly 20 times, if not more, the quantity of light which is obtained in the present incandescent lamp by the same expenditure of energy. This estimate may appear to many exaggerated, but in reality I think it is far from being so. As this statement might be misunderstood I think it necessary to expose clearly the problem with which, in this line of work, we are confronted, and the manner in which, in my opinion, a solution will be arrived at.

Any one who begins a study of the problem will be apt to think that what is wanted in a lamp with an electrode is a very high degree of incandescence of the electrode. There he will be mistaken. The high incandescence of the button is a necessary evil, but what is really wanted is the high incandescence of the gas surrounding the button. In other words, the problem in such a lamp is to bring a mass of gas to the highest possible incandescence. The higher the incandescence, the quicker the mean vibration, the greater is the economy of the light production. But to maintain a mass of gas at a high degree of incandescence in a glass vessel, it will always be necessary to keep the incandescent mass away from the glass; that is, to confine it as much as possible to the central portion of the globe.

In one of the experiments this evening a brush was produced at the end of a wire. This brush was a flame, a source of heat and light. It did not emit much perceptible heat, nor did it glow with an intense light; but is it the less a flame because it does not scorch my hand? Is it the less a flame because it does not hurt my eye by its brilliancy? The problem is precisely to produce in the bulb such a flame, much smaller in size, but incomparably more powerful. Were there means at hand for producing electric impulses of a sufficiently high frequency, and for transmitting them, the bulb could be done away with, unless it were used to protect the electrode, or to economize the energy by confining the heat. But as such means are not at disposal, it becomes necessary to place the terminal in a bulb and rarefy the air in the same. This is done merely to enable the apparatus to perform the work which it is not capable of performing at ordinary air pressure. In the bulb we are able to intensify the action to any degree—so far that the brush emits a powerful light.

The intensity of the light emitted depends principally on the frequency and potential of the impulses, and on the electric density on the surface of the electrodes. It is of the greatest importance to employ the smallest possible button in order to push the density very far. Under the violent impact of the molecules of the gas surrounding it, the small electrode is, of course, brought to an extremely high temperature, but around it is a mass of highly incandescent gas, a flame photosphere, many hundred times the volume of the electrode. With a diamond, carborundum, or zirconia button the photosphere can be as much as one thousand times the volume of the button. Without much reflection one would think that in pushing so far the incandescence of the electrode it would be instantly volatilized. But after a careful consideration he would find that, theoretically, it should not occur, and in this fact—which, however, is experimentally demonstrated—lies principally the future value of such a lamp.

At first, when the bombardment begins, most of the work is performed on the surface of the button, but when a highly conducting photosphere is formed, the button is comparatively relieved. The higher the incandescence of the photosphere the more it approaches in conductivity to that of the electrode, and the more, therefore, the solid and the gas form one conducting body. The consequence is that the further the incandescence is forced the more work comparatively, is performed on the gas, and the less on the electrode. The formation of a powerful photosphere is consequently the very means of protecting the electrode. This protection, of course, is a relative one, and it should not be thought that by pushing the incandescence higher, the electrode is actually less deteriorated. Still, theoretically, with extreme frequencies, this result must be reached, but probably at a temperature too high for most of the refractory bodies known. Given, then, an electrode which can withstand to a very high limit, the effect of the bombardment and outward strain, it would be safe no matter how much it is forced beyond that limit. In an incandescent lamp quite different considerations apply. There the gas is not at all concerned; the whole of the work is performed on the filament, and the life of the lamp diminishes so rapidly with the increase of the degree of incandescence that economical reasons compel us to work it at a low incandescence. But, if an incandescent lamp is operated with currents of very high frequency, the action of the gas cannot be neglected, and the rule for the most economical working must be considered modified.

In order to bring such a lamp with one or two electrodes to a great perfection, it is necessary to employ impulses of very high frequency. The high frequency secures, among others, two chief advantages, which have a most important bearing upon the economy of the light production. First, the deterioration of the electrodes is reduced by reason of the fact that we employ a great many small impacts, instead of a few violent ones which quickly shatter the structure; secondly, the formation of a large photosphere is facilitated.

In order to reduce the deterioration of the electrode to the minimum, it is desirable that the vibration be harmonic, for any suddenness hastens the process of destruction. An electrode lasts much longer when kept at incandescence by currents or impulses, obtained from a high frequency alternator, which rise and fall more or less harmonically, than by impulses obtained from a disruptive discharge coil. In the latter case there is no doubt that most of the damage is done by the fundamental sudden discharge.

One of the elements of loss in such a lamp is the bombardment of the globe. As the potential

* Abstract of a lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the Journal of the Institution.

is very high, the molecules are projected with great speed; they strike the glass, and usually excite a strong phosphorescence. The effect produced is very pretty, but for economical reasons it would be perhaps preferable to prevent, or at least, reduce to the minimum, the bombardment against the globe, as in such a case it is, as a rule, not the object to excite phosphorescence, and as some loss of energy results from the bombardment. This loss in the bulb is principally dependent on the potential of the impulses and on the electric density on the surface of the electrode. In employing very high frequencies the loss of energy by the bombardment is greatly reduced, for first, the potential needed to perform a given amount of work is much smaller; and, secondly, by producing a highly conducting photosphere around the electrode, the same result is obtained as though the electrode were much larger, which is equivalent to a smaller electric density. But, be it by the diminution of the maximum potential or of the density, the gain is effected in the same manner; namely, by avoiding violent shocks, which strain the glass much beyond its limit of elasticity. If the frequency could be brought high enough, the loss due to the imperfect elasticity of the glass would be entirely negligible. The loss due to the bombardment of the globe may, however, be reduced by using two electrodes instead of one. In such case each of the electrodes may be connected to one of the terminals; or else, if it is preferable to use only one wire, one electrode may be connected to one terminal and the other to the ground or to an insulated body of some surface, as, for instance, a shade on the lamp. In the latter case, unless some judgment is used, one of the electrodes glows more intensely than the other.

But, on the whole, I find it preferable when using such high frequencies to employ only one electrode and one connecting wire. I am convinced that the illuminating device of the near future will not require for its operation more than one lead, and, at any rate, it will have no leading-in wire, since the energy required can be as well transmitted through the glass. In experimental bulbs the leading-in wire is most generally used on account of convenience, as in employing condenser coatings in the manner before indicated. For example, there is some difficulty in fitting the parts, but these difficulties would not exist if a great many bulbs were manufactured; otherwise the energy can be conveyed through the glass as well as through a wire, and with these high frequencies the losses are very small. Such illuminating devices will necessarily involve the use of very high potentials, and this, in the eyes of practical men, might be an objectionable feature. Yet, in reality, high potentials are not objectionable—certainly not in the least as far as the safety of the devices is concerned.

There are two ways of rendering an electric appliance safe. One is to use low potentials, the other is to determine the dimensions of the apparatus so that it is safe no matter how high a potential is used. Of the two, the latter seems to me the better way, for then the safety is absolute, unaffected by any possible combination of circumstances which might render even a low-potential appliance dangerous to life and property. But the practical conditions require not only the judicious determination of the dimensions of the apparatus; they likewise necessitate the employment of energy of the proper kind. It is easy, for instance, to construct a transformer capable of giving, when operated from an ordinary alternate current machine of low tension, say 50,000 volts, which might be required to light a highly exhausted phosphorescent tube, so that, in spite of the high potential, it is perfectly safe, the shock from it producing no inconvenience. Still, such a transformer would be expensive, and in itself inefficient; and, besides, what energy was obtained from it would not be economically used for the production of light. The economy demands the employment of energy in the form of extremely rapid vibrations. The problem of producing light has been likened to that of maintaining a certain high-pitch note by means of a bell. It should be said a *barely audible* note; and even these words would not express it, so wonderful is the sensitiveness of the eye. We may deliver powerful blows at long intervals, waste a good deal of energy, and still not get what we want; or we may keep up the note by delivering frequent gentle taps, and get nearer to the object sought by the expenditure of much less energy. In the production of light, as far as the illuminating device is concerned, there can be only one rule; that is, to use as high frequencies as can be obtained; but the means for the production and conveyance of impulses of such character impose, at present at least, great limitations. Once it is decided to use very high frequencies, the return wire becomes unnecessary, and all the appliances are simplified. By the use of obvious means the same result is obtained as though the return wire were used. It is sufficient for this purpose to bring in contact with the bulb, or merely in the vicinity of the same, an insulated body of some surface. The surface need, of course, be the smaller, the higher the frequency and potential used, and necessarily, also, the higher the economy of the lamp or other device.

This plan of working has been resorted to on several occasions this evening. So, for instance, when the incandescence of a button was produced by grasping the bulb with the hand, the body of the experimenter merely serves to intensify the action. The coil being excited to a small potential, not sufficient to bring the button to incandesence when the bulb was hanging from the wire; and incidentally, in order to perform the experiment in a more suitable manner, the button was taken so large that a perceptible time had to elapse before, upon grasping the bulb, it could be rendered incandescent. The contact with the tube was, of course, quite unnecessary. It is easy, by using a rather large bulb with an exceedingly small electrode, to adjust the conditions so that the latter is brought to bright incandescence by the mere approach of the experimenter within a few feet of the bulb, and that the incandescence subsides upon his receding.

(*To be continued.*)

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EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

PART VI.

BY NIKOLA TESLA.

In another experiment, when phosphorescence was excited, a similar bulb was used. Here again again, originally, the potential was not sufficient to excite phosphorescence until the action was intensified—in this case, however, to present a different feature, by touching the socket with a metallic object held in the hand. The electrode in the bulb was a carbon button so large that it could not be brought to incandescence, and thereby spoil the effect produced by phosphorescence.

Again, in another of the early experiments, a bulb was used as illustrated in Fig. 5. In this instance, by touching the bulb with one or two fingers, one or two shadows of the stem inside were projected against the glass, the touch of the finger producing the same result as the application of an external negative electrode under ordinary circumstances.

In all these experiments the action was intensified by augmenting the capacity at the end of the lead connected to the terminal. As a rule, it is not necessary to resort to such means, and would be quite unnecessary with still higher frequencies; but when it *is* desired, the bulb, or tube, can be easily adapted to the purpose.

In Fig. 12, for example, an experimental bulb L is shown, which is provided with a neck n on the top for the application of an external tinfoil coating, which may be connected to a body of larger surface. Such a lamp as illustrated in Fig, 13 may also be lighted by connecting the tinfoil coating on the neck n to the terminal, and the leading-in wire w to an insulated plate. If the bulb stands in a socket upright, as shown in the cut, a shade of conducting material may be slipped in the neck n, and the action thus magnified.

A more perfected arrangement used in some of these bulbs is illustrated in Fig. 14.

It is obviously of advantage in such a lamp to confine as much as possible the heat to the electrode by preventing the circulation of the gas in the bulb. If a very small bulb be taken, it would confine the heat better than a large one, but it might not be of sufficient capacity to be operated from the coil, or, if so, the glass might get too hot. A simple way to improve in this direction is to employ a globe of the required size, but to place a small bulb, the diameter of which is properly estimated, over the refractory button contained in the globe. This arrangement is illustrated in Fig. 15.

The globe L has in this case a large neck n, allowing the small bulb b to slip through. The small bulb is conveniently supported upon the stem s, carrying the refractory button m. It is separated from the aluminium tube a by several layers of mica M, in order to prevent the cracking of the neck by the rapid heating of the aluminium tube upon a sudden turning on of the current. The inside bulb should be as small as possible when it is desired to obtain light only by incandescence of the electrode. If it is desired

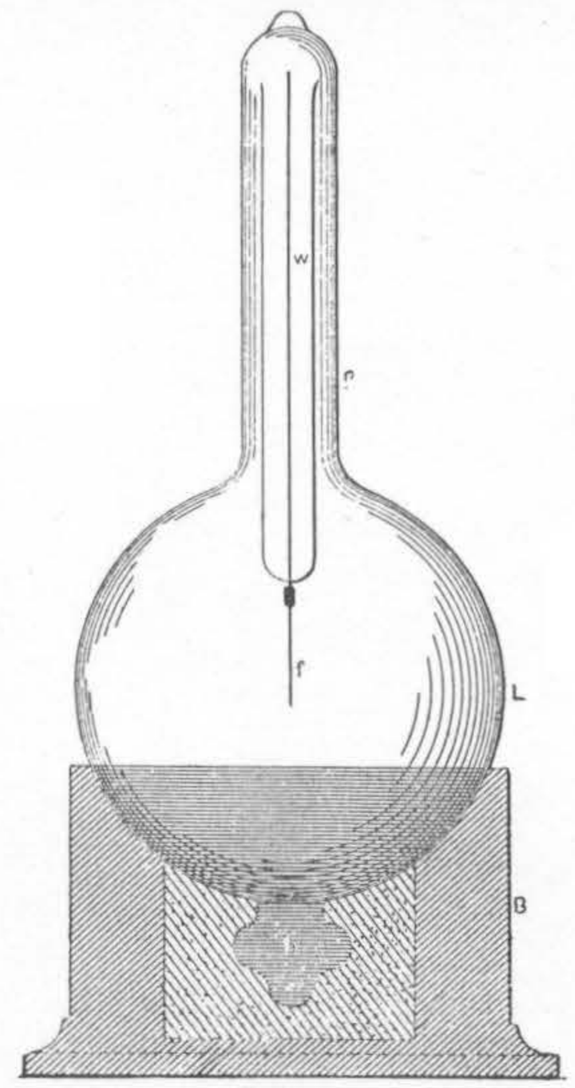

FIG. 12.

to produce phosphorescence, the bulb should be larger, else it would be apt to get too hot, and the phosphorescence would cease. In this arrangement usually only the small bulb shows phosphoresence, as there is practically no bombardment against the outer globe. In some of these bulbs constructed as illustrated in Fig. 15 the small tube was coated with phosphorescent paint, and beautiful effects were obtained. Instead of making the inside bulb large, in order to avoid undue heating, it answers the purpose to make the electrode m larger. In this case the bombardment is weakened by reason of the smaller

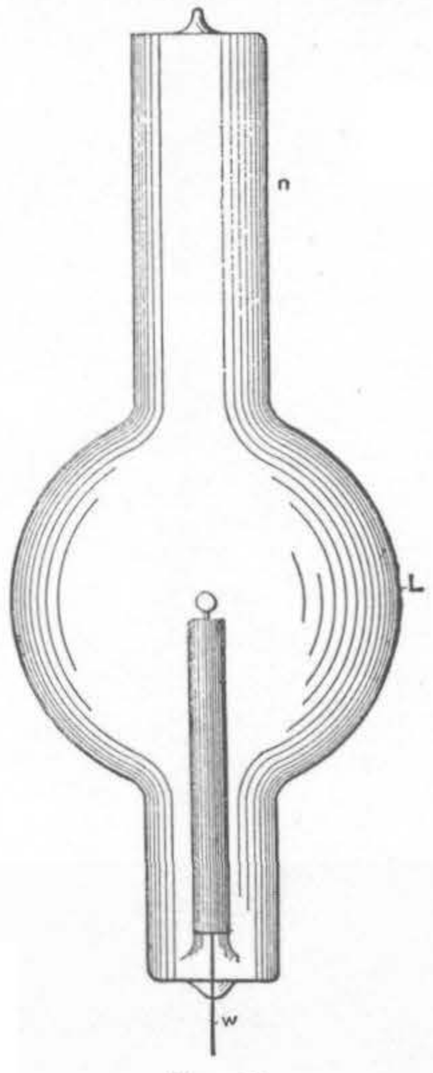

FIG. 13.

electric density.

But by far the better way—the ideal way—would be to reach sufficiently high frequencies. The higher the frequency the slower would be the exchange of the air, and I think that a frequency may be reached at which there would be no exchange whatever of the air molecules around the terminal. We would then produce a flame in which there would be no carrying away of material, and a queer flame it would be, for it would be rigid! With such high frequencies the inertia of the particles would come into play. As the brush, or flame, would gain rigidity in virtue of the inertia of the particles, the exchange of the latter would be prevented. This would necessarily occur, for, the number of the impulses being augmented, the potential energy of each would diminish, so that finally only atomic vibrations could be set up, and the motion of translation through measurable space would cease. Thus an ordinary gas burner connected to a source of rapidly alternating potential might have its efficiency augmented to a certain limit, and this for two reasons—because of the additional vibration imparted, and because of a slowing down of the process of carrying off. But the renewal being rendered difficult, and renewal being necessary to maintain the *burner*, a continued increase of the frequency of the impulses, assuming they could be transmitted to, and impressed upon the flame, would result in the "extinction" of the latter, meaning by this term only the cessation of the chemical process.

I thlnk, however, that in the case of an electrode immersed in a fluid insulating medium, and surrounded by independent carriers of electric charges, which can be acted upon inductively, a sufficiently high frequency of the impulses would probably result in a gravitation of the gas

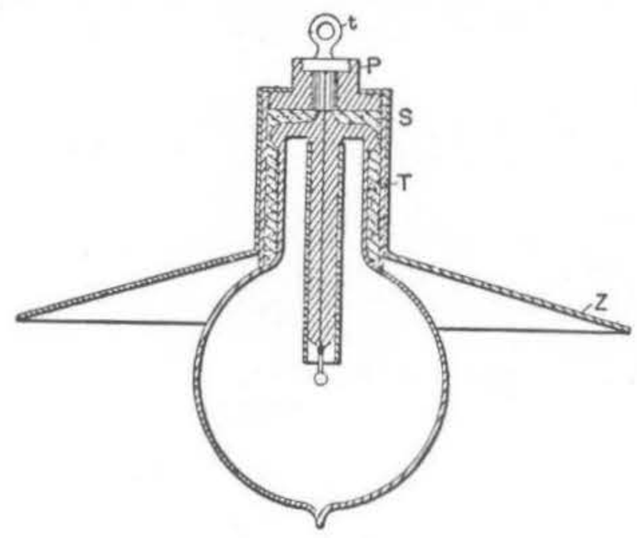

FIG. 14.

all around toward the electrode. For this it would be only necessary to assume that the independent bodies are irregularly shaped; they would then turn toward the electrode their side of the greatest electric density, and this would be a position in which the fluid resistance to approach would be smaller than that offered to the receding.

The general opinion, I do not doubt, is that it is out of question to reach any such frequencies as might—assuming some of the views before expressed to be true—produce any of the results which I have pointed out as mere possibilities. This may be so, but in the course of these investigations, from the observation of many phenomena I have gained the conviction that these frequencies would be much lower than one is apt to estimate at first. In a flame we set up light vibrations by causing molecules, or atoms, to collide. But what is the ratio of the frequency of the collisions and that of the vibrations set up? Certainly it must be incomparably smaller than that of the knocks of the bell and the sound vibrations, or that of the discharges and the oscillations of the condenser. We may cause the molecules of the gas to collide by the use of alternate electric impulses of high frequency, and so we may imitate the process in a flame; and from experiments with frequencies which we are now able to obtain, I think that the result is producible with impulses which are transmissible through a conductor.

In connection with thoughts of a similar nature,

* Abstract of a lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the Journal of the Institution.

it appeared to me of great interest to demonstrate the rigidity of a vibrating gaseous column. Although with such low frequencies as, say 10,000 per second, which I was able to obtain without difficulty from a specially constructed alternator, the task looked discouraging at first, I made a series of experiments. The trials with air at ordinary pressure led to no result, but with air moderately rarefied I obtain what I think to be an unmistakable experimental evidence of the property sought for. As a result of this kind might lead able investigators to conclusions of importance I will describe one of the experiments performed.

It is well known that when a tube is slightly exhausted the discharge may be passed through it in the form of a thin luminous thread. When produced with currents of low frequency, obtained from a coil operated as usual, this thread is inert. If a magnet be approached to it, the part near the same is attracted or repelled, according to the direction of the lines of force of the magnet. It occurred to me that if such a thread would be produced with currents of very high frequency, it shotuld be more or less rigid, and as it was visible it could be easily studied. Accordingly I prepared a tube about one inch in diameter and one metre long, with outside coating at each end. The tube was exhausted to a point at which by a little working the thread discharge could be obtained. It must be remarked here that the general aspect of the tube, and the degree of exhaustion, are quite different from those employed when ordinary low frequency

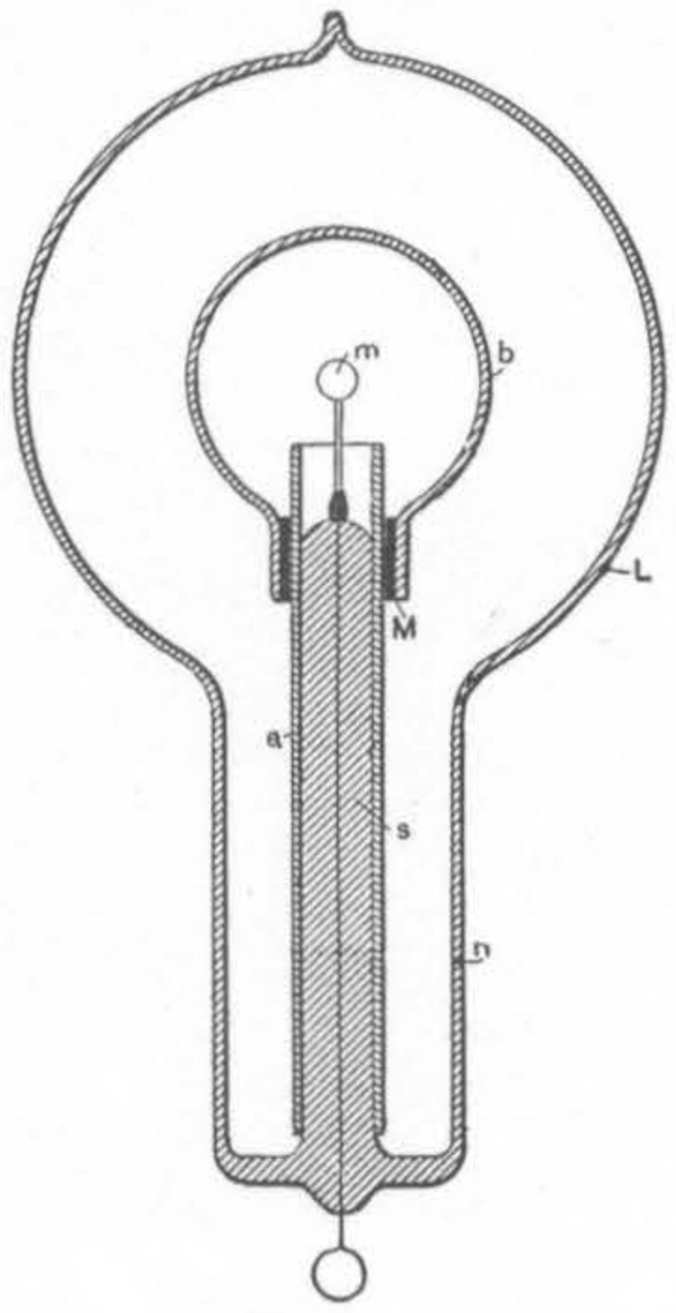

FIG. 15.

currents are used. As it was found preferable to work with one terminal, the tube prepared was suspended from the end of a wire connected to the terminal, the tinfoil coating being connected to the wire, and to the lower coating sometimes a small insulated plate was attached. When the thread was formed it extended through the upper part of the tube and lost itself in the lower end. If it possessed rigidity it resembled, not exactly an elastic cord stretched tight between two supports, but a cord suspended from a height with a small weight attached at the end. When a finger or a magnet was approached to the upper end of the luminous thread, it could be brought locally out of position by electrostatic or magnetic action; and when the disturbing object was very quickly removed, an analogous result was produced just as a suspended cord would be displaced and quickly released near the point of suspension. In doing this the luminous thread was set in vibration, and two very sharply marked nodes, nd a third indistinct one, were formed. The vibration, once set up, continued for fully eight minutes, dying gradually out. The speed of the vibration often varies perceptibly, and it could be observed that the electrostatic attraction of the glass affected the vibrating thread; but it was clear that the electrostatic action was not the cause of the vibration, for the thread was most generally statio....y, and could always be set in vibration by passing the finger quickly near the upper part of the tube. With a magnet the thread could be split in two and both parts vibrated. By approaching the hand to the lower coating of the tube, or insulated plate if attached, the vibration was quickened; also, as far as I could see, by raising the potential or frequency. Thus, either increasing the frequency or passing a stronger discharge of the same frequency corresponded to a tightening of the cord. I did not obtain any experimental evidence with condenser discharges. A luminous band excited in a bulb by repeated discharges of a Leyden jar must possess rigidity, and if deformed and suddenly released should vibrate. But probably the amount of vibrating matter is so small that in spite of the extreme speed the inertia cannot prominently assert itself. Besides, the observation in such a case is rendered extremely difficult on account of the fundamental vibration.

The demonstration of the fact—which still needs better experimental confirmation—that a vibrating gaseous column possesses ridigity, might greatly modify the views of thinkers. When with low frequencies and insignificant potentials indications of that property may be noted, how must a gaseous medium behave under the influence of enormous electrostatic stresses which may be active in the interstellar space and which may alternate with inconceivable rapidity? The existence of such an electrostatic, rhythmically throbbing force—of a vibrating electrostatic field—would show a possible way how solids might have formed from the ultra-gaseous uterus, and how transverse and all kinds of vibrations may be transmitted through a gaseous medium filling all space. Then, ether might be a true fluid, devoid of rigidity, and at rest, it being merely necessary as a connecting link to enable interaction. What determines the rigidity of a body? It must be the speed and the amount of moving matter. In a gas the speed may be considerable, but the density is exceeding small; in a liquid the speed would be likely to be small, though the density may be considerable; and in both cases the inertia resistance offered to displacement is practically *nil*. But place a gaseous (or liquid) column in an intense, rapidly alternating electrostatic field, set the particles vibrating with enormous speeds, then the inertia resistance asserts itself. A body might move with more or less freedom through the vibrating mass, but as a whole it would be rigid.

(To be continued.)

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EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

PART VII.

BY NIKOLA TESLA.

There is a subject which I must mention in connection with these experiments—it is that of high vacua. This is a subject the study of which is not only interesting, but useful, for it may lead to results of great practical importance. In commercial apparatus, such as incandescent lamps, operated from ordinary systems of distribution, a much higher vacuum than obtained at present would not secure a very great advantage. In such a case the work is performed on the filament and the gas is little concerned; the improvement, therefore, would be but trifling. But when we begin to use very high frequencies and potentials, the action of the gas becomes all important, and the degree of exhaustion materially modifies the results. As long as ordinary coils, even very large ones, were used, the study of the subject was limited, because just at a point when it became most interesting it had to be interrupted on account of the "non-striking" vacuum being reached. But presently we are able to obtain from a small disruptive discharge coil potentials much higher than even the largest coil was capable of giving, and, what is more, we can make the potential alternate with great rapidity. Both of these results enable us now to pass a luminous discharge through almost any vacua obtainable, and the field of our investigations is greatly extended. Think we as we may, of all the possible directions to develop a practicable illuminant, the line of high vacua seems to be the most promising at present. But to reach extreme vacua the appliances must be much more improved, and ultimate perfection will not be attained until we shall have discarded the mechanical and perfected an *electrical* vacuum pump. Molecules and atoms can be thrown out of a bulb under the action of an enormost potential: *this* will be the principle of the vacuum pump of the future.

It is a striking fact that the discharge through a gas is established with ever increasing freedom as the frequency of the impulses is augmented. It behaves in this respect quite contrarily to a metallic conductor. In the latter the impedance enters prominently into play as the frequency is increased, but the gas acts much as a series of condensers would; the facility with which the discharge passes through, seems to depend on the rate of change of potential. If it act so, then in a vacuum tube even of great length, and no matter how strong the current, self-induction could not assert itself to any appreciable degree. We have, then, as far as we can now see, in the gas a conductor which is capable of transmitting electric impulses of any frequency which we may be able to produce. Could the frequency be brought high enough, then a queer system of electric distribution, which would be likely to interest gas companies, might be realized: metal pipes filled with gas—the metal being the insulator, the gas the conductor—supplying phosphorescent bulbs, or perhaps devices as yet uninvented. It is certainly possible to take a hollow core of copper, rarify the gas in the same, and by passing impulses of sufficiently high frequency through a circuit around it, bring the gas inside to a high degree of incandescence; but as to the nature of the forces there would be considerable uncertainty, for it would be doubtful whether with such impulses the copper core would act as a static screen. Such paradoxes and apparent impossibilities we encounter at every step in this line of work, and therein lies, to a great extent, the charm of the study.

I have here a short and wide tube which is exhausted to a high degree and covered with a substantial coating of bronze, the coating allowing barely the light to shine through. A metallic

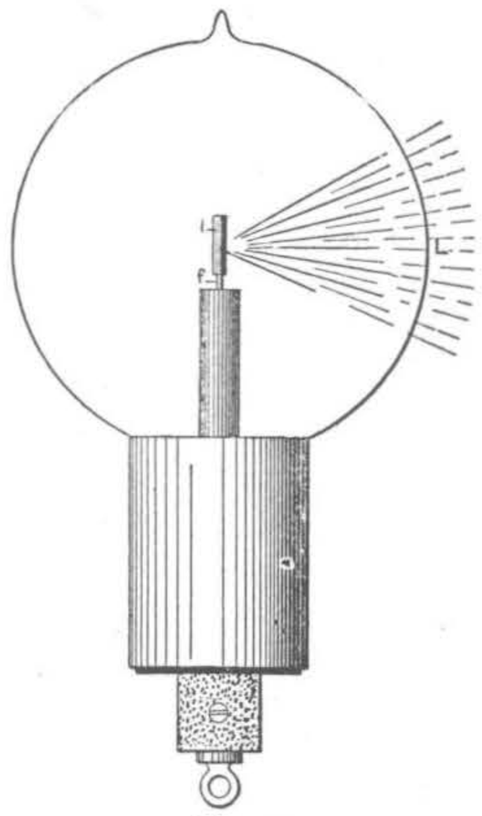


FIG. 16.

clasp, with a hook for suspending the tube, is fastened around the middle portion of the latter, the clasp being in contact with the bronze coating. I now want to light the gas inside by suspending the tube on a wire connected to the coil. Any one who would try the experiment for the first time, not having any previous experience, would probably take care to be quite alone when making the trial, for fear that he might become the joke of his assistants. Still, the bulb lights in spite of the metal coating, and the light can be distinctly perceived through the latter. A long tube covered with aluminium bronze lights when held in one hand—the other touching the terminal of the coil—quite powerfully. It might be objected that the coatings are not sufficiently conducting; still, even if they were highly resistant, they ought to screen the gas. They certainly screen it perfectly in a condition of rest, but not by far perfectly when the charge is surging in the coating. But the loss of energy which occurs within the tube, notwithstanding the screen, is occasioned principally by the presence of the gas. Were we to take a large hollow metallic sphere and fill it with a perfectly-incompressible fluid dielectric, there would be no loss inside of the sphere, and consequently the inside might be considered as perfectly screened, though the potential be very rapidly alternating. Even were the sphere filled with oil, the loss would be incomparably smaller than when the fluid is replaced by a gas, for in the latter case the force produces displacements; that means impact and collisions in the inside.

No matter what the pressure of the gas may be, it becomes an important factor in the heating of a conductor when the electric density is great and the frequency very high. That in the heating of conductors by lightning discharges air is an element of great importance, is almost as certain as an experimental fact. I may illustrate the action of the air by the following experiment: I I take a short tube which is exhausted to a moderate degree and has a platinum wire runnning through the middle from one end to the other. I pass a steady or low frequency current through the wire, and it is heated uniformly in all parts. The heating here is due to conduction, or frictional losses, and the gas around the wire has—as far as we can see—no function to perform. But now let me pass sudden discharges, or a high frequency current, through the wire. Again the wire is heated, this time principally on the ends and least in the middle portion; and if the frequency of the impulses, or the rate of change, is high enough, the wire might as well be cut in the middle as not, for practically all the heating is due to the rarefied gas. Here the gas might only act as a conductor of no impedance, diverting the current from the wire as the impedance of the latter is enormously increased, and merely heating the ends of the wire by reason of their resistance to the passage of the discharge. But it is not at all necessary that the gas in the tube should be conducting; it might be at an extremely low pressure, still the ends of the wire would be heated—as, however, is ascertained by experience—only the two ends would in such case not be electrically connected through the gaseous medium. Now what with these frequencies and potentials occurs in an exhausted tube, occurs in the lightning discharges at ordinary pressure. We only need remember one of the facts arrived at in the course of these investigations, namely, that to impulses of very high frequency the gas at ordinary pressure behaves much in the same manner as though it were at moderately low pressure. I think that in lightning discharges frequently wires or conducting objects are volatilized merely because air is present, and that, were the conductor immersed in an insulating liquid, it would be safe, for then the energy would have to spend itself somewhere else. From the behavior of gases to sudden impulses of high potential I am led to conclude that there can be no surer way of diverting a lightning discharge than by affording it a passage through a volume af gas, if such a thing can be done in a practical manner.

There are two more features upon which I think it necessary to dwell in connection with

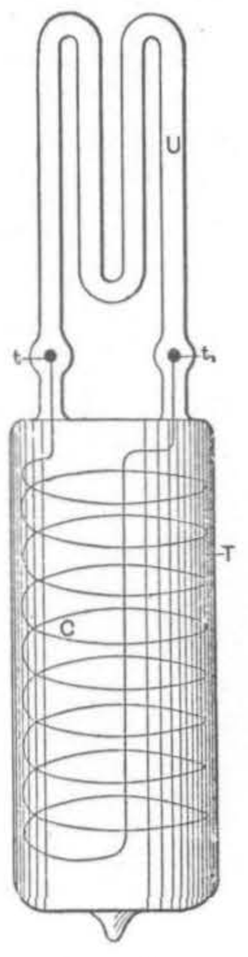


FIG. 17.

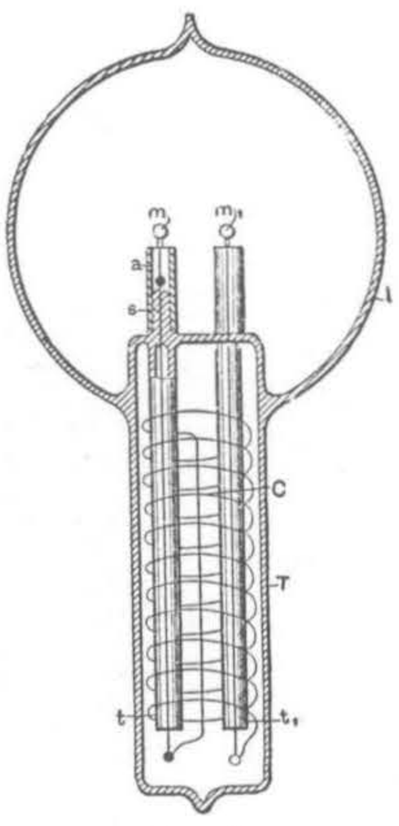


FIG. 18.

these experiments—the "radiant state" and the "non-striking vacuum."

Any one who has studied Crookes' work mus have received the impression that the "radian state" is a property of the gas inseparably connected with an extremely high degree of exhaustion. But it should be remembered that the phenomena observed in an exhausted vessel are limited to the character and capacity of the

* Abstract of a lecture delivered before the Institution of Electrical Engineers at the Royal Institution, on Wednesday evening, February 3, 1892. From the Journal of the Institution.

apparatus which is made use of. I think that in a bulb a molecule or atom does not precisely move in a straight line because it meets no obstacle, but because the velocity imparted to it is sufficient to propel it in a sensibly straight line. The mean free path is one thing, but the velocity—the energy associated with the moving body—is another, and under ordinary circumstances I believe that it is a mere question of potential or speed. A disruptive discharge coil, when the potential is pushed very far, excites phosphorescence and projects shadows, at comparatively low degrees of exhaustion. In a lightning discharge, matter moves in straight lines at ordinary pressure when the mean free path is exceedingly small, and frequently images of wires or other metallic objects have been produced by the particles thrown off in straight lines.

I have prepared a bulb to illustrate by an experiment the correctness of these assertions. In a globe L (Fig. 16) I have mounted upon a lamp filament f a piece of lime l. The lamp filament is connected with a wire which leads into the bulb. The bulb being suspended from a wire connected to the terminal of the coil, and the latter being set to work, the lime piece l and the projecting parts of the filament f are bombarded. The degree of exhaustion is just such that with the potential the coil is capable of giving, phosphorescence of the glass is produced, but disappears as soon as the vacuum is impaired. The lime containing moisture, and moisture being given off as soon as heating occurs, the phosphorescence lasts only for a few moments. When the lime has been sufficiently heated, enough moisture has been given off to impair materially the vacuum of the bulb. As the bombardment goes on, one point of the lime piece is more heated than other points, and the result is that finally practically all the discharge passes through that point which is intensely heated, and a white stream of lime particles (Fig. 16) then breaks forth from that point. This stream is composed of "radiant" matter, yet the degree of exhaustion is low. But the particles move in straight lines because the velocity imparted to them is great, and this is due to three causes—to the great electric density, the high temperature of the small point, and the fact that the particles of lime are easily torn and thrown off—far more easily than those of carbon. With frequencies such as we are able to obtain, the particles are bodily thrown off and projected to a considerable distance; but with sufficiently high frequencies no such thing would occur: in such case only a stress would spread or a vibration would be propagated through the bulb. It would be out of the question to reach any such frequency on the assumption that the atoms move with the speed of light; I believe that such a thing is impossible; for this an enormous potential would be required. With potentials which we are able to obtain, even with a disruptive discharge coil, the speed must be quite insignificant.

As to the "non-striking vacuum," the point to be noted is that it can occur only with low frequency impulses, and it is necessitated by the impossibility of carrying off enough energy with such impulses in high vacuum, since the few atoms which are around the terminal upon coming in contact with the same are repelled and kept at a distance for a comparatively long period of time, and not enough work can be performed to render the effect perceptible to the eye. If the difference of potential between the terminals is raised, the dielectric breaks down. But with very high frequency impulses there is no necessity for such breaking down, since any amount of work can be performed by continually agitating the atoms in the exhausted vessel, provided the frequency is high enough. It is easy to reach—even with frequencies obtained from an alternator as here used—a stage at which the discharge does not pass between two electrodes in a narrow tube, each of these being connected to one of the terminals of the coil, but it is difficult to reach a point at which a luminous discharge would not occur around each electrode.

A thought which naturally presents itself in connection with high frequency currents, is to make use of their powerful electro-dynamic inductive action to produce light effects in a sealed glass globe. The leading-in wire is one of the defects of the present incandescent lamp, and if no other improvement were made, that imperfection at least should be done away with. Following this thought, I have carried on experiments in various directions, of which some were indicated in my former paper. I may here mention one or two more lines of experiment which have been followed up.

Many bulbs were constructed as shown in Fig. 17 and Fig. 18.

In Fig. 17 a wide tube T was sealed to a smaller **M** shaped tube U, of phosphorescent glass. In the tube T was placed a coil C of aluminium wire, the ends of which were provided with small spheres t and t_1 of aluminium, and reached into

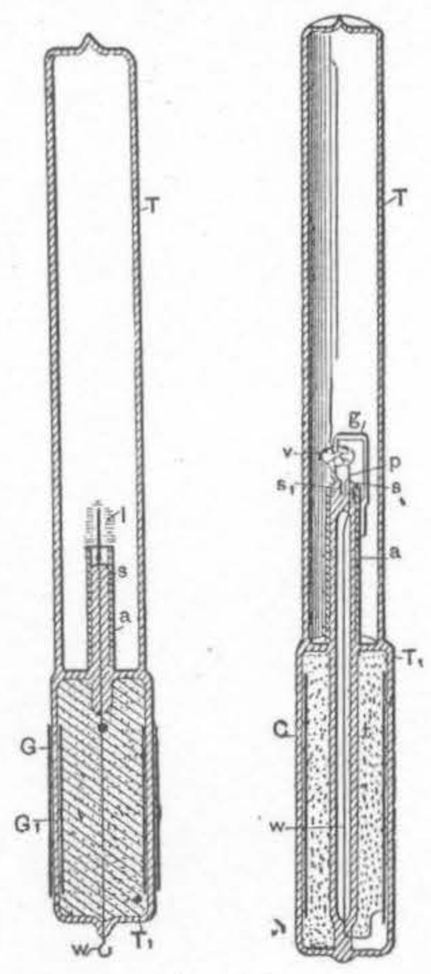


FIG. 19.

the U tube. The tube T was slipped into a socket containing a primary coil through which usually the discharges of Leyden jars were directed, and the rarefied gas in the small U tube was excited to strong luminosity by the high-tension currents induced in the coil C. When Leyden jar discharges were used to induce currents in the coil C, it was found necessary to pack the tube T tightly with insulating powder, as a discharge would occur frequently between the turns of the coil, especially when the primary was thick and the air gap, through which the jars discharged, large, and no little trouble was experienced in this way.

In Fig. 18 is illustrated another form of the bulb constructed. In this case a tube T is sealed to a globe L. The tube contains a coil C, the ends of which pass through two small glass tubes t and t_1, which are sealed to the tube T. Two refractory buttons m and m_1 are mounted on lamp filaments which are fastened to the ends of the wires passing through the glass tubes t and t_1. Generally in bulbs made on this plan the globe L communicated with the tube T. For this purpose the ends of the small tubes t and t_1 were just a trifle heated in the burner, merely to hold the wires, but not to interfere with the communication. The tube T, with the small tubes, wires through the same, and the refractory buttons m and m_1, was first prepared, and then sealed to globe L, whereupon the coil C was slipped in and the connections made to its ends. The tube was then packed with insulating powder, jamming the latter as tight as possible up to very nearly the end, then it was closed and only a small hole left through which the remaineer of the powder was introduced, and finally the end of the tube was closed. Usually in bulbs constructed as shown in Fig. 18, an aluminium tube a was fastened to the upper end s of each of the tubes t and t_1, in order to protect that end against the heat. The buttons m and m_1, could be brought to any degree of incandescence by passing the discharges of Leyden jars around the coil C. In such bulbs with two buttons a very curious effect is produced by the formation of the shadows of each of the two buttons.

Another line of experiment, which has been assiduously followed, was to induce by electrodynamic induction a current or luminous discharge in an exhausted tube or bulb. This matter has received such able treatment at the hands of Prof. J. J. Thomson that I could add but little to what he has made known, even had I made it the special subject of this lecture. Still, since experiences in this line have gradually led me to the present views and results, a few words must be devoted here to this subject.

(To be continued.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.*

PART VIII.

BY NIKOLA TESLA.

It has occurred, no doubt, to many that as a vacuum tube is made longer the electromotive force per uuit length of the tube, necessary to pass a luminous discharge through the latter, gets continually smaller; therefore, if the exhausted tube be made long enough, even with low frequencies a luminous discharge could be induced in such a tube closed upon itself. Such a tube might be placed around a hall or on a ceiling, and at once a simple appliance capable of giving considerable light would be obtained. But this would be an appliance hard to manufacture and extremely unmanageable. It would not do to make the tube up of small lengths, because there would be with ordinary frequencies considerable loss in the coatings, and besides, if coatings were used, it would be better to supply the current directly to the tube by connecting the coatings to a transformer. But even if all objections of such nature were removed, still, with low frequencies the light conversion itself would be inefficient, as I have before stated. In using extremely high frequencies the length of the secondary—in other words, the size of the vessel—can be reduced as far as desired, and the efficiency of the light conversion is increased, provided that means are invented for efficiently obtaining such high frequencies. Thus one is led, from theoretical and practical considerations, to the use of high frequencies, and this means high electromotive forces and smalll currents in the primary. When he works with condenser charges—and they are the only means up to the present known for reaching these extreme frequencies—he gets to electromotive forces of several thousands of volts per turn of the primary. He cannot multiply the electro-dynamic inductive effect by taking more turns in the primary, for he arrives at the conclusion that the best way is to work with one single turn—though he must some sometimes depart from this rule—and he must get along with whatever inductive effect he can obtain with one turn. But before he has long experimented with the extreme frequencies required to set up in a small bulb an electromotive force of several thousands of volts he realizes the great importance of electrostatic effects, and these effects grow relatively to the electro-dynamic in significance as the frequency is increased.

Now, if anything is desirable in this case, it is to increase the frequency, and this would make it still worse for the electro-dynamic effects. On the other hand, it is easy to exalt the electrostatic action as far as one likes by taking more turns on the secondary, or combining self-induction and capacity to raise the potential. It should also be remembered that, in reducing the current to the smallest value, and increasing the potential, the electric impulses of high frequency can be more easily transmitted through a conductor.

These and similar thoughts determined me to devote more attention to the electrostatic phenomena, and to endeavor to produce potentials as high as possible, and alternating as fast as they could be made to alternate. I then found that I could excite vacuum tubes at considerable distance from a conductor connected to a properly constructed coil, and that I could, by converting the oscillatory current of a condenser to a higher potential, establish electrostatic alternating fields which acted through the whole extent of a room, lighting up a tube no matter where it was held in space. I thought I recognized that I had made a step in advance, and I have persevered in this

(*Continued on page* 307.)

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.

(*Continued from page* 305.)

line; but I wish to say that I share with all lovers of science and progress, the one and only desire—to reach a result of utility to men in any direction to which thought or experiment may lead me. I think that this departure is the right one, for I cannot see, from the observation of the phenomena which manifest themselves as the frequency is increased, what there would remain to act between two circuits conveying, for instance, impulses of several hundred millions per second, except electrostatic forces. Even with such trifling frequencies the energy would be practically all potential, and my conviction has grown strong that, to whatever kind of motion light may be due, it is produced by tremendous electrostatic stresses vibrating with extreme rapidity.

Of all these phenomena observed with currents, or electric impulses, of high frequency, the most fascinating for an audience are certainly those noted in an electrostatic field acting through considerable distance, and the best an unskilled lecturer can do is to begin and finish with the exhibition of these singular effects. I take a tube in the hand and move it about, and it is lighted wherever I may hold it; throughout space the invisible forces act. But I may take another tube and it might not light, the vacuum being very high. I excite it by means of a disruptive discharge coil, and now it will light in the electrostatic field. I may put it away for a few weeks or months, still it retains the faculty of being excited. What change have I produced in the tube in the act of exciting it? If a motion imparted to the atoms, it is difficult to perceive how it can persist so long without being arrested by frictional losses; and if a strain exerted in the dielectric, such as a simple electrification would produce, it is easy to see how it may persist indefinitely, but very difficult to understand why such a condition should aid the excitation when we have to deal with potentials which are rapidly alternating.

Since I have exhibited these phenomena for the first time, I have obtained some other interesting effects. For instance, I have produced the incandescence of a button, filament, or a wire enclosed in a tube. To get to this result it was necessary to economize the energy which is obtained from the field and direct most of it on the small body to be rendered incandescent. At the beginning the task appeared difficult, but the experience gathered permitted me to reach the result easily. In Fig. 19, Part VII, two such tubes are illustrated which are prepared for the occasion. In one a short tube T_1, sealed to another long tube T, is provided with a stem s, with a platinum wire sealed in the latter. A very thin lamp filament l is fastened to this copper, and connection to the outside is made through a thin copper wire w. The tube is provided with outside and inside coatings C and C_1, respectively, and it is filled as far as the coatings reach with conducting, and the space above with insulating powder. These coatings are merely used to enable me to perform two experiments with the tube—namely, to produce the effect desired either by direct connection of the body of the experimenter or of another body to the wire w, or by acting inductively through the glass. The stem s is provided with an aluminium tube a, for purposes before explained, and only a small part of the filament reaches out of this tube. By holding the tube T_1 anywhere in the electrostatic field the filament is rendered incandescent.

A more interesting piece of apparatus is also illustrated. The construction is the same as before, only instead of the lamp filament a small platinum wire p, sealed in a stem s, and bent above it in a circle, is connected to the copper wire w, which is joined to an inside coating C. A small stem s_1 is provided with a needle, on the point of which is arranged to rotate very freely a very light fan of mica v. To prevent the fan from falling out, a thin stem of glass g is bent properly and fastened to the aluminium tube. When the glass tube is held anywhere in the electrostatic field the platinum wire becomes incandescent, and the mica vanes are rotated very fast.

Intense phosphorescence may be excited in a bulb by merely connecting it to a plate within the field, and the plate need not be any larger than an ordinary lamp shade. The phosphorescence excited with these currents is incomparably more powerful than with ordinary apparatus. A small phosphorescent bulb, when attached to a wire connected to a coil, emits sufficient light to allow reading ordinary print at a distance of five to six paces. It was of interest to see how some of the phosphrescent bulbs of Professor Crookes would behave with the currents, and he had the kindness to lend me a few for the occasion. The effects produced are magnificent, especially by the sulphide of calcium and sulphide of zinc. From the disruptive discharge coil they glow intensely merely by holding them in the hand and connecing the body to the terminal of the coil.

To whatever results investigations of this kind may lead, their chief interest lies for the present in the possibilities they offer for the production of an efficient illuminating device. In no branch of electric industry is an advance more desired than in the manufacture of light. Every thinker, when considering the barbarous methods employed, the deplorable losses incurred in our best systems of light production, must have asked himself, What is likely to be the light of the future? Is it to be an incandescent solid, as in the present lamp; or an incandescent gas, or a phosphorescent body, or something like a burner, but incomparably more efficient?

There is little chance to perfect a gas burner; not, perhaps, because human ingenuity has been bent upon that problem for centuries without a radical departure having been made—though this argument is not devoid of force—but because in a burner the higher vibrations can never be reached except by passing through all the low ones. For how is a flame produced unless by a fall of lifted weights? Such process cannot be maintained without renewal, and renewal is repeated passing from low to high vibrations. One way only seems to be open to improve a burner, and that is by trying to reach higher degrees of incandescence. Higher incandescence is equivalent to quicker vibration; that means more light from the same material, and that, again, means more economy. In this direction some improvements have been made, but the progress is hampered by many limitations. Discarding, then, the burner, there remain the three ways first mentioned, which are essentially electrical.

Suppose the light of the immediate future to be a solid rendered incandescent by electricity. Would it not seem that it is better to employ a small button than a frail filament? From many considerations it certainly must be concluded that a button is capable of a higher economy, assuming, of course, the difficulties connected with the operation of such a lamp to be effectually overcome. But to light such a lamp we require a high potential; and to get this economically we must use high frequencies.

Such considerations apply even more to the production of light by the incandescence of a gas, or by phosphorescence. In all cases we require high frequencies and high potentials. These thoughts occurred to me a long time ago.

Incidentally we gain, by the use of very high frequencies, many advantages, such as a higher economy in the light production, the possibility of doing away with the leading-in wire, etc.

The question is, how far can we go with frequencies? Ordinary conductors rapidly lose the facility of transmitting electric impulses when the frequency is greatly increased. Assume the means for the production of impulses of very great frequency brought to the utmost perfection, every one will naturally ask how to transmit them when the necessity arises. In transmitting such impulses through conductors we must remember that we have to deal with *pressure* and *flow*, in the ordinary interpretation of these terms. Let the pressure increase to an enormous value, and let the flow correspondingly diminish, then such impulses—variations merely of pressure, as it were—can no doubt be transmitted through a wire even if their feequency be many hundreds of millions per second. It would, of course, be out of question to transmit such impulses through a wire immersed in a gaseous medium, even if the wire were provided with a thick and excellent insulation, for most of the energy would be lost in molecular bombardment and consequent heating. The end of the wire connected to the source would be heated, and the remote end would receive but a trifling part of the energy supplied. The prime necessity, then, if such electric impulses are to be used, is to find means to reduce as much as possible the dissipation.

The first thought is to employ the thinnest possible wire surrounded by the thickest practicable insulation. The next thought is to employ electrostatic screens. The insulation of the wire may be covered with a thin conducting coating and the latter connected to the ground. But this would not do, as then all the energy would pass through the conducting coating to the ground and nothing would get to the end of the wire. If a ground connection is made it can only be made through a conductor offering an enormous impedance, or through a condenser of extremely small capacity. This, however, does not do away with other difficulties.

If the wave length of the impulses is much smaller than the length of the wire, then corresponding short waves will be sent up in the conducting coating, and it will be more or less the same as though the coating were directly connected to earth. It is therefore necessary to cut up the coating in sections much shorter than the wave length. Such an arrangement does not still afford a perfect screen, but it is ten thousand times better than none. I think it preferable to cut up the conducting coating in small sections, even if the current waves be much longer than the coating.

If a wire were provided with a perfect electrostatic screen, it would be the same as though all objects were removed from it at infinite distance. The capacity would then be reduced to the capacity of the wire itself, which would be very small. It would then be possible to send over the wire current vibrations of very high frequencies at enormous distance without affecting greatly the character of the vibrations. A perfect screen is, of course, out of question, but I believe that with a screen such as I have just described, telephony could be rendered practicable across the Atlantic. According to my ideas, the gutta-percha covered wire should be provided with a third conducting

coating sub-divided in sections. On the top of this should be again a layer of gutta-percha and other insulation, and on the top of the whole the armor. But such cables will not be constructed, for ere long intelligence—transmitted without wires—will throb through the earth like a pulse through a living organism. The wonder is that, with the present state of knowledge and the experiences gained, no attempt is being made to disturb the electrostatic or magnetic conditions of the earth, and transmit, if nothing else, intelligence.

It has been my chief aim in presenting these results to point out phenomena or features of novelty, and to advance ideas which I am hopeful will serve as starting points of new departures. It has been my chief desire this evening to entertain you with some novel experiments. Your applause, so frequent and generously accorded, has told me that I have succeeded.

In conclusion, let me thank you most heartily for your kindness and attention, and assure you that the honor I have had in addressing such a distinguished audience, the pleasure I have had in presenting these results to a gathering of so many able m en—and among them also some of those in whose work for many years past I have found enlightenment and constant pleasure—I shall never forget.

(Concluded.)

M. TESLA'S EXPERIMENTS—TO "L."

[33520.]—WITHOUT going very deeply into a description of the apparatus used by M. Tesla in his experiments with electricity at high voltage, and which have been recently described in the "E. M.," it will be well to remember that the essential portions were an alternating dynamo to produce alternating waves of current of considerable quantity (in ampères), but of comparatively low voltage, say 100 volts. This current is passed through one or more transformers (species of induction coils), which transform upwards—i.e., increase the voltage while lowering the ampèrage. To these transformers are connected condensers, to accentuate these effects, and also in special cases rheotomes to increase the rapidity of the alternations. By giving suitable proportions to the transformer, the voltage may be increased from 110 to 50,000, 150,000, or, as shown by Sir W. Thomson, to nearly a million volts, the current in ampères being, of course, diminished in like proportion. If now suitable connections are made to the terminals of the transformer, a number of experiments can be performed. The simplest consists in showing that the whole atmosphere in the neighbourhood of the two conductors (which may be wires or plates, at several feet apart) is in a state of induced strain under the influence of these enormous voltages, and that disruptive discharges take place in the form of faint glowing brushes all along the surfaces of the conductors. Another beautiful experiment, novel in this form, but well known to workers with the Wimshurst machine, is the illumination of vacuum tubes placed in the space neighbouring the conductors.

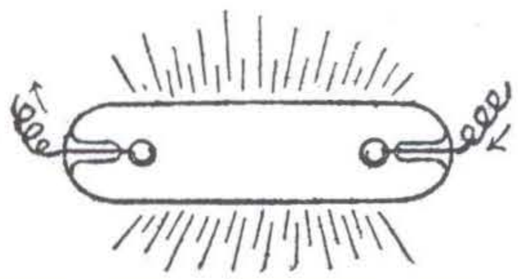
At the Crystal Palace, where these experiments are daily repeated by Messrs. Siemens, with a pressure of about 60,000 volts, and independently by Mr. Swinburne with a pressure of 130,000 volts. These results are well shown, though on a smaller scale than those instituted by M. Tesla, and without any special appliances for increasing the rapidity of the alternations. But the possession of dynamo and transformer is by no means necessary for the production of these experiments. Anyone possessed of a good plate electric machine, or, better still, a Wimshurst capable of giving a 3in. spark, can illuminate vacuum tubes by holding or suspending them anywhere in the vicinity of the machine (within 6in. or 8in.) while the machine is being worked. In fact, considering the small power expended in setting up the high voltage, the results are much more striking in the case of the Wimshurst machine than they are when the dynamo and transformer are employed. The reason of this may probably lie in the fact that, although the actual current in ampères is very small in the case of the Wimshurst machine, as compared to the dynamo and transformer (owing to the enormous resistance of the air between the combs and the plates), yet also the voltage, for this very same reason, is more easily kept high. Among other experiments which can be performed with the high-voltage currents of the transformer are the breaking down of several bodies usually considered good insulators, such as slate, wood, glass, &c., the transmission of power along great distances through very fine wires, incapable of carrying heavy currents, but unaffected by the high voltage, which is afterwards transformed down to lower voltage and larger current by a downward transformer on arriving at the destination where the power is to be utilised in the electro-motor. As it is the quantity of electricity in ampères, irrespective of its voltage, which affects the human frame when current is passed through it, it is stated that, by passing a minute current of only a few milliampères (thousandths of ampères) through a man placed in circuit with one of these high voltage currents, which is afterwards transformed down to a large current at low voltage, which passes into an electro-motor, sufficient energy can be conveyed through the man, without any injury to him, to enable the motor to give ½H.P.

S. Bottone.

NIKOLA TESLA AND HIS BUSINESS.

NIKOLA TESLA'S production of an aurora, in the lecture rooms of New York, London, and Paris, comes as a sequel to experiments that reach back all the way to the famous kite-flying of Franklin. How readily electricity glides into light everybody knows who has walked along a fleecy carpet and applied his finger tip to a bell wire or a water pipe. Indeed, so readily do sparks stream from electrical machinery that such machinery has to be excluded from mines and other places where a spark might cause an explosion. To bring the electric spark to magnitude and continuity has been a task which these many years has occupied an army of inventors. In their progressive steps these inventors have been greatly indebted to the induction coil, especially as improved by Ruhmkorff. His apparatus consists, essentially, of a coil of ordinary wire encircling a second coil formed of extremely fine wire. When a momentary current from a battery or a dynamo is sent through the first coil it induces in the second a current so highly intensified as to flash forth as lightning. In an apparatus of large dimensions this discharge can be thirty inches in length. Developed in form, the induction coil has been indispensable in Tesla's experiments. His work has distinctly diverged from the line of investigation which has given us light as an incident of the intense heat of carbon threads and pencils. He has sought to obtain light directly from electricity, avoiding costly and useless partnership with heat. On this particular track Dr. H. Geissler, of Bonn, labored long ago. In the tubes known by his name he produced a luminous glow of great beauty, sending through highly rarefied gases the pulsations from an induction coil.

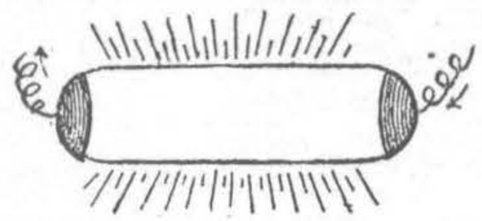
With a better air pump and a more powerful coil, William Crookes, of London, the discoverer of the chemical element thallium and inventor of the radiometer, took up Geissler's experiments and extended



THE FIRST STEP—GEISSLER TUBE, WITH ELECTRODES INSIDE THE GLASS.

them by a very significant step. He discovered that the electrodes or current carriers were fully as effective when attached to the outside of the tube as when brought within it.

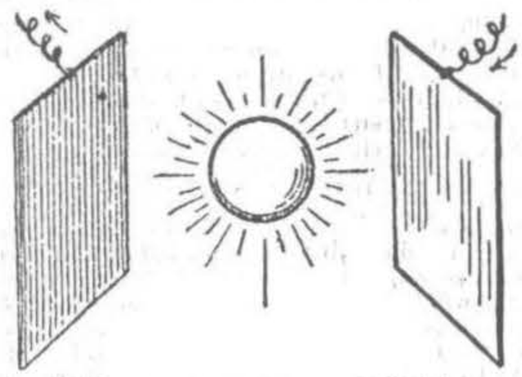
It was at this interesting and suggestive stage of development that Tesla began to solve the problem of how electricity might best be changed into light. He had been engaged in perfecting a generator of alternating currents, a machine of novel and excellent pattern. It occurred to him that these currents gave him a means of experimenting on lines wholly new; for an alternating current differs from a continuous one as puffs of air, now from north, now from south, differ from a constant breeze in either direction. What might he not do were he able to change electricity from a stream to vibrations approaching in period those of light? In the apparatus he used in his lecture at Columbia College last year, Tesla departed very far from the ordinary alternator with but a dozen poles in its circle. On the rim of his rotating disk he had no less than 384 poles, which gave 9,600 alternations per second instead of 300, a customary number. In his later work Tesla adopts the current as delivered by the common alternator used in electric lighting. For increasing the frequency of its reversals he employs a condenser and converter such as he had at Columbia College, but now much developed in form. This contrivance consists of a transformer, of the type familiar to consumers of electric light, with a second transformer having in its circuit a magnetic spark interrupter, from which is obtained discharges in all respects similar to those of the



THE SECOND STEP—CROOKES' 1891 TUBE, WITH ELECTRODES ON THE EXTERIOR OF THE GLASS.

largest induction coil—discharges of high frequency. Connecting this circuit in turn with a condenser, a series of Leyden jars, a surging effect is produced. The currents are raised from vibrations of 25,000 or so per second to between one and two millions. At the same time their pressure is heightened in a corresponding degree. Thus armed with powers wholly new in electrical experiment, Tesla proceeded to win new victories. Whereas Crookes found it enough that his electrodes merely touched the outside of the tube which he was to set aglow, Tesla produces the same luminosity by entirely detaching his electrodes from the tube and retiring them to a distance of several feet.

In the intervening space, with no wires or connections of any kind, he places glass tubes, or globes, which shine as if auroral beams from the northern sky were entrapped in them. The light here is due so to speak to molecular bombardment, to the particles of imprisoned gas striking one another with a velocity so tremendous as to glow visibly. We have a familiar illustration of the same kind of fact when a nail is violently and repeatedly struck by a hammer on an anvil until it reaches glowing heat. But resuming the path of his main purpose, the getting light unaccompanied by heat, Tesla has arrived at results more remarkable still. As fast as he was able to increase the frequency of electric alternations he tried a variety of experiments. Among these was the admitting of more and more air into the exhausted tubes placed in the

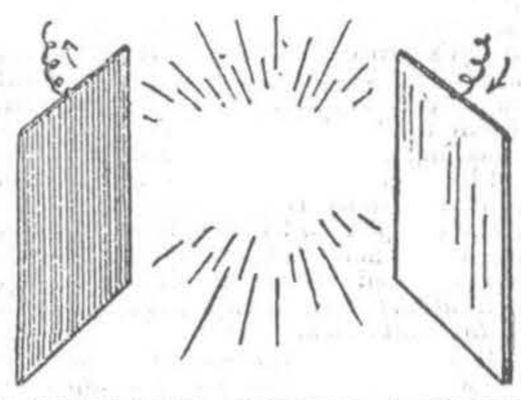


THE THIRD STEP—TESLA 1892 EFFECT, WITH DISTANT EXTERIOR ELECTRODES.

excited electric field. He found to his great delight that the luminous effect persisted, and this to the point when a tube was exhausted in no degree whatever. He was now led to the culmination of his work—the dispensing with tubes altogether, the production of light by agitations of the light-bearing ether so rapid as to provoke vision. In his latest experiments Tesla suspends from the walls of a room two metallic plates, attaches them to the poles of his condenser, and in the intervening space, without tubes, globes, or other objects, creates a soft and diffused glow. The light is fainter, however, than that which shines in a tube or globe brought into the electrified space.

Without any mechanism whatever in view, and from precisely such an alternating current as that fed to arc and incandescent lamps, an effect without example in the art of lighting is made available for the drawing room, the theater, and the picture gallery. In a scheme devised by Mr. John Van Vleck, an electrical engineer of New York, the ordinary current as delivered to a consumer can serve to actuate a motor, can be turned into lamps, or applied to producing the Tesla effect.

Tesla is busily engaged in perfecting his results by successive improvements in the appliances for their production. As his light seems to be unallied with heat, and its user is free from the cost and care of lamps, its further development is awaited with the keenest interest. Yet, even in its present state, the Tesla apparatus must rank with Franklin's kite, which



TESLA'S LATEST EFFECT—A LUMINOUS CLOUD BETWEEN TWO ELECTRODES.

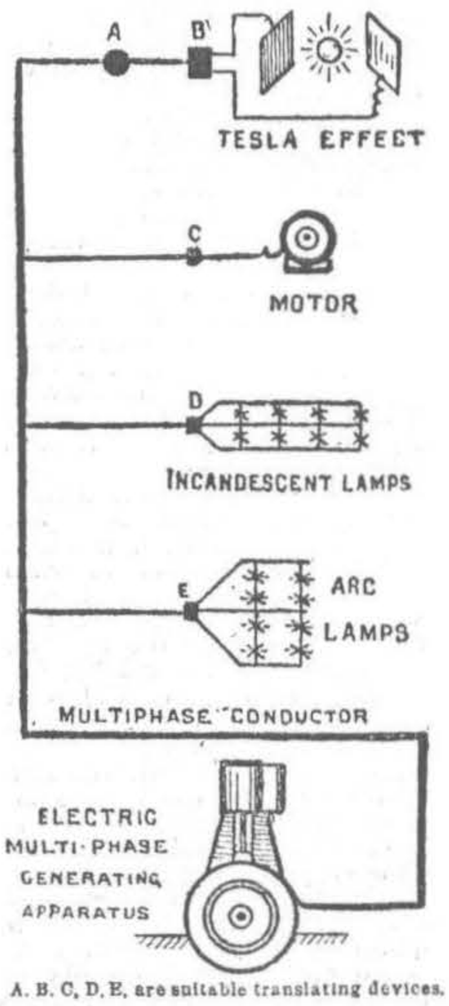
showed electricity and lightning to be one; with Bell's disks, which either electricity or light can arouse to speech; and with Hertz's resonator, which proves to the eye what so long was but an unfulfilled anticipation, that, after all, light is only a particular effect of electro-magnetism.

Indeed, Tesla's experiments make clear that every common flame is but a brilliant manifestation of electro-magnetic energy. Attached to a pole of his condenser, a thread of cotton streams forth with a flame like that of Moses' bush, which burned but was not consumed. From the two terminals of his apparatus are emitted brush-like electric discharges that not only resemble, but are veritable flames. Let the current mount still higher in its pressure, beating still faster, and to touch as well as to sight the identity would instantly become evident. By varying the substances which he exposes to his currents, Tesla produces exquisite effects in color.

Phosphorus with sulphate of zinc gives, for example, a greenish glow of great beauty. With yttrium, artificial diamond, lime, and various metals, other hues appear, and, what is of much promise, the degree of luminosity is increased. In all cases, the light is brightened, too, when above it is placed an ordinary metallic shade. In this path of experiment may lie the object which Tesla has constantly in view, the production of a light brilliant enough to be compared with that of the incandescent bulb. In lines less directly leading to practical utilities his demonstrations abound with suggestiveness. He has shown, for example, how two beautiful phenomena shade into each other, when the phosphorescent gleam of a ruby is brought to incandescence through intermediate stages of excitation. And sending electric impulses through glass stained to canary hue with oxide of uranium, and through solutions of sulphate of quinine he produces fluorescence of a new brilliancy.

AN ELECTRIC COLUMBUS.

In bringing electrical vibrations nearer to the frequency of light than any other inventor has done, Tesla is the Columbus of a new continent for inventive activity. The undulations we call light are stopped by fog, because they occur at a certain rate. Let vibrations of a rate such as Tesla can produce be projected into space, and the possibility dawns for giving ships a new security at sea. An electric station on shore or reef may warn the mariner by sending forth



A. B. C, D, E, are suitable translating devices.

THE VAN VLECK SCHEME FOR SUPPLYING THE TESLA EFFECT, ARC AND INCANDESCENT LAMPS, AND MOTORS, FROM THE SAME SYSTEM.

electric impulses to be received and registered on suitable disks aboard his vessel. And in ocean service of another kind, in quickening the speed of signaling through the cables, there is a promise that Tesla's apparatus can be usefully enlisted. It takes about one-third of a second for a signal to cross the Atlantic, and any device which will shorten this period must proportionally increase the carrying capacity of the submarine wire. That a wide margin for improvement exists here has been demonstrated in the shortening of time in transmission effected since cables were first laid. It is generally supposed that, as used in telegraphy, the electric current has an exceedingly high velocity from which it never varies. Not so. The length and quality of a conductor, the character of its insulation, and the peculiar form of the current, are elements which decide the rate of propagation.

In bridging part of the wide interval between the comparatively slow waves which excite the sensation of sound and the vastly swifter ones which awaken vision, Tesla opens the door to an illimitable realm of experiment. To waves of a new order the old rules of arrest and transmission will not apply. Alexander Graham Bell, in his experiments with the photophone, found that an invisible beam of light easily passed through a sheet of hard rubber. Tesla in the same way finds that insulation is a relative term. Substances that keep ordinary currents strictly to their path are easily pierced by the throbs which he enkindles. Oil, which closes over an electric wound, has therefore to replace cotton, silk, and rubber. It would seem, in truth, as if the electrician will soon be able to choose the special vibration suited to traverse any medium whatever, gaseous, liquid, or solid; that he will encounter no obstacle which he cannot render as it were transparent.

WHO NIKOLA TESLA IS.

Who is this man who has done so much and initiated so much more, before whom the Nestors of European

science sit entranced as he brings before them marvel after marvel? Whence does he come? What country gave him birth only to surrender him to America?

On the southern confines of the empire of Austria-Hungary, Croatia comes to the Adriatic Sea. Here is a land of mixed races, of a history so troubled that its language holds a hundred words for knife, and but one for mercy. Here in the hamlet of Smiljan, Nikola Tesla was born thirty-five years ago. At Carlstadt, in Croatia, and at the polytechnic school in Gratz, Austria, he received his education. As a student of engineering the subject of electricity strongly attracted him, and he devoted his spare time to electrical experiment.

On graduating in 1881 he entered the telegraph service at Buda-Pesth, taking up the electric light and the construction of dynamo machines as his special work. About five years ago he came to the United States. During part of this time he was in the employ of the Westinghouse Co., where he earned the highest esteem as an electrician and as a man. Latterly he has pursued an independent course of experiment, with results briefly touched upon in this article.

In person Tesla might pass for an Italian. He has an Italian sensitiveness of temperament, as well as an Italian excitability. His command of English is capital, and as he unfolds his results to an audience with exquisite dexterity, his enthusiasm is contagious. With inborn resources of the rarest, with excellent education and practical training, with the opportunities of the world focused around him, what of achievement may not the future hold for Nikola Tesla?—*George Iles, in N. Y. Sun.*

Tesla's Lecture in London.

This has now been printed in the New York *Electrical World*, being copied from the *Journal of the Proceedings of the Institution of Electrical Engineers*. It appears to give the highest satisfaction to Americans, who are justly proud of their adopted son. Indeed, the picture of the future of electricity drawn by Mr. Tesla is at once sweepingly novel and alarmingly daring. Whether it is all feasible, and, if so, how soon? are questions that arise unbidden to our lips. One shudders at the thought of 100,000-volt distribution being spoken of as "an easy matter," and transmission through 1,000 miles seems to be certainly unnecessary, although it may be "practicable." 20,000 vibrations per second possibly are "few" in the Tesla school; but it will take some time to familiarise work-a-day electricians with such quantities. Mr. Tesla does not consider high potentials, such as he uses, dangerous. This may be so, and as we have pointed out on several occasions, it is no doubt explainable by the little energy used. But in any practical application large power is a necessary accompaniment, and then we think it somewhat rash to say there will be no danger. Perhaps the human body is not affected by electric currents of very high frequency, and there certainly seem to be grounds for assuming such to be the case, judging from our knowledge of the effects of light, heat and sound waves. Yet the case is "not proven" so far; and subjects for testing the truth of this theory are not so forward in offering their persons for the crucial tests, as one would expect. If things go on as they are doing now, we shall find our knowledge on this point increased by the evidence of an unwilling witness. Mr. Tesla believes that light and heat effects are proportional to the product of the frequency and the square of the potential, and suggests using periods of several millions per second! We do not mind the frequencies so much, but are thankful the "Professor" does not intend using millions of volts, at any rate in this little country.

Tesla's Experiments.—"Some of Mr. Tesla's most striking experiments," remarks Mr. Arthur G. Webster in discussing Ohm's law in the *Electrical World*, "depend on the illumination of tubes or lamps without electrodes, or with but one. An experiment was performed several years ago by a gentleman in Vienna (I think Dr. Moser) with a double Geissler tube without electrodes. One tube surrounded the other, which was exhausted. On bringing the tube near an induction coil, and beginning to exhaust the outer tube, the latter glowed while the inner remained dark, being screened from action by the conducting gas in the outer tube. On highly exhausting the outer tube its conductivity diminished, and the inner tube began to glow, while finally the outer ceased. To my mind this experiment is as instructive as any of Tesla's. There is nothing, of course, in this to detract from the great interest and beauty of Tesla's experiments, but I am inclined to agree with Mr. Wimshurst that the principal difference between these and others is in the expenditure of energy involved."

NOTES.

According to Nikola Tesla, the electrician, the new discovery of carborundum will largely increase the possibilities of electric lighting. Among these possibilities he mentions electric lamps operated without any wires at all, an inexhaustible store of electrical energy on tap everywhere without need of either generation or transmission, and a light at least twenty times more efficient than that now furnished.—*New York Tribune.*

Engineering Magazine August 1892

ELECTRICITY.

Conducted by Franklin L. Pope.

AN interesting example of electric-power transmission is that of the Gold King stamp-mill near Telluride, Col. A Pelton wheel, receiving water through a two-foot steel pipe under 320 feet head, drives the generator at a speed of 833 revolutions, giving 10,000 alternations per minute. The generator, by an automatic compensation, is made to maintain a constant pressure of 3000 volts at the motor, three miles distant. The line runs 2500 feet directly up the mountain from the power station, and thence passes over a rough, and in winter almost inaccessible, country, to the mill. The working motor, being of the synchronous type, requires a special device for starting it, and this is furnished by a small auxiliary motor of the Tesla type. The operation of starting is accomplished by one man in about two minutes. The economical efficiency of the synchronous motor system, exclusive of loss in conductors, is found to be 83.5 per cent. at full load and 74 per cent. at half load. The capacity of the motor is 50 horse-power. This is the first example in this country of the installation of a large alternating motor, but the results already attained indicate that the simplicity, flexibility and wide range of application of the alternating system, are likely to make it,

at least for large enterprises, the system of the future.

An alternating current power-plant is now under construction for a quartz-mill in Colorado which will have a generator of 750 horse-power and a motor of 250 horse-power located at a distance of ten miles. By making use of a pressure of 4000 volts at the generator, and allowing a loss in the line of 20 per cent., the cost of copper in a line of this length becomes only from 10 to 15 per cent. of the aggregate cost of the plant.

SOME OF TESLA'S EXPERIMENTS SIMPLIFIED.

ALTHOUGH six months have elapsed since Nikola Tesla's epoch-making lecture at the Royal Institution, the extraordinary interest excited by his experiments has in no way declined, and there are few who take any practical part in electricity, whether as amateurs or professionals, but have longed to produce for themselves some of the wonderful phenomena which he dealt with so cleverly and withal as modestly. As Lord Rayleigh said, he has "given us food for intellectual contemplation for a long time to come"; but we are not content to contemplate—we want to imitate. Our imaginations have been quickened, and if we cannot go forward on our own account, we at least want to keep pace. Few will have at hand the necessary appliances used by Tesla in producing the brilliant effects which were the wonder of those who were privileged to witness them last February. Hence, we feel sure that our readers will be gratified to learn that, owing to the recent researches of Mons. Andrea Giulio Rossi, it has been discovered that many of Tesla's experiments can be reproduced by means of apparatus which everyone who "dabbles in electricity," or practises it as a profession, will have at hand.

Tesla used an induction coil of a special form, and passed through its primary coil a special oscillatory current in producing high frequency and high potential. The current was sent from an alternating dynamo into the primary of a transformer, the secondary being connected through a magneto-static interrupter to two brass knobs, between which a series of discharges takes place. From these knobs were taken leads to the primary terminals of an induction coil, not directly, however, but through a capacity formed by Leyden jars. It is thus seen that when a spark occurs at the brass knobs an oscillatory discharge surges through the added capacity to the primary of the induction coil. The rate of the oscillation is about one million per second.

One of the most curious and astonishing of the experiments performed by Tesla with this current was to touch the poles of his apparatus with one hand whilst he held a Geissler tube in the other, the latter being instantaneously illuminated. This can be reproduced, so M. Rossi tells us, with a simple Rhumkorff coil.

A coil which would give sparks from five to six centimètres long was employed by Rossi, and he used a current of high period, but having by no means the number of alternations per second which characterised that used by Tesla. On placing one hand on one of the poles of the coil, and holding a Geissler tube in the other hand, the tube became luminous, though not very brilliantly luminous. This luminosity was manifested, too, even when two or three persons joined their hands, the first touching the coil, whilst the third held the tube.

A Geissler tube was illuminated by merely placing it near one of the terminals of the Rhumkorff coil. The light was more intense near the centre of the tube if the latter was isolated; but if held in the hand, the whole of the interior was suffused by an intense glow. The tube became completely luminous also if connected to earth, and not touched by the hand.

Another experiment performed by Rossi was as follows: An insulated Geissler tube was placed at a short distance from the coil, the poles of the latter not being connected. If it were held perpendicular to the generating line of the cylinder (coil), the light, which was evident in the opposite position, disappeared.

The elimination of electrodes in the Geissler tube did not appear to affect the general result. Rossi constructed a tube about a yard long, in which he made a vacuum, then filled it with water vapour, and finally absorbed the latter by means of potash. The tube, when held in the hand near the coil, became brilliantly illuminated. Moreover, by insulating the tube, and then placing it about a yard from the coil, in such a position that the prolongation of its axis would impinge upon one of the poles of the coil, the same result was obtained; but the glow was intensified by approaching the foot towards the tube, whilst one of the hands grasps the other terminal of the coil.

Mons. Rossi considers that these experiments may be performed by anyone who possesses this simple apparatus, and that, in all probability, some of the more complicated experiments of Tesla may be imitated on the small scale by equally simple means. No doubt some of our readers will test this for themselves.

It would be a convenience if some short name could be found for vacuum tubes without electrodes. These were referred to by several speakers at the British Association, both in Papers and in discussion. They have been used for years; but it will be conceded, even by those who, like Dr. Bottomley, have used them largely, that before Tesla's experiments not much attention had been paid to them, and it can be denied by none that he has outstripped all in the brilliant effects which he has produced. The word "vacuum tube" has become more common than "Geissler tube"; but why not use the name "Tesla tube" for one without electrodes, leaving vacuum tube to include both kinds?

SOME OF TESLA'S EXPERIMENTS SIMPLIFIED.

[33904.]—I was rather surprised to read under the above heading that Mr. Rossi had discovered the "novelty" of a vacuum tube being lighted by a Rhumkorff coil, without actually being connected with it. Why, 21 years ago, Edison pointed this out, and attributed it to "etheric force." But every one of M. Tesla's experiments can be performed with ease by anyone possessing a 20in. plate Wimshurst machine. Rings of wire may be made to glow, vacuum tubes can be lit up at a distance, sheets of glass to give coruscation, and finally be perforated; and this without the use of rapidly alternating currents, as I previously pointed out in the "E. M." for May 10, 1892. S. Bottone.

TESLA'S EXPERIMENTS.

[33928.]—I HAVE just returned from a holiday in South Devon, and thus have only now seen the article on "Some of Tesla's Experiments Simplified" (p. 543). Similar experiments to those made by Mons. Andrea Guilio Rossi, as detailed in the above-mentioned article, were performed in my presence by your able contributor, Mr. S. R. Bottone, soon after the Tesla experiments were made public. I had the pleasure of seeing vacuum tubes illuminated by holding them to the prime conductor of a Wimshurst influence machine whilst the machine was in motion, and of holding the tubes myself in close contiguity with various parts of the machine. The tubes were brilliantly illuminated. We also tried similar experiments with an induction coil giving a ¼in spark in air. With one hand resting on the table near the coil, and the other holding a vacuum tube near the discharger of the coil, I got a stream of sparks through the tube, which was nicely illuminated when one end of the tube was held close to the positive pole of the discharger. When held thus close to the pole of the discharger, I felt a slight tingling sensation in the fingers of the hand grasping the tube, thus showing that

current was passing through my body, and through the glass pillars of the discharger. It will thus be seen that Tesla's experiments may be repeated with such homely apparatus as a small machine, or a small spark coil and a few vacuum tubes.

G. E. Bonney.

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THE W. J. JOHNSTON COMPANY, Ltd.,
Times Building, New York,
OR ANY OF THE BRANCH OFFICES.

The Tesla Tube.

ONE of our English contemporaries, commenting on the convenience that would result from the use of a short name—if one can be found—for vacuum tubes without electrodes, suggests that they be called Tesla tubes. This name is suggested because, although these tubes have been used for years, before Tesla's experiments not much attention was given to them, and because Mr. Tesla has "outstripped all in the brilliant effects which he has produced."

Personal.

MR. NIKOLA TESLA.

THIS distinguished electrician has returned to New York, arriving by the "Augusta Victoria," from Hamburg, on August 27. Mr. Tesla sustained a severe bereavement while in Europe in the death of his mother, and was obliged to rest for some time. His magnificent reception at the hands of European electricians has become, like his inventions and researches, part of electrical history; and the honors conferred on him were such as to make Americans very proud of one who has chosen this country as his home.

MR. R. S. DOBBIE, fomerly with the Engineering Department of the Edison General Electric Company, has opened offices in the Times Building, New York. Mr. Dobbie will be glad to see his friends there and may be consulted in reference to new apparatus, inventions, designs, etc. As an old central station man, Mr. Dobbie is also ready to consult in regard to the construction and installation of new plants for lighting and power purposes.

Mr. Dobbie has had an intimate experience with United States, Thomson-Houston, Brush and Edison apparatus, and has made a particular study of designing and testing new apparatus. His card as consulting electrical engineer is to be found in our advertising pages.

MR. F. A. PHELPS, JR., late mechanical engineer at the Schenectady Edison Works, has resigned that position to become associated with Mr. Edison more directly in the latter's various new enterprises, in which Mr. Phelps's ability will find abundant scope.

SOME OF TESLA'S EXPERIMENTS SIMPLIFIED.

[33984.]—WHILE experimenting with an induction coil some time ago; I succeeded in producing an effect which I have never seen described, and if it be a real novelty, will probably be interesting to readers of the "E. M." The effect in question was produced by placing an electric incandescent lamp between the secondary terminals of the coil, when the bulb was instantly illuminated with a strong blue glow. It is necessary to state that the filament of the lamp had been broken off, the vacuum being still maintained. I was struck by the experiment, and tried an uninjured lamp in the same position, but could get no result with it. I then took the former lamp and covered half the bulb (the part farthest from the lamp terminals) with tinfoil, pasting it on carefully. The result when tried with the coil was almost magical. The finest effect was got by connecting the lamp terminals to one terminal of the coil, the other being connected to the tinfoil on lamp. A brilliant effect could also be produced by connecting the lamp to one coil terminal while any earth-connected conductor was allowed to touch the tinfoil. Finally I found that it was quite sufficient to hold the lamp in the hand at a distance of as much as a yard from the coil, whilst the latter was working, to get a good effect. No doubt the action of the lamp was similar to that of a vacuum tube; but it should be remembered that in the case of the lamp, only one conductor penetrated into the interior of the bulb. I should mention that the coil was built to produce ¼in. sparks, and is well-made and insulated.

An idea suggested by one of Tesla's experiments is to pass the secondary current from one coil into the primary of a second coil, in order to produce sparks of a considerable length. I have had no chance of trying this arrangement yet. I would suggest that the insulation of the second coil should be perfection, and that perhaps a condenser would be advantageous. If the arrangement were workable, it is evident that long sparks might be obtained from a couple of small coils, costing together considerably less than one constructed to give the whole spark outright. F. E. P.

LETTERS TO THE EDITOR.

[*We do not hold ourselves responsible for the opinions of our correspondents. The Editor respectfully requests that all communications should be drawn up as briefly as possible.*]

All communications should be addressed to the EDITOR *of the* ENGLISH MECHANIC, 332, *Strand, W.C.*

All Cheques and Post-office Orders to be made payable to J. PASSMORE EDWARDS.

*** *In order to facilitate reference, Correspondents, when speaking of any letter previously inserted, will oblige by mentioning the number of the Letter, as well as the page on which it appears.*

"I would have everyone write what he knows, and as much as he knows, but no more; and that not in this only, but in all other subjects: For such a person may have some particular knowledge and experience of the nature of such a person or such a fountain, that as to other things, knows no more than what everybody does, and yet, to keep a clutter with this little pittance of his, will undertake to write the whole body of physicks, a vice from whence great inconveniences derive their original." —*Montaigne's Essays.*

SOME OF TESLA'S EXPERIMENTS SIMPLIFIED—TO "F.E.P."

[33991.]—THE effects narrated are well known, and are simply proofs of the extent to which the lines of inductive force penetrate the surrounding air.

With reference to the coils connected in series, this also has been done. Of course, the second coil, as it is supplied with an alternating current from the first one, does not need, and, in point of fact, must not have, a contact breaker. Also it is necessary, in order to get good effects, that the primary of the second coil should consist of wire as fine as that of the secondary of the first coil, and that the insulation should be of the most perfect kind. In some experiments detailed a month or so ago in the pages of "Ours," the coil was immersed bodily in resin oil. This second coil is in reality a transformer, and what is gained in E.M.F. is lost in current.

S. Bottone.

[33992.]—MORE than a year ago I made, quite by chance, exactly the same experiment as "F.E.P." relates in letter 33984, with the exception that my lamp was quite sound. I was trying to light a lamp with an induction coil, and, not succeeding, probably because there were not enough ampères, I took off one of the wires from the lamp terminal, when suddenly, on my accidentally touching with the wire the spring of the lamp's socket, the lamp lit up a phosphorescent bluish glow, a little darker near the filament. The same thing occurred in touching the glass bulb with even the isolated portion of the wire from the induction coil; but the greatest brilliancy was obtained when the electrode was terminated by a large metallic surface. I repeated the experiment the next day, but have not been able to repeat it again.

One day, however, my lamp—always perfectly sound—was lying close to one of the electrodes of the induction coil, when on completing the secondary circuit the lamp gave a bluish glow as before, but this time of equal intensity in every part. I never could repeat the experiment. The lamp is a 10-candle one, and the coil gives a 3-millimètre spark.

L. Demengel.

Now that Mr. Nikola Tesla has returned from Europe, we may expect to hear of greater and further advancements in his work with alternating currents of high frequency.

TESLA MOTORS IN EUROPE.

WE understand upon good authority that the reports current in Europe as to the control of Tesla motors secured there by leading concerns are well founded. Three of the largest engineering firms on the continent have acquired the rights for the motor in their respective territories and will proceed to introduce it on a large scale. The concerns are, Ganz & Co. of Buda Pest; the Helios Co. of Cologne, and Schneider & Co. of Creusot, France. The delays usually attendant upon commercial negotiations have been unduly prolonged by the conditions of affairs in Europe; but now that the ground has been cleared, work will be actively pushed. In this country, the Westinghouse Co. have the control of the Tesla motor, and will now push it vigorously.

Tesla's Experiments.

MR. STEINMETZ ON THE EFFECT OF THE ALTERNATING CURRENT UPON THE HUMAN BODY.

Mr. Chas. P. Steinmetz, one of the ablest modern electricians, has, as is well known, taken a lively interest in Mr. Tesla's now famous experiments with high tension currents. Lately Mr. Steinmetz has taken up the question in a letter addressed to the *Electrotechnischer Zeitung* September 16, 1892, and, as this matter is of considerable importance to all electricians, we give a translation of Mr. Steinmetz's letter, to which we invite Mr. Tesla's attention. We shall be pleased to hear from him in reply:

Suppose the engine develops 10 horse-power, then the dynamo cannot produce more than a 500 volt 10 ampere current. Upon transforming this current up to 70,000 volts, with a 50 per cent. efficiency (and this is far in excess of the real efficiency), we find a current of one-thirtieth of an ampere in the secondary circuit. Again, assuming the resistance of the human body to be 2,000 ohms, this current does not exceed two and one-quarter watts, and produces, therefore, a scarcely appreciable effect upon the human system. But the apparatus used for electrocution developed 1,500 volts, with a current strength of three amperes, measured from hand to hand, or 4,500 watts; in other words, the real effective power was 2,000 times greater than that developed upon touching the so called 70,000 volt current.

But even 4,500 watts produced no instantaneous death, and it was found necessary to send the current from the head of the criminal to his leg. The meters then showed seven amperes and 1,500 volts, or 10,000 watts. Result, instantaneous death.

From the above, it is evident that excessively high tension currents are harmless without the necessary amperage. A little computation shows that had there been 70,000 volts tension between the hands of the experimenter, a current of 140 amperes would have passed, *i. e.*, 10,000,000 watts, and such a current would have produced the same effect as a lightning stroke, *i. e.*, immediate disintegration of the body.

In volume 32 of the *Electrotechnischer Zeitung* I find a paper by Mr. Korthals which explains, or rather attempts to explain, the freedom from danger to the human system subjected to a 70,000 volt tension in Mr. Tesla's experiment by the capacity of the human body.

This view is overthrown by Mr. Tesla's own statement which shows that such immunity from danger only exists with a certain adjustment of the condenser in the primary circuit. As soon as this adjustment is changed the spark loses its peculiar, characteristic color, and is no longer harmless.

Again, assuming that Mr. Korthal's explanation be true, the oscillating discharge of a Leyden jar of a much higher periodicity should not affect the human system.

To my mind, however, the reason of this immunity from danger is a much simpler one. In other words, the assertion that the human body was exposed to a tension of 70,000 volts in Mr. Tesla's experiments is nothing but a chimera. I had the pleasure to be present at one of the first lectures of Mr. Tesla. The experimenter included himself in the secondary circuit of the induction coil in series with an air space of several feet. But, as the resistance of the human body is infinitely small, compared to the resistance of an air space of several feet, the experimenter received only an infinitesimal portion of the 70,000 volts. Upon touching, however, the binding posts of the secondary coil, the high tension no longer existed, the circuit being practically short circuited through the human body. The same phenomenon may be observed with any spark coil.

The mistake in Mr. Tesla's conclusion consists in comparing the conditions of this experiment with such as prevail when we touch an ordinary alternating current circuit of constant tension. On the contrary in Tesla's experiment the tension is not constant, but depends directly upon the resistance through which the circuit is closed. In other words, the entire experiment is analogous to the work of a frictional machine. There we easily produce a tension of 100,000 volts, yet sparks drawn directly from the collector are scarcely felt. In my own experience, I have obtained sparks at a distance of two feet from the driving belt of a dynamo machine, which sparks represented a tremendously high electrical tension, nevertheless, I did not feel any effect whatsoever. Under such conditions the actual current passing through the body is infinitesimal and of low tension, while the electrical tension outside the body is consumed in the spark. It is evident that the periodicity is of no consequence as far as this phenomenon is concerned; it only has to be accounted for because the self-induction of the circuit depends upon the rate of change.

Now, a Tesla dynamo has an exceedingly high self-induction besides that of the induction coil, and the added effect of these two factors produces a high degree of self-regulation for continuous currents in the primary circuit, so that the current, the same as in a Westinghouse arc light dynamo, cannot exceed a definite maximum value.

The "Drehstrom" Patent.

BY NIKOLA TESLA.

In the last issue of THE ELECTRICAL WORLD I find an article on my "Drehstrom" patent which appeared originally in *Industries*, and is, I believe, from the pen of the able editor of that journal. Some of the statements made are such as to cause an erroneous opinion to gain ground, which I deem it my duty to prevent—a disagreeable one I may say, as I do not like to express my opinion on a patent, especially if it is my own.

It may be, as the writer states, that the theory of the action of my motor advanced in my paper before the American Institute in May, 1888, is a clumsy one, but this theory was formed by me a number of years before the practical results were announced, the patents being applied for only after it was undoubtedly demonstrated that the motor could fairly compete in efficiency with the direct current motor, and that the invention was one of commercial value. These patents were taken out with the help of some of the ablest attorneys in the United States, well versed in electrical matters; the specifications were drawn up with great care, in view of the importance of the invention, and with proper regard to the state of the art at that period, and had the patents been carefully studied by others there would not have been various features of my system reinvented, and several inventors would have been spared at this late date a keen disappointment.

The writer apprehends that it might be difficult for a non-technical judge to decide whether a motor with two or more separate fields and armatures, coupled together mechanically, does or does not fall under my patent. I do not share his apprehension. Judges are highly educated men, and it does not require much technical knowledge to convince one that it is the same whether two belts driving a rigid arbor are close together or far apart. Nor do I think that it is necessary for the honorable judge to be a partisan of the armature reaction theory in order to recognize the identity of the two arrangements referred to by the writer of the article in question. Indeed, I would seriously doubt the sincerity of a man capable of clear conceptions were he to uphold that the arrangements are essentially different, even if the case should stand exactly as he assumes by way of illustration of "puzzles likely to arise." For where is there a difference? Take, for instance, a form of my two-phase motor There are two sets of field magnets, one at the *neutral* parts of the other. One of the sets, therefore, might as well be removed and placed a distance sideways, but long experience shows that in output, efficiency, cost of construction and in general mechanical respects such an arrangement is inferior. The two sets are connected inductively through the armature body or the windings thereon. Part of the period one set of field magnets acts as a generator, setting up induction currents, which circulate in the field of force of the other set, which may be looked upon as a motor. Part of the period again, the second set becomes the generator and the first the motor, the action being at the same time such that the generated currents are always passed in a definite direction with respect to the field; they are commutated as it were, and a tendency to rotate in a given direction is imparted to the armature. Now place two fields side by side and connect properly the armature windings. Are not the fields again inductively connected? Do not the currents set up by one field cause currents to circulate in the other, and is the action not exactly the same in both cases? This is a fact, no matter what theory is adhered to. The writer says that in the case of two separate structures there is really nothing which may be called rotation of the field. But is there any such thing, when the two structures are merged in one? Is it not in accordance with accepted notions to conceive the imaginary lines as surging simply in the pole projections in exactly the same manner in both the arrangements? Irrespective of the view taken, be it even the more unfair to the inventor, no one is permitted to go so far as to make him responsible, in such a case, for theories and interpretations of his invention. Theories may come and go, but the motor works, a practical result is achieved and the art is advanced through his pains and efforts. But what I desire to point out principally is that in the article above referred to the writer is only assuming a case which cannot occur. He is evidently judging the state of things from my short paper before the American Institute. This paper was written in a hurry, in fact only shortly before the meeting of the Institute, and I was unable to do full justice even to those features upon which, as employé of a company owning the invention, I was permitted to dwell. Allow me to observe that my patent specification was written up more carefully than my paper and the view taken in it is a broader and truer one. While the "clumsy" theory was adapted as the best in explanation of the action of the motor, the invention is *not* represented as dependent entirely on that theory; and in showing a three phase motor with six projections, where it was manifestly more consistent with the accepted popular ideas to assume the "lines of force" as simply surging in the projecting pole pieces, this view was distinctly and advisedly taken, as the following quotation from my foundation patent will show: "The variations in the strength and intensity of the currents transmitted through these circuits (lines and armature) and traversing the coils of the motor produce a steadily progressive shifting of the *resultant attractive force* exerted by the poles upon the armature and consequently keep the armature rapidly rotating." There is, in this instance, no question of a rotating field in the common acceptance of the term of the *resultant attractive force*: there is a question simply of a diagram of force, and it is immaterial for the operation whether the fields are close together or far apart, or even whether, or not, they are inductively connected.

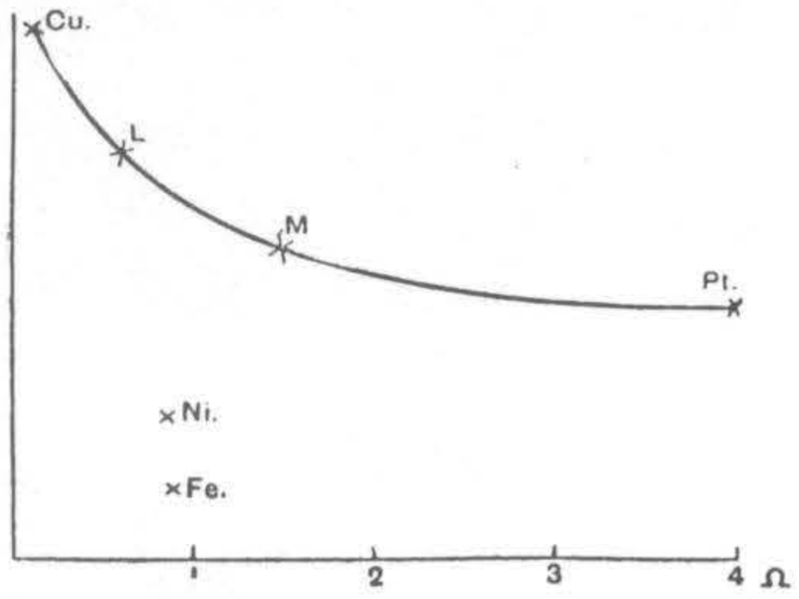
I do not think that in Germany, where the Patent Office is proverbially strict in upholding the rights of the inventor, an illegitimate and unfair appropriation of the invention by others will be tolerated by the courts.

ON THE DISSIPATION OF THE ELECTRICAL ENERGY OF THE HERTZ RESONATOR.*

BY V. BJERKNES.

In introducing conducting wires on different metals into his resonator Hertz asserted that neither the resistance nor the magnetic properties of the metal involved a sensible change in the length of the secondary spark.† We should, therefore, be tempted to conclude that the oscillations are completely independent of the nature of the metal. This independence is, however, only apparent. In my researches I employed a circular resonator having a diameter of 0·40m., and a complete period (double) of 14×10^{-8} second. The poles took the shape of vertical parallel discs 0·008m. apart, and 0·03m. in diameter. In the field constituted by the gap between these discs a piece of aluminium foil, forming an angle of 45deg. with the azimuth of the discs, was suspended by a quartz thread as an electrometer needle. Instead of the secondary spark the deflection of this needle was observed.

In this resonator I employed in succession geometrically identical conducting wires of different metals, and I obtained very different deflections. In the annexed diagram I give the



results obtained with six wires, all of 0·5mm. diameter, but made of copper (Cu), brass (L), nickel (Ni), iron (Fe), German silver (M), and platinum (Pt) respectively. The resistances of the wires are marked as abscissæ, and the ordinates show the deflections of the electrometer needle.

The results given in this figure appear at first glance singularly opposed to those obtained by Hertz. I think, however, that this divergence is only due to the difference of the methods. The oscillations of the resonator commence at zero and rapidly tend to a maximum, and gradually decrease afterwards. By the spark we evidently measure the height of this maximum; by the electrometer we measure the sum of all the oscillations. Owing to damping, this sum may have very different values without materially altering the height of the maximum. Consequently, the observations of Hertz show that the resonator always receives the same amount of electrical energy; the electro-magnetic measurements show that this energy is dissipated more or less quickly, according to the nature of the metal.

The capital point is thus the dissipation. The laws which govern it are represented indirectly by the diagram; a small ordinate corresponding to a rapid dissipation. It will be seen that the four non-magnetic metals ranged themselves on a curve having uniformly decreasing ordinates. On the other hand, the two magnetic metals, that is to say iron and nickel, are quite outside the curve, and the most magnetic metal is that which is the furthest from the curve. I have, therefore, come to the following conclusion:—*The rapidity with which the electrical energy of the resonator is dissipated is increased by the resistance and the magnetism of the conducting wire.* This dissipation may take place in two different ways, by radiation across the dielectric medium or by transformation into heat in the conducting wire. The considerable influence possessed by the physical constants of the metals seems to indicate that the transformation into heat is the principal cause. This transformation takes place in the thin superficial layer along which the electric currents flow. I endeavoured to determine the thickness of this layer with a view of getting to the bottom of the question.

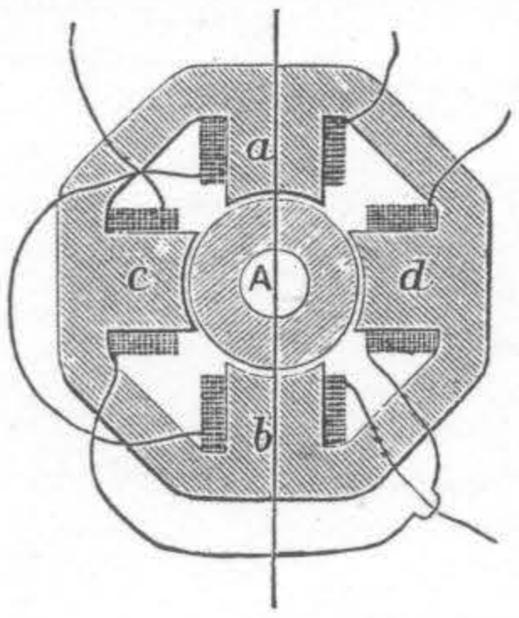
To ascertain this, I covered the iron wire with thicker and thicker electrolytic layers of copper, and I found that the deflections of the electrometer increased, approaching asymptotically to the value of the deflections which took place in the case of the solid copper wire; the difference between the wires disappeared when the layer had a thickness of 0·01mm. I next covered the copper wire with electrolytic layers of iron; even a layer 0·0002mm. thick had an appreciable effect. The deflections very quickly approached the value which they had in the case of the solid iron wire, and all difference disappeared at the moment when the layer exceeded 0·003mm. in thickness. *I conclude, therefore, that the currents penetrate less deeply into the magnetic metals than into the non-magnetic metals.*

This result explains the part played by magnetism in the dissipation of electrical energy. The currents being confined to a thin layer, these would encounter a greater resistance, and consequently there would be a greater generation of heat. This explanation agrees with the theory already put forward by Lord Rayleigh and Herr Stefan. I may remark in conclusion that the penetration of alternating currents into the metals is a phenomenon of the same nature as the penetration of light into them. The results which I have obtained are sufficient to prove that metals are more transparent to luminous undulations, which agrees perfectly with theory.

* From the *Comptes Rendus*, Vol. CXV., No. 19.
† Hertz *Ausbreitung der Elektrischen Kraft*, p. 50.

Operation of the Tesla Alternating Motor.

Rankin Kennedy contributes to the London *Electrical Review* an article on "The Drehstrom Patents" that will



OPERATION OF THE TESLA ALTERNATING MOTOR.

be of interest to many readers in that it gives a good explanation of the actions of a multiphase motor. Mr. Kennedy says, concerning the claims of several inventors: "The whole question, no doubt, will be thrashed out in some law court, the issue being whether Tesla's patent is sweeping enough to rake in the improvements made during the last four years by those other inventors in the same field.

"As one who has worked out a drehstrom motor, which I consider to be a totally different invention from Tesla's, I may be permitted to give my views on the subject. In the first place, let us see what was Tesla's motor.

"It consisted essentially of two magnetic systems, one energized by one alternating current, the other energized by another alternating current, the two currents differing in phase by 90°, and these two magnetic systems acted on an armature having closed coils. The diagram is a simple illustration; *a b* forms one of the magnetic systems, *c d* the other. *A* is the armature.

"The action of such a motor is very simple, although its action has been obscured by the volumes of mathematical analysis and investigations made into it, and also by elaborate attempts to work out the rotary polar theory; its action is quite obviously simply the same as ordinary motors. The poles, *a b*, are at a maximum at the same instant that the poles, *c d*, are a minimum power, consequently the armature coils at that moment form a closed secondary circuit to the primary, *a b*, so that poles are induced in the armature by this secondary current, which are opposite in sign to *a b*, but lag in phase behind *a b*; the poles, being opposite on armature, are repelled by *a b*, and attracted round by *c d*, which poles begin to strengthen as *a b* weakens, till *c d* are at a maximum strength and *a b* at a minimum, when the same cycle begins again, thus producing rotation of the armature, without a commutator.

"Tesla also claims that if armature *A* were made into two armatures, placed side by side on the same shaft, and the poles *a b* acting on one of the armatures and *c d*, one of the pair of poles, being shifted along sideways to embrace one of the armatures acting on the other armature, both armature coils being connected electrically across, that construction would still be a Tesla motor; no doubt it would, but what becomes of the rotary polar theory?

"The writer of this article constructed and exhibited at the Edinburg exhibition a motor working with two Siemens drum armatures connected together to form closed circuits; these were acted on by two laminated magnets excited by two currents in quadrature. Such a construction comes

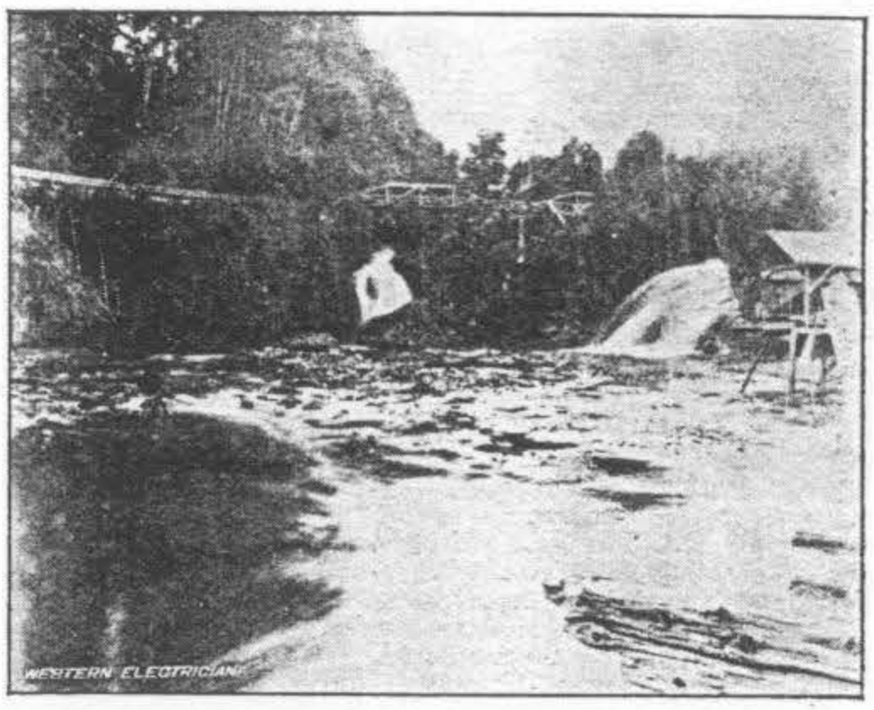


FIG. 2. UTILIZING WATER POWER IN WASHINGTON FOR GENERATING ELECTRICITY.

under Mr. Tesla's claims. Under the best conditions, however, this style of motor is a waster; it is not efficient, and does not start with a load, so that Tesla's claims don't concern it very much.

"Another form was made afterward, which proved considerably superior to Tesla's form. I described it in detail. Other inventors have made improvements, and the question at issue between them and Tesla is whether such constructions come under Tesla's patent right. The general question for electrical engineers is of more importance to your readers, and that is, are multiphase Tesla or drehstrom motors "any good anyhow?" The author's opinion is that they are no good—even the best of them yet designed. They have little or no great starting torque, and require enormous exciting currents. Their only field of usefulness can be in transmitting small powers on board ships or in mines.

"If ordinary high frequency is employed, such as is required for lighting purposes, then motors such as these, wherein the field magnets are excited by the alternating current, the exciting current becomes too large. If the frequency is low, then the mutual induction is too low, and the motor becomes too large for the power it gives out.

"Altogether the drehstrom motor has not so much to recommend it that would make it worth while fighting for it. Two and three-phase currents have more important ap-

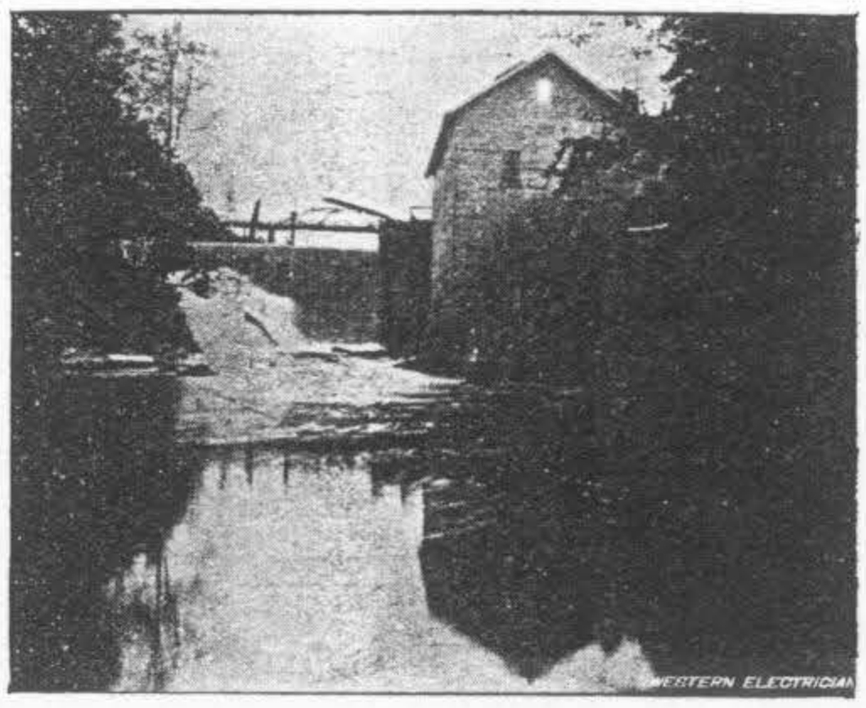


FIG. 4. UTILIZING WATER POWER IN WASHINGTON FOR GENERATING ELECTRICITY.

plications than for driving motors. For transmitting electrical energy to a distance at high pressure, and afterward converting it into low pressure, continuous current for distribution seems to be a more promising application.

"The alternating current motor, which has been a 'long-felt want,' is a small motor to work safely and efficiently on the present existing alternators, with no commutator, if possible; but with a commutator, if you like, provided no skilled attendance is required."

The Westinghouse Electric and Manufacturing Co.

The current year, the Westinghouse Electric & Manufacturing Co. reports, has been the most successful in its history, not only on account of the fact that it leaves the company in a most prosperous financial condition, but also because of the record made during the year by the apparatus manufactured by it. With 1892 the business of the company assumed extraordinary proportions. Contracts, unsolicited in a number of cases, came in very fast, and daily shipments averaged many times the amount of what had ever been experienced prior to the reorganization.

To meet the demand of the many orders, the old works on Garrison Alley, in Pittsburgh, were rearranged so as to give additional room, and to give the company an opportunity of making the most of all available space. A new boiler house was put up with an increased capacity. But as even this was not ample, the company decided to make use of the old Westinghouse air brake works in Allegheny City. In the latter place a machine shop is now being erected and is almost completed, which will be one of the best equipped establishments of its kind in the world. It will be a dynamo shop, the management having decided to utilize it exclusively as a place in which are to be manufactured electric light generators and power generators. Among those in course of construction at present are the large generators which will be used for lighting the World's Fair buildings at Chicago.

This success of the Westinghouse company has been largely due to the character of the apparatus made by it, the rule being to employ only the best materials and workmanship. In the street railway department of the company the Westinghouse motor has kept pace with the improvements made in the science. It is strong, easily handled, can be operated with facility, and runs with scarcely any noise. It has not only manifested its excellence by having been adopted by many of the largest street railway corporations in the country, but the Westinghouse company has also some obtained contracts for replacing other systems.

The same activity which characterized the electric railway business of the company during this year has also manifested itself in all the other departments. The alternating current electric lighting apparatus manufactured by the company, is still maintaining its well

earned reputation. Not only has the Westinghouse lighting system been selected by the World's Fair committee of Chicago to illuminate the World's Fair buildings and grounds at Jackson Park, but the Westinghouse company has also received a large number of orders for central station plants throughout the country.

The company states that it has also made wonderful progress in the construction of apparatus for electrical transmission of power over long distances. As it owns all the patents for the manufacture of the Tesla motor, it holds a very advantageous position in the development of this branch of electrical industry. Electrical transmission of power is one of the latest developments in the electrical business, but the prospects for a wonderful amount of work in this field are already very large. Already a number of plants are in operation with the Westinghouse system, and all of them are reported to have been a success from the start.

ON THE DISSIPATION OF THE ELECTRICAL ENERGY OF THE HERTZ RESONATOR.[1]

BY V. BJERKNES.

In introducing conducting wires of different metals into his resonator Hertz asserted that neither the resistance nor the magnetic properties of the metal involved a sensible change in the length of the secondary spark.[2] We should, therefore, be tempted to conclude that the oscillations are completely independent of the nature of the metal. This independence is, however, only apparent. In my researches I employed a circular resonator having a diameter of 0.40m., and a complete period (double) of 14×10^{-8} second. The poles took the shape of vertical parallel discs 0.008m. apart, and 0.03m. in diameter. In the field constituted by the gap between these dics a piece of aluminum foil, forming an angle of 45 degrees with the azimuth of the discs, was suspended by a quartz thread as an electrometer needle. Instead of the secondary spark the deflection of this needle was observed.

In this resonator I employed in succession geometrically identical conducting wires of different metals, and I obtained very different deflections. In the diagram Fig. 1, I give the results obtained with six wires, all of 0.5mm. diameter, but made of copper (Cu), brass (L), nickel (Ni), iron (Fe), German silver (M), and platinum (Pt) respectively. The resistances of the wires are marked as abscissæ, and the ordinates show the deflections of the electrometer needle.

The results given in this figure appear at first glance singularly opposed to those obtained by Hertz. I think, however, that this divergence is only due to the difference of the methods. The oscillations of the resonator commence at zero and rapidly tend to a maximum, and gradually decrease afterwards. By the spark we evidently measure the height of this maximum; by the electrometer we measure the sum of all the oscillations.

Owing to damping, this sum may have very different values without materially altering the height of the maximum. Consequently, the observations of Hertz show that the resonator

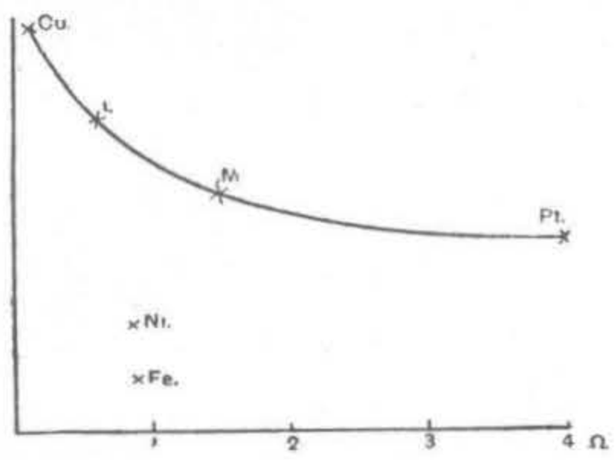


FIG. 1.

always receives the same amount of electrical energy; the electromagnetic measurements show that this energy is dissipated more or less quickly, according to the nature of the metal.

The capital point is thus the dissipation. The laws which govern it are represented indirectly by the diagram; a small ordinate corresponding to a rapid dissipation. It will be seen that the four non-magnetic metals ranged themselves on a curve having uniformly decreasing ordinates. On the other hand, the two magnetic metals, that is to say iron and nickel, are quite outside the curve, and the most magnetic metal is that which is the furthest from the curve. I have, therefore, come to the following conclusion:—*The rapidity with which the electrical energy of the resonator is dissipated is increased by the resistance and the magnetism of the conducting wire.* This dissipation may take place in two different ways, by radiation across the dielectric medium, or by transformation into heat in the conducting wire. The considerable influence possessed by the physical constants of the metals seems to indicate that the transformation into heat is the principal cause. This transformation takes place in the thin superficial layer along which the electric currents flow. I endeavored to determine the thickness of this layer with a view of getting to the bottom of the question.

To ascertain this, I covered the iron wire with thicker and thicker electrolytic layers of copper, and I found that the deflections of the electrometer increased, approaching asymptotically to the value of the deflections which took place in the case of the solid copper wire; the difference between the wires disappeared when the layer had a thickness of 0.01mm. I next covered the copper wire with electrolytic layers of iron; even a layer 0.0002mm. thick had an appreciable effect. The deflections very quickly approached the value which they had in the case of the solid iron wire, and all difference disappeared at the moment when the layer exceeded 0.003mm. in thickness. *I conclude, therefore that the currents penetrate less deeply into the magnetic metals than into the non-magnetic metals.*

This result explains the part played by magnetism in the dissipation of electrical energy. The currents being confined to a thin layer, these would encounter a greater resistance, and consequently there would be a greater generation of heat. This explanation agrees with the theory already put forward by Lord Rayleigh and Herr Stefan. I may remark in conclusion that the penetration of alternating currents into the metals is a phenomenon of the same nature as the penetration of light into them. The results which I have obtained are sufficient to prove that metals are more transparent to luminous undulations, which agrees perfectly with theory.

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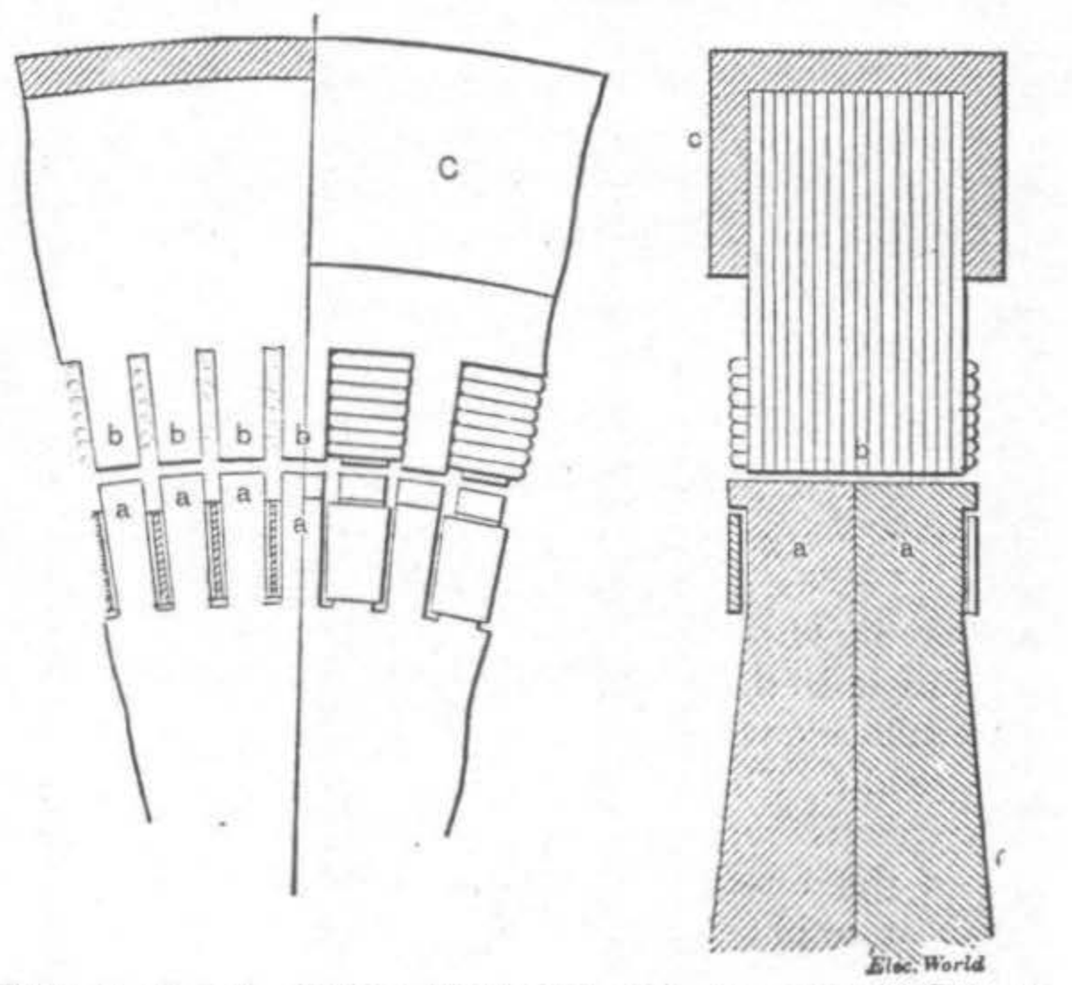
1. From the *Comptes Rendus*, Vol. CXV., No. 19.
2. Hertz *Ausbreitung der Elektrischen Kraft*, p. 50.

Ewing's High Frequency Alternator.

Prof. Ewing, whose tests of the Parsons steam turbine were published in our last issue, recently designed a high frequency alternator adapted to be driven by this high speed turbine. The complete apparatus, consisting of a steam turbine, alternator and a continuous current dynamo, all direct coupled and on the same base plate, was recently presented by Mr. Parsons to the Cambridge Laboratory.

The alternator has a speed of 1,200 revolutions per minute, and generates currents of 70 complete cycles per revolution, making 14,000 complete cycles per second; the output is about five ampères at 100 volts. The machine is intended for experimental purposes and investigation, among others



FIGS. 1 AND 2.—FIELD MAGNET AND ARMATURE POLES.

those of the physiological effects of high frequency alternating currents. The construction of the alternator will be seen in the accompanying diagrams, for which we are indebted to the London *Electrician*, in which Fig. 1 shows a part section and part elevation, while Fig. 2 shows a cross-section parallel to the shaft. *a a* is the field magnet, which revolves, while the armature *b b* is stationary; there are 140 poles in all. The magnets are made of two steel discs, *a a*, as shown in Fig. 2, in which radial cuts are made, thus forming the teeth, *a a a*. The armature is made of 60 plates of sheet iron, each about ten mils in thickness, held together by a cast iron ring, *c c c*; the teeth in these are likewise produced by cutting slots in the discs; the clearance or air gap is one thirty-second of an inch, and the depth of the teeth is three-eighths of an inch. The field magnets are wound with an insulated copper strip, as shown, which passes in a zigzag fashion between the teeth. The armature also is wound with a zigzag winding, only that fine wire is used instead of copper strip. The two steel discs forming the magnets are insulated from each other and act as terminals to lead the exciting current to and from the copper strip.

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ON THE DISSIPATION OF THE ELECTRICAL ENERGY OF THE HERTZ RESONATOR.

BY

Nikola Tesla

ANYONE who, like myself, has had the pleasure of witnessing the beautiful demonstrations with vibrating diaphragms which Prof. Bjerknes, exhibited in person at the Paris Exposition in 1889, must have admired his ability and painstaking care to such a degree, as to have an almost implicit faith in the correctness of observations made by him. His experiments "On the Dissipation of the Electrical Energy of the Hertz Resonator," which are described in the issue of Dec. 14, of THE ELECTRICAL ENGINEER, are prepared in the same ingenious and skillful manner, and the conclusions drawn from them are all the more interesting as they agree with the theories put forth by the most advanced thinkers. There can not be the slighest doubt as to the truth of these conclusions, yet the statements which follow may serve to explain in part the results arrived at in a different manner; and with this object in view I venture to call attention to a condition with which, in investigations such as those of Prof. Bjerknes, the experimenter is confronted.

The apparatus, oscillator and resonator, being immersed in air, or other discontinuous medium, there occurs—as I have pointed out in the description of my recent experiments before the English and French scientific societies—dissipation of energy by what I think might be appropriately called *electric sound waves* or *sound-waves of electrified air*. In Prof. Bjerknes's experiments principally this dissipation in the resonator need be considered, though the sound-waves—if this term be permitted—which emanate from the surfaces at the oscillator may considerably affect the observations made at some distance from the latter. Owing to this dissipation the period of vibration of an air-condenser can not be accurately determined, and I have already drawn attention to this important fact.

These waves are propagated at right angles from the charged surfaces when their charges are alternated, and dissipation occurs, even if the surfaces are covered with thick and excellent insulation. Assuming that the "charge" imparted to a molecule or atom either by direct contact or inductively is proportionate to the electric density of the surface, the dissipation should be proportionate to the square of the density and to the number of waves per second. The above assumption, it should be stated, does not agree with some observations from which it appears that an atom can not take but a certain maximum charge; hence, the charge imparted may be practically independent of the density of the surface, but this is immaterial for the present consideration. This and other points will be decided when accurate quantitative determinations, which are as yet wanting, shall be made. At present it appears certain from experiments with high-frequency currents, that this dissipation of energy from a wire, for instance, is not very far from being proportionate to the frequency of the alternations, and increases very rapidly when the diameter of the wire is made exceedingly small. On the latter point the recently published results of Prof. Ayrton and H. Kilgour on "The Thermal Emissivity of Thin Wires in Air" throw a curious light. Exceedingly thin wires are capable of dissipating a comparatively very great amount of energy by the agitation of the surrounding air, when they are connected to a source of rapidly alternating potential. So in the experiment cited, a thin hot wire is found to be capable of emitting an extraordinarily great amount of heat, especially at elevated temperatures. In the case of a hot wire it must of course be assumed that the increased emissivity is due to the more rapid convection and not, to any appreciable degree, to an increased radiation. Were the latter demonstrated, it would show that a wire, made hot by the application of heat in ordinary ways, behaves in some respects like one, the charge of which is rapidly alternated, the dissipation of energy per unit of surface kept at a certain temperature depending on the curvature of the surface. I do not recall any record of experiments intended to demonstrate this, yet this effect, though probably very small, should certainly be looked for.

A number of observations showing the peculiarity of very thin wires were made in the course of my experiments. I noted, for instance, that in the well-known Crookes instrument the mica vanes are repelled with comparatively greater force when the incandescent platinum wire is exceedingly thin. This observation enabled me to produce the spin of such vanes mounted in a vacuum tube when the latter was placed in an alternating electrostatic field. This however does not prove anything in regard to radiation, as in a highly exhausted vessel the phenomena are principally due to molecular bombardment or convection.

When I first undertook to produce the incandescence of a wire enclosed in a bulb, by connecting it to only *one* of the terminals of a high tension transformer, I could not succeed for a long time. On one occasion I had mounted in a bulb a thin platinum wire, but my apparatus was not adequate to produce the incandescence. I made other bulbs, reducing the length of the wire to a small fraction; still I did not succeed. It then occurred to me that it would be desirable to have the surface of the wire as large as possible, yet the bulk small, and I provided a bulb with an exceedingly thin wire of a bulk about equal to that of the short but much thicker wire. On turning the current on the bulb the wire was instantly fused. A series of subsequent experiments showed, that when the diameter of the wire was exceedingly small, considerably more energy would be dissipated per unit surface at all degrees of exhaustion than was to be expected, even on the assumption that the energy given off was in proportion to the square of the electric density. There is likewise evidence which, though not possessing the certainty of an accurate quantitative determination, is nevertheless reliable because it is the result of a great many observations, namely, that with the increase of the density the dissipation is more rapid for thin than for thick wires.

The effects noted in exhausted vessels with high-frequency currents are merely diminished in degree when the air is at ordinary pressure, but heating and dissipation occurs, as I have demonstrated, under the ordinary atmospheric conditions. Two very thin wires attached to the

terminals of a high-frequency coil are capable of giving off an appreciable amount of energy. When the density is very great, the temperature of the wires may be perceptibly raised, and in such case probably the greater portion of the energy which is dissipated *owing to the presence of a discontinuous medium* is transformed into heat at the surface or in close proximity to the wires. Such heating could not occur in a medium possessing either of the two qualities, namely, perfect incompressibility or perfect elasticity. In fluid insulators, such as oils, though they are far from being perfectly incompressible or elastic to electric displacement, the heating is much smaller because of the continuity of the fluid.

When the electric density of the wire surfaces is small, there is no appreciable local heating, nevertheless energy is dissipated in air by waves, which differ from ordinary sound-waves only because the air is electrified. These waves are especially conspicuous when the discharges of a powerful battery are directed through a short and thick metal bar, the number of discharges per second being very small. The experimenter may feel the impact of the air at distances of six feet or more from the bar, especially if he takes the precaution to sprinkle the face or hands with ether. These waves cannot be entirely stopped by the interposition of an insulated metal plate.

Most of the striking phenomena of mechanical displacement, sound, heat and light which have been observed, imply the presence of a medium of a gaseous structure, that is, one consisting of independent carriers capable of free motion.

When a glass plate is placed near a condenser the charge of which is alternated, the plate emits a sound. This sound is due to the rythmical impact of the air against the plate. I have also found that the ringing of a condenser, first noted by Sir William Thomson, is due to the presence of the air between or near the charged surfaces.

When a disruptive discharge coil is immersed in oil contained in a tank, it is observed that the surface of the oil is agitated. This may be thought to be due to the displacements produced in the oil by the changing stresses, but such is not the case. It is the air above the oil which is agitated and causes the motion of the latter; the oil itself would remain at rest. The displacements produced in it by changing electrostatic stresses are insignificant; to such stresses it may be said to be compressible to but a very small degree. The action of the air is shown in a curious manner for if a pointed metal bar is taken in the hand and held with the point close to the oil, a hole two inches deep is formed in the oil by the molecules of the air, which are violently projected from the point.

The preceding statements may have a general bearing upon investigations in which currents of high frequency and potential are made use of, but they also have a more direct bearing upon the experiments of Prof. Bjerknes which are here considered, namely, the "skin effect," is increased by the action of the air. Imagine a wire immersed in a medium, the conductivity of which would be some function of the frequency and potential difference but such, that the conductivity increases when either or both of these elements are increased. In such a medium, the higher the frequency and potential difference, the greater will be the current which will find its way through the surrounding medium, and the smaller the part which will pass through the central portion of the wire. In the case of a wire immersed in air and traversed by a high-frequency current, the facility with which the energy is dissipated may be considered as the equivalent of the conductivity; and the analogy would be quite complete, were it not that besides the air another medium is present, the total dissipation being merely modified by the presence of the air to an extent as yet not ascertained. Nevertheless, I have sufficient evidence to draw the conclusion, that the results obtained by Prof. Bjerknes are affected by the presence of air in the following manner: 1. The dissipation of energy is more rapid when the resonator is immersed in air than it would be in a practically continuous medium, for instance, oil. 2. The dissipation owing to the presence of air renders the difference between magnetic and non-magnetic metals more striking. The first conclusion follows directly from the preceding remarks; the second follows from the two facts that the resonator receives always the same amount of energy, independent of the nature of the metal, and that the magnetism of the metal increases the impedance of the circuit. A resonator of magnetic metal behaves virtually as though its circuit were longer. There is a greater potential difference set up per unit of length, although this may not show itself in the deflection of the electrometer owing to the lateral dissipation. The effect of the increased impedance is strikingly illustrated in the two experiments of Prof. Bjerknes when copper is deposited upon an iron wire, and next iron upon a copper wire. Considerable thickness of copper deposit was required in the former experiment, but very little thickness of iron in the latter, as should be expected.

Taking the above views, I believe, that in the experiments of Prof. Bjerknes which lead him to undoubtedly correct conclusions, the air is a factor fully as important, if not more so, than the resistance of the metals.

PATENT NOTES.

TESLA'S SYSTEM OF MULTIPHASE DISTRIBUTION.

As is frequently the case, inventions are exploited and worked commercially before the issuance of the patents thereon, and not infrequently much injustice is done to the inventor by reason of the fact that the public is in ignorance of the date of the filing of the application. A striking instance of this character is the patent issued to Mr. Tesla on Dec. 13, 1892, No. 487,796, entitled "System of Electrical Transmission of Power."

While most of the features embodied in this patent are now well known in the art, the fact that the application was filed as far back as May 15, 1888, shows that even at that remarkably early date Mr. Tesla's ideas on the subject were clearly defined. The underlying principle embodied in this patent is to adapt the Tesla system to the type of alternating machinery now in general use. Thus there are described various methods of obtaining the required phase difference with ordinary multipolar alternators, by winding or coupling machines in various ways, together with other features whereby a single generator may run a number of motors either at the same speed as its own or all at different speeds.

In the course of an interesting letter which Mr. Tesla sends us this week in connection with the subject of high-frequency alternators, it is stated that the ordinary rules of the magnetic circuit do not hold good for such rapidly changing currents. Our experience with these currents is so limited that it is quite impossible to say whether the striking phenomena to which they give rise can or cannot be accounted for by the old and well-known laws of electricity. Mr. Tesla has suggested that high-frequency currents are quite harmless physiologically, but no one has ever measured them, and the "skin effect," caused by the tendency of currents to crowd towards the surface of conductors, is of so great importance at these high frequencies that the actual currents are probably very much smaller than they are generally supposed to be. For a similar reason, before applying the laws of the magnetic circuit, the effect of eddy currents in the iron must be carefully borne in mind. Profs. J. J. Thomson and Ewing have shown that, even with such slow alternations as 100 $\sim$, eddy currents considerably disturb the distribution of the lines of force in plates of iron of only half a millimetre thickness. With a frequency of more than 100 times that of ordinary alternating currents, these effects will be of very great importance, and it is idle to talk of the laws of the magnetic circuit unless the eddy currents have been taken into consideration. As regards the power of iron to follow the changes of the magnetising force, it has been conclusively proved by the experiments of Prof. J. J. Thomson and others that iron does really remain magnetic for currents which reverse 20,000 times per second.

TESLA MOTORS OPERATED FROM SINGLE PHASE TWO-WIRE ALTERNATING CIRCUITS.

Those interested in Mr. Tesla's investigations will recall that in 1888 he read a paper before the American Institute of Electrical Engineers laying down the principles of his new multiphase system of operating alternating current motors, of which they have since seen their practical application. The results are covered in two patents which have recently been issued to him.

In this multiphase system it will be remembered, each motor has two or more independent energizing circuits through which are passed alternating currents, having in each circuit such a difference of phase that by their combined or resultant action they produce a rotary progression of the poles or points of maximum magnetic effect of the motor and thereby maintain the rotation of the armature.

To the successful operation of a system of this kind, at least three wires are necessary to convey the different currents, and Mr. Tesla has, therefore, devised means for operating phase motors from the ordinary single-phase alternating circuit, by creating the difference of phase locally at and in the motor.

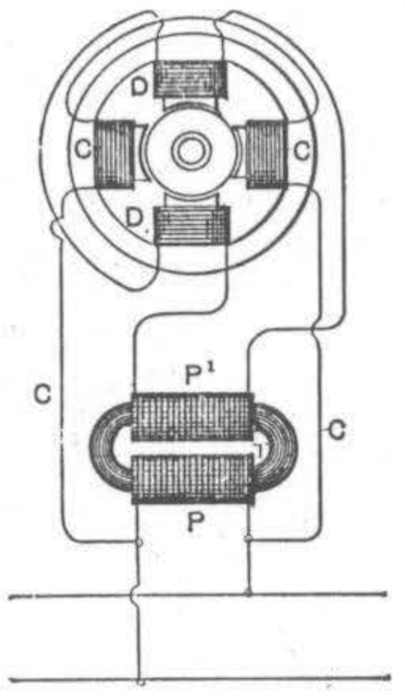


FIG. 1. TESLA MOTOR WITH ENERGIZING CIRCUITS.

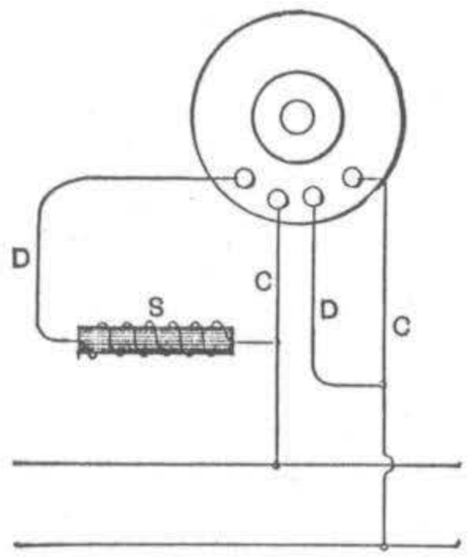


FIG. 2. TESLA MOTOR WITH SELF-INDUCTION COIL.

In all the methods described below, the fundamental idea involved is to pass a single alternating current through both of the energizing circuits of the motor, and to retard the phase of the current in one circuit to a greater or less extent than in the other. The distribution of current between the two motor circuits is effected either by induction or by derivation.

The diagram Fig. 1 shows a motor with two energizing circuits, C and D. One of these circuits, C, is connected directly with the line circuit, while the other set D, is connected up in the secondary circuit of a transformer T. The primary P of this transformer, is connected to the line circuit. The alternations of current in the line tend to establish in their passage through

the coils C, a polarity opposed to that set up in the coils D, and if the currents in the two sets of coils coincided in their phases, no rotary effect would be produced. But the secondary current developed in the coil P of the transformer, will lag behind that in the primary, which lag may be increased to a sufficient extent to practically obtain the same result as though two independent currents were used to energize the motor.

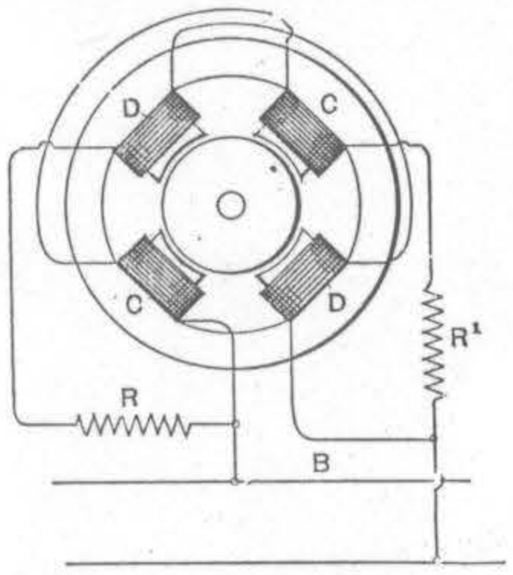


FIG. 3. TESLA MOTOR WITH TWO DEAD RESISTANCES.

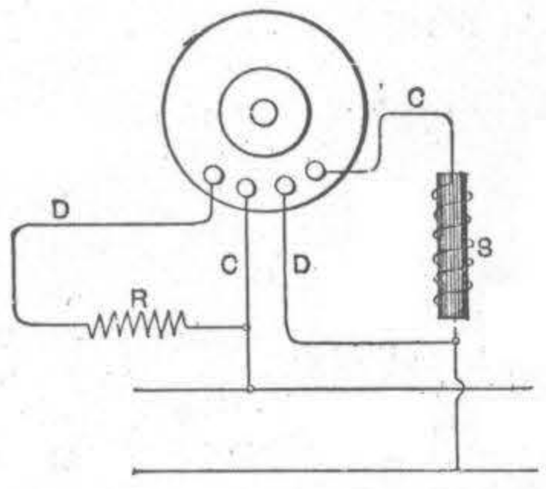
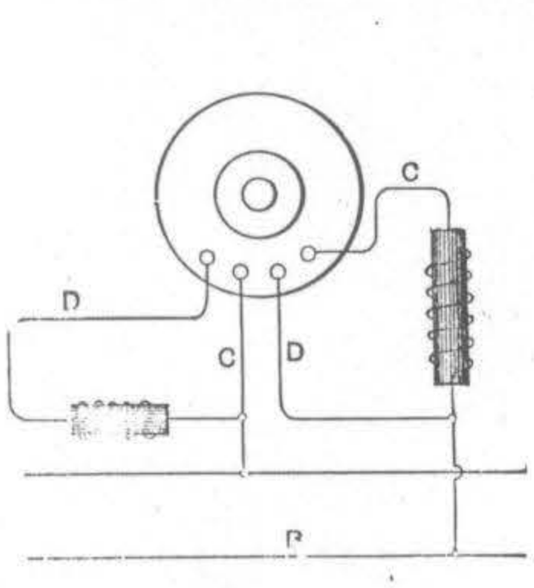


FIG. 4. TESLA MOTOR WITH SELF-INDUCTION COIL AND DEAD RESISTANCE.

In another form, shown in Fig. 2, the arrangement of the parts is similar to that shown in Fig. 6, except that a self-induction coil S, is introduced into one energizing circuit of the motor. The effect of thus increasing the self-induction in one of the circuits is to retard the phases of the current passing therein to a greater extent than in the other circuit, and in this way to secure the necessary difference in phase between the two energizing currents to produce the rotation of the motor.

In Fig. 3 there is shown a type of motor in which two dead resistances R R are included respectively in the energizing coils of the motor. No rotary effect will be produced as long as the resistances are equal, but by varying the resistance in one circuit the retardation of the current in that circuit will be varied and corresponding effects produced. For example, a reduction of the resistance in one circuit imparts to the motor rotation in one direction while a reduction of the resistance in the other circuit will produce a rotation in the opposite direction. By means of the two



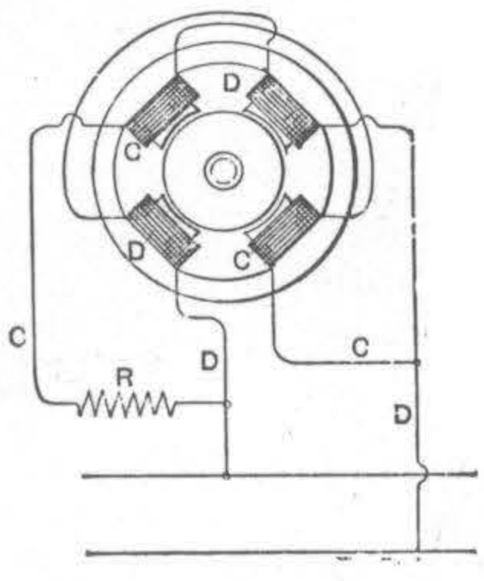


FIG. 5. TESLA MOTOR WITH TWO SELF-INDUCTION COILS.

FIG. 6. TESLA MOTOR WITH ENERGIZING CIRCUITS IN MULTIPLE ARC.

resistances, therefore, capable of variation or of being bodily withdrawn from or inserted in the circuits by simple means, rotation of the motor is secured.

In Fig. 4 a self-induction coil S is included in one of the motor circuits and a dead resistance R in the other. The increased self-induction in one circuit thus produced acts to increase the difference of phase between the current in that motor circuit and the unretarded current in the line circuit. On the other hand, the introduction of the dead resistance in the other motor circuit reduces the retardation and brings the phases of the current in it more closely in accord with those of the unretarded current, thus producing a correspondingly greater difference of phase between the two currents in the energizing circuits C and D.

In Fig. 5, two self-induction coils are shown, one in each motor or energizing circuit. One of these coils is much smaller than the other and has less self-induction or counter-E. M. F. than the other, so that the phases of current will be retarded to a less extent than in the other.

In Fig. 6 the two energizing circuits of the motor are shown connected in multiple arc to the line circuit and in one of these circuits is a resistance R. Assuming the two motor circuits to have the same degree of self-induction no rotary effect will be produced by the passage through them of an alternating current from the line. But if one of the motor circuits, as C, be varied or modified by the introduction of a dead resistance R, the self-induction of that circuit or branch is reduced, and the phases of current therein retarded to a correspondingly less extent. The relative degrees of retardation of the phases of the current in the two motor circuits with respect to those of the unretarded current in the circuit B thus produced, will set up a rotation of the motor.

There is finally another type in which one set of energizing coils is of finer wire than the other or has a greater number of convolutions; or each circuit may contain the same number of convolutions, but be composed of different conductors, as, for instance, one of copper, and the other of German silver.

Simplification of Tesla's Experiments.—When reproducing Tesla's experiments, M. Schœntjes, professor at the University of Gand, has found that they may be reproduced with currents of quite low frequency, though the intensity of the phenomena is less. The ordinary method of carrying out these experiments in the class-room consists in charging a condenser by means of secondary currents from a first Ruhmkorff coil, and passing the discharge—rendered oscillating by a spark passing between the knobs of an exciter — into the primary circuit of a second coil immersed in oil. The currents generated in the secondary coil of this transformer are used to produce the Tesla effect. M. Schœntjes did away with the whole of this arrangement, keeping simply the first coil with an ordinary spring contact-breaker. The coil was 40cm. long and 20cm. diameter. The primary current was taken from accumulators. The following experiments were carried out : (*a*) The two poles of the secondary wire being free, a vacuum tube, with or without electrode, was lighted up when held by the hand or placed on a block of paraffin a foot or so from the coil. A vacuum tube held by one end in the hand was lighted by contact to one of the poles, contact not being necessary. The tube, insulated on a block of paraffin in contact with one only of the poles, became luminous. (*b*) One of the poles being free, and the other connected to a plate of sheet iron sus-

pended from the ceiling by insulating supports: (1) By attaching to the free pole an exhausted bulb furnished with one electrode and a straight carbon filament, the filament became luminous, though very feebly; (2) vacuum tubes, Crookes tubes, and phosphorescent powder tubes became luminous when held in the hand below or near the plate—they seem to go out when passed from one hand to the other along all their length; (3) the tubes became luminous when laid on a block of paraffin below the suspended plate. (*c*) The two poles connected by a wire with an air space for the passage of the spark of the direct induced current: a vacuum tube lighted up when held near the coil. (*d*) The same arrangement as for (*c*), but one of the poles is connected to the suspended plate: tubes lighted up near the coil, and under or near the plate. By using a Foucault contact-breaker, making only five oscillations per second, the preceding experiments still succeed. With a much smaller coil the phenomena occur with practically the same strength. One of the poles of the small coil can be touched with impunity by forming a chain of two persons holding a vacuum tube between them; one person touching one of the poles and the other holding a second vacuum tube in the free hand, both tubes will light.

Dissipation of Energy.—Mr. Nikola Tesla contributes an article on the dissipation of electrical energy of the Hertz resonator to the American *Electrical Engineer*. The apparatus being immersed in air or other discontinuous medium, there occurs a dissipation of energy by "sound-waves of electrified air." Owing to this dissipation the period of vibration of an air-condenser cannot be accurately determined. Mr. Tesla has already drawn attention to this important point. These waves are propagated at right angles from charged surfaces, even if heavily insulated. Assuming that the charge imparted to a molecule or atom by direct contact or inductively is proportionate to the electric density of the surface, the dissipation should be proportionate to the square of the density and to the number of waves per second. From a wire, with high-frequency currents the dissipation is not far from proportionate to the frequency, and increases rapidly when the diameter is small. A wire made hot in the ordinary way behaves in some respects like one the charge of which is rapidly alternating, the dissipation depending on curvature of surface. In his experiments Mr. Tesla noticed that the mica vanes in Crookes's instrument are repelled with greater force when the incandescent wire is exceedingly thin. This observation led Mr. Tesla to produce the spin in alternating electrostatic fields. When he first undertook to produce incandescence of a wire in a bulb by connecting it to one only of the terminals of a high-tension transformer, he could not succeed for a long time. He reduced the length of wire without result. It then occurred to him to make the surface as large as possible, yet the bulk small—taking an exceedingly thin wire—and on turning on the current the wire instantly fused. Two very thin wires attached to the terminals of a high-frequency coil are capable of giving off an appreciable amount of energy. The waves are conspicuous at distances of 6ft., and differ from sound-waves only by being electrified, and cannot be entirely stopped by interposition of an insulated metal plate. The "ringing" of a condenser is due to the presence of air near the charged surfaces. Further, when a disruptive discharge coil is immersed in oil, the surface of the oil is agitated. This is not due to the oil: it is the air above the oil which is agitated. The action of the air is shown in a curious manner, for if a pointed metal bar is held with the point close over the coil, a hole 2in. deep is formed in the oil by the molecules of air violently projected from the point. It seems that the dissipation of energy is more rapid when the resonator is immersed in air than in oil; and the dissipation owing to the presence of air renders the difference between magnetic and non-magnetic metals more striking. A resonator of magnetic metal behaves virtually as if its circuit were longer. The conclusion arrived at from his own and Prof. Bjerknes' experiments, lead to the result that air must be considered as a factor fully as important, if not more so, than the resistance of the metals.

THE ELECTRICIAN:

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NOTES.

It is hard to imagine what a dynamo or an arc lamp would be like if the air, instead of being an insulator, were a conductor; but a moment's thought is enough to show how important the passive properties of air are to electricians. Mr. Tesla, in an article we publish this week, maintains that, under certain exceptional circumstances, the air by no means possesses the convenient properties usually assigned to it. With alternating currents of great rapidity, it appears not only that the distribution of the current is altered in consequence of the "skin effect," but that the air near the conductors receives and dissipates part of the energy of the current. Some of the experiments Mr. Tesla mentions are very remarkable, although none of them are quantitative, and no definite conclusion can be drawn from them. The amount of energy which various air motions actually represent would be an interesting matter to find out, but we are not aware that anyone has yet measured the energy of a musical sound, or of any less regular air disturbance.

ON THE DISSIPATION OF THE ELECTRICAL ENERGY OF THE HERTZ RESONATOR.†

BY NIKOLA TESLA.

Anyone who, like myself, has had the pleasure of witnessing the beautiful demonstrations with vibrating diaphragms which Prof. Bjerknes exhibited in person at the Paris Exposition in 1889, must have admired his ability and painstaking care to such a degree as to have an almost implicit faith in the correctness of observations made by him. His experiments "On the Dissipation of the Electrical Energy of the Hertz Resonator," which are described in the issue of December 14th of the *Electrical Engineer*,‡ are prepared in the same ingenious and skilful manner, and the conclusions drawn from them are all the more interesting as they agree with the theories put forth by the most advanced thinkers. There cannot be the slightest doubt as to the truth of these conclusions, yet the statements which follow may serve to explain in part the

* *Comptes Rendus*, September 19, 1892, Vol. CXV., No. 12. See also *The Electrician*, September 30, 1892, p. 578, Vol. XXIX.

† From the *Electrical Engineer* of New York.

‡ See *The Electrician*, November 18, 1892, p. 69.

results arrived at in different manner ; and with this object in view I venture to call attention to a condition with which, in investigations such as those of Prof. Bjerknes, the experimenter is confronted.

The apparatus, oscillator and resonator, being immersed in air, or other discontinuous medium, there occurs—as I have pointed out in the description of my recent experiments before the English and French scientific socities—dissipation of energy by what I think might be appropriately called *electric sound-waves or sound-waves of electrified air*. In Prof. Bjerknes's experiments principally this dissipation in the resonator need be considered, though the sound-waves—if this term be permitted—which emanate from the surfaces at the oscillator may considerably affect the observations made at some distance from the latter. Owing to this dissipation the period of vibration of an air-condenser cannot be accurately determined, and I have already drawn attention to this important fact.

These waves are propagated at right angles from the charged surfaces when their charges are alternated, and dissipation occurs, even if the surfaces are covered with thick and excellent insulation. Assuming that the "charge" imparted to a molecule or atom either by direct contact or inductively is proportinate to the electric density of the surface, the dissipation should be proportinate to the square of the density and to the number of waves per second. The above assumption, it should be stated, does not agree with some observations from which it appears that an atom cannot take but a certain maximum charge ; hence, the charge imparted may be practically independent of the density of the surface, but this is immaterial for the present consideration. This and other points will be decided when accurate quantitative determinations, which are as yet wanting, shall be made. At present it appears certain from experiments with high-frequency currents, and this dissipation of energy from a wire, for instance, is not very far from being proportionate to the frequency of the alternations, and increases very rapidly when the diameter of the wire is made exceedingly small. On the latter point the recently published results of Prof. Ayrton and H. Kilgour on "The Thermal Emissivity of Thin Wires in Air" throw a curious light. Exceedingly thin wires are capable of dissipating a comparatively very great amount of energy by the agitation of the surrounding air, when they are connected to a source of rapidly alternating potential. So in the experiment cited, a thin hot wire is found to be capable of emitting an extraordinarily great amount of heat, especially at elevated temperatures. In the case of a hot wire it must, of course, be assumed that the increased emissivity is due to the more rapid convection, and not, to any appreciable degree, to an increased radiation. Were the latter demonstrated, it would show that a wire, made hot by the application of heat in ordinary ways, behaves in some respects like one the charge of which is rapidly alternated, the dissipation of energy per unit of surface kept at a certain temperature depending on the curvature of the surface. I do not recall any record of experiments intended to demonstrate this, yet this effect, though probably very small, should certainly be looked for.

A number of observations showing the peculiarity of very thin wires were made in the course of my experiments. I noted, for instance, that in the well-known Crookes instrument the mica vanes are repelled with comparatively greater force when the incandescent platinum wire is exceedingly thin. This observation enabled me to produce the spin of such vanes mounted in a vacuum tube when the latter was placed in an alternating electrostatic field. This, however, does not prove anything in regard to radiation, as in a highly exhausted vessel the phenomena are principally due to molecular bombardment or convection.

When I first undertook to produce the incandescence of a wire enclosed in a bulb, by connecting it to only *one* of the terminals of a high tension transformer, I could not succeed for a long time. On one occasion I had mounted in a bulb a thin platinum wire, but my apparatus was not adequate to produce the incandescence. I made other bulbs, reducing the length of the wire to a small fraction ; still, I did not succeed. It then occurred to me that it would be desirable to have the surface of the wire as large as possible, yet the bulk small, and I provided a bulb with an exceedingly thin wire of a bulk about equal to that of the short but much thicker wire. On turning the current on the bulb the wire was instantly fused. A series of subsequent experiments showed that when the diameter of the wire was exceedingly small, considerably more energy would be dissipated per unit surface at all degrees of exhaustion than was to be expected, even on the assumption that the energy given off was in proportion to the square of the electric density. There is likewise evidence which, though not possessing the certainty of an accurate quantitative determination, is nevertheless reliable because it is the result of a great many observations, namely, that with the increase of the density the dissipation is more rapid for thin than for thick wires.

The effects noted in exhausted vessels with high-frequency currents are merely diminished in degree when the air is at ordinary pressure ; but heating and dissipation occurs, as I have demonstrated, under the ordinary atmospheric conditions. Two very thin wires, attached to the terminals of a high-frequency coil are capable of giving off an appreciable amount of energy. When the density is very great, the temperature of the wires may be perceptibly raised, and in such case probably the greater portion of the energy which is dissipated *owing to the presence of a discontinuous medium* is transformed into heat at the surface or in close proximity to the wires. Such heating could not occur in a medium possessing either of the two qualities, namely, perfect incompressibility or perfect elasticity. In fluid insulators, such as oils, though they are far from being perfectly incompressible or elastic to electric displacement, the heating is much smaller because of the continuity of the fluid.

When the electric density of the wire surfaces is small, there is no appreciable local heating ; nevertheless, energy is dissipated in air by waves, which differ from ordinary sound-waves only because the air is electrified. These waves are especially conspicuous when the discharges of a powerful battery are directed through a short and thick metal bar, the number of discharges per second being very small. The experimenter may feel the impact of the air at distances of six feet or more from the bar, especially if he takes the precaution to sprinkle the face or hands with ether. These waves cannot be entirely stopped by the interposition of an insulated metal plate.

Most of the striking phenomena of mechanical displacement, sound, heat and light which have been observed, imply the presence of a medium of a gaseous structure—that is, one consisting of independent carriers capable of free motion.

When a glass plate is placed near a condenser the charge of which is alternated, the plate emits a sound. This sound is due to the rythmical impact of the air against the plate. I have also found that the ringing of a condenser, first noted by Sir William Thomson, is due to the presence of the air between or near the charged surfaces.

When a disruptive discharge coil is immersed in oil contained in a tank, it is observed that the surface of the oil is agitated. This may be thought to be due to the displacements produced in the oil by the changing stresses, but such is not the case. It is the air above the oil which is agitated and causes the motion of the latter; the oil itself would remain at rest. The displacements produced in it by changing electrostatic stresses are insignificant ; to such stresses it may be said to be compressible to but a very small degree. The action of the air is shown in a curious manner, for if a pointed metal bar is taken in the hand and held with the point close to the oil, a hole two inches deep is formed in the oil by the molecules of the air, which are violently projected from the point.

The preceding statements may have a general bearing upon investigations in which currents of high frequency and potential are made use of, but they also have a more direct bearing upon the experiments of Prof. Bjerknes which are here considered, namely, the "skin effect," is increased by the action of the air. Imagine a wire immersed in a medium, the conductivity of which would be some function of the frequency and potential difference, but such that the conductivity increases when either or both of these elements are increased. In such a medium, the higher the frequency and potential difference the greater will be the current which will find its way through the surrounding medium, and the smaller the part which will pass through the central portion of the wire. In the case of a wire immersed in air and traversed by a high-frequency current, the facility with which the energy is dissipated may be considered as the equivalent of the conductivity ; and the analogy would be quite complete, were it not that besides the air another medium is present, the total dissipation being merely modified by the presence of the air to an extent as yet not ascertained. Nevertheless, I have sufficient evidence to draw the conclusion that the results obtained by Prof. Bjerknes are effected by the presence of air in the following manner :—1. The dissipation of energy is more rapid when the resonator is immersed in air than it would be in a practically continuous medium, for instance, oil. 2. The dissipation owing to the presence of air renders the difference between magnetic and non-magnetic metals more striking. The first conclusion follows directly from the preceding remarks ; the second follows from the two facts that the resonator receives always the same amount of energy, independent of the nature of the metal, and that the magnetism of the metal increases the impedance of the circuit. A resonator of magnetic metal behaves virtually as though its circuit were longer. There is a greater potential difference set up per unit of length, although this may not show itself in the deflection of the electrometer owing to the lateral dissipation. The effect of the increased impedance is strikingly illustrated in the two experiments of Prof. Bjerknes when copper is deposited upon an iron wire, and next iron upon a copper wire. Considerable thickness of copper deposit was required in the former experiment, but very little thickness of iron in the latter, as should be expected.

Taking the above views, I believe, that in the experiments of Prof. Bjerknes, which led him to undoubtedly correct conclusions, the air is a factor fully as important, if not more so, than the resistance of the metals.

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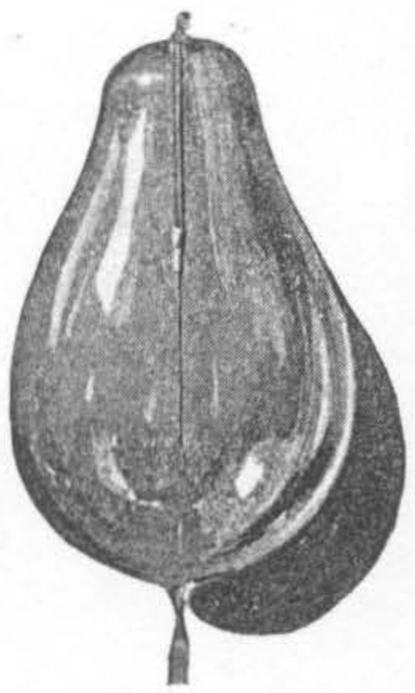
MR. TESLA'S HIGH FREQUENCY WORK.

IT is now nearly a year since Mr. Nikola Tesla, after his brilliant demonstrations here, scored such decided triumphs in the lectures which he delivered abroad at the invitation of various scientific societies; yet the interest which is manifested in his recent work not only by electricians but by many laymen, is such as to make highly welcome the publication of the abstract of Mr. Tesla's lecture, prepared by him for, and just published in, the Transactions of the Royal Institution of England. In this abstract, Mr. Tesla gives a succinct account of the reasonings and experiments which led up to the results obtained by him, and, taken altogether, they present a remarkable array of experimental facts in a field entirely new. Although replete with facts and suggestions, many of them quite new, it must be evident that the paper embodies but a tithe of Mr. Tesla's work in this field, the complete record of which would fill more than one volume of surpassing interest. Those who attend the convention of the National Electric Light Association in St. Louis, next month, will have an opportunity of witnessing some of Mr. Tesla's experiments in a lecture which he has consented to deliver before the Association.

ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.[1]—I.

BY NIKOLA TESLA.



At the first outset this investigation was taken up with the view of studying the effects of rapidly changing electrostatic and electromagnetic stresses. It was thought, from theoretical considerations, that some useful observations would be made in following up this line of experiment by means of properly constructed apparatus; but the anticipations were by far surpassed, for a number of unexpected phenomena were noted, and some novel facts brought to light, which have opened up a new and promising field of research. Some of the results obtained are of special interest on account of their direct bearing upon the problem of producing an efficient illuminant.

The phenomena which are due to the changing character of the stresses are exalted when the time rate of change is increased, hence the study of these phenomena is much facilitated by the employment of apparatus adapted especially for the purpose of carrying on such investigations. With this object in view, several types of alternators were constructed, capable of giving currents of frequencies from 5 to 10,000 and even more. Currents of much higher frequencies used in some of these experiments, were obtained by disruptively discharging condensers.

The construction of the alternators offered at first great difficulties. To obtain these frequencies it was necessary to provide several hundred polar projections, which were necessarily small and offered many drawbacks, and this the more, as exceedingly high peripheral speeds had to be resorted to. In some of the first machines both armature and field had polar projections. These machines produced a curious noise, especially when the armature was started from the state of rest, the field being charged. The most efficient machine was found to be one with a drum armature, the iron body of which consisted of very thin wire annealed with special care. It was, of course, desirable to avoid the employment of iron in the armature, and several machines of this kind, with moving or stationary conductors were constructed, but the results obtained were not quite satisfactory, on account of the great mechanical and other difficulties encountered.

The study of the properties of the high frequency currents obtained from these machines is very interesting, as nearly every experiment discloses something new. Two coils traversed by such a current attract or repel each other with a force which, owing to the imperfection of our sense of touch, seems continuous. An observation, scarcely foreseen, is that a piece of iron, surrounded by a coil through which the current is passing appears to be continuously magnetized. This apparent continuity might be ascribed to the deficiency of the sense of touch, but there is evidence that in currents of such high frequencies one of the impulses preponderates over the other. As might be expected, conductors traversed by such currents are rapidly heated, owing to the increase of the resistance, and the heating effects are relatively much greater in the iron.

The hysteresis losses in iron are so great that an iron core, even if finely subdivided, is heated in an incredibly short time. To give an idea, an ordinary iron wire of $\frac{1}{16}$ inch in diameter inserted within a coil having 250 turns, with a current estimated to be five

1. A lecture delivered before The Royal Institution of Great Britain, Thursday, February 4, 1892. Author's abstract in Transactions.

amperes passing through the coil, becomes within two seconds' time so hot as to scorch wood. Beyond a certain frequency, an iron core, no matter how finely subdivided, exercises a dampening effect, and it was easy to find a point at which the impedance of a coil was not affected by the presence of a core consisting of a bundle of very thin well annealed and varnished iron wires.

Experiments with a telephone, a conductor in a strong magnetic field, or with a condenser or arc, seem to afford certain proof that sounds far above the usually accepted limit of hearing would be perceived if produced with sufficient power.

The arc produced by these currents possesses several interesting features. Usually it emits a note the pitch of which corresponds to twice the frequency of the current, but if the frequency be sufficiently high it becomes noiseless, the limit of audition being determined principally by the linear dimensions of the arc. A curious feature of the arc is its persistency, which is due partly to the inability of the gaseous column to cool and increase considerably in resistance, as in the case with low frequencies, and partly to the tendency of such a high frequency machine to maintain a constant current.

In connection with these machines the condenser affords a particularly interesting study. Striking effects are produced by proper adjustments of capacity and self-induction. It is easy to raise the E. M. F. of the machine to many times the original value by simply adjusting the capacity of a condenser connected in the induced circuit. If the condenser be at some distance from the machine, the difference of potential on the terminals of the latter may be only a small fraction of that on the condenser.

But the most interesting experiences are made when the tension of the currents from the machine is raised by means of an induction coil. In consequence of the enormous rate of change obtainable in the primary current, much higher potential differences are obtained than with coils operated in the usual ways, and, owing to the high frequency, the secondary discharge possesses many striking peculiarities. Both the electrodes behave generally alike, though it appears from some observations that one current impulse preponderates over the other, as before mentioned.

The physiological effects of the high tension discharge are found to be so small that the shock of the coil can be supported without any inconvenience, except perhaps a small burn produced by the discharge upon approaching the hand to one of the terminals. The decidedly smaller physiological effects of these currents are thought to be due either to a different distribution through the body or to the tissues acting as condensers. But in the case of an induction coil with great many turns the harmlessness is principally due to the fact that but little energy is available in the external circuit when the same is closed through the experimenter's body, on account of the great impedance of the coil.

In varying the frequency and strength of the currents through the primary of the coil, the character of the secondary discharge is greatly varied, and no less than five distinct forms are observed:—weak, sensitive thread discharge, a powerful flaming discharge, and three forms of brush or streaming discharges. Each of these possesses certain noteworthy features, but the most interesting to study are the latter. Under certain conditions the streams, which are presumably due to the violent agitation of the air molecules, issue freely from all points of the coil, even through a thick insulation. If there is the smallest air space between the primary and secondary, they will form there and surely injure the coil by slowly warming the insulation. As they form even with ordinary frequencies when the potential is excessive, the air-space must be most carefully avoided.

These high frequency streamers differ in aspect and properties from those produced by a static machine. The wind produced by them is small and should altogether cease if still considerably higher frequencies could be obtained. A peculiarity is that they issue as freely from surfaces as from points. Owing to this, a metallic vane, mounted in one of the terminals of the coil so as to rotate freely, and having one of its sides covered with insulation, is spun rapidly around. Such a vane would not rotate with a steady potential, but with a high-frequency coil it will spin, even if it be entirely covered with insulation, provided the insulation on one side be either thicker or of a higher specific inductive capacity. A Crookes electric radiometer is also spun around when connected to one of the terminals of the coil, but only at very high exhaustion or at ordinary pressures.

There is still another and more striking peculiarity of such a high frequency steamer, namely, it is hot. The heat is easily perceptible with frequencies of about 10,000, even if the potential is not excessively high. The heating effect is, of course, due to the molecular impacts and collisions. Could the frequency and potential be pushed far enough, then a brush could be produced resembling in every particular a flame and giving light and heat, yet without a chemical process taking place. The hot brush, when properly produced, resembles a jet of burning gas escaping under great pressure, and it emits an extraordinary strong smell of ozone. The great ozonizing action is ascribed to the fact that the agitation of the molecules of the air is more violent in such a brush than in the ordinary streamer of a static machine.

But the most powerful brush discharges were produced by employing currents of much higher frequencies than it was possible to obtain by means of the alternators. These currents were obtained by disruptively discharging a condenser and setting up oscillations. In this manner currents of a frequency of several hundred thousand were obtained. Currents of this kind produce striking effects. At these frequencies, the impedance of a copper bar is so great that a potential difference of several hundred volts can be maintained between two points of a short and thick bar, and it is possible to keep an ordinary incandescent lamp burning at full candle power by attaching the terminals of the lamp to two points of the bar no more than a few inches apart. When the frequency is extremely high, nodes are found to exist on such a bar, and it is easy to locate them by means of a lamp.

By converting the high-tension discharges of a low-frequency coil in this manner, it was found practicable to keep a few lamps burning on the ordinary circuit in the laboratory, and by bringing the undulation to a low pitch, it was possible to operate small motors. This plan likewise allows of converting high-tension discharges of one direction into low tension unidirectional currents, by adjusting the circuit so that there are no oscillations. In passing the oscillating discharges through the primary of a specially-constructed coil, it is easy to obtain enormous potential differences with only few turns of the secondary.

Great difficulties were at the beginning experienced in producing a successful coil on this plan. It was found necessary to keep all air, or gaseous matter in general, away from the charged surfaces, and oil immersion was resorted to. The wires used were heavily covered with gutta-percha and wound in oil, or the air was pumped out by means of a Sprengel pump.

The general arrangement was the following: An ordinary induction coil, operated from a low-frequency alternator, was used to charge Leyden jars. The jars were made to discharge over a single or multiple gap through the primary of the second coil. To insure the action of the gap, the arc was blown out by a magnet or air-blast. To adjust the potential in the secondary a small oil condenser was used, or polished brass spheres of different sizes were screwed on the terminals and their distance adjusted.

When the conditions were carefully determined to suit each experiment, magnificent effects were obtained.

Two wires, stretched through the room, each being connected to one of the terminals of the coil, emit streams so powerful that the light from them allows distinguishing the objects in the room; the wires become luminous even if covered with thick and most excellent insulation. When two straight wires, or two concentric circles of wire, are connected to the terminals, and set at the proper distance, a uniform luminous sheet is produced between them. It was possible in this way to cover an area of more than one meter square completely with the streams. By attaching to one terminal a large circle of wire and to the other terminal a small sphere, the streams are focused upon the sphere, produce a strongly lighted spot upon the same, and present the appearance of a luminous cone. A very thin wire glued upon a plate of hard rubber of great thickness, on the opposite side of which is fastened a tinfoil coating, is rendered intensely luminous when the coating is connected to the other terminal of the coil. Such an experiment can be performed also with low frequency currents, but much less satisfactorily.

When the terminals of such a coil, even of a very small one, are separated by a rubber or glass plate, the discharge spreads over the plate in the form of streams, threads, or brilliant sparks, and affords a magnificent display, which cannot be equalled by the largest coil operated in the usual ways. By a simple adjustment it is possible to produce with the coil a succession of brilliant sparks, exactly like with a Holtz machine.

Under certain conditions, when the frequency of the oscillation is very great, white phantom-like streams are seen to break forth from the terminals of the coil. The chief interesting feature about them is, that they stream freely against the outstretched hand or other conducting object without producing any sensation, and the hand may be approached very near to the terminal without a spark being induced to jump. This is due presumably to the fact that a considerable portion of the energy is carried away or dissipated in the streamers, and the difference of potential between the terminal and the hand is diminished.

It is found in such experiments, that the frequency of the vibration and the quickness of succession of the sparks between the knobs affect to a marked degree the appearance of the streams. When the frequency is very low, the air gives way in more or less the same manner as by a steady difference of potential, and the streams consist of distinct threads, generally mingled with thin sparks, which probably correspond to the successive discharges occurring between the knobs. But when the frequency is very high, and the arc of the discharge produces a sound which is loud and smooth (which indicates both that oscillation takes place and that the sparks succeed each other with great rapidity), then the luminous streams formed are perfectly uniform. They are generally of a purplish hue, but when the molecular vibration is increased by raising the potential they assume a white color.

The luminous intensity of the streams increases rapidly when

the potential is increased; and with frequencies of only a few hundred thousand, could the coil be made to withstand a sufficiently high potential difference, there is no doubt that the space around a wire could be made to emit a strong light, merely by the agitation of the molecules of the air at ordinary pressure.

Such discharges of very high frequency which render luminous the air at ordinary pressure we have very likely occasion to witness in the aurora borealis. From many of these experiments it seems reasonable to infer that sudden cosmic disturbances, such as eruptions on the sun, set the electrostatic charge of the earth in an extremely rapid vibration, and produce the glow by the violent agitation of the air in the upper and even in the lower strata. It is thought that if the frequency were low, or even more so if the charge were not at all vibrating, the lower, dense strata would break down as in a lightning discharge. Indications of such breaking down have been repeatedly observed, but they can be attributed to the fundamental disturbances, which are few in number, for the superimposed vibration would be so rapid as to not allow a disruptive break.

The study of these discharge phenomena has led to the recognition of some important facts. It was found that gaseous matter must be most carefully excluded from any dielectric which is subjected to great, rapidly-changing electrostatic stresses. Since it is difficult to exclude the gas perfectly when solid insulators are used, it is necessary to resort to liquid dielectrics. When a solid dielectric is used, it matters little how thick and how good it is; if air be present streamers form, which gradually heat the dielectric and impair its insulating power, and the discharge finally breaks through. Under ordinary conditions the best insulators are those which possess the highest specific inductive capacity, but such insulators are not the best to employ when working with these high frequency currents, for in most cases the higher specific inductive capacity is rather a disadvantage. The prime quality of the insulating medium for these currents is continuity. For this reason principally it is necessary to employ liquid insulators, such as oils. If two metal plates, connected to the terminals of the coil, are immersed in oil and set a distance apart, the coil may be kept working for any length of time without a break occurring, or without the oil being warmed, but if air bubbles are introduced, they become luminous; the air molecules, by their impact against the oil, heat it, and after some time cause the insulation to give way. If, instead of the oil, a solid plate of the best dielectric, even several times thicker than the oil intervening between the metal plates, is inserted between the latter, the air having free access to the charged surfaces, the dielectric invariably is warmed and breaks down. The employment of the oil is advisable or necessary even with low frequencies, if the potentials are such that streamers form, but only in such cases, as is evident from the theory of the action. If the potentials are so low that streamers do not form, then it is even disadvantageous to employ oil, for it may, principally by confining the heat, be the cause of the breaking down of the insulation. The exclusion of gaseous matter is not only desirable on account of the safety of the apparatus, but also on account of economy, especially in a condenser, in which considerable waste of power may occur merely owing to the presence of air, if the electric density on the charged surfaces is great.

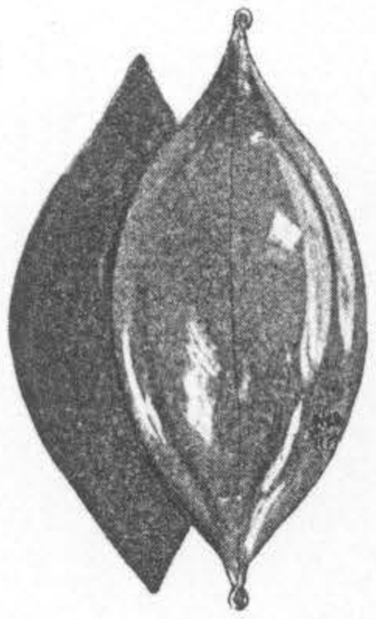
In the course of these investigations a phenomenon of special scientific interest has been observed. It may be ranked among the brush phenomena, in fact it is a kind of brush which forms at, or near, a single terminal in high vacuum. In a bulb with a conducting electrode, even if the latter be of aluminum, the brush has only a very short existence, but it can be preserved for a considerable length of time in a bulb devoid of any conducting electrode. To observe the phenomenon it is found best to employ a large spherical bulb having in its centre a small bulb supported on a tube sealed to the neck of the former. The large bulb being exhausted to a high degree, and the inside of the small bulb being connected to one of the terminals of the coil, under certain conditions there appears a misty haze around the small bulb, which, after passing through some stages, assumes the form of a brush, generally at right angles to the tube supporting the small bulb. When the brush assumes this form it may be brought to a state of extreme sensitiveness to electrostatic and magnetic influence. The bulb hanging straight down, and all objects being remote from it, the approach of the observer within a few paces will cause the brush to fly to the opposite side, and if he walks around the bulb it will always keep on the opposite side. It may begin to spin around the terminal long before it reaches that sensitive stage. When it begins to turn around, principally, but also before, it is affected by a magnet, and at a certain stage it is susceptible to magnetic influence to an astonishing degree. A small permanent magnet, with its poles at a distance of no more than two centimetres, will affect it visibly at a distance of two metres, slowing down or accelerating the rotation according to how it is held relatively to the brush.

When the bulb hangs with the globe down, the rotation is always clockwise. In the southern hemisphere it would occur in the opposite direction and on the (magnetic) equator the brush should not turn at all. The rotation may be reversed by a magnet kept at some distance. The brush rotates best, seemingly, when it is at right angles to the lines of force of the earth. It very likely rotates, when at its maximum speed, in synchronism with the alternations, say 10,000 times a second. The rotation can be slowed down or accelerated by the approach or receding of the observer, or any conducting body, but it cannot be reversed by putting the bulb in any position. Very curious experiments may be performed with the brush when in its most sensitive state. For instance, the brush resting in one position, the experimenter may, by selecting a proper position, approach the hand at a certain considerable distance to the bulb, and he may cause the brush to pass off by merely stiffening the muscles of the arm, the mere change of configuration of the arm and imperceptable displacement being sufficient to disturb the delicate balance. When it begins to rotate slowly, and the hands are held at a proper distance, it is impossible to make the slightest motion without producing a visible effect upon the brush. A metal plate connected to the other terminal of the coil affects it at a great distance, slowing down the rotation often to one turn a second.

It is hoped that this phenomenon will prove a valuable aid in the investigation of the nature of the forces acting in an electrostatic or magnetic field. If there is any motion which is measurable going on in the space, such a brush would be apt to reveal it. It is, so to speak, a beam of light, frictionless, devoid of inertia. On account of its marvellous sensitiveness to electrostatic or magnetic disturbances it may be the means of sending signals through submarine cables with any speed, and even of transmitting intelligence at a distance without wires.

ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.—II.

BY NIKOLA TESLA.



In operating an induction coil with these rapidly alternating currents, it is astonishing to note, for the first time, the great importance of the relation of capacity, self-induction, and frequency as regards the general result. The combination of these elements produces many curious effects. For instance, two metal plates are connected to the terminals and set at a small distance, so that an arc is formed between them. This arc *prevents* a strong current to flow through the coil. If the arc be interrupted by the interposition of a glass plate, the capacity of the condenser obtained counteracts the self-induction, and a stronger current is made to pass The effects of capacity are the most striking, for in these experiments, since the self-induction, and frequency both are high, the critical capacity is very small, and need be but slightly varied to produce a very considerable change. The experimenter brings his body in contact with the terminals of the secondary of the coil, or attaches to one or both terminals insulated bodies of very small bulk, such as exhausted bulbs, and he produces a considerable rise or fall of potential on the secondary, and greatly affects the flow of the current through the primary coil.

In many of the phenomena observed, the presence of the air, or, generally speaking,of a medium of a gaseous nature (using this term not to imply specific properties, but as contradistinction to homogeneity or perfect continuity) plays an important part, as it allows energy to be dissipated by molecular impact or bombardment. The action is thus explained :—

When an insulated body connected to a terminal of the coil is suddenly charged to a high potential, it acts inductively upon the surrounding air, or whatever gaseous medium there might be. The molecules or atoms which are near it are, of course, more attracted, and move through a greater distance than the further ones. When the nearest molecules strike the body they are repelled, and collisions occur at all distances within the inductive distances. It is now clear that, if the potential be steady, but little loss of energy can be caused in this way, for the molecules which are nearest to the body having had an additional charge imparted to them by contact, and not attracted until they have parted, if not with all, at least with most of the additional charge, which can be accomplished only after a great many collisions. This is inferred from the fact that with a steady potential there is but little loss in dry air. When the potential, instead of being steady, is alternating, the conditions are entirely different. In this case a rhythmical bombardment occurs, no matter whether the molecules after coming in contact with the body lose the imparted charge or not, and, what is more, if the charge is not lost, the impacts are only the more violent. Still, if the frequency of

the impulses be very small, the loss caused by the impacts and collisions would not be serious unless the potential were excessive. But when extremely high frequencies and more or less high potentials are used, the loss may be very great. The total energy lost per unit of time is proportionate to the product of the number of impacts per second, or the frequency and the energy lost in each impact. But the energy of an impact must be proportionate to the square of the electric density of the body, on the assumption that the charge imparted to the molecule is proportionate to that density. It is concluded from this that the total energy lost must be proportionate to the product of the frequency and the square of the electric density; but this law needs experimental confirmation. Assuming the preceding considerations to be true, then, by rapidly alternating the potential of a body immersed in an insulating gaseous medium, any amount of energy may be dissipated into space. Most of that energy, then, is not dissipated in the form of long ether waves, propagated to considerable distance, as is thought most generally, but is consumed in impact and collisional losses—that is, heat vibrations—on the surface and in the vicinity of the body. To reduce the dissipation it is necessary to work with a small electric density—the smaller the higher the frequency.

The behavior of a gaseous medium under such rapid alternations of potential makes it appear plausible that electrostatic disturbances of the earth, produced by cosmic events, may have great influence upon the meteorological conditions. When such disturbances occur, both the frequency of the vibrations of the charge and the potential are in all probability excessive, and the energy converted into heat may be considerable. Since the density must be unevenly distributed, either in consequence of the irregularity of the earth's surface, or on account of the condition of the atmosphere in various places, the effect produced would accordingly vary from place to place. Considerable variations in the temperature and pressure of the atmosphere may in this manner be caused at any point of the surface of the earth. The variations may be gradual or very sudden, according to the nature of the original disturbance, and may produce rain and storms, or locally modify the weather in any way.

From many experiences gathered in the course of these investigations it appears certain that in lightning discharges the air is an element of importance. For instance, during a storm a stream may form on a nail or pointed projection of a building. If lightning strikes somewhere in the neighborhood, the harmless static discharge may, in consequence of the oscillations set up, assume the character of a high frequency streamer, and the nail or projection may be brought to a high temperature by the violent impact of the air molecules. Thus, it is thought, a building may be set on fire without the lightning striking it. In like manner small metallic objects may be fused and volatilized—as frequently occurs in lightning discharges—merely because they are surrounded by air. Were they immersed in a practically continuous medium, such as oil, they would probably be safe, as the energy would have to spend itself elsewhere.

An instructive experiment having a bearing on this subject is the following:—A glass tube of an inch or so in diameter and several inches long is taken, and a platinum wire sealed into it, the wire running through the centre of the tube from end to end. The tube is exhausted to a moderate degree. If a steady current is passed through the wire it is heated uniformly in all parts and the gas in the tube is of no consequence. But if high frequency discharges are directed through the wire, it is heated more on the ends than in the middle portion, and if the frequency, or rate of charge, is high enough, the wire might as well be cut in the middle as not, for most of the heating on the ends is due to the rarefied gas. Here the gas might only act as a conductor of no impedance, diverting the current from the wire as the impedance of the latter is enormously increased, and merely heating the ends of the wire by reason of their resistance to the passage of the discharge. But it is not at all necessary that the gas in the tube should be conducting; it might be at an extremely low pressure, still the ends of the wire would be heated; as, however, is ascertained by experience, only the two ends would in such case not be electrically connected through the gaseous medium. Now what with these frequencies and potentials occurs in an exhausted tube, occurs in the lightning discharge at ordinary pressure.

From the facility with which any amount of energy may be carried off through a gas, it is concluded that the best way to render harmless a lightning discharge is to afford it in some way a passage through a volume of gas.

The recognition of some of the above facts has a bearing upon far-reaching scientific investigations in which extremely high frequencies and potentials are used. In such cases the air is an important factor to be considered. So, for instance, if two wires are attached to the terminals of the coil, and streamers issue from them, there is dissipation of energy in the form of heat and light, and the wires behave like a condenser of larger capacity. If the wires be immersed in oil, the dissipation of energy is prevented, or at least reduced, and the apparent capacity is diminished. The action of the air would seem to make it very difficult to tell, from the measured or computed capacity of a condenser in which the air is acted upon, its actual capacity or vibration period, especially if the condenser is of very small surface and is charged to a very high potential. As many important results are dependent upon the correctness of the estimation of the vibration period, this subject demands the most careful scrutiny of other investigators.

In Leyden jars the loss due to the presence of air is comparatively small, principally on account of the great surface of the coatings and the small external action, but if there are streamers on the top, the loss may be considerable, and the period of vibration is affected. In a resonator, the density is small, but the frequency is extreme, and may introduce a considerable error. It appears certain, at any rate, that the periods of vibration of a charged body in a gaseous and in a continuous medium, such as oil, are different, on account of the action of the former, as explained.

Another fact recognized, which is of some consequence, is, that in similar investigations the general considerations of static screening are not applicable when a gaseous medium is present. This is evident from the following experiment: A short and wide glass tube is taken and covered with a substantial coating of bronze, barely allowing the light to shine a little through. The tube is highly exhausted and suspended on a metallic clasp from the end of a wire. When the wire is connected with one of the terminals of the coil, the gas inside of the tube is lighted in spite of the metal coating. Here the metal evidently does not screen the gas inside as it ought to, even if it be very thin and poorly conducting. Yet, in a condition of rest, the metal coating, however thin, screens the inside perfectly.

ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.—III.

(*Concluded.*)

BY NIKOLA TESLA.



One of the most interesting results arrived at in pursuing these experiments, is the demonstration of the fact that a gaseous medium, upon which vibration is impressed by rapid changes of electrostatic potential, is rigid. In illustration of this result an experiment may be cited: A glass tube about 1 inch in diameter and 3 feet long, with outside condenser coatings on the ends, was exhausted to a certain point, when, the tube being suspended freely from a wire connecting the upper coating to one of the terminals of the coil, the discharge appeared in the form of a luminous thread, passing through the axis of the tube. Usually the thread was sharply defined in the upper part of the tube and lost itself in the lower part. When a magnet or the finger was quickly passed near the upper part of the luminous thread, it was brought out of position by magnetic or electrostatic influence, and a transversal vibration like that of a suspended cord, with one or more distinct nodes, was set up, which lasted for a few minutes and gradually died out. By suspending to the lower condenser coating metal plates of different sizes, the speed of the vibration was varied. This vibration would seem to show beyond doubt that the thread possessed rigidity, at least to transversal displacements.

Many experiments were tried to demonstrate this property in

air at ordinary pressure. Though no positive evidence has been obtained, it is thought nevertheless, that a high frequency brush or streamer, if the frequency could be pushed far enough, would be decidedly rigid. A small sphere might then be moved within it quite freely, but if thrown against it the sphere would rebound. An ordinary flame cannot possess rigidity to a marked degree because the vibration is directionless; but an electric arc, it is believed, must possess that property more or less. A luminous band excited in a bulb by repeated discharges of a Leyden jar must also possess rigidity, and if deformed and suddenly released should vibrate.

From like considerations other conclusions of interest may be made. The most probable medium filling the space is one consisting of independent carriers immersed in an insulating fluid. If through this medium enormous electrostatic stresses are assumed to act, which vary rapidly in intensity, it would allow the motion of a body through it, yet it would be rigid and elastic, although the fluid itself might be devoid of these properties. Furthermore, on the assumption that the independent carriers are of any configuration such that the fluid resistance to motion in one direction is greater than in another, a stress of that nature would cause the carriers to arrange themselves in groups, since they would turn to each other their sides of the greatest electric density, in which position the fluid resistance to approach would be smaller than to receding. If in a medium of the above characteristics a brush would be formed by a steady potential, an exchange of the carriers would go on continually, and there would be less carriers per unit of volume in the brush than in the space at some distance from the electrode, this corresponding to rarefaction. If the potential were rapidly changing, the result would be very different; the higher the frequency of the pulses, the slower would be the exchange of the carriers; finally, the motion of translation through measurable space would cease, and, with a sufficiently high frequency and intensity of the stress, the carriers would be drawn towards the electrode, and compression would result.

An interesting feature of these high frequency currents is that they allow to operate all kinds of devices by connecting the device with only one leading wire to the source. In fact, under certain conditions it may be more economical to supply the electrical energy with one lead than with two.

An experiment of special interest is the running, by the use of only one insulated line, of a motor operating on the principle of the rotating magnetic field enunciated by the author a few years ago. A simple form of such a motor is obtained by winding upon a laminated iron core a primary and close to it a secondary coil, closing the ends of the latter and placing a freely movable metal disc within the influence of the moving field. The secondary coil may, however, be omitted. When one of the ends of the primary coil of the motor is connected to one of the terminals of the high-frequency coil and the other end to an insulated metal plate, which, it should be stated, is not absolutely necessary for the success of the experiment, the disc is set in rotation.

Experiments of this kind seem to bring it within the reach of possibility to operate a motor at any point of the earth's surface from a central source, without any connection to the same except through the earth. If, by means of powerful machinery, rapid variations of the earth's potential were produced, a grounded wire reaching up to some height would be traversed by a current which could be increased by connecting the free end of the wire to a body of some size. The current might be converted to low tension and used to operate a motor or other device. The experiment, which would be one of great scientific interest, would probably best succeed on a ship at sea. In this manner, even if it were not possible to operate machinery, intelligence might be transmitted quite certainly.

In the course of this experimental study special attention was devoted to the heating effects produced by these currents, which are not only striking, but open up the possibility of producing a more efficient illuminant. It it sufficient to attach to the coil terminal a thin wire or filament, to have the temperature of the latter perceptibly raised. If the wire or filament be inclosed in a bulb, the heating effect is increased by preventing the circulation of the air. If the air in the bulb be strongly compressed, the displacements are smaller, the impacts less violent, and the heating effect is diminished. On the contrary, if the air in the bulb be exhausted, an inclosed lamp filament is brought to incandescence, and any amount of light may thus be produced.

The heating of the inclosed lamp filament depends on so many things of a different nature, that it is difficult to give a generally applicable rule under which the maximum heating occurs. As regards the size of the bulb, it is ascertained that at ordinary or only slightly differing atmospheric pressures, when air is a good insulator, the filament is heated more in a small bulb, because of the better confinement of heat in this case. At lower pressures, when air becomes conducting, the heating effect is greater in a large bulb, but at excessively high degrees of exhaustion there seems to be, beyond a certain and rather small size of the vessel, no perceptible difference in the heating.

The shape of the vessel is also of some importance, and it has been found of advantage for reasons of economy to employ a spherical bulb with the electrode mounted in its centre, where the rebounding molecules collide. It is desirable on account of economy that all the energy supplied to the bulb from the source should reach without loss the body to be heated. The loss in conveying the energy from the source to the body may be reduced by employing thin wires heavily coated with insulation, and by the use of electrostatic screens. It is to be remarked, that the screen cannot be connected to the ground as under ordinary conditions.

In the bulb itself a large portion of the energy supplied may be lost by molecular bombardment against the wire connecting the body to be heated with the source. Considerable improvement was effected by covering the glass stem containing the wire with a closely fitting conducting tube. This tube is made to project a little above the glass, and prevents the cracking of the latter near the heated body. The effectiveness of the conducting tube is limited to very high degrees of exhaustion. It diminishes the energy lost in bombardment for two reasons: First, the charge given up by the atoms spreads over a greater area, and hence the electric density at any point is small, and the atoms are repelled with less energy than if they would strike against a good insulator; secondly, as the tube is electrified by the atoms which first come in contact with it, the progress of the following atoms against the tube is more or less checked by the repulsion which the electrified tube must exert upon the similarly electrified atoms. This, it is thought, explains why the discharge through a bulb is established with much greater facility when an insulator than when a conductor is present.

During the investigations great many bulbs of different construction, with the electrodes of different material, were experimented upon, and a number of observations of interest were made. It was found that the deterioration of the electrode is the less, the higher the frequency. This was to be expected, as then the heating is effected by many small impacts, instead of by fewer and more violent ones, which quickly shatter the structure. The deterioration is also smaller when the vibration is harmonic. Thus an electrode, maintained at a certain degree of heat, lasts much longer with currents obtained from an alternator, than with those obtained by means of a disruptive discharge. One of the most durable electrodes was obtained from strongly compressed carborundum, which is a kind of carbon recently produced by Mr. E. G. Acheson. From experience, it is inferred, that to be most durable, the electrode should be in the form of a sphere with a highly polished surface.

In some bulbs refractory bodies were mounted in a carbon cup and pushed under the molecular impact. It was observed in such experiments that the carbon cup was heated at first, until a higher temperature was reached; then most of the bombardment was directed against the refractory body, and the carbon was relieved. In general, when different bodies were mounted in the bulb, the hardest fusible would be relieved, and would remain at a considerably lower temperature. This was necessitated by the fact that most of the energy supplied would find its way through the body which was easier fused or "evaporated." Curiously enough it appeared in some of the experiments made, that a body was fused in a bulb under the molecular impact by evolution of less light than when fused by the application of heat in ordinary ways. This may be ascribed to a loosening of the structure of the body under the violent impacts and changing stresses.

Some experiments seem to indicate that under certain conditions a body, conducting, or non-conducting, may, when bombarded, emit light, which to all appearance is due to phosphorescence, but may in reality be caused by the incandescence of an infinitesimal layer, the mean temperature of the body being comparatively small. Such might be the case if each single rythmical impact were capable of instantaneously exciting the retina, and the rythm just high enough to cause a continuous impression in the eye. According to this view, a coil operated by disruptive discharge would be eminently adapted to produce such a result, and it is found by experiment that its power of exciting phosphorescence is extraordinarily great. It is capable of exciting phosphorescence at comparatively low degrees of exhaustion, and also projects shadows at pressures far greater than those at which the mean free path is comparable to the dimensions of the vessel. The latter observation is of some importance, inasmuch as it may modify the generally accepted views in regard to the "radiant state" phenomena.

A thought, which early and naturally suggested itself, was to utilize the great inductive effects of high frequency currents to produce light in a sealed glass vessel without the use of leading-in wires. Accordingly, many bulbs were constructed in which the energy necessary to maintain a button or filament at high incandescence, was supplied through the glass either by electrostatic or electrodynamic induction. It was likewise easy to regulate the intensity of the light emitted by means of an externally applied condenser coating connected to an insulated plate, or simply by means of a plate attached to the bulb which at the same time performed the function of a shade.

A subject of experiment, which has been exhaustively treated by Prof. J. J. Thomson, has been followed up independently by the author from the beginning of this study, namely, to excite by electrodynamic induction a luminous band in a closed tube or bulb,

In observing the behavior of gases, and the luminous phenomena obtained, the importance of the electrostatic effects was noted and it appeared desirable to produce enormous potential differences, alternating with extreme rapidity. Experiments in this direction led to some of the most interesting results arrived at in the course of these investigations. It was found that by rapid alternations of a high electrostatic potential, exhausted tubes could be lighted at considerable distance from a conductor connected to a properly constructed coil, and that it was practicable to establish with the coil an alternating electrostatic field, acting through the whole extent of a room and lighting a tube, wherever it was placed in the same. Phosphorescent bulbs may be excited in such a field, and it is easy to regulate the effect by connecting to the bulb a small insulated metal plate. It was likewise possible to maintain a filament or button mounted in a tube at bright incandescence, and in one experiment, a mica vane was spun by the incandescence of a platinum wire.

It is hoped that the study of these phenomena, and the perfection of the means for obtaining rapidly alternating high potentials, will lead to the production of an efficient illuminant.

The Ewing High-Frequency Alternator and Parsons Steam Turbine.

Mr. Nikola Tesla has sent the following interesting communication to the editor of the London *Electrician:*

In your issue of November 18 I find a description of Prof. Ewing's high-frequency alternator, which has pleased me chiefly because it conveyed to me the knowledge that he, and with him, no doubt, other scientific men, is to investigate the properties of high-frequency currents. With apparatus such as you describe, shortly a number of experimenters, more competent than myself, will be enabled to go over the ground as yet but imperfectly explored, which will undoubtedly result in the observation of novel facts and elimination of eventual errors.

I hope it will not be interpreted as my wishing to detract anything from Prof. Ewing's merit if I state the fact that for a considerable time past I have likewise thought of combining the identical steam turbine with a high-frequency alternator. *Anch' io sono pittore.* I had a number of designs with such turbines, and would have certainly carried them out had the turbines been here easily and cheaply obtainable, and had my attention not been drawn in a different direction. As to the combination, to which you give a rather complicated name, I consider it an excellent one. The advantages of using a high speed turbine are especially great in connection with such alternators. When a belt is used to drive, one must resort to extraordinarily large diameters in order to obtain the necessary speed, and this increases the difficulties and cost of construction in an entirely unreasonable proportion. In the machine used in my recent experiments the weight of the active parts is less than 50 pounds, but there is an additional weight of over 100 pounds in the supporting frame, which a very careful constructor would have probably made much heavier. When running at its maximum speed, and with a proper capacity in the armature circuit, two and one-half horse-power can be performed. The large diameter (30 inches), of course, has the advantage of affording better facility for radiation; but, on the other hand, it is impossible to work with a very small clearance.

I have observed with interest that Prof. Ewing has used a magnet with alternating poles. In my first trials I expected to obtain the best results with a machine of the Mordey type—that is, with one having pole projections of the same polarity. My idea was to energize the field up to the point of the maximum permeability of the iron and vary the induction around that point. But I found that with a very great number of pole projections such a machine would not give good results, although with few projections, and with an armature without iron, as used by Mordey, the results obtained were excellent. Many experiences of similar nature made in the course of my study demonstrate that the ordinary rules for the magnetic circuit do not hold good with high-frequency currents. In ponderable matter magnetic permeability, and also specific inductive capacity, must undergo considerable change when the frequency is varied within wide limits. This would render very difficult the exact determination of the energy dissipated in iron cores by very rapid cycles of magnetization, and of that in conductors and condensers, by very quick reversals of current. Much valuable work remains to be done in these fields, in which it is so easy to observe novel phenomena, but so difficult to make quantitative determinations. The results of Prof. Ewing's systematical research will be awaited with great interest.

It is gratifying to note from his tests that the turbines are being rapidly improved. Though I am aware that the majority of engineers do not favor their adoption, I do not hesitate to say that I believe in their success. I think their principal uses, in no distant future, will be in connection with alternate current motors, by means of which it is easy to obtain a constant and, in any desired ratio, reduced speed. There are objections to their employment for driving direct current generators, as the commutators must be a source of some loss and trouble, on account of the very great speed; but with an alternator there is no objectionable feature whatever. No matter how much one may be opposed to the introduction of the turbine, he must have watches with surprise the development of this curious branch of industry, in which Mr. Parsons has been a pioneer, and everyone must wish him the success which his skill had deserved.

Transmission of Power by Alternating Currents.

A patent recently issued to Nikola Tesla describes a system of transmission of power for which Mr. Tesla filed an application in 1888, in which the number of poles in the motor are less than the number of poles in the generator, thus permitting the motor to be operated at low speed, although the generator may be developing impulses of comparatively high frequency. Mr. Tesla's apparatus is illustrated in the accompanying engraving, wherein is shown, in Fig. 1, a diagram of a generator having a constant field magnet circuit and provided with an armature having two sets of coils adapted to deliver quarter-phase currents into an external circuit. The generator is shown as provided with eight poles, and in Fig. 2 is shown a motor which may be operated by being connected to the four leads running from the generator. The motor having four poles and the generator eight poles, the motor will run at half the speed of the generator.

I had a number of designs with such turbines, and would have certainly carried them out had the turbines been here easily and cheaply obtainable, and had my attention not been drawn in a different direction. As to the combination, to which you give a rather complicated name, I consider it an excellent one. The advantages of using a high-speed turbine are especially great in connection with such alternators. When a belt is used to drive, one must resort to extraordinarily large diameters in order to obtain the necessary speed, and this increases the difficulties and cost of construction in an entirely unreasonable proportion. In the machine used in my recent experiments the weight of the active parts is less than 50 pounds, but there is an additional weight of over 100 pounds in the supporting frame, which a very careful constructor would have probably made much heavier. When running at its maximum speed, and with a proper capacity in the armature circuit, 2½ h. p. can be performed. The large diameter (30 inches), of course, has the advantage of affording better facility for radiation: but, on the other hand, it is impossible to work with a very small clearance.

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Greeley & Co., The E. S., supplies	vii & 280
Harrisburg Foundry & Machine Works, engines	xiii
Hart & Hegeman Mfg. Co., switches	x
Heisler Electric Co., electrical construction engineers	iii
Holman Electrical Co., F., reflector shades.	vii
Holmes, Booth & Haydens, insulated wire	xii
Hulburt Fence & Wire Co.	xi
Johns Mfg. Co., H. W., vulcabeston	v
Lake Co., J. H. & D., pulleys	xi
Leclanche Battery Co., batteries	ix
Lehigh Valley Creosoting Co., creosoted lumber	ix
Marshall, Wm., condensers	vii
Morrison, Geo. H., indicators	xi
National Electric Mfg. Co., dynamo electric machinery	vii
New England Butt Co., braiding machinery.	xiii
Newton Rubber Co., hard rubber	viii
New Jersey Lamp & Bronze Works, electric and gas fixtures	ix
New York Belting and Packing Co., rubber belts	xii
New York & Ohio Co., incandescent lamps	xii
Onondaga Dynamo Co., electrical apparatus	xiv
Ostrander & Co., W. R., supplies	xiii
Palmer Bros., engine castings	280
Partrick & Carter Co., electrical supplies	x
Penn Life Co., insurance	x
Phœnix Glass Co., glass globes	xiv
Phosphor Bronze Smelting Co., castings	xiv
Prentiss Tool & Supply Co., machinery	280
Queen & Co., electrical instruments	280
Railway Equipment Co., elec. r'y supplies	xiv
Reed & Co., F. E., lathes	vii
Rhode Island Tool Co., tools	xiv
Ries Electric Specialty Co., regulating socket	xiii
Ridlon & Co., Frank, general machinery	280
Robinson & Orr, steel rails	280
Rosenbaum, Wm. A., patent attorney	x
Royce & Marean, electrical supplies	xiv
Russell & Co., steam engines	xi
Samson Cordage Works, braided cord	viii
Schuyler Electric Co., arc lighting	xii
Shawmut Fuse Wire Co., fuse wire	xi
Shoemaker, Homer, attorney and counsellor-at-law	280
Standard Paint Co., insulating compounds	xi
Stanley Electric Mfg. Co., transformers	ix
Stocking, E. B., patent attorney	x
Swan & Lane, contractors	x
Tyndall, Wm. D., attorney	x
Walworth Mfg. Co., trolley poles	iii
Wanted	280
Washburn & Moen Mfg. Co., wire	x
Watson & Stillman, hydraulic presses	vii
Western Electric Co., supplies	vii
Westinghouse Electric & Mfg. Co., incandescent lamps	iv
Wilson, Fremont, electrician	280
Willson, H. B., patent attorney	x
Young, Wm., Jr., patents bought	280

HIGH TENSION EXPERIMENTS BY TESLA AND OTHERS.

The experiments of Dr. Schoentjes, described by our correspondent on another page, in which some of the beautiful results achieved by Mr. Tesla with alternating currents of high tension are reproduced, will be examined with interest. Mr. Tesla used, it will be remembered, a specially constructed generator to produce his currents which were raised in tension by an induction coil and in frequency by a spark gap. Dr. Schoentjes, it is said, achieves the same results with a simple vibrator, battery and induction coil, it being possible to operate the vibrator at a rate as low as five beats per second and yet produce many of the results noted by Mr. Tesla. This is certainly going from the complex to the simple, the usual trend of scientific and industrial progress. The experiments are so easily made, that the accuracy of our correspondent's statements can be readily verified. The results he describes would seem to indicate that the phenomena produced by Mr. Tesla are not necessarily connected with extremely high tension or extremely high frequency, unless, indeed, some hitherto unknown vibrant quality resides in the spark gap, periodically produced in the operation of an ordinary buzzer.

There are peculiar features of ordinary high tension electricity yet to be recognized. Our attention was called a few days ago to a new phenomenon, which may be displayed with an ordinary incandescent lamp. If such a lamp be held in one hand and the bulb be struck a few rapid blows with the palm of the other hand, the lamp and filament will glow with a soft radiance sufficient to clearly outline the lamp in a dark room. The radiance continues only so long as the blows continue, which must be frequent and comparatively violent. The peculiar action is more readily awakened by some individuals than by others. Perhaps the dryness of the hands has much to do with it. It is probably a purely static phenomenon, but is interesting.

Tesla's Experiments Simplified.

To the Editor of Electrical Review:

Prof. M. Schoentjes, instructor of electrical engineering at the University of Gant, Belgium, has recently described an extremely simple arrangement of circuits and apparatus, by means of which all of Mr. Tesla's experiments may be repeated.

It will be remembered that Tesla charges a condenser through secondary currents developed in the primary of a Ruhmkorff coil, and then causes the oscillatory discharge from a spark between two terminals to pass through the primary circuit of a second induction coil immersed in oil. The currents set up in the secondary coil surrounding the submersed primary are used for the Tesla experiments.

Professor Schoentjes has succeeded in doing away with the above described complicated arrangement, and employs merely one induction coil connected with a vibrator. The coil is 40 by 20 centimetres, and the energizing current furnishes a number of accumulators.

With this simple arrangement he produces the following phenomena:

(*a*) Both ends of the secondary remain open. 1. A Geissler tube, with or without electrodes, glows if held in the hand of the experimenter or placed upon a block of paraffine at a distance of 30 to 40 centimetres from the coil. 2. The same result is obtained if the tube is held by the experimenter, with one end touching one of the terminals of the secondary; a contact is not required. 3. The same phenomenon is observed when the tube is placed on a block of paraffine, touching with one of its ends one terminal of the secondary coil.

(*b*) Leave one of the terminals of the secondary open and attach the other to a sheet of iron suspended from the ceiling by a nonconductor. 1. Connecting the open terminal to a vacuum bulb, having one electrode and a rectilinear carbon filament, the latter glows. 2. A Crooke's tube prepared with phosphorescing powder glows when the experimenter holds it below the suspended sheet of iron. 3. The tube becomes luminous when placed on a block of paraffine below the iron sheet.

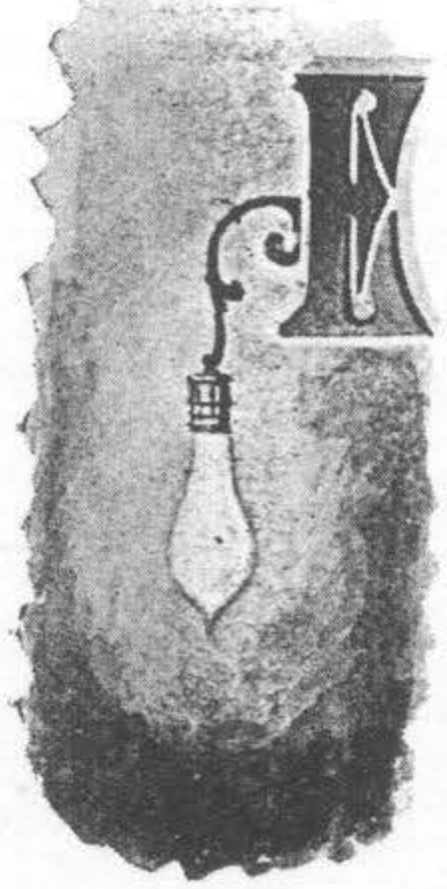
(*c*) The two terminals of the secondary are connected by a metallic conductor having a spark gap. A vacuum tube glows in the neighborhood of the coil.

Using the same arrangement as described under (*c*), but connecting one of the terminals to the metal sheet, we find that vacuum tubes glow if placed either directly under the metal sheet or near it. These experiments succeed at such a low rate of vibration as five oscillations per second and using a much smaller inductorium than the coil the dimensions of which we have described.

Boston, Mass., Jan. 20. V.

ELECTRICAL TRANSMISSION OF POWER FOR MILLS.*

By C. J. H. Woodbury, Vice-Pres. Boston Mfrs. Mutual Fire Ins. Co.



EVERY one of the numerous applications of electricity, excepting incandescent lighting and chemical processes, as electro-plating, requires the use of electric motors ; and some types of dynamos used for incandescent electric lighting contain a regulator which is operated by a motor.

The telegraph receiver is a motor in which the electric impulses produced by the work at the operator's hands at the sending key converts the electricity from the batteries into work. In like manner, electric bells, watchmen's record clocks, railway signals, fire alarms, and even telephones, all are examples of motors. Mr. Edison once exhibited to me a telephone in which a small rod attached to the diaphragm of the receiving telephone was fitted with mechanism by which its rapid longitudinal vibration was converted into circular motion, causing a tiny wheel to revolve very rapidly.

The experiments of Barlow in 1826, by which an electro-magnet was used to cause a continuous revolution, gave rise to many ingenious inventions of devices for producing rotary motions by electricity ; some of the experiments being on a large scale, so extensive, indeed, that a yacht was propellel by one fifty-four years ago, and a railway car forty-one years ago. All of these used the alternate attraction and release of an electro-magnet, giving a reciprocating motion to an armature, and this was easily converted into rotary motion. These devices obtained their electricity from batteries, and were comparable as a matter of principle to a device which might be made by attaching a tiny connecting rod and crank to a telegraph receiver. None of these early electric motors were of any practical value whatsoever in serving for motive power.

The electric motor which is the live issue of to-day is based on the principle that, while a dynamo will generate electricity if power is applied to revolve the armature, yet, on the other hand, if electricity is applied to the dynamo, the armature will revolve. The machine is reversible ; and this reversibility has been wisely called by that eminent mechanician, the late Clerk Maxwell, the greatest invention of the century.

It undoubtedly resulted, as far as public attention was ever called to the matter, from a blunder of a workman engaged in putting up some electric lighting apparatus at the Vienna Exhibition in 1873, by which the wires were connected to one dynamo at one end and to another dynamo at the other end, and when one dynamo started, to the surprise of all, the other was set into rapid motion. As is usually the case with such inventions, there are others who allege that this well-attested incident was the result of design, to illustrate the discovery which they claim to have made previously.

It has been recently found that Dr. Antonio Pacinotti, the inventor of a magneto-electric machine, wrote a description of his machine in an Italian periodical in June, 1864, in which he says that it can be used to generate electricity, or as a motor ; and he therefore is entitled to the credit for the invention of the present electric motor.

* Paper read before New England Cotton Manufacturers' Association.

The relation between magnetism and electricity, by which the magnet of an electric motor can set in revolution by its attraction the copper wires conducting electricity in the armature of an electric motor, is well illustrated by applying a magnet to an incandescent lamp. When the lamp is not illuminated the magnet will not produce any effect upon it, but if the lamp is in use the magnet will attract the filament.

The same machine can and has frequently been used at various times as a dynamo for electric lights and at other times for a motor ; but there are numerous mechanical and electrical modifications essential to obtain the best results in an electric motor. The first use of an electric motor in any of the cotton-mills represented in this association occurred in a thread mill in Newark, where a dynamo was used in 1882 as a motor to run a lot of thread-winding machines.

Electric motors are now used for hundreds of purposes, but this paper will be confined to references to their uses in cotton-mills, and are frequently proportioned to use low-pressure currents of electricity, like those employed for direct incandescent lighting. There are many places where motors can be operated by wires from any of the direct incandescent lighting dynamos ; but, if the power required for the motor is more than about one-fifth that required to keep the whole number of lamps lighted, the lights will rise and fall in brilliancy, like those in an electric car when the motor starts and stops, the lighting service is unsatisfactory and the life of the lamps diminished.

The problem is one which must be worked out in each case ; sometimes, when a small motor is required for use at short intervals during the day, it might be the more economical to use conductors from a large dynamo which is already installed for lighting the mill at other times. If constant service is required from the motor, then a separate generating dynamo is advisable ; and it may be said that in the generality of work it is preferable to put in a generator suitable for furnishing the current to the motors.

The principle holds as good in electric apparatus as in all other machinery, —that more satisfactory results are obtained when there is no attempt made to require a more varied service from any machine than it is fully adequate to furnish.

It is generally advisable to use electricity for the transmission of power at a much higher pressure than that found best suited to incandescent lamps, because there is a great saving in copper for conductors, and a lesser proportion of the electricity absorbed by the resistance of the wires.

The current of 500 volts' pressure used for the trolley system of street-car propulsion is not capable of inflicting serious injury upon mankind, although frequently fatal to horses. There have been motors suited for use on arc-lighting circuits, but I believe that at the present time there are not any of them on the market.

Before deciding to install an electric power plant for a service outside of what is already fixed by precedent, expense, delays and disappointment may be avoided by deciding how much you are willing to experiment ; and, secondly, how much the party doing the work must experiment before the whole installation is in a practical operating condition.

The fact should not be lost sight of that electricity is merely a substitute for other methods of transmission of power. It has its losses at every step in the course, comparable with those of the wear and tear and friction of shafting and belting. Like them, it also costs money, requires attendance, and wears out. It does not in any detail give something for nothing, but the results in comparison with other mechanical means of the transmission of power are merely the addition of a lot of differences. Sometimes these differences are on one side of the account and sometimes on the other.

An installation of motors in one instance may be extremely economical and in another highly expensive, in comparison to ordinary methods of transmission of power.

Electric motors, like water-wheels or steam engines, have their highest efficiency at a point near to their full proper load, and on either side their efficiency in the percentage of electricity converted into work is diminished. The practical operation of some motors has been improved by the use of fly-wheels.

In its application for mill service, the most simple uses are those requiring a variable speed and direction, largely on account of causes outside of the electrical conditions in the construction of such motors. It is especially advantageous for elevators in storehouses or other buildings not requiring power elsewhere. A motor can be attached to any elevator machinery operated by a belt, and the elevator can be managed in the same manner as before, so that the men have nothing either to learn or to forget. The first motor used for operating an elevator in a cotton-mill storehouse was placed in that service in 1882, and is in as good working condition to-day. Another use having a larger field is in its application for railways in mill yards and buildings. The Salmon Falls Manufacturing Company has 2100 feet of track in the mill yard, and is operating a trolley system of cars to move all their cotton, supplies, cloth and coal, with two men, thereby dispensing with the services of a team and three men all of the time, and a fourth man a part of the time. The car makes an average speed of 600 feet per minute, and is always ready for service whenever the water-wheel is running. Other mills use electric railroads from the cloth room to the storehouse with even greater reduction in cost of moving the load.

There are two systems of overhead trolley propulsion; the ordinary single overhead wire, with the current returning through the wheels to the rails and thence back through the earth to the dynamo, is the simplest and the only one that has a practical system of switches in the wires overhead. This system contains a serious objection, in electric sparks constantly occurring in the contact of the wheels with the rails, and liable to ignite any combustible substance there, and therefore could not be safely used inside of mills. For inside use it is necessary to use the double overhead wire system by which the circuit is made between the two wires, without using the rails as conductors. In either case the overhead wires should be thoroughly protected by guard wires whenever there is a possibility of telephone or other wires falling upon them.

Electricity is filling a most useful purpose in operating traveling cranes, and the few storehouses in mills which are provided with traveling cranes use them at such infrequent intervals that it is probable that hand power is still the cheapest method of operation; but for erecting shops, and other places where constant service is required, electricity affords great advantages for working such cranes.

Motors have been applied to calico-printing machines with great success. The absence of heat, small amount of space, little momentum of the revolving parts, and the control by which the machine can be uniformly moved in either direction at any desired speed, are all advantages of the highest practical value.

Other classes of work require that the motor should revolve at as uniform speed as can be obtained by a water-wheel, or better, if possible. Motors will revolve at a constant speed if furnished with a current of uniform pressure. A compound generator will produce a current at a uniform pressure with variations in the load or quantity of current required by the motors; and it will also to some extent compensate for slight variations in the speed at which it is driven. Therefore it may be said that the speed of an electric motor may be more uniform than that of the water-wheel or engine from which it derives the power which it gives forth.

A variation in lights is not a direct measure of variation in a dynamo, because a change of one per cent. in the pressure of the electricity in an incandescent lighting system would cause a variation of several per cent. in the amount of light from the incandescent lamps.

The class of service for the distribution of power throughout a mill as a substitute for belt or rope transmission has not been tried in cotton-mills, but there are many cases where it has been tried in machine shops and yielded excellent results. The amount of power required in cotton-mills is so much greater than in machine shops that the subdivision should be to a smaller unit than a whole room in a large mill. I am convinced that such a distribution of power is mechanically feasible; but will it pay to do so when motors and generators each cost nearly or quite forty dollars per horse-power, or, including wire and foundations, over $100 for every horse-power transmitted?

Another class of applications consists in distributing the electricity from a central station in a mill yard to the various buildings. The most complete plant of this kind is at the Edison Works at Schenectady, where 1700 horse-power is electrically distributed to numerous shops situated at various places on a tract some twenty acres in extent.

The Thomson-Houston Works at Lynn have an extensive electrical distribution of power in their present works, and will have a larger power plant when their new works are completed.

At the Cumberland Mills in Maine 260 horse-power is transmitted over a mile by the Mather electric system, arranged by Messrs. Stone & Webster of the Massachusetts Electrical Engineering Company of Boston; and motors are used to drive paper machinery, giving from poorly governed water-wheels a sufficiently steady motion for calenders; but the compensation by the compound wound generators is not sufficient to remove the effect of all the variations of speed in the water-wheels from appearing in the motors; and these motors cannot run Fourdrinier paper machines, although motors in these mills deriving their power originally from a steam engine perform satisfactory work in driving paper machines. At these same mills an installation of motors is under way for the transmission of 1200 to 2000 horse-power for a distance of seven miles. As water-wheels give sufficiently uniform speed for looms, and as motors do give a more uniform speed, there is but little question as to their mechanical suitability for such work.

The third class of applications for electric motors is in connection with long-distance transmission of power, for the purpose of bringing the energy of a water privilege to a locality more convenient for manufacturing.

The problems of short-distance transmission, already considered, are as different from those involved in the transmission for a long distance as river navigation differs from that on the ocean; and the extent to which these long-distance problems have been mastered was shown by the transmission of 300 horse-power 109 miles, through No. 6 wire, at the Frankfort exhibition in Germany last year. There are power transmissions in California for mining machinery, for long distances, some of them being twenty-seven miles; but I am not aware that any such great distance has been applied for driving textile machinery.

The electric lighting and power used in Hartford, Conn., is derived in part from a water power at Tariffville, ten miles away, and some 300 horse-power is transmitted along the wire that distance, and thence distributed to customers around the city.

The Nonotuck Silk Company is supplying to its mills at Leeds and Haydenville, Mass., power transmitted by electricity from a dam in a rocky gorge in the river about a third of a mile from one mill, and a mile and three-quarters from the other. The installation is not cited as being on a large scale, but because it contains many ingenious features in the manner in which the motors are applied as an auxiliary and a regulator to the water-wheels. The fall of thirty feet is situated between steep banks, where it would not be developed under ordinary conditions, because the spot is unsuitable for the location of a mill. There are two water-wheels in use, one of ninety horse-power, driving

dynamos which furnish 950 incandescent lamps on an alternating system at the mills. The other 130 horse-power water-wheel drives one Thomson-Houston generator of eighty-five horse-power and another of thirty horse-power, the pressure of the current being the same as that used on trolley street cars. At the mills one-third of a mile distant is one motor of forty-five horse-power, two of twenty horse-power, and one of ten horse-power, all supplied by electricity from the eighty-five horse-power generator.

The forty-five horse-power motor belts upon the main shaft, which is driven by two water-wheels having a capacity of 100 horse-power under a twelve and one-half feet fall. The water-wheels are run at full gate without any regulator, but the motor serves as a regulator, running at uniform speed and furnishing the remainder of the power, which has a variable range of twenty-five horse-power. When the water falls too low for the water-wheels and motor to run the mill, a steam engine is belted to the main shaft, the motor and water-wheels furnishing their full capacity, and under these conditions the engine regulates the speed of the whole. It is an important precaution to set the governor on the engine for a speed slightly greater than its proportion to the motor and water-wheels, so that it will lead and also prevent the motor from tending to do more than its proper capacity. The other three motors are used to drive the machinery in an adjoining mill building, and they are connected directly to the shafting, one in each room. The fifty horse-power generator at the power station operates a forty-five horse-power motor in the mill at Haydenville, a mile and three-quarters distant. The arrangement of motor, turbines and engine is the same as at the lower factory, but placed in a more compact manner. Arrangements are being made for an increase in this electric plant.

For long distances it is essential to use electricity at high pressure in order to avoid the necessity of using large wires. For this purpose the electricity is generated in alternating pulsations, known as multiphase currents, at great pressure; and, before entering the building where the motors are situated, the electrical pressure is reduced by a transformer, and in that condition used by the motors. Mr. Nikola Tesla of the Westinghouse Company is the inventor of this type of motors, which have been in practical use for some time in the shops of the Westinghouse Company at Pittsburgh. It is this type of multiphase machines which offers the only feasible means for transmission over distances exceeding a very few miles, without such undue losses as to be out of the question. These motors, being free from commutators or brushes, do not spark, are very compact, and easily start under a full load. Motors using multiphase currents are under construction by the General Electric Company.

There are several places in New England where the power of waterfalls is being applied through electrical apparatus to machinery at a distance, and there are numerous extensive enterprises of this nature under construction.

The electric transmission of power under any practicable conditions of constant or variable speed, at a loss not exceeding twenty per cent., has been shown to be entirely practicable; and the open question in regard to all of these devices, whatever may be their purpose, is but the question of cost.

It was my privilege, at a meeting of the New England Cotton Manufacturers' Association, held ten years ago, to present a paper on the subject of "Electric lighting in mills." The applications of electric illumination have grown during these ten years to such an extent that the daily manufacture of incandescent lamps in this country is now three times the whole number of incandescent lamps then in use in the United States, and I believe that there is no reason to question why there will not be in this decade a comparable increase in the applications of electricity to the transmission of power.

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National Electric Light Association Bulletin
February 1893

SPECIAL EVENING SESSION.

LECTURE BY NIKOLA TESLA ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.

INTRODUCTORY—SOME THOUGHTS ON THE EYE.

When we look at the world around us, on nature, we are impressed with its beauty and grandeur. Each thing we perceive, though it may be vanishingly small, is in itself a world, that is, like the whole of the visible universe, matter and force governed by law—a world, the contemplation of which fills us with feelings of wonder and irresistibly urges us to ceaseless thought and inquiry. But in all this vast world, of all objects our senses reveal to us, the most marvelous, the most appealing to our imagination, appears, no doubt, a highly developed organism, a thinking being. If there is anything fitted to make us admire nature's handiwork, it is certainly this inconceivable structure, which performs its innumerable motions in obedience to external influence. To understand its workings, to get a deeper insight into this nature's masterpiece, has ever been for thinkers a fascinating aim, and after many centuries of arduous research men have arrived at a fair understanding of the functions of its organs and senses. Again, in all the perfect harmony of its parts, of the parts which constitute the material or tangible of our being, of all its organs and senses, the eye is the most wonderful. It is the most precious, the most indispensable of our receptive or directive organs; it is the great gateway through which all

knowledge enters the mind. Of all our organs, it is the one which is in the most intimate relation with that which we call intellect. So intimate is this relation, that it is often said that the very soul shows itself in the eye.

It can be taken as a fact, which the theory of the action of the eye implies, that for each external impression, that is, for each image produced upon the retina, the ends of the visual nerves, concerned in the conveyance of the impression to the mind, must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and therefore upon the retina. Will it ever be within human power to analyze the condition of the retina, when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science, in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he was able to *see* in total darkness the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

Another fact having a bearing on this subject, which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation, is that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, observable even in broad daylight.

The saying, then, that the soul shows itself in the eye, is deeply founded, and we feel that it expresses a great truth. It has a profound meaning even for one who, like a poet or artist, only following his inborn instinct or love for nature, finds delight in aimless thoughts and in the mere contemplation of natural phenomena, but a still more profound meaning for one who, in the spirit of positive scientific investigation, seeks to ascertain the causes of the effects. It is principally the natural philosopher, the physicist, for whom the eye is the subject of the most intense admiration.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting that the very conception of that which is perfect, or seems so to him, has been gained through this same instrument. Firstly, the eye is, as far as our positive knowledge goes, the only organ which is *directly* affected by that subtile medium which, as science teaches us, must fill all space; secondly, it is the most sensitive of our organs, incomparably more sensitive to external impressions than any other.

The organ of hearing implies the impact of ponderable bodies, the organ of smell the transference of detached material particles, and the organs of taste, and of touch or force, the direct contact, or at least some interference of ponderable matter; and this is true even in those

instances of animal organisms in which some of these organs are developed to a degree of truly marvelous perfection. This being so, it seems wonderful that the organ of sight solely should be capable of being stirred by that which all our other organs are powerless to detect, which yet plays an essential part in all natural phenomena, which transmits all energy and sustains all motion and, that most intricate of all, life, but which has properties such that even a scientifically trained mind cannot help drawing a distinction between it and all that is called matter. Considering merely this, and the fact that the eye, by its marvelous power, widens our otherwise very narrow range of perception far beyond the limits of the small world, which is our own, to embrace myriads of other worlds, suns and stars in the infinite depths of the universe, would make it justifiable to assert that it is an organ of a higher order. Its performances are beyond comprehension. Nature, so far as we know, never produced anything more wonderful. We can get barely a faint idea of its prodigious power by analyzing what it does and by comparing. When ether waves impinge upon the human body, they produce the sensations of warmth or cold, pleasure or pain, or perhaps other sensations of which we are not aware, and any degree or intensity of these sensations; which degrees are infinite in number, hence an infinite number of distinct sensations. But our sense of touch, or our sense of force, cannot reveal to us these differences in degree or intensity unless they are very great. Now, we can readily conceive how an organism, such as the human in the eternal process of evolution, or, more philosophically speaking, adaptation to nature, being constrained to the use of only the sense of touch or force, for instance, might develop this sense to such a degree of sensitiveness or perfection that it

would be capable of distinguishing the minutest differences in the temperature of a body even at some distance, to a hundredth, or thousandth, or millionth part of a degree. Yet, even this apparently impossible performance would not begin to compare with that of the eye, which is capable of distinguishing and conveying to the mind in a single instant innumerable peculiarities of the body, be it in form or color or other respects. This power of the eye rests upon two things, namely, the rectilinear propagation of the disturbance by which it is affected, and upon its sensitiveness. To say that the eye is sensitive is not saying anything. Compared with it, all other organs are monstrously crude. The organ of smell which guides a dog on the trail of a deer, the organ of touch or force which guides an insect in its wanderings, the organ of hearing, which is affected by the slightest disturbances of the air, are sensitive organs, to be sure, but what are they compared with the human eye! No doubt it responds to the faintest echoes or reverberations of the medium; no doubt, it brings us tidings from other worlds, infinitely remote, but in a language we cannot as yet always understand. And why not? Because we live in a medium filled with air and other gases, vapors and a dense mass of solid particles flying about. These play an important part in many phenomena; they fritter away the energy of the vibrations before they can reach the eye; they, too, are the carriers of germs of destruction; they get into our lungs and other organs, clog up the channels and imperceptibly, yet inevitably, arrest the stream of life. Could we but do away with all ponderable matter in the line of sight of the telescope, it would reveal to us undreamt of marvels. Even the unaided eye, I think, would be capable of distinguishing in the pure medium small

objects at distances measured probably by hundreds or, perhaps, thousands of miles.

But there is something else about the eye which impresses us still more than these wonderful features which we observe, viewing it from the standpoint of a physicist, merely as an optical instrument—something which appeals to us more than its marvelous faculty of being directly affected by the vibrations of the medium, without interference of gross matter, and more than its inconceivable sensitiveness and discerning power. It is its significance in the processes of life. No matter what one's views on Nature and life may be, he must stand amazed when, for the first time in his thoughts, he realizes the importance of the eye in the physical processes and mental performances of the human organism. And how could it be otherwise, when he realizes that the eye is the means through which the human race has acquired the entire knowledge it possesses, that it controls all our motions; more, still, all our actions.

There is no way of acquiring knowledge except through the eye. What is the foundation of all philosophical systems of ancient and modern times, in fact, of all the philosophy of man? *I am, I think; I think, therefore, I am.* But how could I think, and how would I know that I exist if I had not the eye? For knowledge involves consciousness; consciousness involves ideas, conceptions; conceptions involve pictures or images, and images, the sense of vision, and, therefore, the organ of sight. But how about blind men, will be asked? Yes, a blind man may depict in magnificent poems forms and scenes from real life, from a world he physically does not see. A blind man may touch the keys of an instrument with unerring precision, may build the fastest boat, may discover and invent, calculate and construct, may do still greater wonders;

but all the blind men who have done such things have descended from those who had seeing eyes. Nature may reach the same result in many ways. Like a wave in the physical world, in the infinite ocean of the medium which pervades all, so in the world of organisms, in life, an impulse started proceeds onward; at times, may be, with the speed of light, at times, again, so slowly that for ages and ages it seems to stay, passing through processes of a complexity inconceivable to men, but in all its forms, in all its stages, its energy ever and ever integrally present. A single ray of light from a distant star falling upon the eye of a tyrant in bygone times may have altered the course of his life, may have changed the destiny of nations, may have transformed the surface of the globe, so intricate, so inconceivably complex are the processes in Nature. In no way can we get such an overwhelming idea of the grandeur of Nature as when we consider that in accordance with the law of the conservation of energy, throughout the Infinite, the forces are in a perfect balance, and hence the energy of a single thought may determine the motion of a Universe. It is not necessary that every individual, not even that every generation or many generations, should have the physical instrument of sight, in order to be able to form images and to think, that is, form ideas or conceptions; but some time or other, during the process of evolution, the eye certainly must have existed, else thought, as we understand it, would be impossible; else conceptions, like spirit, intellect, mind, call it as you may, could not exist. It is conceivable that in some other world, in some other beings, the eye is replaced by a different organ, equally or more perfect, but these beings cannot be men.

Now, what prompts us to all voluntary motions and actions of any kind? Again, the eye. If I am con-

scious of the motion, I must have an idea or conception—that is, an image—therefore, the eye. If I am not precisely conscious of the motion, it is because the images are vague or indistinct, being blurred by the superimposition of many. But when I perform the motion, does the impulse which prompts me to the action come from within or from without? The greatest physicists have not disdained to endeavor to answer this and similar questions, and have at times abandoned themselves to the delights of pure and unrestrained thought. Such questions are generally considered not to belong to the realm of positive physical science, but will before long be annexed to its domain. Helmholtz has probably thought more on life than any modern scientist. Lord Kelvin expressed his belief that life's process is electrical, and that there is a force inherent to the organism and determining its motions. Just as much as I am convined of any physical truth I am convinced that the motive impulse must come from the outside; for, consider the lowest organism we know—and there are probably many lower ones—an aggregation of a few cells only. If it is capable of voluntary motion, it can perform an infinite number of motions, all definite and precise. But now a mechanism consisting of a finite number of parts, and few at that, cannot perform an infinite number of definite motions; hence, the impulses which govern its movements must come from the environment. So the atom, the ulterior element of the Universe's structure, is tossed about in space eternally, a play to external influences, like a float in a troubled sea. Were it to stop its motion, *it would die.* Matter at rest, if such a thing could exist, would be matter dead. Death of matter! Never has a sentence of deeper philosphical meaning been uttered. This is the way in which Professor Dewar forcibly

expresses it in the description of his admirable experiments, in which liquid oxygen is handled as one handles water, and air at ordinary pressure is made to condense and even to solidify by the intense cold—experiments which serve to illustrate, in his language, the last feeble manifestations of life, the last quiverings of matter about to die. But human eyes shall not witness such death. There is no death of matter, for throughout the infinite universe all has to move, to vibrate—that is, to live.

I have made the preceding statements at the peril of treading upon metaphysical ground in my desire to introduce the subject of this lecture in a manner not altogether uninteresting, I may hope, to an audience such as I have the honor to address. But now, then, returning to the subject, this divine organ of sight, this indispensable instrument for thought and all intellectual enjoyment, which lays open to us the marvels of this Universe, through which we have acquired what knowledge we possess, and which prompts us to and controls all our physical and mental activity—by what is it affected? By light! What is light?

We have witnessed the great strides which have been made in all departments of science in recent years. So great have been the advances that we cannot refrain from asking ourselves, Is this all true, or is it but a dream? Centuries ago men have lived, have thought, discovered, invented, and have believed that they were soaring, while they were merely proceeding at a snail's pace. So we, too, may be mistaken. But, taking the truth of the observed events as one of the implied facts of science, we must rejoice in the immense progress already made, and still more in the anticipation of what must come, judging from the possibilities opened up by modern research. There is, however, an advance which

we have been witnessing, which must be particularly gratifying to every lover of progress. It is not a discovery, or an invention, or an achievement in any particular direction. It is an advance in all directions of scientific thought and experiment. I mean the generalization of the natural forces and phenomena, the looming up of a certain broad idea on the scientific horizon. It is this idea which has, however, long ago taken possession of the most advanced minds, to which I desire to call your attention, and which I intend to illustrate, in a general way, in these experiments, as the first step in answering the question, "What is light?" and to realize the modern meaning of this word.

It is beyond the scope of my lecture to dwell upon the subject of light in general, my object being merely to bring presently to your notice a certain class of light effects and a number of phenomena observed in pursuing the study of these effects. But to be consistent in my remarks it is necessary to state that according to that idea, now accepted by the majority of scientific men as a positive result of theoretical and experimental investigation, the various forms or manifestations of energy which were generally designated as "electric" or, more precisely, "electromagnetic," are energy manifestations of the same nature as those of radiant heat and light. Therefore, the phenomena of light and heat, and others besides these, may be called electrical phenomena. Thus electrical science has become the mother science of all, and its study has become all important. The day when we shall know exactly what "electricity" is, will chronicle an event probably greater, more important, than any other recorded in the history of the human race. The time will come when the comfort, the very existence, perhaps, of man will depend upon that wonderful agent. For our existence and comfort we

require heat, light and mechanical power. How do we now get all these? We get them from fuel; we get them by consuming material. What will man do when the forests disappear, when the coal fields are exhausted? Only one thing, according to our present knowledge, will remain; that is, to transmit power at great distances. Men will go to the waterfalls, to the tides, which are the stores of an infinitesimal part of Nature's immeasurable energy. There will they harness the energy and transmit the same to their settlements, to warm their homes by, to give them light, and to keep their obedient slaves, the machines, toiling. But how will they transmit this energy if not by electricity? Judge, then, if the comfort, nay, the very existence, of man will not depend on electricity. I am aware that this view is not that of a practical engineer; but neither is it that of an illusionist, for it is certain that power transmission, which, at present, is merely a stimulus to enterprise, will some day be a dire necessity.

It is more important for the student who takes up the study of light phenomena to make himself thoroughly acquainted with certain modern views than to peruse entire books on the subject of light itself, as disconnected from these views. Were I, therefore, to make these demonstrations before students seeking information—and for the sake of the few of those who may be present, give me leave to so assume—it would be my principal endeavor to impress these views upon their minds in this series of experiments.

It might be sufficient for this purpose to perform a simple and well-known experiment. I might take a familiar appliance, a Leyden jar, charge it from a frictional machine, and then discharge it. In explaining to you its permanent state when charged, and its transitory condition when discharging; calling your

attention to the forces which enter into play and to the various phenomena they produce, and pointing out the relation of the forces and phenomena, I might fully succeed in illustrating that modern idea. To the thinker, no doubt, this simple experiment would appeal as much as the most magnificent display. But this is to be an experimental demonstration, and one which should possess besides instructive, also entertaining features, and as such, a simple experiment, such as the one cited, would not go very far towards the attainment of the lecturer's aim. I must, therefore, choose another way of illustrating, more spectacular certainly, but perhaps also more instructive. Instead of the frictional machine and Leyden jar, I shall avail myself in these experiments of an induction coil of peculiar properties, which was described in detail by me in a lecture before the London Institution of Electrical Engineers, in February, 1892. This induction coil is capable of yielding currents of enormous potential differences, alternating with extreme rapidity. With this apparatus I shall endeavor to show you three distinct classes of effects, or phenomena, and it is my desire that each experiment, while serving for the purposes of illustration, shall at the same time teach us some novel truth, or show us some novel aspect of this fascinating science. But before doing this, it seems proper and useful to dwell upon the apparatus employed and method of obtaining the high potentials and high frequency currents which are made use of in these experiments.

ON THE APPARATUS AND METHOD OF CONVERSION.

These high-frequency currents are obtained in a peculiar manner. The method employed was advanced by me about two years ago in an experimental lecture

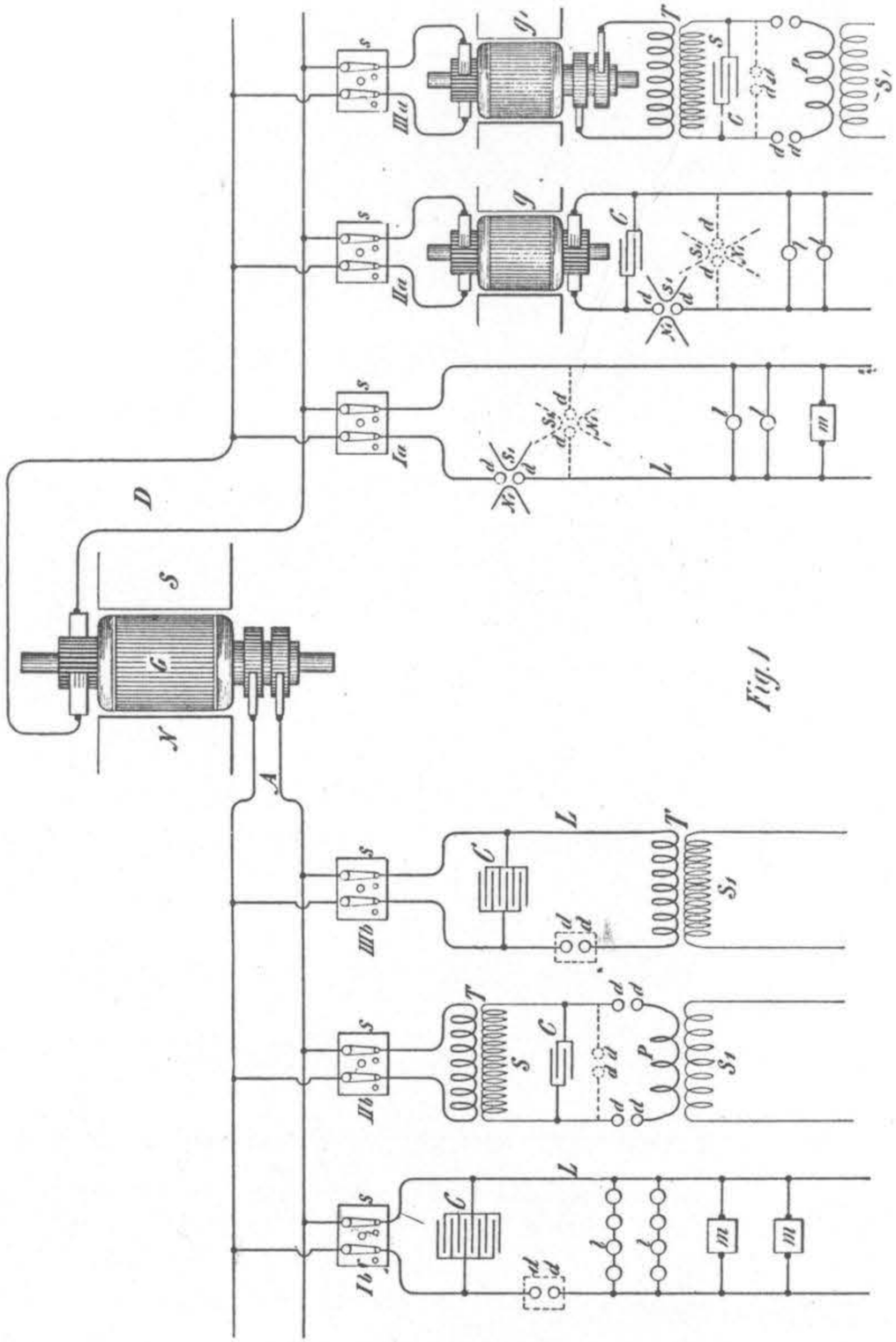


FIG. 1.—PLAN OF CONNECTIONS USED IN THE CONVERSION BY MEANS OF THE DISRUPTIVE ARC DISCHARGE.

before the American Institute of Electrical Engineers. A number of ways, as practiced in the laboratory, of obtaining these currents, either from continuous or low-frequency alternating currents, is diagrammatically indicated in Fig. 1, which will be later described in detail. The general plan is to charge condensers, from a direct or alternate current source, preferably of high tension, and to discharge them disruptively while observing well-known conditions necessary to maintain the oscillations of the current. In view of the general interest taken in high-frequency currents and effects producible by them, it seems to me advisable to dwell at some length upon this method of conversion. In order to give you a clear idea of the action, I will suppose that a continuous current generator is employed, which is often very convenient. It is desirable that the generator should possess such high tension as to be able to break through a small air space. If this is not the case, then auxiliary means have to be resorted to, some of which will be indicated subsequently. When the condensers are charged to a certain potential, the air or insulating space gives way and a disruptive discharge occurs. There is then a sudden rush of current, and generally a large portion of the accumulated electrical energy spends itself. The condensers are thereupon quickly charged, and the same process is repeated in more or less rapid succession. To produce such sudden rushes of current it is necessary to observe certain conditions. If the rate at which the condensers are discharged is the same as that at which they are charged, then, clearly, in the assumed case the condensers do not come into play. If the rate of discharge be smaller than the rate of charging, then, again, the condensers cannot play an important part. But if, on the contrary, the rate of discharging is greater than that of charging, then a succession of rushes of current

is obtained. It is evident that if the rate at which the energy is being dissipated by the discharge is very much greater than the rate of supply to the condensers, the sudden rushes will be comparatively few, with long time intervals between. This always occurs when a condenser of considerable capacity is charged by means of a comparatively small machine. If the rates of supply and dissipation are not widely different, then the rushes of current will be in quicker succession, and this the more, the more nearly equal both the rates are, until natural limitations incident to each case, and depending upon a number of causes, are reached. Thus we are able to obtain from a continuous current generator as rapid a succession of discharges as we like. Of course, the higher the tension of the generator, the smaller need be the capacity of the condensers, and for this reason, principally, it is of advantage to employ a generator of very high tension. Besides, such a generator permits the attaining of greater rates of vibration.

The rushes of current may be of the same direction under the conditions before assumed, but most generally there is an oscillation superimposed upon the fundamental vibration of the current. When the conditions are so determined that there is no oscillation, the current impulses are unidirectional and thus a means is provided of transforming a continuous current of high tension into a direct current of lower tension, which I think may find employment in the arts.

This method of conversion is exceedingly interesting and I was much impressed by its beauty when I first conceived it. It is ideal in certain respects. It involves the employment of no mechanical devices of any kind, and it allows of obtaining currents of any desired frequency from an ordinary circuit, direct or alternating. The frequency of the fundamental dis-

charges depending on the relative rates of supply and dissipation can be readily varied within wide limits by simple adjustments of these quantities, and the frequency of the superimposed vibration by the determination of the capacity, self-induction and resistance of the circuit. The potential of the currents, again, may be raised as high as any insulation is capable of withstanding safely, by combining capacity and self-induction or by induction in a secondary, which need have but comparatively few turns.

As the conditions are often such that the intermittence or oscillation does not readily establish itself, especially when a direct current source is employed, it is of advantage to associate an interrupter with the arc, and I have, some time ago, indicated the use of an air-blast or magnet, or other such device readily at hand. The magnet is employed with special advantage in the conversion of direct currents, as it is then very effective. If the primary source is an alternate current generator, it is desirable, as I have stated on another occasion, that the frequency should be low, and that the currents forming the arc be large, in order to render the magnet more effective.

A form of such discharger, with a magnet, which has been found convenient, and adopted, after some trials, in the conversion of direct currents particularly, is illustrated in Fig. 2. N S are the pole-pieces of a very strong magnet, which is excited by a coil, C. The pole-pieces are slotted for adjustment, and can be fastened in any position by screws, s_1 s_1. The discharge rods d d_1, thinned down on the ends, in order to allow a closer approach of the magnetic pole-pieces, pass through the columns of brass b b_1, and are fastened in position by screws, s_2 s_2. Springs, r r_1, and collars, c c_1, are slipped on the rods, the latter serving to set the points of the

rods at a certain suitable distance by means of screws, s_3 s_3, and the former to draw the points apart. When it is desired to start the arc one of the hard rubber handles h h_1 is tapped quickly with the hand, whereby the points of the rods are brought in contact, but are instantly separated by the springs r r_1. Such an arrangement has been found to be often necessary, namely, in

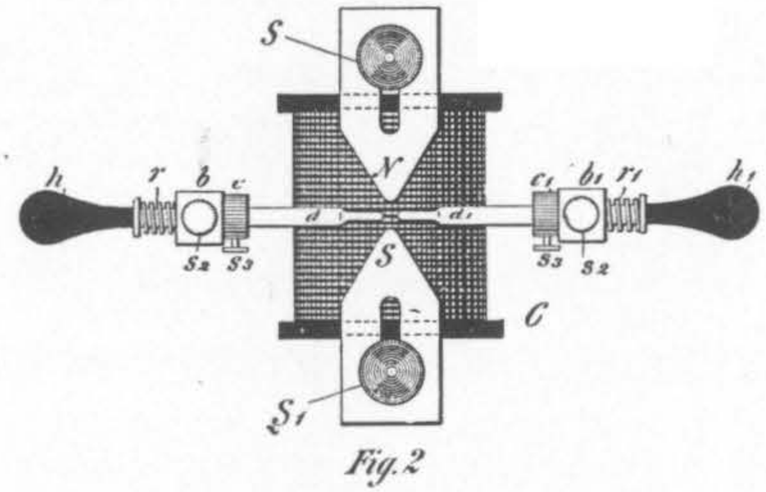


Fig. 2

FIG. 2.—FORM OF DISCHARGER WITH MAGNET USED IN THE DIRECT CURRENT CONVERSION.

cases when the electromotive force was not large enough to cause the discharge to break through the gap, and also when it was desirable to avoid short-circuiting of the generator by the metallic contact of the rods. The rapidity of the interruptions of the current with a magnet depends on the intensity of the magnetic field and on the potential difference at the ends of the arc. The interruptions are generally in such quick succession as to produce a musical sound. Years ago it was observed

that when a powerful induction coil was discharged between the poles of a strong magnet the discharge produced a loud noise not unlike a small pistol shot. It was vaguely stated that the spark was intensified by the presence of the magnetic field. It is now clear that the discharge current, flowing for some time, was interrupted a great number of times by the magnet, thus producing the sound. The phenomenon is especially marked when the field circuit of a large magnet or dynamo is broken in a powerful magnetic field.

When the current through the gap is comparatively large, it is of advantage to slip on the points of the discharge rods pieces of very hard carbon, and let the arc play between the carbon pieces. This preserves the rods, and, besides, has the advantage of keeping the air space hotter, as the heat is not conducted away as quickly through the carbons, and the result is that a smaller electromotive force in the arc gap is required to maintain a succession of discharges.

Another form of discharger which may be employed with advantage in some cases is illustrated in Fig. 3. In this form the discharge rods $d\,d_1$ pass through perforations in a wooden box B, which is thickly coated with mica on the inside, as indicated by the heavy lines. The perforations are provided with mica tubes $m\,m_1$ of some thickness, which are preferably not in contact with the rods $d\,d_1$. The box has a cover C, which is a little larger, and descends on the outside of the box. The spark gap is warmed by a small lamp l, contained in the box. A plate p above the lamp allows the draught to pass only through the chimney c of the lamp, the air entering through holes $o\,o$ in or near the bottom of the box and following the path indicated by the arrows. When the discharger is in operation the door of the box is closed so that the light of the arc is not visible out-

side. It is desirable to exclude the light as perfectly as possible, as it interferes with some experiments. This form of discharger is simple and very effective when properly manipulated. The air being warmed to a certain temperature has its insulating power impaired, it becomes dielectrically weak, as it were, and the consequence is that the arc can be established at much greater

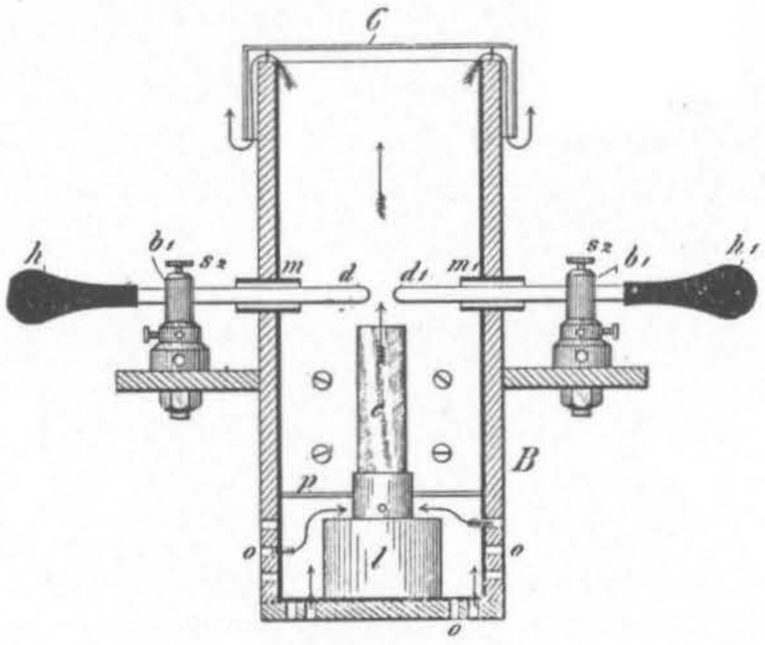


Fig. 3

FIG. 3.—DISCHARGES WITH HOT AIR DRAFT.

distance. The air should, of course, be sufficiently insulating to allow the discharge to pass through the gap *disruptively*. The arc formed under such conditions, when long, may be made extremely sensitive, and the weak draught through the lamp chimney c is quite sufficient to produce rapid interruptions. The adjustment is made by regulating the temperature and velocity of

the draught. Instead of using a lamp, it answers the purpose to provide for a draught of warm air in other ways. A very simple way which has been practiced is to inclose the arc in a long vertical tube, with plates on the top and bottom for regulating the temperature and velocity of the air current. Some provision had to be made for deadening the sound.

The air may also be rendered dielectrically weak by rarefaction. Dischargers of this kind have likewise been used by me in connection with the magnet. A large tube is for this purpose provided with heavy electrodes of carbon or metal, between which the discharge is made to pass, the tube being placed in a powerful magnetic field. The exhaustion of the tube is carried to a point at which the discharge breaks through easily, but the pressure should be more than seventy-five millimeters, at which the ordinary thread discharge occurs. In another form of discharger, combining the features before mentioned, the discharge was made to pass between two adjustable magnetic pole pieces, the space between them being kept at an elevated temperature.

It should be remarked here, that when such, or interrupting devices of any kind, are used and the currents are passed through the primary of a disruptive discharge coil, it is not, as a rule, of advantage to produce a number of interruptions of the current per second greater than the natural frequency of vibration of the dynamo supply circuit, which is ordinarily small. It should also be pointed out here that while the devices mentioned in connection with the disruptive discharge are advantageous under certain conditions, they may be sometimes a source of trouble, as they produce intermittences and other irregularities in the vibration, which it would be very desirable to overcome.

There is, I regret to say, in this beautiful method of

conversion, a defect, which fortunately is not vital, and which I have been gradually overcoming. I will best call attention to this defect, and indicate a fruitful line of work, by comparing the electrical process with its mechanical analogue. The process may be illustrated in this manner: Imagine a tank with a wide opening at the bottom, which is kept closed by spring pressure, but so that it snaps off *suddenly* when the liquid in the tank has reached a certain height. Let the liquid be supplied to the tank by means of a pipe, feeding at a certain rate. When the critical height of the liquid is reached, the spring gives way and the bottom of the tank drops out. Instantly the liquid falls through the wide opening, and the spring, reasserting itself, closes the bottom again. The tank is now filled, and after a certain time interval the same process is repeated. It is clear that if the pipe feeds the liquid quicker than the bottom outlet is capable of letting it pass through, the bottom will remain off, and the tank will still overflow. If the rates of supply are exactly equal, then the bottom lid will remain partially open, and no vibration of the same and of the liquid column will generally occur, though it might, if started by some means. But if the inlet pipe does not feed the liquid fast enough for the outlet, then there will be always vibration. Again, in such case, each time the bottom flaps up or down, the spring and the liquid column, if the pliability of the spring and the inertia of the moving parts are properly chosen, will perform independent vibrations. In this analogue the liquid may be likened to electricity or electrical energy, the tank to the condenser, the spring to the dielectric and the pipe to the conductor through which electricity is supplied to the condenser. To make this analogy quite complete it is necessary to make the assumption that the bottom, each time it gives way, is knocked violently against a

non-elastic stop, this impact involving some loss of energy, and that, besides, some dissipation of energy results, due to frictional losses. In the preceding analogue the liquid is supposed to be under a steady pressure. If the pressure of the liquid be assumed to vary rhythmically, this may be taken as corresponding to the case of an alternating current. The process is then not quite as simple to consider, but the action is the same in principle.

It is desirable, in order to maintain the vibration economically, to reduce the impact and frictional losses as much as possible. As regards the latter, which in the electrical analogue correspond to the losses due to the resistance of the circuits, it is impossible to obviate them entirely, but they can be reduced to a minimum by a proper selection of the dimensions of the circuits and by the employment of thin conductors in the form of strands. But the loss of energy caused by the first breaking through of the dielectric—which in the above example corresponds to the violent knock of the bottom against the inelastic stop—would be more important to overcome. At the moment of the breaking through, the air space has a very high resistance, which is probably reduced to a very small value when the current has reached some strength, and the space is brought to a high temperature. It would materially diminish the loss of energy if the space were always kept at an extremely high temperature, but then there would be no disruptive break. By warming the space moderately by means of a lamp or otherwise, the economy, as far as the arc is concerned, is sensibly increased. But the magnet or other interrupting device does not diminish the loss in the arc. Likewise, a jet of air only facilitates the carrying off of the energy. Air, or a gas in general, behaves curiously in this respect. When two

bodies, charged to a very high potential, discharge disruptively through an air space, any amount of energy may be carried off by the air. This energy is evidently dissipated by bodily carriers, in impact and collisional losses of the molecules. The exchange of the molecules in the space occurs with inconceivable rapidity. A powerful discharge taking place between two electrodes, they may remain entirely cool, and yet the loss in the air may represent any amount of energy. It is perfectly practicable, with very great potential differences in the gap, to dissipate several horse power in the arc of the discharge without even noticing a small increase in the temperature of the electrodes. All the frictional losses occur then practically in the air. If the exchange of the air molecules is prevented, as by enclosing the air hermetically, the gas inside of the vessel is brought quickly to a high temperature, even with a very small discharge. It is difficult to estimate how much of the energy is lost in sound waves, audible or not, in a powerful discharge. When the currents through the gap are large, the electrodes may become rapidly heated; but this is not a reliable measure of the energy wasted in the arc, as the loss through the gap itself may be comparatively small. The air or a gas in general is, at ordinary pressures, at least, clearly not the best medium through which a disruptive discharge should occur. Air or other gas under great pressure is, of course, a much more suitable medium for the discharge gap. I have carried on long-continued experiments in this direction, unfortunately less practicable on account of the difficulties and expense in getting air under great pressure. But even if the medium in the discharge space is solid or liquid, still the same losses take place, though they are generally smaller, for just as soon as the arc is established, the solid or liquid is

volatilized. Indeed, there is no body known which would not be disintegrated by the arc, and it is an open question among scientific men whether an arc discharge could occur at all in the air itself without the particles of the electrodes being torn off. When the current through the gap is very small and the arc very long, I believe that a relatively considerable amount of heat is taken up in the disintegration of the electrodes, which partially on this account may remain quite cold.

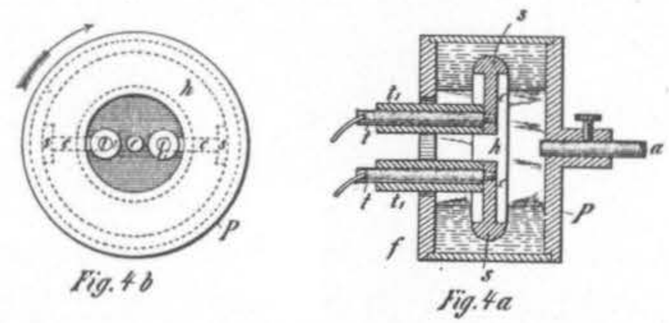
The ideal medium for a discharge gap should only *crack*, and the ideal electrode should be of some material which cannot be disintegrated. With small currents through the gap it is best to employ aluminum, but not when the currents are large. The disruptive break in the air, or, more or less, in any ordinary medium, is not of the nature of a crack, but is rather comparable to the piercing of innumerable bullets through a mass offering great frictional resistance to the motion of the bullets, thus involving considerable loss of energy. A medium which would merely crack when strained electrostatically, and this possibly might be the case with a perfect vacuum—that is, pure ether—would involve a very small loss in the gap, so small as to be entirely negligible, at least theoretically, because a crack may be produced by an infinitely small displacement. In exhausting an oblong bulb provided with two aluminum terminals, with the greatest care I have succeeded in producing such a vacuum that the secondary discharge of a disruptive discharge coil would break disruptively through the bulb in the form of fine spark streams. The curious point was that the discharge would completely ignore the terminals and start far behind the two aluminum plates which served as electrodes. This extraordinarily high vacuum could only be maintained for a very short while. To return to the ideal medium. Think, for the

sake of illustration, of a piece of glass or similar body clamped in a vise, and the latter tightened more and more. At a certain point a minute increase of the pressure will cause the glass to crack. The loss of energy involved in splitting the glass may be practically nothing, for, though the force is great, the displacement need be but extremely small. Now, imagine that the glass would possess the property of closing the crack again perfectly upon a minute diminution of the pressure. This is the way the dielectric in the discharge space should behave; but, inasmuch as there would be always some loss in the gap, the medium, which should be continuous, should exchange through the gap at a rapid rate. In the preceding example, the glass being perfectly closed would mean that the dielectric in the discharge space possesses a great insulating power; the glass being cracked would signify that the medium in the space is a good conductor. The dielectric should vary enormously in resistance by minute variations of the electromotive force across the discharge space. This condition is attained, but in an extremely imperfect manner, by warming the air space to a certain critical temperature, dependent on the electromotive force across the gap, or by otherwise impairing the insulating power of the air. But, as a matter of fact, the air never does break down *disruptively*, if this term be rigorously interpreted, for before the sudden rush of the current occurs, there is always a weak current preceding it, which rises first gradually and then with comparative suddenness. That is the reason why the rate of change is very much greater when glass, for instance, is broken than when the break takes place through an air space of equivalent dielectric strength. As a medium for the discharge space, a solid, or even a liquid, would be preferable therefor. It is somewhat difficult to conceive

of a solid body which would possess the property of closing instantly after it has been cracked. But a liquid, especially under great pressure, behaves practically like a solid, while it possesses the property of closing the crack. Hence, it was thought that a liquid insulator might be more suitable as a dielectric than air. Following out this idea, a number of different forms of dischargers, in which a variety of such insulators, sometimes under great pressure, were employed, have been experimented upon. It is thought sufficient to dwell, in a few words, upon one of the forms experimented upon. One of these dischargers is illustrated in Figs. 4*a* and 4*b*.

A hollow metal pulley P (Fig. 4*a*) was fastened upon an arbor *a*, which by suitable means was rotated at a considerable speed. In the inside of the pulley, but disconnected from the same, was supported a thin disc h_1 (which is shown thick for the sake of clearness) of hard rubber, in which there were embedded two metal segments *s s*, with metallic extensions *c c*, into which were screwed conducting terminals *t t*, covered with thick tubes of hard rubber *t t*. The rubber disc *h*, with its metallic segments s s, was finished in a lathe, and its entire surface highly polished, so as to offer the smallest possible frictional resistance to the motion through a fluid. In the hollow of the pulley an insulating liquid, such as a thin oil, was poured so as to reach very nearly to the opening left in the flange *f*, which was screwed tightly on the front side of the pulley. The terminals *t t* were connected to the opposite coatings of a battery of condensers so that the discharge occurred through the liquid. When the pulley was rotated the liquid was forced against the rim of the pulley, and considerable liquid pressure resulted. In this simple way the discharge gap was filled with a medium which behaved practically like a solid, which possessed the quality of closing

instantly upon the occurrence of the break, and which, moreover, was circulating through the gap at a rapid rate. Very powerful effects were produced by dischargers of this kind with liquid interrupters, of which a number of different forms were made. It was found that, as expected, a longer spark for a given length of wire was obtainable in this way than by using air as an interrupting device. Generally the speed, and, therefore, also the liquid pressure, was limited by reason of the liquid friction in the form of discharger described; but the practically obtainable speed was more than sufficient to



FIGS. 4*a*, 4*b*.—FORM OF DISCHARGER WITH LIQUID INTERRUPTER.

produce a number of breaks suitable for the circuits ordinarily used. In some instances the metal pulley P was provided with a few projections inwardly, and a definite number of breaks was then produced, which could be computed from the speed of rotation of the pulley. Experiments were also carried on with liquids of different insulating power, with the view of reducing the loss in the arc. When an insulating liquid is moderately warmed the loss in the arc is diminished.

A point of some importance was noted in experiments with various dischargers of this kind. It was

found, for instance, that whereas the conditions maintained in these forms were favorable for the production of a great spark length, the currents so obtained were not best suited to the production of light effects. Experience undoubtedly has shown that for such purposes a harmonic rise and fall of the potential is preferable. Be it that a solid is rendered incandescent, or phosphorescent, or be it that energy is transmitted by condenser coating through the glass, it is quite certain that a harmonically rising and falling potential produces less destructive action, and that the vacuum is more permanently maintained. This would be easily explained if it were ascertained that the process going on in an exhausted vessel is of an electrolytic nature.

In the diagrammatical sketch, Fig. 1, which has been already referred to, the cases which are most likely to be met with in practice are illustrated. One has at his disposal either direct or alternating currents from a supply station. It is convenient for an experimenter in an isolated laboratory to employ a machine G, such as illustrated, capable of giving both kinds of currents. In such case it is also preferable to use a machine with multiple circuits, as in many experiments it is useful and convenient to have at one's disposal currents of different phases. In the sketch, D represents the direct and A the alternating circuit. In each of these, three branch circuits are shown, all of which are provided with double lines switches *s s s s s s*. Consider first the direct current conversion; 1*a* represents the simplest case. If the electromotive force of the generator is sufficient to break through a small air space, at least when the latter is warmed or otherwise rendered poorly insulating, there is no difficulty in maintaining a vibration with fair economy by judicious adjustment of the capacity, self-induction and resistance of the circuit L containing the

devices *l l m*. The magnet N, S, can be in this case advantageously combined with the air space. The discharger *d d* with the magnet may be placed either way, as indicated by the full or by the dotted lines. The circuit 1*a* with the connections and devices is supposed to possess dimensions such as are suitable for the maintenance of a vibration. But usually the electromotive force on the circuit or branch 1*a* will be something like 100 volts or so, and in this case it is not sufficient to break through the gap. Many different means may be used to remedy this by raising the electromotive force across the gap. The simplest is probably to insert a large self-induction coil in series with the circuit L. When the arc is established, as by the discharger illustrated in Fig. 2, the magnet blows the arc out the instant it is formed. Now, the extra current of the break, being of high electromotive force, breaks through the gap, and a path of low resistance for the dynamo current being again provided, there is a sudden rush of the current from the dynamo upon the weakening or subsidence of the extra current. This process is repeated in rapid succession, and in this manner I have maintained oscillation with as low as 50 volts, or even less, across the gap. But conversion on this plan is not to be recommended on account of the too heavy currents through the gap and consequent heating of the electrodes: besides, the frequencies obtained in this way are low, owing to the high self-induction necessarily associated with the circuit. It is very desirable to have the electromotive force as high as possible; first, in order to increase the economy of the conversion, and, secondly, to obtain high frequencies. The difference of potential in this electric oscillation is, of course, the equivalent of the stretching force in the mechanical vibration of the spring. To obtain very rapid vibration in a circuit of

some inertia a great stretching force or difference of potential is necessary. Incidentally, when the electromotive force is very great, the condenser which is usually employed in connection with the circuit need have but a small capacity, and many other advantages are gained. With a view of raising the electromotive force to a many times greater value than obtainable from ordinary distribution circuits, a rotating transformer *g* is used, as indicated in Fig. 2*a*, or else a separate high potential machine is driven by means of a motor operated from the generator G. The latter plan is, in fact, preferable, as changes are easier made. The connections from the high tension winding are quite similar to those in branch 1*a* with the exception that a condenser C, which should be adjustable, is connected to the high tension circuits. Usually, also, an adjustable self-induction coil in series with the circuit has been employed in these experiments. When the tension of the currents is very high the magnet ordinarily used in connection with the discharger is of comparatively small value, as it is quite easy to adjust the dimensions of the circuit so that oscillation is maintained. The employment of a steady electromotive force in the high frequency conversion affords some advantages over the employment of alternating electromotive force, as the adjustments are much simpler, and the action can be easier controlled. But, unfortunately, one is limited by the obtainable potential difference. The windings also break down easily, in consequence of the sparks which form between the sections of the armature or commutator when a vigorous oscillation takes place. Besides, these transformers are expensive to build. It has been found by experience that it is best to follow the plan illustrated in Fig. 3*a*. In this arrangement a rotating transformer, *g*, is employed to convert the low tension direct currents

into low frequency alternating currents, preferably also of small tension. The tension of the currents is then raised in a stationary transformer T. The secondary, S, of this transformer is connected to an adjustable condenser, C, which discharges through the gap or discharger, *d d*, placed in either of the ways indicated, through the primary P of a disruptive discharge coil, the high frequency currents being obtained from the secondary S of this coil, as described on previous occasions. This will undoubtedly be found the cheapest and most convenient way of converting direct currents.

The three branches of the circuit A represent the usual cases met in practice when alternating currents are converted. In Fig. 1*b* a condenser C, generally of large capacity, is connected to the circuit L containing the devices *l l*, *m m*. The devices *m m* are supposed to be of high self-induction, so as to bring the frequency of the circuit more or less to that of the dynamo. In this instance the discharger *d d* should best have a number of makes and breaks per second equal to twice the frequency of the dynamo. If not so, then it should have at least a number equal to a multiple or even fraction of the dynamo frequency. It should be observed, referring to 1*b*, that the conversion to a high potential is also effected when the discharger *d d*, which is shown in the sketch, is omitted. But the effects which are produced by currents which rise instantly to high values, as in a disruptive discharge, are entirely different from those produced by dynamo currents which rise and fall harmonically. So, for instance, there might be in a given case a number of makes and breaks at *d d* equal to just twice the frequency of the dynamo; or in other words there may be the same number of fundamental oscillations as would be produced without

the discharge gap, and there might even not be any quicker superimposed vibration; yet the differences of potential at the various points of the circuit, the impedence and other phenomena, dependent upon the rate of change, will bear no similarity in the two cases. Thus, when working with currents discharging disruptively, the element chiefly to be considered is not the frequency, as a student might be apt to believe, but the rate of change per unit of time. With low frequencies, in a certain measure, the same effects may be obtained as with high frequencies, provided the rate of change is sufficiently great. So if a low frequency current is raised to a potential of, say, 75,000 volts and the high tension current passed through a series of high resistance lamp filaments, the importance of the rarefied gas surrounding the filament is clearly noted, as will be seen later; or, if a low frequency current of several thousand amperes is passed through a metal bar, striking phenomena of impedence are observed, just as with currents of high frequencies. But it is, of course, evident that with low frequency currents it is impossible to obtain such rates of change per unit of time as with high frequencies, hence the effects produced by the latter are much more prominent. It was deemed advisable to make the preceding remarks, inasmuch as many more recently described effects have been unwittingly identified with high frequencies. Frequency alone in reality does not mean anything, except when an undisturbed harmonic oscillation is considered.

In the branch *3b* a similar disposition as in *1b* is illustrated, with the difference that the currents discharging through the gap *d d* are used to induce currents in the secondary s of a transformer T. In such case the secondary should be provided with an adjustable condenser for the purpose of tuning it to the primary.

Fig. *2b* illustrates a plan of alternate current high frequency conversion, which is most frequently used and which is found to be most convenient. This plan has been dwelt upon in detail on previous occasions and need not be described here.

Some of these results were obtained by the use of a high frequency alternator. A description of such machines will be found in my original paper before the American Institute of Electrical Engineers, and in periodicals of that period, notably in *The Electrical Engineer* of March 18th, 1891.

I will now proceed with the experiments.

ON PHENOMENA PRODUCED BY ELECTROSTATIC FORCE.

The first class of effects I intend to show you are effects produced by electrostatic force. It is the force which governs the motion of the atoms, which causes them to collide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an infinite variety of ways, according to Nature's fanciful designs, and to form all these wondrous structures we perceive around us; it is, in fact, if our present views be true, the most important force for us to consider in Nature. As the term *electrostatic* might imply a steady electric condition, it should be remarked that in these experiments the force is not constant, but varies at a rate which may be considered moderate, about one million times a second, or thereabouts. This enables me to produce many effects which are not producible with an unvarying force.

When two conducting bodies are insulated and electrified, we say that an electrostatic force is acting between them. This force manifests itself in attractions, repulsions and stresses in the bodies and space or medium without. So great may be the strain exerted

in the air, or whatever separates the two conducting bodies, that it may break down, and we observe sparks or bundles of light, or streamers, as they are called. These streamers form abundantly when the force through the air is rapidly varying. I will illustrate this action of electrostatic force in a novel experiment in which I will employ the induction coil before referred to. The coil is contained in a trough filled with oil, and placed under the table. The two ends of the secondary wire pass through the two thick columns of hard rubber, which protrude to some height above the table. It is necessary to insulate the ends or terminals of the secondary heavily with hard rubber, because even dry wood is by far too poor an insulator for these currents of enormous potential differences. On one of the terminals of the coil I have placed a large sphere of sheet brass, which is connected to a larger insulated brass plate, in order to enable me to perform the experiments under conditions which, as you will see, are more suitable for this experiment. I now set the coil to work and approach the free terminal with a metallic object held in my hand; this simply to avoid burns. As I approach the metallic object to a distance of eight or ten inches a torrent of furious sparks breaks forth from the end of the secondary wire, which passes through the rubber column. The sparks cease when the metal in my hand touches the wire. My arm is now traversed by a powerful electric current, vibrating at about the rate of one million times a second. All around me the electrostatic force makes itself felt, and the air molecules and particles of dust flying about are acted upon and are hammering violently against my body. So great is this agitation of the particles that when the lights are turned out you may see streams of feeble light appear on some parts of my body. When such a streamer breaks out

on any part of the body it produces a sensation like the pricking of a needle. Were the potentials sufficiently high, and the frequency of the vibration rather low, the skin would probably be ruptured under the tremendous strain, and the blood would rush out with great force in the form of fine spray or jet so thin as to be invisible, just as oil will when placed on the positive terminal of a Holtz machine. This breaking through of the skin, though it may seem impossible at first, would perhaps occur by reason of the tissues under the skin being incomparably better conducting. This, at least, appears plausible, judging from some observations.

I can make these streams of light visible to all, by touching with the metallic object one of the terminals as before, and approaching my free hand to the brass sphere, which is connected to the second terminal of the coil. As the hand is approached the air between it and the sphere, or in the immediate neighborhood, is more violently agitated, and you see streams of light now break forth from my finger tips and from the whole hand (Fig. 5). Were I to approach the hand closer, powerful sparks would jump from the brass sphere to my hand, which might be injurious. The streamers offer no particular inconvenience, except that in the ends of the finger tips a burning sensation is felt. They should not be confounded with those produced by an influence machine, because in many respects they behave differently. I have attached the brass sphere and plate to one of the terminals in order to prevent the formation of visible streamers on that terminal, also in order to prevent sparks from jumping at a considerable distance. Besides, the attachment is favorable for the working of the coil.

The streams of light which you have observed issuing from my hand are due to a potential of about 200,000

volts, alternating in rather irregular intervals, something like a million times a second. A vibration of the same amplitude, but four times as fast, to maintain which over 3,000,000 volts would be required, would be more than sufficient to envelop my body in a complete sheet of flame. But this flame would not burn me up; quite contrarily, the probability is that I would not be injured in the least. Yet a hundredth part of that energy, otherwise directed, would be amply sufficient to kill a person.

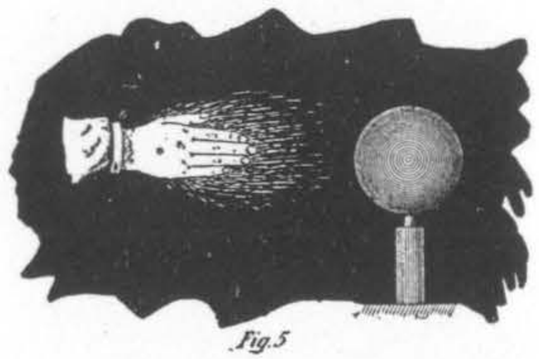


FIG. 5.—ILLUSTRATING THE EFFECT OF VARYING ELECTROSTATIC FORCE WITH A TRANSFORMER OF 200,000 VOLTS PRESSURE.

The amount of energy which may thus be passed into the body of a person depends on the frequency and potential of the currents, and by making both of these very great, a vast amount of energy may be passed into the body without causing any discomfort, except, perhaps, in the arm, which is traversed by a true conduction current. The reason why no pain in the body is felt and no injurious effect noted, is that everywhere, if a current be imagined to flow through the body, the direction of

its flow would be at right angles to the surface; hence the body of the experimenter offers an enormous section to the current, and the density is very small, with the exception of the arm, perhaps, where the density may be considerable. But, if only a small fraction of that energy would be applied in such a way that a current would traverse the body in the same manner as a low frequency current, a shock would be received which might be fatal. A direct or low frequency alternating current is fatal, I think, principally because its distribution through the body is not uniform, as it must divide itself in minute streamlets of great density, whereby some organs are vitally injured. That such a process occurs I have not the least doubt, though no evidence might apparently exist, or be found upon examination. The surest to injure and destroy life is a continuous current, but the most painful is an alternating current of very low frequency. The expression of these views, which are the result of long continued experiment and observation, both with steady and varying currents, is elicited by the interest which is at present taken in this subject, and by the manifestly erroneous ideas which are daily propounded in journals on this subject.

I may illustrate an effect of the electrostatic force by another striking experiment, but before, I must call your attention to one or two facts. I have said before that when the medium between two oppositely electrified bodies is strained beyond a certain limit it gives way and, stated in popular language, the opposite electric charges unite and neutralize each other. This breaking down of the medium occurs principally when the force acting between the bodies is steady, or varies at a moderate rate. Were the variation sufficiently rapid, such a destructive break would not occur, no matter how great the force, for all the energy would be spent

in radiation, convection and mechanical and chemical action. Thus the *spark* length, or greatest distance through which a *spark* will jump between the electrified bodies is the smaller, the greater the variation or time rate of change. But this rule may be taken to be true only in a general way, when comparing rates which are widely different.

I will show you by an experiment the difference in the effect produced by a rapidly varying and a steady or moderately varying force. I have here two large circular brass plates *pp* (Fig. 6*a* and Fig. 6*b*), supported on

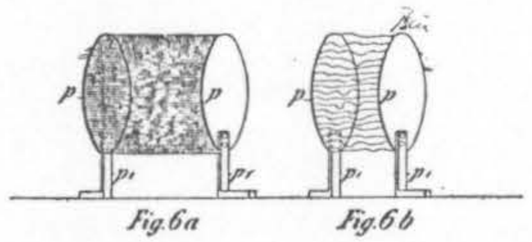


Fig.6a *Fig.6b*

FIGS. 6*a*, 6*b*.—ILLUSTRATING THE EFFECTS OF RAPIDLY VARYING AND STEADY ELECTROSTATIC FORCE.

movable insulating stands on the table, connected to the ends of the secondary of a similar coil to the one used before. I place the plates ten or twelve inches apart and set the coil to work. You see the whole space between the plates, nearly two cubic feet, filled with uniform light, Fig. 6*a*. This light is due to the streamers you have seen in the first experiment, which are now much more intense. I have already pointed out the importance of these streamers in commercial apparatus and their still greater importance in some purely scientific investigations. Often they are too

weak to be visible, but they always exist, consuming energy and modifying the action of the apparatus. When intense, as they are at present, they produce ozone in great quantity, and, also, as Professor Crookes has pointed out, nitrous acid. So quick is the chemical action, that if a coil such as this one is worked for a very long time it will make the atmosphere of a small room unbearable, for the eyes and throat are attacked. But when moderately produced, the streamers refresh the atmosphere wonderfully, like a thunder-storm, and exercise unquestionably a beneficial effect.

In this experiment the force acting between the plates changes in intensity and direction at a very rapid rate. I will now make the rate of change per unit of time much smaller. This I effect by rendering the discharges through the primary of the induction coil less frequent, and also by diminishing the rapidity of the vibration in the secondary. The former result is conveniently secured by lowering the electromotive force over the air gap in the primary circuit; the latter, by approaching the two brass plates to a distance of about three or four inches. When the coil is set to work you see no streamers or light between the plates, yet the medium between them is under a tremendous strain. I still further augment the strain by raising the electromotive force in the primary circuit, and soon you see the air give way and the hall is illuminated by a shower of brilliant and noisy sparks, 6*b*. These sparks could be produced, also, with unvarying force. They have been for many years a familiar phenomenon, though they were usually obtained from entirely different apparatus. In describing these two phenomena so radically different in appearance, I have advisedly spoken of a "force" acting between the plates. It would be in accordance with accepted views to say that there was an "alternating

electromotive force" acting between the plates. This term is quite proper and applicable in all cases where there is evidence of at least a possibility of an essential inter-dependence of the electric state of the plates or electric action in their neighborhood; but if the plates were removed to an infinite distance, or if at a finite distance, there is no probability or necessity whatever for such dependence. I prefer to use the term "electrostatic force," and to say that such a force is acting around each plate or electrified insulated body in general. There is an inconvenience in using this expression, as the term incidentally means a steady electric condition; but a proper nomenclature will eventually settle this difficulty.

I now return to the experiment to which I have already alluded, and with which I desire to illustrate a striking effect produced by a rapidly varying electrostatic force. I attach to the end of the wire *l* (Fig. 7), which is in connection with one of the terminals of the secondary of the induction coil, an exhausted bulb, *b*. This bulb contains a thin carbon filament, *f*, which is fastened to a platinum wire, *w*, sealed in the glass and leading outside of the bulb, where it connects to the wire *l*. The bulb may be exhausted to any degree attainable with ordinary apparatus. Just a moment before you have witnessed the breaking down of the air between the charged brass plates. You know that a plate of glass or any other insulating material would break down in like manner. Had I, therefore, a metallic coating attached to the outside of the bulb or placed near the same, and were this coating connected to the other terminal of the coil, you would be prepared to see the glass give way if the strain were sufficiently increased. Even were the coating not connected to the other terminal, but to an insulated plate, still, if you have followed

recent developments, you would naturally expect a rupture of the glass.

But it will certainly surprise you to note that under the action of the varying electrostatic force, the glass gives way when all other bodies are removed from the bulb. In fact, all the surrounding bodies we perceive might be removed to an infinite distance without affecting the result in the slightest. When the coil is set to

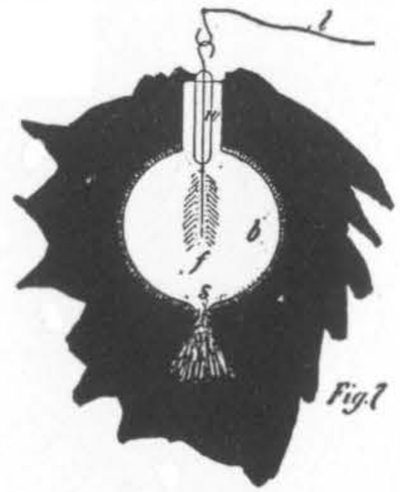


FIG. 7.—BREAKING A BULB ON OPEN CIRCUIT.

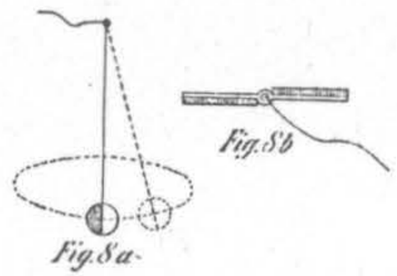
work, the glass is invariably broken through at the seal, or other narrow channel, and the vacuum is quickly impaired. Such a damaging break would not occur with a steady force, even if the same were many times greater. The break is due to the agitation of the molecules of the gas within the bulb, and outside of the same. This agitation, which is generally most violent in the narrow pointed channel near the seal,

causes a heating and rupture of the glass. The rupture would, however, not occur, not even with a varying force, if the medium filling the inside of the bulb, and that surrounding it were perfectly homogeneous. The break occurs much quicker if the top of the bulb is drawn out into a fine fibre. In bulbs used with these coils such narrow, pointed channels must therefore be avoided.

When a conducting body is immersed in air, or similar insulating medium, consisting of, or containing, small, freely movable particles capable of being electrified, and when the electrification of the body is made to undergo a very rapid change—which is equivalent to saying that the electrostatic force acting around the body is varying in intensity—the small particles are attracted and repelled, and their violent impacts against the body may cause a mechanical motion of the latter. Phenomena of this kind are noteworthy, inasmuch as they have not been observed before with apparatus such as has been commonly in use. If a very light conducting sphere be suspended on an exceedingly fine wire, and charged to a steady potential, however high, the sphere will remain at rest. Even if the potential should be rapidly varying, provided that the small particles of matter, molecules or atoms, are evenly distributed, no motion of the sphere should result. But if one side of the conducting sphere is covered with a thick insulating layer, the impacts of the particles will cause the sphere to move about, generally in irregular curves, Fig. 8*a*. In like manner, as I have shown on a previous occasion, a fan of metal sheet, Fig. 8*b*, covered partially with insulating material as indicated, and placed upon the terminal of the coil so as to turn freely in it, is spun around.

All these phenomena you have witnessed, and others

which will be shown later are due to the presence of a medium like air, and would not occur in a continuous medium. The action of the air may be illustrated still



FIGS. 8*a*, 8*b*.—MECHANICAL MOTIONS PRODUCED BY VARYING ELECTROSTATIC FORCE IN A GASEOUS MEDIUM.

better by the following experiment. I take a glass tube *t*, Fig. 9, of about an inch in diameter, which has a platinum wire *w* sealed in the lower end, and to which

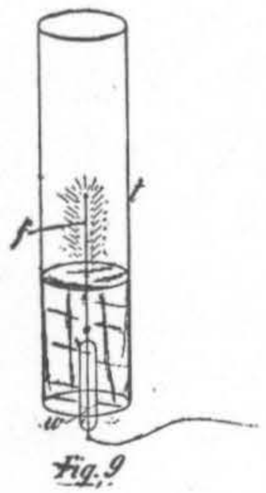


FIG. 9.—SHOWING THE EFFECT OF THE AIR.

is attached a thin lamp filament *f*. I connect the wire with the terminal of the coil and set the coil to work. The platinum wire is now electrified positively and

negatively in rapid succession, and the wire and air inside of the tube are rapidly heated by the impacts of the particles, which may be so violent as to render the filament incandescent. But if I pour oil in the tube, just as soon as the wire is covered with the oil, all action apparently ceases, and there is no marked evidence of heating. The reason of this is that the oil is a practically continuous medium. The displacements in such a continuous medium are, with these frequencies, to all appearance incomparably smaller than in air, hence the work performed in such a medium is insignificant. But oil would behave very differently with frequencies many times as great, for even though the displacements be small, if the frequency were much greater, considerable work might be performed in the oil.

The electrostatic attractions and repulsions between bodies of measurable dimensions are, of all the manifestations of this force, the first so-called *electrical* phenomena noted. But, though they have been known to us for many centuries, the precise nature of the mechanism concerned in these actions is still unknown to us, and has not been even quite satisfactorily explained. What kind of mechanism must that be? We cannot help wondering when we observe two magnets attracting and repelling each other with a force of hundreds of pounds, with apparently nothing between them. We have in our commercial dynamos magnets capable of sustaining in mid-air tons of weight. But what are even these forces acting between magnets when compared with the tremendous attractions and repulsions produced by electrostatic force, to which there is apparently no limit as to intensity. In lightning discharges bodies are often charged to so high a potential that they are thrown away with inconceivable force, and torn asunder, or shattered into fragments. Still, even such effects cannot

compare with the attractions and repulsions which exist between charged molecules or atoms, and which are sufficient to project them with speeds of many kilometres a second, so that under their violent impact bodies are rendered highly incandescent and are volatilized. It is of special interest for the thinker who inquires into the nature of these forces to note that, whereas the actions between individual molecules or atoms occur seemingly under any condition, the attractions and repulsions of bodies of measurable dimensions imply a medium possessing insulating properties. So, if air, either by being rarefied or heated, is rendered more or less conducting, these actions between two electrified bodies practically cease, while the actions between the individual atoms continue to manifest themselves.

An experiment may serve as an illustration and as a means of bringing out other features of interest. Some time ago I showed that a lamp filament or wire mounted in a bulb and connected to one of the terminals of a high tension secondary coil is set spinning, the top of the filament generally describing a circle. This vibration was very energetic when the air in the bulb was at ordinary pressure, and became less energetic when the air in the bulb was strongly compressed; it ceased altogether when the air was exhausted, so as to become comparatively good conducting. I found at that time that no vibration took place when the bulb was very highly exhausted. But I conjectured that the vibration which I ascribed to the electrostatic action between the walls of the bulb and the filament should take place, also, in a highly exhausted bulb. To test this under conditions which were more favorable, a bulb like the one in Fig. 10 was constructed. It comprised a globe, *b*, in the neck of which was sealed a platinum wire, *w*, carrying a thin lamp filament, *f*. In the lower part of the globe a tube,

t, was sealed so as to surround the filament. The exhaustion was carried as far as it was practicable with the apparatus employed.

This bulb verified my expectation, for the filament was set spinning when the current was turned on, and became incandescent. It also showed another interesting feature bearing upon the preceding remarks, namely, when the filament had been kept incandescent some time the narrow tube and the space inside were brought to an elevated temperature, and as the gas in the tube

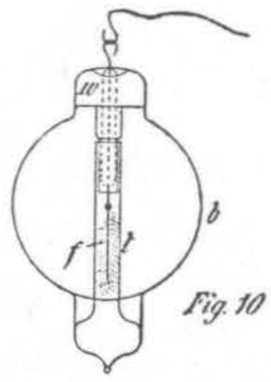


FIG. 10.—SHOWING THE INFLUENCE OF THE CONDUCTIVITY OF THE MEDIUM UPON ELECTROSTATIC ACTIONS THROUGH MEASURABLE DISTANCE.

then became conducting, the electrostatic attraction between the glass and the filament became very weak or ceased, and the filament came to rest. When it came to rest it would glow far more intensely. This was probably due to its assuming the position in the centre of the tube where the molecular bombardment was most intense, and also partly to the fact that the individual impacts were more violent, and that no part of the supplied energy was converted into mechanical movement. Since, in accordance with accepted views, in this experiment the incandescence must be attributed to the impacts of the particles, molecules or atoms in the heated space, these particles must, therefore, in order to explain such action, be assumed to behave as independent carriers of electric charges immersed in an insulating medium; yet there is no attractive force between the glass tube and the filament, because the space in the tube is, as a whole, conducting.

It is of some interest to observe in this connection that, whereas the attraction between two electrified bodies may cease, owing to the impairing of the insulating power of the medium in which they are immersed, the repulsion between the bodies may still be observed. This may be explained in a plausible way. When the bodies are placed at some distance in a poorly conducting medium, such as slightly warmed or rarefied air, and are suddenly electrified, opposite electric charges being imparted to them, these charges equalize more or less by leakage through the air. But if the bodies are similarly electrified there is less opportunity afforded for such dissipation, hence, the repulsion observed in such case is greater than the attraction. Repulsive actions in a gaseous medium are, however, as Professor Crookes has shown, enhanced by molecular bombardment.

ON CURRENT OR DYNAMIC ELECTRICITY PHENOMENA.

So far, I have considered principally effects produced by a varying electrostatic force in an insulating medium, such as air. When such a force is acting upon a conducting body of measurable dimensions it causes within the same or on its surface displacements of the electricity, and gives rise to electric currents; and these produce another kind of phenomena, some of which I shall presently endeavor to illustrate. In presenting this second class of electrical effects I will avail myself prin-

cipally of such as are producible without any return circuit, hoping to interest you the more by presenting these phenomena in a more or less novel aspect.

It has been for a long time customary, owing to the limited experience with vibratory currents, to consider an electric current as something circulating in a closed conducting path. It was astonishing at first to realize that a current may flow through the conducting path even if the latter be interrupted, and it was still more surprising to learn that sometimes it may be even easier to make a current flow under such conditions than

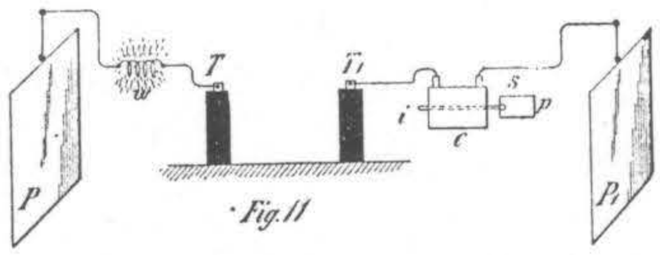


Fig. 11.

Fig 11.—Showing Effects of Currents Flowing Through Open Circuits.

through a closed path. But that old idea is gradually disappearing, even among practical men, and will soon be entirely forgotten.

If I connect an insulated metal plate, P, Fig. 11, to one of the terminals T of the induction coil by means of a wire, though this plate be very well insulated, a current passes through the wire when the coil is set to work. First, I wish to give you evidence that there *is* a current passing through the connecting wire. An obvious way of demonstrating this is to insert between the terminal of the coil and the insulated plate a very thin platinum or

German silver wire, *w*, and bring the latter to incandescence or fusion by the current. This requires a rather large plate or else current impulses of very high potential and frequency. Another way is to take a coil, C, Fig. 11, containing many turns of thin insulated wire, and to insert the same in the path of the current to the plate. When I connect one of the ends of the coil to the wire leading to another insulated plate, P, and its other end to the terminal T_1 of the induction coil, and set the latter to work, a current passes through the inserted coil C, and the existence of the current may be made manifest in various ways. For instance, I insert an iron core, *i*, within the coil. The current being one of very high frequency, if it be of some strength will soon bring the iron core to a noticeably higher temperature, as the hysteresis and current losses are great with such high frequencies. One might take a core of some size—laminated or not, it would matter little—but ordinary iron wire one-sixteenth or one-eighth of an inch thick is suitable for the purpose. While the induction coil is working, a current traverses the inserted coil, and only a few moments are sufficient to bring the iron wire *i* to an elevated temperature sufficient to soften the sealing wax *s*, and cause a paper washer *p*, fastened by it to the iron wire, to fall off. But with the apparatus, such as I have here, other much more interesting demonstrations of this kind can be made. I have a secondary S, Fig. 12, of coarse wire, wound upon a coil similar to the first. In the preceding experiment the current through the coil C, Fig. 11, was very small, but, there being many turns, a strong heating effect was, nevertheless, produced in the iron wire. Had I passed that current through a conductor, in order to show the heating of the latter, the current might have been too small to produce the effect desired. But with this coil

provided with a secondary winding, I can now transform the feeble current of high tension which passes through the primary P into a strong secondary current of low tension, and this current will quite certainly do what I expect. In a small glass tube, *t*, Fig. 12, I have enclosed a coiled platinum wire, *w*, this merely in order to protect the wire. On each end of the glass tube is sealed a terminal of stout wire, to which one of the ends of the platinum wire, *w*, is connected. I join the terminals of the secondary coil to these terminals and insert the primary, *p*, between the insulated plate P_1 and the terminal T_1 of the induction coil as before. The latter being set to work, the platinum wire, *w*, is instantly

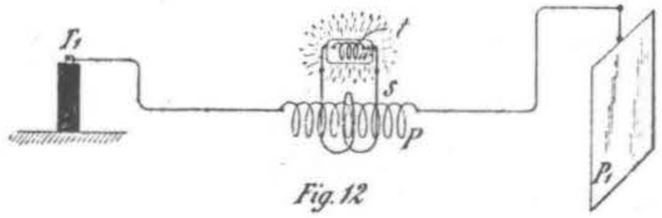


FIG. 12.—CONVERSION ON OPEN CIRCUIT WITH COIL AND INSULATED PLATE.

rendered incandescent, and can be fused, even if it be very thick.

Instead of the platinum wire I now take an ordinary fifty-volt sixteen candle power lamp. When I set the induction coil in operation the lamp filament is brought to high incandescence. It is, however, not necessary to use the insulated plate, for the lamp *l*, Fig. 13, is rendered incandescent even if the plate P_1 be disconnected. The secondary may also be connected to the primary, as indicated by the dotted line in Fig. 13, to do away more or less with the electrostatic induction or to modify the action otherwise.

I may here call attention to a number of interesting observations with the lamp. First, I disconnect one of the terminals of the lamp from the secondary s. When the induction coil plays, a glow is noted which fills the whole bulb. This glow is due to electrostatic induction. It increases when the bulb is grasped with the hand, and the capacity of the experimenter's body thus added to the secondary circuit. The secondary, in effect, is equivalent to a metallic coating, which would be placed near the primary. If the secondary, or its equivalent,

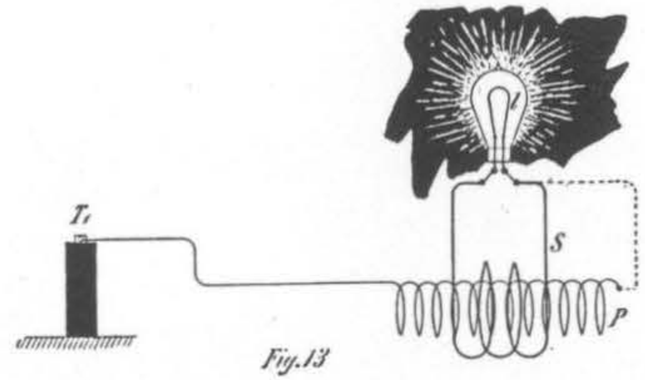
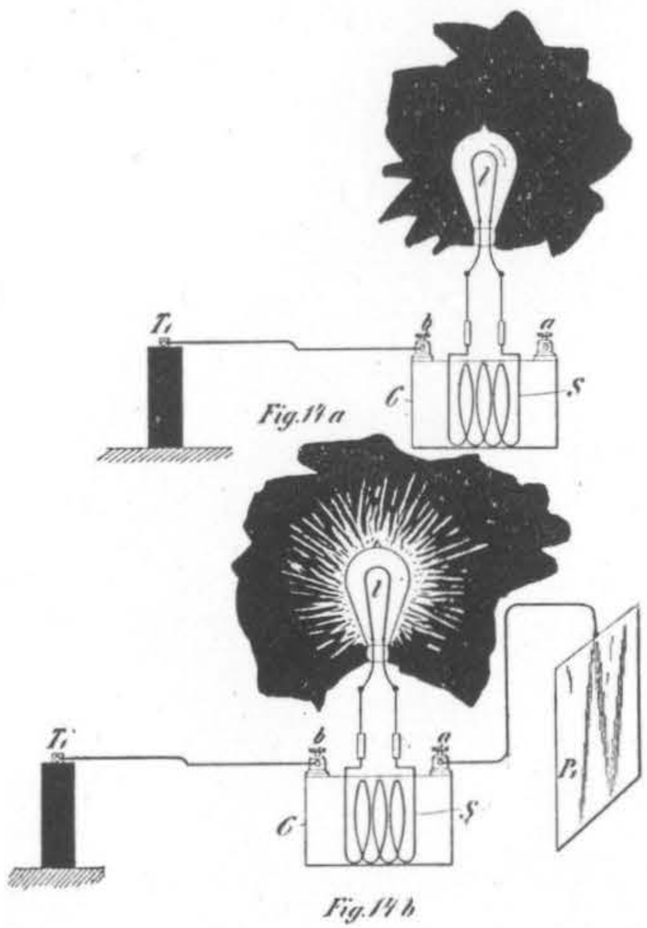


FIG. 13.—CONVERSION ON OPEN CIRCUIT WITH COIL ALONE.

the coating, were placed symmetrically to the primary, the electrostatic induction would be *nil* under ordinary conditions—that is, when a primary return circuit is used—as both halves would neutralize each other. The secondary *is* in fact placed symmetrically to the primary, but the action of both halves of the latter, when only one of its ends is connected to the induction coil, is not exactly equal; hence electrostatic induction takes place, and hence the glow in the bulb. I can nearly equalize the action of both halves of the primary by

connecting the other free end of the same to the insulated plate, as in the preceding experiment. When the plate is connected, the glow disappears. With a smaller plate it would not entirely disappear, and then it would contribute to the brightness of the filament



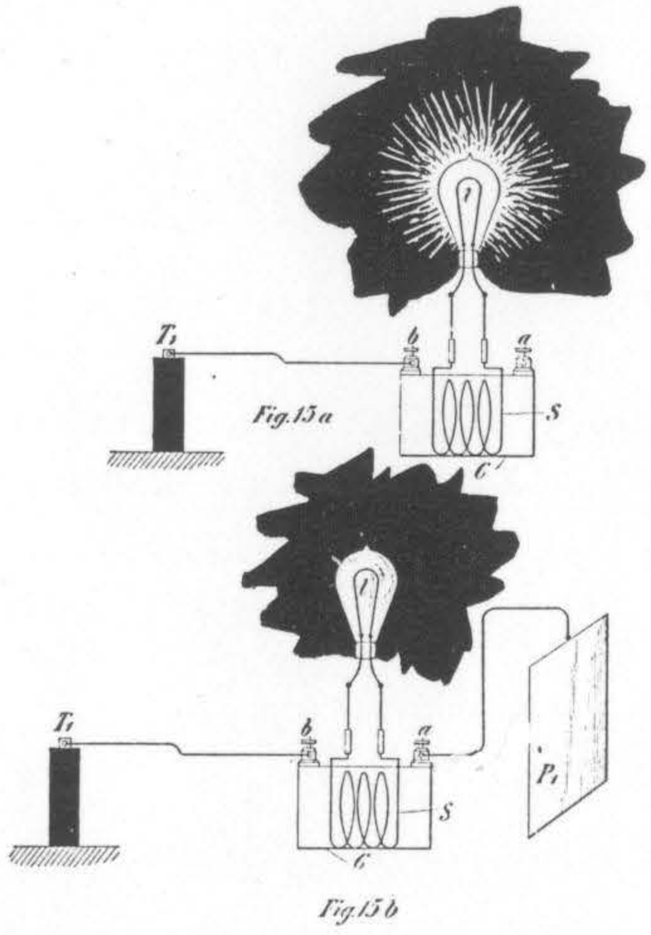
FIGS. 14*a*, 14*b*.—EFFECT OF ATTACHED PLATE WITH LOW FREQUENCIES.

when the secondary is closed, by warming the air in the bulb.

To demonstrate another interesting feature, I have adjusted the coils used in a certain way. I first connect both the terminals of the lamp to the secondary, one

end of the primary being connected to the terminal T_1 of the induction coil, and the other to the insulated plate P_1 as before. When the current is turned on, the lamp glows brightly, as shown in Fig. 14*b*, in which C is a fine wire coil and S a coarse wire secondary wound upon it. If the insulated plate P_1 is disconnected, leaving one of the ends *a* of the primary insulated, the filament becomes dark, or generally it diminishes in brightness (Fig. 14*a*). Connecting again the plate P_1, and raising the frequency of the current, I make the filament quite dark or barely red, Fig. 15*b*. Once more I will disconnect the plate. One will, of course, infer that when the plate is disconnected, the current through the primary will be weakened, that therefore the electromotive force will fall in the secondary S, and that the brightness of the lamp will diminish. This might be the case, and the result can be secured by an easy adjustment of the coils; also by varying the frequency and potential of the currents. But it is perhaps of greater interest to note that the lamp increases in brightness when the plate is disconnected (Fig. 15*a*). In this case all the energy the primary receives is now sunk into it, like the charge of a battery in an ocean cable, but most of that energy is recovered through the secondary and used to light the lamp. The current traversing the primary is strongest at the end *b*, which is connected to the terminal T_1 of the induction coil, and diminishes in strength towards the remote end *a*. But the dynamic inductive effect exerted upon the secondary S is now greater than before when the suspended plate was connected to the primary. These results might have been produced by a number of causes. For instance, the plate P_1 being connected, the reaction from the coil C may be such as to diminish the potential at the terminal T_1 of the induction coil, and therefore weaken the current through the primary

of the coil C. Or the disconnecting of the plate may diminish the capacity effect with relation to the primary of the latter coil to such an extent that the current through it is diminished, though the potential at the terminal T_1 of the induction coil may be the same,



FIGS. 15*a*, 15*b*.—EFFECT OF ATTACHED PLATE WITH HIGH FREQUENCIES.

or even higher. Or the result might have been produced by the change of phase of the primary and secondary currents and consequent reaction. But the chief determining factor is the relation of the self-induc-

tion and capacity of coil C and plate P_1, and the frequency of the currents. The greater brightness of the filament in Fig. 15*a*, is, however, in part due to the heating of the rarefied gas in the lamp by electrostatic induction, which, as before remarked, is greater when the suspended plate is disconnected.

Still another feature of some interest I may here bring to your attention. When the insulated plate is disconnected and the secondary of the coil opened, by approaching a small object to the secondary but very small sparks can be drawn from it, showing that the electrostatic induction is small in this case. But upon the secondary being closed upon itself or through the lamp, the filament glowing brightly, strong sparks are obtained from the secondary. The electrostatic induction is now much greater, because the closed secondary determines a greater flow of current through the primary, and principally through that half of it which is connected to the induction coil. If, now, the bulb be grasped with the hand, the capacity of the secondary with reference to the primary is augmented by the experimenter's body, and the luminosity of the filament is increased; the incandescence now being due partly to the flow of current through the filament, and partly to the molecular bombardment of the rarefied gas in the bulb.

The preceding experiments will have prepared one for the next following results of interest obtained in the course of these investigations. Since I can pass a current through an insulated wire by merely connecting one of its ends to the source of electrical energy; since I can induce by it another current, magnetize an iron core, and, in short, perform all operations as though a return circuit were used, clearly I can also drive a motor by the aid of only one wire. On a former occasion I have described a simple form of motor, comprising a single exciting

coil, an iron core and disc.

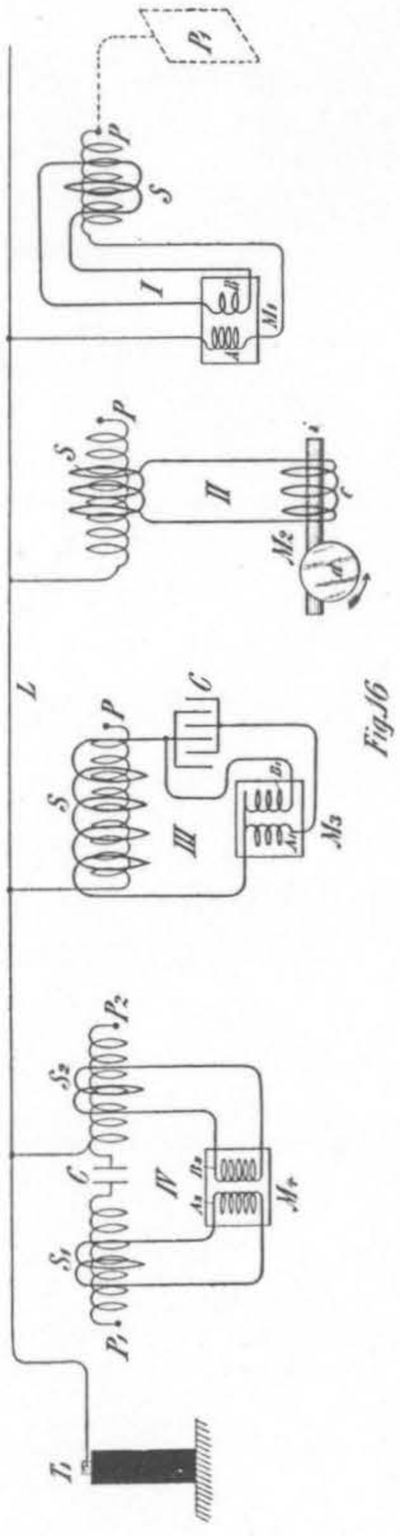


FIG. 16.—WAYS OF OPERATING MOTORS WITH ONLY ONE LEAD.

Fig. 16 illustrates a modified way of operating such an alternate current motor by currents induced in a transformer connected to one lead, and several other arrangements of circuits for operating a certain class of alternate motors founded on the action of currents of differing phase. In view of the present state of the art, it is thought sufficient to describe these arrangements in a few words only. In the diagram, Fig. 16 II shows a primary coil, P, connected with one of its ends to the line L, leading from a high tension transformer terminal, T_1. In inductive relation to this primary P is a secondary S, of coarse wire, in the circuit of which is a coil, *c*. The currents induced in the secondary energize the iron core *i*, which is preferably, but not necessarily, subdivided, and set the metal disc *d* in rotation. Such a motor, M_2, as diagrammatically shown in Fig. 16 II, has been called a "magnetic lag motor," but this expression may be objected to by those who attribute the rotation of the disc to eddy currents circulating in minute paths when the core *i* is finally subdivided. In order to operate such a motor effectively on the plan indicated, the frequencies should not be too high—not more than four or five thousand—though the rotation is produced even with ten thousand per second or more.

In Fig. 16 I, a motor M_1, having two energizing circuits, A and B, is diagrammatically indicated. The circuit A is connected to the line L, and in series with it is a primary P, which may have its free end connected to an insulated plate P_1, such connection being indicated by the dotted lines. The other motor circuit B is connected to the secondary S, which is in inductive relation to the primary P. When the transformer terminal T_1 is alternately electrified, currents traverse the open line L and also circuit A and primary P. The currents through the latter induce secondary currents in the circuit S, which pass through the energizing coil B of the motor. The currents through the secondary S and those through the primary P differ in phase ninety degrees, or nearly so, and are capable of rotating an armature placed in inductive relation to the circuits A and B.

In Fig. 16 III, a similar motor M_3, with two energizing circuits A_1 and B_1, is illustrated. A primary P, connected with one of its ends to the line L, has a secondary S, which is preferably wound for a tolerably high electromotive force, and to which the two energizing circuits of the motor are connected, one directly to the ends of the secondary and the other through a condenser C, by the action of which the currents traversing the circuit A_1 and B_1 are made to differ in phase.

In Fig. 16 IV, still another arrangement is shown.

In this case two primaries P_1 and P_2 are connected to the line L, one through a condenser C of small capacity, and the other directly. The primaries are provided with secondaries S_1 and S_2, which are in series with the energizing circuits A_2 and B_2 and a motor M_3, the condenser C again serving to produce the requisite difference in the phase of the currents traversing the motor circuits. As such phase motors with two or more circuits are now well known in the art, they have been here illustrated diagrammatically. No difficulty whatever is found in operating a motor in the manner indicated or in similar ways, and although such experiments up to this day present only scientific interest, they may at a period not far distant be carried out with practical objects in view.

It is thought useful to devote here a few remarks to the subject of operating devices of all kinds by means of only one leading wire. It is quite obvious that when high frequency currents are made use of, ground connections are—at least when the electromotive force of the currents is great—better than a return wire. Such ground connections are objectionable with steady or low frequency currents, on account of destructive chemical actions of the former, and disturbing influences exerted by both on the neighboring circuits; but with high frequencies these actions practically do not exist. Still, even ground connections become superfluous when the electromotive force is very high, for soon a condition is reached when the current may be passed more economically through open than through closed conductors. Remote as might seem an industrial application of such single wire transmission of energy to one not experienced in such lines of experiment, it will not seem so to anyone who for some time has carried on investigations of such nature. Indeed, I

cannot see why such a plan should not be practicable. Nor should it be thought that for carrying out such a plan currents of very high frequency are implicitly required, for just as soon as potentials of, say, 30,000 volts are used, the single wire transmission may be effected with low frequencies, and experiments have been made by me from which these inferences are made.

When the frequencies are very high, it has been found in laboratory practice quite easy to regulate the effects in the manner shown in diagram, Fig. 17. Here two primaries, P and P_1, are shown, each connected with

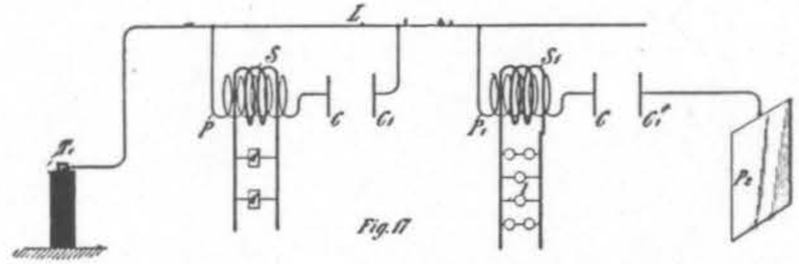


FIG. 17.—SINGLE WIRE CONVERSION AND DISTRIBUTION, WITH SIMPLE MEANS FOR REGULATING THE EFFECTS.

one of its ends to the line L, and with the other end to the condenser plates C and C^1, respectively. Near these are placed other condenser plates, C_1 C^1_1, the former being connected to the line L and the latter to an insulated larger plate P_2. On the primaries are wound secondaries S and S_1 of coarse wire, connected to the devices *m* and *d* respectively. By varying the distances of the condenser plates C and C^1, and C_1 and C_1^1, the currents through the secondaries S and S_1 are varied in intensity. The curious feature is the great sensitiveness, the slightest change in the distance of the plates

producing considerable variations in the intensity or strength of the currents. The sensitiveness may be rendered extreme by making the frequency such that the primary itself, without any plate attached to its free end, satisfies, in conjunction with the closed secondary, the condition of resonance. In such condition an extremely small change in the capacity of the free terminal produces great variations. For instance, I have been able to adjust the conditions so that the mere approach of a person to the coil produces a considerable change in the brightness of the lamps attached to the secondary. Such observations and experiments possess, of course, at present chiefly scientific interest, but they may soon become of practical importance.

Very high frequencies are, of course, not practicable with motors, on account of the necessity of employing iron cores. But one may use sudden discharges of low frequency, and thus obtain certain advantages of high frequency currents without rendering the iron core entirely incapable of following the changes, and without entailing a very great expenditure of energy in the core. I have found it quite practicable to operate with such low frequency disruptive discharges of condensers alternating current motors. A certain class of such motors which I advanced a few years ago, which contain closed secondary circuits, will rotate quite vigorously when the discharges are directed through the exciting coils. One reason that such a motor operates so well with these discharges is that the difference of phase between the primary and secondary currents is ninety degrees, which is generally not the case with harmonically rising and falling currents of low frequency. It might not be without interest to show an experiment with a simple motor of this kind, inasmuch as it is commonly thought that

disruptive discharges are unsuitable for such purposes. The motor is illustrated in Fig. 18. It comprises a rather large iron core *i*, with slots on the top into which are embedded thick copper washers *c c*. In proximity to the core is a freely movable metal disc D. The core is provided with a primary exciting coil C, the ends *a* and *b* of which are connected to the terminals of the secondary S of an ordinary transformer, the primary P of the latter being connected to an alternating distribution circuit or generator G of low or moderate frequency. The terminals of the secondary S are attached to a condenser C, which discharges through

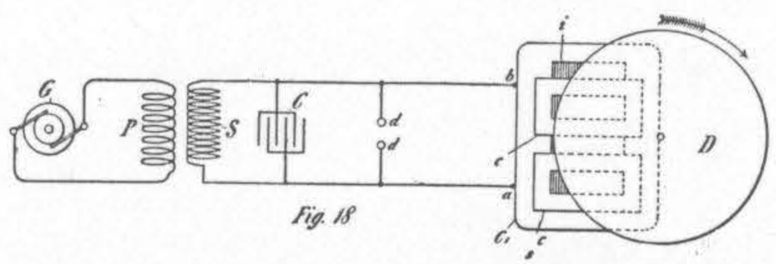
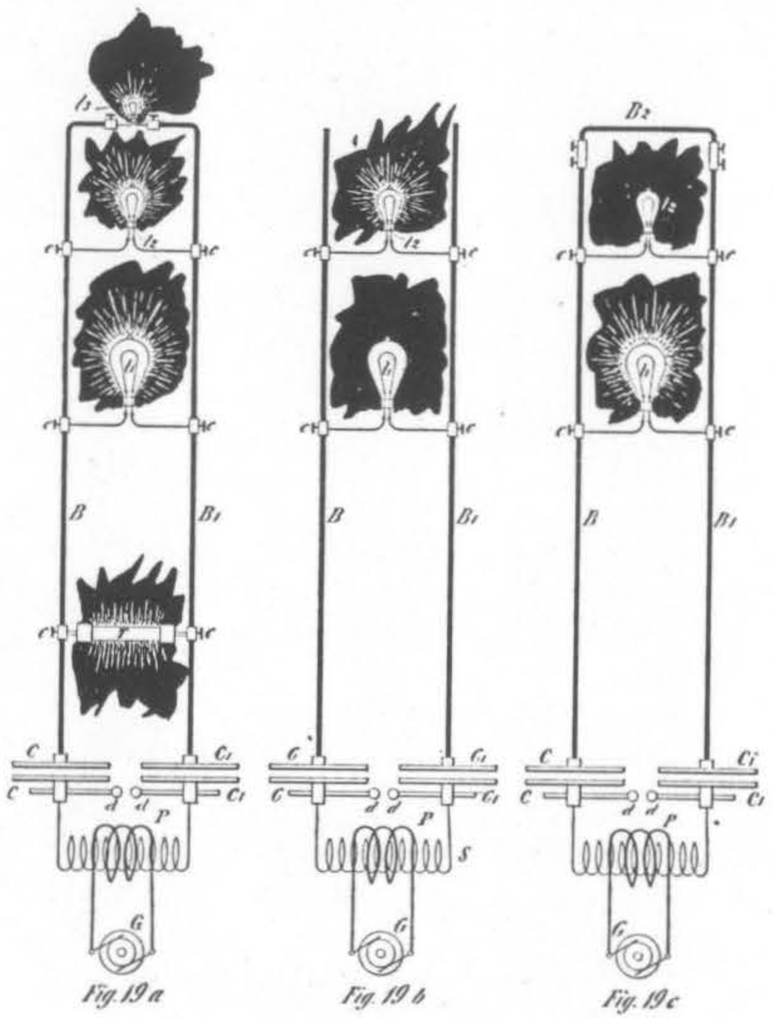


FIG. 18.—OPERATING A MOTOR BY DISRUPTIVE DISCHARGES.

an air gap *d d*, which may be placed in series or shunt to the coil C. When the conditions are properly chosen the disc D rotates with considerable effort, and the iron core *i* does not get very perceptibly hot. With currents from a high frequency alternator, on the contrary, the core gets rapidly hot, and the disc rotates with a much smaller effort. To perform the experiment properly it should be first ascertained that the disc D is not set in rotation when the discharge is not occurring at *d d*. It is preferable to use a large iron core and a condenser of large capacity, so as to bring

the superimposed quicker oscillation to a very low pitch, or to do away with it entirely. By observing certain elementary rules I have also found it practicable to operate ordinary series or shunt direct current motors with such disruptive discharges, and this can be done with or without a return wire.



FIGS. 19*a*, 19*b*, 19*c*.—IMPEDANCE PHENOMENA.

Among the various current phenomena observed, perhaps the most interesting are those of impedance presented by conductors to currents varying at a rapid rate. In my first paper before the American Institute

of Electrical Engineers I have described a few striking observations of this kind. Thus I showed that when such currents or sudden discharges are passed through a thick metal bar, there may be points at the bar only a few inches apart which have a sufficient potential difference between them to maintain at bright incandescence an ordinary filament lamp. I have also ascribed the curious behavior of rarefied gas surrounding a conductor to such sudden rushes of current. These phenomena have been since more carefully studied, and one or two novel experiments of this kind are deemed of sufficient interest to be described here.

With reference to Fig. 19*a*, B and B_1 are very stout copper bars connected at their lower ends to plates C and C_1, respectively, of a condenser, the opposite plates of the latter being connected to the terminals of the secondary S of a high tension transformer, the primary P of which is supplied with alternating currents from an ordinary low frequency dynamo, G, or distribution circuit. The condenser discharges through an adjustable gap, *d d*, as usual. By establishing a rapid vibration it was found quite easy to perform the following curious experiment: The bars B and B_1 were joined at the top by a low voltage lamp, l_3; a little lower was placed by means of clamps, *c c*, a fifty-volt lamp, l_2, and still lower another hundred-volt lamp, l_1, and, finally, at a certain distance below the latter lamp an exhausted tube, T. By carefully determining the positions of these devices it was found practicable to maintain them all at their proper illuminating power. Yet they were all connected in multiple arc to the two stout copper bars, and required widely different pressures. This experiment requires, of course, some time for adjustment, but is quite easily performed.

In Figs. 19*b* and 19*c*, two other experiments are illustrated which, unlike the previous experiment, do not

require very careful adjustments. In Fig. 20*b* two lamps, l_1 and l_2, the former a hundred-volt and the latter a fifty-volt, are placed in certain positions, as indicated, the hundred-volt lamp being below the fifty-volt lamp. When the arc is playing at *d d*, and the sudden discharges passed through the bars B B, the fifty-volt lamp will, as a rule, burn brightly, or, at least, this result is easily secured, while the hundred-volt lamp will burn very low or remain quite dark, Fig. 19*b*. Now, the bars B B may be joined at the top by a thick cross-bar B_2, and it is quite easy to maintain the hundred-volt lamp at full candle power, while the fifty-volt lamp remains dark,

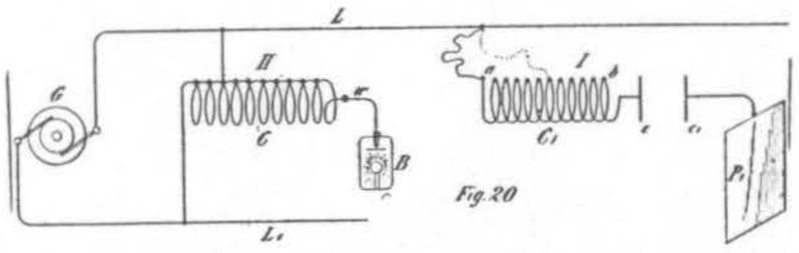


FIG. 20.—PLAN FOLLOWED IN OBSERVING THE EFFECTS OF RESONANCE.

Fig. 19*c*. These results, as I have pointed out previously, should not be considered to be due exactly to frequency, but rather to the time rate of change, which may be great even with low frequencies. A great many other results of the same kind, equally interesting, especially to those who are only used to manipulating steady currents, may be obtained, and they afford precious clues in investigating the nature of electric currents.

In the preceding experiments I have already had occasion to show some light phenomena, and it would be now proper to study these in particular; but to make this investigation more complete, I think it necessary to first make a few remarks on the subject of electrical resonance, which has to be always observed in carrying out these experiments.

ON ELECTRICAL RESONANCE.

The effects of resonance are being more and more noted by engineers, and are becoming of great importance in the practical operation of apparatus of all kinds with alternating currents. A few general remarks may, therefore, be made concerning these effects. It is clear that if we succeed in employing the effects of resonance practically in the operation of electric devices, the return wire will, as a matter of course, become unnecessary, for the electric vibration may be conveyed with one wire just as well as, and sometimes even better than, with two. The question first to answer is, then, whether pure resonance effects are producible. Theory and experiment both show that such is impossible in Nature, for as the oscillation becomes more and more vigorous, the losses in the vibrating bodies and environing media rapidly increase, and necessarily check the vibration, which otherwise would go on increasing forever. It is a fortunate circumstance that pure resonance is not producible, for if it were there is no telling what dangers might not lie in wait for the innocent experimenter. But, to a certain degree, resonance is producible, the magnitude of the effects being limited by the imperfect conductivity and imperfect elasticity of the media, or, generally stated, by frictional losses. The smaller these losses, the more striking are the effects. The same is the case in mechanical vibration. A stout steel bar may be set in vibration by drops of water falling upon it at proper intervals; and with glass, which is more perfectly elastic, the resonance effect is still more remarkable, for

a goblet may be burst by singing into it a note of the proper pitch. The electrical resonance is the more perfectly attained, the smaller the resistance or the impedance of the conducting path, and the more perfect the dielectric. In a Leyden jar discharging through a short stranded cable of thin wires, these requirements are probably best fulfilled, and the resonance effects are, therefore, very prominent. Such is not the case with dynamo machines, transformers and their circuits, or with commercial apparatus in general, in which the presence of iron cores complicates or renders impossible the action. In regard to Leyden jars, with which resonance effects are frequently demonstrated, I would say that the effects observed are often *attributed*, but are seldom *due*, to true resonance, for an error is quite easily made in this respect. This may be undoubtedly demonstrated by the following experiment: Take, for instance, two large insulated metallic plates or spheres, which I shall designate A and B; place them at a certain small distance apart, and charge them from a frictional or influence machine to a potential so high that just a slight increase of the difference of potential between them will cause the small air or insulating space to break down. This is easily reached by making a few preliminary trials. If, now, another plate—fastened on an insulating handle and connected by a wire to one of the terminals of a high tension secondary of an induction coil, which is maintained in action by an alternator (preferably high frequency)—is approached to one of the charged bodies A or B, so as to be nearer to either one of them, the discharge will invariably occur between them; at least, it will if the potential of the coil in connection with the plate is sufficiently high. But the explanation of this will soon be found in the fact that the approached plate acts inductively upon the bodies A and B, and causes a

spark to pass between them. When this spark occurs, the charges which were previously imparted to these bodies from the influence machine must needs be lost, since the bodies are brought in electrical connection through the arc formed. Now, this arc is formed whether there be resonance or not. But even if the spark would not be produced, still there is an alternating electromotive force set up between the bodies when the plate is brought near one of them; therefore, the approach of the plate, if it *does* not always actually, will, at any rate, *tend* to break down the air space by inductive action. Instead of the spheres or plates A and B, we may take the coatings of a Leyden jar with the same result; and in place of the machine, which is a high frequency alternator preferably, because it is more suitable for the experiment and also for the argument, we may take another Leyden jar or battery of jars. When such jars are discharging through a circuit of low resistance, the same is traversed by currents of very high frequency. The plate may now be connected to one of the coatings of the second jar, and when it is brought near to the first jar just previously charged to a high potential from an influence machine, the result is the same as before, and the first jar will discharge through a small air space upon the second being caused to discharge. But both jars and their circuits need not be tuned any closer than a basso profundo is to the note produced by a mosquito, as small sparks will be produced through the air space, or, at least, the latter will be considerably more strained, owing to the setting up of an alternating electromotive force by induction, which takes place when one of the jars begins to discharge. Again, another error of a similar nature is quite easily made. If the circuits of the two jars are run parallel and close together, and

the experiment has been performed of discharging one by the other, and now a coil of wire be added to one of the circuits, whereupon the experiment does not succeed, the conclusion that this is due to the fact that the circuits are now not tuned would be far from being safe; for the two circuits act as condenser coatings, and the addition of the coil to one of them is equivalent to bridging them, at the point where the coil is placed, by a small condenser, and the effect of the latter might be to prevent the spark from jumping through the discharge space by diminishing the alternating electromotive force acting across the same. All these remarks, and many more which might be added but for fear of wandering too far from the subject, are made with the pardonable intention of cautioning the unsuspecting student, who might gain an entirely unwarranted opinion of his skill when seeing every experiment succeed; but they are in no way thrust upon the experienced as novel observations.

In order to make reliable observations of electric resonance effects, it is very desirable, if not necessary, to employ an alternator giving currents which rise and fall harmonically, as in working with make-and-break currents the observations are not always trustworthy, since many phenomena which depend on the rate of change may be produced with frequencies widely different. Even when making such observations with an alternator one is apt to be mistaken. When a circuit is connected to an alternator there are an infinite number of values for capacity and self-induction which, in conjunction, will satisfy the condition of resonance. So there are in mechanics an infinite number of tuning-forks which will respond to a note of a certain pitch, or loaded springs which have a definite period of vibration. But the resonance will be most perfectly attained in that case in

which the motion is effected with the greatest freedom. Now, in mechanics, considering the vibration in the common medium—that is, air—it is of comparatively little importance whether one tuning-fork be somewhat larger than another, because the losses in the air are not very considerable. One may, of course, enclose a tuning-fork in an exhausted vessel, and by thus reducing the air resistance to a minimum obtain better resonant action. Still, the difference would not be very great. But it would make a great difference if the tuning-fork were immersed in mercury. In the electrical vibration it is of enormous importance to arrange the conditions so that the vibration is effected with the greatest freedom. The magnitude of the resonance effect depends, under otherwise equal conditions, on the quantity of electricity set in motion, or on the strength of the current driven through the circuit. But the circuit opposes the passage of the currents by reason of its impedance and, therefore, to secure the best action, it is necessary to reduce the impedance to a minimum. It is impossible to overcome it entirely, but merely in part, for ohmic resistance cannot be overcome. But when the frequency of the impulses is very great, the flow of the current is practically determined by self-induction. Now, self-induction can be overcome by combining it with capacity. If the relation between these is such that at the frequency used they annul each other—that is, have such values as to satisfy the condition of resonance—and the greatest quantity of electricity is made to flow through the external circuit, then the best result is obtained. It is simpler and safer to join the condenser in series with the self-induction. It is clear that in such combinations there will be, for a given frequency, and considering only the fundamental vibration, values which will give the best result with the condenser in shunt to the self-

induction coil; of course, more such values than with the condenser in series. But practical conditions determine the selection. In the latter case, in performing the experiments, one may take a small self-induction and a large capacity, or a small capacity and a large self-induction; but the latter is preferable, because it is inconvenient to adjust a large capacity by small steps. By taking a coil with a very large self-induction, the critical capacity is reduced to a very small value, and the capacity of the coil itself may be sufficient. It is easy, especially by observing certain artifices, to wind a coil through which the impedance will be reduced to the value of the ohmic resistance only; and for any coil there is, of course, a frequency at which the maximum current will be made to pass through the coil. The observation of the relation between self-induction, capacity and frequency is becoming important in the operation of alternate current apparatus, such as transformers or motors, because by a judicious determination of the elements the employment of an expensive condenser becomes unnecessary. Thus it is possible to pass through the coils of an alternating current motor, under the normal working conditions, the required current with a low electromotive force, and do away entirely with the false current, and the larger the motor the easier such a plan becomes practicable; but it is necessary for this to employ currents of very high potential or high frequency.

In Fig. 20 I, is shown a plan which has been followed in the study of the resonance effects by means of a high frequency alternator. C is a coil of many turns, which is divided in small separate sections for the purposes of adjustment. The final adjustment was made sometimes with a few thin iron wires (though this is not always advisable), or with a closed secondary. The coil C is connected with one of its ends to the

line L from the alternator G, and with the other end to one of the plates c of a condenser $c\,c_1$, the plate (c_1) of the latter being connected to a much larger plate P_1. In this manner, both capacity and self-induction were adjusted to suit the dynamo frequency.

As regards the rise of potential through resonant action, of course, theoretically, it may amount to anything, since it depends on self-induction and resistance, and since these may have any value. But in practice one is limited in the selection of these values, and, besides these, there are other limiting causes. One may start with, say, 1,000 volts, and raise the electromotive force to fifty times that value, but one cannot start with 100,000 and raise it to ten times that value, because of the losses in the media, which are great, especially if the frequency is high. It should be possible to start with, for instance, two volts from a high or low frequency circuit of a dynamo, and raise the electromotive force to many hundred times that value. Thus coils of the proper dimensions might be connected each with only one of its ends to the mains from a machine of low electromotive force, and though the circuit of the machine would not be closed, in the ordinary acceptance of the term, yet the machine might be burned out if a proper resonance effect would be obtained. I have not been able to produce, nor have I observed with currents from the dynamo machine, such great rises of potential. It is possible, if not probable, that with currents obtained from apparatus containing iron, the disturbing influence of the latter is the cause that these theoretical possibilities cannot be realized. But if such is the case, I attribute it solely to the hysteresis and Faucault current losses in the core. Generally, it was necessary to transform upward, when the electromotive force was very low, and an ordinary form of induction coil was

usually employed; but sometimes the arrangement illustrated in Fig. 20 II has been found to be convenient. In this case, a coil C is made in a great many sections, a few of these being used as the primary. In this manner, both primary and secondary are adjustable. One end of the coil is connected to the line L_1 from the alternator, and the other line L is connected to the intermediate point of the coil. Such a coil, with adjustable primary and secondary, will be found also convenient in experiments with the disruptive discharge. When true resonance is obtained, the top of the wave must, of course, be on the free end of the coil, as, for instance, at the terminal of the phosphorescence bulb B. This is easily recognized by observing the potential of a point on the wire *w* near to the coil.

In connection with resonance effects and the problems of transmission of energy over a single conductor, which was previously considered, I would say a few words on a subject which constantly fills my thoughts, and which concerns the welfare of all. I mean the transmission of intelligible signals, or, perhaps, even power, to any distance without the use of wires. I am becoming daily more convinced of the practicability of the scheme; and though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realized, yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day. The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical

investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb, by means of powerful machines, the electrostatic condition of the earth, and thus transmit intelligible signals, and, perhaps, power. In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why, then, not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile-posts, the earth may appear very large; but to that happiest of all men, the astronomer, who gazes at the heavens, and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician; for when he considers the speed with which an electric disturbance is propagated through the earth, all his ideas of distance must completely vanish.

A point of great importance would be first to know what is the capacity of the earth, and what charge does it contain if electrified. Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation. If it be a charged body insulated in space, its capacity should be extremely small—less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incom-

parably greater. In any case, it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator or a source of alternating electric currents. One of the terminals of the source would be connected to earth, as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata or free space contains an opposite charge, and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low, and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible, and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents, and carefully observing the potential of the insulated body, and watching for the disturbance at various neighboring points of the earth's surface, resonance might be detected. Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do, and a proper electrical oscillator would have to be produced, and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period

of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface.

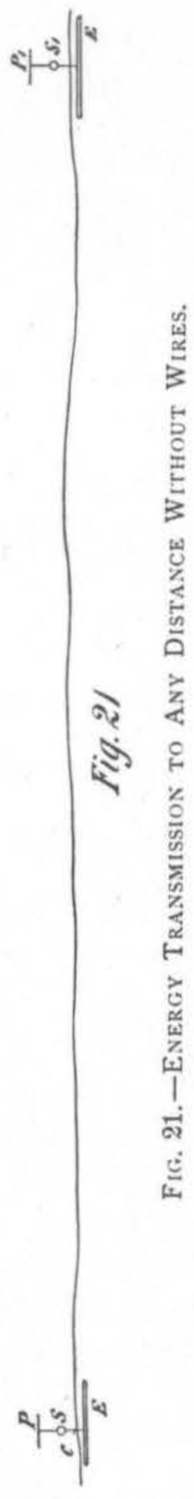


Fig. 21.—Energy Transmission to Any Distance Without Wires.

Assume that a source of alternating currents, s, be connected, as in Fig. 21, with one of its terminals to earth (convenient to the water mains), and with the other to a body of large surface, P. When the electric oscillation is set up, there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to or diverging from the point C, where the ground connection is made. In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body P is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source, s, will set up the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration, at least of a certain low period, upon the earth by means of proper machinery. At what distance such a vibration might

be made perceptible can only be conjectured. I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at the surface could be but extremely small, considering the size of the earth, the air would not act as a very disturbing factor, and there would be not much energy lost through the action of the air, which would be the case if the density were great. Theoretically, then, it could not require a great amount of energy to produce a disturbance perceptible at great distance, or even all over the surface of the globe. Now, it is quite certain that at any point within a certain radius of the source, s, a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source, s_1, Fig. 21, similar to s, or any number of such sources, can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source s_1, if the same be of opposite phase to the source s. I think that, beyond doubt, it is possible to operate electrical devices in a city, through the ground or pipe system, by resonance from an electrical oscillator located at a central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realization of the scheme of transmitting intelligence, or, perhaps, power, to any distance through the earth or environing medium. If this is at all possible, distance does not mean anything. Proper apparatus must first be produced, by means of which the problem can be attacked, and I have devoted much thought to this subject. I am firmly convinced that it can be done, and hope that we shall live to see it done.

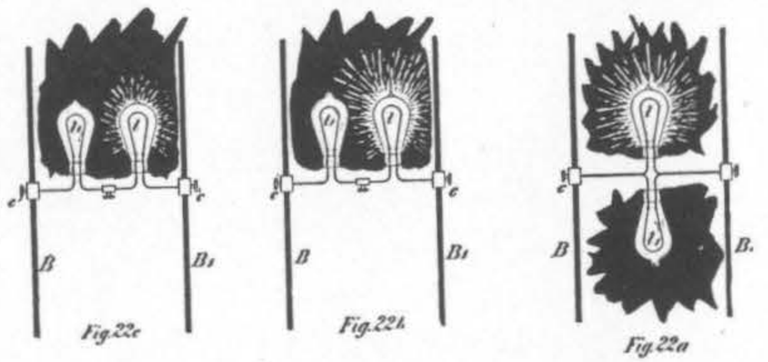
ON THE LIGHT PHENOMENA PRODUCED BY HIGH FREQUENCY CURRENTS OF HIGH POTENTIAL, AND GENERAL REMARKS RELATING TO THE SUBJECT.

Returning now to the light effects, which it has been the chief object to investigate, it is thought proper to divide these effects into four classes: 1. Incandescence of a solid. 2. Phosphorescence. 3. Incandescence or phosphorescence of a rarefied gas; and, 4. Luminosity produced in a gas at ordinary pressure. The first question is, How are these luminous effects produced? In order to answer this question as satisfactorily as I am able to do in the light of accepted views, and with the experience acquired, and to add some interest to this demonstration, I shall dwell here upon a feature which I consider of great importance, inasmuch as it promises, besides, to throw a better light upon the nature of most of the phenomena produced by high frequency electric currents. I have on other occasions pointed out the great importance of the presence of the rarefied gas, or atomic medium in general, around the conductor through which alternate currents of high frequency are passed, as regards the heating of the conductor by the currents. My experiments described some time ago have shown that the higher the frequency and potential difference of the currents, the more important becomes the rarefied gas in which the conductor is immersed, as a factor of the heating. The potential difference, however, is, as I then pointed out, a more important element than the frequency. When both of these are sufficiently high, the heating may be almost entirely due to the presence of the rarefied gas. The experiments to follow will show the importance of the rarefied gas, or generally of gas at ordinary or other pressure, as regards the incandescence or other luminous effects produced by currents of this kind.

I take two ordinary fifty-volt sixteen candle power lamps which are in every respect alike, with the exception that one has been opened at the top and the air has filled the bulb, while the other is at the ordinary degree of exhaustion of commercial lamps. When I attach the lamp which is exhausted to the terminal of the secondary of the coil, which I have already used, as in experiments illustrated in Fig. 15*a*, for instance, and turn on the current, the filament, as you have before seen, comes to high incandescence. When I attach the second lamp, which is filled with air, instead of the former, the filament still glows, but much less brightly. This experiment illustrates only in part the truth of the statements before made. The importance of the filament's being immersed in rarefied gas is plainly noticeable, but not to such a degree as might be desirable. The reason is that the secondary of this coil is wound for low tension, having only 150 turns, and the potential difference at the terminals of the lamp is therefore small. Were I to take another coil with many more turns in the secondary, the effect would be increased, since it depends partially on the potential difference, as before remarked. But since the effect likewise depends on the frequency, it may be properly stated that it depends on the time rate of the variation of the potential difference. The greater this variation, the more important becomes the gas as an element of heating. I can produce a much greater rate of variation in another way, which, besides, has the advantage of doing away with the objections which might be made in the experiment just shown, even if both the lamps were connected in series or multiple arc to the coil, namely, that in consequence of the reactions existing between the primary and secondary coil, the conclusions are rendered uncertain.

This result I secure by charging from an ordinary transformer, which is fed from the alternating current supply station, a battery of condensers, and discharging the latter directly through a circuit of small self-induction, as before illustrated in Figs. 19*a*, 19*b*, 19*c*.

In Figs. 22*a*, 22*b* and 22*c*, the heavy copper bars B B_1, are connected to the opposite coatings of a battery of condensers, or generally in such way that the high frequency or sudden discharges are made to traverse them. I connect first an ordinary fifty-volt incandescent lamp to the bars by means of the clamps *c c*. The dis-



FIGS. 22*a*, 22*b*, 22*c*.—SHOWING THE EFFECT OF THE PRESENCE OF A GASEOUS MEDIUM.

charges being passed through the lamp, the filament is rendered incandescent, though the current through it is very small, and would not be nearly sufficient to produce a visible effect under the conditions of ordinary use of the lamp. Instead of this I now attach to the bars another lamp exactly like the first, but with the seal broken off, the bulb being therefore filled with air at ordinary pressure. When the discharges are directed through the filament, as before, it does not become incandescent. But the result might still be attributed to one of the

many possible reactions. I therefore connect both the lamps in multiple arc, as illustrated in Fig. 22*a*. Passing the discharges through both the lamps, again the filament in the exhausted lamp l glows very brightly, while that in the non-exhausted lamp l_1 remains dark, as previously. But it should not be thought that the latter lamp is taking only a small fraction of the energy supplied to both the lamps; on the contrary, it may consume a considerable portion of the energy, and it may become even hotter than the one which burns brightly. In this experiment the potential difference at the terminals of the lamp varies in sign, theoretically, three to four million times a second. The ends of the filaments are correspondingly electrified, and the gas in the bulbs is violently agitated, and a large portion of the supplied energy is thus converted into heat. In the non-exhausted bulb there being a few million times more gas molecules than in the exhausted one, the bombardment, which is most violent at the ends of the filament, in the neck of the bulb, consumes a large portion of the energy without producing any visible effect. The reason is that, there being many molecules, the bombardment is quantitatively considerable, but the individual impacts are not very violent, as the speeds of the molecules are comparatively small, owing to the small free path. In the exhausted bulb, on the contrary, the speeds are very great and the individual impacts are violent, and, therefore, better adapted to produce a visible effect. Besides, the convection of heat is greater in the former bulb. In both the bulbs the current traversing the filaments is very small, incomparably smaller than that which they require on an ordinary low frequency circuit. The potential difference, however, at the ends of the filaments is very great, and might be possibly 20,000 volts, or more, if the filaments were

straight and their ends far apart. In the ordinary lamp a spark generally occurs between the ends of the filament, or between the platinum wires outside, before such a difference of potential can be reached.

It might be objected, in the experiment before shown, that the lamps being in multiple arc, the exhausted lamp might take a much larger current, and that the effect observed might not be exactly attributable to the action of the gas in the bulbs. Such objections will lose much weight if I connect the lamps in series with the same result. When this is done and the discharges are directed through the filaments, it is again noted that the filament in the non-exhausted bulb l_1 remains dark, while that in the exhausted one (l) glows even more intensely than under its normal conditions of working, Fig. 22*b*. According to general ideas, the current through the filaments should now be the same, were it not modified by the presence of the gas around the filaments.

At this juncture I may point out another interesting feature which illustrates the effect of the rate of change of potential of the currents. I will leave the two lamps connected in series to the bars B, B_1 as in the previous experiment, Fig. 22*b*, but will presently reduce considerably the frequency of the currents, which was excessive in the experiment just before shown. This I may do by inserting a self-induction coil in the path of the discharges, or by augmenting the capacity of the condensers. When I now pass these low-frequency discharges through the lamps, the exhausted lamp l again is as bright as before, but it is noted also that the non-exhausted lamp l_1 glows, though not quite as intensely as the other. Reducing the current through the lamps, I may bring the filament in the latter lamp to redness, and, though the filament in the exhausted

lamp *l* is bright, Fig. 22*c*, the degree of its incandescence is much smaller than in Fig. 22*b*, when the currents were of a much higher frequency.

In these experiments the gas acts in two opposite ways in determining the degree of the incandescence of the filaments; that is, by convection and by bombardment. The higher the frequency and potential of the currents, the more important becomes the bombardment. The convection, on the contrary, should be the smaller, the higher the frequency. When the currents are steady there is practically no bombardment, and convection may, therefore, with such currents, also considerably modify the degree of incandescence, and produce results similar to those just before shown. Thus, if two lamps, exactly alike, one exhausted and one not exhausted, are connected in multiple arc or series to a direct current machine, the filament in the non-exhausted lamp will require a considerably greater current to be rendered incandescent. This result is entirely due to convection, and the effect is the more prominent the thinner the filament. Professor Ayrton and Mr. Kilgour some time ago published quantitative results concerning the thermal emissivity by radiation and convection, in which the effect of thin wires were clearly shown. This effect may be strikingly illustrated by preparing a number of small short glass tubes, each containing through its axis the thinnest obtainable platinum wire. If these tubes be highly exhausted, a number of them may be connected in multiple arc to a direct current machine, and all of the wires may be kept at incandescence with a smaller current than that required to render incandescent a single one of the wires if the tube be not exhausted. Could the tubes be so highly exhausted that convection would be *nil*, then the relative amounts of heat given off by convection and radiation could be determined without

the difficulties attending thermal quantitative measurements. If a source of electric impulses of high frequency and very high potential is employed, a still greater number of the tubes may be taken, and the wires rendered incandescent by a current not capable of warming perceptibly a wire of the same size immersed in air at ordinary pressure, and conveying the energy to all of them.

I may here describe a result which is still more interesting, and to which I have been led by the observation of these phenomena. I noted that small differences in the density of the air produced a considerable difference in the degree of incandescence of the wires, and I thought that, since in a tube through which a luminous discharge is passed the gas is generally not of uniform density, a very thin wire contained in the tube might be rendered incandescent at certain places of smaller density of the gas, while it would remain dark at the places of greater density, where the convection would be greater and the bombardment less intense. Accordingly, a tube, *t*, was prepared, as illustrated in Fig. 23, which contained through the middle a very fine platinum wire, *w*. The tube was exhausted to a moderate degree, and it was found that when it was attached to the terminal of a high frequency coil the platinum wire *w* would indeed become incandescent in patches, as illustrated in Fig. 23. Later a number of these tubes with one or more wires were prepared, each showing this result. The effect was best noted when the striated discharge occurred in the tube, but was also produced when the striæ were not visible, showing that even then the gas in the tube was not of uniform density. The position of the striæ was generally such that the rarefactions corresponded to the places of incandescence or greater brightness on the wire *w*. But in a few instances it was noted that the bright

spots on the wire were covered by the dense parts of the striated discharge, as indicated by *l* in Fig. 23, though the effect was barely perceptible. This was explained in a plausible way by assuming that the convection was not widely different in the dense and rarefied places, and that the bombardment was greater on the dense places of the

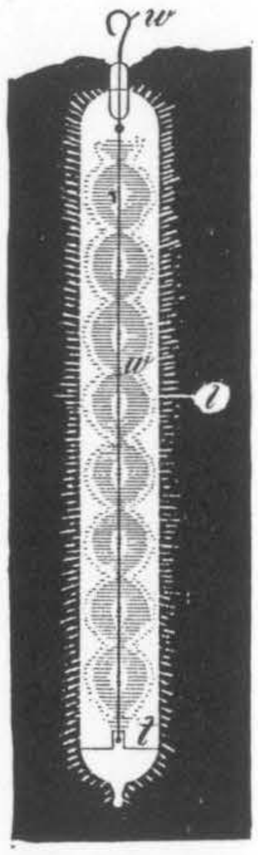


FIG. 23.—CURIOUS INCANDESCENCE OF A WIRE.

striated discharge. It is, in fact, often observed in bulbs that under certain conditions a thin wire is brought to higher incandescence when the air is not too highly rarefied. This is the case when the potential of the coil is not high enough for the vacuum; but the result may be attributed to many different causes. In all cases this

curious phenomenon of incandescence disappears when the tube, or, rather, the wire, acquires throughout a uniform temperature.

Disregarding, now, the modifying effect of convection, there are, then, two distinct causes which determine the incandescence of a wire or filament with varying currents, that is, conduction current and bombardment. With steady currents we have to deal only with the former of these two causes, and the heating effect is a minimum, since the resistance is least to steady flow. When the current is a varying one, the resistance is greater, and hence the heating effect is increased. Thus, if the rate of change of the current is very great, the resistance may increase to such an extent that the filament is brought to incandescence with inappreciable currents, and we are able to take a short and thick block of carbon or other material and bring it to bright incandescence with a current incomparably smaller than that required to bring to the same degree of incandescence an ordinary thin lamp filament with a steady or low frequency current. This result is important, and illustrates how rapidly our views on these subjects are changing, and how quickly our field of knowledge is extending. In the art of incandescent lighting, to view this result in one aspect only, it has been commonly considered as an essential requirement for practical success, that the lamp filament should be thin and of high resistance. But now we know that the resistance to the steady flow of the filament does not mean anything; the filament might as well be short and thick; for if it be immersed in rarefied gas it will become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents. We may conclude from this that it would be of advantage, so far as the lamp is considered, to

employ high frequencies for lighting, as they allow the use of short and thick filaments and smaller currents.

If a wire or filament be immersed in a homogeneous medium, all the heating is due to true conduction current; but if it be enclosed in an exhausted vessel, the conditions are entirely different. Here the gas begins to act, and the heating effect of the conduction current, as is shown in many experiments, may be very small compared with that of the bombardment. This is especially the case if the circuit is not closed and the potentials, of course, very high. Suppose a fine filament enclosed in an exhausted vessel be connected with one of its ends to the terminal of a high tension coil and with its other end to a large insulated plate. Though the circuit is not closed, the filament, as I have before shown, is brought to incandescence. If the frequency and potential be comparatively low, the filament is heated by the current passing *through* it. If the frequency and potential, and principally the latter, be increased, the insulated plate need be but very small, or may be done away with entirely, still the filament will become incandescent, practically all the heating being then due to the bombardment. A practical way of combining both the effects of conduction current and bombardment is illustrated in Fig. 24, in which an ordinary lamp is shown provided with a very thin filament, which has one of the ends of the latter connected to a shade serving the purpose of the insulated plate, and the other end to the terminal of a high tension source. It should not be thought that only rarefied gas is an important factor in the heating of a conductor by varying currents, but gas at ordinary pressure may become important, if the potential difference and frequency of the currents is excessive. On this subject I have already stated that when a conductor is fused by a stroke of

lightning, the current through it may be exceedingly small, not even sufficient to heat the conductor perceptibly were the latter immersed in a homogeneous medium.

From the preceding it is elear that when a conductor of high resistance is connected to the terminals of a

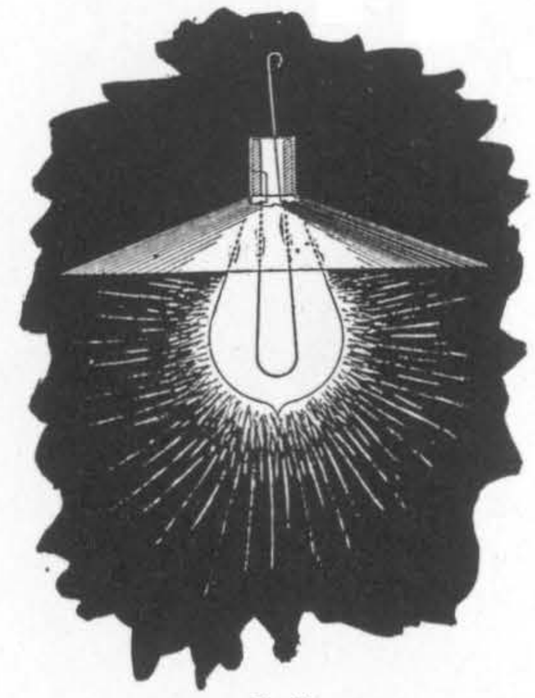


Fig. 24

FIG. 24.—UTILIZING THE HEATING EFFECT OF CONDUCTION CURRENT AND BOMBARDMENT.

source of high frequency currents of high potential, there may occur considerable dissipation of energy, principally on the ends of the conductor, in consequence of the action of the gas surrounding the conductor. Owing to this, the current through a section of the conductor at a point midway between its ends may be

much smaller than through a section near the ends. Furthermore, the current passes principally through the outer portions of the conductor, but this effect is to be distinguished from the skin effect as ordinarily interpreted, for the latter would or should occur also in a continuous incompressible medium. If a great many incandescent lamps are connected in series to a source of such currents, the lamps at the ends may burn brightly, whereas those in the middle may remain entirely dark. This is due principally to bombardment, as before stated. But even if the currents be steady, provided the difference of potential is very great, the lamps at the ends will burn more brightly than those in the middle. In such case, there is no rhythmical bombardment and the result is produced entirely by leakage. This leakage, or dissipation into space when the tension is high, is considerable when incandescent lamps are used, and still more considerable with arcs, for the latter act like flames. Generally, of course, the dissipation is much smaller with steady than with varying currents.

I have contrived an experiment which illustrates in an interesting manner the effect of lateral diffusion. If a very long tube is attached to the terminal of a high frequency coil, the luminosity is greatest near the terminal, and falls off gradually towards the remote end. This is more marked if the tube is narrow.

A small tube, about one-half inch in diameter and twelve inches long, Fig. 25, has one of its ends drawn out into a fine fibre, *f*, nearly three feet long. The tube is placed in a brass socket, T, which can be screwed on the terminal T_1 of the induction coil. The discharge passing through the tube first illuminates the bottom of the same, which is of comparatively large section; but through the long glass fibre the discharge cannot pass.

But gradually the rarefied gas inside becomes warmed and more conducting and the discharge spreads into the glass fibre. This spreading is so slow that it may take half a minute or more until the discharge has worked through up to the top of the glass fibre, then presenting the appearance of a strongly luminous thin thread. By adjusting the potential at the terminal the light may be

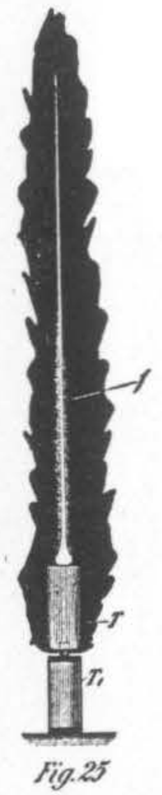


Fig. 25

FIG. 25.—ILLUSTRATING LATERAL DIFFUSION.

made to travel upwards at any speed. Once, however, the glass fibre is heated, the discharge breaks through its entire length instantly. The interesting point to be noted is that the higher the frequency of the currents, or, in other words, the greater relatively the lateral dissipation, at a slower rate may the light be made to propagate through the fibre. This experiment is best per-

formed with a highly exhausted and freshly made tube. When the tube has been used for some time the experiment often fails. It is possible that the gradual and slow impairment of the vacuum is the cause. This slow propagation of the discharge through a very narrow glass tube corresponds exactly to the propagation of heat through a bar warmed at one end. The quicker the heat is carried away laterally the longer time it will take for the heat to warm the remote end. When the

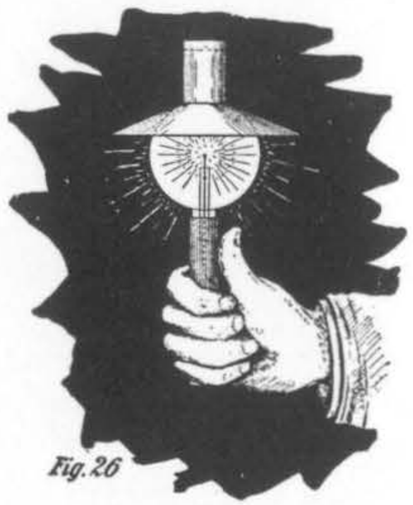


FIG. 26.—INCANDESCENCE OF A SOLID.—ILLUSTRATING FOUR KINDS OF LIGHT EFFECTS PRODUCED BY HIGH FREQUENCY CURRENTS OF HIGH POTENTIAL.

current of a low frequency coil is passed through the fibre from end to end, then the lateral dissipation is small, and the discharge instantly breaks through, almost without exception.

After these experiments and observations, which have shown the importance of the discontinuity or atomic structure of the medium, and which will serve to explain, in a measure, at least, the nature of the four kinds of light effects producible with these currents I

may now give you an illustration of these effects. For the sake of interest, I may do this in a manner which to many of you might be novel. You have seen before that we may now convey the electric vibration to a body by means of a single wire or conductor of any kind. Since the human frame is conducting, I may convey the vibration through my body.

First, as in some previous experiments, I connect



FIG. 27.—PHOSPHORESCENCE.—ILLUSTRATING FOUR KINDS OF LIGHT EFFECTS PRODUCED BY HIGH FREQUENCY CURRENTS OF HIGH POTENTIAL.

my body with one of the terminals of a high-tension transformer and take in my hand an exhausted bulb which contains a small carbon button mounted upon a platinum wire leading to the outside of the bulb, and the button is rendered incandescent as soon as the transformer is set to work (Fig. 26). I may place a conducting shade on the bulb, which serves to intensify the action, but it is not necessary. Nor is it required that

the button should be in conducting connection with the hand through a wire leading through the glass, for sufficient energy may be transmitted through the glass itself by inductive action to render the button incandescent.

Next, I take a highly exhausted bulb containing a strongly phosphorescent body, above which is mounted a small plate of aluminum on a platinum wire leading to the outside, and the currents flowing through my body



FIG. 28.—INCANDESCENCE OR PHOSPHORESCENCE OF RAREFIED GAS.—ILLUSTRATING FOUR KINDS OF LIGHT EFFECTS PRODUCED BY HIGH FREQUENCY CURRENTS OF HIGH POTENTIAL.

excite intense phosphoresence in the bulb, Fig. 27. Next, again, I take in my hand a simple exhausted tube, and in the same manner the gas inside the tube is rendered highly incandescent or phosphorescent, Fig. 28. Finally, I may take in my hand a wire, bare or covered with thick insulation, it is quite immaterial; the electric vibration is so intense as to cover the wire with a luminous film, Fig. 29.

A few words must now be devoted to each of these phenomena. In the first place, I will consider the incandescence of a button or of a solid in general, and dwell upon some facts which apply equally to all these phenomena. It was pointed out before that when a thin conductor, such as a lamp filament, for instance, is connected with one of its ends to the terminal of a transformer of high tension, the filament is brought to



FIG. 29.—LUMINOSITY OF GAS AT ORDINARY PRESSURE.—ILLUSTRATING FOUR KINDS OF LIGHT EFFECTS PRODUCED BY HIGH FREQUENCY CURRENTS OF HIGH POTENTIAL.

incandescence partly by a conduction current and partly by bombardment. The shorter and thicker the filament, the more important becomes the latter; and finally, reducing the filament to a mere button, all the heating must practically be attributed to the bombardment. So in the experiment before shown, the button is rendered incandescent by the rhythmical impact of freely movable small bodies in the bulb. These bodies may be the

molecules of the residual gas, particles of dust, or lumps torn from the electrode; whatever they are, it is certain that the heating of the button is essentially connected with the pressure of such freely movable particles, or of atomic matter in general, in the bulb. The heating is the more intense the greater the number of impacts per second and the greater the energy of each impact. Yet the button would also be heated if it were connected to a source of a steady potential. In such a case electricity would be carried away from the button by the freely movable carriers or particles flying about, and the quantity of electricity thus carried away might be sufficient to bring the button to incandescence by its passage through the latter. But the bombardment could not be of great importance in such case. For this reason, it would require a comparatively very great supply of energy to the button to maintain it at incandescence with a steady potential. The higher the frequency of the electric impulses, the more economically can the button be maintained at incandescence. One of the chief reasons why this is so is, I believe, that with impulses of very high frequency there is less exchange of the freely movable carriers around the electrode, and this means that in the bulb the heated matter is better confined to the neighborhood of the button. If a double bulb, as illustrated in Fig. 30, be made, comprising a large globe, B, and a small one, *b*, each containing, as usual, a filament, *f*, mounted on a platinum wire, w and w_1, it is found that if the filaments *f f* be exactly alike it requires less energy to keep the filament in the globe *b* at a certain degree of incandescence than that in the large globe B. This is due to the confinement of the movable particles around the button. In this case, it is also ascertained that the filament in the small globe *b* is less deteriorated

when maintained a certain length of time at incandescence. This is a necessary consequence of the fact that the gas in the small bulb becomes strongly heated, and, therefore, a very good conductor, and less work is then performed on the button, since the bombardment becomes less intense as the conductivity of the gas increases. In this construction, of course, the small bulb becomes very hot, and when it reaches an elevated temperature, the convection and radiation on the outside increase. On another occasion I have shown bulbs in

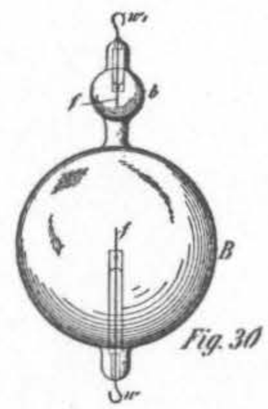


FIG. 30.—SHOWING THE EFFECTS OF CONFINING THE GAS AROUND THE ELECTRODE.

which this drawback was largely avoided. In these instances a very small bulb, containing a refractory button, was mounted in a large globe, and the space between the walls of both was highly exhausted. The outer large globe remained comparatively cool in such constructions. When the large globe was on the pump and the vacuum between the walls maintained permanent by the continuous action of the pump, the outer globe would remain quite cold, while the button in the small bulb was kept at incandescence. But when the

seal was made, and the button in the small bulb maintained incandescent some length of time, the large globe, too, would become warmed. From this I conjecture that if vacuous space (as Prof. Dewar finds) cannot convey heat, it is so merely in virtue of our rapid motion through space, or, generally speaking, by the motion of the medium relatively to us, for a permanent condition could not be maintained without the medium being constantly renewed. A vacuum cannot, according

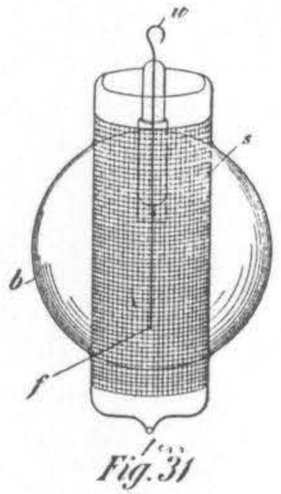


Fig. 31

FIG. 31.—SHOWING THE INEFFICIENCY OF A METAL SCREEN.

to all evidence, be permanently maintained around a hot body.

In these constructions, before mentioned, the small bulb inside would, at least in the first stages, prevent all bombardment against the outer, large globe. It occurred to me then to ascertain how a metal sieve would behave in this respect, and several bulbs, as illustrated in Fig. 31, were prepared for this purpose. In a globe *b*, was mounted a thin filament (or button), *f*, upon a platinum wire, *w*, passing through a glass stem

and leading to the outside of the globe. The filament *f* was surrounded by a metal sieve, *s*. It was found in experiments with such bulbs that a sieve with wide meshes apparently did not in the slightest affect the bombardment against the globe, *b*. When the vacuum was high the shadow of the sieve was clearly projected against the globe, and the latter would get hot in a short while. In some bulbs the sieve, *s*, was connected to a platinum wire sealed in the glass. When this wire was connected to the other terminal of the induction coil (the E. M. F. being kept low in this case), or to an insulated plate, the bombardment against the outer globe, *b*, was diminished. By taking a sieve with fine meshes the bombardment against the globe, *b*, was always diminished; but, even then, if the exhaustion was carried very far, and when the potential of the transformer was very high, the globe, *b*, would be bombarded and heated quickly, though no shadow of the sieve was visible, owing to the smallness of the meshes. But a glass tube or other continuous body mounted so as to surround the filament, did entirely cut off the bombardment, and for a while the outer globe, *b*, would remain perfectly cold. Of course, when the glass tube was sufficiently heated, the bombardment against the outer globe could be noted at once. The experiments with these bulbs seemed to show that the speeds of the projected molecules or particles must be considerable (though quite insignificant when compared with that of light), otherwise it would be difficult to understand how they could traverse a fine metal sieve without being affected, unless it were found that such small particles or atoms cannot be acted upon directly at measurable distances. In regard to the speed of the projected atoms, Lord Kelvin has recently estimated it at about one kilometre a second, or thereabouts, in an ordinary Crookes bulb. As the potentials

obtainable with a disruptive discharge coil are much higher than with ordinary coils, the speeds must, of course, be much greater when the bulbs are lighted from such a coil. Assuming the speed to be as high as five kilometres and uniform through the whole trajectory, as it should be in a very highly exhausted vessel, then if the alternate electrifications of the electrode would be of a frequency of five million, the greatest distance a particle could get away from the electrode would be one millimetre, and if it could be acted upon directly at that distance, the exchange of electrode matter or of the atoms would be very slow, and there would be practically no bombardment against the bulb. This, at least, should be so, if the action of an electrode upon the atoms of the residual gas would be such as upon electrified bodies which we can perceive. A hot body enclosed in an exhausted bulb produces always atomatic bombardment; but a hot body has no definite rhythm, for its molecules perform vibrations of all kinds.

If a bulb containing a button or filament be exhausted as high as is possible with the greatest care and by the use of the best artifices, it is often observed that the discharge cannot, at first, break through; but after some time, probably in consequence of some changes within the bulb, the discharge finally passes through and the button is rendered incandescent. In fact, it appears that the higher the degree of exhaustion, the easier is the incandescence produced. There seem to be no other causes to which the incandescence might be attributed in such case, except to the bombardment or similar action of the residual gas, or of particles of matter in general. But if the bulb be exhausted with the greatest care, can these play an important part? Assume the vacuum in the bulb to be tolerably perfect, the great interest then centres in the question: Is the

medium which pervades all space continuous or atomic? If atomic, then the heating of a conducting button or filament in an exhausted vessel might be due largely to ether bombardment, and then the heating of a conductor in general through which currents of high frequency or high potential are passed must be modified by the behavior of such medium; then, also, the skin effect, the apparent increase of the ohmic resistance, etc., admit, partially, at least, of a different explanation.

It is certainly more in accordance with many phenomena observed with high frequency currents to hold that all space is pervaded with free atoms, rather than to assume that it is devoid of these, and dark and cold, for so it must be, if filled with a continuous medium, since in such there can be neither heat nor light. Is, then, energy transmitted by independent carriers or by the vibration of a continuous medium? This important question is by no means as yet positively answered. But most of the effects which are here considered, especially the light effects, incandescence or phosphorescence, involve the presence of free atoms, and would be impossible without these.

In regard to the incandescence of a refractory button (or filament) in an exhausted receiver, which has been one of the subjects of this investigation, the chief experiences, which may serve as a guide in constructing such bulbs, may be summed up as follows: 1. The button should be as small as possible, spherical, of a smooth or polished surface and of refractory material, which withstands evaporation best. 2. The support of the button should be very thin and screened by an aluminum and mica sheet, as I have described on another occasion. 3. The exhaustion of the bulb should be as high as possible. 4. The frequency of the currents should be as high as practicable. 5. The currents should be of a harmonic

rise and fall, without sudden interruptions. 6. The heat should be confined to the button by enclosing the same in a small bulb, or otherwise. 7. The space between the walls of the small bulb and the outer globe should be highly exhausted.

Most of the considerations just considered which apply to the incandescence of a solid, may likewise be applied to phosphorescence. Indeed, in an exhausted vessel the phosphorescence is, as a rule, primarily excited by the powerful beating of the electrode stream of atoms against the phosphorescent body. Even in many cases where there is no evidence of such a bombardment, I think that phosphorescence is excited by violent impacts of atoms which are not necessarily thrown off from the electrode, but are acted upon from the same inductively, through the medium or through chains of other atoms. That mechanical shocks play an important part in exciting phosphorescence in a bulb, may be seen from the following experiment: If a bulb, constructed as that illustrated in Fig. 10, be taken, and exhausted with the greatest care so that the discharge cannot pass, the filament, *f*, acts by electrostatic induction upon the tube, *t*, and the latter is set in vibration. If the tube, *o*, be rather wide, about an inch or so, the filament may be so powerfully vibrated that whenever it hits the glass tube it excites phosphorescence. But the phosphorescence ceases when the filament comes to rest. The vibration can be arrested and again started by varying the frequency of the currents; namely, the filament has its own period of vibration, and if the frequency of the currents is such that there is resonance, it is set easily vibrating, though the potential of the currents be small. I have often observed that the filament in the bulb is destroyed by such mechanical resonance. The filament vibrates, as a rule, so rapidly that it cannot be seen, and

the experimenter may at first be mystified. When such an experiment as the one described is carefully performed, the potential of the currents need be extremely small, and for this reason I infer that the phosphorescence is then due to the mechanical shock of the filament against the glass, just as it is produced by striking a loaf of sugar with a knife. The mechanical shock produced by the projected atoms is easily noted when a bulb containing a button is grasped in the hand and the current turned on suddenly. I believe that a bulb could be shattered by observing the conditions of resonance.

In the experiment before cited it is, of course, open to say that the glass tube, upon coming in contract with the filament, retains a charge of a certain sign upon the point of contact. If, now, the filament again touches the glass at the same point while it is oppositely charged, the charges equalize under evolution of light. But nothing of importance would be gained by such an explanation. It is unquestionable that the initial charges given to the atoms or to the glass play some part in exciting phosphorescence. So, for instance, if a phosphorescent bulb be first excited by a high frequency coil by connecting it to one of the terminals of the latter, and the degree of luminosity noted; and then the bulb be highly charged from a Holtz machine by attaching it preferably to the positive terminal of the machine, it is found that when the bulb is again connected to the terminal of the high frequency coil, the phosphorescence is far more intense. On another occasion, I have considered the possibility of some phosphorescent phenomena in bulbs being produced by the incandescence of an infinitesimal layer on the surface of the phosphorescent body. Certainly, the impacts of the atoms are powerful enough to produce intense incandescence by the collisions, since they bring quickly to a high temperature

a body of considerable bulk. If any such effect exists, then the best appliance which we know so far, for producing phosphorescence in a bulb, is a disruptive discharge coil giving an enormous potential with but few fundamental discharges, say, 25-30 per second, just enough to produce a continuous impression upon the eye. It is a fact that such a coil excites phosphorescence under most any condition and at all degrees of exhaustion, and I have observed effects which appear to be due to phosphorescence even at ordinary pressures of the atmosphere, when the potentials are extremely high. But if phosphorescent light is produced by the equalization of charges of electrified atoms (whatever this may mean ultimately), then the higher the frequency of the impulses or alternate electrifications, the more economical will be the light production. It is a long known and noteworthy fact that all the phosphorescent bodies are poor conductors of electricity and heat, and that all bodies cease to emit prosphorescent light when they are brought to a certain temperature. Conductors, on the contrary, do not possess this quality. There are but few exceptions to the rule. Carbon is one of them. Becquerel noted that carbon phosphoresces at a certain elevated temperature preceding the dark red. This phenomenon may be easily observed in bulbs provided with a rather large carbon electrode (say a sphere of six millimetres diameter). If the current is turned on after a few seconds, a snow white film covers the electrode just before it gets dark red. Similar effects are noted with other conducting bodies, but many scientific men will probably not attribute them to true phosphorescence. Whether true incandescence has anything to do with phosphorescence, excited by atomic impact or mechanical shocks, still remains to be decided; but it is a fact that all conditions which tend

to localize and increase the heating effect at the point of impact, are almost invariably the most favorable for the production of phosphorescence. So, if the electrode be very small, which is equivalent to saying, in general, that the electric density is great; if the potential be high, and if the gas be highly rarefied—all of which things imply high speed of the projected atoms or matter, and, consequently, violent impacts—the phosphorescence is very intense. If a bulb, provided with a large and small electrode, be attached to the terminal of an induction coil, the small electrode excites phosphorescence, while the large one may not do so because of the smaller electric density, and hence smaller speed of the atoms. A bulb provided with a large electrode may be grasped with the hand while the electrode is connected to the terminal of the coil and it may not phosphoresce; but if, instead of grasping the bulb with the hand, the same be touched with a pointed wire, the phosphorescence at once spreads through the bulb, because of the great density at the point of contact. With low frequencies it seems that gases of great atomic weight excite more intense phosphorescence than those of smaller weight, as, for instance, hydrogen. With high frequencies the observations are not sufficiently reliable to draw a conclusion. Oxygen, as is well known, produces exceptionally strong effects, which may be in part due to chemical action. A bulb with hydrogen residue seems to be most easily excited. Electrodes which are most easily deteriorated produce more intense phosphorescence in bulbs; but the condition is not permanent, because of the impairing of the vacuum and the deposition of the electrode matter upon the phosphorescent surfaces. Some liquids, as oils, for instance, produce magnificent effects of phosphorescence (or fluorescence?), but they last only a few seconds. So if a bulb have a trace of oil on the walls,

and the current is turned on, the phosphorescence only persists for a few moments, until the oil is carried away. Of all bodies so far tried, sulphide of zinc seems to be the most susceptible to phosphorescence. Some samples, obtained through the kindness of Prof. Henry, in Paris, were employed in many of these bulbs. One of the defects of this sulphide is that it loses its quality of emitting light when brought to a temperature which is by no means high. It can, therefore, be used only for feeble intensities. An observation which might deserve notice is that when violently bombarded from an aluminum electrode it assumes a black color; but, singularly enough, it returns to the original condition when it cools down.

The most important fact arrived at in pursuing investigations in this direction is, that in all cases it is necessary, in order to excite phosphorescence with a minimum amount of energy, to observe certain conditions; namely, there is always, no matter what the frequency of the currents, degree of exhaustion and character of the bodies in the bulb, a certain potential (assuming the bulb excited from one terminal) or potential difference (assuming the bulb to be excited with both terminals) which produces the most economical result. If the potential be increased, considerable energy may be wasted without producing any more light; and if it be diminished, then, again, the light production is not so economical. The exact condition under which the best result is obtained seems to depend on many things of a different nature, and it is to be yet investigated by other experimenters; but it will certainly have to be observed when such phosphorescent bulbs are operated, if the best results are to be attained.

Coming now to the most interesting of these phenomena, the incandescence or phosphorescence of gases

at low pressure or at the ordinary pressure of the atmosphere, we must seek the explanation of these phenomena in the same primary causes; that is, in shocks or impacts of the atoms. Just as molecules or atoms beating upon a solid body excite phosphorescence in the same, or render it incandescent, so when colliding among themselves they produce similar phenomena. But this is a very insufficient explanation, and concerns only the crude mechanism. Light is produced by vibrations, which go on at a rate almost inconceivable. If we compute from the energy contained in the form of known radiations in a definite space the force which is necessary to set up such rapid vibrations, we find that though the density of the ether be incomparably smaller than that of any body we know, even hydrogen, the force is something surpassing comprehension. What is this force, which, in mechanical measure, may amount to thousands of tons per square inch? It is electrostatic force in the light of modern views. It is impossible to conceive how a body of measurable dimensions could be charged to so high a potential that the force would be sufficient to produce these vibrations. Long before any such charge could be imparted to the body it would be shattered into atoms. The sun emits light and heat, and so does an ordinary flame or incandescent filament; but in neither of these can the force be accounted for if it be assumed that it is associated with the body as a whole. Only in one way may we account for it, namely, by identifying it with the atom. An atom is so small that if it be charged by coming in contact with an electrified body, and the charge be assumed to follow the same law as in the case of bodies of measurable dimensions, it must retain a quantity of electricity which is fully capable of accounting for these forces and tremendous rates of vibration.

But the atom behaves singularly in this respect; it always takes the same "charge."

It is very likely that resonant vibration plays a most important part in all manifestations of energy in nature. Throughout space all matter is vibrating, and all rates of vibration are represented, from the lowest musical note to the highest pitch of the chemical rays; hence an atom, or complex of atoms, no matter what its period, must find a vibration with which it is in resonance. When we consider the enormous rapidity of the light vibrations, we realize the impossibility of producing such vibrations directly with any apparatus of measurable dimensions, and we are driven to the only possible means of attaining the object of setting up waves of light by electrical means and economically; that is, to affect the molecules or atoms of a gas, to cause them to collide and vibrate. We then must ask ourselves: How can free molecules or atoms be affected?

It is a fact that they can be affected by electrostatic force, as is apparent in many of these experiments. By varying the electrostatic force we can agitate the atoms, and cause them to collide under evolution of heat and light. It is not demonstrated beyond boubt that we can affect them otherwise. If a luminous discharge is produced in a closed exhausted tube, do the atoms arrange themselves in obedience to any other but to electrostatic force acting in straight lines from atom to atom? Only recently I investigated the mutual action between two circuits with extreme rates of vibration. When a battery of a few jars (*c c c c*, Fig. 32) is discharged through a primary, P, of low resistance (the connections being as illustrated in Figs. 19*a*, 19*b*, and 19*c*), and the frequency of vibration be many million, there are great differences of potential between points on the primary not more than a few inches apart. These differences may

be 10,000 volts per inch, if not more, taking the maximum value of the electromotive force. The secondary, *s*, is therefore acted upon by electrostatic induction, which is, in such extreme cases, of much greater importance than the electro-dynamic. To such sudden impulses the primary, as well as the secondary, are poor conductors, and therefore great differences of potential may be produced by electrostatic induction between adjacent points on the secondary. Then sparks may jump between the wires and streamers become visible in the dark, if the

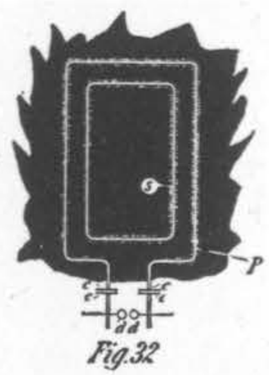


FIG. 32.—ELECTROSTATIC ACTION BETWEEN PRIMARY AND SECONDARY, WITH EXTREMELY HIGH FREQUENCIES.

light of the discharge through the spark gap *d d* be carefully excluded. If, now, we substitute a closed vacuum tube for the metallic secondary *s*, the differences of potential produced in the tube by electrostatic induction from the primary are fully sufficient to excite portions of it; but as the points of certain differences of potential on the primary are not fixed, but are generally constantly changing in position, a luminous band is produced in the tube, apparently not touching the glass, as it should if the points of maximum and mini-

mum differences of potential were fixed on the primary. I do not exclude the possibility of such a tube being excited only by electro-dynamic induction, for very able physicists hold this view; but, in my opinion, there is as yet no positive proof given that atoms of a gas in a closed tube may arrange themselves in chains under the action of an electromotive impulse produced by electro-dynamic induction in the tube. I have been unable so far to produce striæ in a tube, however long, and at whatever degree of exhaustion; that is, striæ at right angles to the supposed direction of the discharge or the axis of the tube; but I have distinctly observed in a large bulb, in which a wide luminous band was produced by passing a discharge of a battery through a wire surrounding the bulb, a circle of feeble luminosity between two luminous bands, one of which was more intense than the other. Furthermore, with my present experience, I do not think that such a gas discharge in a closed tube can vibrate; that is, vibrate as a whole. I am convinced that no discharge through a gas can vibrate. The atoms of a gas behave very curiously in respect to sudden electric impulses. The gas does not seem to possess any appreciable inertia to such impulses; for it is a fact, that the higher the frequency of the impulses, with the greater freedom does the discharge pass through the gas. If the gas possesses no inertia, then it cannot vibrate, for some inertia is necessary for the free vibration. I conclude from this that if a lightning discharge occurs between two clouds, there can be no oscillation, such as would be expected, considering the capacity of the clouds. But if the lightning discharge strike the earth, there is always vibration—in the earth, but not in the cloud. In a gas discharge each atom vibrates at its own rate, but there is no vibration of the conducting gaseous mass as a whole. This is an important consideration in the great problem of producing light economically, for it teaches us that to reach this result we must use impulses of very high frequency and necessarily also of high potential. It is a fact that oxygen produces a more intense light in a tube. It is because oxygen atoms possess some inertia and the vibration does not die out instantly? But then nitrogen should be as good as, and chlorine and vapors of many other bodies much better than, oxygen, unless the magnetic properties of the latter enter prominently into play. Or is the process in the tube of an electrolytic nature? Many observations certainly speak for it, the most important being, that matter is always carried away from the electrodes and the vacuum in a bulb cannot be permanently maintained. If such process takes place in reality, then, again, must we take refuge to high frequencies, for with such, electrolytic action should be reduced to a minimum, if not rendered entirely impossible. It is an undeniable fact that with very high frequencies, provided the impulses be of a harmonic nature, like those obtained from an alternator, there is less deterioration and the vacua are more permanent. With disruptive discharge coils there are sudden rises of potential and the vacua are more quickly impaired, for the electrodes are deteriorated in a very short time. It was observed in some large tubes, which were provided with heavy carbon blocks B B_1, connected to platinum wires w w_1 (as illustrated in Fig. 33), and which were employed in experiments with the disruptive discharge instead of the ordinary air gap, that the carbon particles, under the action of the powerful magnetic field in which the tube was placed, were deposited in regular fine lines in the middle of the tube, as illustrated. These lines were attributed to the deflection or distortion of the discharge by the magnetic field; but why the deposit

occurred principally where the field was most intense did not appear quite clear. A fact of interest, likewise noted, was that the presence of a strong magnetic field increases the deterioration of the electrodes, probably by reason of the rapid interruptions it produces, whereby there is actually a higher electromotive force maintained between the electrodes.

Much would remain to be said about the luminous effects produced in gases at low or ordinary pressures. With the present experiences before us we cannot say that the essential nature of these charming phenomena is sufficiently known. But investigations in this direc-

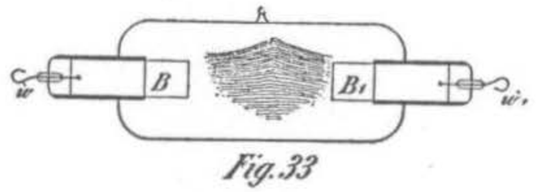


FIG. 33.—CARBON DEPOSIT IN TUBE IN A MAGNETIC FIELD.

tion are being pushed with exceptional ardor. Every line of scientific pursuit has its fascinations; but electrical investigation appears to possess a peculiar attraction, for there is no experiment or observation of any kind in the domain of this wonderful science which would not forcibly appeal to us. Yet to me it seems that of all the many marvelous things we observe, a vacuum tube, excited by an electric impulse from a distance source, bursting forth out of the darkness and illuminating the room with its beautiful light, is as lovely a phenomenon as can greet our eyes. More interesting still it appears when, reducing the fundamental discharges across the

gap to a very small number, and waving the tube about, we produce all kinds of designs in luminous lines. So, by way of amusement, I take a straight long tube, or a square one, or a square attached to a straight tube, and by whirling them about in the hand, I imitate the spokes

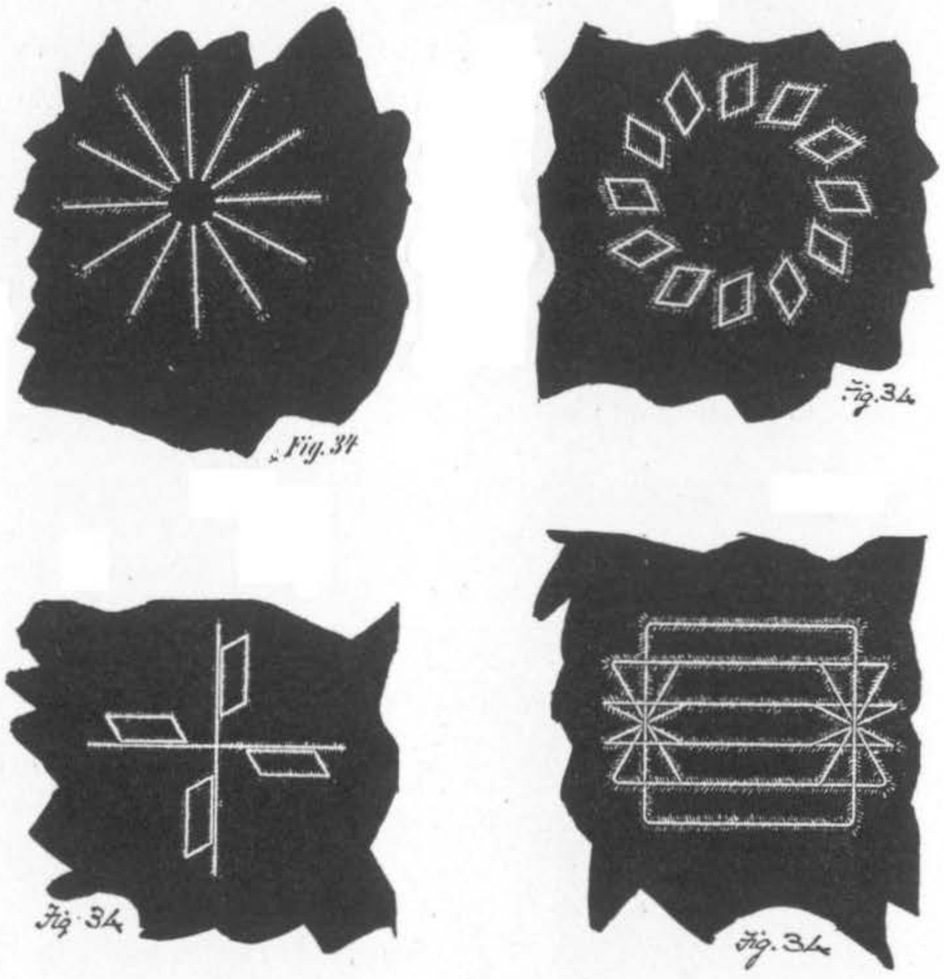


FIG. 34.—SPOKE WHEEL, DRUM WINDING, ALTERNATE MOTOR WINDING, RING WINDING—SOME OF THE DESIGNS PRODUCED BY INTERMITTENT DISCHARGES.

of a wheel, a Gramme winding, a drum winding, an alternate current motor winding, etc. (Fig. 34). Viewed from a distance the effect is weak and much of its beauty is lost; but being near or holding the tube in the hand one cannot resist its charm.

In presenting these insignificant results I have not attempted to arrange and co-ordinate them as would be proper in a strictly scientific investigation, in which every succeeding result should be a logical sequence of the preceding, so that it might be guessed in advance by the careful reader or attentive listener. I have preferred to concentrate my energies chiefly upon advancing novel facts or ideas which might serve as suggestions to others, and this may serve as an excuse for the lack of harmony. The explanations of the phenomena have been given in good faith and in the spirit of a student prepared to find that they admit of a better interpretation. There can be no great harm in a student taking an erroneous view, but when great minds err, the world must dearly pay for their mistakes.

MISCELLANEOUS.

THE PHYSIOLOGICAL AND OTHER EFFECTS OF HIGH FREQUENCY CURRENTS.

BY

Nikola Tesla

IN THE ELECTRICAL ENGINEER of January 25, 1893, I note an article by Mr. A. A. C. Swinton, referring to my experiments with high frequency currents. Mr. Swinton uses in these experiments the method of converting described by me in my paper before the American Institute of Electrical Engineers, in May, 1891, and published in THE ELECTRICAL ENGINEER of July 8, 1891, which has since been employed by a number of experimenters; but it has somewhat surprised me to observe that he makes use of an ordinary vibrating contact-breaker, whereas he could have employed the much simpler method of converting continuous currents into alternating currents of any frequency which was shown by me two years ago. This method does not involve the employment of any moving parts, and allows the experimenter to vary the frequency at will by simple adjustments. I had thought that most electricians were at present familiar with this mode of conversion which possesses many beautiful features.

The effects observed by Mr. Swinton are not new to me and they might have been anticipated by those who have carefully read what I have written on the subject. But I cannot agree with some of the views expressed by him.

First of all, in regard to the physiological effects. I have made a clear statement at the beginning of my published studies, and my continued experience with these currents has only further strengthened me in the opinion then expressed. I stated in my paper, before mentioned, that it is an undeniable fact that currents of very high frequency are less injurious than the low frequency currents, but I have also taken care to prevent the idea from gaining ground that these currents are absolutely harmless, as will be evident from the following quotation: "If received directly from a machine or from a secondary of low resistance, they (high frequency currents) produce more or less powerful effects, and may cause serious injury, especially when used in conjunction with condensers." This refers to currents of ordinary potential differences such as are used in general commercial practice.

As regards the currents of very high potential differences, which were employed in my experiments, I have never considered the current's *strength*, but the *energy* which the human body was capable of receiving without injury, and I have expressed this quite clearly on more than one occasion. For instance, I stated that "the higher the frequency the greater the amount of electrical energy which may be passed through the body without serious discomfort." And on another occasion when a high tension coil was short-circuited though the body of the experimenter I stated that the immunity was due to the fact that less *energy* was available externally to the coil when the experimenter's body joined the terminals. This is practically what Mr. Swinton expresses in another way; namely, by saying that with "high frequency currents it is possible to obtain effects with exceedingly small currents," etc.

In regard to the experiments with lamp filaments, I have, I believe, expressed myself with equal clearness. I have pointed out some phenomena of impedance which at that time (1891) were considered very striking, and I have also pointed out the great importance of the rarefied gas surrounding the filament when we have to deal with currents of such high frequency. The heating of the filament by a comparatively small current is not, as Mr. Swinton thinks, due to its impedance or increased ohmic resistance, but principally to the presence of rarefied gas in the bulb. Ample evidence of the truth of this can be obtained in very many experiments, and to cite them would be merely lengthening this communication unduly.

Likewise, observations made when the experimenter's body was included in the path of the discharge, are, in my opinion, not impedance, but capacity, phenomena. The spark between the hands is the shorter, the larger the surface of the body, and no spark whatever would be obtained if the surface of the body were sufficiently large.

I would here point out that one is apt to fall into the error of supposing that the spark which is produced between two points on a conductor, not very distant from each other, is due to the impedance of the conductor. This is certainly the case when the current is of considerable strength, as for instance when, like in the Faraday experiment or some of Dr. Lodge's, a heavily-charged battery of Leyden jars is discharged through a bent wire. But, when there is a vibration along a wire which is constantly maintained, and the current is inappreciable whereas the potential at the coil terminal is exceedingly high, then lateral dissipation comes into play prominently. There is then, owing to this dissipation, a rapid fall of potential along the wire and high potential differences may exist between points only a short distance apart. This is of course not to be confounded with those differences of potential observed between points when there are fixed waves with ventral and nodal points maintained on a conductor. The lateral dissipation, and not the skin effect, is, I think, the reason why so great an amount of energy may be passed into the body of a person without causing discomfort.

It always affords me great pleasure to note, that something which I have suggested is being employed for some instructive or practical purpose; but I may be pardoned for mentionting that other observations made by Mr. Swinton, and by other experimenters, have recently been brought forward as novel, and arrangements of apparatus which I have suggested have been used repeatedly by some who apparently are in complete ignorance of what I have done in this direction.

PERSONAL.

HONORS TO NIKOLA TESLA.

DURING Mr. Nikola Tesla's sojourn abroad last year, a special deputation of prominent scientific men of Servia was sent to Budapest by the Servian Government to escort him to Belgrade, where the young King Alexander I., of Servia, granted him a special audience and evinced great interest in the work in which Mr. Tesla is engaged. In recognition of his merit, King Alexander has just created Mr. Tesla a Grand Officer of the Order of St. Sava. The insignia of the Order have just been transmitted to Mr. Tesla from Belgrade.

NOTES.

Lecture by Nikola Tesla.—It is announced that a lecture by Mr. Nikola Tesla will be given before the National Electric Light Association this month. The lecture will be illustrated by numerous experiments, and is being looked forward to with great interest in America.

The St. Louis Convention.

With this issue we are enabled to give for the first time the completed programme of the coming convention of the National Electric Light Association, to be held at St. Louis on Feb. 28, and March 1 and 2. No convention of the association has been held under more favorable auspices than that now under consideration, and it needs but a glance over the list of papers to be presented and their authors to satisfy one that they are in character entirely in keeping with the importance of the event of which they are to be a part.

When at Buffalo is was suggested that the meetings be held thereafter only at intervals of a year, the proposition was received at once with favor.

The simple fact that the St. Louis convention is the first to be held under the new regime, has given it somewhat unusual prominence, but there are other things that also contribute in that direction, not the least of which is the fact that it is the last to be held previous to the Exposition convention, and will therefore, in a sense, be preliminary to that most important event, when not only electric light men, but electricians of all kinds from all parts of the world, will be congregated at the city by the lake.

It is no reflection on the interest attaching to the other papers to say that the greatest centres around that to be read on Wednesday evening by Mr. Nikola Tesla, who has already set the world by the ears by his remarkable discoveries in electro-physics. With the laurels still fresh that were accorded him by the savants abroad, the equal of which have been accorded to no one before while living, he promises to open his mouth again, for the first time since he astonished our friends beyond the seas, before this convention. Surely this is an event which may well cause all eyes to turn toward St. Louis.

But this is not all. Prof. George Forbes, the celebrated English engineer, who arrived last week on the Majestic, will read a paper on Wednesday morning on Thermal Storage for Central Stations.

It is thought that many would like to take advantage of their proximity to Chicago to run up there to see the Fair Grounds, in which all are interested, and Mr. Baker, as though he had not already done all that could be asked or expected, has negotiations under way looking toward an arrangement for such a trip at reduced rates. These have not, however, been completed, and no positive announcement can be made at this date.

PROGRAMME ST. LOUIS CONVENTION.

Tuesday, Feb. 28, 1893.

Meeting of the Executive Committee at 9 A. M., parlor of Southern Hotel.

Morning Session, 10:30 o'clock, at Bell Telephone Building.

Address of Welcome, Hon. E. A. Noonan, Mayor of St. Louis.

Address, Pres. James I. Ayer.

Report, Committee of Data.

Afternoon Session, 2 o'clock.

Report, Committee on Safe Wiring.

Report, Committee on World's Columbian Fair.

Paper, A. D. Adams, Wrought vs. Cast Iron for Field Magnet Frames.

Wednesday, March 1.

Morning Session, 10 o'clock.

Paper, Prof. George Forbes, Thermal Storage for Central Stations.

Paper, Charles S. Bradley, Long Distance Transmission of Power.

Paper, L. B. Stillwell, Under What Conditions is the Use of Water Power Economical?

Afternoon Session, 2:30 o'clock.

Paper, E. A. Armstrong, Morals of Corporations.

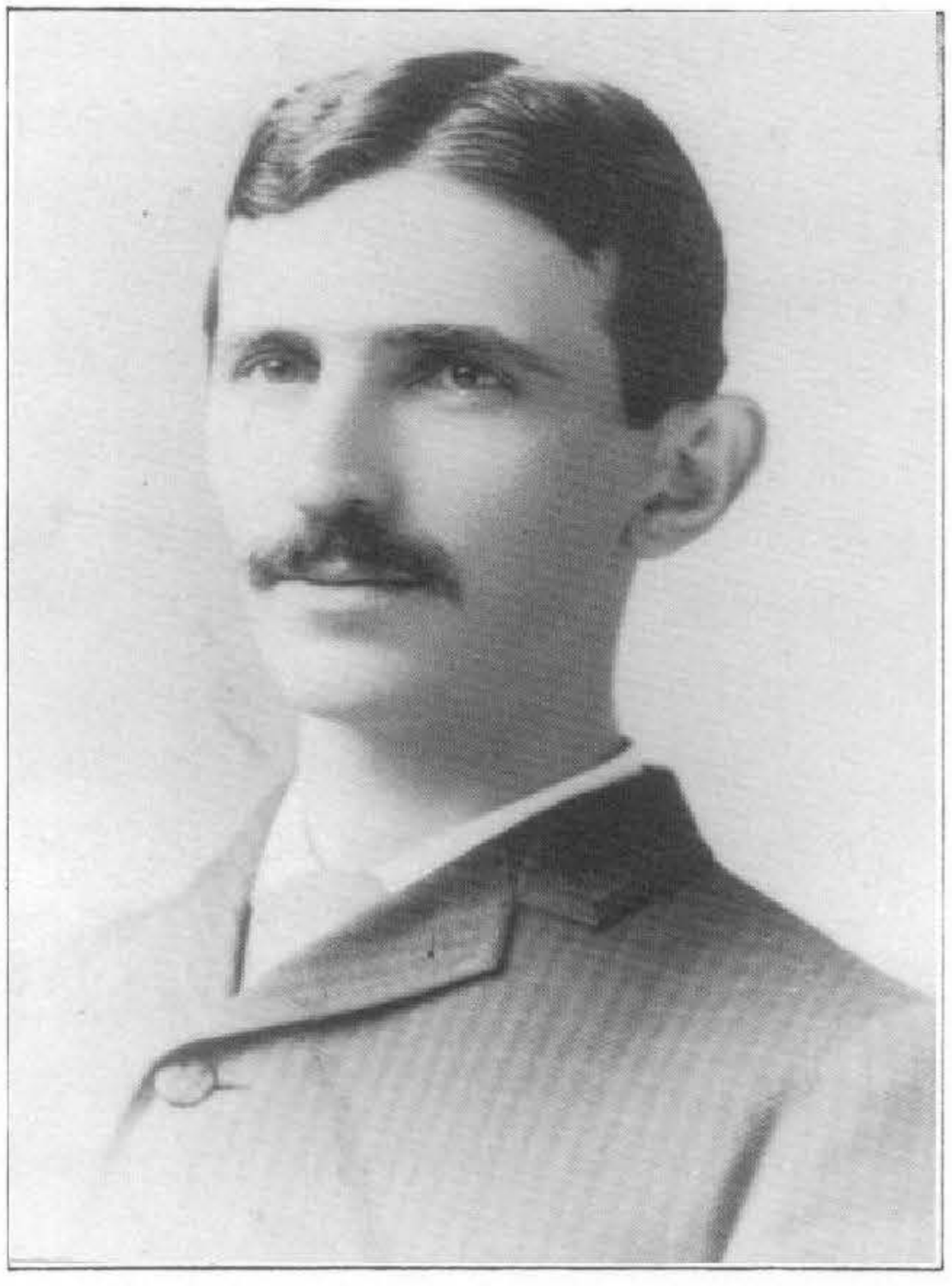
Paper, R. H. Sterling, Some Experiences with the Alternating System.

Paper, William Brophy, Relation of Insurance to Electric Lighting and Power.

Evening Session, 8 o'clock.

Lecture, Nikola Tesla.

Electrical Industries March 1893



Sincerely yours
Nikola Tesla

Mr. Nikola Tesla.

During the past year the electrical world has been much interested in the remarkable demonstrations of the possibilities of electricity that have been made by Mr. Nikola Tesla. Attention was first attracted to Mr. Tesla's work by a lecture which he delivered at Columbia College, New York City, in May, 1891. This lecture showed that the researches of Mr. Tesla were very exhaustive. In January last he sailed for Europe with invitations to lecture before the leading scientific organizations of the continent, and shortly after reaching England he gave a series of experiments in his lectures before the English Institute of Electrical Engineers, which received the highest commendation because of the depth of his researches. Probably no American electrician or scientific man was ever received by the scientific men of Europe with such honors as were conferred upon Mr. Tesla.

Mr. Tesla was born in Servia, but has been in the United States many years and has been connected with the Westinghouse Electric & Manufacturing Company, making extensive researches in connection with the alternating current. Mr. Tesla has demonstrated a number of facts of much importance as to the nature of electricity, and in his experiments has demonstrated in actual practice some of his deductions. Much interest has been attracted by his operating a motor on one wire and even without connecting it with a generator, and in the matter of electric lighting he has produced some startling results which open a field for wide research and give promise of remarkable developments in the near future in the improvement of electric lighting.

THE TESLA LECTURE IN ST. LOUIS.



Nikola Tesla.

THE Tesla lecture was a notable feature of the convention. At first it had been proposed to deliver the lecture in a small hall, but the demand for tickets was so enormous that it was decided, as a matter of sheer necessity, to secure a larger auditorium, and this was found in the Exhibition Theatre, which seats about 4,000 people. It was, of course, practically impossible that all could hear and see, but those who were there could at least say they had seen Mr. Tesla afar off and witnessed some of his most striking experiments. The hall was crowded to suffocation. and the demand for tickets was so great that they were selling briskly for three and five dollars on the steps of the hall. Under such circumstances Mr. Tesla contented himself wisely with showing some of the more "spectacular" of his experiments, and even these were followed at a disadvantage in view of the immense distance from which most of the spectators studied them. After his introduction by Mr. Ayer, the lecturer gave a few minutes to a statement of the conditions involved in his work, and then by means of his high frequency and high voltage currents, aided by disruptive discharge from a condenser through an induction coil—as well as by direct dynamic phenomena, he produced a number of the interesting results that have already made his name famous and have charmed two worlds. He received, unhurt, currents of hundreds of thousands of volts, lit-up tubes and lamps through his body, rendered insulated wires several feet long entirely luminous, showed a motor running under the influence of these million-frequency currents, obtained a number of effects with phosphorescent lamps; and also showed how little in such work the high resistance of the filament had to do with the lighting up of ordinary 50 or 110 volt lamps. His ability to produce such effects, either with a single wire and no return, or without any wires at all, aroused the utmost interest and enthusiasm and the concluding demonstration literally brought down the house, when he showed how by simply carrying lamps or tubes into a room or hall where those currents were being developed, illumination was the immediate result.

In his opening remarks Mr. Tesla enlarged upon the grandeur of Nature, and expressed his opinion that the most wonderful of the external influences that affect us is light. Hence it followed that the most wonderful and important of the organs by which these external influences beat in upon us is the eye. Two facts were specially referred to, one of them being that the eye is the only organ capable of being affected directly by the vibrations of the ether. Another fact was that the eye would be able to distinguish objects at almost any distance, were it not for the minute particles and stray gases filling the intervening space. These absorb the energies of the ether vibrations, but in a pure medium they would travel unchecked, and the range of vision would be infinitely greater. Mr. Tesla then alluded to the importance of the part played by the eye in furnishing the race with its ideas and knowledge, and to its vital function in controlling all our motions and actions. From its teaching were derived consciousness, ideas, conceptions that were impossible without images—and images involved sight.

By these interesting stages, Mr. Tesla led up to the subject of light and thence to the part of electricity in giving us light. The general aim of the discourse was to show and explain the phenomena due to electrostatic forces, followed by phenomena produced by electro-dynamic agencies; and, then, as a third class, the light effects, Mr. Tesla's idea evidently being to give a generalization of these phenomena, and of their relations. It was stated, parenthetically, with regard to the physiological effects produced with the high tension, high frequency currents employed, that a great amount of energy may be sent into the body of a person by their means, merely because the energy was dissipated laterally from the body and was not passed through the body in the direct manner involved in the use of a low frequency current. It was due to this intense rapidity of vibration that the lecturer was able to receive with impunity currents of as high as 250,000 and 300,000 volts, and of an amount which otherwise administered would kill. The lecturer explained that he had so arranged his apparatus that in case of any failure of any part of it, the current would kindly abstain from killing him, and would only knock him down.

Many of the experiments shown have already been seen either in this country or in Europe, yet there were several novel effects

introduced, and even the familiar experiments were performed with apparatus different from that used before. In most of the experiments the ordinary alternating and continuous currents from the central station were used, although Mr. Tesla also had his own special generator running in the basement.

A striking new experiment was to show at the beginning of the lecture, the effect of a varying electrostatic stress through the dielectric. This experiment was performed by grasping one terminal of the high tension transformer giving about 200,000 volts pressure, and approaching the other hand, to the opposite terminal. Streams of violet light then issued from the fingers and the whole hand. (At the lecture on the preceding Friday at the Franklin Institute in Philadelphia, Prof. Houston noticed these streams of light coming also from the lecturer's back, following roughly the line of the vertebral column).

Another experiment was performed showing the action of the air between two condenser plates. By attaching these plates to the high-tension transformer, the whole space between these plates was filled with light, the distance apart being about ten inches. It was pointed out that these streamers consumed considerable energy and developed abundantly ozone and nitrous acid, and it followed that it was necessary to exclude air from high-tension apparatus.

The action of the air was shown in another very striking experiment. Two incandescent lamps exactly alike, one exhausted, the other not, both of the ordinary 50 volt type, were attached in multiple arc, and a current vibrating about one million times a second or thereabouts was passed through the filament. It was demonstrated that the lamp which was exhausted glowed brightly, whereas the other one in which the filament was surrounded by air, at ordinary pressure, did not glow. Yet the latter lamp got hotter than the other. This showed the great importance of the rarefied gas in the heating of a conductor, and it was pointed out that in incandescent lighting a high resistance filament does not at all constitute the really essential element of illumination, along these lines. Also that heavy blocks of metal may be brought to incandescence by minute currents provided they are surrounded by rarefied gas, and provided the potential and frequency of the currents is sufficiently high.

One of the most interesting experiments was the conversion on open circuit. A transformer was taken and the current passed through the high tension winding in such a way that only one terminal was attached to the source of the rapidly alternating current. In spite of this there was a current passing through the primary as though the other terminal was actually attached to the source like an ordinary return circuit. This open circuit transformer contained a secondary low tension winding, and the minute currents passing through the primary were transformed into currents capable of following the ordinary electric wire and lighting up brilliantly an ordinary lamp. It was pointed out that under certain conditions, indeed, such a conversion was quite practicable and that it can be practised with high economy. It was further pointed out that any kind of device such as motors, etc., may be operated in this manner, with one wire or circuit only.

Mr. Tesla in the course of his lecture dwelt upon his method of conversion by means of disruptive discharges from continuous or alternating station supply. There were two kinds of apparatus on the stage, one operated from the alternating circuit and the other from the regular direct current system. A peculiar form of discharger was used contained in a mica-lined wooden box. The spark-gap was warmed by a small lamp underneath, for the purpose of making the air dielectrically weak. This enabled Mr. Tesla to work with a very long gap, a very sensitive arc, and a comparatively small electromotive force in the gap. The effects obtained were thus augmented very materially. It was pointed out that with this method of conversion, there is no difficulty whatever in obtaining sparks of any length. It becomes simply a question of the energy supplied, through what distance the spark will be visible. During the lecture, lamps were operated by this method of conversion. An ordinary 100-volt, a 50-volt and a two-volt lamp were brought up to full candle-power with equal facility. Then a little motor was run by means of these disruptive discharges, it being a phase-motor comprising simply an iron core with a closed secondary coil in it, and a disc armature arranged to rotate above the core. Mr. Tesla remarked rather naïvely that if the demonstration were not quite equal to the expectation, the long continued and weary work on the development of the invention, besides the inability of the experimenter, might be the cause. He went on, in connection with this, to refer to the transmission of power from Niagara and gracefully recognized the presence on the platform of Prof. George Forbes, who is so prominently identified with this great work. Mr. Tesla believed that we were about to see such great powers transmitted long distances, and over one wire.

Continuing, Mr. Tesla remarked that he had shown things of a more spectacular nature with reluctance, yet forced thereto by the desire to gratify those who had shown their interest and formed so large an audience. A number of experiments were performed not seen in this country before, though some had been shown in England. For instance, a phosphorescent bulb was lighted up by being merely held in the hand, and this was a most successful experiment. Mr. Tesla prefaced it by relating a little anecdote of Lord Rayleigh. When he was in London, remarked Mr. Tesla, with much feeling, he had the pleasure of performing this experiment privately before Lord Rayleigh, and he would always remember the trembling eagerness and excitement with which that distinguished scientist witnessed the lamp light up. The appreciation of such men; said Mr. Tesla, repaid him fully for the pains he had been at in working out these phenomena.

In this experiment a number of tubes were taken and flourished or flashed in various ways, and with the current made intermittent at longer intervals by adjusting the spark-gap. Wonderfully beautiful effects were thus produced, the light of the whirled tube being made to look like the white spokes of a wheel of glowing moonbeams. Then some rectangular tubes were taken and flashed or whirled so as to produce curious designs of luminous lines.

A bulb was shown by Mr. Tesla said by him to be so highly exhausted that when the bulb was merely attached to one terminal of the disruptive discharge coil, it would send the sparks across the outside of the globe to the other terminal, which was on the opposite end, rather than pass through the bulb The bulb in question was painted on one side with a phosphorescent powder, or mixture, and threw a most dazzling light, far beyond that yielded by any ordinary phosphorescence. It was pointed out that there was no difficulty whatever in obtaining powerful phosphorescent effect in this way, and that a practical illuminant on these lines needed merely the perfection of the method of conversion above alluded to.

In conclusion the lecturer made fine cotton-covered wires stretched on a frame over the table luminous so that in the dark they looked like attenuated violet caterpillars yards long ; and then within a large rectangle formed by such wires he flourished tubes in the interspace, these tubes flashing with light wherever waved.

After the lecture, so great was the desire of the public to see Mr. Tesla closer, an informal reception was held in the lobby when several hundreds of the leading citizens seized the opportunity and Mr. Tesla's hand in a very vigorous manner.

It should be added that the Electrical Exchange, of St. Louis, presented Mr. Tesla at the beginning of the lecture with a magnificent floral shield, wrought in white carnations with a border of palms and American Beauty roses. It was about four feet in diameter. In the centre was a circle of red carnations bordering a tablet of white ones, beaing the letters in red $C = \frac{E}{R}$.

Around the circumference were the floral letters: "St. Louis Electrical Exchange 1893."

NOTES.

Tesla Lecture.—Mr. Tesla's lecture at St. Louis was attended by 4,000 people, the great Exhibition Theatre being crowded to suffocation. Mr. Tesla had naturally to confine himself mostly to spectacular effects, which were of a very beautiful description. Prof. Forbes was on the platform. Mr. Tesla said he believed we were about to see great powers transmitted long distances and over a single wire. An enthusiastic reception was held after the lecture.

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The Tesla lecture was a notable feature of the convention. At first it had been proposed to deliver the lecture in a small hall, but the demand for tickets was so enormous, that it was decided, as a matter of sheer necessity, to secure a larger auditorium, and this was found in the Exhibition Theatre, which seats about 4,000 people. It was, of course, practically impossible that all could hear and see; but those who were there could at least say they had seen Mr. Tesla afar off, and witnessed some of his most striking experiments. The hall was crowded to suffocation, and the demand for tickets was so great, that they were selling briskly for three and five dollars on the steps of the hall. Under such circumstances, Mr. Tesla contented himself wisely with showing some of the more "spectacular" of his experiments, and even these were followed at a disadvantage in view of the immense distance from which most of the spectators studied them. After his introduction by Mr. Ayer, the lecturer gave a few minutes to a statement of the conditions involved in his work, and then by means of his high frequency and high voltage currents, aided by disruptive discharge from a condenser through an induction coil—as well as by direct dynamic phenomena, he produced a number of the interesting results that have already made his name famous, and have charmed two worlds. He received, unhurt, currents of hundreds of thousands of volts, lit up tubes and lamps through his body, rendered insulated wires several feet long entirely luminous, showed a motor running under the influence of these million-frequency currents, obtained a number of effects with phosphorescent lamps; and also showed how little in such work the high resistance of the filament had to do with the lighting up of ordinary 50 or 110-volt lamps. His ability to produce such effects, either with a single wire and no return, or without any wires at all, aroused the utmost interest and enthusiasm, and the concluding demonstration literally brought down the house, when he showed how, by simply carrying lamps or tubes into a room or hall where those currents were being developed, illumination was the immediate result.

In his opening remarks Mr. Tesla enlarged upon the grandeur of Nature, and expressed his opinion that the most wonderful of the external influences that affect us is light. Hence it followed that the most wonderful and important of the organs by which these external influences beat in upon us is the eye. Two facts were specially referred to, one of them being that the eye is the only organ capable of being affected directly by the vibrations of the ether. Another fact was that the eye would be able to distinguish objects at almost any distance, were it not for the minute particles and stray gases filling the intervening space. These absorb the energies of the ether vibrations, but in a pure medium they would travel unchecked, and the range of vision would be infinitely greater. Mr. Tesla then alluded to the importance of the part played by the eye in furnishing the race with its ideas and knowledge, and to its vital function in controlling all our motions and actions. From its teaching were derived consciousness, ideas, conceptions that were possible without images—and images involved sight.

By these interesting stages Mr. Tesla led up to the subject of light, and thence to the part of electricity in giving us light. The general aim of the discourse was to show and explain the phenomena due to electrostatic forces, followed by phenomena produced by electro-dynamic agencies; and then, as a third class, the light effects, Mr. Tesla's idea evidently being to give a generalisation of these phenomena, and of their relations. It was stated, parenthetically, with regard to the physiological effects produced with the high tension, high frequency currents employed, that a great amount of energy may be sent into the body of a person by their means, merely because the energy was dissipated laterally from the body and was not passed through the body in the direct manner involved in the use of a low frequency current. It was due to this intense rapidity of vibration that the lecturer was able to receive with impunity currents of as high as 250,000 and 300,000 volts, and of an amount which otherwise administered would kill. The lecturer explained that he had so arranged his apparatus that in case of any failure of any part of it, the current would kindly abstain from killing him, and would only knock him down.

Many of the experiments shown have already been seen either in this country or in Europe, yet there were several novel effects introduced, and even the familiar experiments were performed with apparatus different from that used before. In most of the experiments the ordinary alternating and continuous currents from the central station were used, although Mr. Tesla also had his own special generator running in the basement.

A striking new experiment was to show at the beginning of the lecture the effect of a varying electrostatic stress through the dielectric. This experiment was performed by grasping one terminal of the high tension transformer giving about 200,000 volts pressure, and approaching the other hand to the opposite terminal. Streams of violet light then issued from the fingers and the whole hand. (At the lecture on the preceding Friday at the Franklin Institute in Philadelphia, Prof. Houston noticed these streams of light coming, also, from the lecturer's back, following, roughly, the line of the vertebral column.)

Another experiment was performed showing the action of the air between two condenser plates. By attaching these plates to the high-tension transformer, the whole space between these plates was filled with light, the distance apart being about 10 inches. It was pointed out that these streamers consumed considerable energy and developed abundantly ozone and nitrous acid, and it followed that it was necessary to exclude air from high-tension apparatus.

The action of the air was shown in another very striking experiment. Two incandescent lamps exactly alike, one exhausted, the other not, both of the ordinary 50-volt type, were attached in multiple

arc, and a current vibrating about one million times a second, or thereabouts, was passed through the filament It was demonstrated that the lamp which was exhausted glowed brightly, whereas the other one, in which the filament was surrounded by air, at ordinary pressure, did not glow. Yet the latter lamp got hotter than the other. This showed the great importance of the rarefied gas in the heating of a conductor, and it was pointed out that in incandescent lighting a high resistance filament does not at all constitute the really essential element of illumination along these lines. Also that heavy blocks of metal may be brought to incandescence by minute currents provided they are surrounded by rarefied gas, and provided the potential and frequency of the currents is sufficiently high.

One of the most interesting experiments was the conversion on open circuit. A transformer was taken and the current passed through the high tension winding in such a way that only one terminal was attached to the source of the rapidly alternating current. In spite of this there was a current passing through the primary as though the other terminal was actually attached to the source like an ordinary return circuit. This open circuit transformer contained a secondary low tension winding, and the minute currents passing through the primary were transformed into currents capable of following the ordinary electric wire and lighting up brilliantly an ordinary lamp. It was pointed out that under certain conditions, indeed, such a conversion was quite practicable, and that it can be practised with high economy. It was further pointed out that any kind of device such as motors, &c., may be operated in this manner, with one wire or circuit only.

Mr. Tesla, in the course of his lecture, dwelt upon his method of conversion by means of disruptive discharges from continuous or alternating station supply. There were two kinds of apparatus on the stage, one operated from the alternating circuit and the other from the regular direct current system. A peculiar form of discharger was used, contained in a mica-lined wooden box. The spark-gap was warmed by a small lamp underneath, for the purpose of making the air dielectrically weak. This enabled Mr. Tesla to work with a very long gap, a very sensitive arc, and a comparatively small electromotive force in the gap. The effects obtained were thus augmented very materially. It was pointed out that with this method of conversion there is no difficulty whatever in obtaining sparks of any length. It becomes simply a question of the energy supplied through what distance the spark will be visible. During the lecture, lamps were operated by this method of conversion. An ordinary 100-volt, a 50-volt and a 2-volt lamp were brought up to full candle-power with equal facility. Then a little motor was run by means of these disruptive discharges, it being a phase-motor comprising simply an iron core with a closed secondary coil in it, and a disc armature arranged to rotate above the core. Mr. Tesla remarked rather naively that if the demonstration were not quite equal to the expectation, the long continued and weary work on the development of the invention, besides the inability of the experimenter, might be the cause. He went on, in connection with this, to refer to the transmission of power from Niagara, and gracefully recognised the presence on the platform of Prof. George Forbes, who is so prominently identified with this great work. Mr. Tesla believed that we were about to see such great powers transmitted long distances, and over one wire.

Continuing, Mr. Tesla remarked that he had shown things of a more spectacular nature with reluctance, yet forced thereto by the desire to gratify those who had shown their interest and formed so large an audience. A number of experiments were performed not seen in this country before, though some had been shown in England. For instance, a phosphorescent bulb was lighted up by being merely held in the hand, and this was a most successful experiment. Mr. Tesla prefaced it by relating a little anecdote of Lord Rayleigh. When he was in London, remarked Mr. Tesla, with much feeling, he had the pleasure of performing this experiment privately before Lord Rayleigh, and he would always remember the trembling eagerness and excitement with which that distinguished scientist witnessed the lamp lit up. The appreciation of such men, said Mr. Tesla, repaid him fully for the pains he had been at in working out these phenomena.

In this experiment a number of tubes were taken and flourished or flashed in various ways, and with the current made intermittent at longer intervals by adjusting the spark gap. Wonderfully beautiful effects were thus produced, the light of the whirled tube being made to look like the white spokes of a wheel of glowing moonbeams. Then some rectangular tubes were taken and flashed or whirled so as to produce curious designs of luminous lines.

A bulb was shown by Mr. Tesla, said by him to be so highly exhausted that when the bulb was merely attached to one terminal of the disruptive discharge coil, it would send the sparks across the outside of the globe to the other terminal, which was on the opposite end, rather than pass through the bulb. The bulb in question was painted on one side with a phosporescent powder, or mixture, and threw a most dazzling light, far beyond that yielded by any ordinary phosphorescence. It was pointed out that there was no difficulty whatever in obtaining powerful phosphorescent effect in this way, and that a practical illuminant on these lines needed merely the perfection of the method of conversion above alluded to.

In conclusion, the lecturer made fine cotton-covered wires stretched on a frame over the table luminous, so that in the dark they looked like attenuated violet caterpillars yards long; and then, within a large rectangle formed by such wires, he flourished tubes in the interspace, these tubes flashing with light wherever waved.

After the lecture, so great was the desire of the public to see Mr. Tesla closer, an informal reception was held in the lobby, when several hundreds of the leading citizens seized the opportunity and Mr. Tesla's hand in a very vigorous manner.

It should be added that the Electrical Exchange, of St. Louis, presented Mr. Tesla at the beginning of the lecture with a magnificent floral shield, wrought in white carnations with a border of palms and American Beauty roses. It was about 4 feet in diameter. In the centre was a circle of red carnations bordering a tablet of white ones, bearing the letters in red $c = \frac{E}{R}$.

Around the circumference were the floral letters "St. Louis Electrical Exchange, 1893."

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Ferraris vs. Tesla.

THERE still seems to be a doubt in the minds of some people as to whether it was Tesla or Ferraris who first invented or discovered the rotary field as applied to alternating current motors. There seems to be no question that Ferraris invented it before Tesla; this fact, we believe, Tesla himself admits. But it seems to be equally certain that Tesla invented it independently without any knowledge of Ferraris' work, in proof of which it may be of interest to note here that Prof. Ferraris, with becoming modesty, in a personal conversation with the writer, stated that he believed Tesla to have had no knowledge of Ferraris' work, and was therefore an independent inventor of this principle; he furthermore added that Tesla had developed it far more than he, Ferraris, had, for which he deserved great credit, in addition to having been an independent inventor. Such a statement coming directly from Prof. Ferraris himself ought to relieve any one of a doubt, and ought to close the controversy.

On the Rotary Magnetic Field and Multiphase Alternating Current Distribution.

BY LUDWIG GUTMANN.

In the last few years a great deal of attention has been given to the rotary magnetic field, and a review of the principal workers and their devices may be of special interest. In 1885 we find the alternator almost forgotten. It had been abandoned and was found only in laboratories, but otherwise it had hardly any but historic interest. Very rarely such machines as the Ferranti-Thomson, for incandescent lighting, or a Siemens alternator, for either arc or incandescent work, were met. The continuous current machines monopolized the market. They were the only salable devices for commercial lighting, when, unexpectedly, the great prize of the Turin Exposition of 1884 was awarded to Mr. Lucien Gaulard, of Gaulard & Gibbs, London, an eminent French physicist and chemist, for a distribution over long distances, by means of transformers and alternating currents. This result drew the attention of engineers again to the alternating current generators and high tension distribution, especially as it had been found meantime that, commercially, there were great obstacles in the distribution of low tension continuous currents over great areas. From this time on a great many engineers began to experiment and design transformers, as, for instance, Deri, Zipernowski, Ferranti, Siemens, Hopkinson, Kennedy, Kapp, Mordey and also the writer, who at that time was with Messrs. Gaulard & Gibbs. Among the early workers in America was Mr. Stanley.

It was in the early part of 1885 that Prof. Galileo Ferraris was engaged in testing the efficiency of transformers made by Gaulard & Gibbs, as also those of Ganz & Co., which tests were completed in July of that year. During these experiments the fundamental and far-reaching principles of the rotary magnetic field were developed, which were verified by experiments within the two following months. This eminent scientist did not make a secret of his work of obtaining rotation by alternating currents; on the contrary, he showed the devices and experiments, during the latter part of the year 1885, to many prominent workers, such as Mr. Gaulard (London), Mr. Deri (Budapest), Prof. von Beetz (Munich), Prof. G. Mengarini (Rome), Mr. P. Bellani (Italian representative of the Thomson-Houston Company), and many others. Before that time but a single alternating current had been used and studied, and little was known about it. Here, however, the action and laws of two alternating currents were explained and shown by experiments, which are now familiar to every student in the alternating current field. Prof. Ferraris produced his currents of displaced phase by means of converters; but was this clear sighted man ignorant of the fact that the difference in phase could not be accomplished by any other means than those adopted by him? By no means. He had intended to make modifications by building a generator producing currents of displaced phases and larger motors to be operated thereby, but he had been prevented, partly by reasoning, partly by circumstances.

We have here a similar case to that of Prof. Henry. Working in a scientific laboratory, with its limited means, no changes could be attempted with the Siemens alternator, as the winter term had just begun, and the machine was needed for other work by the students; besides, he was perfectly clear in his mind that the application of special designs of generators and the consequent complication of feeding wires would be a great practical inconvenience, which would tend to complicate the system, and considerably reduce its scope and utility. In spite of the advancements made in recent years, he still now maintains the same view, that the motor to solve the problem should be operative on the present systems of two wire distribution. These considerations, more than any others, may have influenced the professor to delay such special modifications and to produce the rotary magnetic field by the simpler methods within his easy reach in using a transformer or derived circuits. The delay of communicating these experiments to the Royal Academy or otherwise publishing these results for almost three years was due to grave private misfortunes, or troubles, which influenced his mind for a considerable time.

As the transformer system developed during the next few years, the need of a meter made itself felt, and we read in 1887 (I think) in English periodicals remarks to that effect, the Ferranti meter being then but little known and less used. Suddenly the great and slowly progressive work was interrupted by the communication of Prof. Ferraris, on March 18, 1888, to the Academy of Science at Turin, of the laws and actions of his "electro-dynamic rotation by alternating currents," which stirred up all constructing engineers, and brought new life and increased vigor for investigations in this unexplored field.

The publication was soon followed by translations in electric periodicals all over the civilized world. The first appeared on May 18, 1888, in the English "Industries," edited at the time by Mr. Gisbert Kapp. Since then this paper, owing to its extreme simplicity, clearness and importance, has now appeared so often in one form or another that we need not go over the ground once more at this place.

Ferraris' "electro-dynamic rotation" can be condensed into the following short sentence: "Rotation of a magnetic field is the resultant of two or more magnetic or magnetizing forces of variable intensity acting at an angle to one another, whose maxima do not coincide, but whose periods are the same."

Two months later Mr. Tesla described his motor built on the same principles. We have here a great contrast: On the one hand a scientist in a great city of Italy, with limited means, and his only purpose, knowledge, light; on the other hand we find a young experimenter, backed by considerable capital, located in the busy metropolis, New York, where the chief motto is, "Time Is Money," and the principal aim "Dollars and Cents." The object, after having found rotation independently, was to get returns for the experiments by making commercial motors.

The respective characteristics are fully embodied in the important work of these distinguished workers. Prof. Ferraris lays down in beautiful and simple language the fundamental law governing this class of machines, while Mr. Tesla explains the action in his own way, which is not fundamental, but builds machines for practical purpose.

While these two men are the most prominent workers in this field, we have also to consider the work of others. Here we have to name first Mr. Bradley, who obtained a patent for a simple generator in October, 1888. It may be called a universal machine, inasmuch as it can be used as a continuous current generator or for alternating or multiphase currents. However, no statements are made in this patent that he expected rotation, or wished to operate motors by two or three alternating currents of displaced phases. This machine, which may be destined to do before long much valuable service, remained unknown to many, even to American workers, especially as there was no immediate demand for the same.

Naturally after a new subject is thoroughly understood we would expect some one to come to the front with a claim of priority, and sometimes with apparent right. In this instance such claims have been raised by the French engineers, M. de Fonville, M. Lontin and M. Marcel Deprez, and later M. Hasselwander, all of whom obtained rotation by either alternating currents or alternating and pulsating or continuous and pulsating currents. However, the question is not who made the first apparatus, but who understood first the subject, the principle of the device, and who in consequence thereof most benefited the world.

For instance, we name for historical reasons the first attempts in dynamo building, but the credit for fundamental and far-reaching work belongs to much later workers, such as Faraday, Hopkinson, Frohlich and Kapp. Similarly in this case, some early inventors may have built motors or small contrivances which produced rotation, but their work remained unnoticed, because the fundamental principle was either not understood by them or did not receive the deserved prominence. It can hardly be said that it was a fault of the time, because the subject has not been in advance of developments, as in those days we know that arc lamps, and later incandescent lamps, were fed directly by alternators, especially of the Siemens and Ferranti types, and power transmission would have been attempted if there had been motors, or at least if the principle on which these early devices had been built had been understood.

It is therefore no surprise that the work of Prof. Ferraris, when explaining rotation by alternating currents in simple language, and based on principles so familiar to us, should sweep like a cyclone over all the civilized world. It is this work which made the understanding of the Tesla motor so simple. The explanations given by Mr. Tesla are as fundamental. However, the criticism by some English workers in their periodicals is often unjust, and based on observations or conclusions derived from a single diagram or a single patent or paper, and consequently erroneous. The writer himself agrees in many respects with Mr. Kennedy; however, he believes that the criticism is too severe, as it is far easier to improve on the fundamental work of others than to do fundamental work oneself. Besides, only the first of Mr. Tesla's patents are based on the production of rotating the magnetic field. There are, however, enough other ones granted, at least in America, which speak of energizing fields, magnets whose poles, or what is the same, whose magnetic flux, do appear at different times without limitation to rotating fields, as Mr. Tesla himself has shown such magnets in parallel planes, instead of in one single structure.

As regards priority, Prof. Ferraris has the earliest publication and is recognized by most civilized nations as the father of the rotary magnetic field, and even should Tesla's applications for patents be taken into consideration, then, to be just, we would have to consider the unsolicited testimony of engineers like Mr. Deri,* which would give Mr. Ferraris the right to go back to 1885 and Tesla to 1887. However, it is thought that publications only can be looked upon as just, as the main point to be considered at all times is, when the public first was made acquainted with a certain development and derived the benefit therefrom.

However, there is sufficient and distinct merit in the work of either scientist. While Prof. Ferraris is the father of "electro-dynamic rotations," Mr. Tesla is the father of the system of distribution by multiphase currents and its applications.

However, in spite of the many weak points which exist at present in the rotary magnetic field, this principle has not been discovered nor this system of distribution been invented simply to be shelved. They both have come to stay, to form their department in power transmission.

The motor is open to improvements, and so is the system, and therefore Mr. Kennedy's statements must be read with reserve, because the case is by no means as hopeless as he describes it. It is only strange that Mr. Kennedy himself has a use for multiphase currents and combines a number of known devices into a system for commercial distribution. In a recent publication he rejects as hopeless everything else except multiphase currents, and instead of using a Tesla transformer he uses three separate converters, where a slight originality is gained at the expense of 25 per cent. more material.

No doubt it is unpleasant to see that a fundamental worker wishes to have all the glory and ignores the work of others necessary to make more economical machines, but this should not influence us not to fully recognize the importance of his work, even if we can devise a multiphase system without using transformers and not covered by his patents, as by their original design, their merits, or the meritorious results to be accomplished, have been brought to the notice of others.

Mr. Kennedy may abandon the use of a single alternating current for such distribution; others, however, will not do so, but will make use of single phase alternators of a safe potential, feeding by means of transformers high tension alternating currents from a distance into sub-stations and supply, aided by storage batteries, currents required for the devices in use at the locality, either low tension, continuous, alternating or multiphase, or all three if necessary. There is no doubt about it that to-day we can derive from a single alternating current all the various forms of currents; but however grand this distribution may seem, it is too complicated. We need simplification and not complication; therefore we should not strive to accommodate all apparatus now manufactured into one system. The solution lies in a simple alternating current motor. In this field there is an enormous scope, so wide even that in spite of the broad Tesla patents he must accustom himself within a year or two to find motors with a rotary magnetic field not covered by his patents, and some dozen other motors, with and without condensers, adapted to accomplish the same results far more economically than the original Tesla motors. To attack this question successfully, it is necessary to know the whole work of others, then devise other means as original, simple and far from their ideas and work as possible. Having accomplished the building of alternating current motors similar to the continuous current series and shunt motors, we will find the continuous current motors soon restricted to isolated plants, while multiphase or other complicated systems will stand on the level with continuous current distributions.

What Electricity Will do for Us

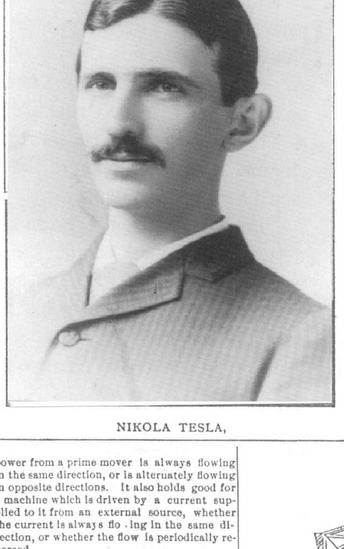
THE SUCCESSFUL UTILIZATION OF NIAGARA POWER—CHEAP TRANSMISSION TO BUFFALO—PROGRESS IN HOUSE-LIGHTING, FACTORY WORK, ETC., ETC.

WRITTEN FOR THE EXPRESS BY MADISON BUELL.

No name is more brilliantly associated with recent progress in electricity than that of Tesla, the Italian who is astonishing the world with his discoveries and wonderful experiments in electrical science. He has given us new thoughts and his experiments have developed and corrected all former notions of the science—given it a new character from that ever before conceived. He has opened a new field of vision, which, in its turn, has to be explored and verified, and which again may lead to newer extensions and developments.

Tesla has, during his many experiments, demonstrated the fact, that one can, under certain conditions, receive unhurt electric currents of hundreds of thousands of volts, and he has lighted up tubes and lamps through his body; rendered long wires entirely luminous; showed motors running under the influence of the million frequency currents; obtained magnificent effects with phosphorescent lamps; and he has often demonstrated how little, in such work, the high resistance of the carbon filament has to do with the lighting up of the ordinary 50 or 110 volt lamp.

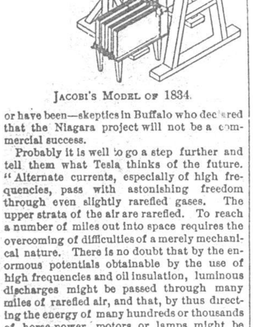
His ability to produce such effects, either with a single wire and no return, or without any wires at all, arouses the utmost interest and enthusiasm wherever witnessed. In regard to the physiological effects produced with high-tension, high-frequency currents, it may be said, that a great amount of energy may be sent into the body of a person by these means, because it is dissipated laterally from the body and not passed through in the direct manner involved in the use of low frequency currents. It is due to the intense rapidity of vibration that Tesla has received with impunity currents as high as 250,000 and 300,000 volts, an amount which otherwise administered would kill him.



NIKOLA TESLA,

Tesla is a firm believer in the transmission of power from Niagara, and believes the time is propitious to see great powers transmitted long distances and over one wire.

If there are any in Buffalo who are skeptical in regard to the success of the transmission of power from Niagara, what will they think or say when they are told that a man like Tesla, says: "the distribution of electrical energy with something like 100,000 volts, and even more, become, at least with high frequencies, so easy that they could hardly be called engineering feats. With oil insulation and alternate current motors, transmissions of power can be effected with safety and upon an industrial basis at distances as much as a thousand miles." Yet there are—



JACOBI'S MODEL OF 1834.

or have been—skeptics in Buffalo who declared that the Niagara project will not be a commercial success.

Probably it is well to go a step further and tell them what Tesla thinks of the future. "Alternate currents, especially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. The upper strata of the air are rarefied. To reach a number of miles out into space requires the overcoming of difficulties of a merely mechanical nature. There is no doubt that by the enormous potentials obtainable by the use of high frequencies and oil insulation, luminous discharges might be passed through many miles of rarefied air, and that, by thus directing the energy of many hundreds or thousands of horse-power, motors or lamps might be operated at considerable distances from stationary sources. Such schemes are mentioned merely as possibilities. We shall have no need to transmit power in this way. We shall have no need to transmit power at all. Ere many generations pass, our machinery will be driven by a power obtainable at any point of the universe. It is a mere question of time, when men will succeed in attaching their machinery to the very wheelwork of Nature."

Prof. Forbes, the consulting electrical engineer for the Niagara project, is impressing upon the English people the importance of their stopping over at Niagara Falls, when they are on their way to visit the Chicago Exhibition. He desires them to see for themselves the way in which the "vast forces are being harnessed to the service of man." He tells them that he has no hesitation in making the statement of a complete success of the utilization of Niagara, and assuring them that the cost at which a horse-power per annum can be sold in the neighborhood of Niagara, or at Buffalo, is "such as to make the enterprise a certain success from a commercial point of view."

In speaking of the electrical part of the scheme, he says: "I feel some diffidence, because we are at the present moment on the eve of settling the type of machinery to be used. I have before me for consideration more than 20 distinct plans of the 5,000 h. p. generators which may be used. Some of these are for continuous currents, others for alternating currents; and while I naturally have definite views as to which of the plans proposed is the most practical, I confess that, even at this time, I have an open mind which would be free to accept anything which seems more valuable than the best design we have received as yet. Of one point I may assure you most definitely, and that is, that there is not the slightest difficulty in making this work successful from an engineering as well as from a commercial point of view. My difficulties have consisted chiefly in the number of different ways by means of which it was possible to attain the results required. The types of machine which have been proposed vary in many essential features, and in none more than in the important item of the weight of the revolving part, which varies in these designs from seven or eight tons up to 60 tons; but it is quite remarkable that in a science of comparatively recent growth, as in the distribution of power electrically, there should be so few differences of opinion as to the means to be adopted, and the character of the machinery to be used. . . . It is consequently a little surprising that electricians are so nearly agreed as to the methods and machinery to be used."

The general reader will observe that Prof. Forbes uses the words "continuous currents" and "alternating currents;" and as Buffalo in the near future is to be the great electrical city of the world, it may be interesting to some of her people to know and for them to understand what these terms mean.

The term "dynamo-electric machine," broadly used, denotes an apparatus in which, by the agency of what is termed electro-magnetic induction, mechanical energy of rotation is converted into the energy of an electric current; or inversely, the energy of such currents is converted into mechanical energy; and the definition holds good whether the current given out by the machine when driven by power from a prime mover is always flowing in the same direction, or is alternately flowing in opposite directions. It also holds good for a machine which is driven by a current supplied to it from an external source, whether the current is always flowing in the same direction, or whether the flow is periodically reversed.

For all practical purposes the term "dynamo-electric-machine" is divided into four classes of machines. First, the dynamo, in which mechanical energy of rotation is converted into the energy of a direct or continuous current. Second, the alternator, in which mechanical energy of rotation is converted into the energy of an alternating current, i. e., flowing alternately in opposite directions. Third, the motor, in which the energy of a direct current is converted into mechanical energy of rotation. And fourth, the alternate current motor, in which the energy of one or more alternating currents is converted into mechanical energy of rotation.

Any one of these four types of apparatus has for its object the conversion of energy from one form into another form. The commercial value of such machines depends upon the ratio between the amount of energy supplied in one form, and the amount obtained in another form. In all classes of machinery losses take place, but in electrical apparatus of this kind the loss is much smaller than in other mechanical appliances.

Dynamos can be built having an efficiency of 90 per cent., whereas in steam engines an efficiency of 75 per cent. is exceptionally high. The dynamo-electric machine is unquestionably the most efficient apparatus at present known in mechanics, and if Buffalo is great now in her days of prosperity, this class of machinery is destined to make her surpassingly great during the next five years.

A trifle over ten years ago, such dynamo-electric machines as were made were of the kind more suitable for the laboratory than for the workshop. They were of small power and imperfectly designed, both electrically and mechanically. They were not made by engineers, but by electricians accustomed to make all kinds of small electric apparatus, and they did not realize the magnitude of the mechanical forces with which they might have to deal in a properly-designed dynamo. After Faraday, in 1831, announced his great discovery of electro-magnetic induction, Pixil produced a magneto-electric machine for alternating and direct currents. He was followed by Henry and Jacobi in 1834. A sketch of Jacobi's motor is given both for comparison and curiosity. Up to 1864 there was a continuous record of improvements, when Pacinnoti made the great invention of the closed armature circuit and commutator; and in 1870 Gramme reinvented the same thing, but Gramme, being a skilled workman, gave practical shape to his invention in the dynamo which bears his name, and which is the prototype of all dynamos with closed-coil armatures.

Today the power of our dynamos and alternators is reckoned by thousands of horse-power. The tendency is in the direction of enormous and powerful machines, and they can only be made in engineering shops fitted with the best of tools and appliances. Apparatus of such magnitude cannot, as in the early days, be made by the "rule of thumb" method of construction. An illustration of the enormous size of the modern dynamo-electric machine of 1893 is given, and the reader may be able to judge of the progress made in the science by comparing it with the Henry apparatus of 1831 [*See page 17.*]

The success of the Niagara project depends upon machinery of this magnitude, and whilst Henry's apparatus is an illustration of the work of a man who studies "science for its own sake," and without regard to practical applications, the modern dynamo-electric machine shows the work of the scientific engineer, who by his knowledge of nature is able to deal with new "engineering problems," and to provide useful solutions when they are presented to him. But an "engineer may be scientific, inasmuch as he has knowledge of nature and the power of applying that knowledge: and he may be practical in the sense that he devises means to attain his ends." But what bears directly upon the "utilization of Niagara," and the success of the scheme may be summed up in the following words: "The complete engineer must give his attention to commercial matters as well; he must know if, when he has devised the means to attain the ends in view, those ends when attained will result in a profit. He must recognize the conditions which render an undertaking so secure that it shall bring in a large return."

Men like Prof. Coleman Sellers, whose knowledge and experience of all classes of machinery; Clemens Herschel, who has devoted his life to the development of hydraulic enterprises; Turretini of Geneva, Burbank and Porter of Niagara Falls and Prof. Forbes of England are not men to engage in such an enterprise as the utilization of Niagara unless sure that it would result in a commercial success.

Prof. Forbes says: "A great number of applications for power have already been received, and it becomes perfectly evident that the establishment of each separate industry will bring to the neighborhood a large number of new industries. Thus we expect very shortly to have a copper refinery for electrolytic processes. This will naturally bring wire manufactories to the spot. Electric cables will also be made there, where the wire can can be obtained cheapest. The wants of the company alone are sufficient to require the establishment of an electrical factory, and the facilities for transporting machinery by land or water will be such as to make it an important center for the manufacture of large electric machinery, either for lighting, for traction or other purposes. And so it appears likely to proceed, the success of one industry leading to the establishment of another, until the whole land of the company, and much more besides, is used up in the raising of what may eventually become the greatest manufacturing center of the United States.

"In order to give facilities of transport to those who establish themselves here, ample wharfage accommodation will be established, a matter which is comparatively easy, since the company owns several miles of river frontage. With the same object in view a terminal railway has been built, and is now at work, connecting the principal streets belonging to the company with the three great lines of railroad which pass beside it. Contracts have already been given out for the construction of laborers' houses, and before long this part of the new city will have made sensible progress.

"The company has also undertaken the water supply of the city, including the old part, which was insufficiently supplied, and they are also dealing with the matter of sewerage.

"Altogether I may briefly state the impression which has been thrust upon me by an examination of the plans and works of the company, in saying that they have taken a most comprehensive view of the situation, and have proceeded up to the present with an amount of caution and foresight that cannot but augur well for the future of the enterprise.

"The Cataract Construction Company has already sunk a shaft sufficient to accommodate three of the 5,000 h. p. turbines which are to be used for the work of distributing light and power. Considerable difficulty was met with in sinking this shaft, by the influx of water through a seam at a depth of about 30 feet below the surface. These difficulties have never interfered with the progress of the work, which has now been successfully carried out. The turbines which are to be used are of 5,000 h. p., revolving at 250 revolutions per minute, of the Girard or impulse type, with a regulator for adjusting the flow of water. Each turbine is double. Attached to the shafts of the turbines are vertical shafts, extending to the surface of the ground, and on the top of these shafts the dynamos are to be mounted, which will transmit electricity, for light and power purposes, to the surrounding districts and to Buffalo. The turbines are from the designs of Messrs. Faesch and Piccard of Geneva, who transmitted the working drawings to America; and the contract for these turbines has now been given out to the I. P. Morris Company of Philadelphia, two turbines having been ordered in the first instance. Twenty of these will be required to utilize the full capacity of the tunnel, which is 100,000 h. p."

The electrical utilization of Niagara, is an assured fact, for all the "fundamental elements required for electrical transmission in a wide range of cases" have been tried with perfect success. They have passed from "experimental investigation into practical engineering." But what a sublime moment it will be for Buffalo, when the victory of grasping and controlling the "waste forces" of Niagara has been won!

What a contrast, the Buffalo of 1793, with Buffalo of 1847 and 1893, will be with that of 1,900! What was Buffalo 95 years ago? "A double log-house, about two squares from Main Street, a little north of Exchange Street, a half log and frame house a little east of the present Mansion House, near Washington Street, a two-story hewed log-house on Exchange Street, from six to eight rods of west of Main Street," which was a tavern kept by a man named Palmer—"an Indian store in a log building on the west side of Main Street north of Exchange Street," and one or two other log-houses, was all of Buffalo in 1798.

Three years afterwards Palmer, who kept the tavern, wrote to Joseph Ellicott the following letter—(this was the first step in an educational line):

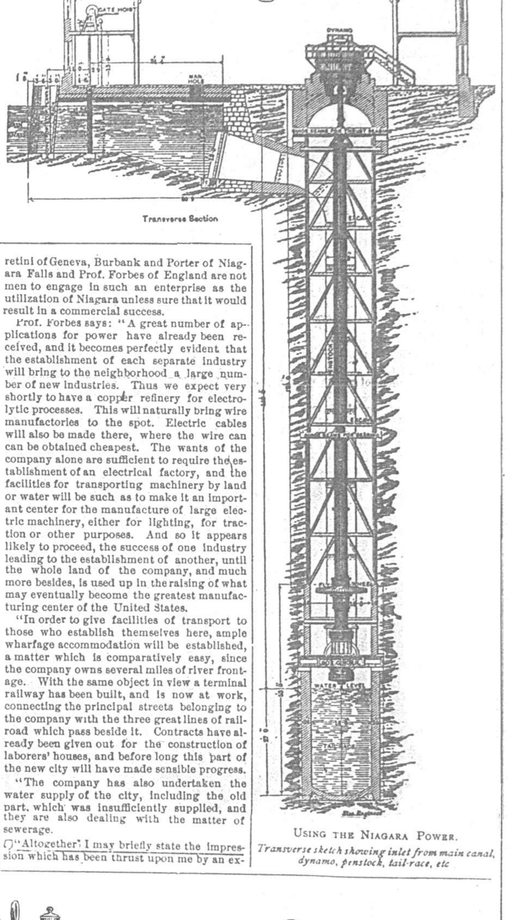
"Sir:—The inhabitants of this place would take it as a particular favor, if you would grant them the liberty of raising a school-house on any lot, in any part of the town, as the New-York Missionary Society have been so good as to furnish them with a school-master, clear of any expense, except boarding, and finding him a school-house; if you will be so good as to grant them that favor, which they will take as a particular mark of esteem."

Palmer added to it: "N. B. Your answer to this would very acceptable, as they had the timber ready to hew out."

Up to 1820, "no lake craft larger than a canoe or French bateau had entered the mouth of Buffalo Creek. The stinted commerce of the lakes had no harbor at the foot of Lake Erie, except Black Rock; vessels discharging freight destined for Buffalo, or taking freight from there, did it at Black Rock, or, laying off the mouth of Buffalo Creek, received and discharged freight by means of small boats."

In 1822 the steamer Superior was built and

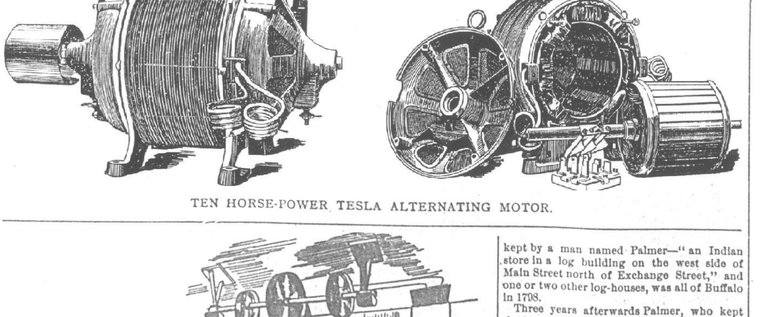
[*Continued on page 3.*]



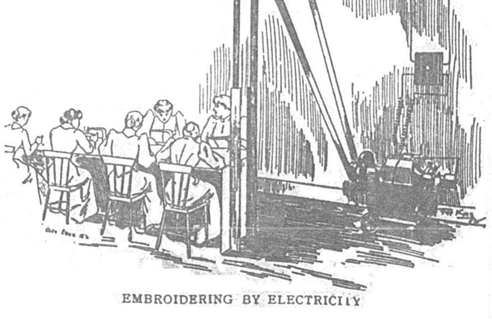
Transverse Section

USING THE NIAGARA POWER.

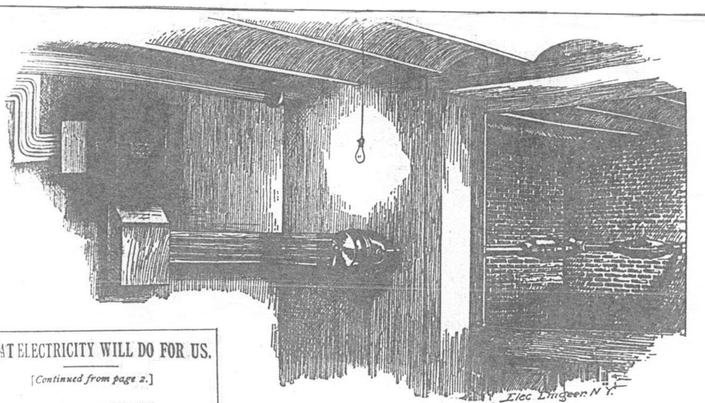
Transverse sketch showing inlet from main canal, dynamo, penstock, tail-race, etc



TEN HORSE-POWER TESLA ALTERNATING MOTOR.



EMBROIDERING BY ELECTRICITY



ENTRANCE OF SERVICE FROM STREET. ABSOLUTE CUT OFF, ETC.

WHAT ELECTRICITY WILL DO FOR US.

[Continued from page 2.]

she was the pioneer of Buffalo commerce.

In 1847 "there were in commission upon the lakes, 98 steamers, 35 propellers, four barges, 82 brigs, 495 schooners, 23 sloops and scows, a total tonnage of 131,460 tons." "The total value of imports of Buffalo from the lakes in 1846 was nearly $20,000,000. The total value of the business of Buffalo and Black Rock, done on the canal, which came from and went on the lakes was $40,000,000. The number of passengers arriving and departing from Buffalo in 1846 was 250,000.

The writer when a boy, in 1846-1847, never neglected to board every steamer or propeller that came into Buffalo Harbor. He has trod the decks of the steamers Superior, Great Western, Julia Palmer, United States, Sultana, Indiana, Illinois, Albany, Empire State and a host of others. Who is there of the present generation that can say the same? Buffalo today is a city of 300,000 inhabitants. What will it be in 1900?

Electricity the prevailing spirit, and Buffalo her especial shrine: the whole region around and above her will be one continual effervescence of energy. At night, she will be so magnificently illuminated that the heavens will be a grand sight, equalling in splendor an auroral display; the gorgeous rays of gold, the phosphorescent sheen of the milky-white cosmos, gleaming bright with rosy blushes, will chase each other up and down the zenith, till the whole heavens shine with the mysterious light; green, yellow and red flames will mingle in every direction, and the constant blaze of the bright flashes of light will fully demonstrate to the surrounding towns that Buffalo is indeed the wonderful Electrical City of the World.

Propositions are now being entertained as to the best electrical method for converting the power and transmitting it in the immediate neighborhood of Niagara Falls and to Buffalo. It is supposed that the rate will be $10 per year per horse-power for 5,000 horse-power or over; $10.50 for 4,500 horse-power; $11 for 4,000 horse-power, and so on down to $21 for 300 horse-power, it being understood that all these estimates are based upon 24 hours' daily use of the current if needed. These rates may be contrasted with the expense of steam-power for a 10-hour day, ranging from $25 to $40. So far as the rates are concerned, it is not known whether these figures include electrical transmission to Buffalo or not; the exact figures will not be given out until the plant is in operation.

Prof. Forbes has given it as his opinion that the power will cost "so much less in Buffalo than that derived from steam plants that it will be an extra inducement" for consumers in this city to use it. "The running expenses" at the Falls "will be a mere nothing; the amount of attention will be small, and the work has been so carefully supervised that it will be almost impossible for any accidents to occur."

The application of electric power from Niagara will enormously increase our growth in every direction. Every industry in the city will have its electric motor, and every day will bring into light some new and novel application of electrical energy. Buffalo and her industries will be the daily topic of conversation of the people in nearly every town and city, and upon their lips will often be heard the words: "Hear ye not the hum of mighty workings?"

The great success of the electric street and suburban roads will be such that the public will, in addition to passenger facilities, demand that of freight transportation. And it will be a daily occurrence to see electric freight cars going over the different roads, destined for the suburbs and outlying towns.

As soon as Hamburg, Williamsville, Lancaster and Tonawanda realize the benefits conferred upon them by the electrical passenger railway, the demand will be made upon such companies for the freight service. It will only be a matter of a few months after these roads are opened for them to secure contracts for carrying the U. S. mails in and out of Buffalo, and the companies deriving Federal protection will be amply repaid thereby.

A road of this character is now in operation from Thomaston to Camden, Me., a distance of nine and one half miles. The style of car used weighs a little over 15 tons and has a carrying capacity of 20,000 pounds. The road itself is built in a most substantial manner, the idea of a freight service having been contemplated from the outset. There is no reason why all the freight traffic between Buffalo and outlying towns should not be done on our electric roads.

When we get our electrical energy from the Falls our machine-shops will be revolutionized. The great mass of leather belting that now fills them, like moving mats of latticework, will be abolished. Electric motors will run the enormous lathes, and also the huge cranes, capable of moving great masses of metal, far beyond anything of a like character at present in use, though we now have them capable of moving over 40,000 pounds with ease. The hot furnaces, foaming boilers and dangerous engines will all be relegated to the scrap pile.

Buildings of any size will have their electric elevators, and one of the most important applications of electrical power will be in the operation of all kinds of elevators and hoisting machines. All of our principal grain elevators with their enormous capacity for handling grain will be thoroughly electrically equipped for that purpose. The liability of elevator fires will be greatly reduced.

The motor will be brought into private houses, where safety and noiselessness are essential, for elevator work.

The electrical pump will become an essential feature wherever it can be used; and no doubt can be entertained that eventually all the pumping of the Niagara water for city purposes will be done by electric-power—power derived from the water itself!

The electrical energy will be used for almost every purpose to which steam is now applied. Our "manufactures and others "mindful of great profits derivable from reduction in expenditures for power," to say nothing of the entire freedom from dirt, oil and smells, will adopt the motor. The long lines of shafting with all the evils of copious lubrication and "costly friction, heavy and expensive belting in complex systems" with large and small pulleys innumerable, will be forever discarded.

There will be a remarkable growth in incandescent lighting, and it will come into constant use in all of our modern residences, not only in those now erected, but in all hereafter to be constructed. The wealthy will desire to "break away from the stiff and conventional ideas embodied in the traditions and practice of what we may call the gas era, and to rescue decorations, books, pictures and tapestries from the quick detriment due to the conditions created by gas in process of consumption."

The architect of today has, for Buffalo, a brilliant opportunity for material improvement, "by studying the highest aesthetic effects that may be reached with correct taste and judgment in this line. Illustrations of what may be done show the advance already made in modern electrical engineering in this direction. Wires from the street may be brought into a vault in the basement or cellar, and are first passed through a switch-coupling; thence carried to the meter, which records the consumption of the current for any and all purposes. The switch should be hermetically sealed, so that water can flow over it or around it without injurious effect. One illustration shows a large hall with a broad stairway set with palms. The lights in the drawing-room and other rooms are controlled from the large switch board shown in this sketch. "The situation is eminently accessible, and yet when the door is closed, the mahogany paneling appears to be intact." When the panel door is open the board is "an ornamental and highly finished piece of work, with polished slate back and all details in brass."



DRAWING-ROOM WITHOUT ELECTRIC FIXTURES: LIGHTED FROM PANELS, ETC.

The exquisite illustration of the drawing-room, "reveals conspicuously an emancipation from all the old ideas prevalent as to methods of lighting, and a very successful experiment in the treatment of light itself, as something fluent and plastic, capable of being distributed for obtaining soft and harmonious effects." Under the regime of electrollers and massive fixtures it could never be obtained. In this drawing-room there is not a single bracket or fixture of any kind; the decorations are white and gold, and the frosted lamps set in the ceiling panels in delicate tulip cups, do not strike the eye individually. "We have not lights, but light." In addition, each of the ornamental lamps disposed of casually about the room carries not only a light under its canopy, but one within the body of the hand-painted vase.

Our architects have in these illustrations an object-lesson of the first importance, and the study of them by the wealthy will teach them what there is in the modern method of utilizing electric light in the House Beautiful, and they can give the freest play to taste and genius.

Some years ago, a statement was made which was deemed a "wild and exuberant flight of fancy," and yet today is a realization.

"It will be possible," wrote this prophet, "for a man to drink at breakfast coffee ground and eat fruit evaporated by electric power. During the morning he will conduct his business with electrically-made pens and paper ruled by electricity, and make his records in electrically-bound books. His seventh-story office, in all probability, being reached by an electric-motor elevator. At luncheon he will be able to discuss sausages, butter and bread, and at night eat ice cream and drink iced water due to the same electrical energy. He will ride all about the place in electric cars, wear shirts and collars mangled and ironed by electric motors, sport in a suit of clothes sewn and a hat blocked by the same means; on holidays ride a merry-go-round propelled by an electric motor, or have his toboggan hauled up the slide with equal facility; be called to church by an electrically-tapped bell, sing hymns to the accompaniment of an electrically-blown organ, be buried in a coffin of electric make, and, last of all, have his name carved on his tombstone by the same subtile, mysterious, all-persuasive and indefatigable agency."

What is this "all-persuasive and indefatigable agency"? The natural sources of energy available for the wants of man are coal and oil pent up in the bowels of the earth, and water accumulated in the highest levels of the land. Energy is expended when coal is burnt and the water falls, and all of our available energy by their use is derived from the sun. Coal is solidified sunlight. Water is condensed sunshine. We mine our coal and liberate our "preserved sunlight," and whenever we can interfere with Nature, we tap our "condensed sunshine," and from the two utilize their energy, for daily use. So, for all practicable purposes, whenever the question is asked, "What is electricity?" it can be answered, "Principally coal, and sometimes water."

"Five pounds of coal consumed in a furnace, per hour flashes 50 pounds of water into steam. The steam in its reconversion to water transfers its energy to a moving mass of machinery, a part of which consists of copper wires forming a portion of an electric circuit. The wires rotate in a magnetic field where work is done on them, and where, in consequence, the mechanical energy of motion is converted into molecular energy of electricity. The five pounds of coal have produced 1¼ h. p., or 1,000 watts in the circuit; in fact, a kilowatt is the scientific unit of power. A watt is the energy expended by an amphere when driven by a volt. It is equivalent to nearly three fourths (actually 0.737) of a foot pound." The amphere is the unit current, and the volt the unit of electrical pressure. A 16-candle lamp requires 100 volts and 0.48 ampheres to bring it into brilliancy. It absorbs 48 watts and therefore 1. c. p. is produced by three watts. A kilowatt hour uniformly expended gives 333 candles continuously, or it will maintain 21 lamps alight; or, if the light be not needed, then the kilowatt of energy can be converted into other forms of energy, as I have already named.

Now, what has all this to do with Buffalo's profit from the utilization of Niagara's power?

How many people in this city realize the fact, or know the total power developed at the falls? How many believe that "4,500,000 h. p. is developed," or that the falls represent "the equivalent of all the steam-power used in the world?"

"It takes five pounds of coal to generate one horse-power for an hour. This water-power is the equivalent of 15,000,000 tons per annum." One is not struck so much by the volume of water that shoots over the precipice, as by the immensity of the power of heat, which is able to evaporate and carry to the great lakes by the winds a volume of water of such magnitude. The enthusiastic spirit of a scientific engineer realizes at once "that the falls is the most gigantic condensing steam engine in the world, of 4,500,000 horse-power. The power in the falls acts as a furnace; the mass velocity of the water acquired by the fall is arrested and converted by fluid friction into molecular velocity, which is heat. The lower river and ocean form the boiler, from which the heated water evaporates; the wind is the engine, by which the steam is carried to the condensers, which are the great lakes. The work done is the work of raising a thousand million pounds weight of steam from the lower river and ocean, to be eventually deposited in the upper lakes every minute of time—not necessarily the same atoms of steam, but their equivalent."

Starting from this grand spectacle of natural force, all other manifestations of force will, when electrically utilized here, set all forces in motion; "not in one way merely, but many ways. It will be as with the weaver's web,

"Where a step stirs a thousand threads,
The shuttles shoot from side to side,
The fibers flow unseen,
And one shock strikes a thousand combinations."

After Buffalo becomes renowned throughout the whole civilized world, by the success of this electrical achievement, what does all the tremendous energy received by her amount to, compared to the principle of the energy exhibited by one of the lowest insects that dances upon God's footstool and charms all human eyes by its luminosity?

There are two spots in the segment of the abdomen of the glow-worm that are more luminous than any other parts, and a constant vibratory motion of this segment emits a light. Its energy is transmitted in the same manner as that of the sun, through an ethereal medium, and it gives light of such a character as to affect the retina of the eye. It is an electrical effect, and it is only one of the many forms that sends it out on its ceaseless journey. The secret workings of the marvelous light contained within the segments of the abdomen of the glow-worm is being imitated, and will yet be the means of obtaining an energy that will light a thousand lamps at a touch.

If we now have one glorious ethereal glow by day, that illumes with its fluid gold, this "world of ours that hangs like a pendant fast by a golden chain in space," when we solve the problem of the glow-worm, then at night we can have "a confluence of ethereal fires that will rival the energy of the light that comes from lamps unnumbered down the steep of heaven."

MADISON BUELL.

SCIENTISTS HONOR NIKOLA TESLA.

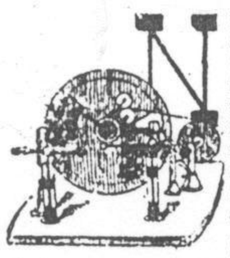
Many of Them Call Him the Most Remarkable Electrician of the Century.

HIS WONDERFUL DISCOVERIES.

He Thinks That the Earth's Electricity Can Be Transmitted Through the Air.

IS AT HEART AN AMERICAN.

What He Has to Say of Electrical Engineering as a Profession for Young Men.



NIKOLA TESLA has been called by scientific men, who do not award praise freely or indiscriminately, "the greatest living electrician." At the recent convention of electricians held in St. Louis a well known electric journal issued daily bulletins or "extras" giving a list of the delegates and distinguished attendants as they arrived at the convention, a programme of the day's proceedings and a special article of immediate interest having reference to the current discussions of the convention.

One evening during the session of the convention Mr. Tesla lectured on some of his recent experiments. The bulletin for that day contained a brief account of his life. So great is the interest taken in this young man that over four thousand copies of the journal containing this biographical sketch were sold upon the streets of St. Louis—something unprecedented in the history of electrical journalism—and in the evening his lecture, in the Grand Music Entertainment Hall, was listened to by a larger audience than had ever been gathered together before in the United States on an occasion of this kind. Many were glad to purchase the complimentary tickets at $4 or $5 apiece.

It is singular that this remarkable man should have come to us from one of the smallest and least known nations of Europe, Montenegro; that he is a young man (only thirty-six years of age), and that the best scientific minds believe he has only begun to give the world the result of valuable researches.

In a recent symposium on the subject of electricity the contributors mentioned his name with a sort of reverence, as one who has an almost magic power over the most hidden secrets of nature. Men in the foremost ranks of science, not only in the United States but in Europe, believe that at no distant day he will announce discoveries which will be as far in advance of our present knowledge of electricity as the telegraph was over the mail coach. He has delivered only three or four lectures—one in Philadelphia, one in St. Louis, another in Paris and another in London—but each lecture has been listened to and applauded by the very crême de la crême of the scientific world.

MODESTY ONE OF HIS VIRTUES.

Another remarkable characteristic about Mr. Tesla—especially when we consider the self-assertive age in which we live—is his modesty. This serves to make him more highly esteemed by his associates and only adds to his renown. His friends might truly exclaim with the old dramatist, "Thy modesty's a flambeau to thy merit."

It is only affirming the truth when it is stated that many of the high compliments he receives annoy him. He honestly does not believe he is entitled to the praise that is continually showered upon him. He is an enthusiastic worker in his profession, but believes that he is only one of the standard bearers in the great march of human progress and that he is as much indebted to other minds who have studied and worked in this new science as others think they are indebted to him. In his famous London lecture, after expressing how deeply he felt the honor of addressing the foremost thinkers of the day, his next sentence showed the character of the man. He said:—

"The results which I have the honor to present before such a gathering I cannot call my own. There are among you not a few who can lay better claim than myself to any feature of merit which this work may contain. I need not mention many names which are world known—names of those among you who are recognized as the leaders in this enchanting science, but one, at least, I must mention—a name which could not be omitted in a demonstration of this kind. It is a name associated with the most beautiful invention ever made. It is Crookes."

Crookes is a writer famous for his descriptions of experiments on radient matter.

A REMARKABLE MOTHER.

Mr. Tesla, like many famous men, had a remarkable mother. She died only two years ago at the age of sixty. She was a simple woman, but in the surrounding territory in which she lived, both far and near, was considered the most remarkable female in the land. She inherited the inventive spirit from Mr. Tesla's grandfather, an inventor and constructor of machinery, who was an exceptionally ingenious man. Old Mrs. Tesla was an indefatigable worker. As a rule she arose at four o'clock in the morning and every day worked until late at night.

The home of the Teslas was in a very wild country, away from any of the conveniences of civilization, and Mrs. Tesla displayed her inventive faculty by constructing nearly all the appliances that were necessary for use in the household, and that, too, without ever having seen patterns from which to make them. For instance, in the matter of weaving she would plant the hemp and flax, get out the fibre, spin thread and then construct the necessary mechanical appliances for weaving, making her own loom and producing for her large family all kinds of cloth from the heaviest, suitable for outdoor garments in the winter, down to the finest pieces, suitable for embroidery work. When she died, so great was she held in esteem, that the whole country for miles around mourned her loss.

Mr. Tesla is such a hard worker that he has little time for social pleasures, if indeed, he has any taste in that direction. He is a bachelor, tall, very spare of build, has dark, deep set eyes, jet black hair and an expression that suggests at once the deep thinker. Though polite and even friendly to newspaper men he has no desire to exploit himself in print. He has been the talk of the scientific world for five years, but the following interview I had with him a few days ago is the first that has ever appeared in any journal:—

TESLA'S AUTOBIOGRAPHY.

My interview with Mr. Tesla commenced with a request that he give me a brief account of his life. He replied:—

"I was born in a little place called Smiljan, on the border country of Austria-Hungary, this special section of territory being known at Lika. I am now thirty-six years of age. I have gone through the educational training that a young man usually receives in Europe, and nearly eighteen years of my life have been spent in schools. I completed my preparatory in Gospich and Carlstatt, and the Polytechnic School in Gratz, Austria. My first employment was in engineering; then I was connected with the Hungarian Government Telegraph Company; afterward I engaged in telephonic work. After this I was interested in the electric light industry, and finally in the transmission of power.

"In 1884 I came to this country, my principal object being to develop certain ideas of inventions which I had vainly tried to develop in Europe. For a while I worked with Edison. In the beginning of 1885 a company was formed in my name. I developed for this company certain inventions, brought out a system of lighting and peculiar appliances belonging to that system. In the following year another company was formed—some time in 1888—the object of which was to introduce a motor of my invention. This motor is based on what is now the well known discovery of the rotating magnetic field, as it is technically called. The best way to give an idea of this discovery to one who is not technically educated in these matters is to put it as follows:—

"A magnet, as it is well known, will attract a piece of wire and hold it. It was my good fortune to discover a method of constructing a magnet in such a way that it would not hold the iron but spin it round and round."

I asked Mr. Tesla to kindly give me some further information in regard to his family.

TESLA'S FAMILY AND HOME.

"My father," he continued, "was a prominent clergyman attached to the Greek Oriental Church; an orator and a writer of note. He was a man highly educated, who spoke fluently a great many languages and also ranked high as a mathematician. He was an omniverous reader and possessed a large library from which it was my privilege to gather a great deal of information during the years of my life spent at home. My uncle, his brother, was another skilled mathematician and professor of a military academy in Austria. He wrote a number of standard works on mathematics.

"My mother died about two years ago. One of her brothers—the youngest—is one of the leading dignitaries in the Greek Oriental Church, having the rank of a cardinal. He is comparatively a young man and a famous orator.

"The section of country in which I was born was an exceedingly wild region—a mountainous and rocky region—with, however, many stretches of beautiful scenery, but poor from the agricultural point of view. In fact, they had a homely though somewhat sacrilegious saying in our land, that when God distributed the rocks over the earth He carried them in a sack, and that when He was above our land the sack broke.

"I was interested in electricity almost from the beginning of my educational career. I read all that I could find on the subject. All the phenomena I witnessed in this line only excited my interest. When I was a mere boy I began to experiment with batteries and induction coils, also with frictional and static machines. When I attended the Polytechnic School at Gratz I began to devote more and more of my time to electrical studies, and after I left the school I may say that, practically, all my time was taken up with the study of electricity.

EVIDENCES OF GENIUS.

"Originally I closely followed up the course of mathematics and physics with the view of graduating as a professor of those sciences. It was, I think, in 1875 or 1876 that we experimented in the Polytechnic School with one of the first practical dynamo machines, which was brought out by M. Gramme, a Frenchman. It occurred to me that a machine might be constructed without the complication of what is technically called commutator and brushes. A commutator is used on electric current generators and motors and on induction coils and elsewhere for changing the direction of currents. The brushes are pieces of copper or other material that bear against the cylindrical surface of the commutator.

"I remember that my professor at that time tried to demonstrate that such a machine was out of the question—in fact, an impossibility. I must confess to a feeling that I, in common with many better men, have had from early youth. As a youth, when I was told that a certain thing was impossible, it only served to arouse within me a spirit of contradiction. In this particular instance I began to think about and to work on a machine made according to the idea that had occurred to me. Day and night, year after year, I worked incessantly.

"After working several years I am happy to say that I was able to produce a motor which is now gradually being introduced in the United States. It is a machine of ideal simplicity, requiring no attention whatever. It should be remembered that in recent years there has been a wonderful advance along almost all electrical lines. What were at one time supposed to be novel or impossible schemes of doubtful accomplishment have proved to be feasible. Encouraged by this condition of affairs I afterward devoted my energies to the production of a more practical illuminant than we have at present and am still pursuing my labors in this direction.

DISCOVERIES ABOUT LIGHT.

"The most wonderful phenomenon in nature is light and the most remarkable feature connected with man's physical life is the eye, which is the only organ capable of being affected directly by the vibrations of the ether. We could see for an immense distance if it were not for gases and particles that fill up the intervening space. These absorb the energies of the air.

"In pursuing this line of work I have had the good fortune to discover some facts, which are certainly novel and which, I am glad to say, have been recognized by scientific men both here and abroad. I think the probable result of these investigations will be the production of a more efficient source of light, thus supplanting the wasteful processes of light production.

"My experiments have been almost entirely confined to alternating currents of high potential. An alternating current is a current changed periodically in direction, and the word potential expresses the force and energy with which these currents are made to pass. In this particular case the force is very great. The fact that a current vibrates back and forth rapidly in this way tends to set up or create waves in the ether, which is a hypothetical thing that was invented to explain the phenomena of light.

"These currents permeate all space—not only the atmosphere, but solids as well—and the waves extend out in concentric spheres indefinitely into space. I utilize these waves in some of my experiments to produce certain phenomena. It is not an electric current in the sense in which we are popularly accustomed to use that term.

TRANSMITTING ENERGY THROUGH AIR.

"These experiments may be further illustrated in this way:—Suppose you throw a stone in the centre of a pool of water. While there would be no transmission of water from the point where the stone landed to the shore yet the waves would reach the shore and exert force on the shore. In a similar way I utilize the force which I obtain in the manner described.

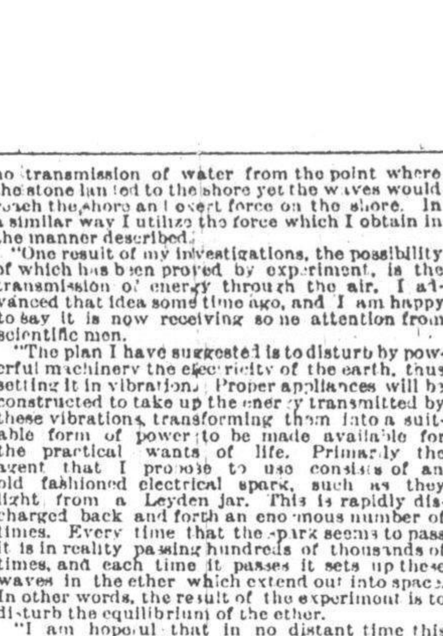
"One result of my investigations, the possibility of which has been proved by experiment, is the transmission of energy through the air. I advanced that idea some time ago, and I am happy to say it is now receiving some attention from scientific men.

"The plan I have suggested is to disturb by powerful machinery the electricity of the earth, thus setting it in vibrations. Proper appliances will be constructed to take up the energy transmitted by these vibrations, transforming them into a suitable form of power to be made available for the practical wants of life. Primarily the agent that I propose to use consists of an old fashioned electrical spark, such as they light from a Leyden jar. This is rapidly discharged back and forth an enormous number of times. Every time that the spark seems to pass it is in reality passing hundreds of thousands of times, and each time it passes it sets up these waves in the ether which extend out into space. In other words, the result of the experiment is to disturb the equilibrium of the ether.

"I am hopeful that in no distant time this method will be deemed worthy of a practical trial. It may be proper to say that among other things I have already demonstrated that we do not need to have two wires to convey an electric current, one wire being sufficient, and, in fact, in some cases, better than two wires."

PHENOMENA OF RESONANCE.

"In the experiments of transmitting power by means of wires the phenomena of resonance is to be observed. If one tuning fork, for instance, is



NIKOLA TESLA.

set into vibration another one of the same pitch, anywhere within reasonable distance, will respond. That is a familiar phenomenon of sound termed resonance. Now, if I set up these etheric vibrations that I speak of to a certain pitch, and my wire is within reach of these vibrations (not necessarily metallically connected) it will respond provided its pitch corresponds with that of the ethoric vibration.

"In that way I obtain energy in another conductor without any metallic connection whatever. Where a single conductor is connected with the source of vibratory energy these waves surge back and forth in that conductor very much as water would in a tube when you reverse it back and forth.

"One of my most interesting experiments is with the incandescent lamp with a single wire to it. I place in the centre of this a piece of very refractory substance of any kind and I connect that with the source of vibratory energy and, with this as a centre, these etheric waves are sent out in concentric spheres and are reflected back from the inner surface of the glass globe upon this small piece of refractory substance. The impact of the molecules of rarified air in this globe create such intense heat in this refractory substance (which is the focus) as to bring it to a high state of incandescence. It is difficult to find a substance that will stand that heat, but I have found some substances that stand it fairly well.

"The transmission through the earth can be effected at any distance; in fact, it matters little whether the distance is small or great.

OF INCALCULABLE VALUE.

"Such a result, if achieved, would of course be of incalculable value to the world and greatly advance the progress of the human race. In this great country (of which I am proud to be a citizen) we have water powers which, in aggregate amount, are sufficient to supply all the needs—in fact, far more than the needs of the whole human race. Take, for instance, Niagara. This famous waterfall is estimated variously all the way from five to six millions horse power. Now, four millions horse power, economically directed, would light every lamp, drive every railroad, propel every ship, heat every store and produce every article manufactured by machinery in the United States.

"It will not be long before we can transmit that power under quite practical conditions, by means of wires with the alternating system, over distances as great as a thousand miles. Engineers now object to the use of very high pressures which would be necessary in such transmissions of power. But I believe the time will come when we shall transmit that energy without any wire.

"Since I have experimentally proved that we can get back electric impulses over one single wire without any return, we may avail ourselves of the earth as a medium of transmission as one difficult obstacle to overcome. In fact, the only serious objection to this scheme is to find a means to localize the energy of vibrations spread over a great area on one spot.

"If this power is to be transmitted across the ocean it will of course involve the expenditure of an enormous quantity of energy. It has been suggested that I can produce a set of lenses made of asphaltum or gutta percha or any other good so-called non conductor of electricity, and can concentrate these rays, or waves, to a focus where their effect would be powerful.

"This plan, if at all practicable, could be applied as well across the Atlantic as it could at shorter distances on land.

METHODS OF PRODUCING LIGHT.

"The present methods of producing light are very wasteful. The electric light is a considerable advance over the gas burner, as far as the energy is concerned; yet even the electric light, as at present produced, is very inefficient. Of the energy of coal we only get about one-third per cent in light in an incandescent lamp; much more, however, in an arc lamp, because in that lamp we can reach a much higher degree of incandescence and because we have the advantage of an economical combination of carbon and oxygen.

"It is true that in recent years some notable improvements have been made in gas burners, and that, from a theoretical point of view, it is possible that a far more efficient burner than the ones at present in use may be produced.

"Probably the most important problem electricians are considering is the production of electricity by an efficient process from coal or other cheap substance; at least, most engineers have this subject in view. I think it is fully as important, and, in the end, perhaps even more important, to apply our skill in discovering how to transmit power from the waterfalls to any distance, for then we would be able to obtain energy without consuming any material, and our coal fields and forests would remain untouched, whereas the production of electricity from some material will involve the rapid consumption of that material.

"One of the problems which is of great importance, and the solution of which we are very likely to witness in a few years, is the transmission of intelligence to any distance without connection. From present experimental evidence it can be quite safely concluded that an attempt to transmit intelligible sounds through the earth from here, for instance, to the European continent without any cable will succeed beyond a doubt. But it is a question whether such a method, which I have advocated for two years, would be available for all purposes, such, for instance, as the use to which the Commercial Cable is put.

"In that case it is questionable whether the scheme would be practicable. But one thing is certain, we will be able to transmit universal time all over the earth, and also be able to send in the same way very important short messages from centre to centre.

AN IMPORTANT FACTOR IN LIFE.

"Electricity is becoming more and more an important factor in our daily life, and more and more closely connected with our comfort. I think, after a considerable lapse of time, it will become practically necessary for our existence. For instance, there is the question of light. The advantages of the electric light are so great that even with the present wasteful methods we have been able to succeed in making practical use of it.

"But what will be our success when we shall be able to produce a hundred times as much light as we do at the present day! To do this is merely a question of time. Electric power is obtained by the use of dangerous, cumbersome and complicated appliances. But we have electric machines now which require no attention whatever and which will, in a few years, supplant all other motors simply because of their higher efficiency and ideal simplicity.

"Even now the cost is very great. Eventually we will be very likely to be able to heat our stoves, warm the water and do our cooking by electricity, and, in fact, to perform any services of this kind required for our domestic needs.

"It has been said that it will be impracticable to heat our houses by means of electricity on account of the great cost of coal; but, as I have said, we are now looking for other methods of getting electrical energy cheap. Even with the present methods any rich man certainly prefers, instead of a stove in his room, to have it warmed by electricity. The method is expensive, but ideal.

"Electric energy can be applied to bicycles, carriages and all sorts of vehicles. It will certainly be applied to rowboats and will probably be so cheap that any man in ordinary circumstances can own a boat and propel it by this means. It would be a gloomy prospect, indeed, for the world if we did not think that this great power will be used to the advantage of the vast majority of the human race and its benefits will not be confined merely to the wealthy.

INTERESTING EXPERIMENTS.

"I am working on some other lines than those of which I have spoken, and if I succeed in my experiments they will be of great interest principally to scientific men. They have also a practical bearing upon what newspapers sometimes call the 'burning questions of the age.' These experiments are quite apart from old notions and the lines which heretofore have taken up my attention. I cannot tell how soon I will complete these experiments.

"Most of my experiments heretofore have involved either rapidly alternating currents of high potential, or have reference to these electrical waves which are set up by alternating currents, and which, if very rapid, will not go through electric batteries at all, but will go through the best insulators. If they are less rapid they will go through electrical conductors fairly well.

"I think I have received full praise for the work in which I have been engaged. There are some experiments which I made a few weeks ago in Philadelphia and St. Louis which interested our scientific men. For their benefit I have a technical account of these experiments in preparation which will be published in the future in the scientific journals.

"Some years ago I demonstrated that a lampate filament could be made to glow from a current from a human hand. The light coming from the hand is produced by the agitation of the particles of molecules of the air. I charge my body with electricity, and from an apparatus which I have devised I can make the electricity vibrate at the rate of a million times a second. The molecules of the air are then violently agitated, so violently that they become luminous, and streams of light then came out from the hand.

"In the same manner I am able to take in the hand a bulb of glass filled with certain substances and make them spring into light; I make light come to an ordinary lamp in a similar way, simply by holding it in the hand.

"When I was in London I had the pleasure of performing one of these experiments privately before Lord Rayleigh. I shall never forget the eagerness and excitement with which that famous scientist saw the lamp light up. I can only say that the appreciation of such men amply repays me for the pains I take in working out such phenomena.

TESLA'S TRIBUTE TO AMERICA.

"When I arrived upon your hospitable shores I eagerly applied myself to work and to learn, and I have persevered in that course. If I have made any special success in this country I attribute it largely to a feature which is characteristic of both the English and American races, that is, their keen and generous appreciation of any work that they think is good.

"I think this country may well boast of its colleges. Take, for instance, Columbia College, Cornell University, Johns Hopkins University or any of the institutions where nowadays electrical engineers are trained.

A GOOD PROFESSION.

"I consider electrical engineering a very good profession for a young man, but it is a profession which requires considerable exercise of intellect. On account of the fascination connected with the study of electricity the profession draws to its ranks an intelligent class of young men.

"Of course it is probably true that the majority of young men who enter the profession are more or less enthusiastic, but in these days, a knowledge of electrical engineering has become almost indispensable for engineers in general.

"Nearly every engineer at the present time follows with great interest its developments. And it is the same with the medical profession, for physicians are realizing more and more that electricity will play a still larger part than it does in the cure of disease.

"For instance, a great amount of electrical energy may be sent into the body by means of high currents, because the energy is dissipated laterally from the body and is not passed through it in a direct manner as it is when a current of low frequency is used. The feeling produced is somewhat different.

"I have also noted the importance of one being prepared for the shock. If you are prepared the effect on the nerves is not nearly as great as when you are not prepared. With these high alternations one feels but little pain in the central portion of the body. A remarkable feature of such high currents is that you feel a burn the moment your hand touches the wire, but beyond that the feeling is scarcely noticeable. I have received currents as high as 30,000 volts, an amount which, if received in any other way, would instantly kill."

APPARATUS FOR PERFORMING THE TESLA EXPERIMENTS.

In performing the Tesla experiments, Prof. M. Schoentjes of the University of Ghent, Belgium, employs a single induction coil connected with a vibrator. The coil is 40 by 20 centimetres, and the energizing current is furnished by a number of accumulators. With this arrangement he produces the following phenomena: (a) Both ends of the secondary remain open. 1. A Geissler tube, with or without electrodes, glows if held in the hand of the experimenter or placed upon a block of paraffine at a distance of thirty or forty centimetres from the coil. 2. The same result is obtained if the tube is held by the experimenter, with one end touching one of the terminals of the secondary; a contact is not required. 3. The same phenomenon is observed when the tube is placed on a block of paraffine, touching with one of its ends one terminal of the secondary coil. (b) Leave one of the terminals of the secondary open, and attach the other to a sheet of iron suspended from the ceiling by a non-conductor. 1. Connecting the open terminal to a vacuum bulb having one electrode and a rectilinear carbon filament, the latter glows. 2. A Crookes tube prepared with phosphorescing powder glows when the experimenter holds it below the suspended sheet of iron. 3. The tube becomes luminous when placed on a block of paraffine below the iron sheet. (c) The two terminals of the secondary are connected by a metallic conductor having a spark gap. A vacuum tube glows in the neighborhood of the coil. Using the same arrangements as described under (c), but connecting one of the terminals to the metal sheet, it is found that vacuum tubes glow if placed either directly under the metal sheet or near it. These experiments succeed at such a low rate of vibration as five oscillations per second, and using a much smaller inductorium than the coil the dimensions of which have been described.

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The first issue of									
1881	contained	28	different	adv'ts.	1888	cont'ined	175	different	adv'ts.
1882	"	45	"	"	1889	"	234	"	"
1883	"	63	"	"	1890	"	289	"	"
1884	"	82	"	"	1891	"	325	"	"
1885	"	100	"	"	1892	"	316	"	"
1886	"	138	"	"	1893	"	317	"	"
1887	"	154	"	"					

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Tesla and His Work.

ELSEWHERE in to-day's issue will be found a highly interesting interview with Mr Nikola Tesla taken from one of our enterprising daily contemporaries. Mr. Tesla, in his own graceful way, tells the story of his life and the history of some of his more important inventions. Perhaps there is no living scientist in whose life and work the general public takes a deeper interest, especially in this country. One of the evidences of his popularity is the wide circulation of THE ELECTRICAL WORLD Daily Bulletin on the evening of his lecture at the recent convention at St. Louis, to which reference is made in the opening paragraphs of the *Herald* article.

Nikola Tesla and His Wonderful Discoveries.*

Nikola Tesla has been called by scientific men, who do not award praise freely or indiscriminately, "the greatest living electrician." At the recent convention of electricians held in St. Louis, a well known electric journal, issued daily bulletins or "extras" giving a list of the delegates and distinguished attendants as they arrived at the convention, a programme of the day's proceedings and a special article of immediate interest having reference to the current discussions of the convention.

One evening during the session of the convention Mr. Tesla lectured on some of his recent experiments. The bulletin for that day contained a brief account of his life. So great is the interest taken in this young man that over four thousand copies of the journal containing this biographical sketch were sold upon the streets of St. Louis—something unprecedented in the history of electrical journalism—and in the evening his lecture, in the Grand Music Entertainment Hall, was listened to by a larger audience than had ever been gathered together before in the United States on an occasion of this kind. Many were glad to purchase the complimentary tickets at $4 or $5 a piece.

It is singular that this remarkable man should have come to us from one of the smallest and least known nations of Europe, Montenegro; that he is a young man (only thirty-six years of age), and that the best scientific minds believe he has only begun to give the world the result of valuable researches.

In a recent symposium on the subject of electricity the contributors mentioned his name with a sort of reverence, as one who has an almost magic power over the most hidden secrets of nature. Men in the foremost ranks of science, not only in the United States but in Europe, believe that at no distant day he will announce discoveries which will be as far in advance of our present knowledge of electricity as the telegraph was over the mail coach. He has delivered only three or four lectures—one in Philadelphia, one in St. Louis, another in Paris and another in London—but each lecture has been listened to and applauded by the very creme de la creme of the scientific world.

MODESTY ONE OF HIS VIRTUES.

Another remarkable characteristic about Mr. Tesla—especially when we consider the self-assertive age in which we live—is his modesty. This serves to make him more highly esteemed by his associates and only adds to his renown. His friends might truly exclaim with the old dramatist, "Thy modesty is a flambeau to thy merit."

It is only affirming the truth when it is stated that many of the high compliments he receives annoy him. He honestly does not believe he is entitled to the praise that is continually showered upon him. He is an enthusiastic worker in his profession, but believes that he is only one of the standard bearers in the great march of human progress and that he is as much indebted to other minds who have studied and worked in this new science as others think they are indebted to him. In his famous London lecture, after expressing how deeply he felt the honor of addressing the foremost thinkers of the day, his next sentence showed the character of the man. He said:

"The results which I have the honor to present before such a gathering I cannot call my own. There are among you not a few who can lay better claim than myself to any feature of merit which this work may contain. I need not mention many names which are world known—names of those among you who are recognized as the leaders in this enchanting science, but one, at least, I must mention—a name which could not be omitted in a demonstration of this kind. It is a name associated with the most beautiful invention ever made. It is Crookes."

Crookes is a writer famous for his descriptions of experiments on radiant matter.

A REMARKABLE MOTHER.

Mr. Tesla, like many famous men, had a remarkable mother. She died only two years ago at the age of sixty. She was a simple woman, but in the surrounding territory in which she lived, both far and near, was considered the most remarkable female in the land. She inherited the inventive spirit from Mr. Tesla's grandfather, an inventor and constructor of machinery, who was an exceptionally ingenious man. Old Mrs. Tesla was an indefatigable worker. As a rule she arose at four o'clock in the morning and every day worked until late at night.

The home of the Teslas was in a very wild country, away from any of the conveniences of civilization, and Mrs. Tesla displayed her inventive faculty by constructing nearly all the appliances that were necessary for use in the household, and that, too, without ever having seen patterns from which to make them. For instance, in the matter of weaving, she would plant the hemp and flax, get out the fibre, spin thread and then construct the necessary mechanical appliances for weaving, making her own loom and producing for her large family all kinds of cloth from the heaviest, suitable for outdoor garments in the winter, down to the finest pieces, suitable for embroidery work. When she died, so great was she held in esteem that the whole country for miles around mourned her loss.

Mr. Tesla is such a hard worker that he has little time for social pleasures, if, indeed, he has any taste in that direction. He is a bachelor, tall, very spare of build, has dark, deep set eyes, jet black hair and an expression that suggests at once the deep thinker. Though polite and even friendly to newspaper men, he has no desire to exploit himself in print. He has been the talk of the scientific world for five years, but the followlwing interview I had with him a few days ago is the first that has ever appeared in any journal:

TESLA'S AUTOBIOGRAPHY.

My interview with Mr. Tesla commenced with a request that he give me a brief account of his life. He replied:

"I was born in a little place called Smiljan, on the border country of Austria-Hungary, this special section of territory being known as Lika. I am now thirty-six years of age. I have gone through the educational training that a young man usually receives in Europe, and nearly eighteen years of my life have been spent in schools. I completed my preparatory in Gospich and Carlstatt, and the Polytechnic School in Gratz, Austria. My first employment was in engineering; then I was connected with the Hungarian Government Telegraph Company; afterward I engaged in telephonic work. After this I was interested in the electric light industry, and finally in the transmission of power.

"In 1884 I came to this country, my principal object being to develop certain ideas of inventions which I had vainly tried to develop in Europe. For a while I worked with Edison. In the beginning of 1885 a company was formed in my name. I developed for this company certain inventions, brought out a system of lighting and peculiar appliances belonging to that system. In the following year another company was formed—some time in 1886—the object of which was to introduce a motor of my invention. This motor is based on what is now the well known discovery of the rotating magnetic field, as it is technically called. The best way to give an idea of this discovery to one who is not technically educated in these matters is to put it as follows:

"A magnet, as it is well known, will attract a piece of wire and hold it. It was my good fortune to discover a method of constructing a magnet in such a way that it would not hold the iron, but spin it round and round."

I asked Mr. Tesla to kindly give me some further information in regard to his family.

TESLA'S FAMILY AND HOME.

"My father," he continued, "was a prominent clergyman attached to the Greek Oriental Church, an orator and a writer of note. He was a man highly educated, who spoke fluently a great many languages and also ranked high as a mathematician. He was an omnivorous reader and possessed a large library from which it was my privilege to gather a great deal of information during the years of my life spent at home. My uncle, his brother, was another skillled mathematician, and professor of a military academy in Austria. He wrote a number of standard works on mathematics.

"My mother died about two years ago. One of her brothers—the youngest—is one of the leading dignitaries in the Greek Oriental Church, having the rank of a cardinal. He is comparatively a young man and a famous orator.

"The section of country in which I was born was an exceedingly wild region—a mountainous and rocky region—with, however, many stretches of beautiful scenery, but poor from the agricultural point of view. In fact, they had a homely though somewhat sacrilegious saying in our land, that when God distributed the rocks over the earth He carried them in a sack, and that when he was above our land the sack broke.

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"I remember that my professor at that time tried to demonstrate that such a machine was out of the question—in fact, an impossibility. I must confess to a feeling that I, in common with many better men, have had from early youth. As a youth, when I was told that a certain thing was impossible, it only served to arouse within me a spirit of contradiction. In this particular instance, I began to think about and to work on a machine made according to the idea that had occurred to me. Day and night, year after year, I worked incessantly.

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"In pursuing this line of work I have had the good fortune to discover some facts, which are certainly novel and which, I am glad to say, have been recognized by scientific men both here and abroad. I think the probable result of these investigations will be the production of a more efficient source of light, thus supplanting the wasteful processes of light production.

"My experiments have been almost entirely confined to alternating currents of high potential. An alternating current is a current changed periodically in direction, and the word potential expresses the force and energy with which these currents are made to pass. In this particular case the force is very great. The fact that a current vibrates back and forth rapidly in this way tends to set up or create waves in the ether, which is a hypothetical thing that was invented to explain the phenomena of light.

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* From the New York *Herald*, April 23, 1893.

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"These experiments may be further illustrated in this way: Suppose you throw a stone in the centre of a pool of water. While there would be no transmission of water from the point where the stone landed to the shore, yet the waves would reach the shore and exert force on the shore. In a similar way I utilize the force which I obtain in the manner described.

"One result of my investigations, the possibility of which has been proved by experiment, is the transmission of energy through the air. I advanced that idea some time ago, and I am happy to say it is now receiving some attention from scientific men.

"The plan I have suggested is to disturb by powerful machinery the electricity of the earth, thus setting it in vibration. Proper appliances will be constructed to take up the energy transmitted by these vibrations, transforming them into a suitable form of power to be made available for the practical wants of life. Primarily the agent that I propose to use consists of an old-fashioned electrical spark, such as they light from a Leyden jar. This is rapidly discharged back and forth an enormous number of times. Every time that the spark seems to pass it is in reality passing hundreds of thousands of times, and each time it passes it sets up these waves in the ether which extend out into space. In other words, the result of the experiment is to disturb the equilibrium of the ether.

"I am hopeful that in no distant time this method will be deemed worthy of a practical trial. It may be proper to say that among other things I have already demonstrated that we do not need to have two wires to convey an electric current, one wire being sufficient, and, in fact, in some cases, better than two wires.

PHENOMENA OF RESONANCE.

"In the experiments of transmitting power by means of wires the phenomena of resonance is to be observed. If one tuning fork, for instance, is set into vibration another one of the same pitch, anywhere within reasonable distance, will respond. That is a familiar phenomena of sound termed resonance. Now, if I set up these etheric vibrations that I speak of to a certain pitch, and my wire is within reach of these vibrations (not necessarily metallically connected) it will respond provided its pitch corresponds with that of the etheric vibration.

"In that way I obtain energy in another conductor without any metallic connection whatever. Where a single conductor is connected with the source of vibratory energy these waves surge back and forth in that conductor very much as water would in a tube when you reverse it back and forth.

"One of my most interesting experiments is with the incandescent lamp with a single wire to it. I place in the centre of this a piece of very refractory substance of any kind and connect that with the source of vibratory energy, and, with this as a centre, these etheric waves are sent out in concentric spheres and are reflected back from the inner surface of the glass globe upon this small piece of refractory substance. The impact of the molecules of rarified air in this globe creates such intense heat in this refractory substance (which is the focus) as to bring it to a high state of incandescence. It is difficult to find a substance that will stand that heat, but I have found some substances that stand it fairly well.

"The transmission through the earth can be effected at any distance; in fact, it matters little whether the distance is small or great.

OF INCALCULABLE VALUE.

"Such a result, if achieved, would, of course, be of incalculable value to the world and greatly advance the progress of the human race. In this great country (of which I am proud to be a citizen) we have water powers which, in aggregate amount, are sufficient to supply all the needs—in fact, far more than the needs—of the whole human race. Take, for instance, Niagara. This famous waterfall is estimated variously all the way from five to six millions horse power. Now, four millions horse power, economically directed, would light every lamp, drive every railroad, propel every ship, heat every store and produce every article manufactured by machinery in the United States.

"It will not be long before we can transmit that power under quite practical conditions, by means of wires with the alternating system, over distances as great as a thousand miles. Engineers now object to the use of very high pressures which would be necessary in such transmissions of power. But I believe the time will come when we shall transmit that energy without any wire.

"Since I have experimentally proved that we can get back electric impulses over one single wire without any return, we may avail ourselves of the earth as a medium of transmission as one difficult obstacle to overcome. In fact, the only serious objection to this scheme is to find a means to concentrate the energy of vibrations spread over a great area on one spot.

"If this power is to be transmitted across the ocean it will, of course, involve the expenditure of an enormous quantity of energy. It has been suggested that I can produce a set of lenses made of asphaltum or gutta percha or any other good so-called non-conductor of electricity, and can concentrate these rays, or waves, to a focus where their effect would be powerful.

"This plan, if at all practicable, could be applied as well across the Atlantic as it could at shorter distances on land.

METHODS OF PRODUCING LIGHT

"The present methods of producing light are very wasteful. The electric light is a considerable advance over the gas burner, as far as efficiency is concerned; yet even the electric light, as at present produced, is very inefficient. Of the energy of coal we only get about one-third per cent. in light in an incandescent lamp; much more, however, in an arc lamp, because in that lamp we can reach much higher degrees of incandescence and because we have the advantage of an economical combination of carbon and oxygen.

"It is true that in recent years some notable improvements have been made in gas burners, and that, from a theoretical point of view, it is possible that a far more efficient burner than the ones at present in use may be produced.

"Probably the most important problem electricians are considering is the production of electricity by an efficient process from coal or other cheap substance; at least, most engineers have this subject in view. I think it is fully as important, and, in the end, perhaps even more important, to apply our skill in discovering how to transmit power from the waterfalls to any distance, for then we would be able to obtain energy, without consuming any material, and our coal fields and forests would remain untouched, whereas the production or electricity from some material will involve the rapid consumption of that material.

"One of the problems which is of great importance, and the solution of which we are very likely to witness in a



Nikola Tesla.

few years, is the transmission of intelligence to any distance without connection. From present experimental evidence it can be quite safely concluded that an attempt to transmit intelligible sounds through the earth from here, for instance, to the European continent without any cable will succeed beyond a doubt. But it is a question whether such a method, which I have advocated for two years, would be available for all purposes, such, for instance, as the use to which the Commercial Cable is put.

"In that case it is questionable whether the scheme would be practicable. But one thing is certain, we will be able to transmit universal time all over the earth, and also be able to send in the same way very important short messages from centre to centre.

"Electricity is becoming more and more an important factor in our daily life, and more and more closely connected with our comfort. I think, after a considerable lapse of time, it will become practically necessary for our existence. For instance, there is the question of light. The advantages of the electric light are so great that even with the present wasteful methods we have been able to succeed in making practical use of it.

"But what will be our success when we shall be able to produce a hundred times as much light as we do at the present day? To do this is merely a question of time. Electric power is obtained by the use of dangerous, cumbersome and complicated appliances. But we have electric machines now which require no attention whatever, and which will in a few years supplant all other motors simply because of their higher efficiency and ideal simplicity.

"Even now the cost is very great. Eventually we will be very likely to be able to heat our stoves, warm the water and do our cooking by electricity, and, in fact, to perform any services of this kind required for our domestic needs.

"It has been said that it will be impracticable to heat our houses by means of electricity on account of the great cost of coal; but, as I have said, we are now looking for other methods of getting electrical energy cheap. Even with the present methods any rich man certainly prefers, instead of a stove in his room, to have it warmed by electricity. The method is expensive, but ideal.

"Electric energy can be applied to bicycles, carriages and all sorts of vehicles. It will certainly be applied to rowboats and will probably be so cheap that any man in ordinary circumstances can own a boat and propel it by this means. It would be a gloomy prospect, indeed, for the world if we did not think that this great power will be used to the advantage of the vast majority of the human race and its benefits will not be confined merely to the wealthy.

INTERESTING EXPERIMENTS.

"I am working on some other lines than those of which I have spoken, and if I succeed in my exepriments they will be of great interest principally to scientific men. They have also a practical bearing upon what newspapers sometimes call the 'burning questions of the age.' These experiments are quite apart from old notions and the lines which heretofore have taken up my attention. I cannot tell how soon I will complete these experiments.

"Most of my experiments heretofore have involved either rapidly alternating currents of high potential, or have reference to these electrical waves which are set up by alternating currents, and which, if very rapid, will not go through electric batteries at all, but will go through the best insulators. If they are less rapid they will go through electrical conductors fairly well.

"I think I have received full praise for the work in which I have been engaged. There are some experiments which I made a few weeks ago in Philadelphia and St. Louis which interested our scientific men. For their benefit I have a technical account of these experiments in preparation which will be published in the future in the scientific journals.

"Some years ago I demonstrated that a lampate filament could be made to glow from a current from a human hand. The light coming from the hand is produced by the agitation of the particles of molecules of the air. I charge my body with electricity, and from an apparatus which I have devised I can make the electricity vibrate at the rate of a million times a second. The molecules of the air are then violently agitated, so violently that they become luminous, and streams of light then came out from the hand.

"In the same manner I am able to take in the hand a bulb of glass filled with certain substances and make them spring into light; I make light come to an ordinary lamp in a similar way, simply by holding it in the hand.

"When I was in London I had the pleasure of performing one of these experiments privately before Lord Rayleigh. I shall never forget the eagerness and excitement with which that famous scientist saw the lamp light up. I can only say that the appreciation of such men amply repays me for the pains I take in working out such phenomena.

TESLA'S TRIBUTE TO AMERICA

"When I arrived upon your hospitable shores I eagerly applied myself to work and to learn, and I have persevered in that course. If I have made any special success in this country I attribute it largely to a feature which is characteristic of both the English and American races; that is, their keen and generous appreciation of any work that they think is good.

"I think this country may well boast of its colleges. Take, for instance, Columbia College, Cornell University, Johns Hopkins University or any of the institutions where nowadays electrical engineers are trained.

A GOOD PROFESSION.

"I consider electrical engineering a very good profession for a young man, but it is a profession which requires considerable exercise of intellect. On account of the fascination connected with the study of electricity the profession draws to its ranks an intelligent class of young men.

"Of course it is probably true that the majority of young men who enter the profession are more or less enthusiastic, but in these days a knowledge of electrical engineering has become almost indispensable for engineers in general.

"Nearly every engineer at the present time follows with great interest its developments. And it is the same with the medical profession, for physicians are realizing more and more that electricity will ply a still larger part than it does in the cure of disease.

"For instance, a great amount of electrical energy may be sent into the body by means of high currents, because the energy is dissipated laterally from the body and is not passed through it in a direct manner as it is when a current of low frequency is used. The feeling produced is somewhat different.

"I have also noted the importance of one being prepared for the shock. If you are prepared the effect on the nerves is not nearly as great as when you are not prepared. With these high alternations one feels but little pain in the central portion of the body. A remarkable feature of such high currents is that you feel a burn the moment your hand touches the wire, but beyond that the feeling is scarcely noticeable. I have received currents as high as 300,000 volts, an amount which, if received in any other way, would instantly kill."

Tesla.—A long and interesting interview with Mr. Nikola Tesla, with an account of his work and history, is given in the New York *Herald* for April 23, and is reproduced in the *Electrical World* of the 29th. His great idea is to disturb by powerful machinery the electricity of the earth, setting it in vibration. Proper appliances would take up the energy transmitted by these vibrations, and he is hopeful that the time is not far distant for giving this method a practical trial. One wire will only be necessary. He even believes the time may come when Niagara's energy will be transmissible without wires. He thinks we might telegraph direct right through the earth; universal time could be thus established, and short important messages could be transmitted simultaneously over the world. A great amount of energy can be sent into the human body by means of high currents, because the energy is dissipated laterally. Mr. Tesla notices also the importance of being prepared for a shock, when the effect on the nerves is not nearly so great. He has received currents of a pressure as high as 300,000 volts with high alternations without harm, streams of light coming from his hand. He thinks the problem of utilising waterfalls to be as important or even more important than that of attempting to obtain electricity direct from coal, for then we have energy without consuming material, and the forests and earth remain untouched.

American Institute Of Electrical Engineers - Transactions
May 17, 1893

A lecture delivered at the Tenth General Meeting of the American Institute of Electrical Engineers, Columbia College, New York, May 17, 1893. President Houston in the Chair.

PRACTICAL ASPECTS OF LOW FREQUENCY ELECTRICAL RESONANCE.

BY M. I. PUPIN, PH. D., COLUMBIA COLLEGE.

Mr. President and Gentlemen of the Institute:—A large part of the subject of the following discourse was discussed by me, but in a different way, in three papers. Two of these appeared in the April and May numbers of the *American Journal of Science*. The third will appear in the June number of the same journal. The method which I have adopted in the following discussion seemed preferable to the mathematical method which I followed in those papers. It is probably just as exact, and certainly a much clearer way of viewing the variable flow of electricity, especially those features of it, which have a more or less direct practical bearing.

1. On the Natural Period of an Electrical Circuit.

An electrical circuit possessing self-induction and capacity behaves in a great many respects as a body does in consequence of its inertia and elasticity. The fundamental reason for this analogy is simply this:—The electromagnetic energy of a coil through which a current flows, has all the characteristic properties of the kinetic energy of a moving body, whereas the energy of the static charge of a condenser has all the characteristic properties of the potential energy of a strained elastic body. If the neutral state of such an electrical circuit is disturbed, it will return to it again after performing a certain number of oscillations about the position of its neutral state. But a return to the neutral state is impossible until the energy which is spent upon the circuit to disturb its neutral state has left the circuit, or to use a more technical expression, until the energy has been dissi-

pated or given off to some other circuit. The two principal causes which produce dissipation and compel the circuit to return to its neutral state again, are frictional resistances and radiation. Just as in the case of vibrating bodies, so also in the case of electrical oscillations, losses due to radiation, especially when no other electrical circuits are near, are exceedingly small when the oscillations are slow. In Herzian oscillations they are quite considerable. In oscillations of the Tesla frequency they are probably not negligible. My remarks refer to electrical oscillations of long period, therefore losses due to frictional resistances are the only losses which I shall consider. Consider now an electrical circuit consisting of a coil A and a condenser B (Fig. 1) in series with it. It is a circuit with localized self-induction and capacity. I trust that my discussion will lose as little in its generality as it will in its practical bearing if I confine it to such circuits only.

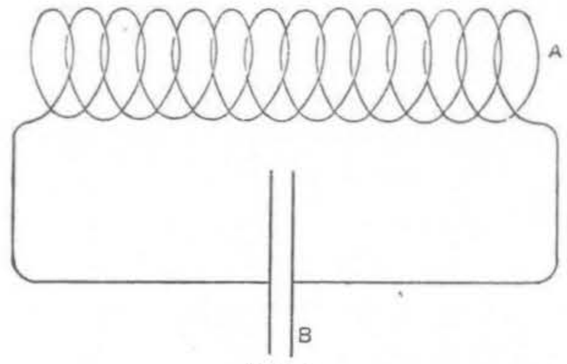

FIG. 1.

Let a sudden electrical impulse disturb the neutral state of this circuit; electrical oscillations will result. These oscillations follow laws practically identical with the laws of the motion of a slowly vibrating body. Their period is constant, as we all know, and it is in general completely determined by *the electromagnetic moment of inertia* and the *dielectric elasticity* of the circuit—that is, by its coefficient of self-induction and its capacity. When, however, frictional losses due to ohmic resistance, magnetic and dielectric hysteresis are large, then the period of this circuit is no longer defined by the self-induction and capacity alone, but it is also influenced by these frictional losses.

When ohmic resistance and hysteresis losses are small enough, then the natural period of the circuit is given by the well-known formula

$$T = \frac{2\pi}{10^8}\sqrt{L\,C}$$

an impulse, say a tap with the finger, and then listen to the vibrations, which in general will last for several minutes, and give us sufficient time to make up our minds as to what the vibrations sound like. In examining the pitch of an electrical circuit it is more convenient to adopt a different method. The reason is that as a rule electrical oscillations are, as pointed out in the example above, much more damped, so that the oscillations resulting from a single impulse would not last long enough to give us sufficient time to see what they look like, or to listen and hear what they sound like. The method suggested by the stroke of a violin bow over the string is preferable. The stroke of the bow produces a series of impulses which quickly succeed each other and maintain the string in uniform vibration. It is interesting now to observe that the same thing can be done with an electrical circuit. Consider the circuit A B C Fig. 4. The condenser B represents the tension on the violin string, coil A represents its inertia. The air-gap C stands for the point where the bow by its stroke excites

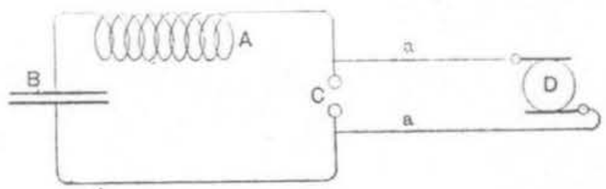

FIG. 4.

the string. If you now wish a musician who plays with a one-sided stroke, use a high potential direct current generator D, and for an alternating stroke substitute an alternator. The discharges at the air-gap C succeeding each other quickly enough, and at proper intervals will maintain in the circuit A B C practically uniform electrical oscillations. This is one of Tesla's favorite circuits, and I have no doubt but that he will accomplish great things with it yet.[1] Bring a few turns of wire of a telephone circuit into inductive influence of this circuit, and you will have in the telephone a musical note of exactly the same pitch as the pitch of the electrical oscillations in the circuit A B C. The note is not perfectly pure. It is marred by the noise of the spark discharge of the air-gap C. Neither is the note of the violin string pure; there is always more or less of the scraping noise of the bow. Just as it is necessary to keep the bow well rosined

1. It must be observed, however, that Hertz, in 1887, produced his oscillations by a circuit of this identical form.

so as to give it a good grip upon the string, so it is necessary to apply a strong current of air or the action of some other of Tesla's devices upon the air-gap C, otherwise an arc is formed and the generator D loses its grip upon the circuit A B C.[2] If we had a number of different coils with condensers like A and B alongside of each other, and arranged in such a way as to be able to place them at will, now the one and now the other, and now again a number of them in multiple under the action of the electrical bow which the generator D keeps moving over the air-gap C and at the same time vary the capacities, we should be able to change the electrical vibrations of our system with that ease, precision and grace which the violin player displays when with the one hand he guides his obedient bow, while the busy fingers of the other hand glide over the trembling strings, eliciting from them delightful notes which blend into pleasing harmonies. So with our system of properly tuned electrical circuits, we could produce harmonies, but they would be harmonies of silence, harmonious oscillations in the ether that affect neither eye, nor ear, nor taste, nor smell. But bring a part of a telephone circuit into inductive action of our harmonic system, and let a skilled experimentalist manipulate a properly constructed keyboard which controls the coils and condensers of the various circuits, and harmonies which before were as silent as the grave, will now agitate the responsive diaphragm of the telephone and produce music that could be made to re-echo in every telephone in the United States.

But after all, such an arrangement when used for such a purpose, would be a mere toy in comparison to the purpose for which our distinguished colleague, Mr. Tesla, employs it. To convert high-potential but small current electrical energy into low-potential big current energy, or *vice versa*, accompanied by all possible variations in the frequency of oscillations was the purpose for which Mr. Tesla constructed the device. To a physicist who delights, not less than the engineer, in neat, simple devices for the accomplishment of big and brilliant effects this device of Tesla naturally appeals more than all his other ingenious inventions. Many a delightful hour have I spent in watching experiments on a circuit like the one in Figure 4. The

2. The importance of blowing out the arc for the production of powerful oscillations seems to have been first recognized by H. Classen, Wiedemann Annal. d. Physik und chemie, Band xixxx, p. 647, 1890.

coil A consisted of a short, stout copper wire; the condenser B consisted of a battery of Leyden jars, which my distinguished teacher, Professor Rood, of Columbia College, kindly lent me. The wires *aa* were thin copper wires connecting the air-gap C to the poles of an induction coil which is now in the hospital. It is a delightful sight to see the stout wire aglow under the powerful agitation of the rapid oscillations, whereas the thin wires *aa* adjoining them remained perfectly cool. Twist now the thick wire A into a few convolutions, say ten or twelve, and surround them by a few hundred turns of fine wire and you will have the now well-known oscillatory transformer with which Mr. Tesla and Professor Elihu Thomson produced some brilliant effects, a transformer that will give you any number of volts especially if,—and now I am going to touch a point which forms the central point of my discourse,—especially if the thin wire coil contains *capacity in series with it, so that the natural period of this circuit is the same as the period of the thick wire coil, that is if the two circuits are in resonance.*

4. On Resonance.

Here again I have borrowed a term employed in music. But a few simple considerations will show you that it is very natural that I should, for the phenomena of sound and those of oscillatory flow of electricity are governed by nearly the same laws. Very high frequency electrical oscillations would in all probability be identical with light, as first announced by immortal Maxwell. It is, therefore, not surprising to find that low frequency electrical oscillations should resemble so much the other group of oscillatory phenomena which next to light pleases our senses best, namely, the phenomena of sound, especially agreeable sound, that is music.

To gain a clear conception of what is meant by electrical resonance consider the following simple mechanical analogon—I call it the *torsional pendulum*:—I used it often with my students in discussing alternating current phenomena and they liked it very much. A heavy bar A (Fig. 5) is suspended on a stiff elastic wire B, which is attached to a plate C whose weight may be neglected. This plate C slides in a groove *aa* which in consequence of friction acts like a brake. Suppose now that the friction between C and *aa* is such that when the angular velocity of C is ω the rate at which heat is generated by the friction between C and

aa is equal to $\omega^2 R$ where R is independent of the angular velocity. This torsional pendulum resembles then very much an electrical circuit having localized self-induction, capacity and ohmic resistance. The moment of inertia of A, the elasticity of B, and the friction in C act exactly the same as the coefficient of self-induction of the coil, the capacity of the condenser, and the ohmic resistance of the circuit. Let $\frac{1}{B}$ stand for the elastic capacity of the wire, that is if the wire be twisted through an angle θ, then the moment of the elastic force which opposes this twisting is $\frac{\theta}{B}$. Let I stand for the moment of inertia of the weight A, then as long as the frictional resistance is within cer-

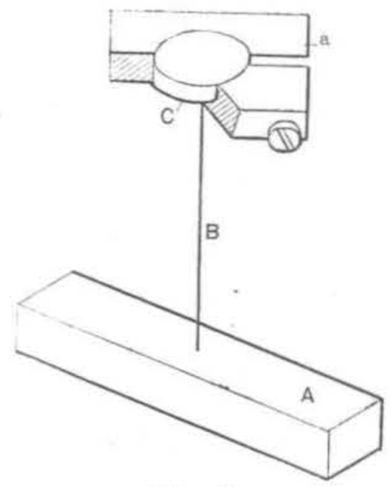

Fig. 5.

tain limits we shall have for the natural period of the pendulum

$$T = 2\pi \sqrt{I \times B}.$$

You see that this expression is exactly the same as the one which expresses the natural period of the circuit in terms of its coefficient of self-induction and capacity.

If this pendulum is set in motion by a single impulse it will oscillate with a constant period. The first elongation will be largest, and the successive elongations will be smaller and smaller, just as represented in Fig. 2, until the pendulum is reduced to rest again. This will happen when the energy of the impulse has been entirely dissipated into heat, which is the work done against frictional resistances in the break at *C*. The smaller this frictional resistance, the longer will the pendulum swing in consequence of the im-

pulse, before it is reduced to rest. On the other hand we can increase the resistance in C to such an extent as to make the swing a-periodic or dead beat, as is for instance the case in the Weston voltmeters and ammeters.

Repeat the impulse at regular intervals, alternating them, the pendulum will keep on swinging; but you can easily see that if the intervals of the impulses are measured off in such a way that every time the pendulum passes through its position of equilibrium, the impulse strikes it, and strikes it in the direction in which the pendulum is moving, then the amplitude of the swing will be much larger than if the intervals of the impulse are not measured off in such a way. In other words when the period of the impulses is the same as the natural period of the pendulum then the swing is largest. The impulses are said then to *be in resonance* with the pendulum.

The same effect will be produced if for the impulses we substitute a periodically but gradually alternating force, say a simple harmonic force, having the same period as the natural period of the pendulum.

Such a force when acting upon the torsional pendulum just described will continually increase the amplitude of the swing, until the swing is so large that the work done during a swing against the frictional resistances, is just equal to the work of the moving force during that time. From that point on, the pendulum will swing with constant amplitude. It is evident, therefore, that the larger *the amplitude of the moving force and the smaller the frictional resistances, the larger will be the amplitude of the swing.* But a large amplitude implies two things:—1st, A *large torsional reaction* in the suspension wire, and secondly, a *large velocity* whenever the pendulum passes through its position of equilibrium.

The bearing of this mechanical analogon upon the electric curcuit having self-induction and capacity is very direct, as I shall presently point out. Let a simple harmonic E. M. F. $E \sin pt$. act upon such a circuit. I shall presently consider a complex harmonic E. M. F., and also circuits possessing Foucault current losses, and losses due to magnetic and dielectric hysteresis. They will form the last, and in my opinion the most important part of my discourse. A simple harmonic E. M. F. acting upon an *elastic electrical circuit* in which the only frictional losses are those due to ohmic resistance, will when its period is the same as the natural

period of the circuit, that is when *it is in resonance with the circuit*, continually increase the amplitude of the electric displacement, that is the amplitude of the condenser charge and therefore also of the current, until the work done against the ohmic resistance is exactly equal to the work of the impressed E. M. F. From this point on the amplitude of the current will remain constant and equal to the amplitude of the impressed E. M. F. divided by the ohmic resistance. Or, to state it in terms which are more generally employed: *Capacity and self-induction neutralize each other when the circuit is in resonance with the impressed* E. M. F.

It is evident also that in a resonant flow, there can be no difference in phase between the current and the impressed E. M. F. Since in this case the current at any moment depends on the E. M. F. and the resistance, and on nothing else.

It is clear, however, that if losses due to Foucault currents, magnetic and dielectric hysteresis are present, then the current cannot be made equal to the ratio between the E. M. F. *and the ohmic resistance by any combination of capacity and self-induction, although as a simple reflection will show, the difference in phase between the current and the* E. M. F. *may be reduced to zero in this case also,*[1] *in which case we should have no false current, as it is generally called.* I shall presently discuss this point a little more fully.

5. Resonance in Circuits with an Impressed Complex Harmonic Electromotive Force.

If the impressed E. M. F. is a complex harmonic, then the circuit may be brought into resonance with any of the component harmonics. I have an apparatus here which is capable of producing E. M. F.'s of almost any complexity. I call it an *electrodynamic current interruptor*, for want of a better name. It consists of a phosphor-bronze wire, the vibrator, a, b, e, (Fig. 6), stretched between the poles of a Weston horseshoe magnet d. A short, thin, amalgamated copper wire b, the dipper, is soldered on the vibrator. The vibrator is stretched like the wire of a monochord, over two hard rubber bridges a e, and its tension can be varied by a screw and lever f. The dipper e whenever it

1. Professor Duncan, of Johns Hopkins University informed me yesterday that he deduced the same result in the course of an investigation, a short account of which he read before this Institute at its General Meeting in Chicago in 1892, "Note on some Experiments with Alternating Currents." TRANSACTIONS, vol. ix, p. 179.

dips into the mercury cup closes an electrical circuit $F\,f\,e\,b\,c\,g\,A$, and the vibrator is then repelled upward by the force of repulsion between the magnet and the current flowing through the vibrator. One gravity cell f is sufficient to work this apparatus. It is evident that the fundamental period of the interrupted current will be equal to the period of the vibrator. To change this period, say to make it equal to the period of this tuning fork, which is 256 complete vibrations per second, I simply strike the tuning fork, hold it then near my ear and by turning the screw f of the stretching lever I vary the tension of the vibrator until the rate of the vibrator and that of the tuning fork are in perfect unison, which can be easily recognized by watching the beats. This whole process of tuning takes up, as you see, only

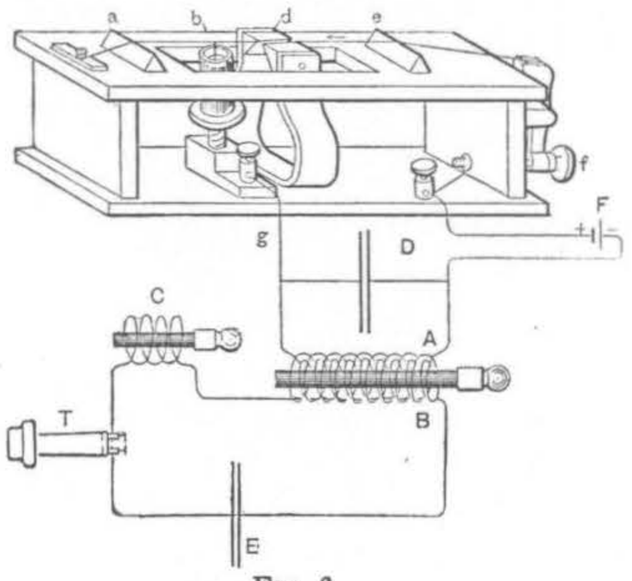

FIG. 6.

a few seconds. In series with the cell F and the vibrator, we have a small coil A, containing a well packed bundle of very thin iron wire, and in shunt with A is a condenser D. This condenser performs the function of bringing this primary circuit into partial resonance with the vibrator which is recognized by the circumstance that at the moment of resonance the spark at the dipper is a minimum.

A simple reflection will show you that the current generated by this interrupter is a complex harmonic. To analyze it into its component harmonics I shall adopt the method employed in acoustics.

A complex sound is analyzed by the well-known resonators of Helmholtz. These resonators are constructed in such a way that

they will respond to one vibration only, and also in a measure to its upper harmonics. To any other vibration they are practically mute. By a number of such resonators we can find out, in the manner first pointed out by Helmholtz, all the vibrations which are contained in a complex sound.

The secondary circuit B C T E, given in the diagram of Fig. 6, performs the function of such a resonator, it is in fact *an adjustable electrical resonator;* C is a small auxiliary coil which you see here; E is a Marshall condenser, and T is a telephone whose note tells me to which of the component harmonics the electrical resonator responds. The telephone is silent now, at any rate as far as you can tell, because the condenser plugs are all out. Now, with this plug, I insert a small capacity. The note which you hear is evidently much higher than even the octave of the vibrator. The electrical flow in the resonating circuit is approximately the same as if we had in it a simple harmonic E. M. F. of the same frequency as this note. I insert another plug, so as to increase the capacity. The note which you now hear is deeper. The difference between the two notes is rendered very striking by making and breaking the contact of the second plug in rapid successions, as I do now. The sound of the two notes, succeeding each other at regular intervals, resembles very much the sound of bagpipes. I insert another plug, so as to increase the capacity still more. The note which you now hear is still deeper. It is the note of the fundamental electrical vibration, which is the same as the vibration of the vibrator. I know that, because, as I continue inserting more and more plugs, you do not perceive any further change in the sound. The capacities which I introduced by the three plugs are to each other very nearly in the ratio of $1 : 9 : 25$, hence the frequencies of the three harmonics contained in the impressed E. M. F. and which I have detected by the resonating secondary circuit are to each other in the ratio of $1 : 3 : 5$.

The impressed E. M. F. can therefore be written

$$E = E_1 \sin pt + E_3 \sin 3\,pt + E_5 \sin 5\,pt.$$

Still higher harmonics are present, but they are too weak to be heard all over this room.

I shall presently discuss a method by means of which we not only detect the presence of these harmonics, as I have just done by means of this telephone, but also determine the relative

strength of each. The method imitates in a certain measure Prof. Langley's bolometric method of determining the distribution of energy in the spectrum of a given complex luminous vibration.

Before making the next step in my discourse I wish to call your attention to an application of resonant circuits (in connection with the electro-dynamic interrupter) to a method of producing simple harmonic currents of constant and easily determinable frequency.[1] I simply tune the vibrator by means of a standard tuning fork, and then weed out the upper harmonics by successive transformations. In this connection I ought to mention that Professor Duncan of Johns Hopkins University informed me several weeks ago that he was also weeding out harmonics. I now remember that I got the expression "weeding out" from him, but I have used it in my papers on "Low Frequency Resonance" without giving him credit for this beautifully selected expression.

6. On the Resonant Rise of Potential.

The question arises now, how are we to tell experimentally whether a circuit is in resonance to an impressed E. M. F. or not? Several methods suggested themselves to my mind in the course of my work. I selected the one which appeared to me to be the most sensitive and most interesting. *It also suggests a new way of transforming electrical energy which some day may perhaps be of some practical importance.* I wish to discuss this method now, but only very briefly.

As I observed before in the discussion of the motion of the torsional pendulum, represented in Fig. 5, when the moving force and the pendulum are in resonance then both the amplitude of oscillation and the amplitude of the velocity reach their maximum value. And so it is also with a circuit possessing self-induction and capacity. By varying gradually the one or the other, the current (which corresponds to the velocity of the pendulum) will continually increase. But the difference of potential in the condenser (which corresponds to the elastic reaction of the suspension wire) will also increase continually. When the point of resonance has been reached then evidently both the current and the difference of potential in the condenser have reached

1. Pupin, "Electrical Oscillations of Low Frequency and their Resonance," *American Journal of Science*, April, 1893.

their maximum values. This maximum difference of potential in the condenser can be many times greater than the impressed E. M. F., because just as in the case of the torsional pendulum the elastic reaction of the suspension wire is an accumulative effect of the moving force, so in the electrical circuit, the potential difference in the condenser is an accumulative effect of the impressed E. M. F. Now since a resonant electrical flow, which we have just considered, consists simply of a transformation of electrokinetic into electrostatic energy, and *vice versa*, during each half period accompanied by a frictional loss due to ohmic resistance, it is evidentthat the amplitudes of these two kinds of energies must be equal to each other, that is, we shall have in the usual notation

$$\tfrac{1}{2} P^2 C = \tfrac{1}{2} L \frac{E^2}{R^2}.$$

But since owing to resonance we have $p^2 L C = 1$, the preceding relation reduces to

$$P^2 = p^2 L^2 \frac{E^2}{R^2} \quad \text{or} \quad P = p L \frac{E}{R}.^{(1)}$$

It is evident, therefore, that with a little more than ordinary frequency, say 350 periods per second, and an inertia coil of considerable self-induction and small resistance high potentials can be obtained in the condenser by bringing the circuit in resonance with the impressed E. M. F.. *Connecting, therefore, the condenser to a voltmeter we can tell very accurately when in the course of our tuning of the circuit we have reached the point of resonance, because, as I shall presently show you, the voltage goes up very rapidly when the condenser capacity or the self-induction are near the point of resonance. It is this electrometric method which I have employed in my investigations on "Low Frequency Resonance."*[2]

The same method can be, and has been employed by several investigators in the study of Herzian oscillations.

To show you how strong this resonant rise of potential can be I have within the last few days wound these two inertia coils (see coil a' b' in Fig. 8) and borrowed this most excellent mica condenser from our well-known electrician, Mr. Wm. Marshall, for which kindness I feel very grateful to him. The impressed E. M. F. is ob-

1. This relation was first obtained, I believe, by Prof. Oliver Lodge. (See a letter by Prof. O. Lodge, London *Electrician*, April 24th, 1891.)
2. *American Journal of Science*, April, May and June, 1893.

tained in the following way: A small 16-pole alternator running at about 2800 revolutions per minute and generating an E. M. F. of about 600 volts feeds the primary of this small transformer (*c d*, Fig. 8.) Diagram Fig. 7 gives the form of armature A and field B of

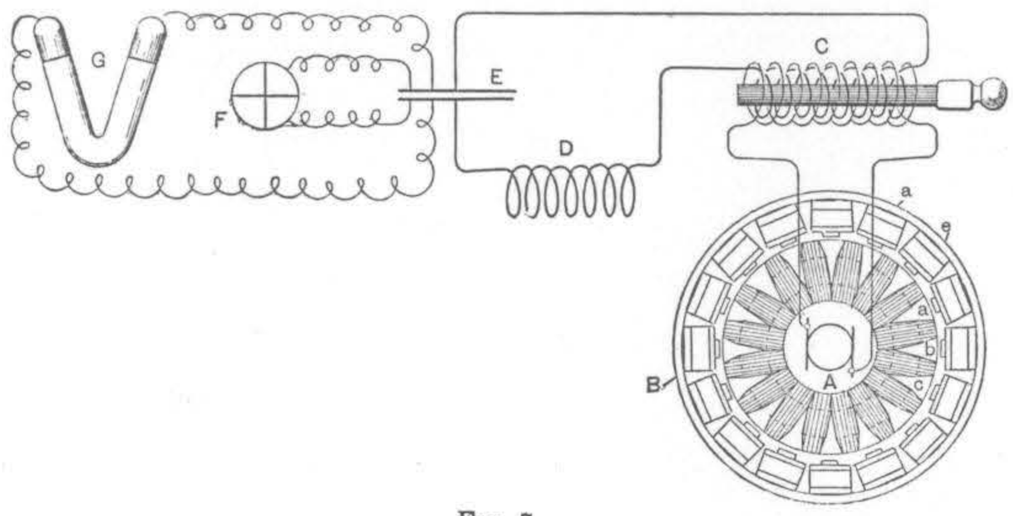

FIG. 7.

the machine. Coils *a b c d e* show how the machine is wound. The transformer consists of a hard rubber spool wound with about 3,000 turns (Fig. 8) of No. 20 A. W. G. wire for the primary. The secondary *h k* consists of about 500 turns of No. 16 wire. A well packed bundle *e* of very fine iron wire is the iron core.

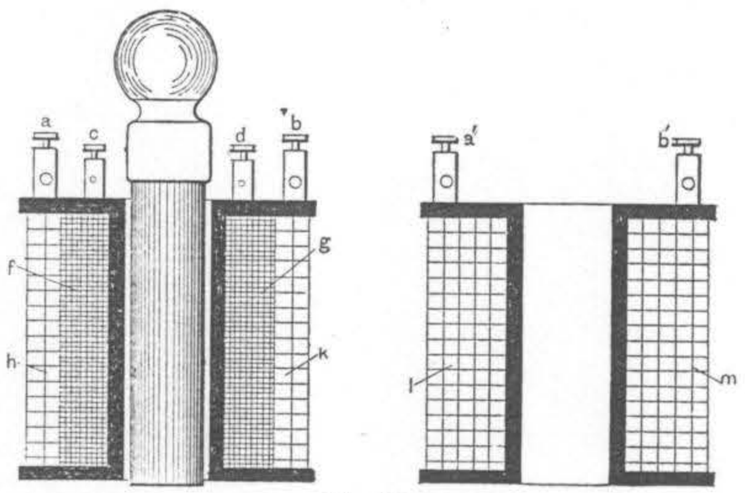

FIG. 8.

This transformer is indicated by C in Fig. 7. In series with the secondary we have inertia coils D and the above mentioned mica condenser E of 0.2 M. F. capacity. The inertia coils consist of hard rubber spools like *a' b'* Fig. 8 wound with No. 14 wire. The

total self-induction of the secondary circuit is about 1 henry, *without iron in the inertia coils*. The poles of the condenser E are connected to a Sir William Thomson electrostatic voltmeter F and also to a vacuum tube G with condenser electrodes, that is to say tinfoil coatings on the outside of the tube. (Indicated by the shaded part in the diagram.) I now start the machine and by weakening the field of the driving motor, I gradually increase the speed of the machine. As you see the voltmeter needle is steadily advancing with the speed. To get the greatest deflection of the needle I ought to have about 350 periods per second. Now I shall advance to very near this speed. The voltmeter indicates now 2,000 volts. The impressed E. M. F. in this secondary resonating circuit is only about 100 volts. Instead of increasing the speed so as to reach the point of perfect resonance I prefer to leave the speed constant, and by gradually inserting these five iron wires to increase the co-efficient of self-induction until that value is reached which with the given speed and capacity brings the circuit in resonance with the impressed E. M. F. I am doing this now and watching the voltmeter needle at the same time. Now the voltmeter indicates 3,000 volts, which is 30 times the value of the original E. M. F. This is the point of resonance, because if I push the iron wire lower, the needle goes back. The point of resonance is very sharply defined, because the slightest motion of the iron wire one way or the other makes quite considerable difference in the reading of the voltmeter. The point of resonance can be shown to a large audience like this much more easily by connecting the poles of the condenser to the tinfoil electrodes of the vacuum tube G. A discharge starts in this tube at about 2,000 volts. Now as I insert these iron wires into the inertia coil you see the intensity of the discharge increases. [The room was darkened.] The point of maximum resonance is clearly marked by the intensity of the discharge, as you see. Now I insert the iron wire too far; as you see the discharge is stopped. I can start it again by raising the iron and stop it again by taking the iron wire entirely out, as you see.

By working with high frequencies and small ohmic resistance any voltage within practical limits can be obtained. Ohmic resistance, however, is not the only thing which limits the resonant rise of potential. *Dielectric hysteresis* and the *peculiar behavior of iron when under the inductive action of a rapidly alternating current*, modify this rise very much. The other day I employed

this home-made condenser in parallel with that Marshall mica condenser. I obtained only 2,000 volts rise, whereas preliminary calculation led me to expect at least 4,000 volts. *But the smell of melting wax reminded me forcibly of the cause of this discrepancy. The home-made condenser got so hot in about two minutes that all the wax* (which when boiling hot was compressed between its mica plates to drive out the air and moisture) *between its plates was melted.* The energy which was thus used up in overcoming the dielectric hysteresis of the wax had prevented the resonant rise from reaching that value which it ought to have reached according to calculation. Taking this condenser out and using the mica condenser alone the rise went right up to a point considerably above 3,000 v. Paraffin and glass behave in a similar way *So that owing to dielectric hysteresis alone the resonant current* (which takes place when capacity and self-induction neutralize each other) *is never equal to the electromotive force divided by the ohmic resistance, and it can be very much less. The presence of iron is incomparably more powerful in destroying the resonant rise of current and potential, as will be seen presently. This is very unfortunate in view of the brilliant expectations which not a few electricians hoped to realize from the employment of condensers in the running of alternating current machinery.*

It is well to observe here that if we substitute a Weston voltmeter for the Thomson Electrostatic Voltmeter F Fig. 7, then we shall have practically the condenser in parallel with the inertia coils. It is easy to see from purely theoretical considerations that the resonant rise will be less in this case. Experiments show that the rise can be then very much less if the resistance of the voltmeter circuit is reduced. *The bearing of this observation on the so-called Ferranti effect with and without a load in the mains needs, I venture to suggest, no further discussion.*

7. Effect of Iron on the Resonant Rise of Potential.

I have already remarked that iron behaves in a peculiar manner when under the inductive action of a resonant flow of electricity. Allow me to call your attention to the diagram of Fig. 9. This curve was obtained with the machine and the circuits which are given in Fig. 7. Except that the inertia coil D had smaller self-induction. Keeping the speed of the machine and the self-induction of the circuits constant, the difference of potential in

the condenser was varied by varying gradually the capacity of the condenser. Taking then the capacities for abscissæ and the corresponding voltmeter readings for ordinates, the curve in Fig. 9 was obtained. As you see the curve has two maxima. The corresponding capacities are to each other as 1 : 9. Hence the

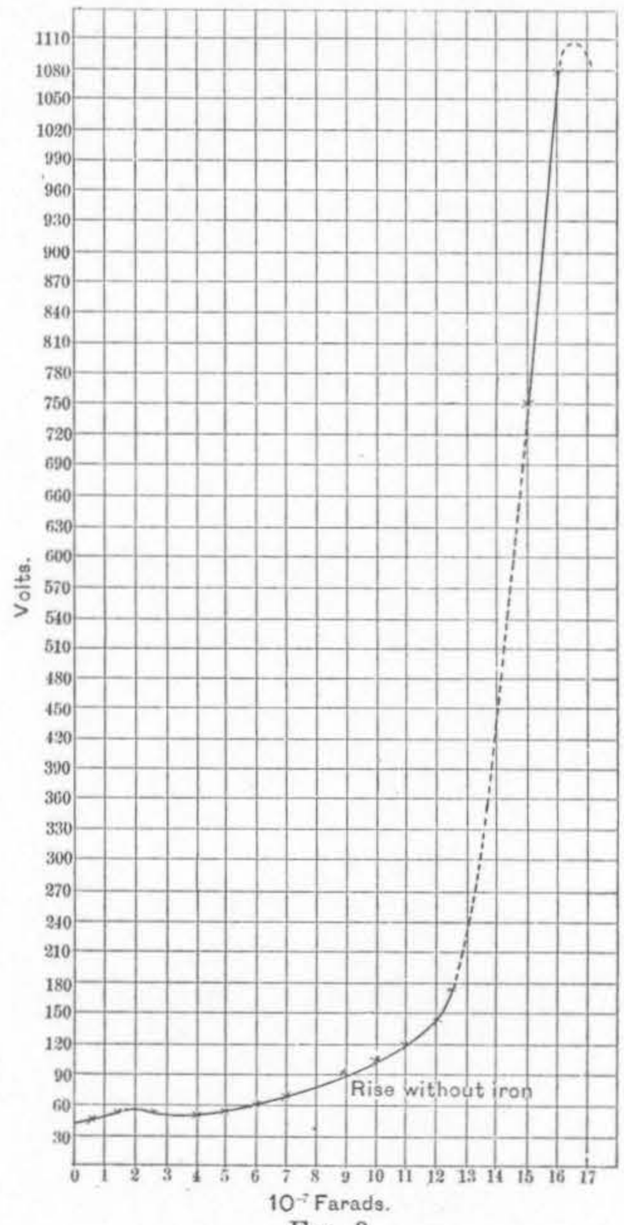

Fig. 9.

impressed E. M. F. can be represented by

$$E = E_1 \sin pt + E_3 \sin 3\,pt.$$

A comparison of the smaller maximum to the larger shows that E_3, the amplitude of the upper harmonic, is very small in comparison to E_1, the amplitude of the fundamental. This is sur-

prising, because from the construction of the alternator one would expect a much stronger deviation of the impressed E. M. F. curve from the simple harmonic.

A similar *harmonic analysis* of the impressed E. M. F. obtained by means of the electrodynamic interruptor gave curves I, II and III Fig. 10. Curve I was obtained by inserting a certain capacity in shunt with the primary coil, and then varying the capacity in the secondary and recording the corresponding voltmeter reading. Capacity was measured off as abscissa and the corresponding voltmeter reading as ordinate. Curves II and III were obtained in the same way but with different capacities in the primary circuit. The impressed E. M. F. in each case can be represented by the following complex harmonic:

$$E = E_1 pt + E_3 in\ 3\ pt + E_5 \sin_5 pt.$$

But the amplitudes, E_1, E_3 and E_5 are different in each case.

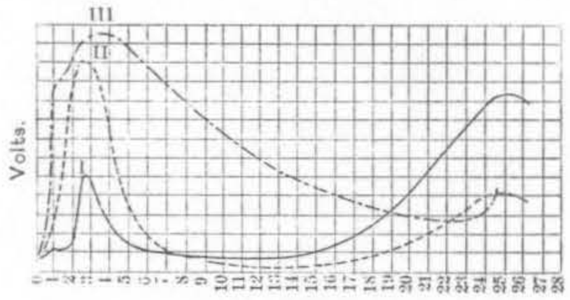

FIG. 10.

You see, therefore, that this method of harmonic analysis by the resonant rise of potential is very sensitive in detecting upper harmonics. Hence the natural conclusion that curve Fig. 9 indicates no strongly developed harmonics, simply because they were not present. Yet it is very difficult to suppose that my alternator generates practically a simple harmonic E. M. F. when one considers the shape of its armature core.[1] This point evidently deserved additional investigation.

I inserted a few iron wires into the inertia coil D, Fig. 7, and found that the upper harmonic, weak as it was, disappeared entirely. The iron wires became hot in a very short time. I suspected that iron when subjected to strong magnetization wipes out the upper harmonics in a resonant circuit. With the electrodynamic interruptor the magnetization of the iron cores is very weak, hence the persistence of upper harmonics. This suspicion was verified in subsequent experiments.

1. The armature core was a Crocker-Wheeler tooth armature.

When the inertia coil D was packed with iron wire then the resonant rise was very much diminished as is evident from the curve in diagram Fig. 11.

Various considerations led me to the conclusion that Foucault current and hysteresis losses were not the only causes of this remarkable diminution of the resonant rise due to the presence of iron. I will mention one only. In one of my experiments I used the primary coil of a small *closed magnet circuit transformer* for the inertia coil and found that as far as I could detect with my apparatus *no resonant rise* could be obtained with 100 volts of impressed E. M. F., no matter how low the frequency was which my machine could produce. About 75 periods per second was the lowest frequency which I employed. If, however, the

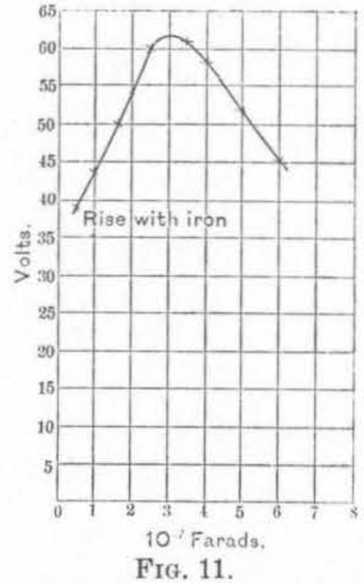

FIG. 11.

secondary coil of this transformer was short-circuited then the resonant rise appeared, but not nearly as strong as it ought to have been, even Foucault currents and hysteresis losses taken into account. The self-induction of the primary (with secondary short-circuited) calculated from the capacity which produced resonance was far too high. *There were unmistakable evidences in this, and in all my other experiments in which iron was present in the inertia coils, that the lower the frequency the stronger were the resonance effects.*

When an alternator giving 125 periods per second was substituted for the alternator in Figure 7, (which gave about 350 to 375 periods per second,) then the resonant rise with iron wire core in the inertia coil D was one-half of that when no core was

used, the impressed E. M. F. being 45 volts. If, however, the impressed E. M. F. was raised, then this difference in the two cases continually diminished. When the impressed E. M. F. was 200 volts, then the resonant rise with iron was more than without it.

There seems to be in the iron a certain reluctance against getting into full swing when under the inductive action of a resonant current. The higher the impressed E. M. F. and the lower the frequency the easier it is to overcome this reluctance. *When the iron has once been set into full swing, then it is possible by careful manipulation to lower the impressed* E. M. F. *and increase the frequency without getting the iron out of this swing. In a closed magnetic circuit this reluctance seems to be exceedingly great.*

With a frequency of 50 periods per second the resonant rise

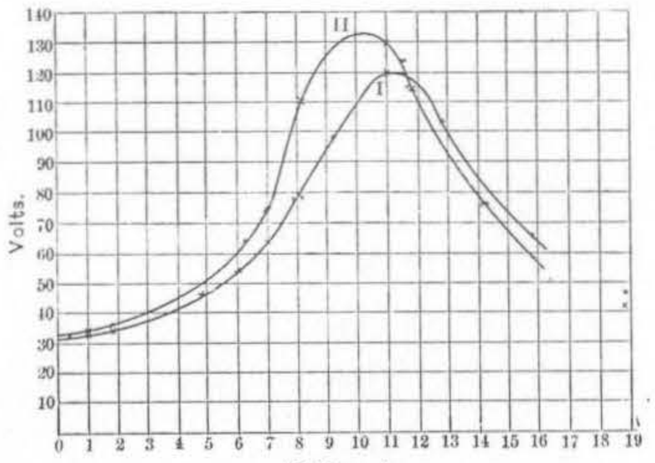

FIG. 12.

with iron was invariably more than without it. Two features in the peculiar behavior of iron were brought out by the resonance experiments with this low frequency machine. These two features, I venture to suggest, deserve more than ordinary attention.

The first peculiar feature is exhibited in the two curves Figure 12. Curve II was obtained when the whole iron wire core (about 500 wires each 40 cm. long and 1 mm. in diameter) was inserted into the inertia coil. The other curve was obtained when only one-half of the core was employed. *The frequency was maintained constant.* From the critical capacity in the two cases it is evident that there was much less difference in the coefficient of self-induction in the two cases than one might expect from the

difference in the quantities of iron, that is, if we suppose that in this case also the natural period of the circuit is independent of the frictional resistances due to magnetic hysteresis. But even if we drop this hypothesis, still the small difference in the capacity in the two cases appears as puzzling as ever. We have resonance in this case also as in any other case, but it is evident that the conditions of resonance are not determined by self-induction and capacity alone. The question arises then, what does resonance mean in this case? Well, it means the largest current and the highest rise of potential, but this maximum potential and current are not necessarily accompanied by zero difference in phase nor by neutralization of self-induction with capacity.[1] The practical bearing of this result needs no further comment.[2]

There is another point to which I wish to call your attention in connection with curves I and II of Fig. 12. It is this: Although curve II was obtained with twice the quantity of iron and therefore, with at least twice the losses due to Foucault currents and hysteresis, [since the magnetizing current which circulated in the inertia coil with resonance corresponding to curve II was considerably larger than that corresponding to resonance of curve I,] yet the rise of potential in curve II was larger than that in curve I. I do not wish to take up too much of your time in showing you all of the difficulties which one encounters in endeavoring to explain these matters satisfactorily. Suffice it to point out merely that these difficulties do exist and that they deserve our most careful attention.

Before making the next step in my discourse I wish to remark that a circuit consisting of the armature of an alternator, a large *inertia coil without iron* and a condenser, all in series, *does not exhibit any of the peculiarities just mentioned, at any rate not to any considerable extent. Such a circuit can be tuned and a high resonant rise of potential can be thus produced, provided, of course, that this rise of potential is not accompanied by so heavy a current as to produce a serious armature reaction. Foucault current and hystersis losses in the armature iron cannot, of course, influence this resonance, since they are taken care of by the motor which rotates the armature.*

1. Professor Duncan informed me yesterday that he arrived at this conclusion in a somewhat different way. See paper already referred to.

2. Especially when Dr. Duncan's more definite conclusions on this point are taken into account.

The second peculiar feature in the behavior of iron when it is under the inductive action of the resonant current of an inertia coil will be exhibited to you in the following experiment: The arrangement is just the same as that given in the diagram of Figure 7, with the following exceptions: This alternating current ammeter is in the resonant circuit. The motion of its index, which I hope can be seen all over the room, will indicate to you the progress of tuning. I watch it on this side by means of a multicellular voltmeter which is denoted by F in the diagram of Figure 7. This four-pole 1 H. P. alternator which Dr. Laudy, of Columbia College, kindly lent me, takes the place of the 16-pole alternator. Inertia coil, alternator and condenser are all in series. The driving motor can easily take care of 2 H. P., so that the speed will remain constant during all variations of the load since as you will presently see the load will never be over 150 watts. The condenser has now 16 M. F. capacity plugged in. The frequency is about 50 periods per second. The impressed E. M. F. is 45 volts. To bring the circuit in resonance with the impressed E. M. F. it is necessary to insert iron wires into the inertia coil. I insert now about 400 wires. It is, as I can see from the voltmeter reading, considerably too much and, therefore, there is no resonance as you can see from the ammeter. I take the iron wire bundle and raise it slowly, and now I can feel by the pull on the bundle and also by the voltmeter reading that I have reached the point of resonance. You can see it by the ammeter deflection. The ammeter indicates 1 ampere; in reality it is about 2 amperes. [This instrument is a lecture room model and its reading must be multiplied by a large correction factor.] Now I lower slowly the iron wire bundle again; the resonance persists. I have reached now the same position from which I started and when there was hardly any resonance effect. But as you see this time the resonance effect is very strong. *But it is a resonance which resembles very much a supersaturated zinc sulphate solution. A very small crystal thrown into such a solution will cause a sudden precipitation of innumerable small crystals. So it is with this resonance. If I now bring a single iron wire near the bundle, its mere approach upsets the resonance almost completely, as you see from the sudden drop of the ammeter needle. But if I add this wire whose mere approach upsets the resonance almost completely and even five other wires to the bundle and then by gently raising it start the resonant flow I can then lower it again without disturbing resonance, as you see it from the deflection of the needle.*

I shall vary now the capacity by taking out carefully one plug after the other. But I must take out these plugs without causing a spark. Here is one plug out, and here another and four more. I have reduced the capacity by 1 M. F. or nearly 7 per cent. of the total capacity. There is hardly any change in the resonance effect, as you see from the ammeter needle. Now I shall carefully put back the plugs and even more than I have taken out, but carefully avoid sparking. As you see, resonance still persists without any apparent change. *Now I take out one plug and vary the capacity by only* 0.1 M. F., *but I take it out in such a way as to produce a strong spark by the removal of the plug. The experiment does not succeed. But here it succeeds at the removal of a* 0.3. M. F. *plug. The collapse of the resonance effect is as you see almost complete. Generally I succeed with even less than a* 0.1 M. F. *plug.*

The same pecularities appear also at higher frequencies, but they are not nearly as clearly defined at frequencies over 100 *as they are at those of less than* 50 *periods per second. They are certainly not due to any change in the speed of the machine, produced by the variation of the load due to the rise of the resonant current.* Nor is it probable that they are due to armature reactions. This last point, however, deserves a closer examination than I have been able to give it as yet.

One more point I feel that I ought to mention before I end my discourse. It is a point which I think may have some practical importance sooner or later. *When a large inertia coil without iron is joined in series with the armature of an alternator and also with a condenser and then the circuit is tuned, so as to analyze harmonically the shape of the impressed* E. M. F. *curve, I find in all the machines that I have tried so far that this curve is almost perfectly free from upper harmonics, even with frequencies of* 50 *periods per second. If, however, the armature is closed by the primary of a transformer then upper harmonics will appear, as for instance, in the arrangement in Figure* 7. I do not think that these upper harmonics are entirely due to the variation of the permeability of the transformer core during each complete cycle, as has been suggested by very competent authority.[1]

1. See Professor Duncan's paper already cited; also H. A. Rowland:—"Notes on the Theory of the Transformer;" Phil. Mag., July, 1892.

A different interpretation of the phenomenon is possible. My experience in this matter favors the view that the upper harmonics are due to the interference between the electromotive forces generated in the alternator and the transformer. I prefer, however, to devote more time to the examination of this exceedingly important subject before venturing to discuss the validity of this possible new interpretation.

Allow me now to sum up briefly the main points of this discourse.

The practical bearing of "Low Frequency Electrical Resonance" in so far as I have worked out the subject seems to rest on the following characteristic features:

It brings out very prominently the purely mechanical character of the phenomena of electricity, and it does that not by referring to carefully prepared delicate experiments of a skilled physicist, but by referring to phenomena which every electrical engineer can observe every day in the testing room, telegraph and telephone stations, and in central stations for power and lighting. A full appreciation of this purely mechanical character of the phenomena of electricity is of the greatest practical importance, for we must remember that the founder of this mechanical view, the immortal Maxwell, in opening this new view of electrical phenomena contributed to the advance of this science as much as, if not more than, any other investigator of this century.

It offers a new, simple, and exceedingly convenient method of transforming electrical energy from low to high potential.

It enables us to observe very accurately the behavior of dielectrics and of iron when under the inductive action of resonant currents, and thus to determine the exact limits within which condensers can be employed in the solution of electrical engineering problems.

It offers a new and exceedingly simple method (the method of harmonic analysis mentioned above) of studying the working of alternating current machinery under various conditions of load.

It points out a new and apparently very promising direction in which the difficult but exceedingly important study of the magnetic properties of iron can be pushed ahead.

In closing my remarks I wish to thank my pupil, Mr. Milton C. Canfield, for the very efficient assistance he has given me in the preparation of this lecture.

Discussion.

The President:—Gentlemen, you have heard Dr. Pupin's admirable paper. Does the Institute wish to make any remarks on it?

Mr. Tesla:—Gentlemen, I do not know whether I can contribute in any way to the clear and skillful exposition which Prof. Pupin has made of the phenomena of resonance. They have been familiar to me for a long time. In fact, two or three years back I began to work on lines in which an observation of some of the rules advanced by Dr. Pupin is an absolute necessity, and one of the reasons why I have only reluctantly consented to deliver a lecture on some high frequency phenomena, which I have shown on two or three occasions was, that I felt inadequate to the task, because in every experiment one has to depend on certain delicate balances and one cannot always feel sure of succeeding in the experiment, especially in a public lecture. Dr. Pupin has admirably succeeded in performing before an audience a number of difficult experiments. I saw this marvellous experiment with the iron core, performed by him last week, I believe, and I have been much impressed with the importance of the molecular condition of the iron. Any observation relating to the iron must be of interest, as it may lead to valuable results, and since I am called upon, I may mention a few of my own experiences, though they might not be in direct connection with the subject treated by our lecturer. About two years ago I observed a curious effect which I abstained from mentioning so far, because I could not explain it to my satisfaction. It was this:—I had an alternator of high frequency operating an induction coil. The secondary of this induction coil was connected to a Cardew voltmeter, and I had made the windings so as to bring the deflection into the best range of voltmeter. A condenser was connected to the alternator. I varied the amount of iron in the core of the coil and observed the rise in the electromotive force. As iron wires were added the electromotive force would continuously rise up to say 100 volts, Then there was a point at which when I added a few iron wires. the electromotive force fell off, about two volts. A further addition did not make any change whatever. I observed that effect repeatedly and repeatedly, but could not satisfactorily explain it. Now in the light of the experiment of Dr. Pupin and with the knowledge we presently possess, I cannot think else than that there was something of the same nature in the phenomenon. The delicate balance which, as Dr. Pupin has shown can be easily upset by the introduction of a single iron wire in the coil, reminds me of an experience with a machine which was regulated by means of an "auxiliary or third brush," a very interesting device, but owing to the extreme sensitiveness not quite commercially available. The idea is to take a dynamo, having the field magnet in series with the circuit and connect a point of the

field coil or of the external circuit by means of an auxiliary brush with a point of the commutator. The sensitiveness obtainable by this means can be anything one chooses, and so great can it be made that the slightest disturbance on the machine may upset the whole circuit, and if there be arc lamps in the circuit, for instance, one may barely tap a lamp thus causing an imperceptible movement of the carbon rod and all the lamps will go out, if the auxiliary brush is in such a position and the field coil so connected that the shifting of the neutral line is an *accumulative* effect. In order to improve the action of the lamp mechanism I had the machine constructed in such a way as to give periodic impulses of a certain intensity, which produced a noticeable vibration in the field magnet, and so well did I know the machine, operating it day and night (for at that time practically all my life was passed in the laboratory), that I could tell from these vibrations, by holding an iron bar in a certain position to the field magnet whether the machine was working properly. I noted then that sometimes all of a sudden the lights would go out. After this had occurred about a dozen times, I recognized that when I came with the iron bar near to, or touched the field magnet I disturbed the field enough to displace the neutral line and the lights would go out because the machine would discharge itself.

Another observation which I may mention about the iron, came to my attention in 1886. I then made some experiments on a so-called "thermo-magnetic generator. This *nihil bonum* principle has no doubt occupied the time of many inventors. I had attacked the problem in quite a different way, sufficiently promising to justify an engineer to enter into an investigation and see what could be done. The method I followed was to enclose in a stove an iron core which closed the circuit of a magnet, this iron core consisting of a box of iron with small sheets of iron running through offering an enormous cooling surface. I used steam passed through the interstices to cool down the iron. My expectation was that the iron would just cool down a little so as to become magnetized when steam was admitted by means of a valve. The circuit of the magnet would then be closed and the valve was automatically shut. thereupon the iron was again heated and demagnetized. To a certain measure the valve worked well, but the vibration was too slow. It generally so happened that when the steam was admitted it would be decomposed and a greenish flame would shoot out of the stove. This indicated that the temperature of the iron was too high. I would bring the temperature of the iron down by admitting two or three times the steam in pressing upon the valve. Every time I did this, the flame would shoot out of the stove. Then there would be a miss for about two or three times in succession, no flame appearing, the iron being cooled sufficiently, but upon doing it the fourth or fifth time which took about a second or two, the flame would shoot out once more. I could not explain this phenomenon. A little later, I obtained the classical work of Dr. Hopkinson on the recalesence and other properties of iron at high temperatures and plainly saw that it was recalescence. The temperature must have just been varied around the critical point. Still another fact which I recollect to have observed in experiments with high frequency currents is, that an iron rod or wire, when an arc is formed through it, burns and sputters with violence, considerably more so with high than with low frequency or direct currents. It is possible that the effect is solely due to the magnetic properties of the iron, but it might be more or less produced by the increased resistance and consequently more intense heat evolution. With great magnetizing forces an iron wire inserted in a high frequency coil is instantly brought to a high temperature. This I have before pointed out, but Dr. Pupin has observed a similar thing with low frequency currents when a condenser is in circuit and resonating action takes place.

I wish to say in regard to converting to high potential, starting from a low potential dynamo, by simply combining capacity and self-induction with the circuit, that is by resonating action, I have in my paper, which has just gone to print, dwelt specifically upon converting in this manner, and in fact I am delighted to see that Dr. Pupin has taken the views he has here expressed. My usual method was to attach to the alternator a coil consisting of a great number of sections, and to associate adjustable capacity with the coil, and then to vary the number of sections and the capacity until the best resonance was obtained. This obviated the employment of a secondary coil; but I found that in adjusting, it was preferable to convert first the low tension currents to such a high potential that the necessary capacity would become extremely small, so as to be reduced merely to that of two small plates, because of the great difficulty of producing a condenser of large capacity adjustable by extremely small steps, which it is necessary to employ when the potentials are small. If we convert to a potential of say 50,000 volts then the capacity becomes very small, and we can just use a few plates immersed in oil, which permit varying the capacity by extremely small degrees, and without sudden, disturbing breaks. This is one of the reasons why I have always preferred to convert in a secondary circuit. The adjustment by varying self-induction by means of an iron core is, as Dr. Pupin's experiment now plainly shows, not always practicable. I think that the experiments we have seen here demonstrate that we are as yet far from having studied the properties of iron thoroughly, and that much remains to be done in this direction. I agree with Dr. Pupin that the condenser, which I had thought was going to be of great help in alternating work, does not really appear to have a great future in connection with apparatus with large iron cores, as motors or transformers, because of the action of the iron, and for one more reason besides, namely, that we can, especially if we have a high potential or high frequency, always

wind a coil so as to take up just enough capacity to be in resonance with the circuit, in so far as the iron core will permit.

I only have to add, that I sincerely thank Dr. Pupin, (which probably is the wish of all), and that I have profited very much by his lecture, which is a clear and precise exposition of the principle, as well as a most interesting experimental demonstration of electrical resonance with a dynamo machine.

[Adjourned.]

[Communicated after Adjournment by Dr. Pupin.]

Mr. Tesla is very kind and generous with his compliments. I do not think, however, that his statement of facts is free from ambiguity. He states that the phenomena of resonance which I have discussed were familiar to him for a long time. My discussion referred to low frequency resonance, whereas Mr. Tesla has, I think, always worked with high frequency apparatus, so that his familiarity with low frequency resonance, the subject which I discuss, is probably not based upon his own experimental investigations. At the time when the Ferranti effect called forth so much valuable discussion in England, Mr. Tesla[1] contributed some remarks to this discussion, which remarks culminated in the following:—"*The writer looked for a case of resonance,*[2] *but he was unable to augment the effect by varying the capacity very carefully and gradually, or by changing the speed of the machine. A case of pure resonance he was unable to obtain. When a condenser was connected to the terminals of the machine* * * * *the capacity which gave the highest* E. M. F. *corresponded most nearly to that which just counteracted the self induction with the existing frequency.*"

Mr. Tesla states also in this article that the highest value of the augmentation of the potential which he was able to obtain by connecting a condenser in series to the armature of his high frequency (10^4 periods per second) machine was *only four or five times the impressed* E. M. F. What then could Mr. Tesla infer from this result in regard to resonance effects with low frequency? Certainly nothing that was encouraging.

At no other time did Mr. Tesla, so far as I am aware, approach the subject of resonance any closer than in the article just referred to.

Perhaps Mr. Tesla means that he was acquainted with the phenomena of low frequency resonance which I discussed from the investigations of other men, like Fleming, Kapp, Glazebrook, Swinburne, Lodge, Blakesley, etc.[3] I appreciate fully the value of the labors of these men, but still I fail to see a very close re-

1. *Electrical World*, N. Y., Feb. 21st, 1891.
2. The meaning of this term Mr. Tesla did not explain.
3. See *London Electrician* for 1889, 1890 and 1891, also "Fleming's Alternate Current Transformer," vol. ii., p. 401.

lation between their work and mine, excepting in one point, and that is, that they as well as I, have shown theoretically that it is possible to produce a high rise of potential by a combination of self-induction and capacity. *I have shown it experimentally also.* But I think that I have pointed out very clearly in the course of my lecture that I did not regard the resonant rise of potential as an end but simply as a means to an end, the end being harmonic analysis of E. M. F's, behavior of iron and dielectrics under the inductive action of resonant currents of low frequency, weeding out of harmonics by means of resonance, etc. With these phenomena Mr. Tesla does not appear to be familiar, either from his own experimental investigations or from investigations of others, excepting those phenomena which Dr. Duncan had investigated some time before me and which I mentioned in the course of my lecture.

NIKOLA TESLA AND HIS WONDERFUL DISCOVERIES.*

NIKOLA TESLA has been called by scientific men, who do not award praise freely or indiscriminately, "the greatest living electrician." At the recent convention of electricians held in St. Louis, a well known electric journal issued daily bulletins or "extras" giving a list of the delegates and distinguished attendants as they arrived at the convention, a programme of the day's proceedings and a special article of immediate interest having reference to the current discussions of the convention.

One evening during the session of the convention Mr. Tesla lectured on some of his recent experiments. The bulletin for that day contained a brief account of his life. So great is the interest taken in this young man that over four thousand copies of the journal containing this biographical sketch were sold upon the streets of St. Louis—something unprecedented in the history of electrical journalism—and in the evening his lecture, in the Grand Music Entertainment Hall, was listened to by a larger audience than had ever been gathered together before in the United States on an occasion of this kind. Many were glad to purchase the complimentary tickets at $4 or $5 apiece.

It is singular that this remarkable man should have come to us from one of the smallest and least known nations of Europe, Montenegro; that he is a young man (only thirty-six years of age), and that the best scientific minds believe he has only begun to give the world the result of valuable researches.

In a recent symposium on the subject of electricity the contributors mentioned his name with a sort of reverence, as one who has an almost magic power over the most hidden secrets of nature. Men in the foremost ranks of science, not only in the United States, but in Europe, believe that at no distant day he will announce discoveries which will be as far in advance of our present knowledge of electricity as the telegraph was over the mail coach. He has delivered only three or four lectures—one in Philadelphia, one in St. Louis, another in Paris and another in London—but each lecture has been listened to and applauded by the very *creme de la creme* of the scientific world.

MODESTY ONE OF HIS VIRTUES.

Another remarkable characteristic about Mr. Tesla—especially when we consider the self-assertive age in which we live—is his modesty. This serves to make him more highly esteemed by his associates and only adds to his renown. His friends might truly exclaim with the old dramatist, "Thy modesty is a flambeau to thy merit."

It is only affirming the truth when it is stated that many of the high compliments he receives annoy him. He honestly does not believe he is entitled to the praise that is continually showered upon him. He is an enthusiastic worker in his profession, but believes that he is only one of the standard bearers in the great march of human progress, and that he is as much indebted to other minds who have studied and worked in this new science as others think they are indebted to him. In his famous London lecture, after expressing how deeply he felt the honor of addressing the foremost thinkers of the day, his next sentence showed the character of the man. He said:

"The results which I have the honor to present before such a gathering I cannot call my own. There are among you not a few who can lay better claim than myself to any feature of merit which this work may contain. I need not mention many names, which are world known—names of those among you who are recognized as the leaders in this enchanting science; but one, at least, I must mention—a name which could not be omitted in a demonstration of this kind. It is a name associated with the most beautiful invention ever made. It is Crookes."

Crookes is a writer famous for his descriptions of experiments on radiant matter.

A REMARKABLE MOTHER.

Mr. Tesla, like many famous men, had a remarkable mother. She died only two years ago at the age of sixty. She was a simple woman, but in the surrounding territory in which she lived, both far and near, was considered the most remarkable female in the land. She inherited the inventive spirit from Mr. Tesla's grandfather, an inventor and constructor of machinery, who was an exceptionally ingenious man. Old Mrs. Tesla was an indefatigable worker. As a rule she arose at four o'clock in the morning and every day worked until late at night.

The home of the Teslas was in a very wild country, away from any of the conveniences of civilization, and Mrs. Tesla displayed her inventive faculty by constructing nearly all the appliances that were necessary for use in the household, and that, too, without ever having seen patterns from which to make them. For instance, in the matter of weaving, she would plant the hemp and flax, get out the fiber, spin thread and then construct the necessary mechanical appliances for weaving, making her own loom and producing for her large family all kinds of cloth from the heaviest, suitable for outdoor garments in the winter, down to the finest pieces, suitable for embroidery work. When she died, so great was she held in esteem that the whole country for miles around mourned her loss.

Mr. Tesla is such a hard worker that he has little time for social pleasures, if, indeed, he has any taste in that direction. He is a bachelor, tall, very spare of build, has dark, deep-set eyes, jet black hair and an expression that suggests at once the deep thinker. Though polite and even friendly to newspaper men, he has no desire to exploit himself in print. He has been the talk of the scientific world for five years, but the following interview I had with him a few days ago is the first that has ever appeared in any journal:

TESLA'S AUTOBIOGRAPHY.

My interview with Mr. Tesla commenced with a request that he give me a brief account of his life. He replied:

"I was born in a little place called Smiljan, on the border country of Austria-Hungary, this special section of territory being known as Lika. I am now thirty-six years of age. I have gone through the educational training that a young man usually receives in Europe, and nearly eighteen years of my life have been spent in schools. I completed my preparatory studies in Gospich and Carlstatt, and the Polytechnic School in Gratz, Austria. My first employment was engineering; then I was connected with the Hungarian Government Telegraph Company; afterward I engaged in telephonic work. After this I was interested in the electric light industry, and finally in the transmission of power.

"In 1884 I came to this country, my principal object being to develop certain ideas of inventions which I had vainly tried to develop in Europe. For a while I worked with Edison. In the beginning of 1885 a company was formed in my name. I developed for this company certain inventions, brought out a system of lighting and peculiar appliances belonging to that system. In the following year another company was formed—some time in 1886—the object of which was to introduce a motor of my invention. This motor is based on what is now the well known discovery of the rotating magnetic field, as it is technically called. The best way to give an idea of this discovery to one who is not technically educated in these matters is to put it as follows:

"A magnet, as it is well known, will attract a piece of wire and hold it. It was my good fortune to discover a method of constructing a magnet in such a way that it would not hold the iron, but spin it round and round."

I asked Mr. Tesla to kindly give me some further information in regard to his family.

TESLA'S FAMILY AND HOME.

"My father," he continued, "was a prominent clergyman attached to the Greek Oriental Church, an orator and a writer of note. He was a man highly educated, who spoke fluently a great many languages and also ranked high as a mathematician. He was an omnivorous reader, and possessed a large library, from which it was my privilege to gather a great deal of information during the years of my life spent at home. My uncle, his brother, was another skilled mathematician, and professor of a military academy in Austria. He wrote a number of standard works on mathematics.

"My mother died about two years ago. One of her brothers—the youngest—is one of the leading dignitaries in the Greek Oriental Church, having the rank of a cardinal. He is comparatively a young man and a famous orator.

"The section of country in which I was born was an exceedingly wild region—a mountainous and rocky region—with, however, many stretches of beautiful scenery, but poor from the agricultural point of view. In fact, they had a homely though somewhat sacrilegious saying in our land that when God distributed the rocks over the earth he carried them in a sack, and that when he was above our land the sack broke.

"I was interested in electricity almost from the beginning of my educational career. I read all that I could find on the subject. All the phenomena I witnessed in this line only excited my interest. When I was a mere boy I began to experiment with batteries

* From the New York *Herald*, April 23, 1893.

and induction coils, also with frictional and static machines. When I attended the Polytechnic School, at Gratz, I began to devote more and more of my time to electrical studies, and after I left the school I may say that, practically, all my time was taken up with the study of electricity.

EVIDENCES OF GENIUS.

"Originally, I closely followed up the course of mathematics and physics, with the view of graduating as a professor of those sciences. It was, I think, in 1875 or 1876 that we experimented in the Polytechnic School with one of the first practical dynamo machines, which was brought out by M. Gramme, a Frenchman. It occurred to me that a machine might be constructed without the complication of what is technically called commutator and brushes. A commutator is used on electric current generators and motors and on induction coils and elsewhere for changing the direction of currents. The brushes are pieces of copper or other material that bear against the cylindrical surface of the commutator.

"I remember that my professor at that time tried to demonstrate that such a machine was out of the question—in fact, an impossibility. I must confess to a feeling that I, in common with many better men, have had from early youth. As a youth, when I was told that a certain thing was impossible, it only served to arouse within me a spirit of contradiction. In this particular instance I began to think about and to work on a machine made according to the idea that had occurred to me. Day and night, year after year, I worked incessantly.

"After working several years I am happy to say that I was able to produce a motor which is now gradually being introduced in the United States. It is a machine of ideal simplicity, requiring no attention whatever. It should be remembered that in recent years there has been a wonderful advance along almost all electrical lines. What were at one time supposed to be novel or impossible schemes of doubtful accomplishment have proved to be feasible. Encouraged by this condition of affairs I have afterward devoted my energies to the production of a more practical illuminant than we have at present, and am still pursuing my labors in this direction.

DISCOVERIES ABOUT LIGHT.

"The most wonderful phenomenon in nature is light, and the most remarkable feature connected with man's physical life is the eye, which is the only organ capable of being affected directly by the vibrations of the ether. We could see for an immense distance if it were not for gases and particles that fill up the intervening space. These absorb the energies of the air.

"In pursuing this line of work I have had the good fortune to discover some facts which are certainly novel and which, I am glad to say, have been recognized by scientific men both here and abroad. I think the probable result of these investigations will be the production of a more efficient source of light, thus supplanting the wasteful processes of light production.

"My experiments have been almost entirely confined to alternating currents of high potential. An alternating current is a current changed periodically in direction, and the word potential expresses the force and energy with which these currents are made to pass. In this particular case the force is very great. The fact that a current vibrates back and forth rapidly in this way tends to set up or create waves in the ether, which is a hypothetical thing that was invented to explain the phenomena of light.

"These currents permeate all space—not only the atmosphere, but solids as well—and the waves extend out in concentric spheres indefinitely into space. I utilize these waves in some of my experiments to produce certain phenomena. It is not an electric current in the sense in which we are popularly accustomed to use that term.

TRANSMITTING ENERGY THROUGH AIR.

"These experiments may be further illustrated in this way: Suppose you throw a stone in the center of a pool of water. While there would be no transmission of water from the point where the stone landed to the shore, yet the waves would reach the shore and exert force on the shore. In a similar way I utilize the force which I obtain in the manner described.

"One result of my investigations, the possibility of which has been proved by experiment, is the transmission of energy through the air. I advanced that idea some time ago, and I am happy to say it is now receiving some attention from scientific men.

"The plan I have suggested is to disturb by powerful machinery the electricity of the earth, thus setting it in vibration. Proper appliances will be constructed to take up the energy transmitted by these vibrations, transforming them into a suitable form of power to be made available for the practical wants of life. Primarily, the agent that I propose to use consists of an old-fashioned electrical spark, such as they light from a Leyden jar. This is rapidly discharged back and forth an enormous number of times. Every time that the spark seems to pass it is in reality passing hundreds of thousands of times, and each time it passes it sets up these waves in the ether which extend out into space. In other words, the result of the experiment is to disturb the equilibrium of the ether.

"I am hopeful that in no distant time this method will be deemed worthy of a practical trial. It may be proper to say that among other things I have already demonstrated that we do not need to have two wires to convey an electric current, one wire being sufficient, and, in fact, in some cases, better than two wires.

PHENOMENA OF RESONANCE.

"In the experiments of transmitting power by means of wires the phenomenon of resonance is to be observed. If one tuning fork, for instance, is set into vibration another one of the same pitch, anywhere within reasonable distance, will respond. That is a familar phenomenon of sound termed resonance. Now, if I set up these etheric vibrations that I speak of to a certain pitch, and my wire is within reach of these vibrations (not necessarily metallically connected) it will respond provided its pitch corresponds with that of the etheric vibration.

"In that way I obtain energy in another conductor without any metallic connection whatever. Where a single conductor is connected with the source of vibratory energy, these waves surge back and forth in that conductor very much as water would in a tube when you reverse it back and forth.

"One of my most interesting experiments is with the incandescent lamp with a single wire to it. I place in the center of this a piece of very refractory substance of any kind and connect that with the source of vibratory energy, and, with this as a center, these etheric waves are sent out in concentric spheres and are reflected back from the inner surface of the glass globe upon this small piece of refractory substance. The impact of the molecules of rarefied air in this globe creates such intense heat in this refractory substance (which is the focus) as to bring it to a high state of incandescence. It is difficult to find a substance that will stand that heat, but I have found some substances that stand it fairly well.

"The transmission through the earth can be effected at any distance; in fact, it matters little whether the distance is small or great.

OF INCALCULABLE VALUE.

"Such a result, if achieved, would, of course, be of incalculable value to the world and greatly advance the progress of the human race. In this great country (of which I am proud to be a citizen) we have water powers which, in aggregate amount, are sufficient to supply all the needs—in fact, far more than the needs—of the whole human race. Take, for instance, Niagara. This famous waterfall is estimated variously all the way from five to six millions horse power. Now, four millions horse power, economically directed, would light every lamp, drive every railroad, propel every ship, heat every store and produce every article manufactured by machinery in the United States.

"It will not be long before we can transmit that power under quite practical conditions, by means of wires with the alternating system, over distances as great as a thousand miles. Engineers now object to the use of very high pressures which would be necessary in such transmissions of power. But I believe the time will come when we shall transmit that energy without any wire.

"Since I have experimentally proved that we can get back electric impulses over one single wire without any return, we may avail ourselves of the earth as a medium of transmission as one difficult obstacle to overcome. In fact, the only serious objection to this scheme is to find a means to concentrate the energy of vibrations spread over a great area on one spot.

"If this power is to be transmitted across the ocean it will, of course, involve the expenditure of an enormous quantity of energy. It has been suggested that I can produce a set of lenses made of asphaltum or gutta percha, or any other good so-called non-conductor of electricity, and can concentrate these rays, or waves, to a focus where their effect would be powerful.

"This plan, if at all practicable, could be applied as well across the Atlantic as it could at shorter distances on land.

METHODS OF PRODUCING LIGHT.

"The present methods of producing light are very wasteful. The electric light is a considerable advance over the gas burner, as far as efficiency is concerned; yet even the electric light, as at present produced, is very inefficient. Of the energy of coal we only get about one-third per cent. in light in an incandescent lamp; much more, however, in an arc lamp, because in that lamp we can reach much higher degrees of incandescence, and because we have the advantage of an economical combination of carbon and oxygen.

"It is true that in recent years some notable improvements have been made in gas burners, and that, from a theoretical point of view, it is possible that a far more efficient burner than the ones at present in use may be produced.

"Probably the most important problem electricians are considering is the production of electricity by an efficient process from coal or other cheap substance; at least most engineers have this subject in view. I think it is fully as important, and, in the end, perhaps even more important, to apply our skill in discovering how to transmit power from the waterfalls to any distance, for then we would be able to obtain energy, without consuming any material, and our coal fields and forests would remain untouched, whereas the production of electricity from some material will involve the rapid consumption of that material.

"One of the problems which is of great importance, and the solution of which we are very likely to witness in a few years, is the transmission of intelligence to any distance without connection. From present experimental evidence it can be quite safely concluded that an attempt to transmit intelligible sounds through the earth from here, for instance, to the European continent, without any cable, will succeed beyond a doubt. But it is a question whether such a method, which I have advocated for two years, would be available for all purposes, such, for instance, as the use to which the Commercial cable is put.

"In that case it is questionable whether the scheme would be practicable. But one thing is certain, we will be able to transmit universal time all over the earth, and also be able to send in the same way very important short messages from center to center.

"Electricity is becoming more and more an important factor in our daily life, and more and more closely connected with our comfort. I think, after a considerable lapse of time, it will become practically necessary for our existence. For instance, there is the question of light. The advantages of the electric light are so great that even with the present wasteful methods we have been able to succeed in making practical use of it.

"But what will be our success when we shall be able to produce a hundred times as much light as we do at the present day? To do this is merely a question of time. Electric power is obtained by the use of dangerous, cumbersome and complicated appliances. But we have electric machines now which require no attention whatever, and which will in a few years supplant all other motors, simply because of their higher efficiency and ideal simplicity.

"Even now the cost is very great. Eventually we will be very likely to be able to heat our stoves, warm the water and do our cooking by electricity, and, in fact, to perform any services of this kind required for our domestic needs.

"It has been said that it will be impracticable to heat our houses by means of electricity, on account of the great cost of coal; but, as I have said, we are now looking for other methods of getting electrical energy cheap. Even with the present methods any rich man certainly prefers, instead of a stove in his room, to have it warmed by electricity. The method is expensive, but ideal.

"Electric energy can be applied to bicycles, carriages and all sorts of vehicles. It will certainly be applied to rowboats, and will probably be so cheap that any man in ordinary circumstances can own a boat and propel it by this means. It would be a gloomy prospect, indeed, for the world if we did not think that this great power will be used to the advantage of the vast majority of the human race, and its benefits will not be confined merely to the wealthy.

INTERESTING EXPERIMENTS.

"I am working on some other lines than those of which I have spoken, and if I succeed in my experiments they will be of great interest, principally to scientific men. They have also a practical bearing upon what newspapers sometimes call the 'burning questions of the age.' These experiments are quite apart from old notions and the lines which heretofore have taken up my attention. I cannot tell how soon I will complete these experiments.

"Most of my experiments heretofore have involved either rapidly alternating currents of high potential or have reference to these electrical waves which are set up by alternating currents, and which, if very rapid, will not go through electric batteries at all, but will go through the best insulators. If they are less rapid, they will go through electrical conductors fairly well.

"I think I have received full praise for the work in which I have been engaged. There are some experiments which I made a few weeks ago in Philadelphia and St. Louis which interested our scientific men. For their benefit I have a technical account of these experiments in preparation, which will be published in the future in the scientific journals.

"Some years ago I demonstrated that a lampate filament could be made to glow from a current from a human hand. The light coming from the hand is produced by the agitation of the particles of molecules of the air. I charge my body with electricity, and from an apparatus which I have devised I can make the electricity vibrate at the rate of a million times a second. The molecules of the air are then violently agitated, so violently that they become luminous, and streams of light then came out from the hand.

"In the same manner I am able to take in the hand a bulb of glass filled with certain substances and make them spring into light; I make light come to an ordinary lamp in a similar way, simply by holding it in the hand.

"When I was in London I had the pleasure of performing one of these experiments privately before Lord Rayleigh. I shall never forget the eagerness and excitement with which that famous scientist saw the lamp light up. I can only say that the appreciation of such men amply repays me for the pains I take in working out such phenomena.

TESLA'S TRIBUTE TO AMERICA.

"When I arrived upon your hospitable shores, I eagerly applied myself to work and to learn, and I have persevered in that course. If I have made any special success in this country, I attribute it largely to a feature which is characteristic of both the English and American races; that is, their keen and generous appreciation of any work that they think is good.

"I think this country may well boast of its colleges. Take, for instance, Columbia College, Cornell University, Johns Hopkins University, or any of the institutions where nowadays electrical engineers are trained.

A GOOD PROFESSION.

"I consider electrical engineering a very good, profession for a young man, but it is a profession which requires considerable exercise of intellect. On account of the fascination connected with the study of electricity the profession draws to its ranks an intelligent class of young men.

"Of course, it is probably true that the majority of young men who enter the profession are more or less enthusiastic, but in these days a knowledge of electrical engineering has become almost indispensable for engineers in general.

"Nearly every engineer at the present time follows with great interest its developments. And it is the same with the medical profession, for physicians are realizing more and more that electricity will play a still larger part than it does in the cure of disease.

"For instance, a great amount of electrical energy may be sent into the body by means of high currents, because the energy is dissipated laterally from the body and is not passed through it in a direct manner, as it is when a current of low frequency is used. The feeling produced is somewhat different.

"I have also noted the importance of one being prepared for the shock. If you are prepared the effect on the nerves is not nearly as great as when you are not prepared. With these high alternations one feels but little pain in the central portion of the body. A remarkable feature of such high currents is that you feel a burn the moment your hand touches the wire, but beyond that the feeling is scarcely noticeable. I have received currents as high as 300,000 volts, an amount which, if received in any other way, would instantly kill."

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VOL. XV. NEW YORK, MAY 31, 1893. No. 265.

MR. TESLA'S LATEST WORK.

IT will be remembered that, a couple of months ago, Mr. Tesla delivered before the Franklin Institute in Philadelphia and the National Electric Light Association at St. Louis, a lecture embodying some of the latest results obtained by him in investigating the effects of high frequency, high potential currents. We gave at the time a careful synopsis of the leading points of the lecture, and are glad now to print it in extenso, supplemented by a number of excellent illustrations, for which our thanks are due Secretary Porter of the N. E. L. A.

Viewing Mr. Tesla's lecture as a whole, one is struck by the variety of methods employed and the mass of novel facts and ideas presented. To enumerate them all would be practically repeating the lecture itself and in this necessarily short comment we must restrict ourselves to the most salient features.

To the superficial reader, Mr. Tesla's introductory remarks may appear as a digression, but the thoughtful reader will find therein much food for meditation and speculation. Throughout his discourse we can trace Mr. Tesla's effort to present in a popular way thoughts and views on the electrical phenomena which have in recent years captivated the scientific world, but of which the general public has as yet merely received an inkling. Mr. Tesla also dwells rather extensively on his well-known method of high-frequency conversion; and the large amount of detail information will be gratefully received by students and experimenters in this virgin field. The employment of apt analogies in explaining the fundamental principles involved makes it easy for all to gain a clear idea of their nature. Again, the ease with which, thanks to Mr. Tesla's efforts, these high-frequency currents may now be obtained from circuits carrying almost any kind of current, cannot fail to result in an extensive broadening of this field of research, which offers so many possibilities. Mr. Tesla, true philosopher as he is, does not hesitate to point out defects in some of his methods, and indicates the lines which to him seem the most promising. It is manifest, judging from the tenor of his remarks, that the production of an economical practical illuminant is now merely awaiting the perfection of this, or analogous methods. Particular stress is laid by Mr. Tesla upon the employment of a medium in which the discharge electrodes should be immersed in order that this method of conversion may be brought to the highest perfection. He has evidently taken pains to give as much useful information as possible to those who wish to follow in his path, as he shows in detail the circuit arrangements to be adopted in all ordinary cases met with in practice, and although these methods were described by him two years ago, this additional information will be timely and welcome.

Coming now to the experiments he dwells first on some phenomena produced by electrostatic force, which he considers in the light of modern theories to be the most important force in nature for us to investigate. At the very outset he shows a strikingly novel experiment illustrating the effect of a rapidly varying electrostatic force in a gaseous medium, by touching with one hand one of the terminals of a 200,000 volt transformer and bringing the other hand to the opposite terminal. The powerful streamers which issued from his hand and astonished his audiences formed a capital illustration of some of the views advanced, and afforded Mr. Tesla an opportunity of pointing out the true reasons why, with these currents, such an amount of energy can be passed through the body with impunity. He then showed by experiment the difference between a steady and a rapidly varying force upon the dielectric. This difference is most strikingly illustrated in the experiment in which a bulb attached to the end of a wire in connection with one of the terminals of the transformer is ruptured, although all extraneous bodies are remote from the bulb. He next illustrates how mechanical motions are produced by a varying electrostatic force acting through a gaseous medium. The importance of the action of the air is particularly illustrated by an interesting experiment.

Taking up another class of phenomena, namely, those of dynamic electricity, Mr. Tesla produces in a number of experiments a variety of effects by the employment of only a single wire with the evident intent of impressing upon his audience the idea that electric vibration or current can be transmitted with ease, without any return circuit; also how currents so transmitted can be converted and used for many practical purposes. A number of experiments are then shown, illustrating the effects of frequency, self-induction and capacity; then a number of ways of operating motive and other devices by the use of a single lead. A number of novel impedance phenomena are also shown which cannot fail to arouse interest.

Mr. Tesla next dwells upon a subject which he thinks of great importance, that is, electrical resonance, which he explains in a popular way. He here expresses his firm

conviction that by observing proper conditions, intelligence, and possibly even power, can be transmitted through the medium or through the earth; and he considers this problem worthy of serious and immediate consideration. The views expressed by Mr. Tesla will certainly interest all who have followed his work.

Coming now to the light phenomena in particular he illustrates the four distinct kinds of these phenomena in an original way which to many must have been a revelation. Mr. Tesla attributes these light effects to molecular or atomic impacts produced by a varying electrostatic stress in a gaseous medium. He illustrates in a series of novel experiments the effect of the gas surrounding the conductor and shows beyond a doubt that with high frequency and high-potential currents, the surrounding gas is of paramount importance in the heating of the conductor. He attributes the heating partially to a conduction current and partially to bombardment, and demonstrates that in many cases the heating may be practically due to the bombardment alone. He points out also that the skin effect is largely modified by the presence of the gas or of an atomic medium in general. He shows also some interesting experiments in which the effect of convection is illustrated. Probably one of the most curious experiments in this connection is that in which a thin platinum wire stretched along the axis of an exhausted tube is brought to incandescence at certain points corresponding to the position of the striæ, while at others it remains dark. This experiment throws an interesting light upon the nature of the striæ and may lead to important revelations.

Mr. Tesla also demonstrates the dissipation of energy through an atomic medium and dwells upon the behavior of vacuous space in conveying heat, and in this connection shows the curious behavior of an electrode stream, from which he concludes that the molecules of a gas probably cannot be acted upon directly at measurable distances.

Mr. Tesla summarizes the chief results arrived at in pursuing his investigations in a manner which will serve as a valuable guide to all who may engage in this work. Perhaps most interest will centre on his general statements regarding the phenomena of phosphorescence, the most important fact revealed in this direction being that when exciting a phosphorescent bulb a certain definite potential gives the most economical result. A great many more observations of Mr. Tesla relating to this subject, of such great interest, might be mentioned, but the careful reader will find in nearly every paragraph a thought or suggestion. The lecture is not one for hasty reading.

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.[1]—I.

BY NIKOLA TESLA.

INTRODUCTORY.—SOME THOUGHTS ON THE EYE.

WHEN we look at the world around us, on Nature, we are impressed with its beauty and grandeur. Each thing we perceive, though it may be vanishingly small, is in itself a world, that is, like the whole of the visible universe, matter and force governed by law,—a world, the contemplation of which fills us with feelings of wonder and irresistibly urges us to ceaseless thought and inquiry. But in all this vast world, of all objects our senses reveal to us, the most marvellous, the most appealing to our imagination, appears no doubt a highly developed organism, a thinking being. If there is anything fitted to make us admire Nature's handiwork, it is certainly this inconceivable structure, which performs its innumerable motions in obedience to external influence. To understand its workings, to get a deeper insight into this Nature's masterpiece, has ever been for thinkers a fascinating aim, and after many centuries of arduous research men have arrived at a fair understanding of the functions of its organs and senses. Again, in all the perfect harmony of its parts, of the parts which constitute the material or tangible of our being, of all its organs and senses, the eye is the most wonderful. It is the most precious, the most indispensable of our receptive or directive organs, it is the great gateway through which all knowledge enters the mind. Of all our organs, it is the one, which is in the most intimate relation with that which we call intellect. So intimate is this relation, that it is often said, that the very soul shows itself in the eye.

It can be taken as a fact, which the theory of the action of the eye implies, that for each external impression, that is, for each image produced upon the retina, the ends of the visual nerves, concerned in the conveyance of the impression to the mind, must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and therefore upon the retina. Will it ever be within human power to analyze the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness, that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems, belonging to the domain of positive physical science, in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he was able to *see*, in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely, that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

Another fact having a bearing on this subject which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation is, that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, observable even in broad daylight.

The saying then, that the soul shows itself in the eye, is deeply founded, and we feel that it expresses a great truth. It has a profound meaning even for one who, like a poet or artist, only following his inborn instinct or love for Nature, finds delight in aimless thoughts and in the mere contemplation of natural phenomena, but a still more profound meaning for one who, in the spirit of positive scientific investigation, seeks to ascertain the causes of the effects. It is principally the natural philosopher, the physicist, for whom the eye is the subject of the most intense admiration.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting, that the very conception of that which is perfect or seems so to him, has been gained through this same instrument. Firstly, the eye is, as far as our positive knowledge goes, the only organ which is *directly* affected by that subtile medium, which as science teaches us, must fill all space; secondly, it is the most sensitive of our organs, incomparably more sensitive to external impressions than any other.

The organ of hearing implies the impact of ponderable bodies, the organ of smell the transference of detached material particles, and the organs of taste, and of touch or force, the direct contact, or at least some interference of ponderable matter, and this is true even in those instances of animal organisms, in which some of these organs are developed to a degree of truly marvelous perfection. This being so, it seems wonderful that the organ of sight solely should be capable of being stirred by that, which all our other organs are powerless to detect, which yet plays an essential part in all natural phenomena, which transmits all energy and sustains all motion and, that most intricate of all, life, but which has properties such that even a scientifically trained mind cannot help drawing a distinction between it and all that is called matter. Considering merely this, and the fact that the eye, by its marvelous power, widens our otherwise very narrow range of perception far beyond the limits of the small world which is our own, to embrace myriads of other worlds, suns and stars in the infinite depths of the universe, would make it justifiable to assert, that it is an organ of a higher order. Its performances are beyond comprehension. Nature as far as we know never produced anything more wonderful. We can get barely a faint idea of its prodigious power by analyzing what it does and by comparing. When ether waves impinge upon the human body, they produce the sensations of warmth or cold, pleasure or pain, or perhaps other sensations of which we are not aware, and any degree or intensity of these sensations, which degrees are infinite in number, hence an infinite number of distinct sensations. But our sense of touch, or our sense of force, cannot reveal to us these differences in degree or intensity, unless they are very great. Now we can readily conceive how an organism, such as the human in the eternal process of evolution, or more philosophically speaking, adaptation to Nature, being constrained to the use of only the sense of touch or force, for instance, might develop this sense to such a degree of sensitiveness or perfection, that it would be capable of distinguishing the minutest differences in the temperature of a body even at some distance, to a hundredth, or thousandth, or millionth part of a degree. Yet, even this apparently impossible performance would not begin to compare with that of the eye, which is capable of distinguishing and conveying to the mind in a single instant innumerable peculiarities of the body, be it in form or color or other respects. This power of the eye rests upon two things, namely, the rectilinear propagation of the disturbance by which it is affected, and upon its sensitiveness. To say that the eye is sensitive is not saying anything. Compared with it, all other organs are monstrously crude. The organ of smell which guides a dog on the trail of a deer, the organ of touch or force which guides an insect in its wanderings, the organ of hearing, which is affected by the slightest disturbances of the air, are sensitive organs, to be sure, but what are they compared with the human eye! No doubt it responds to the faintest echoes or reverberations of the medium; no doubt, it brings us tidings from other worlds, infinitely remote, but in a language we cannot as yet always understand. And why not? Because we live in a medium filled with air and other gases, vapors and a dense mass of solid particles flying-about. These play an important part in many phenomena; they fritter away the energy of the vibrations before they can reach the eye; they too, are the carriers of germs of destruction, they get into our lungs and other organs, clog up the channels and imperceptibly, yet inevitably arrest the stream of life. Could we but do away with all ponderable matter in the line of sight of the telescope, it would reveal to us undreamt of marvels. Even the unaided eye, I think, would be capable of distinguishing in the pure medium, small objects at distances measured probably by hundreds or perhaps thousands of miles.

But there is something else about the eye which impresses us still more than these wonderful features which we observe, viewing it from the standpoint of a physicist, merely as an optical instrument,—something which appeals to us more than its marvelous faculty of being directly affected by the vibrations of the medium, without interference of gross matter, and more than its inconceivable sensitiveness and discerning power. It is its significance in the processes of life. No matter what one's views on Nature and life may be, he must stand amazed when, for the first time in his thoughts, he realizes the importance of the eye in the physical processes and mental performances of the human organism. And how could it be otherwise, when he realizes, that the eye is the means through which the human race has acquired

1. A lecture delivered before the Franklin Institute, at Philadelphia, Feb. 24, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893.

the entire knowledge it possesses, that it controls all our motions, more still, all our actions.

There is no way of acquiring knowledge except through the eye. What is the foundation of all philosophical systems of ancient and modern times, in fact of all the philosophy of man? *I am, I think; I think, therefore I am.* But how could I think and how would I know that I exist, if I had not the eye? For knowledge involves consciousness; consciousness involves ideas, conceptions; conceptions involve pictures or images, and images, the sense of vision, and therefore the organ of sight. But how about blind men, will be asked? Yes, a blind man may depict in magnificent poems forms and scenes from real life, from a world he physically does not see. A blind man may touch the keys of an instrument with unerring precision, may build the fastest boat, may discover and invent, calculate and construct, may do still greater wonders,—but all the blind men who have done such things have descended from those who had seeing eyes. Nature may reach the same result in many ways. Like a wave in the physical world, in the infinite ocean of the medium which pervades all, so in the world of organisms, in life, an impulse started proceeds onward, at times, may be, with the speed of light, at times, again, so slowly that for ages and ages it seems to stay, passing through processes of a complexity inconceivable to men, but in all its forms, in all its stages, its energy ever and ever integrally present. A single ray of light from a distant star falling upon the eye of a tyrant in bygone times, may have altered the course of his life, may have changed the destiny of nations, may have transformed the surface of the globe, so intricate, so inconceivably complex are the processes in Nature. In no way can we get such an overwhelming idea of the grandeur of Nature, as when we consider, that in accordance with the law of the conservation of energy, throughout the Infinite, the forces are in a perfect balance, and hence the energy of a single thought may determine the motion of a Universe. It is not necessary that every individual, not even that every generation or many generations, should have the physical instrument of sight, in order to be able to form images and to think, that is, form ideas or conceptions; but sometime or other, during the process of evolution, the eye certainly must have existed, else thought, as we understand it, would be impossible; else conceptions, like spirit, intellect, mind, call it as you may, could not exist. It is conceivable, that in some other world, in some other beings the eye is replaced by a different organ, equally or more perfect, but these beings cannot be men.

Now what prompts us to all voluntary motions and actions of any kind? Again the eye. If I am conscious of the motion, I must have an idea or conception, that is, an image, therefore the eye. If I am not precisely conscious of the motion, it is, because the images are vague or indistinct, being blurred by the superimposition of many. But when I perform the motion, does the impulse which prompts me to the action come from within or from without? The greatest physicists have not disdained to endeavor to answer this and similar questions and have at times abandoned themselves to the delights of pure and unrestrained thought. Such questions are generally considered not to belong to the realm of positive physical science, but will before long be annexed to its domain. Helmholtz has probably thought more on life than any modern scientist. Lord Kelvin expressed his belief that life's process is electrical and that there is a force inherent to the organism and determining its motions. Just as much as I am convinced of any physical truth I am convinced that the motive impulse must come from the outside. For, consider the lowest organism we know—and there are probably many lower ones—an aggregation of a few cells only. If it is capable of voluntary motion it can perform an infinite number of motions, all definite and precise. But now a mechanism consisting of a finite number of parts and few at that, cannot perform an infinite number of definite motions, hence the impulses which govern its movements must come from the environment. So, the atom, the ulterior element of the Universe's structure, is tossed about in space eternally, a play to external influences, like a float in a troubled sea. Were it to stop its motion *it would die.* Matter at rest, if such a thing could exist, would be matter dead. Death of matter! Never has a sentence of deeper philosophical meaning been uttered. This is the way in which Prof. Dewar forcibly expresses it in the description of his admirable experiments, in which liquid oxygen is handled as one handles water, and air at ordinary pressure is made to condense and even to solidify by the intense cold. Experiments, which serve to illustrate, in his language, the last feeble manifestations of life, the last quiverings of matter about to die. But human eyes shall not witness such death. There is no death of matter, for throughout the infinite universe, all has to move, to vibrate, that is, to live.

I have made the preceding statements at the peril of treading upon metaphysical ground in my desire to introduce the subject of this lecture in a manner not altogether uninteresting, I may hope, to an audience such as I have the honor to address. But now then, returning to the subject, this divine organ of sight, this indispensable instrument for thought and all intellectual enjoyment, which lays open to us the marvels of this universe, through which we have acquired what knowledge we possess, and which prompts us to, and controls, all our physical and mental activity, By what is it affected? By light! What is light?

We have witnessed the great strides which have been made in all departments of science in recent years. So great have been the advances that we cannot refrain from asking ourselves, Is this all true, or is it but a dream? Centuries ago men have lived, have thought, discovered, invented, and have believed that they were soaring, while they were merely proceeding at a snail's pace. So we too may be mistaken. But taking the truth of the observed events as one of the implied facts of science, we must rejoice in the immense progress already made and still more in the anticipation of what must come, judging from the possibilities opened up by modern research. There is, however, an advance which we have been witnessing, which must be particularly gratifying to every lover of progress. It is not a discovery, or an invention, or an achievement in any particular direction. It is an advance in all directions of scientific thought and experiment. I mean the generalization of the natural forces and phenomena, the looming up of a certain broad idea on the scientific horizon. It is this idea which has, however, long ago taken possession of the most advanced minds, to which I desire to call your attention, and which I intend to illustrate, in a general way, in these experiments, as the first step in answering the question "What is light?" and to realize the modern meaning of this word.

It is beyond the scope of my lecture to dwell upon the subject of light in general, my object being merely to bring presently to your notice a certain class of light effects and a number of phenomena observed in pursuing the study of these effects. But to be consistent in my remarks it is necessary to state that according to that idea, now accepted by the majority of scientific men as a positive result of theoretical and experimental investigation, the various forms or manifestations of energy which were generally designated as "electric" or more precisely "electromagnetic" are energy manifestations of the same nature as those of radiant heat and light. Therefore the phenomena of light and heat, and others besides these, may be called electrical phenomena. Thus electrical science has become the mother science of all and its study has become all important. The day when we shall know exactly what "electricity" is, will chronicle an event probably greater, more important than any other recorded in the history of the human race. The time will come when the comfort, the very existence perhaps of man will depend upon that wonderful agent. For our existence and comfort we require heat, light and mechanical power. How do we now get all these? We get them from fuel, we get them by consuming material. What will man do when the forests disappear, when the coal fields are exhausted? Only one thing, according to our present knowledge will remain; that is, to transmit power at great distances. Men will go the waterfalls, to the tides, which are the stores of an infinitesimal part of Nature's immeasurable energy. There will they harness the energy and transmit the same to their settlements, to warm their homes by, to give them light, and to keep their obedient slaves, the machines, toiling. But how will they transmit this energy if not by electricity? Judge then, if the comfort, nay, the very existence, of man will not depend on electricity. I am aware that this view is not that of a practical engineer, but neither is it that of an illusionist, for it is certain, that power transmission which at present is merely a stimulus to enterprise, will some day be a dire necessity.

It is more important for the student, who takes up the study of light phenomena, to make himself thoroughly acquainted with certain modern views, than to peruse entire books on the subject of light itself, as disconnected from these views. Were I therefore to make these demonstrations before students seeking information—and for the sake of the few of those who may be present, give me leave to so assume—it would be my principal endeavor to impress these views upon their minds in this series of experiments.

It might be sufficient for this purpose to perform a simple and well-known experiment. I might take a familiar appliance, a Leyden jar, charge it from a frictional machine, and then discharge it. In explaining to you its permanent state when charged, and its transitory condition when discharging, calling your attention to the forces which enter into play and to the various phenomena they produce, and pointing out the relation of the forces and phenomena, I might fully succeed in illustrating that modern idea. No doubt, to the thinker, this simple experiment would appeal as much as the most magnificent display. But this is to be an experimental demonstration, and one which should possess besides instructive, also entertaining features and as such, a simple experiment, such as the one cited, would not go very far towards the attainment of the lecturer's aim. I must therefore choose another way of illustrating, more spectacular certainly, but perhaps also more instructive. Instead of the frictional machine and Leyden jar, I shall avail myself in these experiments, of an induction coil of peculiar properties, which was described in detail by me in a lecture before the London Institution of Electrical Engineers, in Feb., 1892. This induction coil is capable of yielding currents of enormous potential differences, alternating with extreme rapidity. With this apparatus I shall endeavor to show you three distinct classes of effects, or phenomena, and it is my desire that each experiment, while serving for the purposes of illustration, should at the same time teach us some novel truth, or show us some

novel aspect of this fascinating science. But before doing this, it seems proper and useful to dwell upon the apparatus employed, and method of obtaining the high potentials and high-frequency currents which are made use of in these experiments.

ON THE APPARATUS AND METHOD OF CONVERSION.

These high-frequency currents are obtained in a peculiar manner. The method employed was advanced by me about two years ago in an experimental lecture before the American Institute of Electrical Engineers. A number of ways, as practiced in the laboratory, of obtaining these currents either from continuous or low frequency alternating-currents is diagramatically indicated in Fig. 1, which will be later described in detail. The general plan is to charge condensers, from a direct or alternate-current source, preferably of high-tension, and to discharge them disruptively while observing well-known conditions necessary to maintain the oscillations of the current. In view of the general interest taken in high-frequency currents and effects producible by them, it seems to me advisable to dwell at some length upon this method of conversion. In order to give you a clear idea of the action, I will suppose that a continuous-current generator is employed, which is often very convenient. It is desirable that the generator should possess such high tension as to be able to break through a small air space. If this is not the case, then auxiliary means have to be resorted to, some of which will be indicated subsequently. When the condensers are charged to a certain potential, the air or insulating space gives way and a disruptive discharge occurs. There is then a sudden rush of current and generally a large portion of the accumulated electrical energy spends itself. The condensers are thereupon quickly charged and the same process is repeated in more or less rapid succession. To produce such sudden rushes of current it is necessary to observe certain conditions. If the rate at which the condensers are discharged is the same as that at which they are charged, then, clearly, in the assumed case the condensers do not come into play. If the rate of discharge be smaller than the rate of charging, then, again, the condensers cannot play an important part. But if, on the contrary, the rate of discharging is greater than that of charging, then a succession of rushes of current is obtained. It is evident that, if the rate at which the energy is being dissipated by the discharge is very much greater than the rate of supply to the condensers, the sudden rushes will be comparatively few, with long-time intervals between. This always occurs when a condenser of considerable capacity is charged by means of a comparatively small machine. If the rates of supply and dissipation are not widely different, then the rushes of current will be in quicker succession, and this the more, the more nearly equal both the rates are, until natural limitations incident to each case and depending upon a number of causes are reached. Thus we are able to obtain from a continuous-current generator as rapid a succession of discharges as we like. Of course, the higher the tension of the generator, the smaller need be the capacity of the condensers, and for this reason, principally, it is of advantage to employ a generator of very high tension. Besides, such a generator permits the attaining of greater rates of vibration.

The rushes of current may be of the same direction under the conditions before assumed, but most generally there is an oscillation superimposed upon the fundamental vibration of the current. When the conditions are so determined that there are no oscillation, the current impulses are unidirectional and thus a means is provided of transforming a continuous current of high tension into a direct current of lower tension, which I think may find employment in the arts.

This method of conversion is exceedingly interesting and I was much impressed by its beauty when I first conceived it. It is ideal in certain respects. It involves the employment of no mechanical devices of any kind, and it allows of obtaining currents of any desired frequency from an ordinary circuit, direct or alternating. The frequency of the fundamental discharges depending on the relative rates of supply and dissipation can be readily varied within wide limits by simple adjustments of these quantities, and the frequency of the superimposed vibration by the determination of the capacity, self-induction and resistance of the circuit. The potential of the currents, again, may be raised as high as any insulation is capable of withstanding safely by combining capacity and self-induction or by induction in a secondary, which need have but comparatively few turns.

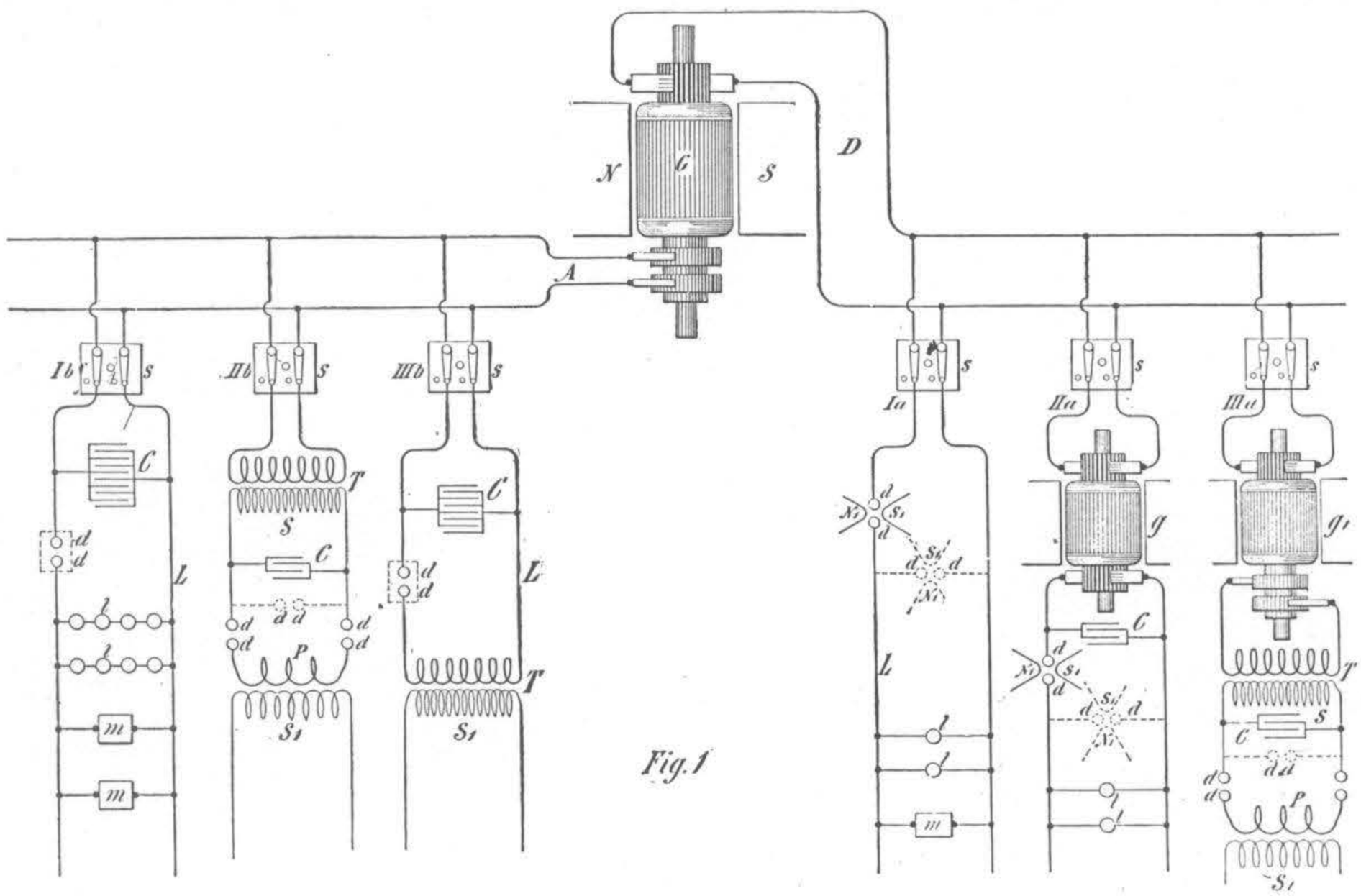


Fig. 1

FIG. 1.—PLAN OF CONNECTIONS USED IN THE CONVERSION BY MEANS OF THE DISRUPTIVE ARC DISCHARGE.

As the conditions are often such that the intermittence or oscillation does not readily establish itself, especially when a direct current source is employed, it is of advantage to associate an interrupter with the arc, and I have, some time ago, indicated the use of an air-blast or magnet, or other such device readily at hand. The magnet is employed with special advantage in the conversion of direct currents, as it is then very effective. If the primary source is an alternate current generator, it is desirable, as I have stated on another occasion, that the frequency should be low, and that the currents forming the arc be large, in order to render the magnet more effective.

A form of such discharger with a magnet which has been found convenient, and adopted after some trials, in the conversion of direct currents particularly, is illustrated in Fig. 2. N S are the pole pieces of a very strong magnet which is excited by a coil C. The pole pieces are slotted for adjustment and can be fastened in any position by screws s_1 s_1. The discharge rods d d_1 thinned down on the ends in order to allow a closer approach of the magnetic pole pieces, pass through the columns of brass b b_1 and are fastened in position by screws s_2 s_2. Springs r r_1 and collars c c_1 are slipped on the rods, the latter serving to set the points of the

rods at a certain suitable distance by means of screws s_3 s_3, and the former to draw the points apart. When it is desired to start the arc, one of the hard rubber handles h h_1 is tapped quickly with the hand, whereby the points of the rods are brought in contact but are instantly separated by the springs r r_1. Such an arrangement has been found to be often necessary, namely in cases when the E. M. F. was not large enough to cause the discharge to break through the gap, and also when it was desirable to avoid short circuiting of the generator by the metallic contact of the rods. The rapidity of the interruptions of the current with a magnet depends on the intensity of the magnetic field and on the potential difference at the ends of the arc. The interruptions are generally in such quick succession as to produce a musical sound. Years ago it was observed that when a powerful induction coil is discharged between the poles of a strong magnet the discharge produced a loud noise not unlike a small pistol shot. It was vaguely stated that the spark was intensified by the presence of the magnetic field. It is now clear that the discharge current, flowing for some time, was interrupted a great number of times by the magnet, thus producing the sound. The phenomenon is especially marked when the field circuit of a large magnet or dynamo is broken in a powerful magnetic field.

When the current through the gap is comparatively large, it is of advantage to slip on the points of the discharge rods pieces of very hard carbon and let the arc play between the carbon pieces. This preserves the rods and besides has the advantage of keeping the air space hotter, as the heat is not conducted away as quickly through the carbons, and the result is that a smaller E. M. F. in the arc gap is required to maintain a succession of discharges.

The air may be rendered dielectrically weak also by rarefaction. Dischargers of this kind have likewise been used by me in connection with the magnet. A large tube is for this purpose provided with heavy electrodes of carbon or metal, between which the discharge is made to pass, the tube being placed in a powerful magnetic field. The exhaustion of the tube is carried to a point at which the discharge breaks through easily, but the pressure should be more than 75 millimetres, at which the ordinary thread discharge occurs. In another form of discharger, combining the features before mentioned, the discharge was made to pass between two adjustable magnetic pole pieces, the space between them being kept at an elevated temperature.

It should be remarked here that when such, or interrupting devices of any kind, are used and the currents are passed through the primary of a disruptive discharge coil, it is not, as a rule, of advantage to produce a number of interruptions of the current per second greater than the natural frequency of vibration of the dynamo supply circuit, which is ordinarily small. It should also be pointed out here, that while the devices mentioned in connection with the disruptive discharge are advantageous under certain conditions, they may be sometimes a source of trouble, as they produce intermittences and other irregularities in the vibration which it would be very desirable to overcome.

There is, I regret to say, in this beautiful method of conversion a defect, which fortunately is not vital, and which I have been gradually overcoming. I will best call attention to this defect and indicate a fruitful line of work by comparing the electrical process with its mechanical analogue. The process may be illustrated in this manner. Imagine a tank with a wide opening at

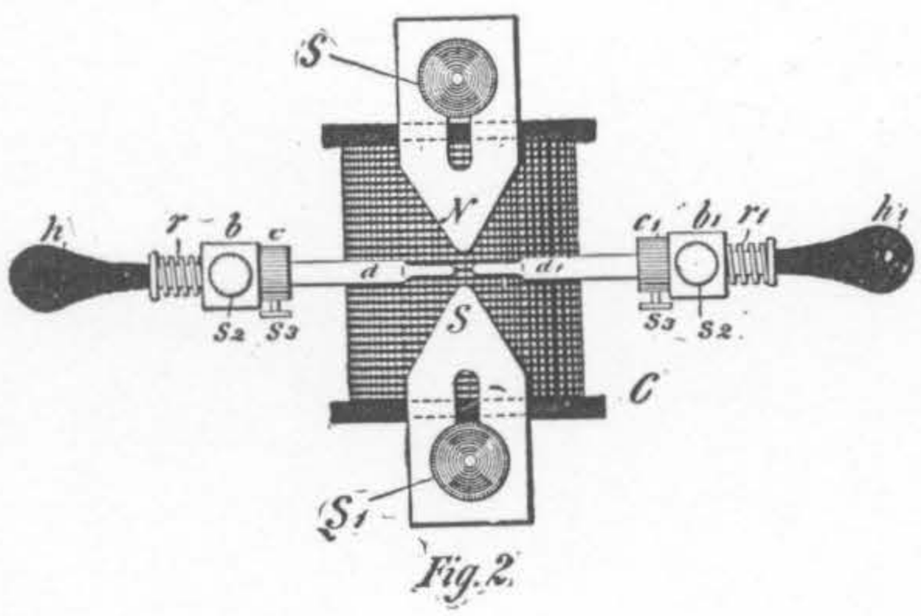


Fig. 2.

FIG. 2.—FORM OF DISCHARGER WITH MAGNET USED IN THE DIRECT CURRENT CONVERSION.

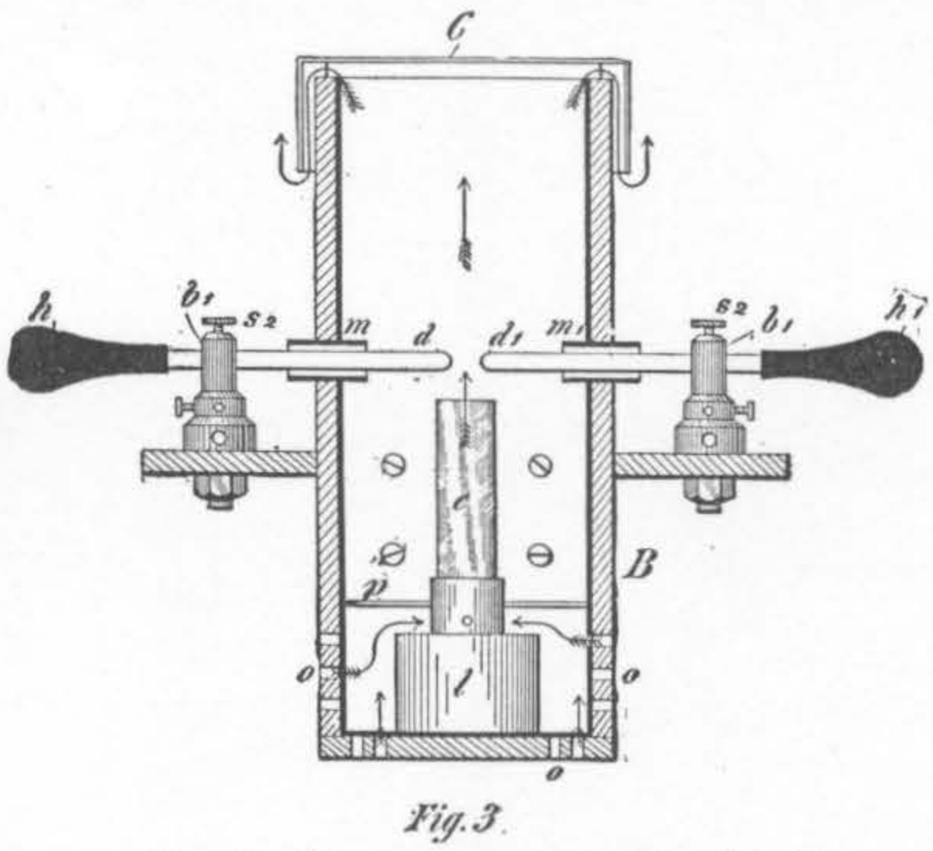


Fig. 3.

FIG. 3.—DISCHARGER WITH HOT AIR DRAFT.

Another form of discharger which may be employed with advantage in some cases is illustrated in Fig. 3. In this form the discharge rods d d_1 pass through perforations in a wooden box B, which is thickly coated with mica on the inside, as indicated by the heavy lines. The perforations are provided with mica tubes m m_1 of some thickness, which are preferably not in contact with the rods d d_1. The box has a cover C which is a little larger and descends on the outside of the box. The spark gap is warmed by a small lamp l contained in the box. A plate p above the lamp allows the draught to pass only through the chimney c of the lamp, the air entering through holes o o in or near the bottom of the box and following the path indicated by the arrows. When the discharger is in operation the door of the box is closed so that the light of the arc is not visible outside. It is desirable to exclude the light as perfectly as possible, as it interferes with some experiments. This form of discharger is simple and very effective when properly manipulated. The air being warmed to a certain temperature has its insulating power impaired, it becomes dielectrically weak, as it were, and the consequence is that the arc can be established at much greater distance. The air should, of course, be sufficiently insulating to allow the discharge to pass through the gap *disruptively*. The arc formed under such conditions, when long, may be made extremely sensitive, and the weak draught through the lamp chimney c is quite sufficient to produce rapid interruptions. The adjustment is made by regulating the temperature and velocity of the draught. Instead of using a lamp it answers the purpose to provide for a draught of warm air in other ways. A very simple way which has been practiced is to inclose the arc in a long vertical tube with plates on the top and bottom for regulating the temperature and velocity of the air current. Some provision had to be made for deadening the sound.

the bottom, which is kept closed by spring pressure, but so that it snaps off *suddenly* when the liquid in the tank has reached a certain height. Let the fluid be supplied to the tank by means of a pipe feeding at a certain rate. When the critical height of the liquid is reached, the spring gives way and the bottom of the tank drops out. Instantly the liquid falls through the wide opening, and the spring, reasserting itself, closes the bottom again. The tank is now filled, and after a certain time interval the same process is repeated. It is clear, that if the pipe feeds the fluid quicker than the bottom outlet is capable of letting it pass through, the bottom will remain off and the tank will still overflow. If the rates of supply are exactly equal, then the bottom lid will remain partially open and no vibration of the same and of the liquid column will generally occur, though it might, if started by some means. But if the inlet pipe does not feed the fluid fast enough for the outlet, then there will be always vibration. Again, in such case, each time the bottom flaps up or down, the spring and the liquid column, if the pliability of the spring and the inertia of the moving parts are properly chosen, will perform independent vibrations. In this analogue the fluid may be likened to electricity or electrical energy, the tank to the condenser, the spring to the dielectric and the pipe to the conductor through which electricity is supplied to the condenser. To make this analogy quite complete it is necessary to make the assumption, that the bottom, each time it gives way, is knocked violently against a non-elastic stop, this impact involving some loss of energy, and that, besides, some dissipation of energy results, due to frictional losses. In the preceding analogue the liquid is supposed to be under a steady pressure. If the pressure of the fluid be assumed to vary rhythmically, this may be taken as corresponding to the case of an alternating current. The process is then not quite as simple to consider, but the action is the same in principle.

It is desirable, in order to maintain the vibration economically, to reduce the impact and frictional losses as much as possible. As regards the latter, which in the electrical analogue correspond to the losses due to the resistance of the circuits, it is impossible to obviate them entirely, but they can be reduced to a minimum by a proper selection of the dimensions of the circuits and by the employment of thin conductors in the form of strands. But the loss of energy caused by the first breaking through of the dielectric—which in the above example corresponds to the violent knock of the bottom against the inelastic stop—would be more important to overcome. At the moment of the breaking through, the air space has a very high resistance, which is probably reduced to a very small value when the current has reached some strength, and the space is brought to a high temperature. It would materially diminish the loss of energy, if the space were always kept at an extremely high temperature, but then there would be no disruptive break. By warming the space moderately by means of a lamp or otherwise, the economy as far as the arc is concerned is sensibly increased. But the magnet or other interrupting device does not diminish the loss in the arct Likewise, a jet of air only facilitates the carrying off of the energy. Air, or a gas in general, behaves curiously in this respect When two bodies, charged to a very high potential, discharge disruptively through an air space, any amount of energy may be carried off by the air. This energy is evidently dissipated by bodily carriers, in impact and collisional losses of the molecules. The exchange of the molecules in the space occurs with inconceivable rapidity. A powerful discharge taking place between two electrodes, they may remain entirely cool, and yet the loss in the air may represent any amount of energy. It is perfectly practicable, with very great potential differences in the gap, to dissipate several horse-power in the arc of the discharge without even noticing a small increase in the temperature of the electrodes. All the frictional losses occur then practically in the air. If the exchange of the air molecules is prevented, as by enclosing the air hermetically, the gas inside of the vessel is brought quickly to a high temperature, even with a very small discharge. It is difficult to estimate how much of the energy is lost in sound waves, audible or not, in a powerful discharge. When the currents through the gap are large, the electrodes may become rapidly heated, but this is not a reliable measure of the energy wasted in the arc, as the loss through the gap itself may be comparatively small. The air or a gas in general is, at ordinary pressures at least, clearly not the best medium through which a disruptive discharge should occur. Air or other gas under great pressure is of course a much more suitable medium for the discharge gap. I have carried on long-continued experiments in this direction, unfortunately less practicable on account of the difficulties and expense in getting air under great pressure. But even if the medium in the discharge space is solid or liquid, still the same losses take place, though they are generally smaller, for just as soon as the arc is established, the solid or liquid is volatilized. Indeed, there is no body known which would not be disintegrated by the arc, and it is an open question among scientific men, whether an arc discharge could occur at all in the air itself without the particles of the electrodes being torn off. When the current through the gap is very small and the arc very long, I believe that a relatively considerable amount of heat is taken up in the disintegration of the electrodes, which partially on this account may remain quite cold.

The ideal medium for a discharge gap should only *crack*, and the ideal electrode should be of some material which cannot be disintegrated. With small currents through the gap it is best to employ aluminum, but not when the currents are large. The disruptive break in the air, or more or less in any ordinary medium, is not of the nature of a crack, but it is rather comparable to the piercing of innumerable bullets through a mass offering great frictional resistance to the motion of the bullets, this involving considerable loss of energy. A medium which would merely crack when strained electrostatically—and this possibly might be the case with a perfect vacuum, that is, pure ether—would involve a very small loss in the gap, so small as to be entirely negligible, at least theoretically, because a crack may be produced by an infinitely small displacement. In exhausting an oblong bulb provided with two aluminum terminals with the greatest care I have succeeded in producing such a vacuum that the secondary discharge of a disruptive discharge coil would break through disruptively through the bulb in the form of fine spark streams. The curious point was that the discharge would completely ignore the terminals and start far behind the two aluminum plates, which served as electrodes. This extraordinarily high vacuum could only be maintained for a very short while. To return to the ideal medium, think, for the sake of illustration, of a piece of glass or similar body clamped in a vice, and the latter lightened more and more. At a certain point a minute increase of the pressure will cause the glass to crack. The loss of energy involved in splitting the glass may be practically nothing, for though the force is great, the displacement need be but extremely small. Now imagine that the glass would possess the property of closing again perfectly the crack upon a minute diminution of the pressure. This is the way the dielectric in the discharge space should behave. But inasmuch as there would be always some loss in the gap the medium which should be continuous should exchange through the gap at a rapid rate. In the preceding example, the glass being perfectly closed, it would mean that the dielectric in the discharge space possesses a great insulating power ; the glass being cracked, it would signify that the medium in the space is a good conductor. The dielectric should vary enormously in resistance by minute variations of the E. M. F. across the discharge space. This condition is attained but in an extremely imperfect manner, by warming the air space to a certain critical temperature, dependent on the E. M. F. across the gap, or by otherwise impairing the insulating power of the air. But as a matter of fact the air does never break down *disruptively*, if this term be rigorously interpreted, for before the sudden rush of the current occurs, there is always a weak current preceding it, which rises first gradually and then with comparative suddenness. That is the reason why the rate of change is very much greater when glass, for instance, is broken through, than when the break takes place through an air space of equivalent dielectric strength. As a medium for the discharge space a solid, or even a liquid would be preferable therefore. It is somewhat difficult to conceive of a solid body which would possess the property of closing instantly after it has been cracked. But a liquid, especially under great pressure, behaves practically like a solid, while it possesses the property of closing the crack. Hence it was thought that a liquid insulator might be more suitable as a dielectric than air. Following out this idea, a number of different forms of dischargers in which a variety of such insulators, sometimes under great pressure, were employed, have been experimented upon. It is thought sufficient to dwell in a few words upon one of the forms experimented upon. One of these dischargers is illustrated in Figs. 4*a* and 4*b*.

A hollow metal pulley P (Fig. 4*a*), was fastened upon an arbor *a*, which by suitable means was rotated at a considerable speed. In the inside of the pulley, but disconnected from the same, was supported a thin disc *h* (which is shown thick for the sake of clear-

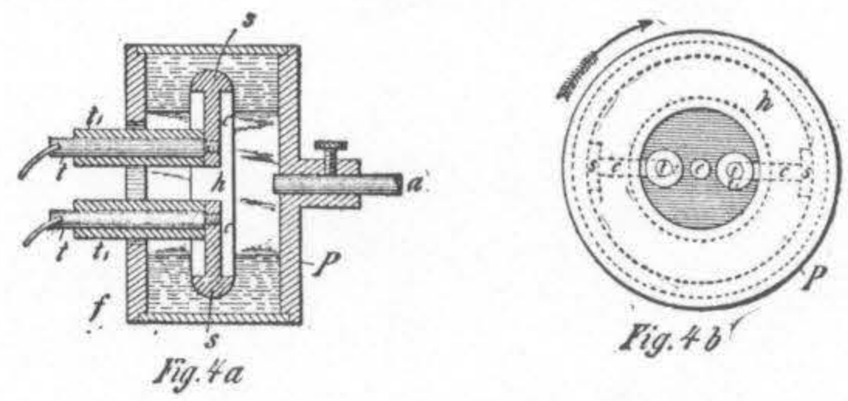


Fig. 4a Fig. 4b

FIGS. 4*a* AND 4*b*.—FORM OF DISCHARGER WITH LIQUID INTERRUPTER.

ness), of hard rubber, in which there were embedded two metal segments *s s* with metallic extensions *e e* into which were screwed conducting terminals *t t* covered with thick tubes of hard rubber *t t*. The rubber disc *h* with its metallic segments *s s*, was finished in a lathe, and its entire surface highly polished so as to offer the smallest possible frictional resistance to the motion through a fluid. In the hollow of the pulley an insulating liquid such as a thin oil was poured so as to reach very nearly to the opening left in the flange *f*, which was screwed tightly on the front side of the pulley. The terminals *t t*, were connected to the opposite coatings of a battery of condensers so that the discharge occurred through the liquid. When the pulley was rotated the liquid was forced against the rim of the pulley and considerable fluid pressure resulted. In this simple way the discharge gap was filled with a medium which behaved practically like a solid, which possessed the quality of closing instantly upon the occurrence of the break, and which moreover was circulating through the gap at a rapid rate. Very powerful effects were produced by dischargers of this kind with liquid interrupters, of which a number of different forms were made. It was found that, as expected, a longer spark for a given length of wire was obtainable in this way than by using air as an interrupting device. Generally the speed, and therefore also the fluid pressure, was limited by reason of the fluid friction, in the form of discharger described, but the practically obtainable speed was more than sufficient to produce a number of breaks suitable for the circuits ordinarily used. In some instances the metal pulley P was provided with a few projections inwardly. and a definite number of breaks was then produced which could be computed from the speed of rotation of the pulley. Experiments were also carried on with liquids of different insulating power with the view of reducing the loss in the arc. When an insulating liquid is moderately warmed the loss in the arc is diminished.

A point of some importance was noted in experiments with various dischargers of this kind. It was found, for instance, that whereas the conditions maintained in these forms were favorable for the production of a great spark length, the current so obtained were not best suited to the production of

light effects. Experience undoubtedly has shown, that for such purposes a harmonic rise and fall of the potential is preferable. Be it that a solid is rendered incandescent, or phosphorescent, or be it that energy is transmitted by condenser coating through the glass, it is quite certain that a harmonically rising and falling potential produces less destructive action, and that the vacuum is more permanently maintained. This would be easily explained if it were ascertained that the process going on in an exhausted vessel is of an electrolytic nature.

In the diagrammatical sketch, Fig. 1, which has been already referred to, the cases which are most likely to be met with in practice are illustrated. One has at his disposal either direct or alternating currents from a supply station. It is convenient for an experimenter in an isolated laboratory to employ a machine G such as illustrated, capable of giving both kinds of currents. In such case it is also preferable to use a machine with multiple circuits, as in many experiments it is useful and convenient to have at one's disposal currents of different phases. In the sketch, D represents the direct and A the alternating circuit. In each of these, three branch circuits are shown, all of which are provided with double line switches *ssssss*. Consider first the direct current conversion; I*a* represents the simplest case. If the E. M. F of the generator is sufficient to break through a small air space, at least when the latter is warmed or otherwise rendered poorly insulating, there is no difficulty in maintaining a vibration with fair economy by judicious adjustment of the capacity, self-induction and resistance of the circuit L containing the devices *l l m*. The magnet N, S, can be in this case advantageously combined with the air space. The discharger *d d* with the magnet may be placed either way, as indicated by the full or by the dotted lines. The circuit I*a* with the connections and devices is supposed to possess dimensions such as are suitable for the maintenance of a vibration. But usually the E. M. F on the circuit or branch I*a* will be something like 100 volts or so, and in this case it is not sufficient to break through the gap. Many different means may be used to remedy this by raising the E. M. F. across the gap. The simplest is probably to insert a large self-induction coil in series with the circuit L. When the arc is established, as by the discharger illustrated in Fig. 2, the magnet blows the arc out the instant it is formed. Now the extra current of the break, being of high E. M. F., breaks through the gap, and a path of low resistance for the dynamo current being again provided, there is a sudden rush of the current from the dynamo upon the weakening or subsidence of the extra current. This process is repeated in rapid succession, and in this manner I have maintained oscillation with as low as 50 volts, or even less, across the gap. But conversion on this plan is not to be recommended on account of the too heavy currents through the gap and consequent heating of the electrodes; besides, the frequencies obtained in this way are low, owing to the high self-induction necessarily associated with the circuit. It is very desirable to have the E. M. F. as high as possible, first, in order to increase the economy of the conversion, and, secondly, to obtain high frequencies. The difference of potential in this electric oscillation is, of course, the equivalent of the stretching force in the mechanical vibration of the spring. To obtain very rapid vibration in a circuit of some inertia a great stretching force or difference of potential is necessary. Incidentally, when the E. M. F. is very great, the condenser which is usually employed in connection with the circuit need have but a small capacity, and many other advantages are gained. With a view of raising the E. M. F. to a many times greater value than obtainable from ordinary distribution circuits, a rotating transformer *g* is used, as indicated at II*a*, Fig. 1, or else a separate high potential machine is driven by means of a motor operated from the generator G. The latter plan is in fact preferable, as changes are easier made. The connections from the high tension winding are quite similar to those in branch I*a* with the exception that a condenser C, which should be adjustable, is connected to the high tension circuit. Usually, also, an adjustable self-induction coil in series with the circuit has been employed in these experiments. When the tension of the currents is very high the magnet ordinarily used in connection with the discharger is of comparatively small value, as it is quite easy to adjust the dimensions of the circuit so that oscillation is maintained. The employment of a steady E. M. F. in the high frequency conversion affords some advantages over the employment of alternating E. M. F. as the adjustments are much simpler and the action can be easier controlled. But unfortunately one is limited by the obtainable potential difference. The windings also break down easily in consequence of the sparks which form between the sections of the armature or commutator when a vigorous oscillation takes place. Besides, these transformers are expensive to build. It has been found by experience that it is best to follow the plan illustrated at III*a*. In this arrangement a rotating transformer *g*, is employed to convert the low tension direct currents into low frequency alternating currents, preferably also of small tension. The tension of the currents is then raised in a stationary transformer T. The secondary S of this transformer is connected to an adjustable condenser C which discharges through the gap or discharger *d d*, placed in either of the ways indicated, through the primary P of a disruptive discharge coil, the high frequency currents being obtained from the secondary S of this coil, as described on previous occasions. This will undoubtedly be found the cheapest and most convenient way of converting direct currents.

The three branches of the circuit A represent the usual cases met in practice when alternating currents are converted. In Fig. I*b* a condenser C, generally of large capacity, is connected to the circuit L containing the devices *l l*, *m m*. The devices *m m* are supposed to be of high self-induction so as to bring the frequency of the circuit more or less to that of the dynamo. In this instance the discharger *d d* should best have a number of makes and breaks per second equal to twice the frequency of the dynamo. If not so, then it should have at least a number equal to a multiple or even fraction of the dynamo frequency. It should be observed, referring to I*b*, that the conversion to a high potential is also effected when the discharger *d d*, which is shown in the sketch, is omitted. But the effects which are produced by currents which rise instantly to high values, as in a disruptive discharge, are entirely different from those produced by dynamo currents which rise and fall harmonically. So, for instance, there might be in a given case a number of makes and breaks at *d d* equal to just twice the frequency of the dynamo, or in other words there may be the same number of fundamental oscillations as would be produced without the discharge gap, and there might even not be any quicker superimposed vibration; yet the differences of potential at the various points of the circuit, the impedance and other phenomena, dependent upon the rate of change, will bear no similarity in the two cases. Thus, when working with currents discharging disruptively, the element chiefly to be considered is not the frequency, as a student might be apt to believe, but the rate of change per unit of time. With low frequencies in a certain measure the same effects may be obtained as with high frequencies, provided the rate of change is sufficiently great. So if a low frequency current is raised to a potential of say 75,000 volts and the high tension current passed through a series of high resistance lamp filaments, the importance of the rarefied gas surrounding the filament is clearly noted, as will be seen later; or, if a low frequency current of several thousand amperes is passed through a metal bar, striking phenomena of impedance are observed, just as with currents of high frequencies. But it is, of course, evident that with low frequency currents it is impossible to obtain such rates of change per unit of time as with high frequencies, hence the effects produced by the latter are much more prominent. It was deemed advisable to make the preceding remarks, inasmuch as many more recently described effects have been unwittingly identified with high frequencies. Frequency alone in reality does not mean anything, except when an undisturbed harmonic oscillation is considered.

In the branch III*b* a similar disposition as in I*b* is illustrated, with the difference that the currents discharging through the gap *d d* are used to induce currents in the secondary S of a transformer T. In such case the secondary should be provided with an adjustable condenser for the purpose of tuning it to the primary.

II*b* illustrates a plan of alternate current high frequency conversion which is most frequently used and which is found to be most convenient. This plan has been dwelt upon in detail on previous occasions and need not be described here.

Some of these results were obtained by the use of a high frequency alternator. A description of such machines will be found in my original paper before the American Institute of Electrical Engineers, and in periodicals of that period, notably in THE ELECTRICAL ENGINEER of March 18, 1891.

I will now proceed with the experiments.

MISCELLANEOUS.

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.[1]—II.

BY NIKOLA TESLA.

ON PHENOMENA PRODUCED BY ELECTROSTATIC FORCE.

The first class of effects I intend to show you are effects produced by electrostatic force. It is the force which governs the motion of the atoms, which causes them to collide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an infinite variety of ways, according to Nature's fanciful designs, and to form all these wondrous structures we perceive around us; it is, in fact, if our present views be true, the most important force for us to consider in Nature. As the term *electrostatic* might imply a steady electric condition, it should be remarked, that in these experiments the force is not constant, but varies at a rate which may be considered moderate, about one million times a second, or thereabouts. This enables me to produce many effects which are not producible with an unvarying force.

When two conducting bodies are insulated and electrified, we say that an electrostatic force is acting between them. This force manifests itself in attractions, repulsions and stresses in the bodies and space or medium without. So great may be the strain exerted in the air, or whatever separates the two conducting bodies, that it may break down, and we observe sparks or bundles of light or streamers, as they are called. These streamers form abundantly when the force through the air is rapidly varying. I will illustrate this action of electrostatic force in a novel experiment in which I will employ the induction coil before referred to. The coil is contained in a trough filled with oil, and placed under the table. The two ends of the secondary wire pass through the two thick columns of hard rubber, which protrude to some height above the table. It is necessary to insulate the ends or terminals of the secondary heavily with hard rubber, because even dry wood is by far too poor an insulator for these currents of enormous potential differences. On one of the terminals of the coil, I have placed a large sphere of sheet brass, which is connected to a larger insulated brass plate, in order to enable me to perform the experiments under conditions, which, as you will see, are more suitable for this experiment. I now set the coil to work and approach the free terminal with a metallic object held in my hand, this simply to avoid burns. As I approach the metallic object to a distance of eight or ten inches, a torrent of furious sparks breaks forth from the end of the secondary wire, which passes through the rubber column. The sparks cease when the metal in my hand touches the wire. My arm is now traversed by a powerful electric current, vibrating at about the rate of one million times a second. All around me the electrostatic force makes itself felt, and the air molecules and particles of dust flying about are acted upon and are hammering violently against my body. So great is this agitation of the particles, that when the lights are turned out you may see streams of feeble light appear on some parts of my body. When such a streamer breaks out on any part of the body, it produces a sensation like the pricking of a needle. Were the potentials sufficiently high and the frequency of the vibration

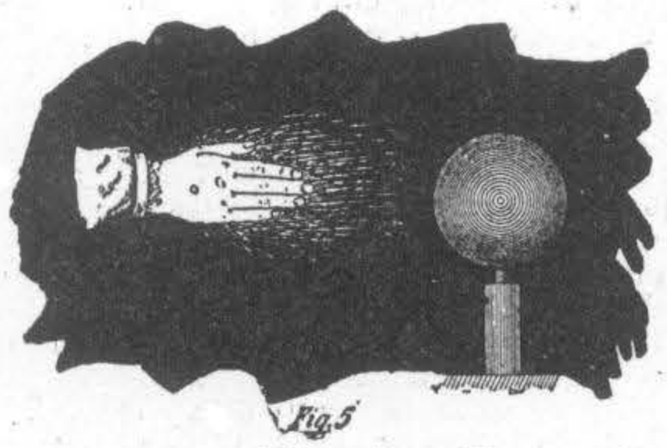


FIG. 5.—ILLUSTRATING THE EFFECT OF VARYING ELECTROSTATIC FORCE WITH A TRANSFORMER OF 200,000 VOLTS PRESSURE.

rather low, the skin would probably be ruptured under the tremendous strain, and the blood would rush out with great force in the form of fine spray or jet so thin as to be invisible, just as oil will when placed on the positive terminal of a Holtz machine. This breaking through of the skin though it may seem impossible at first, would perhaps occur, by reason of the tissues under the skin being incomparably better conducting. This, at least, appears plausible, judging from some observations.

I can make these streams of light visible to all, by touching with the metallic object one of the terminals as before, and approaching my free hand to the brass sphere, which is connected to the second terminal of the coil. As the hand is approached, the air between it and the sphere, or in the immediate neigborhood, is more violently agitated and you see streams of light now break forth from my finger tips and from the whole hand (Fig. 5). Were I to approach the hand closer, powerful sparks would jump from the brass sphere to my hand, which might be injurious. The streamers offer no particular inconvenience, except that in the ends of the finger tips a burning sensation is felt. They should not be confounded with those produced by an influence machine because in many respects they behave differently. I have attached the brass sphere and plate to one of the terminals in order to prevent the formation of visible streamers on that terminal, also in order to prevent sparks from jumping at a considerable distance. Besides, the attachment is favorable for the working of the coil.

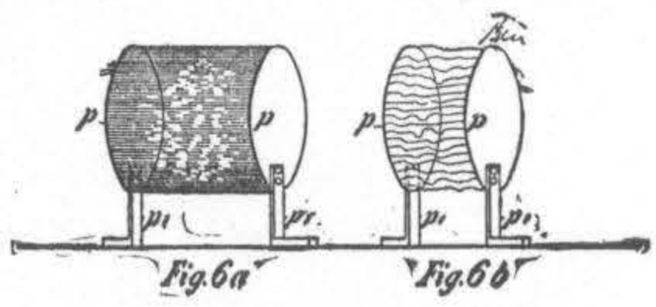


FIG. 6*a*. } ILLUSTRATING THE EFFECTS OF RAPIDLY VARYING, AND
FIG. 6*b*. } STEADY, ELECTROSTATIC FORCE.

The streams of light which you have observed issuing from my hand are due to a potential of about 200,000 volts, alternating in rather irregular intervals, something like a million times a second. A vibration of the same amplitude, but four times as fast, to maintain which over 3,000,000 volts would be required, would be more than sufficient to envelop my body in a complete sheet of flame. But this flame would not burn me up; quite contrarily, the probability is that I would not be injured in the least. Yet a hundredth part of that energy, otherwise directed, would be amply sufficient to kill a person.

The amount of energy which may thus be passed into the body of a person depends on the frequency and potential of the currents, and by making both of these very great, a vast amount of energy may be passed into the body without causing any discomfort, except perhaps, in the arm, which is traversed by a true conduction current. The reason why no pain in the body is felt, and no injurious effect noted, is that everywhere, if a current be imagined to flow through the body, the direction of its flow would be at right angles to the surface; hence the body of the experimenter offers an enormous section to the current, and the density is very small, with the exception of the arm perhaps, where the density may be considerable. But if only a small fraction of that energy would be applied in such a way that a current would traverse the body in the same manner as a low frequency current, a shock would be received which might be fatal. A direct or low frequency alternating current is fatal I think, principally because its distribution through the body is not uniform, as it must divide itself in minute streamlets of great density, whereby some organs are vitally injured. That such a process occurs I have not the least doubt, though no evidence might apparently exist, or be found upon examination. The surest to injure and destroy life, is a continuous current, but the most painful is an alternating current of very low frequency. The expression of these views, which are the result of long continued experiment and observation, both with steady and varying currents. is elicited by the interest which is at present taken in this subject, and by the manifestly erroneous ideas which are daily propounded in journals, on this subject.

I may illustrate an effect of the electrostatic force by another striking experiment, but before, I must call your attention to one or two facts. I have said before, that when the medium between two oppositely electrified bodies is strained beyond a certain limit it gives way and, stated in popular language, the opposite electric charges unite and neutralize each other. This breaking down of the medium occurs principally when the force acting between the bodies is steady, or varies at a moderate rate. Were the variation sufficiently rapid, such a destructive break would not occur, no matter how great the force, for all the energy would be spent in radiation, convection and mechanical and chemical action, Thus the *spark* length, or greatest distance through which a *spark* will jump between the electrified bodies is the smaller, the greater the variation or time rate of change. But this rule may be taken to be true only in a general way, when comparing rates which are widely different.

I will show you by an experiment the difference in the effect produced by a rapidly varying and a steady or moderately varying force. I have here two large circular brass plates *pp*, (Fig. 6*a* and Fig. 6*b*), supported on movable insulating stands on the table, connected to the ends of the secondary of a coil similar to the one used before. I place the plates ten or twelve inches apart and set the coil to work. You see the whole space between

1. A lecture delivered before the Franklin Institute, at Philadelphia, Feb. 24, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893.

the plates, nearly two cubic feet, filled with uniform light, Fig. 6*a*. This light is due to the streamers you have seen in the first experiment, which are now much more intense. I have already pointed out the importance of these streamers in commercial apparatus and their still greater importance in some purely scientific investigations. Often they are too weak to be visible, but they always exist, consuming energy and modifying the action of the apparatus. When intense, as they are at present, they produce ozone in great quantity, and also, as Professor Crookes has pointed out, nitrous acid. So quick is the chemical action, that if a coil such as this one, is worked for a very long time it will make the atmosphere of a small room unbearable, for the eyes and throat are attacked. But when moderately produced, the streamers refresh the atmosphere wonderfully, like a thunderstorm, and exercise unquestionably a beneficial effect.

In this experiment the force acting between the plates changes in intensity and direction at a very rapid rate. I will now make the rate of change per unit time much smaller. This I effect by rendering the discharges through the primary of the induction coil less frequent, and also by diminishing the rapidity of the vibration in the secondary. The former result is conveniently secured by lowering the E. M. F. over the air gap in the primary circuit, the latter by approaching the two brass plates to a distance of about three or four inches. When the coil is set to work you see no streamers or light between the plates, yet the medium between them is under a tremendous strain. I still further augment the strain by raising the E. M. F. in the primary circuit, and soon you see the air give way and the hall is illuminated by a shower of brilliant and noisy sparks, 6*b*. These sparks could be produced also with unvarying force; they have been for many years a familiar phenomenon, though they were usually obtained from entirely different apparatus. In describing these two phenomena so radically different in appearance, I have advisedly spoken of a "force" acting between the plates. It would be in accordance with accepted views to say, that there was an "alternating E. M. F." acting between the plates. This term is quite proper and applicable in all cases where there is evidence of at least a possibility of an essential inter-dependence of the electric state of the plates, or electric action in their neighborhood. But if the plates were removed to an infinite distance, or if at a finite distance, there is no probability or necessity whatever for such dependence. I prefer to use the term "electrostatic force," and to say that such a force is acting around each plate or electrified insulated body in general. There is an inconvenience in using this expression as the term incidentally means a steady electric condition; but a proper nomenclature will eventually settle this difficulty.

I now return to the experiment to which I have already alluded, and with which I desire to illustrate a striking effect produced by a rapidly varying electrostatic force. I attach to the end of the wire, *l* (Fig. 7), which is in connection with one of the terminals of the secondary of the induction coil, an exhausted bulb *b*. This bulb contains a thin carbon filament *f*, which is fastened to a platinum wire *w*, sealed in the glass and leading out-

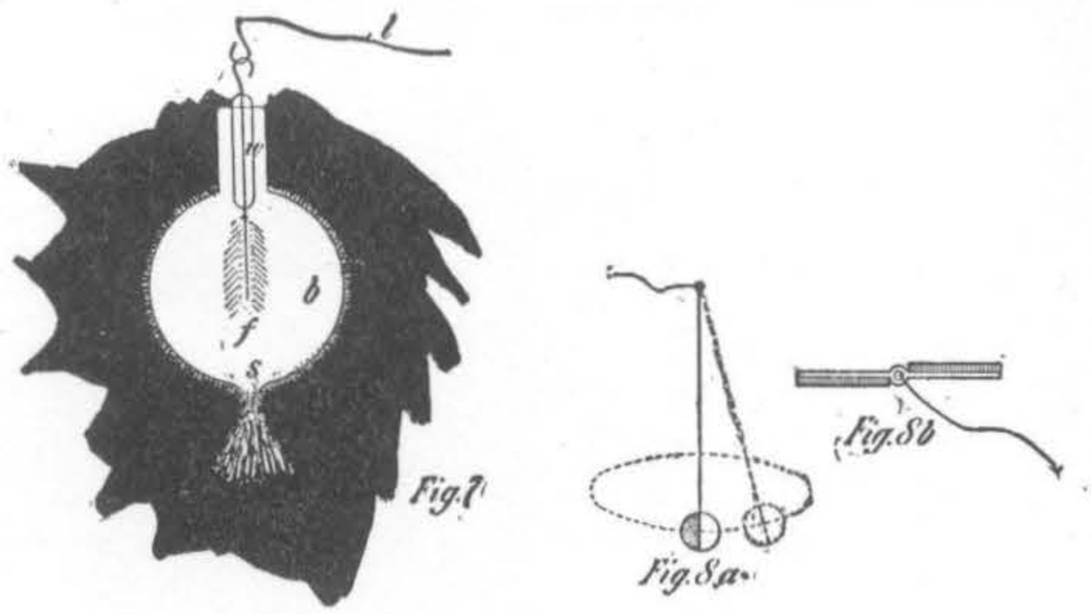


Fig. 7

Fig. 8*a*

Fig. 8*b*

FIG. 7.—BREAKING A BULB ON OPEN CIRCUIT.

FIG. 8*a*. } MECHANICAL MOTIONS PRODUCED BY VARYING ELECFIG. 8*b*. } TROSTATIC FORCE IN A GASEOUS MEDIUM.

side of the bulb, where it connects to the wire *l*. The bulb may be exhausted to any degree attainable with ordinary apparatus. Just a moment before, you have witnessed the breaking down of the air between the charged brass plates. You know that a plate of glass, or any other insulating material, would break down in like manner. Had I therefore a metallic coating attached to the outside of the bulb, or placed near the same, and were this coating connected to the other terminal of the coil, you would be prepared to see the glass give way if the strain were sufficiently increased. Even were the coating not connected to the other terminal, but to an insulated plate, still, if you have followed recent developments, you would naturally expect a rupture of the glass.

But it will certainly surprise you to note that under the action of the varying electrostatic force, the glass gives way when all other bodies are removed from the bulb. In fact, all the surrounding bodies we perceive might be removed to an infinite distance without affecting the result in the slightest. When the coil is set to work, the glass is invariably broken through at the seal, or other narrow channel, and the vacuum is quickly impaired. Such a damaging break would not occur with a steady force, even if the same were many times greater. The break is due to the agitation of the molecules of the gas within the bulb, and outside of the same. This agitation, which is generally most violent in the narrow pointed channel near the seal, causes a heating and rupture of the glass. This rupture, would, however, not occur, not even with a varying force, if the medium filling the inside of the bulb,

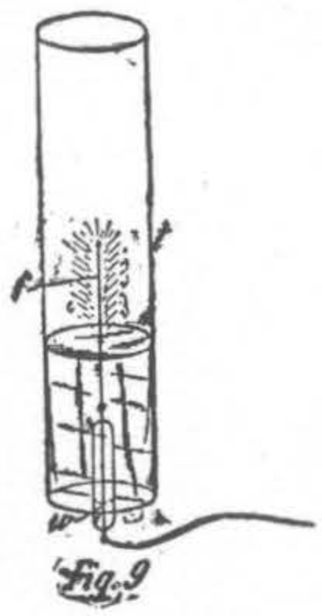


Fig. 9

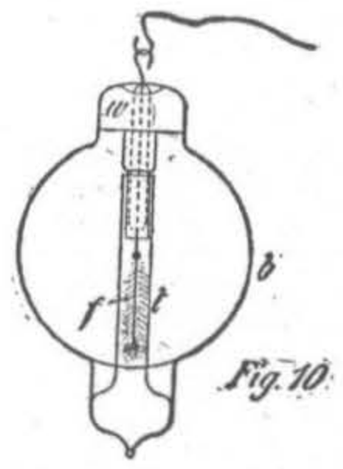


Fig. 10

FIG. 9.—SHOWING THE EFFECT OF THE AIR.

FIG. 10.—SHOWING THE INFLUENCE OF THE CONDUCTIVITY OF THE MEDIUM UPON ELECTROSTATIC ACTIONS THROUGH MEASURABLE DISTANCE.

and that surrounding it were perfectly homogeneous. The break occurs much quicker if the top of the bulb is drawn out into a fine fibre. In bulbs used with these coils such narrow, pointed channels must therefore be avoided.

When a conducting body is immersed in air, or similar insulating medium, consisting of, or containing, small freely movable particles capable of being electrified, and when the electrification of the body is made to undergo a very rapid change—which is equivalent to saying that the electrostatic force acting around the body is varying in intensity,—the small particles are attracted and repelled, and their violent impacts against the body may cause a mechanical motion of the latter. Phenomena of this kind are noteworthy in as much as they have not been observed before with apparatus such as has been commonly in use. If a very light conducting sphere be suspended on an exceedingly fine wire, and charged to a steady potential, however high, the sphere will remain at rest. Even if the potential would be rapidly varying, provided that the small particles of matter, molecules or atoms, are evenly distributed, no motion of the sphere should result. But if one side of the conducting sphere is covered with a thick insulating layer, the impacts of the particles will cause the sphere to move about, generally in irregular curves, Fig. 8*a*. In like manner, as I have shown on a previous occasion, a fan of metal sheet, Fig. 8*b*, covered partially with insulating material as indicated, and placed upon the terminal of the coil so as to turn freely in it, is spun around.

All these phenomena you have witnessed and others which will be shown later, are due to the presence of a medium like air, and would not occur in a continuous medium. The action of the air may be illustrated still better by the following experiment. I take a glass tube *t*, Fig. 9, of about an inch in diameter, which has a platinum wire *w* sealed in the lower end, and to which is attached a thin lamp filament *f*. I connect the wire with the terminal of the coil and set the coil to work. The platinum wire is now electrified positively and negatively in rapid succession and the wire and air inside of the tube is rapidly heated by the impacts of the particles, which may be so violent as to render the filament incandescent. But if I pour oil in the tube, just as soon as the wire is covered with the oil, all action apparently ceases and there is no marked evidence of heating. The reason of this is that the oil is a practically continous medium. The displacements in such a continous medium are, with these frequencies, to all appearance incomparably smaller than in air, hence the work performed in such a medium is insignificant. But oil would behave very differently with frequencies many times as great, for even though the displacements be small, if the frequency were much greater considerable work might be performed in the oil.

The electrostatic attractions and repulsions between bodies of measurable dimensions are, of all the manifestations of this force, the first so-called *electrical* phenomena noted. But though they

have been known to us for many centuries, the precise nature of the mechanism concerned in these actions is still unknown to us, and has not been even quite satisfactorily explained. What kind of mechanism must that be? We cannot help wondering when we observe two magnets attracting and repelling each other with a force of hundreds of pounds with apparently nothing between them. We have in our commercial dynamos magnets capable of sustaining in mid-air tons of weight. But what are even these forces acting between magnets when compared with the tremendous attractions and repulsions produced by electrostatic force, to which there is apparently no limit as to intensity. In lightning discharges bodies are often charged to so high a potential that they are thrown away with inconceivable force and torn asunder or shattered into fragments. Still even such effects cannot compare with the attractions and repulsions which exist between charged molecules or atoms, and which are sufficient to project them with speeds of many kilometres a second so that under their violent impact bodies are rendered highly incandescent and are

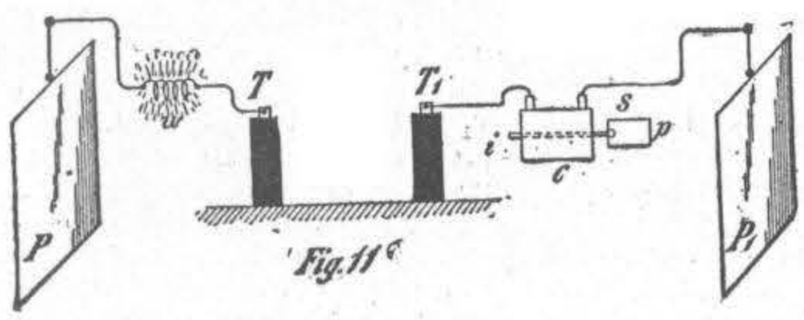


FIG. 11.—SHOWING EFFECTS OF CURRENTS FLOWING THROUGH OPEN CIRCUITS.

volatilized. It is of special interest for the thinker who inquires into the nature of these forces to note, that whereas the actions between individual molecules or atoms occur seemingly under any condition, the attractions and repulsions of bodies of measurable dimensions imply a medium possessing insulating properties. So, if air, either by being rarefied or heated, is rendered more or less conducting, these actions between two electrified bodies practically cease, while the actions between the individual atoms continue to manifest themselves.

An experiment may serve as an illustration and as a means of bringing out other features of interest. Some time ago I showed that a lamp filament or wire mounted in a bulb and connected to one of the terminals of a high tension secondary coil is set spinning, the top of the filament generally describing a circle. This vibration was very energetic when the air in the bulb was at ordinary pressure and became less energetic when the air in the bulb was strongly compressed. It ceased altogether when the air was exhausted so as to become comparatively good conducting. I found at that time that no vibration took place when the bulb was very highly exhausted. But I conjectured that the vibration which I ascribed to the electrostatic action between the walls of the bulb and the filament should take place also in a highly exhausted bulb. To test this under conditions which were more favorable, a bulb like the one in Fig. 10, was constructed. It comprised a globe *b* in the neck of which was sealed a platinum wire *w* carrying at thin lamp filament *f*. In the lower part of the globe a tube *t* was sealed so as to surround the filament. The exhaustion was carried as far as it was practicable with the apparatus employed.

This bulb verified my expectation, for the filament was set spinning when the current was turned on, and became incandescent. It also showed another interesting feature, bearing upon the preceding remarks, namely, when the filament had been kept incandescent some time the narrow tube and the space inside was brought to an elevated temperature, and as the gas in the tube then became conducting, the eletrostatic attraction between the glass and the filament became very weak or ceased and the filament came to rest. When it came to rest it would glow far more intensely. This was probably due to its assuming the position in the centre of the tube where the molecular bombardment was most intense, and also partly to the fact that the individual impacts were more violent and that no part of the supplied energy was converted into mechanical movement. Since, in accordance with accepted views, in this experiment the incandescence must be attributed to the impacts of the particles, molecules or atoms in the heated space, these particles must therefore, in order to explain such action, be assumed to behave as independent carriers of electric charges immersed in an insulating medium; yet there is no attractive force between the glass tube and the filament because the space in the tube is, as a whole, conducting.

It is of some interest to observe in this connection that whereas the attraction between two electrified bodies may cease owing to the impairing of the insulating power of the medium in which they are immersed, the repulsion between the bodies may still be observed. This may be explained in a plausible way. When the bodies are placed at some distance in a poorly conducting medium, such as slightly warmed or rarefied air, and are suddenly electrified, opposite electric charges being imparted to them, these charges equalize more or less by leakage through the air. But if the bodies are similarly electrified, there is less opportunity afforded for such dissipation, hence the repulsion observed in such case is greater than the attraction. Repulsive actions in a gaseous medium are however, as Prof. Crookes has shown, enhanced by molecular bombardment.

ON CURRENT OR DYNAMIC ELECTRICITY PHENOMENA.

So far, I have considered principally effects produced by a varying electrostatic force in an insulating medium, such as air. When such a force is acting upon a conducting body of measurable dimensions, it causes within the same, or on its surface, displacements of the electricity and gives rise to electric currents, and these produce another kind of phenomena, some of which I shall presently endeavor to illustrate. In presenting this second class of electrical effects, I will avail myself principally of such as are producible without any return circuit, hoping to interest you the more by presenting these phenomena in a more or less novel aspect.

It has been for a long time customary, owing to the limited experience with vibratory currents, to consider an electric current as something circulating in a closed conducting path. It was astonishing at first to realize that a current may flow through the conducting path even if the latter be interrupted, and it was still more surprising to learn, that sometimes it may be even easier to make a current flow under such conditions than through a closed path. But that old idea is gradually disappearing, even among practical men, and will soon be entirely forgotten.

If I connect an insulated metal plate P, Fig. 11, to one of the terminals T of the induction coil by means of a wire, though this plate be very well insulated, a current passes through the wire when the coil is set to work. First I wish to give you evidence that there *is* a current passing through the connecting wire. An obvious way of demonstrating this is to insert between the terminal of the coil and the insulated plate a very thin platinum or german silver wire *w* and bring the latter to incandescence or fusion by the current. This requires a rather large plate or else current impulses of very high potential and frequency. Another way is to take a coil C, Fig. 11, containing many turns of thin insulated wire and to insert the same in the path of the current to the plate. When I connect one of the ends of the coil to the wire leading to another insulated plate P, and its other end to the terminal T_1 of the induction coil, and set the latter to work, a current passes through the inserted coil C and the existence of the current may be made manifest in various ways. For instance, I insert an iron core *i* within the coil. The current being one of very high frequency, if it be of some strength, will soon bring the iron core to a noticeably higher temperature, as the hysteresis and current losses are great with such high frequencies. One might take a core of some size, laminated or not, it would matter little; but ordinary iron wire $\frac{1}{16}$th or $\frac{1}{8}$th of an inch thick is suitable for the purpose. While the induction coil is working a current traverses the inserted coil and only a few moments are sufficient to bring the iron wire *i* to an elevated temperature sufficient to soften the sealing-wax *s*, and cause a paper washer *p* fastened by it to the iron wire to fall off. But with the apparatus such as I have here other, much more interesting, demonstrations of this kind can be made. I have a secondary S, Fig. 12, of coarse wire, wound upon a coil similar to the first. In the preceding experiment the current through the coil C, Fig. 11, was very small, but there being many turns a strong heating effect was, nevertheless,

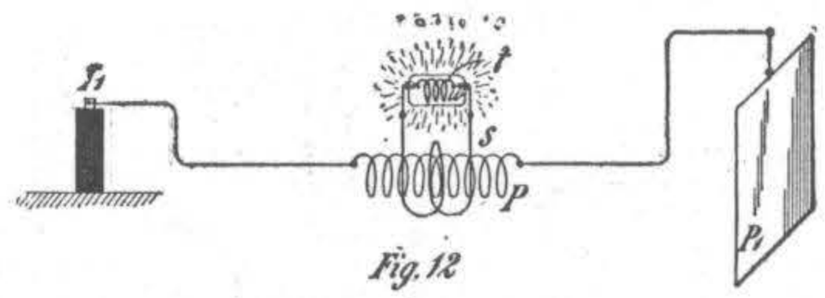


FIG. 12.—CONVERSION ON OPEN CIRCUIT WITH COIL AND INSULATED PLATE.

produced in the iron wire. Had I passed that current through a conductor in order to show the heating of the latter, the current might have been too small to produce the effect desired. But with this coil provided with a secondary winding, I can now transform the feeble current of high tension which passes through the primary P into a strong secondary current of low tension, and this current will quite certainly do what I expect. In a small glass tube (*t*, Fig. 12), I have enclosed a coiled platinum wire, *w*, this merely in order to protect the wire. On each end of the glass tube is sealed a terminal of stout wire to which one of the ends of the platinum wire *w*, is connected. I join the terminals of the secondary coil to these terminals and insert the primary *p*, between the insulated plate P_1 and the terminal T_1 of the induction coil as before. The latter being set to work, instantly the platinum wire *w* is rendered incandescent and can be fused even if it be very thick.

Instead of the platinum wire I now take an ordinary 50-volt 16 c. p. lamp. When I set the induction coil in operation the lamp filament is brought to high incandescence. It is, however, not necessary to use the insulated plate, for the lamp (*l*, Fig. 13) is rendered incandescent even if the plate P_1 be disconnected. The secondary may also be connected to the primary as indicated by

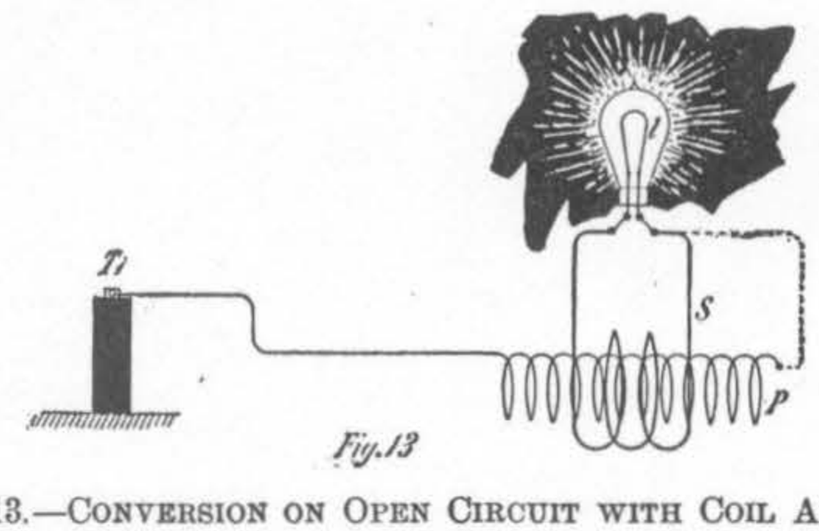
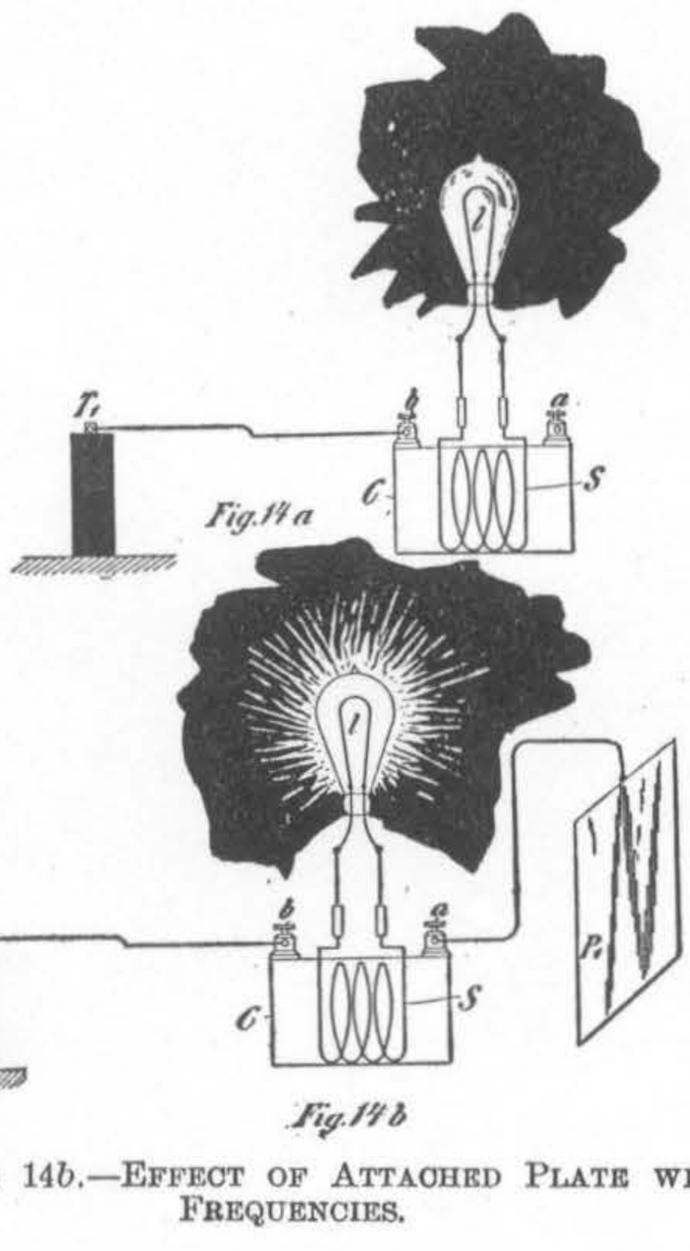


Fig. 13.

FIG. 13.—CONVERSION ON OPEN CIRCUIT WITH COIL ALONE.

the dotted line in Fig. 13, to do away more or less with the electrostatic induction or to modify the action otherwise.

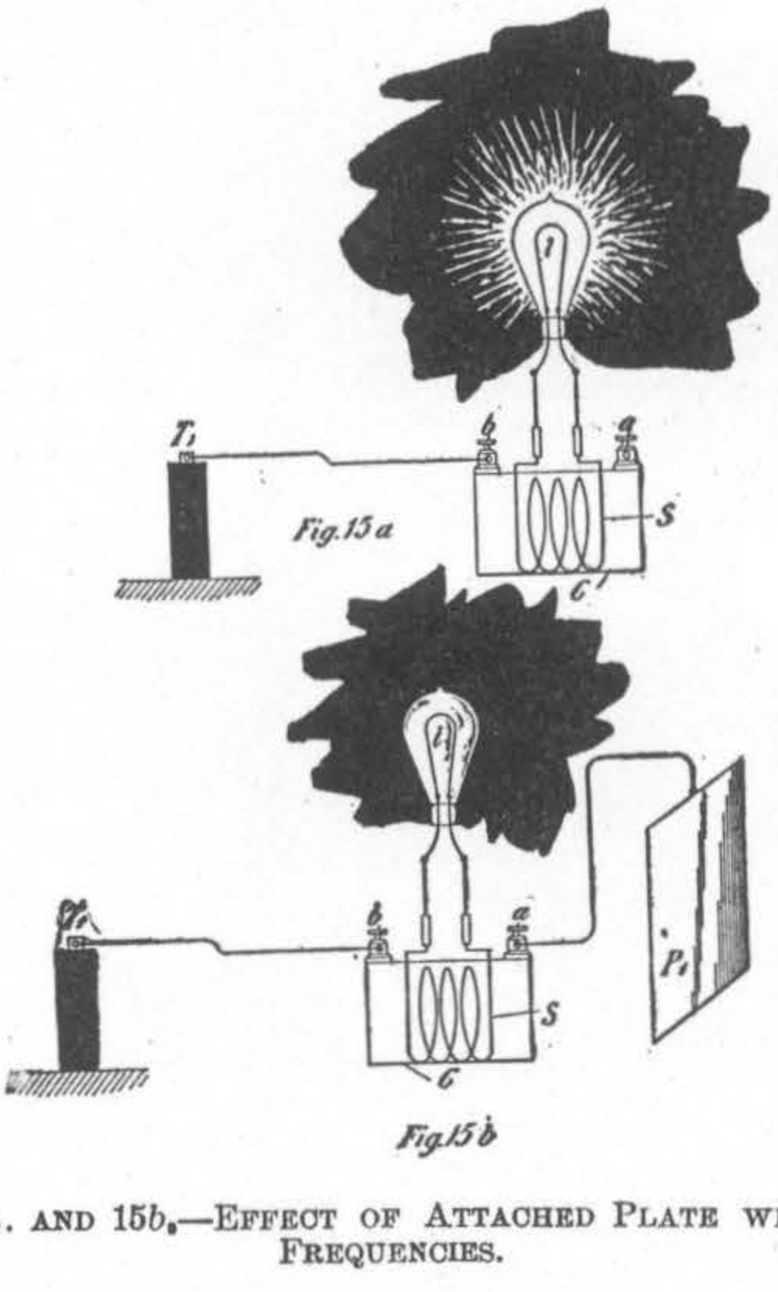
I may here call attention to a number of interesting observations with the lamp. First, I disconnect one of the terminals of the lamp from the secondary S. When the induction coil plays, a glow is noted which fills the whole bulb. This glow is due to electrostatic induction. It increases when the bulb is grasped with the hand, and the capacity of the experimenter's body thus added to the secondary circuit. The secondary, in effect, is equivalent to a metallic coating, which would be placed near the primary. If the secondary, or its equivalent, the coating, were placed symmetrically to the primary, the electrostatic induction would be nil under ordinary conditions, that is, when a primary return circuit is used, as both halves would neutralize each other. The



FIGS. 14*a*. AND 14*b*.—EFFECT OF ATTACHED PLATE WITH LOW FREQUENCIES.

secondary *is* in fact placed symmetrically to the primary, but the action of both halves of the latter, when only one of its ends is connected to the induction coil, is not exactly equal; hence electrostatic induction takes place, and hence the glow in the bulb. I can nearly equalize the action of both halves of the primary by connecting the other, free end of the same to the insulated plate, as in the preceding experiment. When the plate is connected, the glow disappears. With a smaller plate it would not entirely disappear and then it would contribute to the brightness of the filament when the secondary is closed, by warming the air in the bulb.

To demonstrate another interesting feature, I have adjusted the coils used in a certain way. I first connect both the terminals of the lamp to the secondary, one end of the primary being connected to the terminal T_1 of the induction coil and the other to the insulated plate P_1 as before. When the current is turned on, the lamp glows brightly, as shown in Fig. 14*b*, in which C is a fine wire coil and S a coarse wire secondary wound upon it. If the insulated plate P_1 is disconnected, leaving one of the ends *a* of the primary insulated, the filament becomes dark or generally it diminishes in brightness (Fig. 14*a*). Connecting again the plate P_1 and raising the frequency of the current I make the filament quite dark or barely red, Fig. 15*b*. Once more I will disconnect the plate. One will of course infer that when the plate is disconnected, the current through the primary will be weakened, that therefore the E. M. F. will fall in the secondary S, and that the brightness of the lamp will diminish. This might be the case and the result can be secured by an easy adjustment of the coils; also by varying the frequency and potential of the currents. But it is perhaps of greater interest to note, that the lamp increases in brightness when the plate is disconnected (Fig. 15*a*). In this case all the energy the primary receives is now sunk into it, like the charge of a battery in an ocean cable, but most of that energy is recovered through the secondary and used to light the lamp. The current traversing the primary is strongest at the end *b* which is connected to the terminal T_1 of the induction coil, and diminishes in strength towards the remote end *a*. But the dynamic inductive effect exerted upon the secondary S is now greater than before when the suspended plate was connected to the primary. These results might have been produced by a number of causes. For instance, the plate P_1 being connected, the reaction from the coil C may be such as to diminish the potential at the terminal T_1 of the induction coil, and therefore weaken the current through the primary of the coil C. Or the disconnecting of the plate may diminish the capacity effect with relation to the primary of the latter coil to such an extent that the current through it is diminished, though the potential at the terminal T_1 of the induction coil may be the same or even higher. Or the result might have been produced by the change of phase of the primary and secondary currents and consequent reaction. But the chief determining factor is the relation of the self-induction and capacity of coil C and plate



FIGS. 15*a*. AND 15*b*.—EFFECT OF ATTACHED PLATE WITH HIGH FREQUENCIES.

P_1 and the frequency of the currents. The greater brightness of the filament in Fig. 15*a*, is however, in part due to the heating of the rarefied gas in the lamp by electrostatic induction, which, as before remarked, is greater when the suspended plate is disconnected.

Still another feature of some interest I may here bring to your attention. When the insulated plate is disconnected and the secondary of the coil opened, by approaching a small object to the secondary, but very small sparks can be drawn from it, showing that the electrostatic induction is small in this case. But upon the secondary being closed upon itself or through the lamp, the filament glowing brightly, strong sparks are obtained from the secondary. The electrostatic induction is now much greater,

because the closed secondary determines a greater flow of current through the primary and principally through that half of it which is connected to the induction coil. If now the bulb be grasped with the hand, the capacity of the secondary with reference to the primary is augmented by the experimenter's body and the luminosity of the filament is increased, the incandescence now being due partly to the flow of current through the filament and partly to the molecular bombardment of the rarefied gas in the bulb.

The preceding experiments will have prepared one for the next following results of interest, obtained in the course of these investigations. Since I can pass a current through an insulated wire merely by connecting one of its ends to the source of electrical energy, since I can induce by it another current, magnetize an iron core, and in short, perform all operations, as though a return circuit were used, clearly I can also drive a motor by the aid of only one wire. On a former occasion I have described a simple form of motor comprising a single exciting coil, an iron core and disc. Fig. 16, illustrates a modified way of operating such an alternate current motor by currents induced in a transformer connected to one lead, and several other arrangements of circuits for operating a certain class of alternate motors founded on the action of currents of differing phase. In view of the present state of the art it is thought sufficient to describe these arrangements in a few words only. In the diagram, Fig. 16 II., shows a primary coil P, connected with one of its ends to the line L leading from a high tension transformer terminal T_1. In inductive relation to this primary P is a secondary S of coarse wire in the circuit of which is a coil *c*. The currents induced in the secondary energize the iron core *i*, which is preferably, but not necessarily, subdivided, and set the metal disc *d* in rotation. Such a motor M_2, as diagrammatically shown in Fig. 16 II., has been called a "magnetic lag motor," but this expression may be objected to by those who attribute the rotation of the disc to eddy currents circulating in minute paths when the core *i* is finally subdivided. In order to operate such a motor effectively on the plan indicated, the frequencies should not be too high, not more than four or five thousand, though the rotation is produced even with ten thousand per second, or more.

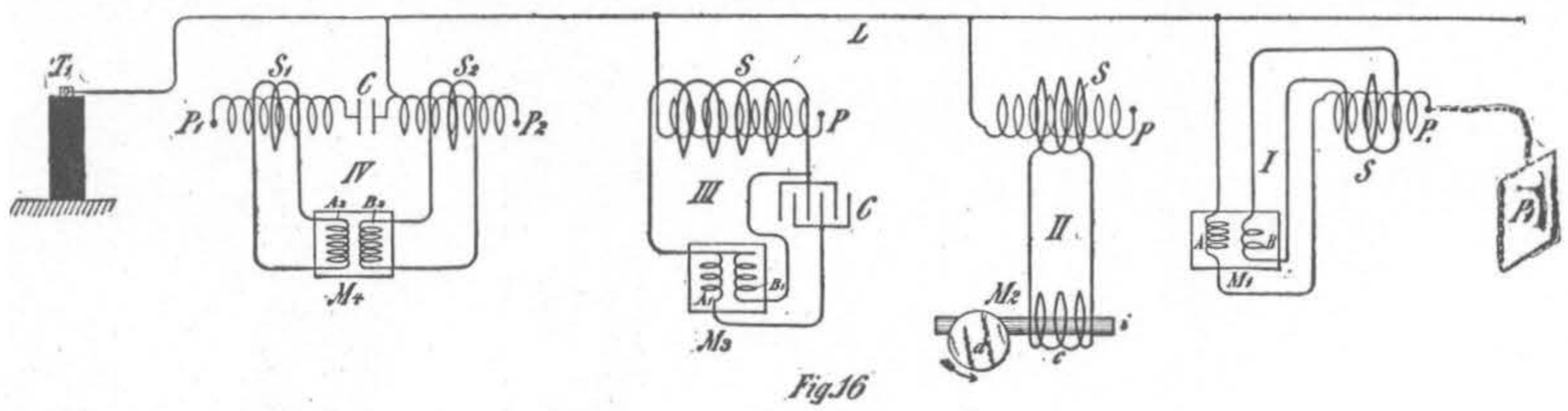


Fig. 16

FIG. 16.—WAYS OF OPERATING MOTORS WITH ONLY ONE LEAD.

In Fig. 16 I., a motor M_1, having two energizing circuits, A and B, is diagrammatically indicated. The circuit A is connected to the line L and in series with it is a primary P, which may have its free end connected to an insulated plate P_1, such connection being indicated by the dotted lines. The other motor circuit B is connected to the secondary S which is in inductive relation to the primary P. When the transformer terminal T_1 is alternately electrified, currents traverse the open line L and also circuit A and primary P. The currents through the latter induce secondary currents in the circuit S, which pass through the energizing coil B of the motor. The currents through the secondary S and those through the primary P differ in phase 90 degrees, or nearly so, and are capable of rotating an armature placed in inductive relation to the circuits A and B.

In Fig. 16 III., a similar motor M_3 with two energizing circuits A_1 and B_1 is illustrated. A primary P, connected with one of its ends to the line L has a secondary S, which is preferably wound for a tolerably high E. M. F., and to which the two energizing circuits of the motor are connected, one directly to the ends of the secondary and the other through a condenser C, by the action of which the currents traversing the circuit A_1 and B_1 are made to differ in phase.

In Fig. 16 IV still another arrangement is shown. In this case two primaries P_1 and P_2 are connected to the line L, one through a condenser C of small capacity, and the other directly. The primaries are provided with secondaries S_1 and S_2 which are in series with the energizing circuits A_2 and B_2 and a motor M_4, the condenser C again serving to produce the requisite difference in the phase of the currents traversing the motor circuits. As such phase motors with two or more circuits are now well known in the art, they have been here illustrated diagrammatically. No difficulty whatever is found in operating a motor in the manner indicated or in similar ways, and although such experiments up to this day present only scientific interest, they may at a period not far distant, be carried out with practical objects in view.

It is thought useful to devote here a few remarks to the subject of operating devices of all kinds by means of only one leading wire. It is quite obvious, that when high-frequency currents are made use of, ground connections are—at least when the E. M. F. of the currents is great—better than a return wire. Such ground connections are objectionable with steady or low frequency currents on account of destructive chemical actions of the former and disturbing influences exerted by both on the neighboring circuits; but with high frequencies these actions practically do not exist. Still, even ground connections become superfluous when the E. M. F. is very high, for soon a condition is reached, when the current may be passed more economically through open, than through closed conductors. Remote as might seem an industrial application of such single wire transmission of energy to one not experienced in such lines of experiment, it will not seem so to anyone who for some time has carried on investigations of such nature. Indeed I cannot see why such a plan should not be practicable. Nor should it be thought that for carrying out such a plan currents of very high frequency are expressly required, for just as soon as potentials of say 30,000 volts are used, the single wire transmission may be effected with low frequencies, and experiments have been made by me from which these inferences are made.

When the frequencies are very high it has been found in laboratory practice quite easy to regulate the effects in the manner shown in diagram Fig. 17. Here two primaries P and P are shown, each connected with one of its ends to the line L and with the other end to the condenser plates C and C^1, respectively. Near these are placed other condenser plates C_1 and $C^1{}_1$, the former being connected to the line L and the latter to an insulated larger plate P_2. On the primaries are wound secondaries S and S_1 of coarse wire, connected to the devices *m* and *d* respectively. By varying the distances of the condenser plates C and C^1, and C_1 and $C_1{}^1$, the currents through the secondaries S and S_1 are varied in intensity. The curious feature is the great sensitiveness, the slightest change in the distance of the plates producing considerable variations in the intensity or strength of the currents. The sensitiveness may be rendered extreme by making the frequency

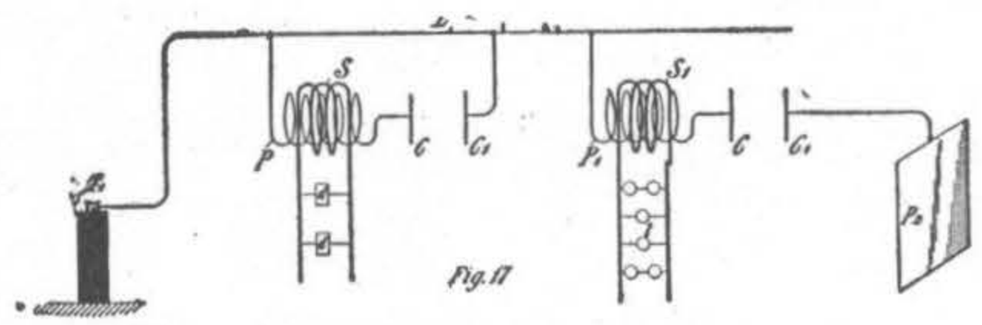


Fig. 17

FIG. 17.—SINGLE WIRE CONVERSION AND DISTRIBUTION, WITH SIMPLE MEANS FOR REGULATING THE EFFECTS.

such, that the primary itself without any plate attached to its free end satisfies, in conjunction with the closed secondary, the condition of resonance. In such condition an extremely small change in the capacity of the free terminal produces great variations. For instance, I have been able to adjust the conditions so that the mere approach of a person to the coil produces a considerable change in the brightness of the lamps attached to the secondary. Such observations and experiments possess of course, at present, chiefly scientific interest, but they may soon become of practical importance.

Very high frequencies are of course not practicable with motors on account of the necessity of employing iron cores. But one may use sudden discharges of low frequency and thus obtain certain advantages of high-frequency currents without rendering the iron core entirely incapable of following the changes and without entailing a very great expenditure of energy in the core.

I have found it quite practicable to operate with such low frequency disruptive discharges of condensers, alternating-current motors. A certain class of such motors which I advanced a few years ago, which contain closed secondary circuits, will rotate quite vigorously when the discharges are directed through the exciting coils. One reason that such a motor operates so well with these discharges is that the difference of phase between the primary and secondary currents is 90 degrees, which is generally

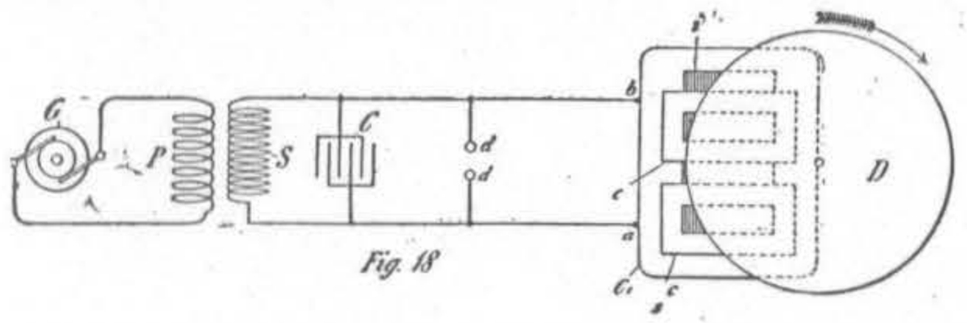


FIG. 18.—OPERATING A MOTOR BY DISRUPTIVE DISCHARGES.

not the case with harmonically rising and falling currents of low frequency. It might not be without interest to show an experiment with a simple motor of this kind, inasmuch as it is commonly thought that disruptive discharges are unsuitable for such purposes. The motor is illustrated in Fig. 18. It comprises a rather large iron core *i* with slots on the top into which are embedded thick copper washers *c c*. In proximity to the core is a freely-movable metal disc D. The core is provided with a primary exciting coil C the ends *a* and *b* of which are connected to the terminals of the secondary S of an ordinary transformer, the primary P of the latter being connected to an alternating distritribution circuit or generator G of low or moderate frequency. The terminals of the secondary S are attached to a condenser C which discharges through an air gap *d d* which may be placed in series or shunt to the coil C. When the conditions are properly chosen the disc D rotates with considerable effort and the iron core *i* does not get very perceptibly hot. With currents from a high-frequency alternator, on the contrary, the core gets rapidly hot and the disc rotates with a much smaller effort. To perform the experiment properly it should be first ascertained that the disc D is not set in rotation when the discharge is not occurring at *d d*. It is preferable to use a large iron core and a condenser of large capacity so as to bring the superimposed quicker oscillation to a very low pitch or to do away with it entirely. By observing certain elementary rules I have also found it practicable to operate ordinary series or shunt direct-current motors with such disruptive discharges, and this can be done with or without a return wire.

IMPEDANCE PHENOMENA.

Among the various current phenomena observed perhaps the most interesting are those of impedance presented by conductors to currents varying at a rapid rate. In my first paper before the American Institute of Electrical Engineers, I have described a few striking observations of this kind. Thus I showed that when such currents or sudden discharges are passed through a thick metal bar there may be points at the bar only a few inches apart, which have a sufficient potential difference between them to maintain at bright incandescence an ordinary filament lamp. I have also described the curious behavior of rarefied gas surrounding a conductor due to such sudden rushes of current. These phenomena have been since more carefully studied and one or two novel experiments of this kind are deemed of sufficient interest to be described here.

With reference to Fig. 19*a*, B and B_1 are very stout copper bars connected at their lower ends to plates C and C_1 respectively, of a

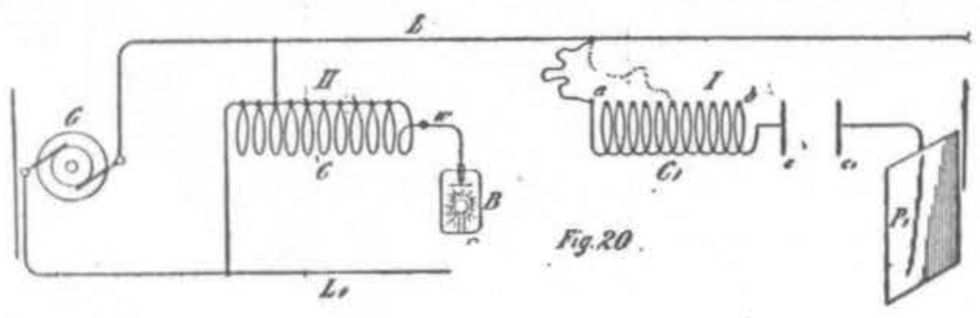
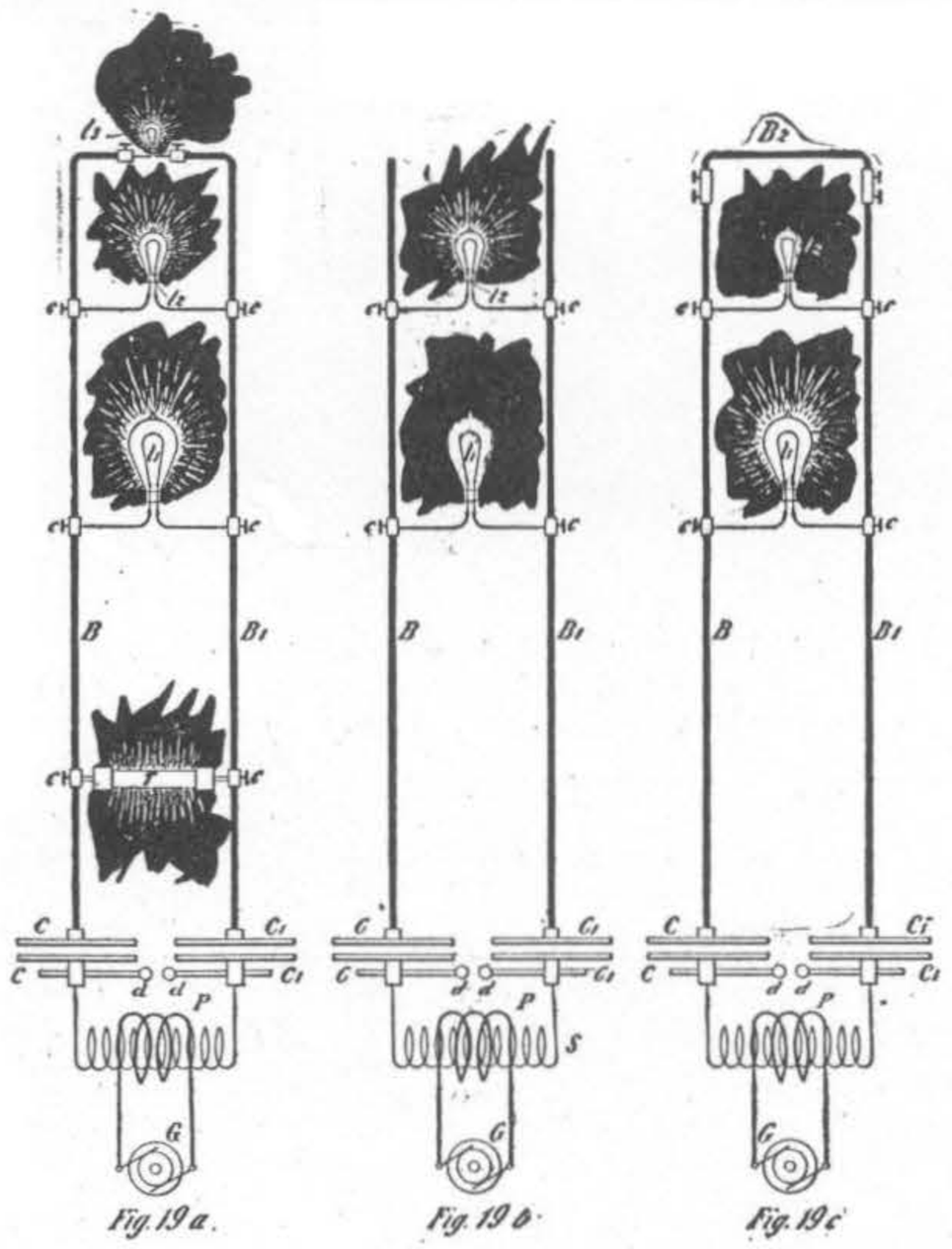


FIG. 20.—PLAN FOLLOWED IN OBSERVING THE EFFECTS OF RESONANCE.

condenser, the opposite plates of the latter being connected to the terminals of the secondary S of a high-tension transformer, the primary P of which is supplied with alternating currents from an ordinary low-frequency dynamo G or distribution circuit. The condenser discharges through an adjustable gap *d d* as usual. By establishing a rapid vibration it was found quite easy to perform the following curious experiment. The bars B and B_1 were joined at the top by a low-voltage lamp l_3; a little lower, was placed by means of clamps *c c*, a 50-volt lamp l_2 and still lower another 100-volt lamp l_1, and finally at a certain distance below the latter lamp an exhausted tube T. By carefully determining the positions of these devices it was found practicable to maintain them all at their proper illuminating power. Yet they were all connected in multiple arc to the two stout copper bars and required widely different pressures. This experiment requires of course some time for adjustment but is quite easily performed.

In Figs. 19*b* and 19*c*, two other experiments are illustrated which, unlike the previous experiment, do not require very careful adjustments. In Fig. 19*b*, two lamps l_1 and l_2, the former a 100-volt and the latter a 50-volt are placed in certain positions as indicated, the 100-volt lamp being below the 50-volt lamp. When the arc is playing at *d d* and the sudden discharges are passed through the bars B B_1 the 50-volt lamp will as a rule burn brightly, or at least this result is easily secured, while the 100-volt lamp will burn very low or remain quite dark, Fig. 19*b*. Now the bars B B_1 may be joined at the top by a thick cross-bar B_2 and it is quite easy to maintain the 100-volt lamp at full candle-power while the 50-volt lamp remains dark, Fig. 19*c*. These results, as I have pointed out previously, should not be considered to be due exactly to frequency but rather to the time rate of change which may be great even with low frequencies. A great many other results of the same kind equally interesting, especially to those who are only used



FIGS. 19*a*, 19*b* AND 19*c*.—IMPEDANCE PHENOMENA.

to manipulate steady currents, may be obtained and they afford precious clues in investigating the nature of electric currents.

In the preceding experiments I have already had occasion to show some light phenomena and it would now be proper to study these in particular; but to make this investigation more complete I think it necessary to make first a few remarks on the subject of electrical resonance which has to be always observed in carrying out these experiments.

MISCELLANEOUS.

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.[1]—III.

BY NIKOLA TESLA.

ON ELECTRICAL RESONANCE.

The effects of resonance are being more and more noted by engineers and are becoming of great importance in the practical operation of apparatus of all kinds with alternating currents. A few general remarks may therefore be made concerning these effects. It is clear, that if we succeed in employing the effects of resonance practically in the operation of electric devices the return wire will, as a matter of course, become unnecessary, for the electric vibration may be conveyed with one wire just as well, and sometimes even better, than with two. The question first to answer is, then, whether pure resonance effects are producible. Theory and experiment both show that such is impossible in Nature, for as the oscillation becomes more and more vigorous the losses in the vibrating bodies and environing media rapidly increase and necessarily check the vibration which otherwise would go on increasing forever. It is a fortunate circumstance that pure resonance is not producible, for if it were there is no telling what dangers might not lie in wait for the innocent experimenter. But to a certain degree resonance is producible, the magnitude of the effects being limited by the imperfect conductivity and imperfect elasticity of the media or, generally stated, by frictional losses. The smaller these losses, the more striking are the effects. The same is the case in mechanical vibration. A stout steel bar may be set in vibration by drops of water falling upon it at proper intervals; and with glass, which is more perfectly elastic, the resonance effect is still more remarkable, for a goblet may be burst by singing into it a note of the proper pitch. The electrical resonance is the more perfectly attained, the smaller the resistance or the impedance of the conducting path and the more perfect the dielectric. In a Leyden jar discharging through a short stranded cable of thin wires these requirements are probably best fulfilled, and the resonance effects are therefore very prominent. Such is not the case with dynamo machines, transformers and their circuits, or with commercial apparatus in general in which the presence of iron cores complicates or renders impossible the action. In regard to Leyden jars with which resonance effects are frequently demonstrated, I would say that the effects observed are often *attributed* but are seldom *due* to true resonance, for an error is quite easily made in this respect. This may be undoubtedly demonstrated by the following experiment. Take, for instance, two large insulated metallic plates or spheres which I shall designate A and B, place them at a certain small distance apart and charge them from a frictional or influence machine to a potential so high that just a slight increase of the difference of potential between them will cause the small air or insulating space to break down. This is easily reached by making a few preliminary trials. If now another plate—fastened on an insulating handle and connected by a wire to one of the terminals of a high tension secondary of an induction coil, which is maintained in action by an alternator (preferably high frequency)—is approached to one of the charged bodies A or B, so as to be nearer to either one of them, the discharge will invariably occur between them; at least it will, if the potential of the coil in connection with the plate is sufficiently high. But the explanation of this will soon be found in the fact that the approached plate acts inductively upon the bodies A and B and causes a spark to pass between them. When this spark occurs, the charges, which were previously imparted to these bodies from the influence machine, must needs be lost, since the bodies are brought in electrical connection through the arc formed. Now this arc is formed whether there be resonance or not. But even if the spark would not be produced, still there is an alternating E. M. F. set up between the bodies when the plate is brought near one of them; therefore the approach of the plate, if it *does* not always, actually, will, at any rate, *tend*, to break down the air space by inductive action. Instead of the spheres or plates A and B we may take the coatings of a Leyden jar with the same result, and in place of the machine, which is a high frequency alternator preferably, because it is more suitable for the experiment and also for the argument, we may take another Leyden jar or battery of jars. When such jars are discharging through a circuit of low resistance the same is traversed by currents of very high frequency. The plate may now be connected to one of the coatings of the second jar, and when it is brought near to the first jar just previously charged to a high potential from an influence machine, the result is the same as before, and the first jar will discharge through a small air space upon the second being caused to discharge. But both jars and their circuits need not be tuned any closer than a basso profundo is to the note produced by a mosquito, as small sparks will be produced through the air space, or at least the latter will be considerably more strained owing to the setting up of an alternating E. M. F. by induction, which takes place when one of the jars begins to discharge. Again another error of a similar nature is quite easily made. If the circuits of the two jars are run parallel and close together, and the experiment has been performed of discharging one by the other, and now a coil of wire be added to one of the circuits whereupon the experiment does not succeed, the conclusion that this is due to the fact that the circuits are now not tuned, would be far from being safe. For the two circuits act as condenser coatings and the addition of the coil to one of them is equivalent to bridging them, at the point where the coil is placed, by a small condenser, and the effect of the latter might be to prevent the spark from jumping through the discharge space by diminishing the alternating E. M. F. acting across the same. All these remarks, and many more which might be added but for fear of wandering too far from the subject, are made with the pardonable intention of cautioning the unsuspecting student, who might gain an entirely unwarranted opinion of his skill when seeing every experiment succeed; but they are in no way thrust upon the experienced as novel observations.

In order to make reliable observations of electric resonance effects it is very desirable, if not necessary, to employ an alternator giving currents which rise and fall harmonically, as in working with make and break currents the observations are not always trustworthy, since many phenomena, which depend on the rate of change, may be produced with frequencies widely different. Even when making such observations with an alternator one is apt to be mistaken. When a circuit is connected to an alternator there are an infinite number of values for capacity and self-induction which, in conjunction, will satisfy the condition of resonance. So there are in mechanics an infinite number of tuning forks which will respond to a note of a certain pitch, or loaded springs which have a definite period of vibration. But the resonance will be most perfectly attained in that case in which the motion is effected with the greatest freedom. Now in mechanics, considering the vibration in the common medium—that is, air—it is of comparatively little importance whether one tuning fork be somewhat larger than another, because the losses in the air are not very considerable. One may of course enclose a tuning fork in an exhausted vessel and by thus reducing the air resistance to a minimum obtain better resonant action. Still the difference would not be very great. But it would make a great difference if the tuning fork were immersed in mercury. In the electrical vibration it is of enormous importance to arrange the conditions so that the vibration is effected with the greatest freedom. The magnitude of the resonance effect depends, under otherwise equal conditions, on the quantity of electricity set in motion or on the strength of the current driven through the circuit. But the circuit opposes the passage of the currents by reason of its impedance and therefore, to secure the best action it is necessary to reduce the impedance to a minimum. It is impossible to overcome it entirely, but merely in part, for ohmic resistance cannot be overcome. But when the frequency of the impulses is very great, the flow of the current is practically determined by self-induction. Now self-induction can be overcome by combining it with capacity. If the relation between these is such, that at the frequency used they annul each other, that is, have such values as to satisfy the condition of resonance and the greatest quantity of electricity is made to flow through the external circuit, then the best result is obtained. It is simpler and safer to join the condenser in series with the self-induction. It is clear that in such combinations there will be, for a given frequency, and considering only the fundamental vibration, values which will give the best result, with the condenser in shunt to the self-induction coil; of course more such values than with the condenser in series. But practical conditions determine the selection. In the latter case in performing the experiments one may take a small self-induction and a large capacity or a small capacity and a large self-induction, but the latter is preferable, because it is inconvenient to adjust a large capacity by small steps. By taking a coil with a very large self-induction the critical capacity is reduced to a very small value, and the capacity of the coil itself may be sufficient. It is easy, especially by observing certain artifices, to wind a coil through which the impedance will be reduced to the value of the ohmic resistance only and for any coil there is, of course, a frequency at which the maximum current will be made to pass through the coil. The observation of the relation between self-induction, capacity and frequency is becoming important in the operation of alternate current apparatus, such as transformers or motors, because by a judicious determination of the elements the employment of an expensive condenser becomes unnecessary. Thus it is possible to pass through the coils of an alternating current motor under the normal working conditions the required current with a low E. M. F. and do away entirely with the false current, and the larger the motor the easier such a plan becomes practicable; but it is necessary for this to employ currents of very high potential or high frequency.

In Fig. 20 I is shown (see THE ELECTRICAL ENGINEER, June 7, 1893) a plan which has been followed in the study of the resonance effects by means of a high frequency alternator. C is a coil of many turns, which is divided in small sepa-

1. A lecture delivered before the Franklin Institute, at Philadelphia, Feb. 24, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893.

rate sections for the purposes of adjustment. The final adjustment was made sometimes with a few thin iron wires (though this is not always advisable) or with a closed secondary. The coil C is connected with one of its ends to the line L from the alternator G and with the other end to one of the plates c of a condenser $c\,c_1$, the plate (c_1) of the latter being connected to a much larger plate P_1. In this manner both capacity and self-induction were adjusted to suit the dynamo frequency.

As regards the rise of potential through resonant action, of course, theoretically, it may amount to anything since it depends on self-induction and resistance and since these may have any value. But in practice one is limited in the selection of these values and besides these, there are other limiting causes. One may start with, say, 1,000 volts and raise the E. M. F. to 50 times that value, but one cannot start with 100,000 and raise it to ten times that value because of the losses in the media which are great, especially if the frequency is high. It should be possible to start with, for instance, two volts from a high or low frequency circuit of a dynamo and raise the E. M. F. to many hundred times that value. Thus coils of the proper dimensions might be connected each with only one of its ends to the mains from a machine of low E. M. F., and though the circuit of the machine would not be closed in the ordinary acceptance of the term, yet the machine might be burned out if a proper resonance effect would be obtained. I have not been able to produce, nor have I observed with currents from the dynamo machine, such great rises of potential. It is possible, if not probable, that with currents obtained from apparatus containing iron the disturbing influence of the latter is the cause that these theoretical possibilities cannot be realized. But if such is the case I attribute it solely to the hysteresis and Faucault current losses in the core. Generally it was necessary to transform upward, when the E. M. F. was very low, and usually an ordinary form of induction coil was employed, but sometimes the arrangement illustrated in Fig. 20 II, has been found to be convenient. In this case a coil C is made in a great many sections, a few of these being used as the primary. In this manner both primary and secondary are adjustable. One end of the coil is connected to the line L_1 from the alternator, and the other line L is connected to the intermediate point of the coil. Such a coil with adjustable primary and secondary will be found also convenient in experiments with the disruptive discharge. When true resonance is obtained the top of the wave must of course be on the free end of the coil as, for instance, at the terminal of the phosphorescence bulb B. This is easily recognized by observing the potential of a point on the wire w nearer to the coil.

In connection with resonance effects and the problem of transmission of energy over a single conductor which was previously considered, I would say a few words on a subject which constantly fills my thoughts and which concerns the welfare of all. I mean the transmission of intelligible signals or perhaps even power to any distance without the use of wires. I am becoming daily more convinced of the practicability of the scheme; and though I know full well that the great maj rity of scientific men will not believe that such results can be practically and immediately realized, yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day. The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb by means of powerful machines the electrostatic condition of the earth and thus transmit intelligible signals and perhaps power. In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why then not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile-posts the earth may appear very large, but to that happiest of all men, the astronomer, who gazes at the heavens and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician, for when he considers the speed with which an electric disturbance is propagated through the earth all his ideas of distance must completely vanish.

A point of great importance would be first to know what is the capacity of the earth? and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation. If it be a charged body insulated in space its capacity should be extremely small, less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is, by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric currents. One of the terminals of the source would be connected to earth as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata or free space contains an opposite charge and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body and watching for the disturbance at various neighboring points of the earth's surface resonance might be detected. Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do and a proper electrical oscillator would have to be produced and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface.



Fig. 21

FIG. 21.—ENERGY TRANSMISSION TO ANY DISTANCE WITHOUT WIRES.

Assume that a source of alternating currents S be connected, as in Fig. 21, with one of its terminals to earth (conveniently to the water mains) and with the other to a body of large surface P. When the electric oscillation is set up there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to, or diverging from, the point C where the ground connection is made. In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body P is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source S will set up the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration at least of a certain low period upon the earth, by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured. I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at the surface could be but extremely small considering the size of the earth, the air would not act as a very disturbing factor and there would be not much energy lost through the action of the air which would be the case if the density were great. Theoretically, then, it could not require a great amount of energy to produce a disturbance perceptible at great distance, or even all over the surface of the globe. Now it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source S_1 Fig. 21, similar to S, or any number of such sources can be set to work in synchronism with the latter and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S_1 if the same be of opposite phase to the source S. I think that beyond doubt it is possible to operate electrical devices in a city through the ground or pipe system by resonance from an electrical

oscillator located at a central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realization of the scheme of transmitting intelligence or perhaps power to any distance through the earth or environing medium. If this is at all possible, distance does not mean anything. Proper apparatus must first be produced by means of which the problem can be attacked and I have devoted much thought to this subject. I am firmly convinced that it can be done and hope that we shall live to see it done.

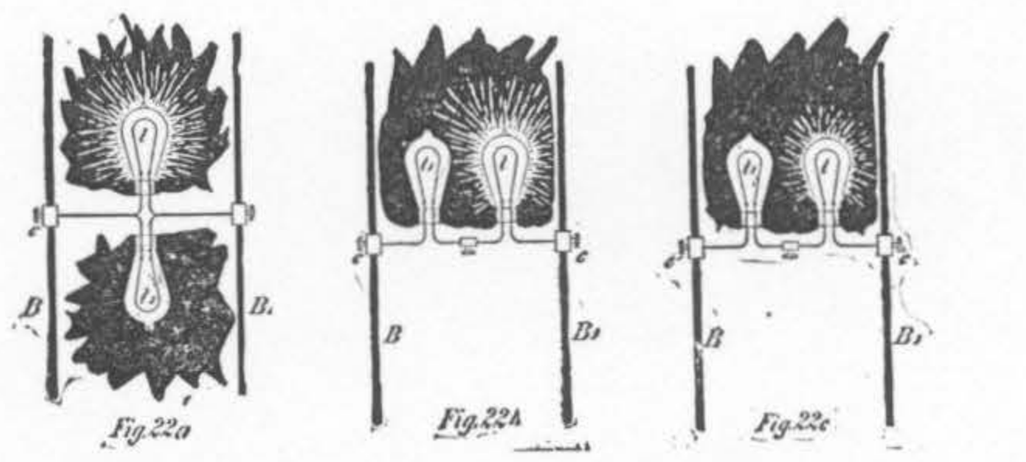
ON THE LIGHT PHENOMENA PRODUCED BY HIGH-FREQUENCY CURRENTS OF HIGH POTENTIAL AND GENERAL REMARKS RELATING TO THE SUBJECT.

Returning now to the light effects which it has been the chief object to investigate, it is thought proper to divide these effects into four classes: 1. Incandescence of a solid. 2. Phosphorescence. 3. Incandescence or phosphorescence of a rarefied gas, and 4. Luminosity produced in a gas at ordinary pressure. The first question is, How are these luminious effects produced? In order to answer this question as satisfactorily as I am able to do in the light of accepted views and with the experience acquired, and to add some interest to this demonstration, I shall dwell here upon a feature which I consider of great importance, inasmuch as it promises, besides, to throw a better light upon the nature of most of the phenomena produced by high-frequency electric currents. I have on other occasions pointed out the great importance of the presence of the rarefied gas, or atomic medium in general, around the conductor through which alternate currents of high frequency are passed, as regards the heating of the conductor by the currents. My experiments described some time ago have shown that the higher the frequency and potential difference of the currents, the more important becomes the rarefied gas in which the conductor is immersed, as a factor of the heating. The potential difference, however, is, as I then pointed out, a more important element than the frequency. When both of these are sufficiently high, the heating may be almost entirely due to the presence of the rarefied gas. The experiments to follow will show the importance of the rarefied gas, or generally of gas at ordinary or other pressure as regards the incandescence or other luminous effects produced by currents of this kind.

I take two ordinary 50-volt 16 c. p. lamps which are in every respect alike, with the exception, that one has been opened at the top and the air has filled the bulb, while the other is at the ordinary degree of exhaustion of commercial lamps. When I attach the lamp which is exhausted to the terminal of the secondary of the coil, which I have already used as in experiments illustrated in Fig. 15*a* for instance, and turn on the current, the filament as you have before seen comes to high incandescence. When I attach the second lamp, which is filled with air, instead of the former, the filament still glows, but much less brightly. This experiment illustrates only in part the truth of the statements before made. The importance of the filament's being immersed in rarefied gas is plainly noticeable but not to such a degree as might be desirable. The reason is that the secondary of this coil is wound for low tension, having only 150 turns, and the potential difference at the terminals of the lamp is therefore small. Were I to take another coil with many more turns in the secondary, the effect would be increased, since it depends partially on the potential difference, as before remarked. But since the effect likewise depends on the frequency, it may be properly stated that it depends on the time rate of the variation of the potential difference. The greater this variation the more important becomes the gas as an element of heating. I can produce a much greater rate of variation in another way, which, besides has the advantage of doing away with the objections, which might be made in the experiment just shown, even if both the lamps were connected in series or multiple arc to the coil, namely, that in consequence of the reactions existing between the primary and secondary coil the conclusions are rendered uncertain. This result I secure by charging from an ordinary transformer, which is fed from the alternating current supply station, a battery of condensers, and discharging the latter directly through a circuit of small self-induction, as before illustrated in Fig. 19*a*, 19*b*, 19*c*.

In Figs. 22*a*, 22*b* and 22*c*, the heavy copper bars BB_1, are connected to the opposite coatings of a battery of condensers, or generally in such way, that the high frequency or sudden discharges are made to traverse them. I connect first an ordinary 50-volt incandescent lamp to the bars by means of the clamps *cc*. The discharges being passed through the lamp, the filament is rendered incandescent, though the current through it is very small, and would not be nearly sufficient to produce a visible effect under the conditions of ordinary use of the lamp. Instead of this I now attach to the bars another lamp exactly like the first, but with the seal broken off, the bulb being therefore filled with air at ordinary pressure. When the discharges are directed through the filament, as before, it does not become incandescent. But the result might still be attributed to one of the many possible reactions. I therefore connect both the lamps in multiple arc as illustrated in Fig. 22*a*. Passing the discharges through both the lamps, again the filament in the exhausted lamp *l* glows very brightly while that in the non-exhausted lamp l_1 remains dark, as previously. But it should not be thought that the latter lamp is taking only a small fraction of the energy supplied to both the lamps; on the contrary, it may consume a considerable portion of the energy and it may become even hotter than the one which burns brightly. In this experiment the potential difference at the terminals of the lamps varies in sign theoretically three to four million times a second. The ends of the filaments are correspondingly electrified, and the gas in the bulbs is violently agitated and a large portion of the supplied energy is thus converted into heat. In the non-exhausted bulb there being a few million times more gas molecules than in the exhausted one, the bombardment, which is most violent at the ends of the filament, in the neck of the bulb, consumes a large portion of the energy without producing any visible effect. The reason is that, there being many molecules, the bombardment is quantitatively considerable, but the individual impacts are not very violent, as the speeds of the molecules are comparatively small owing to the small free path. In the exhausted bulb on the contrary the speeds are very great and the individual impacts are violent and therefore better adapted to produce a visible effect. Besides, the convection of heat is greater in the former bulb. In both the bulbs the current traversing the filaments is very small, incomparably smaller than that which they require on an ordinary low-frequency circuit. The potential difference, however, at the ends of the filaments is very great and might be possibly 20,000 volts or more, if the filaments were straight and their ends far apart. In the ordinary lamp a spark generally occurs between the ends of the filament or between the platinum wires outside, before such a difference of potential can be reached.

It might be objected in the experiment before shown that the lamps, being in multiple arc, the exhausted lamp might take a much larger current and that the effect observed might not be exactly attributable to the action of the gas in the bulbs. Such objections will lose much weight if I connect the lamps in series, with the same result. When this is done and the discharges are directed through the filaments it is again noted, that the filament



FIGS. 22*a*, 22*b* AND 22*c*.—SHOWING THE EFFECT OF THE PRESENCE OF A GASEOUS MEDIUM.

in the non-exhausted bulb l_1 remains dark while that in the exhausted one (*l*) glows even more intensely than under its normal conditions of working, Fig. 22*b*. According to general ideas the current through the filaments should now be the same, were it not modified by the presence of the gas around the filaments.

At this juncture I may point out another interesting feature, which illustrates the effect of the rate of change of potential of the currents. I will leave the two lamps connected in series to the bars BB_1 as in the previous experiment, Fig. 22*b*, but will presently reduce considerably the frequency of the currents, which was excessive in the experiment just before shown. This I may do by inserting a self-induction coil in the path of the discharges, or by augmenting the capacity of the condensers. When I now pass these low-frequency discharges through the lamps, the exhausted lamp *l* again is as bright as before but it is noted also that the non-exhausted lamp l_1 glows, though not quite as intensely as the other. Reducing the current through the lamps, I may bring the filament in the latter lamp to redness, and, though the filament in the exhausted lamp *l* is bright, Fig. 22*c*, the degree of its incandescence is much smaller than in Fig. 22*b*, when the currents were of a much higher frequency.

In these experiments the gas acts in two opposite ways in determining the degree of the incandescence of the filaments, that is, by convection and bombardment. The higher the frequency and potential of the currents, the more important becomes the bombardment. The convection on the contrary should be the smaller, the higher the frequency. When the currents are steady, there is practically no bombardment and convection may therefore with such currents also considerably modify the degree of incandescence and produce results similar to those just before shown. Thus, if two lamps exactly alike, one exhausted and one not exhausted, are connected in multiple arc or series to a direct-current machine, the filament in the non-exhausted lamp will require a considerably greater current to be rendered incandescent. This result is entirely due to convection and the effect is the more prominent

the thinner the filament. Professor Ayrton and Mr. Kilgour some time ago published quantitative results concerning the thermal emissivity by radiation and convection in which the effect of thin wires was clearly shown. This effect may be strikingly illustrated by preparing a number of small short glass tubes, each containing through its axis the thinnest obtainable platinum wire. If these tubes be highly exhausted, a number of them may be connected in multiple arc to a direct-current machine and all of the wires may be kept at incandescence with a smaller current than that required to render incandescent a single one of the wires if the tube be not exhausted. Could the tubes be so highly exhausted that convection would be nil, then the relative amounts of heat given off by convection and radiation could be determined without the difficulties attending thermal qnantitative measurements. If a source of electric impulses of high frequency and very high potential is employed, a still greater number of the tubes may be taken and the wires rendered incandescent by a current not capable of warming perceptibly a wire of the same size immersed in air at ordinary pressure, and conveying the energy to all of them.

I may here describe a result which is still more interesting, and to which I have been led by the observation of these phenomena. I noted that small differences in the density of the air produced a considerable difference in the degree of incandescence of the wires, and I thought that, since in a tube, through which a luminous discharge is passed, the gas is generally not of uniform density, a very thin wire contained in the tube might be rendered incandescent at certain places of smaller density of the gas, while it would remain dark at the places of greater density, where the convection would be greater and the bombardment less intense, Accordingly a tube *t* was prepared, as illustrated in Fig. 23, which contained through the middle a very fine platinum wire *w*. The tube was exhausted to a moderate degree and it was found that when it was attached to the terminal of a high-frequency coil the platinum wire *w* would, indeed, become incandescent in patches, as illustrated in Fig. 23. Later a number of these tubes with one or more wires were prepared, each showing this result. The effect was best noted when the striated discharge occurred in the tube, but was also produced when the striæ were not visible, showing that, even then, the gas in the tube was not of uniform density. The position of the striæ was generally such, that the rarefactions corresponded to the places of incandescence or greater brightness on the wire *w*. But in a few instances it was noted, that the bright spots on the wire were covered by the dense parts of the striated discharge as indicated by *l* in Fig. 23, though the effect was barely perceptible. This was explained in a plausible way by assuming, that the convection was not widely different in the dense and rarefied places, and that the bombardment was greater on the dense places of the striated discharge. It is, in fact, often observed in bulbs, that under certain conditions a thin wire is brought to higher incandescence when the air is not too highly rarefied. This is the case when the potential of the coil is not high enough for the vacuum, but the result may be attributed to many different causes. In all cases this curious phenomenon of incandescence disappears when the tube, or rather the wire, acquires throughout a uniform temperature.

Disregarding now the modifying effect of convection there are then two distinct causes which determine the incandescence of a wire or filament with varying currents, that is, conduction current and bombardment. With steady currents we have to deal only with the former of these two causes, and the heating effect is a minimum, since the resistance is least to steady flow. When the current is a varying one, the resistance is greater and hence the heating effect is increased. Thus if the rate of change of the current is very great, the resistance may increase to such an extent that the filament is brought to incandescence with inappreciable currents, and we are able to take a short and thick block of carbon or other material and bring it to bright incandescence with a current incomparably smaller than that required to bring to the same degree of incandescence an ordinary thin lamp filament with a steady or low frequency current. This result is important, and illustrates how rapidly our views on these subjects are changing, and how quickly our field of knowledge is extending. In the art of incandescent lighting, to view this result in one aspect only, it has been commonly considered as an essential requirement for practical success, that the lamp filament should be thin and of high resistance. But now we know that the resistance to the steady flow of the filament does not mean anything; the filament might as well be short and thick; for if it be immersed in rarefied gas it will become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents. We may conclude from this, that it would be of advantage, so far as the lamp is considered, to employ high frequencies for lighting, as they allow the use of short and thick filaments and smaller currents.

If a wire or filament be immersed in a homogeneous medium, all the heating is due to true conduction current, but if it be enclosed in an exhausted vessel the conditions are entirely different. Here the gas begins to act and the heating effect of the conduction current, as is shown in many experiments, may be very small compared with that of the bombardment. This is especially the case if the circuit is not closed and the potentials are of course very high. Suppose a fine filament enclosed in an exhausted vessel be connected with one of its ends to the terminal of a high tension coil and with its other end to a large insulated plate. Though the circuit is not closed, the filament, as I have before shown, is brought to incandescence. If the frequency and potential be comparatively low, the filament is heated by the current passing *through* it. If the frequency and potential, and principally the latter, be increased, the insulated plate need be but very small, or may be done away with entirely; still the filament will become incandescent, practically all the heating being then due to the bombardment. A practical way of combining both the effects of conduction current and bombardment is illustrated in Fig. 24, in which an ordinary lamp is shown provided with a very thin filament which has one of the ends of the latter connected to a shade serving the purpose of the insulated plate, and the other end to the terminal of a high tension source. It should not be thought that only rarefied gas is an important factor in the heating of a conductor by varying currents, but gas at ordinary pressure may become important, if the potential difference and frequency of the currents is excessive. On this subject I have already stated, that when a conductor is fused by a stroke of lightning, the current through it may be exceedingly small, not even sufficient to heat the conductor perceptibly, were the latter immersed in a homogeneous medium.

From the preceding it is clear that when a conductor of high resistance is connected to the terminals of a source of high frequency currents of high potential, there may occur considerable

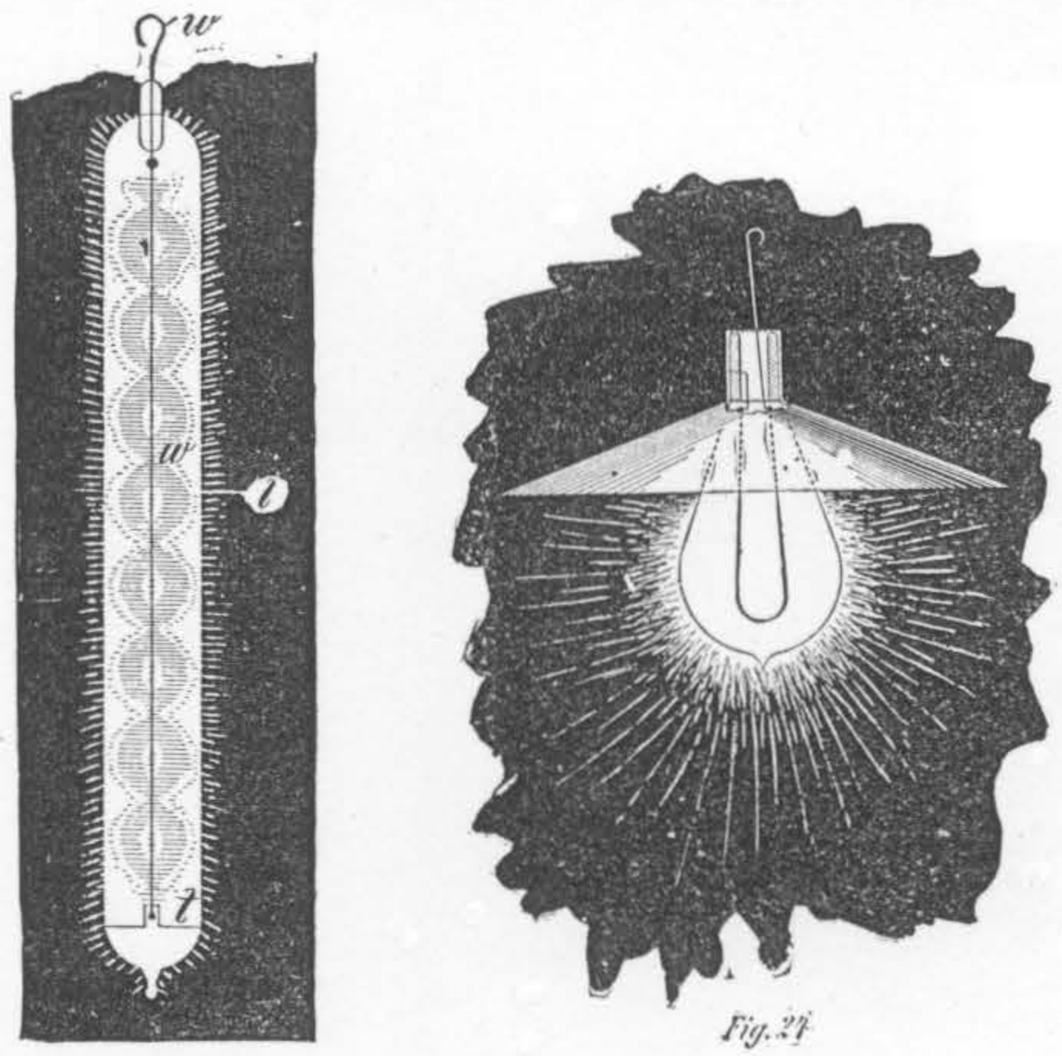


FIG. 23.—CURIOUS INCANDESCENCE OF A WIRE.
FIG. 24.—UTILIZING THE HEATING EFFECT OF CONDUCTION CURRENT AND BOMBARDMENT.

dissipation of energy, principally on the ends of the conductor, in consequence of the action of the gas surrounding the conductor. Owing to this, the current through a section of the conductor at a point midway between its ends may be much smaller than through a section near the ends. Furthermore, the current passes principally through the outer portions of the conductor, but this effect is to be distinguished from the skin effect as ordinarily interpreted, for the latter would or should occur also in a continuous incompressible medium. If a great many incandescent lamps are connected in series to a source of such currents, the lamps at the ends may burn brightly, whereas those in the middle may remain entirely dark. This is due principally to bombardment, as before stated. But even if the currents be steady, provided the difference of potential is very great, the lamps at the ends will burn more brightly than those in the middle. In such case there is no rhythmical bombardment and the result is produced entirely by leakage. This leakage or dissipation into space when the tension is high, is considerable when incandescent lamps are used, and still more considerable with arcs, for the latter act like flames. Generally, of course, the dissipation is much smaller with steady, than with varying currents.

MISCELLANEOUS.

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.[1]—IV.

BY NIKOLA TESLA.

I have contrived an experiment which illustrates in an interesting manner the effect of lateral diffusion. If a very long tube is attached to the terminal of a high frequency coil, the luminosity is greatest near the terminal and falls off gradually towards the remote end. This is more marked if the tube is narrow.

A small tube about one-half inch in diameter and twelve inches long, Fig. 25, has one of its ends drawn out into a fine fibre *f* nearly three feet long. The tube is placed in a brass socket T which can be screwed on the terminal T_1 of the induction coil. The discharge passing through the tube first illuminates the bottom of the same, which is of comparatively large section; but through the long glass fibre the discharge cannot pass. But gradually the rarefied gas inside becomes warmed and more conducting and the discharge spreads into the glass fibre. This spreading is so slow, that it may take half a minute or more until the discharge has worked through up to the top of the glass fibre, then presenting the appearance of a strongly luminous thin thread. By adjusting the potential at the terminal the light may be made to travel upwards at any speed. Once, however, the glass fibre is heated, the

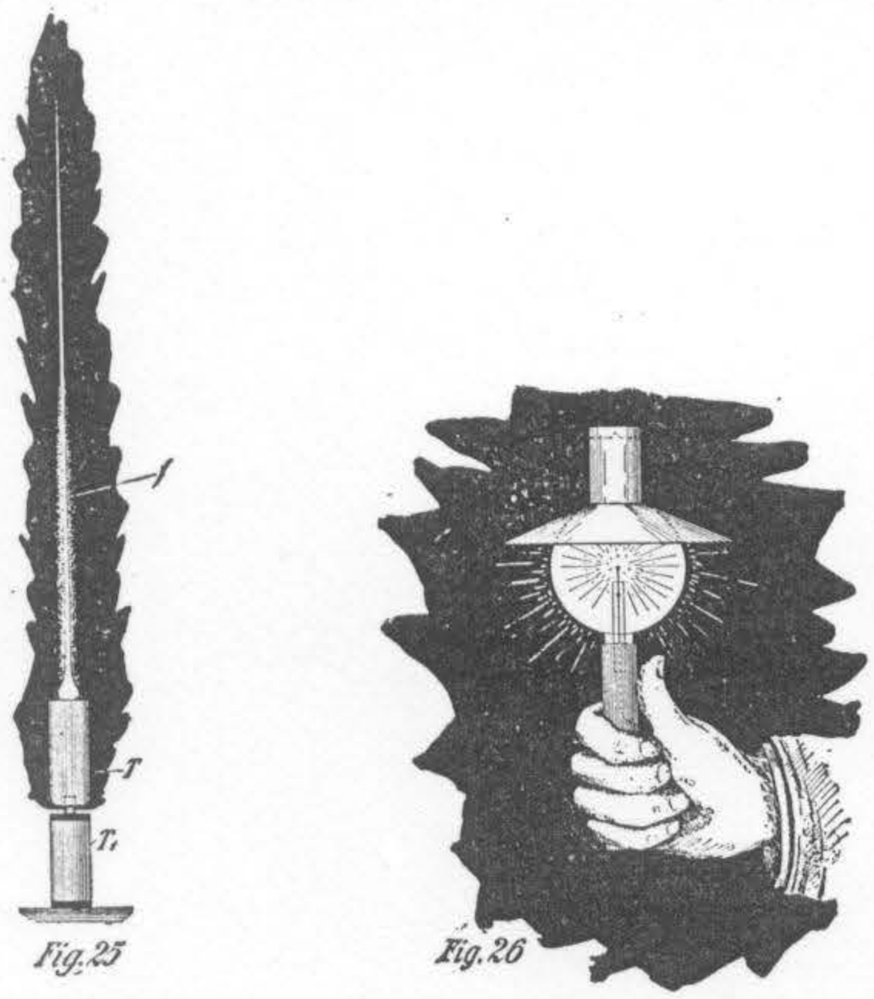


FIG. 25.—ILLUSTRATING LATERAL DIFFUSION.
FIG. 26.—INCANDESCENCE OF A SOLID.

discharge breaks through its entire length instantly. The interesting point to be noted is that, the higher the frequency of the currents, or in other words, the greater relatively the lateral dissipation, at a slower rate may the light be made to propagate through the fibre. This experiment is best performed with a highly exhausted and freshly made tube. When the tube has been used for some time the experiment often fails. It is possible that the gradual and slow impairment of the vacuum is the cause. This slow propagation of the discharge through a very narrow glass tube corresponds exactly to the propagation of heat through a bar warmed at one end. The quicker the heat is carried away laterally the longer time it will take for the heat to warm the remote end. When the current of a low frequency coil is passed through the fibre from end to end, then the lateral dissipation is small and the discharge instantly breaks through almost without exception.

After these experiments and observations which have shown the importance of the discontinuity or atomic structure of the medium and which will serve to explain, in a measure at least, the nature of the four kinds of light effects produceable with these currents, I may now give you an illustration of these effects. For the sake of interest I may do this in a manner which to many of you might be novel. You have seen before that we may now convey the electric vibration to a body by means of a single wire or conductor of any kind. Since the human frame is conducting I may convey the vibration through my body.

First, as in some previous experiments, I connect my body with one of the terminals of a high-tension transformer and take in my hand an exhausted bulb which contains a small carbon button mounted upon a platinum wire leading to the outside of the bulb,

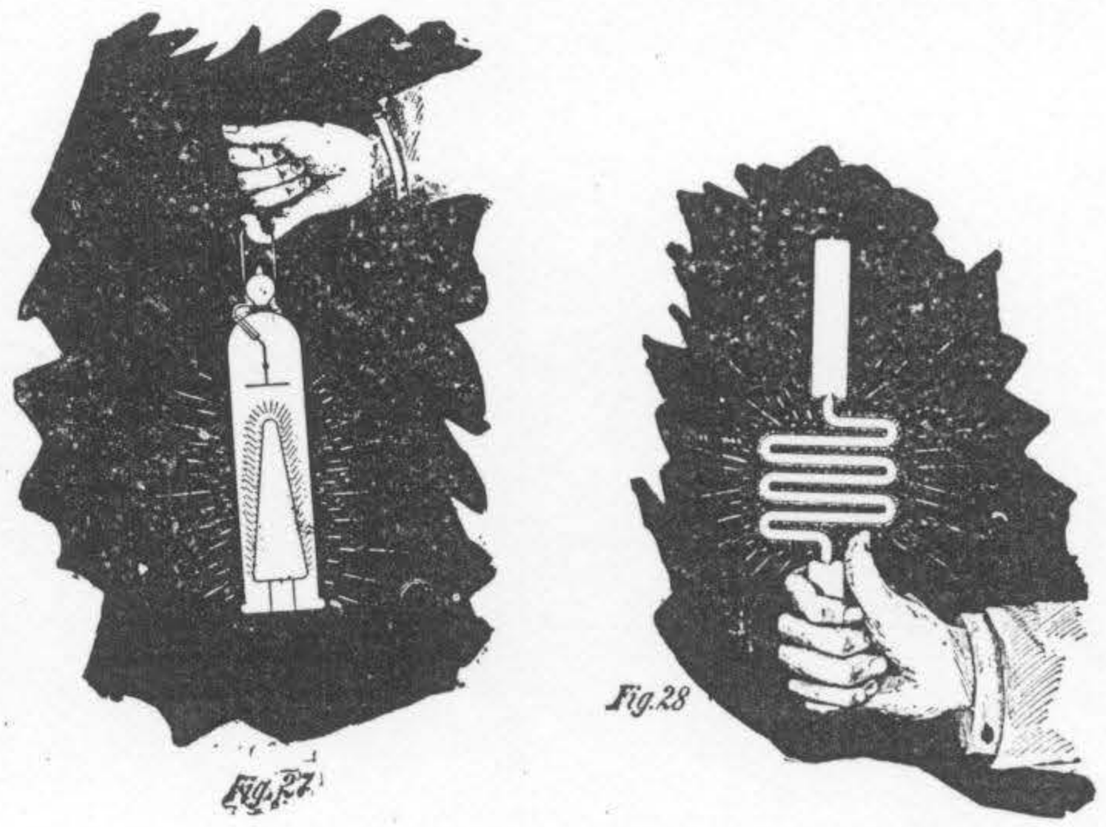


FIG. 27.—PHOSPHORESCENCE.
FIG. 28.—INCANDESCENCE OR PHOSPHORESCENCE OF RAREFIED GAS.

and the button is rendered incandescent as soon as the transformer is set to work (Fig. 26). I may place a conducting shade on the bulb which serves to intensify the action, but is not necessary. Nor is it required that the button should be in conducting connection with the hand through a wire leading through the glass, for sufficient energy may be transmitted through the glass itself by inductive action to render the button incandescent.

Next I take a highly exhausted bulb containing a strongly phosphorescent body, above which is mounted a small plate of aluminum on a platinum wire leading to the outside, and the currents flowing through my body excite intense phosphorescence in the bulb, Fig. 27. Next again I take in my hand a simple exhausted tube, and in the same manner the gas inside the tube is rendered highly incandescent or phosphorescent, Fig. 28. Finally, I may take in my hand a wire, bare or covered with thick insulation, it is quite immaterial; the electric vibration is so intense as to cover the wire with a luminous film, Fig. 29.

A few words must now be devoted to each of these phenomena. In the first place, I will consider the incandescence of a button or of a solid in general, and dwell upon some facts which apply equally to all these phenomena. It was pointed out before that when a thin conductor, such as a lamp filament, for instance, is connected with one of its ends to the terminal of a transformer of high tension the filament is brought to incandescence partly by a conduction current and partly by bombardment. The shorter

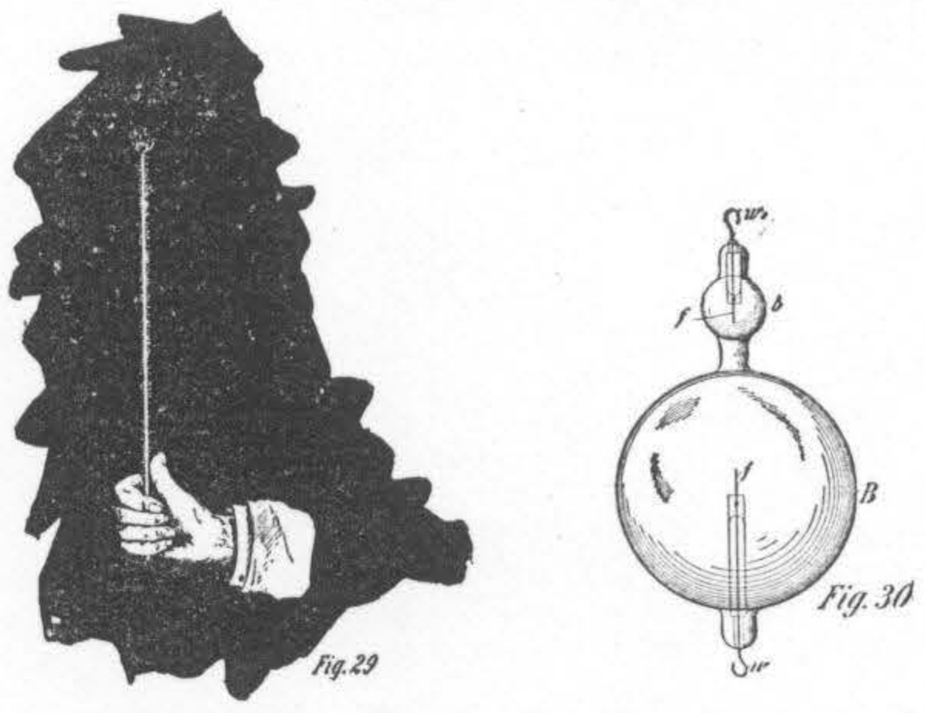


FIG. 29.—LUMINOSITY OF GAS AT ORDINARY PRESSURE, ILLUSTRATING WITH FIGS. 26, 27 AND 28 FOUR KINDS OF LIGHT EFFECTS PRODUCED BY HIGH-FREQUENCY CURRENTS OF HIGH POTENTIAL.
FIG. 30.—SHOWING THE EFFECT OF CONFINING THE GAS AROUND THE ELECTRODE.

and thicker the filament the more important becomes the latter and finally, reducing the filament to a mere button, all the heating must practically be attributed to the bombardment. So in the experiment before shown, the button is rendered incandescent

1. A lecture delivered before the Franklin Institute, at Philadelphia, Feb. 24 1893, and before the National Electric Light Association, at St. Louis, Mo, March 1, 1893.

by the rhythmical impact of freely movable small bodies in the bulb. These bodies may be the molecules of the residual gas, particles of dust or lumps torn from the electrode; whatever they are, it is certain that the heating of the button is essentially connected with the pressure of such freely movable particles, or of atomic matter in general in the bulb. The heating is the more intense the greater the number of impacts per second and the greater the energy of each impact. Yet the button would be heated also if it were connected to a source of a steady potential. In such a case electricity would be carried away from the button by the freely movable carriers or particles flying about and the quantity of electricity thus carried away might be sufficient to bring the button to incandescence by its passage through the latter. But the bombardment could not be of great importance in such case. For this reason it would require a comparatively very great supply of energy to the button to maintain it at incandescence with a steady potential. The higher the frequency of the electric impulses the more economically can the button be maintained at incandescence. One of the chief reasons why this is so, is, I believe, that with impulses of very high frequency there is less exchange of the freely movable carriers around the electrode and this means, that in the bulb the heated matter is better confined to the neighborhood of the button. If a double bulb, as illustrated in Fig. 30, be made, comprising a large globe B and a small one *b*, each containing as usual a filament *f* mounted on a platinum wire *w* and w_1 it is found, that if the filaments *ff* be exactly alike, it requires less energy to keep the filament in the globe *b* at a certain degree of incandescence, than that in the large globe B. This is due to the confinement of the movable particles around the button. In this case it is also ascertained, that the filament in the small globe *b* is less deteriorated when maintained a certain length of time at incandescence. This is a necessary consequence of the

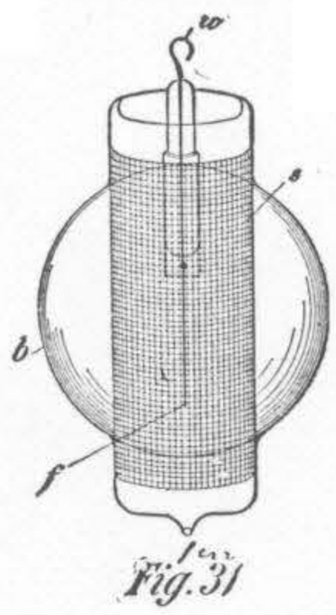


FIG. 31.—SHOWING THE INEFFICACY OF A METAL SCREEN.

fact that the gas in the small bulb becomes strongly heated and therefore a very good conductor, and less work is then performed on the button, since the bombardment becomes less intense as the conductivity of the gas increases. In this construction, of course, the small bulb becomes very hot and when it reaches an elevated temperature the convection and radiation on the outside increase. On another occasion I have shown bulbs in which this drawback was largely avoided. In these instances a very small bulb, containing a refractory button, was mounted in a large globe and the space between the walls of both was highly exhausted. The outer large globe remained comparatively cool in such constructions. When the large globe was on the pump and the vacuum between the walls maintained permanent by the continuous action of the pump, the outer globe would remain quite cold, while the button in the small bulb was kept at incandescence. But when the seal was made, and the button in the small bulb maintained incandescent some length of time, the large globe too would become warmed. From this I conjecture that if vacuous space (as Prof. Dewar finds) cannot convey heat, it is so merely in virtue of our rapid motion through space or, generally speaking, by the motion of the medium relatively to us, for a permanent condition could not be maintained without the medium being constantly renewed. A vacuum cannot, according to all evidence, be permanently maintained around a hot body.

In these constructions, before mentioned, the small bulb inside would, at least in the first stages, prevent all bombardment against the outer, large globe. It occurred to me then to ascertain how a metal sieve would behave in this respect, and several bulbs, as illustrated in Fig. 31, were prepared for this purpose. In a globe *b*, was mounted a thin filament *f* (or button) upon a platinum wire *w* passing through a glass stem and leading to the outside of the globe. The filament *f* was surrounded by a metal sieve *s*. It was found in experiments with such bulbs that a sieve with wide meshes apparently did not in the slightest affect the bombardment against the globe *b*. When the vacuum was high the shadow of the sieve was clearly projected against the globe and the latter would get hot in a short while. In some bulbs the sieve *s* was connected to a platinum wire sealed in the glass. When this wire was connected to the other terminal of the induction coil (the E. M. F. being kept low in this case), or to an insulated plate, the bombardment against the outer globe *b* was diminished. By taking a sieve with fine meshes the bombardment against the globe *b* was always diminished, but even then if the exhaustion was carried very far, and when the potential of the transformer was very high, the globe *b* would be bombarded and heated quickly, though no shadow of the sieve was visible owing to the smallness of the meshes. But a glass tube or other continuous body mounted so as to surround the filament, did entirely cut off the bombardment and for a while the outer globe *b* would remain perfectly cold. Of course when the glass tube was sufficiently heated the bombardment against the outer globe could be noted at once. The experiments with these bulbs seemed to show that the speeds of the projected molecules or particles must be considerable (though quite insignificant when compared with that of light), otherwise it would be difficult to understand how they could traverse a fine metal sieve without being affected, unless it were found, that such small particles or atoms cannot be acted upon directly at measurable distances. In regard to the speed of the projected atoms, Lord Kelvin has recently estimated it at about one kilometre a second or thereabouts in an ordinary Crookes bulb. As the potentials obtainable with a disruptive discharge coil are much higher than with ordinary coils, the speeds must, of course be much greater when the bulbs are lighted from such a coil. Assuming the speed to be as high as five kilometres and uniform through the whole trajectory, as it should be in a very highly exhausted vessel, then if the alternate electrifications of the electrode would be of a frequency of five million, the greatest distance a particle could get away from the electrode would be one millimetre, and if it could be acted upon directly at that distance, the exchange of electrode matter or of the atoms would be very slow and there would be practically no bombardment against the bulb. This at least should be so, if the action of an electrode upon the atoms of the residual gas would be such as upon electrified bodies which we can perceive. A hot body enclosed in an exhausted bulb produces always atomatic bombardment, but a hot body has no definite rhythm, for its molecules perform vibrations of all kinds.

If a bulb containing a button or filament be exhausted as high as is possible with the greatest care and by the use of the best artifices, it is often observed that the discharge cannot, at first, break through, but after some time, probably in consequence of some changes within the bulb, the discharge finally passes through and the button is rendered incandescent. In fact, it appears that the higher the degree of exhaustion the easier is the incandescence produced. There seem to be no other causes to which the incandescence might be attributed in such case except to the bombardment or similar action of the residual gas, or of particles of matter in general. But if the bulb be exhausted with the greatest care can these play an important part? Assume the vacuum in the bulb to be tolerably perfect the great interest then centres in the question: Is the medium which pervades all space continuous or atomic? If atomic, then the heating of a conducting button or filament in an exhausted vessel might be due largely to ether bombardment, and then the heating of a conductor in general through which currents of high frequency or high potential are passed must be modified by the behavior of such medium; then also the skin effect, the apparent increase of the ohmic resistance, etc., admit, partially, at least, of a different explanation.

It is certainly more in accordance with many phenomena observed with high-frequency currents to hold that all space is pervaded with free atoms, rather than to assume that it is devoid of these, and dark and cold, for so it must be, if filled with a continuous medium, since in such there can be neither heat nor light. Is then energy transmitted by independent carriers or by the vibration of a continuous medium? This important question is by no means as yet positively answered. But most of the effects which are here considered, especially the light effects, incandescence, or phosphorescence, involve the presence of free atoms and would be impossible without these.

In regard to the incandescence of a refractory button (or filament) in an exhausted receiver, which has been one of the subjects of this investigation, the chief experiences, which may serve as a guide in constructing such bulbs, may be summed up as follows: 1. The button should be as small as possible, spherical, of a smooth or polished surface and of refractory material which withstands evaporation best. 2. The support of the button should be very thin and screened by an aluminum and mica sheet as I have described on another occasion. 3. The exhaustion of the bulb should be as high as possible. 4. The frequency of the currents should be as high as practicable. 5. The currents should be of a harmonic rise and fall, without sudden interruptions. 6. The heat should be confined to the button by inclosing the same in a small bulb or otherwise. 7. The space between the walls of the small bulb and the outer globe should be highly exhausted.

Most of the considerations which apply to the incandescence of a solid just considered may likewise be applied to phosphorescence. Indeed, in an exhausted vessel the phosphorescence is,

as a rule, primarily excited by the powerful beating of the electrode stream of atoms against the phosphorescent body. Even in many cases, where there is no evidence of such a bombardment, I think that phosphorescence is excited by violent impacts of atoms, which are not necessarily thrown off from the electrode but are acted upon from the same inductively through the medium or through chains of other atoms. That mechanical shocks play an important part in exciting phosphorescence in a bulb may be seen from the following experiment. If a bulb, constructed as that illustrated in Fig. 10, be taken and exhausted with the greatest care so that the discharge cannot pass, the filament *f* acts by electrostatic induction upon the tube *t* and the latter is set in vibration. If the tube *o* be rather wide, about an inch or so, the filament may be so powerfully vibrated that whenever it hits the glass tube it excites phosphorescence. But the phosphorescence ceases when the filament comes to rest. The vibration can be arrested and again started by varying the frequency of the currents. Namely, the filament has its own period of vibration, and if the frequency of the currents is such that there is resonance, it is set easily vibrating, though the potential of the currents be small. I have often observed that the filament in the bulb is destroyed by such mechanical resonance. The filament vibrates as a rule so rapidly that it cannot be seen and the experimenter may at first be mystified. When such an experiment as the one described is carefully performed, the potential of the currents need be extremely small, and for this reason I infer that the phosphorescence is then due to the mechanical shock of the filament against the glass, just as it is produced by striking a loaf of sugar with a knife. The mechanical shock produced by the projected atoms is easily noted when a bulb containing a button is grasped in the hand and the current turned on suddenly. I believe that a bulb could be shattered by observing the conditions of resonance.

MISCELLANEOUS.

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.[1]—V.

(*Concluded*).

BY NIKOLA TESLA.

In the experiment before cited it is, of course, open to say, that the glass tube upon coming in contact with the filament, retains a charge of a certain sign upon the point of contact. If now the filament again touches the glass at the same point while it is oppositely charged, the charges equalize under evolution of light. But nothing of importance would be gained by such an explanation. It is unquestionable that the initial charges given to the atoms or to the glass play some part in exciting phosphorescence. So, for instance, if a phosphorescent bulb be first excited by a high frequency coil by connecting it to one of the terminals of the latter and the degree of luminosity noted, and then the bulb be highly charged from a Holtz machine by attaching it preferably to the positive terminal of the machine, it is found that when the bulb is again connected to the terminal of the high frequency coil, the phosphorescence is far more intense. On another occasion I have considered the possibility of some phosphorescent phenomena in bulbs being produced by the incandescence of an infinitesimal layer on the surface of the phosphorescent body. Certainly, the impacts of the atoms are powerful enough to produce intense incandescence by the collisions, since they bring quickly to a high temperature a body of considerable bulk. If any such effect exists, then the best appliance for producing phosphorescence in a bulb, which we know so far, is a disruptive discharge coil giving an enormous potential with but few fundamental discharges, say 25–30 per second, just enough, to produce a continuous impression upon the eye. It is a fact that such a coil excites phosphorescence under almost any condition and at all degrees of exhaustion, and I have observed effects which appear to be due to phosphorescence even at ordinary pressures of the atmosphere, when the potentials are extremely high. But if phosphorescent light is produced by the equalization of charges of electrified atoms (whatever this may mean ultimately), then the higher the frequency of the impulses or alternate electrifications, the more economical will be the light production. It is a long known and noteworthy fact that all the phosphorescent bodies are poor conductors of electricity and heat, and that all bodies cease to emit phosphorescent light when they are brought to a certain temperature. Conductors on the contrary do not possess this quality. There are but few exceptions to the rule. Carbon is one of them. Becquerel noted that carbon phosphoresces at a certain elevated temperature preceding the dark red. This phenomenon may be easily observed in bulbs provided with a rather large carbon electrode (say a sphere of six millimetres diameter). If the current is turned on after a few seconds, a snow white film covers the electrode, just before it gets dark red. Similar effects are noted with other conducting bodies, but many scientific men will probably not attribute them to true phosphorescence. Whether true incandescence has anything to do with phosphorescence excited by atomic impact or mechanical shocks still remains to be decided, but it is a fact that all conditions, which tend to localize and increase the heating effect at the point of impact, are almost invariably the most favorable for the production of phosphorescence. So, if the electrode be very small, which is equivalent to saying in general, that the electric density is great, if the potential be high, and if the gas be highly rarefied, all of which things imply high speed of the projected atoms, or matter, and consequently violent impacts—the phosphorescence is very intense. If a bulb provided with a large and small electrode be attached to the terminal of an induction coil, the small electrode excites phosphorescence while the large one may not do so, because of the smaller electric density and hence smaller speed of the atoms. A bulb provided with a large electrode may be grasped with the hand while the electrode is connected to the terminal of the coil and it may not phosphoresce; but if instead of grasping the bulb with the hand, the same be touched with a pointed wire, the phosphorescence at once spreads through the bulb, because of the great density at the point of contact. With low frequencies it seems that gases of great atomic weight excite more intense phosphorescence than those of smaller weight, as for instance, hydrogen. With high frequencies the observations are not sufficiently reliable to draw a conclusion. Oxygen, as is well-known, produces exceptionally strong effects, which may be in part due to chemical action. A bulb with hydrogen residue seems to be most easily excited. Electrodes which are most easily deteriorated produce more intense phosphorescence in bulbs, but the condition is not permanent because of the impairing of the vacuum and the deposition of the electrode matter upon the phosphorescent surfaces. Some liquids as oils, for instance, produce magnificent effects of phosphorescense (or fluorescence?), but they last only a few seconds. So if a bulb have a trace of oil on the walls and the current is turned on, the phophorescence only persists for a few moments until the oil is carried away. Of all bodies so far tried, sulphide of zinc seems to be the most susceptible to phosphorescence. Some samples obtained obtained through the kindness of Prof. Henry in Paris, were employed in many of these bulbs. One of the defects of this sulphide is, that it loses its quality of emitting light when brought to a temperature which is by no means high. It can therefore, be used only for feeble intensities. An observation which might deserve notice is, that when violently bombarded from an aluminum electrode it assumes a black color, but singularly enough, it returns to the original condition when it cools down.

The most important fact arrived at in pursuing investigations in this direction is, that in all cases it is necessary, in order to excite phosphorescence with a minimum amount of energy, to observe certain conditions. Namely, there is always, no matter what the frequency of the currents, degree of exhaustion and character of the bodies in the bulb, a certain potential (assuming the bulb excited from one terminal) or potential difference (assuming the bulb to be excited with both terminals) which produces the most economical result. If the potential be increased, considerable energy may be wasted without producing any more light, and if it be diminished, then again the light production is not as economical. The exact condition under which the best result is obtained seems to depend on many things of a different nature and it is to be yet investigated by other experimenters, but it will certainly have to be observed when such phosphorescent bulbs are operated, if the best results are to be attained.

Coming now to the most interesting of these phenomena, the incandescence or phosphorescence of gases, at low pressures or at the ordinary pressure of the atmosphere, we must seek the explanation of these phenomena in the same primary causes, that is, in shocks or impacts of the atoms. Just as molecules or atoms beating upon a solid body excite phosphorescence in the same or render it incandescent, so when colliding among themselves they produce similar phenomena. But this is a very insufficient explanation and concerns only the crude mechanism. Light is produced by vibrations which go on at a rate almost inconceivable. If we compute, from the energy contained in the form of known radiations in a definite space the force which is necessary to set up such rapid vibrations, we find, that though the density of the ether be incomparably smaller than that of any body we know, even hydrogen, the force is something surpassing comprehension. What is this force, which in mechanical measure, may amount to thousands of tons per square inch? It is electrostatic force in the light of modern views. It is impossible to conceive how a body of measurable dimensions could be charged to so high a potential that the force would be sufficient to produce these vibrations. Long before any such charge could be imparted to the body it would be shattered into atoms. The sun emits light and heat, and so does an ordinary flame or incandescent filament, but in neither of these can the force be accounted for if it be assumed that it is associated with the body as a whole. Only in one way may we account for it, namely, by identifying it with the atom. An atom is so small, that if it be charged by coming in contact with an electrified body and the charge be assumed to follow the same law as in the case of bodies of measurable dimensions, it must retain a quantity of electricity which is fully capable of accounting for these forces and tremendous rates of vibration. But the atom behaves singularly in this respect, it always takes the same "charge."

It is very likely that resonant vibration plays a most important part in all manifestations of energy in nature. Throughout space all matter is vibrating, and all rates of vibration are represented, from the lowest musical note to the highest pitch of the chemical rays, hence an atom, or complex of atoms, no matter what its period, must find a vibration with which it is in resonance. When we consider the enormous rapidity of the light vibrations, we realize the impossibility of producing such vibrations directly with any apparatus of measurable dimensions, and we are driven to the only possible means of attaining the object of setting up waves of light by electrical means and economically, that is, to affect the molecules or atoms of a gas, to cause them to collide and vibrate. We then must ask ourselves—How can free molecules or atoms be affected?

It is a fact that they can be affected by electrostatic force, as is apparent in many of these experiments. By varying the electrostatic force we can agitate the atoms, and cause them to collide under evolution of heat and light. It is not demonstrated beyond doubt that we can affect them otherwise. If a luminous discharge is produced in a closed exhausted tube, do the atoms arrange themselves in obedience to any other but to electrostatic force acting in straight lines from atom to atom? Only recently I investigated the mutual action between two circuits with extreme rates of vibration. When a battery of a few jars (*c c c c*, Fig. 32) is discharged through a primary P of low resistance (the connections being as illustrated in Figs. 19*a*, 19*b* and 19*c*), and the frequency of vibration be many million there are great differences of potential between points on the primary not more than a few inches apart. These differences may be 10,000 volts per inch, if not more, taking the maximum value of the E. M. F.

1. A lecture delivered before the Franklin Institute, at Philadelphia, Feb. 24 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893.

The secondary *s* is therefore acted upon by electrostatic induction, which is in such extreme cases of much greater importance than the electro-dynamic. To such sudden impulses the primary as well as the secondary are poor conductors, and therefore great differences of potential may be produced by electrostatic induction between adjacent points on the secondary. Then sparks may jump between the wires and streamers become visible in the dark if the light of the discharge through the spark gap *d d* be carefully excluded. If now we substitute a closed vacuum tube for the metallic secondary *s*, the differences of potential produced in the tube by electrostatic induction from the primary are fully suffi-



Fig. 32.

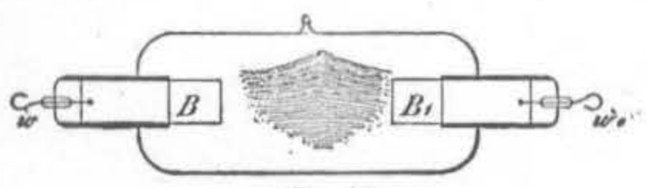


Fig. 33.

FIG. 32.—ELECTROSTATIC ACTION BETWEEN PRIMARY AND SECONDARY, WITH EXTREMELY HIGH FREQUENCIES.
FIG. 33.—CARBON DEPOSIT IN TUBE IN A MAGNETIC FIELD.

cient to excite portions of it; but as the points of certain differences of potential on the primary are not fixed, but are generally constantly changing in position, a luminous band is produced in the tube, apparently not touching the glass, as it should, if the points of maximum and minimum differences of potential were fixed on the primary. I do not exclude the possibility of such a tube being excited only by electro-dynamic induction, for very able physicists hold this view; but in my opinion, there is as yet no positive proof given that atoms of a gas in a closed tube may arrange themselves in chains under the action of an electromotive impulse produced by electro-dynamic induction in the tube. I have been unable so far to produce striæ in a tube, however long, and at whatever degree of exhaustion, that is, striæ at right angles to the supposed direction of the discharge or the axis of the tube, but I have distinctly observed in a large bulb, in which a wide luminous band was produced by passing a discharge of a battery through a wire surrounding the bulb, a circle of feeble luminosity between two luminous bands, one of which was more intense than the other. Furthermore, with my present experience I do not think that such a gas discharge in a closed tube can vibrate, that is, vibrate as a whole. I am convinced that no discharge through a gas can vibrate. The atoms of a gas behave very curiously in respect to sudden electric impulses. The gas does not seem to possess any appreciable inertia to such impulses, for it is a fact, that the higher the frequency of the impulses, with the greater freedom does the discharge pass through the gas. If the gas possesses no inertia then it cannot vibrate, for some inertia is necessary for the free vibration. I conclude from this that if a lightning discharge occurs between two clouds, there can be no oscillation, such as would be expected, considering the capacity of the clouds. But if the lightning discharge strike the earth, there is always vibration—in the earth, but not in the cloud. In a gas discharge each atom vibrates at its own rate, but there is no vibration of the conducting gaseous mass as a whole. This is an important consideration in the great problem of producing light economically, for it teaches us that to reach this result we must use impulses of very high frequency and necessarily also of high potential. It is a fact that oxygen produces a more intense light in a tube. Is it because oxygen atoms possess some inertia and the vibration does not die out instantly? But then nitrogen should be as good, and chlorine and vapors of many other bodies much better than oxygen, unless the magnetic properties of the latter enter prominently into play. Or, is the process in the tube of an electrolytic nature? Many observations certainly speak for it, the most important being, that matter is always carried away from the electrodes and the vacuum in a bulb cannot be permanently maintained. If such process takes place in reality, then again must we take refuge in high frequencies, for with such, electrolytic action should be reduced to a minimum, if not rendered entirely impossible. It is an undeniable fact that with very high frequencies, provided the impulses be of a harmonic nature, like those obtained from an alternator, there is less deterioration and the vacua are more permanent. With disruptive discharge coils there are sudden rises of potential and the vacua are more quickly impaired, for the electrodes are deteriorated in a very short time. It was observed in some large tubes, which were provided with heavy carbon blocks B B_1, connected to platinum wires w w_1 (as illustrated in Fig. 33), and which were employed in experiments with the disruptive discharge instead of the ordinary air gap, that the carbon particles under the action of the powerful magnetic field in which the tube was placed, were deposited in regular fine lines in the middle of the tube as illustrated. These lines were attributed to the deflection or distortion of the discharge by the magnetic field, but why the deposit occurred principally where the field was most intense did not appear quite clear. A fact of interest, likewise noted, was that the presence of a strong magnetic field increases the deterioration of the electrodes, probably by reason of the rapid interruptions it produces, whereby there is actually a higher E. M. F. maintained between the electrodes.

Much would remain to be said about the luminous effects produced in gases at low or ordinary pressures. With the present experiences before us we cannot say that the essential nature of these charming phenomena is sufficiently known. But investigations in this direction are being pushed with exceptional ardor. Every line of scientific pursuit has its fascinations, but electrical investigation appears to possess a peculiar attraction, for there is no experiment or observation of any kind in the domain of this wonderful science which would not forcibly appeal to us. Yet to me it seems, that of all the many marvelous things we observe, a vacuum tube, excited by an electric impulse from a distant source, bursting forth out of the darkness and illuminating the room with its beautiful light, is as lovely a phenomenon as can greet our eyes. More interesting still it appears when, reducing the fundamental discharges across the gap to a very small number and waving the tube about we produce all kinds of designs in luminous lines. So by way of amusement, I take a straight long tube, or a square one, or a square attached to a straight tube and by whirling them about in the hand, I imitate the spokes of a wheel, a Gramme winding, a drum winding, an alternate current motor winding, etc. (Fig. 34). Viewed from a distance the effect is weak and much of its beauty is lost, but being near or holding the tube in the hand one cannot resist its charm.

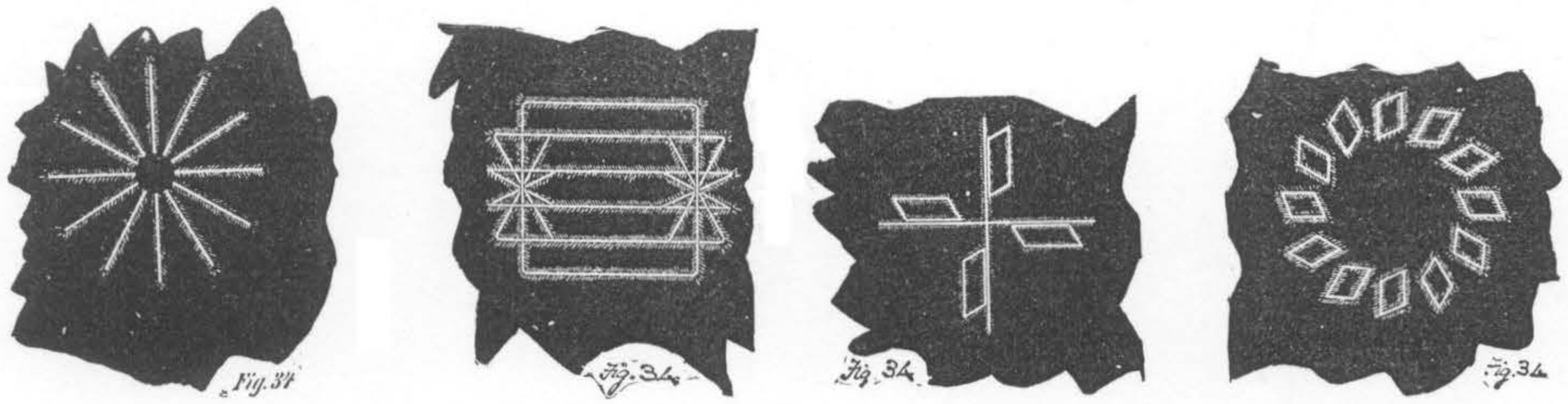


FIG. 34. { SPOKE WHEEL, DRUM WINDING, ALTERNATE MOTOR WINDING, RING WINDING, } SOME OF THE DESIGNS PRODUCED BY INTERMITTENT DISCHARGES.

In presenting these insignificant results I have not attempted to arrange and co-ordinate them as would be proper in a strictly scientific investigation in which every succeeding result should be a logical sequence of the preceding, so that it might be guessed in advance by the careful reader or attentive listener. I have preferred to concentrate my energies chiefly upon advancing novel facts or ideas which might serve as suggestions to others, and this may serve as an excuse for the lack of harmony. The explanations of the phenomena have been given in good faith and in the spirit of a student prepared to find that they admit of a better interpretation. There can be no great harm in a student taking an erroneous view, but when great minds err, the world must dearly pay for their mistakes.

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.

INTRODUCTORY—SOME THOUGHTS ON THE EYE.

BY NIKOLA TESLA.*

When we look at the world around us, on Nature, we are impressed with its beauty and grandeur. Each thing we perceive, though it may be vanishingly small, is in itself a world, that is, like the whole of the visible universe, matter and force governed by law—a world, the contemplation of which fills us with feelings of wonder and irresistibly urges us to ceaseless thought and inquiry. But in all this vast world, of all objects our senses reveal to us, the most marvelous, the most appealing to our imagination, appears no doubt a highly developed organism, a thinking being. If there is anything fitted to make us admire Nature's handiwork, it is certainly this inconceivable structure, which performs its innumerable motions in obedience to external influence. To understand its workings, to get a deeper insight into this Nature's masterpiece, has ever been for thinkers a fascinating aim, and after many centuries of arduous research men have arrived at a fair understanding of the functions of its organs and senses. Again, in all the perfect harmony of its parts, of the parts which constitute the material or tangible of our being, of all its organs and senses, the eye is the most wonderful. It is the most precious, the most indispensable of our receptive or directive organs; it is the great gateway through which all knowledge enters the mind. Of all our organs, it is the one which is in the most intimate relation with that which we call intellect. So intimate is this relation that it is often said that the very soul shows itself in the eye.

It can be taken as a fact, which the theory of the action of the eye implies, that for each external impression, that is, for each image produced upon the retina, the ends of the visual nerves, concerned in the conveyance of the impression to the mind, must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and therefore upon the retina. Will it ever be within human power to analyze the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science, in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he was able to *see*, in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

Another fact having a bearing on this subject which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation, is, that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, observable even in broad daylight.

The saying, then, that the soul shows itself in the eye is deeply founded, and we feel that it expresses a great truth. It has a profound meaning even for one who, like a poet or artist, only following his inborn instinct or love for Nature, finds delight in aimless thoughts and in the mere contemplation of natural phenomena, but a still more profound meaning for one who, in the spirit of positive scientific investigation, seeks to ascertain the causes of the effects. It is principally the natural philosopher, the physicist, for whom the eye is the subject of the most intense admiration.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting that the very conception of that which is perfect, or seems so to him, has been gained through this same instrument. Firstly, the eye is, as far as our positive knowledge goes, the only organ which is *directly* affected by that subtle medium which, as science teaches us, must fill all space; secondly, it is the most sensitive of our organs, incomparably more sensitive to external impressions than any other.

The organ of hearing implies the impact of ponderable bodies, the organ of smell the transference of detached material particles, and the organs of taste and of touch or force the direct contact, or at least some interference of ponderable matter; and this is true even in those instances of animal organisms in which some of these organs are developed to a degree of truly marvelous perfection. This being so, it seems wonderful that the organ of sight solely should be capable of being stirred by that which all our other organs are powerless to detect, which yet plays an essential part in all natural phenomena, which transmits all energy and sustains all motion and, that most intricate of all, life, but which has properties such that even a scientifically trained mind cannot help drawing a distinction between it and all that is called matter. Considering merely this, and the fact that the eye, by its marvelous power, widens our otherwise very narrow range of perception far beyond the limits of the small world which is our own, to embrace myriads of other worlds, suns and stars in the infinite depths of the universe, would make it justifiable to assert that it is an organ of a higher order. Its performances are beyond comprehension. Nature, as far as we know, never produced anything more wonderful. We can get barely a faint idea of its prodigious power by analyzing what it does and by comparing. When ether waves impinge upon the human body, they produce the sensations of warmth or cold, pleasure or pain, or perhaps other sensations of which we are not aware, and any degree or intensity of these sensations, which degrees are infinite in number, hence an infinite number of distinct sensations. But our sense of touch, or our sense of force, cannot reveal to us these differences in degree or intensity unless they are very great. Now we can readily conceive how an organism such as the human, in the eternal process of evolution, or more philosophically speaking adaptation to Nature, being constrained to the use of only the sense of touch or force, for instance, might develop this sense to such a degree of sensitiveness or perfection that it would be capable of distinguishing the minutest differences in the temperature of a body even at some distance, to a hundredth, or thousandth, or millionth part of a degree. Yet, even this apparently impossible performance would not begin to compare with that of the eye, which is capable of distinguishing and conveying to the mind in a single instant innumerable peculiarities of the body, be it in form or color or other respects. This power of the eye rests upon two things, namely, the rectilinear propagation of the disturbance by which it is affected, and upon its sensitiveness. To say that the eye is sensitive is not saying anything. Compared with it all other organs are monstrously crude. The organ of smell which guides a dog on the trail of a deer, the organ of touch or force which guides an insect in its wanderings, the organ of hearing, which is affected by the slightest disturbance of the air, are sensitive organs, to be sure, but what are they compared with the human eye! No doubt it responds to the faintest echoes or reverberations of the medium; no doubt it brings us tidings from other worlds infinitely remote, but in a language we cannot as yet always understand. And why not? Because we live in a medium filled with air and other gases, vapors and a dense mass of solid particles flying about. These play an important part in many phenomena; they fritter away the energy of the vibrations before they can reach the eye; they, too, are the carriers of germs of destruction, they get into our lungs and other organs, clog up the channels and imperceptibly yet inevitably arrest the stream of life. Could we but do away with all ponderable matter in the line of sight of the telescope it would reveal to us undreamt of marvels. Even the unaided eye, I think, would be capable of distinguishing in the pure medium small objects at distances measured probably by hundreds or perhaps thousands of miles.

But there is something else about the eye which impresses us still more than these wonderful features which we observe, viewing it from the standpoint of a physicist, merely as an optical instrument—something which appeals to us more than its marvelous faculty of being directly affected by the vibrations of the medium, without interference of gross matter, and more than its inconceivable sensitiveness and discerning power. It is its significance in the processes of life. No matter what one's views on Nature and life may be, he must stand amazed when, for the first time in his thoughts, he realizes the importance of the eye in the physical processes and mental performances of the human organism. And how could it be otherwise, when he realizes that the eye is the means through which the human race has acquired the entire knowledge it possesses, that it controls all our motions—more still, all our actions.

There is no way of acquiring knowledge except through the eye. What is the foundation of all philosophical systems of ancient and modern times, in fact of all the philosophy of man? *I am, I think; I think, therefore I am.* But how could I think and how would I know that I exist if I had not the eye? For knowledge involves consciousness; consciousness involves ideas, conceptions; conceptions involve pictures or images, and images the sense of vision, and therefore the organ of sight. But how about blind men will be asked? Yes, a blind man may depict in magnificent poems forms and scenes from real life, from a world he physically does not see. A blind man may touch the keys of an instrument with unerring precision, may build the fastest boat, may discover and invent, calculate and construct, may do still greater wonders—but all the blind men who have done such things have descended from those who had seeing eyes. Nature may reach the same result in many ways. Like a wave in the physical world, in the infinite ocean of the medium which pervades all, so in the world of organisms, in life, an impulse started proceeds onward, at times may be with the speed of light, at times again so slowly that for ages and ages it seems to stay, passing through processes of a complexity inconceivable to man, but in all its forms, in all its stages, its energy, ever and ever integrally present. A single ray of

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*A lecture delivered before the Franklin Institute at Philadelphia, Feb. 24, 1893, and before the National Electric Light Association at St. Louis, Mo., March 1, 1893.

A SIMPLE EXPERIMENT.

To obtain those luminous tube effects which created so much non-technical bewonderment last year, Mr. Nikola Tesla employed a whole armoury of appliances, including a special high-frequency alternator, oil transformers, and special magnetic interrupters. Mr. Nikola Tesla no sooner showd us how to do the thing in an elaborate manner than, as is invariably the case, everyone was showing everyone else how to obtain similiar effects by the most simple contrivances. The limit in this direction appears, however, to have been reached by M. P. Marsillac, who, in *La Lumière Electrique* for April 22nd, described the following rudimentary arrangement.

M. Marsillac employs three Lalande and Chaperon cells of the French telegraph pattern; a Ruhmkorff coil ten centimetres long by 3in. diameter, with an extra sensitive trembler break, and a thin-glass Geissler tube 10 or 15 centimetres long. With this toyshop apparatus, M. Marsillac is able to reproduce one of the most striking of Mr. Tesla's experiments. Shades we had all known increased the effective illumination obtainable from a given source of light, but when on that historic Thursday evening, at the Royal institution last year, Mr. Tesla applied a shade to one of his single-wire glow lamps, the candle-power of the lamp went up as well the candle-feet on the table below, we seemed to be getting dangerously close to perpetual motion in the shape of an indefinitely large amount of light derived from an indefi-

nitely small source of power. It is this pretty electrostatic experiment that M. Marsillac reproduces with the simple appliances above mentioned. He connects one terminal of the tube

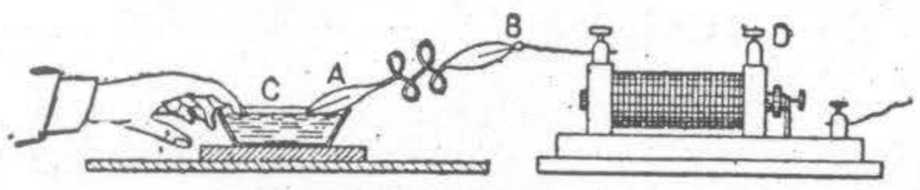


FIG. 1.

to one terminal of the coil, as shown (Fig. 1), having previously filed down the other tube wire, and dips the free end of the tube into a little china dish, C, resting on a sheet of ebonite, and containing either pure water, salt water, sulphate of copper, &c., &c. On dipping the finger into the liquid the tube commences to glow. Once started in this way the glow persists even if the finger is withdrawn from the liquid. On lifting the tube out of the liquid (Fig. 2) and bringing the hand up close to it the glow also continues.

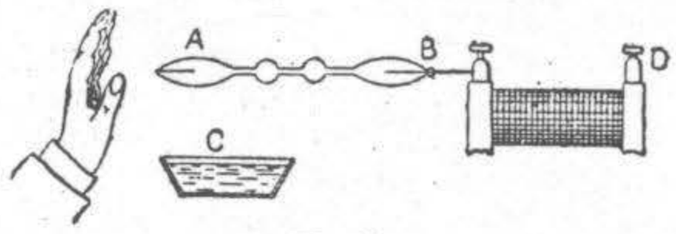


FIG. 2.

On Light and Other High Frequency Phenomena.*

BY NIKOLA TESLA.

INTRODUCTORY.—SOME THOUGHTS ON THE EYE.

When we look at the world around us, on Nature, we are impressed with its beauty and grandeur. Each thing we perceive, though it may be vanishingly small, is in itself a world, that is, like the world of the visible universe, matter and force governed by law—a world,



NIKOLA TESLA.

the contemplation of which fills us with feelings of wonder and irresistibly urges us to ceaseless thought and inquiry. But in all this vast world, of all objects our senses reveal to us, the most marvelous, the most appealing to our imagination, appears no doubt a highly developed organism, a thinking being. If there is anything fitted to make us admire Nature's handiwork, it is certainly this inconceivable structure, which performs its innumerable motions in obedience to external influence. To understand its workings, to get a deeper insight into this Nature's masterpiece, has ever been for thinkers a fascinating aim, and after many centuries of arduous research men have arrived at a fair understanding of the functions of its organs and senses. Again, in all the perfect harmony of its parts, of the parts which constitute the material or tangible of our being, of all its organs and senses, the eye is the most wonderful. It is the most precious, the most indispensable of our receptive or directive organs, it is the great gateway through which all knowledge enters the mind. Of all our organs it is the one which is in the most intimate relation with that which we call intellect. So intimate is this relation, that it is often said that the very soul shows itself in the eye.

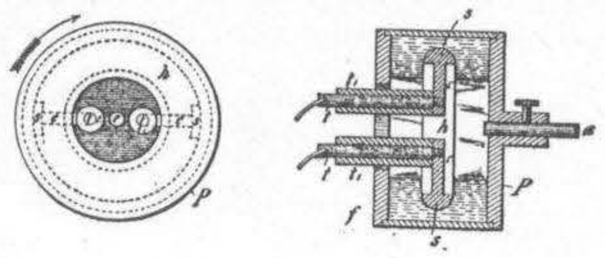
It can be taken as a fact which the theory of the action of the eye implies, that for each external impression, that is, for each image produced upon the retina, the ends of the visual nerves, concerned in the conveyance of the impression to the mind, must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and therefore upon the retina. Will it ever be within human power to analyze the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he was able to see, in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

Another fact having a bearing on this subject which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation, is that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, observable even in broad daylight.

The saying then that the soul shows itself in the eye is deeply founded, and we feel that it expresses a great truth. It has a profound meaning even for one who, like a poet or artist, only following his inborn instinct or love for Nature, finds delight in aimless thoughts and in the mere contemplation of natural phenomena, but a still more profound meaning for one who, in the spirit of positive scientific investigation, seeks to ascertain the causes of the effects. It is principally the natural philosopher, the physicist, for whom the eye is the subject of the most intense admiration.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting that the very conception of that which is perfect, or seems so to him, has been gained through this same instrument. First, the eye is, as far as our positive knowledge goes, the only organ which is directly affected by that subtile medium, which, as science teaches us, must fill all space; secondly, it is the most sensitive of our organs, incomparably more sensitive to external impressions than any other.

The organ of hearing implies the impact of ponderable bodies, the organ of smell the transference of detached material particles, and the organs of taste and of touch or force, the direct contact, or at least some interference of ponderable matter, and this is true even in those instances of animal organisms, in which some of these organs are developed to a degree of truly marvelous perfection. This being so, it seems wonderful that the organ of sight solely should be capable of being stirred by that which all our other organs are powerless to detect, which yet plays an essential part in all natural phenomena, which transmits all energy and sustains all motion, and, that most intricate of all, life, but which has properties such that even a scientifically trained mind cannot help drawing a distinction between it and all that is called matter. Considering merely this, and the fact that the eye, by its marvelous power, widens our otherwise very narrow range of perception far beyond the limits of the small world which is our own, to embrace myriads of other worlds, suns and stars in the infinite depths of the universe, would make it justifiable to assert that it is an organ of a higher order. Its performances are beyond comprehension. Nature, as far as we know, never produced anything more wonderful. We can get barely a faint idea of its prodigious power by analyzing what it does and by comparing. When ether waves impinge upon the human body, they produce the sensations of warmth or cold, pleasure or pain, or perhaps other sensations of which we are not aware, and any degree or intensity of these sensations, which degrees are infinite in number, hence an infinite number of distinct sensations. But our sense of touch, or our sense of force, cannot reveal to us these differences in degree or intensity, unless they are very great. Now we can readily conceive how an organism, such as the human in the eternal process of evolution, or, more philosophically speaking, adaptation to Nature, being constrained to the use of only the sense of touch or force, for instance, might develop this sense to such a degree of sensitiveness or perfection that it would be capable of distinguishing the minutest differences in the temperature of a body even at some distance, to a hundredth, or thousandth, or millionth part of a degree Yet, even this apparently impossible performance would not begin to compare with that of the eye, which is capable of distinguishing and conveying to the mind in a single instant innumerable peculiarities of the body, be it in form or color or other respects. This power of the eye rests upon two things, namely, the rectilinear propagation of the disturbance by which it is affected, and upon its sensitiveness. To say that the eye is sensitive is not saying anything. Compared with it, all other organs are monstrously crude. The organ of smell which guides a dog on the trail of a deer, the organ of touch or force which guides an insect in its wanderings, the organ of hearing, which is effected by the slightest disturbances of the air, are sensitive organs, to be sure, but what are they compared with the human eye! No doubt it responds to the faintest echoes or reverberations of the medium; no doubt, it brings us tidings from other worlds, infinitely remote, but in a language we cannot as yet always understand. And why not? Because we live in a medium filled with air and other gases, vapors and a dense mass of solid particles flying about. These play an important part in many phenomena; they fritter away the energy of the vibrations before they can reach the eye; they too, are the carriers of germs of destruction, they get into our lungs and other organs, clog up the channels and imperceptibly, yet inevitably, arrest the stream of life. Could we but do away with all ponderable matter in the line of sight of the telescope, it would reveal to us undreamt of marvels. Even the unaided eye, I think, would be capable of distinguishing in the pure medium small objects at distances measured probably by hundreds or perhaps thousands of miles.



FIGS. 4a AND 4b.—FORM OF DISCHARGER WITH LIQUID INTERRUPTER.

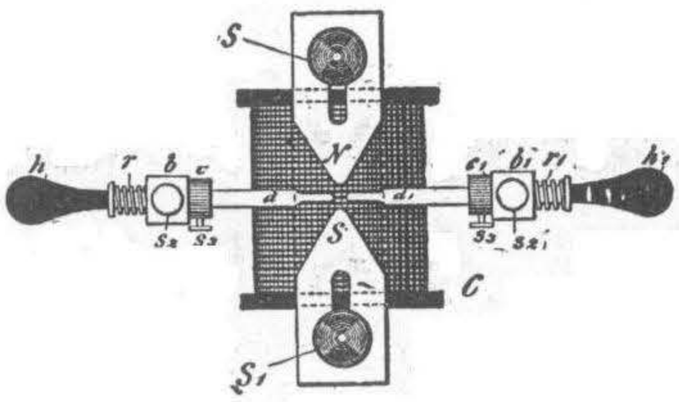


FIG. 2.—FORM OF DISCHARGER WITH MAGNET USED IN THE DIRECT CURRENT CONVERSION.

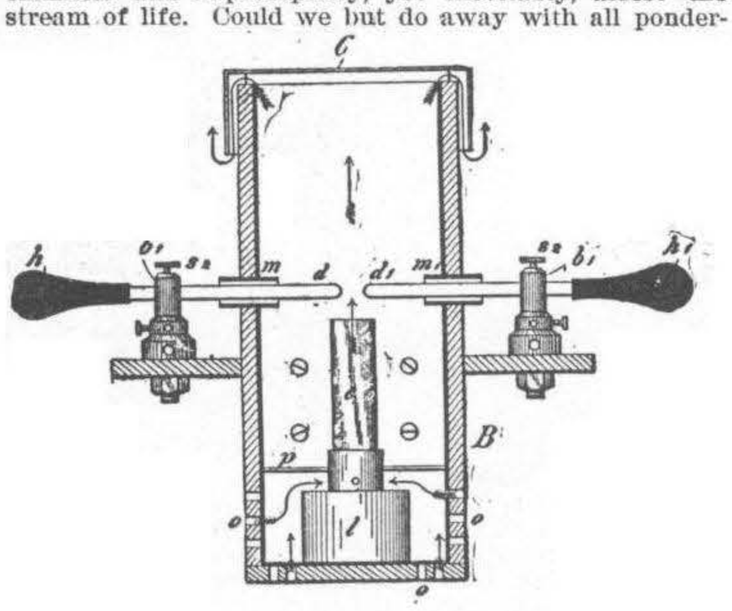


FIG. 3.—DISCHARGES WITH HOT AIR DRAFT.

But there is something else about the eye which impresses us still more than these wonderful features which we observe, viewing it from the standpoint of a physicist, merely as an optical instrument—something which appeals to us more than its marvelous faculty of being directly affected by the vibrations of the medium, without interference of gross matter, and more than its inconceivable sensitiveness and discerning power It is its significance in the processes of life. No matter what one's views on Nature and life may be, he must stand amazed when, for the first time in his thoughts, he realizes the importance of the eye in the physical processes and mental performances of the human organism. And how could it be otherwise, when he realizes that the eye is the means through which the human race has acquired the entire knowledge it possesses, that it controls all our motions, more still, all our actions.

There is no way of acquiring knowledge except through the eye. What is the foundation of all philosophical systems of ancient and modern times, in fact of all the philosophy of man? I am, I think; I think, therefore I am. But how could I think and how would I know that I exist, if I had not the eye? For knowledge involves consciousness; consciousness involves ideas, conceptions; conceptions involve pictures or images, and images the sense of vision, and therefore the organ of sight. But how about blind men, will be asked? Yes, a blind man may depict in magnificent poems forms and scenes from real life, from a world he physically does not see. A blind man may touch the keys of an instrument with unerring precision, may build the fastest boat, may discover and invent, calculate and construct, may do still greater wonders—but all the blind men who have done such things have descended from those who had seeing eyes. Nature may reach the same result in many ways. Like a wave in the physical world, in the infinite ocean of the medium which pervades all, so in the world of organisms, in life, an impulse started proceeds onward, at times, maybe with the speed of light, at times, again, so slowly that for ages and ages it seems to stay, passing through processes of a complexity inconceivable to men, but in all its forms, in all its stages, its energy ever and ever integrally present. A single ray of light from a distant star falling upon the eye of a tyrant in bygone times may have altered the course of his life, may have changed the destiny of nations, may have transformed the surface of the globe, so intricate, so inconceivably complex are the processes in

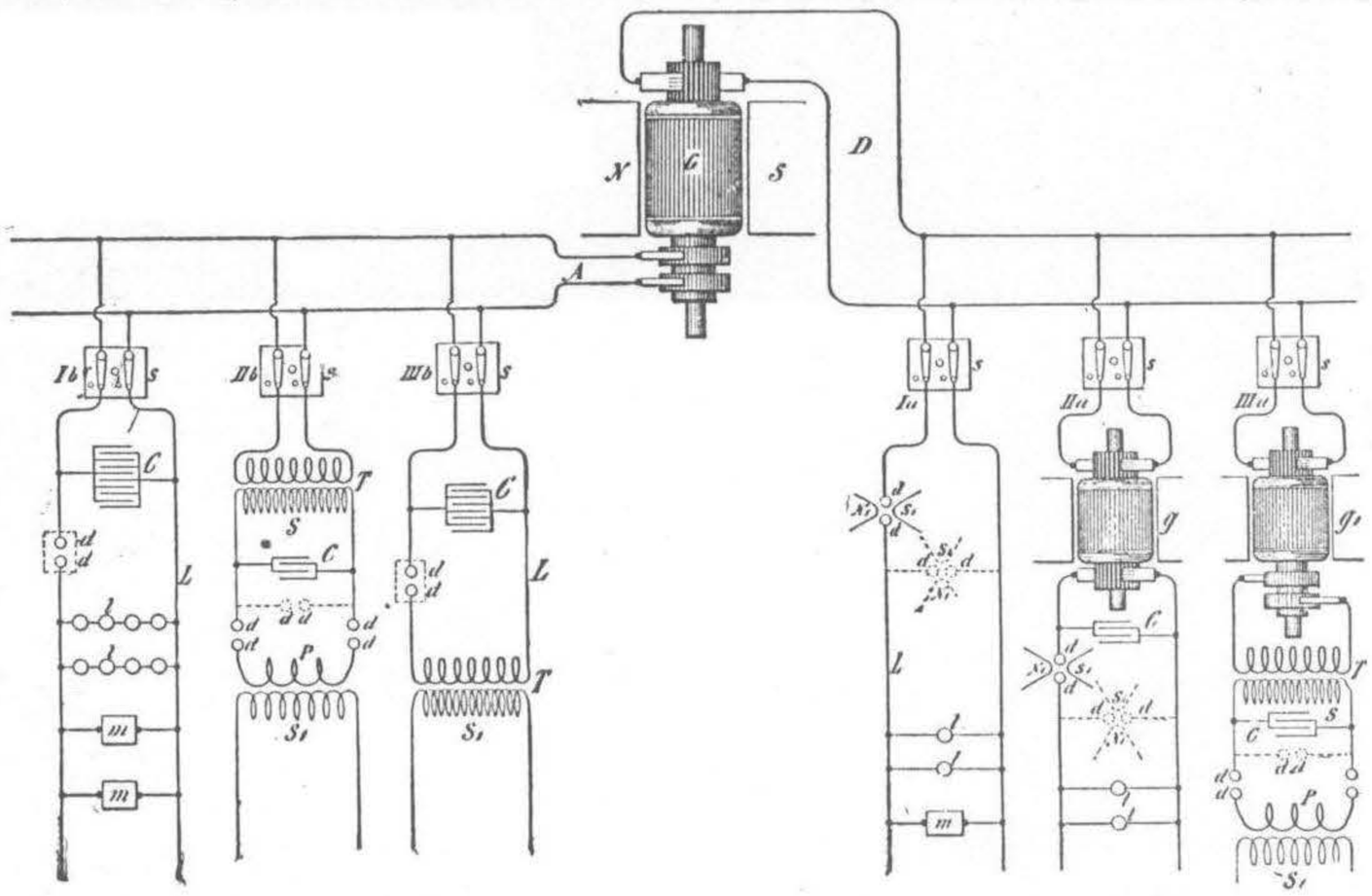


FIG. 1.—PLAN OF CONNECTIONS USED IN THE CONVERSION BY MEANS OF THE DISRUPTIVE ARC DISCHARGE.

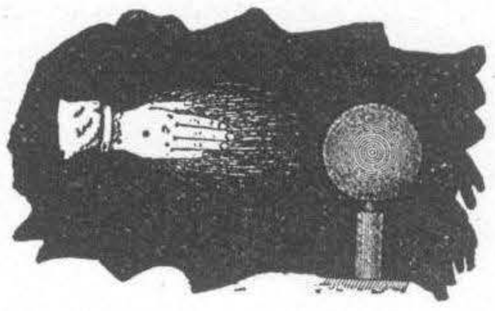
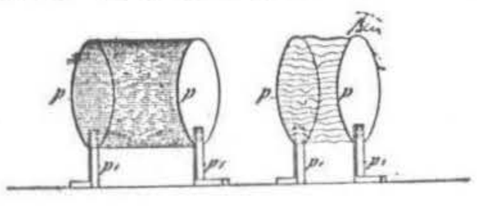


FIG. 5.—ILLUSTRATING THE EFFECT OF VARYING ELECTROSTATIC FORCE WITH A TRANSFORMER OF 200,000 VOLTS PRESSURE.

* A lecture delivered before the Franklin Institute, at Philadelphia, Feb. 24, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893.

Nature. In no way can we get such an overwhelming idea of the grandeur of Nature than when we consider that in accordance with the law of the conservation of energy, throughout the infinite, the forces are in a perfect balance, and hence the energy of a single thought may determine the motion of a universe. It is not necessary that every individual, not even that every generation or many generations, should have the physical instrument of sight, in order to be able to form images and to think, that is, form ideas or conceptions; but sometime or other, during the process of evolution, the eye certainly must have existed, else thought, as we understand it, would be impossible; else conceptions,



Figs. 6a and 6b.—Illustrating the Effects of Rapidly Varying and Steady Electrostatic Force.

like spirit, intellect, mind, call it as you may, could not exist. It is conceivable that in some other world, in some other beings, the eye is replaced by a different organ, equally or more perfect, but these beings cannot be men.

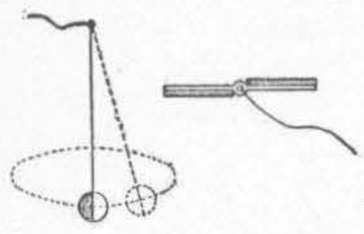
Now what prompts us to all voluntary motions and actions of any kind? Again the eye. If I am conscious of the motion, I must have an idea of conception, that is, an image, therefore the eye. If I am not precisely conscious of the motion, it is because the images are vague or indistinct, being blurred by the superimposition of many. But when I perform the motion, does the impulse which prompts me to the action come from within or from without? The greatest physicists have not disdained to endeavor to answer this and similar questions, and have at times abandoned themselves to the delights of pure and unrestrained thought. Such questions are generally considered not to belong to the realm of positive physical science, but will before long be annexed to its domain. Helmholtz has probably thought more on life than any modern scientist. Lord Kelvin expressed his belief that life's process is electrical, and that there is a force inherent to the organism and determining its motions. Just as much as I am convinced of any physical truth I am convinced that the motive impulse must come from the outside. For, consider the lowest organism we know—and there are probably many lower ones—an aggregation of a few cells only. If it is capable of voluntary motion, it can perform an infinite number of motions, all definite and precise. But now a mechanism consisting of a finite number of parts, and a few at that, cannot perform an infinite number of definite motions, hence the impulses which govern its movements must come from the environment. So the atom, the ulterior element of the universe's structure, is tossed about in space eternally, a play to external influences, like a float in a troubled sea. Were it to stop its motion it would die. Matter at rest, if such a thing could exist, would be matter dead. Death of matter! Never has a sentence of deeper philosophical meaning been uttered. This is the way in which Prof. Dewar forcibly expresses it in the description of his admirable experiments, in which liquid oxygen is handled as one handles water, and air at ordinary pressure is made to condense and even to solidify by the intense cold. Experiments, which serve to illustrate, in his language, the last feeble manifestations of life, the last quiverings of matter about to die. But human eyes shall not witness such death. There is no death of matter, for throughout the infinite universe all has to move, to vibrate; that is, to live.

I have made the preceding statements at the peril of treading upon metaphysical ground in my desire to introduce the subject of this lecture in a manner not altogether uninteresting, I may hope, to an audience such as I have the honor to address. But, now then, returning to the subject, this divine organ of sight, this indispensable instrument for thought and all intellectual enjoyment, which lays open to us the marvels of this universe, through which we have acquired what knowledge we possess, and which prompts us to, and controls, all our physical and mental activity. By what is it affected? By light! What is light?

We have witnessed the great strides which have been made in all departments of science in recent years. So great have been the advances that we cannot refrain from asking ourselves, Is this all true, or is it but a dream? Centuries ago men have lived, have thought, discovered, invented, and have believed that they were soaring, while they were merely proceeding at a snail's pace. So we, too, may be mistaken. But taking the truth of the observed events as one of the implied facts of science, we must rejoice in the immense progress already made, and still more in the anticipation of what



Fig. 7.—Breaking a Bulb on Open Circuit.



Figs. 8a and 8b.—Mechanical Motions Produced by Varying Electrostatic Force in a Gaseous Medium.

must come, judging from the possibilities opened up by modern research. There is, however, an advance which we have been witnessing, which must be particularly gratifying to every lover of progress. It is not a discovery, or an invention, or an achievement in any particular direction. It is an advance in all directions of scientific thought and experiment. I mean the generalization of the natural forces and phenomena, the looming up of a certain broad idea on the scientific horizon. It is this idea which has, however, long ago taken possession of the most advanced minds, to which I desire to call your attention, and which I intend to illustrate, in a general way, in these experiments, as the first step in answering the question. "What is light?" and to realize the modern meaning of this word.

It is beyond the scope of my lecture to dwell upon the subject of light in general, my object being merely to bring presently to your notice a certain class of light effects and a number of phenomena observed in pursuing the study of these effects. But to be consistent in my remarks it is necessary to state that according to that idea, now accepted by the majority of scientific men as a positive result of theoretical and experimental investigation, the various forms or manifestations of energy which were generally designated as "electric," or more precisely "electromagnetic," are energy manifestations of the same nature as those of radiant heat and light. Therefore, the phenomena of light and heat, and others besides these, may be called electrical phenomena. Thus electrical science has become the mother science of all, and its study has become all important. The day when we shall know what "electricity" is will chronicle an event probably greater, more important than any other recorded in the history of the human race. The time will come when the comfort, the very existence perhaps of man will depend upon that wonderful agent. For our existence and comfort we require heat, light and mechanical power. How do we now get all these? We get them from fuel, we get them by consuming material. What will man do when the forests disappear? when the coalfields are exhausted? Only one thing, according to our present knowledge will remain; that is, to transmit power at great distances. Men will go to the waterfalls, to the tides, which are the stores of an infinitesimal part of Nature's immeasurable energy. There will they harness the energy and transmit the same to their settlements, to warm their homes by, to give them light, and to keep their obedient slaves, the machines, toiling. But how will they transmit this energy if not by electricity? Judge then, if the comfort, nay, the very existence, of man will not depend on electricity. I am aware that this view is not that of a practical engineer, but neither is it that of an illusionist, for it is certain that power transmission, which at present is merely a stimulus to enterprise, will some day be a dire necessity.

It is more important for the student who takes up the study of light phenomena to make himself thoroughly acquainted with certain modern views, than to peruse entire books on the subject of light itself, as disconnected from these views. Were I, therefore, to make these demonstrations before students seeking information—and for the sake of the few of those who may be present, give me leave to so assume—it would be my principal endeavor to impress these views upon their minds in this series of experiments.

It might be sufficient for this purpose to perform a simple and well known experiment. I might take a familiar appliance, a Leyden jar, charge it from a frictional machine, and then discharge it. In explaining to you its permanent state when charged, and its transitory condition when discharging, calling your attention to the forces which enter into play and to the various phenomena they produce, and pointing out the relation of the forces and phenomena, I might fully succeed in illustrating that modern idea. No doubt, to the thinker, this simple experiment would appeal as much as the most magnificent display. But this is to be an experimental demonstration, and one which should possess, besides instructive, also entertaining features, and, as such, a simple experiment, such as the one cited, would not go very far toward the attainment of the lecturer's aim. I must, therefore, choose another way of illustrating, more spectacular, certainly, but perhaps also more instructive. Instead of the frictional machine and Leyden jar I shall avail myself in these experiments of an induction coil of peculiar properties, which was described in detail by me in a lecture before the London Institution of Electrical Engineers, in February, 1892. This induction coil is capable of yielding currents of enormous potential differences, alternating with extreme rapidity. With this apparatus I shall endeavor to show you three distinct classes of effects, or phenomena, and it is my desire that each experiment, while serving for the purposes of illustration, should, at the same time, teach us some novel truth, or show us some novel aspect of this fascinating science. But before doing this it seems proper and useful to dwell upon the apparatus employed, and method of obtaining the high potentials and high frequency currents which are made use of in these experiments.

On the Apparatus and Method of Conversion.

These high frequency currents are obtained in a peculiar manner. The method employed was advanced by me about two years ago in an experimental lecture before the American Institute of Electrical Engineers. A number of ways, as practiced in the laboratory, of obtaining these currents, either from continuous or low frequency alternating currents, is diagrammatically indicated in Fig. 1, which will be later described in detail. The general plan is to charge condensers, from a direct or alternate current source, preferably of high tension, and to discharge them disruptively while observing well known conditions necessary to maintain the oscillations of the current. In view of the general interest taken in high frequency currents and effects producible by them, it seems to me advisable to dwell at some length upon this method of conversion. In order to give you a clear idea of the action, I will suppose that a continuous current generator is employed, which is often very convenient. It is desirable that the generator should possess such high tension as to be able to break through a small air space. If this is not the case, then auxiliary means have to be resorted to, some of which will be indicated subsequently. When the condensers are charged to a certain potential, the air, or insulating space, gives way and a disruptive discharge occurs. There is then a sudden rush of current, and generally a large portion of the accumulated electrical energy spends itself. The condensers are thereupon quickly charged, and the same process is repeated in more or less rapid succession. To produce such sudden rushes of current it is necessary to observe certain conditions. If the rate at which the condensers are discharged is the same as that at which they are charged, then, clearly, in the assumed case the condensers do not come into play. If the rate of discharge be smaller than the rate of charging, then, again, the condensers cannot play an important part. But if, on the contrary, the rate of discharging is greater than that of charging, then a succession of rushes of current is obtained. It is evident that, if the rate at which the energy is being dissipated by the discharge is very much greater than the rate of supply to the condensers, the sudden rushes will be comparatively few, with long time intervals between. This always occurs when a condenser of considerable capacity is charged by means of a comparatively small machine. If the rates of supply and dissipation are not widely different, then the rushes of current will be in quicker succession, and this the more, the more nearly equal both the rates are, until natural limitations incident to each case and depending upon a number of causes are reached. Thus we are able to obtain from a continuous-current generator as rapid a succession of discharges as we like. Of course, the higher the tension of the generator, the smaller need be the capacity of the condensers, and for this reason, principally, it is of advantage to employ a generator of very

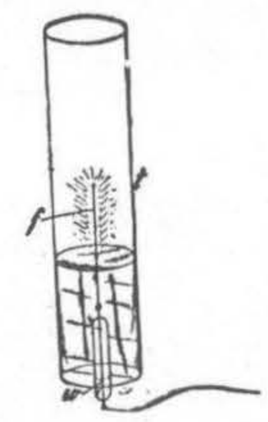


Fig. 9.—Showing the Effect of the Air.

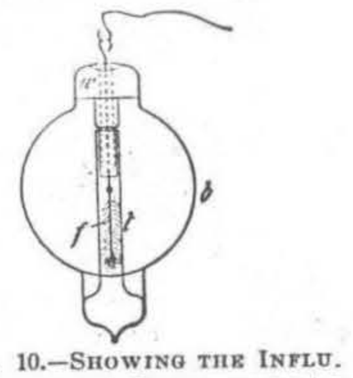


Fig. 10.—Showing the Influence of the Conductivity of the Medium Upon Electrostatic Actions Through Measurable Distance.

high tension. Besides, such a generator permits the attaining of greater rates of vibration.

The rushes of current may be of the same direction under the conditions before assumed, but most generally there is an oscillation superimposed upon the fundamental vibration of the current. When the conditions are so determined that there are no oscillations, the current impulses are unidirectional and thus a means is provided of transforming a continuous current of high tension into a direct current of lower tension, which I think may find employment in the arts.

This method of conversion is exceedingly interesting and I was much impressed by its beauty when I first conceived it. It is ideal in certain respects. It involves the employment of no mechanical devices of any kind, and it allows of obtaining currents of any desired frequency from an ordinary circuit, direct or alternating. The frequency of the fundamental discharges depending on the relative rates of supply and dissipation can be readily varied within wide limits by simple adjustments of these quantities, and the frequency of the superimposed vibration by the determination of the capacity, self-induction and resistance of the circuit. The potential of the currents, again, may be raised as high as any insulation is capable of withstanding safely by combining capacity and self-induction or by induction in a secondary, which need have but comparative few turns.

As the conditions are often such that the intermittance or oscillation does not readily establish itself, especially when a direct current source is employed, it is of advantage to associate an interrupter with the arc, and I have, some time ago, indicated the use of an air-blast or magnet, or other such device readily at hand. The magnet is employed with special advantage in the conversion of direct currents, as it is then very effective. If the primary source is an alternate current generator, it is desirable, as I have stated on another occasion, that the frequency should be low, and that the currents forming the arc be large, in order to render the magnet more effective.

A form of such discharger with a magnet which has been found convenient, and adopted after some trials, in the conversion of direct currents particularly, is illustrated in Fig. 2. N S are the pole pieces of a very strong magnet which is excited by a coil C. The pole pieces are slotted for adjustment and can be fastened in any position by screws s_1 s_1. The discharge rods d d_1 thinned down on the ends in order to allow a closer approach of the magnetic pole pieces, pass through the columns of brass b b_1 and are fastened in position by screws s_2 s_2. Springs r r_1 and collars c c_1 are slipped on the rods, the latter serving to set the points of the rods at a certain suitable distance by means of screws s_3 s_3, and the former to draw the points apart. When it is desired to start the arc, one of the hard rubber handles h h_1 is tapped quickly with the hand, whereby the points of the rods are brought in contact, but are instantly separated by the springs r r_1. Such an arrangement has been found to be often necessary, namely in cases when the E. M. F. was not large enough to cause the discharge to break through the gap, and also when it was desirable to avoid short circuiting of the generator by the metallic contact of the rods. The rapidity of the interruptions of the current with a magnet depends on the intensity of the magnetic field and on the potential difference at the ends of the arc. The interruptions are generally in such quick succession as to produce a musical sound. Years ago it was observed that when a powerful induction coil is discharged between the poles of a strong magnet the

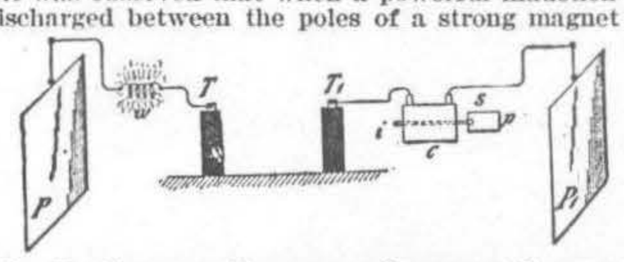


Fig. 11.—Showing Effects of Currents Flowing Through Open Circuits.

discharge produced a loud noise not unlike a small pistol shot. It was vaguely stated that the spark was intensified by the presence of the magnetic field. It is now clear that the discharge current, flowing for some time, was interrupted a great number of times by the magnet, thus producing the sound. The phenomenon is especially marked when the field circuit of a large magnet or dynamo is broken in a powerful magnetic field.

When the current through the gap is comparatively large, it is of advantage to slip on the points of the discharge rods pieces of very hard carbon and let the arc play between the carbon pieces. This preserves the rods and besides has the advantage of keeping the air space

hotter, as the heat is not conducted away as quickly through the carbons, and the result is that a smaller E. M. F. in the arc gap is required to maintain a succession of discharges.

Another form of discharger which may be employed with advantage in some cases is illustrated in Fig. 3. In this form the discharge rods d d_1 pass through perforations in a wooden box B, which is thickly coated with mica on the inside, as indicated by the heavy lines. The perforations are provided with mica tubes m m_1 of some thickness, which are preferably not in contact with the rods d d_1. The box has a cover C which is a little larger and descends on the outside of the box. The spark gap is warmed by a small lamp l contained in the box. A plate p above the lamp allows the draught to pass only through the chimney c of the lamp, the air entering through holes o o in or near the bottom of the box and following the path indicated by the arrows. When the discharger is in operation the door of the box is closed so that the light of the arc is not visible outside. It is desirable to exclude the light as perfectly as

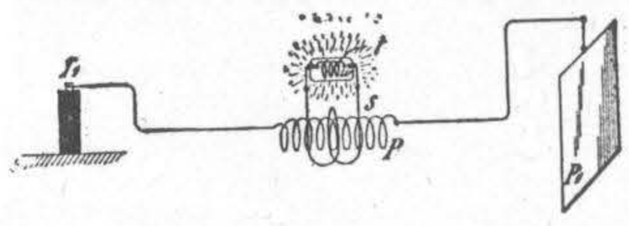


FIG. 12.—CONVERSION ON OPEN CIRCUIT WITH COIL AND INSULATED PLATE.

possible, as it interferes with some experiments. This form of discharger is simple and very effective when properly manipulated. The air being warmed to a certain temperature has its insulating power impaired, it becomes dielectrically weak, as it were, and the consequence is that the arc can be established at much greater distance. The air should, of course, be sufficiently insulating to allow the discharge to pass through the gap disruptively. The arc formed under such conditions, when long, may be made extremely sensitive, and the weak draught through the lamp chimney c is quite sufficient to produce rapid interruptions. The adjustment is made by regulating the temperature and velocity of the draught. Instead of using a lamp it answers the purpose to provide for a draught of warm air in other ways. A very simple way which has been practiced is to inclose the arc in a long vertical tube with plates on the top and bottom for regulating the temperature and velocity of the air current. Some provision had to be made for deadening the sound.

The air may be rendered dielectrically weak also by rarefaction. Dischargers of this kind have likewise been used by me in connection with the magnet. A large tube is for this purpose provided with heavy electrodes of carbon or metal, between which the discharge is made to pass, the tube being placed in a powerful magnetic field. The exhaustion of the tube is carried to a point at which the discharge breaks through easily, but the pressure should be more than 75 millimetres, at which the ordinary thread discharge occurs. In another form of discharger, combining the features before mentioned, the discharge was made to pass between two adjustable magnetic pole pieces, the space between them being kept at an elevated temperature.

It should be remarked here that when such, or interrupting devices of any kind, are used and the currents are passed through the primary of a disruptive discharge coil, it is not, as a rule, of advantage to produce a number of interruptions of the current per second greater than the natural frequency of vibration of the dynamo supply circuit, which is ordinarily small. It should also be pointed out here, that while the devices mentioned in connection with the disruptive discharge are advantageous under certain conditions, they may be sometimes a source of trouble, as they produce intermittences and other irregularities in the vibration which it would be very desirable to overcome.

There is, I regret to say, in this beautiful method of conversion a defect, which fortunately is not vital, and which I have been gradually overcoming. I will best call attention to this defect and indicate a fruitful line of work by comparing the electrical process with its mechanical analogue. The process may be illustrated in this manner. Imagine a tank with a wide opening at the bottom, which is kept closed by spring pressure, but so that it snaps off suddenly when the liquid in the tank has reached a certain height. Let the fluid be supplied to the tank by means of a pipe feeding at a certain rate. When the critical height of the liquid is reached, the spring gives way and the bottom of the tank drops out. Instantly the liquid falls through the wide opening, and the spring, reasserting itself, closes the bottom again. The tank is now filled, and after a certain time interval

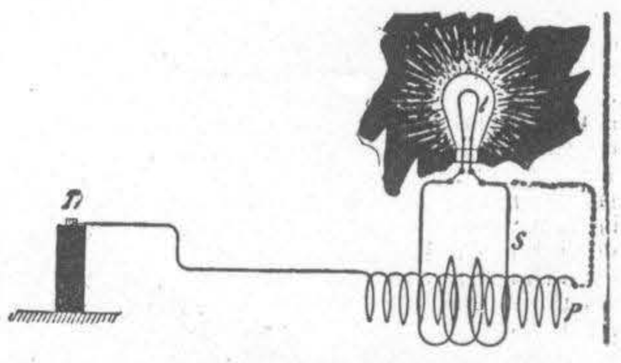


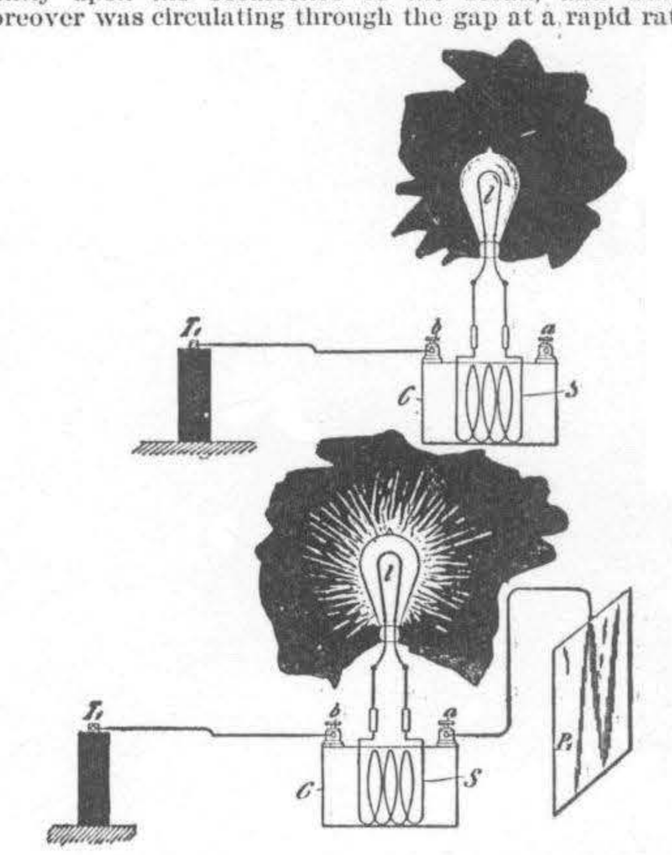
FIG. 13.—CONVERSION ON OPEN CIRCUIT WITH COIL ALONE.

the same process is repeated. It is clear, that if the pipe feeds the fluid quicker than the bottom outlet is capable of letting it pass through, the bottom will remain off and the tank will still overflow. If the rates of supply are exactly equal, then the bottom lid will remain partially open and no vibration of the same and of the liquid column will generally occur, though it might, if started by some means. But if the inlet pipe does not feed the fluid fast enough for the outlet, then there will be always vibration. Again, in such cases, each time the bottom flaps up or down the spring and the liquid column, if the pliability of the spring and the inertia of the moving parts are properly chosen, will perform independent vibrations. In this analogue the fluid may be likened to electricity or electrical energy, the tank to the condenser, the spring to the dielectric and the pipe to the conductor through which electricity is supplied to the condenser. To make this analogy quite complete it is necessary to make the assumption that the bottom, each time it gives way, is knocked violently against a non-elastic stop, this impact involving some loss of energy, and that, besides, some dissipation of energy results, due to frictional losses. In the preceding analogue the liquid is supposed to be under a steady pressure. If the pressure of the fluid be assumed to vary rhythmically, this may be taken as corresponding to the case of an alternating current. The process is then not quite as simple to consider, but the action is the same in principle.

It is desirable, in order to maintain the vibration economically, to reduce the impact and frictional losses as much as possible. As regards the latter, which in the electrical analogue correspond to the losses due to the resistance of the circuits, it is impossible to obviate them entirely, but they can be reduced to a minimum by a proper selection of the dimensions of the circuits and by the employment of thin conductors in the form of strands. But the loss of energy caused by the first breaking through of the dielectric—which in the above example corresponds to the violent knock of the bottom against the inelastic stop—would be more important to overcome. At the moment of the breaking through, the air space has a very high resistance, which is probably reduced to a very small value when the current has reached some strength, and the space is brought to a high temperature. It would materially diminish the loss of energy if the space were always kept at an extremely high temperature, but then there would be no disruptive break. By warming the space moderately by means of a lamp or otherwise the economy as far as the arc is concerned is sensibly increased. But the magnet or other interrupting device does not diminish the loss in the arc. Likewise, a jet of air only facilitates the carrying off of the energy. Air, or a gas in general, behaves curiously in this respect. When two bodies, charged to a very high potential, discharge disruptively through an air space, any amount of energy may be carried off by the air. This energy is evidently dissipated by bodily carriers, in impact and collisional losses of the molecules. The exchange of the molecules in the space occurs with inconceivable rapidity. A powerful discharge taking place between two electrodes, they may remain entirely cool, and yet the loss in the air may represent any amount of energy. It is perfectly practicable, with very great potential differences in the gap, to dissipate several horse power in the arc of the discharge without even noticing a small increase in the temperature of the electrodes. All the frictional losses occur then practically in the air. If the exchange of the air molecules is prevented, as by inclosing the air hermetically, the gas inside of the vessel is brought quickly to a high temperature, even with a very small discharge. It is difficult to estimate how much of the energy is lost in sound waves, audible or not, in a powerful discharge. When the currents through the gap are large, the electrodes may become rapidly heated, but this is not a reliable measure of the energy wasted in the arc, as the loss through the gap itself may be comparatively small. The air or a gas in general is, at ordinary pressures at least, clearly not the best medium through which a disruptive discharge should occur. Air or other gas under great pressure is of course a much more suitable medium for the discharge gap. I have carried on long-continued experiments in this direction, unfortunately less practicable on acount of the difficulties and expense in getting air under great pressure. But even if the medium in the discharge space is solid or liquid, still the same losses take place, though they are generally smaller, for just as soon as the arc is established the solid or liquid is volatilized. Indeed, there is no body known which would not be disintegrated by the arc, and it is an open question among scientific men whether an arc discharge could occur at all in the air itself without the particles of the electrodes being torn off. When the current through the gap is very small and the arc very long, I believe that a relatively considerable amount of heat is taken up in the disintegration of the electrodes, which partially on this account may remain quite cold.

The ideal medium for a discharge gap should only crack, and the ideal electrode should be of some material which cannot be disintegrated. With small currents through the gap it is best to employ aluminium, but not when the currents are large. The disruptive break in the air, or more or less in any ordinary medium, is not of the nature of a crack, but it is rather comparable to the piercing of innumerable bullets through a mass offering great frictional resistance to the motion of the bullets, this involving considerable loss of energy. A medium which would merely crack when strained electrostatically —and this possibly might be the case with a perfect vacuum, that is, pure ether—would involve a very small loss in the gap, so small as to be entirely negligible, at least theoretically, because a crack may be produced by an infinitely small displacement. In exhausting an oblong bulb provided with two aluminium terminals with the greatest care I have succeeded in producing such a vacuum that the secondary discharge of a disruptive discharge coil would break disruptively through the bulb in the form of fine spark streams. The curious point was that the discharge would completely ignore the terminals and start far behind the two aluminium plates which served as electrodes. This extraordinarily high vacuum could only be maintained for a very short while. To return to the ideal medium, think, for the sake of illustration, of a piece of glass or similar body clamped in a vise, and the latter lightened more and more. At a certain point a minute increase of the pressure will cause the glass to crack. The loss of energy involved in splitting the glass may be practically nothing, for though the force is great the displacement need be but extremely small. Now imagine that the glass would possess the property of closing again perfectly the crack upon a minute diminution of the pressure. This is the way the dielectric in the discharge space should behave. But inasmuch as there would be always some loss in the gap the medium which should be continuous should exchange through the gap at a rapid rate. In the preceding example, the glass being perfectly closed, it would mean that the dielectric in the discharge space possesses a great insulating power; the glass being cracked, it would signify that the medium in the space is a good conductor. The dielectric should vary enormously in resistance by minute variations of the E. M. F. across the discharge space. This condition is attained, but in an extremely imperfect manner, by warming the air space to a certain critical temperature, dependent on the E. M. F. across the gap, or by otherwise impairing the insulating power of the air. But as a matter of fact the air does never break down disruptively, if this term be rigorously interpreted, for before the sudden rush of the current occurs, there is always a weak current preceding it, which rises first gradually and then with comparative suddenness. That is the reason why the rate of change is very much greater when glass, for instance, is broken through, than when the break takes place through an air space of equivalent dielectric strength. As a medium for the discharge space a solid, or even a liquid would be preferable therefore. It is somewhat difficult to conceive of a solid body which would possess the property of closing instantly after it has been cracked. But a liquid, especially under great pressure, behaves practically like a solid, while it possesses the property of closing the crack. Hence it was thought that a liquid insulator might be more suitable as a dielectric than air. Following out this idea, a number of different forms of dischargers, in which a variety of such insulators, sometimes under great pressure, were employed, have been experimented upon. It is thought sufficient to dwell in a few words upon one of the forms experimented upon. One of these dischargers is illustrated in Figs. 4a and 4b.

A hollow metal pulley P (Fig. 4a), was fastened upon an arbor a, which by suitable means was rotated at a considerable speed. In the inside of the pulley, but disconnected from the same, was supported a thin disc h_1 (which is shown thick for the sake of clearness), of hard rubber, in which there were embedded two metal segments s s with metallic extensions e e into which were screwed conducting terminals t t *covered with thick* tubes of hard rubber t t. The rubber disc h, with its metallic segments S S, was finished in a lathe, and its entire surface highly polished so as to offer the smallest possible frictional resistance to the motion through a fluid. In the hollow of the pulley an insulating liquid such as a thin oil was poured so as to reach very nearly to the opening left in the flange f, which was screwed tightly on the front side of the pulley. The terminals t t were connected to the opposite coatings of a battery of condensers so that the discharge occurred through the liquid. When the pulley was rotated the liquid was forced against the rim of the pulley and considerable fluid pressure resulted. In this simple way the discharge gap was filled with a medium which behaved practically like a solid, which possessed the quality of closing instantly upon the occurrence of the break, and which moreover was circulating through the gap at a rapid rate.



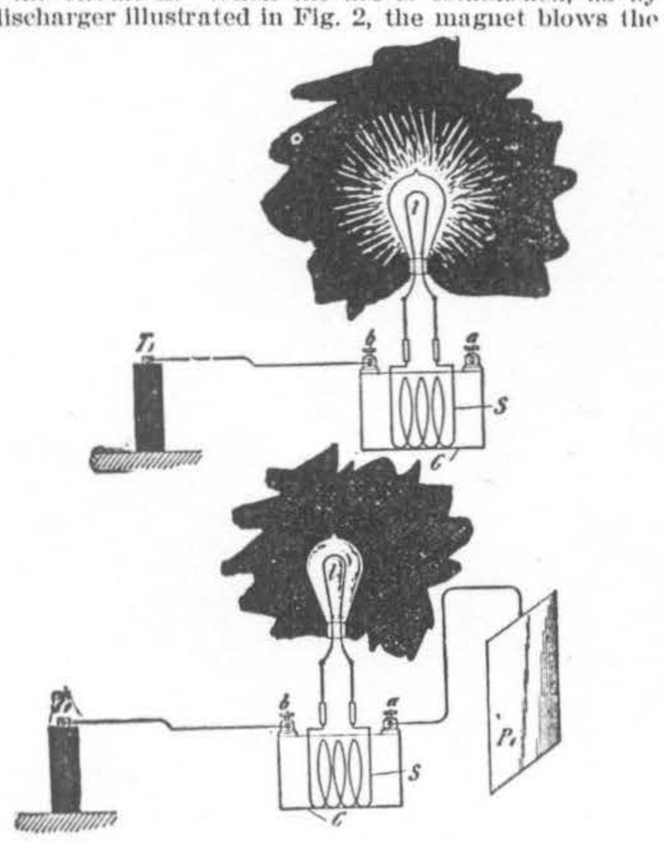
FIGS. 14a AND 14b.—EFFECT OF ATTACHED PLATE WITH LOW FREQUENCIES.

Very powerful effects were produced by dischargers of this kind with liquid interrupters, of which a number of different forms were made. It was found that, as expected, a longer spark for a given length of wire was obtainable in this way than by using air as an interrupting device. Generally the speed, and therefore also the fluid pressure, was limited by reason of the fluid friction, in the form of discharger described, but the practically obtainable speed was more than sufficient to produce a number of breaks suitable for the circuits ordinarily used. In some instances the metal pulley P was provided with a few projections inwardly, and a definite number of breaks was then produced which could be computed from the speed of rotation of the pulley. Experiments were also carried on with liquids of different insulating power with the view of reducing the loss in the arc. When an insulating liquid is moderately warmed the loss in the arc is diminished.

A point of some importance was noted in experiments with various discharges of this kind. It was found, for instance, that whereas the conditions maintained in these forms were favorable for the production of a great spark length, the currents so obtained were not best suited to the production of light effects. Experience undoubtedly has shown that for such purposes a harmonic rise and fall of the potential is preferable. Be it that a solid is rendered incandescent, or phosphorescent, or be it that energy is transmitted by condenser coating through the glass, it is quite certain that a harmonically rising and falling potential produces less destructive action, and that the vacuum is more permanently maintained. This would be easily explained if it were ascertained that the process going on in an exhausted vessel is of an electrolytic nature.

In the diagrammatical sketch, Fig. 1, which has been already referred to, the cases which are most likely to be met with in practice are illustrated. One has at his disposal either direct or alternating currents from a supply station. It is convenient for an experimenter in an isolated laboratory to employ a machine G, such as illustrated, capable of giving both kinds of currents. In such case it is also preferable to use a machine with multiple circuits, as in many experiments it is useful and convenient to have at one's disposal currents of different phases. In the sketch, D represents the direct and A the alternating current. In each of these, three branch circuits are shown, all of which are provided with double lines switches s s s s s s. Consider first the direct cur-

rent conversion; 1a represents the simplest case. If the E. M. F. of the generator is sufficient to break through a small air space, at least when the latter is warmed or otherwise rendered poorly insulating, there is no difficulty in maintaining a vibration with fair economy by judicious adjustment of the capacity, self-induction and resistance of the circuit L containing the devices l l m. The magnet N S can be in this case advantageously combined with the air space. The discharger d d with the magnet may be placed either way, as indicated by the full or by the dotted lines. The circuit 1a with the connections and devices is supposed to possess dimensions such as are suitable for the maintenance of a vibration. But usually the E. M. F. on the circuit or branch 1a will be something like 100 volts or so, and in this case it is not sufficient to break through the gap. Many different means may be used to remedy this by raising the E. M. F. across the gap. The simplest is probably to insert a large self-induction coil in series with the circuit L. When the arc is established, as by the discharger illustrated in Fig. 2, the magnet blows the



Figs. 15a and 15b.—Effect of Attached Plate with High Frequencies.

arc out the instant it is formed. Now the extra current of the break, being of high E. M. F., breaks through the gap, and a path of low resistance for the dynamo current being again provided, there is a sudden rush of the current from the dynamo upon the weakening or subsidence of the extra current. This process is repeated in rapid succession, and in this manner I have maintained oscillation with as low as 50 volts, or even less, across the gap. But conversion on this plan is not to be recommended on account of the too heavy currents through the gap and consequent heating of the electrodes; besides, the frequencies obtained in this way are low, owing to the high self-induction necessarily associated with the circuit. It is very desirable to have the E. M. F. as high as possible, first, in order to increase the economy of the conversion, and, secondly, to obtain high frequencies. The difference of potential in this electric oscillation is, of course, the equivalent of the stretching force in the mechanical vibration of the spring. To obtain very rapid vibration in a circuit of some inertia a great stretching force or difference of potential is necessary. Incidentally, when the E. M. F. is very great, the condenser which is usually employed in connection with the circuit need have but a small capacity, and many other advantages are gained. With a view of raising the E. M. F. to a many times greater value than obtainable from ordinary distribution circuits a rotating transformer g is used, as indicated in Fig. 2a, or else a separate high potential machine is driven by means of a motor operated from the generator G. The latter plan is in fact preferable, as changes are easier made. The connections from the high tension winding are quite similar to those in branch 1a with the exception that a condenser C, which should be adjustable, is connected to the high tension circuit. Usually, also, an adjustable self-induction coil in series with the circuit has been employed in these experiments. When the tension of the currents is very high the magnet ordinarily used in connection with the discharger is of comparatively small value, as it is quite easy to adjust the dimensions of the circuit so that oscillation is maintained. The employment of a steady E. M. F. in the high frequency conversion affords some advantages over the employment of alternating E. M. F., as the adjustments are much simpler and the action can be easier controlled. But unfortunately one is limited by the obtainable potential difference. The windings also break down easily in consequence of the sparks which form between the sections of the armature or commutator when a vigorous oscillation takes place. Besides, these transformers are expensive to build. It has been found by experience that it is best to follow the plan illustrated in Fig. 3a. In this arrangement a rotating transformer g is employed to convert the low tension direct currents into low frequency alternating currents, preferably also of small tension. The tension of the currents is then raised in a stationary transformer T. The secondary S of this transformer is connected to an adjustable condenser C which discharges through the gap or discharger d d, placed in either of the ways indicated, through the primary P of a disruptive discharge coil, the high frequency currents being obtained from the secondary S of this coil, as described on previous occasions. This will undoubtedly be found the cheapest and most convenient way of converting direct currents.

The three branches of the circuit A represent the usual cases met in practice when alternating currents are converted. In Fig. 1b a condenser C, generally of large capacity, is connected to the circuit L containing the devices l l, m m. The devices m m are supposed to be of high self-induction so as to bring the frequency of the circuit more or less to that of the dynamo. In this instance the discharger d d should best have a number of makes and breaks per second equal to twice the frequency of the dynamo. If not so, then it should have at least a number equal to a multiple or even fraction of the dynamo frequency. It should be observed, referring to 1b, that the conversion to a high potential is also effected when the discharger d d, which is shown in the sketch, is omitted. But the effects which are produced by currents which rise instantly to high values, as in a disruptive discharge, are entirely different from those produced by dynamo currents which rise and fall harmonically. So, for instance, there might be in a given case a number of makes and breaks at d d equal to just twice the frequency of the dynamo, or, in other words, there may be the same number of fundamental oscillations as would be produced without the discharge gap, and there might even not be any quicker superimposed vibration; yet the differences of potential at the various points of the circuit, the impedance and other phenomena, dependent upon the rate of change, will bear no similarity in the two cases. Thus, when working with currents discharging disruptively, the element chiefly to be considered is not the frequency, as a student might be apt to believe, but the rate of change per unit of time. With low frequencies in a certain measure the same effects may be obtained as with high frequencies, provided the rate of change is sufficiently great. So if a low frequency current is raised to a potential of say 75,000 volts, and the high tension current passed through a series of high resistance lamp filaments, the importance of the rarefied gas surrounding the filament is clearly noted, as will be seen later; or, if a low frequency current of several thousand amperes is passed through a metal bar, striking phenomena of impedance are observed, just as with currents of high frequencies. But it is, of course, evident that with low frequency currents it is impossible to obtain such rates of change per unit of time as with high frequencies, hence the effects produced by the latter are much more prominent. It was deemed advisable to make the preceding remarks, inasmuch as many more recently described effects have been unwittingly identified with high frequencies. Frequency alone in reality does not mean anything, except when an undisturbed harmonic oscillation is considered.

In the branch 3b a similar disposition as in 1b is illustrated, with the difference that the currents discharging through the gap d d are used to induce currents in the secondary S of a transformer T. In such case the secondary should be provided with an adjustable condenser for the purpose of tuning it to the primary.

Fig. 2b illustrates a plan of alternate current high frequency conversion, which is most frequently used, and which is found to be most convenient. This plan has been dwelt upon in detail on previous occasions, and need not be described here.

Some of these results were obtained by the use of a high frequency alternator. A description of such machines will be found in my original paper before the American Institute of Electrical Engineers, and in periodicals of that period, notably in the "Electrical Engineer" of March 18, 1891.

I will now proceed with the experiments.

On Phenomena Produced by Electrostatic Force.

The first class of effects I intend to show you are effects produced by electrostatic force. It is the force which governs the motion of the atoms, which causes them to collide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an infinite variety of ways, according to Nature's fanciful designs, and to form all these wondrous structures we perceive around us; it is, in fact, if our present views be true, the most important force for us to consider in Nature. As the term electrostatic might imply a steady electric condition, it should be remarked that in these experiments the force is not constant, but varies at a rate which may be considered moderate, about one million times a second, or thereabouts. This enables me to produce many effects which are not producible with an unvarying force.

When two conducting bodies are insulated and electrified, we say that an electrostatic force is acting between

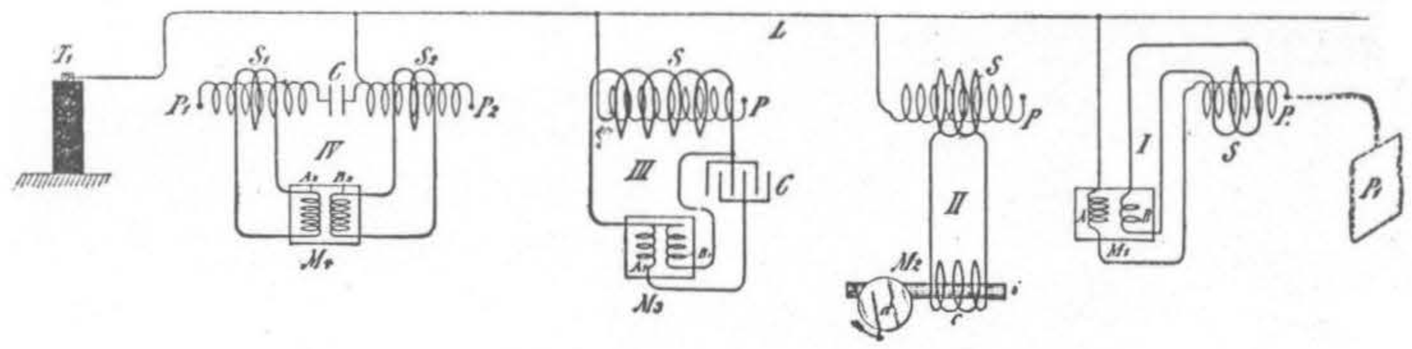


Fig. 16.—Ways of Operating Motors with Only One Lead.

them. This force manifests itself in attractions, repulsions and stresses in the bodies and space or medium without. So great may be the strain exerted in the air, or whatever separates the two conducting bodies, that it may break down, and we observe sparks or bundles of light or streamers, as they are called. These streamers form abundantly when the force through the air is rapidly varying. I will illustrate this action of electrostatic force in a novel experiment in which I will employ the induction coil before referred to. The coil is contained in a trough filled with oil, and placed under the table. The two ends of the secondary wire pass through the two thick columns of hard rubber, which protrude to some height above the table. It is necessary to insulate the ends or terminals of the secondary heavily with hard rubber, because even dry wood is by far too poor an insulator for these currents of enormous potential differences. On one of the terminals of the coil I have placed a large sphere of sheet brass, which is connected to a larger insulated brass plate, in order to enable me to perform the experiments under conditions which, as you will see, are more suitable for this experiment. I now set the coil to work and approach the free terminal with a metallic object held in my hand, this simply to avoid burns. As I approach the metallic object to a distance of eight or ten inches, a torrent of furious sparks breaks forth from the end of the secondary wire, which passes through the rubber column. The sparks cease when the metal in my hand touches the wire. My arm is now traversed by a powerful electric current, vibrating at about the rate of one million times a second. All around me the electrostatic force makes itself felt, and the air molecules and particles of dust flying about are acted upon and hammering violently against my body. So great is this agitation of the particles, that when the lights are turned out you may see streams of feeble light appear on some parts of my body. When such a streamer breaks out on any part of the body it produces a sensation like the pricking of a needle. Were the potentials sufficiently high and the frequency of the vibration rather low, the skin would probably be ruptured under the tremendous strain, and the blood would rush out with great force in the form of fine spray or jet so thin as to be invisible, just as oil will when placed on the positive terminal of a Holtz machine. This breaking through of the skin, though it may seem impossible at first, would perhaps occur by reason of the tissues under the skin being incomparably better conducting. This, at least, appears plausible, judging from some observations.

I can make these streams of light visible to all, by touching with the metallic object one of the terminals as before, and approaching my free hand to the brass sphere, which is connected to the second terminal of the coil. As the hand is approached the air between it and the sphere, or in the immediate neighborhood, is more violently agitated and you see streams of light now break forth from my finger tips and from the whole hand (Fig. 5). Were I to approach the hand closer, powerful sparks would jump from the brass sphere to my hand, which might be injurious. The streamers offer no particular inconvenience, except that in the ends of the finger tips a burning sensation is felt. They should not be confounded with those produced by an influence machine, because in many respects they behave differently. I have attached the brass sphere and plate to one of the terminals in order to prevent the formation of visible streamers on that terminal, also in order to prevent sparks from jumping at a considerable distance. Besides, the attachment is favorable for the working of the coil.

The streams of light which you have observed issuing from my hand are due to a potential of about 200,000 volts, alternating in rather irregular intervals, something like a million times a second. A vibration of the same amplitude, but four times as fast, to maintain which over 3,000,000 volts would be required, would be more than sufficient to envelop my body in a complete sheet of flame. But this flame would not burn me up; quite contrarily, the probability is that I would not be injured in the least. Yet a hundredth part of that energy, otherwise directed, would be amply sufficient to kill a person.

The amount of energy which may thus be passed into the body of a person depends on the frequency and potential of the currents, and by making both of these very great, a vast amount of energy may be passed into the body without causing any discomfort, except, perhaps, in the arm, which is traversed by a true conduction current. The reason why no pain in the body is felt, and no injurious effect noted, is that everywhere, if a current be imagined to flow through the body, the direction of its flow would be at right angles to the surface; hence the body of the experimenter offers an enormous section to the current, and the density is very small, with the exception of the arm, perhaps, where the density may be considerable. But if only a small fraction of that energy would be applied in such a way that a current would traverse the body in the same manner as a low frequency current, a shock would be received which might be fatal. A direct or low frequency alternating current is fatal, I think, principally because its distribution through the body is not uniform, as it must divide itself in minute streamlets of great density, whereby some organs are vitally injured. That such a process occurs I have not the least doubt, though no evidence might apparently exist or be found upon examination. The surest to injure and destroy life is a continuous current, but the most painful is an alternating current of very low frequency. The expression of these views, which are the result of long-continued experiment and observation, both with steady and varying currents, is elicited by the interest which is at present taken in this subject, and by the manifestly erroneous ideas which are daily propounded in journals on this subject.

I may illustrate an effect of the electrostatic force by another striking experiment, but, before, I must call your attention to one or two facts. I have said before, that when the medium between two oppositely electrified bodies is strained beyond a certain limit it gives way and, stated in popular language, the opposite electric charges unite and neutralize each other. This breaking down of the medium occurs principally when the force acting between the bodies is steady, or varies at a moderate rate. Were the variation sufficiently rapid such a destructive break would not occur, no matter how great the force, for all the energy would be spent in radiation, convection and mechanical and chemical action. Thus the spark length, or greatest distance through which a spark will jump between the electrified bodies, is the smaller the greater the variation or time rate of change. But this rule may be taken to be true only in a general way, when comparing rates which are widely different.

I will show you by an experiment the difference in the effect produced by a rapidly varying and a steady or moderately varying force. I have here two large circular brass plates p p (Fig. 6a and Fig. 6b), supported on movable insulating stands on the table, connected to the ends of the secondary of a similar coil as the one used before. I place the plates 10 or 12 inches apart, and set the coil to work. You see the whole space between the plates, nearly two cubic feet, filled with uniform light, Fig. 6a. This light is due to the streamers you have seen

in the first experiment, which are now much more intense. I have already pointed out the importance of these streamers in commercial apparatus and their still greater importance in some purely scientific investigations. Often they are too weak to be visible, but they always exist, consuming energy and modifying the action of the apparatus. When intense, as they are at present, they produce ozone in great quantity, and also, as Prof. Crookes has pointed out, nitrous acid. So quick is the chemical action that if a coil such as this one is worked for a very long time, it wil make the atmosphere of a small room unbearable, for the eyes and throat are attacked. But when moderately produced the streamers refresh the atmosphere wonderfully, like a thunderstorm, and exercise unquestionably a beneficial effect.

In this experiment the force acting between the plates changes in intensity and direction at a very rapid rate. I will now make the rate of change per unit time much smaller. This I effect by rendering the discharges through the primary of the induction coil less frequent, and also by diminishing the rapidity of the vibration in the secondary. The former result is conveniently secured by lowering the E. M. F. over the air gap in the primary circuit, the latter, by approaching the two brass plates to a distance of about three or four inches. When the coil is set to work you see no streamers or light between the plates, yet the medium between them is under a tremendous strain. I still further augment the strain by raising the E. M. F. in the primary circuit, and soon you see the air give way and the hall is illuminated by a shower of brilliant and noisy sparks, Fig. 6b. These sparks could be produced also with unvarying force; they have been for many years a familiar phenomenon, though they were usually obtained from entirely different apparatus. In describing these two phenomena, so radically different in appearance, I have advisedly spoken of a "force" acting between the plates. It would be in accordance with accepted views to say that there was an "alternating E. M. F." acting between the plates. This term is quite proper and applicable in all cases where there is evidence of at least a possibility of an essential interdependence of the electric state of the plates, or electric action in their neighborhood. But if the plates were removed to an infinite distance, or if at a finite distance, there is no probability or necessity whatever for such dependence. I prefer to us the term "electrostatic force," and to say that such a force is acting around each plate or electrified insulated body in general. There is an inconvenience in using this expression, as the term incidentally means a steady electric condition; but a proper nomenclature will eventually settle this difficulty.

I now return to the experiment to which I have already alluded, and with which I desire to illustrate a striking effect produced by a rapidly varying electrostatic force. I attach to the end of the wire, l (Fig. 7), which is in connection with one of the terminals of the secondary of the induction coil, an exhausted bulb b. This bulb contains a thin carbon filament f, which is fastened to a platinum wire w, sealed in the glass and leading outside of the bulb, where it connects to the wire l. The bulb may be exhausted to any degree attainable with ordinary apparatus. Just a moment before, you have witnessed the breaking down of the air between the charged brass plates. You know that a plate of glass, or any other insulating material, would break down in like manner. Had I, therefore, a metallic coating attached to the outside of the bulb, or placed near the same, and were this coating connected to the other terminal of the coil, you would be prepared to see the glass give way if the strain were sufficiently increased. Even were the coating not connected to the other terminal, but to an insulated plate, still, if you have followed recent developments, you would naturally expect a rupture of the glass.

But it will certainly surprise you to note that under the action of the varying electrostatic force the glass gives way when all other bodies are removed from the bulb. In fact, all the surrounding bodies we perceive might be removed to an infinite distance without affecting the result in the slightest. When the coil is set to work, the glass is invariably broken through at the seal, or other narrow channel, and the vacuum is quickly impaired. Such a damaging break would not occur with a steady force, even if the same were many times greater. The break is due to the agitation of the molecules of the gas within the bulb, and outside of the same. This agitation, which is generally most violent in the narrow pointed channel near the seal, causes a heating and rupture of the glass. This rupture, would, however, not occur, not even with a varying force, if the medium filling the inside of the bulb and that surrounding it were perfectly homogeneous. The break occurs much quicker if the top of the bulb is drawn out into a fine fibre. In bulbs used with these coils such narrow, pointed channels must therefore be avoided.

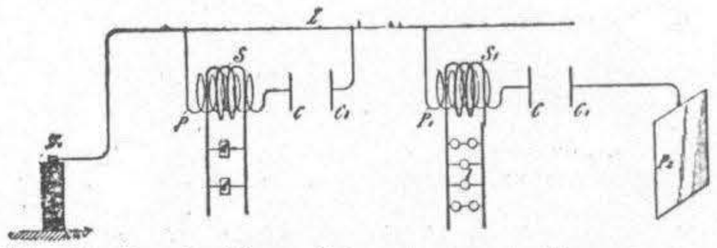


FIG. 17.—SINGLE WIRE CONVERSION AND DISTRIBUTION, WITH SIMPLE MEANS FOR REGULATING THE EFFECTS.

When a conducting body is immersed in air, or similar insulating medium, consisting of, or containing, small freely movable particles capable of being electrified, and when the electrification of the body is made to undergo a very rapid change—which is equivalent to saying that the electrostatic force acting around the body is varying in intensity—the small particles are attracted and repelled, and their violent impacts against the body may cause a mechanical motion of the latter. Phenomena of this kind are noteworthy, inasmuch as they have not been observed before with apparatus such as has been commonly in use. If a very light conducting sphere be suspended on an exceedingly fine wire, and charged to a steady potential, however high, the sphere will remain at rest. Even if the potential would be rapidly varying, provided that the small particles of matter, molecules or atoms, are evenly distributed, no motion of the sphere should result. But if one side of the conducting sphere is covered with a thick insulating layer, the impacts of the particles will cause the sphere to move about, generally in irregular curves, Fig. 8a. In like manner, as I have shown on a previous occasion, a fan of metal sheet, Fig. 8b, covered partially with insulating material as indicated, and placed upon the terminal of the coil so as to turn freely in it, is spun around.

All these phenomena you have witnessed, and others, which will be shown later, are due to the presence of a medium like air, and would not occur in a continuous medium. The action of the air may be illustrated still better by the following experiment: I take a glass tube t, Fig. 9, of about an inch in diameter, which has a platinum wire w sealed in the lower end, and to which is attached a thin lamp filament f. I connect the wire with the terminal of the coil and set the coil to work. The platinum wire is now electrified positively and negatively in rapid succession, and the wire and air inside of the tube are rapidly heated by the impacts of the particles, which may be so violent as to render the filament incandescent. But if I pour oil in the tube, just as soon as

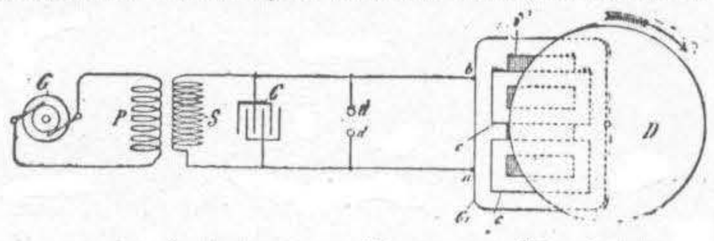


FIG. 18.—OPERATING A MOTOR BY DISRUPTIVE DISCHARGES.

the wire is covered with the oil, all action apparently ceases and there is no marked evidence of heating. The reason of this is that the oil is a practically continuous medium. The displacements in such a continuous medium are, with these frequencies, to all appearance incomparably smaller than in air, hence the work performed in such a medium is insignificant. But oil would behave very differently with frequencies many times as great, for even though the displacements be small, if the frequency were much greater, considerable work might be performed in the oil.

The electrostatic attractions and repulsions between bodies of measurable dimensions are, of all the manifestations of this force, the first so-called electrical phenomena noted. But though they have been known to us for many centuries, the precise nature of the mechanism concerned in these actions is still unknown to us, and has not been even quite satisfactorily explained. What kind of mechanism must that be? We cannot help wondering when we observe two magnets attracting and repelling each other with a force of hundreds of pounds with apparently nothing between them. We have in our commercial dynamos magnets capable of sustaining in midair tons of weight. But what are even these forces acting between magnets when compared with the tremendous attractions and repulsions produced by electrostatic force, to which there is apparently no limit as to intensity. In lightning discharges bodies are often charged to so high a potential that they are thrown away with inconceivable force and torn asunder or shattered into fragments. Still even such effects cannot compare with the attractions and repulsions which exist between charged molecules or atoms, and which are sufficient to project them with speeds of many kilometres a second, so that under their violent impact bodies are rendered highly incandescent and are volatilized. It is of special interest for the thinker who inquires into the nature of these forces to note, that whereas the actions between individual molecules or atoms occur seemingly under any condition, the attractions and repulsions of bodies of measurable dimensions imply a medium possessing insulating properties. So, if air, either by being rarefied or heated, is rendered more or less conducting, these actions between two electrified bodies practically cease, while the actions between the individual atoms continue to manifest themselves.

An experiment may serve as an illustration and as a means of bringing out other features of interest. Some time ago I showed that a lamp filament or wire mounted in a bulb and connected to one of the terminals of a high tension secondary coil is set spinning, the top of the filament generally describing a circle. This vibration was very energetic when the air in the bulb was at ordinary pressure, and became less energetic when the air in the bulb was strongly compressed. It ceased altogether when the air was exhausted, so as to become comparatively good conducting. I found at that time that no vibration took place when the bulb was very highly exhausted. But I conjectured that the vibration which I ascribed to the electrostatic action between the walls of the bulb and the filament should take place also in a highly exhausted bulb. To test this under conditions which were more favorable, a bulb like the one in Fig. 10 was constructed. It comprised a globe b, in the neck of which was sealed a platinum wire w carrying a thin lamp filament f. In the lower part of the globe a tube t was sealed so as to surround the filament. The exhaustion was carried as far as it was practicable with the apparatus employed.

This bulb verified my expectation, for the filament was set spinning when the current was turned on, and became incandescent. It also showed another interesting feature, bearing upon the preceding remarks, namely, when the filament had been kept incandescent some time, the narrow tube and the space inside were brought to an elevated temperature, and as the gas in the tube then became conducting the electrostatic attraction between the glass and the filament became very weak or ceased, and the filament came to rest. When it came to rest it would glow far more intensely. This was probably due to its assuming the position in the centre of the tube where the molecular bombardment was most intense, and also partly to the fact that the individual impacts were more violent and that no part of the supplied energy was converted into mechanical movement. Since, in accordance with accepted views, in this experiment the incandescence must be attributed to the impacts of the particles, molecules or atoms in the heated space, these particles must, therefore, in order to explain such action, be assumed to behave as independent carriers of electric charges immersed in an insulating medium; yet there is no attractive force between the glass tube and the filament because the space in the tube is, as a whole, conducting.

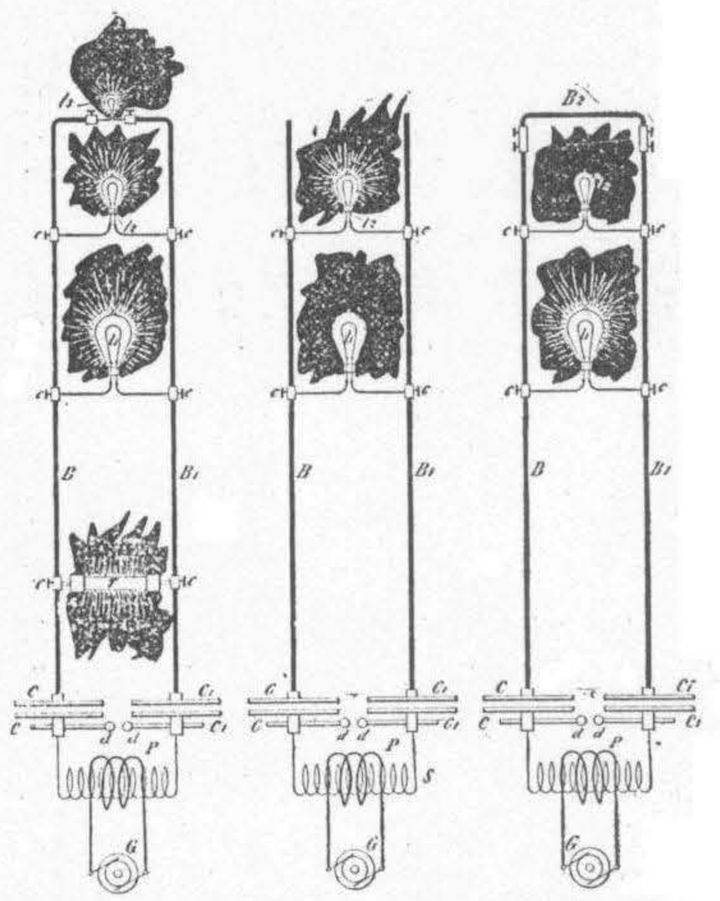
It is of some interest to observe in this connection that whereas the attraction between two electrified bodies may cease owing to the impairing of the insulating power of the medium in which they are immersed, the repulsion between the bodies may still be observed. This may be explained in a plausible way. When the bodies are placed at some distance in a poorly conducting medium, such as slightly warmed or rarefied air, and are suddenly electrified, opposite electric charges being imparted to them, these charges equalize more or less by leakage through the air. But if the bodies are similarly electrified, there is less opportunity afforded for such dissipation, hence the repulsion observed in such case is greater than the attraction. Repulsive actions in a gaseous medium are, however, as Prof. Crookes has shown, enhanced by molecular bombardment.

ON CURRENT OR DYNAMIC ELECTRICITY PHENOMENA.

So far, I have considered principally effects produced by a varying electrostatic force in an insulating medium, such as air. When such a force is acting upon a conducting body of measurable dimensions, it causes within the same, or on its surface, displacements of the electricity and gives rise to electric currents, and these produce another kind of phenomena, some of which I shall presently endeavor to illustrate. In presenting this second class of electrical effects, I will avail myself principally of such as are producible without any return circuit, hoping to interest you the more by presenting these phenomena in a more or less novel aspect.

It has been for a long time customary, owing to the limited experience with vibratory currents, to consider an electric current as something circulating in a closed conducting path. It was astonishing at first to realize that a current may flow through the conducting path even if the latter be interrupted, and it was still more surprising to learn that sometimes it may be even easier to make a current flow under such conditions than through a closed path. But that old idea is gradually disappearing, even among practical men, and will soon be entirely forgotten.

If I connect an insulated metal plate P, Fig. 11, to one of the terminals T of the induction coil by means of a wire, though this plate be very well insulated, a current passes through the wire when the coil is set to work. First I wish to give you evidence that there is a current passing through the connecting wire. An obvious way of demonstrating this is to insert between the terminal of the coil and the insulated plate a very thin platinum or German silver wire w and bring the latter to incandescence or fusion by the current. This requires a rather large plate or else current impulses of very high potential and frequency. Another way is to take a coil C, Fig. 11, containing many turns of thin insulated wire, and to insert the same in the path of the current to the plate. When I connect one of the ends of the coil to the wire leading to another insulated plate P, and its other end to the terminal T_1 of the induction coil, and set the latter to work, a current passes through the inserted coil C and the existence of the current may be made manifest in various ways. For instance, I insert an iron core i within the coil. The current being one of very high frequency, if it be of some strength, will soon bring the iron core to a noticeably higher temperature, as the hysteresis and current losses are great with such high frequencies. One might take a core of some size, laminated or not, it would matter little; but ordinary iron wire 1-16 or 1-8 of an inch thick is suitable for the purpose. While the induction coil is working, a current traverses the inserted coil, and only a few moments are sufficient to bring the iron wire i to an elevated temperature sufficient to soften the sealing-wax s, and cause a paper washer p, fastened by it to the iron wire to fall off. But with the apparatus such as I have here, other, much



FIGS. 19a, 19b AND 19c.—IMPEDANCE PHENOMENA.

more interesting, demonstrations of this kind can be made. I have a secondary S, Fig. 12, of coarse wire, wound upon a coil similar to the first. In the preceding experiment the current through the coil C, Fig. 11, was very small, but there being many turns a strong heating effect was, nevertheless, produced in the iron wire. Had I passed that current through a conductor in order to show the heating of the latter, the current might have been too small to produce the effect desired. But with this coil provided with a secondary winding I can now transform the feeble current of high tension which passes through the primary P into a strong secondary current of low tension, and this current will quite certainly do what I expect. In a small glass tube (t, Fig. 12) I have inclosed a coiled platinum wire, w, this merely in order to protect the wire. On each end of the glass tube is sealed a terminal of stout wire to which one of the ends of the platinum wire, w, is connected. I join the terminals of the secondary coil to these terminals and insert the primary p, between the insulated plate P_1 and the terminal T_1 of the induction coil as before. The latter being set to work, instantly the platinum wire w

is rendered incandescent, and can be fused even if it be very thick.

Instead of the platinum wire I now take an ordinary 50-volt 16-c. p. lamp. When I set the induction coil in operation the lamp filament is brought to high incandescence. It is, however, not necessary to use the insulated plate, for the lamp (l, Fig. 13) is rendered incandescent even if the plate P1 be disconnected. The secondary may also be connected to the primary as indicated by the dotted line in Fig. 13, to do away more or less with the electrostatic induction or to modify the action otherwise.

I may here call attention to a number of interesting observations with the lamp. First, I disconnect one of the terminals of the lamp from the secondary S. When the induction coil plays, a glow is noted which fills the whole bulb. This glow is due to electrostatic induction.

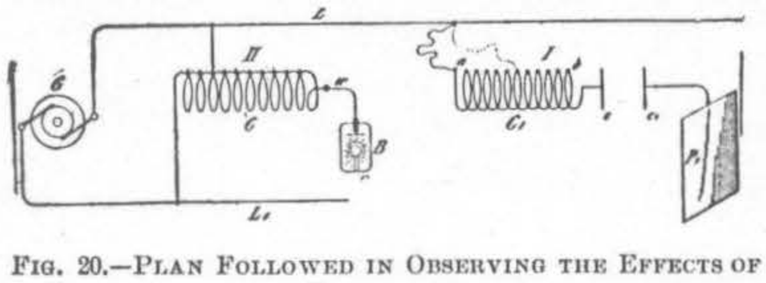


FIG. 20.—PLAN FOLLOWED IN OBSERVING THE EFFECTS OF RESONANCE.

It increases when the bulb is grasped with the hand, and the capacity of the experimenter's body thus added to the secondary circuit. The secondary, in effect, is equivalent to a metallic coating, which would be placed near the primary. If the secondary, or its equivalent, the coating, were placed symmetrically to the primary, the electrostatic induction would be nil under ordinary conditions, that is, when a primary return circuit is used, as both halves would neutralize each other. The secondary is, in fact, placed symmetrically to the primary, but the action of both halves of the latter, when only one of its ends is connected to the induction coil, is not exactly equal; hence, electrostatic induction takes place, and hence the glow in the bulb. I can nearly equalize the action of both halves of the primary by connecting the other free end of the same to the insulated plate, as in the preceding experiment. When the plate is connected, the glow disappears. With a smaller plate it would not entirely disappear, and then it would contribute to the brightness of the filament when the secondary is closed, by warming the air in the bulb.

To demonstrate another interesting feature, I have adjusted the coils used in a certain way. I first connect both the terminals of the lamp to the secondary, one end of the primary being connected to the terminal T_1 of the induction coil, and the other to the insulated plate P_1 as before. When the current is turned on, the lamp glows brightly, as shown in Fig. 14b, in which C is a fine wire coil and S a coarse wire secondary wound upon it. If the insulated plate P_1 is disconnected, leaving one of the ends a of the primary insulated, the filament becomes dark or generally it diminishes in brightness (Fig. 14a). Connecting, again, the plate P_1 and raising the frequency of the current, I make the filament quite dark or barely red, Fig. 15b. Once more I will disconnect the plate. One will, of course, infer that when the plate is disconnected, the current through the primary will be weakened, that therefore the E. M. F. will fall in the secondary S, and that the brightness of the lamp will diminish. This might be the case, and the result can be secured by an easy adjustment of the coils; also by varying the frequency and potential of the currents. But it is perhaps of greater interest to note that the lamp increases in brightness when the plate is disconnected (Fig. 15a). In this case all the energy the primary receives is now sunk into it, like the charge of a battery into an ocean cable, but most of that energy is recovered through the secondary and used to light the lamp. The current traversing the primary is strongest at the end b, which is connected to the terminal T_1 of the induction coil, and diminishes in strength towards the remote end a. But the dynamic inductive effect exerted upon the secondary S is now greater than before when the suspended plate was connected to the primary. These results might have been produced by a number of causes. For instance, the plate P_1 being connected, the reaction from the coil C may be such as to diminish the potential at the terminal T_1 of the induction coil, and therefore weaken the current through the primary of the coil C. Or the disconnecting of the plate may diminish the capacity effect with relation to the primary of the latter coil to such an extent that the current through it is diminished, though the potential at the terminal T_1 of the induction coil may be the same or even higher. Or the result might have been produced by the change of phase of the primary and secondary currents and consequent reaction. But the chief determining factor is the relation of the self-induction and capacity of coil C and plate P_1, and the frequency of the currents. The greater brightness of the filament in Fig. 15a is, however, in part due to the heating of the rarefied gas in the lamp by electrostatic induction, which, as before remarked, is greater when the suspended plate is disconnected.

Still another feature of some interest I may here bring to your attention. When the insulated plate is disconnected and the secondary of the coil opened, by approaching a small object to the secondary, but very small sparks

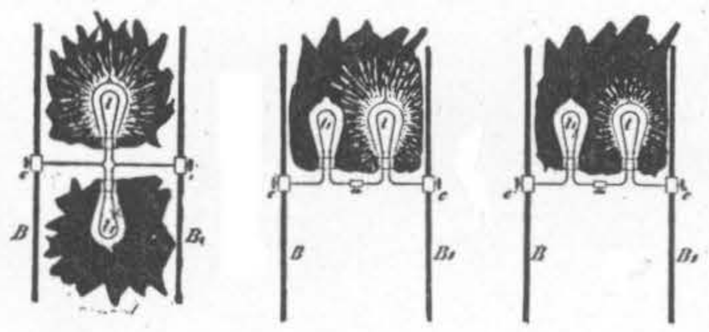


FIG. 21.—ENERGY TRANSMISSION TO ANY DISTANCE WITHOUT WIRES.

can be drawn from it, showing that the electrostatic induction is small in this case. But upon the secondary being closed upon itself or through the lamp, the filament glowing brightly, strong sparks are obtained from the secondary. The electrostatic induction is now much greater, because the closed secondary determines a greater flow of current through the primary, and principally through that half of it which is connected to the induction coil. If now the bulb be grasped with the hand, the capacity of the secondary with reference to the primary is augmented by the experimenter's body and the luminosity of the filament is increased, the incandescence now being due partly to the flow of current through the filament and partly to the molecular bombardment of the rarefied gas in the bulb.

The preceding experiments will have prepared one for the next following results of interest, obtained in the course of these investigations. Since I can pass a current through an insulated wire merely by connecting one of its ends to the source of electrical energy, since I can induce by it another current, magnetize an iron core, and, in short, perform all operations, as though a return circuit were used, clearly I can also drive a motor by the aid of only one wire. On a former occasion I have described a simple form of motor, comprising a single exciting coil, an iron core and disc. Fig. 16 illustrates a modified way of operating such an alternate current motor by currents induced in a transformer connected to one lead, and several other arrangements for circuits for operating a certain class of alternate motors founded on the action of currents of differing phase. In view of the present state of the art it is thought sufficient to describe these arrangements in a few words only. In the diagram, Fig. 16 II. shows a primary coil P, connected with one of its ends to the line L leading from a high tension transformer terminal T_1. In inductive relation to this primary P is a secondary S of coarse wire in the circuit of which is a coil c. The currents induced in the secondary energize the iron core i, which is preferably, but not necessarily, subdivided, and set the metal disc d in rotation. Such a motor M_2, as diagrammatically shown in Fig. 16 II., has been called a "magnetic lag motor," but this expression may be objected to by those who attribute the rotation of the disc to eddy currents circulating in minute paths when the core i is finally subdivided. In order to operate such a motor effectively on the plan indicated the frequencies should not be too high, not more than four or five thousand, though the rotation is produced even with ten thousand per second, or more.

In Fig. 16 I. a motor M_1, having two energizing circuits, A and B, is diagrammatically indicated. The circuit A is connected to the line L, and in series with it is a primary P, which may have its free end connected to an insulated plate P_1, such connection being indicated by the dotted lines. The other motor circuit B is connected to the secondary S, which is in inductive relation to the primary p. When the transformer terminal T_1 is alternately electrified, currents traverse the open line L and also circuit A and primary P. The currents through the latter induce secondary currents in the circuit S, which pass through the energizing coil B of the motor. The currents through the secondary S and those through the primary P differ in phase 90 degrees, or nearly so,



FIGS. 22a, 22b AND 22c.—SHOWING THE EFFECT OF THE PRESENCE OF A GASEOUS MEDIUM.

and are capable of rotating an armature placed in inductive relation to the circuits A and B.

In Fig. 16 III. a similar motor M_3 with two energizing circuits A_1 and B_1 is illustrated. A primary P, connected with one of its ends to the line L, has a secondary S, which is preferably wound for a tolerably high E. M. F., and to which the two energizing circuits of the motor are connected, one directly to the ends of the secondary, and the other through a condenser C, by the action of which the currents traversing the circuit A_1 and B_1 are made to differ in phase.

In Fig 16 IV. still another arrangement is shown. In this case two primaries P_1 and P_2 are connected to the line L, one through a condenser C of small capacity, and the other directly. The primaries are provided with secondaries S_1 and S_2, which are in series with the energizing circuits A_2 and B_2 and a motor M_2, the condenser C again serving to produce the requisite difference in the phase of the currents traversing the motor circuits. As such phase motors with two or more circuits are now well known in the art, they have been here illustrated diagrammatically. No difficulty whatever is found in operating a motor in the manner indicated, or in similar ways, and although such experiments up to this day present only scientific interest, they may at a period not far distant be carried out with practical objects in view.

It is thought useful to devote here a few remarks to the subject of operating devices of all kinds by means of only one leading wire. It is quite obvious that when high-frequency currents are made use of, ground connections are—at least when the E. M. F. of the currents is great—better than a return wire. Such ground connections are objectionable with steady or low frequency currents, on account of destructive chemical actions of the former, and disturbing influences exerted by both on the neighboring circuits; but with high frequencies these actions practically do not exist. Still, even ground connections become superfluous when the E. M. F. is very high, for soon a condition is reached when the current may be passed more economically through open than through closed conductors. Remote as might seem an industrial application of such single wire transmission of energy to one not experienced in such lines of experiment, it will not seem so to any one who for some time has carried on investigations of such nature. Indeed, I cannot see why such a plan could not be practicable. Nor should it be thought that for carrying at such a plan currents of very high frequency are implicitly required, for just as soon as potentials of, say, 30,000 volts are used the single wire transmission may be effected with low frequencies, and experiments have been made by me from which these inferences are made.

When the frequencies are very high it has been found in laboratory practice quite easy to regulate the effects in the manner shown in diagram Fig. 17. Here two primaries P and P' are shown, each connected with one of its ends to the line L, and with the other end to the condenser plates C and C', respectively. Near these are placed other condenser plates C_1 and C'_1, the former being connected to the line L, and the latter to an insulated larger plate P_2. On the primaries are wound secondaries S and S_1 of coarse wire, connected to the devices m and d respectively. By varying the distances of the condenser plates C and C_1, and C_1 and C_1', the currents through the secondaries S and S_1 are varied in intensity. The curious feature is the great sensitiveness, the slightest change in the distance of the plates producing considerable variations in the intensity or strength of the currents. The sensitiveness may be rendered extreme by making the frequency such that the primary itself without any plate attached to its free end satisfies, in conjunction with the closed secondary, the condition of resonance. In such condition an extremely small change in the capacity of the free terminal produces great variations. For instance, I have been able to adjust the conditions so that the mere approach of a person to the coil produces a considerable change in the brightness of the lamps attached to the secondary. Such observations and experiments possess of course at present chiefly scientific interest, but they may soon become of practical importance.

Very high frequencies are of course not practicable with motors on account of the necessity of employing iron cores. But one may use sudden discharges of low frequency and thus obtain certain advantages of high-frequency currents without rendering the iron core entirely incapable of following the changes and without entailing a very great expenditure of energy in the core. I have found it quite practicable to operate, with such low frequency disruptive discharges of condensers, alternating current motors. A certain class of such motors which I advanced a few years ago, which contain closed secondary circuits, will rotate quite vigorously when the discharges are directed through the exciting coils. One reason that such a motor operates so well with these discharges is that the difference of phase between the primary and secondary currents is 90 degrees, which is generally not the case with harmonically rising and falling currents of low frequency. It might not be without interest to show an experiment with a simple motor of this kind, inasmuch as it is commonly thought that disruptive discharges are unsuitable for such purposes. The motor is illustrated in Fig. 18. It comprises a rather large iron core i with slots on the top into which are imbedded thick copper washers c c. In proximity to the core is a freely movable metal disc D. The core is provided with a primary exciting coil C, the ends a and b of which are connected to the terminals of the secondary S of an ordinary transformer, the primary P of the latter being connected to an alternating distribution circuit or generator G of low or moderate frequency. The terminals of the secondary S are attached to a condenser C which discharges through an open air gap d d, which may be placed in series or shunt to the coil C. When the conditions are properly chosen the disc D rotates with considerable effort, and the iron core i does not get very perceptibly hot. With currents from a high-frequency alternator, on the contrary, the core gets rapidly hot and the disc rotates with a much smaller effort. To perform the experiment properly it should be first ascertained that the disc D is not set in rotation when the discharge is not occurring at d d. It is preferable to use a large iron core and a condenser of large capacity so as to bring the superimposed quicker oscillation to a very low pitch or to do away with it entirely. By observing certain elementary rules I have also found it practicable to operate ordinary series or shunt direct-current motors with such disruptive discharges, and this can be done with or without a return wire.

Among the various current phenomena observed perhaps the most interesting are those of impedance presented by conductors to currents varying at a rapid rate. In my first paper before the American Institute of Electrical Engineers I have described a few striking observations of this kind. Thus I showed that when such currents or sudden discharges are passed through a thick



FIG. 23.—CURIOUS INCANDESCENCE OF A WIRE.



FIG. 25.—ILLUSTRATING LATERAL DIFFUSION.

metal bar there may be points at the bar only a few inches apart which have a sufficient potential difference between them to maintain at bright incandescence an ordinary filament lamp. I have also described the curious behavior of rarefied gas surrounding a conductor to such sudden rushes of current. These phenomena have been since more carefully studied, and one or two novel experiments of this kind are deemed of sufficient interest to be described here.

With reference to Fig. 19a B and B_1 are very stout copper bars, connected at their lower ends to plates C and C_1, respectively, of a condenser, the opposite plates of the latter being connected to the terminals of the secondary S of a high-tension transformer, the primary P of which is supplied with alternating currents from an

ordinary low-frequency dynamo G, or distribution circuit. The condenser discharges through an adjustable gap d d as usual. By establishing a rapid vibration it was found quite easy to perform the following curious experiment: The bars B and B_1 were joined at the top by a low-voltage lamp l_3; a little lower was placed, by means of clamp c c, a 50-volt lamp l_2 and still lower another 100-volt lamp l_1 and finally at a certain distance below the latter lamp an exhausted tube T. By carefully determining the positions of these devices it was found practicable to maintain them all at their proper illuminating power. Yet they were all connected in multiple arc to the two stout copper bars and required widely different pressures This experiment requires, of course, some time for adjustment, but is quite easily performed.

In Figs. 19b and 19c, two other experiments are illustrated which, unlike the previous experiment, do not require very careful adjustments. In Fig. 20b, two lamps l_1 and l_2, the former a 100-volt and the latter a

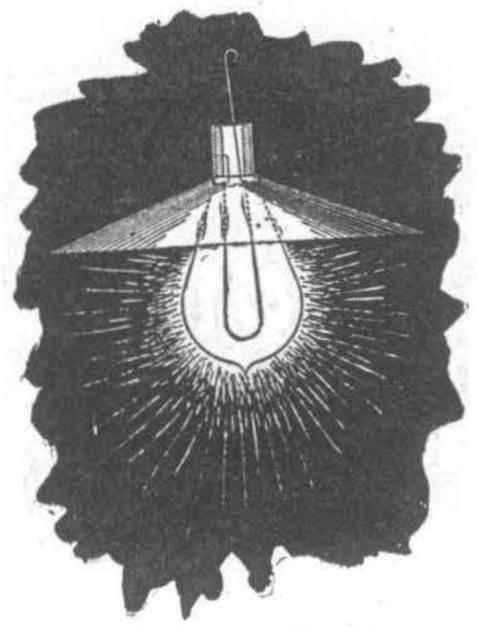


FIG. 24.—UTILIZING THE HEATING EFFECT OF CONDUCTION CURRENT AND BOMBARDMENT.

50-volt, are placed in certain positions as indicated, the 100-volt lamp being below the 50-volt lamp. When the arc is playing at d d, and the sudden discharges passed through the bars B B the 50-volt lamp will, as a rule, burn brightly, or, at least, this result is easily secured, while the 100-volt lamp will burn very low or remain quite dark, Fig. 19b. Now the bars B B may be joined at the top by a thick cross-bar B_2, and it is quite easy to maintain the 100-volt lamp at full candle-power while the 50-volt lamp remains dark, Fig. 19c. These results, as I have pointed out previously, should not be considered to be due exactly to frequency, but rather to the time rate of change which may be great even with low frequencies. A great many other results of the same kind equally interesting, especially to those who are only used to manipulate steady currents, may be obtained, and they afford precious clues in investigating the nature of electric currents.

In the preceding experiments I have already had occasion to show some light phenomena, and it would be now proper to study those in particular; but to make this investigation more complete I think it necessary to first make a few remarks on the subject of electrical resonance, which has to be always observed in carrying out these experiments.

ON ELECTRICAL RESONANCE.

The effects of resonance are being more and more noted by engineers, and are becoming of great importance in the practical operation of apparatus of all kinds with alternating currents. A few general remarks may therefore be made concerning these effects. It is clear, that if we succeed in employing the effects of resonance practically in the operation of electric devices, the return wire will, as a matter of course, become unnecessary, for the electric vibration may be conveyed with one wire just as well, and sometimes even better, than with two. The question first to answer is, then, whether pure resonance effects are producible. Theory and experiment both show that such is impossible in Nature, for as the oscillation becomes more and more vigorous the losses in the vibrating bodies and environing media rapidly increase, and necessarily check the vibration which otherwise would go on increasing forever. It is a fortunate circumstance that pure resonance is not producible, for if it were there is no telling what dangers might not lie in wait for the innocent experimenter. But to a certain degree resonance is producible, the magnitude of the effects being limited by the imperfect conductivity and imperfect elasticity of the media, or, generally stated, by frictional losses. The smaller these losses, the more striking are the effects. The same is the case in mechanical vibration. A stout steel bar may be set in vibration by drops of water falling upon it at proper intervals; and with glass, which is more perfectly elastic, the resonance effect is still more remarkable, for a goblet may be burst by singing into it a note of the proper pitch. The electrical resonance is the more perfectly attained, the smaller the resistance or the impedance of the conducting path, and the more perfect the dielectric. In a Leyden jar discharging through a short, stranded cable of thin wires these requirements are probably best fulfilled, and the resonance effects are, therefore, very prominent. Such is not the case with dynamo machines, transformers and their circuits, or with commercial apparatus in general in which the presence of iron cores complicates or renders impossible the action. In regard to Leyden jars with which resonance effects are frequently demonstrated, I would say that the effects observed are often attributed, but are seldom due, to true resonance, for an error is quite easily made in this respect. This may be undoubtedly demonstrated by the following experiment. Take, for instance, two large insulated metallic plates or spheres, which I shall designate A and B, place them at a certain small distance apart, and charge them from a frictional or influence machine to a potential so high that just a slight increase of the difference of potential between them will cause the small air or insulating space to break ...n. This is easily reached by making a few preliminary trials. If, now, another plate—fastened on an insulating handle, and connected by a wire to one of the terminals of a high tension secondary of an induction coil, which is maintained in action by an alternator (preferably high frequency)—is approached to one of the charged bodies A or B, so as to be nearer to either one of them, the discharge will invariably occur between them; at least it will if the potential of the coil in connection with the plate is sufficiently high. But the explanation of this will soon be found in the fact that the approached plate acts inductively upon the bodies A and B, and causes a spark to pass between them. When this spark occurs, the charges which were previously imparted to these bodies from the influence machine must needs be lost, since the bodies are brought in electrical connection through the arc formed. Now, this arc is formed whether there be resonance or not. But even if the spark would not be produced, still there is an alternating E. M. F. set up between the bodies when the plate is brought near one of them; therefore, the approach of the plate, if it does not always, actually will, at any rate tend, to break down the air space by inductive action. Instead of the spheres or plates A and B we may take the coatings of a Leyden jar with the same result, and in place of the machine, which is a high frequency alternator preferably, because it is more suitable for the experiment, and also for the argument, we may take another Leyden jar or battery of jars. When such jars are discharging through a circuit of low resistance the same is traversed by currents of very high frequency. The plate may now be connected to one of the coatings of the second jar, and when it is brought near to the first jar just previously charged to a high potential from an influence machine the result is the same as before, and the first jar will discharge through a small air space upon the second being caused to discharge. But both jars and their circuits need not be tuned any closer than a basso profundo is to the note produced by a mosquito, as small sparks will be produced through the air space, or at least the latter will be considerably more strained owing to the setting up of an alternating E. M. F. by induction, which takes place when one of the jars begins to discharge. Again, another error of a similar nature is quite easily made. If the circuits of the two jars are run parallel and close together, and the experiment has been performed of discharging one by the other, and now a coil of wire be added to one of the circuits whereupon the experiment does not succeed, the conclusion that this is due to the fact that the circuits are now not tuned would be far from being safe. For the two circuits act as condenser coatings, and the addition of the coil to one of them is equivalent to bridging them, at the point where the coil is placed, by a small condenser, and the effect of the latter might be to prevent the spark from jumping through the discharge space by diminishing the alternating E. M. F. acting across the same. All these remarks, and many more which might be added but for fear of wandering too far from the subject, are made with the pardonable intention of cautioning the unsuspecting student, who might gain an entirely unwarranted opinion of his skill when seeing every experiment succeed; but they are in no way thrust upon the experienced as novel observations.

In order to make reliable observations of electric resonance effects it is very desirable, if not necessary, to employ an alternator giving currents which rise and fall harmonically, as in working with make and break currents the observations are not always trustworthy, since many phenomena, which depend on the rate of change, may be produced with frequencies widely different. Even when making such observations with an alternator one is apt to be mistaken. When a circuit is connected to an alternator there are an infinite number of values for capacity and self-induction which, in conjunction, will satisfy the condition of resonance. So there are in mechanics an infinite number of tuning forks which will respond to a note of a certain pitch, or loaded springs which have a definite period of vibration. But the resonance will be most perfectly attained in that case in which the motion is effected with the greatest freedom. Now in mechanics, considering the vibration in the common medium—that is, air—it is of comparatively little importance whether one tuning fork be somewhat larger than another, because the losses in the air are not very considerable. One may, of course, inclose a tuning fork in an exhausted vessel, and by thus reducing the air resistance to a minimum obtain better resonant action. Still the difference would not be very great. But it would make a great difference if the tuning fork were immersed in mercury. In the electrical vibration it is of enormous importance to arrange the conditions so that the vibration is effected with the greatest freedom. The magnitude of the resonance effect depends, under otherwise equal conditions, on the quantity of electricity set in motion or on the strength of the current driven through the circuit. But the circuit opposes the passage of the currents by reason of its impedance, and, therefore, to secure the best action, it is necessary to reduce the impedance to a minimum. It is impossible to overcome it entirely, but merely in part, for ohmic resistance cannot be overcome. But when the frequency of the impulses is very great, the flow of the current is practically determined by self-induction. Now self-induction can be overcome by combining it with capacity. If the relation between these is such that at the frequency used they annul each other, that is, have such values as to satisfy the condition of resonance, and the greatest quantity of electricity is made to flow through the external circuit, then the best result is obtained. It is simpler and safer to join the condenser in series with the self-induction. It is clear that in such combinations there will be, for a given frequency, and considering only the fundamental vibration, values which will give the best result, with the condenser in shunt to the self-induction coil; of course, more such values than with the condenser in series. But practical conditions determine the selection. In the latter case in performing the experiments one may take a small self-induction and a large capacity or a small capacity and a large self-induction, but the latter is preferable, because it is convenient to adjust a large capacity by small steps. By taking a coil with a very large self-induction, the critical capacity is reduced to a very small value, and the capacity of the coil itself may be sufficient. It is easy, especially by observing certain artifices, to wind a coil through which the impedance will be reduced to the value of the ohmic resistance only, and for any coil there is, of course, a frequency at which the maximum current will be made to pass through the coil. The observation of the relation between self-induction, capacity and frequency is becoming important in the operation of alternate current apparatus, such as transformers or motors, because by a judicious determination of the elements the employment of an expensive condenser becomes unnecessary. Thus it is possible to pass through the coils of an alternating current motor under the normal working conditions the required current with a low E. M. F. and do away entirely with the false current, and the larger the motor the easier such a plan becomes practicable; but it is necessary for this to employ currents of very high potential or high frequency.

In Fig. 20 I is shown a plan which has been followed in the study of the resonance effects by means of a high-frequency alternator. C is a coil of many turns, which is divided in small separate sections for the purposes of adjustment. The final adjustment was made sometimes with a few thin iron wires (though this is not always advisable), or with a closed secondary. The coil C is connected with one of its ends to the line L from the alternator G, and with the other end to one of the plates c of a condenser c c_1, the plate (c_1) of the latter being connected to a much larger plate P_1. In this manner, both capacity and self-induction were adjusted to suit the dynamo frequency.

As regards the rise of potential through resonant action, of course, theoretically, it may amount to anything since it depends on self-induction and resistance, and since these may have any value. But in practice one is limited in the selection of these values, and besides these, there are other limiting causes. One may start with, say, 1,000 volts, and raise the E. M. F. to 50 times that value, but one cannot start with 100,000 and raise it to 10 times that value, because of the losses in the media, which are great, especially if the frequency is high. It should be possible to start with, for instance, two volts from a high or low frequency circuit of a dynamo, and raise the E. M. F. to many hundred times that value. Thus coils of the proper dimensions might be connected each with only one of its ends to the mains from a machine of low E. M. F., and though the circuit of the machine would not be closed in the ordinary acceptance of the term, yet the machine might be burned out if a proper resonance effect would be obtained. I have not been able to produce, nor have I observed with currents from the dynamo machine, such great rises of potential. It is possible, if not probable, that with currents obtained from apparatus containing iron, the disturbing influence of the latter is the cause that these theoretical possibilities cannot be realized. But if such is the case, I attribute it solely to the hysteresis and Foucault current losses in the core. Generally it was necessary to transform upward, when the E. M. F. was very low, and usually an ordinary form of induction coil was employed, but sometimes the arrangement illustrated in Fig. 20 II has been found to be convenient. In this case a coil C is made in a great many sections, a few of these being used as the primary. In this manner both primary and secondary are adjustable. One end of the coil is connected to the line L_1 from the alternator, and the other line, L, is connected to the intermediate point of the coil. Such a coil with adjustable primary and secondary will be found also convenient in experiments with the disruptive discharge. When true resonance is obtained, the top of the wave must, of course, be on the free end of the coil, as, for instance, at the terminal of the phosphorescence bulb B. This is easily recognized by observing the potential on a point on the wire w nearer to the coil.

In connection with resonance effects and the problem of transmission of energy over a single conductor, which was previously considered, I would say a few words on a subject which constantly fills my thoughts, and which concerns the welfare of all. I mean the transmission of intelligible signals, or perhaps even power, to any distance without the use of wires. I am becoming daily more con-

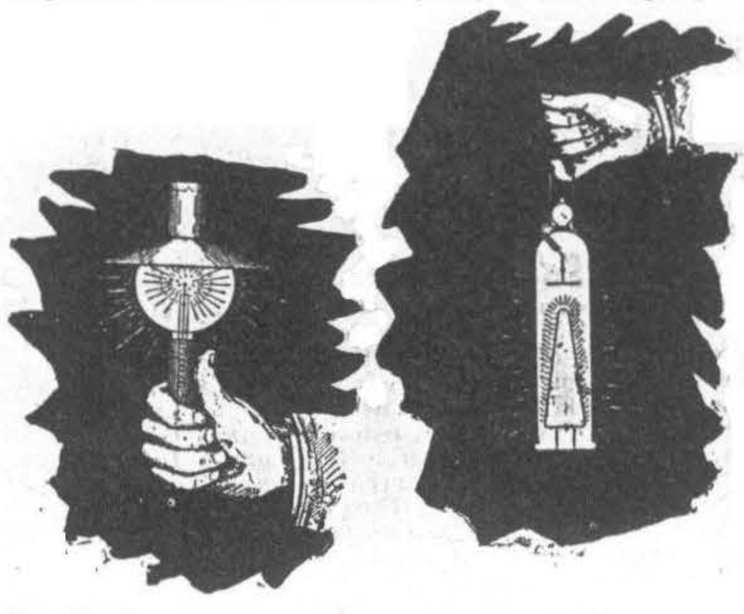


FIG. 26.—INCANDESCENCE OF A SOLID.

FIG. 27.—PHOSPHERENCE.

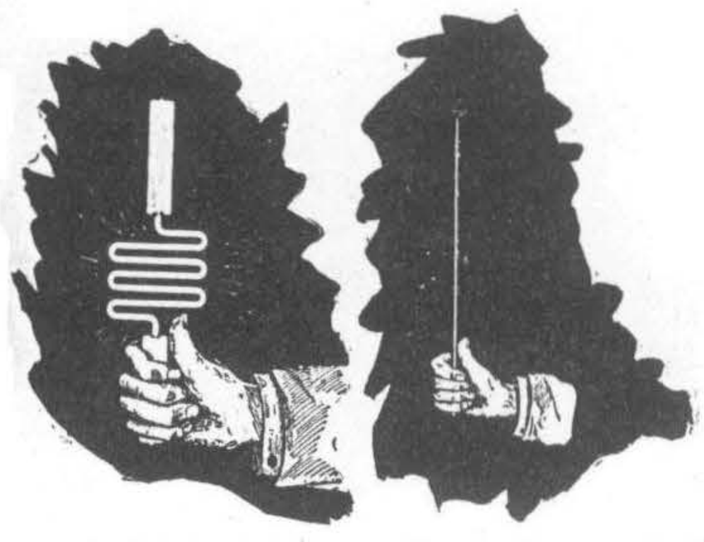


FIG. 28.—INCANDESCENCE OR PHOSPHERENCE OF RAREFIED GAS.

FIG. 29.—LUMINOSITY OF GAS AT ORDINARY PRESSURE.

FOUR KINDS OF LIGHT EFFECTS BY HIGH FREQUENCY CURRENTS OF HIGH POTENTIAL.

vinced of the practicability of the scheme; and though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realized, yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day. The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations.

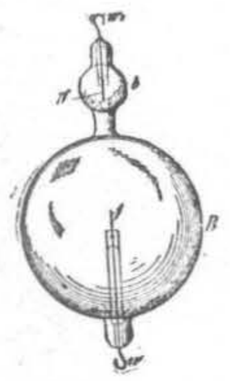


FIG. 30.—SHOWING THE EFFECT OF CONFINING THE GAS AROUND THE ELECTRODE.

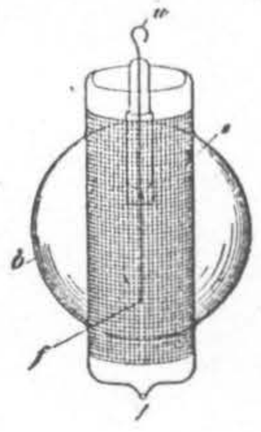


FIG. 31.—SHOWING THE INEFFICIENCY OF A METAL SCREEN.

Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb by means of powerful machines the electrostatic condition of the earth and thus transmit intelligible signals and perhaps power. In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why then not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile-posts the earth may appear very large, but to that happiest of all men, the astronomer, who gazes at the heavens and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician, for when he considers the speed with which an electric disturbance is propagated through the earth all his ideas of distance must completely vanish.

A point of great importance would be, first, to know what is the capacity of the earth and what charge does it contain if electrified? Though we have no positive evidence of a charged body, existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation. If it be a charged body insulated in space its capacity should be extremely small, less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and, that is, by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric currents. One of the terminals of the source would be connected to earth as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata or free space contains an opposite charge and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body and watching for the disturbance at various neighboring points of the earth's surface resonance might be detected. Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do, and a proper electrical oscillator would have to be produced, and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface.

Assume that a source of alternating currents S be connected, as in Fig. 21, with one of its terminals to earth (conveniently to the water mains) and with the other to a body of large surface P. When the electric oscillation is set up there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to, or diverging from, the point C where the ground connection is made. In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body P is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source S will set up the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration at least of a certain low period upon the earth, by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured. I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at the surface could be but extremely small considering the size of the earth, the air would not act as a very disturbing factor and there would be not much energy lost through the action of the air, which would be the case if the density were great. Theoretically, then, it could not require a great amount of energy to produce a disturbance perceptible at great distance, or even all over the surface of the globe. Now it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source S_1, Fig. 21, similar to S, or any number of such sources can be set to work in synchronism with the latter and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S_1 if the same be of opposite phase to the source S. I think that beyond doubt it is possible to operate electrical devices in a city through the ground or pipe system by resonance from an electrical oscillator located at a central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realization of the scheme of transmitting intelligence or perhaps power to any distance through the earth or environing medium. If this is at all possible, distance does not mean anything. Proper apparatus must first be produced by means of which the problem can be attacked, and I have devoted much thought to this subject. I am firmly convinced that it can be done and hope that we shall live to see it done.

ON THE LIGHT PHENOMENA PRODUCED BY HIGH-FREQUENCY CURRENTS OF HIGH POTENTIAL, AND GENERAL REMARKS RELATING TO THE SUBJECT.

Returning now to the light effects which it has been the chief object to investigate, it is thought proper to divide these effects into four classes: 1. Incandescence of a solid. 2. Phosphorescence. 3. Incandescence or phosphorescence of a rarefied gas, and 4. Luminosity produced in a gas at ordinary pressure. The first question is, How are these luminous effects produced? In order to answer this question as satisfactorily as I am able to do in the light of accepted views and with the experience acquired, and to add some interest to this demonstration, I shall dwell here upon a feature which I consider of great importance, inasmuch as it promises, besides, to throw a better light upon the nature of most of the phenomena produced by high-frequency electric currents. I have on other occasions pointed out the great importance of the presence of the rarefied gas, or atomic medium in general, around the conductor through which alternate currents of high frequency are passed, as regards the heating of the conductor by the currents. My experiments described some time ago have shown that the higher the frequency and potential difference of the currents, the more important becomes the rarefied gas in which the conductor is immersed, as a factor of the heating. The potential difference, however, is, as I then pointed out, a more important element than the frequency. When both of these are sufficently high, the heating may be almost entirely due to the presence of the rarefied gas. The experiments to follow will show the importance of the rarefied gas, or generally of gas at ordinary or other pressure as regards the incandescence or other luminous effects produced by currents of this kind.



FIG. 32.—ELECTROSTATIC ACTION BETWEEN PRIMARY AND SECONDARY, WITH EXTREMELY HIGH FREQUENCIES.

I take two ordinary 50-volt 16-c. p. lamps which are in every respect alike, with the exception that one has been opened at the top and the air has filled the bulk, while the other is at the ordinary degree of exhaustion of commercial lamps. When I attach the lamp, which is exhausted, to the terminal of the secondary of the coil, which I have already used as in experiments illustrated in Fig. 15*a* for instance, and turn on the current, the filament, as you have before seen, comes to high incandescence. When I attach the second lamp, which is filled with air, instead of the former, the filament still glows, but much less brightly. This experiment illustrates only in part the truth of the statements before made. The importance of the filament's being immersed in rarefied gas is plainly noticeable, but not to such a degree as might be desirable. The reason is that the secondary of this coil is wound for low tension, having only 150 turns, and the potential difference at the terminals of the lamp is therefore small. Were I to take another coil with many more turns in the secondary, the effect would be increased, since it depends partially on the potential difference, as before remarked. But since the effect likewise depends on the frequency, it may be properly stated that it depends on the time rate of the variation of the potential difference. The greater this variation, the more important becomes the gas as an element of heating. I can produce a much greater rate of variation in another way, which besides has the advantage of doing away with the objections which might be made in the experiment just shown, even if both the lamps were connected in series or multiple arc to the coil, namely, that in consequence of the reactions existing between the primary and secondary coil the conclusions are rendered uncertain. This result I secure by charging from an ordinary transformer, which is fed from the alternating current supply station, a battery of condensers, and discharging the latter directly through a circuit of small self-induction, as before illustrated in Figs. 19a, 19b, 19c.

In Figs. 22a, 22b and 22c the heavy copper bars B, B_1 are connected to the opposite coatings of a battery of condensers, or generally in such way that the high frequency or sudden discharges are made to traverse them. I connect first an ordinary 50-volt incandescent lamp to the bars by means of the clamps c, c. The discharges being passed through the lamp, the filament is rendered incandescent, though the current through it is very small, and would not be nearly sufficient to produce a visible effect under the conditions of ordinary use of the lamp. Instead of this I now attach to the bars another lamp exactly like the first, but with the seal broken off, the bulb being therefore filled with air at ordinary pressure. When the discharges are directed through the filament, as before, it does not become incandescent. But the result might still be attributed to one of the many possible reactions. I therefore connect both the lamps in multiple arc as illustrated in Fig. 22a. Passing the discharges through both the lamps, again the filament in the exhausted lamp l glows very brightly, while that in the non-exhausted lamp l_1 remains dark; as, previously. But it should not be thought that the latter lamp is taking only a small fraction of the energy supplied to both the lamps; on the contrary, it may consume a considerable portion of the energy, and it may become even hotter than the one which burns brightly. In this experiment the potential difference at the terminals of the lamps varies in sign theoretically three to four million times a second. The ends of the filaments are correspondingly electrified, and the gas in the bulbs is violently agitated and a large portion of the supplied energy is thus converted into heat. In the non-exhausted bulb, there being a few million times more gas molecules than in the exhausted one, the bombardment, which is most violent at the ends of the filament, in the neck of the bulb, consumes a large portion of the energy without producing a any visible effect. The reason is that, there being many molecules, the bombardment is quantitatively considerable, but the individual impacts are not very violent, as the speeds of the molecules are comparatively small owing to the small free path. In the exhausted bulb, on the contrary, the speeds are very great, and the individual impacts are violent and therefore better adapted to produce a visible effect. Besides, the convection of heat is greater in the former bulb. In both the bulbs the current traversing the filaments is very small, incomparably smaller than that which they require on an ordinary low-frequency circuit. The potential difference, however, at the ends of the filaments is very great and might be possibly 20,000 volts or more if the filaments were straight and their ends far apart. In the ordinary lamp a spark generally occurs between the ends of the filament or between the platinum wires outside, before such a difference of potential can be reached.

It might be objected, in the experiment before shown, that, the lamps being in multiple arc, the exhausted lamp might take a much larger current, and that the effect observed might not be exactly attributable to the action of the gas in the bulbs. Such objections will lose much weight if I connect the lamps in series with the same result. When this is done, and the discharges are directed through the filaments, it is again noted that the filament in the non-exhausted bulb, l_1, remains dark, while that in the exhausted one, l, glows even more intensely than under its normal conditions of working, Fig. 22b. According to general ideas, the current through the filaments should now be the same, were it not modified by the presence of the gas around the filaments.

At this juncture I may point out another interesting feature, which illustrates the effect of the rate of change of potential of the currents. I will leave the two lamps connected in series to the bars B, B_1, as in the previous experiment, Fig. 22b, but will presently reduce considerably the frequency of the currents, which was excessive in the experiment just before shown. This I may do by inserting a self-induction coil in the path of the discharges, or by augmenting the capacity of the condensers. When I now pass these low frequency discharges through the lamps, the exhausted lamp, l, again is as bright as before, but it is noted also that the non exhausted lamp, l_1, glows, though not quite as intensely as the other. Reducing the current through the lamps, I may bring the filament in the latter lamp to redness, and, though the filament in the exhausted lamp l, is bright, Fig. 22c, the degree of its incandescence is much smaller than in Fig. 22b, when the currents were of a much higher frequency.

In these experiments the gas acts in two opposite ways in determining the degree of the incandescence of the filaments; that is, by convection and bombardment. The higher the frequency and potential of the currents, the more important becomes the bombardment. The convection, on the contrary, should be the smaller, the higher the frequency. When the currents are steady, there is practically no bombardment, and convection may therefore with such currents also considerably modify the degree of incandescence and produce results similar to those just before shown. Thus, if two lamps exactly alike, one exhausted and one not exhausted, are connected in multiple arc or series to a direct current machine, the filament in the non-exhausted lamp will require a considerably greater current to be rendered incandescent. This result is entirely due to convection, and the effect is the more prominent the thinner the filament. Prof. Ayrton and Mr. Kilgour some time ago published quantitative results concerning the thermal emissivity by radiation and convection, in which the effect of thin wires was clearly shown. This effect may be strikingly illustrated by preparing a number of small, short glass tubes, each containing through its axis the thinnest obtainable platinum wire. If these tubes be highly exhausted, a number of them may be connected in multiple arc to a direct current machine, and all of the wires may be kept at incandescence with a smaller current than that required to render incandescent a single one of the wires if the tube be not exhausted. Could the tubes be so highly exhausted that convection would be nil, then the relative amounts of heat given off by convection and radiation could be determined without the difficulties attending thermal quantitative measurements. If a source of electric impulses of high frequency and very high potential is employed, a still greater number of the tubes may be taken and the wires rendered incandescent by a current not capable of warming perceptibly a wire of the same size immersed in air at ordinary pressure, and conveying the energy to all of them.

I may here describe a result which is still more interesting, and to which I have been led by the observation of these phenomena. I noted that small differences in the



FIG. 33.—CARBON DEPOSIT IN TUBE IN A MAGNETIC FIELD.

density of the air produced a considerable difference in the degree of incandescence of the wires, and I thought that, since in a tube, through which a luminous discharge is passed, the gas is generally not of uniform density, a very thin wire contained in the tube might be rendered incandescent at certain places of smaller density of the gas, while it would remain dark at the places of greater density, where the convection would be greater and the bombardment less intense. Accordingly a tube, t, was prepared, as illustrated in Fig. 23, which contained through the middle a very fine platinum wire w. The tube was exhausted to a moderate degree, and it was found that when it was attached to the terminal of a high frequency coil the platinum wire w would, indeed, become incandescent in patches, as illustrated in Fig. 23. Later a

number of these tubes with one or more wires were prepared, each showing this result. The effect was best noted when the striated discharge occurred in the tube, but was also produced when the striæ were not visible, showing that, even then, the gas in the tube was not of uniform density. The position of the striæ was generally such that the rarefactions corresponded to the places of incandescence or greater brightness on the wire w. But in a few instances it was noted that the bright spots on the wire were covered by the dense parts of the striated discharge as indicated by 1 in Fig. 23, though the effect was barely perceptible. This was explained in a plausible way by assuming, that the convection was not widely different in the dense and rarefied places, and that the bombardment was greater on the dense places of the striated discharge. It is, in fact, often observed in bulbs that under certain conditions a thin wire is brought to higher incandescence when the air is not too highly rarefied. This is the case when the potential of the coil is not high enough for the vaccum, but the result may be attributed to many different causes. In all cas s this curious phenomenon of incandescence disappears when the tube, or rather the wire, acquires throughout a uniform temperature.

Disregarding now the modifying effect of convection, there are then two distinct causes which determine the incandescence of a wire or filament with varying currents; that is, conduction current and bombardment. With steady currents we have to deal only with the former of these two causes, and the heating effect is a minimum, since the resistance is least to steady flow. When the current is a varying one, the resistance is greater, and hence the heating effect is increased. Thus, if the rate of change of the current is very great, the resistance may increase to such an extent that the filament is brought to incandescence with inappreciable currents; and we are able to take a short and thick block of carbon or other material and bring it to bright incandescence with a current incomparably smaller than that required to bring to the same degree of incandescence an ordinary thin lamp filament with a steady or low frequency current. This result is important, and illustrates how rapidly our views on these subjects are changing and how quickly our field of knowledge is extending. In the art of incandescent lighting, to view this result in one aspect only, it has been commonly considered as an essential requirement for practical success that the lamp filament should be thin and of high resistance, But now we know that the resistance to the steady flow of the filament does not mean anything; the filament might as well be short and thick; for if it be immersed in rarefied gas it will become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents. We may conclude from this that it would be of advantage, so far as the lamp is considered, to employ high frequencies for lighting, as they allow the use of short and thick filaments and smaller currents.

If a wire or filament be immersed in a homogeneous medium, all the heating is due to true conduction current; but if it be inclosed in an exhausted vessel, the conditions are entirely different. Here the gas begins to act, and the heating effect of the conduction current, as shown in many experiments, may be very small compared with that of the bombardment. This is especially the case if the circuit is not closed and the potentials, of course, very high. Suppose a fine filament inclosed in an exhausted vessel be connected with one of its ends to the terminal of a high tension coil, and with its other end to a large insulated plate. Though the circuit is not closed, the filament, as I have before shown, is brought to incandescence. If the frequency and potential be comparatively low, the filament is heated by the current passing *through* it. If the frequency and potential, and principally the latter, be increased, the insulated plate need be but very small, or may be done away with entirely; still the filament will become incandescent, practically all the heating being then due to the bombardment. A practical way of combining both the effects of conduction current and bombardment is illustrated in Fig. 24, in which an ordinary lamp is shown provided with a very thin filament which has one of the ends of the latter connected to a shade serving the purpose of the insulated plate, and the other end to the terminal of a high tension source. It should not be thought that only rarefied gas is an important factor in the heating of a conductor by varying currents, but gas at ordinary pressure may become important, if the potential difference and frequency of the currents is excessive. On this subject I have already stated that when a conductor is fused by a stroke of lightning the current through it may be exceedingly small, not even sufficient to heat the conductor perceptibly were the latter immersed in a homogeneous medium.

From the preceding it is clear that when a conductor of high resistance is connected to the terminals of a source of high frequency currents of high potential, there may occur considerable dissipation of energy, principally on the ends of the conductor, in consequence of the action of the gas surrounding the conductor. Owing to this, the current through a section of the conductor at a point midway between its ends may be much smaller than through a section near the ends. Furthermore, the current passes principally through the outer portions of the conductor, but this effect is to be distinguished from the skin effect as ordinarily interpreted, for the latter would or should occur also in a continuous incompressible medium. If a great many incandescent lamps are connected in series to a source of such currents, the lamps at the ends may burn brightly, whereas those in the middle may remain entirely dark. This is due principally to bombardment, as before stated. But even if the currents be steady, provided the difference of potential is very great, the lamps at the ends will burn more brightly than those in the middle. In such case there is no rhythmical bombardment and the result is produced entirely by leakage. This leakage or dissipation into space when the tension is high is considerable when incandescent lamps are used, and still more considerable with arcs, for the latter act like flames. Generally, of course, the dissipation is much smaller with steady than with varying currents.

I have contrived an experiment which illustrates in an interesting manner the effect of lateral diffusion. If a very long tube is attached to the terminal of a high frequency coil, the luminosity is greatest near the terminal and falls off gradually toward the remote end. This is more marked if the tube is narrow.

A small tube about one-half inch in diameter and twelve inches long, Fig. 25, has one of its ends drawn out into a fine fibre f nearly three feet long. The tube is placed in a brass socket T which can be screwed on the terminal T_1 of the induction coil. The discharge passing through the tube first illuminates the bottom of the same, which is of comparatively large section; but through the long glass fibre the discharge cannot pass. But gradually the rarefied gas inside becomes warmed and more conducting, and the discharge spreads into the glass fibre. This spreading is so slow that it may take half a minute or more until the discharge has worked through up to the top of the glass fibre, then presenting the appearance of a strongly luminous thin thread. By adjusting the potential at the terminal the light may be made to travel upward at any speed. Once, however, the glass fibre is heated the discharge breaks through its entire length instantly. The interesting point to be noted is that, the higher the frequency of the currents, or in other words the greater relatively the lateral dissipation, at a slower rate may the light be made to propagate through the fibre. This experiment is best performed with a highly exhausted and freshly made tube. When the tube has been used for some time the experiment often fails. It is possible that the gradual and slow impairment of the vacuum is the cause. This slow propagation of the discharge through a very narrow glass tube corresponds exactly to the propagation of heat through a bar warmed at one end. The quicker the heat is carried away laterally the longer time it will take for the heat to warm the remote end. When the current of a low frequency coil is passed through the fibre from end to end, then the lateral dissipation is small, and the discharge instantly breaks through almost without exception.

After these experiments and observations, which have shown the importance of the discontinuity or atomic structure of the medium, and which will serve to explain, in a measure at least, the nature of the four kinds of light effects produceable with these currents, I may now give you an illustration of these effects. For the sake of interest I may do this in a manner which to many of you might be novel. You have seen before that we may now convey the electric vibration to a body by means of a single wire or conductor of any kind. Since the human frame is conducting I may convey the vibration through my body.

First, as in some previous experiments, I connect my body with one of the terminals of a high tension transformer, and take in my hand an exhausted bulb which contains a small carbon button mounted upon a platinum wire leading to the outside of the bulb, and the button is rendered incandescent as soon as the transformer is set to work (Fig. 26). I may place a conducting shade on the bulb which serves to intensify the action, but it is not necessary. Nor is it required that the button should be in conducting connection with the hand through a wire leading through the glass, for sufficient energy may be transmitted through the glass itself by inductive action to render the button incandescent.

Next I take a highly exhausted bulb containing a strongly phosphorescent body, above which is mounted a small plate of aluminum on a platinum wire leading to the outside, and the currents flowing through my body excite intense phosphorescence in the bulb, Fig. 27. Next again I take in my hand a simple exhausted tube, and in the same manner the gas inside the tube is rendered highly incandescent or phosphorescent, Fig. 28. Finally, I may take in my hand a wire—bare or covered with thick insulation, it is quite immaterial; the electric vibration is so intense as to cover the wire with a luminous film, Fig 29.

A few words must now be devoted to each of these phenomena. In the first place, I will consider the incandescence of a button or of a solid in general, and dwell upon some facts which apply equally to all these phenomena. It was pointed out before that when a thin conductor, such as a lamp filament, for instance, is connected with one of its ends to the terminal of a transformer of high tension, the filament is brought to incandescence partly by a conduction current and partly by bombardment. The shorter and thicker the filament, the more important becomes the latter, and, finally, reducing the filament to a mere button, all the heating must practically be attributed to the bombardment. So in the experiment before shown, the button is rendered incandescent by the rhythmical impact of freely movable small bodies in the bulb. These bodies may be the molecules of the residual gas, particles of dust or lumps torn from the electrode; whatever they are, it is certain that the heating of the button is essentially connected with the pressure of such freely movable particles, or of atomic matter in general in the bulb. The heating is the more intense the greater the number of impacts per second and the greater the energy of each impact. Yet the button would be heated also if it were connected to a source of steady potential. In such a case electricity would be carried away from the button by the freely movable carriers or particles flying about, and the quantity of electricity thus carried away might be sufficient to bring the button to incandescence by its passage through the latter. But the bombardment could not be of great importance in such case. For this reason it would require a comparatively very great supply of energy to the button to maintain it at incandescence with a steady potential. The higher the frequency of the electric impulses, the more economically can the button be maintained at incandesence. One of the chief reasons why this is so, is, I believe, that with impulses of very high frequency there is less exchange of the freely movable carriers around the electrode, and this means that in the bulb the heated matter is better confined to the neighborhood of the button. If a double bulb, as illustrated in Fig. 30, be made, comprising a large globe B and a small one b, each containing as usual a filament f mounted on a platinum wire w and w_1 it is found, that if the filaments f f be exactly alike, it requires less energy to keep the filament in the globe b at a certain degree of incandescence than in the large globe, B. This is due to the confinement of the movable particles around the button. In this case, it is also ascertained, that the filament in the small globe b is less deteriorated when maintained a certain length of time at incandescence. This is a necessary consequence of the fact that the gas in the small bulb becomes strongly heated and therefore a very good conductor, and less work is then performed on the button, since the bombardment becomes less intense as the conductivity of the gas increases. In this construction, of course, the small bulb becomes very hot, and when it reaches an elevated temperature the convection and radiation on the outside increase. On another occasion, I have shown bulbs in which this drawback was largely avoided. In these instances a very small bulb, containing a refractory button, was mounted in a large globe, and the space between the walls of both was highly exhausted. The outer large globe remained comparatively cool in such constructions. When the large globe was on the pump and the vacuum between the walls maintained permanent by the continuous action of the pump, the outer globe would remain quite cold, while the button in the small bulb was kept at incandescence. But when the seal was made, and the button in the small bulb maintained incandescent some length of time, the large globe too would become warmed. From this I conjectured that if vacuous space (as Prof. Dewar finds) cannot convey heat, it is so merely in virtue of our rapid motion through space or, generally speaking, by the motion of the medium relatively to us, for a permanent condition could not be maintained without the medium being constantly renewed. A vacuum cannot, according to all evidence, be permanently maintained around a hot body.

In these constructions, before mentioned, the small bulb inside would, at least in the first stages, prevent all bombardment against the outer, large globe. It occurred to me then, to ascertain how a metal sieve would behave in this respect, and several bulbs, as illustrated in Fig. 31, were prepared for this purpose. In a globe, b, was mounted a thin filament f (or button) upon a platinum wire w passing through a glass stem and leading to the outside of the globe. The filament f was surrounded by a metal sieve s. It was found in experiments with such bulbs that a sieve with wide meshes apparently did not in the slightest affect the bombardment against the globe b. When the vacuum was high, the shadow of the sieve was clearly projected against the globe, and the latter would get hot in a short while. In some bulbs the sieve was connected to a platinum wire sealed in the glass. When this wire was connected to the other terminal of the induction coil (the E. M. F. being kept low in this case) or to an insulated plate, the bombardment against the outer globe b was diminished. By taking a sieve with fine meshes the bombardment against the globe b was diminished, but even then if the exhaustion was carried very far, and when the potential of the transformer was very high, the globe b would be bombarded and heated quickly, though no shadow of the sieve was visible owing to the smallness of the meshes. But a glass tube or other continuous body mounted so as to surround the filament, did entirely cut off the bombardment and for a while the outer globe b would remain perfectly cold. Of course, when the glass tube was sufficiently heated, the bombardment against the outer globe could be noted at once. The experiments with these bulbs seemed to show that the speeds of the projected molecules or particles must be considerable (though quite insignificant when compared with that of light), otherwise it would be difficult to understand how they could traverse a fine metal sieve without being affected, unless it were found that such small particles or atoms cannot be acted upon directly at measurable distances. In regard to the speed of the projected atoms, Lord Kelvin has recently estimated it at about one kilometre a second or thereabouts in an ordinary Crookes bulb. As the potentials obtainable with a disruptive discharge coil are much higher than with ordinary coils, the speeds must, of course, be much greater when the bulbs are lighted from such a coil. Assuming the speed to be as high as five kilometres and uniform through the whole trajectory, as it should be in a very highly exhausted vessel, then if the alternate electrifications of the electrode would be of a frequency of five million, the greatest distance a particle could get away from the electrode would be one millimetre, and if it could be acted upon directly at that distance, the exchange of electrode matter or of the

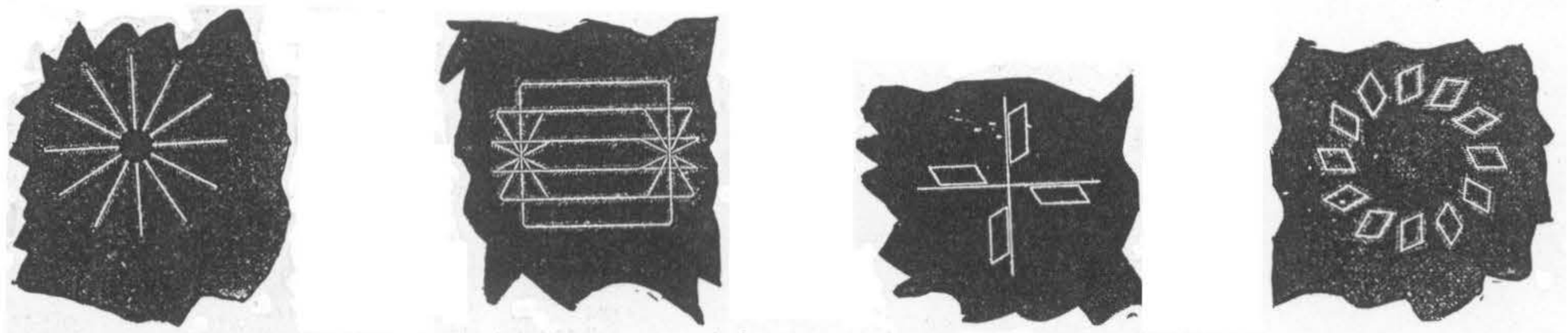


FIG. 34.—SPOKE WHEEL. DRUM WINDING. ALTERNATE MOTOR WINDING. RING WINDING.

SOME OF THE DESIGNS PRODUCED BY INTERMITTENT DISCHARGES.

atoms would be very slow, and there would be practically no bombardment against the bulb. This at least should be so, if the action of an electrode upon the atoms of the residual gas would be such as upon electrified bodies which we can perceive. A hot body inclosed in an exhausted bulb produces always atomatic bombardment, but a hot body has no definite rhythm, for its molecules perform vibrations of all kinds.

If a bulb containing a button or filament be exhausted as high as is possible with the greatest care and by the use of the best artifices, it is often observed that the discharge cannot, at first, break through, but after some time, probably in consequence of some changes within the bulb, the discharge finally passes through and the button is rendered incandescent. In fact, it appears that the higher the degree of exhaustion, the easier is the incandescence produced. There seems to be no other causes which the incandescence might be attributed in such case, except to the bombardment or similar action of the residual gas, or of particles of matter in general. But if the bulb be exhausted with the greatest care, can these play an important part? Assume the vacuum in the bulb to be tolerably perfect, the great interest then centres in the question: Is the medium which pervades all space continuous or atomic? If atomic then the heating of a conducting button or filament in an exhausted vessel might be due largely to etherbombardment, and then the heating of a conductor in general through which currents of high frequency or high potential are passed must be modified by the behavior of such medium; then also the skin effect, the apparent increase of the ohmic resistance, etc., admit, partially, at least, of a different explanation.

It is certainly more in accordance with many phenomena observed with high-frequency currents to hold that all space is pervaded with free atoms, rather than to assume that it is devoid of these, and dark and cold, for so it must be, filled with a continuous medium, since in such there can be neither heat nor light. Is, then, energy transmitted by independent carriers or by the vibration of a continuous medium? This important question is by no means as yet positively answered. But most of the effects which are here considered, especially the light effects, incandescence, or phosphorescence, involve the presence of free atoms and would be impossible without these.

In regard to the incandescence of a refractory button (or filament) in an exhausted receiver, which has been one of the subjects of this investigation, the chief experiences, which may serve as a guide in constructing such bulbs, may be summed up as follows: 1. The button should be as small as possible, spherical, of a smooth or polished surface and of refractory material, which withstands evaporation best. 2. The support of the button should be very thin and screened by an aluminum and mica sheet, as I have described on another occasion. 3. The exhaustion of the bulb should be as high as possible. 4. The frequency of the currents should be as high as practicable. 5. The currents should be of a harmonic rise and fall, without sudden interruptions. 6. The heat should be confined to the button by inclosing the same in a small bulb or otherwise. 7. The space between the walls of the small bulb and the outer globe should be highly exhausted.

Most of the considerations which apply to the incandescence of a solid just considered may likewise be applied to phosphorescence. Indeed, in an exhausted vessel the phosphorescence is, as a rule, primarily excited by the powerful beating of the electrode stream of atoms against the phosphorescent body. Even in many cases, where there is no evidence of such a bombardment, I think that phosphorescence is excited by violent impacts of atoms, which are not necessarily thrown off from the electrode, but are acted upon from the same inductively through the medium or through chains of other atoms. That mechanical shocks play an important part in exciting phosphorescence in a bulb may be seen from the following experiment. If a bulb, constructed as that illustrated in Fig. 10, be taken and exhausted with the greatest care so that the discharge cannot pass, the filament f acts by electrostatic induction upon the tube t, and the latter is set in vibration. If the tube o be rather wide, about an inch or so, the filament may be so powerfully vibrated that whenever it hits the glass tube it excites phosphorescence. But the phosphorescence ceases when the filament comes to rest. The vibration can be arrested and again started by varying the frequency of the currents. Namely, the filament has its own period of vibration, and if the frequency of the currents is such that there is resonance, it is set easily vibrating, though the potential of the currents be small. I have often observed that the filament in the bulb is destroyed by such mechanical resonance. The filament vibrates as a rule so rapidly that it cannot be seen, and the experimenter may at first be mystified. When such an experiment as the one described is carefully performed, the potential of the currents need be extremely small, and for this reason I infer that the phosphoresence is then due to the mechanical shock of the filament against the glass, just as it is produced by striking a loaf of sugar with a knife. The mechanical shock produced by the projected atoms is easily noted when a bulb containing a button is grasped in the hand and the current turned on suddenly. I believe that a bulb could be shattered by observing the conditions of resonance.

In the experiment before cited it is, of course, open to say that the glass tube upon coming in contact with the filament retains a charge of a certain sign upon the point of contact. If now the filament again touches the glass at the same point while it is oppositely charged, the charges equalize under evolution of light. But nothing of importance would be gained by such an explanation. It is unquestionable that the initial charges given to the atoms or to the glass play some part in exciting phosphorescence. So, for instance, if a phosphorescent bulb be first excited by a high frequency coil by connecting it to one of the terminals of the latter and the degree of luminosity noted, and then the bulb be highly charged from a Holtz machine by attaching it preferably to the positive terminal of the machine, it is found that when the bulb is again connected to the terminal of the high frequency coil, the phosphorescence is far more intense. On another occasion I have considered the possibility of some phosphorescent phenomena in bulbs being produced by the incandescence of an infinitesimal layer on the surface of the phosphorescent body. Certainly, the impacts of the atoms are powerful enough to produce intense incandescence by the collisions, since they bring quickly to a high temperature a body of considerable bulk. If any such effect exists, then the best appliance for producing phosphorescence in a bulb, which we know so far, is a disruptive discharge coil giving an enormous potential with but few fundamental discharges, say 25-30 per second, just enough, to produce a continuous impression upon the eye. It is a fact that such a coil excites phosphorescence under most any condition and at all degrees of exhaustion, and I have observed effects which appear to be due to phosphorescence even at ordinary pressures of the atmosphere, when the potentials are extremely high. But if phosphorescent light is produced by the equalization of charges of electrified atoms (whatever this may mean ultimately), then the higher the frequency of the impulses or alternate electrifications, the more economical will be the light production. It is a long known and noteworthy fact that all the phosphorescent bodies are poor conductors of electricity and heat, and that all bodies cease to emit phosphorescent light when they are brought to a certain temperature. Conductors on the contrary do not possess this quality. There are but few exceptions to the rule. Carbon is one of them. Becquerel noted that carbon phosphorescences at a certain elevated temperature preceding the dark red. This phenomenon may be easily observed in bulbs provided with a rather large carbon electrode (say a sphere of six millimetres diameter). If the current is turned on after a few seconds, a snow white film covers the electrode, just before it gets dark red. Similar effects are noted with other conducting bodies, but many scientific men will probably not attribute them to true phosphorescence. Whether true incandescence has anything to do with phosphorescence excited by atomic impact or mechanical shocks still remains to be decided, but it is a fact that all conditions, which tend to localize and increase the heating effect at the point of impact, are almost invariably the most favorable for the production of phosphorescence. So, if the electrode be very small, which is equivalent to saying in general, that the electric density is great, if the potential be high, and if the gas be highly rarefied, all of which things imply high speed of the projected atoms, or matter, and consequently violent impacts—the phosphorescence is very intense. If a bulb provided with a large and small electrode be attached to the terminal of an induction coil, the small electrode excites phosphorescence while the large one may not do so, because of the smaller electric density and hence smaller speed of the atoms. A bulb provided with a large electrode may be grasped with the hand while the electrode is connected to the terminal of the coil and it may not phosphoresce; but if instead of grasping the bulb with the hand, the same be touched with a pointed wire, the phosphorescence at once spreads through the bulb, because of the great density at the point of contact. With low frequencies it seems that gases of great atomic weight excite more intense phosphorescence than those of smaller weight, as for instance, hydrogen. With high frequencies the observations are not sufficiently reliable to draw a conclusion. Oxygen, as is well known, produces exceptionally strong effects, which may be in part due to chemical action. A bulb with hydrogen residue seems to be most easily excited. Electrodes which are most easily deteriorated produce more intense phosphorescence in bulbs, but the condition is not permanent because of the impairing of the vacuum and the deposition of the electrode matter upon the phosphorescent surfaces. Some liquids as oils, for instance, produce magnificent effects of phosphorescense (or fluorescence?), but they last only a few seconds. So if a bulb have a trace of oil on the walls and the current is turned on, the phophorescence only persists for a few moments until the oil is carried away. Of all bodies so far tried, sulphide of zinc seems to be the most susceptible to phosphorescence. Some samples obtained through the kindness of Prof. Henry in Paris, were employed in many of these bulbs. One of the defects of this sulphide is, that it loses its quality of emitting light when brought to a temperature which is by no means high. It can therefore, be used only for feeble intensities. An observation which might deserve notice is, that when violently bombarded from an aluminium electrode it assumes a black color, but singularly enough, it returns to the original condition when it cools down.

The most important fact arrived at in pursuing investigations in this direction is, that in all cases it is necessary, in order to excite phosphorescence with a minimum amount of energy, to observe certain conditions. Namely, there is always, no matter what the frequency of the currents, degree of exhaustion and character of the bodies in the bulb, a certain potential (assuming the bulb excited from one terminal) or potential difference (assuming the bulb to be excited with both terminals) which produces the most economical result. If the potential be increased, considerable energy may be wasted without producing any more light, and if it be diminished, then again the light production is not as economical. The exact condition under which the best result is obtained seems to depend on many things of a different nature, and it is to be yet investigated by other experimenters, but it will certainly have to be observed when such phosphorescent bulbs are operated, if the best results are to be attained.

Coming now to the most interesting of these phenomena, the incandescence or phosphorescence of gases, at low pressures or at the ordinary pressure of the atmosphere, we must seek the explanation of these phenomena in the same primary causes, that is, in shocks or impacts of the atoms. Just as molecules or atoms beating upon a solid body excite phosphorescence in the same or render it incandescent, so when colliding among themselves they produce similar phenomena. But this is a very insufficient explanation and concerns only the crude mechanism. Light is produced by vibrations which go on at a rate almost inconceivable. If we compute, from the energy contained in the form of known radiations in a definite space the force which is necessary to set up such rapid vibrations, we find, that though the density of the ether be incomparably smaller than that of any body we know, even hydrogen, the force is something surpassing comprehension. What is this force, which in mechanical measure may amount to thousands of tons per square inch? It is electrostatic force in the light of modern views. It is impossible to conceive how a body of measurable dimensions could be charged to so high a potential that the force would be sufficient to produce these vibrations. Long before any such charge could be imparted to the body it would be shattered into atoms. The sun emits light and heat, and so does an ordinary flame or incandescent filament, but in neither of these can the force be accounted for if it be assumed that it is associated with the body as a whole. Only in one way may we account for it, namely, by identifying it with the atom. An atom is so small, that if it be charged by coming in contact with an electrified body and the charge be assumed to follow the same law as in the case of bodies of measurable dimensions, it must retain a quantity of electricity which is fully capable of accounting for these forces and tremendous rates of vibration. But the atom behaves singularly in this respect, it always takes the same "charge."

It is very likely that reasonant vibration plays a most important part in all manifestations of energy in nature. Throughout space all matter is vibrating, and all rates of vibration are represented, from the lowest musical note to the highest pitch of the chemical rays, hence an atom, or complex of atoms, no matter what its period, must find a vibration with which it is in resonance. When we consider the enormous rapidity of the light vibrations, we realize the impossibility of producing such vibrations directly with any apparatus of measurable dimensions, and we are driven to the only possible means of attaining the object of setting up waves of light by electrical means and economically, that is, to affect the molecules or atoms of a gas, to cause them to collide and vibrate. We then must ask ourselves—How can free molecules or atoms be affected?

It is a fact that they can be affected by electrostatic force, as is apparent in many of these experiments. By varying the electrostatic force we can agitate the atoms, and cause them to collide under evolution of heat and light. It is not demonstrated beyond doubt that we can affect them otherwise. If a luminous discharge is produced in a closed exhausted tube, do the atoms arrange themselves in obedience to any other but to electrostatic force acting in straight lines from atom to atom? Only recently I investigated the mutual action between two circuits with extreme rates of vibration. When a battery of a few jars (c c c c, Fig. 32) is discharged through a primary P of low resistance (the connections being as illustrated in Figs. 19a, 19b and 19c), and the frequency of vibration be many million there are great differences of potential between points on the primary not more than a few inches apart. These differences may be 10,000 volts per inch, if not more, taking the maximum value of the E. M. F. The secondary s is therefore acted upon by electrostatic induction, which is in such extreme cases of much greater importance than the electrodynamic. To such sudden impulses the primary as well as the secondary are poor conductors, and therefore great differences of potential may be produced by electrostatic induction between adjacent points on the secondary. Then sparks may jump between the wires and streamers become visible in the dark if the light of the discharge through the spark gap d d be carefully excluded. If now we substitute a closed vacuum tube for the metallic secondary s, the differences of potential produced in the tube by electrostatic induction from the primary are fully sufficient to excite portions of it; but as the points of certain differences of potential on the primary are not fixed, but are generally constantly changing in position, a luminous band is produced in the tube, apparently not touching the glass, as it should, if the points of maximum and minimum differences of potential were fixed on the primary. I do not exclude the possibility of such a tube being excited only by electro-dynamic induction, for very able physicists hold this view; but in my opinion, there is as yet no positive proof given that atoms of a gas in a closed tube may arrange themselves in chains under the action of an electromotive impulse produced by electro-dynamic induction in the tube. I have been unable so far to produce striae in a tube, however long, and at whatever degree of exhaustion, that is, striae at right angles to the supposed direction of the discharge or the axis of the tube, but I have distinctly observed in a large bulb, in which a wide luminous band was produced by passing a discharge of a battery through a wire surrounding the bulb, a circle of feeble luminosity between two luminous bands, one of which was more intense than the other. Furthermore, with my present experience I do not think that such a gas discharge in a closed tube can vibrate, that is, vibrate as a whole. I am convinced that no discharge through a gas can vibrate. The atoms of a gas behave very curiously in respect to sudden electric impulses. The gas does not seem to possess any appreciable inertia to such impulses, for it is a fact, that the higher the frequency of the impulses, with the greater freedom does the discharge pass through the gas. If the gas possesses no inertia then it cannot vibrate, for some inertia is necessary for the free vibration. I conclude from this that if a lightning discharge occurs between two clouds, there can be no oscillation, such as would be expected, considering the capacity of the clouds. But if the lightning discharge strike the earth, there is always vibration —in the earth, but not in the cloud. In a gas discharge each atom vibrates at its own rate, but there is no vibration of the conducting gaseous mass as a whole. This is an important consideration in the great problem of producing light economically, for it teaches us that to reach this result we must use impulses of very high frequency and necessarily also of high potential. It is a fact that oxygen produces a more intense light in a tube. Is it because oxygen atoms possess some inertia and the vibration does not die out instantly? But then nitrogen should be as good, and chlorine and vapors of many other bodies much better than oxygen, unless the magnetic properties of the latter enter prominently into play. Or, is the process in the tube of an electrolytic nature? Many observations certainly speak for it, the most important being, that matter is always carried away from the electrodes and the vacuum in a bulb cannot be permanently maintained. If such process takes places in reality, then again must we take refuge to high frequencies, for with such, electrolytic action should be reduced to a minimum, if not rendered entirely impossible. It is an undeniable fact that with very high frequencies, provided the impulses be of a harmonic nature, like those obtained from an alternator, there is less deterioration and the vacua are more permanent. With disruptive discharge coils there are sudden rises of potential and the vacua are more quickly impaired, for the electrodes are deteriorated in a very short time. It was observed in some large tubes, which were provided with heavy carbon blocks B B_1, connected to platinum wires w w_1 (as illustrated in Fig. 33), and which were employed in ex-

periments with the disruptive discharge instead of the ordinary air gap, that the carbon particles under the action of the powerful magnetic field in which the tube was placed, were deposited in regular fine lines in the middle of the tube as illustrated. These lines were attributed to the deflection or distortion of the discharge by the magnetic field, but why the deposit occurred principally where the field was most intense did not appear quite clear. A fact of interest, likewise noted, was that the presence of a strong magnetic field increases the deterioration of the electrodes, probably by reason of the rapid interruptions it produces, whereby there is actually a higher E. M. F. maintained between the electrodes.

Much would remain to be said about the luminous effects produced in gases at low or ordinary pressures. With the present experiences before us we cannot say that the essential nature of these charming phenomena is sufficiently known. But investigations in this direction are being pushed with exceptional ardor. Every line of scientific pursuit has its fascinations, but electrical investigation appears to possess a peculiar attraction, for there is no experiment or observation of any kind in the domain of this wonderful science which would not forcibly appeal to us. Yet to me it seems, that of all the many marvelous things we observe, a vacuum tube, excited by an electric impulse from a distant source, bursting forth out of the darkness and illuminating the room with its beautiful light, is as lovely a phenomenon as can greet our eyes. More interesting still it appears when, reducing the fundamental discharges across the gap to a very small number and waving the tube about we produce all kinds of designs in luminous lines. So, by way of amusement, I take a straight long tube, or a square one, or a square attached to a straight tube, and by whirling them about in the hand, I imitate the spokes of a wheel, a Gramme winding, a drum winding, an alternate current motor winding, etc. (Fig. 34). Viewed from a distance the effect is weak and much of its beauty is lost, but being near or holding the tube in the hand, one cannot resist its charm.

'In presenting these insignificant results I have not attempted to arrange and co-ordinate them, as would be proper in a strictly scientific investigation, in which every succeeding result should be a logical sequence of the preceding, so that it might be guessed in advance by the careful reader or attentive listener. I have preferred to concentrate my energies chiefly upon advancing novel facts or ideas which might serve as suggestions to others, and this may serve as an excuse for the lack of harmony. The explanations of the phenomena have been given in good faith and in the spirit of a student prepared to find that they admit of a better interpretation. There can be no great harm in a student taking an erroneous view, but when great minds err, the world must dearly pay for their mistakes.

Light and Other High Frequency Phenomena.[1]

By Nikola Tesla.

PART I.

When we look at the world around us, on nature, we are impressed with its beauty and grandeur. Each thing we perceive, though it may be vanishingly small is in itself a world, that is, like the whole of the visible universe, matter and force governed by law—a world, the contemplation of which fills us with feelings of wonder and irresistibly urges us to ceasless thought and inquiry. But in all this vast world, of all objects our senses reveal to us, the most marvelous, the most appealing to our imagination, appears no doubt a highly developed organism,a thinking being. If there is anything fitted to make us admire nature's handiwork, it is certainly this inconceivable structure, which performs its innumerable motions in obedience to external influence. To understand its workings, to get a deeper insight into this nature's masterpiece, has ever been for thinkers a fascinating aim, and after many centuries of arduous research men have arrived at a fair understanding of the functions of its organs and senses. Again, in all the perfect harmony of its parts, of the parts which constitute the material or tangible of our being,of all its organs and senses, the eye is the most wonderful. It is the most precious, the most indispensable of our receptive or directive organs; it is the great gateway through which all knowledge enters the mind. Of all our organs it is the one which is in the most intimate relation with that which we call intellect. So intimate is this relation that it is often said that the very soul shows itself in the eye.

It can be taken as a fact, which the theory of the action of the eye implies, that for each external impression, that is for each image produced upon the retina, the ends of the visual nerves concerned in the conveyance of the impression to the mind must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and therefore upon the retina. Will it ever be within human power to analyze the condition of the retina when disturbed by thought or reflex action by the help of some optical or other means of such sensitiveness that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science, in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he was able to see, in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

Another fact having a bearing on this subject which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation, is that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, observable even in broad daylight.

The saying, then, that the soul shows itself in the eye, is deeply founded, and we feel that it expresses a great truth. It has a profound meaning even for one who, like a poet or artist, only following his inborn instinct or love for nature, finds delight in aimless thoughts and in the mere contemplation of natural phenomena, but a still more profound meaning for one who, in the spirit of positive scientific investigation, seeks to ascertain the causes of the effects. It is principally the natural philosopher, the physicist, for whom the eye is the subject of the most intense admiration.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting that the very conception of that which is perfect, or seems so to him, has been gained through this same instrument. Firstly, the eye is, as far as our positive knowledge goes, the only organ which is directly affected by that subtile medium which, science teaches us, must fill all space; secondly, it is the most sensitive of our organs, incomparably more sensitive to the external impressions than any other.

The organ of hearing implies the impact of ponderable bodies, the organ of smell the transference of detached material particles, and the organs of taste and of touch or force the direct contact or at least some interference of ponderable matter, and this is true even in those instances of animal organisms, in which some of these organs are developed to a degree of truly marvelous perfection. This being so, it seems wonderful that the organ of sight solely should be capable of being stirred by that which all our other organs are powerless to detect, which yet plays an essential part in all natural phenomena, which transmits all energy and sustains all motion and, that most intricate of all, life, but which has properties such that even a scientifically trained mind cannot help drawing a distinction between it and all that is called matter. Considering merely this, and the fact that the eye, by its marvelous power, widens our otherwise very narrow range of perception far beyond the limits of the small world which is our own, to embrace myriads of other worlds, suns and stars in the infinite depths of the universe, would make it justifiable to assert that it is an organ of a higher order. Its performances are beyond comprehension. Nature as far as we know never produced anything more wonderful. We can get barely a faint idea of its prodigious power by analyzing what it does and by comparing. When either waves impinge upon the human body, they produce the sensations of warmth or cold, pleasure or pain, or perhaps other sensations of which we are not aware, and any degree or intensity of these sensations, which degrees are infinite in number, hence an infinite number of distinct sensations. But our sense of touch or our sense of force cannot reveal to us these differences in degree or intensity, unless they are very great. Now we can readily conceive how an organism, such as the human in the eternal process of evolution, or, more philosophically speaking, adaptation to nature, being constrained to the use of only the sense of touch or force, for instance, might develop this sense to such a degree of sensitiveness or perfection that it would be capable of distinguishing the minutest differences in the temperature of a body even at some distance, to a hundredth or thousandth or millionth part of a degree. Yet even this apparently impossible performance would not begin to compare with that of the eye, which is capable of distinguishing and conveying to the mind in a single instant innumerable peculiarities of the body, be it in form or color or other respects. This power of the eye rests upon two things, namely, the rectilinear propagation of the disturbance by which it is affected, and upon its sensitiveness. To say that the eye is sensitive is not saying anything. Compared with it, all other organs are monstrously crude. The organ of smell which guides a dog on the trail of a deer, the organ of touch or force which guides an insect in its wanderings, the organ of hearing, which is affected by the slightest disturbances of the air, are sensitive organs, to be sure, but what are they compared with the human eye! No doubt it responds to the faintest echoes or reverberations of the medium; no doubt, it brings us tidings from other worlds, infinitely remote, but in a language we cannot as yet always understand. And why not? Because we live in a medium filled with air and other gases, vapors and a dense mass of solid particles flying about. These play an important part in many phenomena; they fritter away the energy of the vibrations before they can reach the eye; they too are the carriers of germs of destruction; they get into our lungs and other organs, clog up the channels and imperceptibly yet inevitably arrest the stream of life. Could we but do away with all ponderable matter in the line of sight of the telescope, it would reveal to us undreamt-of marvels. Even the unaided eye, I think, would be capable of distinguishing in the pure medium small objects at distances measured probably by hundreds or perhaps thousands of miles.

But there is something else about the eye which impresses us still more than these wonderful features which we observe, viewing it from the standpoint of a physicist, merely as an optical instrument—something which appeals to us more than its marvelous faculty of being directly affected by the vibrations of the medium, without interference of gross matter, and more than its inconceivable sensitiveness and discerning power. It is its significance in the processes of life. No matter what one's views on nature and life may be, he must stand amazed when, for the first time in his thoughts, he realizes the importance of the eye in the physical processes and mental performances of the human organism. And how could it be otherwise, when he realizes, that the eye is the means through which the human race has acquired the entire knowledge it possesses, that it controls all our motions, more still, all our actions.

There is no way of acquiring knowledge except through the eye. What is the foundation of all philosophical systems of ancient and modern times, in fact of all the philosophy of man? *I am, I think; I think, therefore I am.* But how could I think and how would I know that I exist, if I had not the eye? For knowledge involves consciousness; consciousness involves ideas, conceptions; conceptions involve pictures or images, and images, the sense of vision, and therefore the organ of sight. But how about blind men, will be asked? Yes, a blind man may depict in magnificent poems forms and scenes from real life, from a world he physically does not see. A blind man may touch the keys of an instrument with unerring precision, may build the fastest boat, may discover and invent, calculate and construct, may do still greater wonders —but all the blind men who have done such things have descended from those who had seeing eyes. Nature may reach the same result in many ways. Like a wave in the physical world, in the infinite ocean of the medium which pervades all, so in the world of organisms, in life, an impulse started proceeds onward, at times, may be, with the speed of light, at times, again, so slowly that for ages and ages it seems to stay, passing through processes of a complexity inconceivable to men, but in all its forms, in all its stages, its energy ever and ever integrally present. A single ray of light from a distant star falling upon the eye of a tyrant in bygone times may have altered the course of his life, may have changed the destiny of nations, may have transformed the surface of the globe, so intricate, so inconceivably complex are the the processes in Nature. In no way can we get such an overwhelming idea of the grandeur of Nature, than when we consider, that in accordance with the law of the conservation of energy, throughout the Infinite, the forces are in a perfect balance, and hence the energy of a single thought may determine the motion of a universe. It is not necessary that every individual, not even that every generation or many generations, should have the physical instrument of sight, in order to be able to form images and to think, that is, form ideas or conceptions; but sometime or other during the process of evolution, the eye certainly must have existed, else thought, as we understand it, would be impossible; else conceptions, like spirit, intellect, mind, call it as you may, could not exist. It is conceivable that in some other world, in some

1. A lecture delivered before the Franklin Institute at Philadelphia, February 24, 1893, and before the National Electric Light association at St. Louis, Mo., March 1, 1893.

other beings, the eye is replaced by a different organ, equally or more perfect, but these beings cannot be men.

Now what prompts us to all voluntary motions and actions of any kind? Again the eye. If I am conscious of the motion, I must have an idea or conception, that is, an image, therefore the eye. If I am not precisely conscious of the motion, it is because the images are vague or indistinct, being blurred by the superimposition of many. But when I perform the motion, does the impulse which prompts me to the action come from within or from without? The greatest physicists have not disdained to endeavor to answer this and similar questions and have at times abandoned themselves to the delights of pure and unrestrained thought. Such questions are generally considered not to belong to the realm of positive physical science, but will before long be annexed to its domain. Helmholtz has probably thought more on life than any modern scientist. Lord Kelvin expressed his belief that life's process is electrical and that there is a force inherent to the organism and determining its motions. Just as much as I am convinced of any physical truth I am convinced that the motive impulse must come from the outside. For, consider the lowest organism we know—and there are probably many lower ones—an aggregation of a few cells only. If it is capable of voluntary motion it can perform an infinite number of motions, all definite and precise. But now a mechanism consisting of a finite number of parts, and few at that, cannot perform an infinite number of definite motions, hence the impulses which govern its movements must come from the environment. So, the atom, the ulterior element of the universe's structure, is tossed about in space eternally, a play to external influences, like a float in a troubled sea. Were it to stop its motion it would die. Matter at rest, if such a thing could exist, would be matter dead. Death of matter! Never has a sentence of deeper philosophical meaning been uttered. This is the way in which Prof. Dewar forcibly expresses it in the description of his admirable experiments, in which liquid oxygen is handled as one handles water, and air at ordinary pressure is made to condense and even to solidify by the intense cold—experiments, which serve to illustrate, in his language, the last feeble manifestations of life, the last quiverings of matter about to die. But human eyes shall not witness such death. There is no death of matter, for throughout the infinite universe all has to move, to vibrate, that is, to live.

I have made the preceding statements at the peril of treading upon metaphysical ground in my desire to introduce the subject of this lecture in a manner not altogether uninteresting, I may hope, to an audience such as I have the honor to address. But now then, returning to the subject, this divine organ of sight, this indispensable instrument for thought and all intellectual enjoyment, which lays open to us the marvels of this universe, through which we have acquired what knowledge we possess, and which prompts us to, and controls, all our physical and mental activity—by what is it affected? By light! What is light?

We have witnessed the great strides which have been made in all departments of science in recent years. So great have been the advances that we cannot refrain from asking ourselves: Is this all true, or is it but a dream? Centuries ago men have lived, have thought, discovered, invented, and have believed that they were soaring, while they were merely proceeding at a snail's pace. So we too may be mistaken. But taking the truth of the observed events as one of the implied facts of science, we must rejoice in the immense progress already made and still more in the anticipation of what must come, judging from the possibilities opened up by modern research. There is, however, an advance which we have been witnessing, which must be particularly gratifying to every lover of progress. It is not a discovery, or an invention, or an achievement in any particular direction. It is an advance in all directions of scientific thought and experiment. I mean the generalization of the natural forces of phenomena, the looming up of a certain broad idea on the scientific horizon. It is this idea which has, however, long ago taken possession of the most advanced minds, to which I desire to call your attention and which I intend to illustrate, in a general way, in these experiments, as the first step in answering the question "What is light?" and to realize the modern meaning of this word.

It is beyond the scope of my lecture to dwell upon the subject of light in general, my object being merely to bring presently to your notice a certain class of light effects and a number of phenomena observed in pursuing the study of these effects. But to be consistent in my remarks it is necessary to state that according to that idea, now accepted by the majority of scientific men as a positive result of theoretical and experimental investigation, the various forms or manifestations of energy which were generally designated as "electric" or more precisely "electro-magnetic" are energy manifestations of the same nature as those of radiant heat and light. Therefore the phenomena of light and heat and others besides these may be called electrical phenomena. Thus electrical science has become the mother science of all and its study has become all important. The day when we shall know exactly what "electricity" is will chronicle an event probably greater, more important than any other recorded in the history of the human race. The time will come when the comfort, the very existence perhaps, of man will depend upon that wonderful agent. For our existence and comfort we require heat, light and mechanical power. How do we now get all these? We get them from fuel, we get them by consuming material. What will man do when the forests disappear, when the coal fields are exhausted? Only one thing, according to our present knowledge will remain; that is, to transmit power at great distances. Men will go to waterfalls, to the tides, which are the stores of an infinitesimal part of nature's immeasurable energy. There will they harness the energy and transmit the same to their settlements, to warm their homes by, to give them light, and to keep their obedient slaves, the machines, toiling. But how will they transmit this energy if not by electricity? Judge then, if the comfort, nay, the very existence, of man will not depend on electricity. I am aware that this view is not that of a practical engineer, but neither is it that of an illusionist, for it is certain that power transmission, which at present is merely a stimulus to enterprise, will some day be a dire necessity.

It is more important for the student, who takes up the study of light phenomena to make himself thoroughly acquainted with certain modern views, than to peruse entire books on the subject of light itself, as disconnected from these views. Were I therefore to make these demonstrations before students seeking information—and for the sake of the few of those who may be present, give me leave to so assume—it would be my principal endeavor to impress these views upon their minds in this series of experiments.

It might be sufficient for this purpose to perform a simple and well-known experiment. I might take a familiar appliance, a Leyden jar, charge it from a frictional machine, and then discharge it. In explaining to you its permanent state when charged and its transitory condition when discharging, calling your attention to the forces which enter into play and to the various phenomena they produce, and pointing out the relation of the forces and phenomena, I might fully succeed in illustrating that modern idea. No doubt, to the thinker, this simple experiment would appeal as much as the most magnificent display. But this is to be an experimental demonstration, and one which should possess instructive as well as entertaining features, and as such a simple experiment, like the one cited, would not go very far toward the attainment of the lecturer's aim. I must therefore choose another way of illustrating, more spectacular certainly, but perhaps also more instructive. Instead of the frictional machine and Leyden jar, I shall avail myself in these experiments of an induction coil of peculiar properties, which was described in detail by me in a lecture before the London Institution of Electrical Engineers, in February, 1892. This induction coil is capable of yielding currents of enormous potential differences, alternating with extreme rapidity. With this apparatus I shall endeavor to show you three distinct classes of effects, or phenomena, and it is my desire that each experiment, while serving for the purposes of illustration, should at the same time teach us some novel truth, or show us some novel aspect of this fascinating science. But before doing this, it seems proper and useful to dwell upon the apparatus employed, and method of obtaining the high potentials and high frequency currents which are made use of in these experiments.

Light and Other High Frequency Phenomena.

By Nikola Tesla.

PART II.

These high frequency currents are obtained in a peculiar manner. The method employed was advanced by me about two years ago in an experimental lecture before the American Institute of Electrical Engineers. A number of ways, as practiced in the laboratory, of obtaining these currents either from continuous or low frequency alternating currents is diagramatically indicated in Fig. 1, which will be later described in detail. The general plan is to charge condensers from a direct or alternate current source, preferably of high tension, and to discharge them disruptively while observing well-known conditions necessary to maintain the oscillations of the current. In view of the general interest taken in high frequency currents and effects producible by them, it seems to me advisable to dwell at some length upon this method of conversion. In order to give you a clear idea of the action, I will suppose that a continuous current generator is employed, which is often very convenient. It is desirable that the generator should possess such high tension as to be able to break through a small air space. If this is not the case, then auxiliary means have to be resorted to, some of which will be indicated subsequently. When the condensers are charged to a certain potential, the air or insulating space gives way and a disruptive discharge occurs. There is then a sudden rush of current and generally a large portion of the accumulated electrical energy spends itself. The condensers are thereupon quickly charged and the same process is repeated in more or less rapid succession. To produce such sudden rushes of current it is necessary to observe certain conditions. If the rate at which the condensers are discharged is the same as that at which they are charged, then, clearly, in the assumed case the condensers do not come into play. If the rate of discharge be smaller than the rate of charging, then, again, the condensers cannot play an important part. But if, on the contrary, the rate of discharging is greater than that of charging, then a succession of rushes of current is obtained. It is evident that, if the rate at which the energy is being dissipated by the discharge is very much greater than the rate of supply to the condensers, the sudden rushes will be comparatively few, with long time intervals between. This always occurs when a condenser of considerable capacity is charged by means of a comparatively small machine. If the rates of supply and dissipation are not widely different, then the rushes of current will be in quicker succession, and this the more, the more nearly equal both the rates are, until natural limitations incident to each case and depending upon a number of causes are reached. Thus we are able to obtain from a continuous current generator as rapid a succession of discharges as we like. Of course, the higher the tension of the generator the smaller need be the capacity of the condensers, and for this reason, principally, it is of advantage to employ a generator of very high tension. Besides such a generator permits the attaining of greater rates of vibration.

The rushes of current may be of the same direction under the conditions before assumed, but most generally there is an oscillation superimposed upon the fundamental vibration of the current. When the conditions are so determined that there is no oscillation, the current impulses are unidirectional, and thus a means is provided of transforming a continuous current of high tension into a direct current of lower tension, which I think may find employment in the arts.

This method of conversion is exceedingly interesting, and I was much impressed by its beauty when I first conceived it. It is ideal in certain respects. It involves the employment of no mechanical devices of any kind, and it allows of obtaining currents of any desired frequency from an ordinary circuit, direct or alternating. The frequency of the fundamental discharges depending on the relative rates of supply and dissipation can be readily varied within wide limits by simple adjustments of these quantities, and the frequency of the superimposed vibration by the determination of the capacity, self-induction and resistance of the circuit. The potential of the currents, again, may be raised as high as any insulation is capable of withstanding safely by combining capacity and self-induction or by induction in a secondary, which need have but comparatively few turns.

As the conditions are often such that the intermittance or oscillation does not readily establish itself, especially when a direct current source is employed, it is of advantage to associate an interrupter with the arc, and I have, sometime ago, indicated the use of an air blast or magnet, or other such device readily at hand. The magnet is employed with especial advantage in the conversion of direct currents, as it is then very effective. If the primary source is an alternate current generator, it is desirable, as I have stated on another occasion, that the frequency should be low, and and that the currents forming the arc be large, in order to render the magnet more effective.

A form of such discharger with a magnet which has been found convenient, and adopted after some trials, in the conversion of direct currents particularly, is illustrated in Fig. 2. $N S$ are the pole pieces of a very strong magnet which is excited by a coil c. The pole pieces are slotted for adjustment and can be fastened in any position by screws s_1 s_1. The discharge rods d d_1, thinned down on the ends in order to allow a closer approach of the magnetic pole pieces, pass through the column of brass b b_1 and are fastened in position by screws s_2 s_2. Springs r r_1 and collars c c_1 are slipped on the rods, the latter serving to set the points of the rods at a certain suitable distance by means of screws s_3 s_3, and the former to draw the points apart. When it is desired to start the arc, one of the hard rubber handles h h_1 is tapped quickly with the hand, whereby the points of the rods are brought in contact but are instantly separated by the springs r r_1. Such an arrangement has been found to be often necessary, namely, in cases when the electromotive force was not large enough to cause the discharge to break through the gap, and also when it was desirable to avoid short circuiting of the generator by the metallic contact of the rods. The rapidity of the interruptions of the current with a magnet depends on the intensity of the magnetic field and on the potential difference at the ends of the arc. The interruptions are generally in such quick succession as to produce a musical sound. Years ago it was observed that when a powerful induction coil is discharged between the poles of a strong magnet the discharge produced a loud noise not unlike a small pistol shot. It was vaguely stated that the spark was intensified by the presence of the magnetic field. It is now clear that the discharge current, flowing for some time, was interrupted a great number of times by the magnet, thus producing the sound. The phenomenon is especially marked when the field circuit of a large magnet or dynamo is broken in a powerful magnetic field.

When the current through the gap is comparatively large, it is of advantage to slip on the points of the discharge rods pieces of very hard carbon and let the arc play between the carbon pieces. This preserves the rods and besides has the advantage of keeping the air space hotter, as the heat is not conducted away as quickly through the carbons, and the result is that a smaller electromotive force in the arc gap is required to maintain a succession of discharges.

Another form of discharger which may be employed with advantage in some cases is illustrated in Fig. 3. In this form the discharge rods d d_1 pass through perforations in a wooden box B, which is thickly coated with mica on the inside, as indicated by the heavy lines. The perforations are provided with mica tubes m m_1 of some thickness, which are preferably not in contact with the rods d d_1. The box has a cover C, which is a little larger and descends on the outside of the box. The spark gap is warmed by a small lamp l contained in a box. A plate p above the lamp

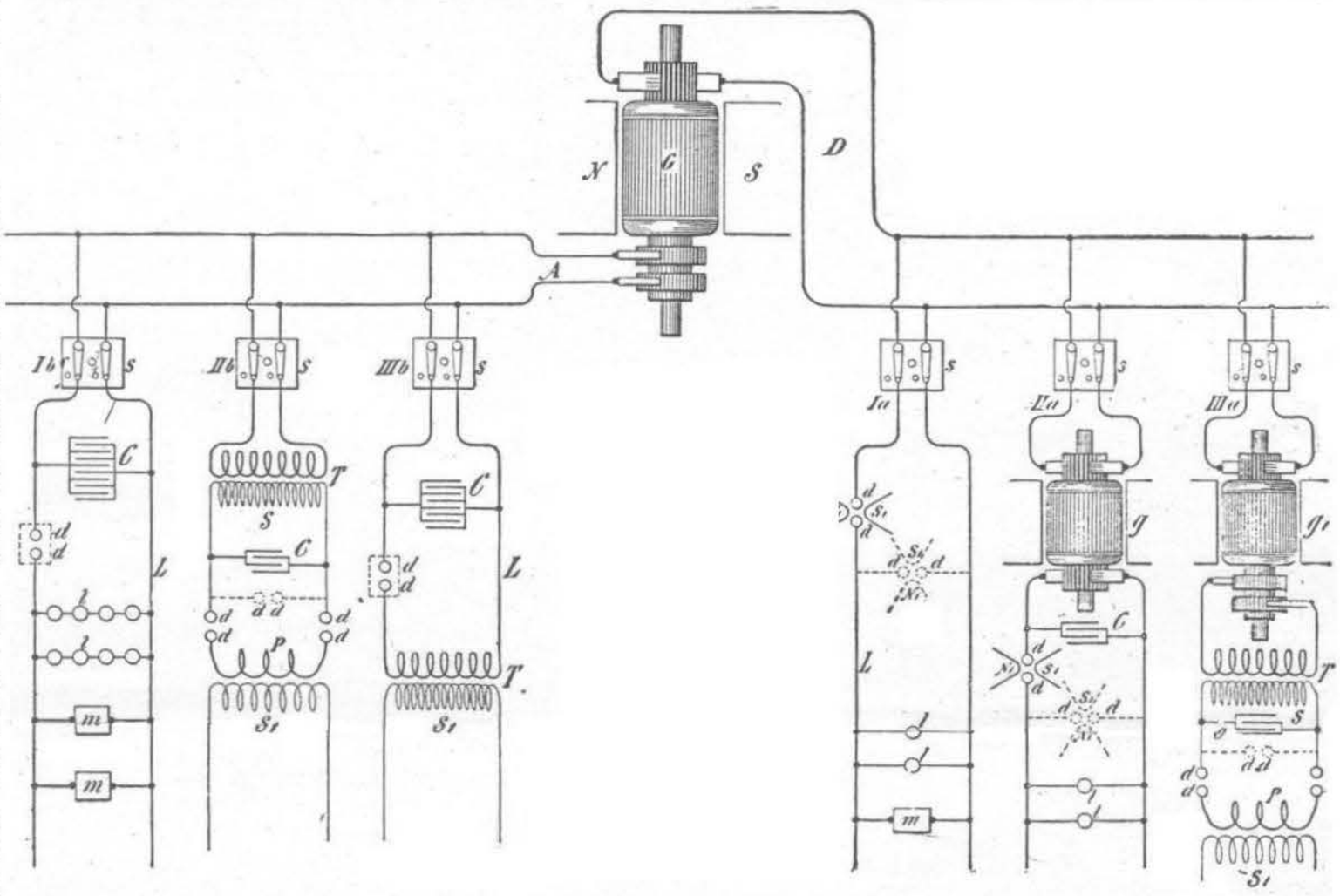


FIG. 1. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—PLAN OF CONNECTIONS USED IN THE CONVERSION BY MEANS OF THE DISRUPTIVE ARC DISCHARGE.

allows the draught to pass only through the chimney c of the lamp, the air entering through holes o o in or near the bottom of the box and following the path indicated by the arrows. When the discharger is in operation the door of the box is closed so that the light of the arc is not visible outside. It is desirable to exclude the light as perfectly as possible, as it interferes with some experiments. This form of discharger is simple and very effective when properly manipulated. The air being warmed to a certain temperature has its insulating power impaired, it becomes dielectrically weak, as it were, and the consequence is that the arc can be established at much greater distance. The air should, of course, be sufficiently insulating to allow the discharge to pass through the gap disruptively The arc formed under such conditions, when long, may be made extremely sensitive, and the weak draught through the lamp chimney c is quite sufficient to produce rapid interruptions. The adjustment is made by regulating the temperature and velocity of the draught. Instead of using a lamp it answers the purpose to provide for a draught of warm air in other ways. A very simple way which has been practiced is to inclose the arc in a long vertical tube with plates on the top and bottom for regulating the temperature and velocity of the air current. Some provision had to be made for deadening the sound.

The air may be rendered dielectrically weak, also, by rarefaction. Dischargers of this kind have likewise been used by me in connection with the magnet. A large tube is for this purpose provided with heavy electrodes of carbon or metal, between which the discharge is made to pass, the tube being placed in a powerful magnetic field. The exhaustion of the tube is carried to a point at which the discharge breaks through easily, but the pressure should be more than 75 millimeters, at which the ordinary thread discharge occurs. In another form of discharger, combining the features before mentioned, the discharge was made to pass between two adjustable magnetic pole pieces, the space between them being kept at an elevated temperature.

It should be remarked here that when such or interrupting devices of any kind are used and the currents are passed through the primary of a disruptive discharge coil, it is not, as a rule, of advantage to produce a number of interruptions of the current per second greater than the natural frequency of vibration of the dynamo supply circuit, which is ordinarily small. It should also be pointed out here that while the devices mentioned in connection with the disruptive discharges are advantageous under certain conditions, they may be sometimes a source of trouble, as they produce intermittences and other irregularities in the vibration which it would be very desirable to overcome.

There is, I regret to say, in this beautiful method of conversion a defect, which fortunately is not vital, and which I have been gradually overcoming. I will best call attention to this defect and indicate a fruitful line of work by comparing the electrical process with its mechanical analogue. The process may be illustrated in this manner. Imagine a tank with a wide opening at the bottom, which is kept closed by spring pressure, but so that it snaps off suddenly when the liquid in the tank has reached a certain height. Let the fluid be supplied to the tank by means of a pipe feeding at a certain rate. When the critical height of the liquid is reached, the spring gives way and the bottom of the tank drops out. Instantly the liquid falls through the wide opening, and the spring, reasserting itself, closes the bottom again. The tank is now filled, and after a certain time interval the same process is repeated. It is clear, that if the pipe feeds the fluid quicker than the bottom outlet is capable of letting it pass through, the bottom will remain off and the tank will still overflow. If the rates of supply are exactly equal, then the bottom lid will remain partially open and no vibration of the same and of the liquid column will generally occur, though it might, if started by some means. But if the inlet pipe does not feed the fluid fast enough for the outlet, then there will be always vibration. Again, in such case, each time the bottom flaps up or down, the spring and the liquid column, if the pliability of the spring and the inertia of the moving parts are properly chosen, will perform independent vibrations. In this analogue the fluid may be likened to electricity or electrical energy, the tank to the condenser, the spring to the dielectric and the pipe to the conductor through which electricity is supplied to the condenser. To make this analogy quite complete it is necessary to make the assumption that the bottom, each time it gives way, is knocked violently against a non-elastic stop, this impact involving some loss of energy, and that, besides, some dissipation of energy results, due to frictional losses. In the preceding analogue the liquid is supposed to be under a steady pressure. If the pressure of the fluid be assumed to vary rhythmically, this may be taken as corresponding to the case of an alternating current. The process is then not quite as simple to consider, but the action is the same in principle.

It is desirable, in order to maintain the vibration economically, to reduce the impact and frictional losses as much as possible. As regards the latter, which in the electrical analogue correspond to the losses, due to the resistance of the circuits, it is impossible to obviate them entirely, but they can be reduced to minimum by a proper selection of the dimensions of the circuits and by the employment of thin conductors in the form of strands. But the loss of energy caused by the first breaking through of the dielectric—which in the above example corresponds to the violent knock of the bottom against the inelastic stop—would be more important to overcome. At the moment of the breaking through the air space has a very high resistance, which is probably reduced to a very small value when the current has reached some strength, and the space is brought to a high temperature. It would materially diminish the loss of energy if the space were always kept at an extremely high temperature, but then there would be no disruptive break. By warming the space moderately by means of a lamp or otherwise, the economy as far as the arc is concerned is sensibly increased. But the magnet or other interrupting

device does not diminsh the loss in the arc. Likewise, a jet of air only facilitates the carrying off of the energy. Air, or a gas in general, behaves curiously in this respect. When two bodies, charged to a very high potential, discharge disruptively through an air space, any amount of energy may be carried off by the air. This energy is evidently dissipated by bodily carriers, in compact and collisional losses of the molecules. The exchange of the molecules in the space occurs with inconceivable rapidity. A powerful discharge taking place between two electrodes, they may remain entirely cool, and yet the loss in the air may represent any amount of energy. It is perfectly practicable, with very great potential differences in the gap, to dissipate several horse power in the arc of the discharge without even noticing a small increase in the temperature of the electrodes. All the frictional losses occur, then, practically in the air. If the exchange of the air molecules is prevented, as by enclosing the air hermetically, the gas inside of the vessel is brought quickly to a high temperature, even with a very small discharge. It is difficult to estimate how much of the energy is lost in sound waves, audible or not, in a powerful discharge. When the currents through the gap are large, the electrodes may become rapidly heated, but this is not a reliable measure of the energy wasted in the arc, as the loss through the gap itself may be comparatively small. The air or a gas in general is, at ordinary pressures at least, clearly not the best medium through which a disruptive discharge should occur. Air or other gas under great pressure is of course a much more suitable medium for the discharge gap. I have carried on long-continued experiments in this direction, unfortunately less practicable on account of the difficulties and expense in getting air under great pressure. But even if the medium in the discharge space is solid or liquid, still the same losses take place, though they are generally smaller, for just as soon as the arc is established, the solid or liquid is volatilized. Indeed, there is no body known which would not be disintegrated by the arc, and it is an open question among scientific men whether an arc discharge could occur at all in the air itself without the particles of the electrodes being torn off. When the current through the gap is very small and the arc very long, I believe that a relatively considerable amount of heat is taken up in the disintegration of the electrodes, which partially on this account may remain quite cold.

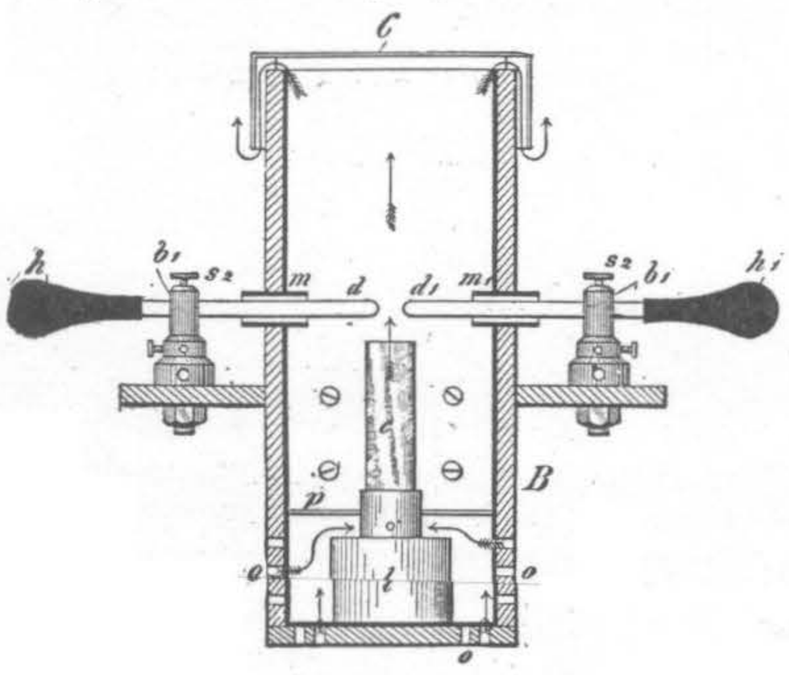
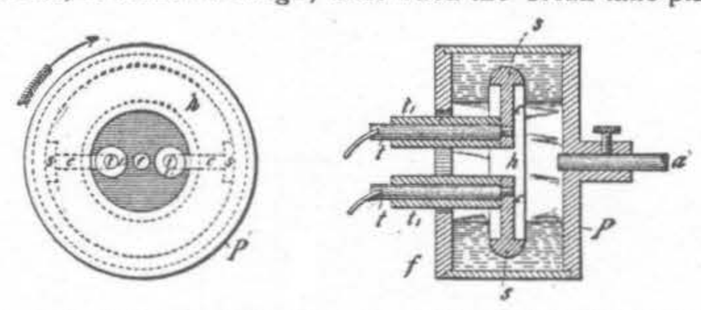


FIG. 3. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA. —DISCHARGES WITH HOT AIR DRAFT.

The ideal medium for a discharge gap should only crack, and the ideal electrode should be of some material which cannot be disintegrated. With small currents through the gap it is best to employ aluminum, but not when the currents are large. The disruptive break in the air, or more or less in any ordinary medium, is not of the nature of a crack, but it is rather comparable to the piercing of innumerable bullets through a mass offering great frictional resistance to the motion of the bullets, this involving considerable loss of energy. A medium which would merely crack when strained electrostatically—and this possibly might be the case with a perfect vacuum, that is, pure ether—would involve a very small loss in the gap, so small as to be entirely negligible, at least theoretically, because a crack may be produced by an infinitely small displacement. In exhausting an oblong bulb provided with two aluminum terminals with the greatest care I have succeeded in producing such a vacuum that the secondary discharge of a disruptive discharge coil would break through disruptively through the bulb in the form of fine spark streams. The curious point was that the discharge would completely ignore the terminals and start far behind the two aluminum plates which served as electrodes. This extraordinarily high vacuum could only be maintained for a very short while. To return to the ideal medium, think, for the sake of illustration, of a piece of glass or similar body clamped in a vise, and the latter tightened more and more. At a certain point a minute increase of the pressure will cause the glass to crack. The loss of energy involved in splitting the glass may be practically nothing, for though the force is great, the displacement need be but extremely small. Now imagine that the glass would possess the property of closing again perfectly the crack upon a minute diminution of the pressure. This is the way the dielectric in the discharge space should behave. But inasmuch as there would be always some loss in the gap the medium, which should be continuous, should exchange through the gap at a rapid rate. In the preceding example, the glass being perfectly closed, it would mean that the dielectric in the discharge space posseses a great insulating power; the glass being cracked, it would signify that the medium in the space is a good conductor. The dielectric should vary enormously in resistance by minute variations of the electromotive force across the discharge space. This condition is attained but in an extremely imperfect manner, by warming the air space to a certain critical temperature, dependent on the electromotive force across the gap or by otherwise impairing the insulating power of the air But as a matter of fact the air does never break down disruptively, if this term be rigorously interpreted, for before the sudden rush of the current occurs, there is always a weak current preceding it, which rises first gradually and then with comparative suddenness. That is the reason why the rate of change is very much greater when glass, for instance, is broken through, than when the break take place through an air space of equivalent dielectric strength. As a medium for the discharge space a solid or even a liquid would be preferable therefore. It is somewhat difficult to conceive of a solid body which will possess the property of closing instantly after it has been cracked. But a liquid, especially under great pressure, behaves practically like a solid, while it possesses the property of closing the crack. Hence it was thought that a liquid insulator might be more suitable as a dielectric than air. Following out this idea, a number of different forms of dischargers, in which a variety of such insulators, sometimes under great pressure were employed, have been experimented upon. It is thought sufficient to dwell in a few words upon one of the forms experimented upon. One of these dischargers is illustrated in Figs. 4*a* and 4*b*.



FIGS. 4*a* AND 4*b*. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—FORM OF DISCHARGER WITH LIQUID INTERRUPTER.

A hollow metal pulley *P* (Fig. 4*a*) was fastened upon an arbor *a*, which by suitable means was rotated at a considerable speed. In the inside of the pulley, but disconnected from the same, was supported a thin disc h_1 (which is shown thick for the sake of clearness), of hard rubber, in which there were embedded two metal segments *s s* with metallic extensions *e e*, into which were screwed conducting terminals *t t* covered with thick tubes of hard rubber *t t*. The rubber disc *h*, with its metallic segments *s s*, was finished in a lathe, and its entire surface highly polished so as to offer the smallest possible frictional resistance to the motion through a fluid. In the hollow of the pulley an insulating liquid, such as a thin oil, was poured so as to reach very nearly to the opening left in the flange *f*, which was screwed tightly on the front side of the pulley. The terminals *t t* were connected to the opposite coatings of a battery of condensers so that the discharge occured through the liquid. When the pulley was rotated the liquid was forced against the rim of the pulley and considerable fluid pressure resulted. In this simple way the discharge gap was filled with a medium which behaved practically like a solid, which possessed the quality of closing instantly upon the occurrence of the break, and which, moreover, was circulating through the gap at a rapid rate. Very powerful effects were produced by dischargers of this kind with liquid interrupters, of which a number of different forms were made. It was found that, as expected, a longer spark for a given length of wire was obtainable in this way than by using air as an interrupting device. Generally the speed, and therefore also the fluid pressure, was limited by reason of the fluid friction, in the form of discharger described, but the practically obtainable speed was more than sufficient to produce a number of breaks suitable for the circuits ordinarily used. In some instances the metal pulley P was provided with a few projections inwardly, and a definite number of breaks was then produced, which could be computed from the speed of rotation of the pulley. Experiments were also carried on with liquids of different insulating power with the view of reducing the loss in the arc. When an insulating liquid is moderately warmed the loss in the arc is diminished.

A point of some importance was noted in experiments with various dischargers of this kind. It was found, for instance, that whereas the conditions maintained in these forms were favorable for the production of a great spark length, the currents so obtained were not best suited to the production of light effects. Experience undoubtedly has shown, that for such purposes a harmonic rise and fall of the potential is preferable. Be it that a solid is rendered incandescent or phosphorescent, or be it that energy is transmitted by condenser coating through the glass, it is quite certain that a harmonically rising and falling potential produces less destructive action, and that the vaccum is more permanently maintained. This would be easily explained if it were ascertained that the process going on in an exhausted vessel is of an electrolytic nature.

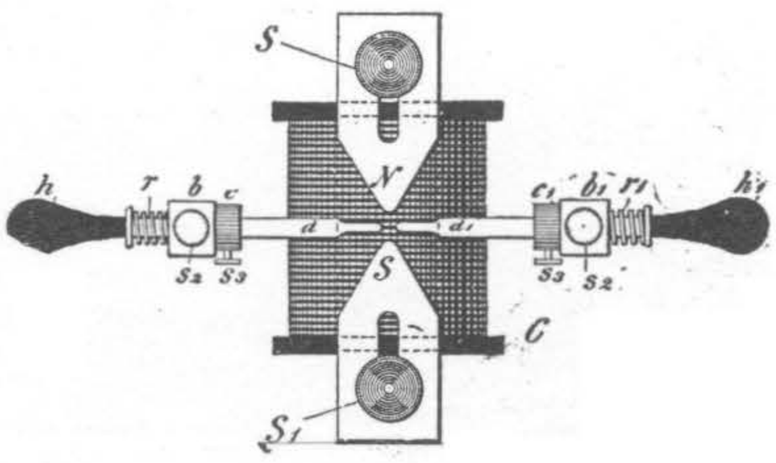
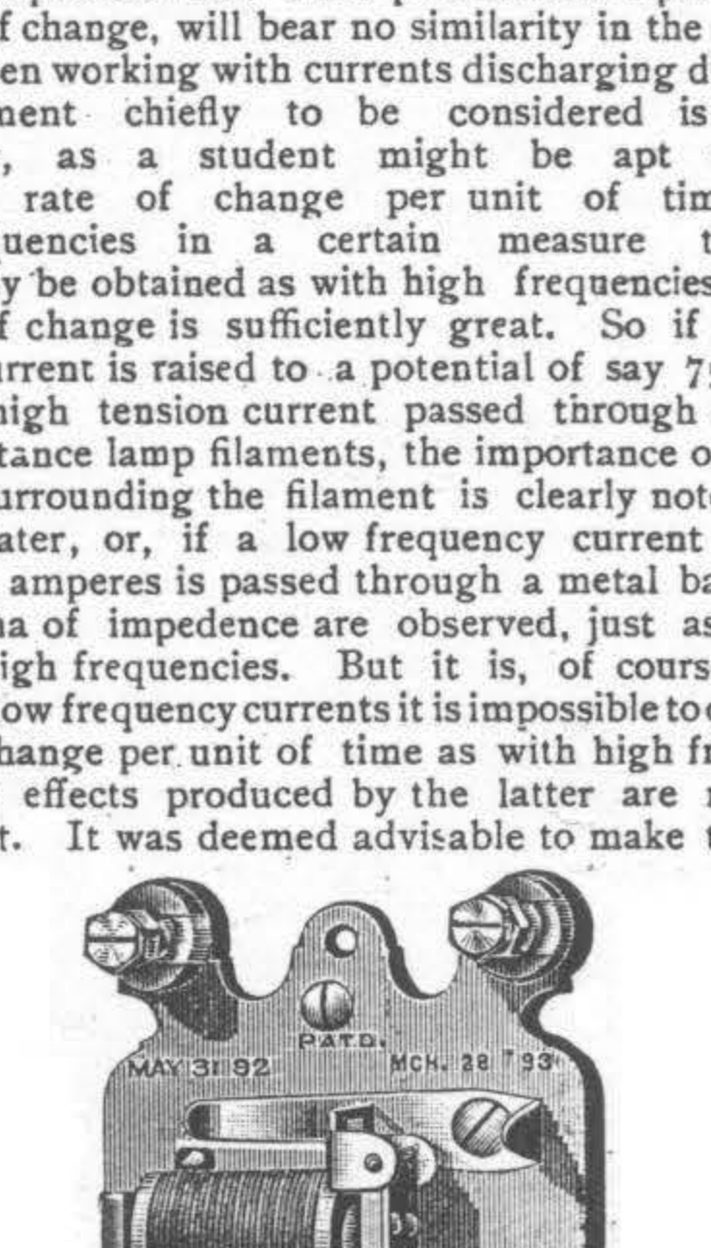


FIG. 2. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA. —FORM OF DISCHARGER WITH MAGNET USED IN THE DIRECT CURRENT CONVERSION.

In the diagrammatical sketch, Fig. 1, which has been already referred to, the cases which are most likely to be met with in practice are illustrated. One has at his disposal either direct or alternating currents from a supply station. It is convenient for an experimenter in an isolated laboratory to employ a machine *G* such as illustrated, capable of giving both kinds of currents. In such case it is also preferable to use a machine with multiple circuits, as in many experiments it is useful and convenient to have at one's disposal currents of different phases. In the sketch *D* represents the direct and *A* the alternating circuit. In each of these three branch circuits are shown, all of which are provided with double lines switches *s s s s s s*. Consider first the direct current conversion; *Ia* represents the simplest case. If the electromotive force of the generator is sufficient to break through a small air space, at least when the latter is warmed or otherwise rendered poorly insulating, there is no difficulty in maintaining a vibration with fair economy by judicious adjustment of the capacity, self-induction and resistance of the circuit *L* containing the devices *l l m*. The magnet *N S* can be in this case advantageously combined with the air space. The discharger *d d* with the magnet may be placed either way as indicated by the full or by the dotted lines. The circuit *Ia* with the connections and devices is supposed to possess dimensions such as are suitable for the maintenance of a viabration. But usually the electromotive force on the circuit or branch *Ia* will be something like 100 volts or so, and in this case it is not sufficient to break through the gap. Many different means may be use to remedy this by raising the electromotive force across the gap. The simplest is probably to insert a large self-induction coil in series with the circuit *L*. When the arc is established, as by the discharger, illustrated in Fig. 2, the magnet blows the arc out the instant it is formed. Now the extra current of the break, being of high electromotive force, breaks through the gap, and a path of low resistance for the dynamo current being again provided, there is a sudden rush of the current from the dynamo upon the weakening or subsidence of the extra current. This process is repeated in rapid succession, and in this manner I have maintained oscillation with as low as 50 volts, or even less, across the gap. But conversion on this plan is not to be recommended on account of the too heavy currents through the gap and consequent heating of the electrodes; besides, the frequencies obtained in this way are low, owing to the high self-induction necessarily associated with the circuit. It is very desirable to have the electromotive force as high as possible, first, in order to increase the economy of the conversion, and, secondly, to obtain high frequencies. The difference of potential in this electric oscillation is, of course, the equivalent of the stretching force in the mechanical vibration of the spring. To obtain very rapid vibration in a circuit of some inertia a great stretching force or difference of potential is necessary. Incidentally, when the electromotive force is very great, the condenser which is usually employed in connection with the circuit need have but a small capacity, and many other advantages are gained. With a view of raising the electromotive force to a many times greater value than obtainable from ordinary distribution circuits, a rotating transformer *g* is used, as indicated in Fig. 2*a*, or else a separate high potential machine is driven by means of a motor operated from the generator *G*. The latter plan is in fact preferable, as changes are easier made. The connections from the high tension winding are quite similar to those in branch 1*a* with the exception that a condenser *c*, which should be adjustable, is connected to the high tension circuit. Usually, also, an adjustable self-induction coil in series with the circuit has been employed in these experiments. When the tension of the currents is very high the magnet ordinarily used in connection with the discharger is of comparatively small value, as it is quite easy to adjust the dimensions of the circuit so that oscillation is maintained. The employment of a steady electromotive force in the high frequency conversion affords some advantages over the employment of alternating electromotive force, as the adjustments are much simpler and the action can be easier controlled. But unfortunately one is limited by the obtainable potential difference. The windings also break down easily in consequence of the sparks which form between the sections of the armature or commutator when a vigorous oscillation takes place. Besides, these transformers are expensive to build. It has been found by experience that it is best to follow the plan illustrated in Fig. 3*a*. In this arrangement a rotating transformer *g* is employed to convert the low tension direct currents into low frequency alternating currents, preferably also of small tension. The tension of the currents is then raised in a stationary transformer *T*. The secondary *s* of this transformer is connected to an adjustable condenser *C*, which discharges through the gap or discharger *dd*, placed in either of the ways indicated, through the primary *P* of a disruptive discharge coil, the high frequency currents being obtained from the secondary *S* of this coil, as described on previous occasions. This will undoubtedly be found the cheapest and most convenient way of converting direct currents.

The three branches of the circuit *A* represent the usual cases met in practice when alternating currents are converted. In Fig. 1*b* a condenser *C*, generally of large capacity, is connected to the circuit *L*, containing the devices *ll*, *mm*. The devices *m m* are supposed to be of high self induction, so as to bring the frequency of the circuit more-

or less to that of the dynamo. In this instance the discharger *d d* should best have a number of makes and breaks per second equal to twice the frequency of the dynamo. If not so, then it should have at least a number equal to a multiple or even fraction of the dynamo frequency. It should be observed, referring to 1*b*, that the the conversion to a high potential is also effected when the discharger *dd*, which is shown in the sketch, is omitted. But the effects which are produced by currents which rise instantly to high values, as in a disruptive discharge, are entirely different from those produced by dynamo currents which rise and fall harmonically. So, for instance, there might be in a given case a number of makes and breaks at *d d* equal to just twice the frequency of the dynamo, or in other words there may be the same number of fundamental oscillations as would be produced without the discharge gap, and there might even not be any quicker superimposed vibration; yet the differences of potential at the various points of the circuit, the impedence and other phenomena dependent upon the rate of change, will bear no similarity in the two cases. Thus, when working with currents discharging disruptively the element chiefly to be considered is not the frequency, as a student might be apt to believe, but the rate of change per unit of time. With low frequencies in a certain measure the same effects may be obtained as with high frequencies, provided the rate of change is sufficiently great. So if a low frequency current is raised to a potential of say 75,000 volts and the high tension current passed through a series of high resistance lamp filaments, the importance of the rarefied gas surrounding the filament is clearly noted, as will be seen later, or, if a low frequency current of several thousand amperes is passed through a metal bar, striking phenomena of impedence are observed, just as with currents of high frequencies. But it is, of course, evident that with low frequency currents it is impossible to obtain such rates of change per unit of time as with high frequencies, hence the effects produced by the latter are much more prominent. It was deemed advisable to make the preceding remarks, inasmuch as many more recently described effects have been unwittingly identified with high frequencies. Frequency alone in reality does not mean anything, except when an undisturbed harmonic oscillation is considered.



HUEBEL & MANGER BELL.

In the branch 3*b* a similar disposition as in 1*b* is illustrated, with the difference that the currents discharging through the gap *dd* are used to induce currents in the secondary *S* of a transformer *T*. In such case the secondary should be provided with an adjustable condenser for the purpose of tuning it to the primary.

Fig. 2*b* illustrates a plan of alternate current high frequency conversion, which is most frequently used and which is found to be most convenient. This plan has been dwelt upon in detail on previous occasions and need not be described here.

Some of these results were obtained by the use of a high frequency alternator. A description of such machines will be found in my original paper before the American Institute of Electrical Engineers and in periodicals of that period.

Light and Other High Frequency Phenomena.

By Nikola Tesla.

PART III.

The first class of effects I intend to show you are effects produced by electrostatic force. It is the force which governs the motion of the atoms, which causes them to collide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an infinite variety of ways, according to Nature's fanciful designs, and to form all these wondrous structures we perceive around us; it is, in fact, if our present views be true, the most important force for us to consider in Nature. As the term electrostatic might imply a steady electric condition, it should be remarked that in these experiments the force is not constant, but varies at a rate which may be considered moderate, about one million times a second, or thereabouts. This enables me to produce many effects which are not producible with an unvarying force.

When two conducting bodies are insulated and electrified, we say that an electrostatic force is acting between them. This force manifests itself in attractions, repulsions and stresses in the bodies and space or medium without. So great may be the strain exerted in the air, or whatever separates the two conducting bodies, that it may break down, and we observe sparks or bundles of light or streamers, as they are called. These streamers form abundantly when the force through the air is rapidly varying. I will illustrate this action of electrostatic force in a novel experiment in which I will employ the induction coil before referred to. The coil is contained in a trough filled with oil, and placed under the table. The two ends of the secondary wire pass through the two thick columns of hard rubber, which protrude to some height above the table. It is necessary to insulate the ends or terminals of the secondary heavily with hard rubber, because even dry wood is by far too poor an insulator for these currents of enormous potential differences. On one of the terminals of the coil I I have placed a large sphere of sheet brass, which is connected to a larger insulated brass plate, in order to enable me to perform the experiments under conditions which, as you will see, are more suitable for this experiment. I now set the coil to work and approach the free terminal with a metallic object held in my hand, this simply to avoid burns. As I approach the metallic object to a distance of eight or ten inches, a torrent of furious sparks break forth from the end of the secondary wire, which passes through the rubber column. The sparks cease when the metal in my hand touches the wire. My arm is now traversed by a powerful electric current, vibrating at about the rate of one million times a second. All around me the electrostatic force makes itself felt, and the air molecules and particles of dust flying about are acted upon and are hammering violently against my body. So great is this agitation of the particles, that when the lights are turned out you may see streams of feeble light appear on some parts of my body. When such a streamer breaks out on any part of the body, it produces a sensation like the pricking of a needle. Were the potentials sufficiently high and the frequency of the vibration rather low, the skin would probably be ruptured under the tremendous strain, and the blood would rush out with great force in the form of fine spray or jet so thin as to be invisible, just as oil will when placed on the positive terminal of a Holtz machine. This breaking through of the skin, though it may seem impossible at first, would perhaps occur, by reason of the tissues under the skin being incomparably bettter conducting. This, at least, appears plausible, judging from some observations.

I can make these streams of light visible to all, by touching with the metallic object one of the terminals as before, and approaching my free hand to the brass sphere, which is connected to the second terminal of the coil. As the hand is approached the air between it and the sphere, or in the immediate neighborhood, is more violently agitated and you see streams of light now break forth from my finger tips and from the whole hand, Fig. 5. Were I to approach the hand closer, powerful sparks would jump from the brass sphere to my hand, which might be injurious. The streamers offer no particular inconvenience, except that in the ends of the finger tips a burning sensation is felt. They should not be confounded with those produced by an influence machine because in many respects they behave differently. I have attached the brass sphere and plate to one of the terminals in order to prevent the formation of visible streamers on that terminal, also in order to prevent sparks from jumping at a considerable distance. Besides, the attachment is favorable for the working of the coil.

The streams of light which you have observed issuing from my hand are due to a potential of about 200,000 volts, alternating in rather irregular intervals, something like a million times a second. A vibration of the same amplitude, but four times as fast, to maintain which over 3,000,000 volts would be required, would be more than sufficient to envelop my body in a complete sheet of flame. But this



FIG. 9. ELECTRICITY AT THE WORLD'S FAIR—FRENCH INCANDESCENT LIGHT FIXTURE, ELECTRICITY BUILDING.

flame would not burn me up; quite contrarily, the probability is that I would not be injured in the least. Yet a hundredth part of that energy, otherwise directed, would be amply sufficient to kill a person.

The amount of energy which may thus be passed into the body of a person depends on the frequency and potential of the currents, and by making both of these very great, a vast amount of energy may be passed into the body without causing any discomfort, except perhaps, in the arm which is traversed by a true conduction current. The reason why no pain in the body is felt and no injurious effect noted is that everywhere, if a current be imagined to flow through the body, the direction of its flow would be at right angles to the surface; hence the body of the experimenter offers an enormous section to the current, and the density is very small, with the exception of the arm perhaps, where the density may be considerable. But if only a small fraction of that energy would be applied in such a way that a current would traverse the body in the same manner as a low frequency current, a shock would be received which might be fatal. A direct or low frequency alternating current is fatal, I think, principally because its distribution through the body is not uniform, as it must divide itself in minute streamlets of great density, whereby some organs are vitally injured. That such a process occurs I have not the least doubt, though no evidence might apparently exist or be found upon examination. The surest to injure and destroy life is a continuous current, but the most painful is an alternating current of very low frequency. The expression of these views, which are the result of long continued experiment and observation, both with steady and varying currents, is elicited by the interest which is at present taken in this subject, and by the manifestly erroneous ideas which are daily propounded in journals on this subject.

I may illustrate an effect of the electrostatic force by another striking experiment, but before doing so I must call your attention to one or two facts. I have said that when the medium between two oppositely electrified bodies is strained beyond a certain limit it gives way and, stated in popular language, the opposite electric charges unite and neutralize each other. This breaking down of the medium occurs principally when the force acting between the bodies is steady, or varies at a moderate rate. Were the variation sufficiently rapid, such a destructive break would not occur, no matter how great the force, for all the energy would be spent in radiation, convection and

mechanical and chemical action. Thus the spark length or greatest distance through which a spark will jump between the electrified bodies *o* is the smaller, the greater the variation or time rate of change. But this rule may be taken to be true only in a general way, when comparing rates which are widely different.

I will show you by an experiment the difference in the effect produced by a rapidly varying and a steady or moderately varying force. I have here two large circular brass plates *p p*, Fig. 6*a* and Fig. 6*b*, supported on movable insulating stands on the table, connected to the ends of the secondary of a similar coil as the one used before. I place the plates ten or twelve inches apart and set the coil to work. You see the whole space between the plates, nearly two cubic feet, filled with uniform light, Fig 6*a*. This light is due to the streamers you have seen in the first experiment, which are now much more intense. I have already pointed out the importance of these streamers in commercial apparatus and their still greater importance in some purely scientific investigations. Often they are too weak to be visible, but they always exist, consuming energy and modifying the action of the apparatus. When intense, as they are at present, they produce ozone in great quantity and also, as Professor Crookes has pointed out, nitrous acid. So quick is the chemical action, that if a coil, such as this one, is worked for a very long time it will make the atmosphere of a small room unbearable, for the eyes and throat are attacked. But when moderately produced, the streamers refresh the atmosphere wonderfully, like a thunder-storm, and exercise unquestionably a beneficial effect.

In this experiment the force acting between the plates changes in intensity and direction at a very rapid rate. I will now make the rate of change per unit time much smaller. This I effect by rendering the discharges through the primary of the induction coil less frequent, and also by diminishing the rapidity of the vibration in the secondary. The former result is conveniently secured by lowering the electromotive force over the air gap in the primary circuit, the latter by approaching the two brass plates to a distance of about three or four inches. When the coil is set to work you see no streamers or light between the plates, yet the medium between them is under a tremendous strain. I still further augment the strain by raising the electromotive force in the primary circuit, and soon you see the air give way and the hall is illuminated by a shower of brilliant and noisy sparks, 6*b*. These sparks could be produced also with unvarying force; they have been for many years a familiar phenomenon, though they were usually obtained from entirely different apparatus. In describing these two phenomena, so radically different in appearance, I have advisedly spoken of a "force" acting between the plates. It would be in accordance with accepted views to say that there was an "alternating electromotive force" acting between the plates. This term is quite proper and applicable in all cases where there is evidence of at least a possibility of an essential inter-dependence of the electric state of the plates or electric action in their neighborhood. But if the plates were removed to an infinite distance, or if at a finite distance, there is no probability or necessity whatever for such dependence. I prefer to use the term "electrostatic force," and to say that such a force is acting around each plate or electrified insulated body in general. There is an inconvenience in using this expression, as the term incidentally means a steady electric condition; but a proper nomenclature will eventually settle this difficulty.

I now return to the experiment to which I have already alluded, and with which I desire to illustrate a striking effect produced by a rapidly varying electrostatic force. I attach to the end of the wire, L, Fig. 7, which is in connection with one of the terminals of the secondary of the induction coil, an exhausted bulb *b*. This bulb contains a thin carbon filament F, which is fastened to a platinum wire *w*, sealed in the glass and leading outside of the bulb, where it connects to the wire L. The bulb may be exhausted to any degree attainable with ordinary apparatus. Just a moment before, you have witnessed the breaking down of the air between the charged brass plates. You know that a plate of glass, or any other insulating material would break down in like manner. Had I therefore a metallic coating attached to the outside of the bulb, or placed near the same, and were this coating connected to the other terminal of the coil, you would be prepared to see the glass give way if the strain were sufficiently increased. Even were the coating not connected to the other terminal, but to an insulated plate, still, if you have followed recent developments, you would naturally expect a rupture of the glass.

But it will certainly surprise you to note that under the action of the varying electrostatic force, the glass gives way when all other bodies are removed from the bulb. In fact, all the surrounding bodies we perceive might be removed to an infinite distance without affecting the result in the slightest. When the coil is set to work, the glass is invariably broken through at the seal, or other narrow channel, and the vacuum is quickly impaired. Such a damaging break would not occur with a steady force, even if the same were many times greater. The break is due to the agitation of the molecules of the gas within the bulb and outside of the same. This agitation, which is generally most violent in the narrow pointed channel near the seal, causes a heating and rupture of the glass. This rupture would, however, not occur, not even with a varying force, if the medium filling the inside of the bulb and that surrounding it were perfectly homogeneous. The break occurs much quicker if the top of the bulb is drawn out into a fine fiber. In bulbs used with these coils such narrow, pointed channels must therefore be avoided.

When a conducting body is immersed in air or similar insulating medium consisting of or containing small freely movable particles capable of being electrified, and when the electrification of the body is made to undergo a very rapid change—which is equivalent to saying that the electrostatic force acting around the body is varying in intensity—the small particles are attracted and repelled, and their violent impacts against the body may cause a mechanical motion of the latter. Phenomena of this kind are noteworthy, inasmuch as they have not been observed before with apparatus such as has been commonly in use. If a very light conducting sphere be suspended on an exceedingly fine wire, and charged to a steady potential, however high, the sphere will remain at rest. Even if the potential would be rapidly varying, provided that the small particles of matter, molecules or atoms, are evenly distributed, no motion of the sphere should result. But if one side of the conducting sphere is covered with a thick insulating layer, the impacts of the particles will cause the sphere to move about, generally in irregular curves, Fig. 8*a*. In like manner, as I have shown on a previous occasion, a fan of metal sheet, Fig. 8*b*, covered partially with insulating material, as indicated, and placed upon the terminal of the coil so as to turn freely in it, is spun around.

All these phenomena you have witnessed and others which will be shown later are due to the presence of a medium like air, and would not occur in a continuous medium. The action of the air may be illustrated still better by the following experiment. I take a glass tube *t*, Fig. 9, of about an inch in diameter, which has a platinum wire *w* sealed in the lower end, and to which is attached a thin lamp filament *f*. I connect the wire with the terminal of the coil and set the coil to work. The platinum wire is now electrified positively and negatively in rapid succession, and the wire and air inside of the tube are rapidly heated by the impacts of the particles, which may be so violent as to render the filament incandescent. But if I pour oil in the tube, just as soon as the wire is covered with the oil, all action apparently ceases, and there is no marked evidence of heating. The reason of this is that the oil is a practically continuous medium. The displacements in such a continuous medium are, with these frequencies, to all appearance incomparably smaller than in air; hence the work performed in such a medium is insignificant. But oil would behave very differently with frequencies many times as great, for even though the displacements be small, if the frequency were much greater, considerable work might be performed in the oil.

The electrostatic attractions and repulsions between bodies of measurable dimensions are, of all the manifestations of this force, the first so-called electrical phenomena noted. But though they have been known to us for many centuries, the precise nature of the mechanism concerned in these actions is still unknown to us, and has not been even quite satisfactorily explained. What kind of mechanism must that be? We cannot help wondering when we observe two magnets attracting and repelling each other with a force of hundreds of pounds with apparently nothing between them. We have in our commercial dynamos magnets capable of sustaining in mid-air tons of weight. But what are even these forces acting between magnets when compared with the tremendous attractions and repulsions produced by electrostatic force, to which there is apparently no limit as to intensity. In lightning discharges bodies are often charged to so high a potential that they are thrown away with inconceivable force and torn asunder or shattered into fragments. Still even such effects cannot compare with the attractions and repulsions which exist between charged molecules or atoms, and which are sufficient to project them with speeds of many kilometers a second so that under their violent impact bodies are rendered highly incandescent and are volatilized. It is of special interest for the thinker who inquires into the nature of these forces to note that whereas the actions between individual molecules or atoms occur seemingly under any condition, the attractions and repulsions of bodies of measurable dimensions imply a medium possessing insulating properties. So, if air, either by being rarefied or heated, is rendered more or less conducting, these actions between two electrified bodies practically cease, while the actions between the individual atoms continue to manifest themselves.

An experiment may serve as an illustration and as a means of bringing out other features of interest. Some time ago I showed that a lamp filament or wire mounted in a bulb and connected to one of the terminals of a high tension secondary coil is set spinning, the top of the filament generally describing a circle. This vibration was very energetic when the air in the bulb was at ordinary pressure and became less energetic when the air in the bulb was strongly compressed. It ceased altogether when the air was exhausted so as to become comparatively good conducting. I found at that time that no vibration took place when the bulb was very highly exhausted. But I conjectured that the vibration which I ascribed to the electrostatic action between the walls of the bulb and the filament should take place also in a highly exhausted bulb. To test this under conditions which were more favorable a bulb like the one in Fig. 10 was constructed. It comprised a globe *b* in the neck of which was sealeded a platinum wire *w* carrying a thin lamp filament *f*. In the lower part of the globe a tube *t* was sealed so as to surround the filament. The exhaustion was carried as far as it was practicable with the apparatus employed.

This bulb verified my expectation, for the filament was set spinning when the current was turned on and became incandescent. It also showed another interesting feature bearing upon the preceding remarks, namely, when the filament had been kept incandescent some time the narrow tube and the space inside was brought to an elevated temperature, and as the gas in the tube then became conducting the electrostatic attraction between the glass and the filament became very weak or ceased, and the filament came to rest. When it came to rest it would glow far more intensely. This was probably due to its assuming the position in the center of the tube where the molecular bombardment was most intense, and also partly to the fact that the individual impacts were more violent and that no part of the supplied energy was converted into mechanical movement. Since, in accordance with accepted views, in this experiment the incandescence must be attributed to the impacts of the particles, molecules or atoms in the heated space, these particles must, therefore, in order to explain such action, be assumed to behave as independent carriers of electric charges immersed in an insulating medium, yet there is no attractive force between the glass tube and the filament because the space in the tube is, as a whole, conducting.

It is of some interest to observe in this connection that whereas the attraction between two electrified bodies may cease, owing to the impairing of the insulating power of the medium in which they are immersed, the repulsion between the bodies may still be observed. This may be explained in a plausible way. When the bodies are placed at some distance in a poorly conducting medium, such as slightly warmed or rarefied air, and are suddenly electrified, opposite electric charges being imparted to them, these charges equalize more or less by leakage through the air. But if the bodies are similarly electrified, there is less opportunity afforded for such dissipation, hence the repulsion observed in such case is greater than the attraction. Repulsive actions in a gaseous medium are, however, as Prof. Crookes has shown, enhanced by molecular bombardment.

(*Continued on page* 315).

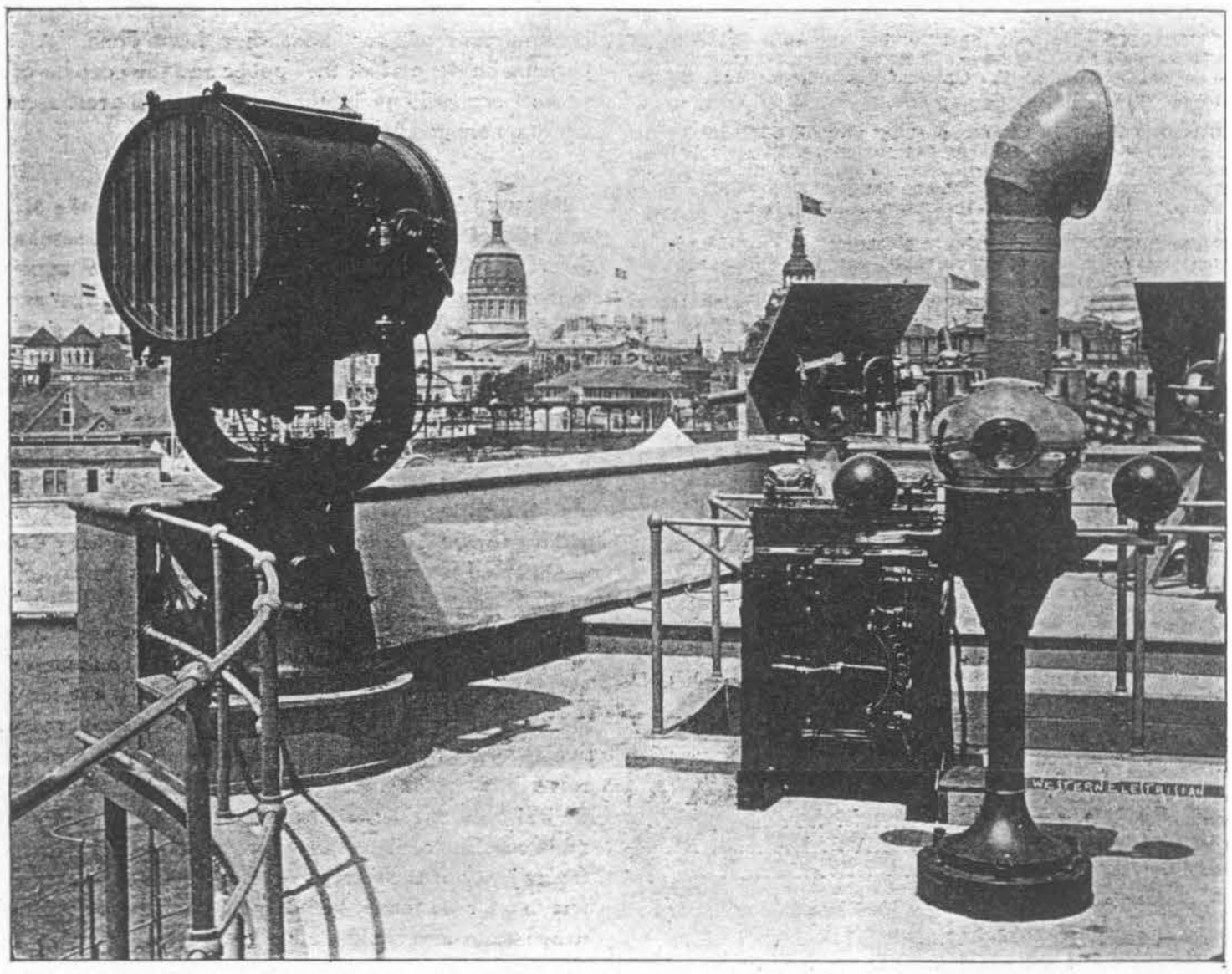


FIG. 7. ELECTRICITY AT THE WORLD'S FAIR.—SEARCH-LIGHT ON THE BATTLE-SHIP ILLINOIS.

Light and other High Frequency Phenomena.

(*Continued from page* 313).

So far, I have considered principally effects produced by a varying electrostatic force in an insulating medium, such as air. When such a force is acting upon a conducting body of measurable dimensions, it causes within the same, or on its surface, displacements of the electricity and gives rise to electric currents, and these produce another kind of phenomena, some of which I shall presently endeavor to illustrate. In presenting this second class of electrical effects, I will avail myself principally of such as are producible without any return circuit, hoping to interest you

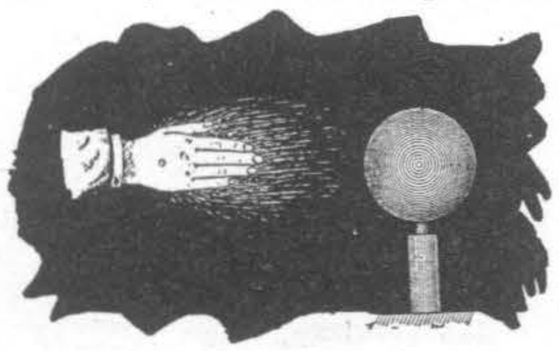
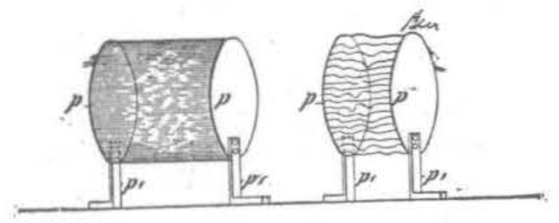


FIG. 5. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—EFFECT OF VARYING ELECTROSTATIC FORCE WITH A TRANSFORMER OF 200,000 VOLTS PRESSURE.

the more by presenting these phenomena in a more or less novel aspect.

It has been for a long time customary, owing to the limited experience with vibratory currents, to consider an electric current as something circulating in a closed conducting path. It was astonishing at first to realize that a current may flow through the conducting path even if the latter be interrupted, and it was still more surprising to learn, that sometimes it may be even easier to make a current flow under such conditions than through a closed path. But that old idea is gradually disappearing, even among practical men, and will soon be entirely forgotten.

If I connect an insulated metal plate P, Fig. 11, to one of the terminals T of the induction coil by means of a wire, though this plate be very well insulated, a current passes through the wire when the coil is set to work. First I wish to give you evidence that there is a current passing through the connecting wire. An obvious way of demonstrating this is to insert between the terminal of the coil and the insulated plate a very thin platinum or german silver wire w and



FIGS. 6*a* AND 6*b*. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—EFFECTS OF RAPIDLY VARYING AND STEADY ELECTROSTATIC FORCE.

bring the latter to incandescence or fusion by the current. This requires a rather large plate or else current impulses of very high potential and frequency. Another way is to take a coil C, Fig. 11, containing many turns of thin insulated wire and to insert the same in the path of the current to the plate. When I connect one of the ends of the coil to the wire leading to another insulated plate P, and its other end to the terminal T, of the induction coil, and set the latter to work, a current passes through the inserted coil c and the existence of the current may be made manifest in various ways For instance, I insert an iron core i within the coil. The current being one of very high frequency, if it be of some strength, will soon bring the iron core to a noticeably higher temperature, as the hystereris and current losses are great with such high frequencies. One might take a core of some size, laminated or not, it would matter little; but ordinary iron wire 1-16 or 1-8 of an inch thick is suitable for the purpose. While the induction coil is working a current traverses the inserted coil and only a few moments are sufficient to bring the iron wire i to an elevated temperature sufficient to soften the sealing-wax s, and cause a paper washer p fastened by it

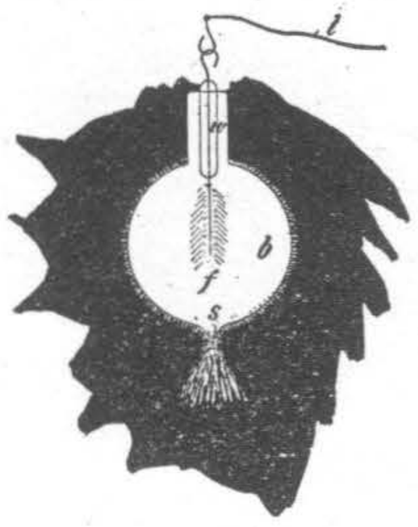
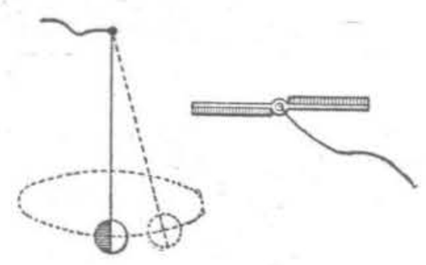


FIG. 7. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—BREAKING A BULB ON OPEN CIRCUIT.

to the iron wire to fall off. But with the apparatus such as I have here, other, much more interesting, demonstrations of this kind can be made. I have a secondary S, Fig. 12, of coarse wire, wound upon a coil similar to the first. In the preceding experiment the current through the coil c, Fig. 11, was very small, but there being many turns a strong heating effect was, nevertheless, produced in the iron wire. Had I passed that current through a conductor in order to show the heating of the latter, the current might have been too small to produce the effect desired. But with this coil provided with a secondary winding, I can now transform the feeble current of high tension which passes through the primary P into a strong secondary current of low tension, and this current will quite certainly do what I expect. In a small glass tube (t, Fig. 12) I have enclosed a coiled platinum wire, w, this merely in order to protect the wire. On each end of the glass tube is sealed a terminal of stout wire to which one of the ends of the platinum wire w, is connected. I join the terminals of the secondary coil to these terminals and insert the primary p, between the insulated plate P_1 and the terminal T_1 of the induction coil as before. The latter being set to work, instantly the platinum wire w is rendered incandescent and can be fused even if it be very thick.

Instead of the platinum wire I now take an ordinary 50-volt 16 candle power lamp. When I set the induction coil in operation the lamp filament is brought to high incandescence. It is, however, not necessary to use the insulated plate, for the lamp l, Fig. 13, is rendered incandescent even if the plate P_1 be disconnected. The secondary may also be connected to the primary as indicated by the dotted line in Fig. 13, to do away, more or less, with the electrostatic induction or to modify the action otherwise.

I may here call attention to a number of interesting observations with the lamp. First, I disconnect one of the terminals of the lamp from the secondary S. When the induction coil plays, a glow is noted which fills the whole bulb. This glow is due to electrostatic induction. It in-



FIGS. 8*a* AND 8*b*. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—MECHANICAL MOTIONS PRODUCED BY VARYING ELECTROSTATIC FORCE IN A GASEOUS MEDIUM.

creases when the bulb is grasped with the hand, and the capacity of the experimenter's body thus added to the secondary circuit. The secondary, in effect, is equivalent to a metallic coating, which would be placed near the primary. If the secondary or its equivalent, the coating, were placed symmetrically to the primary, the electrostatic induction would be nil under ordinary conditions—that is, when a primary return circuit is used, as both halves would neutralize each other. The secondary is, in fact, placed symmetrically to the primary, but the action of both halves of the latter, when only one of its ends is connected to the induction coil, is not exactly equal; hence electrostatic induction takes place, and hence the glow in the bulb. I can nearly equalize the action of both halves of the primary by connecting the other, free end of the same to the insulated plate, as in the preceding experiment. When the plate is connected the glow disappears. With a smaller plate it would not entirely disappear, and then it would contribute to the brightness of the filament

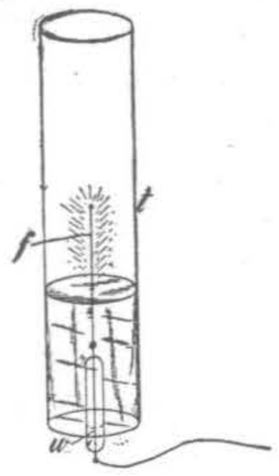


FIG. 9. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—SHOWING THE EFFECT OF THE AIR.

when the secondary is closed, by warming the air in the bulb.

To demonstrate another interesting feature, I have adjusted the coils used in a certain way. I first connect both the terminals of the lamp to the secondary, one end of the primary being connected to the terminal T_1 of the introduction coil and the other to the insulated plate P_1 as before. When the current is turned on, the lamp glows brightly, as shown in Fig. 14*b*, in which C is a fine wire coil and S a coarse wire secondary wound upon it. If the insulated plate P_1 is disconnected, leaving one of the ends a of the primary insulated, the filament becomes dark or generally it diminishes in brightness, Fig. 14*a*. Connecting again the plate P_1 and raising the frequency of the current I make the filament quite dark or barely red, Fig. 15*b*. Once more I will disconnect the plate. One will of course infer that when the plate is disconnected, the current through the primary will be weakened, that therefore the electromotive force will fall in the secondary S, and that the brightness of the lamp will diminish. This might be the case and the result can be secured by an easy adjustment of the coils; also by varying the frequency and potential of the currents. But it is perhaps of greater interest to note that the lamp increases in brightness when the plate is disconnected, Fig. 15*a*. In this case all the energy the primary receives is now sunk into it, like the charge of a battery in an ocean cable, but most of that energy is recovered through the secondary and used to light the lamp. The current traversing the primary is strongest at the end b, which is connected to the terminal T_1 of the induction coil, and diminishes in strength towards the remote end a. But the dynamic inductive effect exerted upon the secondary S is now greater than before when the suspended plate was connected to the primary. These results might have been produced by a number of causes. For instance, the plate P_1 being connected, the reaction from the coil C may be such as to diminish the potential at the terminal T_1 of the induction coil, and therefore weaken the current through

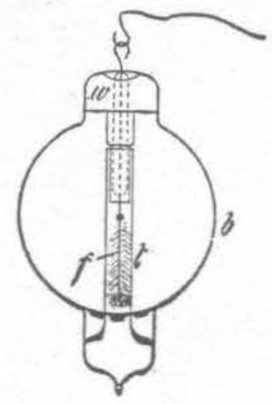


FIG. 10. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—SHOWING THE INFLUENCE OF THE CONDUCTIVITY OF THE MEDIUM UPON ELECTROSTATIC ACTIONS THROUGH MEASURABLE DISTANCE.

the primary of the coil C. Or the disconnecting of the plate may diminish the capacity effect with relation to the primary of the latter coil to such an extent that the current through it is diminished, though the potential at the terminal T_1 of the induction coil may be the same or even higher. Or the result might have been produced by the change of phase of the primary and secondary currents and consequent reaction. But the chief determining factor is the relation of the self-induction and capacity of coil C and plate P_1 and the frequency of the currents. The greater brightness of the filament in Fig. 15*a* is, however, in part due to the heating of the rarefied gas in the lamp by electrostatic induction, which, as before remarked, is greater when the suspended plate is disconnected.

Still another feature of some interest I may bring to your attention. When the insulated plate is disconnected and the secondary of the coil opened, by approaching a small object to the secondary, but very small sparks can be drawn from it, showing that the electrostatic induction

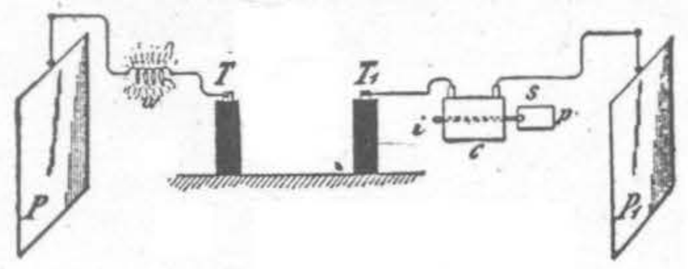


FIG. 11. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—SHOWING EFFECTS OF CURRENTS FLOWING THROUGH OPEN CIRCUITS.

is small in this case. But upon the secondary being closed upon itself or through the lamp, the filament glowing brightly, strong sparks are obtained from the secondary. The electrostatic induction is now much greater, because the closed secondary determines a greater flow of current through the primary and principally through that half of it which is connected to the induction coil. If now the bulb be grasped with the hand, the capacity of the secondary with reference to the primary is augmented by the experimenter's body and the luminosity of the filament is increased, the incandescence now being due partly to the flow of current through the filament and partly to the molecular bombardment of the rarefied gas in the bulb.

The preceding experiments will have prepared one for the next following results of interest, obtained in the course of these investigations. Since I can pass a current through an insulated wire, merely by connecting one of its ends to the source of electrical energy; since I can induce by it another current, magnetize an iron core, and in short, perform all operations, as though a return circuit were used, clearly I can also drive a motor by the aid of only one wire. On a former occasion I have described a simple form of motor comprising a single exciting coil, an iron core and disc. Fig. 16 illustrates a modified way of operating such an alternate current motor by currents induced in a transformer connected to one lead, and several other

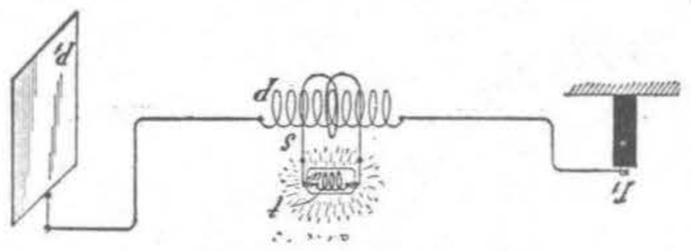


FIG. 12. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—CONVERSION ON OPEN CIRCUIT WITH COIL AND INSULATED PLATE.

arrangements of circuits for operating a certain class of alternate motors founded on the action of currents of different phase. In view of the present state of the art it is thought sufficient to describe these arrangements in a few words only. In the diagram, Fig. 16 II., shows a primary coil P, connected with one of its ends to the line L leading from a high tension transformer terminal T_2. In inductive relation to this primary P is a secondary S of coarse wire in the circuit of which is a coil c. The currents induced in the secondary energize the iron core i, which is preferably, but not necessarily, subdivided, and set the metal disc d in rotation. Such a motor M_2, as dia-

grammatically shown in Fig. 16 II., has been called a "magnetic lag motor," but this expression may be objected to by those who attribute the rotation of the disc to eddy currents circulating in minute paths when the core i is finally subdivided. In order to operate such a motor effectively on the plan indicated, the frequencies should not be too high, nor more than four or five thousand, though the rotation is produced even with ten thousand per second or more.

In Fig. 16 I a motor M_1, having two energizing circuits, A and B, is diagrammatically indicated. The circuit A is connected to the line L, and in series with it is a primary P, which may have its free end connected to an insulated plate P_1, such connection being indicated by the dotted lines. The other motor circuit B is connected to the secondary S, which is in inductive relation to the primary P. When the transformer terminal T_1 is alternately electrified, currents traverse the open line L and also circuit A and primary P. The currents through the latter induce secondary currents in the circuit S, which pass through the energizing coil B of the motor. The currents through the secondary S and those through the primary P differ in phase 90 degrees, or nearly so, and are capable of rotating an armature placed in inductive relation to the circuits A and B.

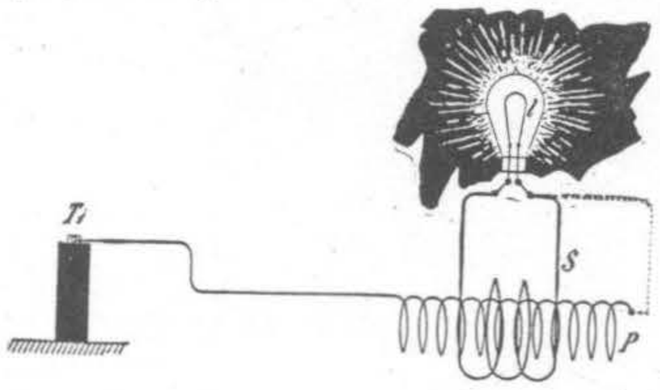
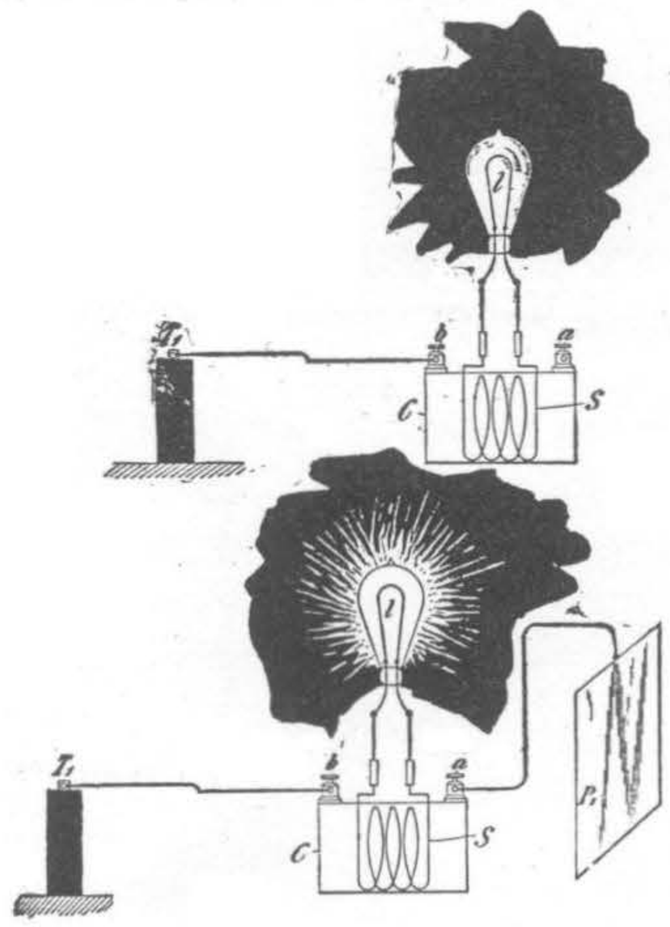


FIG. 13. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—CONVERSION ON OPEN CIRCUIT WITH COIL ALONE.

In Fig. 16 III., a similar motor M_3 with two energizing circuits A_1 and B_1, is illustrated. A primary P, connected with one of its ends to the line L has a secondary S, which is preferably wound for a tolerably high electromotive force, and to which the two energizing circuits of the motor are connected, one directly to the ends of the secondary and the other through a condenser C, by the action of which the currents traversing the circuit A_1 and B_1 are made to differ in phase.

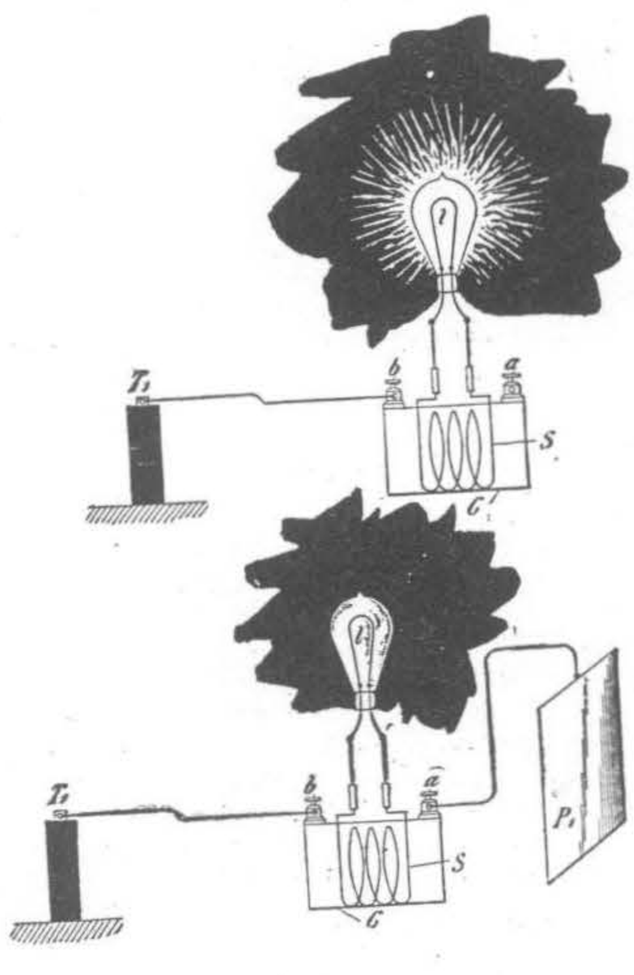


FIGS. 14a AND 14b. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—EFFECT OF ATTACHED PLATE WITH LOW FREQUENCIES.

In Fig. 16 IV. still another arrangement is shown. In this case two primaries P_1 and P_2 are connected to the line L, one through a condenser C of small capacity, and the other directly. The primaries are provided with secondaries S_1 and S_2, which are in series with the energizing circuits A_2 and B_2 and a motor M_3, the condenser C again serving to produce the requisite difference in the phase of the currents traversing the motor circuits. As such phase motors with two or more circuits are now well known in the art, they have been here illustrated diagrammatically. No difficulty whatever is found in operating a motor in the manner indicated or in similar ways, and although such experiments up to this day present only scientific interest, they may at a period not far distant be carried out with practical objects in view.

FIG. 17. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—SINGLE WIRE CONVERSION AND DISTRIBUTION WITH SIMPLE MEANS FOR REGULATING THE EFFECTS

It is thought useful to devote here a few remarks to the subject of operating devices of all kinds by means of only one leading wire. It is quite obvious that when high frequency currents are made use of ground connections are—at least when the electromotive force of the current is great—better than a return wire. Such ground connections are objectionable with steady or low frequency currents on account of destructive chemical actions of the former and disturbing influences exerted by both on the neighboring circuits; but with high frequencies these actions practically do not exist. Still, even ground connections become superfluous when the electromotive force is very high, for soon a condition is reached when the current may be passed more economically through open than through closed conductors. Remote as might seem an industrial application of such single wire transmission of energy to one not experienced in such lines of experiment, it will not seem so to anyone who for some time has carried on investigations of such nature. Indeed I cannot see why such a plan should not be practicable. Nor should it be thought that for carrying at such a plan currents of very high frequency are implicitly required, for just as soon as potentials of say 30,000 volts are used the single wire transmission may be effected with low frequencies, and experiments have been made by me from which these inferences are made.



FIGS. 15a AND 15b. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—EFFECT OF ATTACHED PLATE WITH HIGH FREQUENCIES.

When the frequencies are very high it has been found in laboratory practice quite easy to regulate the effects in the manner shown in diagram, Fig. 17. Here two primaries P and P are shown, each connected with one of its ends to the line L and with the other end to the condenser plates C and C^1, respectively. Near these are placed other condenser plates C^1 and C^1_1, the former being connected to the line L and the latter to an insulated larger plate P^2. On the primaries are wound secondaries S and S^1 of coarse wire, connected to the devices M and D respectively. By varying the distances of the condenser plates C and C^1, and C_1 and $C_1{}^1$, the currents through the secondaries S and S_1 are varied in intensity. The curious feature is the great sensitiveness, the slightest change in the distance of the plates producing considerable variations in the intensity or strength of the currents. The sensitiveness may be rendered extreme by making the frequency such that the primary itself, without any plate attached to its free end satisfies, in conjunction with the closed secondary, the condition of resonance. In such condition an extremely small change in the capacity of the free terminal produces great variations. For instance, I have been able to adjust the conditions so that the mere approach of a person to the coil produces a considerable change in the brightness of the lamps attached to the secondary. Such observations and experiments possess, of course, at present, chiefly scientific interest, but they may soon become of practical importance.

Very high frequencies are of course not practicable with motors on account of the necessity of employing iron cores. But one may use sudden discharges of low frequency and thus obtain certain advantages of high-frequency currents without rendering the iron core entirely incapable of following the changes and without entailing a very great expenditure of energy in the core. I have found it quite practicable to operate with such low frequency disruptive discharges of condensers alternating current motors. A certain class of such motors which I advanced a few years ago, which contain closed secondary circuits, will rotate quite vigorously when the discharges are directed through the exciting coils. One reason that such a motor operates so well with these discharges is that the difference of phase between the primary and secondary currents is 90 degrees,

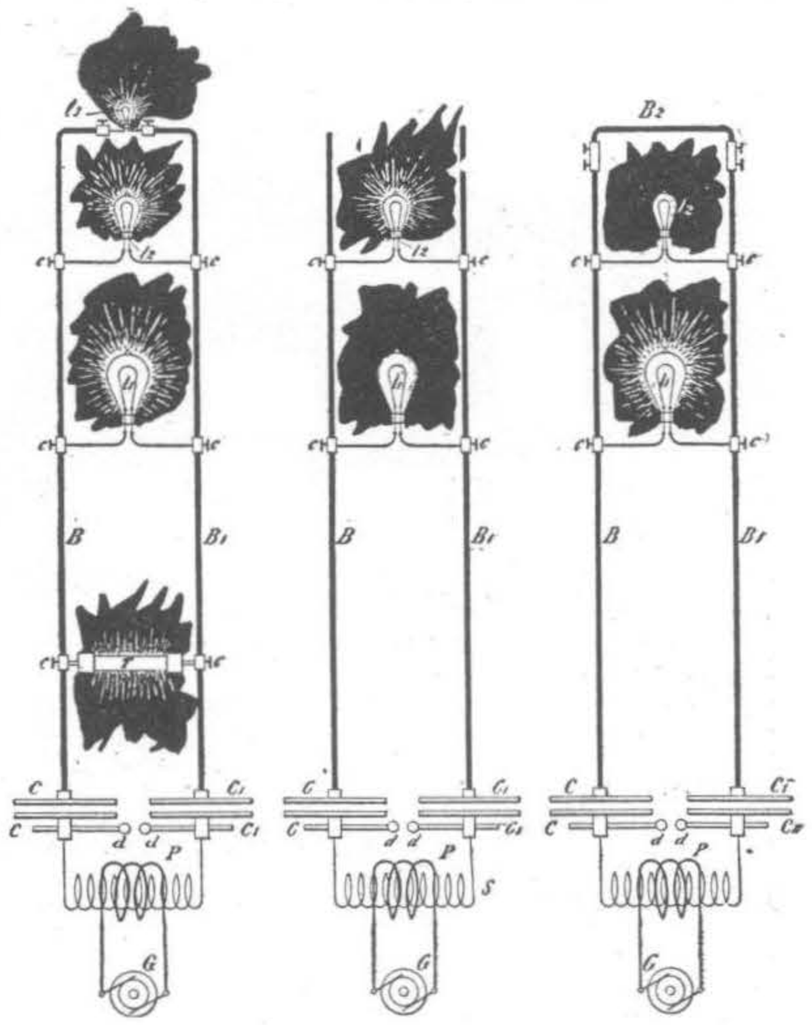


FIG. 19a, 19b, AND 19c. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—IMPEDANCE PHENOMENA.

which is generally not the case with harmonically rising and falling currents of low frequency. It might not be without interest to show an experiment with a simple motor of this kind, inasmuch as it is commonly thought that disruptive discharges are unsuitable for such purposes. The motor is illustrated in Fig. 18. It comprises a rather large iron core I with slots on the top into which are embedded thick copper washers C C. In proximity to the core is a freely-movable metal disc D. The core is provided with a primary exciting coil C, the ends A and B of which are connected to the terminals of the secondary S of an ordinary transformer, the primary P of the latter being

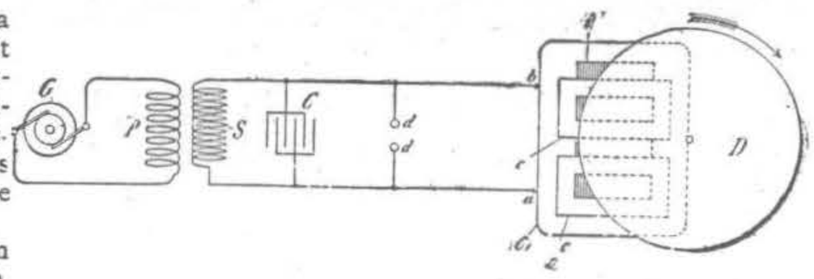


FIG. 18. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—OPERATING A MOTOR BY DISRUPTIVE DISCHARGES.

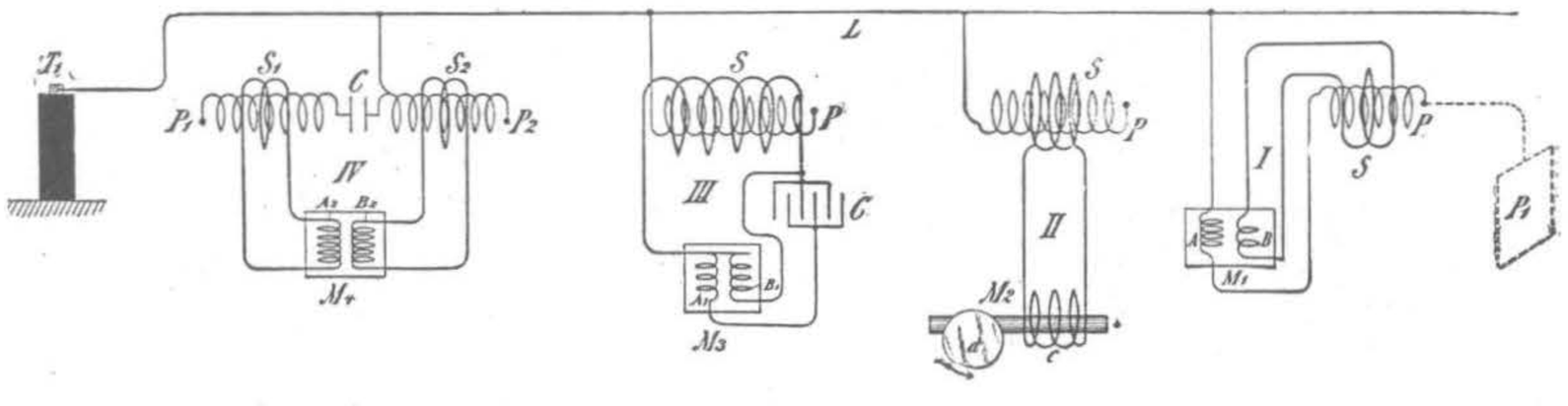


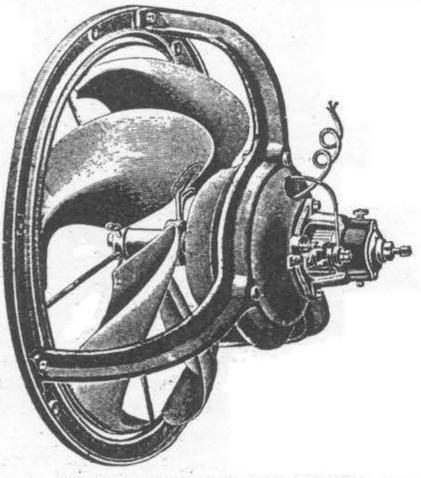
FIG. 16. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—WAYS OF OPERATING MOTORS WITH ONLY ONE LEAD.

connected to an alternating distribution circuit or generator G of low or moderate frequency. The terminals of the secondary S are attached to a condenser C which discharges through an air gap D D which may be placed in series or shunt to the coil C. When the conditions are properly chosen the disc D rotates with considerable effort and the iron core I does not get very perceptibly hot. With currents from a high-frequency alternator, on the contrary, the core gets rapidly hot and the disc rotates with a much smaller effort. To perform the experiment properly it should be first ascertained that the disc D is not set in rotation when the discharge is not occurring at D D. It is preferable to use a large iron core and a condenser of large capacity so as to bring the superimposed quicker oscillation to a very low pitch or to do away with it entirely. By observing certain elementary rules I have also found it practicable to operate ordinary series or shunt direct current motors with such disruptive discharges, and this can be done with or without a return wire.

Among the various current phenomena observed perhaps the most interesting are those of impedance presented by conductors to currents varying at a rapid rate. In my first

paper before the American Institute of Electrical Engineers I described a few striking observations of this kind. Thus I showed that when such currents or sudden discharges are passed through a thick metal bar there may be points at the bar only a few inches apart, which have a sufficient potential difference between them to maintain at bright incandescence an ordinary filament lamp. I have also described the curious behavior of rarefied gas surrounding a conductor to such sudden rushes of current. These phenomena have been since more carefully studied and one or two novel experiments of this kind are deemed of sufficient interest to be described here.

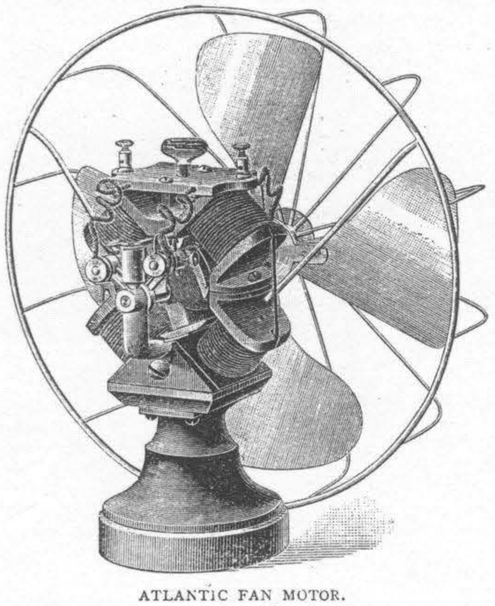
With reference to Fig. 19 A, B and B_1, are very stout copper bars, connected at their lower ends to plates C and C_1, respectively, of a condenser, the opposite plates of the latter being



LUNDELL EXHAUST FAN OUTFIT.

connected to the terminals of the secondary S of a high tension transformer, the primary P of which is supplied with alternating currents from an ordinary low frequency dynamo G or distribution circuit. The condenser discharges through an adjustable gap D D as usual. By establishing a rapid vibration it was found quite easy to perform the following curious experiment. The bars B and B_1 were joined at the top by a low voltage lamp L_3; a little lower was placed by means of clamps C C a 50 volt lamp L_2 and still lower another 100-volt lamp L_1, and finally at a certain distance below the latter lamp an exhausted tube T. By carefully determining the positions of these devices it was found practicable to maintain them all at their proper illuminating power. Yet they were all connected in multiple arc to the two stout copper bars and required widely different pressures. This experiment requires, of course, some time for adjustment, but is quite easily performed.

In Figs. 19 B and 19 C two other experiments are illustrated which, unlike the previous experiment, do not require very careful adjustments. In Fig. 20 B, two lamps L_1 and L_2, the former a 100 volt and the latter a 50 volt, are placed in certain positions as indicated, the 100 volt lamp being below the 50 volt lamp. When the arc is playing at D D and the sudden discharges passed through the bars B B the 50 volt lamp will, as a rule, burn brightly, or at least this result is easily secured, while the 100 volt lamp will burn very low or remain quite dark, Fig. 19 B. Now the bars B B may be joined at the top by a thick cross bar B_2 and it is quite easy to maintain the 100 volt lamp at full candle power, while the the 50 volt lamp remains dark, Fig. 19C. These results, as I have pointed out previously, should not be considered to be due exactly to frequency but rather to the time rate of change which may be great even with low frequencies. A great many other results of the same kind equally interesting, especially to those who are only used to



ATLANTIC FAN MOTOR.

manipulate steady currents, may be obtained and they afford precious clues in investigating the nature of electric currents.

In the preceding experiments I have already had occasion to show some light phenomena, and it would be now proper to study these in particular; but to make this investigation more complete I think it necessary to first make a few remarks on the subject of electrical resonance which has to be always observed in carrying out these experiments.

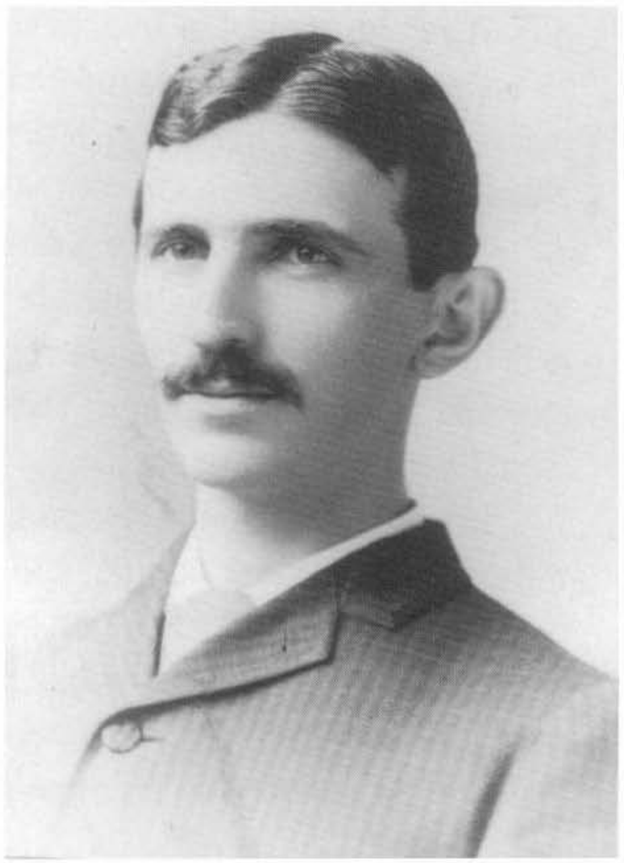
WESTERN ELECTRICIAN.

Light and Other High Frequency Phenomena.

By Nikola Tesla.

PART IV.

The effects of resonance are being more and more noted by engineers and are becoming of great importance in the practical operation of apparatus of all kinds with alternating currents. A few general remarks may therefore be made concerning these effects. It is clear that if we succeed in employing the effects of resonance practically in the operation of electric devices the return wire will, as a matter of course, become unnecessary, for the electric vibration may be conveyed with one wire just as well, and sometimes even better than with two. The question first to answer is, then, whether pure resonance effects are producible. Theory and experiment both show that such is impossible in nature, for as the oscillation becomes more and more vigorous the losses in the vibrating bodies and environing media rapidly increase and necessarily check the vibration, which otherwise would go on increasing forever. It is a fortunate circumstance that pure resonance is not producible, for if it were there is no telling what dangers might not lie in wait for the innocent experimenter. But to a certain degree resonance is producible, the magnitude of the effects being limited by the imperfect conductivity and imperfect elasticity of the media or, generally stated, by frictional losses. The smaller these losses, the more striking are the effects. The same is the case in mechanical vibration. A stout steel bar may be set in vibration by drops of water falling upon it at proper intervals; and with glass, which is more perfectly elastic, the resonance effect is still more remarkable, for a goblet may be burst by singing into it a note of the proper pitch. The electrical resonance is the more perfectly attained, the smaller the resistance or the impedance of the conducting path and the more perfect the dielectric. In a Leyden jar discharging through a short stranded cable of thin wires these requirements are probably best fulfilled, and the resonance effects are therefore very prominent. Such is not the case with dynamo machines, transformers and their circuits, or with commercial apparatus in general in which the presence of iron cores complicates or renders impossible the action. In regard to Leyden jars with which resonance effects are frequently demonstrated, I would say that the effects observed are often attributed but are seldom due to true resonance, for an error is quite easily made in this respect. This may be undoubtedly demonstrated by the following experiment. Take, for instance, two large insulated metallic plates or spheres which I shall designate A and B, place them at a certain small distance apart and charge them from a fractional or influence machine to a potential so high that just a slight increase of the difference of potential between them will cause the small air or insulating space to break down. This is easily reached by making a few preliminary trials. If now another plate—fastened on



an insulating handle and connected by a wire to one of the terminals of a high tension secondary of an induction coil, which is maintained in action by an alternator (preferably high frequency)—is approached to one of the charged bodies A or B, so as to be nearer to either one of them, the discharge will invariably occur between them, at least it will, if the potential of the coil in connection with the plate is sufficiently high. But the explanation of this will soon be found in the fact that the approached plate acts inductively upon the bodies A and B and causes a spark to pass between them. When this spark occurs, the charges, which were previously imparted to these bodies from the influence machine, must needs be lost, since the bodies are brought in electrical connnection through the arc formed. Now this arc is formed whether there be resonance or not But even if the spark would not be produced, still there is an alternating electromotive force set up between the bodies when the plate is brought near one of them; therefore the approach of the plate, if it does not always actually, will, at any rate, tend, to break down the air space by inductive action. Instead of the spheres or plates A and B we may take the coatings of a Leyden jar with the same result, and in place of the machine, which is a high frequency alternator preferably, because it is more suitable for the experiment and also for the argument, we may take another Leyden jar or battery of jars. When such jars are discharging through a circuit of low resistance the same is traversed by currents of very high frequency. The plate may now be connected to one of the coatings of the second jar, and when it is brought near to the first jar just previously charged to a high potential from an influence machine, the result is the same as before, and the first jar will discharge through a small air space upon the second being caused to discharge. But both jars and their circuits need not be tuned any closer than a basso profundo is to the note produced by a mosquito, as small sparks will be produced through the air space, or at least the latter will be considerably more strained owing to the setting up of an alternating electromotive force by induction, which takes place when one of the jars begins to discharge. Again another error of a similar nature is quite easily made. If the circuits of the two jars are run parallel and close together, and the experiment has been performed of discharging one by the other, and now a coil of wire be added to one of the circuits whereupon the experiment does not succeed, the conclusion that this is due to the fact that the circuits are now not tuned, would be far from being safe. For the two circuits act as condenser coatings and the addition of the coil to one of them is equivalent to bridging them, at the point where the coil is placed, by a small condenser, and the effect of the latter might be to prevent the spark from jumping through the discharge space by diminishing the alternating electricmotive force acting across the same. All these remarks, and many more which might be added but for fear of wandering too far from the subject, are made with the pardonable intention of cautioning the unsuspecting student, who might gain an entirely unwarranted opinion of his skill when seeing every experiment succeed; but they are in no way thrust upon the experienced as novel observations.

In order to make reliable observations, of electric resonance effects it is very desirable, if not necessary, to employ an alternator giving currents which rise and fall harmonically, as in working with make and break currents the observations are not always trustworthy, since many phenomena, which depend on the rate of change, may be produced with frequencies widely different. Even when making such observations with an alternator one is apt to be mistaken. When a circuit is connected to an alternator there are an infinite number of values for capacity and self-induction which, in conjunction, will satisfy the condition of resonance. So there are in mechanics an infinite number of tuning forks which will respond to a note of a certain pitch, or loaded springs which have a definite period of vibration. But the resonance will be most perfectly attained in that case in which the motion is effected with the greatest freedom. Now in mechanics, considering the vibration in the common medium—that is, air—it is of comparatively little importance whether one tuning fork be somewhat larger than another, because the losses in the air are not very considerable. One may of course inclose a tuning fork in an exhausted vessel and by thus reducing the air resistance to a minimum obtain better resonant action. Still the difference would not be very great. But it would make a great difference if the tuning fork were immersed in mercury. In the electrical vibration it is of enormous importance to arrange the conditions so that the vibration is effected with the greatest freedom. The magnitude of the resonance effect depends, under otherwise equal conditions, on the quantity of electricity set in motion or on the strength of the current driven through the circuit. But the circuit opposes the passage of the currents by reason of its impedance, and, therefore, to secure the best action it is necessary to reduce the impedance to a minimum. It is impossible to overcome it entirely, but merely in part, for ohmic resistance cannot be overcome. But when the frequency of the impulses is very great the flow of the current is practically determined by self-induction. Now, self-induction can be overcome by combining it with capacity. If the relation between these is such that at the frequency used they annul each other, that is, have such values as to satisfy the condition of resonance and the greatest quantity of electricity is made to flow through the external circuit, then the best result is obtained. It is simpler and safer

(*Continued on page* 327).

Light and other High Frequency Phenomena.

(*Continued from page 325*).

to join the condenser in series with the self-induction. It is clear that in such combinations there will be, for a given frequency, and considering only the fundamental vibration, values which will give the best result, with the condenser in shunt to the self-induction coil; of course more such values than with the condenser in series. But practical conditions determine the selection. In the latter case in performing the experiments one may take a small self-induction and a large capacity or a small capacity and a large self-induction, but the latter is preferable, because it is inconvenient to adjust a large capacity by small steps. By taking a coil with a very large self-induction the critical capacity is

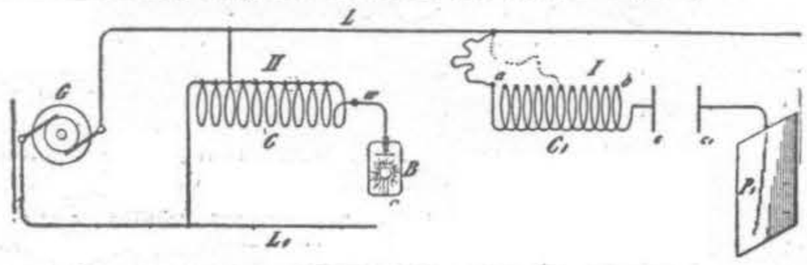


FIG. 20. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—PLAN FOLLOWED IN OBSERVING THE EFFECTS OF RESONANCE.

reduced to a very small value, and the capacity of the coil itself may be sufficent. It is easy, especially by observing certain artifices, to wind a coil through which the impedance will be reduced to the value of the ohmic resistance only and for any coil there is, of course, a frequency at which the maximum current will be made to pass through the coil. The observation of the relation between self-induction, capacity and frequency is becoming important in the operation of alternate current apparatus, such as transformers or motors, because by a judicious determination of the elements the employment of an expensive condenser becomes unnecessary. Thus it is possible to pass through the coils of an alternating current motor under the normal working conditions the required current with a low electromotive force and do away entirely with the false current, and the larger the motor the easier such a plan becomes practicable; but it is necessary for this to employ currents of very high potential or bigh frequency.

In Fig. 20 *i* is shown a plan which has been followed in the study of the resonance effects by means of a high frequency alternator. *C* is a coil of many turns, which is divided in small separate sections for the purposes of adjustment. The final adjustment was made sometimes with a few thin iron wires (though this is not always advisable) or with a closed secondary. The coil *C* is connected with one of its ends to the line *L* from the alternator *G*, and with the other end to one of the plates *c* of a condenser cc_1, the plate c_1 of the latter being connected to a much larger plate P_1. In this manner both capacity and self-induction were adjusted to suit the dynamo frequency.

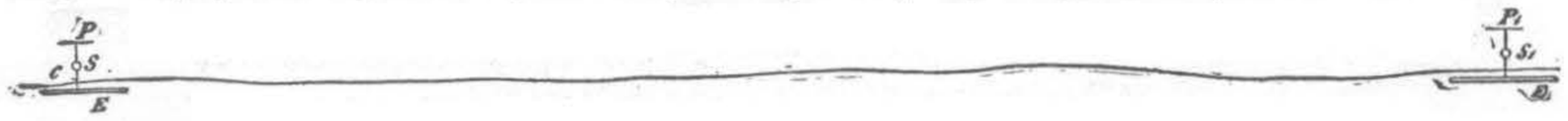


FIG. 21. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—ENERGY TRANSMISSION TO ANY DISTANCE WITHOUT WIRES.

As regards the rise of potential through resonant action, of course, theoretically, it may amount to anything since it depends on self-induction and resistance, and since these may have any value. But in practice one is limited in the selection of these values, and besides these there are other limiting causes. One may start with, say, 1,000 volts, and raise the electromotive force to fifty times that value, but one cannot start with 100,000 and raise it to ten times that value because of the losses in the media, which are great, especially if the frequency is high. It should be possible to start with, for instance, two volts from a high or low frequency circuit of a dynamo and raise the electromotive force to many hundred times that value. Thus coils of the proper dimensions might be connected each with only one of its ends to the mains from a machine of low electromotive force, and though the circuit of the machine would not be closed in the ordinary acceptance of

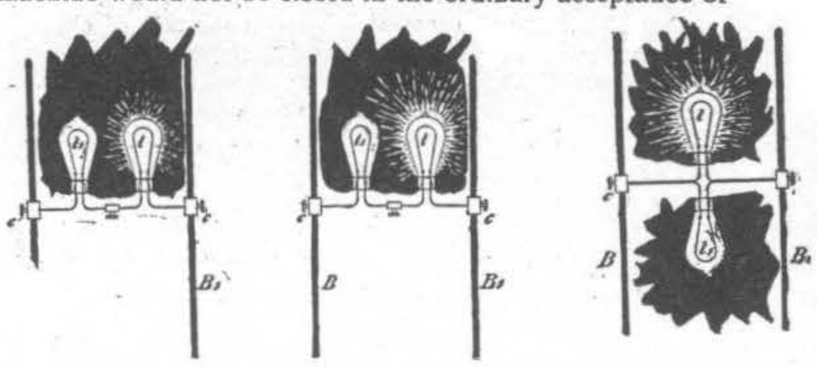


FIG. 22*a*, 22*b* AND 22*c*. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—SHOWING THE EFFECT OF THE PRESENCE OF A GASEOUS MEDIUM.

the term, yet the machine might be burned out if a proper resonance effect would be obtained. I have not been able to produce, nor have I observed with currents from the dynamo machine, such great rises of potential. It is possible, if not probable, that with currents obtained from apparatus containing iron the disturbing influence of the latter is the cause that these theoretical possibilities cannot be realized. But if such is the case I attribute it solely to the hysteresis and Faucault current losses in the core. Generally it was necessary to transform upward, when the electromotive force was very low, and usually an ordinary form of induction coil was employed, but sometimes the arrangement illustrated in Fig. 20 II has been found to be convenient. In this case a coil *C* is made in a great many sections, a few of these being used as the primary. In this manner both primary and secondary are adjustable. One end of the coil is connected to the line L_1 from the alternator, and the other line *L* is connected to the intermediate point of the coil. Such a coil with adjustable primary and secondary will be found also convenient in experiments with the disruptive discharge. When true resonance is obtained the top of the wave must of course be on the free end of the coil as, for instance, at the terminal of the phosphoresence bulb *B*. This is easily recognized by observing the potential of a point on the wire *w* nearer to the coil.

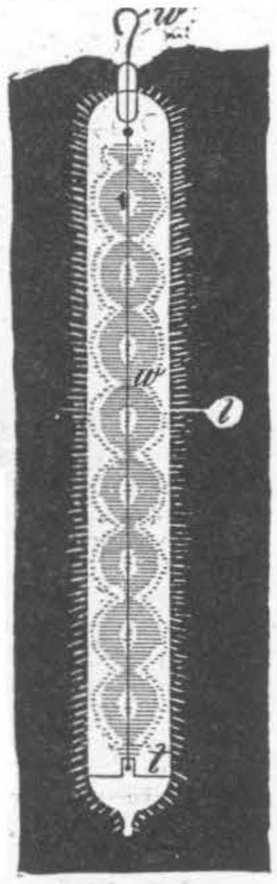


FIG. 23. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—CURIOUS INCANDESCENCE OF A WIRE.

In connection with resonance effects and the problem of transmission of energy over a single conductor which was previously considered, I would say a few words on a subject which constantly fills my thoughts and which concerns the welfare of all. I mean the transmission of intelligible signals or perhaps even power to any distance without the use of wires. I am becoming daily more convinced of the practicability of the scheme; and though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realized, yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day. The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb

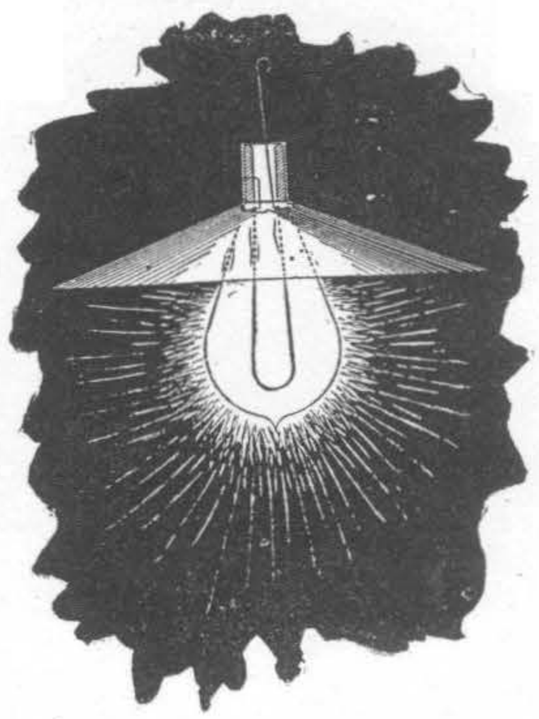


FIG. 24. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—UTILIZING THE HEATING EFFECT OF CONDUCTION CURRENT AND BOMBARDMENT.

by means of powerful machines the electrostatic condition of the earth and thus transmit intelligible signals and perhaps power. In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why then not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile-posts the earth may appear very large, but to that happiest of all men, the astronomer, who gazes at the heavens and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician, for when he considers the speed with which an electric disturbance is propagated through the earth all his ideas of distance must completely vanish.

A point of great importance would be first to know what is the capacity of the earth, and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation. If it be a charged body insulated in space its capacity should be extremely small, less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may

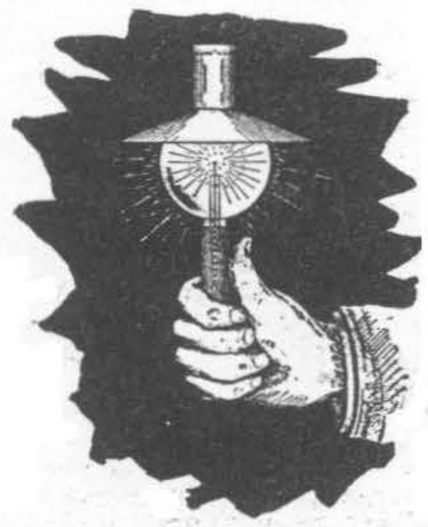


FIG. 26. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—INCANDESCENCE OF A SOLID.



FIG. 25. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—ILLUSTRATING LATERAL DIFFUSION.



FIG. 27. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—PHOSPHORESCENCE.

and that is by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric currents. One of the terminals of the source would be connected to earth as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata or free space contains an opposite charge and that, together with th

earth. they form a condenser of very large capacity. In such case the period of vibration may be very low and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body and watching for the disturbance at various neighboring points of the earth's surface resonance might be detected. Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do and a proper electrical oscillator would have to be produced and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface.

Assume that a source of alternating currents S be connected, as in Fig 21, with one of its terminals to earth (conveniently to the water mains) and with the other to a body of large surface P. When the electric oscillation is set up there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to, or diverging from, the point C where the ground connection is made. In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body P is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source S will set up the same electrical movement as though its circuit were closed. Thus, it is certainly practicable to impress an electric vibration at least of a certain low period, upon the earth, by means of proper machinery. At what distance such a vibration, might be made perceptible can only be conjectured. I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at the surface could be but extremely small considering the size of the earth, the air would not act as a very disturbing factor and there would be not much energy lost through the action of the air which would be the case if the density were great. Theoretically, then, it could not require a great amount of energy to produce a disturbance perceptible at great distance, or even all over the surface of the globe. Now it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source S_1 Fig. 21, similar to S, or any number of such sources can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S_1 if the same be of opposite phase to the source S. I think that beyond doubt it is possible to operate electrical devices in a city through the ground or pipe system by resonance from an electrical oscillator located at a central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realization of the scheme of transmitting intelligence or perhaps power to any distance through the earth or environing medium. If this is at all possible, distance does not mean anything. Proper apparatus must first be produced by means of which the problem can be attacked, and I have devoted much thought to this subject. I am firmly convinced that it can be done and hope that we shall live to see it done.

Returning now to the light effects which it has been the chief object to investigate, it is thought proper to divide these effects into four classes: 1. Incandescence of a solid. 2. Phosphoresence. 3. Incandescence or phosphorescence of a rarefied gas, and 4, Luminosity produced in a gas at ordinary pressure. The first question is: How are these luminous effects produced? In order to answer this question as satisfactorily as I am able to do in the light of accepted views and with the experience acquired, and to add some interest to this demonstration, I shall dwell here upon a feature which I consider of great importance, inasmuch as it promises, besides, to throw a better light upon the nature of most of the phenomena produced by high frequency electric currents. I have on other occasions pointed out the great importance of the presence of the rarefied gas or atomic medium in general around the conductor through which alternate currents of high frequency are passed, as regards the heating of the conductor by the currents. My experiments, described some time ago, have shown that the higher the frequency and potential difference of the currents the more important becomes the rarefied gas in which the conductor is immersed as a factor of the heating. The potential difference, however, is, as I then pointed out, a more important element than the frequency. When both of these are sufficiently high the heating may be almost entirely due to the presence of the rarefied gas. The experiments to follow will show the importance of the rarefied gas, or generally of gas at ordinary or other pressure, as regards the incandescence or other luminous effects produced by currents of this kind.

I take two ordinary 50 volt 16 candle power lamps which are in every respect alike, with the exception that one has been opened at the top and the air has filled the bulb, while the other is at the ordinary degree of exhaustion of commercial lamps. When I attach the lamp which is exhausted to the terminal of the secondary of the coil, which I have already used, as in experiments illustrated in Fig. 15a for instance, and turn on the current, the filament as you have before seen comes to high incandescence. When I attach the second lamp, which is filled with air, instead of the former, the filament still glows, but much less brightly. This experiment illustrates only in part the truth of the statements before made. The importance of the filaments being immersed in rarefied gas is plainly noticeable but not to such a degree as might be desirable. The reason is that the secondary of this coil is wound for low tension, having only 150 turns, and the potential difference at the terminals of the lamp is therefore small. Were I to take another coil with many more turns in the secondary, the effect would be increased, since it depends partially on the potential difference, as before remarked. But since the effect likewise depends on the frequency, it may be properly stated that it depends on the time rate of the variation of the potential difference. The greater this variation the more important becomes the gas as an element of heating. I can produce a much greater rate of variation in another way, which, besides, has the advantage of doing away with the objections, which might be made in the experiment just shown, even if both the lamps were connected in series or multiple arc to the coil, namely, that in consequence of the reactions existing between the primary and secondary coil the conclusions are rendered uncertain. This result I secure by charging from an ordinary transformer, which is fed from the alternating current supply station, a battery of condensers, and discharging the latter directly through a circuit of small self-induction, as before illustrated in Figs. 19a, 19b, 19c.

In Figs. 22a, 22b and 22c, the heavy copper bars BB_1 are connected to the opposite coatings of a battery of condensers, or generally in such way that the high frequency or sudden discharges are made to traverse them. I connect first an ordinary 50 volt incandescent lamp to the bars by means of the clamps cc. The discharges being passed through the lamp, the filament is rendered incandescent, though the current through it is very small, and would not be nearly sufficient to produce a visible effect under the conditions of ordinary use of the lamp. Instead of this I now attach to the bars another lamp exactly like the first, but with the seal broken off, the bulb being therefore filled with air at ordinary pressure. When the discharges are directed through the filament, as before, it does not become incandescent. But the result might still be attributed to one of the many possible reactions. I therefore connect both the lamps in multiple arc as illustrated in Fig. 22a. Passing the discharges through both the lamps, again the filament in the exhausted lamp l glows very brightly, while that in the non-exhausted lamp l_1 remains dark as previously. But it should not be thought that the latter lamp is taking only a small fraction of the energy supplied to both the lamps; on the contrary, it may consume a considerable portion of the energy, and it may become even hotter than the one which burns brightly. In this experiment the potential difference at the terminals of the lamps varies in sign theoretically three to four million times a second. The ends of the filaments are correspondingly electrified, and the gas in the bulbs is violently agitated and a large portion of the supplied energy is thus converted into heat. In the non-exhausted bulb there being a few million times more gas molecules than in the exhausted one, the bombardment, which is most violent at the ends of the filament in the neck of the bulb, consumes a large portion of the energy without producing any visible effect. The reason is that there being many molecules, the bombardment is quantitatively considerable, but the individual impacts are not very violent. The speeds of the molecules are comparatively small, owing to the small free path. In the exhausted bulb, on the contrary, the speeds are very great, and the individual impacts are violent, and therefore better adapted to produce a visible effect. Besides, the convection of heat is greater in the former bulb. In both the bulbs the current traversing the filaments is very small, incomparably smaller than that which they require on an ordinary low frequency circuit. The potential difference, however, at the ends of the filaments is very great, and might be possibly 20,000 volts or more, if the filaments were straight and their ends far apart. In the ordinary lamp a spark generally occurs between the ends of the filament or between the platinum wires outside, before such a difference of potential can be reached.

It might be objected in the experiment before shown that the lamps, being in multiple arc, the exhausted lamp might take a much larger current and that the effect observed might not be exactly attributable to the action of the gas in the bulbs. Such objections will lose much weight if I connect the lamps in series, with the same result. When this is done and the discharges are directed through the filaments it is again noted that the filament in the non-exhausted bulb l_1 remains dark, while that in the exhausted one (l) glows even more intensely than under its normal conditions of working, Fig. 22b. According to general ideas the current through the filaments should now be the same, were it not modified by the presence of the gas around the filaments.

At this juncture I may point out another interesting feature, which illustrates the effect of the rate of change of potential of the currents. I will leave the two lamps connected in series to the bars BB_1 as in the previous experiment, Fig. 22b, but will presently reduce considerably the frequency of the currents, which was excessive in the experiment just before shown. This I may do by inserting a self-induction coil in the path of the discharges, or by augmenting the capacity of the condensers. When I now pass these low-frequency discharges through the lamps, the exhausted lamp l again is as bright as before, but it is noted also that the non-exhausted lamp l_1 glows, though not quite as intensely as the other. Reducing the current through the lamps, I may bring the filament in the latter lamp to redness, and, though the filament in the exhausted lamp l is bright, Fig. 22c, the degree of its incandescence is much smaller than in Fig. 22b, when the currents were of a much higher frequency.

In these experiments the gas acts in two opposite ways in determining the degree of the incandescence of the filaments, that is, by convection and bombardment. The higher the frequency and potential of the currents, the more important becomes the bombardment. The convection on the contrary should be the smaller, the higher the frequency. When the currents are steady, there is practically no bombardment and convection may therefore with such currents also considerably modify the degree of incandescence and produce results similar to those just before shown. Thus, if two lamps exactly alike, one exhausted and one not exhausted, are connected in multiple arc or series to a direct current machine, the filament in the non-exhausted lamp will require a considerably greater current to be rendered incandescent. This result is entirely due to convection and the effect is the more prominent the thinner the filament. Professor Ayrton and Mr. Kilgour some time ago published quantitative results concerning the thermal emissivity by radiation and convection in which the effect of thin wires was clearly shown. This effect may be strikingly illustrated by preparing a number of small short glass tubes, each containing through its axis the thinnest obtainable platinum wire. If these tubes be highly exhausted, a number of them may be connected in multiple arc to a direct-current machine and all of the wires may be kept at incandescence with a smaller current than that required to render incandescent a single one of the wires if the tube be not exhausted. Could the tubes be so highly exhausted that convection would be nil, then the relative amounts of heat given off by convection and radiation could be determined without the difficulties attending thermal quantitative measurements. If a source of electric impulses of high frequency and very high potential is employed, a still greater number of the tubes may be taken and the wires rendered incandescent by a current not capable of warming perceptibly a wire of the same size immersed in air at ordinary pressure, and conveying the energy to all of them.

I may here describe a result which is still more interesting, and to which I have been led by the observation of these phenomena. I noted that small differences in the density of the air produced a considerable difference in the degree of incandescence of the wires, and I thought that, since in a tube, through which a luminous discharge is passed, the gas is generally not of uniform density, a very thin wire contained in the tube might be rendered incandescent at certain places of smaller density of the gas, while it would remain dark at the places of greater density where the convection would be greater and the bombardment less intense. Accordingly a tube t was prepared, as illustrated in Fig. 23, which contained through the middle a very fine platinum wire w. The tube was exhausted to a moderate degree and it was found that when it was attached to the terminal of a high frequency coil the platinum wire w would, indeed, become incandescent in patches, as illustrated in Fig. 23. Later a number of these tubes with one or more wires were prepared, each showing this result. The effect was best noted when the striated discharge occurred in the tube, but was also produced when the striæ were not visible, showing that, even then, the gas in the tube was not of uniform density. The position of the striæ was generally such that the rarefactions corresponded to the places of incandescence or greater brightness on the wire w. But in a few instances it was noted that the bright spots on the wire were covered by the dense parts of the striated discharge as indicated by l in Fig. 23, though the effect was barely perceptible. This was explained in a plausible way by assuming, that the convection was not widely different in the dense and rarefied places, and that the bombardment was greater on the dense places of the striated discharge. It is, in fact, often observed in bulbs, that under certain conditions a thin wire is brought to higher incandescence when the air is not too highly rarefied. This is the case when the potential of the coil is not high enough for the vacuum, but the result may be attributed to many different causes. In all cases this curious phenomenon of incandescence disappears when the tube, or rather the wire, acquires throughout a uniform temperature.

Disregarding now the modifying effect of convection there are then two distinct causes which determine the incandescence of a wire or filament with varying currents, that is, conduction current and bombardment. With steady currents we have to deal only with the former of these two causes, and the heating effect is a minimum, since the resistance is least to steady flow. When the current is a varying one, the resistance is greater and hence the heating effect is increased. Thus if the rate of change of the current is very great, the resistance may increase to such an extent that the filament is brought to incandescence with inappreciable currents, and we are able to take a short and thick block of carbon or other material and bring it to bright incandescence with a current incomparably smaller than that required to bring to the same degree of incandescence an ordinary thin lamp filament with a steady or low frequency current. This result is important, and illustrates how rapidly our views on these subjects are changing, and how quickly our field of knowledge is extending. In the art of incandescent lighting, to view this result in one aspect only, it has been commonly considered as an essential requirement for practical success, that the lamp filament should be thin and of high resistance. But now we know that the resistance to the steady flow of the filament does not mean anything; the filament might as well be short and thick; for if it be immersed in rarefied gas it will become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents. We may conclude from this, that it would be of advantage, so far as the lamp is considered, to employ high frequencies for lighting, as they allow the use of short and thick filaments and smaller currents.

If a wire or filament be immersed in a homogeneous medium, all the heating is due to true conduction current, but if it be enclosed in an exhausted vessel the conditions are entirely different. Here the gas begins to act, and the heating effect of the conduction current, as is shown in

many experiments, may be very small compared with that of the bombardment. This is especially the case if the circuit is not closed, and the potentials, of course, very high. Suppose a fine filament enclosed in an exhausted vessel be connected with one of its ends to the terminal of a high tension coil and with its other end to a large insulated plate. Though the circuit is not closed, the filament, as I have before shown, is brought to incandescence. If the frequency and potential be comparatively low, the filament is heated by the current passing through it. If the frequency and potential, and principally the latter, be increased, the insulated plate need be but very small, or may be done away with entirely, still the filament will become incandescent, practically all the heating being then due to the bombardment. A practical way of combining both the effects of conduction current and bombardment is illustrated in Fig. 24, in which an ordinary lamp is shown, provided with a very thin filament, which has one of the ends of the latter connected to a shade serving the purpose of the insulated plate, and the other end to the terminal of a high tension source. It should not be thought that only rarefied gas is an important factor in the

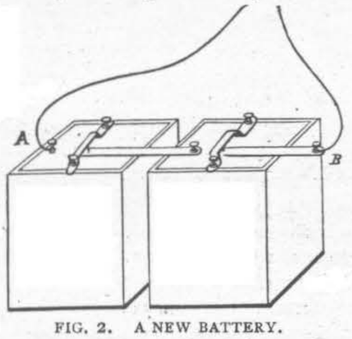


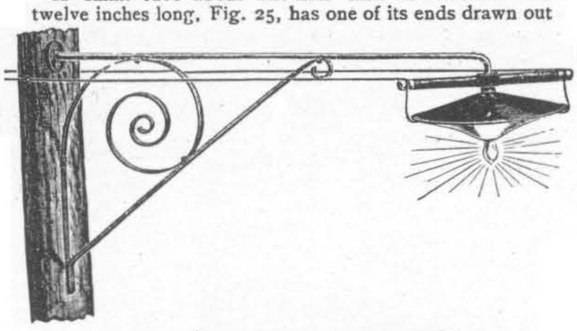
FIG. 2. A NEW BATTERY.

heating of a conductor by varying currents, but gas at ordinary pressure may become important if the potential difference and frequency of the currents is excessive. On this subject I have already stated that when a conductor is fused by a stroke of lightning the current through it may be exceedingly small, not even sufficient to heat the conductor perceptibly were the latter immersed in a homogeneous medium.

From the preceding it is clear that when a conductor of high resistance is connected to the terminals of a source of high frequency currents of high potential, there may occur considerable dissipation of energy, principally on the ends of the conductor, in consequence of the action of the gas surrounding the conductor. Owing to this, the current through a section of the conductor at a point midway between its ends may be much smaller than through a section near the ends. Furthermore, the current passes principally through the outer portions of the conductor, but this effect is to be distinguished from the skin effect as ordinarily interpreted, for the latter would or should occur also in a continuous incompressible medium. If a great many incandescent lamps are connected in series to a source of such currents, the lamps at the ends may burn brightly, whereas those in the middle may remain entirely dark. This is due principally to bombardment, as before stated. But even if the currents be steady, provided the difference of potential be very great, the lamps at the ends will burn more brightly than those in the middle. In such case there is no rhythmical bombardment and the result is produced entirely by leakage. This leakage or dissipation into space when the tension is high is considerable when incandescent lamps are used, and still more considerable with arcs, for the latter act like flames. Generally, of course, the dissipation is much smaller with steady than with varying currents.

I have contrived an experiment which illustrates in an interesting manner the effect of lateral diffusion. If a very long tube is attached to the terminal of a high frequency coil, the luminosity is greatest near the terminal and falls off gradually toward the remote end. This is more marked if the tube is narrow.

A small tube about one-half inch in diameter and twelve inches long, Fig. 25, has one of its ends drawn out



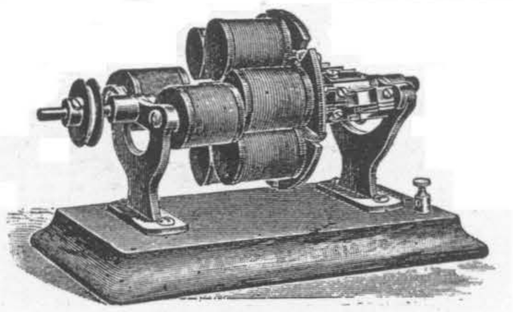
CUTTER'S BOULEVARD STREET HOOD.

into a fine fiber f nearly three feet long. The tube is placed in a brass socket T, which can be screwed on the terminal T_1 of the induction coil. The discharge passing through the tube first illuminates the bottom of the same, which is of camparatively large section; but through the long glass fiber the discharge cannot pass. But gradually the rarefied gas inside becomes warmed and more conducting and the discharge spreads into the glass fibre. This spreading is so slow that it may take half a minute or more until the discharge has worked through up to the top of the glass fiber, then presenting the appearance of a strongly luminous thin thread. By adjusting the potential at the terminal the light may be made to travel upward at any speed. Once, however, the glass fiber is heated the discharge breaks through its entire length instantly. The interesting point to be noted is that, the higher the frequency of the currents, or in other words, the greater relatively the lateral dissipation, at a slower rate may the light be made to propagate through the fiber. This experiment is best performed with a highly exhausted and freshly made tube. When the tube has been used for some time the experiment often fails. It is possible that the gradual and slow impairment of the vacuum is the cause. This slow propagation of the discharge through a very narrow glass tube corresponds exactly to the propagation of heat through a bar warmed at one end. The quicker the heat is carried away laterally the longer time it will take for the heat to warm the remote end. When the current of a low frequency coil is passed through the fiber from end to end, then the lateral dissipation is small and the discharge instantly breaks through almost without exception.

After these experiments and observations, which have shown the importance of the discontinuity or atomic structure of the medium and which will serve to explain, in a measure at least, the nature of the four kinds of light effects produceable with these currents, I may now give you an illustration of these effects. For the sake of interest I may do this in a manner which to many of you might be novel. You have seen before that we may now convey the electric vibration to a body by means of a single wire or conductor of any kind. Since the human frame is conducting I may convey the vibration through my body.

First, as in some previous experiments, I connect my body with one of the terminals of a high tension transformer and take in my hands an exhausted bulb which contains a small carbon button mounted upon a platinum wire leading to the outside of the bulb, and the button is rendered incandescent as soon as the transformer is set to work, Fig. 26. I may place a conducting shade on the bulb, which serves to intensify the action, but is not necessary. Nor is it required that the button should be in conducting connection with the hand through a wire leading through the glass, for sufficient energy may be transmitted through the glass itself by inductive action to render the button incandescent.

Next I take a highly exhausted bulb containing a strongly phosphorescent body, above which is mounted a small plate of aluminum on a platinum wire leading to the



MASON MOTOR.

outside, and the currents flowing through my body excite intense phosphorescence in the bulb, Fig. 27.

Light and Other High Frequency Phenomena.

By Nikola Tesla.

PART V.

I take in my hand a simple, exhausted tube, and in the same manner the gas inside the tube is rendered highly incandescent or phosphorescent, Fig. 28. Finally, I may take in my hand a wire, bare or covered with a thick insulation, it is quite immaterial; the electric vibration is so intense as to cover the wire with a luminous film, Fig. 29.

A few words must now be devoted to each of these phenomena. In the first place I will consider the incandescence of a button or of a solid in general and dwell upon some facts which apply equally to all these phenomena. It was pointed out before that when a thin con-



FIG. 28. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—INCANDESCENCE OR PHOSPHORESCENCE OF RAREFIED GAS. ILLUSTRATING FOUR KINDS OF LIGHT EFFECTS PRODUCED BY HIGH FREQUENCY CURRENTS OF HIGH POTENTIAL.

ductor, such as a lamp filament, for instance, is connected with one of its ends to the terminal of a transformer of high tension, the filament is brought to incandescence partly by a conduction current and partly by bombardment. The shorter and thicker the filament the more important becomes the latter and finally, reducing the filament to a mere button, all the heating must practically be attributed to the bombardment. So in the experiment before shown, the button is rendered incandescent by the rhythmical impact of freely movable small bodies in the bulb. These bodies may be the molecules of the residual gas, particles of dust or lumps torn from the electrode; whatever they are, it is certain that the heating of the button is essentially connected with the pressure of such freely movable particles, or of atomic matter in general in the bulb. The heating is the more intense the greater the number of impacts per second and the greater the energy of each impact. Yet the button would be heated also if it were connected to a source of a steady potential. In such a case electricity would be carried away from the button by the freely movable carriers or particles flying about, and the quantity of electricity thus carried away might be sufficient to bring the button to incandescence by its passage through the latter. But the bombardment could not be of great importance in such case. For this reason it would require a comparatively very great supply of energy to the button to maintain it at incandescence with a steady potential. The higher the frequency of the electric impulses the more economically can the button be maintained at incandescence. One of the chief reasons why this is so is, I believe, that with impulses of very high frequency there is less exchange of the freely

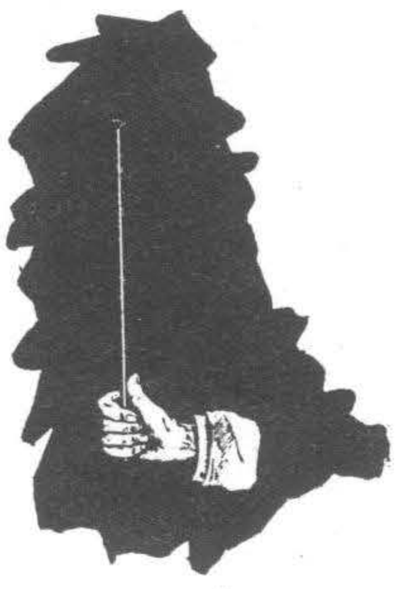


FIG. 29. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—LUMINOSITY OF GAS AT ORDINARY PRESSURE, ILLUSTRATING FOUR KINDS OF LIGHT EFFECTS PRODUCED BY HIGH FREQUENCY CURRENTS OF HIGH POTENTIAL.

movable carriers around the electrode and this means, that in the bulb the heated matter is better confined to the neighborhood of the button If a double bulb, as illustrated in Fig. 30, be made, comprising a large globe B and a small one b, each containing as usual a filament f mounted on a plantium wire w and w, it is found that if the filaments ff be exactly alike, it requires less energy to keep the filament in the globe b at a certain degree of incandescence, than that in the large globe B. This is due to the confinement of the movable particles around the button. In this case it is also ascertained, that the filament in the small globe b is less deteriorated when maintained a certain length of time at incandescence. This is a necessary consequence of the fact that the gas in the small bulb becomes strongly heated and therefore a very good conductor, and less work is then performed on the button, since the bombardment becomes less intense as the conductivity of the gas increases. In this construction, of course, the small bulb becomes very hot and when it reaches an elevated temperature the convection and radiation on the outside increase. On another occasion I have shown bulbs in which this drawback was largely avoided. In these instances a very small bulb, containing a refractory button, was mounted in a large globe and the space between the walls of both was highly exhausted. The outer large globe remained comparatively cool in such constructions. When the large globe was on the pump and the vacuum between the walls maintained permanent by the continuous action of the pump, the outer globe would remain quite cold, while the button in the small bulb was kept at incandescence. But when the seal was made, and the button in the small bulb maintained incandescent some length of time, the large globe too would become warmed. From this I conjecture that if vacuous space (as Prof. Dewar finds) cannot convey heat, it is so merely in virtue of our rapid motion through space, or,

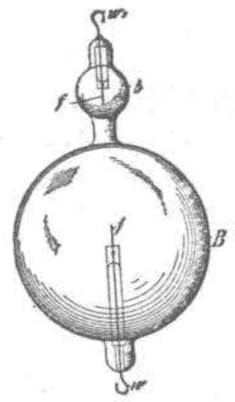


FIG. 30. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—SHOWING THE EFFECT OF CONFINING THE GAS AROUND THE ELECTRODE.

generally speaking, by the motion of the medium relatively to us, for a permanent condition could not be maintained without the medium being constantly renewed. A vacuum cannot, according to all evidence, be permanently maintained around a hot body.

In these constructions, before mentioned, the small bulb inside would, at least in the first stages, prevent all bombardment against the outer, large globe. It occurred to me, then, to ascertain how a metal sieve would behave in this respect, and several bulbs, as illustrated in Fig. 31, were prepared for this purpose. In a globe b, was mounted a thin filament f (or button) upon a platinum wire w passing through a glass stem and leading to the outside of the globe. The filament f was surrounded by a

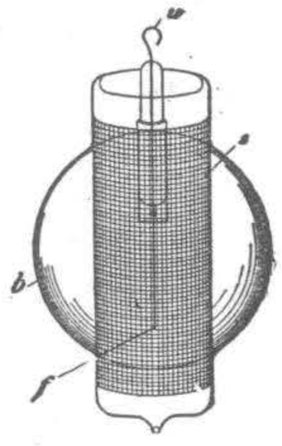


FIG. 31. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—SHOWING THE INEFFICIENCY OF A METAL SCREEN.

metal sieve s. It was found in experiments with such bulbs that a sieve with wide meshes apparently did not in the slightest affect the bombardment against the globe b. When the vacuum was high the shadow of the sieve was clearly projected against the globe and the latter would get hot in a short while. In some bulbs the sieve s was connected to a platinum wire sealed in the glass. When this wire was connected to the other terminal or the induction coil (the electromotive force being kept low in this case), or to an insulated plate, the bombardment against the outer globe b was diminished. By taking a sieve with fine meshes the bombardment against the globe b was always diminished, but even then if the exhaustion was carried very far, and when the potential of the tranformer was very high, the globe b would be bombarded and heated quickly, though no shadow of the sieve was visible owing to the smallness of the meshes. But a glass tube or other continuous body mounted so as to surround the filament, did entirely cut off the bombardment and for a while the outer globe b would remain perfectly cold. Of course when the glass tube was sufficiently heated the bombardment against the outer globe could be noted at once. The experiments with these bulbs seemed to show that the speeds of the projected molecules or particles must be considerable (though quite insignificant when compared with that of light), otherwise it would be difficult to understand how they could traverse a fine metal sieve without being affected, unless it were found that such small particles or atoms cannot be acted upon directly at measureable distances. In regard to the speed of the projected atoms Lord Kelvin has recently estimated it at about one kilometer a second, or thereabouts, in an ordinary Crookes bulb. As the potentials obtainable with a disruptive dis-

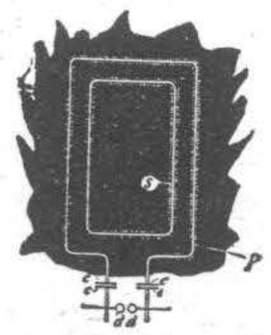
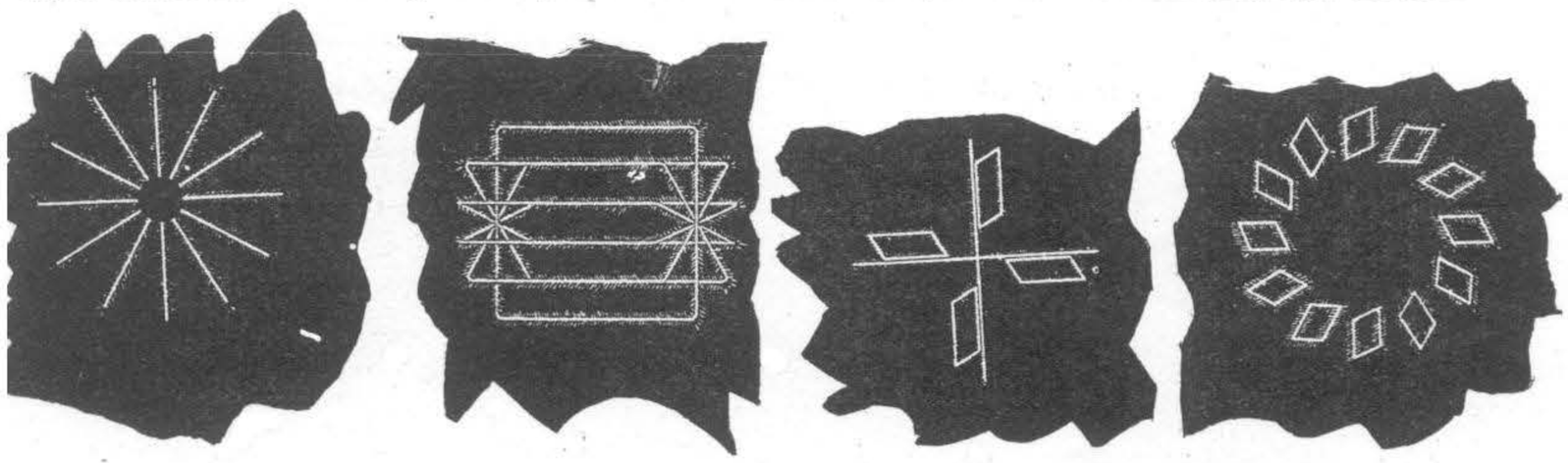


FIG. 32. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—ELECTROSTATIC ACTION BETWEEN PRIMARY AND SECONDARY, WITH EXTREMELY HIGH FREQUENCIES.

charge coil are much higher than with ordinary coils, the speeds must, of course, be much greater when the bulbs are lighted from such a coil. Assuming the speed to be as high as five kilometres and uniform through the whole trajectory, as it should be, in a very highly exhausted vessel, then if the alternate electrifications of the electrode would be of a frequency of five million, the greatest distance a particle could get away from the electrode would be one millimetre, and if it could be acted upon directly at that distance the exchange of electrode matter or of the atoms would be very slow, and there would be practically no bombardment against the bulb. This at least should be so, if the action of an electrode upon the atoms



FIGS. 34*a*, 34*b*, 34*c* AND 34*d*. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—SPOKE WHEEL, DRUM WINDING, ALTERNATE MOTOR WINDING, RING WINDING. SOME OF THE DESIGNS PRODUCED BY INTERMITTENT DISCHARGES.

of the residual gas would be such as upon electrified bodies which we can perceive. A hot body enclosed in an exhausted bulb produces always atomatic bombardment, but a hot body has no definite rhythm, for its molecules perform vibrations of all kinds.

If a bulb containing a button or filament be exhausted as high as is possible with the greatest care and by the use of the best artifices, it is often observed that the discharge cannot, at first, break though, but after sometime, probably in consequence of some changes within the bulb, the discharge finally passes through and the button is rendered incandescent. In fact, it appears that the higher the degree of exhaustion the easier is the incandescence produced. There seems to be no other causes to which the incandescence might be attributed in such case except to the bombardment or similar action of the residual gas, or of particles of matter in general. But if the bulb be exhausted with the greatest care can these play an important part? Assume the vacuum in the bulb to be tolerably perfect the great interest then centres in the question: Is the medium which pervades all space continuous or atomic? If atomic then the heating of a conducting button or filament in an exhausted vessel might be due largely to ether bombardment, and then the heating of a conductor in general through which currents of high frequency or high potential are passed must be modified by the behavior of such medium; then also the skin effect, the apparent increase of the ohmic resistance, etc., admit, partially, at least, of a different explanation.

It is certainly more in accordance with many phenomena

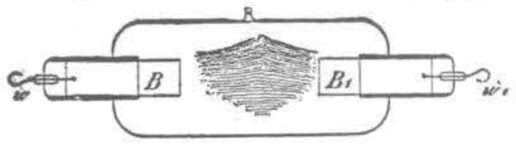


FIG. 33. LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.—CARBON DEPOSIT IN TUBE IN A MAGNETIC FIELD.

observed with high frequency currents to hold that all space is pervaded with free atoms, rather than to assume that it is devoid of these, and dark and cold, for so it must be, if filled with a continuous medium, since in such there can be neither heat nor light. Is then energy transmitted by independent carriers or by the vibration of a continuous medium? This important question is by no means as yet positively answered. But most of the effects which are here considered, especially the light effects, incandescence,

or phosphorescence, involve the presence of free atoms and would be impossible without these.

In regard to the incandescence of a refractory button (or filament) in an exhausted receiver, which has been one of the subjects of this investigation, the chief experiences, which may serve as a guide in constructing such bulbs, may be summed up as follows: 1. The button should be as small as possible, spherical, of a smooth or polished surface and of refractory material which withstands evaporation best. 2. The support of the button should be very thin and screened by an aluminum and mica sheet as I have described on another occasion. 3. The exhaustion of the bulb should be as high as possible. 4. The frequency of the currents should be as high as practicable. 5. The currents should be of a harmonic rise and fall, without sudden interruptions. 6. The heat should be confined to the button by inclosing the same in a small bulb or otherwise. 7. The space between the walls of the small bulb and the outer globe should be highly exhausted.

Most of the considerations which apply to the incandescence of a solid just considered may likewise be applied to phosphoresence. Indeed, in an exhausted vessel the phosphoresence is, as a rule, primarily excited by the powerful beating of the electrode stream of atoms against the phosphorescent body. Even in many cases where there is no evidence of such a bombardment, I think that phosphorescence is excited by violent impacts of atoms, which are not necessarily thrown off from the electrode but are acted upon from the same inductively through the medium or through chains of other atoms. That mechanical shocks play an important part in exciting phosphorescence in a bulb may be seen from the following experiment: If a bulb, constructed as that illustrated in Fig. 10, be taken and exhausted with the greatest care so that the discharge cannot pass, the filament *f* acts by electrostatic induction upon the tube *t* and the latter is set in vibration. If the tube *o* be rather wide, about an inch or so, the filament may be so powerfully vibrated that whenever it hits the glass tube it excites phosphoresence. But the phosphorescence ceases when the filament comes to rest. The vibration can be arrested and again started by varying the frequency of the currents. Namely, the filament has its own period of vibration, and if the frequency of the currents is such that there is resonance, it is set easily vibrating, though the potential of the currents be small. I have often observed that the filament in the bulb is destroyed by such mechanical resonance. The filament vibrates as a rule so rapidly that it cannot be seen and the experimenter may at first be mystified. When such an experiment as the one described is carefully performed, the potential of the currents need be extremely small, and for this reason I infer that the phosphorescence is then due to the mechanical shock of the filament against the glass, just as it is produced by striking a loaf of sugar with a knife. The mechanical shock produced by the projected atoms is easily noted when a bulb containing a button is grasped in the hand and the current turned on suddenly. I believe that a bulb could be shattered by observing the conditions of resonance.

Light and Other High Frequency Phenomena.

By Nikola Tesla.

PART VI.

In the experiment before cited it is, of course, open to say that the glass tube upon coming in contact with the filament, retains a charge of a certain sign upon the point of contact. If now the filament again touches the glass at the same point while it is oppositely charged, the charges equalize under evolution of ligh t. But nothing of importance would be gained by such an explanation. It is unquestionable that the initial charges given to the atoms or to the glass play some part in exciting phosphorescence. So, for instance, if a phosphorescent bulb be first excited by a high frequen cy coil by connecting it to one of the terminals of the latter and the degree of luminosity noted, and then the bulb be highly charged from a Holtz machine by attaching it preferably to the positive terminal of the machine, it is found that when the bulb is again connected to the terminal of the high frequency coil, the phosphorescence is far more intense. On another occasion I have considered the possibility of some phosphorescent phenomena in bulbs being produced by the incandescence of an infinitesimal layer on the surface of the phosphorescent body. Certainly, the impacts of the atoms are powerful enough to produce intense incandescence by the collisions, since they bring quickly to a high temperature a body of considerable bulk. If any such effect exists, then the best appliance for producing phosphorescence in a bulb, which we know so far, is a disrupt ive discharge coil giving an enormous potential with but few fundamental discharges, say 25 to 30 per second, just enough, to produce a continuous impression upon the eye. It is a fact that such a coil excites phosphorescence under most any condition and at all degrees of exhaustion, and I have observed effects which appear to be due to phosphorescence even at ordinary pressures of the atmosphere, when the potentials are extremely high. But if phosphorescent light is produced by the equalization of charges of electrified atoms (whatever this may mean ultimately), then the higher the frequency of the impulses or alternate electrifications, the more economical will be the light production. It is a long known and noteworthy fact that all the phosphorescent bodies are poor conductors of electricity and heat, and that all bodies cease to emit phosphorescent light when they are brought to a certain temperature. Conductors, on the contrary, do not possess this quality. There are but few exceptions to the rule. Carbon is one of them. Becquerel noted that carbon phosphoresces at a certain elevated temperature preceding the dark red. This phenomena may be easily observed in bulbs provided with a rather large carbon electrode (say a sphere of six millimeters diameter). If the current is turned on after a few seconds a snow white film covers the electrode, just before it gets dark red. Similar effects are noted with other conducting bodies, but many scientific men will probably not attribute them to true phosphorescence. Whether true incandescence has anything to do with phosphorescence excited by atomic impact or mechanical shocks still remains to be decided, but it is a fact that all conditions which tend to localize and increase the heating effect at the point of impact, are almost invariably the most favorable for the production of phosphorescence. So, if the electrode be very small, which is equivalent to saying in general, that the electric density is great, if the potential be high, and if the gas be highly rarefied, all of which things imply high speed of the projected atoms, or matter, and consequently violent impacts—the phosphorescence is very intense. If a bulb provided with a large and small electrode be attached to the terminal of an induction coil, the small electrode excites phosphorescence while the large one may not do so, because of the smaller electric density and hence smaller speed of the atoms. A bulb provided with a large electrode may be grasped with the hand while the electrode is connected to the terminal of the coil and it may not phosphoresce; but if instead of grasping the bulb with the hand, the same be touched with a pointed wire, the phosphorescence at once spreads through the bulb, because of the great density at the point of contact. With low frequencies it seems that gases of great atomic weight excite more intense phosphorescence than those of smaller weight, as for instance, hydrogen. With high frequencies the observations are not sufficiently reliable to draw a conclusion. Oxygen, as is well known, produces exceptionally strong effects, which may be in part due to chemical action. A bulb with hydrogen residue seems to be most easily excited. Electrodes which are most easily deteriorated produce more intense phosphorescence in bulbs, but the condition is not permanent because of the impairing of the vacuum and the deposition of the electrode matter upon the phosohorescent surfaces. Some liquids as oil, for instance, produce magnificent effects of phosphorescence (or fluorescence?), but they last only a few seconds. So if a bulb has a trace of oil on the walls and the current is turned on, the phosphorescence only persists for a few moments until the oil is carried away. Of all bodies so far tried, sulphide of zinc seems to be the most susceptible to phosphorescence. Some samples obtained through the kindness of Prof. Henry in Paris, were employed in many of these bulbs. One of the defects of this sulphide is that it loses its quality of emitting light when brought to a temperature which is by no means high. It can therefore be used only for feeble intensities. An observation which might deserve notice is that when violently bombarded from an aluminum electrode it assumes a black color, but singularly enough, it returns to the original condition when it cools down.

The most important fact arrived at in pursuing investigations in this direction is that in all cases it is necessary, in order to excite phosphorescence with a minimum amount of energy, to observe certain conditions; namely, there is always, no matter what the frequency of the currents, degree of exhaustion and character of the bodies in the bulb, a certain potential (assuming the bulb excited from one terminal) or potential difference (assuming the bulb to be excited with both terminals) which produces the most economical result. If the potential be increased considerable energy may be wasted without producing any more light, and if it be diminished, then again the light production is not as economical. The exact condition under which the best result is obtained seems to depend on many things of a different nature and it is to be yet investigated by other experimenters, but it will certainly have to be observed when such phosphorescent bulbs are operated, if the best results are to be attained.

Coming now to the most interesting of these phenomena, the incandescence or phosphorescence of gases, at low pressures or at the ordinary pressure of the atmosphere, we must seek the explanation of these phenomena in the same primary causes, that is, in shocks or impacts of the atoms. Just as molecules or atoms beating upon a solid body excite phosphorescence in the same or render it incandescent, so when colliding among themselves they produce similar phenomena. But this is a very insufficient explanation and concerns only the crude mechanism. Light is produced by vibrations which go on at a rate almost inconceivable. If we compute, from the energy contained in the form of known radiations in a definite space the force which is necessary to set up such rapid vibrations, we find, that though the density of the ether be incomparably smaller than that of any body we know, even hydrogen, the force is something surpassing comprehension. What is this force, which in mechanical measure, may amount to thousands of tons per square inch? It is electrostatic force in the light of modern views. It is impossible to conceive how a body of measurable dimensions could be charged to so high a potential that the force would be sufficient to produce these vibrations. Long before any such charge could be imparted to the body it would be shattered into atoms. The sun emits light and heat, and so does an ordinary flame or incandescent filament, but in neither of these can the force be accounted for if it be assumed that it is associated with the body as a whole. Only in one way may we account for it; namely, by identifying it with the atom. An atom is so small, that if it be charged by coming in contact with an electrified body and the charge be asssumed to follow the same law as in the case of bodies of measurable dimensions, it must retain a quantity of electricity which is fully capable of accounting for these forces and tremendous rates of vibration. But the atom behaves singularly in this respect, it always takes the same "charge."

It is very likely that resonant vibration plays a most important part in all manifestations of energy in nature. Throughout space all matter is vibrating, and all rates of vibration are represented, from the lowest musical note to the highest pitch of the chemical rays, hence an atom or complex of atoms, no matter what its period, must find a vibration with which it is in resonance. When we consider the enormous rapidity of the light vibrations, we realize the impossibility of producing such vibrations directly with any apparatus of measurable dimensions, and we are driven to the only possible means of attaining the object of setting up waves of light by electrical means and economically, that is, to affect the molecules. or atoms of a gas, to cause them to collide and vibrate. We then must ask ourselves—how can free molecules or atoms be affected?

It is a fact that they can be affected by electrostatic force, as is apparent in many of these experiments. By varying the electrostatic force we can agitate the atoms, and cause them to collide under evolution of heat and light. It is not demonstrated beyond doubt that we can affect them otherwise. If a luminous discharge is produced in a closed exhausted tube, do the atoms arrange themselves in obedience to any other but to electrostatic force acting in straight lines from atom to atom? Only recently I investigated the mutual action between two circuits with extreme rates of vibration. When a battery of a few jars (*c c c c*, Fig. 32,) is discharged through a primary *P* of low resistance (the connections being as illustrated in Figs. 19*a*, 19*b* and 19*c*), and the frequency of vibration be many million there are great differences of potential between points on the primary not more than a few inches apart. These differences may be 10,000 volts per inch, if not more, taking the maximum value of the electromotive force. The secondary *s* is therefore acted upon by electrostatic induction, which is in such extreme cases of much greater importance than the electro-dynamic. To such sudden impulses the primary as well as the secondary are poor conductors, and therefore great differences of potential may be produced by electrostatic induction between adjacent points on the secondary. Then sparks may jump between the wires and streamers become visible in the dark if the light of the discharge through the spark gap *d d* be carefully excluded. If now we substitute a closed vacuum tube for the metallic secondary *s*, the differences of potential produced in the tube by electrostatic induction from the primary are fully sufficient to excite portions of it; but as the points of certain differences of potential on the primary are not fixed, but are generally constantly changing in position, a luminous band is produced in the tube, apparently not touching the glass, as it should, if the points of maximum and minimum differences of potential were fixed on the primary. I do not exclude the possibility of such a tube being excited only by electro-dynamic induction, for very able physicists hold this view; but in my opinion, there is as yet no positive proof given that atoms of a gas in a closed tube may arrange themselves in chains under the action of an electromotive impulse produced by electro-dynamic induction in the tube. I have been unable so far to produce striæ in a tube, however long, and at whatever degree of exhaustion, that is, striæ at right angles to the supposed direction of the discharge or the axis of the tube, but I have distinctly observed in a large bulb, in which a wide luminious band was produced by passing a discharge of a battery through a wire surrounding the bulb, a circle of feeble luminiosity between two luminious bands, one of which was more intense than the other. Furthermore, with my present experience I do not think that such a gas discharge in a closed tube can vibrate, that is, vibrate as a whole. I am convinced that no discharge through a gas can vibrate. The atoms of a gas behave very curiously in respect to sudden electric impulses. The gas does not seem to possess any appreciable inertia to such impulses, for it is a fact that the higher the frequency of the impulses,

with the greater freedom does the discharge pass through the gas. If the gas posesses no inertia then it cannot vibrate, for some inertia is necessary for the free vibration. I conclude from this that if a lightning discharge occurs between two clouds, there can be no oscilation, such as would be expected, considering the capacity of the clouds. But if the lightning discharge strike the earth, there is always vibration—in the earth, but not in the cloud. In a gas discharge each atom vibrates at its own rate, but there is no vibration of the conducting gaseous mass as a whole. This is an important consideration in the great problem of producing light economically, for it teaches us that to reach this result we must use impulses of very high frequency and necessarily also of high potential It is a fact that oxygen produces a more intense light in a tube. Is it because oxygen atoms possess some inertia and the vibration does not die out instantly? But then nitrogen should be as good, and chlorine and vapors of many other bodies much better than oxygen, unless the magnetic properties of the latter enter prominently into play. Or, is the process in the tube of an electrolytic nature? Many observations certainly speak for it, the most important being, that matter is always carried away from the electrodes and the vacuum in a bulb cannot be permanently maintained. If such process takes place in reality, then again must we take refuge in high frequencies, for with such, electrolytic action should be reduced to a minimum, if not rendered entirely impossible. It is an undeniable fact that with very high frequencies, provided the impulses be of a harmonic nature, like those obtained from an alternator, there is less deterioration and the vacua are more permanent. With disruptive discharge coils there are sudden rises of potential and the vacua are more quickly impaired, for the electrodes are deteriorated in a very short time. It was observed in some large tubes, which were provided with heavy carbon blocks B B_1, connected to platinum wires w w_1 (as illustrates in Fig. 33), and which were employed in experiments with the disruptive discharge instead of the ordinary air gap, that the carbon particles under the action of the powerful magnetic field in which the tube was placed, were deposited in regular fine lines in the middle of the tube as illustrated. These lines were attributed to the deflection or distortion of the discharge by the magnetic field, but why the deposit occurred principally where the field was most intense did not appear quite clear. A fact of interest, likewise noted, was that the presence of a strong magnetic field increases the deterioration of the electrodes, probably by reason of the rapid interruptions it produces, whereby there is actually higher electromotive force maintained between the electrodes.

Much would remain to be said about the luminous effects produced in gases at low or ordinary pressures. With the present experiences before us we cannot say that the essential nature of these charming phenomena is sufficiently known. But investigations in this direction are being pushed with exceptional ardor. Every line of scientific pursuit has its fascinations, but electrical investigation appears to possess a peculiar attraction, for there is no experiment or observation of any kind in the domain of this wonderful science which would not forcibly appeal to us. Yet to me it seems, that of all the many marvelous things we observe, a vacuum tube, excited by an electric impulse from a distant source, bursting forth out of the darkness and illuminating the room with its beautiful light, is as lovely a phenomenon as can greet our eyes. More interesting still it appears when, reducing the fundamental discharges across the gap to a very small number and waving the tube about we produce all kinds of designs in luminous lines. So by way of amusement, I take a straight long tube, or a square one, or a square attached to a straight tube and by whirling them about in the hand, I imitate the spokes of a wheel, a Gramme winding, a drum winding, an alternate current motor winding, etc. Fig. 34. Viewed from a distance the effect is weak and much of) its beauty is lost, but being near or holding the tube in the hand one cannot resist its charm.

In presenting these insignificant results I have not attempted to arrange and co-ordinate them as would be proper in a strictly scientific investigation in which every succeeding result should be a logical sequence of the preceeding, so that it might be guessed in advance by the careful reader or attentive listener. I have preferred to concentrate my energies chiefly upon advancing novel facts or ideas which might serve as suggestions to others, and this may serve as an excuse for the lack of harmony. The explanations of the phenomena have been given in good faith and in the spirit of a student prepared to find that they admit of a better interpretation. There can be no great harm in a student taking an erroneous view, but when great minds err, the world must dearly pay for their mistakes.

LEGAL NOTES.

THE TESLA POLYPHASE PATENTS—WESTINGHOUSE vs. THOMSON-HOUSTON ELECTRIC CO.

Two suits have just been instituted against the Thomson-Houston Company by the Westinghouse Electric and Manufacturing Company and the Tesla Electric Company. These suits are based upon four patents of Nikola Tesla relating to the system of transmitting electric power by "multiphase" alternating electric currents. The patents said to be infringed were issued May 1st, 1888, and are numbered respectively 381,968, 381,969, 382,280 and 382,281. We give below the claims of the two latter patents which are the method patents, the two former claiming the apparatus.

The claim of patent No. 382,280 is: "The method herein described of electrically transmitting power, which consists in producing a continuously progressive shifting of the polarities of either or both elements (the armature or field magnet or magnets) of a motor by developing alternating currents in independent circuits, including the magnetizing coils of either or both elements, as herein set forth."

The claim of patent No. 382,281 is: "The method herein described of transmitting power by electromagnetic motors, which consists in continuously and progressively shifting the poles of one element of the motor by alternating currents and magnetizing the other element by a direct or continuous current, as set forth."

The suit has been brought in the U. S. Circuit Court at Hartford, and a specific infringement is in the plant for transmitting power from Farmington to Hartford.

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.[1]

BRILLIANTLY worded, comprehensive, and strikingly illustrated was a lecture delivered by Mr. Nikola Tesla, of which a report has just reached us. In his own words :—

[1] A lecture delivered before the Franklin Institute, at Philadelphia, Feb. 24, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893.

"In presenting these insignificant results I have not attempted to arrange and co-ordinate them as would be proper in a strictly scientific investigation in which every succeeding result should be a logical sequence of the preceding, so that it might be guessed in advance by the careful reader or attentive listener. I have preferred to concentrate my energies chiefly upon advancing novel facts or ideas which might serve as suggestions to others, and this may serve as an excuse for the lack of harmony. The explanations of the phenomena have been given in good faith, and in the spirit of a student prepared to find that they admit of a better interpretation. There can be no great harm in a student taking an erroneous view, but when great minds err, the world must dearly pay for their mistakes."

The following extracts will serve to show the character of the discourse :—

The Action of the Eye.

It can be taken as a fact, which the theory of the action of the eye implies, that for each external impression, that is, for each image produced upon the retina, the ends of the visual nerves concerned in the conveyance of the impression to the mind, must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and therefore upon the retina. Will it ever be within human power to analyse the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness, that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science, in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he was able to *see*, in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

Another fact having a bearing on this subject which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation is, that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, observable even in broad daylight.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting that the very conception of that which is perfect or seems so to him, has been gained through this same instrument. Firstly, the eye is, as far as our positive knowledge goes, the only organ which is *directly* affected by that subtile medium, which, as science teaches us, must fill all space; secondly, it is the most sensitive of our organs, incomparably more sensitive to external impressions than any other.

This divine organ of sight, this indispensable instrument for thought and all intellectual enjoyment, which lays open to us the marvels of this universe, through which we have acquired what knowledge we possess, and which prompts us to, and controls, all our physical and mental activity. By what is it affected? By light! What is light?

It is beyond the scope of my lecture to dwell upon the subject of light in general, my object being merely to bring presently to your notice a certain class of light effects and a number of phenomena observed in pursuing the study of these effects. But to be consistent in my remarks it is necessary to state that according to that idea, now accepted by the majority of scientific men as a positive result of theoretical and experimental investigation, the various forms of manifestations of energy which were generally designated as "electric" or more precisely "electromagnetic" are energy manifestations of the same nature as those of radiant heat and light. Therefore the phenomena of light and heat, and others besides these, may be called electrical phenomena. Thus electrical science has become the mother science of all and its study has become all-important. The day when we shall know exactly what "electricity" is, will chronicle an event probably greater, more important than any other recorded in the history of the human race.

Transformation of Currents.

Mr. Tesla then went on to describe the apparatus employed, and the method of obtaining the high potentials and high frequency currents which are made use of in his experiments. In order to explain the transformation of currents he used the following analogy :—

Imagine a tank with a wide opening at the bottom, which is kept closed by spring pressure, but so that it snaps off *suddenly* when the liquid in the tank has reached a certain height. Let the fluid be supplied to the tank by means of a pipe feeding at a certain rate. When the critical height of the liquid is reached, the spring gives way and the bottom of the tank drops out. Instantly the liquid falls through the wide opening, and the spring, reasserting itself, closes the bottom again. The tank is now filled, and after a certain time interval the same process is repeated. It is clear that if the pipe feeds the fluid quicker than the bottom outlet is capable of letting it pass through, the bottom will remain off and the tank will still overflow. If the rates of supply are exactly equal, then the bottom lid will remain partially open, and no vibration of the same and of the liquid column will generally occur, though it might, if started by some means. But if the inlet pipe does not feed the fluid fast enough for the outlet, then there will be always vibration. Again, in such case, each time the bottom flaps up or down, the spring and the liquid column, if the pliability of the spring and the inertia of the moving parts are properly chosen, will perform independent vibrations. In this analogue the fluid may be likened to electricity or electrical energy, the tank to the condenser, the spring to the dielectric, and the pipe to the conductor through which electricity is supplied to the condenser. To make this analogy quite complete it is necessary to make the assumption, that the bottom, each time it gives way, is knocked violently against a non-elastic stop, this impact involving some loss of energy, and that, besides, some dissipation of energy results, due to frictional losses. In the preceding analogue the liquid is supposed to be under a steady pressure. If the pressure of the fluid be assumed to vary rhythmically, this may be taken as corresponding to the case of an alternating current. The process is then not quite as simple to consider, but the action is the same in principle.

Electrostatic Force.

After showing that the human body could be traversed by a powerful electric current vibrating at about the rate of one million times per second, Mr. Tesla said :—

The amount of energy which may thus be passed into the body of a person depends on the frequency and potential of the currents, and by making both of these very great, a vast amount of energy may be passed into the body without causing any discomfort except perhaps in the arm, which is traversed by a true conduction current. The reason why no pain in the body is felt, and no injurious effect noted, is that everywhere, if a current be imagined to flow through the body, the direction of its flow would be at right angles to the surface; hence the body of the experimenter offers an enormous section to the current, and the density is very small, with the exception of the arm perhaps, where the density may be considerable. But if only a small fraction of that energy would be applied in such a way that a current would traverse the body in the same manner as a low frequency current, a shock would be received which might be fatal. A direct or low-frequency alternating current is fatal I think, principally because its distribution through the body is not uniform, as it must divide itself in minute streamlets of great density, whereby some organs are vitally injured. That such a process occurs I have not the least doubt, though no evidence might apparently exist or be found upon examination. The surest to injure and destroy life is a continuous current, but the most painful is an alternating current of very low frequency. The expression of these views, which are the result of long-continued experiment and observation, both with steady and varying currents, is elicited by the interest which is at present taken in this subject and by the manifestly erroneous ideas which are daily propounded in journals on this subject.

The electrostatic attractions and repulsions between bodies of measurable dimensions are, of all the manifestations of this force,

the first so-called *electrical* phenomena noted. But though they have been known to us for many centuries, the precise nature of the mechanism concerned in these actions is still unknown to us, and has not been even quite satisfactorily explained. What kind of mechanism must that be? We cannot help wondering when we observe two magnets attracting and repelling each other with a force of hundreds of pounds with apparently nothing between them. We have in our commercial dynamos magnets capable of sustaining in mid-air tons of weight. But what are even these forces acting between magnets when compared with the tremendous attractions and repulsions produced by electrostatic force, to which there is apparently no limit as to intensity. In lightning discharges bodies are often charged to so high a potential that they are thrown away with inconceivable force and torn asunder or shattered into fragments. Still even such effects cannot compare with the attractions and repulsions which exist between charged molecules or atoms, and which are sufficient to project them with speeds of many kilometres a second so that under their violent impact bodies are rendered highly incandescent and are volatilized. It is of special interest for the thinker who inquires into the nature of these forces to note, that whereas the actions between individual molecules or atoms occur seemingly under any condition, the attractions and repulsions of bodies of measurable dimensions imply a medium possessing insulating properties. So, if air, either by being rarefied or heated, is rendered more or less conducting, these actions between two electrified bodies practically cease, while the actions between the individual atoms continue to manifest themselves.

Single-wire Transmission.

It has been for a long time customary, owing to the limited experience with vibratory currents, to consider an electric current as something circulating in a closed conducting path. It was astonishing at first to realise that a current may flow through the conducting path even if the latter be interrupted, and it was still more surprising to learn, that sometimes it may be even easier to make a current flow under such conditions than through a closed path. But that old idea is gradually disappearing, even among practical men, and will soon be entirely forgotten.

It is thought useful to devote here a few remarks to the subject of operating devices of all kinds by means of only one leading wire. It is quite obvious, that when high-frequency currents are made use of, ground connections are—at least, when the E.M.F. of the currents is great—better than a return wire. Such ground connections are objectionable with steady or low frequency currents on account of destructive chemical actions of the former and disturbing influences exerted by both on the neighbouring circuits; but with high frequencies these actions practically do not exist. Still, even ground connections become superfluous when the E.M.F. is very high, for soon a condition is reached when the current may be passed more economically through open, than through closed conductors. Remote as might seem an industrial application of such single wire transmission of energy to one not experienced in such lines of experiment, it will not seem so to any one who for some time has carried on investigations of such nature. Indeed I cannot see why such a plan should not be practicable. Nor should it be thought that for carrying at such a plan currents of very high frequency are implicitly required, for just as soon as potentials of say 30,000 volts are used, the single wire transmission may be effected with low frequencies, and experiments have been made by me from which these inferences are made.

Electrical Resonance.

Some remarks and experiments were then made with regard to electrical resonance. Continuing, Mr. Tesla said:—

In connection with resonance effects and the problem of transmission of energy over a single conductor which was previously considered, I would say a few words on a subject which constantly fills my thoughts and which concerns the welfare of all. I mean the transmission of intelligible signals or perhaps even power to any distance without the use of wires. I am becoming daily more convinced of the practicability of the scheme, and though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realised, yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day. The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb by means of powerful machines the electrostatic condition of the earth, and thus transmit intelligible signals and perhaps power. In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why then not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile-posts the earth may appear very large, but to that happiest of all men, the astronomer, who gazes at the heavens and by their standard judges the magnitude of our globe, it appears very small. And so, I think, it must seem to the electrician, for when he considers the speed with which an electric disturbance is propagated through the earth all his ideas of distance must completely vanish.

A point of great importance would be first to know what is the capacity of the earth? and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation. If it be a charged body insulated in space its capacity should be extremely small, less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric currents. One of the terminals of the source would be connected to earth, as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata or free space contains an opposite charge and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body and watching for the disturbance at various neighbouring points of the earth's surface resonance might be detected. Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do and a proper electrical oscillator would have to be produced and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface.

Production of Light.

The light effects which it has been the chief object to investigate can be divided into four classes: (1) Incandescence of a solid. (2) Phosphorescence. (3) Incandescence or phosphorescence of a rarefied gas, and (4) Luminosity produced in a gas at ordinary pressure. The first question is, How are these luminous effects produced? In order to answer this question as satisfactorily as I am able to do in the light of accepted views and with the experience

acquired, and to add some interest to this demonstration, I shall dwell here upon a feature which I consider of great importance, inasmuch as it promises, besides, to throw a better light upon the nature of most of the phenomena produced by high frequency electric currents. I have on other occasions pointed out the great importance of the presence of the rarefied gas, or atomic medium in general, around the conductor through which alternate currents of high frequency are passed, as regards the heating of the conductor by the currents. My experiments described some time ago have shown that the higher the frequency and potential difference of the currents, the more important becomes the rarefied gas in which the conductor is immersed, as a factor of the heating. The potential difference, however, is, as I then pointed out, a more important element than the frequency. When both of these are sufficiently high, the heating may be almost entirely due to the presence of the rarefied gas. [Experiments were performed showing the importance of the rarefied gas, or generally of gas at ordinary or other pressure as regards the incandescence or other luminous effects produced by currents of this kind.]

Incandescent Lamps.

Disregarding now the modifying effect of convection, there are two distinct causes which determine the incandescence of a wire or filament with varying currents, that is, conduction current and bombardment. With steady currents we have to deal only with the former of these two causes, and the heating effect is a minimum, since the resistance is least to steady flow. When the current is a varying one the resistance is greater, and hence the heating effect is increased. Thus if the rate of change of the current is very great, the resistance may increase to such an extent that the filament is brought to incandescence with inappreciable currents, and we are able to take a short and thick block of carbon or other material and bring it to bright incandescence with a current incomparably smaller than that required to bring to the same degree of incandescence an ordinary thin lamp filament with a steady or low frequency current. This result is important, and illustrates how rapidly our views on these subjects are changing, and how quickly our field of knowledge is extending. In the art of incandescent lighting, to view this result in one aspect only, it has been commonly considered as an essential requirement for practical success, that the lamp filament should should be thin and of high resistance. But now we know that the resistance to the steady flow of the filament does not mean anything; the filament might as well be short and thick; for if it be immersed in rarefied gas it will become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents. We may conclude from this, that it would be of advantage, so far as the lamp is considered, to employ high frequencies for lighting, as they allow the use of short and thick filaments and smaller currents.

If a wire or filament be immersed in a homogeneous medium, all the heating is due to true conduction current, but if it be enclosed in an exhausted vessel the conditions are entirely different. Here the gas begins to act and the heating effect of the conduction current, as is shown in many experiments, may be very small compared with that of the bombardment. This is especially the case if the circuit is not closed and the potentials of course very high. Suppose a fine filament enclosed in an exhausted vessel be connected with one of its ends to the terminal of a high tension coil and with its other end to a large insulated plate. Though the circuit is not closed, the filament, as I have before shown, is brought to incandescence. If the frequency and potential be comparatively low, the filament is heated by the current passing *through* it. If the frequency and potential, and principally the latter, be increased, the insulated plate need be but very small, or may be done away with entirely; still the filament will become incandescent, practically all the heating being then due to the bombardment. . . . It should not be thought that only rarefied gas is an important factor in the heating of a conductor by varying currents, but gas at ordinary pressure may become important, if the potential difference and frequency of the currents is excessive. On this subject I have already stated, that when a conductor is fused by a stroke of lightning, the current through it may be exceedingly small, not even sufficient to heat the conductor perceptibly, were the latter immersed in a homogeneous medium.

From the preceding it is clear that when a conductor of high resistance is connected to the terminals of a source of high frequency currents of high potential, there may occur considerable dissipation of energy, principally on the ends of the conductor, in consequence of the action of the gas surrounding the conductor. Owing to this, the current through a section of the conductor at a point midway between its ends may be much smaller than through a section near the ends. Furthermore, the current passes principally through the outer portions of the conductor, but this effect is to be distinguished from the skin effect as ordinarily interpreted, for the latter would or should occur also in a continuous incompressible medium. If a great many incandescent lamps are connected in series to a source of such currents, the lamps at the ends may burn brightly, whereas those in the middle may remain entirely dark. This is due principally to bombardment, as before stated. But even if the currents be steady, provided the difference of potential is very great, the lamps at the ends may burn more brightly than those in the middle. In such case there is no rhythmical bombardment, and the result is produced entirely by leakage. This leakage or dissipation into space, when the tension is high, is considerable when incandescent lamps are used, and still more considerable with arcs, for the latter act like flames. Generally, of course, the dissipation is much smaller with steady than with varying currents.

Incandescence of Gases.

Coming now to the incandescence or phosphorescence of gases at low pressures or at the ordinary pressure of the atmosphere, we must seek the explanation of these phenomena in shocks or impacts of the atoms. Just as molecules or atoms beating upon a solid body excite phosphorescence in the same or render it incandescent, so when colliding among themselves they produce similar phenomena. But this is a very insufficient explanation, and concerns only the crude mechanism. Light is produced by vibrations which go on at a rate almost inconceivable. If we compute, from the energy contained in the form of known radiations in a definite space the force which is necessary to set up such rapid vibrations, we find, that though the density of the ether be incomparably smaller than that of any body we know, even hydrogen, the force is something surpassing comprehension. What is this force, which in mechanical measure, may amount to thousands of tons per square inch? It is electrostatic force in the light of modern views. It is impossible to conceive how a bod of measurable dimensions could be charged to so high a potential that the force would be sufficient to produce these vibrations. Long before any such charge could be imparted to the body it would be shattered into atoms. The sun emits light and heat, and so does an ordinary flame or incandescent filament, but in neither of these can the force be accounted for if it be assumed that it is associated with the body as a whole. Only in one way may we account for it, namely, by identifying it with the atom. An atom is so small, that if it be charged by coming in contact with an electrified body and the charge be assumed to follow the same law as in the case of bodies of measurable dimensions, it must retain a quantity of electricity which is fully capable of accounting for these forces and tremendous rates of vibration. But the atom behaves singularly in this respect, it always takes the same "charge."

It is very likely that resonant vibration plays a most important part in all manifestations of energy in nature. Throughout space all matter is vibrating, and all rates of vibration are represented, from the lowest musical note to the highest pitch of the chemical rays, hence an atom, or complex of atoms, no matter what its period, must find vibration with which it is in resonance. When we consider the enormous rapidity of the light vibrations, we realise the impossibility of producing such vibrations directly with any apparatus of measurable dimensions and we are driven to the only possible means of attaining the object of setting up waves of light by electrical means and economically, that is, to affect the molecules or atoms of a gas, to cause them to collide and vibrate.

Much would remain to be said about the luminous effects produced in gases at low or ordinary pressures. With the present experiences before us we cannot say that the essential nature of these charming phenomena is sufficiently known. But investigations in this direction are being pushed with exceptional ardour. Every line of scientific pursuit has its fascinations, but electrical investigation appears to possess a peculiar attraction, for there is no experiment or observation of any kind in the domain of this wonderful science which would not forcibly appeal to us. Some beautiful experiments with a vacuum tube concluded the lecture.

ON LIGHT AND OTHER HIGH - FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

INTRODUCTORY.—SOME THOUGHTS ON THE EYE.

When we look at the world around us, on Nature, we are impressed with its beauty and grandeur. Each thing we perceive, though it may be vanishingly small, is in itself a world—that is, like the whole of the visible universe, matter and force governed by law—a world, the contemplation of which fills us with feelings of wonder and irresistibly urges us to ceaseless thought and enquiry. But in all this vast world, of all objects our senses reveal to us, the most marvellous, the most appealing to our imagination, appears, no doubt, a highly developed organism, a thinking being. If there is anything fitted to make us admire Nature's handiwork, it is certainly this inconceivable structure, which performs its innumerable motions in obedience to external influence. To understand its workings, to get a deeper insight into this Nature's masterpiece, has ever been for thinkers a fascinating aim, and after many centuries of arduous research men have arrived at a fair understanding of the functions of its organs and senses. Again, in all the perfect harmony of its parts, of the parts which constitute the material or tangible of our being, of all its organs and senses, the eye is the most wonderful. It is the most precious, the most indispensable of our receptive or directive organs, it is the great gateway through which all knowledge enters the mind. Of all our organs, it is the one which is in the most intimate relation with that which we call intellect. So intimate is this relation that it is often said that the very soul shows itself in the eye.

It can be taken as a fact, which the theory of the action of the eye implies, that for each external impression—that is, for each image produced upon the retina—the ends of the visual nerves, concerned in the conveyance of the impression to the mind, must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and, therefore, upon the retina. Will it ever be within human power to analyse the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness, that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he was able to see, in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

Another fact having a bearing on this subject which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation, is that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, observable even in broad daylight.

The saying, then, that the soul shows itself in the eye is deeply founded, and we feel that it expresses a great truth. It has a profound meaning even for one who, like a poet or artist, only following his inborn instinct or love for Nature, finds delight in aimless thoughts, and in the mere contemplation of natural phenomena, but a still more profound meaning for one who in the spirit of positive scientific investigation seeks to ascertain the causes of the effects. It is principally the natural philosopher, the physicist, for whom the eye is the subject of the most intense admiration.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting that the very conception of that which is perfect, or seems so to him, has been gained through this same instrument. Firstly, the eye is, as far as our positive knowledge goes, the only organ which is directly affected by that subtle medium, which, as science teaches us, must fill all space; secondly, it is the most sensitive of our organs, incomparably more sensitive to external impressions than any other.

The organ of hearing implies the impact of ponderable bodies, the organ of smell the transference of detached material particles, and the organs of taste, and of touch or force, the direct contact, or at least some interference of ponderable matter, and this is true even in those instances of animal organisms in which some of these organs are developed to a degree of truly marvellous perfection. This being so, it seems wonderful that the organ of sight solely should be capable of being stirred by that which all our other organs are powerless to detect, which yet plays an essential part in all natural phenomena, which transmits all energy and sustains all motion and, that most intricate of all, life, but which has properties such that even a scientifically-trained mind cannot help drawing a distinction between it and all that is called matter. Considering merely this, and the fact that the eye, by its marvellous power, widens our otherwise very narrow range of perception far beyond the limits of the small world which is our own, to embrace myriads of other worlds, suns, and stars in the infinite depths of the universe, would make it justifiable to assert that it is an organ of a higher order. Its performances are beyond comprehension. Nature, as far as we know, never produced anything more wonderful. We can get barely a faint idea of its prodigious power by analysing what it does and by comparing. When ether waves impinge upon the human body, they produce the sensations of warmth or cold, pleasure or pain, or perhaps other sensations of which we are not aware, and any degree or intensity of these sensations, which degrees are infinite in number, hence an infinite number of distinct sensations. But our sense of touch, or our sense of force, cannot reveal to us these differences in degree or intensity, unless they are very great. Now we can readily conceive how an organism, such as the human in the eternal process of evolution, or more philosophically speaking, adaptation to Nature, being constrained to the use of only the sense of touch or force, for instance, might develop this sense to such a degree of sensitiveness or perfection that it would be capable of distinguishing the minutest differences in the temperature of a body, even at some distance, to a hundredth, or thousandth, or millionth part of a degree. Yet even this apparently impossible performance would not begin to compare with that of the eye, which is capable of distinguishing and conveying to the mind in a single instant innumerable peculiarities of the body, be it in form or colour or other respects. This power of the eye rests upon two things—namely, the rectilinear propagation of the disturbance by which it is affected, and upon its sensitiveness. To say that the eye is sensitive is not saying anything. Compared with it, all other organs are monstrously crude. The organ of smell which guides a dog on the trail of a deer, the organ of touch or force which guides an insect in its wanderings, the organ of hearing, which is affected by the slightest disturbances of the air, are sensitive organs, to be sure, but what are they compared with the human eye! No doubt it responds to the faintest echoes or reverberations of the medium; no doubt it brings us tidings from other worlds, infinitely remote, but in a language we cannot as yet always understand. And why not? Because we live in a medium filled with air and other gases, vapours and a dense mass of solid particles flying about. These play an important part in many phenomena; they fritter away the energy of the vibrations before they can reach the eye; they, too, are the carriers of germs of destruction, they get into our lungs and other organs, clog up the channels and imperceptibly, yet inevitably, arrest the stream of life. Could we but do away with all ponderable matter in the line of sight of the telescope, it would reveal to us undreamt-of marvels. Even the unaided eye, I think, would be capable of distinguishing, in the pure medium, small objects at distances measured probably by hundreds, or perhaps thousands, of miles.

But there is something else about the eye which impresses us still more than these wonderful features which we observe, viewing it from the standpoint of a physicist, merely as an optical instrument—something which appeals to us more than its marvellous faculty of being directly affected by the vibrations of the medium, without interference of gross matter, and more than its

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inconceivable sensitiveness and discerning power. It is its significance in the processes of life. No matter what one's views on Nature and life may be, he must stand amazed when for the first time in his thoughts he realises the importance of the eye in the physical processes and mental performances of the human organism. And how could it be otherwise, when he realises that the eye is the means through which the human race has acquired the entire knowledge it possesses, that it controls all our motions, more still, all our actions.

There is no way of acquiring knowledge except through the eye. What is the foundation of all philosophical systems of ancient and modern times; in fact, of all the philosophy of man? I am, I think; I think, therefore I am. But how could I think, and how would I know that I exist if I had not the eye? For knowledge involves consciousness; consciouness involves ideas, conceptions; conceptions involve pictures or images, and images the sense of vision, and therefore the organ of sight. But how about blind men, will be asked? Yes, a blind man may depict in magnificent poems forms and scenes from real life, from a world he physically does not see. A blind man may touch the keys of an instrument with unerring precision, may build the fastest boat, may discover and invent, calculate and construct, may do still greater wonders—but all the blind men who have done such things have descended from those who had seeing eyes. Nature may reach the same result in many ways. Like a wave in the physical world, in the infinite ocean of the medium which pervades all, so in the world of organisms, in life, an impulse started proceeds onward, at times, may be, with the speed of light, at times, again, so slowly that for ages and ages it seems to stay, passing through processes of a complexity inconceivable to men, but in all its forms, in all its stages, its energy ever and ever integrally present. A single ray of light from a distant star falling upon the eye of a tyrant in bygone times may have altered the course of his life, may have changed the destiny of nations, may have transformed the surface of the globe, so intricate, so inconceivably complex are the processes in Nature. In no way can we get such an overwhelming idea of the grandeur of Nature than when we consider, that in accordance with the law of the conservation of energy, throughout the Infinite, the forces are in a perfect balance, and hence the energy of a single thought may determine the motion of a universe. It is not necessary that every individual, not even that every generation or many generations, should have the physical instrument of sight in order to be able to form images and to think—that is, form ideas or conceptions; but some time or other during the process of evolution the eye certainly must have existed, else thought, as we understand it, would be impossible, else conceptions, like spirit, intellect, mind, call it as you may, could not exist. It is conceivable that in some other world, in some other beings, the eye is replaced by a different organ, equally or more perfect, but these beings cannot be men.

Now, what prompts us to all voluntary motions and actions of any kind? Again the eye. If I am conscious of the motion, I must have an idea or conception—that is, an image—therefore the eye. If I am not precisely conscious of the motion, it is because the images are vague or indistinct, being blurred by the superimposition of many. But when I perform the motion, does the impulse which prompts me to the action come from within or from without? The greatest physicists have not disdained to endeavour to answer this and similar questions and have at times abandoned themselves to the delights of pure and unrestrained thought. Such questions are generally considered not to belong to the realm of positive physical science, but will before long be annexed to its domain. Helmholtz has probably thought more on life than any modern scientist. Lord Kelvin expressed his belief that life's process is electrical, and that there is a force inherent to the organism and determining its motions. Just as much as I am convinced of any physical truth I am convinced that the motive impulse must come from the outside. For consider the lowest organism we know—and there are probably many lower ones—an aggregation of a few cells only. If it is capable of voluntary motion it can perform an infinite number of motions, all definite and precise. But now a mechanism consisting of a finite number of parts, and few at that, cannot perform an infinite number of definite motions, hence the impulses which govern its movements must come from the environment. So, the atom, the ulterior element of the universe's structure, is tossed about in space eternally, a play to external influences, like a float in a troubled sea. Were it to stop its motion it would die. Matter at rest, if such a thing could exist, would be matter dead. Death of matter! Never has a sentence of deeper philosophical meaning been uttered. This is the way in which Prof. Dewar forcibly expresses it in the description of his admirable experiments, in which liquid oxygen is handled as one handles water, and air at ordinary pressure is made to condense and even to solidify by the intense cold. Experiments which serve to illustrate in his language the last feeble manifestations of life, the last quiverings of matter about to die. But human eyes shall not witness such death. There is no death of matter, for throughout the infinite universe all has to move, to vibrate—that is, to live.

I have made the preceding statements at the peril of treading upon metaphysical ground in my desire to introduce the subject of this lecture in a manner not altogether uninteresting, I may hope, to an audience such as I have the honour to address. But now then, returning to the subject, this divine organ of sight, this indispensable instrument for thought and all intellectual enjoyment which lays open to us the marvels of this universe, through which we have acquired what knowledge we possess, and which prompts us to and controls all our physical and mental activity, by what is it affected? By light! What is light?

We have witnessed the great strides which have been made in all departments of science in recent years. So great have been the advances that we cannot refrain from asking ourselves, Is this all true, or is it but a dream? Centuries ago men have lived, have thought, discovered, invented, and have believed that they were soaring, while they were merely proceeding at a snail's pace. So we too may be mistaken. But taking the truth of the observed events as one of the implied facts of science, we must rejoice in the immense progress already made, and still more in the anticipation of what must come, judging from the possibilities opened up by modern research. There is, however, an advance which we have been witnessing, which must be particularly gratifying to every lover of progress. It is not a discovery, or an invention, or an achievement in any particular direction. It is an advance in all directions of scientific thought and experiment. I mean the generalisation of the natural forces and phenomena, the looming up of a certain broad idea on the scientific horizon. It is this idea which has, however, long ago taken possession of the most advanced minds, to which I desire to call your attention, and which I intend to illustrate, in a general way, in these experiments, as the first step in answering the question "What is light?" and to realise the modern meaning of this word.

It is beyond the scope of my lecture to dwell upon the subject of light in general, my object being merely to bring presently to your notice a certain class of light effects and a number of phenomena observed in pursuing the study of these effects. But to be consistent in my remarks it is necessary to state that according to that idea, now accepted by the majority of scientific men as a positive result of theoretical and experimental investigation, the various forms or manifestations of energy which were generally designated as "electric," or, more precisely, "electromagnetic," are energy manifestations of the same nature as those of radiant heat and light. Therefore the phenomena of light and heat, and others besides these, may be called electrical phenomena. Thus electrical science has become the mother science of all, and its study has become all-important. The day when we shall know exactly what "electricity" is will chronicle an event probably greater, more important than any other recorded in the history of the human race. The time will come when the comfort, the very existence, perhaps, of man will depend upon that wonderful agent. For our existence and comfort we require heat, light, and mechanical power. How do we now get all these? We get them from fuel, we get them by consuming material. What will man do when the forests disappear, when the coalfields are exhausted? Only one thing, according to our present knowledge will remain—that is, to transmit power at great distances. Men will go to the waterfalls, to the tides, which are the stores of an infinitesimal part of Nature's immeasurable energy. There will they harness the energy and transmit the same to their settlements, to warm their homes by, to give them light, and to keep their obedient slaves—the machines—toiling. But how will they transmit this energy if not by electricity? Judge then, if the comfort, nay, the very existence, of man will not depend on electricity. I am aware that this view is not that of a practical engineer, but neither is it that of an illusionist, for it is certain that power transmission, which at present is merely a stimulus to enterprise, will some day be a dire necessity.

It is more important for the student who takes up the study of light phenomena to make himself thoroughly acquainted with certain modern views than to peruse entire books on the subject of light itself, as disconnected from these views. Were I therefore to make these demonstrations before students seeking information—and for the sake of the few of those who may be present, give me leave to so assume—it would be my principal endeavour to impress these views upon their minds in this series of experiments.

It might be sufficient for this purpose to perform a simple and well-known experiment. I might take a familiar appliance—a Leyden jar—charge it from a frictional machine, and then discharge it. In explaining to you its permanent state when charged and its transitory condition when discharging, calling your attention to the forces which enter into play and to the various phenomena they produce, and pointing out the relation of the forces and phenomena, I might fully succeed in illustrating that modern idea. No doubt, to the thinker this simple experiment would appeal as much as the most magnificent display. But this is to be an experimental demonstration, and one which should possess besides instructive, also entertaining features, and as such a simple experiment, such as the one cited, would not go very far towards the attainment of the lecturer's aim. I must therefore choose another way of illustrating, more spectacular, certainly, but perhaps, also, more instructive. Instead of the frictional machine and Leyden jar, I shall avail myself in these experiments of an induction coil of peculiar properties, which was described in detail by me in a lecture before the London Institution of Electrical Engineers, in February, 1892. This induction coil is capable of yielding currents of enormous potential differences, alternating with extreme rapidity. With this apparatus I shall endeavour to show you three distinct classes of effects, or phenomena, and it is my desire that each experiment, while serving for the purposes of illustration, should at the same time teach us some novel truth, or show us some novel aspect of this fascinating science. But before doing this, it seems proper and useful to dwell upon the apparatus employed, and method of obtaining the high potentials and high-frequency currents which are made use of in these experiments.

On the Apparatus and Method of Conversion.

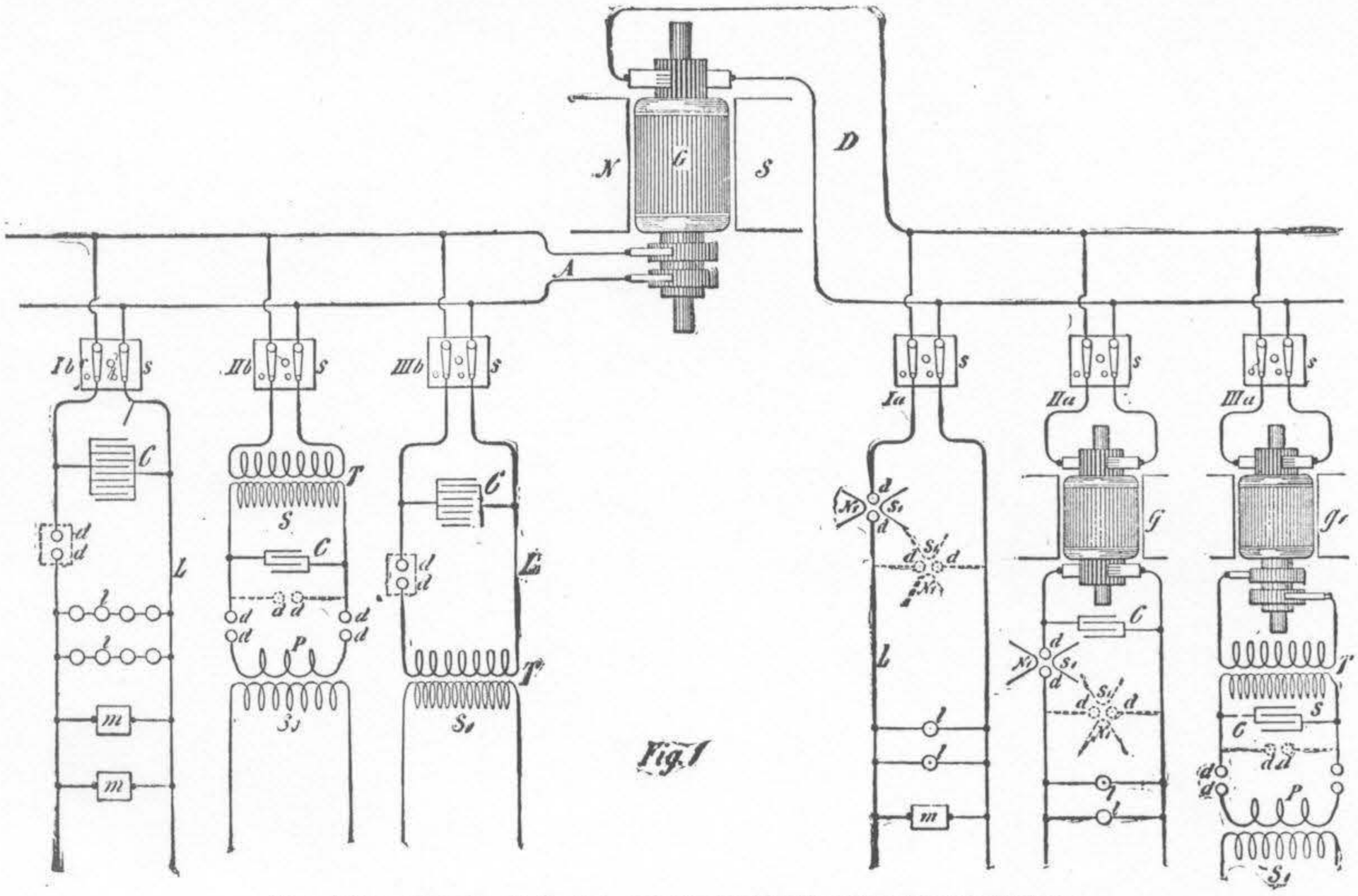
These high-frequency currents are obtained in a peculiar manner. The method employed was advanced by me about two years ago in an experimental lecture before the American Insti-

tute of Electrical Engineers. A number of ways, as practised in the laboratory, of obtaining these currents either from continuous or low-frequency alternating currents is diagrammatically indicated in Fig. 1, which will be later described in detail. The general plan is to charge condensers from a direct or alternate current source, preferably of high tension, and to discharge them disruptively while observing well-known conditions necessary to maintain the oscillations of the current. In view of the general interest taken in high-frequency currents and effects producible by them, it seems to me advisable to dwell at some length upon this method of conversion. In order to give you a clear idea of the action, I will suppose that a continuous-current generator is employed, which is often very convenient. It is desirable that the generator should possess such high tension as to be able to break through a small air-space. If this is not the case, then auxiliary means have to be resorted to, some of which will be indicated subsequently. When the condensers are charged to a certain potential, the air or insulating space gives way and a disruptive discharge occurs. There is then a sudden rush of current, and generally a large portion of the accumulated electrical energy spends itself. The condensers are thereupon quickly charged, and the same process is repeated in more or less rapid succession. To produce such sudden rushes of current it is necessary to observe certain conditions. If the rate at which the condensers are discharged is the same as that which they are charged, then, clearly, in the assumed case the condensers do not come into play. If the rate of discharge be smaller than the rate of charging, then, again, the condensers cannot play an important part. But if, on the contrary, the rate of discharging is greater than that of charging, then a succession of rushes of current is obtained. It is evident that, if the rate at which the energy is being dissipated by the discharge is very much greater than the rate of supply to the condensers, the sudden rushes will be comparatively few, with long-time intervals between. This always occurs when a condenser of considerable capacity is charged by means of a comparatively small machine. If the rates of supply and dissipation are not widely different, then the rushes of current will be in quicker succession, and this the more, the more nearly equal both the rates are, until natural limitations incident to each case and depending upon a number of causes are reached. Thus we are able to obtain from a continuous-current generator as rapid a succession of discharges as we like. Of course, the higher the tension of the generator, the smaller need be the capacity of the condensers, and for this reason, principally, it is of advantage to employ a generator of very high tension. Besides, such a generator permits the attaining of greater rates of vibration.

The rushes of current may be of the same direction under the conditions before assumed, but most generally there is an oscillation superimposed upon the fundamental vibration of the current. When the conditions are so determined that there are no oscillations, the current impulses are unidirectional, and thus a means is provided of transforming a continuous current of high tension into a direct current of lower tension, which I think may find employment in the arts.

This method of conversion is exceedingly interesting, and I was much impressed by its beauty when I first conceived it. It is ideal in certain respects. It involves the employment of no mechanical devices of any kind, and it allows of obtaining currents of any desired frequency from an ordinary circuit, direct or alternating. The frequency of the fundamental discharges depending on the relative rates of supply and dissipation can be readily varied within wide limits by simple adjustments of these quantities, and the frequency of the superimposed vibration by the determination of the capacity, self-induction, and resistance of the circuit. The potential of the currents, again, may be raised as high as any insulation is capable of withstanding safely, by combining capacity and self-induction, or by induction in a secondary, which need have but comparatively few turns.

As the conditions are often such that the intermittence or oscillation does not readily establish itself, especially when a direct current source is employed, it is of advantage to associate an interrupter with the arc, and I have, some time ago, indicated the use of an air-blast or magnet, or other such device readily at hand. The magnet is employed with special advantage in the conversion of direct currents, as it is then very effective. If the primary source is an alternate-current generator, it is desirable, as I have stated on another occasion, that the frequency should be low, and that the currents forming the arc be large, in order to render the magnet more effective.



Plan of Connections Used in the Conversion by Means of the Disruptive Arc Discharge.

(To be continued.)

ON LIGHT AND OTHER HIGH-FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(Continued from page 583.)

A form of such discharger with a magnet which has been found convenient, and adopted after some trials, in the conversion of direct currents particularly, is illustrated in Fig. 2. N S are the pole-pieces of a very strong magnet which is excited by a coil, C. The pole-pieces are slotted for adjustment and can be fastened in any position by screws, s_1 s_1. The discharge rods, d d_1, thinned down on the ends in order to allow a closer approach of the magnetic pole-pieces, pass through the columns of brass, b b_1, and are fastened in position by screws, s_2, s_2. Springs, r, r_1, and collars, c, c_1, are slipped on the rods, the latter serving to set the points of the rods at a certain suitable distance by means of screws, s_3, s_3, and the former to draw the points apart. When it is desired to start the arc, one of the hard rubber handles, h, h_1, is tapped quickly with the hand, whereby the points of the rods are brought in contact, but are instantly separated by the springs, r, r_1. Such an arrangement has been found to be often necessary—namely, in cases when the E.M.F. was not large enough to cause the discharge to break through the gap, and also when it was desirable to avoid short-circuiting of the generator by the metallic contact of the rods. The rapidity of the interruptions of the current with a magnet depends on the intensity of the magnetic field and on the potential difference at the ends of the arc. The interruptions are generally in such quick succession as to produce a musical sound. Years ago it was observed that when a powerful induction coil is discharged between the poles of a strong magnet the discharge produced a loud noise not unlike a small pistol shot. It was vaguely stated that the spark was intensified by the presence of the magnetic field. It is now clear that the discharge current, flowing for some time, was interrupted a great number of times by the magnet, thus producing the sound. The phenomenon is especially marked when the field circuit of a large magnet or dynamo is broken in a powerful magnetic field.

When the current through the gap is comparatively large, it is of advantage to slip on the points of the discharge rods pieces of very hard carbon, and let the arc play between the carbon pieces. This preserves the rods and besides has the advantage of keeping the air-space hotter, as the heat is not conducted away as quickly through the carbons, and the result is that a smaller E.M.F. in the arc gap is required to maintain a succession of discharges.

Another form of discharger which may be employed with advantage in some cases is illustrated in Fig. 3. In this form the discharge rods, d d_1, pass through perforations in a wooden box, B, which is thickly coated with mica on the inside, as indicated by the heavy lines. The perforations are provided with mica tubes, m m_1, of some thickness, which are preferably not in contact with the rods, d d_1. The box has a cover, C, which is a little larger and descends on the outside of the box. The spark gap is warmed by a small lamp, l, contained in the box. A plate, p, above the lamp allows the draught to pass only through the chimney, c, of the lamp, the air entering flows through holes, oo, in or near the bottom of the box, and following the path indicated by the arrows. When the discharger is in operation, the door of the box is closed, so that the light of the arc is not visible outside.

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893; and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893.

It is desirable to exclude the light as perfectly as possible, as it interferes with some experiments. This form of discharger is simple, and very effective when properly manipulated. The air being warmed to a certain temperature has its insulating power impaired, it becames dielectrically weak, as it were, and the consequence is that the arc can be established at much greater distance. The air should of course be sufficiently insulating to allow the discharge to pass through the gap disruptively. The arc formed under such conditions when long may be made extremely sensitive, and the weak draught through the lamp chimney, c, is quite sufficient to produce rapid interruptions. The adjustment is made by regulating the temperature and velocity of the draught. Instead of using a lamp it answers the purpose to provide for a draught of warm air in other ways. A very simple way which has been practised is to enclose the arc in a long vertical tube with plates on the top and bottom for regulating the temperature and velocity of the air current. Some provision had to be made for deadening the sound.

The air may be rendered dielectrically weak also by rarefaction. Dischargers of this kind have likewise been used by me in connection with the magnet. A large tube is for this purpose provided with heavy electrodes of carbon or metal, between which the discharge is made to pass, the tube being placed in a powerful magnetic field. The exhaustion of the tube is carried to a point at which the discharge breaks through easily, but the pressure should be more than 75 millimetres, at which the ordinary thread discharge occurs. In another form of discharger, combining the features before mentioned, the discharge was made to pass between two adjustable magnetic pole-pieces, the space between them being kept at an elevated temperature.

It should be remarked here that when such, or interrupting devices of any kind, are used and the currents are passed through the primary of a disruptive discharge coil, it is not, as a rule, of advantage to produce a number of interruptions of the current per second greater than the natural frequency of vibration of the dynamo supply circuit, which is ordinarily small. It should also

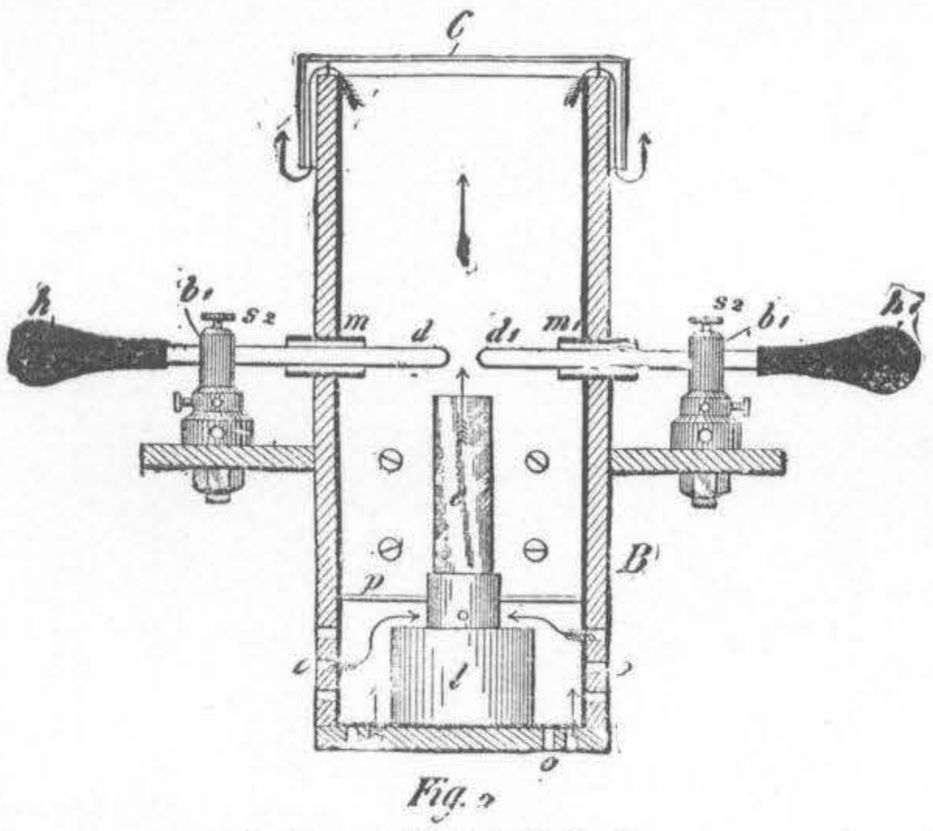


Fig. 1.

Discharges with Hot-Air Draft.

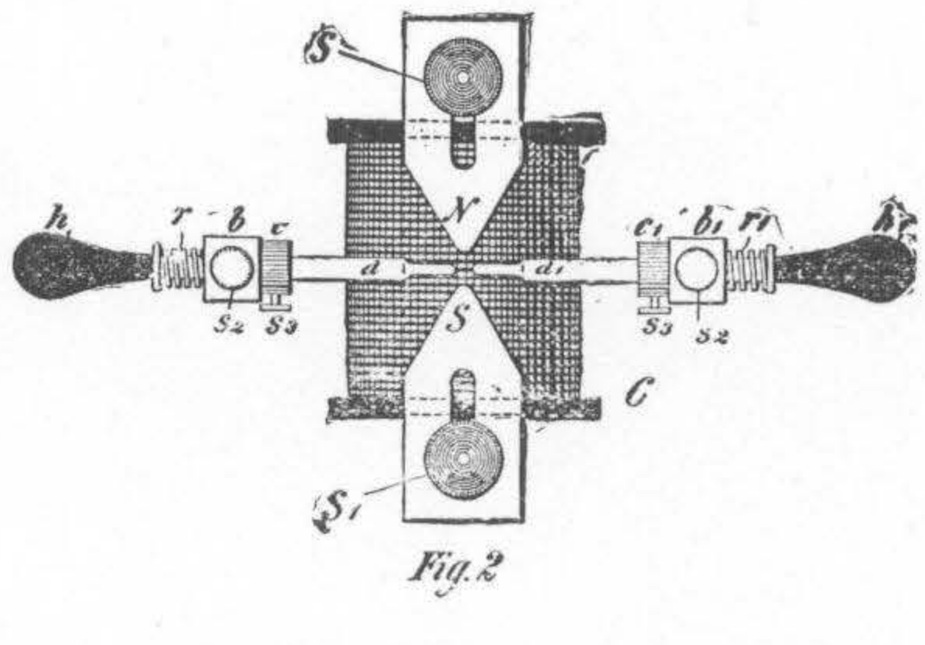


Fig. 2.

Form of Discharger with Magnet Used in the Direct-Current Conversion.

be pointed out here that while the devices mentioned in connection with the disruptive discharge are advantageous under certain conditions, they may be sometimes a source of trouble, as they produce intermittences and other irregularities in the vibration which it would be very desirable to overcome.

There is, I regret to say, in this beautiful method of conversion a defect which, fortunately, is not vital, and which I have been gradually overcoming. I will best call attention to this defect and indicate a fruitful line of work by comparing the electrical process with its mechanical analogue. The process may be illustrated in this manner. Imagine a tank with a wide opening at the bottom, which is kept closed by spring pressure, but so that it snaps off suddenly when the liquid in the tank has reached a certain height. Let the fluid be supplied to the tank by means of a pipe feeding at a certain rate. When the critical height of the liquid is reached, the spring gives way and the bottom of the tank drops out. Instantly the liquid falls through the wide opening, and the spring, reasserting itself, closes the bottom again. The tank is now filled, and after a certain time interval the same process is repeated. It is clear that if the pipe feeds the fluid quicker than the bottom outlet is capable of letting it pass through, the bottom will remain off and the tank will still overflow. If the rates of supply are exactly equal, then the bottom lid will remain partially open and no vibration of the same and of the liquid column will generally occur, though it might, if started by some means. But if the inlet pipe does not feed the fluid fast enough for the outlet, then there will be always vibration. Again, in such case, each time the bottom flaps up or down, the spring and the liquid column, if the pliability of the spring and the inertia of the moving parts are properly chosen, will perform independent vibrations. In this analogue the fluid may be likened to electricity or electrical energy, the tank to the condenser, the spring to the dielectric, and the pipe to the conductor through which electricity is supplied to the condenser. To make this analogy quite complete it is necessary to make the assumption that the bottom, each time it gives away, is knocked violently against a non-elastic stop, this impact involving some loss of energy, and that, besides some dissipation of energy results, due to frictional losses. In the preceding analogue the liquid is supposed to be under a steady pressure. If the pressure of the fluid be assumed to vary rhythmically, this may be taken as corresponding to the case of an alternating current. The process is then not quite as simple to consider, but the action is the same in principle.

It is desirable, in order to maintain the vibration economically, to reduce the impact and frictional losses as much as possible. As regards the latter, which in the electrical analogue correspond to the losses due to the resistance of the circuits, it is impossible to obviate them entirely, but they can be reduced to a minimum by a proper selection of the dimensions of the circuits and by the employment of thin conductors in the form of strands. But the loss of energy caused by the first breaking through of the dielectric—which in the above example corresponds to the violent knock of the bottom against the inelastic stop—would be more important to overcome. At the moment of the breaking through, the air-space has a very high resistance, which is probably reduced to a very small value when the current has reached some strength, and the space is brought to a high temperature. It would materially diminish the loss of energy if the space were always kept at an extremely high temperature, but then there would be no disruptive break. By warming the space moderately by means of a lamp or otherwise, the economy as far as the arc is concerned is sensibly increased ; but the magnet or other interrupting device does not diminish the loss in the arc. Likewise, a jet of air only facilitates the carrying off of the energy. Air, or a gas in general, behaves curiously in this respect. When two bodies, charged to a very high potential discharge disruptively through an air-space, any amount of energy may be carried off by the air. This energy is evidently dissipated by bodily carriers in impact and collisional losses of the molecules. The exchange of the molecules in the space occurs with inconceivable rapidity. A powerful discharge taking place between two electrodes, they may remain entirely cool, and yet the loss in the air may represent any amount of energy. It is perfectly practicable, with very great potential differences in the gap, to dissipate several horse-power in the arc of the discharge without even noticing a small increase in the temperature of the electrodes. All the frictional losses occur then practically in the air. If the exchange of the air molecules is prevented, as by enclosing the air hermetically, the gas inside of the vessel is brought quickly to a high temperature, even with a very small discharge. It is difficult to estimate how much of the energy is lost in sound waves, audible or not, in a powerful discharge. When the currents through the gap are large, the electrodes may become rapidly heated, but this is not a reliable measure of the energy wasted in the arc, as the loss through the gap itself may be comparatively small. The air or a gas in general is, at ordinary pressures at least, clearly not the best medium through which a disruptive discharge should occur. Air, or other gas under great pressure, is, of course, a much more suitable medium for the discharge gap. I have carried on long-continued experiments in this direction, unfortunately less practicable on account of the difficulties and expense in getting air under great pressure. But even if the medium in the discharge space is solid or liquid, still the same losses take place, though they are generally smaller, for just as soon as the arc is established the solid or liquid is volatilised. Indeed, there is no body known which would not be disintegrated by the arc, and it is an open question among scientific men whether an arc discharge could occur at all in the air itself without the particles of the electrodes being torn off. When the current through the gap is very small and the arc very long, I believe that a relatively considerable amount of heat is taken up in the disintegration of the electrodes, which partially on this account may remain quite cold.

The ideal medium for a discharge gap should only crack, and the ideal electrode should be of some material which cannot be disintegrated. With small currents through the gap it is best to employ aluminium, but not when the currents are large. The disruptive break in the air, or more or less in any ordinary medium, is not of the nature of a crack, but it is rather comparable to the piercing of innumerable bullets through a mass offering great

frictional resistance to the motion of the bullets, this involving considerable loss of energy. A medium which would merely crack when strained electrostatically—and this possibly might be the case with a perfect vacuum, that is, pure ether—would involve a very small loss in the gap, so small as to be entirely negligible, at least theoretically, because a crack may be produced by an infinitely small displacement. In exhausting an oblong bulb provided with two aluminium terminals with the greatest care I have succeeded in producing such a vacuum that the secondary discharge of a disruptive discharge coil would break through disruptively through the bulb in the form of fine spark streams. The curious point was that the discharge would completely ignore the terminals and start far behind the two aluminium plates which served as electrodes. This extraordinarily high vacuum could only be maintained for a very short while. To return to the ideal medium, think, for the sake of illustration, of a piece of glass or similar body clamped in a vice, and the latter lightened more and more. At a certain point a minute increase of the pressure will cause the glass to crack. The loss of energy involved in splitting the glass may be practically nothing, for though the force is great the displacement need be but extremely small. Now, imagine that the glass would possess the property of closing again perfectly the crack upon a minute diminution of the pressure. This is the way the dielectric in the discharge space should behave. But inasmuch as there would be always some loss in the gap, the medium which should be continuous should exchange through the gap at a rapid rate. In the preceding example, the glass being perfectly closed, it would mean that the dielectric in the discharge space possesses a great insulating power; the glass being cracked, it would signify that the medium in the space is a good conductor. The dielectric should vary enormously in resistance by minute variations of the E.M.F. across the discharge space. This condition is attained but in an extremely imperfect manner, by warming the air-space to a certain critical temperature, dependent on the E M.F. across the gap, or by otherwise impairing the insulating power of the air. But as a matter of fact the air does never break down disruptively, if this term be rigorously interpreted, for before the sudden rush of the current occurs, there is always a weak current preceding it, which rises first gradually and then with comparative suddenness. That is the reason why the rate of change is very much greater when glass, for instance, is broken through, than when the break takes place through an air-space of equivalent dielectric strength. As a medium for the discharge space a

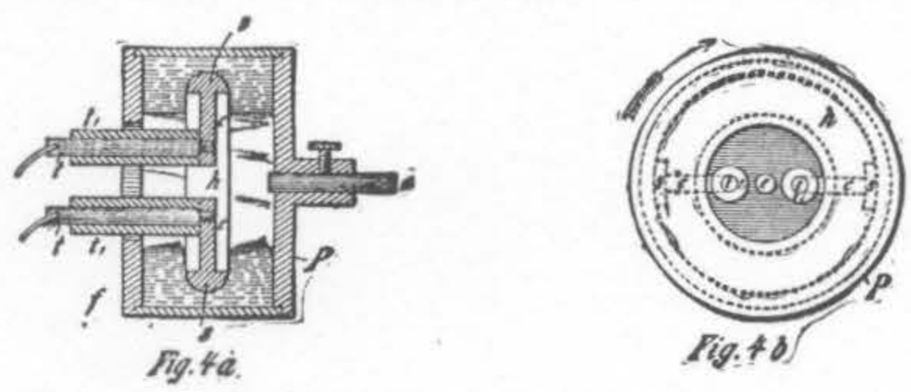


Fig. 4a. Fig. 4b

Form of Discharger with Liquid Interrupter.

solid, or even a liquid would be preferable therefore. It is somewhat difficult to conceive of a solid body which would possess the property of closing instantly after it has been cracked. But a liquid, especially under great pressure, behaves practically like a solid, while it possesses the property of closing the crack. Hence it was thought that a liquid insulator might be more suitable as a dielectric than air. Following out this idea, a number of different forms of dischargers in which a variety of such insulators, sometimes under great pressure, were employed, have been experimented upon. It is thought sufficient to dwell in a few words upon one of the forms experimented upon. One of these dischargers is illustrated in Figs. 4*a* and 4*b*

A hollow metal pulley, P (Fig. 4*a*), was fastened upon an arbor, *a*, which by suitable means was rotated at a considerable speed. In the inside of the pulley, but disconnected from the same, was supported a thin disc, h_1 (which is shown thick for the sake of clearness), of hard rubber, in which there were embedded two metal segments, *s s*, with metallic extensions, *e e*, into which were screwed conducting terminals, *t t*, covered with thick tubes of hard rubber, *t t*. The rubber disc *h*, with its metallic segments, S S, was finished in a lathe, and its entire surface highly polished, so at to offer the smallest possible frictional resistance to the motion through a fluid. In the hollow of the pulley an insulating liquid, such as a thin oil, was poured so as to reach very nearly to the opening left in the flange, *f*, which was screwed tightly on the front side of the pulley. The terminals, *t t*, were connected to the opposite coatings of a battery of condensers, so that the discharge occurred through the liquid. When the pulley was rotated, the liquid was forced against the rim of the pulley and considerable fluid pressure resulted. In this simple way the discharge gap was filled with a medium which behaved practically like a solid, which possessed the quality of closing instantly upon the occurrence of the break, and which, moreover, was circulating through the gap at a rapid rate. Very powerful effects were produced by dischargers of this kind with liquid interrupters, of which a number of different forms were made. It was found that, as expected, a longer spark for a given length of wire was obtainable in this way than by using air as an interrupting device. Generally the speed, and therefore also the fluid pressure, was limited by reason of the fluid friction, in the form of discharger described, but the practically obtainable speed was more than sufficient to produce a number of breaks suitable for the circuits ordinarily used. In some instances the metal pulley, P, was provided with a few projections inwardly, and a definite number of breaks was then produced which could be computed from the speed of rotation of the pulley. Experiments were also carried on with liquids of different insulating power with the view of reducing the loss in the arc. When an insulating liquid is moderately warmed the loss in the arc is diminished.

A point of some importance was noted in experiments with various dischargers of this kind. It was found, for instance, that whereas the conditions maintained in these forms were favourable for the production of a great spark length, the current so obtained were not best suited to the production of light effects. Experience undoubtedly has shown that for such purposes a harmonic rise and fall of the potential is preferable. Be it that a solid is rendered incandescent, or phosphorescent, or be it that energy is transmitted by condenser coating through the glass, it is quite certain that a harmonically rising and falling potential produces less destructive action, and that the vacuum is more permanently maintained. This would be easily explained if it were ascertained that the process going on in an exhausted vessel is of an electrolytic nature.

(To be continued.)

ON LIGHT AND OTHER HIGH-FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(Continued from page 610.)

In the diagrammatical sketch, Fig. 1, which has been already referred to, the cases which are most likely to be met with in practice are illustrated. One has at his disposal either direct or alternating currents from a supply station. It is convenient for an experimenter in an isolated laboratory to employ a machine, G, such as illustrated, capable of giving both kinds of currents. In such case it is also preferable to use a machine with multiple circuits, as in many experiments it is useful and convenient to have at one's disposal currents of different phases. In the sketch, D represents the direct, and A the alternating circuit. In each of these three branch circuits are shown, all of which are provided with double lines switches, *s s s s s s*. Consider first the direct-current conversion—I*a* represents the simplest case. If the E.M.F. of the generator is sufficient to break through a small air-space, at least when the latter is warmed or otherwise rendered poorly insulating, there is no difficulty in maintaining a vibration with fair economy by judicious adjustment of the capacity, self-induction, and resistance of the circuit, L, containing the devices, *l l m*. The magnet, N S, can be in this case advantageously combined with the air-space. The discharger, *d d*, with the magnet may be placed either way, as indicated by the full or by the dotted lines. The circuit, I*a*, with the connections and devices is supposed to possess dimensions such as are suitable for the maintenance of a vibration. But usually the E.M.F. on the circuit or branch, I*a*, will be something like 100 volts or so, and in this case it is not sufficient to break through the gap. Many different means may be used to remedy this by raising the E.M.F. across the gap. The simplest is probably to insert a large self-induction coil in series with the circuit L. When the arc is established, as by the discharger illustrated in Fig. 2, the magnet blows the arc out the instant it is formed. Now the extra current of the break, being of high E.M.F., breaks through the gap, and a path of low resistance for the dynamo current being again provided, there is a sudden rush of the current from the dynamo upon the weakening or subsidence of the extra current. This process is repeated in rapid succession, and in this manner I have maintained oscillation with as low as 50 volts, or even less, across the gap. But conversion on this plan is not to be recommended on account of the too heavy currents through the gap and consequent heating of the electrodes; besides, the frequencies obtained in this way are low, owing to the high self-induction necessarily associated with the circuit. It is very desirable to have the E.M.F. as high as possible; first, in order to increase the economy of the conversion, and secondly, to obtain high frequencies. The difference of potential in this electric oscillation is, of course, the equivalent of the stretching force in the mechanical vibration of the spring. To

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893; and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893.

obtain very rapid vibration in a circuit of some inertia a great stretching force or difference of potential is necessary. Incidentally when the E.M.F. is very great, the condenser which is usually employed in connection with the circuit need have but a small capacity, and many other advantages are gained. With a view of raising the E.M.F. to a many times greater value than obtainable from ordinary distribution circuits, a rotating transformer, *y*, is used, as indicated in Fig. 2*a*, or else a separate high-potential machine is driven by means of a motor operated from the generator, G. The latter plan is, in fact, preferable, as changes are easier made. The connections from the high-tension winding are quite similar to those in branch 1*a*, with the exception that a condenser, C, which should be adjustable, is connected to the high-tension circuit. Usually, also, an adjustable self-induction coil in series with the circuit has been employed in these experiments. When the tension of the currents is very high the magnet ordinarily used in connection with the discharger is of comparatively small value, as it is quite easy to adjust the dimensions of the circuit so that oscillation is maintained. The employment of a steady E.M.F. in the high-frequency conversion affords some advantages over the employment of alternating E.M.F., as the adjustments are much simpler and the action can be easier controlled. But unfortunately one is limited by the obtainable potential difference. The windings also break down easily in consequence of the sparks which form between the sections of the armature or commutator when a vigorous oscillation takes place. Besides, these transformers are expensive to build. It has been found by experience that it is best to follow the plan illustrated in Fig. 3*a*. In this arrangement a rotating transformer, *g*, is employed to convert the low-tension direct currents into low-frequency alternating currents, preferably also of small tension. The tension of the currents is then raised in a stationary transformer, T. The secondary, S, of this transformer is connected to an adjustable condenser, C, which discharges through the gap or discharger, *d d*, placed in either of the ways indicated, through the primary, P, of a disruptive discharge coil, the high-frequency currents being obtained from the secondary, S, of this coil, as described on previous occasions. This will undoubtedly be found the cheapest and most convenient way of converting direct currents.

The three branches of the circuit, A, represent the usual cases met in practice when alternating currents are converted. In Fig. 1*b* a condenser, C, generally of large capacity, is connected to the circuit, L, containing the devices, *l l*, *m m*. The devices, *m m*, are supposed to be of high self-induction so as to bring the frequency of the circuit more or less to that of the dynamo. In this instance the discharger, *d d*, should best have a number of makes and breaks per second equal to twice the frequency of the dynamo. If not so, then it should have at least a number equal to a multiple or even fraction of the dynamo frequency. It should be observed, referring to Fig. 1*b*, that the conversion to a high potential is also effected when the discharger, *d d*, which is shown in the sketch, is omitted. But the effects which are produced by currents which rise instantly to high values, as in a disruptive discharge, are entirely different from those produced by dynamo currents which rise and fall harmonically. So, for instance, there might be in a given case a number of makes and breaks at *d d* equal to just twice the frequency of the dynamo, or in other words, there may be the same number of fundamental oscillations as would be produced without the discharge gap, and there might even not be any quicker superimposed vibration; yet the differences of potential at the various points of the circuit, the impedance and other phenomena, dependent upon the rate of change, will bear no similarity in the two cases. Thus, when working with currents discharging disruptively, the element chiefly to be considered is not the frequency, as a student might be apt to believe, but the rate of change per unit of time. With low frequencies in a certain measure the same effects may be obtained as with high frequencies, provided the rate of change is sufficiently great. So if a low-frequency current is raised to a potential of, say, 75,000 volts and the high-tension current passed through a series of high-resistance lamp filaments, the importance of the rarefied gas surrounding the filament is clearly noted, as will be seen later; or, if a low-frequency current of several thousand amperes is passed through a metal bar, striking phenomena of impedance are observed, just as with currents of high frequencies. But it is, of course, evident that with low-frequency currents it is impossible to obtain such rates of change per unit of time as with high frequencies, hence the effects produced by the latter are much more prominent. It was deemed advisable to make the preceding remarks, inasmuch as many more recently described effects have been unwittingly identified with high frequencies. Frequency alone, in reality, does does not mean anything, except when an undisturbed harmonic oscillation is considered.

In the branch, 3*b*, a similar disposition as in 1*b* is illustrated, with the difference that the currents discharging through the gap, *d d*, are used to induce currents in the secondary, S, of a transformer, T. In such case the secondary should be provided with an adjustable condenser for the purpose of tuning it to the primary.

Fig. 2*b* illustrates a plan of alternate-current high-frequency conversion which is most frequently used and which is found to be most convenient. This plan has been dwelt upon in detail on previous occasions and need not be described here.

Some of these results were obtained by the use of a high-frequency alternator. A description of such machines will be found in my original paper before the American Institute of Electrical Engineers, and in periodicals of that period, notably in the *Electrical Engineer* of March 18, 1891. I will now proceed with the experiments.

On Phenomena Produced by Electrostatic Force.

The first class of effects I intend to show you are effects produced by electrostatic force. It is the force which governs the motion of the atoms, which causes them to colide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an infinite variety of ways, according to Nature's fanciful designs, and to form all these wondrous structures we perceive around us. It is, in fact, if our present views be true, the most important force for us to consider in nature. As the term electrostatic might imply a steady electric condition, it should be remarked that in these experiments the force is not constant, but varies at a rate which may be considered moderate—about one million times a second, or thereabouts. This enables me to produce many effects which are not produceable with an unvarying force.

When two conducting bodies are insulated and electrified, we say that an electrostatic force is acting between them. This force manifests itself in attractions, repulsions, and stresses in the bodies, and space or medium without. So great may be the strain exerted in the air, or whatever separates the two conducting bodies, that it may break down, and we observe sparks or bundles of light, or streamers, as they are called. These streamers form abundantly when the force through the air is rapidly varying. I will illustrate this action of electrostatic force in a novel experiment, in which I will employ the induction coil before referred to. The coil is contained in a trough filled with oil, and placed under the table. The two ends of the secondary wire pass through the two thick columns of hard rubber, which protrude to some height above the table. It is necessary to insulate the ends or terminals of the secondary heavily with hard rubber, because even dry wood is by far too poor an insulator for these currents of enormous potential differences. On one of the terminals of the coil I have placed a large sphere of sheet brass, which is connected to a larger insulated brass plate, in order to enable me to perform the experiment under conditions which, as you will see, are more suitable for this experiment. I now set the coil to work, and approach the free terminal with a metallic object held in my hand—this simply to avoid burns. As I approach the metallic object to a distance of eight or ten inches, a torrent of furious sparks breaks forth from the end of the secondary wire, which passes through the rubber column. The sparks cease when the metal in my hand touches the wire. My arm is now traversed by a powerful electric current,

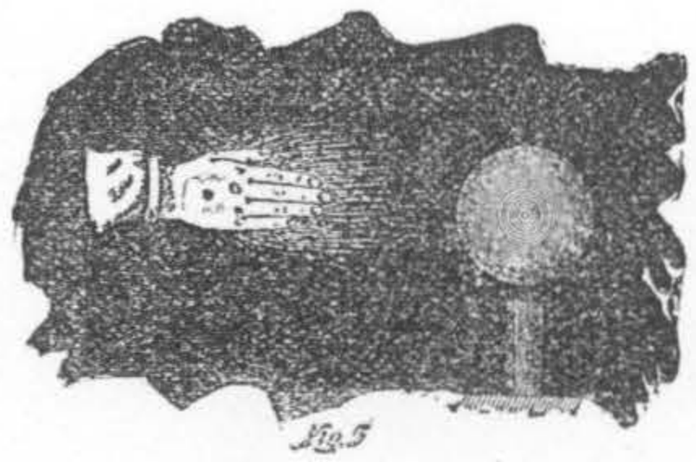


Fig. 5

Illustrating the Effect of Varying Electrostatic Force with a Transformer 200,000 volts Pressure.

vibrating at about the rate of one million times a second. All around me the electrostatic force makes itself felt, and the air molecules and particles of dust flying about are acted upon and are hammering violently against my body. So great is this agitation of the particles, that when the lights are turned out you may see streams of feeble light appear on some parts of my body. When such a streamer breaks out on any part of the body, it produces a sensation like the pricking of a needle. Were the potentials sufficiently high and the frequency of the vibration rather low, the skin would probably be ruptured under the tremendous strain, and the blood would rush out with great force in the form of fine spray or jet so thin as to be invisible just as oil will when placed on the positive terminal of a Holtz machine. This breaking through of the skin, though it may seem impossible at first, would perhaps occur, by reason of the tissues under the skin being incomparably better conducting. This, at least, appears plausible judging from some observations.

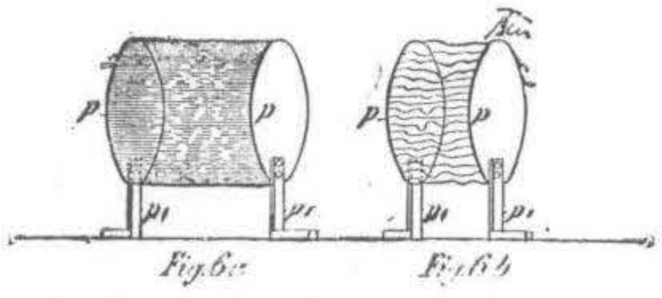
I can make these streams of light visible to all by touching with the metallic object one of the terminals as before, and approaching my free hand to the brass sphere, which is connected to the second terminal of the coil. As the hand is approached the air between it and the sphere, or in the immediate neighbourhood, is more violently agitated, and you see streams of light now break forth from my finger tips, and from the whole hand, Fig. 5. Were I to approach the hand closer, powerful sparks would jump from the brass sphere to my hand, which might be injurious. The streamers offer no particular inconvenience, except that in the ends of the finger tips a burning sensation is felt. They should not be confounded with those produced by an influence machine because in many respects they behave differently. I have attached the brass sphere and plate to one of the terminals in order to prevent the formation of visible streamers on that terminal, also in order to prevent sparks from jumping at a considerable distance. Besides, the attachment is favourable for the working of the coil.

The streams of light which you have observed issuing from my hand are due to a potential of about 200,000 volts, alternating in rather irregular intervals, something like a million times a second. A vibration of the same amplitude, but four times as fast, to maintain which over 3,000,000 volts would be required, would be more than sufficient to envelope my body in a complete sheet of flame.

But this flame would not burn me up; quite contrarily, the probability is that I would not be injured in the least. Yet a hundredth part of that energy, otherwise directed, would be amply sufficient to kill a person.

The amount of energy which may thus be passed into the body of a person depends on the frequency and potential of the currents, and by making both of these very great, a vast amount of energy may be passed into the body without causing any discomfort, except perhaps in the arm, which is traversed by a true conduction current. The reason why no pain in the body is felt, and no injurious effect noted, is that everywhere, if a current be imagined to flow through the body, the direction of its flow would be at right angles to the surface; hence the body of the experimenter offers an enormous section to the current, and the density is very small, with the exception of the arm perhaps, where the density may be considerable. But if only a small fraction of that energy would be applied in such a way that a current would traverse the body in the same manner as a low-frequency current, a shock would be received which might be fatal. A direct or low-frequency alternating current is fatal, I think, principally because its distribution through the body is not uniform, as it must divide itself in minute streamlets of great density, whereby some organs are vitally injured. That such a process occurs I have not the least doubt, though no evidence might apparently exist, or be found upon examination. The surest to injure and destroy life is a continuous current, but the most painful is an alternating current of very low frequency. The expression of these views, which are the result of long continued experiment and observation, both with steady and varying currents, is elicited by the interest which is at present taken in this subject, and by the manifestly erroneous ideas which are daily propounded in journals on this subject.

I may illustrate an effect of the electrostatic force by another striking experiment, but before, I must call your attention to one or two facts. I have said before that when the medium between two oppositely electrified bodies is strained beyond a certain limit it gives way and, stated in popular language, the opposite electric charges unite and neutralise each other. This breaking down of the medium occurs principally when the force acting between the bodies is steady, or varies at a moderate rate. Were the variation sufficiently rapid, such a destructive break would not occur, no matter how great the force, for all the energy would be spent in radiation, convection, and mechanical and chemical action. Thus



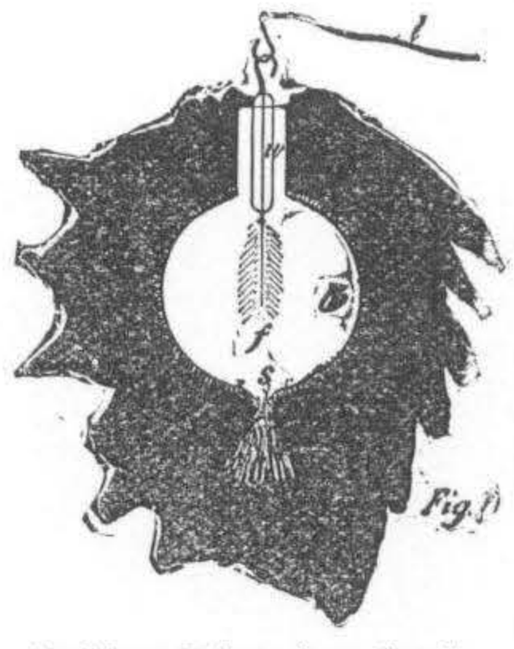
Illustrating the Effects of Rapidly-Varying and Steady Electrostatic Force.

the spark length, or greatest distance through which a spark will jump between the electrified bodies, is the smaller the greater the variation or time rate of change. But this rule may be taken to be true only in a general way, when comparing rates which are widely different.

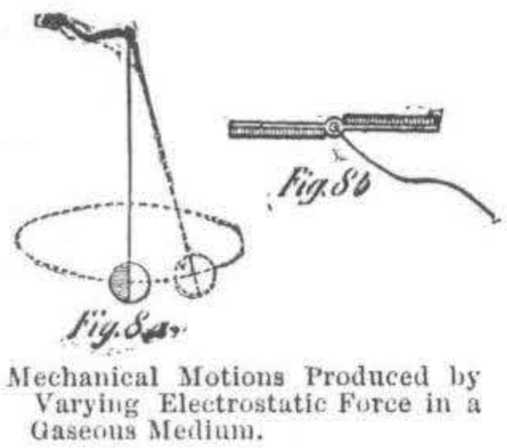
I will show you by an experiment the difference in the effect produced by a rapidly varying and a steady or moderately varying force. I have here two large circular brass plates, $p\,p$ (Fig. 6*a* and Fig. 6*b*), supported on movable insulating stands on the table, connected to the ends of the secondary of a similar coil as the one used before. I place the plates 10in. or 12in. apart and set the coil to work. You see the whole space between the plates, nearly two cubic feet, filled with uniform light, Fig. 6*a*. This light is due to the streamers you have seen in the first experiment, which are now much more intense. I have already pointed out the importance of these streamers in commercial apparatus and their still greater importance in some purely scientific investigations. Often they are too weak to be visible, but they always exist, consuming energy and modifying the action of the apparatus. When intense, as they are at present, they produce ozone in great quantity, and also, as Prof. Crookes has pointed out, nitrous acid. So quick is the chemical action, that if a coil such as this one, is worked for a very long time it will make the atmosphere of a small room unbearable, for the eyes and throat are attacked. But when moderately produced, the streamers refresh the atmosphere wonderfully, like a thunderstorm, and exercise unquestionably a beneficial effect.

In this experiment the force acting between the plates changes in intensity and direction at a very rapid rate. I will now make the rate of change per unit time much smaller. This I effect by rendering the discharges through the primary of the induction coil less frequent, and also by diminishing the rapidity of the vibration in the secondary. The former result is conveniently secured by lowering the E.M.F. over the air gap in the primary circuit, the latter, by approaching the two brass plates to a distance of about three or four inches. When the coil is set to work you see no streamers or light between the plates, yet the medium between them is under a tremendous strain. I still further augment the strain by raising the E.M.F. in the primary circuit, and soon you see the air give way and the hall is illuminated by a shower of brilliant and noisy sparks, 6*b*. These sparks could be produced also with unvarying force; they have been for many years a familiar phenomenon, though they were usually obtained from entirely different apparatus. In describing these two phenomena so radically different in appearance, I have advisedly spoken of a "force" acting between the plates. It would be in accordance with accepted views to say, that there was an "alternating E.M.F." acting between the plates. This term is quite proper and applicable in all cases where there is evidence of at least a possibility of an essential inter-dependence of the electric state of the plates, or electric action in their neighbourhood. But if the plates were removed to an infinite distance, or if at a finite distance, there is no probability or necessity whatever for such dependence. I prefer to use the term "electrostatic force," and to say that such a force is acting around each plate or electrified insulated body in general. There is an inconvenience in using this expression, as the term incidentally means a steady electric condition; but a proper nomenclature will eventually settle this difficulty.

I now return to the experiment to which I have already alluded, and with which I desire to illustrate a striking effect produced by a rapidly varying electrostatic force. I attach to the end of the wire, l (Fig. 7), which is in connection with one of the terminals of the secondary of the induction coil, an exhausted bulb, b. This bulb contains a thin carbon filament, f, which is fastened to a platinum wire, w, sealed in the glass and leading outside of the bulb, where it connects to the wire l. The bulb may be exhausted to any degree attainable with ordinary apparatus. Just a moment before, you have witnessed the breaking down of the air between the charged brass plates You know that a plate of glass, or any other insulating material, would break down in like manner. Had I therefore a metallic coating attached to the outside of the bulb, or placed near the same, and were this coating connected to the other terminal of the coil, you would be prepared to see the glass give way if the strain were sufficiently increased. Even were the coating not connected to the other terminal, but to an insulated plate, still, if you have followed recent developments, you would naturally expect a rupture of the glass.



Breaking a Bulb on Open Circuit



Mechanical Motions Produced by Varying Electrostatic Force in a Gaseous Medium.

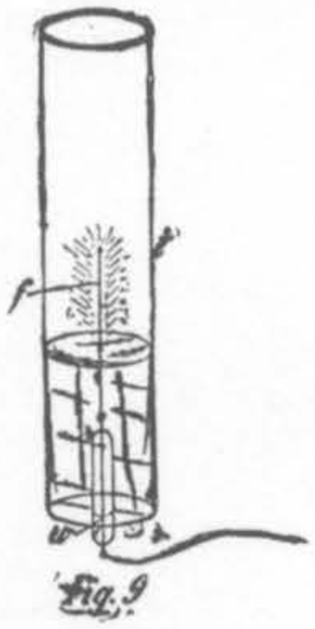
But it will certainly surprise you to note that under the action of the varying electrostatic force, the glass gives way when all other bodies are removed from the bulb. In fact, all the surrounding bodies we perceive might be removed to an infinite distance without affecting the result in the slightest. When the coil is set to work, the glass is invariably broken through at the seal, or other narrow channel, and the vacuum is quickly impaired. Such a damaging break would not occur with a steady force, even if the same were many times greater. The break is due to the agitation of the molecules of the gas within the bulb, and outside of the same. This agitation, which is generally most violent in the narrow, pointed channel near the seal, causes a heating and rupture of the glass. This rupture would, however, not occur, not even with a varying force, if the medium filling the inside of the bulb, and that surrounding it, were perfectly homogeneous. The break occurs much quicker if the top of the bulb is drawn out into a fine fibre. In bulbs used with these coils, such narrow, pointed channels must therefore be avoided.

When a conducting body is immersed in air, or similar insulating medium, consisting of, or containing, small freely movable particles capable of being electrified, and when the electrification of the body is made to undergo a very rapid change—which is equivalent to saying that the electrostatic force acting around the body is varying in intensity—the small particles are attracted and repelled, and their violent impacts against the body may cause a mechanical motion of the latter. Phenomena of this kind are noteworthy, inasmuch as they have not been observed before with apparatus such as has been commonly in use. If a very light conducting sphere be suspended on an exceedingly fine wire, and charged to a steady potential, however high, the sphere will remain at rest. Even if the potential would be rapidly varying, provided that the small particles of matter, molecules or atoms, are evenly distributed, no motion of the sphere should result. But if one side of the conducting sphere is covered with a thick insulating layer, the impacts of the particles will cause the sphere to move about generally in irregular curves, Fig. 8*a*. In like manner, as I have shown on a previous occasion, a fan of metal sheet, Fig. 8*b*, covered partially with insulating material as indicated, and placed upon the terminal of the coil so as to turn freely in it, is spun around.

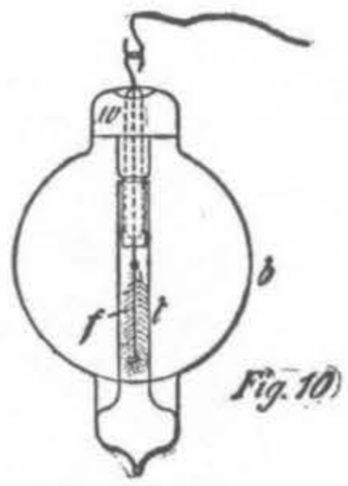
All these phenomena you have witnessed, and others, which will be shown later, are due to the presence of a medium-like air, and would not occur in a continuous medium. The action of the air may be illustrated still better by the following experiment: I take a glass tube, t, of about an inch in diameter, which has a

platinum wire, *w*, sealed in the lower end, and to which is attached a thin lamp filament, *f*. I connect the wire with the terminal of the coil and set the coil to work. The platinum wire is now electrified positively and negatively in rapid succession, and the wire and air inside of the tube are rapidly heated by the impacts of the particles, which may be so violent as to render the filament incandescent. But if I pour oil in the tube, just as soon as the wire is covered with the oil, all action apparently ceases, and there is no marked evidence of heating. The reason of this is that the oil is a practically continuous medium. The displacements in such a continuous medium are, with these frequencies, to all appearance incomparably smaller than in air, hence the work performed in such a medium is insignificant. But oil would behave very differently with frequencies many times as great, for even though the displacements be small, if the frequency were much greater, considerable work might be performed in the oil.

The electrostatic attractions and repulsions between bodies of measurable dimensions are, of all the manifestations of this force, the first so-called electrical phenomena noted. But though they have been known to us for many centuries, the precise nature of the mechanism concerned in these actions is still unknown to us, and has not been even quite satisfactorily explained. What kind of mechanism must that be? We cannot help wondering when we observe two magnets attracting and repelling each other with a force of hundreds of pounds with apparently nothing between them. We have in our commercial dynamos magnets capable of sustaining in mid-air tons of weight. But what are even these forces acting between magnets when compared with the tremendous attractions and repulsions produced by electrostatic force, to which there is apparently no limit as to intensity. In lightning discharges bodies are often charged to so high a potential that they are thrown away with inconceivable force and torn asunder or shattered into fragments. Still even such effects cannot compare with the attractions and repulsions which exist between charged molecules or atoms, and which are sufficient to project them with speeds of many kilometres a second, so that under their violent impact bodies are rendered highly incandescent and are volatilised. It is of special interest for the thinker who enquires into the nature of these forces to note, that whereas the



Showing the Effect of the Air.



Showing the Influence of the Conductivity of the Medium upon Electrostatic Actions through Measurable Distance.

actions between individual molecules or atoms occur seemingly under any condition, the attractions and repulsions of bodies of measurable dimensions imply a medium possessing insulating properties. So if air, either by being rarefied or heated, is rendered more or less conducting, these actions between two electrified bodies practically cease, while the actions between the individual atoms continue to manifest themselves.

An experiment may serve as an illustration and as a means of bringing out other features of interest. Some time ago I showed that a lamp filament or wire mounted in a bulb and connected to one of the terminals of a high-tension secondary coil is set spinning, the top of the filament generally describing a circle. This vibration was very energetic when the air in the bulb was at ordinary pressure, and became less energetic when the air in the bulb was strongly compressed. It ceased altogether when the air was exhausted, so as to become comparatively good conducting. I found at that time that no vibration took place when the bulb was very highly exhausted. But I conjectured that the vibration which I ascribed to the electrostatic action between the walls of the bulb and the filament should take place also in a highly-exhausted bulb. To test this under conditions which were more favourable, a bulb like the one in Fig. 10 was constructed. It comprised a globe, *b*, in the neck of which was sealed a platinum wire, *w*, carrya thin lamp filament, *f*. In the lower part of the globe a tube, *t*, was sealed so as to surround the filament. The exhaustion was carried as far as it was practicable with the apparatus employed.

(To be continued.)

ON LIGHT AND OTHER HIGH-FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(Continued from page 634.)

This bulb verified my expectation, for the filament was set spinning when the current was turned on, and became incandescent. It also showed another interesting feature, bearing upon the preceding remarks—namely, when the filament had been kept incandescent some time, the narrow tube and the space inside were brought to an elevated temperature, and as the gas in the tube then became conducting, the electrostatic attraction between the glass and the filament became very weak or ceased, and the filament came to rest. When it came to rest it would glow far more intensely. This was probably due to its assuming the position in the centre of the tube where the molecular bombardment was most intense, and also partly to the fact that the individual impacts were more violent, and that no part of the supplied energy was converted into mechanical movement. Since, in accordance with accepted views, in this experiment the incandescence must be attributed to the impacts of the particles, molecules, or atoms in the heated space, these particles must, therefore, in order to explain such action, be assumed to behave as independent carriers of electric charges immersed in an insulating medium; yet there is no attractive force between the glass tube and the filament because the space in the tube is, as a whole, conducting.

It is of some interest to observe in this connection that whereas the attraction between two electrified bodies may cease owing to the impairing of the insulating power of the medium in which they are immersed, the repulsion between the bodies may still be observed. This may be explained in a plausible way. When the bodies are placed at some distance in a poorly conducting medium, such as slightly warmed or rarefied air, and are suddenly electrified, opposite electric charges being imparted to them, these charges equalise more or less by leakage through the air. But if the bodies are similarly electrified, there is less opportunity afforded for such dissipation, hence the repulsion observed in such case is greater than the attraction. Repulsive actions in a gaseous medium are, however, as Prof. Crookes has shown, enhanced by molecular bombardment.

On Current or Dynamic Electricity Phenomena.

So far, I have considered principally effects produced by a varying electrostatic force in an insulating medium, such as air. When such a force is acting upon a conducting body of measurable dimensions, it causes within the same, or on its surface, displacements of the electricity and gives rise to electric currents, and these produce another kind of phenomena, some of which I shall presently endeavour to illustrate. In presenting this second class of electrical effects, I will avail myself principally of such as are producible without any return circuit, hoping to interest you the more by presenting these phenomena in a more or less novel aspect.

It has been for a long time customary, owing to the limited experience with vibratory currents, to consider an electric current as something circulating in a closed conducting path. It was astonishing at first to realise that a current may flow through the conducting path even if the latter be interrupted, and it was still more surprising to learn that sometimes it may be even easier to make a current flow under such conditions than through a closed path. But that old idea is gradually disappearing, even among practical men, and will soon be entirely forgotten.

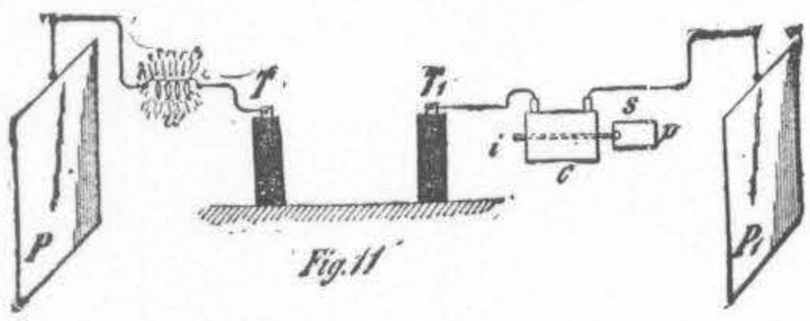


Fig. 11

Showing Effects of Currents Flowing through Open Circuits.

If I connect an insulated metal plate, P, Fig. 11, to one of the terminals, T, of the induction coil by means of a wire, though this plate be very well insulated, a current passes through the wire when the coil is set to work. First I wish to give you evidence that there is a current passing through the connecting wire. An obvious way of demonstrating this is to insert between the terminal of the coil and the insulated plate a very thin platinum or German-silver wire, *w*, and bring the latter to incandescence or fusion by the current. This requires a rather large plate or else current impulses of very high potential and frequency. Another way is to take a coil, C, Fig. 11, containing many turns of thin insulated wire, and to insert the same in the path of the current to the plate. When I connect one of the ends of the coil to the wire leading to another insulated plate, P, and its other end to the terminal, T_1, of the induction coil, and set the latter to work, a current passes through the inserted coil, C, and the existence of the current may be made manifest in various ways. For instance, I insert an iron core, *i*, within the coil. The current being one of very high frequency, if it be of some strength, will soon bring the iron core to a noticeably higher temperature, as the hysteresis and current losses are great with such high frequencies. One might take a core of some size, laminated or not, it would matter little; but ordinary iron wire, $\frac{1}{16}$th or $\frac{1}{8}$th of an inch thick, is suitable for the purpose. While the induction coil is working a current traverses the inserted coil, and only a few moments are sufficient to bring the iron wire, *i*, to an elevated temperature sufficient to soften the sealing-wax, *s*, and cause a paper washer, *p*, fastened by it to the iron wire to fall off. But with the apparatus such as I have here, other much more interesting demonstrations of this kind can be made. I have a secondary, S, Fig. 12, of coarse wire, wound upon a coil similar to the first. In the preceding experiment the current through the coil, C (Fig. 11), was very small, but there being many turns a strong heating effect was, nevertheless, produced in the iron wire. Had I passed that current through a conductor in order to show the heating of the latter, the current might have been too small to produce the effect desired. But with this coil provided with a secondary winding, I can now transform the feeble current of high tension which passes through the primary, P, into a strong secondary current of low tension, and this current will quite certainly do what I expect. In a small

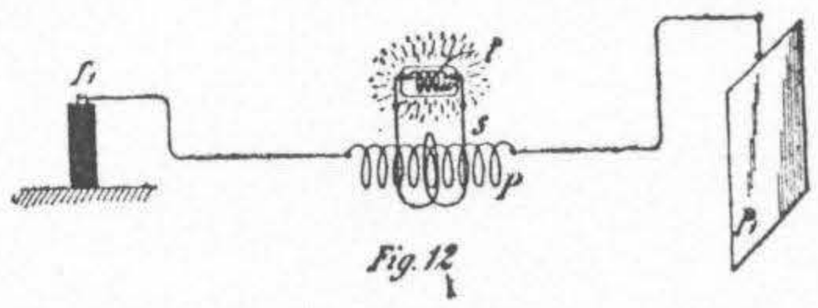


Fig. 12

Conversion on Open Circuit with Coil and Insulated Plate.

glass tube (*t*, Fig. 12) I have enclosed a coiled platinum wire, *w*—this merely in order to protect the wire. On each end of the glass tube is sealed a terminal of stout wire to which one of the ends of the platinum wire, *w*, is connected. I join the terminals of the secondary coil to these terminals and insert the primary, *p*, between the insulated plate, P_1, and the terminal, T_1, of the induction coil as before. The latter being set to work, instantly the platinum wire, *w*, is rendered incandescent and can be fused even if it be very thick.

Instead of the platinum wire I now take an ordinary 50-volt 16-c.p. lamp. When I set the induction coil in operation the lamp filament is brought to high incandescence. It is, however, not necessary to use the insulated plate, for the lamp (*l*, Fig. 13) is rendered incandescent, even if the plate, P_1, be disconnected. The secondary may also be connected to the primary as indicated by the dotted line in Fig. 13, to do away, more or less, with the electrostatic induction, or to modify the action otherwise.

I may here call attention to a number of interesting observations with the lamp. First, I disconnect one of the terminals of the lamp from the secondary, S. When the induction coil plays, a glow is noted which fills the whole bulb. This glow is due to electrostatic induction. It increases when the bulb is grasped with the hand, and the capacity of the experimenter's body thus

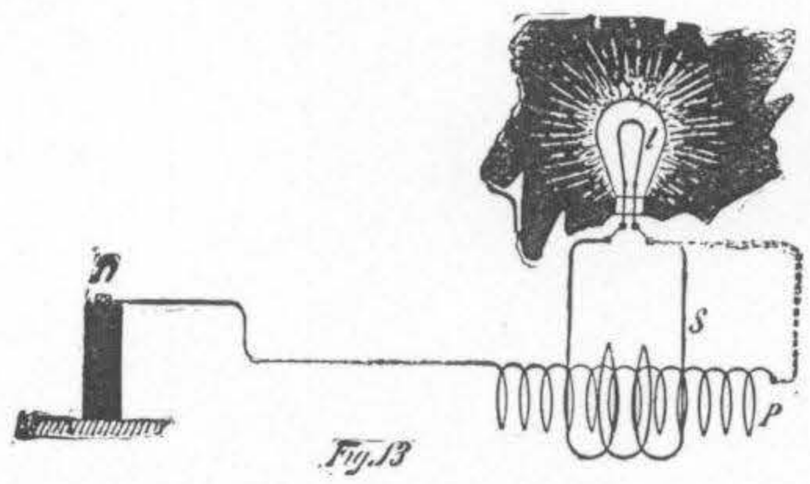


Fig. 13

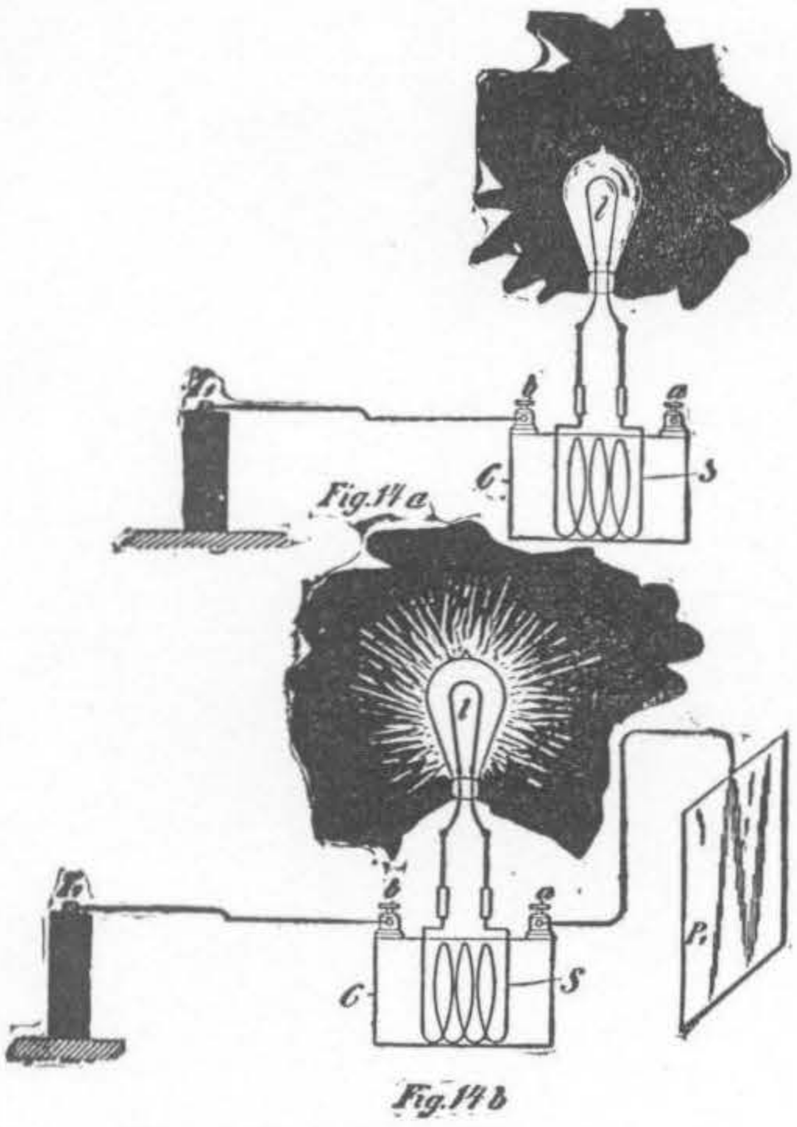
Conversion on Open Circuit with Coil alone.

added to the secondary circuit. The secondary, in effect, is equivalent to a metallic coating, which would be placed near the primary. If the secondary, or its equivalent, the coating, were placed symmetrically to the primary, the electrostatic induction would be nil under ordinary conditions—that is, when a primary return circuit is used—as both halves would neutralise each other. The secondary is, in fact, placed symmetrically to the primary, but the action of both halves of the latter. when only one of its ends is connected to the induction coil, is not exactly equal; hence, electrostatic induction takes place, and hence the glow in the bulb. I can nearly equalise the action of both halves of the primary by connecting the other free end of the same to the insulated plate, as in the preceding experiment. When the plate is connected, the glow disappears. With a smaller plate it would not entirely disappear, and then it would contribute to the brightness of the filament when the secondary is closed, by warming the air in the bulb.

To demonstrate another interesting feature, I have adjusted the coils used in a certain way. I first connect both the terminals of the lamp to the secondary, one end of the primary being connected to the terminal, T_1, of the induction coil, and the other to the insulated plate, P_1, as before. When the current is turned on,

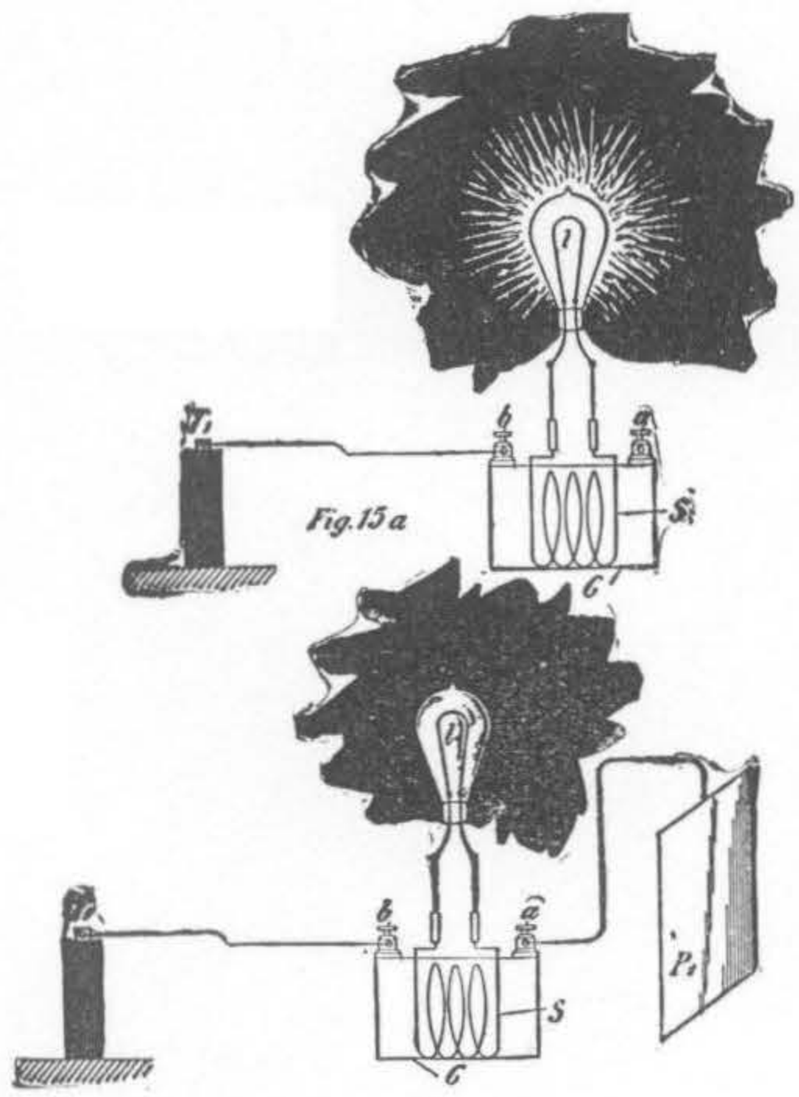
* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893; and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893.

the lamp glows brightly, as shown in Fig. 14*b*, in which C is a fine-wire coil, and S a coarse-wire secondary wound upon it. If the insulated plate, P_1, is disconnected, leaving one of the ends, *a*, of the primary insulated, the filament becomes dark, or generally it diminishes in brightness, Fig. 14*a*. Connecting again the plate, P_1, and raising the frequency of the current, I make the filament quite dark or barely red, Fig. 15*b*. Once more I will disconnect the plate. One will of course infer that when the plate is disconnected



Effect of Attached Plate with Low Frequencies.

the current through the primary will be weakened, that therefore the E.M.F. will fall in the secondary, S, and that the brightness of the lamp will diminish. This might be the case, and the result can be secured by an easy adjustment of the coils ; also by varying the frequency and potential of the currents. But it is perhaps of greater interest to note that the lamp increases in brightness when the plate is disconnected, Fig. 15*a*. In this case all the energy



Effect of Attached Plate with High Freqnencies.

the primary receives is now sunk into it, like the charge of a battery in an ocean cable, but most of that energy is recovered through the secondary and used to light the lamp. The current traversing the primary is strongest at the end, *b*, which is connected to the terminal, T_1, of the induction coil, and diminishes in strength towards the remote end, *a*. But the dynamic inductive effect exerted upon the secondary, S, is now greater than before, when the suspended plate was connected to the primary. These results might have been produced by a number of causes. For instance, the plate, P_1, being connected, the reaction from the coil, C, may be such as to diminish the potential at the terminal, T_1, of the induction coil, and therefore weaken the current through the primary of the coil, C. Or the disconnecting of the plate may diminish the capacity effect with relation to the primary of the latter coil to such an extent that the current through it is diminished, though the potential at the terminal, T_1, of the induction coil may be the same or even higher. Or the result might have been produced by the change of phase of the primary and secondary currents and consequent reaction. But the chief determining factor is the relation of the self-induction and capacity of coil, C, and plate, P_1, and the frequency of the currents. The greater brightness of the filament in Fig. 15*a* is, however, in part due to the heating of the rarefied gas in the lamp by electrostatic induction, which, as before remarked, is greater when the suspended plate is disconnected.

Still another feature of some interest I may here bring to your attention. When the insulated plate is disconnected and the secondary of the coil opened, by approaching a small object to the secondary, but very small sparks can be drawn from it, showing that the electrostatic induction is small in this case. But upon the secondary being closed upon itself or through the lamp, the filament glowing brightly, strong sparks are obtained from the secondary. The electrostatic induction is now much greater, because the closed secondary determines a greater flow of current through the primary and principally through that half of it which is connected to the induction coil. If now the bulb be grasped with the hand, the capacity of the secondary with reference to the primary is augmented by the experimenter's body and the luminosity of the filament is increased, the incandescence now being due partly to the flow of current through the filament and partly to the molecular bombardment of the rarefied gas in the bulb.]

(*To be continued.*)

ON LIGHT AND OTHER HIGH-FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(Continued from page 650, Vol. XI.)

The preceding experiments will have prepared one for the next following results of interest obtained in the course of these investigations. Since I can pass a current through an insulated wire merely by connecting one of its ends to the source of electrical energy, since I can induce by it another current, magnetise an iron core, and, in short, perform all operations as though a return circuit were used, clearly I can also drive a motor by the aid of only one wire. On a former occasion I have described a simple form of motor comprising a single exciting coil, an iron core and disc. Fig. 16 illustrates a modified way of operating such an alternate-current motor by currents induced in a transformer connected to one lead, and several other arrangements of circuits for operating a certain class of alternate motors founded on the action of currents of differing phase. In view of the present state of the art it is thought sufficient to describe these arrangements in a few words only. In the diagram, Fig. 16 II., shows a primary coil, P, connected with one of its ends to the line, L, leading from a high-tension transformer terminal, T_1. In inductive relation to this primary, P, is a secondary, S, of coarse wire, in the circuit of which is a coil, *c*. The currents induced in the secondary energise the iron core, *i*, which is preferably, but not necessarily, subdivided, and set the metal disc, *d*, in rotation. Such a motor, M_2, as diagrammatically shown in Fig. 16 II., has been called a "magnetic

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893; and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893.

lag motor," but this expression may be objected to by those who attribute the rotation of the disc to eddy currents circulating in minute paths when the core, *i*, is finally subdivided. In order to operate such a motor effectively on the plan indicated, the frequencies should not be too high, not more than 4,000 or 5,000, though the rotation is produced even with 10,000 per second, or more.

In Fig. 16 I., a motor, M_1, having two energising circuits, A and B, is diagrammatically indicated. The circuit A is connected to the line, L, and in series with it is a primary, P, which may have its free end connected to an insulated plate, P_1, such connection being indicated by the dotted lines. The other motor circuit, B, is connected to the secondary, S, which is in inductive relation to the primary, P. When the transformer terminal, T_1, is alternately electrified, currents traverse the open line, L, and also circuit A and primary, P. The currents through the latter induce secondary currents in the circuit, S, which pass through the energising coil, B, of the motor. The currents through the secondary, S, and those through the primary, P, differ in phase 90deg , or nearly so, and are capable of rotating an armature placed in inductive relation to the circuits, A and B.

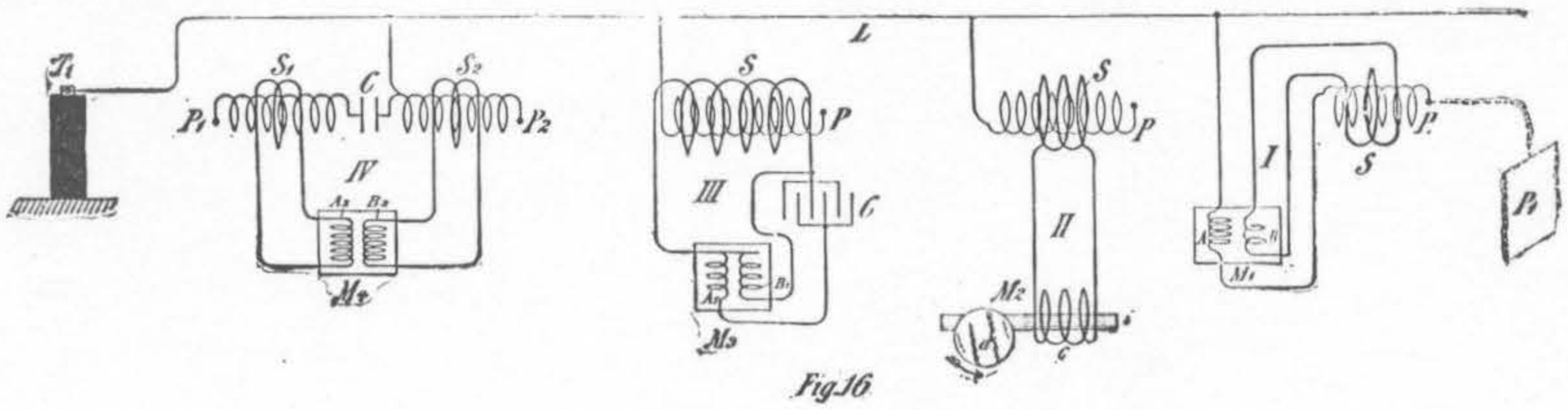


Fig. 16.

Ways of Operating Motors with only One Lead.

In Fig. 16 III., a similar motor, M_3, with two energising circuits, A_1 and B_1, is illustrated. A primary, P, connected with one of its ends to the line, L, has a secondary, S, which is preferably wound for a tolerably high E.M.F., and to which the two energising circuits of the motor are connected, one directly to the ends of the secondary and the other through a condenser, C, by the action of which the currents traversing the circuit, A_1 and B_1, are made to differ in phase.

In Fig. 16 IV. still another arrangement is shown. In this case two primaries, P_1 and P_2, are connected to the line, L—one through a condenser, C, of small capacity, and the other directly. The primaries are provided with secondaries, S_1 and S_2, which are in series with the energising circuits, A_2 and B_2, and a motor, M_3, the condenser, C, again serving to produce the requisite difference in the phase of the currents traversing the motor circuits. As such phase motors with two or more circuits are now well known in the art, they have been here illustrated diagrammatically. No difficulty whatever is found in operating a motor in the manner indicated or in similar ways, and although such experiments up to this day present only scientific interest, they may at a period not far distant, be carried out with practical objects in view.

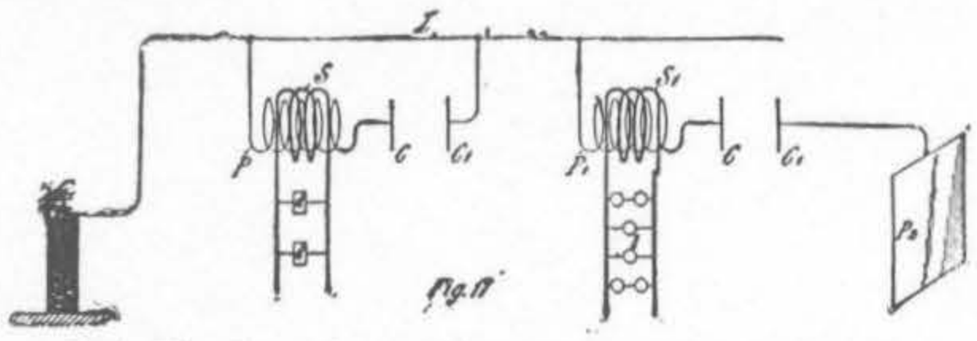


Fig. 17.

Single-Wire Conversion and Distribution, with Simple Means for Regulating the Effects.

It is thought useful to devote here a few remarks to the subject of operating devices of all kinds by means of only one leading wire. It is quite obvious, that when high-frequency currents are made use of, ground connections are—at least when the E.M.F. of the currents is great—better than a return wire. Such ground connections are objectionable with steady or low-frequency currents on account of destructive chemical actions of the former and disturbing influences exerted by both on the neighbouring circuits, but with high frequencies these actions practically do not exist. Still, even ground connections become superfluous when the E.M.F. is very high, for soon a condition is reached when the current may be passed more economically through open than through closed conductors. Remote as might seem an industrial application of such single-wire transmission of energy to one not experienced in such lines of experiment, it will not seem so to anyone who for some time has carried on investigations of such nature. Indeed, I cannot see why such a plan should not be practicable. Nor should it be thought that for carrying out such a plan currents of very high frequency are implicitly required, for just as soon as potentials of, say, 30,000 volts are used, the single-wire transmission may be effected with low frequencies, and experiments have been made by me from which these inferences are made.

When the frequencies are very high it has been found in laboratory practice quite easy to regulate the effects in the manner shown in diagram, Fig. 17. Here two primaries, P and P, are shown, each connected with one of its ends to the line, L, and with the other end to the condenser plates, C and C^1, respectively. Near these are placed other condenser plates, C_1 and C_1^1, the former being connected to the line, L, and the latter to an insulated larger plate, P_2. On the primaries are wound secondaries, S and S_1, of coarse wire, connected to the devices *m* and *d* respectively. By varying the distances of the condenser plates, C and C^1, and C_1 and C_1^1, the currents through the secondaries, S and S_1, are varied in intensity. The curious feature is the great sensitiveness, the slightest change in the distance of the plates producing considerable variations in the intensity or strength of the currents. The sensitiveness may be rendered extreme by making the frequency such that the primary itself without any plate attached to its free end satisfies, in conjunction with the closed secondary the condition of resonance. In such condition an extremely small change in the capacity of the free terminal produces great variations. For instance, I have been able to adjust the conditions so that the mere approach of a person to the coil produces a considerable change in the brightness of the lamps attached to the secondary. Such observations and experiments possess of course at present chiefly scientific interest, but they may soon become of practical importance.

Very high frequencies are, of course, not practicable with motors on account of the necessity of employing iron cores. But one may use sudden discharges of low frequency and thus obtain certain advantages of high-frequency currents without rendering the iron core entirely incapable of following the changes, and without entailing a very great expenditure of energy to the core. I have found it quite practicable to operate with such low frequency disruptive discharges of condensers alternating-current motors. A certain class of such motors which I advanced a few years ago, which contain closed secondary circuits, will rotate quite vigorously when the discharges are directed through the exciting coils. One reason that such a motor operates so well with these discharges is that the difference of phase between the primary and secondary currents is 90deg., which is generally not the case with harmonically rising and falling currents of low frequency. It might not be without interest to show an experiment with a simple motor of this kind, inasmuch as it is commonly thought that disruptive discharges are unsuitable for such purposes. The motor is illustrated in Fig. 18. It comprises a rather large iron core, *i*, with slots on the top into which are embedded thick copper washers, *c c*. In proximity to the core is

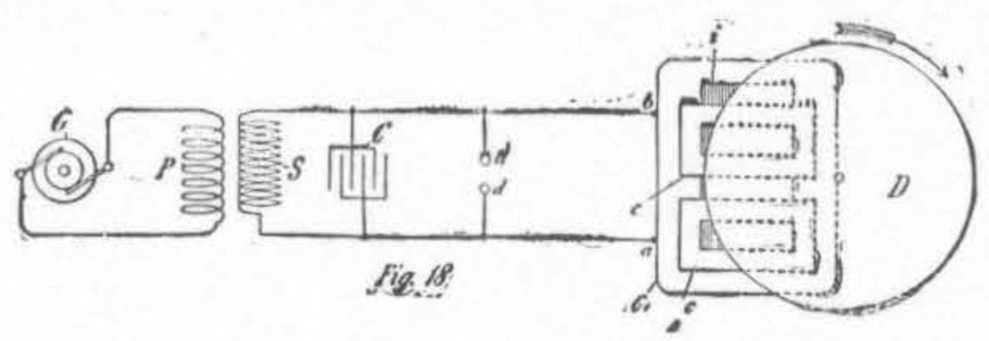


Fig. 18.

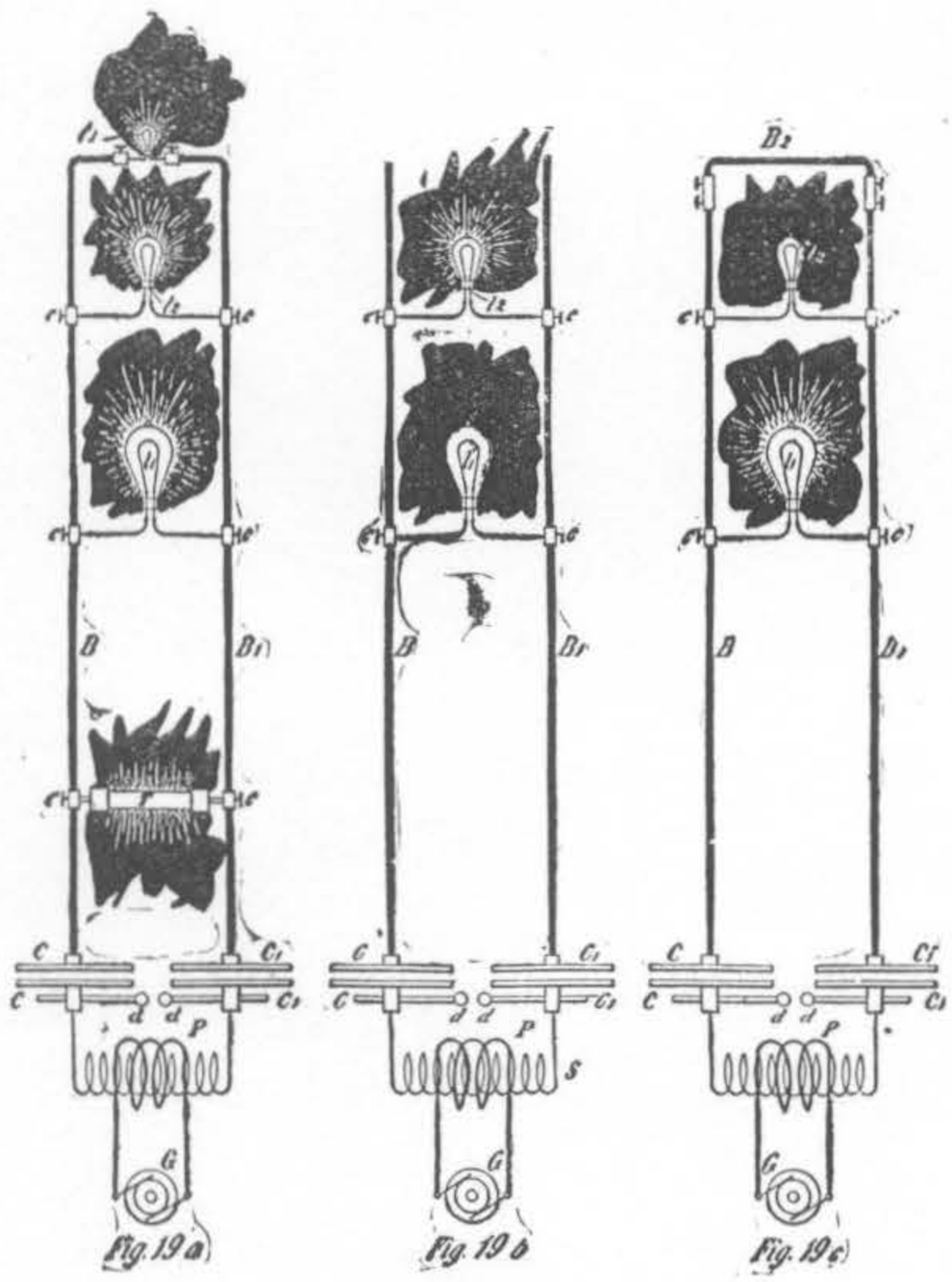
Operating a Motor by Disruptive Discharges.

a freely movable metal disc, D. The core is provided with a primary exciting coil, C, the ends, *a* and *b*, of which are connected to the terminals of the secondary, S, of an ordinary transformer, the primary, P, of the latter being connected to an alternating distribution circuit or generator, G, of low or moderate frequency. The terminals of the secondary, S, are attached to a condenser, C, which discharges through an air-gap, *d d*, which may be placed in series or shunt to the coil C. When the conditions are properly chosen the disc, D, rotates with considerable effort and the iron core, *i*, does not get very perceptibly hot. With currents from a high-frequency alternator, on the contrary, the core gets rapidly hot and the disc rotates with a much smaller effort. To perform the experiment properly it should be first ascertained that the disc, D, is not set in rotation when the discharge is not occurring at *d d*. It is preferable to use a large iron core and a condenser of large capacity so as to bring the superimposed quicker oscillation to a very low pitch, or to do away with it entirely. By observing certain elementary rules I have also found it practicable to operate ordinary series or shunt direct-current motors with such disruptive discharges, and this can be done with or without a return wire.

Among the various current phenomena observed perhaps the most interesting are those of impedance presented by conductors to currents varying at a rapid rate. In my first paper before the American Institute of Electrical Engineers, I have described a few striking observations of this kind. Thus I showed that when such currents or sudden discharges are passed through a thick metal

bar there may be points at the bar only a few inches apart, which have a sufficient potential difference between them to maintain at bright incandescence an ordinary filament lamp. I have also described the curious behaviour of rarefied gas surrounding a conductor to such sudden rushes of current. These phenomena have been since more carefully studied, and one or two novel experiments of this kind are deemed of sufficient interest to be described

With reference to Fig. 19*a*, B and B_1 are very stout copper bars connected at their lower ends to plates, C and C_1, respectively, of a condenser, the opposite plates of the latter being connected to the terminals of the secondary, S, of a high-tension transformer, the primary, P, of which is supplied with alternating currents from an ordinary low-frequency dynamo, G, or distribution circuit. The condenser discharges through an adjustable gap, *d d*, as usual. By establishing a rapid vibration it was found quite easy to perform the following curious experiment. The bars, B and B_1, were joined at the top by a low-voltage lamp, l_3; a little lower was placed by means of clamps, *c c*, a 50-volt lamp, l_2, and still lower another 100-volt lamp, l_1, and finally at a certain distance below the latter lamp, an exhausted tube, T. By carefully determining the positions of these devices it was found practicable to maintain them all at their proper illuminating power. Yet they were all connected in multiple arc to the two stout copper bars and required widely different pressures. This experiment requires, of course, some time for adjustment, but is quite easily performed.



Impedance Phenomena.

In Figs. 19*b* and 19*c*, two other experiments are illustrated, which, unlike the previous experiment, do not require very careful adjustments. In Fig. 20*b*, two lamps, l_1 and l_2 (the former a 100-volt and the latter a 50-volt) are placed in certain positions as indicated, the 100-volt lamp being below the 50-volt lamp. When the arc is playing at *d d*, and the sudden discharges passed through the bars, B B, the 50-volt lamp will as a rule burn brightly, or at least this result is easily secured, while the 100-volt lamp will burn very low or remain quite dark, Fig. 19*b*. Now the bars, B B, may be joined at the top by a thick cross-bar, B_2, and it is quite easy to maintain the 100-volt lamp at full candle-power while the 50-volt lamp remains dark, Fig. 19*c*. These results, as I have pointed out previously, should not be considered to be due exactly to frequency, but rather to the time rate of change which may be great even with low frequencies. A great many other results of the same kind equally interesting, especially to those who are only used to manipulate steady currents, may be obtained, and they afford precious clues in investigating the nature of electric currents.

In the preceding experiments I have already had occasion to show some light phenomena, and it would be now proper to study these in particular; but to make this investigation more complete I think it necessary to first make a few remarks on the subject of electrical resonance, which has to be always observed in carrying out these experiments.

(To be continued.)

ON LIGHT AND OTHER HIGH-FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(Continued from page 19).

ON ELECTRICAL RESONANCE.

The effects of resonance are being more and more noted by engineers and are becoming of great importance in the practical operation of apparatus of all kinds with alternating currents. A few general remarks may therefore be made concerning these effects. It is clear that if we succeed in employing the effects of resonance practically in the operation of electric devices the return wire will, as a matter of course, become unnecessary, for the electric vibration may be conveyed with one wire just as well, and sometimes even better, than with two. The question first to answer is, then, whether pure resonance effects are producible. Theory and experiment both show that such is impossible in Nature, for as the oscillation becomes more and more vigorous the losses in the vibrating bodies and environing media rapidly increase and necessarily check the vibration which otherwise would go on increasing for ever. It is a fortunate circumstance that pure resonance is not producible, for if it were there is no telling what dangers might not lay in wait for the innocent experimenter. But to a certain degree resonance is producible, the magnitude of the effects being limited by the imperfect conductivity and imperfect elasticity of the media or, generally stated, by frictional losses. The smaller these losses, the more striking are the effects. The same is the case in mechanical vibration. A stout steel bar may be set in vibration by drops of water falling upon it at proper intervals; and with glass, which is more perfectly elastic, the resonance effect is still more remarkable, for a goblet may be burst by singing into it a note of the proper pitch. The electrical resonance is the more perfectly attained, the smaller the resistance or the impedance of the conducting path and the more perfect the dielectric. In a Leyden jar discharging through a short stranded cable of thin wires these requirements are probably best fulfilled, and the resonance effects are therefore very prominent. Such is not the case with dynamo machines, transformers and their circuits, or with commercial apparatus in general in which the presence of iron cores complicates or renders impossible the action. In regard to Leyden jars with which resonance effects are frequently demonstrated, I would say that the effects observed are often attributed but are seldom due to true resonance, for an error is quite easily made in this respect. This may be undoubtedly demonstrated by the following experiment. Take, for instance, two large insulated metallic plates or spheres which I shall designate A and B, place them at a certain small distance apart and charge them from a frictional or influence machine to a potential so high that just a slight increase of the difference of potential between them will cause the small air or insulating space to break down. This is easily reached by making a few preliminary trials. If now another plate—fastened on an insulating handle and connected by a wire to one of the terminals of a high-tension secondary of an induction coil, which is maintained in action by an alternator (preferably high frequency)—is approached to one of the charged bodies, A or B, so as to be nearer to either one of them, the discharge will invariably occur between them; at least, it will if the potential of the coil in connection with the plate is sufficiently high. But the explanation of this will soon be found in the fact that the approached plate acts inductively upon the bodies A and B, and causes a spark to pass between them. When this spark occurs, the charges which were previously imparted to these bodies from the influence machine must needs be lost, since the bodies are brought in electrical connection through the arc formed. Now this arc is formed whether there be resonance or not. But even if the spark would not be produced, still there is an alternating E.M.F. set up between the bodies when the plate is brought near one of them; therefore the approach of the plate, if it does not always actually, will, at any rate, tend to break down the air space by inductive action. Instead of the spheres or plates, A and B, we may take the coatings of a Leyden jar with the same result, and in place of the machine, which is a high-frequency alternator preferably, because it is more suitable for the experiment, and also for the argument, we may take another Leyden jar or battery of jars. When such jars are discharging through a circuit of low resistance the same is traversed by currents of very high frequency. The plate may now be connected to one of the coatings of the second jar, and when it is brought near to the first jar just previously charged to a high potential from an influence machine, the result is the same as before, and the first jar will discharge through a small air space upon the second being caused to discharge. But both jars and their circuits need not be tuned any closer than a basso profundo is to the note produced by a mosquito, as small sparks will be produced through the air space, or at least the latter will be considerable more strained owing to the setting up of an alternating E.M F. by induction, which takes place when one of the jars begins to discharge. Again, another error of a similar nature is quite easily made. If the circuits of the two jars are run parallel and close together, and the experiment has been performed of discharging one by the other, and now a coil of wire be added to one of the circuits whereupon the experiment does not succeed, the conclusion that this is due to the fact that the circuits are now not tuned, would be far from being safe. For the two circuits act as condenser coatings and the addition of the coil to one of them is equivalent to bridging them, at the point where the coil is placed, by a small condenser, and the effect of the latter might be to prevent the spark from jumping through the discharge space by diminishing the alternating E.M.F. acting across the same. All these remarks, and many more which might be added but for fear of wandering too far from the subject, are made with the pardonable intention of cautioning the unsuspecting student, who might gain an entirely unwarranted opinion of his skill when seeing every experiment succeed, but they are in no way thrust upon the experienced as novel observations.

In order to make reliable observations of electric resonance effects it is very desirable, if not necessary, to employ an alternator giving currents which rise and fall harmonically, as in working with make and break currents the observations are not always trustworthy, since many phenomena which depend on the rate of change may be produced with frequencies widely different. Even when making such observations with an alternator one is apt to be mistaken. When a circuit is connected to an alternator there are an infinite number of values for capacity and self-induction which, in conjunction, will satisfy the condition of resonance. So there are in mechanics an infinite number of tuning-forks which will respond to a note of a certain pitch, or loaded springs which have a definite period of vibration. But the resonance will be most perfectly attained in that case in which the motion is effected with the greatest freedom. Now in mechanics, considering the vibration in the common medium—that is, air—it is of comparatively little importance whether one tuning-fork be somewhat larger than another, because the losses in the air are not very considerable. One may, of course, enclose a tuning-fork in an exhausted vessel and by thus reducing the air resistance to a minimum obtain better resonant action. Still the difference would not be very great. But it would make a great difference if the tuning-fork were immersed in mercury. In the electrical vibration it is of enormous importance to arrange the conditions so that the vibration is effected with the greatest freedom. The magnitude of the resonance effect depends, under otherwise equal conditions, on the quantity of electricity set in motion or on the strength of the current driven through the circuit. But the circuit opposes the passage of the currents by reason of its impedance, and therefore to secure the best action it is necessary to reduce

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893; and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893.

the impedance to a minimum. It is impossible to overcome it entirely, but merely in part, for ohmic resistance cannot be overcome. But when the frequency of the impulses is very great, the flow of the current is practically determined by self-induction. Now self-induction can be overcome by combining it with capacity. If the relation between these is such that at the frequency used they annul each other—that is, have such values as to satisfy the condition of resonance and the greatest quantity of electricity is made to flow through the external circuit—then the best result is obtained. It is simpler and safer to join the condenser in series with the self-induction. It is clear that in such combinations there will be, for a given frequency, and considering only the fundamental vibration, values which will give the best result, with the condenser in shunt to the self-induction coil; of course more such values than with the condenser in series. But practical conditions determine the selection. In the latter case in performing the experiments one may take a small self-induction and a large capacity or a small capacity and a large self-induction, but the latter is preferable, because it is inconvenient to adjust a large capacity by small steps. By taking a coil with a very large self-induction the critical capacity is reduced to a very small value, and the capacity of the coil itself may be sufficient. It is easy, especially by observing certain artifices, to wind a coil through which the impedance will be reduced to the value of the ohmic resistance only, and for any coil there is, of course, a frequency at which the maximum current will be made to pass through the coil. The observation of the relation between self-induction, capacity, and frequency is becoming important in the operation of alternate-current apparatus, such as transformers or motors, because by a judicious determination of the elements the employment of an expensive condenser becomes unnecessary. Thus it is possible to pass through the coils of an alternating-current motor under the normal working conditions the required current with a low E.M.F., and do away entirely with the false current, and the larger the motor the easier such a plan becomes practicable; but it is necessary for this to employ currents of very high potential or high frequency.

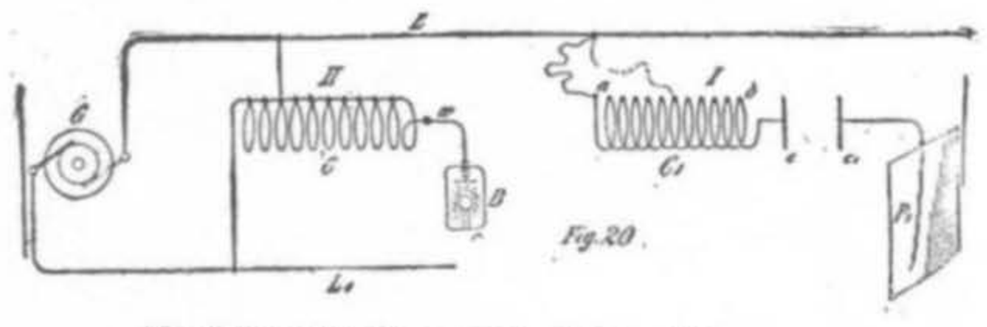


Fig. 20.

Plan followed in Observing the Effects of Resonance.

In Fig. 20 I. is shown a plan which has been followed in the study of the resonance effects by means of a high-frequency alternator. C is a coil of many turns, which is divided in small separate sections for the purposes of adjustment. The final adjustment was made sometimes with a few thin iron wires (though this is not always advisable), or with a closed secondary. The coil, C, is connected with one of its ends to the line, L, from the alternator, G, and with the other end to one of the plates, c, of a condenser, $c\,c_1$, the plate, c_1, of the latter being connected to a much larger plate, P_1. In this manner both capacity and self-induction were adjusted to suit the dynamo frequency.

(To be continued.)

ON LIGHT AND OTHER HIGH-FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(Continued from page 64.)

As regards the rise of potential through resonant action, of course, theoretically, it may amount to anything, since it depends on self-induction and resistance, and since these may have any value. But in practice, one is limited in the selection of these values, and besides these, there are other limiting causes. One may start with, say, 1,000 volts, and raise the E.M.F. to 50 times that value, but one cannot start with 100,000 and raise it to 10 times that value because of the losses in the media, which are great, especially if the frequency is high. It should be possible to start with, for instance, two volts from a high or low frequency circuit of a dynamo and raise the E.M.F. to many hundred times that value. Thus coils of the proper dimensions might be connected each with only one of its ends to the mains from a machine of low E.M.F., and though the circuit of the machine would not be closed in the ordinary acceptance of the term, yet the machine might be burned out if a proper resonance effect would be obtained. I have not been able to produce, nor have I observed with currents from the dynamo machine, such great rises of potential. It is possible, if not probable, that with currents obtained from apparatus containing iron the disturbing influence of the latter is the cause that these theoretical possibilities cannot be realised ; but if such is the case, I attribute it solely to the hysteresis and Foucault current losses in the core. Generally it was necessary to transform upward, when the E.M.F. was very low, and usually an ordinary form of induction coil was employed, but sometimes the arrangement illustrated in Fig. 20 II. has been found to be convenient. In this case a coil, C, is made in a great many sections, a few of these being used as the primary. In this manner both primary and secondary are adjustable. One end of the coil is connected to the line, L_1, from the alternator, and the other line, L, is connected to the intermediate point of the coil. Such a coil with adjustable primary and secondary will be found also convenient in experiments with the disruptive discharge. When true resonance is obtained, the top of the wave must of course be on the free end of the coil, as for instance, at the terminal of the phosphorescence bulb, B. This is easily recognised by observing the potential of a point on the wire, *w*, nearer to the coil.

In connection with resonance effects and the problem of transmission of energy over a single conductor which was previously considered, I would say a few words on a subject which constantly fills my thoughts, and which concerns the welfare of all. I mean the transmission of intelligible signals, or perhaps even power to any distance without the use of wires. I am becoming daily more convinced of the practicability of the scheme ; and though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realised, yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day. The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb by means of powerful machines the electrostatic condition of the earth and thus transmit intelligible signals and perhaps power. In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why then not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile-posts the earth may appear very large, but to that happiest of all men, the astronomer, who gazes at the heavens and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician, for when he considers the speed with which an electric disturbance is propagated through the earth all his ideas of distance must completely vanish.

A point of great importance would be first to know what is the capacity of the earth? and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation. If it be a charged body insulated in space its capacity should be extremely small—less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is, by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric currents. One of the terminals of the source would be connected to earth, as, for instance, to the city water-mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata or free space contains an opposite charge and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible and connect the ends of the high-tension secondary to the ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body and watching for the disturbance at various neighbouring points of the earth's surface resonance might be detected. Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do and a proper electrical oscillator would have to be produced, and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface.

Assume that a source of alternating currents, S, be connected, as in Fig. 21, with one of its terminals to earth (conveniently to the water-mains) and with the other to a body of large surface, P. When the electric oscillation is set up there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to, or diverging from, the point, C, where the ground connection is made. In this manner neighbouring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body, P, is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source, S, will set up the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration, at least of a certain low period upon the earth, by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured. I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that since in such an experiment the electrical density at the surface could be but extremely small considering the size of the earth, the air would not act as a very disturbing factor, and there would be not much energy lost through the

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action of the air, which would be the case if the density were great. Theoretically, then, it could not require a great amount of energy to produce a disturbance perceptible at a great distance, or even all over the surface of the globe. Now it is quite certain that at any point within a certain radius of the source, S, a properly-adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source, S_1 (Fig. 21) similar to S, or any number of such sources can be set to work in synchronism with the latter and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S_1 if the same be of opposite phase to the source S. I think that beyond doubt it is possible to operate electrical devices in a city through the ground or pipe system by resonance from an electrical oscillator located at a



Fig. 21

Energy Transmission to Any Distance Without Wires.

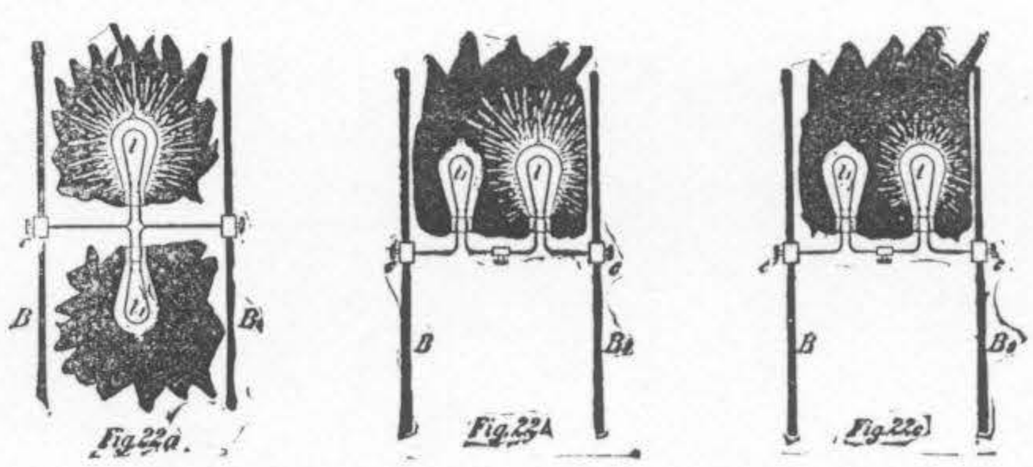
central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realisation of the scheme of transmitting intelligence or perhaps power to any distance through the earth or environing medium. If this is at all possible, distance does not mean anything. Proper apparatus must first be produced by means of which the problem can be attacked, and I have devoted much thought to this subject. I am firmly convinced that it can be done, and hope that we shall live to see it done.

ON THE LIGHT PHENOMENA PRODUCED BY HIGH-FREQUENCY CURRENTS OF HIGH POTENTIAL AND GENERAL REMARKS RELATING TO THE SUBJECT.

Returning now to the light effects which it has been the chief object to investigate, it is thought proper to divide these effects into four classes: (1) incandescence of a solid; (2) phosphorescence; (3) incandescence or phosphorescence of a rarefied gas; and (4) luminosity produced in a gas at ordinary pressure. The first question is, How are these luminous effects produced? In order to answer this question as satisfactorily as I am able to do in the light of accepted views, and with the experience acquired, and to add some interest to this demonstration, I shall dwell here upon a feature which I consider of great importance, inasmuch as it promises besides to throw a better light upon the nature of most of the phenomena produced by high-frequency electric currents. I have on other occasions pointed out the great importance of the presence of the rarefied gas, or atomic medium in general, around the conductor through which alternate currents of high frequency are passed, as regards the heating of the conductor by the currents. My experiments described some time ago have shown that the higher the frequency and potential difference of the currents, the more important becomes the rarefied gas in which the conductor is immersed as a factor of the heating. The potential difference however, is, as I then pointed out, a more important element than the frequency. When both of these are sufficiently high, the heating may be almost entirely due to the presence of the rarefied gas. The experiments to follow will show the importance of the gas, or generally of gas at ordinary or other pressure as regards the incandescence or other luminous effects produced by currents, of this kind.

I take two ordinary 50-volt 16-c.p. lamps which are in every respect alike, with the exception that one has been opened at the top and the air has filled the bulb, while the other is at the ordinary degree of exhaustion of commercial lamps. When I attach the lamp which is exhausted to the terminal of the secondary of the coil, which I have already used as in experiments illustrated in Fig. 15*a*, for instance, and turn on the current, the filament, as you have before seen, comes to high incandescence. When I attach the second lamp, which is filled with air, instead of the former, the filament still glows, but much less brightly. This experiment illustrates only in part the truth of the statements before made. The importance of the filaments being immersed in rarefied gas is plainly noticeable, but not to such a degree as might be desirable. The reason is that the secondary of this coil is wound for low tension, having only 150 turns, and the potential difference at the terminals of the lamps is therefore small. Were I to take another coil with many more turns in the secondary, the effect would be increased, since it depends partially on the potential difference, as before remarked. But since the effect likewise depends on the frequency, it may be properly stated that it depends on the time rate of the variation of the potential difference. The greater this variation, the more important becomes the gas as an element of heating. I can produce a much greater rate of variation in another way, which besides has the advantage of doing away with the objections which might be made in the experiment just shown, even if both the lamps were connected in series or multiple arc to the coil—namely, that in consequence of the reactions existing between the primary and secondary coil the conclusions are rendered uncertain. This result I secure by charging from an ordinary transformer, which is fed from the alternating-current supply station, a battery of condensers, and discharging the latter directly through a circuit of small self-induction, as before illustrated in Figs. 19*a*, 19*b*, 19*c*.

In Figs. 22*a*, 22*b*, and 22*c*, the heavy copper bars, B B_1, are connected to the opposite coatings of a battery of condensers, or generally in such way that the high-frequency or sudden discharges are made to traverse them. I connect first an ordinary 50-volt incandescent lamp to the bars by means of the clamps, *c c*. The discharges being passed through the lamp, the filament is rendered incandescent, though the current through it is very small, and would not be nearly sufficient to produce a visible effect under the conditions of ordinary use of the lamp. Instead of this I now attach to the bars another lamp exactly like the first, but with the seal broken off, the bulb being therefore filled with air at ordinary pressure. When the discharges are directed through the filament, as before, it does not become incandescent. But the result might still be attributed to one of the many possible reactions. I therefore connect both the lamps in multiple arc, as illustrated in Fig. 22*a*. Passing the discharges through both the lamps, again the filament in the exhausted lamp, *l*, glows very brightly, while that in the non-exhausted lamp, l_1, remains dark, as previously. But it should not be thought that the latter lamp is taking only a small fraction of the energy supplied to both the lamps; on the contrary, it may consume a considerable portion of the energy, and it may become even hotter than the one which burns brightly. In this experiment the potential difference at the terminals of the lamps varies in sign theoretically three to four million times a second. The ends of the filaments are correspondingly electrified, and the gas in the bulbs is violently agitated, and a large portion of the supplied energy is thus converted into heat. In the non-exhausted bulb there being a few million times more gas molecules than in the exhausted one, the bombardment, which is most violent at the ends of the filament, in the neck of the bulb, consumes a large portion of the energy without producing any visible effect. The reason is that there being many molecules, the bombardment is quantitatively considerable, but the individual impacts are not very violent, as the speeds of the molecules are comparatively small owing to the small free path. In the exhausted bulb, on the contrary, the speeds are very great and the individual impacts are violent, and therefore better adapted to produce a visible effect. Besides, the convection of heat is greater in the former bulb. In both the bulbs the current traversing the filaments is very small. incomparably smaller than that which they require in an ordinary low-frequency circuit. The potential difference, however, at the ends of the filaments is very great, and might be possibly 20,000 volts or more if the filaments were straight and their ends far apart. In the ordinary lamp a spark generally occurs between the ends of the filament or between the platinum wires outside, before such a difference of potential can be reached.



Showing the Effect of the Presence of a Gaseous Medium.

It might be objected in the experiment before shown that the lamps, being in multiple arc, the exhausted lamp might take a much larger current and that the effect observed might not be exactly attributable to the action of the gas in the bulbs. Such objections will lose much weight if I connect the lamp in series, with the same result. When this is done and the discharges are directed through the filaments it is again noted that the filament in the non-exhausted bulb, l_1, remains dark, while that in the exhausted one, *l*, glows even more intensely than under its normal conditions of working, Fig. 22*b*. According to general ideas the current through the filaments should now be the same, were it not modified by the presence of the gas around the filaments.

At this juncture I may point out another interesting feature, which illustrates the effect of the rate of change of potential of the currents. I will leave the two lamps connected in series to the bars, B B_1, as in the previous experiment, Fig. 22*b*, but will presently reduce considerably the frequency of the currents, which was excessive in the experiment just before shown. This I may do by inserting a self-induction coil in the path of the discharges, or by augmenting the capacity of the condensers. When I now pass these low-frequency discharges through the lamps, the exhausted lamp, *l*, again is as bright as before, but it is noted also that the non-exhausted lamp, l_1, glows, though not quite as intensely as the other. Reducing the current through the lamps, I may bring the filament in the latter lamp to redness, and though the filament in the exhausted lamp, *l*, is bright, Fig. 22*c*, the degree of its incandescence is much smaller than in Fig. 22*b*, when the currents were of a much higher frequency.

(To be continued.)

ON LIGHT AND OTHER HIGH-FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(Continued from page 83.)

In these experiments the gas acts in two opposite ways in determining the degree of the incandescence of the filaments—that is, by convection and bombardment. The higher the frequency and potential of the currents, the more important becomes the bombardment. The convection, on the contrary, should be the smaller, the higher the frequency. When the currents are steady, there is practically no bombardment, and convection may therefore with such currents also considerably modify the degree of incandescence and produce results similar to those just before shown. Thus, if two lamps exactly alike, one exhausted and one not exhausted, are connected in multiple arc or series to a direct-current machine, the filament in the non-exhausted lamp will require a considerably greater current to be rendered incandescent. The result is entirely due to convection, and the effect is the more prominent the thinner the filament. Prof. Ayrton and Mr. Kilgour some time ago published quantitative results concerning the thermal emissivity by radiation and convection in which the effect of thin wires was clearly shown. This effect may be strikingly illustrated by preparing a number of small short glass tubes, each containing through its axis the thinnest obtainable platinum wire. If these tubes be highly exhausted, a number of them may be connected in multiple arc to a direct-current machine, and all of the wires may be kept at incandescence with a smaller current than that required to render incandescent a single one of the wires

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if the tube be not exhausted. Could the tubes be so highly exhausted that convection would be nil, then the relative amounts of heat given off by convection and radiation could be determined without the difficulties attending thermal quantitative measurements. If a source of electric impulses of high frequency and very high potential is employed, a still greater number of the tubes may be taken, and the wires rendered incandescent by a current not capable of warming perceptibly a wire of the same size immersed in air at ordinary pressure, and conveying the energy to all of them.

I may here describe a result which is still more interesting, and to which I have been led by the observation of these phenomena. I noted that small differences in the density of the air produced a considerable difference in the degree of incandescence of the wires, and I thought that, since in a tube through which a luminous discharge is passed the gas is generally not of uniform density, a very thin wire contained in the tube might be rendered incandescent at certain places of smaller density of the gas, while it would remain dark at the places of greater density, where the convection would be greater and the bombardment less intense. Accordingly a tube, *t*, was prepared, as illustrated in Fig. 23, which contained through the middle a very fine platinum wire, *w*. The tube was exhausted to a moderate degree, and it was found that when it was attached to the terminal of a high-frequency coil the platinum wire, *w*, would, indeed, become incandescent in patches, as illustrated in Fig. 23. Later, a number of these tubes with one or more wires were prepared, each showing this result. The effect was best noted when the striated discharge occurred in the tube, but was also produced when the striæ were not visible, showing that even then the gas in the tube was not of uniform density. The position of the striæ was generally such that the rarefactions corresponded to the places of incandescence or greater

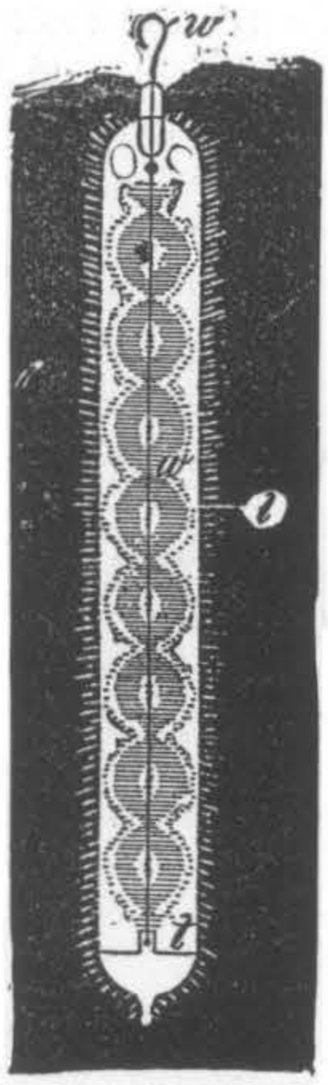

FIG. 23.—Curious Incandescence of a Wire.

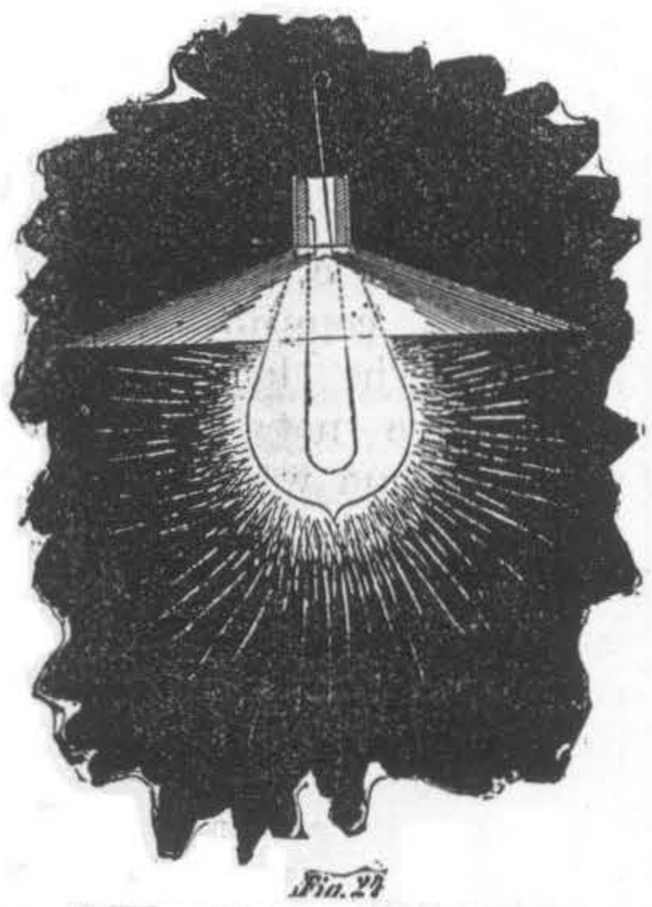

Fig. 24

Utilising the Heating Effect of Conduction Current and Bombardment.

brightness on the wire, *w*. But in a few instances it was noted that the bright spots on the wire were covered by the dense parts of the striated discharge, as indicated by *l* in Fig. 23, though the effect was barely perceptible. This was explained in a plausible way by assuming that the convection was not widely different in the dense and rarefied places of the striated discharge. It is, in fact, often observed in bulbs that, under certain conditions, a thin wire is brought to higher incandescence when the air is not too highly rarefied. This is the case when the potential of the coil is not high enough for the vacuum, but the result may be attributed to many different causes. In all cases this curious phenomenon of incandescence disappears when the tube, or rather the wire, acquires throughout a uniform temperature.

Disregarding now the modifying effect of convection, there are then two distinct causes which determine the incandescence of a wire or filament with varying currents—that is, conduction current and bombardment. With steady currents we have to deal only with the former of these two causes, and the heating effect is a minimum, since the resistance is least to steady flow. When the current is a varying one, the resistance is greater, and hence the heating effect is increased. Thus, if the rate of change of the current is very great, the resistance may increase to such an extent that the filament is brought to incandescence with inappreciable currents, and we are able to take a short and thick block of carbon or other material and bring it to bright incandescence with a current incomparably smaller than that required to bring to the same degree of incandescence an ordinary thin lamp filament with a steady or low-frequency current. This result is important, and illustrates how rapidly our views on these subjects are changing, and how quickly our field of knowledge is extending. In the art of incandescent lighting, to view this result in one aspect only, it has been commonly considered as an essential requirement for practical success that the lamp filament should be thin and of high resistance. But now we know that the resistance of the steady flow of the filament does not mean anything; the filament might as well be short and thick, for if it be immersed in rarefied gas it will become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents. We may conclude from this that it would be of advantage, so far as the lamp is considered, to employ high frequencies for lighting, as they allow the use of short and thick filaments and smaller currents.

If a wire or filament be immersed in a homogeneous medium, all the heating is due to true conduction current, but if it be enclosed in an exhausted vessel the conditions are entirely different. Here the gas begins to act and the heating effect of the conduction current, as is shown in many experiments, may be very small compared with that of the bombardment. This is especially the case if the circuit is not closed, and the potentials, of course, very high. Suppose a fine filament enclosed in an exhausted vessel be connected with one of its ends to the terminal of a high-tension coil and with its other end to a large insulated plate. Though the circuit is not closed, the filament, as I have before shown, is brought to incandescence. If the frequency and potential be comparatively low, the filament is heated by the current passing through it. If the frequency and potential, and principally the latter, be increased, the insulated plate need be but very small, or may be done away with entirely; still, the filament will become incandescent, practically all the heating being then due to the bombardment. A practical way of combining both the effects of conduction current and bombardment is illustrated in Fig. 24, in which an ordinary lamp is shown provided with a very thin filament, which has one of the ends of the latter connected to a shade serving the purpose of the insulated plate, and the other end to the terminal of a high-tension source. It should not be thought that only rarefied gas is an important



Fig. 25

Illustrating Lateral Diffusion.



Fig. 26

Incandescence of a Solid.

factor in the heating of a conductor by varying currents, but gas at ordinary pressure may become important if the potential difference and frequency of the currents is excessive. On this subject I have already stated that when a conductor is fused by a stroke of lightning, the current through it may be exceedingly small, not even sufficient to heat the conductor perceptibly, were the latter immersed in a homogeneous medium.

From the preceding it is clear that when a conductor of high resistance is connected to the terminals of a source of high-frequency currents of high potential there may occur considerable dissipation of energy, principally on the ends of the conductor, in consequence of the action of the gas surrounding the conductor. Owing to this, the current through a section of the conductor at a point midway between its ends may be much smaller than through a section near the ends. Furthermore, the current passes principally through the outer portions of the conductor, but this effect is to be distinguished from the skin effect as ordinarily interpreted, for the latter would or should occur also in a continuous incompressible medium. If a great many incandescent lamps are connected in series to a source of such currents the lamps at the ends may burn brightly, whereas those in the middle may remain entirely dark. This is due principally to bombardment, as before stated. But even if the currents be steady, provided the difference of potential be very great, the lamps at the ends will burn more brightly than those in the middle. In such case there is no rhythmical bombardment and the result is produced entirely by leakage. This leakage or dissipation into space when the tension is high is considerable when incandescent lamps are used, and still more considerable with arcs, for the latter act like flames. Generally, of course, the dissipation is much smaller with steady than with varying currents.

I have contrived an experiment which illustrates in an interest-

ing manner the effect of lateral diffusion. If a very long tube is attached to the terminal of a high-frequency coil, the luminosity is greatest near the terminal and falls off gradually towards the remote end. This is more marked if the tube is narrow.

A small tube about ½in. in diameter and 12in. long, Fig. 25, has one of its ends drawn out into a fine fibre, *f*, nearly 3ft. long. The tube is placed in a brass socket, T, which can be screwed on the terminal, T_1, of the induction coil. The discharge passing through the tube first illuminates the bottom of the same, which is of comparatively large section ; but through the long glass fibre the discharge cannot pass. But gradually the rarefied gas inside becomes warmed and more conducting, and the discharge spreads into the glass fibre. This spreading is so slow that it may take half a minute or more until the discharge has worked through up to the top of the glass fibre, then presenting the appearance of a strongly luminous thin thread. By adjusting the potential at the terminal the light may be made to travel upwards at any speed. Once, however, the glass fibre is heated the discharge breaks through its entire length instantly. The interesting point to be noted is that the higher the frequency of the currents, or, in other words, the greater relatively the lateral dissipation, at a slower rate may the light be made to propagate through the fibre. This experiment is best performed with a highly-exhausted and freshly-made tube. When the tube has been used for some time the experiment often fails. It is possible that the gradual and slow impairment of the vacuum is the cause. This slow propagation of the discharge through a very narrow glass tube corresponds exactly to the propagation of heat through a bar warmed at one end. The quicker the heat is carried away laterally, the longer time it will take for the heat to warm the remote end. When the current of a low-frequency coil is passed through the fibre from end to end, then the lateral dissipation is small, and the discharge instantly breaks through almost without exception.

After these experiments and observations which have shown the importance of the discontinuity or atomic structure of the medium and which will serve to explain, in a measure at least, the nature of the four kinds of light effects producible with these currents, I may now give you an illustration of these effects. For the sake of interest I may do this in a manner which to many of you might be novel. You have seen before that we may now convey the electric vibration to a body by means of a single wire or conductor of any kind. Since the human frame is conducting, I may convey the vibration through my body.

First, as in some previous experiments, I connect my body with one of the terminals of a high-tension transformer, and take in my hand an exhausted bulb which contains a small carbon button mounted upon a platinum wire leading to the outside of the bulb, and the button is rendered incandescent as soon as the transformer is set to work, Fig. 26. I may place a conducting shade on the bulb, which serves to intensify the action, but it is not necessary. Nor is it required that the button should be in conducting connection with the hand through a wire leading through the glass, for sufficient energy may be transmitted through the glass itself by inductive action to render the button incandescent.

(To be continued.)

ON LIGHT AND OTHER HIGH-FREQUENCY PHENOMENA.*

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(Concluded from page 111.)

Next, I take a highly-exhausted bulb containing a strongly phosphorescent body, above which is mounted a small plate of aluminium on a platinum wire leading to the outside, and the currents flowing through my body excite intense phosphorescence



Phosphorescence.

in the bulb, Fig. 27. Next, again, I take in my hand a simple exhausted tube, and in the same manner the gas inside the tube is rendered highly incandescent or phosphorescent, Fig. 28. Finally, I may take in my hand a wire, bare or covered with thick insulation—it is quite immaterial ; the electric vibration is so intense as to cover the wire with a luminous film, Fig. 29.

A few words must now be devoted to each of these phenomena. In the first place, I will consider the incandescence of a button or of a solid in general, and dwell upon some facts which apply equally to all these phenomena. It was pointed out before that when a thin conductor, such as a lamp filament, for instance, is connected with one of its ends to the terminal of a transformer of high tension, the filament is brought to incandescence partly by a conduction current and partly by bombardment. The shorter and thicker the filament the more important becomes the latter, and finally, reducing the filament to a mere button, all the heating must practically be attributed to the bombardment. So in the experiment before shown, the button is rendered incandescent by the rhythmical impact of freely movable small bodies in the bulb. These bodies may be the molecules of the residual gas, particles of dust, or lumps torn from the electrode ; whatever they are, it is certain that the heating of the button is essentially connected with the pressure of such freely movable particles, or of atomic matter in general in the bulb. The heating is the more intense the greater the number of impacts per second, and the greater the energy of each impact. Yet the button would be

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heated also if it were connected to a source of a steady potential. In such a case electricity would be carried away from the button by the freely movable carriers or particles flying about, and the quantity of electricity thus carried away might be sufficient to bring the button to incandescence by its passage through the latter. But the bombardment could not be of great importance in such case. For this reason, it would require a comparatively very great supply of energy to the button to maintain it at incandescence with a steady potential. The higher the frequency of the electric impulses, the more economically can the button be maintained at incandescence. One of the chief reasons why this is so is, I believe, that with impulses of very high frequency there is less exchange of the freely movable carriers around the electrode, and this means that in the bulb the heated matter is better confined to the neighbourhood of the button. If a double bulb,



Incandescence or Phosphorescence of Rarefied Gas.

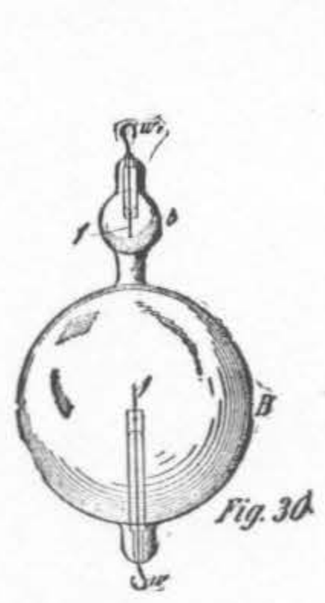
as illustrated in Fig. 30, be made, comprising a large globe, B, and a small one, b, each containing, as usual, a filament, f, mounted on platinum wire, w and w_1, it is found that if the filaments, ff, be exactly alike, it requires less energy to keep the filament in the globe, b, at a certain degree of incandescence than that in the large globe, B. This is due to the confinement of the movable particles around the button. In this case it is also ascertained that the filament in the small globe, b, is less deteriorated when maintained a certain length of time at incandescence. This is a necessary consequence of the fact that the gas in the small bulb becomes strongly heated, and therefore a very good conductor, and less work is then performed on the button, since the bombardment becomes less intense as the conductivity of the gas increases. In this construction of course the small bulb becomes very hot, and when it reaches an elevated temperature the convection and radiation on the outside increase. On another occasion I have shown bulbs in which this drawback was largely avoided. In these instances a very small bulb containing a refractory button was mounted in a large globe and the space between the walls of both was highly exhausted.



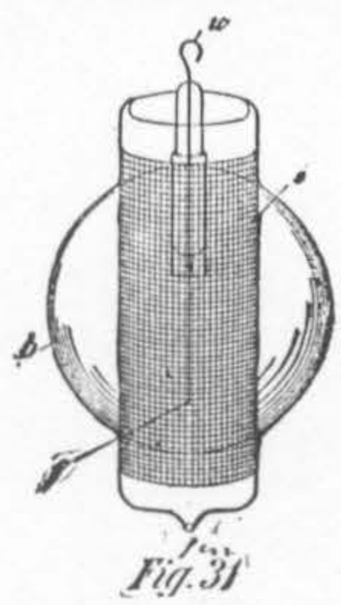
Luminosity of Gas at Ordinary Pressure.

The outer large globe remained comparatively cool in such constructions. When the large globe was on the pump, and the vacuum between the walls maintained permanent by the continuous action of the pump, the outer globe would remain quite cold, while the button in the small bulb was kept at incandescence. But when the seal was made, and the button in the small bulb maintained incandescent some length of time, the large globe, too, would become warmed. From this I conjecture that if vacuous space (as Prof. Dewar finds) cannot convey heat, it is so merely in virtue of our rapid motion through space, or, generally speaking, by the motion of the medium relatively to us, for a permanent condition could not be maintained without the medium being constantly renewed. A vacuum cannot, according to all evidence, be permanently maintained around a hot body.

In these constructions before mentioned the small bulb inside would, at least, in the first stages, prevent all bombardment against the outer large globe. It occurred to me then to ascertain how a metal sieve would behave in this respect, and several bulbs, as illustrated in Fig. 31, were prepared for this purpose. In a globe, b, was mounted a thin filament, f (or button), upon a platinum wire, w, passing through a glass stem and leading to the outside of the globe. The filament, f, was surrounded by a metal sieve, s. It was found in experiments with such bulbs that a sieve with wide meshes apparently did not in the slightest affect the bombardment against the globe, b. When the vacuum was high the shadow of the sieve was clearly projected against the globe and the latter would get hot in a short while. In some bulbs the sieve, s, was connected to a platinum wire sealed in the glass. When this wire was connected to the other terminal of the induction coil (the E.M.F. being kept low in this case), or to an insulated plate, the bombardment against the outer globe, b, was diminished. By taking a sieve with fine meshes the bombardment against the globe, b, was always diminished, but even then, if the exhaustion was carried very far, and when the potential of the transformer was very high, the globe, b, would be bombarded and heated quickly, though no shadow of the sieve was visible owing to the smallness of the meshes. But a glass tube or other continuous body mounted so as to surround the filament did entirely cut off the bombardment, and for a while the outer globe, b, would remain perfectly cold. Of course when the glass tube was sufficiently heated the bombardment against the outer globe, could be noted at once. The experiments with these bulbs seemed to show that the speeds of the projected molecules or particles must be considerable (though quite insignificant when compared with that of light), otherwise it would be difficult to understand how they could traverse a fine metal sieve without being affected, unless it were found that such small particles or atoms cannot be acted upon directly at measurable distances. In regard to the speed of the projected atoms, Lord Kelvin has recently estimated it at about one kilometre a second or thereabouts in an ordinary Crookes bulb. As the potentials obtainable with a disruptive discharge coil are much higher than with ordinary coils, the speeds must of course be much greater when the bulbs are lighted from such a coil. Assuming the speed to be as high as five kilometres and



Showing the Effect of Confining the Gas Around the Electrode.



Showing the Inefficiency of a Metal Screen.

uniform through the whole trajectory, as it should be in a very highly-exhausted vessel, then if the alternate electrifications of the electrode would be of a frequency of 5,000,000, the greatest distance a particle could get away from the electrode would be one millimetre, and if it could be acted upon directly at that distance, the exchange of electrode matter or of the atoms would be very slow, and there would be practically no bombardment against the bulb. This, at least, should be so, if the action of an electrode upon the atoms of the residual gas would be such as upon electrified bodies which we can perceive. A hot body enclosed in an exhausted bulb produces always atomic bombardment, but a hot body has no definite rhythm, for its molecules perform vibrations of all kinds.

If a bulb containing a button or filament be exhausted as high as is possible with the greatest care and by the use of the best artifices, it is often observed that the discharge cannot at first break through, but after some time, probably in consequence of some changes within the bulb, the discharge finally passes through and the button is rendered incandescent. In fact, it appears that the higher the degree of exhaustion the easier is the incandescence produced. There seems to be no other causes to which the incandescence might be attributed in such case except to the bombardment or similar action of the residual gas, or of particles of matter in general. But if the bulb be exhausted with the greatest care, can these play an important part? Assume the vacuum in the bulb to be tolerably perfect, the great interest then centres in the question, Is the medium which pervades all space continuous or atomic? If atomic, then the heating of a conducting button or filament in an exhausted vessel might be due largely to ether bombardment, and then the heating of a conductor in general through which currents of high frequency or high potential are passed must be modified by the behaviour of such medium; then also the skin effect, the apparent increase of ohmic resistance, etc., admit partially, at least, of a different explanation.

It is certainly more in accordance with many phenomena observed with high-frequency currents to hold that all space is pervaded with free atoms rather than to assume that it is devoid of these, and dark and cold, for so it must be if filled with a continuous medium, since in such there can be neither heat nor light. Is then energy transmitted by independent carriers or by the vibration of a continuous medium? This important question s

by no means as yet positively answered. But most of the effects which are here considered, especially the light effects—incandescence or phosphorescence—involve the presence of free atoms, and would be impossible without these.

In regard to the incandescence of a refractory button (or filament) in an exhausted receiver, which has been one of the subjects of this investigation, the chief experiences which may serve as a guide in constructing such bulbs may be summed up as follows: (1) The button should be as small as possible, spherical, of a smooth or polished surface and of refractory material which withstands evaporation best. (2) The support of the button should be very thin and screened by an aluminium and mica sheet as I have described on another occasion. (3) The exhaustion of the bulb should be as high as possible. (4) The frequency of the currents should be as high as practicable. (5) The currents should be of a harmonic rise and fall, without sudden interruptions. (6) The heat should be confined to the button by enclosing the same in a small bulb or otherwise. (7) The space between the walls of the small bulb and the outer globe should be highly exhausted.

Most of the considerations which apply to the incandescence of a solid just considered may likewise be applied to phosphorescence. Indeed, in an exhausted vessel the phosphorescence is, as a rule, primarily excited by the powerful beating of the electrode stream of atoms against the phosphorescent body. Even in many cases where there is no evidence of such a bombardment, I think that phosphorescence is excited by violent impacts of atoms which are not necessarily thrown off from the electrode, but are acted upon from the same inductively through the medium or through chains of other atoms. That mechanical shocks play an important part in exciting phosphorescence in a bulb may be seen from the following experiment. If a bulb constructed as that illustrated in Fig. 10 be taken, and exhausted with the greatest care so that the discharge cannot pass, the filament, *f*, acts by electrostatic induction upon the tube, *t*, and the latter is set in vibration. If the tube, *o*, be rather wide—about an inch or so—the filament may be so powerfully vibrated that whenever it hits the glass tube it excites phosphorescence. But the phosphorescence ceases when the filament comes to rest. The vibration can be arrested and again started by varying the frequency of the currents—namely, the filament has its own period of vibration—and if the frequency of the currents is such that there is resonance, it is set easily vibrating, though the potential of the currents be small. I have often observed that the filament in the bulb is destroyed by such mechanical resonance. The filament vibrates, as a rule, so rapidly that it cannot be seen, and the experimenter may at first be mystified. When such an experiment as the one described is carefully performed, the potential of the currents need be extremely small, and for this reason I infer that the phosphorescence is then due to the mechanical shock of the filament against the glass, just as it is produced by striking a loaf of sugar with a knife. The mechanical shock produced by the projected atoms is easily noted when a bulb containing a button is grasped in the hand, and the current turned on suddenly. I believe that a bulb could be shattered by observing the conditions of resonance.

In the experiment before cited it is, of course, open to say that the glass tube, upon coming in contact with the filament, retains a charge of a certain sign upon the point of contact. If now the filament again touches the glass at the same point while it is oppositely charged, the charges equalise under evolution of light. But nothing of importance would be gained by such an explanation. It is unquestionable that the initial charges given to the atoms or to the glass play some part in exciting phosphorescence. So, for instance, if a phosphorescent bulb be first excited by a high-frequency coil by connecting it to one of the terminals of the latter and the degree of luminosity noted, and then the bulb be highly charged from a Holtz machine by attaching it preferably to the positive terminal of the machine, it is found that when the bulb is again connected to the terminal of the high-frequency coil, the phosphorescence is far more intense. On another occasion I have considered the possibility of some phosphorescent phenomena in bulbs being produced by the incandescence of an infinitesimal layer on the surface of the phosphorescent body. Certainly, the impacts of the atoms are powerful enough to produce intense incandescence by the collisions, since they bring quickly to a high temperature a body of considerable bulk. If any such effect exists, then the best appliance for producing phosphorescence in a bulb which we know so far is a disruptive discharge coil giving an enormous potential with but few fundamental discharges, say 25-30 per second, just enough to produce a continuous impression upon the eye. It is a fact that such a coil excites phosphorescence under most any condition and at all degrees of exhaustion, and I have observed effects which appear to be due to phosphorescence even at ordinary pressures of the atmosphere, when the potentials are extremely high. But if phosphorescent light is produced by the equalisation of charges of electrified atoms (whatever this may mean ultimately), then the higher the frequency of the impulses, or alternate electrifications, the more economical will be the light production. It is a long known and noteworthy fact that all the phosphorescent bodies are poor conductors of electricity and heat, and that all bodies cease to emit phosphorescent light when they are brought to a certain temperature. Conductors, on the contrary, do not possess this quality. There are but few exceptions to the rule. Carbon is one of them. Becquerel noted that carbon phosphoresces at a certain elevated temperature preceding the dark red. This phenomenon may be easily observed in bulbs provided with a rather large carbon electrode (say, a sphere of six millimetres diameter. If the current is turned on after a few seconds a snow-white film covers the electrode, just before it gets dark red. Similar effects are noted with other conducting bodies, but many scientific men will probably not attribute them to true phosphorescence. Whether true incandescence has anything to do with phosphorescence excited by atomic impact or mechanical shocks still remains to be decided, but it is a fact that all conditions which tend to localise and increase the heating effect at the point of impact are almost invariably the most favourable for the production of phosphorescence. So, if the electrode be very small, which is equivalent to saying in general that the electric density is great, if the potential be high, and if the gas be highly rarefied—all of which things imply high speed of the projected atoms, or matter, and consequently violent impacts—the phosphorescence is very intense. If a bulb provided with a large and small electrode be attached to the terminal of an induction coil, the small electrode excites phosphorescence while the large one may not do so, because of the smaller electric density and hence smaller speed of the atoms. A bulb provided with a large electrode may be grasped with the hand while the electrode is connected to the terminal of the coil, and it may not phosphoresce; but if instead of grasping the bulb with the hand, the same be touched with a pointed wire, the phosphorescence at once spreads through the bulb, because of the great density at the point of contact. With low frequencies it seems that gases of great atomic weight excite more intense phosphorescence than those of smaller weight, as, for instance, hydrogen. With high frequencies the observations are not sufficiently reliable to draw a conclusion. Oxygen, as is well known, produces exceptionally strong effects, which may be in part due to chemical action. A bulb with hydrogen residue seems to be most easily excited. Electrodes which are most easily deteriorated produce more intense phosphorescence in bulbs, but the condition is not permanent because of the impairing of the vacuum and the deposition of the electrode matter upon the phosphorescent surfaces. Some liquids, as oils, for instance, produce magnificent effects of phosphorescence (or fluorescence?), but they last only a few seconds; so if a bulb have a trace of oil on the walls, and the current is turned on, the phosphorescence only persists for a few moments until the oil is carried away. Of all bodies so far tried, sulphide of zinc seems to be the most susceptible to phosphorescence. Some samples obtained through the kindness of Prof. Henry, in Paris, were employed in many of these bulbs. One of the defects of this sulphide is that it loses its quality of emitting light when brought to a temperature which is by no means high. It can therefore be used only for feeble intensities. An observation which might deserve notice is that when violently bombarded from an aluminium electrode it assumes a black colour, but, singularly enough, it returns to the original condition when it cools down.

The most important fact arrived at in pursuing investigations in this direction is that in all cases it is necessary, in order to excite phosphorescence with a minimum amount of energy, to observe certain conditions. Namely, there is always, no matter what the frequency of the currents, degree of exhaustion and character of the bodies in the bulb, a certain potential (assuming the bulb excited from one terminal) or potential difference (assuming the bulb to be excited with both terminals) which produces the most economical result. If the potential be increased, considerable energy may be wasted without producing any more light, and if it be diminished, then again the light production is not as economical. The exact condition under which the best result is obtained seems to depend on many things of a different nature, and it is yet to be investigated by other experimenters; but it will certainly have to be observed when such phosphorescent bulbs are operated if the best results are to be attained.

Coming now to the most interesting of these phenomena, the incandescence or phosphorescence of gases, at low pressures or at the ordinary pressure of the atmosphere, we must seek the explanation of these phenomena in the same primary causes—that is, in shocks or impacts of the atoms. Just as molecules or atoms beating upon a solid body excite phosphorescence in the same or render it incandescent, so when colliding among themselves they produce similar phenomena; but this is a very insufficient explanation, and concerns only the crude mechanism. Light is produced by vibrations which go on at a rate almost inconceivable. If we compute from the energy contained in the form of known radiations in a definite space the force which is necessary to set up such rapid vibrations, we find that though the density of the ether be incomparably smaller than that of any body we know—even hydrogen—the force is something surpassing comprehension. What is this force, which in mechanical measure may amount to thousands of tons per square inch? It is electrostatic force in the light of modern views. It is impossible to conceive how a body of measurable dimensions could be charged to so high a potential that the force would be sufficient to produce these vibrations. Long before any such charge could be imparted to the body it would be shattered into atoms. The sun emits light and heat, and so does an ordinary flame or incandescent filament, but in neither of these can the force be accounted for if it be assumed that it is associated with the body as a whole. Only in one way may we account for it—namely, by identifying it with the atom. An atom is so small, that if it be charged by coming in contact with an electrified body and the charge be assumed to follow the same law as in the case of bodies of measurable dimensions, it must retain a quantity of electricity which is fully capable of accounting for these forces and tremendous rates of vibration. But the atom behaves singularly in this respect—it always takes the same "charge."

It is very likely that resonant vibration plays a most important part in all manifestations of energy in nature. Throughout space all matter is vibrating, and all rates of vibration are represented, from the lowest musical note to the highest pitch of the chemical

rays, hence an atom, or complex of atoms, no matter what its period, must find a vibration with which it is in resonance. When we consider the enormous rapidity of the light vibrations, we realise the impossibility of producing such vibrations directly with any apparatus of measurable dimensions, and we are driven to the only possible means of attaining the object of setting up waves of light by electrical means and economically—that is, to affect the molecules or atoms of a gas, to cause them to collide and vibrate We then must ask ourselves : How can free molecules or atoms be affected ?

It is a fact that they can be affected by electrostatic force, as is apparent in many of these experiments. By varying the electrostatic force we can agitate the atoms, and cause them to collide under evolution of heat and light. It is not demonstrated beyond doubt that we can affect them otherwise. If a luminous discharge is produced in a closed exhausted tube, do the atoms arrange themselves in obedience to any other but to electrostatic force acting in straight lines from atom to atom ? Only recently I investigated the mutual action between two circuits with extreme rates of vibration. When a battery of a few jars (*c c*

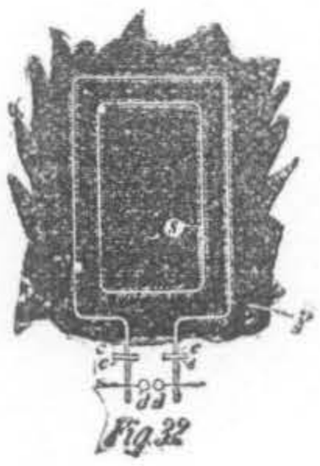


Fig. 32

Electrostatic Action Between Primary and Secondary, with Extremely High Frequencies.

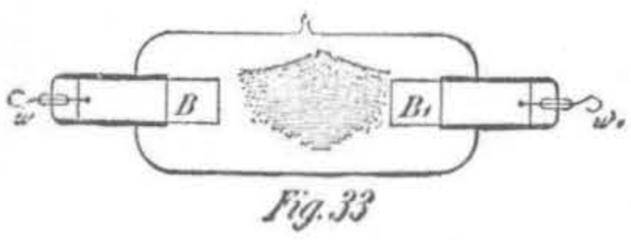
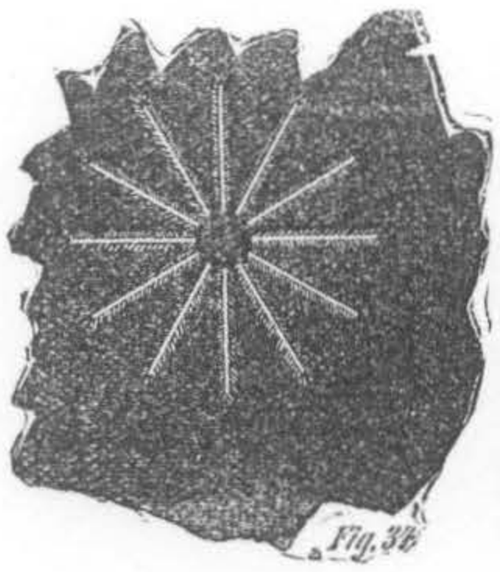


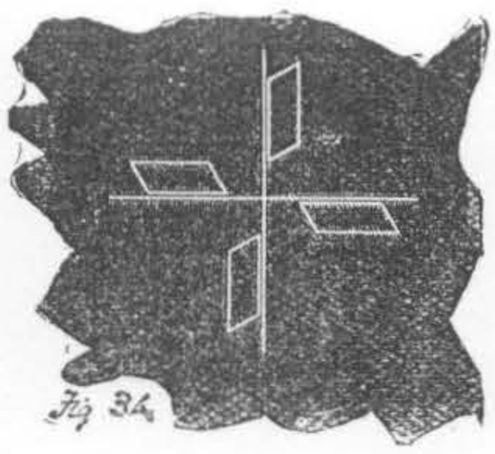
Fig. 33

Carbon Deposit in Tube in a Magnetic Field.

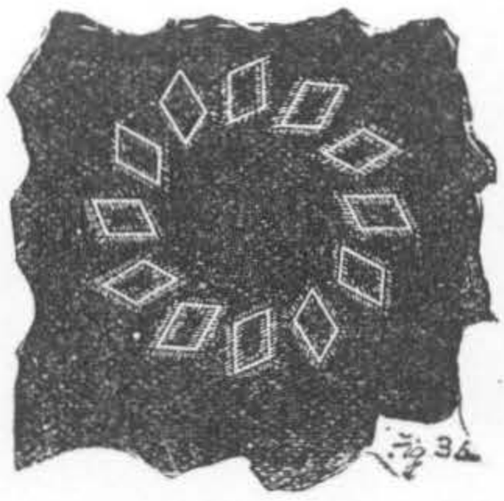
c c, Fig. 32) is discharged through a primary, P, of low resistance (the connections being as illustrated in Figs. 19*a*, 19*b*, 19*c*), and the frequency of vibration be many million, there are great differences of potential between points on the primary not more than a few inches apart. These differences may be 10,000 volts per inch, if not more, taking the maximum value of the E.M.F. The secondary, *s*, is therefore acted upon by electrostatic induction, which is in such extreme cases of much greater importance than the electro-dynamic. To such sudden impulses the primary, as well as the secondary, are poor conductors, and therefore great differences of potential may be produced by electrostatic induction between adjacent points on the secondary. Then sparks may jump between the wires and streamers become visible in the dark if the light of the discharge through the spark gap, *d d*, be carefully excluded. If now we substitute a closed vacuum tube for the metallic secondary, *s*, the differences of potential produced in the tube by electrostatic induction from the primary are fully sufficient to excite portions of it ; but as the points of certain differences of potential on the primary are not fixed, but are generally constantly changing in position, a luminous band is produced in the tube, apparently not touching the glass, as it should if the points of maximum and minimum differences of potential were fixed on the primary. I do not exclude the possibility of such a tube being excited only by electro-dynamic induction, for very able physicists hold this view ; but, in my opinion, there is as yet no positive proof given that atoms of a gas in a closed tube may arrange themselves in chains under the action of an electromotive impulse produced by electro-dynamic induction in the tube. I have been unable so far to produce striæ in a tube, however long, and at whatever degree of exhaustion—that is, striæ at right angles to the supposed direction of the discharge or the axis of the tube, but I have distinctly observed in a large bulb, in which a wide luminous band was produced by passing a discharge of a battery through a wire surrounding the bulb, a circle of feeble luminosity between two luminous bands, one of which was more intense than the other. Furthermore, with my present experience I do not think that such a gas discharge in a closed tube can vibrate—that is, vibrate as a whole. I am convinced that no discharge through a gas can vibrate. The atoms of a gas behave very curiously in respect to sudden electric impulses. The gas does not seem to possess any appreciable inertia to such impulses, for it is a fact that the higher the frequency of the impulses, with the greater freedom does the discharge pass through the gas. If the gas possesses no inertia then it cannot vibrate, for some inertia is necessary for the free vibration. I conclude from this that if a lightning discharge occurs between two clouds, there can be no oscillation, such as would be expected, considering the capacity of the clouds. But if the lightning discharge strike the earth, there is always vibration—in the earth, but not in the cloud. In a gas discharge each atom vibrates at its own rate, but there is no vibration of the conducting gaseous mass as a whole. This is an important consideration in the great problem of producing light economically, for it teaches us that to reach this result we must use impulses of very high frequency and necessarily also of high potential. It is a fact that oxygen produces a more intense light in a tube. Is it because oxygen atoms possess some inertia and the vibration does not die out instantly ? But then nitrogen should be as good, and chlorine and vapours of many other bodies much better than oxygen, unless the magnetic properties of the latter enter prominently into play. Or, is the process in the tube of an electrolytic nature ? Many observations certainly speak for it, the most important being that matter is always carried away from the electrodes and the vacuum in a bulb cannot be permanently maintained. If such process takes place in reality, then, again, must we take refuge to high frequencies, for with such electrolytic action should be reduced to a minimum, if not rendered entirely impossible. It is an undeniable fact that with very high frequencies, provided the impulses be of a harmonic nature, like those obtained from an alternator, there is less deterioration and the vacua are more permanent. With disruptive discharge coils there are sudden rises of potential and the vacua are more quickly impaired, for the electrodes are deteriorated in a very short time. It was observed in some large tubes, which were provided with heavy carbon blocks, B B_1, connected to platinum wires, *w* w_1 (as illustrated in Fig. 33), and which were employed in experiments with the disruptive discharge instead of the ordinary air gap, that the carbon particles under the action of the powerful magnetic field in which the tube was placed, were deposited in regular fine lines in the middle of the tube as illustrated. These lines were attributed to the deflection or distortion of the discharge by the magnetic field, but why the deposit occurred principally where the field was most intense did not appear quite clear. A fact of interest, likewise noted, was that the presence of a strong magnetic field increases the deterioration of the electrodes, probably by reason of the rapid interruptions it produces, whereby there is actually a higher E.M F. maintained between the electrodes.



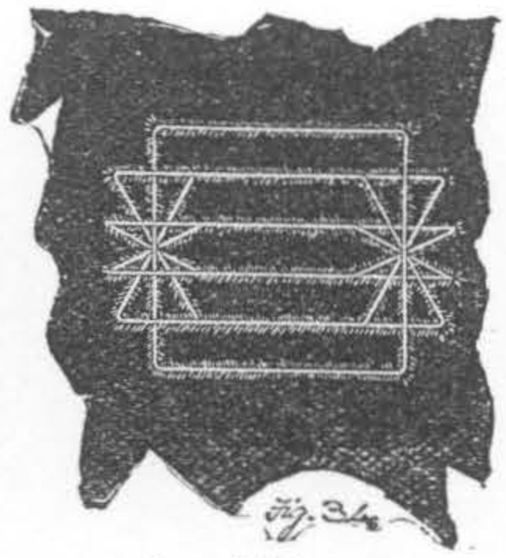
Spoke Wheel



Alternate-Motor Winding.



Ring Winding.



Drum Winding.

Some of the Designs Produced by Intermittent Discharges.

Much would remain to be said about the luminous effects produced in gases at low or ordinary pressures. With the present experiences before us we cannot say that the essential nature of these charming phenomena is sufficiently known. But investigations in this direction are being pushed with exceptional ardour. Every line of scientific pursuit has its fascinations, but electrical investigation appears to possess a peculiar attraction, for there is no experiment or observation of any kind in the domain of this wonderful science which would not forcibly appeal to us. Yet to me it seems, that of all the many marvellous things we observe, a vacuum tube, excited by an electric impulse from a distant source, bursting forth out of the darkness and illuminating the room with its beautiful light, is as lovely a phenomenon as can greet our eyes. More interesting still it appears when, reducing the fundamental discharges across the gap to a very small number and waving the tube about, we produce all kinds of designs in luminous lines. So, by way of amusement, I take a straight long tube, or a square one, or a square attached to a straight tube, and by whirling them about in the hand I imitate the spokes of a wheel, a Gramme winding, a drum winding, an alternate-current motor winding, etc., Fig. 34. Viewed from a distance, the effect is weak and much of its beauty is lost ; but being near, or holding the tube in the hand, one cannot resist its charm.

In presenting these insignificant results I have not attempted to arrange and co-ordinate them as would be proper in a strictly

scientific investigation in which every succeeding result should be a logical sequence of the preceding, so that it might be guessed in advance by the careful reader or attentive listener. I have preferred to concentrate my energies chiefly upon advancing novel facts or ideas which might serve as suggestions to others, and this may serve as an excuse for the lack of harmony. The explanations of the phenomena have been given in good faith and in the spirit of a student prepared to find that they admit of a better interpretation. There can be no great harm in a student taking an erroneous view, but when great minds err the world must dearly pay for their mistakes.

Nikola Tesla's Paper.—We are indebted to the editors of the New York *Electrical World* for their courtesy in supplying us with the illustrations for Mr. Tesla's paper, the second portion of which appears in this issue.

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

INTRODUCTORY.—SOME THOUGHTS ON THE EYE.

WHEN we look at the world around us, on Nature, we are impressed with its beauty and grandeur. Each thing we perceive, though it may be vanishingly small, is in itself a world, that is, like the whole of the visible universe, matter and force governed by law—a world, the contemplation of which fills us with feelings of wonder, and irresistibly urges us to ceaseless thought and inquiry. But in all this vast world, of all objects our senses reveal to us, the most marvellous, the most appealing to our imagination, appears no doubt a highly developed organism, a thinking being. If there is anything fitted to make us admire Nature's handiwork, it is certainly this inconceivable structure, which performs its innumerable motions in obedience to external influence. To understand its workings, to get a deeper insight into this Nature's masterpiece, has ever been for thinkers a fascinating aim, and after many centuries of arduous research men have arrived at a fair understanding of the functions of its organs and senses. Again, in all the perfect harmony of its parts, of the parts which constitute the material or tangible of our being, of all its organs and senses, the eye is the most wonderful. It is the most precious, the most indispensable of our receptive or directive organs, it is the great gateway through which all knowledge enters the mind. Of all our organs, it is the one, which is in the most intimate relation with that which we call intellect. So intimate is this relation, that it is often said that the very soul shows itself in the eye.

It can be taken as a fact, which the theory of the action of the eye implies, that for each external impression, that is, for each image produced upon the retina, the ends of the visual nerves, concerned in the conveyance of the impression to the mind, must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and therefore upon the retina. Will it ever be within human power to analyse the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness, that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems, belonging to the domain of positive physical science, in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he was able to *see*, in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

Another fact having a bearing on this subject which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation is, that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, observable even in broad daylight.

The saying, then, that the soul shows itself in the eye is deeply founded, and we feel that it expresses a great truth. It has a profound meaning even for one who, like a poet or artist, only following his inborn instinct or love for Nature, finds delight in aimless thoughts and in the mere contemplation of natural phenomena, but a still more profound meaning for one who, in the spirit of positive scientific investigation, seeks to ascertain the causes of the effects. It is principally the natural philosopher, the physicist, for whom the eye is the subject of the most intense admiration.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting that the very conception of that which is perfect, or seems so to him, has been gained through the same in-

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strument. Firstly, the eye is, as far as our positive knowledge goes, the only organ which is *directly* affected by that subtile medium, which, as science teaches us, must fill all space; secondly, it is the most sensitive of our organs, imcomparably more sensitive to external impressions than any other.

The organ of hearing implies the impact of ponderable bodies, the organ of smell the transference of detached material particles, and the organs of taste, and of touch or force, the direct contact, or at least some interference of ponderable matter, and this is true even in those instances of animal organisms, in which some of these organs are developed to a degree of truly marvellous perfection. This being so, it seems wonderful that the organ of sight solely should be capable of being stirred by that which all our other organs are powerless to detect, which yet plays an essential part in all natural phenomena, which transmits all energy and sustains all motion, and, that most intricate of all, life, but which has properties such that even a scientifically trained mind cannot help drawing a distinction between it and all that is called matter. Considering merely this, and the fact that the eye, by its marvellous power, widens our otherwise very narrow range of perception far beyond the limits of the small world which is our own, to embrace myriads of other worlds, suns and stars in the infinite depths of the universe, would make it justifiable to assert that it is an organ of a higher order. Its performances are beyond comprehension. Nature, as far as we know, never produced anything more wonderful. We can get barely a faint idea of its prodigious power by analysing what it does, and by comparing. When ether waves impinge upon the human body, they produce the sensations of warmth or cold, pleasure or pain, or perhaps other sensations of which we are not aware, and any degree or intensity of these sensations, which degrees are infinite in number, hence an infinite number of distinct sensations. But our sense of touch, or our sense of force, cannot reveal to us these differences in degree or intensity, unless they are very great. Now we can readily conceive how an organism, such as the human in the eternal process of evolution, or, more philosophically speaking, adaptation to Nature, being constrained to the use of only the sense of touch or force, for instance, might develop this sense to such a degree of sensitiveness or perfection, that it would be capable of distinguishing the minutest differences in the temperature of a body even at some distance, to a hundredth, or thousandth, or millionth part of a degree. Yet, even this apparently impossible performance would not begin to compare with that of the eye, which is capable of distinguishing and conveying to the mind in a single instant innumerable peculiarities of the body, be it in form or colour, or other respects. This power of the eye rests upon two things, namely, the rectilinear propagation of the disturbance by which it is effected, and upon its sensitiveness. To say that the eye is sensitive is not saying anything. Compared with it, all other organs are monstrously crude. The organ of smell which guides a dog on the trail of a deer, the organ of touch or force which guides an insect in its wanderings, the organ of hearing, which is affected by the slightest disturbances of the air, are sensitive organs, to be sure, but what are they compared with the human eye! No doubt it responds to the faintest echoes or reverberations of the medium; no doubt, it brings us tidings from other worlds, infinitely remote, but in a language we cannot as yet always understand. And why not? Because we live in a medium filled with air and other gases, vapours, and a dense mass of solid particles flying about. These play an important part in many phenomena; they fritter away the energy of the vibrations before they can reach the eye; they, too, are the carriers of germs of destruction, they get into our lungs and other organs, clog up the channels, and imperceptibly, yet inevitably, arrest the stream of life. Could we but do away with all ponderable matter in the line of sight of the telescope it would reveal to us undreamt of marvels. Even the unaided eye, I think, would be capable of distinguishing in the pure medium small objects at distances measured probably by hundreds or perhaps thousands of miles.

But there is something else about the eye which impresses us still more than these wonderful features which we observe, viewing it from the standpoint of a physicist, merely as an optical instrument —something which appeals to us more than its marvellous faculty of being directly affected by the vibrations of the medium, without interference of gross matter, and more than its inconceivable sensitiveness and discerning power. It is its significance in the processes of life. No matter what one's views on Nature and life may be, he must stand amazed when, for the first time in his thoughts, he realises the importance of the eye in the physical processes and mental performances of the human organism. And how could it be otherwise, when he realises that the eye is the means through which the human race has acquired the entire knowledge it possesses, that it controls all our motions, more still, all our actions.

There is no way of acquiring knowledge except through the eye. What is the foundation of all philosophical systems of ancient and modern times, in fact of all the philosophy of man? *I am, I think; I think, therefore I am.* But how could I think and how would I know that I exist, if I had not the eye? For knowledge involves consciousness; consciousness involves ideas, conceptions; conceptions involve pictures or images, and images, the sense of vision, and therefore the organ of sight. But how about blind men will be asked? Yes, a blind man may depict in magnificent poems forms and scenes from real life, from a world he physically does not see. A blind man may touch the keys of an instrument with unerring precision, may build the fastest boat, may discover and invent, calculate and construct, may do still greater wonders—but all the blind men who have done such things have descended from those who had seeing eyes. Nature may reach the same result in many ways. Like a wave in the physical world, in the infinite ocean of the medium which pervades all, so in the world of organisms, in life, an impulse started proceeds onward, at times, may be, with the speed of light, at times, again, so slowly that for ages and ages it seems to stay, passing through processes of a complexity inconceivable to men, but in all its forms, in all its stages, its energy ever and ever integrally present. A single ray of light from a distant star falling upon the eye of a tyrant in bygone times, may have altered the course of his life, may have changed the destiny of nations, may have transformed the surface of the globe, so intricate, so inconceivably complex are the processes in Nature. In no way can we get such an overwhelming idea of the grandeur of Nature, than when we consider, that in accordance with the law of the conservation of energy, throughout the Infinite, the forces are in a perfect balance, and hence the energy of a single thought may determine the motion of a Universe. It is not necessary that every individual, not even that every generation or many generations, should have the physical instrument of sight, in order to be able to form images and to think, that is, form ideas or conceptions; but sometime or other, during the process of evolution, the eye certainly must have existed, else thought, as we understand it, would be impossible; else conceptions, like spirit, intellect, mind, call it as you may, could not exist. It is conceivable, that in some other world, in some other beings the eye is replaced by a different organ, equally or more perfect, but these beings cannot be men.

Now what prompts us to all voluntary motions and actions of any kind? Again the eye. If I am conscious of the motion, I must have an idea or conception, that is, an image, therefore the eye. If I am not precisely conscious of the motion, it is because the images are vague or indistinct, being blurred by the superimposition of many. But when I perform the motion, does the impulse which prompts me to the action come from within or from without? The greatest physicists have not disdained to endeavour to answer this and similar questions, and have at times abandoned themselves to the delights of pure and unrestrained thought. Such questions are generally considered not to belong to the realm of positive physical science, but will before long be annexed to its domain. Helmholtz has probably thought more on life than any modern scientist. Lord Kelvin expressed his belief that life's process is electrical, and that there is a force inherent to the organism, and determining its motions. Just as much as I am convinced of any physical truth, I am convinced that the motive impulse must come from the outside. For consider the lowest organism we know—and there are probably many lower ones—an aggregation of a few cells only. If it is capable of voluntary motion, it can perform an infinite number of motions, all definite and precise. But now a mechanism consisting of a finite number of parts, and few at that, cannot perform an infinite number of definite motions, hence the impulses which govern its movements must come from the environment. So the atom, the ulterior element of the Universe's structure, is tossed about in space eternally, a play to external influences, like a float in a troubled sea. Were it to stop its motion *it would die.* Matter at rest, if such a thing could exist, would be matter dead. Death of matter! Never has a sentence of deeper philosophical meaning been uttered. This is the way in which Prof. Dewar forcibly expresses it in the description of his admirable experiments, in which liquid oxygen is handled as one handles water, and air at ordinary pressure is made to condense and even to solidify by the intense cold. Experiments which serve to illustrate, in his language, the last feeble manifestations of life, the last quiverings of matter about to die. But human eyes shall not witness such death. There is no death of matter; for throughout the infinite universe all has to move, to vibrate, that is, to live.

I have made the preceding statements at the peril of treading upon metaphysical ground, in my desire to introduce the subject of this lecture in a manner not altogether uninteresting, I may hope, to an audience such as I have the honour to address. But now then, returning to the subject, this divine organ of sight, this indispensable instrument for thought and all intellectual enjoyment, which lays open to us the marvels of this universe, through which we have acquired what knowledge we possess, and which prompts us to, and controls, all our physical and mental activity. By what is it affected? By light! What is light?

We have witnessed the great strides which have been made in all departments of science in recent years. So great have been the advances, that we cannot refrain from asking ourselves, Is this all true, or is it but a dream? Centuries ago men have lived, have thought, discovered, invented, and have believed that they were soaring, while they were merely proceeding at a snail's pace. So we, too, may be mistaken. But taking the truth of the observed events as one of the implied facts of science, we must rejoice in the immense progress already made, and still more in the anticipation of what must come, judging from the possibilities opened up by modern research. There is, however, an advance which we have been witnessing, which must be particularly gratifying to every lover of progress. It is not a discovery, or an invention, or an achievement in any particular direction. It is an advance in all directions of scientific thought and experiment. I mean the generalisation of the natural forces and phenomena, the looming up of a certain broad idea on the scientific horizon. It is this idea which has, however, long ago taken possession of the most advanced minds, to which I desire to call your attention, and which I intend to illustrate, in a general way, in these experiments, as the first step in answering the question "What is light?" and to realise the modern meaning of this word.

It is beyond the scope of my lecture to dwell upon the subject of light in general, my object being merely to bring presently to your notice a certain class of light effects and a number of phenomena observed in pursuing the study of these effects. But to be consistent in my remarks it is necessary to state that according to that idea, now accepted by the majority of scientific men as a positive result of theoretical and experimental investigation, the various forms or manifestations of energy which were generally designated as "electric," or more precisely "electro-magnetic," are energy manifestations of the same nature as those of radiant heat and light. Therefore the phenomena of light and heat, and others besides these, may be called electrical phenomena. Thus electrical science has

become the mother science of all, and its study has become all important. The day when we shall know exactly what "electricity" is, will chronicle an event probably greater, more important than any other recorded in the history of the human race. The time will come when the comfort, the very existence perhaps of man will depend upon that wonderful agent. For our existence and comfort we require heat, light, and mechanical power. How do we now get all these? We get them from fuel, we get them by consuming material. What will man do when the forests disappear, when the coal fields are exhausted? Only one thing, according to our present knowledge will remain; that is, to transmit power at great distances. Men will go to the waterfalls, to the tides, which are the stores of an infinitesimal part of Nature's immeasurable energy. There will they harness the energy and transmit the same to their settlements, to warm their homes by, to give them light, and to keep their obedient slaves, the machines, toiling. But how will they transmit this energy if not by electricity? Judge then, if the comfort, nay, the very existence of man will not depend on electricity, I am aware that this view is not that of a practical engineer, but neither is it that of an illusionist, for it is certain that power transmission, which at present is merely a stimulus to enterprise, will some day be a dire necessity.

It is more important for the student, who takes up the study of light phenomena, to make himself thoroughly acquainted with certain modern views, than to peruse entire books on the subject of light itself, as disconnected from these views. Were I, therefore, to make these demonstrations before students seeking information—and for the sake of the few of those who may be present, give me leave to so assume—it would be my principal endeavour to impress these views upon their minds in this series of experiments.

It might be sufficient for this purpose to perform a simple and well-known experiment. I might take a familiar appliance, a Leyden jar, charge it from a frictional machine, and then discharge it. In explaining to you its permanent state when charged, and its transitory condition when discharging, calling your attention to the forces which enter into play and to the various phenomena they produce, and pointing out the relation of the forces and phenomena, I might fully succeed in illustrating that modern idea. No doubt, to the thinker, this simple experiment would appeal as much as the most magnificent display. But this is to be an experimental demonstration, and one which should possess besides instructive, also entertaining features, and as such, a simple experiment, such as the one cited, would not go very far towards the attainment of the lecturer's aim. I must therefore choose another way of illustrating, more spectacular, certainly, but perhaps also more instructive. Instead of the frictional machine and Leyden jar, I shall avail myself in these experiments of an induction coil of peculiar properties, which was described in detail by me in a lecture before the London Institution of Electrical Engineers, in February, 1892. This induction coil is capable of yielding currents of enormous potential differences, alternating with extreme rapidity. With this apparatus I shall endeavour to show you three distinct classes of effects, or phenomena, and it is my desire that each experiment, while serving for the purposes of illustration, should at the same time teach us some novel truth, or show us some novel aspect of this fascinating science. But before doing this, it seems proper and useful to dwell upon the apparatus employed and method of obtaining the high potentials and high-frequency currents which are made use of in these experiments.

(*To be continued.*)

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(*Continued from page* 684.)

ON THE APPARATUS AND METHOD OF CONVERSION.

THESE high frequency currents are obtained in a peculiar manner. The method employed was advanced by me about two years ago in an experimental lecture before the American Institute of Electrical Engineers. A number of ways, as practised in the laboratory, of obtaining these currents either from continuous or low frequency alternating currents is diagrammatically indicated in fig. 1, which will be later described in detail. The general plan is to charge condensers from a direct or alternate current source, preferably of high tension, and to discharge them disruptively, while observing well-known conditions necessary to maintain the oscillations of the current. In view of the general interest taken in high frequency currents, and effects producible by them, it seems to me advisable to dwell at some length upon this method of conversion. In order to give you a clear idea of the action, I will suppose that a continuous current generator is employed, which is often very convenient. It is desirable that the generator should possess such high tension as to be able to break through a small air space. If this is not the case, then auxiliary means have to be resorted to, some of which will be indicated subsequently. When the condensers are charged to a certain potential, the air or insulating space gives way, and a disruptive discharge occurs. There is then a sudden rush of current, and generally a large portion of the accumulated electrical energy spends itself. The condensers are thereupon quickly charged, and the same process is repeated in more or less rapid succession. To produce such sudden rushes of current, it is necessary to observe certain conditions. If the rate at which the condensers are discharged is the same as that at which they are charged, then, clearly, in the assumed case the condensers do not come into play. If the rate of discharge be smaller than the rate of charging, then, again, the condensers cannot play an important part. But if, on the contrary, the rate of discharging is greater than that of charging, then a succession of rushes of current is obtained. It is evident that, if the rate at which the energy is being dissipated by the discharge is very much greater than the rate of supply to the condensers, the sudden rushes will be comparatively few, with long-time intervals between. This always occurs when a condenser of considerable capacity is charged by means of a comparatively small machine. If the rates of supply and dissipation are not widely different, then the rushes of current will be in quicker succession, and this the more, the more nearly equal both the rates are, until natural limitations incident to each case, and depending upon a number of causes, are reached. Thus we are able to obtain from a continuous current generator as rapid a succession of discharges as we like. Of course, the higher the tension of the generator, the smaller need be

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the capacity of the condensers, and for this reason, principally, it is of advantage to employ a generator of very high tension. Besides, such a generator permits the attaining of greater rates of vibration.

The rushes of current may be of the same direction under the conditions before assumed, but most generally there is an oscillation superimposed upon the fundamental vibration of the current. When the conditions are so determined that there are no oscillations, the current impulses are unidirectional, and thus a means is provided of transforming a continuous current of high tension into a direct current of lower tension, which I think may find employment in the arts.

This method of conversion is exceedingly interesting, and I was much impressed by its beauty when I first conceived it. It is ideal in certain respects. It involves the employment of no mechanical devices of any kind, and it allows of obtaining currents of any desired frequency from an ordinary circuit, direct or alternating. The frequency of the fundamental discharges depending on the relative rates of supply and dissipation can be readily varied within wide limits by simple adjustments of these quantities, and the frequency of the superimposed vibration by the determination of the capacity, self-induction and resistance of the circuit. The potential of the currents, again, may be raised as high as any insulation is capable of withstanding safely by combining capacity and self-induction or by induction in a secondary, which need have but comparatively few turns.

As the conditions are often such that the intermittance or oscillation does not readily establish itself, especially when a direct current source is employed, it is of advantage to associate an interrupter with the arc, and I have, some time ago, indicated the use of an air blast or magnet, or other such device readily at hand. The magnet is employed with special advantage in the conversion of direct currents, as it is then very effective. If the primary source is an alternate current generator, it is desirable, as I have stated on another occasion, that the frequency should be low, and that the currents forming the arc be large, in order to render the magnet more effective.

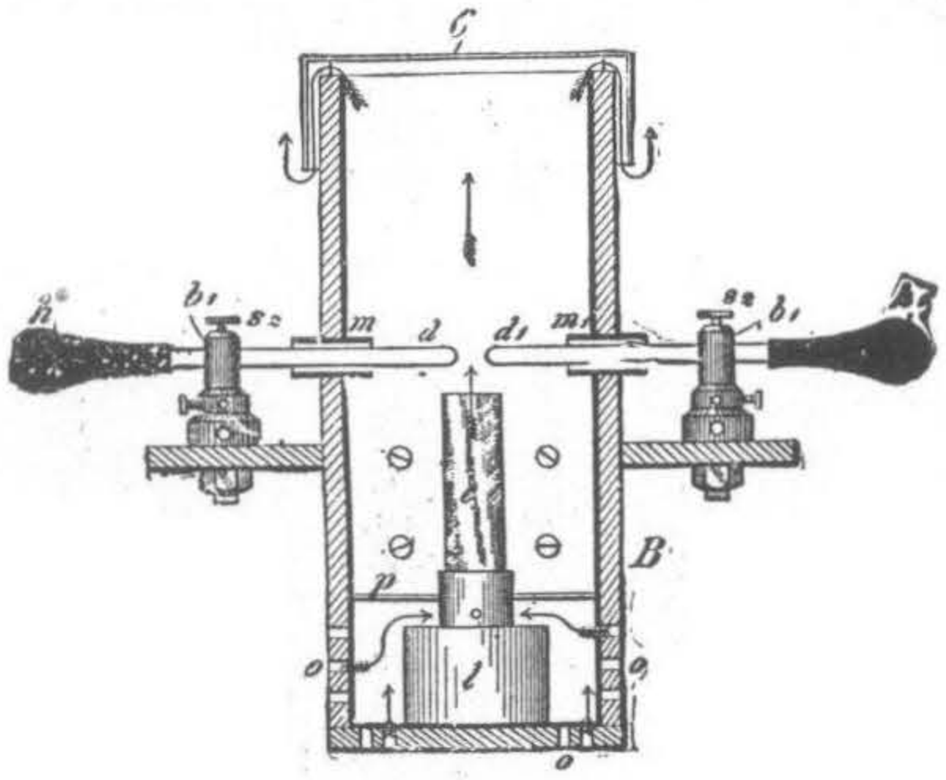


Fig. 3

DISCHARGES WITH HOT AIR DRAFT.

the carbons, and the result is that a smaller E.M.F. in the arc gap is required to maintain a succession of discharges.

Another form of discharger which may be employed with advantage in some cases is illustrated in fig. 3. In this form the discharge rods, d, d_1, pass through perforations in a wooden box, B, which is thickly coated with mica on the inside, as indicated by the heavy lines. The perforations are provided with mica tubes, m, m_1, of some thickness, which are preferably not in contact with the rods, d, d_1. The box has a cover, C, which is a little larger, and descends on the outside of the box. The spark gap is warmed by a small lamp, l, contained in the box. A plate, p, above the lamp allows the draught to pass only through the chimney, c, of the lamp, the air entering through holes, o, o, in or near the bottom of the box and following the path indicated by the arrows. When the discharger is in operation the door of the box is closed so that the light of the arc is not visible outside. It is desirable to exclude the light as perfectly as possible, as it interferes with some experiments. This form of discharger is simple and very effective when properly manipulated. The air being warmed to a certain temperature has its insulating power impaired, it becomes dielectrically weak, as it were, and the consequence is that the arc can be established at much greater distance. The air should, of course, be sufficiently insulating to allow the discharge to pass through the gap *disruptively*. The arc formed under such conditions, when long, may be made extremely sensitive, and the weak draught through the lamp chimney, c, is quite sufficient to produce rapid interruptions. The adjustment is made by regulating the temperature and velocity of the draught. Instead of using a lamp it answers the purpose to provide for a draught of warm air in other ways. A very simple way which has been practised is to enclose the arc in a long vertical tube with plates on the top and bottom for regulating the temperature and velocity of the air current. Some provision had to be made for deadening the sound.

The air may be rendered dielectrically weak also by rarefaction. Dischargers of this kind have likewise been used by me in connection with the magnet. A large tube is for this purpose provided with heavy electrodes of carbon or metal, between which the discharge is made to pass, the tube being placed in a powerful magnetic field. The exhaustion of the tube is carried to a point at which the discharge breaks through easily, but the pressure should be more than 75 millimetres, at which the ordinary thread discharge occurs. In another form of discharger, combining the features before mentioned, the discharge was made to pass between two adjustable magnetic pole pieces, the space between them being kept at an elevated temperature.

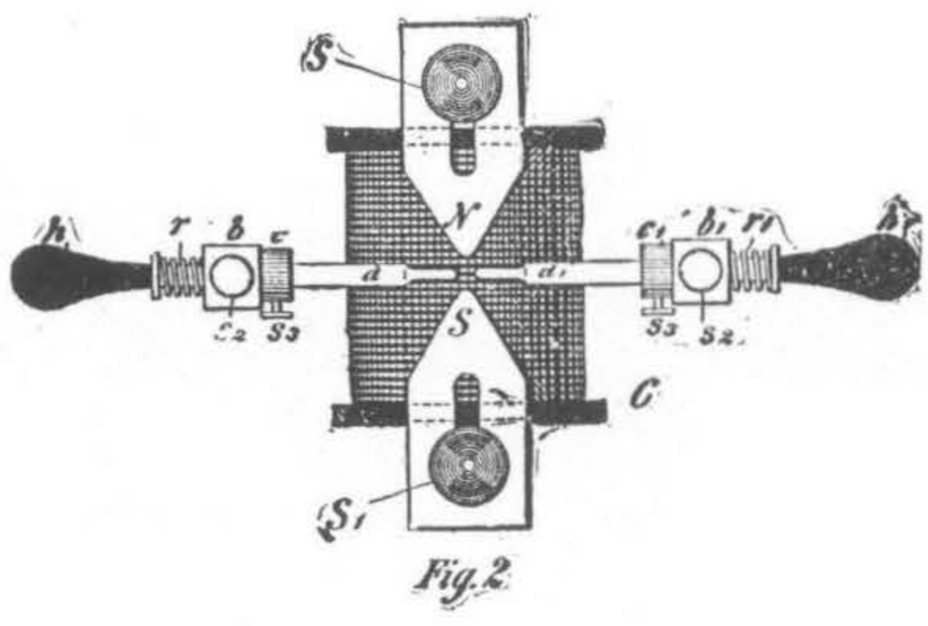


Fig. 2.

FORM OF DISCHARGER WITH MAGNET USED IN THE DIRECT CURRENT CONVERSION.

A form of such discharger with a magnet which has been found convenient, and adopted after some trials, in the conversion of direct currents particularly, is illustrated in fig. 2. N, S, are the pole pieces of a very strong magnet which is excited by a coil, C. The pole pieces are slotted for adjustment, and can be fastened in any position by screws, S, S_1. The discharge rods, d, d_1, thinned down on the ends in order to allow a closer approach of the magnetic pole pieces, pass through the columns of brass, b, b_1, and are fastened in position by screws, s_2, s_2. Springs, r, r_1, and collars, c, c_1, are slipped on the rods, the latter serving to set the points of the rods at a certain suitable distance by means of screws, s_3, s_3, and the former to draw the points apart. When it is desired to start the arc, one of the hard rubber handles, h, h_1, is tapped quickly with the hand, whereby the points of the rods are brought in contact, but are instantly separated by the springs, r, r_1. Such an arrangement has been found to be often necessary, namely, in cases when the E.M.F. was not large enough to cause the discharge to break through the gap, and also when it was desirable to avoid short circuiting of the generator by the metallic contact of the rods. The rapidity of the interruptions of the current with a magnet depends on the intensity of the magnetic field and on the potential difference at the ends of the arc. The interruptions are generally in such quick succession as to produce a musical sound. Years ago it was observed that when a powerful induction coil is discharged between the poles of a strong magnet the discharge produced a loud noise not unlike a small pistol shot. It was vaguely stated that the spark was intensified by the presence of the magnetic field. It is now clear that the discharge current, flowing for some time, was interrupted a great number of times by the magnet, thus producing the sound. The phenomenon is especially marked when the field circuit of a large magnet or dynamo is broken in a powerful magnetic field.

When the current through the gap is comparatively large, it is of advantage to slip on the points of the discharge rods pieces of very hard carbon, and let the arc play between the carbon pieces. This preserves the rods, and besides has the advantage of keeping the air space hotter, as the heat is not conducted away as quickly through

It should be remarked here that when such, or interrupting devices of any kind, are used and the currents are passed through the primary of a disruptive discharge coil, it is not, as a rule, of advantage to produce a number of interruptions of the current per second greater than the natural frequency of vibration of the dynamo supply circuit, which is ordinarily small. It should also be pointed out here, that while the devices mentioned in connection with the disruptive discharges are advantageous under certain conditions, they may be sometimes a source of trouble, as they produce intermittencies and other irregularities in the vibration which it would be very desirable to overcome.

There is, I regret to say, in this beautiful method of conversion a defect, which fortunately is not vital, and which I have been gradually overcoming. I shall best call attention to this defect and indicate a fruitful line of work by comparing the electrical process with its mechanical analogue. The process may be illustrated in this manner. Imagine a tank with a wide opening at the bottom, which is kept closed by spring pressure, but so that it snaps off *suddenly* when the liquid in the tank has reached a certain height. Let the fluid be supplied to the tank by means of a pipe feeding at a certain rate. When the critical height of the liquid is reached, the spring gives way and the bottom of the tank drops out. Instantly the liquid falls through the wide opening, and the spring, reasserting itself, closes the bottom again. The tank is now filled, and after a certain time interval the same process is repeated. It is clear, that if the pipe feeds the fluid quicker than the bottom outlet is capable of letting it pass through, the bottom will remain off and the tank will still overflow. If the rates of supply are exactly equal, then the bottom lid

will remain partially open and no vibration of the same and of the liquid column will generally occur, though it might, if started by some means. But if the inlet pipe does not feed the fluid fast enough for the outlet, then there will be always vibration. Again, in such case, each time the bottom flaps up or down, the spring and the liquid column, if the pliability of the spring and the inertia of the moving parts are properly chosen, will perform independent vibrations. In this analogue the fluid may be likened to electricity or electrical energy, the tank to the condenser, the spring to the dielectric, and the pipe to the conductor through which electricity is supplied to the condenser. To make this analogy quite complete it is necessary to make the assumption, that at the bottom, each time it gives way, is knocked violently against a non-elastic stop, this impact involving some loss of energy, and that, besides, some dissipation of energy results, due to frictional losses. In the preceding analogue the liquid is supposed to be under a steady pressure. If the pressure of the fluid be assumed to vary rhythmically, this may be taken as corresponding to the case of an alternating current. The process is then not quite as simple to consider, but the action is the same in principle.

It is desirable, in order to maintain the vibration economically, to reduce the impact and frictional losses as much as possible. As regards the latter, which in the electrical analogue correspond to the losses due to the resistance of the circuits, it is impossible to obviate them entirely, but they can be reduced to a minimum by a proper selection of the dimensions of the circuits and by the employment of thin conductors in the forms of strands. But the loss of energy caused by the first breaking through of the dielectric—which in the above example corresponds to the violent knock of the bottom against the inelastic stop—would be more important to overcome. At the moment of the breaking through, the air space has a very high resistance, which is probably reduced to a very small value when the current has reached some strength, and the space is brought to a high temperature. It would materially diminish the loss of energy if the space were always kept at an extremely high temperature, but then there would be no disruptive break. By warming the space moderately by means of a lamp or otherwise, the economy as far as the arc is concerned is sensibly increased. But the magnet or other interrupting device does not diminish the loss in the arc. Likewise, a jet of air only facilitates the carrying off of the energy. Air, or a gas in general, behaves curiously in this respect. When two bodies, charged to a very high potential, discharge disruptively through an air space, any amount of energy may be carried off by the air. This energy is evidently dissipated by bodily carriers, in impact and collisional losses of the molecules. The exchange of the molecules in the space occurs with inconceivable rapidity. A powerful discharge taking place between two electrodes, they may remain entirely cool, and yet the loss in the air may represent any amount of energy. It is perfectly practicable, with very great potential differences in the gap, to dissipate several horse-power in the arc of the discharge without even noticing a small increase in the temperature of the electrodes. All the frictional losses occur then practically in the air. If the exchange of the air molecules is prevented, as by enclosing the air hermetically, the gas inside of the vessel is brought quickly to a high temperature, even with a very small discharge. It is difficult to estimate how much of the energy is lost in sound waves, audible or not, in a powerful discharge. When the currents through the gap are large, the electrodes may become rapidly heated, but this is not a reliable measure of the energy wasted in the arc, as the loss through the gap itself may be comparatively small. The air or a gas in general is, at ordinary pressures at least, clearly not the best medium through which a disruptive discharge should occur. Air or other gas under great pressure is of course a much more suitable medium for the discharge gap. I have carried on long-continued experiments in this direction, unfortunately less practicable on account of the difficulties and expense in getting air under great pressure. But even if the medium in the discharge space is solid or liquid, still the same losses take place, though they are generally smaller, for just as soon as the arc is established the solid or liquid is volatilised. Indeed, there is no body known which would not be disintegrated by the arc, and it is an open question among scientific men whether an arc discharge could occur at all in the air itself without the particles of the electrodes being torn off. When the current through the gap is very small and the arc very long, I believe that a relatively considerable amount of heat is taken up in the disintegration of the electrodes, which partially on this account may remain quite cold.

The ideal medium for a discharge gap should only *crack*, and the ideal electrode should be of some material which cannot be disintegrated. With small currents through the gap, it is best to employ aluminum, but not when the currents are large. The disruptive break in the air, or more or less in any ordinary medium, is not of the nature of a crack, but it is rather comparable to the piercing of innumerable bullets through a mass offering great frictional resistance to the motion of the bullets, this involving considerable loss of energy. A medium which would merely crack when strained electrostatically—and this possibly might be the case with a perfect vacuum, that is, pure ether—would involve a very small loss in the gap, so small as to be entirely negligible, at least theoretically, because a crack may be produced by an infinitely small displacement. In exhausting an oblong bulb provided with two aluminum terminals with the greatest care, I have succeeded in producing such a vacuum, that the secondary discharge of a disruptive discharge coil would break disruptively through the bulb in the form of fine spark streams. The curious point was that the discharge would completely ignore the terminals, and start far behind the two aluminum plates which served as electrodes. This extraordinarily high vacuum could only be maintained for a very short while. To return to the ideal medium, think, for the sake of illustration, of a piece of glass or similar body clamped in a vice, and the latter lightened more and more. At a certain point a minute increase of the pressure will cause the glass to crack. The loss of energy involved in splitting the glass may be practically nothing; for though the force is great, the displacement need be but extremely small. Now imagine that the glass would possess the property of closing again perfectly the crack upon a minute diminution of the pressure. This is the way the dielectric in the discharge space should behave. But inasmuch as there would be always some loss in the gap, the medium, which should be continuous, should exchange through the gap at a rapid rate. In the preceding example, the glass being perfectly closed, it would mean that the dielectric in the discharge space possesses a great insulating power; the glass being cracked, it would signify that the medium in the space is a good conductor. The dielectric should vary enormously in resistance by minute variations of the E.M.F. across the discharge space. This condition is attained, but in an extremely imperfect manner, by warming the air space to a certain critical temperature, dependent on the E.M.F. across the gap, or by otherwise impairing the insulating power of the air. But as a matter of fact, the air does never break down *disruptively*, if this term be rigorously interpreted, for before the sudden rush of the current occurs, there is always a weak current preceding it, which rises first gradually, and then with comparative suddenness. That is the reason why the rate of change is very much greater when glass, for instance, is broken through, than when the break takes place through an air space of equivalent dielectric strength. As a medium for the discharge space, a solid, or even a liquid would be preferable therefore. It is somewhat difficult to conceive of a solid body which would possess the property of closing instantly after it has been cracked. But a liquid, especially under great pressure, behaves practically like a solid, while it possesses the property of closing the crack. Hence it was thought that a liquid insulator might be more suitable as a dielectric than air. Following out this idea, a number of different forms of dischargers, in which a variety of such insulators, sometimes under great pressure, were employed, have been experimented upon. It is thought sufficient to dwell in a few words upon one of the forms experimented upon. One of these dischargers is illustrated in figs. 4*a* and 4*b*.

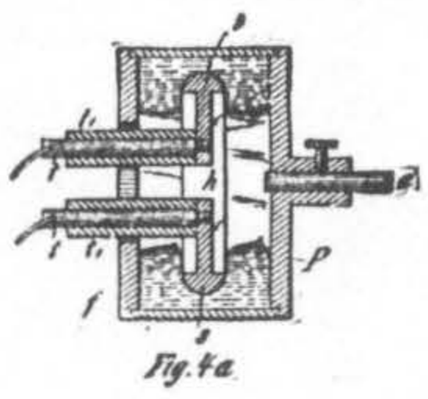


Fig. 4a.

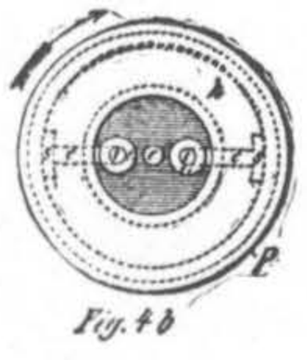


Fig. 4b.

FORM OF DISCHARGER WITH LIQUID INTERRUPTER.

A hollow metal pulley, P (fig. 4*a*), was fastened upon an arbour, *a*, which by suitable means was rotated at a considerable speed. In the inside of the pulley, but disconnected from the same, was supported a thin disc, *h* (which is shown thick for the sake of clearness), of hard rubber, in which there were embedded two metal segments, *s*, *s*, with metallic extensions, *e*, *e*, into which were screwed conducting terminals, *t*, *t*, covered with thick tubes of hard rubber, t_1, t_1. The rubber disc, *h*, with its metallic segments, *s*, *s*, was finished in a lathe, and its entire surface highly polished so as to offer the smallest possible frictional resistance to the motion through a fluid. In the hollow of the pulley an insulating liquid such as a thin oil was poured so as to reach very nearly to the opening left in the flange, *f*, which was screwed tightly on the front side of the pulley. The terminals, *t*, *t*, were connected to the opposite coatings of a battery of condensers so that the discharge occurred through the liquid. When the pulley was rotated the liquid was forced against the rim of the pulley and considerable fluid pressure resulted. In this simple way the discharge gap was filled with a medium which behaved practically like a solid, which possessed the quality of closing instantly upon the occurrence of the break, and which moreover was circulating through the gap at a very rapid rate. Very powerful effects were produced by dischargers of this kind with liquid interrupters, of which a number of different forms were made. It was found that, as expected, a longer spark for a given length of wire was obtainable in this way than by using air as an interrupting device. Generally the speed, and therefore also the fluid pressure, was limited by reason of the fluid friction, in the form of discharger described, but the practically obtainable speed was more than sufficient to produce a number of breaks suitable for the circuits ordinarily used. In some instances the metal pulley, *p*, was provided with a few projections inwardly, and a definite number of breaks was then produced which could be computed from the speed of rotation of the pulley. Experiments were also carried on with liquids of different insulating power with the view of reducing the loss in the arc. When an insulating liquid is moderately warmed the loss in the arc is diminished.

A point of some importance was noted in experiments with various dischargers of this kind. It was found, for instance, that whereas the conditions maintained in these forms were favourable for the production of a great spark length, the current so obtained were not best suited to the production of light effects. Experience undoubtedly has shown, that for such purposes, a harmonic rise and fall of the potential is preferable. Be it that a solid is rendered incandescent, or phosphorescent, or be it that energy is transmitted by condenser coating through the glass, it is quite certain that a harmonically rising and failing potential produces less destructive action, and that the vacuum is more permanently maintained. This would be easily explained if it were ascertained that the process going on in an exhausted vessel is of an electrolytic nature.

(To be continued.)

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(*Continued from page* 716.)

In the diagrammatical sketch, fig. 1, which has been already referred to, the cases which are most likely to be met with in practice are illustrated. One has at his disposal either direct or alternating currents from a supply station. It is convenient for an experimenter in an isolated laboratory to employ a machine, G, such as illustrated, capable of giving both kinds of currents. In such case it is also preferable to use a machine with multiple circuits, as in many experiments it is useful and convenient to have at one's disposal currents of different phases. In the sketch, D represents the direct, and A the alternating circuit. In each of these, three branch circuits are shown, all of which are provided with double lines switches, *s*, *s*, *s*, *s*, *s*, *s*. Consider, first, the direct current conversion; I, *a* represents the simplest case. If the E.M.F. of the generator is sufficient to break through a small air space, at least when the latter is warmed or otherwise rendered poorly insulating, there is no difficulty in maintaining a vibration with fair economy by judicious adjustment of the capacity, self-induction and resistance of the circuit, L, containing the devices, *l*, *l*, *m*. The magnet, N, S, can be in this case advantageously combined with the air space. The discharger, *d*, *d*, with the magnet may be placed either way, as indicated by the full or by the dotted lines. The circuit, I, *a*, with the connections and devices is supposed to possess dimensions such as are suitable for the maintenance of a vibration. But usually the E.M.F. on the circuit or branch, I, *a*, will be something like 100 volts or so, and in this case it is not sufficient to break through the gap. Many different means may be used to remedy this by raising the E.M.F. across the gap. The simplest is probably to insert a large self-induction coil in series with the circuit, L. When the arc is established, as by the discharger illustrated in fig. 2, the magnet blows the arc out the instant it is formed. Now the extra current of the break, being of high E.M.F., breaks through the gap, and a path of low resistance for the dynamo current being again provided, there is a sudden rush of the current from the dynamo upon the weakening or subsidence of the extra current. This process is repeated in rapid succession, and in this manner I have maintained oscillation with as low as 50 volts, or even less, across the gap. But conversion on this plan is not to be recommended on account of the too heavy currents through the gap and consequent heating of the electrodes; besides, the frequencies obtained in this way are low, owing to the high self-induction necessarily associated with the circuit. It is very desirable to have the E.M.F. as high as possible, first, in order to increase the economy of the conversion, and, secondly, to obtain high frequencies. The difference of potential in this electric oscillation is, of course, the equivalent of the stretching force in the mechanical vibration of the spring. To obtain very rapid vibration in a circuit of some inertia a great stretching force or difference of potential is necessary. Incidentally, when the E.M.F. is very great, the condenser which is usually employed in connection with the circuit need have but a small capacity, and many other advantages are gained. With a view of raising the E.M.F. to a many times greater value than obtainable from ordinary distribution circuits, a rotating transformer, *g*, is used, as indicated in fig. 2*a*, or else a separate high potential machine is driven by means of a motor operated from the generator, G. The latter plan is in fact preferable, as changes are easier made. The connections from the high tension winding are quite similar to those in branch 1*a*, with the exception that a condenser, C, which should be adjustable, is connected to the high tension circuit. Usually, also, an adjustable self-induction coil in series with the circuit has been employed in these experiments. When the tension of the currents is very high the magnet ordinarily used in connection with the discharger is of comparatively small value, as it is quite easy to adjust the dimensions of the circuit so that oscillation is maintained. The employment of a steady E.M.F. in the high frequency conversion affords some advantages over the employment of alternating E.M.F. as the adjustments are much simpler and the action can be easier controlled. But unfortunately one is limited by the obtainable potential difference. The windings also break down easily in consequence of the sparks which form between the sections of the armature or commutator when a vigorous oscillation takes place. Besides, these transformers are expensive to build. It has been found by experience that it is best to follow the plan illustrated in fig. 3*a*. In this arrangement a rotating transformer, *g*, is employed to convert the low tension direct currents into low frequency alternating currents, preferably also of small tension. The tension of the currents is then raised in a stationary transformer, T. The secondary, S, of this transformer is connected to an adjustable condenser, C, which discharges through the gap or discharger, *d*, *d*, placed in either of the ways indicated, through the primary, P, of a disruptive discharge coil, the high frequency currents being obtained from the secondary, S, of this coil, as described on previous occasions. This will undoubtedly be found the cheapest and most convenient way of converting direct currents.

The three branches of the circuit, A, represent the usual cases met in practice when alternating currents are converted. In fig. 1*b* a condenser, C, generally of large capacity, is connected to the circuit, L, containing the devices, *l*, *l*, *m*, *m*. The devices, *m*, *m*, are supposed to be of high self-induction so as to bring the frequency of the circuit more or less to that of the dynamo. In this instance the discharger, *d*, *d*, should best have a number of makes and brakes per second equal to twice the frequency of the dynamo. If not so, then it should have at least a number equal to a multiple or even fraction of the dynamo frequency. It should be observed, referring to 1*b*, that the conversion to a high potential is also effected when the discharger, *d*, *d*, which is shown in the sketch, is omitted. But the effects which are produced by currents which rise instantly to high values, as in a disruptive discharge, are entirely different from those produced by dynamo currents which rise and fall harmonically. So, for instance, there might be in a given case a number of makes and breaks at *d*, *d*, equal to just twice the frequency of the dynamo, or, in other words, there may be the same number of fundamental oscillations as would be produced without the discharge gap, and there might even not be any quicker superimposed vibrations; yet the differences of potential at the various points of the circuit, the impedence and other phenomena dependent upon the rate of change, will bear no similarity in the two cases. Thus, when working with currents discharging disruptively, the element chiefly to be considered is not the frequency, as a student might be apt to believe, but the rate of change per unit of time. With low frequencies in a certain measure the same effects may be obtained as with high frequencies, provided the rate of change is sufficiently great. So if a low frequency current is raised to a potential of, say, 75,000 volts, and the high tension current passed through a series of high resistance lamp filaments, the importance of the rarefied gas surrounding the filament is clearly noted, as will be seen later; or, if a low frequency current of several thousand ampères is passed through a metal bar striking phenomena of impedence are observed, just as with currents of high frequencies. But it is, of course, evident that with low frequency currents it is impossible to obtain such rates of change per unit of time as with high frequencies, hence the effects produced by the latter are much more prominent. It was deemed advisable to make the preceding remarks, inasmuch as many more recently described effects have been unwittingly identified with high frequencies. Frequency alone in reality does not mean anything, except when an undisturbed harmonic oscillation is considered.

In the branch 3*b* a similar disposition as in 1*b* is illustrated, with the difference that the currents discharging through the gap, *d*, *d*, are used to induce currents in the secondary, S, of a transformer, T. In such case the secondary should be provided with an adjustable condenser for the purpose of tuning it to the primary.

Fig. 2*b* illustrates a plan of alternate current high frequency conversion which is most frequently used, and which is found to be most convenient. This plan has been dwelt upon in detail on previous occasions, and need not be described here.

Some of these results were obtained by the use of a high frequency alternator. A description of such machines will be found in my original paper before the American Institute of Electrical Engineers, and in periodicals of that period, notably, in the *Electrical Engineer* of March 18th, 1891.

I will now proceed with the experiments.

ON PHENOMENA PRODUCED BY ELECTROSTATIC FORCE.

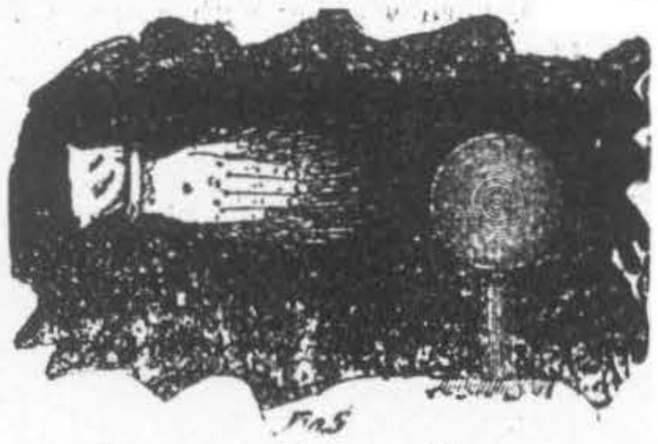
The first class of effects I intend to show you are effects produced by electrostatic force. It is the force which governs the motion of the atoms, which causes them to collide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an infinite variety of ways, according to Nature's fanciful designs, and to form all these wondrous structures we perceive around us; it is, in fact, if our present views be true, the most important force for us to consider in Nature. As the term *electrostatic* might imply a steady electric condition, it should be remarked that in these experiments the force is not constant, but varies at a rate which may be considered moderate, about one million times a second, or thereabouts. This enables me to produce many effects which are not producible with an unvarying force.

When two conducting bodies are insulated and electrified, we say that an electrostatic force is acting between them. This force manifests itself in attractions, repulsions and stresses in the bodies and space or medium without. So great may be the strain exerted in the air, or whatever separates the two conducting bodies, that it may break down, and we observe sparks or bundles of light or streamers, as they are called. These streamers form abundantly when the force through the air is rapidly varying. I will illustrate this action of electrostatic force in a novel experiment in which I will employ the induction coil before referred to. The coil is contained in a trough filled with oil, and placed under the table. The two ends of the secondary wire pass through the two thick columns of hard rubber, which protude to some height above the table. It is necessary to insulate the ends or terminals of the secondary heavily with hard rubber, because even dry wood is by far too poor an insulator for these currents of enormous potential differences. On one of the terminals of the coil I have placed a large sphere of sheet brass, which is connected to a larger insulated brass plate, in order to enable me to perform the experiments under conditions which, as you will see, are more suitable for this experiment. I now set the coil to work and approach the free terminal with a metallic object held in my hand, this simply to avoid burns. As I approach the metallic object to a distance of 8 or 10 inches, a torrent of furious sparks breaks forth from the end of the secondary wire, which passes through the rubber column. The sparks cease when the metal in my hand touches the wire. My arm is now traversed by a powerful electric current, vibrating at about the rate of one million times a second. All around me the electrostatic force makes itself felt, and the air molecules and particles of dust flying about are acted upon and are hammering violently against my body. So great is this agitation of the particles, that when the lights are turned out you may see streams of feeble light appear on some parts of my body.

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24th, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1st, 1893.

When such a streamer breaks out on any part of the body it produces a sensation like the pricking of a needle. Were the potentials sufficiently high and the frequency of the vibration rather low, the skin would probably be ruptured under the tremendous strain, and the blood would rush out with great force in the form of fine spray or jet so thin as to be invisible, just as oil will when placed on the positive terminal of a Holtz machine. This breaking through of the skin, though it may seem impossible at first, would perhaps occur by reason of the tissues under the skin being incomparably better conducting. This, at least, appears plausible, judging from some observations.

I can make these streams of light visible to all, by touching with the metallic object one of the terminals as before, and approaching my free hand to the brass sphere, which is connected to the second terminal of the coil. As the hand is approached the air between it and the sphere, or in the immediate neighbourhood, is more violently agitated, and you see streams of light now break forth from my finger tips and from the whole hand (fig. 5). Were I to approach the



ILLUSTRATING THE EFFECT OF VARYING ELECTROSTATIC FORCE WITH A TRANSFORMER OF 200,000 VOLTS PRESSURE.

hand closer, powerful sparks would jump from the brass sphere to my hand, which might be injurious. The streamers offer no particular inconvenience, except that in the ends of the finger tips a burning sensation is felt. They should not be confounded with those produced by the influence machine, because in many respects they behave differently. I have attached the brass sphere and plate to one of the terminals in order to prevent the formation of visible streamers on that terminal, also in order to prevent sparks from jumping at a considerable distance. Besides, the attachment is favourable for the working of the coil.

The streams of light which you have observed issuing from my hand are due to a potential of about 200,000 volts, alternating in rather irregular intervals, something like a million times a second. A vibration of the same amplitude, but four times as fast, to maintain which over 3,000,000 volts would be required, would be more than sufficient to envelop my body in a complete sheet of flame. But this flame would not burn me up; quite contrarily; the probability is that I would not be injured in the least. Yet a hundrdth part of that energy, otherwise directed, would be amply sufficient to kill a person.

The amount of energy which may thus be passed into the body of a person depends on the frequency and potential of the currents, and by making both of these very great, a vast amount of energy may be passed into the body without causing any discomfort, except, perhaps, in the arm, which is traversed by a true conduction current. The reason why no pain in the body is felt, and no injurious effect noted, is that everywhere, if a current be imagined to flow through the body, the direction of its flow would be at right angles to the surface; hence the body of the experimenter offers an enormous section to the current, and the density is very small, with the exception of the arm, perhaps, where the density may be considerable. But if only a small fraction of that energy should be applied in such a way that a current would traverse the body in the same manner as a low frequency current, a shock would be received which might be fatal. A direct or low frequency alternating current is fatal, I think, principally because its distribution through the body is not uniform, as it must divide itself in minute streamlets of great density, whereby some organs are vitally injured. That such a process occurs I have

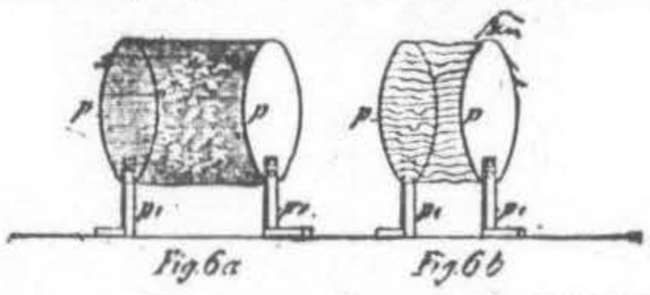


Fig. 6a Fig. 6b

ILLUSTRATING THE EFFECTS OF RAPIDIY VARYING AND STEADY ELECTROSTATIC FORCE.

not the least doubt, though no evidence might apparently exist, or be found upon examination. The surest to injure and destroy life is a continuous current, but the most painful is an alternating current of very low frequency. The expression of these views, which are the result of long continued experiment and observation, both with steady and varying currents, is elicited by the interest which is at present taken in this subject, and by the manifestly erroneous ideas which are daily propounded in journals on this subject.

I may illustrate an effect of the electrostatic force by another striking experiment, but before, I must call your attention to one or two facts. I have said before, that when the medium between two oppositely electrified bodies is strained beyond a certain limit it gives way, and, stated in popular language, the opposite electric charges unite and neutralise each other. This breaking down of the medium occurs principally when the force acting between the bodies is steady, or varies at a moderate rate. Were the variation sufficiently rapid, such a destructive break would not occur, no matter how great the force, for all the energy would be spent in radiation, convection, and mechanical and chemical action. Thus the *spark* length, or greatest distance through which a *spark* will jump between the electrified bodies is the smaller, the greater the variation or time rate of change. But this rule may be taken to be true only in a general way, when comparing rates which are widely different.

I will show you by an experiment the difference in the effect produced by a rapidly varying and a steady or moderately varying force. I have here two large circular brass plates, *p*, *p* (fig. 6*a* and fig. 6*b*), supported on movable insulating stands on the table, connected to the ends of the secondary of a similar coil as the one used before. I place the plates ten or twelve inches apart and set the coil to work. You see the whole space between the plates, nearly 2 cubic feet, filled with uniform light fig. 6*a*. This light is due to the streamers you have seen in the first experiment, which are now much more intense. I have already pointed out the importance of these streamers in commercial apparatus and their still greater importance in some purely scientific investigations. Often they are too weak to be visible, but they always exist, consuming energy and modifying the action of the apparatus. When intense, as they are at present, they produce ozone in great quantity, and also, as Prof. Crookes has pointed out, nitrous acid. So quick is the chemical action, that if a coil such as this one, is worked for a very long time it will make the atmosphere of a small room unbearable, for the eyes and throat are attacked. But when moderately produced, the streamers refresh the atmosphere wonderfully, like a thunderstorm, and exercise unquestionably a beneficial effect.

In this experiment the force acting between the plates changes in intensity and direction at a very rapid rate. I will now make the rate of change per unit time much smaller. This I effect by rendering the discharges through the primary of the induction coil less frequent, and also by diminishing the rapidity of the vibration in the secondary. The former result is conveniently secured by lowering the E.M.F. over the air gap in the primary circuit, the latter, by approaching the two brass plates to a distance of about 3 or 4 inches. When the coil is set to work you see no streamers or light between the plates, yet the medium between them is under a tremendous strain. I still further augment the strain by raising the E.M.F. in the primary circuit, and soon you see the air give way and the hall is illuminated by a shower of brilliant and noisy sparks, 6*b*. These sparks could be produced also with unvarying force; they have been for many years a familiar phenomenon, though they were usually obtained from entirely different apparatus. In describing these two phenomena so radically different in appearance, I have advisedly spoken of a "force" acting between the plates. It would be in accordance with accepted views to say, that there was an "alternating E.M.F." acting between the plates. This term is quite proper and applicable in all cases where there is evidence of at least a possibility of an essential inter-dependence of the electric state of the plates, or electric action in their neighbourhood. But if the plates were removed to an infinite distance, or if at a finite distance, there is no probability or necessity whatever for such dependence. I prefer to use the term "electrostatic force," and to say that such a force is acting around each plate or electrified insulated body in general. There is an inconvenience in using this expression as the term incidentally means a steady electric condition; but a proper nomenclature will eventually settle this difficulty.

I now return to the experiment to which I have already alluded, and with which I desire to illustrate a striking effect produced by a rapidly varying electrostatic force. I attach to the end of the wire, *l* (fig. 7), which is in connection with one of the terminals of the

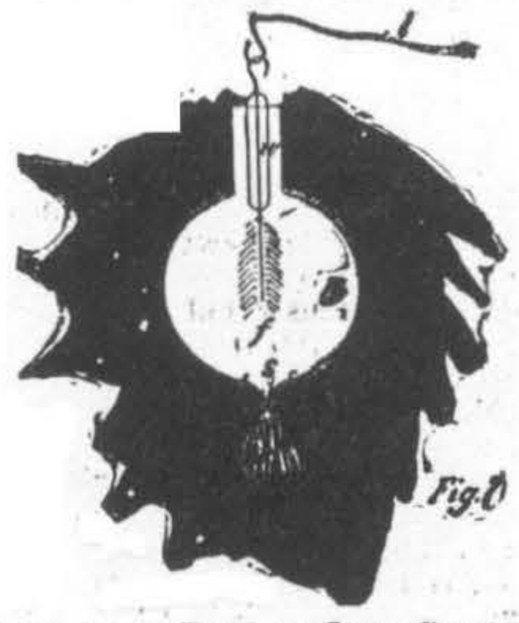


Fig. 7

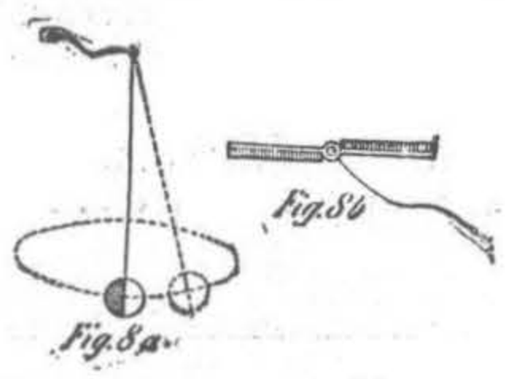
BREAKING A BULB ON OPEN CIRCUIT.

secondary of the induction coil, an exhausted bulb, *b*. This bulb contains a thin carbon filament, *f*, which is fastened to a platinum wire, *w*, sealed in the glass and leading outside of the bulb, where it connects to the wire, *l*. The bulb may be exhausted to any degree attainable with ordinary apparatus. Just a moment before, you have witnessed the breaking down of the air between the charged brass plates. You know that a plate of glass, or any other insulating material, would break down in like manner. Had I, therefore, a metallic coating attached to the outside of the bulb, or placed near the same, and were this coating connected to the other terminal of the coil, you would be prepared to see the glass give way if the strain were sufficiently increased. Even were the coating not connected to the other terminal, but to an insulated plate, still, if you have followed recent developments, you would naturally expect a rupture of the glass.

But it will certainly surprise you to note that under the action of the varying electrostatic force the glass gives way when all other bodies are removed from the bulb. In fact, all the surrounding bodies

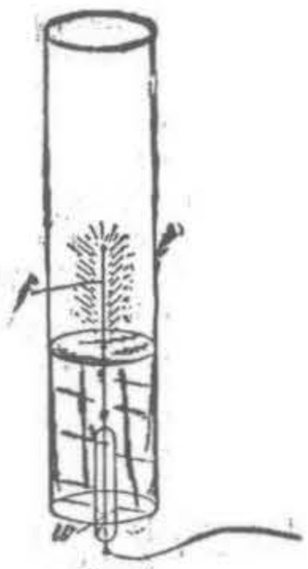
we perceive might be removed to an infinite distance without affecting the result in the slightest. When the coil is set to work, the glass is invariably broken through at the seal, or other narrow channel, and the vacuum is quickly impaired. Such a damaging break would not occur with a steady force, even if the same were many times greater. The break is due to the agitation of the molecules of the gas within the bulb, and outside the same. This agitation, which is generally most violent in the narrow pointed channel near the seal, causes a heating and rupture of the glass. This rupture would, however, not occur, not even with a varying force, if the medium filling the inside of the bulb, and that surrounding it, were perfectly homogeneous. The break occurs much quicker if the top of the bulb is drawn out into a fine fibre. In bulbs used with these coils such narrow pointed channels must, therefore, be avoided.

When a conducting body is immersed in air, or similar insulating medium, consisting of, or containing, small freely movable particles capable of being electrified, and when the electrification of the body is made to undergo a very rapid change—which is equivalent to saying that the electrostatic force acting around the body is varying in intensity—the small particles are attracted and repelled, and their violent impacts against the body may cause a mechanical motion of the latter. Phenomena of this kind are noteworthy, inasmuch as they have not been observed before with apparatus such as has been commonly in use. If a very light conducting sphere be suspended on an exceedingly fine wire, and charged to a steady potential, however high, the sphere will remain at rest. Even if the potential would be rapidly varying, provided that the small particles of matter, molecules or atoms, are evenly distributed, no motion of the sphere should result. But if one side of the conducting sphere is covered with a thick insulating layer, the impacts of the particles will cause the sphere to move about, generally in irregular curves, fig. 8*a*. In like manner, as I have shown on a previous occasion, a fan of metal sheet, fig. 8*b*, covered partially with insulating material as indicated, and placed upon the terminal of the coil so as to turn freely in it, is spun around.

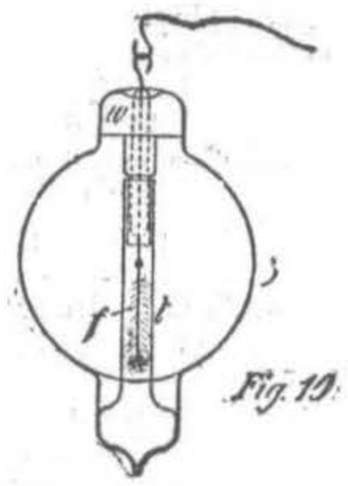


MECHANICAL MOTIONS PRODUCED BY VARYING ELECTROSTATIC FORCE IN A GASEOUS MEDIUM.

All these phenomena you have witnessed, and others which will be shown later, are due to the presence of a medium like air, and would not occur in a continuous medium. The action of the air may be illustrated still better by the following experiment. I take a glass tube, *t*, fig. 9, of about an inch in diameter, which has a platinum wire, *w*, sealed in the lower end, and to which is attached a thin lamp filament, *f*. I connect the wire with the terminal of the coil, and set the coil to work. The platinum wire is now electrified positively and negatively in rapid succession, and the wire and air inside of the tube is rapidly heated by the impacts of the particles, which may be so violent as to render the filament incandescent. But if I pour oil in the tube, just as soon as the wire is covered with the oil, all action apparently ceases, and there is no marked evidence of heating. The reason of this is that the oil is a practically continuous medium. The displacements in such a continuous medium are, with these frequencies, to all appearance incomparably smaller than in air, hence the work performed in such a medium is insignificant. But oil would behave very differently with frequencies many times as great, for even though the displacements be small, if the frequency were much greater, considerable work might be performed in the oil.



SHOWING THE EFFECT OF THE AIR.



SHOWING THE INFLUENCE OF THE CONDUCTIVITY OF THE MEDIUM UPON ELECTROSTATIC ACTIONS THROUGH MEASURABLE DISTANCE.

The electrostatic attractions and repulsions between bodies of measurable dimensions are, of all the manfestations of this force, the first so-called *electrical* phenomena noted. But though they have been known to us for many centuries, the precise nature of the mechanism concerned in these actions is still unknown to us, and has not been even quite satisfactorily explained. What kind of mechanism must that be? We cannot help wondering when we observe two magnets attracting and repelling each other with a force of hundreds of pounds with apparently nothing between them. We have in our commercial dynamos magnets capable of sustaining in mid-air tons of weight. But what are even these forces acting between magnets when compared with the tremendous attractions and repulsions produced by electrostatic force, to which there is apparently no limit as to intensity. In lightning discharges bodies are often charged to so high a potential that they are thrown away with inconceivable force and torn asunder or shattered into fragments. Still, even such effects cannot compare with the attractions and repulsions which exist between charged molecules or atoms, and which are sufficient to project them with speeds of many kilometres a second, so that under their violent impact bodies are rendered highly incandescent and are volatilised. It is of special interest for the thinker who inquires into the nature of these forces to note, that whereas the actions between individual molecules or atoms occur seemingly under any condition, the attractions and repulsions of bodies of measurable dimensions imply a medium possessing insulating properties. So, if air, either by being rarefied or heated, is rendered more or less conducting, these actions between two electrified bodies practically cease, while the actions between the individual atoms continue to manifest themselves.

An experiment may serve as an illustration and as a means of bringing out other features of interest. Some time ago I showed that a lamp filament or wire mounted in a bulb and connected to one of the terminals of a high tension secondary coil is set spinning, the top of the filament generally describing a circle. This vibration was very energetic when the air in the bulb was at ordinary pressure and became less energetic when the air in the bulb was strongly compressed. It ceased altogether when the air was exhausted so as to become comparatively good conducting. I found at that time that no vibration took place when the bulb was very highly exhausted. But I conjectured that the vibration which I ascribed to the electrostatic action between the walls of the bulb and the filament should take place also in a highly exhausted bulb. To test this under conditions which were more favourable, a bulb like the one in fig. 10 was constructed. It comprised a globe, *b*, in the neck of which was sealed a platinum wire, *w*, carrying a thin lamp filament, *f*. In the lower part of the globe a tube, *t*, was sealed so as to surround the filament. The exhaustion was carried as far as it was practicable with the apparatus employed.

This bulb verified my expectation, for the filament was set spinning when the current was turned on, and became incandescent. It also showed another interesting feature, bearing upon the preceding remarks, namely, when the filament had been kept incandescent some time, the narrow tube and the space inside was brought to an elevated temperature, and as the gas in the tube then became conducting, the electrostatic attraction between the glass and the filament became very weak or ceased and the filament came to rest. When it came to rest it would glow far more intensely. This was probably due to its assuming the position in the centre of the tube where the molecular bombardment was most intense, and also partly to the fact that the individual impacts were more violent and that no part of the supplied energy was converted into mechanical movement. Since, in accordance with accepted views, in this experiment the incandescence must be attributed to the impacts of the particles, molecules or atoms in the heated space, these particles must therefore, in order to explain such action, be assumed to behave as independent carriers of electric charges immersed in an insulating medium; yet there is no attractive force between the glass tube and the filament because the space in the tube is, as a whole, conducting.

It is of some interest to observe in this connection that whereas the attraction between two electrified bodies may cease owing to the impairing of the insulating power of the medium in which they are immersed, the repulsion between the bodies may still be observed. This may be explained in a plausible way. When the bodies are placed at some distance in a poorly conducting medium, such as slightly warmed or rarefied air, and are suddenly electrified, opposite electric charges being imparted to them, these charges equalise more or less by leakage through the air. But if the bodies are similarly electrified, there is less opportunity afforded for such dissipation, hence the repulsion observed in such case is greater than the attraction. Repulsive actions in a gaseous medium are however, as Prof. Crookes has shown, enhanced by molecular bombardment.

(To be continued.)

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(*Continued from page* 757, *Vol.* 32.)

ON CURRENT OR DYNAMIC ELECTRICITY PHENOMENA.

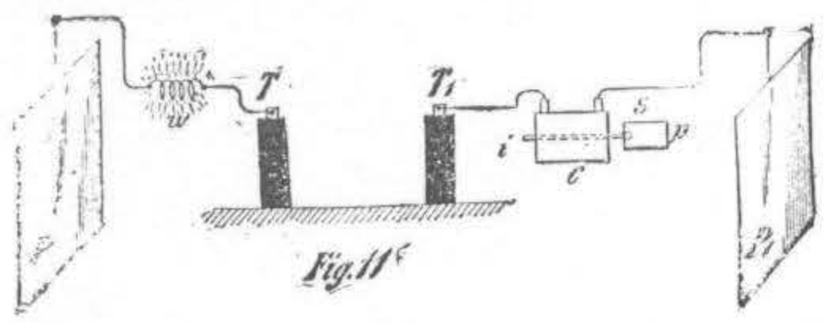
So far, I have considered principally effects produced by a varying electrostatic force in an insulating medium, such as air. When such a force is acting upon a conducting body of measurable dimensions, it causes within the same, or on its surface, displacements of the electricity and gives rise to electric currents, and these produce another kind of phenomena, some of which I shall presently endeavour to illustrate. In presenting this second class of electrical effects, I will avail myself principally of such as are producible without any

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24th, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1st, 1893.

return circuit, hoping to interest you the more by presenting these phenomena in a more or less novel aspect.

It has been for a long time customary, owing to the limited experience with vibratory currents, to consider an electric current as something circulating in a closed conducting path. It was astonishing at first to realise that a current may flow through the conducting path even if the latter be interrupted, and it was still more surprising to learn that sometimes it may be even easier to make a current flow under such conditions than through a closed path. But that old idea is gradually disappearing, even among practical men, and will soon be entirely forgotten.

If I connect an insulated metal plate, P, fig. 11, to one of the ter-



SHOWING EFFECTS OF CURRENTS FLOWING THROUGH OPEN CIRCUITS.

minals, T, of the induction coil by means of a wire, though this plate be very well insulated, a current passes through the wire when the coil is set to work. First I wish to give you evidence that there *is* a current passing through the connecting wire. An obvious way of demonstrating this is to insert between the terminal of the coil and the insulated plate a very thin platinum or German silver wire, *w*, and bring the latter to incandescence or fusion by the current. This requires a rather large plate, or else current impulses of very high potential and frequency. Another way is to take a coil, C, fig. 11, containing many turns of thin insulated wire, and to insert the same in the path of the current to the plate. When I connect one of the ends of the coil to the wire leading to another insulated plate, P, and its other end to the terminal, T_1, of the induction coil, and set the latter to work, a current passes through the inserted coil, C, and the existence of the current may be made manifest in various ways. For instance, I insert an iron core, *i*, within the coil. The current being one of very high frequency, if it be of some strength, will soon bring the iron core to a noticeably higher temperature, as the hysteresis and current losses are great with such high frequencies. One might take a core of some size, laminated or not, it would matter little; but ordinary iron wire, $\frac{1}{16}$th or $\frac{1}{8}$th of an inch thick, is suitable for the purpose. While the induction coil is working, a current traverses the inserted coil, and only a few moments are sufficient to bring the iron wire, *i*, to an elevated temperature sufficient to soften the sealing-wax, *s*, and cause a paper washer, *p*, fastened by it to the iron wire,

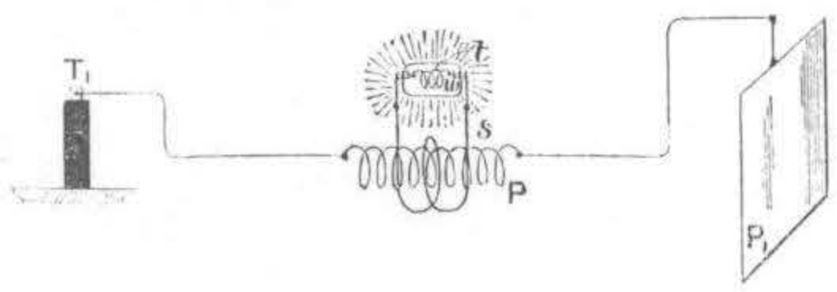


FIG. 12.—CONVERSION ON OPEN CIRCUIT WITH COIL AND INSULATED PLATE.

to fall off. But with the apparatus such as I have here, other much more interesting demonstrations of this kind can be made. I have a secondary, S, fig. 12, of coarse wire, wound upon a coil similar to the first. In the preceding experiment the current through the coil, C, fig. 11, was very small; but there being many turns, a strong heating effect was, nevertheless, produced in the iron wire. Had I passed that current through a conductor, in order to show the heating of the latter, the current might have been too small to produce the effect desired. But with this coil provided with a secondary winding, I can now transform the feeble current of high tension which passes through the primary, P, into a strong secondary current of low tension, and this current will quite certainly do what I expect. In a small

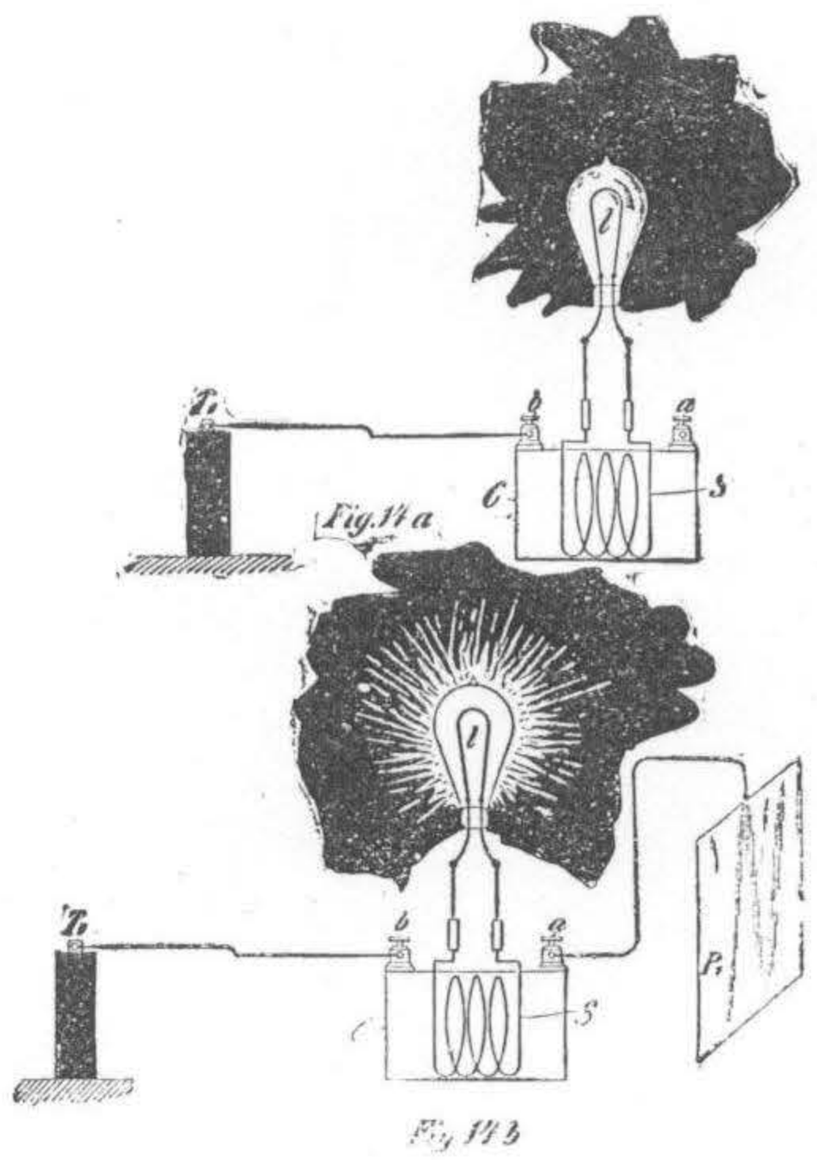
CONVERSION ON OPEN CIRCUIT WITH COIL ALONE.

glass tube (*t*, fig. 12), I have enclosed a coiled platinum wire, *w*, this merely in order to protect the wire. On each end of the glass tube is sealed a terminal of stout wire, to which one of the ends of the platinum wire, *w*, is connected. I join the terminals of the secondary coil to these terminals, and insert the primary, *p*, between the insulated plate, P_1, and the terminal, T_1, of the induction coil, as before. The latter being set to work, instantly the platinum wire, *w*, is rendered incandescent, and can be fused, even if it be very thick.

Instead of the platinum wire I now take an ordinary 50-volt 16 C.P. lamp. When I set the induction coil in operation the lamp filament is brought to high incandescence. It is, however, not necessary to use the insulated plate, for the lamp (*l*, fig. 13) is rendered incandescent even if the plate, P_1, be disconnected. The secondary may also be connected to the primary as indicated by the dotted line in fig. 13, to do away more or less with the electrostatic induction or to modify the action otherwise.

I may here call attention to a number of interesting observations with the lamp. First, I disconnect one of the terminals of the lamp from the secondary, S. When the induction coil plays, a glow is noted which fills the whole bulb. This glow is due to electrostatic induction. It increases when the bulb is grasped with the hand, and the capacity of the experimenter's body thus added to the secondary circuit. The secondary, in effect, is equivalent to a metallic coating, which would be placed near the primary. If the secondary, or its equivalent, the coating, were placed symmetrically to the primary, the electrostatic induction would be nil under ordinary conditions, that is, when a primary return circuit is used, as both halves would neutralise each other. The secondary *is* in fact placed symmetrically to the primary, but the action of both halves of the latter, when only one of its ends is connected to the induction coil, is not exactly equal; hence electrostatic induction takes place, and hence the glow in the bulb. I can nearly equalise the action of both halves of the primary by connecting the other free end of the same to the insulated plate, as in the preceding experiment. When the plate is connected, the glow disappears. With a smaller plate it would not entirely disappear, and then it would contribute to the brightness of the filament when the secondary is closed, by warming the air in the bulb.

To demonstrate another interesting feature, I have adjusted the coils used in a certain way. I first connect both the terminals of the lamp to the secondary, one end of the primary being connected to the terminal, T_1, of the induction coil, and the other to the insulated plate, P_1, as before. When the current is turned on the lamp glows brightly, as shown in fig. 14*b*, in which C is a fine wire coil and S a



EFFECT OF ATTACHED PLATE WITH LOW FREQUENCIES.

coarse wire secondary wound upon it. If the insulated plate, P_1, is disconnected, leaving one of the ends, *a*, of the primary insulated, the filament becomes dark, or generally it diminishes in brightness (fig. 14*a*). Connecting again the plate, P_1, and raising the frequency of the current, I make the filament quite dark or barely red, fig. 15*b*. Once more I will disconnect the plate. One will, of course, infer that when the plate is disconnected the current through the primary will be weakened, that therefore the E.M.F. will fall in the secondary, S, and that the brightness of the lamp will diminish. This might be the case, and the result can be secured by an easy adjustment of the coils, also by varying the frequency and potential of the currents. But it is, perhaps, of greater interest to note that the lamp increases in brightness when the plate is disconnected (fig. 15*a*). In this case, all the energy the primary receives is now sunk into it, like the charge of a battery in an ocean cable, but most of that energy is recovered through the secondary and used to light the lamp. The current traversing the primary is strongest at the end, *b*, which is connected to the terminal, T_1, of the induction coil, and diminishes in strength towards the remote end, *a*. But the dynamic inductive effect exerted upon the secondary, S, is now greater than before, when the suspended plate was connected to the primary. These results might have been produced by a number of causes. For instance, the plate, P_1, being connected, the reaction from the coil, C, may be such as to diminish the potential at the terminal, T_1, of the induction coil, and therefore weaken the current through the primary of the coil, C. Or the disconnecting of the plate may diminish the capacity effect with relation to the primary of the latter coil to such an extent that the current through it is diminished, though the potential at the terminal, T_1, of

the induction coil may be the same or even higher. Or the result might have been produced by the change of phase of the primary and secondary currents and consequent reaction. But the chief determining factor is the relation of the self-induction and capacity of coil, C, and plate, P_1, and the frequency of the currents. The greater brightness of the filament in fig. 15*a* is, however, in part due to the heating of the rarefied gas in the lamp by electrostatic induction, which, as before remarked, is greater when the suspended plate is disconnected.

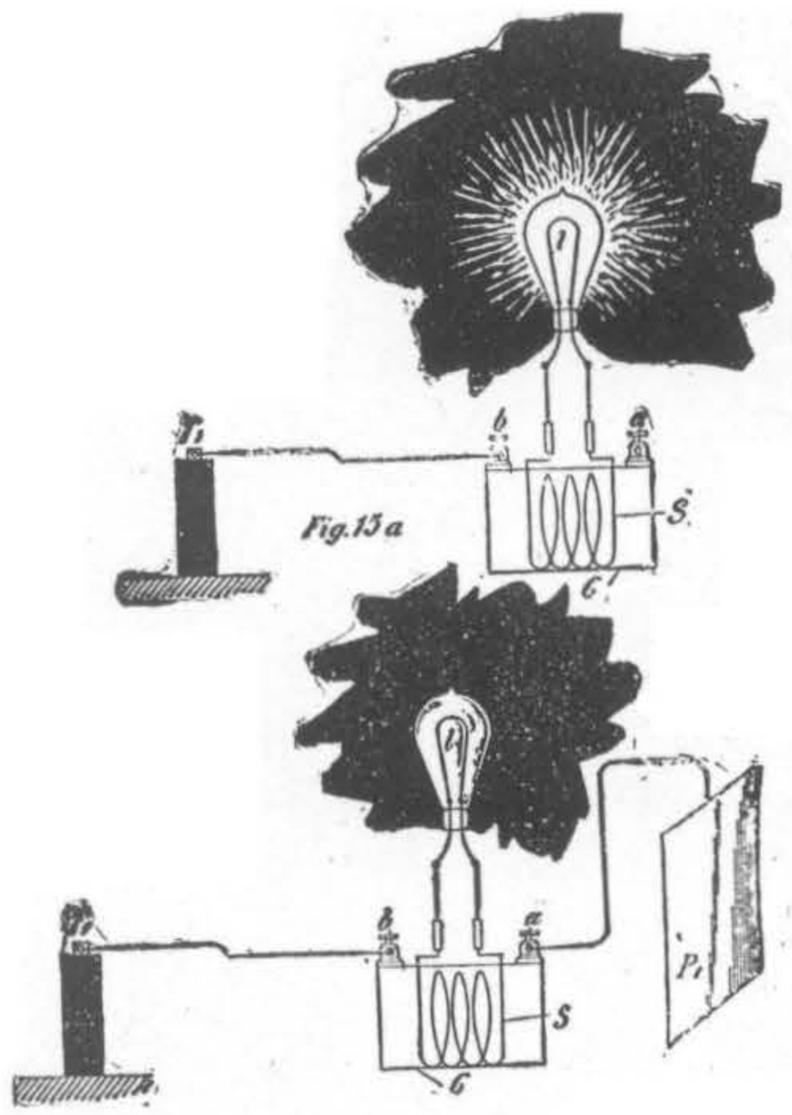


Fig. 15a

Fig. 15b

EFFECT OF ATTACHED PLATE WITH HIGH FREQUENCIES.

Still another feature of some interest I may here bring to your attention. When the insulated plate is disconnected and the secondary of the coil opened, by approaching a small object to the secondary, but very small sparks can be drawn from it, showing that the electrostatic induction is small in this case. But upon the secondary being closed upon itself or through the lamp, the filament glowing brightly, strong sparks are obtained from the secondary. The electrostatic induction is now much greater, because the closed secondary determines a greater flow of current through the primary, and principally through that half of it which is connected to the induction coil. If now the bulb be grasped with the hand, the capacity of the secondary with reference to the primary is augmented by the experimenter's body, and the luminosity of the filament is increased, the incandescence now being due partly to the flow of current through the filament and partly to the molecular bombardment of the rarefied gas in the bulb.

in the circuit of which is a coil, *c*. The currents induced in the secondary energise the iron core, *i*, which is preferably, but not necessarily, subdivided, and set the metal disc, *d*, in rotation. Such a motor, M_2, as diagrammatically shown in fig. 16 II., has been called a "magnetic lag motor," but this expression may be objected to by those who attribute the rotation of the disc to eddy currents circulating in minute paths, when the core, *i*, is finally subdivided. In order to operate such a motor effectively on the plan indicated, the frequencies should not be too high, not more than 4,000 or 5,000, and though the rotation is produced even with 10,000 per second, or more.

In fig. 16 I., a motor, M_1, having two energising circuits, A and B, is diagrammatically indicated. The circuit, A, is connected to the line, L, and in series with it is a primary, P, which may have its free end connected to an insulated plate, P_1, such connection being indicated by the dotted lines. The other motor circuit, B, is connected to the secondary, S, which is in inductive relation to the primary, P. When the transformer terminal, T_1, is alternately electrified, currents traverse the open line, L, and also circuit, A, and primary, P. The currents through the latter induce secondary currents in the circuit, S, which pass through the energising coil, B, of the motor. The currents through the secondary, S, and those through the primary, P, differ in phase 90°, or nearly so, and are capable of rotating an armature placed in inductive relation to the circuits, A and B.

In fig. 16 III., a similar motor, M_3, with two energising circuits, A_1 and B_1, is illustrated. A primary, P, connected with one of its ends to the line, L, has a secondary, S, which is preferably wound for a tolerably high E.M.F., and to which the two energising circuits of the motor are connected, one directly to the ends of the secondary, and the other through a condenser, C, by the action of which the currents traversing the circuit, A_1 and B_1, are made to differ in phase.

In fig. 16 IV., still another arrangement is shown. In this case two primaries, P_1 and P_2, are connected to the line, L, one through a condenser, C, of small capacity, and the other directly. The primaries are provided with secondaries, S_1 and S_2, which are in series with the energising circuits, A_2 and B_2, and a motor, M_3, the condenser, C, again serving to produce the requisite difference in the phase of the currents traversing the motor circuits. As such phase motors, with two or more circuits, are now well known in the art, they have been here illustrated diagrammatically. No difficulty whatever is found in operating a motor in the manner indicated, or in similar ways, and although such experiments up to this day present only scientific interest, they may, at a period not far distant, be carried out with practical objects in view.

It is thought useful to devote here a few remarks to the subject of operating devices of all kinds, by means of only one leading wire. It is quite obvious that when high frequency currents are made use of, ground connections are—at least when the E.M.F. of the currents is great—better than a return wire. Such ground connections are objectionable with steady or low frequency currents, on account of destructive chemical actions of the former, and disturbing influences exerted by both on the neighbouring circuits; but with high frequencies, these actions practically do not exist. Still, even ground connections become superfluous when the E.M.F. is very high, for soon a condition is reached when the current may be passed more economically through open than through closed conductors. Remote as might seem an industrial application of such single wire transmission of energy to one not experienced in such lines of experiment, it will not seem so to anyone who for some time has carried on investigations of such nature. Indeed, I cannot see why such a plan should not be practicable. Nor should it be thought that, for carrying at such a plan, currents of very high frequency are implicitly required, for just as soon as potentials of, say, 30,000 volts are used, the single

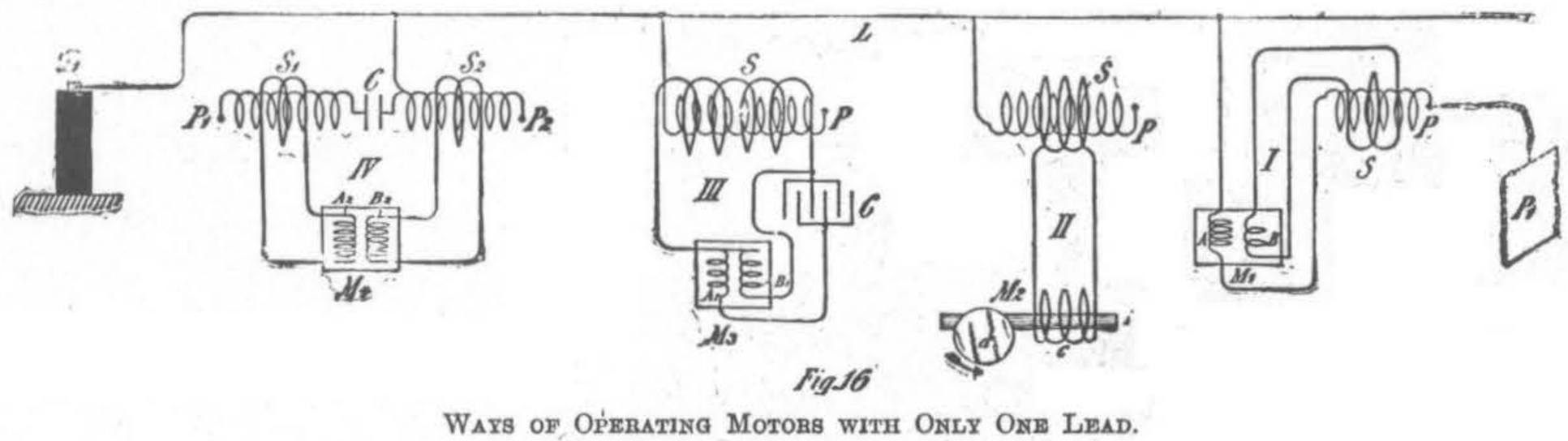


Fig. 16

WAYS OF OPERATING MOTORS WITH ONLY ONE LEAD.

The preceding experiments will have prepared one for the next following results of interest obtained in the course of these investigations. Since I can pass a current through an insulated wire merely by connecting one of its ends to the source of electrical energy, since I can induce by it another current, magnetise an iron core, and, in short, perform all operations as though a return circuit were used, clearly I can also drive a motor by the aid of only one wire. On a former occasion I have described a simple form of motor comprising a single exciting coil, an iron core and disc. Fig. 16 illustrates a modified way of operating such an alternate current motor by currents induced in a transformer connected to one lead, and several other arrangements of circuits for operating a certain class of alternate motors founded on the action of currents of differing phase. In view of the present state of the art, it is thought sufficient to describe these arrangements in a few words only. In the diagram, Fig. 16 II., shows a primary coil, P, connected with one of its ends to the line, L, leading from a high tension transformer terminal, T_1. In inductive relation to this primary, P, is a secondary, S, of coarse wire, wire transmission may be effected with low frequencies, and experiments have been made by me, from which these inferences are made.

(To be continued.)

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(*Continued from page 24.*)

When the frequencies are very high it has been found in laboratory practice quite easy to regulate the effects in the manner shown in diagram, fig. 17. Here two primaries, P and P, are shown, each connected with one of its ends to the line, L, and with the other end to the condenser plates, C and C^1, respectively. Near these are placed other condenser plates, C_1 and $C^1{}_1$, the former being connected to the line, L, and the latter to an insulated larger plate, P_2. On the primaries are wound secondaries, S and S_1, of coarse wire, connected to the devices, *m* and *d*, respectively. By varying the distances of the condenser plates, C and C^1, and C_1, and $C_1{}^1$, the currents through the secondaries, S and S_1, are varied in intensity. The curious feature is the great sensitiveness, the slightest change in the distance of the

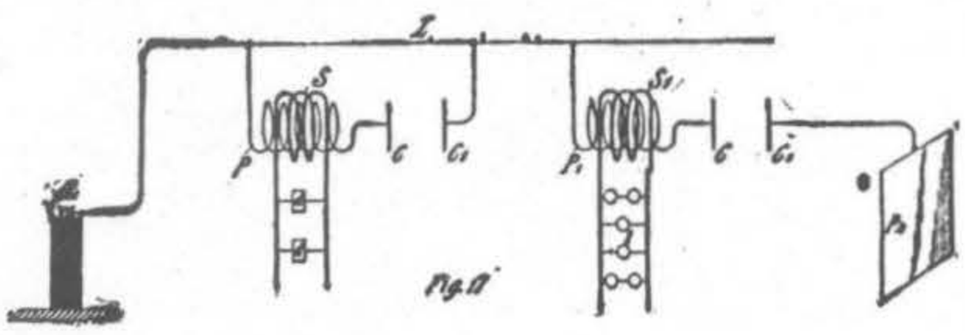


Fig. 17.

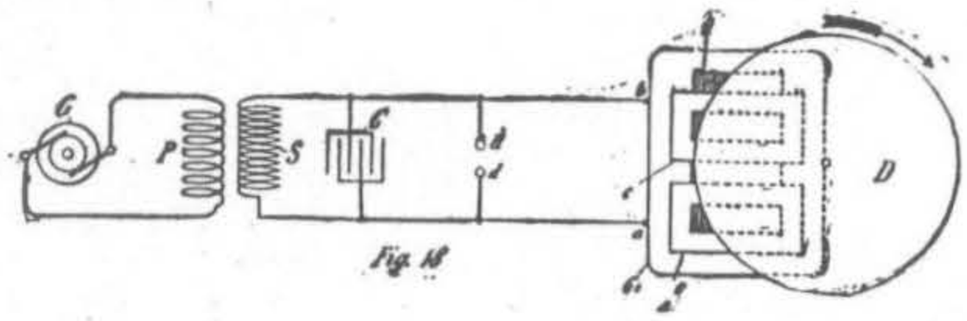


Fig. 18.

plates producing considerable variations in the intensity or strength of the currents. The sensitiveness may be rendered extreme by making the frequency such that the primary itself without any plate attached to its free end satisfies, in conjunction with the closed secondary, the condition of resonance. In such condition an extremely small change in the capacity of the free terminal produces great variations. For instance, I have been able to adjust the conditions so that the mere approach of a person to the coil produces a considerable change in the brightness of the lamps attached to the secondary. Such observations and experiments possess, of course, at present, chiefly scientific interest, but they may soon become of practical importance.

Very high frequencies are, of course, not practicable with motors, on account of the necessity of employing iron cores. But one may use sudden discharges of low frequency, and thus obtain certain advantages of high frequency currents without rendering the iron core entirely incapable of following the changes, and without entailing a very great expenditure of energy in the core. I have found it quite practicable to operate with such low frequency disruptive discharges of condensers, alternating current motors. A certain class of such motors which I advanced a few years ago, which contain closed secondary circuits, will rotate quite vigorously when the discharges are directed through the exciting coils. One reason that such a motor operates so well with these discharges is that the difference of phase between the primary and secondary currents is 90°, which is generally not the case with harmonically-rising and falling currents of low frequency. It might not be without interest to show an experiment with a simple motor of this kind, inasmuch as it is commonly thought that disruptive discharges are unsuitable for such purposes. The motor is illustrated in fig. 18. It comprises a rather large iron core, *i*, with slots on the top into which are embedded thick copper washers, *c*, *c*. In proximity to the core is a freely movable metal disc, D. The core is provided with a primary exciting coil, C, the ends, *a* and *b*, of which are connected to the terminals of the secondary, S, of an ordinary transformer, the primary, P, of the latter being connected to an alternating distribution circuit or generator, G, of low or moderate frequency. The terminals of the secondary, S, are attached to a condenser, C, which discharges through an air gap, *d*, *d*, which may be placed in series or shunt to the coil, C. When the conditions are properly chosen the disc, D, rotates with considerable effort, and the iron core, *i*, does not get very perceptibly hot. With currents from a high frequency alternator, on the contrary, the core gets rapidly hot, and the disc rotates with a much smaller effort. To perform the experiment properly, it should be first ascertained that the disc, D, is not set in rotation when the discharge is not occurring at *d*, *d*. It is preferable to use a large iron core and a condenser of large capacity, so as to bring the superimposed quicker oscillation to a very low pitch, or to do away with it entirely. By observing certain elementary rules I have also found it practicable to operate ordinary series or shunt direct current motors with such disruptive discharges, and this can be done with or without a return wire.

Among the various current phenomena observed, perhaps the most interesting are those of impedance presented by conductors to currents varying at a rapid rate. In my first paper before the American Institute of Electrical Engineers, I have described a few striking observations of this kind. Thus I showed that when such currents or sudden discharges are passed through a thick metal bar there may be points at the bar only a few inches apart, which have a sufficient potential difference between them to maintain at bright incandescence an ordinary filament lamp. I have also described the curious behaviour of rarefied gas surrounding a conductor to such sudden rushes of current. These phenomena have been since more carefully studied and one or two novel experiments of this kind are deemed of sufficient interest to be described here.

With reference to fig. 19*a*, B and B_1, are very stout copper bars connected at their lower ends to plates, C and C_1, respectively, of a condenser, the opposite plates of the latter being connected to the terminals of

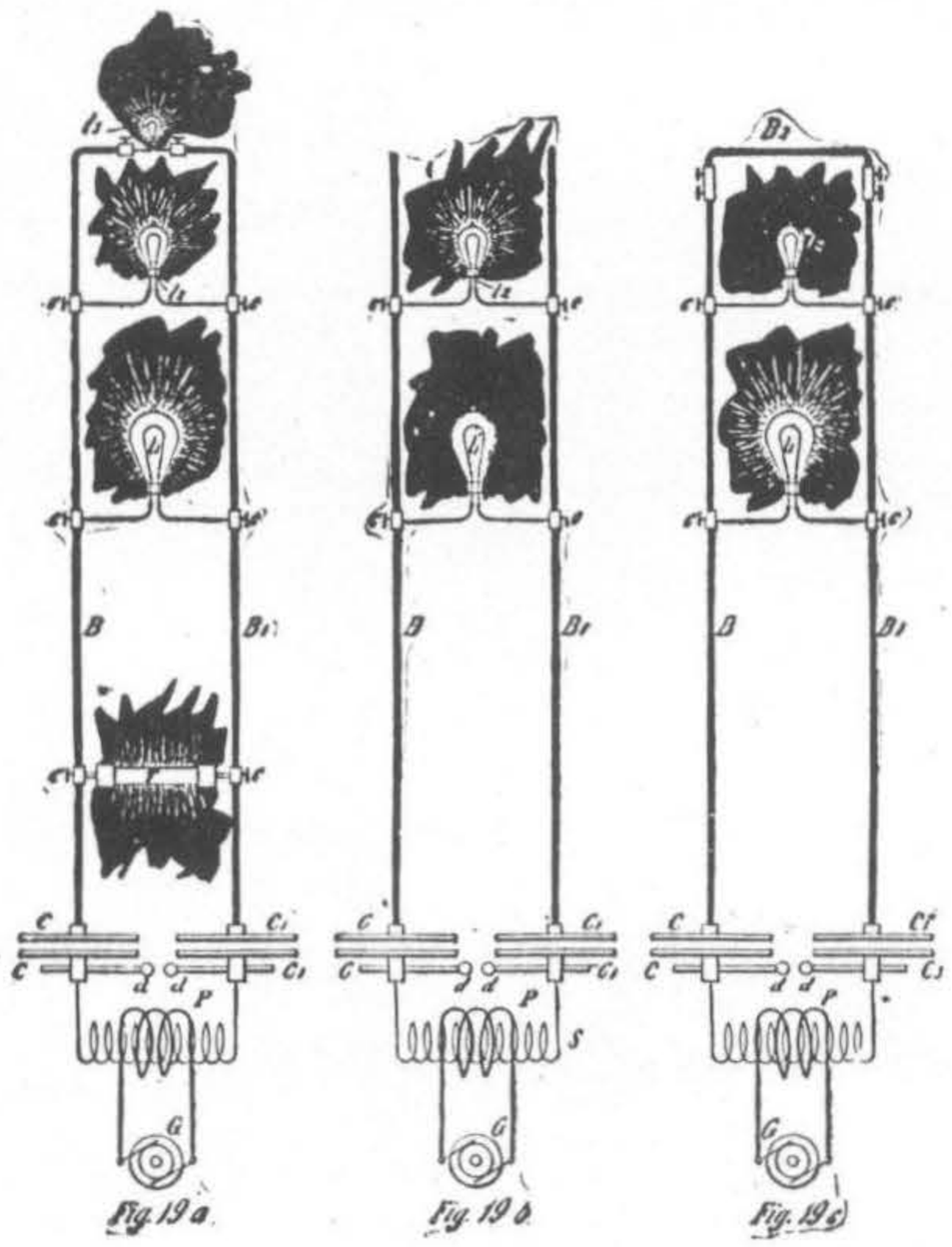


Fig. 19a. Fig. 19b. Fig. 19c.

the secondary, S, of a high-tension transformer, the primary, P, of which is supplied with alternating currents from an ordinary low-frequency dynamo, G, or distribution circuit. The condenser discharges through an adjustible gap, *d*, *d*, as usual. By establishing a rapid vibration it was found quite easy to perform the following curious experiment. The bars, B and B_1, were joined at the top by a low-voltage lamp, l_3; a little lower, was placed by means of clamps, *c*, *c*, a 50-volt lamp, l_2, and still lower, another 100-volt lamp, l_1, and finally, at a certain distance below the latter lamp an exhausted tube, T. By carefully determining the positions of these devices it was found practicable to maintain them all at their proper illuminating power. Yet they were all connected in multiple arc to the two stout copper bars and required widely different pressures. This experiment requires, of course, some time for adjustment, but is quite easily performed.

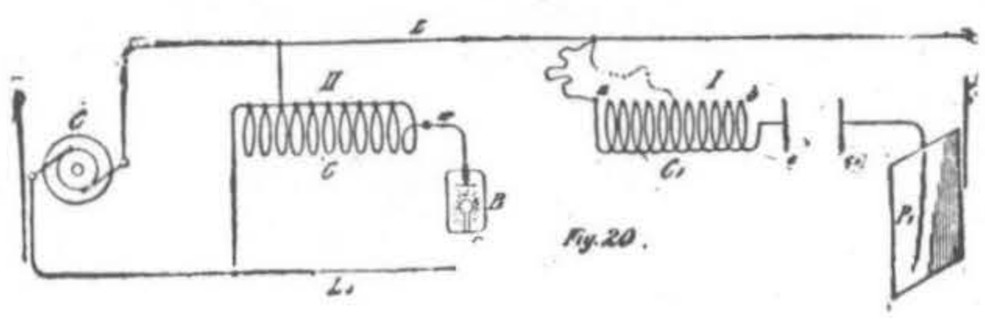


Fig. 20.

In figs. 19*b* and 19*c*, two other experiments are illustrated which, unlike the previous experiment, do not require very careful adjustment. In fig. 20*b*, two lamps, l_1 and l_2, the former a 100-volt and the latter a 50-volt, are placed in certain positions as indicated, the 100-volt lamp being below the 50-volt lamp. When the arc is playing at, *d*, *d*, and the sudden discharges passed through the bars, B, B, the 50-volt lamp will, as a rule, burn brightly, or at least this result is easily secured, while the 100-volt lamp will burn very low or remain quite dark, fig. 19*b*. Now the bars, B, B, may be joined at the top by a thick cross bar, B_2, and it is quite easy to maintain the 100-volt lamp at full candle-power while the 50-volt lamp remains dark, fig. 19*c*. These results, as I have pointed out previously, should not be considered to be due exactly to frequency, but rather to the time rate of change, which may be great even with low frequencies. A great many other results of the same kind, equally interesting, especially to those who are only used to manipulate steady currents, may be obtained, and they afford precious clues in investigating the nature of electric currents.

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24th, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1st, 1893.

In the preceding experiments I have already had occasion to show some light phenomena, and it would be now proper to study these in particular; but to make this investigation more complete, I think it necessary to first make a few remarks on the subject of electrical resonance, which has to be always observed in carrying out these experiments.

ON ELECTRICAL RESONANCE.

The effects of resonance are being more and more noted by engineers, and are becoming of great importance in the practical operation of apparatus of all kinds with alternating currents. A few general remarks may therefore be made concerning these effects. It is clear that, if we succeed in employing the effects of resonance practically in the operation of electric devices, the return wire will, as a matter of course, become unnecessary, for the electric vibration may be conveyed with one wire just as well, and sometimes even better, than with two. The question first to answer is, then, whether pure resonance effects are producible? Theory and experiment both show that such is impossible in Nature, for as the oscillation becomes more and more vigorous, the losses in the vibrating bodies and environing media rapidly increase, and necessarily check the vibration which otherwise would go on increasing for ever. It is a fortunate circumstance that pure resonance is not producible, for if it were there is no telling what dangers might not lie in wait for the innocent experimenter. But to a certain degree resonance is producible, the magnitude of the effects being limited by the imperfect conductivity and imperfect elasticity of the media, or, generally stated, by frictional losses. The smaller these losses, the more striking are the effects. The same is the case in mechanical vibration. A stout steel bar may be set in vibration by drops of water falling upon it at proper intervals; and with glass, which is more perfectly elastic, the resonance effect is still more remarkable, for a goblet may be burst by singing into it a note of the proper pitch. The electrical resonance is the more perfectly attained the smaller the resistance or the impedance of the conducting path and the more perfect the dielectric. In a Leyden jar discharging through a short stranded cable of thin wires these requirements are probably best fulfilled, and the resonance effects are therefore very prominent. Such is not the case with dynamo machines, transformers and their circuits, or with commercial apparatus in general in which the presence of iron cores complicates, or renders impossible, the action. In regard to Leyden jars, with which resonance effects are frequently demonstrated, I would say that the effects observed are often *attributed*, but are seldom *due*, to true resonance, for an error is quite easily made in this respect. This may be undoubtedly demonstrated by the following experiment. Take, for instance, two large insulated metallic plates or spheres which I shall designate A and B, place them at a certain small distance apart and charge them from a frictional or influence machine to a potential so high that just a slight increase of the difference of potential between them will cause the small air or insulating space to break down. This is easily reached by making a few preliminary trials. If now another plate—fastened on an insulating handle and connected by a wire to one of the terminals of a high tension secondary of an induction coil, which is maintained in action by an alternator (preferably high frequency)—is approached to one of the charged bodies, A or B, so as to be nearer to either one of them, the discharge will invariably occur between them; at least it will, if the potential of the coil in connection with the plate is sufficiently high. But the explanation of this will soon be found in the fact that the approached plate acts inductively upon the bodies, A and B, and causes a spark to pass between them. When this spark occurs, the charges, which were previously imparted to these bodies from the influence machine, must needs be lost, since the bodies are brought in electrical connection through the arc formed. Now this arc is formed whether there be resonance or not. But even if the spark would not be produced, still there is an alternating E.M.F. set up between the bodies when the plate is brought near one of them; therefore the approach of the plate, if it *does* not always, actually, will, at any rate, *tend*, to break down the air space by inductive action. Instead of the spheres or plates, A and B, we may take the coatings of a Leyden jar with the same result, and in place of the machine, which is a high frequency alternator preferably, because it is more suitable for the experiment and also for the argument, we may take another Leyden jar or battery of jars. When such jars are discharging through a circuit of low resistance the same is traversed by currents of very high frequency. The plate may now be connected to one of the coatings of the second jar, and when it is brought near to the first jar just previously charged to a high potential from an influence machine, the result is the same as before, and the first jar will discharge through a small air space upon the second being caused to discharge. But both jars and their circuits need not be tuned any closer than a basso profundo is to the note produced by a mosquito, as small sparks will be produced through the air space, or at least the latter will be considerably more strained owing to the setting up of an alternating E.M.F. by induction, which takes place when one of the jars begin to discharge. Again, another error of a similar nature is quite easily made. If the circuits of the two jars are run parallel and close together, and the experiment has been performed of discharging one by the other, and now a coil of wire be added to one of the circuits whereupon the experiment does not succeed, the conclusion that this is due to the fact that the circuits are now not tuned, would be far from being safe. For the two circuits act as condenser coatings and the addition of the coil to one of them is equivalent to bridging them, at the point where the coil is placed, by a small condenser, and the effect of the latter might be to prevent the spark from jumping through the discharge space by diminishing the alternating E.M.F. acting across the same. All these remarks, and many more which might be added but for fear of wandering too far from the subject, are made with the pardonable intention of cautioning the unsuspecting student, who might gain an entirely unwarranted opinion of his skill when seeing every experiment succeed; but they are in no way thrust upon the experienced as novel observations.

In order to make reliable observations of electric resonance effects, it is very desirable, if not necessary, to employ an alternator giving currents which rise and fall harmonically, as in working with make and break currents the observations are not always trustworthy, since many phenomena, which depend on the rate of change, may be produced with frequencies widely different. Even when making such observations with an alternator one is apt to be mistaken. When a circuit is connected to an alternator there are an infinite number of values for capacity and self-induction which, in conjunction, will satisfy the condition of resonance. So there are in mechanics an infinite number of tuning forks which will respond to a note of a certain pitch, or loaded springs which have a definite period of vibration. But the resonance will be most perfectly attained in that case in which the motion is effected with the greatest freedom. Now, in mechanics, considering the vibration in the common medium—that is, air—it is of comparatively little importance whether one tuning fork be somewhat larger than another, because the losses in the air are not very considerable. One may, of course, enclose a tuning fork in an exhausted vessel, and, by thus reducing the air resistance to a minimum, obtain better resonant action. Still, the difference would not be very great. But it would make a great difference if the tuning fork were immersed in mercury. In the electrical vibration it is of enormous importance to arrange the conditions so that the vibration is effected with the greatest freedom. The magnitude of the resonance effect depends, under otherwise equal conditions, on the quantity of electricity set in motion, or on the strength of the current driven through the circuit. But the circuit opposes the passage of the currents by reason of its impedance, and, therefore, to secure the best action it is necessary to reduce the impedance to a minimum. It is impossible to overcome it entirely, but merely in part, for ohmic resistance cannot be overcome. But when the frequency of the impulses is very great, the flow of the current is practically determined by self-induction. Now, self-induction can be overcome by combining it with capacity. If the relation between these is such that at the frequency used they annul each other, that is, have such values as to satisfy the condition of resonance, and the greatest quantity of electricity is made to flow through the external circuit, then the best result is obtained. It is simpler and safer to join the condenser in series with the self-induction. It is clear that in such combinations there will be, for a given frequency, and considering only the fundamental vibration, values which will give the best result with the condenser in shunt to the self-induction coil; of course, more such values than with the condenser in series. But practical conditions determine the selection. In the latter case, in performing the experiments one may take a small self-induction and a large capacity, or a small capacity and a large self-induction, but the latter is preferable, because it is inconvenient to adjust a large capacity by small steps. By taking a coil with a very large self-induction the critical capacity is reduced to a very small value, and the capacity of the coil itself may be sufficient. It is easy, especially by observing certain artifices, to wind a coil through which the impedance will be reduced to the value of the ohmic resistance only, and for any coil there is, of course, a frequency at which the maximum current will be made to pass through the coil. The observation of the relation between self-induction, capacity, and frequency is becoming important in the operation of alternate current apparatus, such as transformers or motors, because by a judicious determination of the elements the employment of an expensive condenser becomes unnecessary. Thus it is possible to pass through the coils of an alternating current motor under the normal working conditions the required current with a low E.M.F., and do away entirely with the false current, and the larger the motor the easier such a plan becomes practicable; but it is necessary for this to employ currents of very high potential or high frequency.

In fig. 20 I is shown a plan which has been followed in the study of the resonance effects by means of a high frequency alternator. C is a coil of many turns, which is divided in small separate sections for the purposes of adjustment. The final adjustment was made sometimes with a few thin iron wires (though this is not always advisable) or with a closed secondary. The coil, C, is connected with one of its ends to the line, L, from the alternator, G, and with the other end to one of the plates, c, of a condenser, c, c_1, the plate (c_1) of the latter being connected to a much larger plate, P_1. In this manner both capacity and self-induction were adjusted to suit the dynamo frequency.

As regards the rise of potential through resonant action, of course, theoretically, it may amount to anything, since it depends on self-induction and resistance, and since these may have any value. But in practice one is limited in the selection of these values, and besides these, there are other limiting causes. One may start with, say, 1,000 volts, and raise the E.M.F. to 50 times that value, but one cannot start with 100,000 and raise it to 10 times that value, because of the losses in the media, which are great, especially if the frequency is high. It should be possible to start with, for instance, 2 volts from a high or low frequency circuit of a dynamo, and raise the E.M.F. to many hundred times that value. Thus coils of the proper dimensions might be connected each with only one of its ends to the mains from a machine of low E.M.F., and though the circuit of the machine would not be closed in the ordinary acceptance of the term, yet the machine might be burned out if a proper resonance effect would be obtained. I have not been able to produce, nor have I observed with currents from the dynamo machine, such great rises of potential. It is possible, if not probable, that with currents obtained from apparatus containing iron the disturbing influence of the latter is the cause that these theoretical possibilities cannot be realised. But if such is the case, I attribute it solely to the hysteresis and Foucault

current losses in the core. Generally it was necessary to transform upward, when the E.M.F. was very low, and usually an ordinary form of induction coil was employed, but sometimes the arrangement illustrated in fig. 2011, has been found to be convenient. In this case a coil, C, is made in a great many sections, a few of these being used as the primary. In this manner both primary and secondary are adjustable. One end of the coil is connected to the line, L_1, from the alternator, and the other line, L, is connected to the intermediate point of the coil. Such a coil with adjustable primary and secondary will be found also convenient in experiments with the disruptive discharge. When true resonance is obtained the top of the wave must, of course, be on the free end of the coil as, for instance, at the terminal of the phosphorescence bulb, B. This is easily recognised by observing the potential of a point on the wire, *w*, nearer to the coil.

(To be continued.)

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.†

BY NIKOLA TESLA.

(*Continued from page* 53.)

In connection with resonance effects and the problem of transmission of energy over a single conductor which was previously considered, I would say a few words on a subject which constantly fills my thoughts and which concerns the welfare of all. I mean the transmission of intelligible signals or perhaps even power to any distance without the use of wires. I am becoming daily more convinced of the practicability of the scheme; and though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realised, yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day. The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb by means of powerful machines the electrostatic condition of the earth and thus transmit intelligible signals and perhaps power. In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why then not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile-posts the earth may appear very large, but to that happiest of all men, the astronomer, who gazes at the heavens and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician, for when he considers the speed with which an electric disturbance is propagated through the earth all his ideas of distance must completely vanish.

A point of great importance would be first to know what is the capacity of the earth? and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation. If it be a charged body insulated in space its capacity should be extremely small, less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in the free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is, by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely-electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric currents. One of the terminals of the source would be connected to earth, as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata or free space contains an opposite charge, and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low, and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible, and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body, and watching for the disturbance at various neighbouring points of the earth's surface resonance might be detected. Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do, and a proper electrical oscillator would have to be produced, and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface.

Assume that a source of alternating currents, S, be connected, as in fig. 21, with one of its terminals to earth (conveniently to the water mains) and with the other to a body of large surface, P. When the electric oscillation is set up there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to, or diverging from, the point, C, where the ground connection is made. In this manner neighbouring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body, P, is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source, S, will set up the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration at least of a certain low period upon the earth, by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured. I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at the surface could be but extremely small, considering the size of the earth, the air would not act as a very disturbing factor, and there would be not much energy lost through the action of the air, which would be the case if the density were great. Theoretically, then, it could not require a great amount of energy to produce a disturbance perceptible at great distance, or even all over the surface of the globe. Now, it is quite certain that at any point within a certain radius of the source, S, a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source, S_1, fig. 21, similar to S, or any number of such sources can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source, S_1, if the same be of opposite phase to the source, S. I think that beyond

* "Equivalent Resistance, Self Induction and Capacity of Parallel Circuits with Harmonic Impressed Electromotive Force." Bedell and Crehore, *Phil. Mag.* September, 1892.

† A lecture delivered before the Franklin Institute, at Philadelphia, February 24th, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1st, 1893.

doubt it is possible to operate electrical devices in a city through the ground or pipe system by resonance from an electrical oscillator located at a central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realisation of the scheme of transmitting intelligence, or perhaps power, to any distance through the earth or environing medium. If this is at all possible, distance does not mean anything. Proper apparatus must first be produced by means of which the problem can be attacked, and I have devoted much thought to this subject. I am firmly convinced that it can be done, and hope that we shall live to see it done.

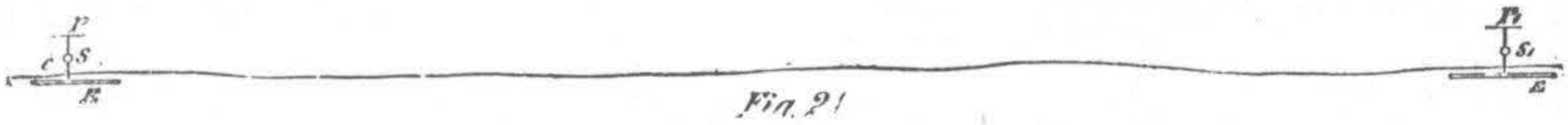


Fig. 21

ENERGY TRANSMISSION TO ANY DISTANCE WITHOUT WIRES.

ON THE LIGHT PHENOMENA PRODUCED BY HIGH-FREQUENCY CURRENTS OF HIGH POTENTIAL AND GENERAL REMARKS RELATING TO THE SUBJECT.

Returning now to the light effects which it has been the chief object to investigate, it is thought proper to divide these effects into four classes: 1. Incandescence of a solid. 2. Phosphorescence. 3. Incandescence or phosphorescence of a rarefied gas, and 4. Luminosity produced in a gas at ordinary pressure. The first question is, How are these luminous effects produced? In order to answer this question as satisfactorily as I am able to do in the light of accepted views, and with the experience acquired, and to add some interest to this demonstration, I shall dwell here upon a feature which I consider of great importance, inasmuch as it promises, besides, to throw a better light upon the nature of most of the phenomena produced by high-frequency electric currents. I have on other occasions pointed out the great importance of the presence of the rarefied gas, or atomic medium in general, around the conductor through which alternate currents of high frequency are passed, as regards the heating of the conductor by the currents. My experiments described some time ago have shown that the higher the frequency and potential difference of the currents, the more important becomes the rarefied gas in which the conductor is immersed, as a factor of the heating. The potential difference, however, is, as I then pointed out, a more important element than the frequency. When both of these are sufficiently high, the heating may be almost entirely due to the presence of the rarefied gas. The experiments to follow will show the importance of the rarefied gas, or generally of gas at ordinary or other pressure as regards the incandescence or other luminous effects produced by currents of this kind.

I take two ordinary 50 volt 16 C.P. lamps which are in every respect alike, with the exception, that one has been opened at the top and the air has filled the bulb, while the other is at the ordinary degree of exhaustion of commercial lamps. When I attach the lamp which is exhausted to the terminal of the secondary of the coil, which I have already used as in experiments illustrated in fig. 15*a* for instance, and turn on the current, the filament as you have before seen comes to high incandescence. When I attach the second lamp, which is filled with air, instead of the former, the filament still glows, but much less brightly. This experiment illustrates only in part the truth of the statements before made. The importance of the filament's being immersed in rarefied gas is plainly noticeable but not to such a degree as might be desirable. The reason is that the secondary of this coil is wound for low tension, having only 150 turns, and the potential difference at the terminals of the lamp is therefore small. Were I to take another coil with many more turns in the secondary, the effect would be increased, since it depends partially on the potential difference, as before remarked. But since the effect likewise depends on the frequency, it may be properly stated that it depends on the time rate of the variation of the potential difference. The greater this variation the more important becomes the gas as an element of heating. I can produce a much greater rate of variation in another way, which, besides has the advantage of doing away with the objections, which might be made in the experiment just shown, even if both the lamps were connected in series or multiple arc to the coil, namely, that in consequence of the reactions existing between the primary and secondary coil the conclusions are rendered uncertain. This result I secure by charging from an ordinary transformer, which is fed from the alternating current supply station, a battery of condensers, and discharging the latter directly through a circuit of small self-induction, as before illustrated in fig. 19*a*, 19*b*, 19*c*.

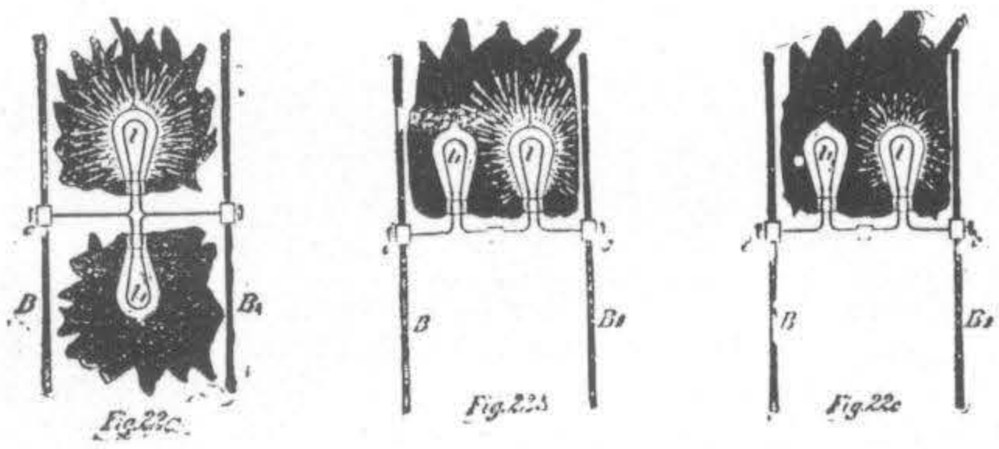


Fig. 22c Fig. 22b Fig. 22c

SHOWING THE EFFECT OF THE PRESENCE OF A GASEOUS MEDIUM.

In figs. 22*a*, 22*b*, and 22*c*, the heavy copper bars, BB_1, are connected to the opposite coatings of a battery of condensers, or generally in such way, that the high frequency or sudden discharges are made to traverse them. I connect first an ordinary 50-volt incandescent lamp to the bars by means of the clamps, *cc*. The discharges being passed through the lamp, the filament is rendered incandescent, though the current through it is very small, and would not be nearly sufficient to produce a visible effect under the conditions of ordinary use of the lamp. Instead of this I now attach to the bars another lamp exactly like the first, but with the seal broken off, the bulb being therefore filled with air at ordinary pressure. When the discharges are directed through the filament, as before, it does not become incandescent. But the result might still be attributed to one of the many possible reactions. I therefore connect both the lamps in multiple arc, as illustrated in fig. 22*a*. Passing the discharges through both the lamps, again the filament in the exhausted lamp, l, glows very brightly, while that in the non-exhausted lamp, l_1, remains dark, as previously. But it should not be thought that the latter lamp is taking only a small fraction of the energy supplied to both the lamps; on the contrary, it may consume a considerable portion of the energy and it may become even hotter than the one which burns brightly. In this experiment the potential difference at the terminals of the lamps varies in sign theoretically three to four million times a second. The ends of the filaments are correspondingly electrified, and the gas in the bulbs is violently agitated, and a large portion of the supplied energy is thus converted into heat. In the non-exhausted bulb there being a few million times more gas molecules than in the exhausted one, the bombardment, which is most violent at the ends of the filament, in the neck of the bulb, consumes a large portion of the energy without producing any visible effect. The reason is that, there being many molecules, the bombardment is quantitatively considerable, but the individual impacts are not very violent, as the speeds of the molecules are comparatively small, owing to the small free path. In the exhausted bulb, on the contrary, the speeds are very great, and the individual impacts are violent, and therefore better adapted to produce a visible effect. Besides, the convection of heat is greater in the former bulb. In both the bulbs the current traversing the filaments is very small, incomparably smaller than that which they require on an ordinary low-frequency circuit. The potential difference, however, at the ends of the filaments is very great, and might be possibly 20,000 volts or more, if the filaments were straight and their ends far apart. In the ordinary lamp a spark generally occurs between the ends of the filament or between the platinum wires outside, before such a difference of potential can be reached.

It might be objected in the experiment before shown, that the lamps, being in multiple arc, the exhausted lamp might take a much larger current, and that the effect observed might not be exactly attributable to the action of the gas in the bulbs. Such objections will lose much weight if I connect the lamps in series, with the same result. When this is done, and the discharges are directed through the filaments, it is again noted that the filament in the non-exhausted bulb, l_1, remains dark, while that in the exhausted one (l) glows even more intensely than under its normal conditions of working, fig. 22*b*. According to general ideas, the current through the filaments should now be the same, were it not modified by the presence of the gas around the filaments.

At this juncture I may point out another interesting feature, which illustrates the effect of the rate of change of potential of the currents. I will leave the two lamps connected in series to the bars, B, B_1, as in the previous experiment, fig. 22*b*, but will presently reduce considerably the frequency of the currents, which was excessive in the experiment just before shown. This I may do by inserting a self-induction coil in the path of the discharges, or by augmenting the capacity of the condensers. When I now pass these low-frequency discharges through the lamps, the exhausted lamp, l, again is as bright as before, but it is noted also that the non-exhausted lamp, l_1, glows, though not quite as intensely as the other. Reducing the current through the lamps, I may bring the filament in the latter lamp to redness, and though the filament in the exhausted lamp, l, is bright, fig. 22*c*, the degree of its incandescence is much smaller than in fig. 22*b*, when the currents were of a much higher frequency.

In these experiments the gas acts in two opposite ways in determining the degree of the incandescence of the filaments, that is, by convection and bombardnent. The higher the frequency and potential of the currents, the more important becomes the bombardment. The convection, on the contrary, should be the smaller, the higher the frequency. When the currents are steady, there is practically no bombardment, and convection may therefore, with such currents, also considerably modify the degree of incandescence and produce results similar to those just before shown. Thus, if two lamps exactly alike, one exhausted and one not exhausted, are connected in multiple arc or series to a direct current machine, the filament in the non-exhausted lamp will require a considerably greater current to be rendered incandescent. This result is entirely due to convection, and the effect is the more prominent the thinner the filament. Prof. Ayrton and Mr. Kilgour, some time ago published quantitative results concerning the thermal emissivity by radiation and convection in which the effect of thin wires was clearly shown. This effect may be strikingly illustrated by preparing a number of small short glass tubes, each containing through its axis the thinnest obtainable platinum wire. If these tubes be highly exhausted, a number of them

may be connected in multiple arc to a direct-current machine, and all of the wires may be kept at incandescence with a smaller current than that required to render incandescent a single one of the wires if the tube be not exhausted. Could the tubes be so highly exhausted that convection would be nil, then the relative amounts of heat given off by convection and radiation could be determined without the difficulties attending thermal quantitative measurements. If a source of electric impulses of high frequency and very high potential is employed, a still greater number of the tubes may be taken, and the wires rendered incandescent by a current not capable of warming perceptibly a wire of the same size immersed in air at ordinary pressure, and conveying the energy to all of them.

I may here describe a result which is still more interesting, and to which I have been led by the observation of these phenomena. I noted that small differences in the density of the air produced a considerable difference in the degree of incandescence of the wires, and I thought that, since in a tube, through which a luminous discharge is passed, the gas is generally not of uniform density, a very thin wire contained in the tube might be rendered incandescent at certain places of smaller density of the gas, while it would remain dark at the places of greater density, where the convection would be greater, and the bombardment less intense. Accordingly a tube, *t*, was prepared, as illustrated in fig. 23, which contained through the middle

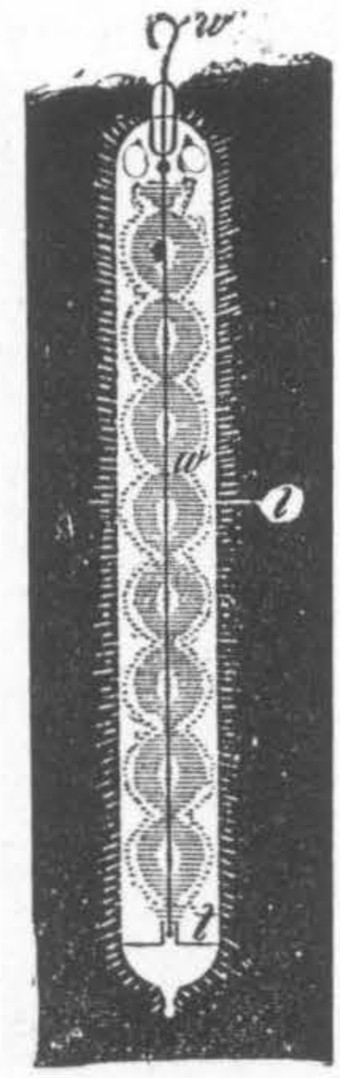


FIG. 23.—CURIOUS INCANDESCENCE OF A WIRE.

a very fine platinum wire, *w*. The tube was exhausted to a moderate degree, and it was found that when it was attached to the terminal of a high-frequency coil, the platinum wire, *w*, would, indeed, become incandescent in patches, as illustrated in fig. 23. Later, a number of these tubes, with one or more wires, were prepared, each showing this result. The effect was best noted when the striated discharge occurred in the tube, but was also produced when the striæ were not visible, showing that, even then, the gas in the tube was not of uniform density. The position of the striæ was generally such, that the rarefactions corresponded to the places of incandescence or greater brightness on the wire, *w*. But in a few instances it was noted that the bright spots on the wire were covered by the dense parts of the striated discharge, as indicated by *l* in fig. 23, though the effect was barely perceptible. This was explained in a plausible way by assuming that the convection was not widely different in the dense and rarefied places, and that the bombardment was greater on the dense places of the striated discharge. It is, in fact, often observed in bulbs, that under certain conditions a thin wire is brought to higher incandescence when the air is not too highly rarefied. This is the case when the potential of the coil is not high enough for the vacuum, but the result may be attributed to many different causes. In all cases this curious phenomenon of incandescence disappears when the tube, or rather the wire, acquires throughout a uniform temperature.

Disregarding now the modifying effect of convection there are then two distinct causes which determine the incandescence of a wire or filament with varying currents, that is, conduction current and bombardment. With steady currents we have to deal only with the former of these two causes, and the heating effect is a minimum, since the resistance is least to steady flow. When the current is a varying one, the resistance is greater, and hence the heating effect is increased. Thus if the rate of change of the current is very great, the resistance may increase to such an extent that the filament is brought to incandescence with inappreciable currents, and we are able to take a short and thick block of carbon or other material and bring it to bright incandescence with a current incomparably smaller than that required to bring to the same degree of incandescence an ordinary thin lamp filament with a steady or low frequency current. This result is important, and illustrates how rapidly our views on these subjects are changing, and how quickly our field of knowledge is extending. In the art of incandescent lighting, to view this result in one aspect only, it has been commonly considered as an essential requirement for practical success, that the lamp filament should be thin and of high resistance. But now we know that the resistance to the steady flow of the filament does not mean anything; the filament might as well be short and thick; for if it be immersed in rarefied gas it will become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents. We may conclude from this, that it would be of advantage, so far as the lamp is considered, to employ high frequencies for lighting, as they allow the use of short and thick filaments and smaller currents.

(To be continued.)

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(*Continued from page* 83.)

If a wire or filament be immersed in a homogeneous medium, all the heating is due to true conduction current, but if it be enclosed in an exhausted vessel the conditions are entirely different. Here the gas begins to act, and the heating effect of the conduction current, as is shown in many experiments, may be very small compared with that of the bombardment. This is especially the case if the circuit is not closed and the potentials of course very high. Suppose a fine filament enclosed in an exhausted vessel be connected with one of its ends to the terminal of a high tension coil and with its other end to a large insulated plate. Though the circuit is not closed, the filament, as I have before shown, is brought to incandescence. If the frequency and potential be comparatively low, the filament is heated by the current passing *through* it. If the frequency and potential, and principally the latter, be increased, the insulated plate need be but very small, or may be done away with entirely; still the filament will become incandescent, practically all the heating being then due to the bombardment. A practical way of combining both the effects of conduction current and bombardment is illustrated in fig. 24, in which an ordinary lamp is

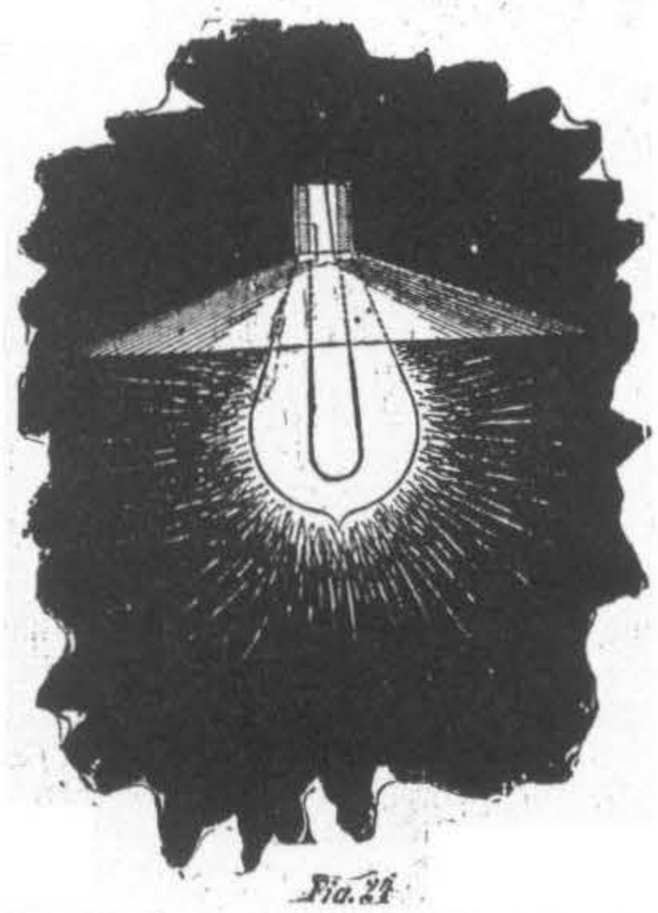


Fig. 24.

UTILISING THE HEATING EFFECT OF CONDUCTION CURRENT AND BOMBARDMENT.

shown, provided with a very thin filament, which has one of the ends of the latter connected to a shade serving the purpose of the insulated plate, and the other end to the terminal of a high tension source. It should not be thought that only rarefied gas is an important factor in the heating of a conductor by varying currents, but gas at ordinary pressure may become important, if the potential difference and frequency of the currents is excessive. On this subject I have already stated, that when a conductor is fused by a stroke of lightning, the current through it may be exceedingly small, not even sufficient to heat the conductor perceptibly, were the latter immersed in a homogeneous medium.

From the preceding it is clear that when a conductor of high resistance is connected to the terminals of a source of high-frequency currents of high potential, there may occur considerable dissipation of energy, principally on the ends of the conductor, in consequence of the action of the gas surrounding the conductor. Owing to this, the current, through a section of the conductor at a point midway between its ends, may be much smaller than through a section near the ends. Furthermore, the current passes principally through the outer portions of the conductor; but this effect is to be distinguished from the skin effect as ordinarily interpreted, for the latter would or should occur also in a continuous incompressible medium. If a great many incandescent lamps are connected in series to a source of such currents, the lamps at the ends may burn brightly, whereas those in the middle may remain entirely dark. This is due principally to bombardment, as before stated. But even if the currents be steady, provided the difference of potential is very great, the lamps at the ends will burn more brightly than those in the middle. In such case there is no rhythmical bombardment, and the result is produced entirely by leakage. This leakage or dissipation into space, when the tension is high, is considerable when incandescent lamps are used, and still more considerable with arcs, for the latter act like flames. Generally, of course, the dissipation is much smaller with steady than with varying currents.

I have contrived an experiment which illustrates in an interesting manner the effect of lateral diffusion. If a very long tube is attached to the terminal of a high-frequency coil, the luminosity is greatest near the terminal, and falls off gradually towards the remote end. This is more marked if the tube is narrow.

A small tube about ½ inch in diameter, and 12 inches long, fig. 25, has one of its ends drawn out into a fine fibre, *f*, nearly 3 feet long. The tube is placed in a brass socket, T, which can be screwed on the terminal, T_1, of the induction coil. The discharge passing through the tube first, illuminates the bottom of the same, which is of comparatively large section; but through the long glass fibre the discharge cannot pass. But gradually the rarefied gas inside becomes warmed and more conducting, and the discharge spreads into the glass fibre. This spreading is so slow, that it may take half a minute or more until the discharge has worked through up to the top of the glass fibre, then presenting the appearance of a strongly luminous thin thread. By adjusting the potential at the terminal, the light may be made to travel upwards at any speed. Once, however, the glass fibre is heated, the discharge breaks through its entire length instantly. The interesting point to be noted is that, the higher the frequency of the currents, or in other words, the greater relatively the lateral dissipation, at a slower rate may the light be made to propagate through the fibre. This experiment is best performed with a highly exhausted and freshly made tube. When the tube has been used for some time, the experiment often fails. It is possible that the gradual and slow impairment of the vacuum is the cause. This slow propagation of the discharge through a very narrow glass tube corresponds exactly to the propagation of heat through a bar warmed at one end. The quicker the heat is carried away laterally, the longer time it will take for the heat to warm the remote end. When the current of a low frequency coil is passed through the fibre from end to end, then the lateral dissipation is small, and the discharge instantly breaks through almost without exception.

After these experiments and observations, which have shown the importance of the discontinuity or atomic structure of the medium, and which will serve to explain, in a measure, at least, the nature of the four kinds of light effects produceable with these currents, I may now give you an illustration of these effects. For the sake of interest, I may do this in a manner which, to many of you, might be novel. You have seen before that we may now convey the electric vibration to a body by means of a single wire or conductor of any kind. Since the human frame is conducting, I may convey the vibration through my body.

First, as in some previous experiments. I connect my body with one of the terminals of a high tension transformer, and take in my hand an exhausted bulb, which contains a small carbon button mounted upon a platinum wire, leading to the outside of the bulb, and the button is rendered incandescent as soon as the transformer is set to work (fig. 26). I may place a conducting shade on the bulb, which serves to intensify the action, but is not necessary. Nor is it required that the button should be in conducting connection with the hand through a wire leading through the glass, for sufficient energy may be transmitted through the glass itself by inductive action to render the button incandescent.

Next I take a highly exhausted bulb containing a strongly phosphorescent body, above which is mounted a small plate of aluminium on a platinum wire leading to the outside, and the currents flowing through my body excite intense phosphorescence in the bulb, fig. 27. Next again I take in my hand a simple exhausted tube, and in the same manner the gas inside the tube is rendered highly incandescent or phosphorescent, fig. 28. Finally, I may take in my hand a wire, bare, or covered with thick insulation, it is quite immaterial; the electric vibration is so intense, as to cover the wire with a luminous film, fig. 29.

A few words must now be devoted to each of these phenomena. In the first place, I will consider the incandescence of a button or of a solid in general, and dwell upon some facts which apply equally to all these phenomena. It was pointed out before that when a thin conductor, such as a lamp filament, for instance, is connected with one of its ends to the terminal of a transformer of high tension the filament is brought to incandescence partly by a conduction current and partly by bombardment. The shorter and thicker the filament the more important becomes the latter and finally, reducing the filament to a mere button, all the heating must practically be attributed to the bombardment. So in the experiment before shown, the button is rendered incandescent by the rhythmical impact of freely movable small bodies in the bulb. These bodies may be the molecules of the residual gas, particles of dust or lumps torn from the electrode; whatever they are, it is certain that the heating of the button is essentially connected with the pressure of such freely movable particles, or of atomic matter in general in the bulb. The heating is the more intense the greater the number of impacts per second and the greater the energy of each impact. Yet the button would be heated also if it were connected to a source of a steady potential. In such a case electricity would be carried away from the button by the freely movable carriers or particles flying about, and the quantity of electricity thus carried away might be sufficient to bring the button to incandescence by its passage through the latter. But the bombardment could not be of great importance in such case. For this reason it would require a comparatively very great supply of energy to the button to maintain it at incandescence with a steady potential. The higher the frequency of the electric

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24th, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1st, 1893.

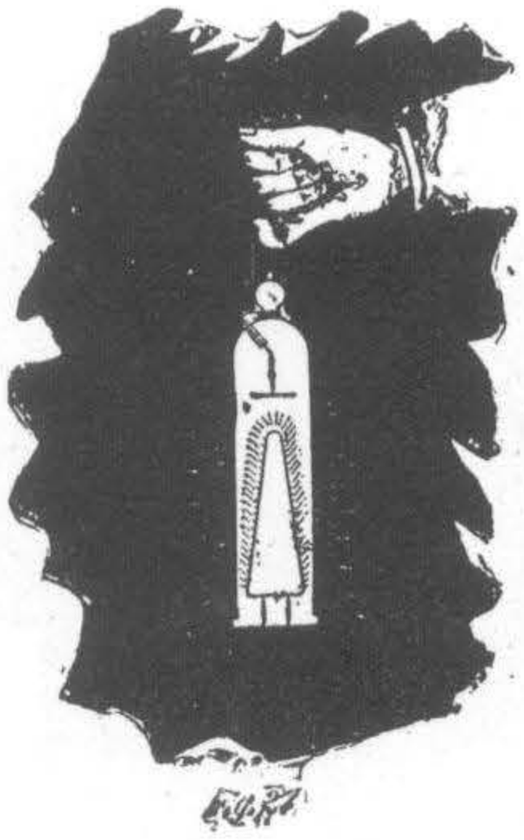
impulses the more economically can the button be maintained at incandescence. One of the chief reasons why this is so, is, I believe, that with impulses of very high frequency there is less exchange of the freely movable carriers around the electrode, and this means, that in the bulb the heated matter is better confined to the neighbourhood of the button. If a double bulb, as illustrated in fig. 30,



ILLUSTRATING LATERAL DIFFUSION.



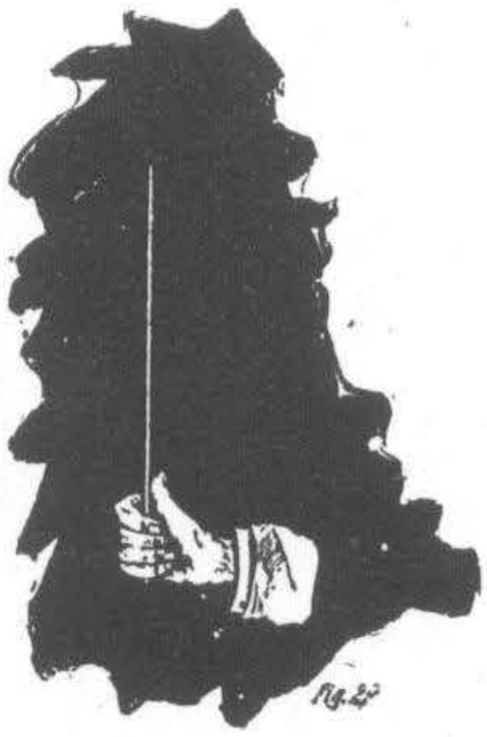
INCANDESCENCE OF A SOLID.



PHOSPHORESCENCE.

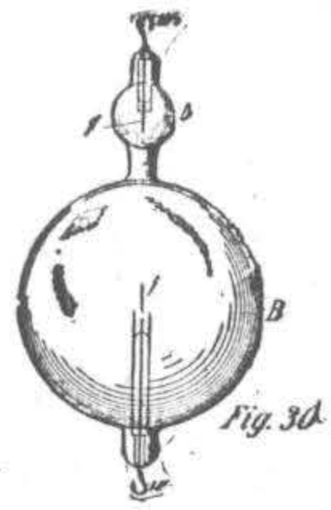


INCANDESCENCE OR PHOSPHORESCENCE OF RAREFIED GAS.



LUMINOSITY OF GAS AT ORDINARY PRESSURE.

be made, comprising a large globe, B, and a small one, *b*, each containing as usual a filament, *f*, mounted on a platinum wire, *w* and w_1, it is found that if the filaments, *f*, *f*, be exactly alike, it requires less energy to keep the filament in the globe, *b*, at a certain degree of incandescence, than that in the large globe, B. This is due to the confinement of the movable particles around the button. In this case it is also ascertained that the filament in the small globe, *b*, is less deteriorated when maintained a certain length of time at incandescence. This is a necessary consequence of the fact that the gas in the small bulb becomes strongly heated and therefore a very good conductor, and less work is then performed on the button, since the bombardment becomes less intense as the conductivity of the gas increases. In this construction, of course, the small bulb becomes very hot, and when it reaches an elevated temperature the convection and radiation on the outside increase. On another occasion I have shown bulbs in which this drawback was largely avoided. In these instances a very small bulb, containing a refractory button, was mounted in a large globe, and the space between the walls of both



SHOWING THE EFFECT OF CONFINING THE GAS AROUND THE ELECTRODE.

was highly exhausted. The outer large globe remained comparatively cool in such constructions. When the large globe was on the pump and the vacuum between the walls maintained permanent by the continuous action of the pump, the outer globe would remain quite cold, while the button in the small bulb was kept at incandescence. But when the seal was made, and the button in the small bulb maintained incandescent some length of time, the large globe too would become warmed. From this I conjecture that if vacuous space (as Prof. Dewar finds) cannot convey heat, it is so merely in virtue of our rapid motion through space or, generally speaking, by the motion of the medium relatively to us, for a permanent condition could not be maintained without the medium being constantly renewed. A vacuum cannot, according to all evidence, be permanently maintained around a hot body.

(To be continued.)

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(*Continued from page* 111.)

In these constructions, before mentioned, the small bulb inside would, at least in the first stages, prevent all bombardment against the outer, large globe. It occurred to me then to ascertain how a metal sieve would behave in this respect, and several bulbs, as illustrated in fig. 31, were prepared for this purpose. In a globe, *b*, was mounted a thin filament, *f* (or button) upon a platinum wire, *w*, passing through a glass stem and leading to the outside of the globe. The filament, *f*, was surrounded by a metal sieve, *s*. It was found in experiments with such bulbs that a sieve with wide meshes apparently did not in the slightest affect the bombardment against the globe, *b*. When the vacuum was high the shadow of the sieve was clearly projected against the globe, and the latter would get hot in a short while. In some bulbs the sieve, *s*, was connected to a platinum wire sealed in the glass. When this wire was connected to the other terminal of the induction coil (the E.M.F. being kept low in this case), or to an insulated plate, the bombardment against the outer globe, *b*, was diminished. By taking a sieve with fine meshes the bombardment against the globe, *b*, was always diminished, but even then if the exhaustion was carried very far, and when the potential of the transformer was very high, the globe, *b*, would be bombarded and heated quickly, though no shadow of the sieve was visible owing to the smallness of the meshes. But a glass tube or other continuous body mounted so as to surround the filament, entirely cut off the bombardment, and for a while the outer globe, *b*, would remain perfectly cold. Of course, when the glass tube was sufficiently heated the bombardment against the outer globe could be noted at once. The experiments with these bulbs seemed to show that the speeds of the projected molecules or particles must be considerable (though quite insignificant when compared with that of light), otherwise it would be difficult to understand how they could traverse a fine metal sieve without being affected, unless it were found that such small particles or atoms cannot be acted upon directly at measurable distances. In regard to the speed of the projected atoms, Lord Kelvin has recently estimated it at about one kilometre a second or thereabouts in an ordinary Crookes bulb. As the potentials obtainable with a disruptive discharge coil are much higher than with ordinary coils, the speeds must, of course, be much greater

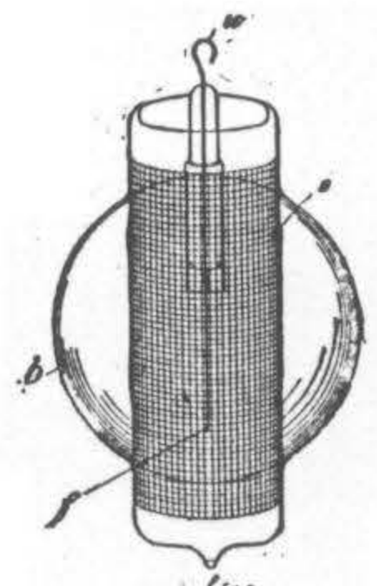


Fig. 31

SHOWING THE INEFFICIENCY OF A METAL SCREEN.

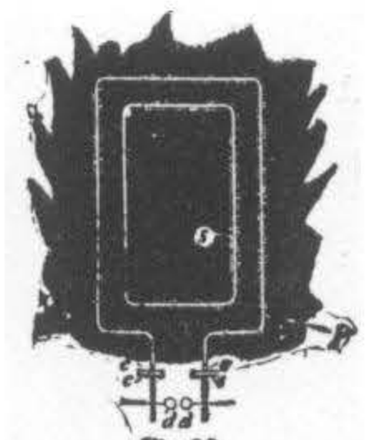


Fig. 32

ELECTROSTATIC ACTION BETWEEN PRIMARY AND SECONDARY, WITH EXTREMELY HIGH FREQUENCIES,

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24th, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1st, 1893.

when the bulbs are lighted from such a coil. Assuming the speed to be as high as 5 kilometres, and uniform through the whole trajectory, as it should be in a very highly exhausted vessel, then if the alternate electrifications of the electrode would be of a frequency of five million, the greatest distance a particle could get away from the electrode would be one millimetre, and if it could be acted upon directly at that distance, the exchange of electrode matter or of the atoms would be very slow, and there would be practically no bombardment against the bulb. This at least should be so, if the action of an electrode upon the atoms of the residual gas would be such as upon electrified bodies which we can perceive. A hot body enclosed in an exhausted bulb produces always atomatic bombardment, but a hot body has no definite rhythm, for its molecules perform vibrations of all kinds.

If a bulb containing a button or filament be exhausted as high as is possible, with the greatest care, and by the use of the best artifices, it is often observed that the discharge cannot, at first, break through, but after some time, probably in consequence of some changes within the bulb, the discharge finally passes through, and the button is rendered incandescent. In fact, it appears that the higher the degree of exhaustion, the easier is the incandescence produced. There seems to be no other causes to which the incandescence might be attributed in such case, except to the bombardment or similar action of the residual gas, or of particles of matter in general. But if the bulb be exhausted with the greatest care, can these play an important part? Assume the vacuum in the bulb to be tolerably perfect, the great interest then centres in the question: Is the medium which pervades all space continuous or atomic? If atomic, then the heating of a conducting button or filament in an exhausted vessel might be due largely to ether bombardment, and then the heating of a conductor in general through which currents of high frequency or high potential are passed, must be modified by the behaviour of such medium; then, also, the skin effect, the apparent increase of the ohmic resistance, &c., admit partially, at least, of a different explanation.

It is certainly more in accordance with many phenomena observed with high-frequency currents to hold that all space is pervaded with free atoms, rather than to assume that it is devoid of these, and dark and cold, for so it must be, if filled with a continuous medium, since in such there can be neither heat nor light. Is then energy transmitted by independent carriers, or by the vibration of a continuous medium? This important question is by no means as yet positively answered. But most of the effects which are here considered, especially the light effects, incandescence, or phosphorescence, involve the presence of free atoms, and would be impossible without these.

In regard to the incandescence of a refractory button (or filament) in an exhausted receiver, which has been one of the subjects of this investigation, the chief experiences, which may serve as a guide in constructing such bulbs, may be summed up as follows: 1. The button should be as small as possible, spherical, of a smooth or polished surface, and of refractory material which withstands evaporation best. 2. The support of the button should be very thin, and screened by an aluminium and mica sheet, as I have described on another occasion. 3. The exhaustion of the bulb should be as high as possible. 4. The frequency of the currents should be as high as practicable. 5. The currents should be of a harmonic rise and fall, without sudden interruptions. 6. The heat should be confined to the button by enclosing the same in a small bulb or otherwise. 7. The space between the walls of the small bulb and the outer globe should be highly exhausted.

Most of the considerations which apply to the incandescence of a solid just considered may likewise be applied to phosphorescence. Indeed, in an exhausted vessel, the phosphorescence is, as a rule, primarily excited by the powerful beating of the electrode stream of atoms against the phosphorescent body. Even in many cases, where there is no evidence of such a bombardment, I think that phosphorescence is excited by violent impacts of atoms, which are not necessarily thrown off from the electrode, but are acted upon from the same inductively through the medium or through chains of other atoms. That mechanical shocks play an important part in exciting phosphorescence in a bulb may be seen from the following experiment. If a bulb, constructed as that illustrated in fig. 10. be taken and exhausted with the greatest care, so that the discharge cannot pass, the filament, *f*, acts by electrostatic induction upon the tube, *t*, and the latter is set in vibration. If the tube, *o*, be rather wide, about an inch or so, the filament may be so powerfully vibrated that whenever it hits the glass tube it excites phosphorescence. But the phosphorescence ceases when the filament comes to rest. The vibration can be arrested and again started by varying the frequency of the currents. Namely, the filament has its own period of vibration, and if the frequency of the currents is such that there is resonance, it is set easily vibrating, though the potential of the currents be small. I have often observed that the filament in the bulb is destroyed by such mechanical resonance. The filament vibrates, as a rule, so rapidly, that it cannot be seen, and the experimenter may at first be mystified. When such an experiment as the one described is carefully performed, the potential of the currents need be extremely small, and for this reason I infer that the phosphorescence is then due to the mechanical shock of the filament against the glass, just as it is produced by striking a loaf of sugar with a knife. The mechanical shock produced by the projected atoms is easily noted when a bulb, containing a button, is grasped in the hand, and the current turned on suddenly. I believe that a bulb could be shattered by observing the conditions of resonance.

In the experiment before cited it is, of course, open to say, that the glass tube, upon coming in contact with the filament, retains a charge of a certain sign upon the point of contact. If now the filament again touches the glass at the same point while it is oppositely charged, the charges equalise under evolution of light. But nothing of importance would be gained by such an explanation. It is unquestionable that the initial charges given to the atoms or to the glass play some part in exciting phosphorescence. So, for instance, if a phosphorescent bulb be first excited by a high frequency coil by connecting it to one of the terminals of the latter and the degree of luminosity noted, and then the bulb be highly charged from a Holtz machine by attaching it preferably to the positive terminal of the machine, it is found that when the bulb is again connected to the terminal of the high frequency coil, the phosphorescence is far more intense. On another occasion I have considered the possibility of some phosphorescent phenomena in bulbs being produced by the incandescence of an infinitesimal layer on the surface of the phosphorescent body. Certainly, the impacts of the atoms are powerful enough to produce intense incandescence by the collisions, since they bring quickly to a high temperature a body of considerable bulk. If any such effect exists, then the best appliance for producing phosphorescence in a bulb, which we know so far, is a disruptive discharge coil giving an enormous potential with but few fundamental discharges, say, 25—30 per second, just enough to produce a continuous impression upon the eye. It is a fact that such a coil excites phosphorescence under almost any condition and at all degrees of exhaustion, and I have observed effects which appear to be due to phosphorescence even at ordinary pressures of the atmosphere, when the potentials are extremely high. But if phosphorescent light is produced by the equalisation of charges of electrified atoms (whatever this may mean ultimately), then the higher the frequency of the impulses or alternate electrifications, the more economical will be the light production. It is a long known and noteworthy fact that all the phosphorescent bodies are poor conductors of electricity and heat, and that all bodies cease to emit phosphorescent light when they are brought to a certain temperature. Conductors, on the contrary, do not possess this quality. There are but few exceptions to the rule. Carbon is one of them. Becquerel noted that carbon phosphoresces at a certain elevated temperature preceding the dark red. This phenomenon may be easily observed in bulbs provided with a rather large carbon electrode (say a sphere of six millimetres diameter). If the current is turned on after a few seconds, a snow-white film covers the electrode, just before it gets dark red. Similar effects are noted with other conducting bodies, but many scientific men will probably not attribute them to true phosphorescence. Whether true incandescence has anything to do with phosphorescence excited by atomic impact or mechanical shocks, still remains to be decided, but it is a fact that all conditions, which tend to localise and increase the heating effect at the point of impact, are almost invariably the most favourable for the production of phosphorescence. So, if the electrode be very small, which is equivalent to saying, in general, that the electric density is great, if the potential be high, and if the gas be highly rarefied, all of which things imply high speed of the projected atoms, or matter, and consequently violent impacts—the phosphorescence is very intense. If a bulb provided with a large and small electrode be attached to the terminal of an induction coil, the small electrode excites phosphorescence, while the large one may not do so, because of the smaller electric density and hence smaller speed of the atoms. A bulb provided with a large electrode may be grasped with the hand while the electrode is connected to the terminal of the coil, and it may not phosphoresce; but if instead of grasping the bulb with the hand, the same be touched with a pointed wire, the phosphorescence at once spreads through the bulb, because of the great density at the point of contact. With low frequencies it seems that gases of great atomic weight excite more intense phosphorescence than those of smaller weight, as, for instance, hydrogen. With high frequencies the observations are not sufficiently reliable to draw a conclusion. Oxygen, as is well known, produces exceptionally strong effects, which may be in part due to chemical action. A bulb with hydrogen residue seems to be most easily excited. Electrodes which are most easily deteriorated produce more intense phosphorescence in bulbs, but the condition is not permanent because of the impairing of the vacuum and the deposition of the electrode matter upon the phosphorescent surfaces. Some liquids, as oils, for instance, produce magnificent effects of phosphorescence (or fluorescence?), but they last only a few seconds. So if a bulb have a trace of oil on the walls, and the current is turned on, the phosphorescence only persists for a few moments until the oil is carried away. Of all bodies so far tried, sulphide of zinc seems to be the most susceptible to phosphorescence. Some samples obtained through the kindness of Prof. Henry, in Paris, were employed in many of these bulbs. One of the defects of this sulphide is, that it loses its quality of emitting light when brought to a temperature which is by no means high. It can, therefore, be used only for feeble intensities. An observation which might deserve notice is, that when violently bombarded from an aluminium electrode it assumes a black colour, but, singularly enough, it returns to the original condition when it cools down.

The most important fact arrived at in pursuing investigations in this direction is, that in all cases it is necessary, in order to excite phosphorescence with a minimum amount of energy, to observe certain conditions. Namely, there is always, no matter what the frequency of the currents, degree of exhaustion and character of the bodies in the bulb, a certain potential (assuming the bulb excited from one terminal) or potential difference (assuming the bulb to be excited with both terminals) which produces the most economical result. If the potential be increased, considerable energy may be wasted without producing any more light, and if it be diminished, then again the light production is not as economical. The exact condition under which the best result is obtained seems to depend on many things of a different nature and it is to be yet investigated by other experimenters, but it will certainly have to be observed when such phosphorescent bulbs are operated, if the best results are to be attained.

(To be continued.)

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(*Concluded from page* 154.)

Coming now to the most interesting of these phenomena, the incandescence or phosphorescence of gases, at low pressures or at the ordinary pressure of the atmosphere, we must seek the explanation of these phenomena in the same primary causes, that is, in shocks or impacts of the atoms. Just as molecules or atoms beating upon a solid body excite phosphorescence in the same or render it incandescent, so when colliding among themselves they produce similar phenomena. But this is a very insufficient explanation and concerns only the crude mechanism. Light is produced by vibrations which go on at a rate almost inconceivable. If we compute, from the energy contained in the form of known radiations in a definite space the force which is necessary to set up such rapid vibrations, we find, that though the density of the ether be incomparably smaller than that of any body we know, even hydrogen, the force is something surpassing comprehension. What is this force, which in mechanical measure, may amount to thousands of tons per square inch? It is electrostatic force in the light of modern views. It is impossible to conceive how a body of measurable dimensions could be charged to so high a potential that the force would be sufficient to produce these vibrations. Long before any such charge could be imparted to the body it would be shattered into atoms. The sun emits light and heat, and so does an ordinary flame or incandescent filament, but in neither of these can the force be accounted for if it be assumed that it is associated with the body as a whole. Only in one way may we account for it, namely, by identifying it with the atom. An atom is so small, that if it be charged by coming in contact with an electrified body and the charge be assumed to follow the same law as in the case of bodies of measurable dimensions, it must retain a quantity of electricity which is fully capable of accounting for these forces and tremendous rates of vibration. But the atom behaves singularly in this respect, it always takes the same "charge."

It is very likely that resonant vibration plays a most important part in all manifestations of energy in nature. Throughout space all matter is vibrating, and all rates of vibration are represented, from the lowest musical note to the highest pitch of the chemical rays, hence an atom, or complex of atoms, no matter what its period, must find a vibration with which it is in resonance. When we consider the enormous rapidity of the light vibrations, we realise the impossibility of producing such vibrations directly with any apparatus of measurable dimensions, and we are driven to the only possible means of attaining the object of setting up waves of light by electrical means and economically, that is, to affect the molecules or atoms of a gas, to cause them to collide and vibrate. We then must ask ourselves, How can free molecules or atoms be affected?

It is a fact that they can be affected by electrostatic force, as is apparent in many of these experiments. By varying the electrostatic force we can agitate the atoms, and cause them to collide under evolution of heat and light. It is not demonstrated beyond doubt that we can affect them otherwise. If a luminous discharge is produced in a closed exhausted tube, do the atoms arrange themselves in obedience to any other but to electrostatic force acting in straight lines from atom to atom? Only recently I investigated the mutual action between two circuits with extreme rates of vibration. When a battery of a few jars (*c*, *c*, *c*, *c*, fig. 32) is discharged through a primary, P, of low resistance (the connections being as illustrated in figs. 19*a*, 19*b*, and 19*c*), and the frequency of vibration be many million, there are great differences of potential between points on the primary not more than a few inches apart. These differences may be 10,000 volts per inch, if not more, taking the maximum value of the E.M.F. The secondary, *s*, is therefore acted upon by electrostatic induction, which is in such extreme cases of much greater importance than the electro-dynamic. To such sudden impulses the primary as well as the secondary are poor conductors, and therefore great differences of potential may be produced by electrostatic induction between adjacent points on the secondary. Then sparks may jump between the wires and streamers become visible in the dark if the light of the discharge through the spark gap, *d*, *d*, be carefully excluded. If now we substitute a closed vacuum tube for the metallic secondary, *s*, the differences of potential produced in the tube by electrostatic induction from the primary are fully sufficient to excite portions of it; but as the points of certain differences of potential on the primary are not fixed, but are generally constantly changing in position, a luminous band is produced in the tube, apparently not touching the glass, as it should, if the points of maximum and minimum differences of potential were fixed on the primary. I do not exclude the possibility of such a tube being excited only by electro-dynamic induction, for very able physicists hold this view; but, in my opinion, there is as yet no positive proof given that atoms of a gas in a closed tube may arrange themselves in chains under the action of an electromotive impulse produced by electro-dynamic induction in the tube. I have been unable, so far, to produce striæ in a tube, however long, and at whatever degree of exhaustion, that is, striæ at right angles to the supposed direction of the discharge or the axis of the tube, but I have distinctly observed in a large bulb, in which a wide luminous band was produced by passing a discharge of a battery through a wire surrounding the bulb, a circle of feeble luminosity between two luminous bands, one of which was more intense than the other. Furthermore, with my present experience, I do not think that such a gas discharge in a closed tube can vibrate, that is, vibrate as a whole. I am convinced that no discharge through a gas can vibrate. The atoms of a gas behave very curiously in respect to sudden electric impulses. The gas does not seem to possess any appreciable inertia to such impulses, for it is a fact that the higher the frequency of the impulses, with the greater freedom does the discharge pass through the gas. If the gas possesses no inertia, then it cannot vibrate, for some inertia is necessary for the free vibration. I conclude from this that if a lightning discharge occurs between two clouds, there can be no oscillation, such as would be expected, considering the capacity of the clouds. But if the lightning discharge strike the earth, there is always vibration—in the earth, but not in the air. In a gas discharge each atom vibrates at its own rate, but there is no vibration of the conducting gaseous mass as a whole. This is an important consideration in the great problem of producing light economically, for it teaches us that to reach this result we must use impulses of very high frequency and necessarily also of high potential. It is a fact that oxygen produces a more intense light in a tube. Is it because oxygen atoms possess some inertia and the vibration does not die out instantly? But then nitrogen should be as good, and chlorine and vapours of many other bodies much better than oxygen, unless the magnetic properties of the latter enter prominently into play. Or, is the process in the tube of an electrolytic nature? Many observations certainly speak for it, the most important being, that matter is always carried away from the electrodes and the vacuum in a bulb cannot be permanently maintained. If such process takes place in reality, then again must we take refuge to high frequencies, for with such, electrolytic action should be reduced to a minimum, if not rendered entirely impossible. It is an undeniable fact that with very high frequencies, provided the impulses be of a harmonic nature, like those obtained from an alternator, there is less deterioration and the vacua are more permanent. With disruptive discharge coils there are sudden rises of potential and the vacua are more quickly impaired, for the electrodes are deteriorated in a very short time. It was observed in some large tubes, which were provided with heavy carbon blocks, B, B_1, connected to platinum wires, w, w_1, (as illustrated in fig. 33),

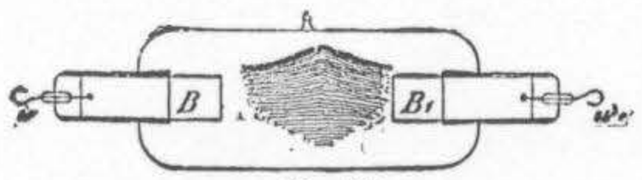
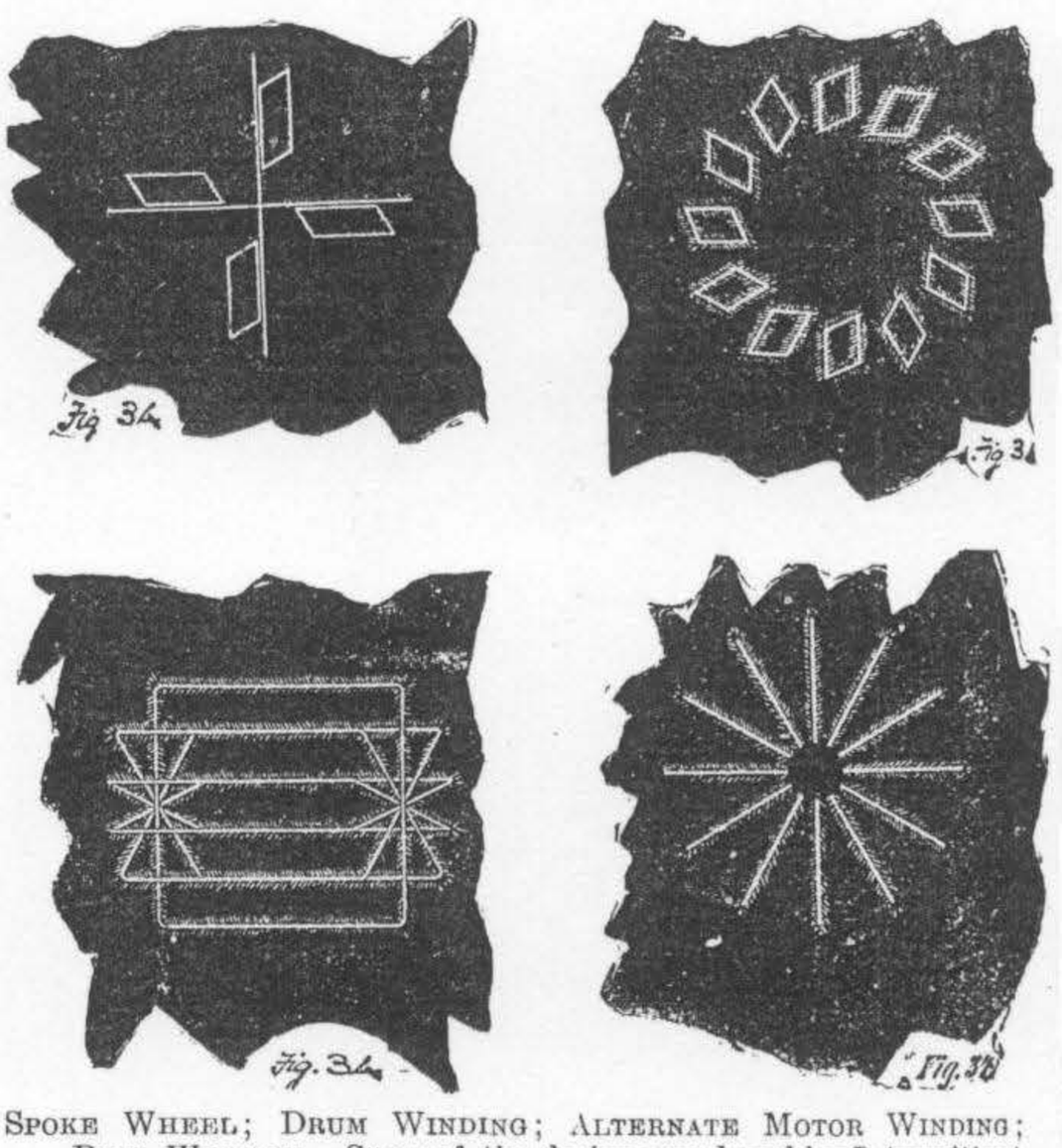


Fig. 33

CARBON DEPOSIT IN TUBE IN A MAGNETIC FIELD.

and which were employed in experiments with the disruptive discharge instead of the ordinary air gap, that the carbon particles under the action of the powerful magnetic field in which the tube was placed, were deposited in regular fine lines in the middle of the tube as illustrated. These lines were attributed to the deflection or distortion of the discharge by the magnetic field, but why the deposit occurred principally where the field was most intense did not appear quite clear. A fact of interest, likewise noted, was that the presence of a strong magnetic



SPOKE WHEEL; DRUM WINDING; ALTERNATE MOTOR WINDING; RING WINDING.—Some of the designs produced by Intermittent Discharges.

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24th, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1st, 1893.

field increases the deterioration of the electrodes, probably by reason of the rapid interruptions it produces, whereby there is actually a higher E.M.F. maintained between the electrodes.

Much would remain to be said about the luminous effects produced in gases at low or ordinary pressures. With the present experiences before us, we cannot say that the essential nature of these charming phenomena is sufficiently known. But investigations in this direction are being pushed with exceptional ardour. Every line of scientific pursuit has its fascinations, but electrical investigation appears to possess a peculiar attraction, for there is no experiment or observation of any kind in the domain of this wonderful science which would not forcibly appeal to us. Yet to me it seems, that of all the many marvellous things we observe, a vacuum tube, excited by an electric impulse from a distant source, bursting forth out of the darkness and illuminating the room with its beautiful light, is as lovely a phenomenon as can greet our eyes. More interesting still it appears when, reducing the fundamental discharges across the gap to a very small number and waving the tube about we produce all kinds of designs in luminous lines. So, by way of amusement, I take a straight long tube, or a square one, or a square attached to a straight tube and by whirling them about in the hand, I imitate the spokes of a wheel, a Gramme winding, a drum winding, an alternate current motor winding, &c. (fig. 34). Viewed from a distance the effect is weak, and much of its beauty is lost, but being near, or holding the tube in the hand, one cannot resist its charm.

In presenting these insignificant results, I have not attempted to arrange and co-ordinate them, as would be proper in a strictly scientific investigation, in which every succeeding result should be a logical sequence of the preceding, so that it might be guessed in advance by the careful reader or attentive listener. I have preferred to concentrate my energies chiefly upon advancing novel facts or ideas which might serve as suggestions to others, and this may serve as an excuse for the lack of harmony. The explanations of the phenomena have been given in good faith and in the spirit of a student prepared to find that they admit of a better interpretation. There can be no great harm in a student taking an erroneous view, but when great minds err, the world must dearly pay for their mistakes.

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NOTES.

Mr. Nikola Tesla's lecture, delivered in February last before the Franklin Institute at Philadelphia, and before the National Electric Light Association in March, has now been published in the American papers, and the first part of an abstract of it will be found in another column. On the whole, it is a disappointment, but Mr. Tesla's work is difficult to appreciate. The lecture begins with a long introduction on the value of vision as a connecting link between our consciousness and the world we live in. This leads to the consideration of light, and our abstract begins with the experimental part of the lecture. From a very large number of experiments having no very clear connection, we have selected those which are either novel, or which may be said to be self-contained. Many of those who have watched Mr. Tesla's work would like to see him concentrate his energies on some definite object, experimental rather than speculative, and having a direct bearing either on the elucidation of some branch of electrical or electro-optical science, or some utilitarian application. When we heard that many of his new lamps were patented, we expected that he would undertake an Edison-like investigation and produce some useful result. On the other hand, he might have turned off on the purely scientific lines of Prof. J. J. Thomson, lines which, we should think, would be more agreeable to Mr. Nikola Tesla than mere inventing. If a few quantitative determinations of current, voltage, or even of frequency, had been given in the lecture, it would have had a definite scientific value. To reduce even one out of the fifty experiments to a complete research, would be worth all the other forty-nine brilliant and suggestive demonstrations.

ON LIGHT AND OTHER HIGH-FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

A number of ways, as practised in the laboratory, of obtaining high-frequency currents either from continuous or low-frequency alternating currents are diagrammatically indicated in Fig. 1, which will be later described in detail. The general plan is to charge condensers, from a direct or alternate-current source, preferably of high-tension, and to discharge them disruptively while observing well-known conditions necessary to maintain the oscillations of the current. In view of the general interest taken in high-frequency currents and effects producible by them, it seems to me advisable to dwell at some length upon this method of conversion. In order to give you a clear idea of the action, I will suppose that a continuous-current generator is employed, which is often very convenient. It is desirable that the generator should possess such high tension as to be able to break through a small air-space. If this is not the case, then auxiliary means have to be resorted to, some of which will be indicated subsequently. When the condensers are charged to a certain potential, the air or insulating space gives way and a disruptive discharge occurs. There is then a sudden rush of current, and generally a large portion of the accumulated electrical energy spends itself. The condensers are thereupon

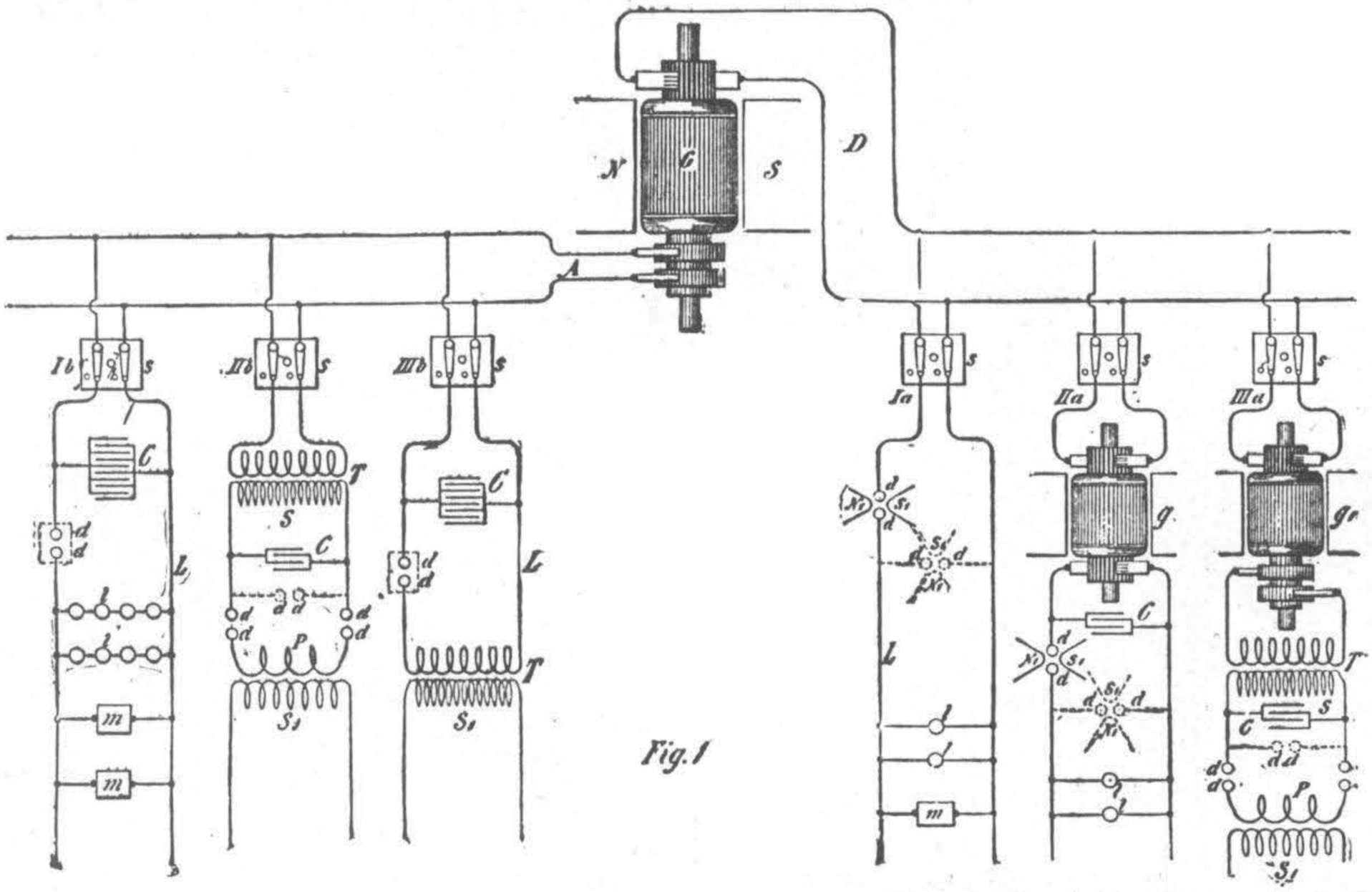


Fig. 1

Plan of Connections Used in the Conversion by Means of the Disruptive Arc Discharge.

quickly charged, and the same process is repeated in more or less rapid succession. To produce such sudden rushes of current it is necessary to observe certain conditions. If the rate at which the condensers are discharged is the same as that at which they are charged, then, clearly, in the assumed case the condensers do not come into play. If the rate of discharge be smaller than the rate of charging, then, again, the condensers cannot play an important part. But if, on the contrary, the rate of discharging is greater than that of charging, then a succession of rushes of current is obtained.

A form of discharger with a magnet which has been found convenient, and adopted after some trials, in the conversion of direct currents particularly, is illustrated in Fig. 2. N S are the pole-pieces of a very strong magnet which is excited by a coil C. The pole-pieces are slotted for adjustment and can be fastened in any position by screws s_1 s_1. The discharge rods d d_1 thinned down on the ends in order to allow a closer approach of the magnetic pole-pieces, pass through the columns of brass b b_1, and are fastened in position by screws s_2 s_2. Springs r r_1 and collars c c_1 are slipped on the rods, the latter serving to set the points of the rods at a certain suitable distance by means of screws s_3 s_3, and the former to draw the points apart. When it is desired to start the arc, one of the hard rubber handles h h_1 is tapped quickly with the hand, whereby the points of the rods are brought in contact, but are instantly separated by the springs r r_1. Such an arrangement has been found to be often necessary, namely, in cases when the E.M.F. was not large enough to cause the discharge to break through the gap, and also when it was desirable to avoid short circuiting of the generator by the metallic contact of the rods. The rapidity of the interruptions of the current with a magnet depends on the intensity of the magnetic field and on the potential difference at the ends of the arc.

When the current through the gap is comparatively large, it is of advantage to slip on the points of the discharge rods pieces of very hard carbon and let the arc play between the carbon pieces. This preserves the rods and besides has the advantage of keeping the air-space hotter, as the heat is not conducted away as quickly through the carbons, and the result is that a smaller E.M.F. in the arc gap is required to maintain a succession of discharges.

In another form of discharger the discharge rods pass through perforations in a wooden box, which is thickly coated with mica on the inside. The spark-gap is warmed by a small lamp contained in the box. The air being warmed to a certain temperature has its insulating power impaired, it becomes dielectrically weak, as it were, and the consequence is that the arc can be established at much greater distance. The air should, of course, be sufficiently insulating to allow the discharge to pass through the gap *disruptively*. The arc formed under such conditions, when long, may be made extremely sensitive, and the weak draught through the lamp chimney is quite sufficient to produce rapid interruptions. The adjustment is made by regulating the temperature and velocity of the draught.

It should be remarked here that when such, or interrupting devices of any kind, are used and the currents are passed through the primary of a disruptive discharge coil, it is not, as a rule, of advantage to produce a number of interruptions of the current per second greater than the natural frequency of vibration of the dynamo supply circuit, which is ordinarily small.

The ideal medium for a discharge gap should only *crack*, and the ideal electrode should be of some material which cannot be disintegrated. With small currents through the gap it is best to employ aluminum, but not when the currents are large. The disruptive break in the air, or more or less in any ordinary medium, is not of the nature of a crack, but it is rather comparable to the piercing of innumerable bullets through a mass offering great frictional resistance to the motion of the bullets, this involving considerable loss of energy. As a medium for the discharge space a solid, or even a liquid, would be preferable therefore. It is somewhat difficult to conceive of a solid body which would possess the property of closing instantly after it has been cracked. But a liquid, especially under great pressure, behaves practically like a

* Abstract of a lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893. We are indebted to the *Electrical World*, of New York, for the blocks illustrating this lecture.

solid, while it possesses the property of closing the crack. Hence it was thought that a liquid insulator might be more suitable as a dielectric than air. Following out this idea, a number of different forms of dischargers in which a variety of such insulators sometimes under great pressure were employed, have been experimented upon. It is thought sufficient to dwell, in a few words, upon one of the forms experimented upon. One of these dischargers is illustrated in Figs. 4*a* and 4*b*.

A hollow metal pulley, P (Fig. 4*a*), was fastened upon an arbor, *a*, which by suitable means was rotated at a considerable speed. In the inside of the pulley, but disconnected from the same, was supported a thin disc h_1 (which is shown thick for the sake of clearness) of hard rubber, in which there were embedded two metal segments, *s s*, with metallic extensions, *e e*, into which were screwed conducting terminals, *t t*, covered with thick tubes of hard rubber, *t t*. The rubber disc, *h*, with its metallic segments, S S, was

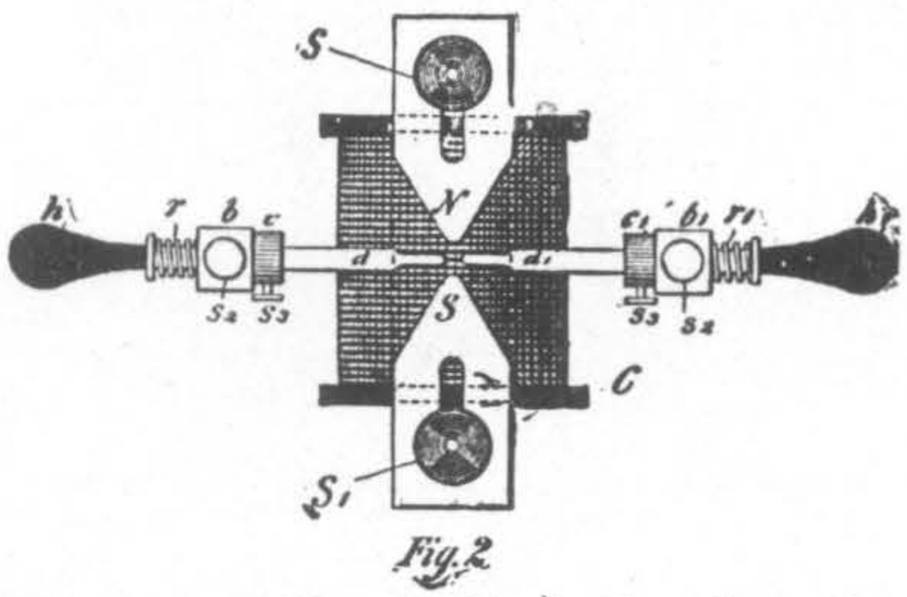


Fig. 2.

Form of Discharger with Magnet Used in the Direct-Current Conversion.

finished in a lathe, and its entire surface highly polished so as to offer the smallest possible frictional resistance to the motion through a fluid. In the hollow of the pulley an insulating liquid, such as a thin oil, was poured, so as to reach very nearly to the opening left in the flange *f*, which was screwed tightly on the front side of the pulley. The terminals, *t t*, were connected to the opposite coatings of a battery of condensers, so that the discharge occurred through the liquid. When the pulley was rotated the liquid was forced against the rim of the pulley, and considerable fluid pressure resulted. In this simple way the discharge gap was filled with a medium which behaved practically like a solid, which possessed the quality of closing instantly upon the occurrence of the break, and which, moreover, was circulating through the gap at a rapid rate. Very powerful effects were produced by dischargers of this kind with liquid interrupters, of which a number of different forms were made. It was found that, as expected, a longer spark for a given length of wire was obtainable in this way than by using air as an interrupting device.

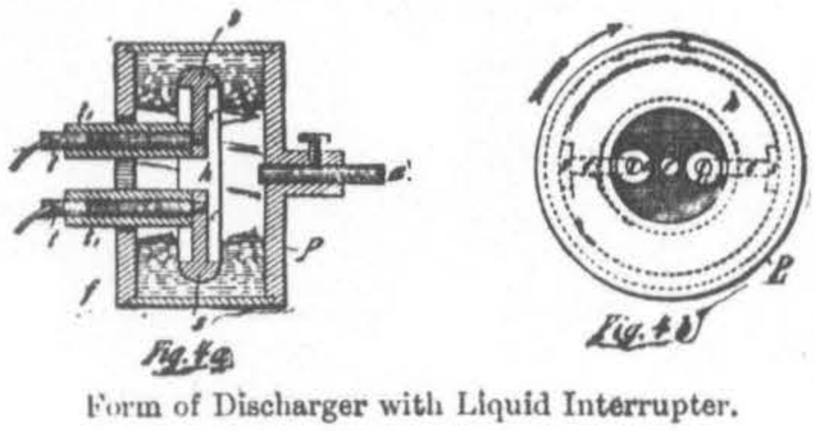


Fig. 4a *Fig. 4b*

Form of Discharger with Liquid Interrupter.

In the diagrammatical sketch (Fig. 1) which has been already, referred to, the cases which are most likely to be met with in practice are illustrated. One has at his disposal either direct or alternating currents from a supply station. It is convenient for an experimenter in an isolated laboratory to employ a machine G such as illustrated, capable of giving both kinds of currents. In such case it is also preferable to use a machine with multiple circuits, as in many experiments it is useful and convenient to have at one's disposal currents of different phases. In the sketch, D represents the direct and A the alternating circuit. In each of these, three branch circuits are shown, all of which are provided with double lines switches, *s s s s s s*. Consider first the direct current conversion; I*a* represents the simplest case. If the E.M.F. of the generator is sufficient to break through a small air-space, at least, when the latter is warmed or otherwise rendered poorly insulating, there is no difficulty in maintaining a vibration with fair economy by judicious adjustment of the capacity, self-induction and resistance of the circuit L containing the devices *l l m*. The magnet N, S, can be in this case advantageously combined with the air-space. The discharger *d d* with the magnet may be placed either way, as indicated by the full or by the dotted lines. The circuit I*a* with the connections and devices is supposed to possess dimensions such as are suitable for the maintenance of a vibration. But usually the E.M.F. on the circuit or branch (Fig. 1), I*a* will be something like 100 volts or so, and in this case it is not sufficient to break through the gap. Many different means may be used to remedy this by raising the E.M.F. across the gap. The simplest is probably to insert a large self-induction coil in series with the circuit L. When the arc is established, as by the discharger (illustrated in Fig. 2), the magnet blows the arc out the instant it is formed. Now the extra current of the break, being of high E.M.F., breaks through the gap, and a path of low resistance for the dynamo current being again provided, there is a sudden rush of the current from the dynamo upon the weakening or subsidence of the extra current. This process is repeated in rapid succession, and in this manner I have maintained oscillation with as low as 50 volts, or even less, across the gap. But conversion on this plan is not to be recommended, on account of the too heavy currents through the gap and consequent heating of the electrodes; besides, the frequencies obtained in this way are low, owing to the high self-induction necessarily associated with the circuit. It is very desirable to have the E.M.F. as high as possible, firstly, in order to increase the economy of the conversion, and, secondly, to obtain high frequencies. The difference of potential in this electric oscillation is, of course, the equivalent of the stretching force in the mechanical vibration of the spring. To obtain very rapid vibration in a circuit of some inertia a great stretching force or difference of potential is necessary. Incidentally, when the E.M.F. is very great, the condenser, which is usually employed in connection with the circuit, need have but a small capacity, and many other advantages are gained. With a view of raising the E.M.F. to a many times greater value than obtainable from ordinary distribution circuits, a rotating transformer *g* is used, as indicated in Fig. II*a*., or else a separate high-potential machine is driven by means of a motor operated from the generator G. The latter plan is in fact preferable, as changes are easier made. The connections from the high-tension winding are quite similar to those in branch 1*a* with the exception that a condenser C, which should be adjustable, is connected to the high-tension circuit. Usually, also, an adjustable self-induction coil in series with the circuit has been employed in these experiments. When the tension of the currents is very high the magnet ordinarily used in connection with the discharger is of comparatively small value, as it is quite easy to adjust the dimensions of the circuit so that oscillation is maintained. The employment of a steady E.M.F. in the high-frequency conversion affords some advantages over the employment of alternating E.M.F., as the adjustments are much simpler and the action can be easier controlled. But, unfortunately, one is limited by the obtainable potential difference. The windings also break down easily in consequence of the sparks which form between the sections of the armature or commutator when a vigorous oscillation takes place. Besides, these transformers are expensive to build. It has been found by experience that it is best to follow the plan illustrated in Fig. 1, III*a*. In this arrangement a rotating transformer *g* is employed to convert the low-tension direct currents into low-frequency alternating currents, preferably also of small tension. The tension of the currents is then raised in a stationary transformer T. The secondary S of this transformer is connected to an adjustable condenser C which discharges through the gap or discharger *d d*, placed in either of the ways indicated, through the primary P of a disruptive discharge coil, the high-frequency currents being obtained from the secondary S of this coil, as described on previous occasions. This will undoubtedly be found the cheapest and most convenient way of converting direct currents.

The three branches of the circuit A represent the usual cases met in practice when alternating currents are converted. In Fig. 1, I*b* a condenser C, generally of large capacity, is connected to the circuit L containing the devices *l l*, *m m*. The devices *m m* are supposed to be of high self-induction so as to bring the frequency of the circuit more or less to that of the dynamo. In this instance the discharger *d d* should best have a number of makes and breaks per second equal to twice the frequency of the dynamo. If not so, then it should have at least a number equal to a multiple or even fraction of the dynamo frequency. It should be observed, referring to (Fig. 1), I*b*, that the conversion to a high potential is also effected when the discharger *d d*, which is shown in the sketch, is omitted. But the effects which are produced by currents which rise instantly to high values, as in a disruptive discharge, are entirely different from those produced by dynamo currents which rise and fall harmonically. So, for instance, there might be in a given case a number of makes and breaks at *d d* equal to just twice the frequency of the dynamo, or, in other words, there may be the same number of fundamental oscillations as would be produced without the discharge gap, and there might even not be any quicker superimposed vibration; yet the differences of potential at the various points of the circuit, the impedence and other phenomena,

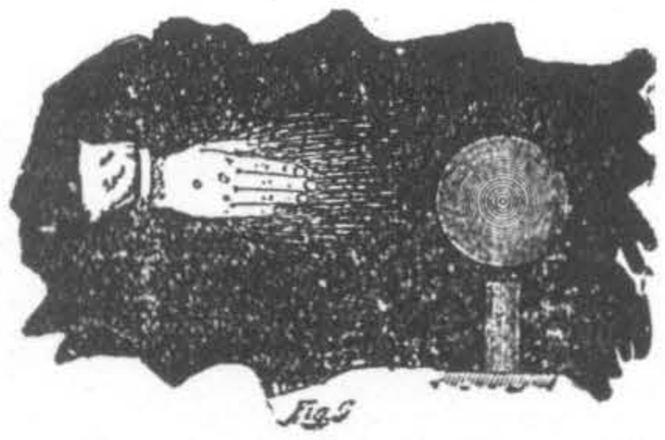
dependent upon the rate of change, will bear no similarity in the two cases. Thus, when working with currents discharging disruptively, the element chiefly to be considered is not the frequency, as a student might be apt to believe, but the rate of change per unit of time. With low frequencies in a certain measure the same effects may be obtained as with high frequencies, provided the rate of change is sufficiently great. So, if a low-frequency current is raised to a potential of, say, 75,000 volts and the high-tension current passed through a series of high-resistance lamp filaments, the importance of the rarefied gas surrounding the filament is clearly noted, as will be seen later; or, if a low-frequency current of several thousand amperes is passed through a metal bar, striking phenomena of impedence are observed, just as with currents of high frequencies. But it is, of course, evident that with low-frequency currents it is impossible to obtain such rates of change per unit of time as with high frequencies, hence the effects produced by the latter are much more prominent. It was deemed advisable to make the preceding remarks, inasmuch as many more recently described effects have been unwittingly identified with high frequencies. Frequency alone in reality does not mean anything, except when an undisturbed harmonic oscillation is considered.

In the branch Fig. 1 III.*b* a similar disposition to that in 1*b* is illustrated, with the difference that the currents discharging through the gap *d d* are used to induce currents in the secondary S of a transformer, T. In such case the secondary should be provided with an adjustable condenser for the purpose of tuning it to the primary.

Fig. 1 II.*b* illustrates a plan of alternate-current high-frequency conversion which is most frequently used, and which is found to be most convenient. This plan has been dwelt upon in detail on previous occasions, and need not be described here.

I will now proceed with the experiments.

On one of the terminals of the coil I have placed a large sphere of sheet brass, which is connected to a larger insulated brass plate, in order to enable me to perform the experiments under conditions, which, as you will see, are more suitable for this experiment. I now set the coil to work, and approach the free terminal with a metallic object held in my hand, this simply to avoid burns. As

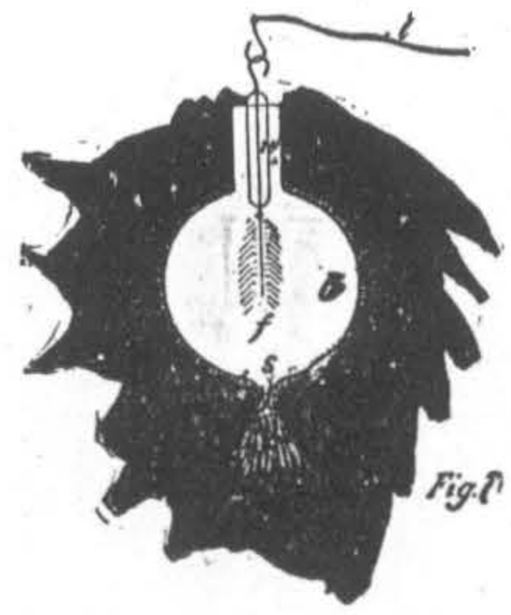


Illustrating the Effect of Varying Electrostatic Force with a Transformer of 200,000 Volts Pressure.

I approach the metallic object to a distance of 8in. or 10in., a torrent of furious sparks breaks forth from the end of the secondary wire, which passes through the rubber column. My arm is now traversed by a powerful electric current, vibrating at about the rate of one million times a second. I can make these streams of light visible to all, by touching with the metallic object one of the terminals as before, and approaching my free hand to the brass sphere, which is connected to the second terminal of the coil. As the hand is approached, the air between it and the sphere, or in the immediate neighbourhood, is more violently agitated, and you see streams of light now break forth from my finger tips and from the whole hand (Fig. 5). Were I to approach the hand closer, powerful sparks would jump from the brass sphere to my hand, which might be injurious. The streamers offer no particular inconvenience, except that in the ends of the finger tips a burning sensation is felt. They should not be confounded with those produced by an influence machine, because in many respects they behave differently. I have attached the brass sphere and plate to one of the terminals, in order to prevent the formation of visible streamers on that terminal, also in order to prevent sparks from jumping at a considerable distance. Attachment is favourable for the working of the coil.

The streams of light which you have observed issuing from my hand are due to a potential of about 200,000 volts, alternating in rather irregular intervals, something like a million times a second. A vibration of the same amplitude, but four times as fast, to maintain which over 3,000,000 volts would be required, would be more than sufficient to envelop my body in a complete sheet of flame. But this flame would not burn me up; quite contrarily, the probability is that I would not be injured in the least. Yet a hundredth part of that energy, otherwise directed, would be amply sufficient to kill a person.

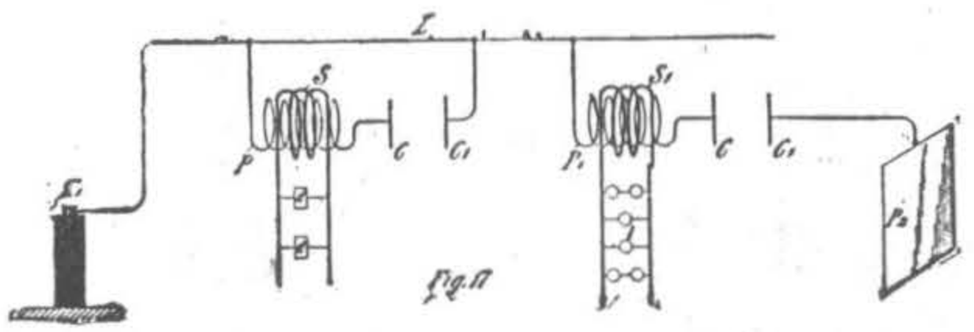
The amount of energy which may thus be passed into the body of a person depends on the frequency and potential of the currents, and by making both of these very great, a vast amount of energy, may be passed into the body without causing any discomfort, except perhaps, in the arm, which is traversed by a true conduction current. The reason why no pain in the body is felt, and no injurious effect noted, is that everywhere, if a current be imagined to flow through the body, the direction of its flow would be at right angles to the surface; hence the body of the experimenter offers an enormous section to the current, and the density is very small, with the exception of the arm, perhaps, where the density may be considerable. But if only a small fraction of that energy would be applied in such a way that a current would traverse the body in the same manner as a low-frequency current, a shock would be received which might be fatal.



Breaking a Bulb on Open Circuit.

I now return to the experiment to which I have already alluded, and with which I desire to illustrate a striking effect produced by a rapidly varying electrostatic force. I attach to the end of the wire *l* (Fig. 7), which is in connection with one of the terminals of the secondary of the induction coil, an exhausted bulb *b*. This bulb contains a thin carbon filament, *f*, which is fastened to a platinum wire, *w*, sealed in the glass, and leading outside of the bulb, where it connects to the wire *l*. The bulb may be exhausted to any degree attainable with ordinary apparatus. Just a moment before you have witnessed the breaking down of the air between the charged brass plates. You know that a plate of glass, or any other insulating material, would break down in like manner. Had I, therefore, a metallic coating attached to the outside of the bulb, or placed near the same, and were this coating connected to the other terminal of the coil, you would be prepared to see the glass give way if the strain were sufficiently increased. Even were the coating not connected to the other terminal, but to an insulated plate, still, if you have followed recent developments, you would naturally expect a rupture of the glass.

But it will certainly surprise you to note that under the action of the varying electrostatic force, the glass gives way when all other bodies are removed from the bulb. In fact, all the surrounding bodies we perceive might be removed to an infinite distance without affecting the result in the slightest. When the coil is set to work, the glass is invariably broken through at the seal, or other



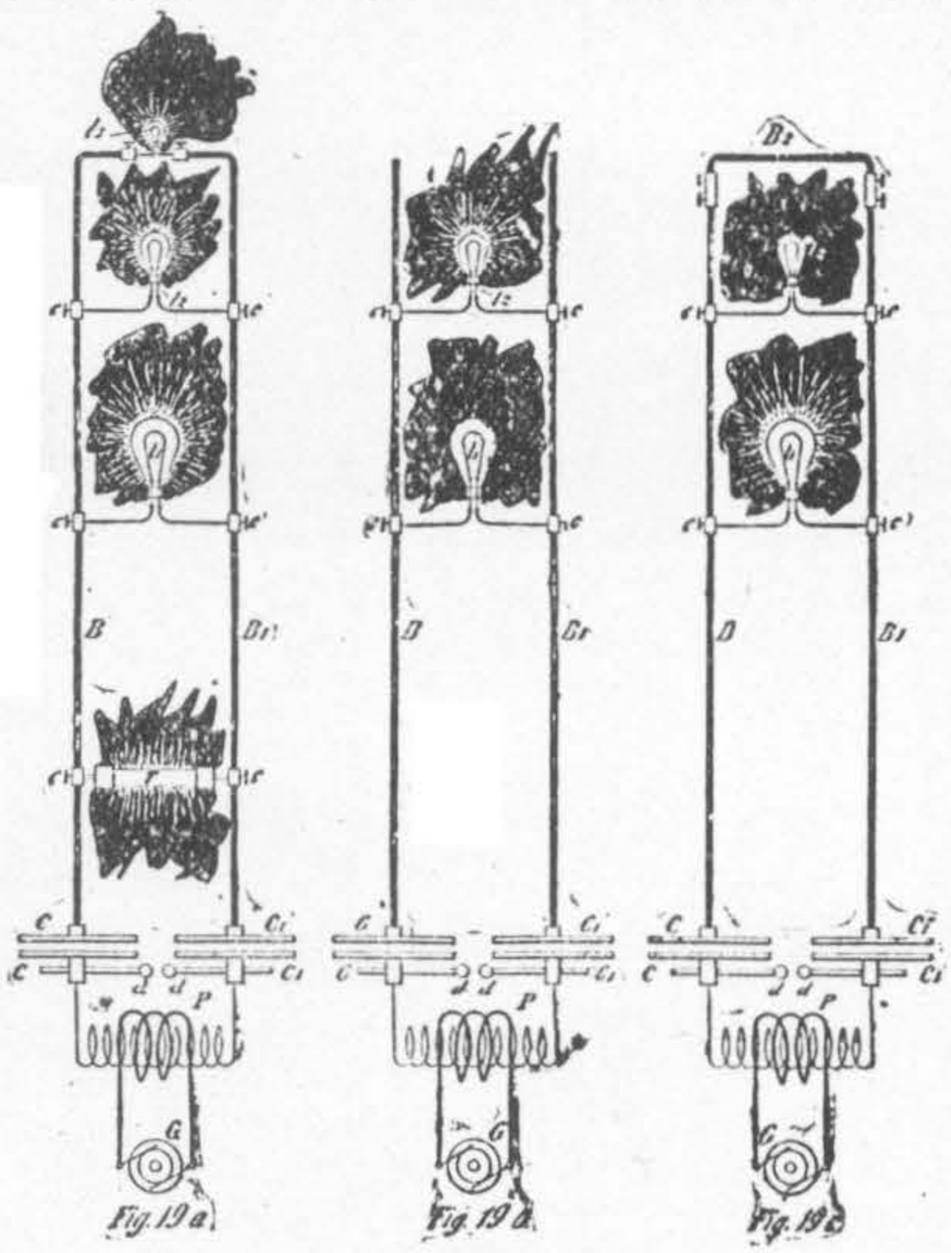
Single-wire Conversion and Distribution, with Simple Means for Regulating the Effects.

narrow channel, and the vacuum is quickly impaired. Such a damaging break would not occur with a steady force, even if the same were many times greater. The break is due to the agitation of the molecules of the gas within the bulb and outside of the same. This agitation, which is generally most violent in the narrow-pointed channel near the seal, causes a heating and rupture of the glass. This rupture would, however, not occur, not even with a varying force, if the medium filling the inside of the bulb and that surrounding it were perfectly homogeneous. The break occurs much quicker if the top of the bulb is drawn out into a fine fibre. In bulbs used with these coils such narrow-pointed channels must therefore be avoided.

When the frequencies are very high it has been found in laboratory practice quite easy to regulate the effects in the manner shown in diagram Fig. 17. Here two primaries P and P are shown, each connected with one of its ends to the line L, and with the other end to the condenser plates C and C^1, respectively. Near these are placed other condenser plates C_1 and C^1_1, the former being

connected to the line L and the latter to an insulated larger plate, P_2. On the primaries are wound secondaries S and S_1 of coarse wire. By varying the distances of the condenser plates C and C^1, the currents through the secondaries S and S^1 are varied in intensity. The curious feature is the great sensitiveness, the slightest change in the distance of the plates producing considerable variations in the intensity or strength of the currents. The sensitiveness may be rendered extreme by making the frequency such, that the primary itself without any plate attached to its free end satisfies, in conjunction with the closed secondary, the condition of resonance. In such condition an extremely small change in the capacity of the free terminal produces great variations. For instance, I have been able to adjust the conditions so that the mere approach of a person to the coil produces a considerable change in the brightness of the lamps attached to the secondary. Such observations and experiments possess, of course, at present chiefly scientific interest, but they may soon become of practical importance.

Among the various current phenomena observed perhaps the most interesting are those of impedence presented by conductors to currents varying at a rapid rate. In my first Paper before the American Institute of Electrical Engineers, I have described a few striking observations of this kind. Thus I showed that when such currents or sudden discharges are passed through a thick metal bar there may be points at the bar only a few inches apart, which have a sufficient potential difference between them to maintain at bright incandescence an ordinary filament lamp. I have also described the curious behaviour of rarefied gas surrounding a

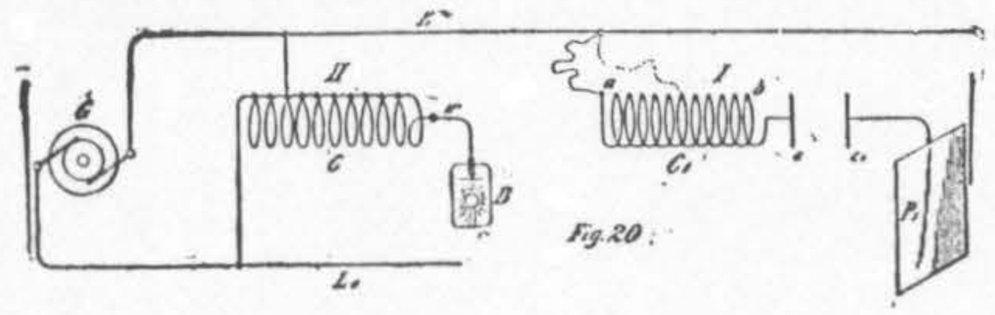


Impedance Phenomena.

conductor to such sudden rushes of current. These phenomena have been since more carefully studied and one or two novel experiments of this kind are deemed of sufficient interest to be described here.

With reference to Fig. 19*a*, B and B_1 are very stout copper bars connected at their lower ends to plates C and C_1 respectively of a condenser, the opposite plates of the latter being connected to the terminals of the secondary S of a high-tension transformer, the primary P of which is supplied with alternating currents from an ordinary low-frequency dynamo G or distribution circuit. The condenser discharges through an adjustable gap *d d* as usual. By establishing a rapid vibration, it was found quite easy to perform the following curious experiment :—The bars B and B_1 were joined at the top by a low-voltage lamp l_3 ; a little lower, was placed, by means of clamps *c c*, a 50-volt lamp l_2, and still lower another 100-volt lamp l_1 ; and finally, at a certain distance below the latter lamp, an exhausted tube T. By carefully determining the positions of these devices, it was found practicable to maintain them all at their proper illuminating power. Yet they were all connected in multiple arc to the two stout copper bars, and required widely different pressures. This experiment requires, of course, some time for adjustment, but is quite easily performed.

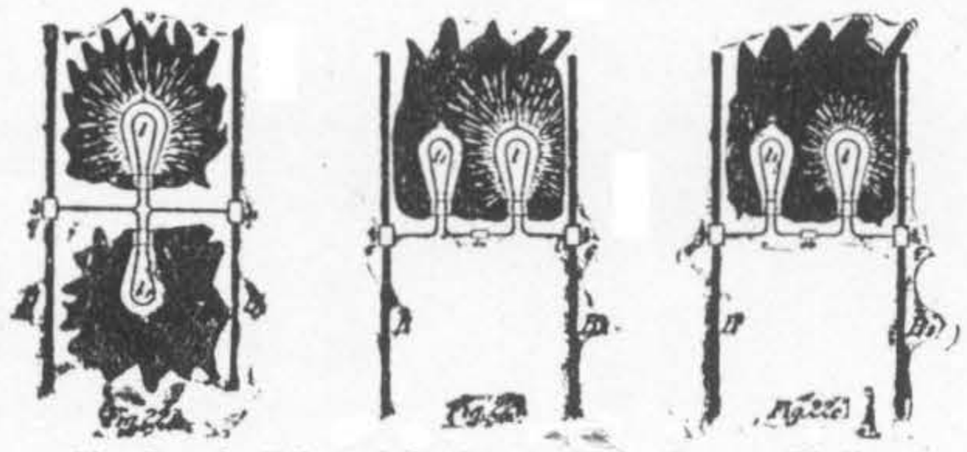
In Figs. 19*b* and 19*c*, two other experiments are illustrated, which, unlike the previous experiment, do not require very careful adjustments. In Fig. 22*b*, two lamps, l_1 and l_2, the former a 100-volt and the latter a 50-volt, are placed in certain positions as indicated, the 100-volt lamp being below the 50-volt lamp. When the arc is playing at *d d*, and the sudden discharges passed through the bars B B, the 50-volt lamp will, as a rule, burn brightly, or at least this result is easily secured, while the 100-volt lamp will burn very low or remain quite dark (Fig. 19*b*). Now the bars B B may be joined at the top by a thick cross-bar B_2, and it is quite easy to maintain the 100-volt lamp at full candle-power while the 50-volt lamp remains dark (Fig. 19*c*). These results, as I have pointed out previously, should not be considered to be due exactly to frequency, but rather to the time rate of change, which may be great even with low frequencies.



Plan Followed in Observing the Effects of Resonance.

In Fig. 20, I., is shown a plan which has been followed in the study of the resonance effects by means of a high-frequency alternator. C is a coil of many turns, which is divided in small separate sections for the purposes of adjustment. The final adjustment was made sometimes with a few thin iron wires (though this is not always advisable) or with a closed secondary. The coil C is connected with one of its ends to the line L from the alternator G and with the other end to one of the plates *c* of a condenser *c* c_1, the plate (c_1) of the latter being connected to a much larger plate P_1. In this manner both capacity and self-induction were adjusted to suit the dynamo frequency.

As regards the rise of potential through resonant action, of course, theoretically, it may amount to anything since it depends on self-induction and resistance and since these may have any value. But in practice one is limited in the selection of these values, and besides these there are other limiting causes. One may start with, say, 1,000 volts, and raise the E.M.F. to 50 times that value, but one cannot start with 100,000 and raise it to ten times that value because of the losses in the media, which are great, especially if the frequency is high. It should be possible to start with, for instance, two volts from a high or low frequency circuit of a dynamo and raise the E.M.F. to many hundred times that value. Thus coils of the proper dimensions might be connected each with only one of its ends to the mains from a machine of low E.M.F., and though



Showing the Effect of the Presence of a Gaseous Medium.

the circuit of the machine would not be closed in the ordinary acceptance of the term, yet the machine might be burned out if a proper resonance effect would be obtained. I have not been able to produce, nor have I observed with currents from the dynamo machine, such great rises of potential. It is possible, if not probable, that with currents obtained from apparatus containing iron the disturbing influence of the latter is the cause that these theoretical possibilities cannot be realised. But if such is the case I attribute it solely to the hysteresis and Foucault current losses in the core. Generally it was necessary to transform upward, when the E.M.F. was very low, and usually an ordinary form of induction coil was employed, but sometimes the arrangement illustrated in Fig. 20, II., has been found to be convenient. In this case a coil C is made in a great many sections, a few of these being used as the primary. In this manner both primary and secondary are adjustable. One end of the coil is connected to the line L_1 from the alternator, and the other line L is connected to the intermediate point of the coil. Such a coil with adjustable primary and secondary will be found also convenient in experiments with the disruptive discharge. When true resonance is obtained the top of the wave must of course be on the free end of the coil as, for instance, at the terminal of the phosphorescence bulb B. This is easily recognised by observing the potential of a point on the wire *w* nearer to the coil.

In connection with resonance effects and the problem of transmission of energy over a single conductor, which was previously considered, I would say a few words on a subject which constantly fills my thoughts and which concerns the welfare of all. I mean the transmission of intelligible signals, or perhaps even power, to any distance without the use of wires. We now know that electric vibration may be transmitted through a single conductor. Why, then, not try to avail ourselves of the earth for this purpose?

A point of great importance would be first to know what is the capacity of the earth; and what charge does it contain if electrified. Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation. If it be a charged body insulated in space its capacity should be extremely small, less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is, by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric currents. One of the terminals of the source would be connected to earth as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata, or free space, contains an opposite charge, and that, together with the earth, they form a condenser of very large capacity. It is certainly practicable to impress an electric vibration, at least of a certain low period, upon the earth, by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured. I think that beyond doubt it is possible to operate electrical devices in a city through the ground or pipe system by resonance from an electrical oscillator located at a central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realisation of the scheme of transmitting intelligence or, perhaps, power to any distance through the earth or environing medium.

On the Light Phenomena produced by High-frequency Currents of High Potential and General Remarks relating to the Subject.

Returning now to the light effects which it has been the chief object to investigate, it is thought proper to divide these effects into four classes:—(1) Incandescence of a solid; (2) Phosphorescence; (3) Incandescence or phosphorescence of a rarefied gas; and (4) Luminosity produced in a gas at ordinary pressure. The first question is, How are these luminous effects produced?

In Figs. 22*a*, 22*b*, and 22*c* the heavy copper bars B B_1 are connected to the opposite coatings of a battery of condensers, or generally in such way that the high frequency or sudden discharges are made to traverse them. I connect first an ordinary 50-volt incandescent lamp to the bars by means of the clamps *c c*. The discharges being passed through the lamp, the filament is rendered incandescent, though the current through it is very small, and would not be nearly sufficient to produce a visible effect under the conditions of ordinary use of the lamp. Instead of this I now attach to the bars another lamp exactly like the first, but with the seal broken off, the bulb being therefore filled with air at ordinary pressure. When the discharges are directed through the filament, as before, it does not become incandescent. But the result might still be attributed to one of the many possible reactions. I therefore connect both the lamps in multiple arc as illustrated in Fig. 22*a*. Passing the discharges through both the lamps, again the filament in the exhausted lamp *l* glows very brightly, while that in the non-exhausted lamp l_1 remains dark, as previously. But it should not be thought that the latter lamp is taking only a small fraction of the energy supplied to both the lamps; on the contrary, it may consume a considerable portion of the energy and it may become even hotter than the one which burns brightly. In this experiment the potential difference at the terminals of the lamps varies in sign theoretically three to four million times a second. The ends of the filaments are correspondingly electrified, and the gas in the bulbs is violently agitated and a large portion of the supplied energy is thus converted into heat. In the non-exhausted bulb there being a few million times more gas molecules than in the exhausted one, the bombardment, which is most violent at the ends of the filament, in the neck of the bulb, consumes a large portion of the energy without producing any visible effect. The reason is that, there being many molecules, the bombardment is quantitatively considerable, but the individual impacts are not very violent, as the speeds of the molecules are comparatively small owing to the small free path. In the exhausted bulb, on the contrary, the speeds are very great and the individual impacts are violent, and therefore better adapted to produce a visible effect. Besides, the convection of heat is greater in the former bulb. In both the bulbs the current traversing the filaments is very small, incomparably smaller than that which they require on an ordinary low-frequency circuit. The potential difference, however, at the ends of the filaments is very great and might be possibly 20,000 volts or more, if the filaments were straight and their ends far apart. In the ordinary lamp a spark generally occurs between the ends of the filament or between the platinum wires outside before such a difference of potential can be reached.

It might be objected in the experiment before shown that the lamps being in multiple arc, the exhausted lamp might take a much larger current, and that the effect observed might not be exactly attributable to the action of the gas in the bulbs. Such objections will lose much weight if I connect the lamps in series, with the same result. When this is done, and the discharges are directed through the filaments, it is again noted that the filament in the non-exhausted bulb, l_1, remains dark, while that in the exhausted one, *l*, glows even more intensely than under its normal conditions of working (Fig. 22*b*). According to general ideas the current through the filaments should now be the same, were it not modified by the presence of the gas around the filaments.

At this juncture I may point out another interesting feature, which illustrates the effect of the rate of change of potential of the currents. I will leave the two lamps connected in series to the bars B B_1, as in the previous experiment (Fig. 22*b*), but will presently reduce considerably the frequency of the currents, which was excessive in the experiment just before shown. This I may do by inserting a self-induction coil in the path of the discharges, or by augmenting the capacity of the condensers. When I now pass these low-frequency discharges through the lamps, the exhausted lamp, *l*, again is as bright as before, but it is noted also that the non-exhausted lamps, l_1, glows, though not quite as intensely as the other. Reducing the current through the lamps, I may bring the filament in the latter lamp to redness, and, though the filament in the exhausted lamp, *l*, is bright (Fig. 22*c*), the degree of its incandescence is much smaller than in Fig. 22*b*, when the currents were of a much higher frequency.

(To be continued.)

ON LIGHT AND OTHER HIGH-FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

(Concluded from page 156.)

I noticed that small variations in the density of the air produced a considerable difference in the degree of incandescence of the

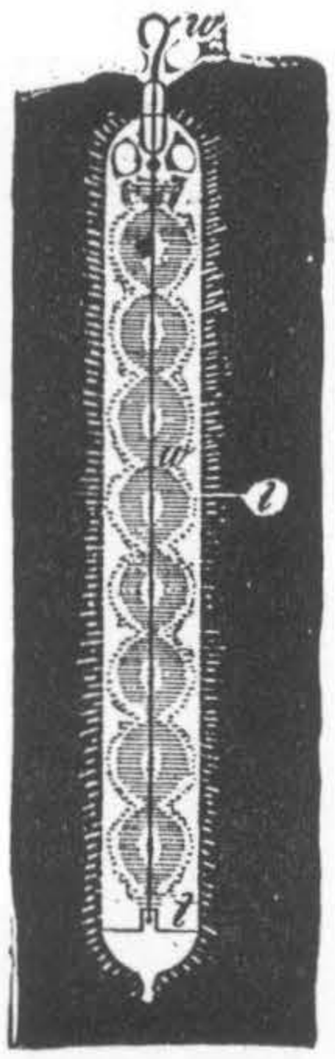


FIG. 23.—Curious Incandescence of a Wire.

wires, and I thought that, since in a tube, through which a luminous discharge is passed, the gas is generally not of uniform density; a very thin wire contained in the tube might be rendered incandescent at certain places of smaller density of the gas, while it would remain dark at the places of greater density, where the convection would be greater and the bombardment less intense. Accordingly, a tube, *t*, was prepared, as illustrated in Fig. 23, which contained through the middle a very fine platinum wire, *w*. The tube was exhausted to a moderate degree, and it was found that when it was attached to the terminal of a high-frequency coil the platinum wire *w* would, indeed, become incandescent in patches, as illustrated in Fig. 23. Later a number of these tubes with one or more wires, were prepared, each showing this result. The effect was best noted when the striated discharge occurred in the tube, but was also produced when the striæ were not visible, showing that, even then, the gas in the tube was not of uniform density. The position of the striæ was generally such, that the rarefactions corresponded to the places of incandescence or greater brightness on the wire *w*. But in a few instances it was noted that the bright spots on the wire were covered by the dense parts of the striated discharge, as indicated by *l* in Fig. 23, though the effect was barely perceptible. This was explained in a plausible way by assuming that the convection was not widely different in the dense and rarefied places, and that the bombardment was greater on the dense places of the striated discharge. It is, in fact, often observed in bulbs, that under certain conditions a thin wire is brought to higher incandescence when the air is not too highly rarefied. This is the case when the potential of the coil is not high enough for the vacuum, but the result may be attributed to many different causes. In all cases this curious phenomenon of incandescence disappears when the tube, or rather the wire, acquires throughout a uniform temperature.

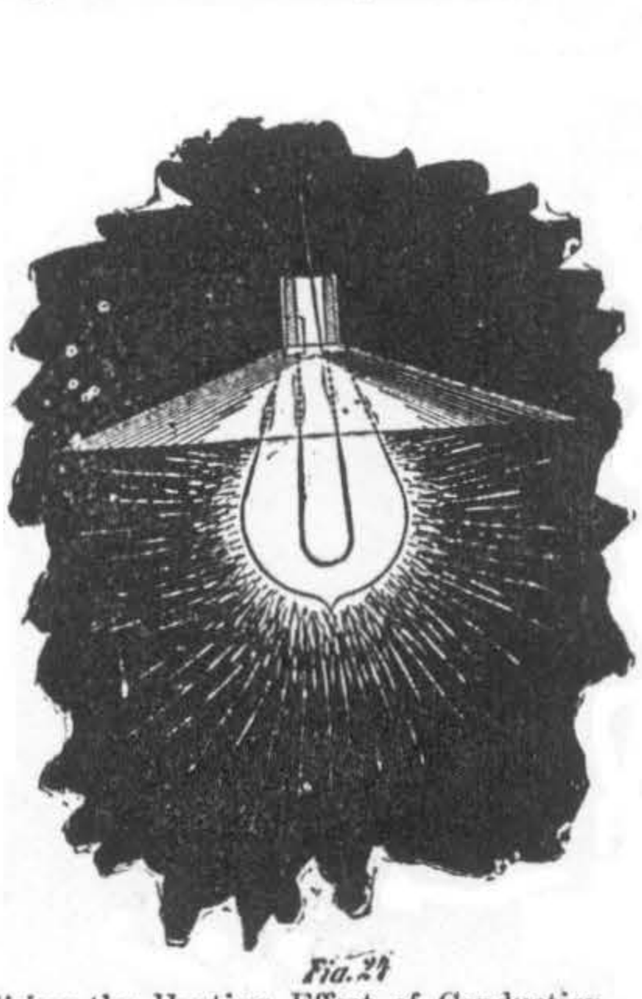


FIG. 24.

Utilising the Heating Effect of Conduction Current and Bombardment.



FIG. 25.

Illustrating Lateral Diffusion.

Disregarding now the modifying effect of convection, there are then two distinct causes which determine the incandescence of a wire or filament with varying currents, that is, conduction current and bombardment. With steady currents, we have to deal only with the former of these two causes, and the heating effect is a minimum, since the resistance is least to steady flow. When the current is a varying one, the resistance is greater, and hence the heating effect is increased. Thus, if the rate of change of the current is very great, the resistance may increase to such an extent that the filament is brought to incandescence with inappreciable currents, and we are able to take a short and thick block of carbon or other material and bring it to bright incandescence with a current incomparably smaller than that required to bring to the same degree of incandescence an ordinary thin lamp filament with a steady or low-frequency current. This result is important, and illustrates how rapidly our views on these subjects are changing, and how quickly our field of knowledge is extending. In the art of incandescent lighting, to view this result in one aspect only, it has been commonly considered as an essential requirement for practical success, that the lamp filament should be thin and of high resistance. But now we know that the resistance to the steady flow of the filament does not mean anything; the filament might as well be short and thick; for if it be immersed in rarefied gas it will become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents.

I have contrived an experiment which illustrates, in an interesting manner, the effect of lateral diffusion. If a very long tube

* Abstract of a lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893, and before the National Electric Light Association, at St. Louis, Mo., March 1, 1893. We are indebted to the *Electrical World*, of New York, for the blocks illustrating this lecture.

is attached to the terminal of a high-frequency coil, the luminosity is greatest near the terminal, and falls off gradually towards the remote end. This is more marked if the tube is narrow.

A small tube about ½in. in diameter and 12in. long (Fig. 25) has one of its ends drawn out into a fine fibre *f* nearly 3ft. long. The tube is placed in a brass socket T, which can be screwed on the terminal T_1 of the induction coil. The discharge passing through the tube first illuminates the bottom of the same, which is of comparatively large section; but through the long glass fibre the discharge cannot pass. But gradually the rarefied gas inside becomes warmed and more conducting and the discharge spreads into the glass fibre. This spreading is so slow that it may take half a minute or more until the discharge has worked through up to the top of the glass fibre, then presenting the appearance of a strongly luminous thin thread. By adjusting the potential at the terminal the light may be made to travel upwards at any speed. Once, however, the glass fibre is heated the discharge breaks through its entire length instantly. The interesting point to be noted is that, the higher the frequency of the currents, or, in other words, the greater relatively the lateral dissipation, at a slower rate may the light be made to propagate through the fibre. This experiment is best performed with a highly exhausted and freshly made tube. When the tube has been used for some time the experiment often fails. It is possible that the gradual and slow impairment of the vacuum is the cause. This slow propagation of the discharge through a very narrow glass tube corresponds exactly to the propagation heat through a bar warmed at one end. The quicker the heat is carried away laterally the longer time it will take for the heat to warm the remote end. When the current of a low frequency coil is passed through the fibre from end to end, then the lateral dissipation is small and the discharge instantly breaks through almost without exception.



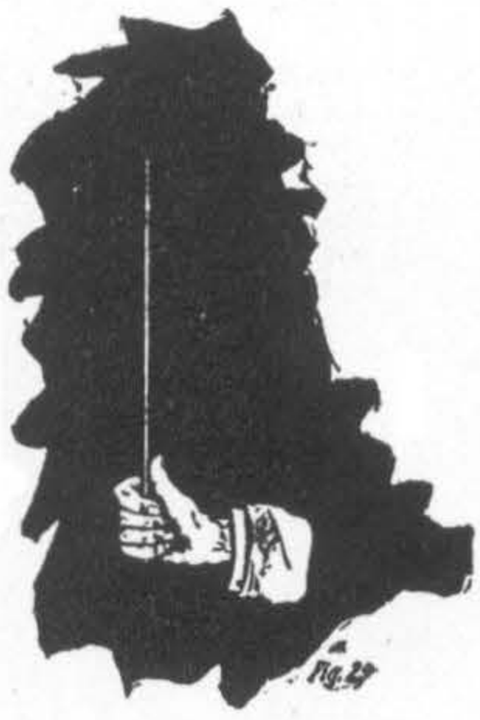
Incandescence of a Solid.



Phosphorescence.



Incandescence or Phosphorescence of Rarefied Gas.



Luminosity of Gas at Ordinary Pressure.

Illustrating Four Kinds of Light Effects Produced by High Frequency Currents of High Potential.

After these experiments and observations which have shown the importance of the discontinuity or atomic structure of the medium, and which will serve to explain, in a measure at least, the nature of the four kinds of light effects producible with these currents, I may now give you an illustration of these effects. For the sake of interest I may do this in a manner which to many of you might be novel. You have seen before that we may now convey the electric vibration to a body by means of a single wire or conductor of any kind. Since the human frame is conducting I may convey the vibration through my body.

First, as in some previous experiments, I connect my body with one of the terminals of a high-tension transformer, and take in my hand an exhausted bulb which contains a small carbon button mounted upon a platinum wire leading to the outside of the bulb, and the button is rendered incandescent as soon as the transformer is set to work (Fig. 26). I may place a conducting shade on the bulb, which serves to intensify the action, but is not necessary. Nor is it required that the button should be in conducting connection with the hand through a wire leading through the glass, for sufficient energy may be transmitted through the glass itself by inductive action to render the button incandescent.

Next I take a highly exhausted bulb, containing a strongly phosphorescent body, above which is mounted a small plate of aluminum on a platinum wire leading to the outside, and the currents flowing through my body excite intense phosphorescence in the bulb (Fig. 27). Next, again, I take in my hand a simple exhausted tube, and in the same manner the gas inside the tube is rendered highly incandescent or phosphorescent (Fig. 28). Finally, I may take in my hand a wire, bare or covered with thick insulation, it is quite immaterial; the electric vibration is so intense as to cover the wire with a luminous film (Fig. 29).

In the first place, I will consider the incandescence of a button or of a solid in general, and dwell upon some facts which apply equally to all these phenomena. It was pointed out before that when a thin conductor, such as a lamp filament, for instance, is connected with one of its ends to the terminal of a transformer of high tension, the filament is brought to incandescence partly by a conduction current and partly by bombardment. The shorter and thicker the filament the more important becomes the latter, and finally, reducing the filament to a mere button, all the heating must practically be attributed to the bombardment. So in the experiment before shown, the button is rendered incandescent by the rhythmical impact of freely movable small bodies in the bulb. These bodies may be the molecules of the residual gas, particles of dust or lumps torn from the electrode; whatever they are, it is certain that the heating of the button is essentially connected with the pressure of such freely movable particles, or of atomic matter in general in the bulb. The heating is the more intense the greater the number of impacts per second and the greater the energy of each impact. Yet the button would be heated also if it were connected to a source of a steady potential. In such a case electricity would be carried away from the button by the freely movable carriers or particles flying about, and the quantity of electricity thus carried away might be sufficient to bring the button to incandescence by its passage through the latter. But the bombardment could not be of great importance in such case. For this reason it would require a comparatively very great supply of energy to the button to maintain it at incandescence with a steady potential. The higher the frequency of the electric impulses the more economically can the button be maintained at incandescence. One of the chief reasons why this is so, is, I believe, that with impulses of very high frequency there is less exchange of the freely movable carriers around the electrode, and this means than in the bulb the heated matter is better confined to the neighbourhood of the button.

In regard to the incandescence of a refractory button (or filament) in an exhausted receiver, which has been one of the subjects of this investigation, the chief experiences which may serve as a guide in constructing such bulbs, may be summed up as follows: (1) The button should be as small as possible, spherical of a smooth or polished surface, and of refractory material which withstands evaporation best; (2) The support of the button should be very thin and screened by an aluminium and mica sheet, as I have described on another occasion; (3) The exhaustion of the bulb should be as high as possible; (4) The frequency of the currents should be as high as practicable; (5) The currents should be of a harmonic rise and fall without sudden interruptions; (6) The heat should be confined to the button, by inclosing the same in a small bulb or otherwise; (7) The space between the walls of the small bulb and the outer globes should be highly exhausted.

Most of the considerations which apply to the incandescence of a solid just considered may likewise be applied to phosphorescence. Indeed, in an exhausted vessel the phosphorescence is, as a rule, primarily excited by the powerful beating of the electrode stream of atoms against the phosphorescent body. Even in many cases, where there is no evidence of such a bombardment, I think that phosphorescence is excited by violent impacts of atoms, which are not necessarily thrown off from the electrode, but are acted upon from the same inductivity through the medium, or through chains of other atoms.

Coming now to the most interesting of these phenomena, the incandescence or phosphorescence of gases, at low pressures or at

the ordinary pressure of the atmosphere, we must seek the explanation of these phenomena in the same primary causes, that is, in shocks or impacts of the atoms. Just as molecules or atoms beating upon a solid body excite phosphoresence in the same or render it incandescent, so when colliding among themselves they produce similar phenomena. But this is a very insufficient explanation, and concerns only the crude mechanism. Light is produced by vibrations which go on at a rate almost inconceivable. If we compute, from the energy contained in the form of known radiations in a definite space the force which is necessary to set up such rapid vibrations, we find, that though the density of the ether be incomparably smaller than that of any body we know, even hydrogen, the force is something surpassing comprehension. What is this force, which in mechanical measure may amount to thousands of tons per square inch? It is electrostatic force in the light of modern views. It is impossible to conceive how a body of measurable dimensions could be charged to so high a potential that the force would be sufficient to produce these vibrations. Long before any such charge could be imparted to the body it would be shattered into atoms. The sun emits light and heat, and so does an ordinary flame or incandescent filament, but in neither of these can the force be accounted for if it be assumed that it is associated with the body as a whole. Only in one way may we account for it, namely, by identifying it with the atom. An atom is so small, that if it be charged by coming in contact with an electrified body, and the charge be assumed to follow the same law as in the case of bodies of measurable dimensions, it must retain a quantity of electricity which is fully capable of accounting for these forces and tremendous rates of vibration. But the atom behaves singularly in this respect; it always takes the same "charge."

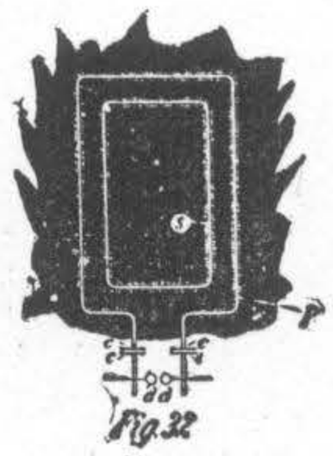


Fig. 32

Electrostatic Action Between Primary and Secondary, with Extremely High Frequencies.

We then must ask ourselves: How can free molecules or atoms be affected? It is a fact that they can be affected by electrostatic force, as is apparent in many of these experiments. By varying the electrostatic force we can agitate the atoms, and cause them to collide under evolution of heat and light. It is not demonstrated beyond doubt that we can affect them otherwise. If a luminous discharge is produced in a closed exhausted tube, do the atoms arrange themselves in obedience to any other but to electrostatic force acting in straight lines from atom to atom? Only recently I investigated the mutual action between two circuits with extreme rates of vibration. When a battery of a few jars (*c c c c*, Fig. 32) is discharged through a primary P of low resistance (the connections being as illustrated in Figs. 19*a*, 19*b*, and 19*c*), and the frequency of vibration be many millions, there are great differences of potential between points on the primary not more than a few inches apart. These differences may be 10,000 volts per inch, if not more, taking the maximum value of the E.M.F. The secondary *s* is, therefore, acted upon by electrostatic induction, which is in such extreme cases of much greater importance than the electro-dynamic. To such sudden impulses the primary as well as the secondary are poor conductors, and therefore, great differences of potential may be produced by electrostatic induction between adjacent points on the secondary. Then sparks may jump between the wires and streamers become visible in the dark if the light of the discharge through the spark gap *d d* be carefully excluded. If, now we substitute a closed vacuum tube for the metallic secondary *s*, the differences of potential produced in the tube by electrostatic induction from the primary are fully sufficient to excite portions of it; but as the points of certain differences of potential on the primary are not fixed, but are generally constantly changing in position, a luminous band is produced in the tube, apparently not touching the glass, as it should, if the points of maximum and minimum differences of potential were fixed on the primary. I do not exclude the possibility of such a tube being excited only by electro-dynamic induction, for very able physicists hold this view; but, in my opinion, there is as yet no positive proof given that atoms of a gas in a closed tube may arrange themselves in chains under the action of an electromotive impulse produced by electro-dynamic induction in the tube. I have been unable so far to produce striæ in a tube, however long, and at whatever degree of exhaustion, that is, striæ at right angles to the supposed direction of the discharge or the axis of the tube, but I have distinctly observed in a large bulb, in which a wide luminous band was produced by passing a discharge of a battery through a wire surrounding the bulb, a circle of feeble luminosity between two luminous bands, one of which was more intense than the other. Furthermore, with my present experience I do not think that such a gas discharge in a closed tube can vibrate, that is, vibrate as a whole. I am convinced that no discharge through a gas can vibrate. The atoms of a gas behave very curiously in respect to sudden electric impulses. The gas does not seem to possess any appreciable inertia to such impulses, for it is a fact that the higher the frequency of the impulses, with the greater freedom does the discharge pass through the gas. If the gas possesses no inertia, then it cannot vibrate, for some inertia is necessary for the free vibration. I conclude from this that if a lightning discharge occurs between two clouds, there can be no oscillation, such as would be expected, considering the capacity of the clouds. But if the lightning discharge strike the earth, there is always vibration—in the earth, but not in the cloud. In a gas discharge each atom vibrates at its own rate; but there is no vibration of the conducting gaseous mass as a whole. This is an important consideration in the great problem of producing light economically, for it teaches us that to reach this result we must use impulses of very high frequency, and necessarily also of high potential.

Much would remain to be said about the luminous effects produced in gases at low or ordinary pressures. With the present experiences before us, we cannot say that the essential nature of these charming phenomena is sufficiently known. But investigations in this direction are being pushed with exceptional ardour. Every line of scientific pursuit has its fascinations, but electrical investigation appears to possess a peculiar attraction, for there is no experiment or observation of any kind in the domain of this wonderful science which would not forcibly appeal to us. Yet to me it seems that, of all the many marvellous things we observe, a vacuum tube, excited by an electric impulse from a distant source, bursting forth out of the darkness and illuminating the roam with its beautiful light, is as lovely a phenomenon as can greet our eyes. Viewed from a distance the effect is weak, and much of its beauty is lost, but being near, or holding the tube in one hand, one cannot resist its charm.

In presenting these insignificant results I have not attempted to arrange and co-ordinate them as would be proper in a strictly scientific investigation, in which every succeeding result should be a logical sequence of the preceding, so that it might be guessed in advance by the careful reader or attentive listener. I have preferred to concentrate my energies chiefly upon advancing novel facts or ideas which might serve as suggestions to others, and this may serve as an excuse for the lack of harmony. The explanations of the phenomena have been given in good faith, and in the spirit of a student prepared to find that they admit of better interpretation. There can be no great harm in a student taking an erroneous view; but when great minds err, the world must dearly pay for their mistakes.

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VOL. XXI. NEW YORK, JUNE 10, 1893. NO. 23

On Light and Other High Frequency Phenomena.

THE lecture of Mr. Nikola Tesla, the full text of which was given in the last issue of THE ELECTRICAL WORLD, deserves more than the brief notice it received in our editorial columns at that time, for it is only after a most careful perusal that the salient features of this important work are brought to light and its real value fully appreciated. The results of scientific research are usually laid before the world in so technical and uninteresting a form that when an investigator clothes his thoughts in language that is at once beautiful in its simplicity and accurate in its expression, the public instantly marks its approval, as is evidenced by the keen interest taken in every public utterance of Mr. Tesla. This lecture, even in a more marked degree than the previous ones, is an illustration of the peculiarly happy style which characterizes Mr. Tesla's writings, and it stands almost alone in the annals of science for the importance of its subject matter, the elevation of its thought and the grace and beauty of its expression. While it is called a lecture, it is in reality a scientific treatise, and in the effort to make it popular, technical accuracy has not in any way been sacrificed. Mr. Tesla has embodied in this lecture only the latest results and newest developments of his work along this line of investigation, and it is a report of the progress made since his last contribution, repeating only such matter from his previous lectures as was necessary for a clear understanding of the subject. After a beautiful peroration upon the wonders of "that divine organ of sight," the human eye, he states that it is his intention to inquire into the nature of that by which it (the eye) is affected, and to illustrate in a general way the answer to the question "What is light?" in the modern sense of the word. A brief description of the mechanism of disruptive discharges is given, and several methods to lower disruptive resistance are shown, and attention is called to a means of transforming a continuous current of high tension into a direct current of low tension, which, it is thought, may find employment in the arts. An apt mechanical analogy makes plain the nature of a disruptive discharge, and the great loss of energy in disruptive effects in air by the bombardment of the molecules and by sound waves is referred to. Six different methods of obtaining high rates of vibration are given, and the author then proceeds to an experimental illustration of phenomena produced by electrostatic force. Some beautiful experiments are performed, and the exact nature of electrostatic force defined. It is also explained why high frequency currents of enormous energy are not injurious. All these phenomena are due to the presence of a medium like air, and would not occur in a continuous medium. It is under the head of current or dynamic electricity phenomena, which is next taken up, that some of the most interesting results from a practical standpoint are obtained. It is shown that not only may currents be made to flow through open circuits, but they may be made to do work, such as lighting a lamp or operating a motor. A number of ways of running a multiphase motor are described, and it is stated that although such experiments at the present time are only of scientific interest, the day is not far distant when they may have a practical value. Mr. Tesla further states that he has found it practicable to operate ordinary series or shunt direct current motors with disruptive discharges, and that too without a return wire. The subject of electrical resonance is here taken up for the first time in any of the public lectures of Mr. Tesla, and is very thoroughly treated, particularly in reference to its practical details. This is a subject of great importance, and the value of Mr. Tesla's work along this line cannot be over-estimated. In connection with resonance effects and the problem of transmission of energy over a single conductor, we may well quote here the author's own words: "My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day. The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations." The light effects proper are divided into four classes, which are then treated at considerable length. The great importance of the presence of a rarefied gas or atomic medium for the production of heating effects is insisted upon, and it is shown that there are two distinct causes which determine the incandescence of a wire or filament with varying currents, conduction current and bombardment. The incandescence of a refractory button receives considerable attention, while that most interesting subject, phosphorescence, is dealt with at some length, and many interesting facts brought out. The explanation of the incandescence or phosphorescence of gas at low or ordinary pressure is sought in the same primary causes, viz., the shocks or impacts of the atoms. Many other points in this most fascinating lecture might be brought into prominence, for there are scattered throughout its entire length facts of the greatest value and hints of future developments which may revolutionize not only this department, but the whole world of science. This patient investigator is seeking not alone the practical development of electricity but the fundamental principles of all science; to use his own words: "The day when we shall know what 'electricity' is will chronicle an event probably greater, more important than any other recorded in the history of the human race." And who is doing more to advance that day than Nikola Tesla?

Mind-Reading.—It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and therefore upon the retina. Will it ever be within human power to analyze the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science in the solution of which many, if not the majority, of scientific men implicitly believe.—*Nikola Tesla, in the Electric World, New York.*

TESLA.

We commenced in our last issue the complete text of the lecture by Mr. Nikola Tesla delivered before the Franklin Institute, and also before the National Electric Light Association in America. We shall not enter into any discussion upon the probable outcome of Tesla's experiments, opening as they do an almost entirely new field of exploration—following investigations of Crookes and others—but would point out that, although what we term statical electricity has for many years seemed to have little or no practical outcome, the discoveries of Crookes, Spottiswoode, Tesla, and others, may lead to some very practical applications in this branch of electricity. Mr. Tesla's lectures in America, as well as that delivered at the Royal Institution in England, and fully reported in our columns, consist to a very large extent of practical demonstrations fully illustrated and explained in the text. We think, however, in these American lectures Mr. Tesla has taken us more into his confidence, and given us an indication of what we may term his mind work. He gives us, in fact, the text upon which he is labouring. As will be seen by an examination of his lecture, the first portion of it is devoted to a consideration of the eye. As the lecturer points out, the eye is the only human organ directly affected by that subtle medium which scientific men tell us occupies all space, and which they term ether. If we accept the scientific jargon of the day and accept this view of the ether and its endowment with all the properties required to demonstrate the correctness of the scientific views put forward relating to light and electricity, the difficulties are greatly lessened. Some people, however, unfortunately, do not accept the modern views, but think they may be as far astray as were the views of the ancient Greeks with regard to astronomical questions. Mr. Tesla points out that in recent years—and we cordially agree with almost all he says—the scientific advances have been extremely rapid. Centuries ago men thought and invented and imagined they were soaring ahead, while we, who look back at their work, see that they were really going at a snail's pace. We can but ask as to the reality of our advance, Are we not in the same position as men centuries ago, thinking we are advancing rapidly, and will not the men who come centuries after us look back and say they imagined they were soaring rapidly, but in reality they were moving very slowly?

But whatever may be the criticism upon the text which is causing Mr. Tesla to work, there can be but one view in regard to the energy he has thrown into his investigations and the wonderful facility which he seems to possess of looking into the very nature of these mysterious phenomena. According to the existing scientific view, electromagnetic phenomena are manifestations of energy which is supposed to be of the same class as those of radiant heat and light—that is, manifestations of energy through the medium of the ether. Our present knowledge leads the author of these lectures to look far ahead, and to point out that "the day when we shall know what electricity is, will chronicle an event probably greater and more important than any other recorded in the history of the human race. The time will come when the comfort, the very existence, perhaps, of man, will depend upon that wonderful agent." The author goes on to point out that when our coalfields are exhausted and our forests have disappeared, one thing will remain, according to our present knowledge—that is, to transmit power at great distances. Men will go to where Nature provides the power; they will harness the waterfalls, and transmit the energy from the points where Nature provides it to the points where they require it. Habitations and factories at a distance of hundreds—perhaps thousands—of miles may be supplied with heat, light, and energy, according to the requirements, from the centres which Nature provides. Such, we take it, is the text which has induced Mr. Tesla to work, and which he describes in the earlier part of his lecture.

The remaining part is descriptive of apparatus and experiments—experiments of the most ingenious and convincing character, giving results which must appeal in the strongest manner to everyone engaged in industrial operations, indicating, as they do, a new sphere of industrial activity. Mr. Tesla, like all real workers, is extremely modest as regards his achievements, but we cannot allow without protest these results to be considered as insignificant—the term he gives to them; and we think our readers will agree with us, when they have read the whole of his lecture, that far from being insignificant they are of the greatest significance, and that even in the short interval which has elapsed since his lecture in England and his lecture in America, considerable progress has been made in the direction in which he has devoted his attention.

Who is Tessler?—The following extract from the *Cape Times* may interest our readers :—" Tessler lectured over here a few years ago, and since then he has pursued his investigations much further. His new lecture, delivered in the States, has just been issued, and is being perused with absorbing interest by electricians. Tessler is described to me by a former colleague as an exceptionally fearless man. The first experiments which he made exposed him to the most fearful risks. He literally played with forces of electricity—up to a hundred thousand volts—which might, for aught he knew, have reduced him to a cinder any moment."

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ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

INTRODUCTORY.

Some Thoughts on the Eye.—When we look at the world around us, on nature, we are impressed with its beauty and grandeur. Each thing we perceive, though it may be vanishingly small, is in itself a world; each, like the whole visible universe, is a world of matter and force governed by law—a world, the contemplation of which fills us with feelings of wonder and irresistibly urges us to ceaseless thought and inquiry. But in all this vast world, of all the objects our senses reveal to us, the most marvellous,

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893, and before the National Electric Light Association, at St. Louis, March 1, 1893.

the most appealing to our imagination, appears no doubt in highly developed organism, a thinking being. If there is anything fitted to make us admire nature's handiwork, it is certainly this inconceivable structure, which performs its innumerable motions in obedience to external influence. To understand its workings, to get a deeper insight into this nature's masterpiece, has ever been for thinkers a fascinating aim, and after many centuries of arduous research men have arrived at a fair understanding of the functions of its organs and senses. Again, in all the perfect harmony of its parts, of the parts which constitute the material or tangible of our being, of all its organs and senses, the eye is the most wonderful. It is the most precious, the most indispensable of our receptive or directive organs, it is the great gateway through which all knowledge enters the mind. Of all our organs, it is the one which is in the most intimate relation with that which we call intellect. So intimate is this relation, that it is often said, the very soul shows itself in the eye.

It can be taken as a fact, which the theory of the action of the eye implies that for each external impression; that is, for each image produced upon the retina, the ends of the visual nerves concerned in the conveyance of the impression to the mind, must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and therefore upon the retina. Will it ever be within human power to analyze the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness, that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science, in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he

was able to *see*, in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

There is another fact bearing on this subject, which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation, viz: that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, and observable even in broad daylight.

The saying, then, that the soul shows itself in the eye, is deeply founded, and we feel that it expresses a great truth. It has a profound meaning even for one who, like a poet or artist, following only his inborn instinct or love for nature, finds delight in aimless thoughts and in the mere contemplation of natural phenomena, but a still more profound meaning for one who, in the spirit of positive scientific investigation, seeks to ascertain the causes of the effects. It is the natural philosopher, the physicist, for whom the eye is the subject of the most intense admiration.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting that the very conception of that which is perfect, or seems so to him, has been gained through this same instrument. Firstly, the eye is, as far as our positive knowledge goes, the only organ which is *directly* affected by that subtile medium, which as science teaches us, must fill all space; secondly, it is the most sensitive of our organs, incomparably more sensitive to external impressions than any other.

The organ of hearing requires the impact of ponderable bodies, the organ of smell the transference of detached material particles, and the organs of taste, and of touch or

force, the direct contact, or at least some interference of ponderable matter, and this is true even in those instances of animal organisms, in which some of these organs are developed to a degree of truly marvellous perfection. This being so, it seems wonderful that the organ of sight alone should be capable of being stirred by that which all our other organs are powerless to detect, which yet plays an essential part in all natural phenomena, which transmits all energy and sustains all motion and life, but which has properties such that even a scientifically trained mind cannot help drawing a distinction between it and all that is called matter. Considering merely this, and the fact that the eye, by its marvellous power, widens our otherwise very narrow range of perception far beyond the limits of the small world which is our own, and enables it to embrace myriads of other worlds, suns and stars in the infinite depths of the universe, it would seem justifiable to assert that the eye is an organ of a higher order than others. Its performances are beyond comprehension. Nature, as far as we know, never produced anything more wonderful. We can get barely a faint idea of its prodigious power by analyzing what it does and by comparing. When ether waves impinge upon the human body, they produce the sensations of warmth or cold, pleasure or pain, or perhaps other sensations of which we are not aware, and any degree or intensity of these sensations, which degrees are infinite in number, hence an infinite number of distinct sensations. But our sense of touch, or our sense of force, cannot reveal to us these differences in degree or intensity, unless they are very great. Now we can readily conceive how an organism, such as the human in the eternal process of evolution, or more philosophically speaking, adaptation to nature, being constrained to the use of only the sense of touch or force, for instance, might develop this sense to such a degree of sensitiveness or perfection, that it would be capable of distinguishing the minutest differences in the temperature of a body even at some distance, to a hundredth, or thousandth, or millionth part of a degree. Yet even this apparently impossible performance would not begin to compare with that of the

eye, which is capable of distinguishing and conveying to the mind in a single instant innumerable peculiarities of the body, be it in form or color or other respects. This power of the eye rests upon two things, namely, the rectilinear propagation of the disturbance by which it is affected, and its sensitiveness. To say that the eye is sensitive is not saying anything. Compared with it all other organs are monstrously crude. The organ of smell which guides a dog on the trail of a deer, the organ of touch or force which guides an insect in its wanderings, the organ of hearing, which is affected by the slightest disturbances of the air, are sensitive organs, to be sure, but what are they compared with the human eye? No doubt it responds to the faintest echoes or reverberations of the medium; no doubt, it brings us tidings from other worlds, infinitely remote, but in a language we cannot as yet always understand. And why not? Because we live in a medium filled with air and other gases and vapors and a dense mass of solid particles flying about. These play an important part in many phenomena; they fritter away the energy of the vibrations before they can reach the eye; they, too, are the carriers of germs of destruction, they get into our lungs and other organs, clog up the channels, and imperceptibly yet inevitably arrest the stream of life. Could we but do away with all ponderable matter in the line of sight of the telescope, it would reveal to us umdreamt-of marvels. Even the unaided eye, I think, would be capable of distinguishing in the pure medium, small ojects at distances measured probably by hundreds or perhaps thousands of miles.

But there is something else about the eye which impresses us still more than these wonderful features which we observe, viewing it from the standpoint of a physicist, merely as an optical instrument—something which appeals to us more than its marvellous faculty of being directly affected by the vibrations of the medium, without interference of gross matter, and more than its inconceivable sensitiveness and discerning power. It is its significance in the processes of life. No matter what one's views of nature and life may be, he must stand amazed when, for the first time in his

thoughts, he realizes the importance of the eye in the physical processes and mental performances of the human organism. And how could it be otherwise, when he realizes that the eye is the means through which the human race has acquired the entire knowledge it possesses, that it controls all our motions, more still, all our actions.

There is no way of acquiring knowledge except through the eye. What is the foundation of all philosophical systems of ancient and modern times; in fact, of all the philosophy of man? *I am, I think; I think; therefore, I am.* But how could I think and how would I know that I exist if I had not the eye? For knowledge involves consciousness; consciousness involves ideas, conceptions; conceptions involve pictures or images, and images the sense of vision, and, therefore, the organ of sight. But how about blind men, will be asked? Yes, a blind man may depict in magnificent poems forms and scenes from real life, from a world he physically does not see. A blind man may touch the keys of an instrument with unerring precision, may build the fastest boat, may discover and invent, calculate and construct, may do still greater wonders—but all the blind men who have done such things have descended from those who had seeing eyes. Nature may reach the same result in many ways. Like a wave in the physical world, in the infinite ocean of the medium which pervades all, so in the world of organisms, in life, an impulse started proceeds onward, at times, may be, with the speed of light, at times, again, so slowly, that for ages and ages it seems to stay, passing through processes of a complexity inconceivable to men, but in all its forms, in all its stages, its energy ever and ever integrally present. A single ray of light from a distant star falling upon the eye of a tyrant in by-gone times, may have altered the course of his life, may have changed the destiny of nations, may have transformed the surface of the globe, so intricate, so inconceivably complex are the processes in nature. In no way can we get such an overwhelming idea of the grandeur of nature as when we consider that in accordance with the law of the conservation of energy, throughout the infinite, the forces are

in a perfect balance, and hence the energy of a single thought may determine the motion of a universe. It is not necessary that every individual, not even that every generation or many generations, should have the physical instrument of sight, in order to be able to form images and to think; that is, to form ideas or conceptions; but at some time or other, during the process of evolution, the eye certainly must have existed; else thought, as we understand it, would be impossible; else conceptions, like spirit, intellect, mind, call it as you may, could not exist. It is conceivable, that in some other world, in some other beings, the eye is replaced by a different organ, equally or more perfect, but these beings cannot be men.

Now, what prompts us to all voluntary motions and actions of any kind? Again, the eye. If I am conscious of the motion, I must have an idea or conception; that is, an image; therefore the eye. If I am not precisely conscious of the motion, it is because the images are vague or indistinct, being blurred by the superimposition of many. But when I perform the motion, does the impulse which prompts me to the action come from within or from without? The greatest physicists have not disdained to endeavor to answer this and similar questions, and have at times abandoned themselves to the delights of pure and unrestrained thought. Such questions are generally considered not to belong to the realm of positive physical science, but before long they will be annexed to its domain. Helmholtz has probably thought more on life than any other modern scientist. Lord Kelvin expressed his belief that life's process is electrical and that there is a force inherent in the organism and determining its motions. Just as much as I am convinced of any physical truth, I am convinced that the motive impulse must come from the outside. For, consider the lowest organism we know—and there are probably many lower ones—an aggregation of a few cells only. If it is capable of voluntary motion it can perform an infinite number of motions, all definite and precise. But now a mechanism consisting of a finite number of parts and a few at that, cannot perform an infinite number of definite motions; hence the impulses

which govern its movements must come from the environment. So, the atom, the ulterior element of the universe's structure, is tossed about in space eternally, the toy of external influences, like a float in a troubled sea. Were it to stop its motion *it would die.* Matter at rest, if such a thing could exist, would be matter dead. Death of matter! Never has a sentence of deeper philosophical meaning been uttered. This is the way in which Professor Dewar forcibly expresses it in the description of his admirable experiments, in which liquid oxygen is handled as one handles water, and air at ordinary pressure is made to condense and even to solidify by the intense cold: experiments, which serve to illustrate, as he says, the last feeble manifestations of life, the last quiverings of matter about to die. But human eyes shall not witness such death. There is no death of matter, for throughout the infinite universe, all has to move, to vibrate; that is, to live.

I have made the preceding statements at the peril of treading upon metaphysical ground in my desire to introduce the subject of this lecture in a manner not altogether uninteresting, I may hope, to an audience such as I have the honor to address. But now, then, returning to the subject, this divine organ of sight, this indispensable instrument for thought and all intellectual enjoyment, which lays open to us the marvels of this universe, through which we have acquired what knowledge we possess, and which prompts us to, and controls, all our physical and mental activity. By what is it affected? By light! What is light?

We have witnessed the great strides which have been made in all departments of science in recent years. So great have been the advances that we cannot refrain from asking ourselves, Is this all true, or is it but a dream? Centuries ago men lived, thought, discovered, and invented, and they believed that they were soaring, while they were merely proceeding at a snail's pace. So we, too, may be mistaken. But taking the truth of the observed events as one of the implied facts of science, we must rejoice in the immense progress already made and still more in the anticipation of what must come, judging from the

possibilities opened up by modern research. There is, however, an advance which we have been witnessing, which must be particularly gratifying to every lover of progress. It is not a discovery, or an invention, or an achievement in any particular direction. It is an advance in all directions of scientific thought and experiment. I mean the generalization of the natural forces and phenomena, the looming up of a certain broad idea on the scientific horizon. It is this idea, which, however, long ago took possession of the most advanced minds, to which I desire to call your attention, and which I intend to illustrate, in a general way, in these experiments, as the first step in answering the question, "What is light?" and to realize the modern meaning of this word.

It is beyond the scope of my lecture to dwell upon the subject of light in general, my object being merely to bring presently to your notice a certain class of light effects and a number of phenomena observed in pursuing the study of these effects. But to be consistent in my remarks, it is necessary to state that according to that idea, now accepted by the majority of scientific men as a positive result of theoretical and experimental investigation, the various forms or manifestations of energy which were generally designated as "electric" or more precisely "electro-magnetic" are energy manifestations of the same nature as those of radiant heat and light. Therefore, the phenomena of light and heat, and others besides these, may be called electrical phenomena. Thus, electrical science has become the mother science of all and its study has become all important. The day when we shall know exactly what "electricity" is, will chronicle an event probably greater, more important, than any other recorded in the history of the human race. The time will come when the comfort, perhaps the very existence, of man will depend upon that wonderful agent. For our existence and comfort we require heat, light and mechanical power. How do we now get all these? We get them from fuel, we get them by consuming material. What will man do when the forests disappear; when the coal fields are exhausted? Only one

thing, according to our present knowledge, will remain: that is, to transmit power at great distances. Men will go to the waterfalls, to the tides, which are the stores of an infinitesimal part of nature's immeasurable energy. There will they harness the energy and transmit the same to their settlements, to warm their homes, to give them light and to keep their obedient slaves, the machines, toiling. But how will they transmit this energy if not by electricity? Judge then, if the comfort, nay, the very existence of man, will not depend on electricity. I am aware that this view is not that of a practical engineer, but neither is it that of an illusionist, for it is certain, that power transmission, which at present is merely a stimulus to enterprise, will some day be a dire necessity.

It is more important for the student who takes up the study of light phenomena, to make himself thoroughly acquainted with certain modern views, than to peruse entire books on the subject of light itself, as disconnected from these views. Were I therefore to make these demonstrations before students seeking information—and for the sake of the few of these who may be present, give me leave to so assume—it would be my principal endeavor to impress these views upon their minds in this series of experiments.

It might be sufficient for this purpose to perform a simple and well-known experiment. I might take a familiar appliance, a Leyden jar, charge it from a frictional machine, and then discharge it. In explaining to you its permanent state when charged, and its transitory condition when discharging, calling your attention to the forces which enter into play and to the various phenomena they produce, and pointing out the relation of the forces and phenomena, I might fully succeed in illustrating that modern idea. No doubt, to the thinker, this simple experiment would appeal as much as the most magnificent display. But this is to be an experimental demonstration, and one which should possess besides instructive, also entertaining features; and as such, a simple experiment, such as the one cited, would not go very far towards the attainment of the lecturer's aim. I must therefore choose another way of illustrating, more

spectacular certainly, but perhaps also more instructive. Instead of the frictional machine and Leyden jar, I shall avail myself in these experiments of an induction coil of peculiar properties, which was described in detail by me in a lecture before the London Institution of Electrical Engineers, in February, 1892. This induction coil is capable of yielding currents of enormous potential differences, alternating with extreme rapidity. With this apparatus I shall endeavor to show you three distinct classes of effects, or phenomena, and it is my desire that each experiment, while serving for the purposes of illustration, should at the same time teach us some novel truth, or show us some novel aspect of this fascinating science. But before doing this, it seems proper and useful to dwell upon the apparatus employed, and upon the method of obtaining the high potentials and high frequency currents which are made use of in these experiments.

On the Apparatus and Method of Conversion.—These high frequency currents are obtained in a peculiar manner. The method employed was advanced by me about two years ago in an experimental lecture before the American Institute of Electrical Engineers. A number of ways, as practised in the laboratory, of obtaining these currents either from continuous or low frequency alternating currents is diagrammatically indicated in *Fig. 1*, which will be later described in detail. The general plan is to charge condensers, from a direct or alternate current source, preferably of high tension, and to discharge them disruptively while observing well-known conditions necessary to maintain the oscillations of the current. In view of the general interest taken in high frequency currents and in the effects producible by them, it seems to me advisable to dwell at some length upon this method of conversion. In order to give you a clear idea of the action, I will suppose that we employ a continuous current generator which is often very convenient. It is desirable that the generator should possess such high tension as to be able to break through a small air space. If this is not the case, then auxiliary means have to be resorted to, some of which will be indicated subsequently. When the conden-

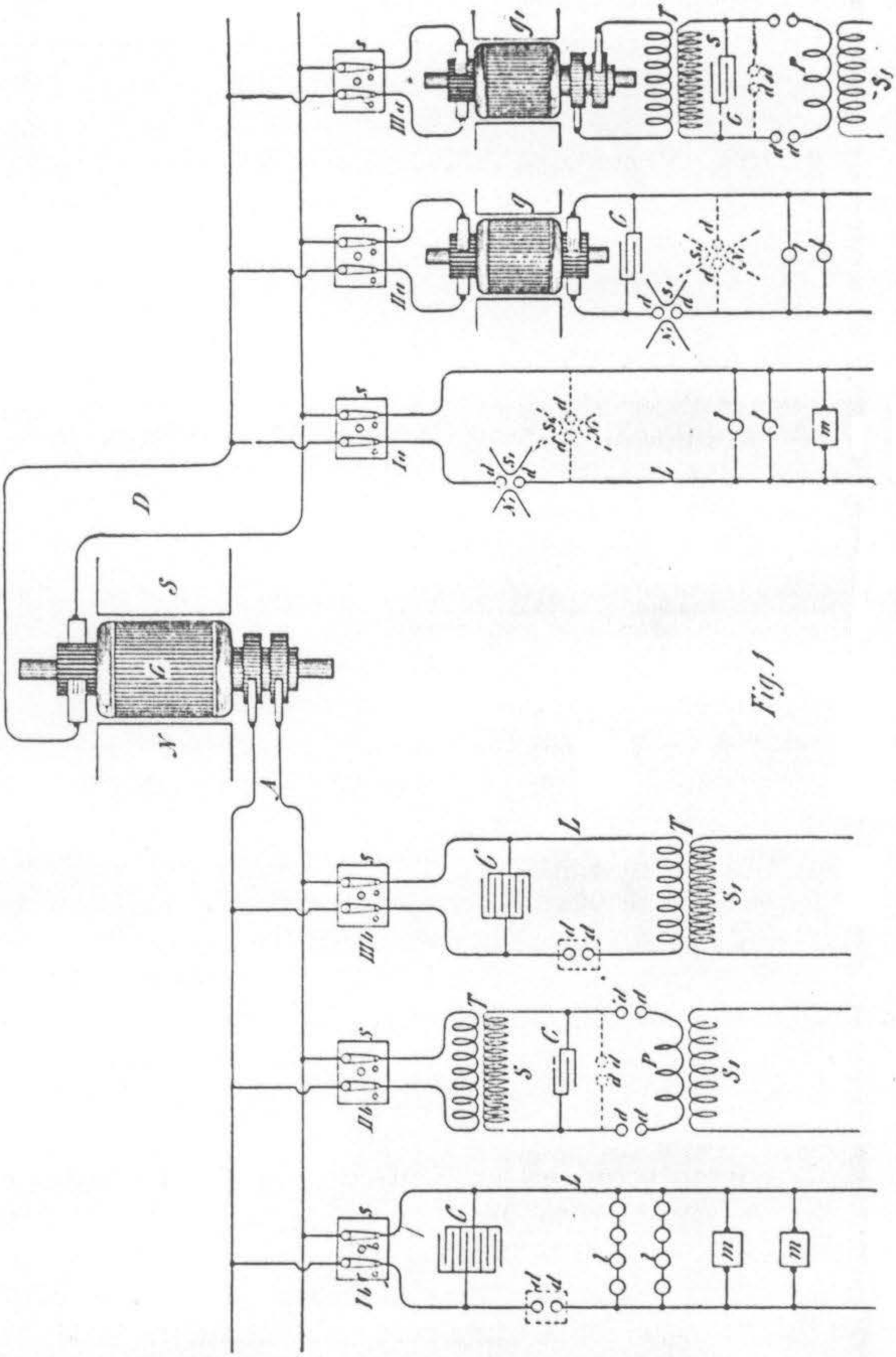

FIG. 1.—Plan of connection used in the conversion by means of the disruptive arc discharge.

sers are charged to a certain potential, the air or insulating space gives way and a disruptive discharge occurs. There is then a sudden rush of current and generally a large portion of

the accumulated electrical energy spends itself. The condensers are thereupon quickly charged and the same process is repeated in more or less rapid succession. To produce such sudden rushes of current it is necessary to observe certain conditions. If the rate at which the condensers are discharged is the same as that at which they are charged, then, clearly, in the assumed case the condensers do not come into play. If the rate of discharge be smaller than the rate of charging, then, again, the condensers cannot play an important part. But if, on the contrary, the rate of discharging is greater than that of charging, then a succession of rushes of current is obtained. It is evident that if the rate at which the energy is being dissipated by the discharge is very much greater than the rate of supply to the condensers, the sudden rushes will be comparatively few, with long-time intervals between. This always occurs when a condenser of considerable capacity is charged by means of a comparatively small machine. If the rates of supply and dissipation are not widely different, then the rushes of current will be in quicker succession, and the more so, the more nearly equal both rates are, until natural limitations, incident to each case and depending upon a number of causes, are reached. Thus we are able to obtain from a continuous current generator as rapid a succession of discharges as we like. Of course, the higher the tension of the generator, the smaller need be the capacity of the condensers, and for this reason, principally, it is of advantage to employ a generator of very high tension. Besides, such a generator permits the attaining of greater rates of vibration.

The rushes of current may be of the same direction under the conditions before assumed, but most generally there is an oscillation superimposed upon the fundamental vibration of the current. When the conditions are so determined that there is no oscillation, the current impulses are unidirectional and thus a means is provided of transforming a continuous current of high tension into a direct current of lower tension, which I think may find employment in the arts.

This method of conversion is exceedingly interesting, and

I was much impressed by its beauty when I first conceived it. It is ideal in certain respects. It involves the use of no mechanical devices of any kind, and it allows of obtaining currents of any desired frequency from an ordinary circuit, direct or alternating. The frequency of the fundamental discharges, depending as it does on the relative rates of supply and dissipation, can readily be varied within wide limits by simple adjustments of these quantities, and the frequency of the superimposed vibration by the determination of the capacity, self-induction and resistance of the circuit. The potential of the currents, again, may be raised as high as any insulation is capable of withstanding safely, by combining capacity and self-induction, or by induction in a secondary, which need have but comparatively few turns.

As the conditions are often such that the intermittence or oscillation does not readily establish itself, especially when a direct current source is employed, it is of advantage to associate an interrupter with the arc, and I indicated, some time ago, the use of an air-blast or magnet, or other such device readily at hand. The magnet is employed with special advantage in the conversion of direct currents, as it is then very effective. If the primary source is an alternate current generator, it is desirable, as I stated on a former occasion, that the frequency should be low, and that the currents forming the arc be large, in order to render the magnet more effective.

A form of such discharger with a magnet, which has been found convenient and adopted after some trials, in the conversion of direct currents particularly, is illustrated in *Fig. 2*. *N* and *S* are the pole pieces of a very strong magnet which is excited by a coil *C*. The pole pieces are slotted for adjustment and can be fastened in any position by screws s_1 s_1. The discharge rods d d_1 thinned down on the ends in order to allow a closer approach of the magnetic pole pieces, pass through the columns of brass b b_1 and are fastened in position by screws s_2 s_2. Springs r r_1 and collars c c_1 are slipped on the rods, the latter serving to set the points of the rods at a certain suitable distance by means of screws s_3 s_3, and the former to draw the points apart. When it is

desired to start the arc, one of the hard rubber handles h h_1 is tapped quickly with the hand whereby the points of the rods are brought in contact, but are instantly separated by springs r r_1. Such an arrangement has been found to be often necessary, namely, in cases when the E. M. F. was not great enough to cause the discharge to break through the gap, and also when it was desirable to avoid short-circuiting of the generator by the metallic contact of the rods. The rapidity of the interruptions of the current with a magnet depends on the intensity of the magnetic field and on the potential difference at the ends of the arc. The interruptions are generally in such quick succession as to produce a

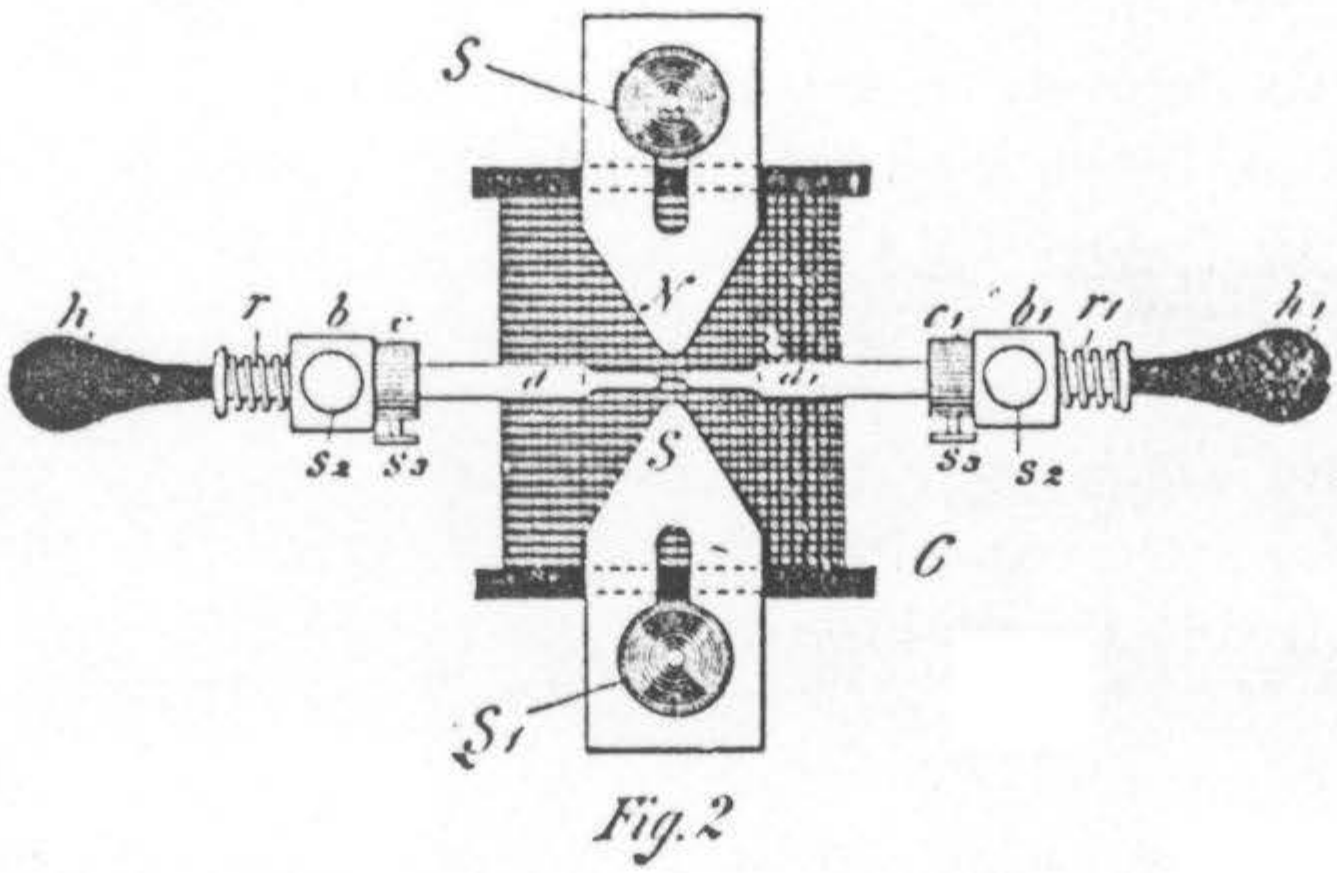

Fig. 2

FIG. 2.—Form of discharger with magnet used in the direct-current conversion.

musical sound. Years ago it was observed that when a powerful induction coil is discharged between the poles of a strong magnet, the discharge produced a loud noise not unlike a small pistol shot. It was vaguely stated that the spark was intensified by the presence of the magnetic field. It is now clear that the discharge current, flowing for some time, was interrupted a great number of times by the magnet, thus producing the sound. The phenomenon is especially marked when the field circuit of a large magnet or dynamo is broken in a powerful magnetic field.

When the current through the gap is comparatively large, it is of advantage to slip on the points of the dis-

charge rods pieces of very hard carbon and let the arc play between the carbon pieces. This preserves the rods, and besides has the advantage of keeping the air space hotter, as the heat is not conducted away as quickly through the carbons. The result is that a smaller E. M. F. in the arc gap is sufficient to maintain a succession of discharges.

Another form of discharger which may be employed with advantage in some cases is illustrated in *Fig. 3*. In this form the discharge rods $d\ d_1$ pass through perforations in a wooden box *B*, which is thickly coated with mica on the inside, as indicated by the heavy lines. The perforations are provided with mica tubes $m\ m_1$ of some thickness, which are preferably not in contact with the rods $d\ d_1$. The box has a cover *C*, which is a little larger than the box and descends on the outside of it. The spark gap is warmed by a small lamp *l* contained in the box. A plate *p* above the lamp allows the draught to pass only through the chimney *c* of the lamp, the air entering through holes *o o* in or near the bottom of the box and following the path indicated by the arrows. When the discharger is in operation the door of the box is closed so that the light of the arc is not visible outside. It is desirable to exclude the light as perfectly as possible, as it interferes with some experiments. This form of discharger is simple and very effective when properly manipulated. The air, being warmed to a certain temperature, has its insulating power impaired. It becomes dielectrically weak, as it were, and the consequence is that the arc can be established at much greater distance. The air should, of course, be sufficiently insulating to allow the discharge to pass through the gap *disruptively*. The arc formed under such conditions, when long, may be made extremely sensitive, and the weak draught through the lamp chimney *c* is quite sufficient to produce rapid interruptions. The adjustment is made by regulating the temperature and velocity of the draught. Instead of using a lamp, it answers the purpose to provide for a draught of warm air in other ways. A very simple way which has been practised is to inclose the arc in a long vertical tube with plates on the top and bottom for regulating the temperature and velocity

of the air current. Some provision had to be made for deadening the sound.

The air may be rendered dielectrically weak also by rarefaction. Dischargers of this kind have likewise been used by me in connection with the magnet. For this purpose a large tube is provided with heavy electrodes of carbon or metal, between which the discharge is made to pass, the tube being placed in a powerful magnetic field. The exhaustion of the tube is carried to a point at which the discharge breaks through easily, but the pressure should be more than seventy-five millimetres, at which the ordinary

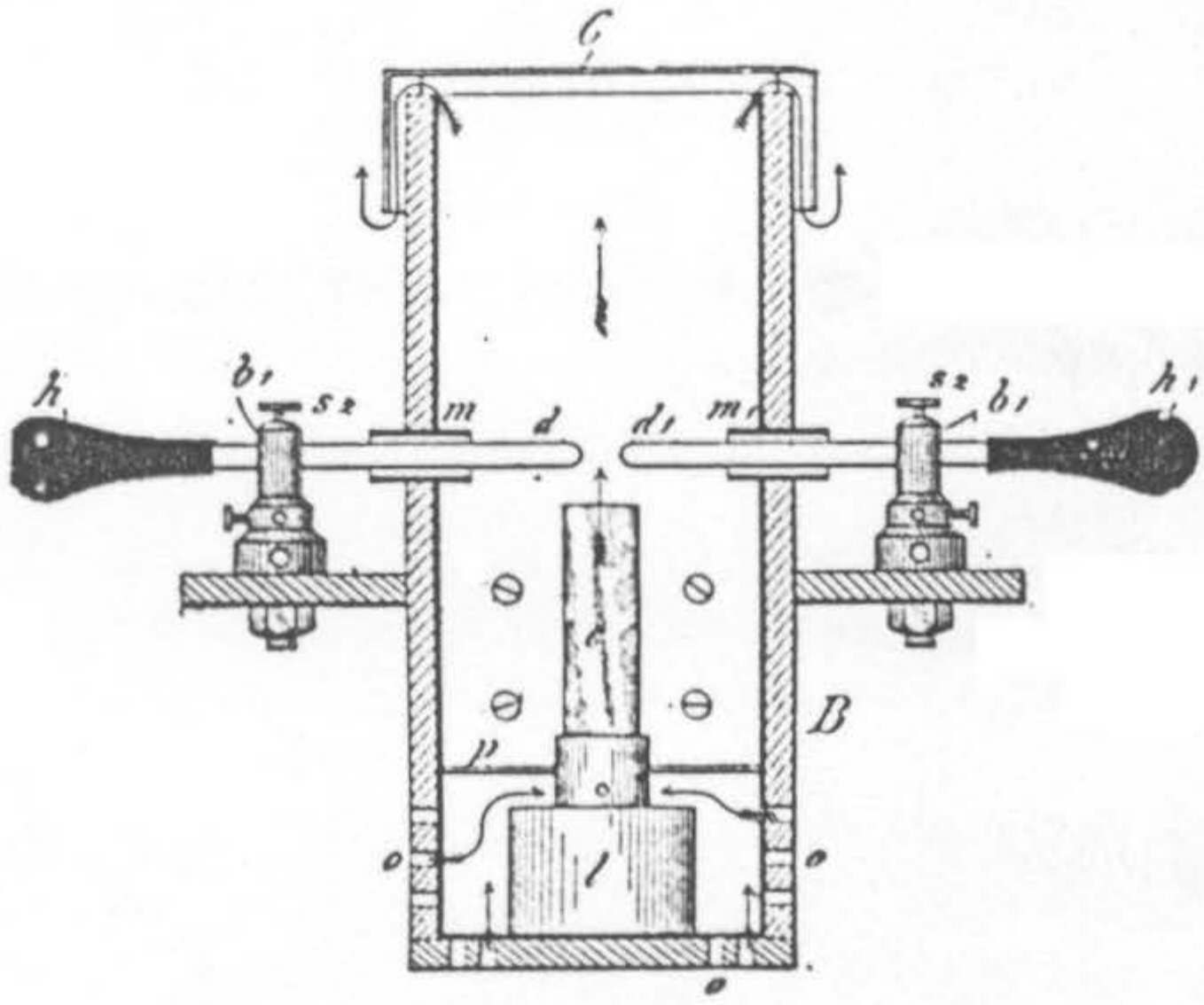

Fig. 3

FIG 3.—Discharger with hot-air draft.

thread discharge occurs. In another form of discharger, combining the features before mentioned, the discharge was made to pass between two adjustable magnetic pole pieces, the space between them being kept at an elevated temperature.

It should be remarked here that when interrupting devices of this or any other kind are used, and the currents are passed through the primary of a disruptive discharge coil, it is not, as a rule, of advantage to produce a number of interruptions of the current per second greater than the natural frequency of vibration of the dynamo supply circuit,

which is ordinarily small. It should also be pointed out here, that while the devices mentioned in connection with the disruptive discharge are advantageous under certain conditions, they may sometimes be a source of trouble, as they produce intermittences and other irregularities in the vibration which it would be very desirable to overcome.

There is, I reget to say, in this beautiful method of conversion, a defect, which fortunately is not vital, and which I have been gradually overcoming. I can best call attention to this defect and indicate a fruitful line of work by comparing the electrical process with its mechanical analogue. The process may be illustrated in this manner: Imagine a tank with a wide opening at the bottom, which is kept closed by spring pressure, but so that it snaps off *suddenly* when the liquid in the tank has reached a certain height. Let the fluid be supplied to the tank by means of a pipe feeding at a certain rate. When the critical height of the liquid is reached, the spring gives way and the bottom of the tank drops out. Instantly the liquid falls through the wide opening, and the spring, reasserting itself, closes the bottom again. The tank is now filled, and after a certain time interval the same process is repeated. But it is clear that if the pipe feeds the fluid quicker than the bottom outlet is capable of letting it pass through, the bottom will remain off and the tank will still overflow. If the rates of supply are exactly equal, then the bottom lid will remain partially open and no vibration of the same and of the liquid column will generally occur, though it might, if started by some means. But if the inlet pipe does not feed the fluid fast enough for the outlet, then there will always be vibration. Again, in such case, each time the bottom flaps up or down, the spring and the liquid column, if the pliability of the spring and the inertia of the moving parts are properly chosen, will perform independent vibrations. In this analogue the fluid may be likened to electricity or dielectric, and the pipe to the conductor through which electricity is supplied to the condenser. To make this analogy quite complete it is necessary to make the assumption that the bottom, each time it gives way, is knocked violently against

a non-elastic stop, this impact involving some loss of energy, and that, besides, some dissipation of energy results, due to frictional losses. In the preceding analogue the liquid is supposed to be under a steady pressure. If the pressure of the fluid be assumed to vary rhythmically, this may be taken as corresponding to the case of an alternating current. The process is then not so easily followed, but then action is the same in principle.

[*To be continued.*]

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ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

[*Continued from p. 19.*]

It is desirable, in order to maintain the vibration economically, to reduce the impact and frictional losses as much as possible. As regards the latter, which in the electrical analogue correspond to the losses due to the resistance of the circuits, it is impossible to obviate them entirely, but they can be reduced to a minimum by a proper selection of the dimensions of the circuits and by the employment of thin conductors in the form of strands. But the loss of energy caused by the first breaking through of the dielectric—which

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893, and before the National Electric Light Association, at St. Louis, March 1, 1893.

in the above example corresponds to the violent knock of the bottom against the inelastic stop—would be more important to overcome. At the moment of the breaking through, the air space has a very high resistance, which is probably reduced to a very small value when the current has reached some strength, and the space is brought to a high temperature. It would materially diminish the loss of energy, if the space were always kept at an extremely high temperature, but then there would be no disruptive break. By warming the space moderately by means of a lamp or otherwise, the economy, as far as the arc is concerned, is sensibly increased. But the magnet or other interrupting device does not diminish the loss in the arc. Likewise, a jet of air only facilitates the carrying off of the energy. Air, or a gas in general, behaves curiously in this respect.

When two bodies, charged to a very high potential, discharge disruptively through an air space, any amount of energy may be carried off by the air. This energy is evidently dissipated by bodily carriers, in impact and collisional losses of the molecules. The exchange of the molecules in the space occurs with inconceivable rapidity. When a powerful discharge takes place between two electrodes, they may remain entirely cool, and yet the loss in the air may represent any amount of energy. It is quite practicable, with very great potential differences in the gap, to dissipate several horse-power in the arc of the discharge without even noticing a small increase in the temperature of the electrodes. All the frictional losses occur then practically in the air. If the exchange of the air molecules is prevented, as by enclosing the air hermetically, the gas inside of the vessel is brought quickly to a high temperature even with a very small discharge. It is difficult to estimate how much of the energy is lost in sound waves, audible or not, in a powerful discharge. When the currents through the gap are large, the electrodes may become rapidly heated, but this is not a reliable measure of the energy wasted in the arc, as the loss through the gap itself may be comparatively small. The air, or a gas in general, is, at ordinary pressures at least, clearly not the best medium through

which a disruptive discharge should occur. Air or other gas under great pressure is of course a much more suitable medium for the discharge gap. I have carried on long-continued experiments in this direction, unfortunately less practicable on account of the difficulties and expense in getting air under great pressure. But whether the medium in the discharge space be solid or liquid, the same losses take place, though they are generally smaller, for just as soon as the arc is established, the solid or liquid is volatilized. Indeed, there is no body known which would not be disintegrated by the arc, and it is an open question among scientific men, whether an arc discharge could occur at all in the air itself without the particles of the electrodes being torn off. When the current through the gap is very small and the arc very long, I believe that a relatively considerable amount of heat is taken up in the disintegration of the electrodes, which partially on this account may remain quite cold.

The ideal medium for a discharge gap should only *crack*, and the ideal electrode should be of some material which cannot be disintegrated. With small currents through the gap it is best to employ aluminum, but not when the currents are large. The disruptive break in the air, or in any ordinary medium, is not of the hature of a crack, but it is rather comparable to the piercing of innumerable bullets through a mass offering great frictional resistance to the motion of the bullets, thus involving considerable loss of energy. A medium which would merely crack when strained electrostatically—and this possibly might be the case with a perfect vacuum; that is, in pure ether—would involve a very small loss in the gap, so small as to be entirely negligible, at least theoretically, because a crack may be produced by an infinitely small displacement. In exhausting, with the greatest care, an oblong bulb provided with two aluminum terminals, I have succeeded in producing so high a vacuum that the secondary discharge of a disruptive discharge coil would break through disruptively through the bulb in the form of fine spark streams. The curious point was that the discharge would completely

ignore the terminals and start far behind the two aluminum plates which served as electrodes. This extraordinarily high vacuum could only be maintained for a very short time.

To return to the ideal medium, think, for the sake of illustration, of a piece of glass or similar body clamped in a vise, and the latter tightened more and more. At a certain point a minute increase of the pressure will cause the glass to crack. The loss of energy involved in splitting the glass may be practically nothing, for though the force is great, the displacement need be but extremely small. Now imagine that the glass possesses the property of perfectly closing the crack upon a minute diminution of the pressure. This is the way the dielectric in the discharge space should behave. But inasmuch as there would be always some loss in the gap, the medium which should be continuous should exchange through the gap at a rapid rate.

In the preceding example, the glass being perfectly closed, it would mean that the dielectric in the discharge space possesses a great insulating power; the glass being cracked, it would signify that the medium in the space is a good conductor. The dielectric should vary enormously in resistance by minute variations of the E. M. F. across the discharge space. This condition is attained, but in an extremely imperfect manner, by warming the air space to a certain critical temperature, dependent on the E. M. F. across the gap, or by otherwise impairing the insulating power of the air. But as a matter of fact the air never breaks down *disruptively*, if this term be rigorously interpreted, for before the sudden rush of the current occurs, there is always a weak current preceding it, which rises first gradually and then with comparative suddenness. That is the reason why the rate of change is very much greater when glass, for instance, is broken through, than when the break takes place through an air space of equivalent dielectric strength. As a medium for the discharge space a solid, or even a liquid would be preferable. It is somewhat difficult to conceive of a solid body which

would possess the property of closing instantly after it has been cracked. But a liquid, especially under great pressure, behaves practically like a solid, while it possesses the property of closing the crack. Hence it was thought that a liquid insulator might be more suitable as a dielectric than air. Following out this idea, a number of different forms of dischargers, in which a variety of such insulators, sometimes under great pressure, were employed, have been tried. It is thought sufficient to dwell in a few words upon one of the forms experimented upon. One of these dischargers is illustrated in *Figs. 4a* and *4b*.

A hollow metal pulley *P*, (*Fig. 4a*,) was fastened upon an arbor *a*, which by a suitable means was rotated at a considerable speed. In the inside of the pulley, but disconnected from the same, was supported a thin disc h_1 (which is

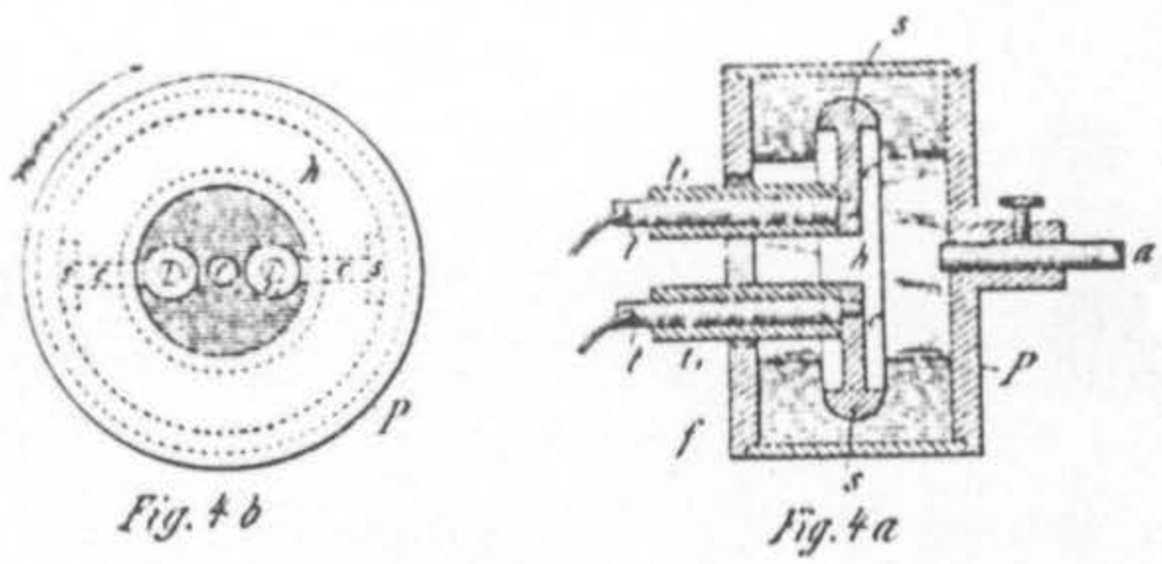


Fig. 4b *Fig. 4a*

Form of discharger with liquid interrupter.

shown thick for the sake of clearness) of hard rubber, in which there were embedded two metal segments *s s*, with metallic extensions *e e*, into which were screwed conducting terminals *t t*, covered with thick tubes of hard rubber *t t*. The rubber disc *h*, with its metallic segments *s s*, was finished in a lathe, and its entire surface highly polished so as to offer the smallest possible frictional resistance to motion through a fluid. In the hollow of the pulley an insulating liquid, such as a thin oil, was poured so as to reach very nearly to the opening left in the flange *f*, which was screwed tightly on the front side of the pulley. The terminals *t t* were connected to the opposite coatings of a battery of condensers so that the discharge occurred through the liquid. When the pulley was rotated the liquid was forced against the rim of the pulley and con-

siderable fluid pressure resulted. In this simple way the discharge gap was filled with a medium which behaved practically like a solid, which possessed the quality of closing instantly upon the occurrence of the break, and which moreover was circulating through the gap at a rapid rate.

Very powerful effects were produced by dischargers of this kind with liquid interrupters, of which a number of different forms were made. It was found, as expected, that a longer spark for a given length of wire was obtainable in this way than by using air as an interrupting device. In the form of discharger described, the speed, and, therefore, also the fluid pressure, were limited by reason of the fluid friction, but the practically obtainable speed was more than sufficient to produce a number of breaks suitable for the circuits ordinarily used. In some instances the metal pulley *P*, was provided with a few projections inwardly, and a definite number of breaks was then produced which could be computed from the speed of rotation of the pulley. Experiments were also carried on with liquids of different insulating powers, with the view of reducing the loss in the arc. When an insulating liquid is moderately warmed the loss in the arc is diminished.

A point of some importance was noted in experiments with various dischargers of this kind. It was found, for instance, that, whereas the conditions maintained in these forms were favorable for the production of a great spark length, the current so obtained were not best suited to the production of light effects. Experience undoubtedly has shown, that for such purpose a harmonic rise and fall of the potential is preferable. Whether it be that a solid is rendered incandescent, or phosphorescent, or that energy is transmitted by the condenser coating through the glass, it is certain that a harmonically rising and falling potential produces less destructive action, and that the vacuum is more permanently maintained. This would be easily explained if it were ascertained that the process going on in an exhausted vessel is of an electrolytic nature.

In the diagrammatical sketch, *Fig. 1*, which has already

been referred to, the cases which are most likely to be met with in practice are illustrated. One has at his disposal either direct or alternating currents from a supply station. It is convenient for an experimenter in an isolated laboratory, to employ a machine *G*, such as illustrated, capable of giving both kinds of currents. In such case it is also preferable to use a machine with multiple circuits, as in many experiments it is useful and convenient to have at one's disposal currents of different phases. In the sketch, *D* represents the direct, and *A*, the alternating circuit. In each of these, three branch circuits are shown, all of which are provided with double line switches, *s s s s s s*. Consider first, the direct current conversion; *1a* represents the simplest case. If the E. M. F. of the generator is sufficient to break through a small air space, at least when the latter is warmed or otherwise rendered poorly insulating, there is no difficulty in maintaining a vibration with fair economy by judicious adjustment of the capacity, self-induction and resistance of the circuit *L* containing the devices *l l m*. The magnet *N S*, in this case, can advantageously be combined with the air space. The discharger *d d*, with the magnet, may be placed either way, as indicated by the full, or by the dotted, lines. The circuit *1a* with the connections and devices is supposed to possess dimensions such as are suitable for the maintenance of a vibration. But usually the E. M. F. on the circuit or branch *1a* will be something like 100 volts or so, and in this case it is not sufficient to break through the gap. Many different means may be used to remedy this by raising the E. M. F. across the gap. The simplest is probably to insert a large self-induction coil in series with the circuit *L*. When the arc is established, as by the discharger illustrated in *Fig. 2*, the magnet blows the arc out the instant it is formed. Now the extra current of the break, being of high E. M. F., breaks through the gap, and a path of low resistance for the dynamo current being again provided, there is a sudden rush of the current from the dynamo upon the weakening or subsidence of the extra current. This process is repeated in rapid succession, and in this manner I have maintained

oscillation with as low as fifty volts, or even less, across the gap. But conversion on this plan is not to be recommended on account of the too heavy currents through the gap and consequent heating of the electrodes; besides, the frequencies obtained in this way are low, owing to the high self-induction necessarily associated with the circuit. It is very desirable to have the E. M. F. as high as possible, firstly, in order to increase the economy of the conversion; and, secondly, to obtain high frequencies. The difference of potential in this electric oscillation is, of course, the equivalent of the stretching force in the mechanical vibration of the spring. To obtain very rapid vibration in a circuit of some inertia, a great stretching force or difference of potential is necessary. Incidentally, when the E. M. F. is very great, the condenser which is usually employed in connection with the circuit need have but a small capacity, and many other advantages are gained. With a view of raising the E. M. F. to a many times greater value than that obtainable from ordinary distribution circuits, a rotating transformer *g* is used, as indicated in *Fig. 2a*, or else a separate high potential machine is driven by means of a motor operated from the generator *G*. The latter plan is in fact preferable, as changes are more easily made. The connections from the high tension winding are quite similar to those in branch *1a*, with the exception that a condenser *C*, which should be adjustable, is connected to the high tension circuit. Usually, also, an adjustable self-induction coil in series with the circuit has been employed in these experiments. When the tension of the currents is very high the magnet ordinarily used in connection with the discharger is of comparatively small value, as it is quite easy to adjust the dimensions of the circuit so that oscillation is maintained.

The employment of a steady E. M. F. in the high frequency conversion affords some advantages over the employment of alternating E. M. F., as the adjustments are much simpler and the action can be more easily controlled. But unfortunately one is limited by the obtainable potential difference. The windings also break down easily in consequence of the sparks which form between the sections of the armature

or commutator when a vigorous oscillation takes place. Besides, these transformers are expensive to build. It has been found by experience that it is best to follow the plan illustrated in *Fig. 3a*. In this arrangement a rotating transformer *g* is employed to convert the low tension direct currents into low frequency alternating currents, preferably also of small tension. The tension of the currents is then raised in a stationary transformer *T*. The secondary *S* of this transformer is connected to an adjustable condenser *C*, which discharges through the gap or discharger *d d*, placed in either of the ways indicated, through the primary *P* of a disruptive discharge coil, the high frequency currents being obtained from the secondary *S* of this coil, as described on previous occasions. This will undoubtedly be found the cheapest and most convenient way of converting direct currents.

The three branches of the circuit *A*, represent the usual cases met in practice when alternating currents are converted. In *Fig. 1b*, a condenser *C*, generally of large capacity, is connected to the circuit *L*, containing the devices *l l m m*. The devices *m m* are supposed to be of high self-induction so as to bring the frequency of the circuit more or less to that of the dynamo. In this instance the discharger *d d* should best have a number of makes and breaks per second equal to twice the frequency of the dynamo. If not so, then it should have at least a number equal to a multiple or even a fraction of the dynamo frequency. It should be observed, referring to *1b*, that the conversion to a high potential is also affected when the discharger *d d*, which is shown in the sketch, is omitted. But the effects which are produced by currents which rise instantly to high values, as in a disruptive discharge, are entirely different from those produced by dynamo currents which rise and fall harmonically. So, for instance, there might be, in a given case, a number of makes and breaks at *d d*, equal to just twice the frequency of the dynamo, or in other words there may be the same number of fundamental oscillations as would be produced without the discharge gap, and there might even not be any quicker superimposed vibration; yet

the differences of potential at the various points of the circuit, the impedence and other phenomena, dependent upon the rate of change, will bear no similarity in the two cases. Thus, when working with currents discharging disruptively, the element chiefly to be considered, is not the frequency, as a student might be apt to believe, but the rate of change per unit of time. With low frequencies, in a certain measure, the same effects may be obtained as with high frequencies, provided the rate of change is sufficiently great. So, if a low frequency current is raised to a potential of (say) 75,000 volts and the high tension current passed through a series of high resistance lamp filaments, the importance of the rarefied gas surrounding the filament is clearly noted, as will be seen later; or, if a low frequency current of several thousand ampères is passed through a metal bar, striking phenomena of impedence are observed, just as with currents of high frequencies. But it is, of course, evident that with low frequency currents, it is impossible to obtain such rates of change per unit of time as with high frequencies, hence the effects produced by the latter are much more prominent. It was deemed advisable to make the preceding remarks, inasmuch as many more recently described effects have been unwittingly identified with high frequencies. Frequency alone in reality does not mean anything, except when an undisturbed harmonic oscillation is considered.

In the branch *3b*, a similar disposition as in *1b*, is illustrated, with the difference that the currents discharging through the gap *d d* are used to induce currents in the secondary *S* of a transformer *T*. In such case the secondary should be provided with an adjustable condenser for the purpose of tuning it to the primary.

Fig. 2b illustrates a plan of alternate current high frequency conversion which is most frequently used and which is found to be most convenient. This plan has been dwelt upon in detail on previous occasions and need not be described here.

Some of these results were obtained by the use of a high frequency alternator. A description of such machines will

be found in my original paper before the American Institute of Electrical Engineers, and in the periodicals of that period, notably in *The Electrical Engineer*, of March 18, 1891.

I will now proceed with the experiments:

On Phenomena produced by Electrostatic Force.—The first class of effects I intend to show you, are effects produced by electrostatic force. It is the force which governs the motion of the atoms, which causes them to collide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an infinite variety of ways, according to nature's fanciful designs, and to form all these wondrous structures we perceive around us; it is, in fact, if our present views be true, the most important force in nature for us to consider. As the term *electrostatic* might imply a steady electric condition, it should be remarked, that in these experiments the force is not constant, but varies at a rate which may be considered moderate, about 1,000,000 times a second, or thereabouts. This enables me to produce many effects which are not producible with an unvarying force.

When two conducting bodies are insulated and electrified, we say that an electrostatic force is acting between them. This force manifests itself in attractions, repulsions and stresses in the bodies and in the space or medium without. So great may be the strain exerted in the air, or whatever separates the two conducting bodies, that it may break down, and we observe sparks or bundles of light, or streamers, as they are called. These streamers form abundantly when the force through the air is rapidly varying. I will illustrate this action of electrostatic force in a novel experiment in which I will employ the induction coil before referred to. The coil is contained in a trough filled with oil, and placed under the table. The two ends of the secondary wire pass through the two thick columns of hard rubber, which protrude to some height above the table. It is necessary to insulate heavily the ends or terminals of the secondary with hard rubber, because even dry wood is by far too poor an insulator for these currents of enormous potential differences. On one of the terminals of the coil, I have placed

a large sphere of sheet brass, which is connected to a larger insulated brass plate, in order to enable me to perform the experiments under conditions, which, as you will see, are more suitable for this experiment. I now set the coil to work and approach the free terminal with a metallic object held in my hand; this, simply to avoid burns. As I approach the metallic object to a distance of eight or ten inches, a torrent of furious sparks breaks forth from the end of the secondary wire, which passes through the rubber column. The sparks cease when the metal in my hand touches the wire. My arm is now traversed by a powerful electric current, vibrating at about the rate of 1,000,000 times a second. All around me the electrostatic force makes itself felt, and the air molecules and particles of dust flying about are acted upon and are hammering violently against my body. So great is this agitation of the particles, that when the lights are turned out you may see streams of feeble light appear on some parts of my body. When such a streamer breaks out on any part of the body, it produces a sensation like the pricking of a needle. Were the potentials sufficiently high and the frequency of the vibration rather low, the skin would probably be ruptured under the tremendous strain, and the blood would rush out with great force in the form of fine spray, or jet, so thin as to be invisible, just as oil will when placed on the positive terminal of a Holtz machine. This breaking through of the skin, though it may seem impossible at first, would perhaps occur, by reason of the tissues under the skin being incomparably better conducting. This, at least, appears plausible, judging from some observations.

I can make these streams of light visible to all, by touching with the metallic object one of the terminals as before, and approaching my free hand to the brass sphere, which is connected to the second terminal of the coil. As the hand is approached, the air between it and the sphere, or in the immediate neighborhood, is more violently agitated and you see streams of light now break forth from my finger tips and from the whole hand (*Fig. 5*). Were I to approach the hand closer, powerful sparks would jump from the brass

sphere to my hand, which might be injurious. The streamers offer no particular inconvenience, except that in the ends of the finger tips a burning sensation is felt. They should not be confounded with those produced by an influence machine, because, in many respects, they behave differently. I have attached the brass sphere and plate to one of the terminals in order to prevent the formation of visible streamers on that terminal, also, in order to prevent sparks from jumping to a considerable distance. Besides, the attachment is favorable for the working of the coil.

The streams of light, which you have observed issuing from my hand, are due to a potential of about 200,000 volts, alternating in rather irregular intervals, something like 1,000,000 times a second. A vibration of the same amplitude,

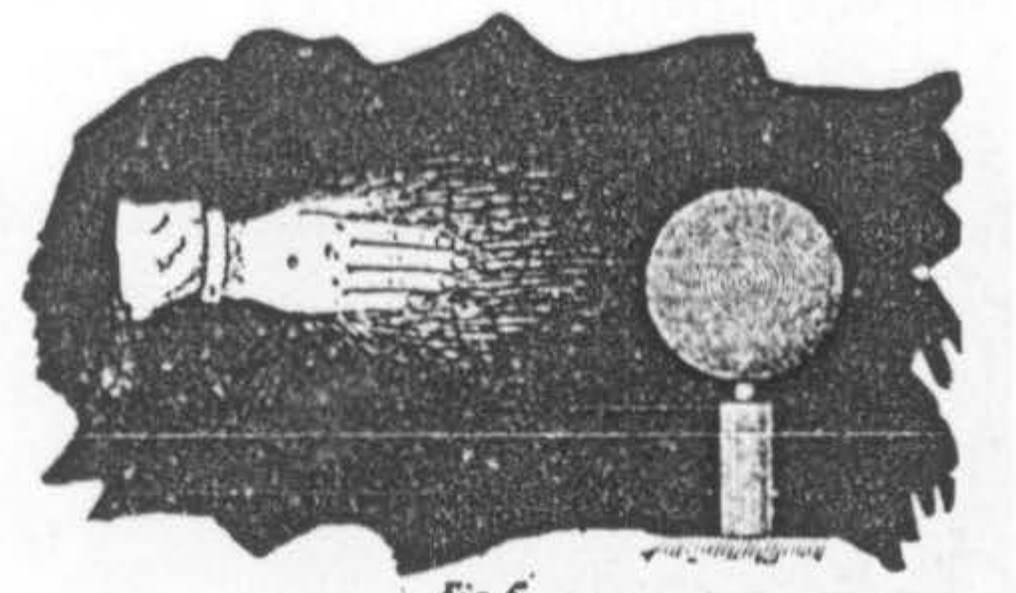


Fig. 5

Illustrating the effect of varying electrostatic force with a transformer of 200,000 volts pressure..

but four times as fast to maintain which, over 3,000,000 volts would be required, would be more than sufficient to envelop my body in a complete sheet of flame. But this flame would not burn me up; quite the reverse, the probability is that I would not be injured in the least. Yet a hundredth part of that energy, otherwise directed, would be amply sufficient to kill a person.

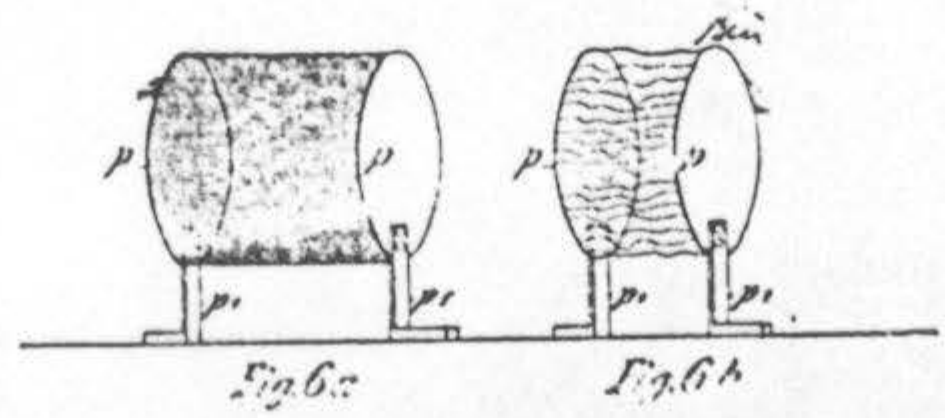
The amount of energy which may thus be passed into the body of a person depends on the frequency and potential of the currents, and by making both of these very great, a vast amount of energy may be passed into the body without causing any discomfort, except perhaps, in the arm, which is traversed by a true conduction current. The reason why no pain in the body is felt, and no injurious effect

noted, is, that everywhere, if a current be imagined to flow through the body, the direction of its flow would be at right angles to the surface; hence the body of the experimenter offers an enormous section to the current, and the density is very small, with the exception of the arm, perhaps, where the density may be considerable. But if only a small fraction of that energy would be applied in such a way that a current would traverse the body in the same manner as a low frequency current, a shock would be received which might be fatal. A direct or low frequency alternating current is fatal, I think, principally because its distribution through the body is not uniform, as it must divide itself in minute streamlets of great density, whereby some organs are vitally injured. That such a process occurs I have not the least doubt, though no evidence might apparently exist, or be found upon examination. The surest to injure and destroy life, is a continuous current, but the most painful is an alternating current of very low frequency. The expression of these views, which are the result of long-continued experiment and observation, both with steady and varying currents, is elicited by the interest which is at present taken in this subject, and by the manifestly erroneous ideas which are daily propounded in the journals.

I may illustrate an effect of the electrostatic force by another striking experiment, but before, I must call your attention to one or two facts. I have said before, that when the medium between two oppositely electrified bodies is strained beyond a certain limit, it gives way, and, stated in popular language, the opposite electric charges unite and neutralize each other. This breaking down of the medium occurs principally when the force acting between the bodies is steady, or varies at a moderate rate. Were the variation sufficiently rapid, such a destructive break would not occur, no matter how great the force, for all the energy would be spent in radiation, convection and mechanical and chemical action. Thus the *spark* length, or greatest distance through which a *spark* will jump between the electrified bodies is the smaller, the greater the variation or time rate of change. But this rule may be taken to be true only in a

general way, when comparing rates which are widely different.

I will show you by an experiment the difference in the effect produced by a rapidly varying, and a steady or moderately varying force. I have here two large circular brass plates *p p* (*Figs. 6a* and *6b*), supported on movable insulating stands on the table, and connected to the ends of the secondary of a similar coil as the one used before. I place the plates ten or twelve inches apart and set the coil to work. You see the whole space between the plates, nearly two cubic feet, filled with uniform light, *Fig. 6a*. This light is due to the streamers you have seen in the first experiment, which are now much more intense. I have already pointed out the importance of these streamers in commercial apparatus and their still greater importance in some

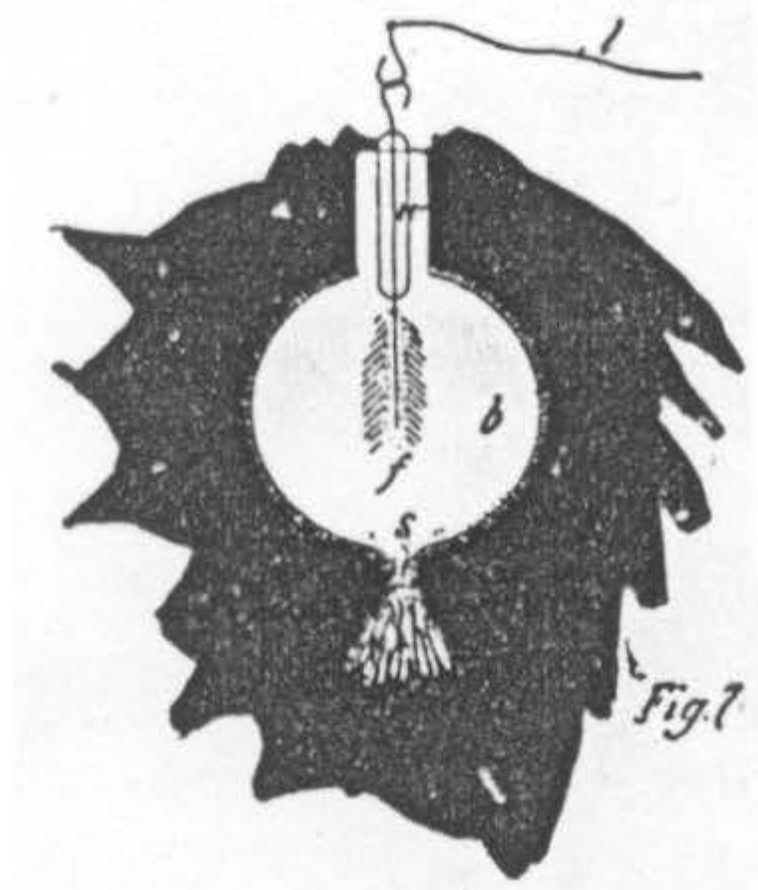


Illustrating the effects of rapidly varying and steady electrostatic force.

purely scientific investigations. Often they are too weak to be visible, but they always exist, consuming energy and modifying the action of the apparatus. When intense, as they are at present, they produce ozone in great quantity, and also, as Professor Crookes has pointed out, nitrous acid. So quick is the chemical action, that if a coil such as this one, is worked for a very long time it will make the atmosphere of a small room unbearable, for the eyes and throat are attacked. But when moderately produced, the streamers refresh the atmosphere wonderfully, like a thunder storm, and exercise unquestionably a wholesome effect.

In this experiment the force acting between the plates changes in intensity and direction at a very rapid rate. I will now make the rate of change per unit time much smaller. This I effect by rendering the discharges through the primary of the induction coil less frequent, and also by

diminishing the rapidity of the vibration in the secondary. The former result is convenientiy secured by lowering the E. M. F. over the air gap in the primary circuit; the latter, by approaching the two brass plates to a distance of about three or four inches. When the coil is set to work you see no streamers or light between the plates, yet the medium between them is under a tremendous strain. I still further augment the strain by raising the E. M. F. in the primary circuit, and soon you see the air give way and the hall is illuminated by a shower of brilliant and noisy sparks, *Fig. 6b*. These sparks could be produced also with unvarying force; they have been for many years a familiar phenomenon, though they were usually obtained from entirely different



Breaking a bulb on open circuit.

apparatus. In describing these two phenomena, so radically different in appearance, I have advisedly spoken of a "force" acting between the plates. It would be in accordance with accepted views to say that there was an "alternating E. M. F." acting between the plates. This term is quite proper and applicable in all cases where there is evidence of at least a possibility of an essential interdependence of the electric state of the plates, or electric action in their neighborhood. But whether the plates be removed to an infinite distance, or to a finite distance, there is no probability or necessity whatever for such dependence. I prefer to use the term "electrostatic force," and to say that such a force is acting around each plate or electrified

insulated body in general. There is an inconvenience in using this expression as the term incidentally means a steady electric condition; but a proper nomenclature will eventually settle this difficulty.

I now return to the experiment to which I have already alluded, and with which I desire to illustrate a striking effect produced by a rapidly varying electrostatic force. I attach to the end of the wire *l* (*Fig. 7*), which is in connection with one of the terminals of the secondary of the induction coil, an exhausted bulb *b*. This bulb contains a thin carbon filament *f*, which is fastened to a platinum wire *w*, sealed in the glass and leading outside of the bulb, where it connects to the wire *l*. The bulb may be exhausted to any degree attainable with ordinary apparatus. Just a moment before, you have witnessed the breaking down of the air between the charged brass plates. You know that a plate of glass, or any other insulating material, would break down in like manner. Had I therefore a metallic coating attached to the outside of the bulb, or placed near the same, and were this coating connected to the other terminal of the coil, you would be prepared to see the glass give way if the strain were sufficiently increased. Even were the coating not connected to the other terminal, but to an insulated plate, still, if you have followed recent developments, you would naturally expect a rupture of the glass.

But it will certainly surprise you to note that under the action of the varying electrostatic force, the glass gives way when all other bodies are removed from the bulb. In fact, all the surrounding bodies we perceive might be removed to an infinite distance without affecting the result in the slightest. When the coil is set to work, the glass is invariably broken through at the seal, or other narrow channel, and the vacuum is quickly impaired. Such a damaging break would not occur with a steady force, even if the same were many times greater. The break is due to the agitation of the molecules of the gas within the bulb, and outside of the same. This agitation, which is generally most violent in the narrow pointed channel near the seal, causes a heating and rupture of the glass. This rupture would, how-

ever, not occur, not even with a varying force, if the medium filling the inside of the bulb, and that surrounding it, were perfectly homogeneous. The break occurs much more quickly if the top of the bulb is drawn out into a fine fibre. In bulbs used with these coils such narrow, pointed channels must therefore be avoided.

[*To be continued.*]

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ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

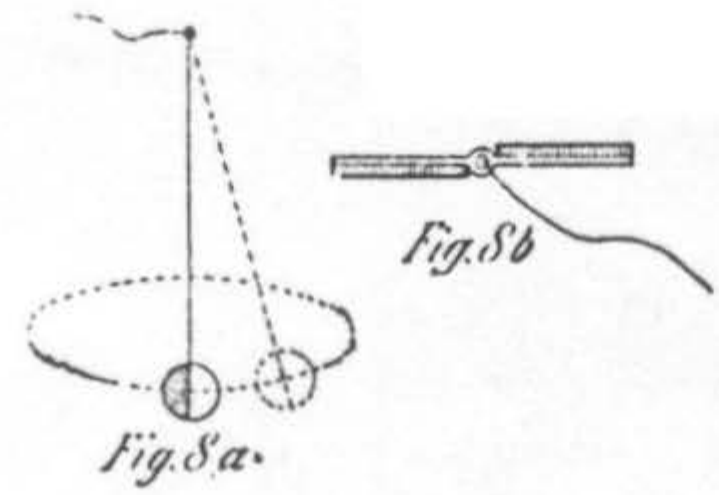
BY NIKOLA TESLA.

[*Continued from p. 98.*]

When a conducting body is immersed in air, or similar insulating medium, consisting of, or containing, small freely movable particles capable of being electrified, and when the electrification of the body is made to undergo a very rapid change—which is equivalent to saying that the electrostatic force acting around the body is varying in intensity—the small particles are attracted and repelled, and their violent impacts against the body may cause a mechanical motion of the latter. Phenomena of this kind are note-

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893, and before the National Electric Light Association, at St. Louis, March 1, 1893.

worthy inasmuch as they have not been observed before with apparatus such as has been commonly in use. If a very light conducting sphere be suspended on an exceedingly fine wire, and charged to a steady potential, however high, the sphere will remain at rest. Even if the potential be rapidly varying, provided that the small particles of matter, molecules or atoms, are evenly distributed, no motion of the sphere should result. But if one side of the conducting sphere is covered with a thick insulating layer, the impacts of the particles will cause the sphere to move about, generally in irregular curves, *Fig. 8a.* In like manner, as I have shown on a previous occasion, a fan of metal sheet, *Fig. 8b*, covered partially with insulating material as indicated, and placed upon the terminal of the coil so as to turn freely in it, is caused to spin around.



Mechanical motions produced by varying electrostatic force in a gaseous medium.

All these phenomena you have witnessed and others which will be shown later, are due to the presence of a medium like air, and would not occur in a continuous medium. The action of the air may be illustrated still better by the following experiment. I take a glass tube *t*, *Fig. 9*, of about an inch in diameter, which has a platinum wire *w* sealed in the lower end, and to which is attached a thin lamp filament *f*. I connect the wire with the terminal of the coil and set the coil to work. The platinum wire is now electrified positively and negatively in rapid succession, and the wire and air inside of the tube are rapidly heated by the impacts of the particles, which may be so violent as to render the filament incandescent. But if I pour oil in the tube, just as soon as the wire is covered with the oil, all action apparently ceases and there is no marked evidence

of heating. The reason of this is that the oil is a practically continuous medium. The displacements in such a continuous medium are, with these frequencies, to all appearance incomparably smaller than in air, hence the work performed in such a medium is insignificant. But oil would behave very differently with frequencies many times as great, for even though the displacements be small, if the frequency were much greater considerable work might be performed in the oil.

The electrostatic attractions and repulsions between bodies of measurable dimensions are, of all the manifestations of this force, the first so-called *electrical* phenomena noted. But though they have been known to us for many

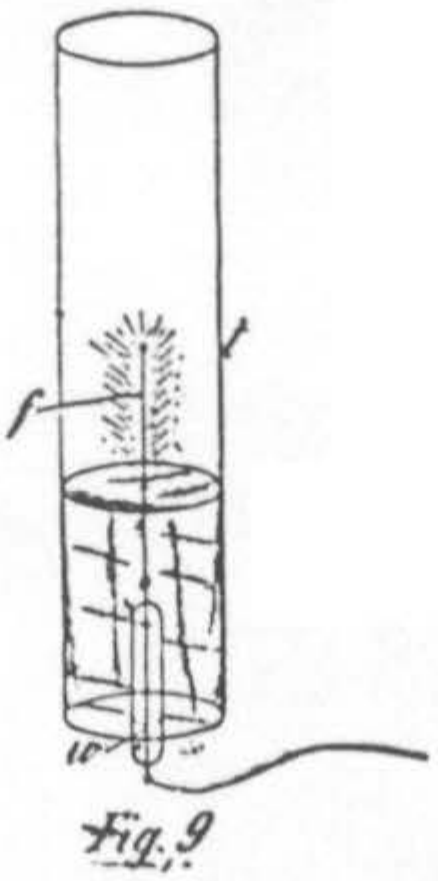


Fig. 9

Showing the effect of the air.

centuries, the precise nature of the mechanism concerned in these actions is still unknown to us, and has not even been quite satisfactorily explained. What kind of mechanism must that be? We cannot help wondering when we observe two magnets attracting and repelling each other with a force of hundreds of pounds with apparently nothing between them. We have in our commercial dynamos magnets capable of sustaining in mid-air tons of weight. But what are even these forces acting between magnets when compared with the tremendous attractions and repulsions produced by electrostatic force, to which there is apparently no limit as to intensity. In lightning discharges, bodies are often charged to so high a potential that they

are thrown away with inconceivable force and torn asunder or shattered into fragments. Still even such effects cannot compare with the attractions and repulsions which exist between charged molecules or atoms, and which are sufficient to project them with speeds of many kilometres a second, so that under their violent impact bodies are rendered highly incandescent and are volatilized. It is of special interest for the thinker who inquires into the nature of these forces to note, that whereas the actions between individual molecules or atoms occur seemingly under any conditions, the attractions and repulsions of bodies of measurable dimensions imply a medium possessing insulating properties. So, if air, either by being rarefied or heated, is

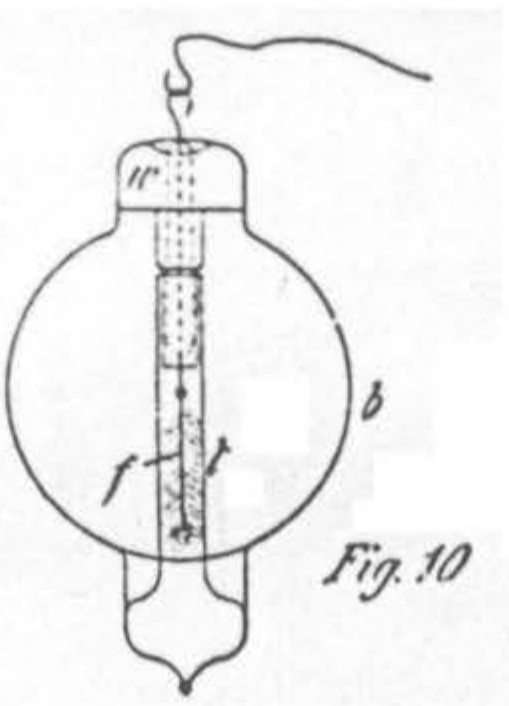


Fig. 10

Showing the influence of the conductivity of the medium upon electrostatic actions through measurable distance.

rendered more or less conducting, these actions between two electrified bodies practically cease, while the actions between the individual atoms continue to manifest themselves.

An experiment may serve as an illustration and as a means of bringing out other features of interest. Some time ago I showed that a lamp filament or wire mounted in a bulb and connected to one of the terminals of a high tension secondary coil is set spinning, the top of the filament generally describing a circle. This vibration was very energetic when the air in the bulb was at ordinary pressure, and became less energetic when the air in the bulb was strongly compressed. It ceased altogether when the air was exhausted so as to become a comparatively good con-

ductor. I found at that time that no vibration took place when the bulb was very highly exhausted. But I conjectured that the vibration which I ascribed to the electrostatic action between the walls of the bulb and the filament should take place also in a highly exhausted bulb. To test this under conditions which were more favorable, a bulb, like the one in *Fig. 10*, was constructed. It comprised a globe *b*, in the neck of which was sealed a platinum wire *w*, carrying a thin lamp filament *f*. In the lower part of the globe a tube *t*, was sealed so as to surround the filament. The exhaustion was carried as far as practicable with the apparatus employed.

This bulb verified my expectation, for the filament was set spinning when the current was turned on, and became incandescent. It also showed another interesting feature, bearing upon the preceding remarks; namely, when the filament had been kept incandescent some time the narrow tube and the space inside was brought to an elevated temperature, and as the gas in the tube then became conducting, the electrostatic attraction between the glass and the filament became very weak or ceased and the filament came to rest. When it came to rest it would glow far more intensely. This was probably due to its assuming the position in the centre of the tube where the molecular bombardment was most intense, and also partly to the fact that the individual impacts were more violent and that no part of the supplied energy was converted into mechanical movement. Since, in accordance with accepted views, in this experiment the incandescence must be attributed to the impacts of the particles, molecules or atoms, in the heated space, these particles must, therefore, in order to explain such action, be assumed to behave as independent carriers of electric charges immersed in an insulating medium; yet there is no attractive force between the glass tube and the filament because the space in the tube is, as a whole, conducting.

It is of some interest to observe, at this point, that whereas the attraction between two electrified bodies may cease owing to the impairing of the insulating power of the

medium in which they are immersed, the repulsion between the bodies may still be observed. This may be explained in a plausible way. When the bodies are placed at some distance apart in a poorly conducting medium, such as slightly warmed or rarefied air, and are suddenly electrified, opposite electric charges being imparted to them, these charges are equalized more or less by leakage through the air. But if the bodies are similarly electrified, less opportunity is afforded for such dissipation, hence the repulsion observed in such case is greater than the attraction. Repulsive action in a gaseous medium is, however, as Professor Crookes has shown, enhanced by molecular bombardment.

On Current or Dynamic Electricity Phenomena.—So far, I have considered principally effects produced by a varying electrostatic force in an insulating medium, such as air. When such a force is acting upon a conducting body of measurable dimensions, it causes within the same, or on its surface, displacements of the electricity and gives rise to electric currents, and these produce another kind of phenomena, some of which I shall presently endeavor to illustrate. In presenting this second class of electrical effects, I will avail myself principally of such as are producible without any return circuit, hoping to interest you the more by presenting these phenomena in a more or less novel aspect.

It has been for a long time customary, owing to the limited experience with vibratory currents, to consider an electric current as something circulating in a closed conducting path. It was astonishing at first to realize that a current may flow through the conducting path even if the latter be interrupted, and it was still more surprising to learn, that sometimes it may even be easier to make a current flow under such conditions than through a closed path. But that old idea is gradually disappearing, even among practical men, and will soon be entirely forgotten.

If I connect, by means of a wire, an insulated metal plate *P*, *Fig. 11*, to one of the terminals *T*, of the induction coil though this plate be very well insulated, a current passes through the wire when the coil is set to work. First, I wish

to give you evidence that there is a current passing through the connecting wire. An obvious way of demonstrating this is to insert between the terminal of the coil and the insulated plate a very thin platinum or German-silver wire *w*, and bring the latter to incandescence, or fusion, by the current. This requires a rather large plate or else current impulses of very high potential and frequency. Another way is to take a coil *C*, *Fig. 11*, containing many turns of thin insulated wire and to insert the same in the path of the current to the plate. When I connect one of the ends of the coil to the wire leading to another insulated plate *P*, and its other end to the terminal *T*, of the induction coil, and set the latter to work, a current passes through the inserted coil *C*, and the existence of the current may be made manifest in various ways. For instance, I insert an iron core *i*

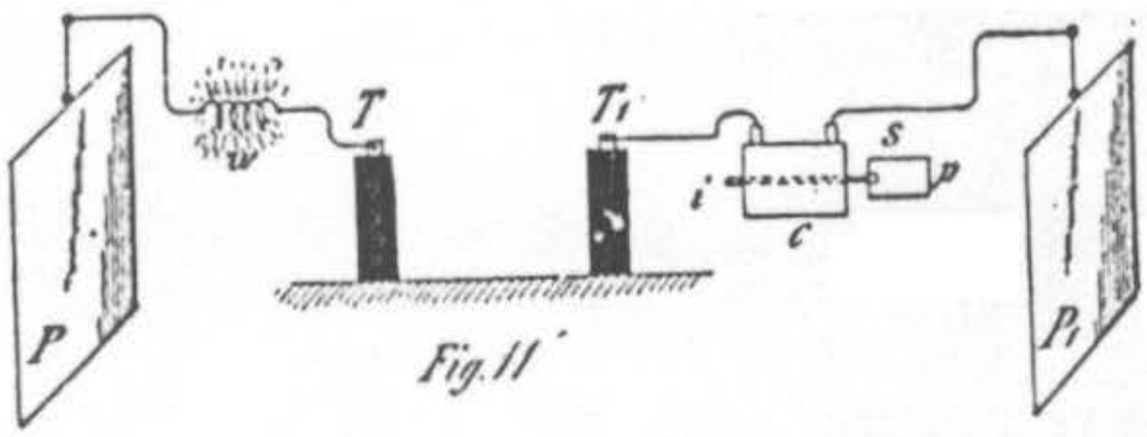


Fig. 11

Showing effects of currents flowing through open circuits.

within the coil. The current being one of the very high frequency, will, if it be of some strength, soon bring the iron core to a noticeably higher temperature, as the hysteresis and current losses are great with such high frequencies.

One might take a core of some size, laminated or not, it would matter little; but ordinary iron wire one-sixteenth or one-eighth of an inch thick is suitable for the purpose. While the induction coil is working, a current traverses the inserted coil and only a few moments are sufficient to bring the iron wire *i*, to an elevated temperature sufficient to soften the sealing wax *s*, and cause a paper washer *p*, fastened by it to the iron wire to fall off. But with the apparatus, such as I have here, other much more interesting demonstrations of this kind can be made. I have a secondary *S*, *Fig. 12*, of coarse wire wound upon a coil similar to the first. In the preceding experiment the

current through the coil *C*, *Fig. 11*, was very small, but there being many turns, a strong, heating effect was, nevertheless, produced in the iron wire. Had I passed that current through a conductor in order to show the heating of the latter, the current might have been too small to produce the effect desired. But with this coil provided with a secondary winding, I can now transform the feeble current of high tension which passes through the primary *P*, into a strong secondary current of low tension, and this current will certainly do what I expect. In a small glass tube (*t*, *Fig. 12*), I have enclosed a coiled platinum wire *w*, merely in order to protect the wire. On each end of the glass tube is sealed a terminal of stout wire, to which one of the ends of the platinum wire *w* is connected. I join the terminals of the secondary coil to these terminals and insert the primary *p*, between the insulated plate P_1 and the

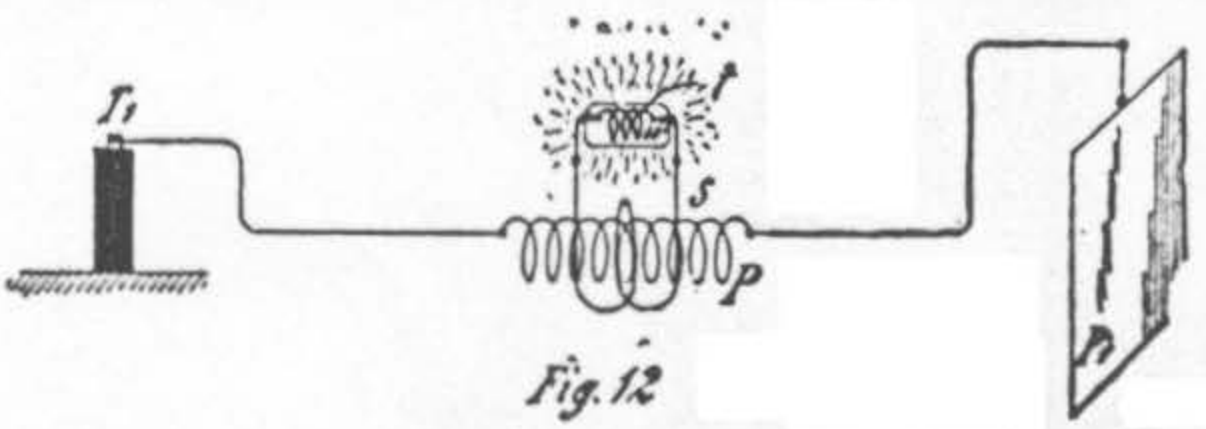


Fig. 12

Conversion on open circuit with coil and insulated plate.

terminal T_1 of the induction coil, as before. The latter being set to work, the platinum wire *w*, is instantly rendered incandescent and can be fused even if it be very thick.

Instead of the platinum wire I now take an ordinary fifty-volt sixteen candle-power lamp. When I set the induction coil in operation, the lamp filament is brought to high incandescence. It is, however, not necessary to use the insulated plate, for the lamp (*l*, *Fig. 13*) is rendered incandescent even if the plate P_1 be disconnected. The secondary may also be connected to the primary as indicated by the dotted line in *Fig. 13*, to do away more or less with the electrostatic induction, or to modify the action otherwise.

I may here call attention to a number of interesting observations with the lamp. First, I disconnect one of the terminals of the lamp from the secondary *S*. When the induction coil plays, a glow is noted which fills the whole

bulb. This glow is due to electrostatic induction. It increases when the bulb is grasped with the hand, and the capacity of the experimenter's body thus added to the secondary circuit. The secondary, in effect, is equivalent to a metallic coating, which would be placed near the primary. If the secondary, or its equivalent, the coating, were placed symmetrically to the primary, the electrostatic induction would be *nil* under ordinary conditions; that is, when a primary return circuit is used, as both halves would neutralize each other. The secondary *is* in fact placed symmetrically to the primary, but the action of both halves of the latter, when only one of its ends is connected to the induction coil, is not exactly equal; hence, electrostatic induction takes place, and hence the glow in the bulb. I

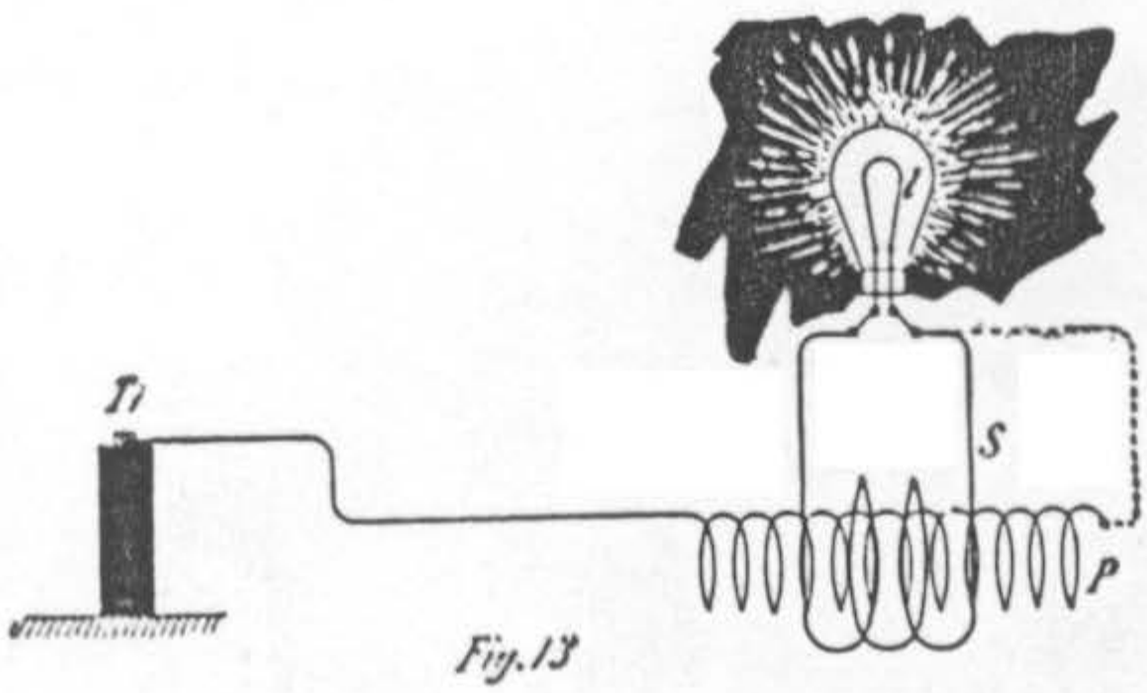


Fig. 13

Conversion on open circuit with coil alone.

can nearly equalize the action of both halves of the primary by connecting the other, free, end of the same to the insulated plate, as in the preceding experiment. When the plate is connected, the glow disappears. With a smaller plate it would not entirely disappear, and then it would contribute to the brightness of the filament when the secondary is closed, by warming the air in the bulb.

To demonstrate another interesting feature, I have adjusted the coils used in a certain way. I first connect both the terminals of the lamp to the secondary, one end of the primary being connected to the terminal T_1, of the induction coil and the other to the insulated plate P_1, as before. When the current is turned on, the lamp glows brightly, as shown in *Fig. 14b*, in which *C* is a fine wire coil

and S a coarse wire secondary wound upon it. If the insulated plate P_1 be disconnected, leaving one of the ends a of the primary insulated, the filament becomes dark or generally it diminishes in brightness (*Fig. 14a*). Connecting again the plate P_1, and raising the frequency of the current I make the filament quite dark or barely red (*Fig. 15b*). Once more I will disconnect the plate. One will of course infer that when the plate is disconnected, the current

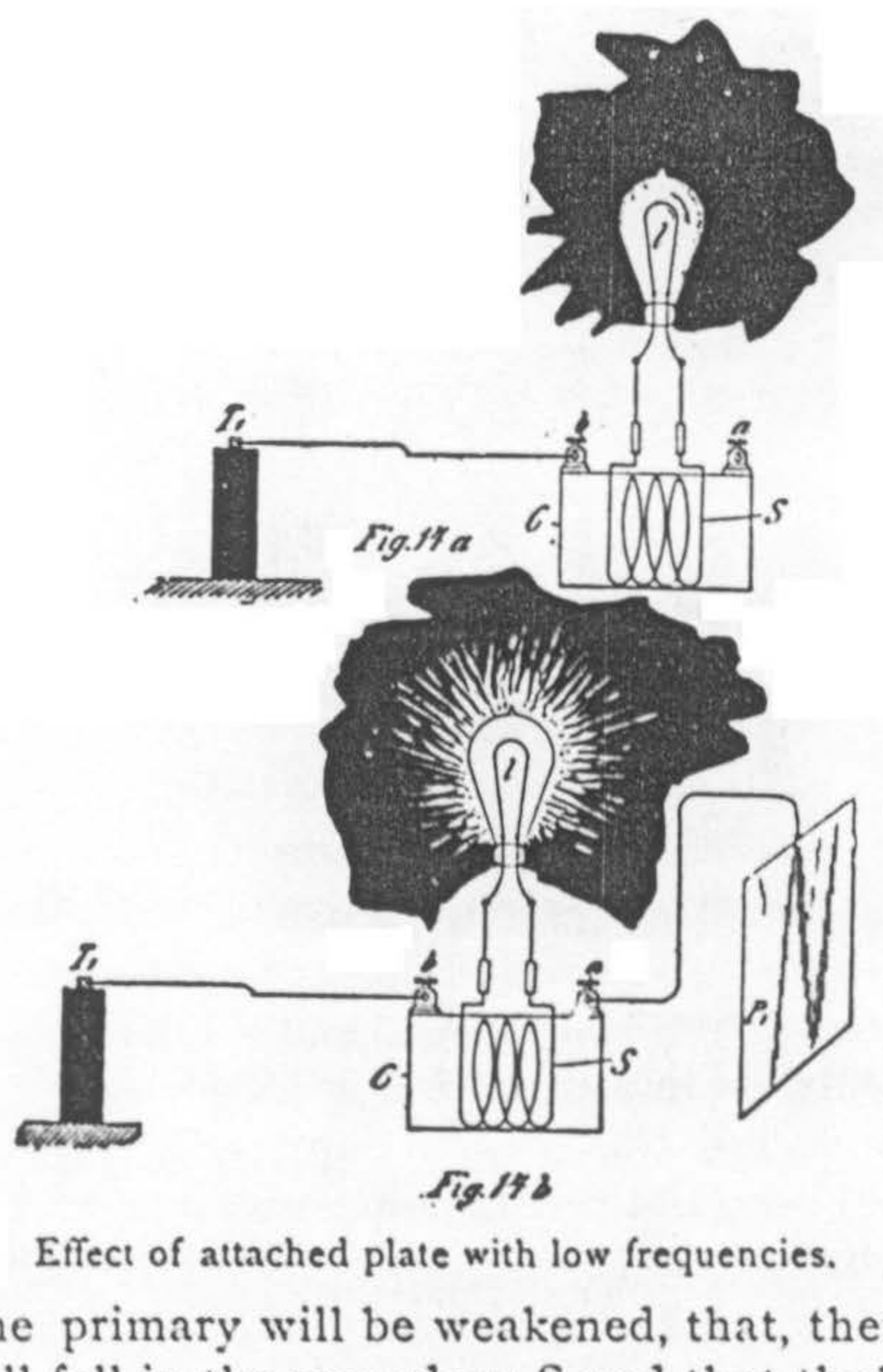
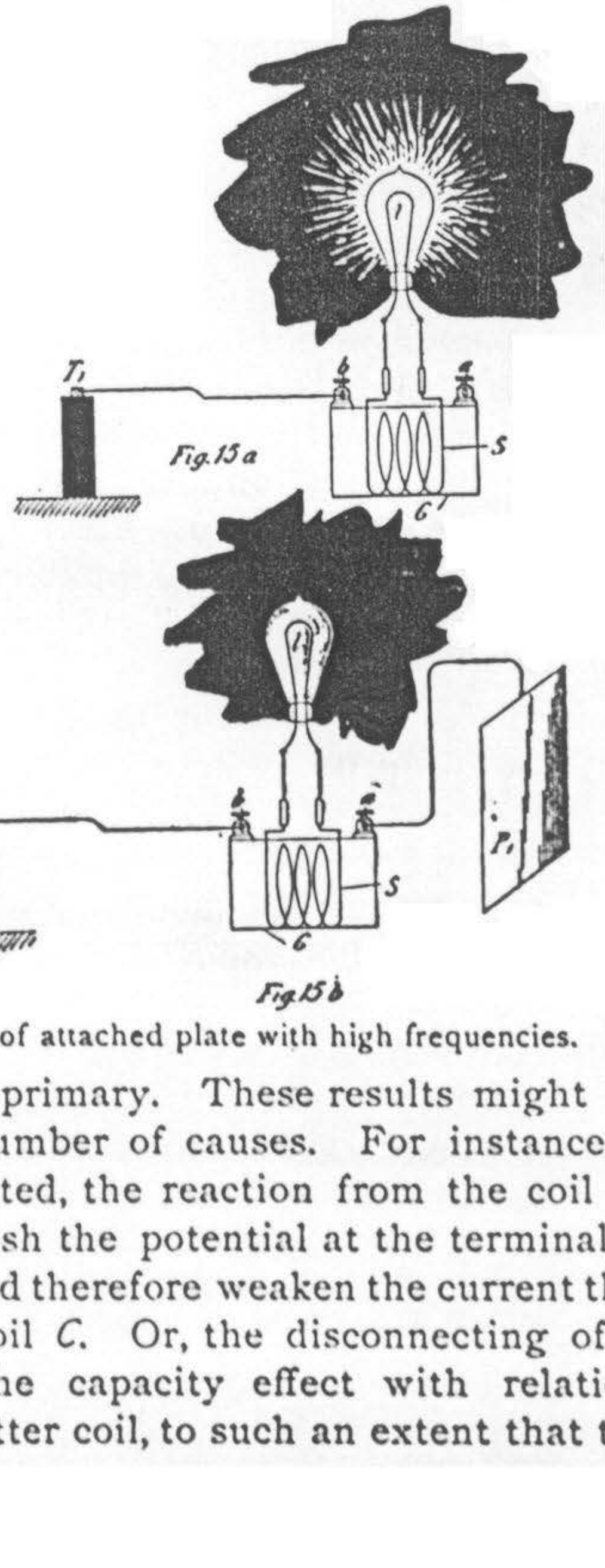


Fig. 14b

Effect of attached plate with low frequencies.

through the primary will be weakened, that, therefore, the E. M. F. will fall in the secondary S, and that the brightness of the lamp will diminish. This might be the case and the result can be secured by an easy adjustment of the coils; also by varying the frequency and potential of the currents. But it is perhaps of greater interest to note, that the lamp increases in brightness when the plate is disconnected (*Fig. 15a*). In this case all the energy the primary receives

is now sunk into it, like the charge of a battery in an ocean cable, but most of that energy is recovered through the secondary and used to light the lamp. The current traversing the primary is strongest at the end *b*, which is connected to the terminal T_1, of the induction coil, and diminishes in strength toward the remote end *a*. But the dynamic inductive effect exerted upon the secondary *S* is now greater than before when the suspended plate was



Effect of attached plate with high frequencies.

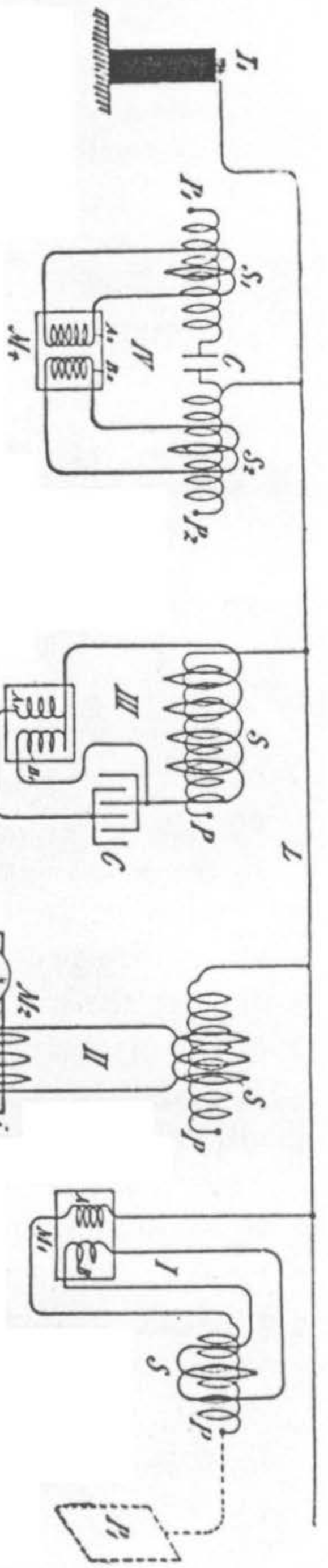
connected to the primary. These results might have been produced by a number of causes. For instance, the plate P_1, being connected, the reaction from the coil *C*, may be such as to diminish the potential at the terminal T_1, of the induction coil, and therefore weaken the current through the primary of the coil *C*. Or, the disconnecting of the plate may diminish the capacity effect with relation to the primary of the latter coil, to such an extent that the current

through it is diminished, though the potential at the terminal T_1, of the induction coil may be the same or even higher. Or, the result might have been produced by the change of phase of the primary and secondary currents and consequent reaction. But the chief determining factor is the relation of the self-induction and capacity of coil C and plate P_1, and the frequency of the currents. The greater brightness of the filament in *Fig. 15a* is, however, in part due to the heating of the rarefied gas in the lamp by electrostatic induction, which as before remarked, is greater when the suspended plate is disconnected.

Still another feature of some interest I may here bring to your attention. When the insulated plate is disconnected and the secondary of the coil opened, by approaching a small object to the secondary, only very small sparks can be drawn from it, showing that in this case the electrostatic induction is small. But upon the secondary being closed upon itself, or through the lamp, the filament glowing brightly strong sparks are obtained from the secondary. The electrostatic induction is now much greater, because the closed secondary determines a greater flow of current through the primary and principally through that half of it which is connected to the induction coil. If now the bulb be grasped with the hand, the capacity of the secondary with reference to the primary is augmented by the experimenter's body and the luminosity of the filament is increased, the incandescence now being due partly to the flow of current through the filament, and partly to the molecular bombardment of the rarefied gas in the bulb.

The preceding experiments will have prepared one for the next following results of interest, obtained in the course of these investigations. Since I can pass a current through an insulated wire merely by connecting one of its ends to the source of electrical energy; since I can induce by it another current, magnetize an iron core, and in short, perform all operations, as though a return circuit were used, clearly I can also drive a motor by the aid of only cne wire. On a former occasion I described a simple form of motor comprising a single exciting coil, an iron core and

disc. *Fig. 16* illustrates a modified way of operating such an alternate current motor by currents induced in a transformer connected to one lead, and several other arrangements of circuits for operating a certain class of alternate motors founded on the action of currents of differing phase. In view of the present state of the art it is thought sufficient to describe these arrangements in a few words only. The diagram, *Fig. 16II*, shows a primary coil *P*, connected by one of its ends to the line *L*, leading from a high tension transformer terminal T_1. In inductive relation to this primary *P*, is a secondary *S*, of coarse wire in the circuit of which is a coil *c*. The currents induced in the secondary energize the iron core *i*, which is preferably, but not necessarily, subdivided, and set the metal disc *d*, in rotation. Such a motor M_2, as diagramatically shown in *Fig. 16II*, has been called a "magnetic lag motor," but this expression may be objected to by those who attribute the rotation of the disc to eddy currents circulating in minute paths when the core *i* is finally subdivided. In order to operate such a motor effectively on the plan indicated, the frequencies should not be too high, not more than 4,000 or 5,000, though the rotation is produced even with 10,000 per second, or more.



In *Fig. 16I*, a motor M_1, having two energizing circuits, *A* and *B*, is diagrammatically indicated. The circuit *A* is

connected to the line L, and in series with it is a primary P, which may have its free end connected to an insulated plate P_1, such connection being indicated by the dotted lines. The other motor circuit B is connected to the secondary S, which is in inductive relation to the primary P. When the transformer terminal T_1 is alternately electrified, currents traverse the open line L and also circuit A and primary P. The currents through the latter induce secondary currents in the circuit S, which pass through the energizing coil B of the motor. The currents through the secondary S, and those through the primary P, differ in phase 90°, or nearly so, and are capable of rotating an armature placed in inductive relation to the circuits A and B.

In *Fig. 16III*, a similar motor M_3, with two energizing circuits, A_1 and B_1, is illustrated. A primary P, connected with one of its ends to the line L, has a secondary S, which is preferably wound for a tolerably high E. M. F., and to which the two energizing circuits of the motor are connected, one directly to the ends of the secondary and the other through a condenser C, by the action of which the currents traversing the circuit A_1 and B_1 are made to differ in phase.

In *Fig. 16IV*, still another arrangement is shown. In this case two primaries P_1 and P_2 are connected to the line L, one through a condenser C of small capacity, and the other directly. The primaries are provided with secondaries S_1 and S_2, which are in series with the energizing circuits A_2 and B_2, and a motor M_3, the condenser C again serving to produce the requisite difference in the phase of the currents traversing the motor circuits. As such phase motors with two or more circuits are now well-known in the art, they have been here illustrated diagrammatically. No difficulty whatever is found in operating a motor in the manner indicated or in similar ways, and although such experiments up to this day present only scientific interest, they may at a period not far distant, be carried out with practical objects in view.

It is thought useful to devote here a few remarks to the subject of operating devices of all kinds by means of only

one leading wire. It is quite obvious, that when high frequency currents are made use of, ground connections are —at least when the E. M. F. of the currents is great—better than a return wire. Such ground connections are objectionable with steady or low frequency currents on account of destructive chemical actions of the former and disturbing influences exerted by both on the neighboring circuits; but with high frequencies these actions practically do not exist. Still, even ground connections become superfluous when the E. M. F. is very high, for soon a condition is reached, when the current may be passed more economically through open than through closed conductors. Remote as might seem an industrial application of such single wire transmission of energy to one not experienced in such lines of experiment, it will not seem so to any one who for some time has carried on investigations of such nature. Indeed, I cannot see why such a plan should not be practicable. Nor should it be thought that for carrying out such a plan currents of very high frequency are necessarily required, for just as soon as potentials of (say) 30,000 volts are used, the single wire transmission may be effected with low frequencies, and experiments have been made by me from which these inferences are made.

When the frequencies are very high it has been found in laboratory practice quite easy to regulate the effects in the manner shown in diagram, *Fig. 17*. Here two primaries P and P are shown, each connected with one of its ends to the line L, and with the other end to the condenser plates C and C', respectively. Near these are placed other condenser plates C_1 and C'_1, the former being connected to the line L and the latter to an insulated larger plate P_2. On the primaries are wound secondaries S and S_1, of coarse wire, connected to the devices m and d, respectively. By varying the distances of the condenser plates C and C', and C_1, and C'_1, the currents through the secondaries S and S_1 are varied in intensity. The curious feature is the great sensitiveness, the slighest change in the distance of the plates producing considerable variations in the intensity or strength of the currents. The sensitiveness may be

rendered extreme by making the frequency such, that the primary itself without any plate attached to its free end satisfies, in conjunction with the closed secondary, the condition of resonance. In such condition an extremely small change in the capacity of the free terminal produces great variations. For instance, I have been able to adjust the conditions so that the mere approach of a person to the coil produces a considerable change in the brightness of the lamps attached to the secondary. Such observations and experiments possess, of course, at present, chiefly scientific interest, but they may soon become of practical importance.

Very high frequencies are, of course, not practicable with motors on account of the necessity of employing iron cores. But one may use sudden discharges of low frequency and thus obtain certain advantages of high frequency currents

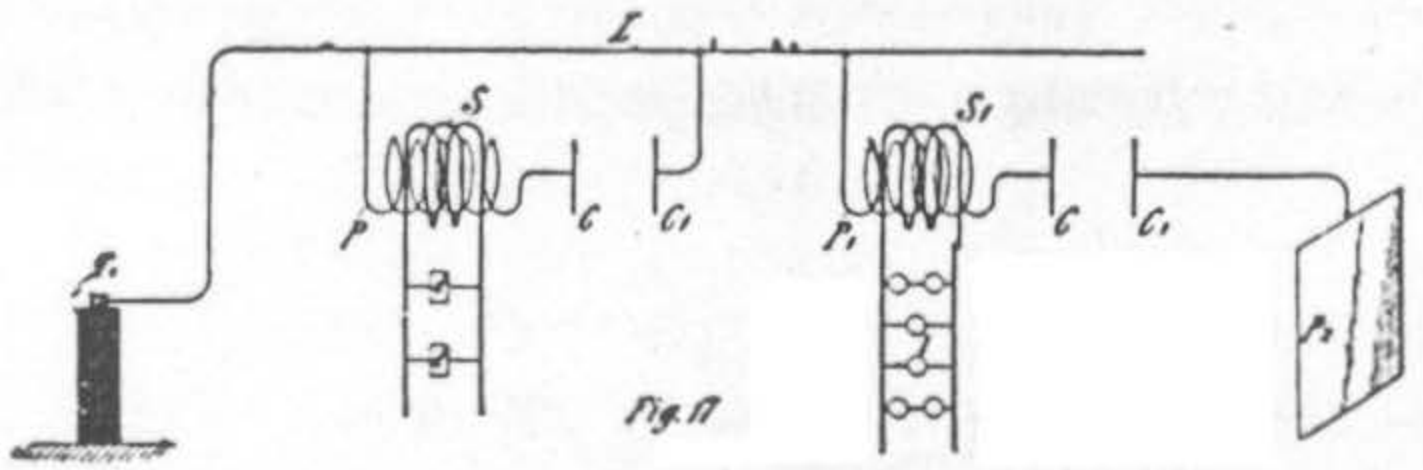


Fig. 11

Single wire conversion and distribution, with simple means for regulating the effects.

without rendering the iron core entirely incapable of following the changes and without entailing a very great expenditure of energy in the core. I have found it quite practicable to operate alternating current motors with such low frequency disruptive discharges of condensers. A certain class of such motors which I described a few years ago, which contain closed secondary circuits will rotate quite vigorously when the discharges are directed through the exciting coils. One reason that such a motor operates so well with these discharges is that the difference of phase between the primary and secondary currents is 90°, which is generally not the case with harmonically rising and falling currents of low frequency. It may not be without interest to show an experiment with a simple motor of this kind, inasmuch as it is commonly thought that disruptive discharges are unsuitable for such purposes. The motor is

illustrated in *Fig. 18*. It comprises a rather large iron core *i*, with slots on the top into which are embedded thick copper washers *c c*. In proximity to the core is a freely movable metal disc *D*. The core is provided with a primary exciting coil *C*, the ends *a* and *b*, of which are connected to the terminals of the secondary *s* of an ordinary transformer, the primary *P*, of the latter being connected to an alternating distribution circuit, or generator *G*, of low or moderate frequency. The terminals of the secondary *s* are attached to a condenser *C*, which discharges through an air gap *d d*, which may be placed in series or shunt to the coil *C*. When the conditions are properly chosen, the disc *D* rotates with considerable effort and the iron core *i* does not get very perceptibly hot. With currents from a high frequency alternator, on the contrary, the core gets rapidly hot and

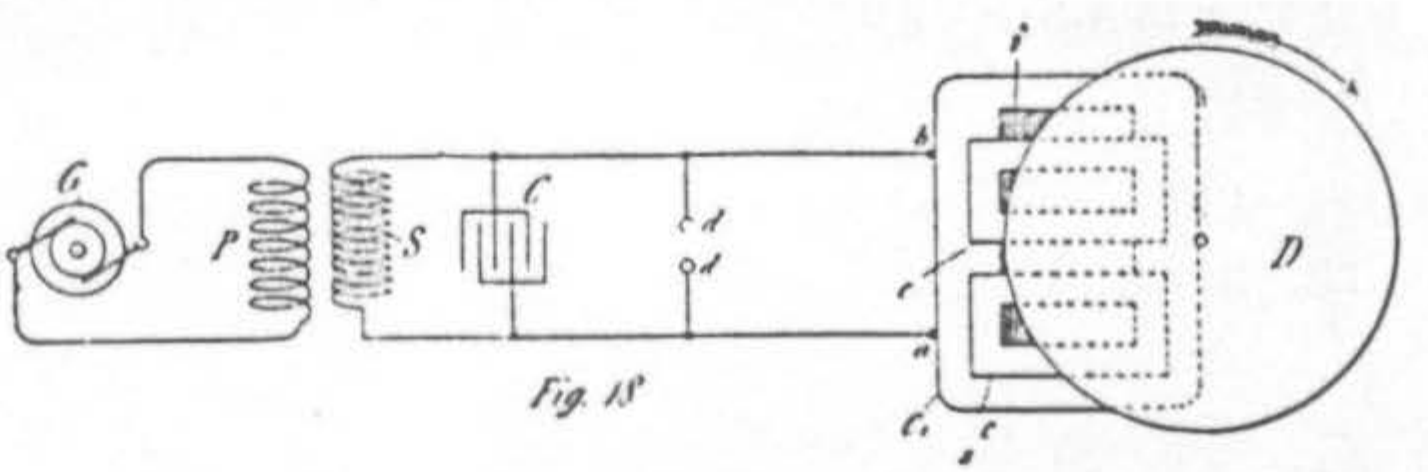


Fig. 18

Operating a motor by disruptive discharges.

the disc rotates with a much smaller effort. To perform the experiment properly it should be first ascertained that the disc *D* is not set in rotation when the discharge is not occurring at *d d*. It is preferable to use a large iron core and a condenser of large capacity, so as to bring the superimposed quicker oscillation to a very low pitch or to do away with it entirely. By observing certain elementary rules I have also found it practicable to operate ordinary series, or shunt direct current motors, with such disruptive discharges, and this can be done with or without a return wire.

[*To be continued.*]

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

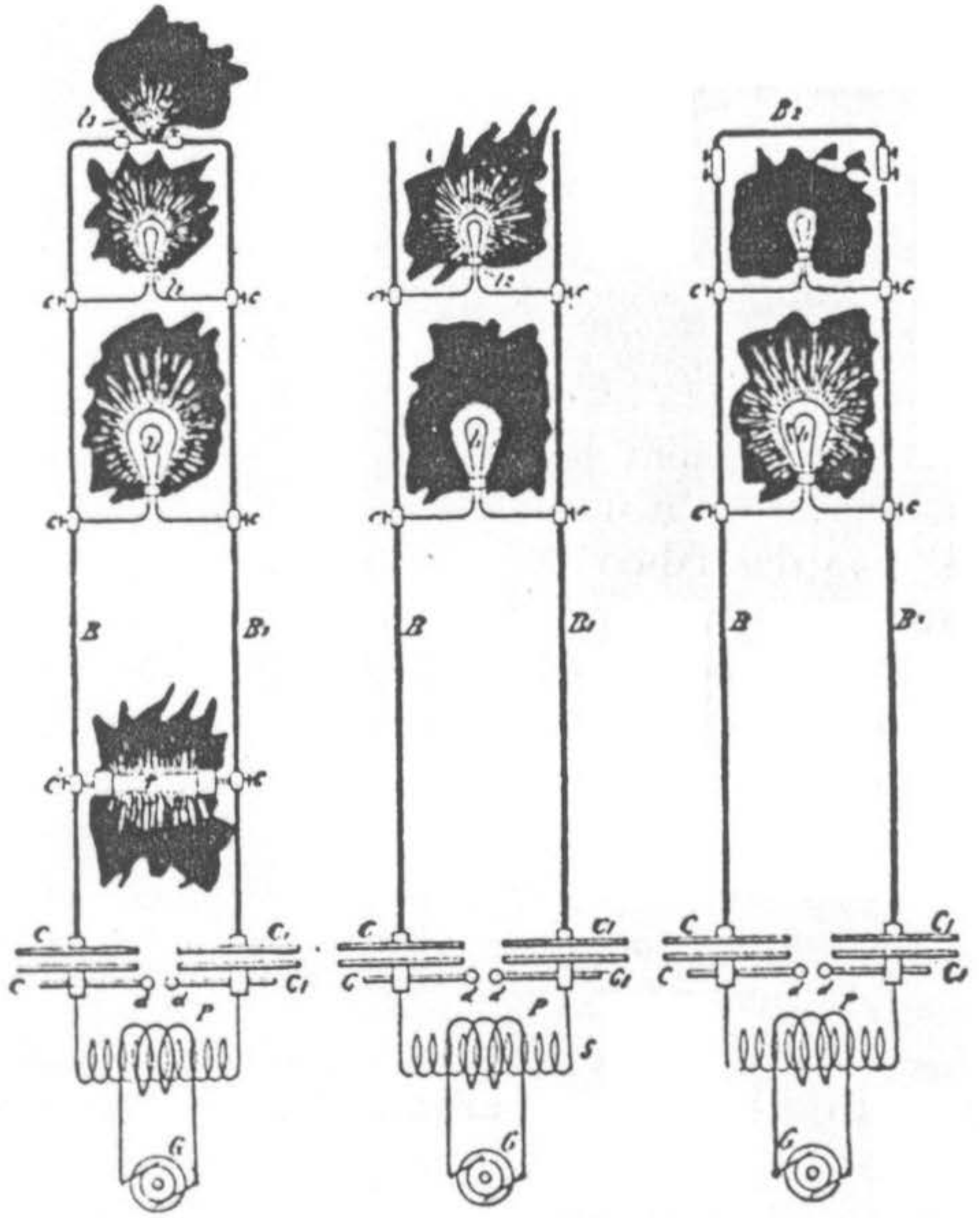
[*Continued from p. 177.*]

Among the various current phenomena observed, perhaps, the most interesting are those of impedance presented by conductors to currents varying at a rapid rate. In my first paper before the American Institute of Electrical Engineers, I described a few striking observations of this kind. Thus I showed that when such currents or sudden discharges are passed through a thick metal bar there may be points at the bar only a few inches apart, which have a sufficient potential difference between them to maintain at bright incandescence an ordinary filament lamp. I also described the curious behavior of rarefied gas surrounding a conductor to such sudden rushes of current. These phenomena have been since more carefully studied and one or two novel experiments of this kind are deemed of sufficient interest to be described here.

With reference to *Fig.* 19*a*, *B* and B_1 are very stout copper bars connected at their lower ends to plates *C* and C_1, respectively, of a condenser, the opposite plates of the latter being connected to the terminals of the secondary *S*, of a high tension transformer, the primary *P*, of which, is supplied with alternating currents from an ordinary low frequency dynamo *G*, or distribution circuit. The condenser discharges through an adjustable gap *d d*, as usual. By establishing a rapid vibration it was found quite easy to perform the following curious experiment: The bars *B* and B_1 were joined at the top by a low voltage lamp l_3; a little lower, was placed, by means of clamps *c c*, a fifty-volt lamp l_2, and still lower another 100-volt lamp l_1, and finally at a certain

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893, and before the National Electric Light Association, at St. Louis, March 1, 1893.

distance below the latter lamp, an exhausted tube *T*. By carefully determining the positions of these devices it was found practicable to maintain them all at their proper illuminating power. Yet they were all connected in multiple arc to the two stout copper bars and required widely different pressures. This experiment requires, of course, some time for adjustment, but is quite easily performed.



FIGS. 19*a*, 19*b*, 19*c*.—Impedance phenomena.

In *Figs. 19b* and *19c*, two other experiments are illustrated which, unlike the previous experiment, do not require very careful adjustments. In *Fig. 20b*, two lamps l_1 and l_2, the former a 100-volt and the latter a fifty-volt are placed in certain positions as indicated, the 100-volt lamp being below the fifty-volt lamp. When the arc is playing at *d d*, and the sudden discharges passed through the bars *B B*, the fifty-volt lamp will, as a rule, burn brightly, or at least this

result is easily secured, while the 100-volt lamp will burn very low or remain quite dark, *Fig. 19b*. Now the bars *B B*, may be joined at the top by a thick cross bar B_2, and it is quite easy to maintain the 100-volt lamp at full candle-power while the fifty-volt lamp remains dark, *Fig. 19c*. These results, as I have previously pointed out, should not be considered to be due exactly to frequency, but rather to the time rate of change which may be great, even with low frequencies. A great many other results of the same kind, equally interesting, especially to those who are only used to manipulate steady currents, may be obtained and they afford precious clues in investigating the nature of electric currents.

In the preceding experiments I have already had occasion to show some light phenomena and it would be now proper to study these in particular; but to make this investigation

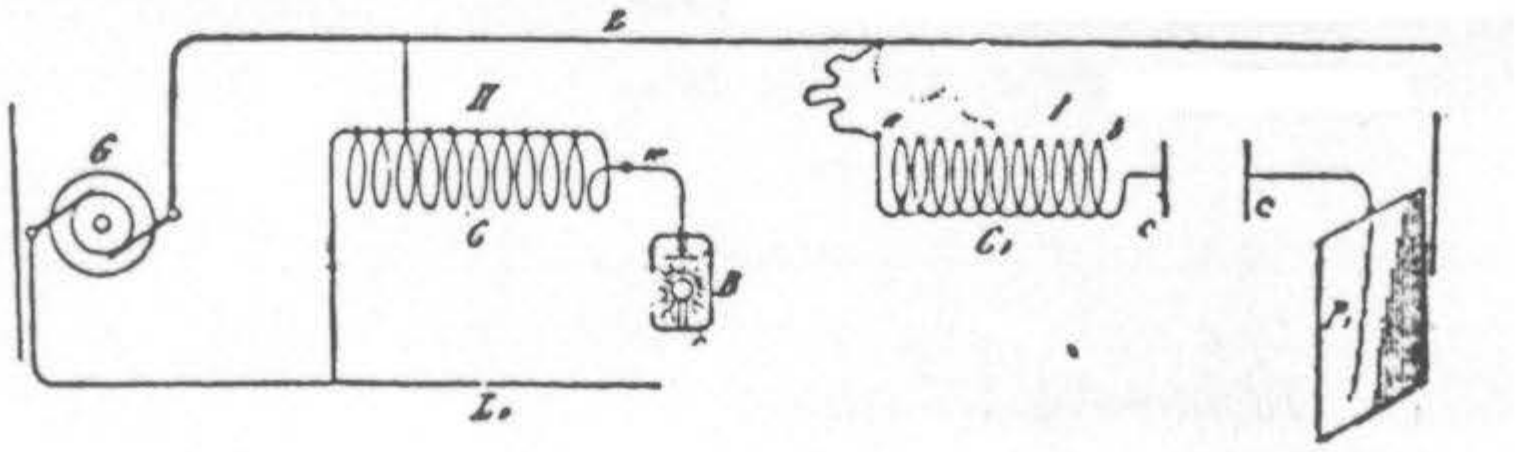


FIG. 20.—Plan followed in observing the effects of resonance.

more complete, I think it necessary first to make a few remarks on the subject of electrical resonance which must always be observed in carrying out these experiments.

On Electrical Resonance.—The effects of resonance are being more and more noted by engineers and are becoming of great importance in the practical operation of apparatus of all kinds with alternating currents. A few general remarks may therefore be made concerning these effects. It is clear that if we succeed in employing the effects of resonance practically in the operation of electric devices the return wire will, as a matter of course, become unnecessary, for the electric vibration may be conveyed with one wire just as well, and sometimes even better, than with two. The question first to answer is, then, Whether pure resonance effects are producible? Theory and experiment both show that such is impossible in nature, for as the oscilla-

tion becomes more and more vigorous the losses in the vibrating bodies and environing media rapidly increase and necessarily check the vibration which otherwise would go on increasing forever. It is a fortunate circumstance that pure resonance is not producible, for if it were there is no telling what dangers might lie in wait for the innocent experimenter. But to a certain degree resonance is producible, the magnitude of the effects being limited by the imperfect conductivity and imperfect elasticity of the mediator, generally stated by frictional losses. The smaller these losses, the more striking are the effects. The same is the case in mechanical vibration. A stout steel bar may be set in vibration by drops of water falling upon it at proper intervals; and with glass, which is more perfectly elastic, the resonance effect is still more remarkable, for a goblet may be burst by singing into it a note of the proper pitch. The electrical resonance is the more perfectly attained, the smaller the resistance or the impedance of the conducting path and the more perfect the dielectric. In a Leyden jar discharging through a short stranded cable of thin wires these requirements are probably best fulfilled, and the resonance effects are therefore very prominent. Such is not the case with dynamo machines, transformers and their circuits, or with commercial apparatus in general in which the presence of iron cores complicates or renders impossible the action. In regard to Leyden jars with which resonance effects are frequently demonstrated, I would say that the effects observed are often *attributed* but are seldom *due* to true resonance, for an error is quite easily made in this respect. This may positively be demonstrated by the following experiment: Take, for instance, two large insulated metallic plates or spheres, which I shall designate *A* and *B*, place them at a certain small distance apart and charge them from a frictional or influence machine to a potential so high that just a slight increase of the difference of potential between them will cause the small air or insulating space to break down. This is easily reached by making a few preliminary trials. If now another plate—fastened on an insulating handle

and connected by a wire to one of the terminals of a high tension secondary of an induction coil, which is maintained in action by an alternator (preferably high frequency)—is approached to one of the charged bodies *A* or *B*, so as to be nearer to either one of them, the discharge will invariably occur between them; at least it will, if the potential of the coil in connection with the plate is sufficiently high. But the explanation of this is to be sought in the fact that the approached plate acts inductively upon the bodies *A* and *B* and causes a spark to pass between them. When this spark occurs, the charges, which were previously imparted to these bodies from the influence machine, must needs be lost, since the bodies are brought in electrical connection through the arc formed. Now this arc is formed whether there be resonance or not. But, even if the spark would not be produced, there is still an alternating E. M. F. set up between the bodies when the plate is brought near one of them; therefore, the approach of the plate, if it *does* not always, actually, will, at any rate, *tend*, to break down the air space by inductive action. Instead of the spheres, or plates, *A* and *B*, we may take the coatings of a Leyden jar with the same result, and in place of the machine, which is preferably a high frequency alternator, because it is more suitable for the experiment and also for the argument, we may take another Leyden jar or battery of jars. When such jars are discharging through a circuit of low resistance the same is traversed by currents of very high frequency. The plate may now be connected to one of the coatings of the second jar, and when it is brought near to the first jar just previously charged to a high potential from an influence machine, the result is the same as before, and the first jar will discharge through a small air space upon the second being caused to discharge. But both jars and their circuits need not be tuned any closer than a basso profundo is to the note produced by a mosquito, as small sparks will be produced through the air space or at least the latter will be considerably more strained owing to the setting up of an alternating E. M. F. by induction, which takes place when one of the jars

begins to discharge. Again another error of a similar nature is quite easily made. If the circuits of the two jars are run parallel and close together, and the experiment has been performed of discharging one by the other, and now a coil of wire be added to one of the circuits whereupon the experiment does not succeed, the conclusion that this is due to the fact that the circuits are now not tuned, would be far from being safe. For the two circuits act as condenser coating and the addition of the coil to one of them is equivalent to bridging them, at the point where the coil is placed, by a small condenser, and the effect of the latter might be to prevent the spark from jumping through the discharge space by diminishing the alternating E. M. F. acting across the same. All these remarks, and many more which might be added but for fear of wandering too far from the subject, are made with the pardonable intention of cautioning the unsuspecting student, who might gain an entirely unwarranted opinion of his skill when seeing every experiment succeed; but they are in no way thrust upon the experienced as novel observations.

In order to make reliable observations of electric resonance effects it is very desirable, if not necessary, to employ an alternator giving currents which rise and fall harmonically, as in working with make- and break-currents the observations are not always trustworthy, since many phenomena, which depend on the rate of change, may be produced with frequencies widely different. Even when making such observations with an alternator one is apt to be mistaken. When a circuit is connected to an alternator there are an infinite number of values for capacity and self-induction which, in conjunction, will satisfy the condition of resonance. So there are in mechanics an infinite number of tuning forks which will respond to a note of a certain pitch, or loaded springs which have a definite period of vibration. But the resonance will be most perfectly attained in that case in which the motion is effected with the greatest freedom. Now in mechanics, considering the vibration in the common medium—that is, air—it is of com-

paratively little importance whether one tuning fork be somewhat larger than another, because the losses in the air are not very considerable. One may, of course, enclose a tuning fork in an exhausted vessel and by thus reducing the air resistance to a minimum obtain better resonant action. Still the difference would not be very great. But it would make a great difference if the tuning fork were immersed in mercury. In the electrical vibration it is of enormous importance to arrange the conditions so that the vibration is effected with the greatest freedom. The magnitude of the resonance effect depends, under otherwise equal conditions, on the quantity of electricity set in motion or on the strength of the current driven through the circuit. But the circuit opposes the passage of the currents by reason of its impedance and therefore, to secure the best action, it is necessary to reduce the impedance to a minimum. It is impossible to overcome it entirely, but merely in part, for ohmic resistance cannot be overcome. But when the frequency of the impulses is very great, the flow of the current is practically determined by self-induction. Now, self-induction can be overcome by combining it with capacity. If the relation between these is such, that at the frequency used they annul each other; that is, have such values as to satisfy the condition of resonance and the greatest quantity of electricity is made to flow through the external circuit, then the best result is obtained. It is simpler and safer to join the condenser in series with the self-induction. It is clear that in such combinations there will be, for a given frequency, and considering only the fundamental vibration, values which will give the best result, with the condenser in shunt to the self-induction coil; of course, more such values than with the condenser in series. But practical conditions determine the selection. In the latter case in performing the experiments one may take a small self-induction and a large capacity or a small capacity and a large self-induction, but the latter is preferable, because it is inconvenient to adjust a large capacity by small steps. By taking a coil with a very large self-induction the critical capacity is reduced to a very small

value, and the capacity of the coil itself may be sufficient. It is easy, especially by observing certain artifices, to wind a coil through which the impedance will be reduced to the value of the ohmic resistance only and for any coil there is, of course, a frequency at which the maximum current will be made to pass through the coil. The observation of the relation between self-induction, capacity and frequency is becoming important in the operation of alternate current apparatus, such as transformers or motors, because by a judicious determination of the elements the employment of an expensive condenser becomes unnecessary. Thus it is possible to pass through the coils of an alternating current motor under the normal working conditions the required current with a low E. M. F. and do away entirely with the false current, and the larger the motor the easier such a plan becomes practicable; but it is necessary for this to employ currents of very high potential or high frequency.

In *Fig. 201* is shown a plan which has been followed in the study of the resonance effects by means of a high frequency alternator. *C* is a coil of many turns, which is divided in small separate sections for the purposes of adjustment. The final adjustment was made sometimes with a few thin iron wires (though this is not always advisable) or with a closed secondary. The coil *C* is connected with one of its ends to the line *L* from the alternator *G* and with the other end to one of the plates *c* of a condenser $c\ c_1$, the plate (c_1) of the latter being connected to a much larger plate P_1. In this manner both capacity and self-induction were adjusted to suit the dynamo frequency.

As regards the rise of potential through resonant action, of course, theoretically, it may amount to anything since it depends on self-induction and resistance and since these may have any value. But in practice one is limited in the selection of these values, and besides these, there are other limiting causes. One may start with (say) 1,000 volts and raise the E. M. F. to fifty times that value, but one cannot start with 100,000 and raise it to ten times that value, because of the losses in the media which are great, espe-

cially if the frequency is high. It should be possible to start with, for instance, two volts from a high or low frequency circuit of a dynamo and raise the E. M. F. to many hundred times that value. Thus coils of the proper dimensions might be connected each with only one of its ends to the mains from a machine of low E. M. F., and though the circuit of the machine would not be closed in the ordinary acceptance of the term, yet the machine might be burned out if a proper resonance effect would be obtained. I have not been able to produce, nor have I observed with currents from the dynamo machine, such great rises of potential. It is possible, if not probable, that with currents obtained from apparatus containing iron the disturbing influence of the latter is the cause that these theoretical possibilities cannot be realized. But if such is the case I attribute it solely to the hysteresis and Faucault current losses in the core. Generally it was necessary to transform upward, when the E. M. F. was very low, and usually an ordinary form of induction coil was employed, but sometimes the arrangement illustrated in *Fig. 20II*, has been found to be convenient. In this case a coil C is made in a great many sections, a few of these being used as the primary. In this manner both primary and secondary are adjustable. One end of the coil is connected to the line L_1 from the alternator, and the other line L is connected to the intermediate point of the coil. Such a coil with adjustable primary and secondary will be found also convenient in experiments with the disruptive discharge. When true resonance is obtained the top of the wave must, of course, be on the free end of the coil as, for instance, at the terminal of the phosphorescence bulb B. This is easily recognized by observing the potential of a point on the wire w nearer to the coil.

In connection with resonance effects and the problem of transmission of energy over a single conductor which was previously considered, I would say a few words on a subject which constantly fills my thoughts and which concerns the welfare of all. I mean the transmission of intelligible signals or perhaps even power to any distance without the

use of wires. I am becoming daily more convinced of the practicability of the scheme; and though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realized yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must some day be carried out. The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb by means of powerful machines the electrostatic condition of the earth and thus transmit intelligible signals and perhaps power. In fact what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why then not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile posts the earth may appear very large, but to that happiest of all men the astronomer, who gazes at the heavens and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician, for when he considers the speed with which an electric disturbance is propagated through the earth all his ideas of distance must completely vanish.

A point of great importance would be first to know what is the capacity of the earth? and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probably that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view

of its origin—it must have retained a charge, as it occurs in all processes of mechanical separation. If it be a charged body insulated in space, its capacity should be extremely small less than one-thousanth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is, by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric current. One of the terminals of the source would be connected to earth, as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata or free space contains an opposite charge, and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body and watching for the disturbance at various neighboring points of the earth's surface resonance might be detected. Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do and a proper electrical oscillator would have to be produced and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration,

it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface.



FIG. 21.—Energy transmission to any distance without wires.

Assume that a source of alternating currents *S* be connected, as in *Fig. 21*, with one of its terminals to earth (conveniently to the water mains) and with the other to a body of large surface *P*. When the electric oscillation is set up there will be a movement of electricity in and out of *P*, and alternating currents will pass through the earth, converging to, or diverging from the point *C* where the ground connection is made. In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body *P* is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of *P*. The conditions might be adjusted so that the generator or source *S* will set up the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration at least of a certain low period upon the earth, by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured. I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at the surface could be but extremely small considering the size of the earth, the air would not act as a very disturbing factor, and there would be not much energy lost through the action of the air which would be the case if the density were great. Theoretically,

then, it could not require a great amount of energy to produce a disturbance perceptible at great distance, or even all over the surface of the globe. Now it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source S_1, *Fig. 21*, similar to S, or any number of such sources can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S_1 if the same be of opposite phase to the source S. I think that beyond doubt it is possible to operate electrical devices in a city through the ground or pipe system by resonance from an electrical oscillator located at a central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realization of the scheme of transmitting intelligence or perhaps power to any distance through the earth or environing medium. If this is at all possible, distance does not mean anything. Proper apparatus must first be produced by means of which the problem can be attacked, and I have devoted much thought to this subject. I am firmly convinced that it can be done, and hope that we shall live to see it done.

On the Light Phenomena produced by High Frequency Currents of High Potential and General Remarks Relating to the Subject.—Returning now to the light effects which it has been the chief object to investigate, it is thought proper to divide these effects in four classes:

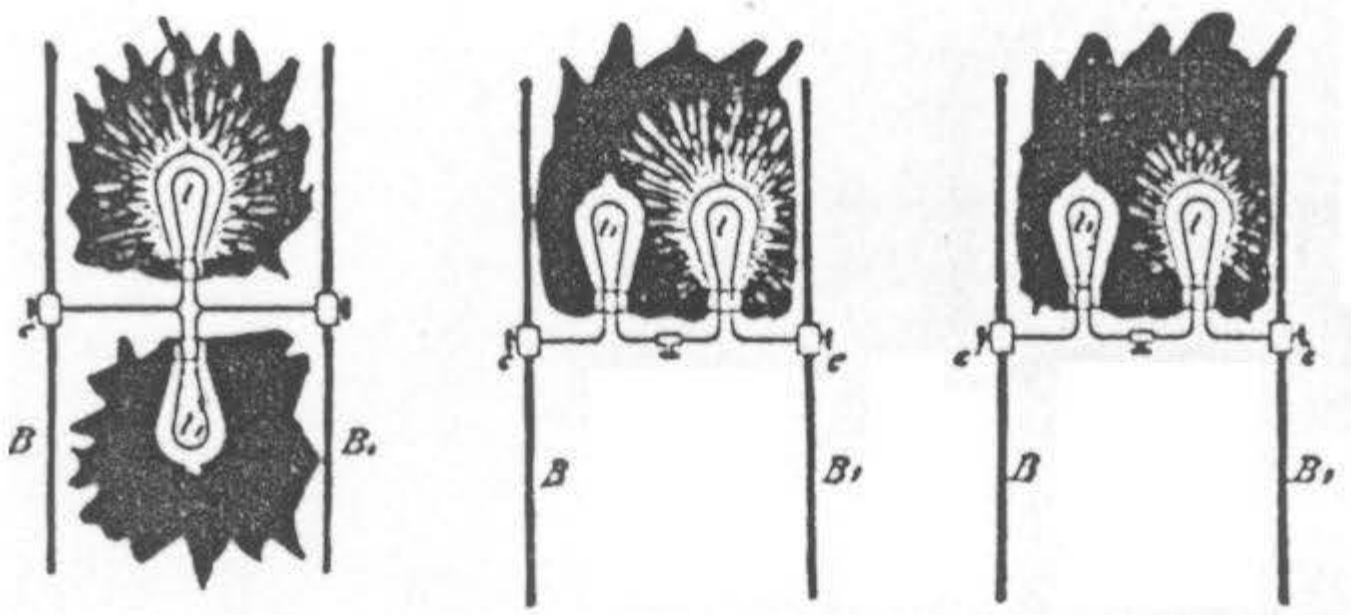
(1) Incandescence of a solid.
(2) Phosphorescence.
(3) Incandescence or phosphorescence of a rarefied gas.
(4) Luminosity produced in a gas at ordinary pressure.

The first question is: How are these luminous effects produced? In order to answer this question as satisfactorily as I am able to do in the light of accepted views and with the experience acquired, and to add some interest to this demonstration, I shall dwell here upon a feature which I consider of great importance, inasmuch as it promises,

besides, to throw a better light upon the nature of most of the phenomena produced by high frequency electric currents. I have on other occasions pointed out the great importance of the presence of the rarefied gas, or atomic medium in general, around the conductor through which alternate currents of high frequency are passed, as regards the heating of the conductor by the currents. My experiments described some time ago have shown that the higher the frequency and potential difference of the currents, the more important becomes the rarefied gas in which the conductor is immersed, as a factor of the heating. The potential difference, however, is, as I then pointed out, a more important element than the frequency. When both of these are sufficiently high, the heating may be almost entirely due to the presence of the rarefied gas. The experiments to follow will show the importance of the rarefied gas, or generally of gas at ordinary or other pressure as regards the incandescence or other luminous effects produced by currents of this kind.

I take two ordinary fifty-volt sixteen candle-power lamps which are in every respect alike, with the exception that one has been opened at the top and the air has filled the bulb, while the other is at the ordinary degree of exhaustion of commercial lamps. When I attach the lamp which is exhausted to the terminal of the secondary of the coil, which I have already used as in experiments illustrated in *Fig. 15a*, for instance, and turn on the current, the filament as you have before seen comes to high incandescence. When I attach the second lamp, which is filled with air, instead of the former, the filament still glows, but much less brightly. This experiment illustrates only in part the truth of the statements before made. The importance of the filament's being immersed in rarefied gas is plainly noticeable but not to such a degree as might be desirable. The reason is that the secondary of this coil is wound for low tension, having only 150 turns, and the potential difference at the terminals of the lamp is therefore small. Were I to take another coil with many more turns in the secondary, the effect would be increased, since it depends partially on the potential differ-

ence, as before remarked. But since the effect likewise depends on the frequency, it may be properly stated that it depends on the time rate of the variations of the potential difference. The greater this variation the more important becomes the gas as an element of heating. I can produce a much greater rate of variation in another way, which, besides, has the advantage of doing away with the objections, which might be made in the experiment just shown, even if both the lamps were connected in series or multiple arc to the coil, namely, that in consequence of the reactions existing between the primary and secondary coil the conclusions are rendered uncertain. This result I secure by charging from an ordinary transformer, which is fed from the alternating current supply station, a battery of condensers,



FIGS. 22*a*, 22*b*, 22*c*.—Showing the effect of the presence of a gaseous medium.

and discharging the latter directly through a circuit of small self-induction, as before illustrated in *Figs. 19a*, *19b*, *19c*.

In *Figs. 22a*, *22b* and *22c*, the heavy copper bars B B_1 are connected to the opposite coatings of a battery of condensers, or generally in such way that the high frequency or sudden discharges are made to traverse them. I connect first an ordinary fifty-volt incandescent lamp to the bars by means of the clamps *c c*. The discharges being passed through the lamp, the filament is rendered incandescent, though the current through it is very small, and would not be nearly sufficient to produce a visible effect under the conditions of ordinary use of the lamp. Instead of this, I now attach to the bars another lamp exactly like the first, but with the seal broken off, the bulb being therefore

filled with air at ordinary pressure. When the discharges are directed through the filament, as before, it does not become incandescent. But the result might still be attributed to one of the many possible reactions. I therefore connect both the lamps in multiple arc, as illustrated in *Fig. 22a*. Passing the discharges through both the lamps, again the filament in the exhausted lamp l glows very brightly while that in the non-exhausted lamp l_1 remains dark, as previously. But it should not be thought that the latter lamp is taking only a small fraction of the energy supplied to both the lamps; on the contrary, it may consume a considerable portion of the energy and it may become even hotter than the one which burns brightly. In this experiment the potential difference at the terminals of the lamps varies in sign theoretically 3,000,000 or 4,000,000 times a second. The ends of the filaments are correspondingly electrified, and the gas in the bulbs is violently agitated and a large portion of the supplied energy is thus converted into heat. In the non-exhausted bulb there being a few million times more gas molecules than in the exhausted one, the bombardment, which is most violent at the ends of the filament, in the neck of the bulb, consumes a large portion of the energy without producing any visible effect. The reason is that, there being many molecules, the bombardment is quantitatively considerable, but the individual impacts are not very violent, as the speeds of the molecules are comparatively small, owing to the small free path. In the exhausted bulb, on the contrary, the speeds are very great and the individual impacts are violent, and therefore better adapted to produce a visible effect. Besides, the convection of heat is greater in the former bulb. In both the bulbs the current traversing the filaments is very small, incomparably smaller than that which they require on an ordinary low frequency circuit. The potential difference, however, at the ends of the filaments is very great and might be possibly 20,000 volts or more, if the filaments were straight and their ends far apart. In the ordinary lamp a spark generally occurs between the ends of the filament or between the platinum wires outside, before such a difference of potential can be reached.

It might be objected in the experiment before shown that the lamps, being in multiple arc, the exhausted lamp might take a much larger current, and that the effect observed might not be exactly attributable to the action of the gas in the bulbs. Such objections will lose much weight if I connect the lamps in series, with the same result. When this is done and the discharges are directed through the filaments it is again noted that the filament in the non-exhausted bulb *l* remains dark, while that in the exhausted one (*l*) glows even more intensely than under its normal condition of working, *Fig. 22b*. According to general ideas the current through the filaments should now be the same, were it not modified by the presence of the gas around the filaments.

At this juncture I may point out another interesting feature, which illustrates the effect of the rate of change of potential of the currents. I will leave the two lamps connected in series to the bars B B_1, as in the previous experiment, *Fig. 22b*, but will presently reduce considerably the frequency of the currents, which was excessive in the experiment just before shown. This I may do by inserting a self-induction coil in the path of the discharges, or by augmenting the capacity of the condensers. When I now pass these low frequency discharges through the lamps, the exhausted lamp *l* again is as bright as before, but it is noted also that the non-exhausted lamp *l* glows, though not quite as intensely as the other. Reducing the current through the lamps, I may bring the filament in the latter lamp to redness, and, though the filament in the exhausted lamp *l* is bright, *Fig. 22c*, the degree of its incandescence is much smaller than in *Fig. 22b*, when the currents were of a much higher frequency.

In these experiments the gas acts in two opposite ways in determining the degree of the incandescence of the filaments; that is, by convection and bombardment. The higher the frequency and potential of the currents, the more important becomes the bombardment. The convection, on the contrary, should be the smaller, the higher the frequency. When the currents are steady there is practically no bom-

bardment and convection may therefore with such currents also considerably modify the degree of incandescence and produce results similar to those just before shown. Thus, if two lamps exactly alike, one exhausted and one not exhausted, are connected in multiple arc, or series, to a direct current machine, the filament in the non-exhausted lamp will require a considerably greater current to be rendered incandescent. This result is entirely due to convection and the effect is the more prominent the thinner the filament. Professor Ayrton and Mr. Kilgour some time ago published quantitative results concerning the thermal emissivity by radiation and convection in which the effect of thin wires was clearly shown. This effect may be strikingly illustrated by preparing a number of small short glass tubes, each containing through its axis the thinnest obtainable platinum wire. If these tubes be highly exhausted, a number of them may be connected in multiple arc to a direct current machine and all of the wires may be kept at incandescence with a smaller current than that required to render incandescent a single one of the wires if the tube be not exhausted. Could the tubes be so highly exhausted that convection would be *nil*, then the relative amounts of heat given off by convection and radiation could be determined without the difficulties attending thermal quantitative measurements. If a source of electric impulses of high frequency and very high potential is employed, a still greater number of the tubes may be taken and the wires rendered incandescent by a current not capable of warming perceptibly a wire of the same size immersed in air at ordinary pressure, and conveying the energy to all of them.

I may here describe a result which is still more interesting, and to which I have been led by the observation of these phenomena. I noted that small differences in the density of the air produced a considerable difference in the degree of incandescence of the wires, and I thought that, since in a tube, through which a luminous discharge is passed, the gas is generally not of uniform density, a very thin wire contained in the tube might be rendered incandescent at certain places where the density of the gas was low,

while it would remain dark at the places of greater density, where the convection would be greater and the bombardment less intense. Accordingly a tube *t* was prepared, as illustrated in *Fig. 23*, which contained through the middle a very fine platinum wire *w*. The tube was exhausted to a moderate degree, and it was found that when it was attached to the terminal of a high-frequency coil, the platinum wire *w* would, indeed, become incandescent in patches, as illustrated in *Fig. 23*. Later, a number of these tubes with one

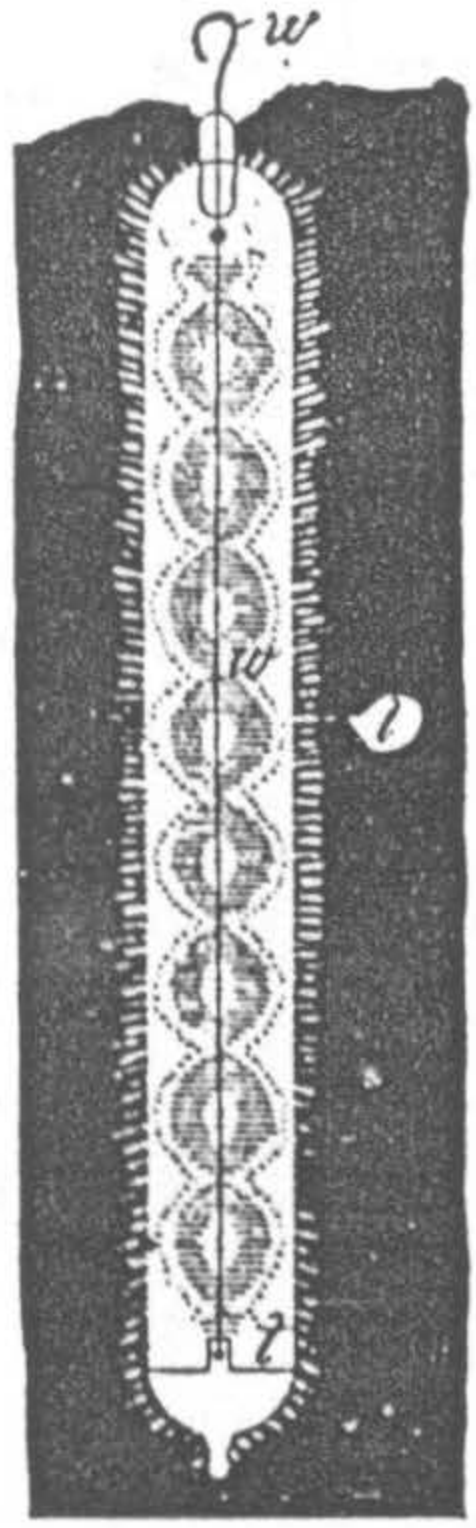


FIG. 23.—Curious incandescence of a wire.

or more wires were prepared, each showing this result. The effect was best noted when the striated discharge occurred in the tube, but was also produced when the striæ were not visible, showing that, even then, the gas in the tube was not of uniform density. The position of the striæ was generally such, that the rarefactions corresponded to the places of incandescence, or greater brightness on the wire *w*. But in a few instances, it was noted, that the bright spots on the wire were covered by the dense parts of the

striated discharge as indicated by *l* in *Fig. 23*, though the effect was barely perceptible. This was explained in a plausible way by assuming, that the convection was not widely different in the dense and rarefied places, and that the bombardment was greater on the dense places of the striated discharge. It is, in fact, often observed in bulbs that under certain conditions a thin wire is brought to higher incandescence when the air is not too highly rarefied. This is the case when the potential of the coil is not high enough for the vacuum, but the result may be attributed to many different causes. In all cases this curious phenomenon of incandescence disappears when the tube, or rather the wire, acquires throughout a uniform temperature.

Disregarding now the modifying effect of convection, there are then two distinct causes which determine the incandescence of a wire or filament with varying currents; that is, conduction current and bombardment. With steady currents we have to deal only with the former of these two causes, and the heating effect is a minimum, since the resistance is least to steady flow. When the current is a varying one, the resistance is greater, and hence the heating effect is increased. Thus, if the rate of change of the current is very great, the resistance may increase to such an extent that the filament is brought to incandescence with inappreciable currents, and we are able to take a short and thick block of carbon or other material and bring it to bright incandescence with a current incomparably smaller than that required to bring to the same degree of incandescence an ordinary thin lamp filament with a steady or low frequency current. This result is important, and illustrates how rapidly our views on these subjects are changing, and how quickly our field of knowledge is extending. In the art of incandescent lighting, to view this result in one aspect only, it has been commonly considered as an essential requirement for practical success, that the lamp filament should be thin and of high resistance. But now we know that the resistance to the steady flow of the filament does not mean anything; the filament might as well be short and thick; for if it be immersed in rarefied gas it will

become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents. We may conclude from this, that it would be of advantage, so far as the lamp is considered, to employ high frequencies for lighting, as they allow the use of short and thick filaments and smaller currents.

[*To be concluded.*]

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

[*Continued from p. 279.*]

If a wire or filament be immersed in a homogeneous medium, all the heating is due to true conduction current, but if it be enclosed in an exhausted vessel the conditions are entirely different. Here the gas begins to act and the heating effect of the conduction current, as is shown in many experiments, may be very small compared with that of the bombardment. This is especially the case if the circuit is not closed and the potentials of course very high. Suppose a fine filament enclosed in an exhausted vessel be connected with one of its ends to the terminal of a high tension coil and with its other end to a large insulated plate. Though the circuit is not closed, the filament, as I have before shown, is brought to incandescence. If the frequency and potential be comparatively low, the filament is heated by the current passing *through it*. If the frequency and potential, and principally the latter, be increased, the insulated plate need be but very small, or may be done away with entirely; still the filament will become incandescent, practically all the heating being then due to the bombardment. A practical way of combining both the effects of conduction current and bombardment is illustrated in *Fig. 24*, in which an ordinary lamp is shown provided with a very thin filament which has one of the ends of the latter connected to a shade serving the purpose of the insulated plate, and the other end to the terminal of a high tension source. It should not be thought that only rarefied gas is an important factor in the heating of a conductor by varying currents, but gas at ordinary pressure may

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893, and before the National Electric Light Association, at St. Louis, March 1, 1893.

become important, if the potential difference and frequency of the currents is excessive. On this subject I have already stated, that when a conductor is fused by a stroke of lightning, the current through it may be exceedingly small, not even sufficient to heat the conductor perceptibly, were the latter immersed in a homogeneous medium.

From the preceding it is clear that when a conductor of high resistance is connected to the terminals of a source of high frequency currents of high potential, there may occur

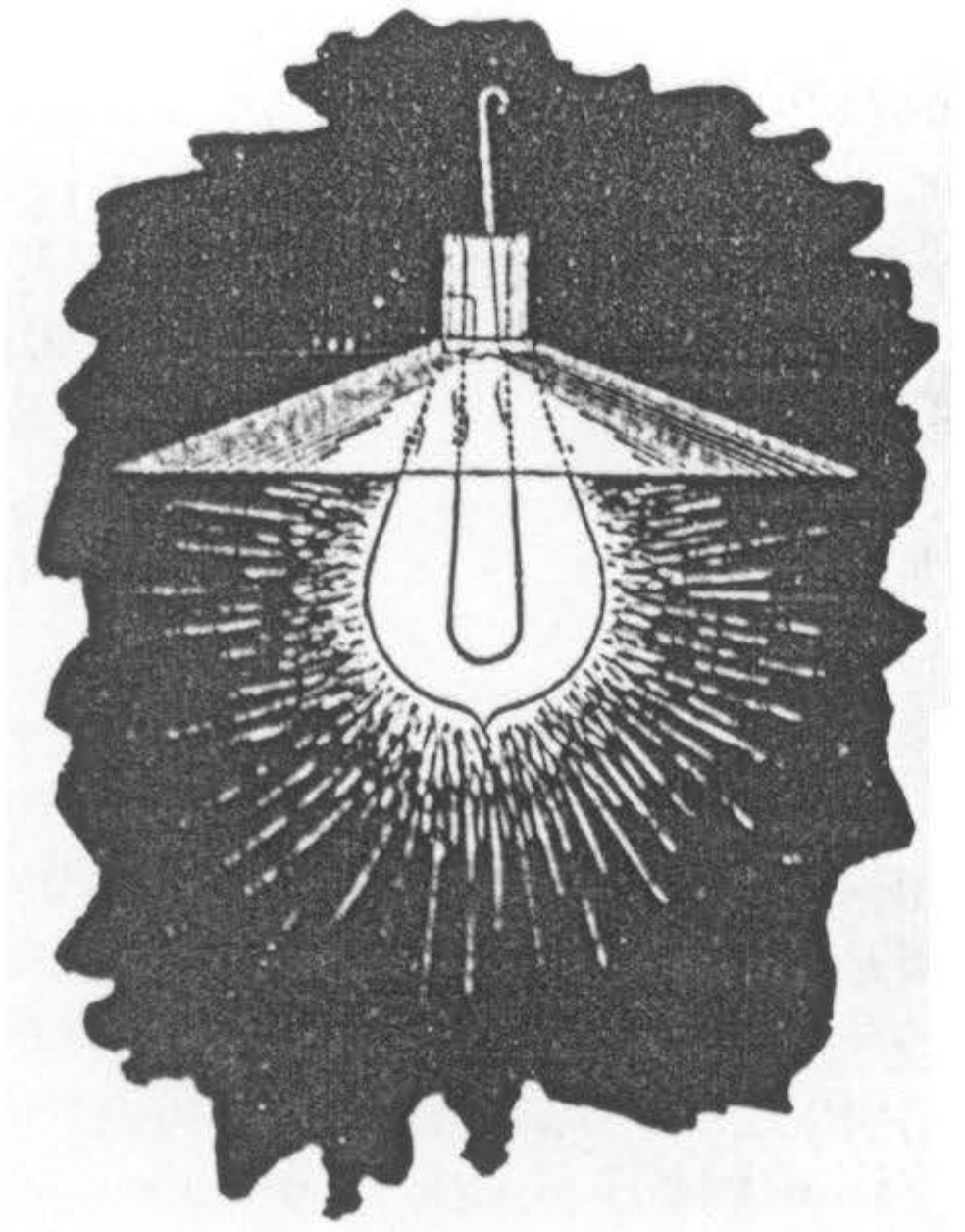


FIG. 24.—Utilizing the heating effect of conduction current and bombardment.

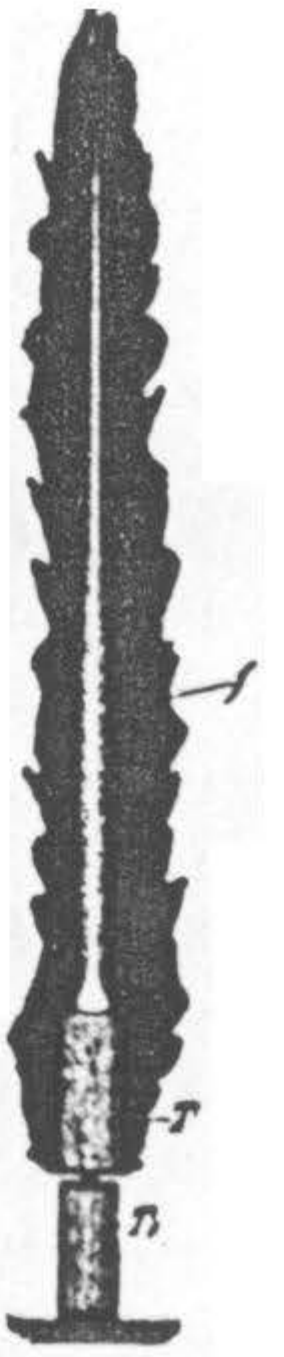


FIG. 25.—Illustrating lateral diffusion.

considerable dissipation of energy, principally on the ends of the conductor in consequence of the action of the gas surrounding the conductor. Owing to this, the current through a section of the conductor at a point midway between its ends may be much smaller than through a section near the ends. Furthermore, the current passes principally through the outer portions of the conductor, but this effect is to be distinguished from the skin effect as ordinarily interpreted, for the latter would or should occur also in a continuous incompressible medium. If a great many incandescent

lamps are connected in series to a source of such currents, the lamps at the ends may burn brightly, whereas those in the middle may remain entirely dark. This is due principally to bombardment, as before stated. But even if the currents be steady, provided the difference of potential is very great, the lamps at the ends will burn more brightly than those in the middle. In such case there is no rhythmical bombardment and the result is produced entirely by leakage. This leakage, or dissipation into space, when the tension is high, is considerable when incandescent lamps are used, and still more considerable with arcs, for the latter act like flames. Generally, of course, the dissipation is much smaller with steady, than with varying currents.

I have contrived an experiment which illustrates in an interesting manner the effect of lateral diffusion. If a very long tube be attached to the terminal of a high frequency coil, the luminosity is greatest near the terminal and falls off gradually towards the remote end. This is more marked if the tube is narrow.

A small tube about one-half inch in diameter and twelve inches long, *Fig. 25*, has one of its ends drawn out into a fine fibre *f* nearly three feet long. The tube is placed in a brass socket *T*, which can be screwed on the terminal T_1 of the induction coil. The discharge passing through the tube first illuminates the bottom of the same, which is of comparatively large section; but through the long glass fibre the discharge cannot pass. But gradually the rarefied gas inside becomes warmed and more conducting and the discharge spreads into the glass fibre. This spreading is so slow, that it may take half a minute or more until the discharge has worked through up to the top of the glass fibre, then presenting the appearance of a strongly luminous thin thread. By adjusting the potential at the terminal, the light may be made to travel upwards at any speed. Once, however, the glass fibre is heated the discharge breaks through its entire length instantly. The interesting point to be noted is that, the higher the frequency of the currents, or, in other words, the greater relatively the lateral dissipation, the slower will be the rate at which the light be made to

propagate through the fibre. This experiment is best performed with a highly exhausted and freshly made tube. When the tube has been used for some time the experiment often fails. It is possible that the gradual and slow impairment of the vacuum is the cause. This slow propagation of the discharge through a very narrow glass tube corresponds exactly to the propagation of heat through a bar warmed at one end. The more quickly the heat is carried away laterally the longer will be the time required for the heat to warm the remote end. When the current of a low frequency coil is passed through the fibre from end to end, then the lateral dissipation is small and the discharge instantly breaks through almost without exception.

After these experiments and observations which have shown the importance of the discontinuity, or atomic structure, of the medium, and which will serve to explain, in a measure at least, the nature of the four kinds of light-effects producible with these currents, I may now give you an illustration of these effects. For the sake of interest I may do this in a manner which to many of you might be novel. You have seen before that we may now convey the electric vibration to a body by means of a single wire or conductor of any kind. Since the human frame is conducting I may convey the vibration through my body.

First, as in some previous experiments, I connect my body with one of the terminals of a high-tension transformer and take in my hand an exhausted bulb which contains a small carbon button mounted upon a platinum wire leading to the outside of the bulb, and the button is rendered incandescent as soon as the transformer is set to work (*Fig. 26*). I may place a conducting shade on the bulb which serves to intensify the action, but this is not necessary. Nor is it required that the button should be in conducting connection with the hand through a wire leading through the glass, for sufficient energy may be transmitted through the glass itself, by inductive action, to render the button incandescent.

Next I take a highly exhausted bulb containing a strongly phosphorescent body, above which is mounted a small plate

of aluminum on a platinum wire leading to the outside, and the currents flowing through my body excite intense phos



FIG. 26.—Incandescence of a solid.



FIG. 27.—Phosphorescence.



FIG. 28.—Incandescence or phosphorescence of rarefied gas.



FIG. 29.—Luminosity of gas at ordinary pressure.

Illustrating four kinds of light effects produced by high frequency currents of high potential.

phorescence in the bulb, *Fig. 27*. Next, again I take in my hand a simple exhausted tube, and in the same manner the

gas inside the tube is rendered highly incandescent, or phosphorescent, *Fig. 28.* Finally, I may take in my hand a wire, whether it be bare, or covered with thick insulation, is quite immaterial, when the electric vibration is so intense as to cover the wire with a luminous film, *Fig. 29.*

A few words must now be devoted to each of these phenomena. In the first place, I will consider the incandescence of a button, or of a solid in general, and dwell upon some facts which apply equally to all these phenomena. It was pointed out before that when a thin conductor, such as a lamp filament, for instance, is connected with one of its ends to the terminal of a transformer of high tension, the filament is brought to incandescence partly by a conduction current and partly by bombardment. The shorter and thicker the filament the more important becomes the latter, and finally, reducing the filament to a mere button, all the heating must practically be attributed to the bombardment. So in the experiment before shown, the button is rendered incandescent by the rhythmical impact of freely movable small bodies in the bulb. These bodies may be the molecules of the residual gas, particles of dust, or lumps torn from the electrode; whatever they are, it is certain that the heating of the button is essentially connected with the pressure of such freely movable particles, or of atomic matter in general, in the bulb. The heating is the more intense the greater the number of impacts per second and the greater the energy of each impact. Yet the button would be heated also if it were connected to a source of a steady potential. In such a case electricity would be carried away from the button by the freely movable carriers or particles flying about, and the quantity of electricity thus carried away might be sufficient to bring the button to incandescence by its passage through the latter. But the bombardment could not be of great importance in such case. For this reason it would require a comparatively very great supply of energy to the button to maintain it at incandescence with a steady potential. The higher the frequency of the electric impulses, the more economically can the button be maintained at incandescence. One of

the chief reasons why this is so, is, I believe, that with impulses of very high frequency there is less exchange of the freely movable carriers around the electrode, and this means, that in the bulb the heated matter is confined more rigorously to the neighborhood of the button. If a double bulb, as illustrated in *Fig. 30*, be made, comprising a large globe *B* and a small one *b*, each containing as usual a filament *f*, mounted on a platinum wire *w* and w_1, it is found, that if the filaments *f f* be exactly alike, it requires less energy to keep the filament in the globe *b* at a certain degree of incandescence, than that in the large globe *B*. This is due to the confinement of the movable particles around the button. In this case, it is also ascertained, that the filament in the small globe *b* is less deteriorated when maintained a

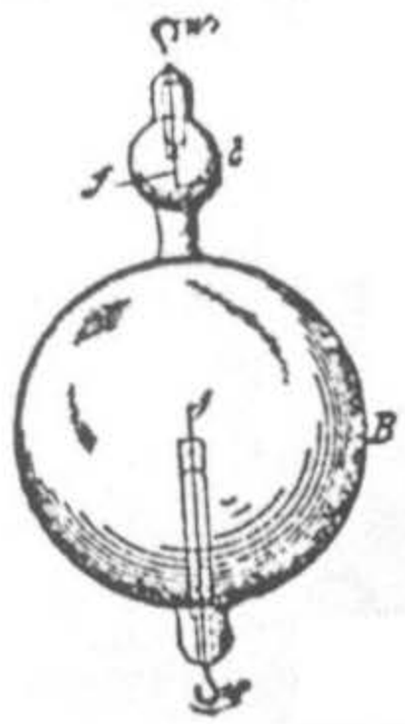


FIG. 30.—Showing the effect of confining the gas around the electrode.

certain length of time at incandescence. This is a necessary consequence of the fact that the gas in the small bulb becomes strongly heated and, therefore, a very good conductor, and less work is then performed on the button, since the bombardment becomes less intense as the conductivity of the gas increases. In this construction, of course, the small bulb becomes very hot and when it reaches an elevated temperature the convection and radiation on the outside increase. On another occasion, I have shown bulbs in which this drawback was largely avoided. In these instances a very small bulb, containing a refractory button, was mounted in a large globe and the space between the walls of both was highly exhausted. The outer large globe remained comparatively cool in such

constructions. When the large globe was on the pump and the vacuum between the walls maintained permanent by the continuous action of the pump, the outer globe would remain quite cold, while the button in the small bulb was kept at incandescence. But when the seal was made, and the button in the small bulb was maintained incandescent some length of time, the large globe also, would become warmed. From this I conjectured that if vacuous space (as Professor Dewar finds) cannot convey heat, it is so merely in virtue of our rapid motion through space, or, generally speaking, by the motion of the medium relatively to us, for a permanent condition could not be maintained without the medium being constantly renewed. A vacuum cannot,

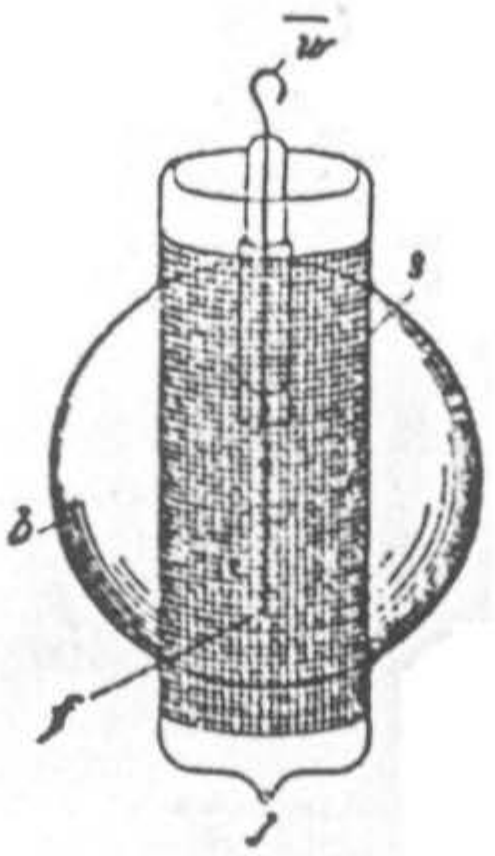


FIG. 31.—Showing the inefficiency of a metal screen.

according to all evidence, be permanently maintained around a hot body.

In these constructions, before mentioned, the small bulb inside would, at least in the first stages, prevent all bombardment against the outer, large globe. It occurred to me then to ascertain how a metal sieve would behave in this respect, and several bulbs, as illustrated in *Fig. 31*, were prepared for this purpose. In a globe *b*, was mounted a thin filament *f* (or button) upon a platinum wire *w* passing through a glass stem, and leading to the outside of the globe. The filament *f* was surrounded by a metal sieve *s*. It was found in experiments with such bulbs that a sieve with wide meshes apparently did not in the slightest degree affect

the bombardment against the globe *b*. When the vacuum was high, the shadow of the sieve was clearly projected against the globe, and the latter would get hot in a short while. In some bulbs the sieve *s* was connected to a platinum wire sealed in the glass. When this wire was connected to the other terminal of the induction coil (the E.M.F. being kept low in this case), or to an insulated plate, the bombardment against the outer globe *b* was diminished. By taking a sieve with fine meshes, the bombardment against the globe *b* was always diminished, but even then, if the exhaustion was carried very far, and when the potential of the transformer was very high, the globe *b* would be bombarded and heated quickly, though no shadow of the sieve was visible owing to the smallness of the meshes. But a glass tube, or other continuous body, mounted so as to surround the filament, did entirely cut off the bombardment, and for a while the outer globe *b* would remain perfectly cold. Of course, when the glass tube was sufficiently heated the bombardment against the outer globe could be noted at once. The experiments with these bulbs seemed to show that the speeds of the projected molecules, or particles, must be considerable (though quite insignificant when compared with that of light), otherwise it would be difficult to understand how they could traverse a fine metal sieve without being affected, unless it were found that such small particles, or atoms, cannot be acted upon directly at measurable distances. In regard to the speed of the projected atoms, Lord Kelvin has recently estimated it at about one kilometre a second, or thereabouts, in an ordinary Crookes bulb. As the potentials obtainable with a disruptive discharge coil are much higher than with ordinary coils, the speeds must, of course, be much greater when the bulbs are lighted from such a coil. Assuming the speed to be as high as five kilometres and uniform through the whole trajectory, as it should be in a very highly exhausted vessel, then if the alternate electrifications of the electrode would be of a frequency of 5,000,000, the greatest distance a particle could get away from the electrode would be one millimetre, and if it could be acted upon directly at that distance, the

exchange of electrode matter, or of the atoms, would be very slow, and there would be practically no bombardment against the bulb. This at least should be so, if the action of an electrode upon the atoms of the residual gas would be such as upon electrified bodies which we can perceive. A hot body enclosed in an exhausted bulb produces always atomic bombardment, but a hot body has no definite rhythm, for its molecules perform vibrations of all kinds.

If a bulb containing a button or filament, be exhausted as high as is possible with the greatest care and by the use of the best artifices, it is often observed that the discharge cannot, at first, break through, but after some time, probably in consequence of some changes within the bulb, the discharge finally passes through and the button is rendered incandescent. In fact, it appears that the higher the degree of exhaustion the easier is the incandescence produced. There seems to be no other cause to which the incandescence might be attributed in such case except to the bombardment, or similar action, of the residual gas, or of particles of matter in general. But if the bulb be exhausted with the greatest care can these play an important part? Assume the vacuum in the bulb to be tolerably perfect the great interest then centres in the question: Is the medium which pervades all space continuous or atomic? If atomic then the heating of a conducting button or filament in an exhausted vessel might be due largely to ether bombardment, and then the heating of a conductor in general through which currents of high frequency or high potential are passed must be modified by the behavior of such medium; then also the skin effect, the apparent increase of the ohmic resistance, etc., admit partially, at least, of a different explanation.

[*To be concluded.*]

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ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

[*Concluded from p. 360.*]

It is certainly more nearly in accord with many phenomena observed with high frequency currents to hold that all space is pervaded by free atoms, than to assume that it is devoid of these, and dark and cold; for so it must be if filled with a continuous medium, since in such there can be neither heat nor light. Is then energy transmitted by independent carriers, or by the vibration of a continuous medium? This important question is as yet by no means positively answered. But most of the effects which are

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893, and before the National Electric Light Association, at St. Louis, March 1, 1893.

here considered, especially the light effects, incandescence, or phosphorescence, involve the presence of free atoms and would be impossible without these.

In regard to the incandescence of a refractory button (or filament) in an exhausted receiver, which has been one of the subjects of this investigation, the chief precautions, to be observed in constructing such bulbs, may be summed up as follows:

(1) The button should be as small as possible, spherical, of a smooth or polished surface and of that refractory material which best withstands evaporation.

(2) The support of the button should be very thin, and screened by an aluminum and mica sheet, such as I have described on another occasion.

(3) The exhaustion of the bulb should be as high as possible.

(4) The frequency of the currents should be as high as practicable.

(5) The currents should be of a harmonic rise and fall, without sudden interruptions.

(6) The heat should be confined to the button by enclosing the same in a small bulb or otherwise.

(7) The space between the walls of the small bulb and the outer bulb should be highly exhausted.

Most of the considerations which we have just considered as applying to the incandescence of a solid may likewise be applied to phosphorescence. Indeed, in an exhausted vessel the phosphorescence is, as a rule, primarily excited by the powerful beating of the electrode stream of atoms against the phosphorescent body. Even in many cases where there is no evidence of such a bombardment, I think that phosphorescence is excited by violent impacts of atoms, which are not necessarily thrown off from the electrode but are inductively acted upon from the same through the medium or through chains of other atoms. That mechanical shocks play an important part in exciting phosphorescence in a bulb may be seen from the following experiment. If a bulb, constructed like that illustrated in *Fig. 10*, be exhausted as thoroughly as possible, so that the discharge

cannot pass, the filament *f* acts by electrostatic induction upon the tube *t* and the latter is set in vibration. If the tube *o* be rather wide, about an inch or so, the filament may be so powerfully vibrated that when it strikes the glass tube it excites phosporescence. The phosphorescence, however, ceases when the filament comes to rest. The vibration can be arrested and again started by varying the frequency of the currents. Obviously, the filament has its own period of vibration, and if the frequency of the currents is such that there is resonance, it is easily set vibrating, though the potential of the currents be small. I have often observed that the filament in the bulb is destroyed by such mechanical resonance. The filament vibrates, as a rule, so rapidly that it cannot be seen, and the experimenter may at first be mystified. When such an experiment as the one described is carefully performed, the potential of the currents may be extremely small, and for this reason I infer that the phosphorescence is then due to the mechanical shock of the filament against the glass, just as it is produced by striking a loaf of sugar with a knife. The mechanical shock produced by the projected atoms is easily noted when a bulb containing a button is grasped in the hand and the current turned on suddenly. I believe that a bulb could be shattered by observing the conditions of resonance.

In the experiment before cited, it may of course be said that the glass tube, upon coming into contact with the filament,retains upon the point of contact a charge of a certain sign. If now the filament again touches the glass on the same point while it is oppositely charged, the charges equalize, with an evolution of light. But nothing of importance would be gained by such an explanation. It is unquestionable that the initial charges given to the atoms or to the glass play some part in exciting phosphorescence. So, for instance, if a phosphorescent bulb be first excited by a high frequency coil, by connecting it to one of the terminals of the latter, and the degree of luminosity noted, and then the bulb be highly charged from a Holtz machine by attaching it preferably to the positive terminal of the machine,

it is found that when the bulb is again connected to the terminal of the high frequency coil, the phosphorescence is far more intense. On a previous occasion I considered the possibility of some phosphorescent phenomena in bulbs being produced by the incandescence of an infinitesimal layer on the surface of the phosphorescent body. Certainly, the impacts of the atoms are powerful enough to produce intense incandescence by their collisions, since they quickly bring to a high temperature a body of considerable bulk. If any such effect exists, then the best known appliance for producing phosphorescence in a bulb, is a disruptive discharge coil giving an enormous potential with but few fundamental discharges, say 25 to 30 per second, just enough to produce a continuous impression upon the eye. It is a fact that such a coil excites phosphorescence under almost any conditions and at all degrees of exhaustion, and I have observed effects which appear to be due to phosphorescence even at ordinary pressures of the atmosphere, when the potentials are extremely high. But if phosphorescent light is produced by the equalization of charges of electrified atoms (whatever this may mean ultimately), then the higher the frequency of the impulses or alternate electrifications, the more economical will be the light production. It is a long known and noteworthy fact that all the phosphorescent bodies are poor conductors of electricity and heat, and that all bodies cease to emit phosphorescent light when they are brought to a certain temperature. Conductors, on the contrary, do not possess this quality. There are but few exceptions to the rule. Carbon is one of them. Becquerel noted that carbon phosphoresces at a certain elevated temperature preceding the dark red. This phenomenon may easily be observed in bulbs provided with a rather large carbon electrode (say a sphere of six millimetres diameter). If the current be turned on after a few seconds, a snow-white film covers the electrode, just before it becomes dark red. Similar effects are noted with other conducting bodies, but probably not many scientific men will attribute them to true phosphorescence. Whether true incandescence has anything to do with phosphorescence

excited by atomic impact or mechanical shocks, still remains to be determined, but it is a fact that those conditions which tend to localize and increase the heating effect at the point of impact are almost invariably the most favorable for the production of phosphorescence. So, if the electrode be very small, in other words, if in general, the electric density is great, if the potential be high, and if the gas be highly rarefied (conditions implying high speed of the projected atoms, or matter, and consequently violent impacts), the phosphorescence is very intense. If a bulb provided with a large and a small electrode be attached to the terminal of an induction coil, the small electrode excites phosphorescence, while the large one may not do so, because of the smaller electric density and hence smaller speed of the atoms. A bulb provided with a large electrode may be grasped with the hand while the electrode is connected to the terminal of the coil and it may not phosphoresce, but if, instead of grasping the bulb with the hand, the same be touched with a pointed wire, the phosphorescence at once spreads through the bulb, because of the great density at the point of contact. With low frequencies it seems that gases of great atomic weight excite more intense phosphorescence than those of smaller weight, as for instance, hydrogen. With high frequencies the observations are not sufficiently reliable to justify a conclusion. Oxygen, as is well known, produces exceptionally strong effects, which may in part be due to chemical action. A bulb with hydrogen residue seems to be most easily excited. Those electrodes which are most easily deteriorated produce the most intense phosphorescence in bulbs, but the condition is not permanent because of the impairing of the vacuum and the deposition of the electrode matter upon the phosphorescent surfaces. Some liquids, as oils for instance, produce magnificent effects of phosphorescence (or fluorescence?), but they last only a few seconds. So if a bulb have a trace of oil on the walls and the current is turned on, the phosphorescence only persists for a few moments until the oil is carried away. Of all bodies so far tried, sulphide of zinc seems to be the most susceptible to phosphorescence. Some samples obtained in Paris through the

kindness of Professor Henry were employed in many of these bulbs. One of the defects of this sulphide is, that it loses its quality of emitting light when brought to a very moderate temperature. It can, therefore, be used only for feeble intensities. An observation which might deserve notice is, that when violently bombarded from an aluminum electrode it assumes a black color, but singularly, it returns to the original condition when it cools down.

The most important fact arrived at in pursuing investigations in this direction is, that in all cases it is necessary, in order to excite phosphorescence with a minimum amount of energy, to bear in mind that no matter what may be the frequency of the currents, the degree of exhaustion and the character of the bodies in the bulb, there is always a certain potential (assuming the bulb excited from one terminal) or potential difference (assuming the bulb to be excited with both terminals) which produces the most economical result. If the potential be increased, considerable energy may be wasted without producing any more light, and if it be diminished, then again the light production is not as economical. The exact condition under which the best result is obtained seems to depend on many different circumstances, and the subject requires further investigation. In the meantime the required condition must be approximated as closely as possible in order to obtain the most favorable results.

Coming now to the most interesting of these phenomena, the incandescence or phosphorescence of gases, at low pressures or at the ordinary pressure of the atmosphere, we must seek the explanation of these phenomena in the same primary causes; that is, in shocks or impacts of the atoms. Just as molecules or atoms beating upon a solid body excite phosphorescence in the same or render it incandescent, so when colliding among themselves they produce similar phenomena. But this is a very insufficient explanation and concerns only the crude mechanism. Light, as is well-known, is produced by vibrations, of inconceivable rapidity. If we compute, from the energy contained in the form of known radiations in a definite space, the force which is

necessary to set up such rapid vibrations, we find that though the density of the ether is incomparably less than that of hydrogen or of any other known body, the force is something surpassing comprehension. What is this force, which, in mechanical measure, may amount to thousands of tons per square inch? In the light of modern views, we call it electrostatic force. It is impossible to conceive how a body of measurable dimensions could be charged to so high a potential that the force would be sufficient to produce these vibrations. Long before any such charge could be imparted to the body it would be shattered into atoms. The sun emits light and heat, and so does an ordinary flame or incandescent filament, but in neither of these can the force be accounted for if it be assumed that it is associated with the body as a whole. Only in one way may we account for it, namely, by identifying it with the atom. An atom is so small, that if it be charged by coming in contact with an electrified body and if the charge be assumed to follow the same law as in the case of bodies of measurable dimensions, it must retain a quantity of electricity capable of accounting for these forces and for these tremendous rates of vibration. But the atom behaves singularly in this respect; it always takes the same "charge."

It is very likely that resonant vibration plays a most important part in all manifestations of energy in nature. Throughout space all matter is vibrating, and all rates of vibration are represented, from the lowest musical note to the highest pitch of the chemical rays; hence, an atom, or a complex of atoms, no matter what its period, must find a vibration with which it is in resonance. When we consider the enormous rapidity of the light vibration, we realize the impossibility of producing such vibrations directly with any apparatus of measurable dimensions, and we are driven to the only possible economical means of electrically setting up waves of light, that is, by so affecting the molecules or atoms of a gas as to cause them to collide and vibrate. We must then ask ourselves, how can free molecules or atoms be thus affected?

That they can be affected by electrostatic force, is

apparent from many of these experiments. By varying the electrostatic force we can agitate the atoms and cause them to collide so as to evolve heat and light. It is not incontestably demonstrated that we can affect them otherwise. If a luminous discharge is produced in a closed exhausted tube, do the atoms arrange themselves in obedience to any other than electrostatic force acting in straight lines from atom to atom? Only recently I investigated the mutual action between two circuits with extreme rates of vibration. If a battery of a few jars (*cc*, *cc*, *Fig. 32*) be discharged through a primary *P* of low resistance (the connections being as illustrated in *Figs. 19a*, *19b* and *19c*), and if the frequency of vibration be many million, there are great differences of potential between points on the primary not

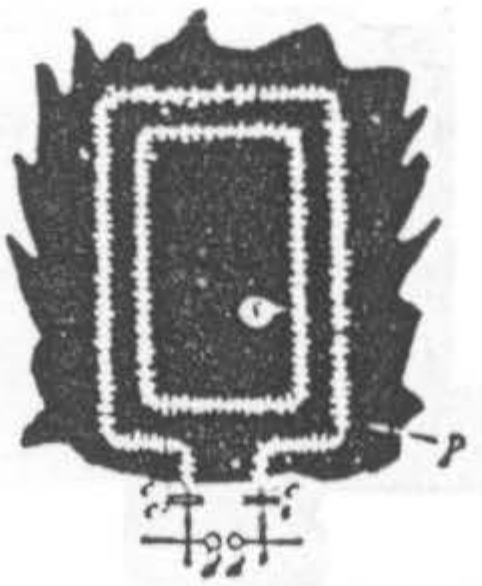

FIG. 32.—Electrostatic action between primary and secondary, with extremely high frequencies.

more than a few inches apart. These differences may be 10,000 volts per inch, if not more, taking the maximum value of the E.M.F. The secondary *s* is therefore acted upon by electrostatic induction, which is in such extreme cases of much greater importance than the electro-dynamic. To such sudden impulses the primary as well as the secondary are poor conductors, and therefore great differences of potential may be produced by electrostatic induction between adjacent points on the secondary. Sparks then may leap between the wires and streamers become visible in the dark if the light of the discharge through the spark gap *d d* be carefully excluded. If now we substitute a closed vacuum tube for the metallic secondary *s*, the differences of potential produced in the tube by electrostatic induction from

the primary are fully sufficient to excite portions of it; but as the points of certain differences of potential on the primary are not fixed, but are, generally, constantly changing in position, a luminous band is produced in the tube, apparently not touching the glass, as it should if the points of maximum and minimum differences of potential were fixed on the primary. I do not exclude the possibility of such a tube being excited by electro-dynamic induction only, for very able physicists hold this view; but, in my opinion, there is as yet no positive proof given that atoms of a gas in a closed tube may arrange themselves in chains under the action of an electro-motive impulse produced by electro-dynamic induction in the tube. I have been unable so far to produce striæ in a tube however long, and at whatever degree of exhaustion; that is, striæ at right angles to the supposed direction of the discharge or the axis of the tube, but I have distinctly observed in a large bulb, in which a wide luminous band was produced by passing a discharge of a battery through a wire surrounding the bulb, a circle of feeble luminosity between two luminous bands, one of which was more intense than the other. Furthermore, with my present experience of the subject, I do not think that such a gas discharge in a closed tube can vibrate as a whole. I am convinced that no discharge through a gas can vibrate. The atoms of a gas behave very curiously in respect to sudden electric impulses. The gas does not seem to possess any appreciable inertia to such impulses, for it is a fact, that the higher the frequency of the impulses, the greater the freedom with which the discharge passes through the gas. If the gas possesses no inertia it cannot vibrate, for some inertia is necessary for free vibration. I conclude from this that if a lightning discharge occurs between two clouds, there can be no oscillation, such as would be expected in view of the capacity of the clouds. But if the lightning discharge strike the earth, there is always vibration in the earth, but not in the cloud. In a gas discharge each atom vibrates at its own rate, but there is no vibration of the conducting gaseous mass as a whole. This is an important consideration in the great problem of producing light eco-

nomically, for it teaches us that to reach this result we must use impulses of very high frequency and necessarily also of high potential. It is a fact that oxygen produces a more intense light than hydrogen, in a tube. This is because oxygen atoms possess more inertia and the vibration does not die out instantly. But then nitrogen should be as good, as oxygen, while chlorine, and the vapors of many bodies should be much better unless the magnetic properties of oxygen come prominently into play. Or, is the process in the tube of an electrolytic nature? Many observations certainly indicate that it is, the most important of these being that matter is always carried away from the electrodes, so that the vacuum in a bulb cannot be permanently maintained. If such a process takes place in reality, then again must we have recourse to high frequencies, for, with such, electrolytic action should be reduced to a minimum, if not rendered entirely impossible. It is an undeniable fact that with very high frequencies, provided the impulses be of a

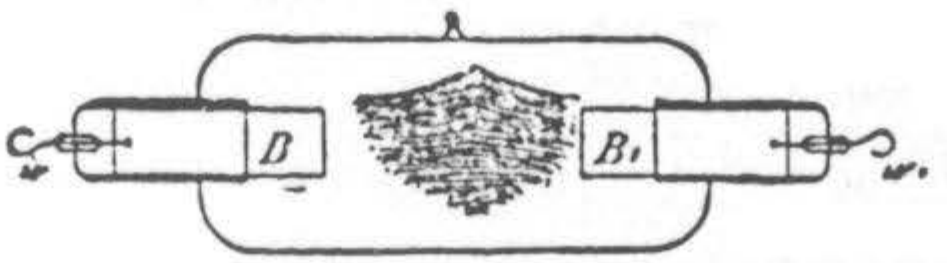

FIG. 33.—Carbon deposit in tube in a magnetic field.

harmonic nature, like those obtained from an alternator, there is less deterioration and the vacua are more permanent. With disruptive discharge coils, there are sudden rises of potential and the vacua are more quickly impaired, for the electrodes are deteriorated in a very short time. It was observed in some large tubes, which were provided with heavy carbon blocks $B\ B_1$, connected to platinum wires w w_1 (as illustrated in *Fig. 33*), and which were employed in experiments with the disruptive discharge instead of the ordinary air gap, that the carbon particles under the action of the powerful magnetic field in which the tube was placed, were deposited in regular fine lines in the middle of the tube, as illustrated. These lines were attributed to the deflection or distortion of the discharge by the magnetic field, but why the deposit occurred principally where the field was most intense did not appear quite clear. A fact of interest like-

wise noted was that the presence of a strong magnetic field increases the deterioration of the electrodes, probably by reason of the rapid interruptions it produces, whereby there is actually a higher E.M.F. maintained between the electrodes.

Much might be said about the luminous effects produced in gases at low or ordinary pressures. With the present experiences before us, we cannot say that the intimate nature of these charming phenomena is sufficiently

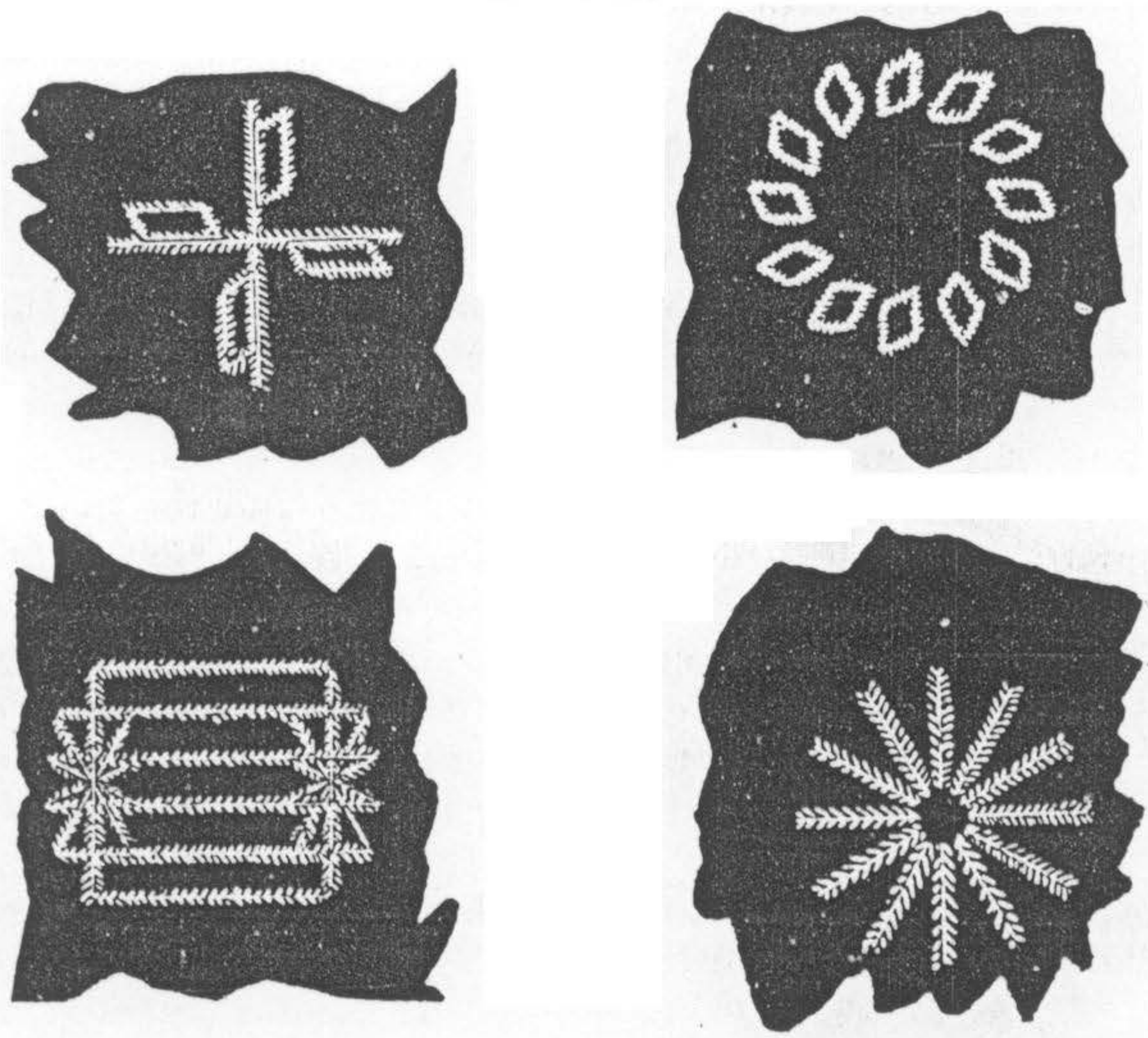

FIG. 34.—Spoke wheel, drum winding, alternate motor winding, ring winding. Some of the designs produced by intermittent discharges.

known. But investigations in this direction are being pushed with exceptional ardor. Every line of scientific pursuit has its fascinations, but electrical investigation appears to possess a peculiar attraction, for there is no experiment or observation of any kind in the dominion of this wonderful science which would not forcibly appeal to us. Yet to me it seems, that of all the many marvellous things we observe, a vacuum tube, when, excited by an

electric impulse from a distant source, it bursts forth, out of the darkness illuminating the room with its beautiful light, is as lovely a phenomenon as can greet our eyes. More interesting still it appears when, by reducing the fundamental discharges across the gap to a very small number and waving the tube about we produce all kinds of designs in luminous lines. So, by way of amusement, I take a long straight tube, or a square one, or a square attached to a straight tube, and by whirling them about in the hand I imitate the spokes of a wheel, a Gramme winding, a drum winding, an alternate current motor winding, etc. (*Fig 34.*) When seen from a distance the effect is weakened and much of its beauty is lost, but to one who sees the phenomenon close at hand it is irresistibly charming.

In presenting these insignificant results, I have not attempted to arrange and coördinate them as would be proper in a strictly scientific investigation in which every succeeding result should be a logical sequel of the preceding one, so that it might be guessed in advance by the careful reader or attentive listener. I have preferred to concentrate my energies chiefly upon advancing novel facts or ideas which might serve as suggestions to others, and this may serve as an excuse for the lack of harmony. The explanations of the phenomena have been given in good faith and in the spirit of a student prepared to find that they admit of a better interpretation. There can be no great harm in a student taking an erroneous view, but when great minds err, the world must dearly pay for their mistakes.

TESLA ON THE ELECTRICAL TRANSMISSION OF ENERGY.

THE following extract from the long lecture delivered recently by Mr. Nikola Tesla will be found of especial interest from several points of view:—Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far; but I do firmly believe that it is practicable to disturb, by means of powerful machines, the electrostatic condition of the earth, and thus transmit intelligible signals and perhaps power. In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why, then, not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile-posts the earth may appear very large; but to that happiest of all men, the astronomer, who gazes at the heavens and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician, for when he considers the speed with which an electric disturbance is propagated through the earth, all his ideas of distance must completely vanish.

A point of great importance would be, first, to know what is the capacity of the earth and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation. If it be a charged body insulated in space, its capacity should be extremely small, less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case, it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric currents. One of the terminals of the source would be connected to earth, as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata or free space contains an opposite charge, and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low, and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible, and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body, and watching for the disturbance at various neighbouring points of the earth's surface, resonance



might be detected. Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do, and a proper electrical oscillator would have to be produced, and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface.

Assume that a source of alternating currents S be connected, as in the figure, with one of its terminals to earth (conveniently to the water mains) and with the other to a body of large surface P. When the electric oscillation is set up, there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to

or diverging from the point C where the ground connection is made. In this manner neighbouring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body P is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source S will set up the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration at least of a certain low period upon the earth by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured. I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at the surface could be but extremely small considering the size of the earth, the air would not act as a very disturbing factor, and there would be not much energy lost through the action of the air, which would be the case if the density were great. Theoretically, then, it could not require a great amount of energy to produce a disturbance perceptible at great distance or even all over the surface of the globe. Now, it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source S_1, similar to S, or any number of such sources can be set to work in synchronism with the latter and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S_1 if the same be of opposite phase to the source S. I think that, beyond doubt, it is possible to operate electrical devices in a city through the ground or pipe system by resonance from an electrical oscillator located at a central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realisation of the scheme of transmitting intelligence or perhaps power to any distance through the earth or environing medium. If this is at all possible distance does not mean anything. Proper apparatus must first be produced by means of which the problem can be attacked, and I have devoted much thought to this subject. I am firmly convinced that it can be done, and hope that we shall live to see it done.

WORLD'S FAIR DEPARTMENT.

WESTINGHOUSE WORK AT THE FAIR.

Our readers will recall, in The Electrical Engineer of April 26, a description of the Westinghouse Machinery Hall service plant from which so large a part of the grounds

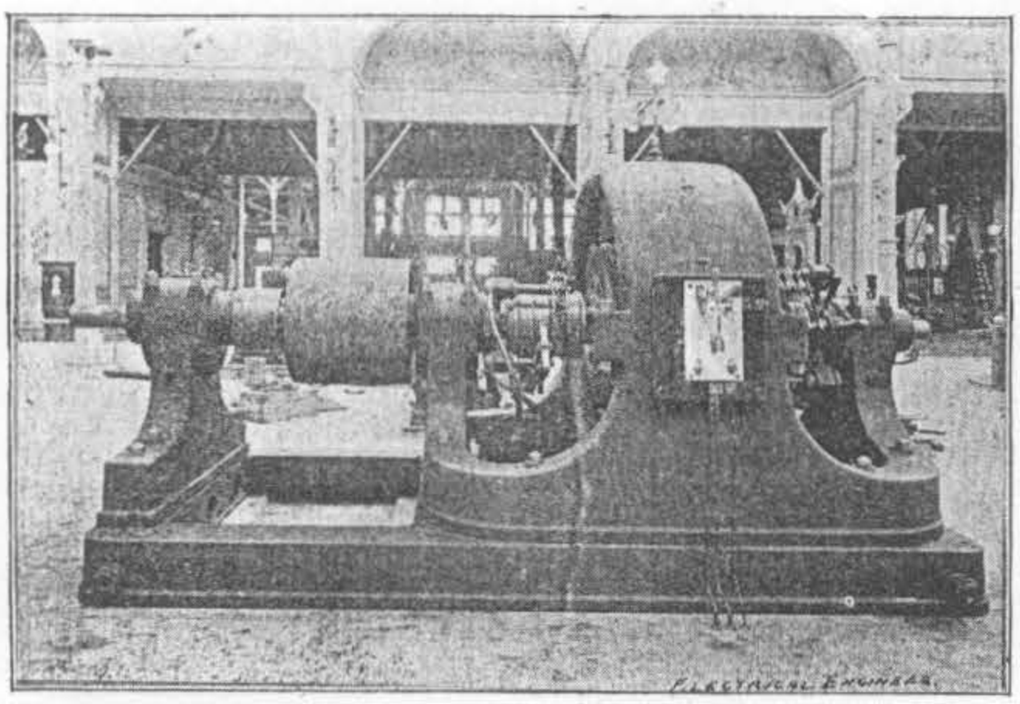

Fig. 1.—500 H. P. Westinghouse Rotating Transformer.

and buildings are lighted, and which is capable of supplying 189,600 16-c. p. lamps. At the time the article referred to was written, the plant was just being put in and was in a very backward condition. It will not, then, be amiss, now that it is complete, and nearly all the generators are in operation, to refer to it once more in connection with a brief review of the company's work at the Fair.

The power plant, occupying the space between columns E, 13 and E, 25 in the south nave of Machinery Hall, consists of six 750 kilowatt two-phase alternators, two of which are belted to a 3,000 h. p. Allis engine and the other four to 1,000 h. p. engines built by the Fraser & Chalmers, McIntosh & Seymour, Buckeye, and Atlas companies, respectively; six 750 kilowatt two-phase alternators, each directly connected with a 1,000 h. p. Westinghouse Columbian steeple engine; two 240 kilowatt single-phase alternators, each belted to a 350 h. p. Westinghouse compound engine, and three 75 kilowatt exciters directly driven by 100 h. p. Westinghouse compound engines.

The great white marble switchboard is designed for 12 two-phase and two single-phase alternators, four exciters and 40 circuits and controls nearly all the incandescent and a large number of arc lights in the grounds and buildings including the Midway Plaisance. The switches are so arranged that any one of the 40 circuits can be instantly connected with any of the 14 alternators, and regulating devices are provided for accurately adjusting the candle power of the lamps. All of the incandescent lamps are of the Sawyer-Man stopper type and the arcs are run from Westinghouse constant potential alternating current.

In the Electricity Building the exhibits of the company cover about 15,000 square feet of floor space and while standard Westinghouse alternating current lighting apparatus is fully represented, special attention has been given to recent developments and improvements in the field of applied electricity. In the space marked by the "Golden Pavilion" toward the northern end of the building is a complete power transmission plant using the Tesla polyphase system and touched upon in The Electrical Engineer of June 21, under the title of "Progress in the Electricity Building." It will be remembered that within this one space are shown a generating station, a high tension transmission circuit about 30 feet long and a receiving and distributing station. The first contains a 500 h. p. two-phase alternating current generator, a 5 h. p. direct current exciter, a marble switchboard and the necessary step-up transformers. In practice the generator and exciter would naturally be driven by water power and the former is, in fact, directly belted to a Pelton water wheel, but as water power is not available, instead of the wheel driving the generator the generator drives the wheel, or rather both generator and wheel are driven by a 500 h. p. Tesla polyphase motor with a rotating field, and the exciter by a 5 h. p. motor of the same type, both operated by current from the large two-phase alternators in Machinery Hall.

The switchboard at the generating station is connected with that at the receiving station by a four-wire overhead circuit. The high tension current is here transformed to 500 volts and distributed to various local circuits. A 500 h. p. two-phase Tesla motor and rotary transformer receives alternating current from the step-down transformers and, exercising its function of motor, drives a Worthington pump and a 40-light Westinghouse alternating current arc light dynamo. As a transformer it delivers direct current at 500 volts to two 30 h. p. railway motors mounted on a standard Dorner & Dutton truck, a 60 h. p. motor driving an Ingersoll & Sargent air compressor and several constant potential arc lamps. A 60 h. p. machine of the same type is shown supplied with two-phase alternating current from the reducing transformers. As a transformer it delivers current at 50 volts for electrolytic work, etc. Beside this is a 60 h. p. two-phase synchronous Tesla motor directly coupled to a 45 kilowatt Westinghouse slow speed constant potential alternator for incandescent lighting.

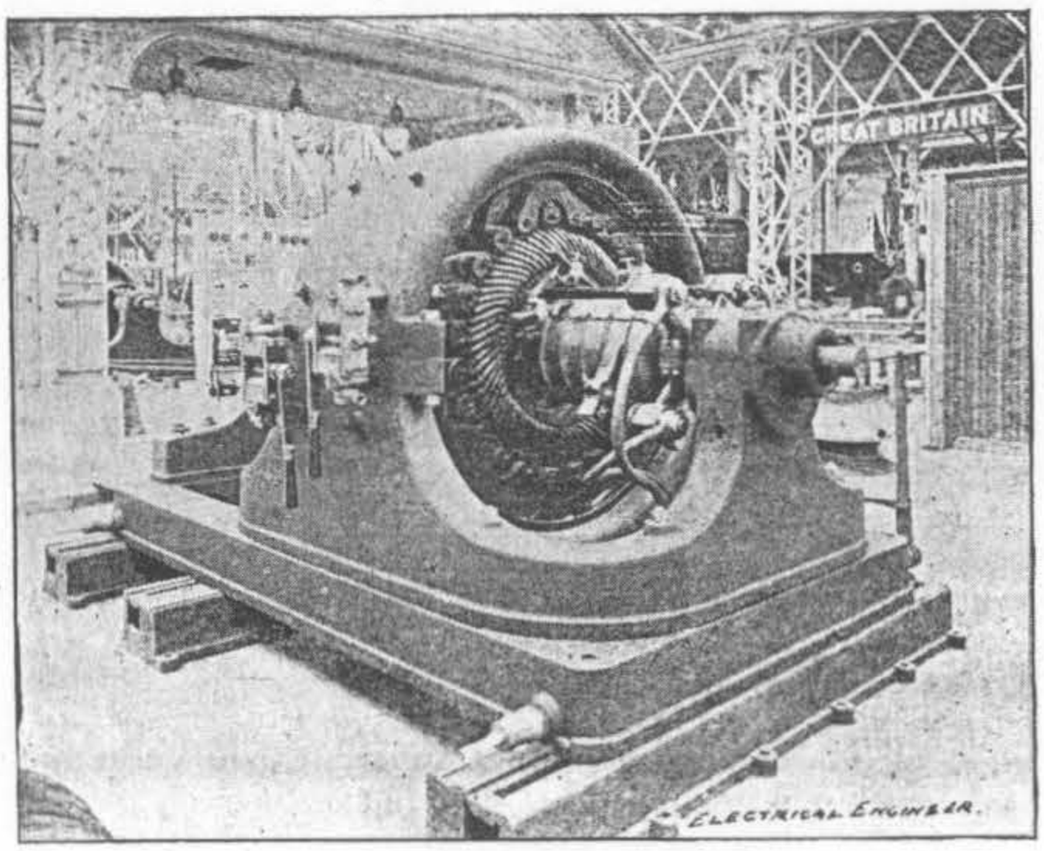

Fig. 2.—500 H. P. Two-Phase Tesla Motor.

While this system permits the use of exceedingly high tension for transmission over great distances, it delivers both alternating and direct current at any potential at the receiving end of a single circuit from one dynamo at the generating station. In no case is the value of its applica-

tion more apparent than in mining. Direct current from the rotary transformers is excellently adapted to haulage and hoisting, while the air compressors, lights, etc., may be operated by either the same current or that from the reducing transformers.

The street railway exhibit in the Electricity Building was fully described and illustrated in THE ELECTRICAL ENGINEER, of July 5. In addition to this, however, there are three supplementary Westinghouse exhibits. Thus, in

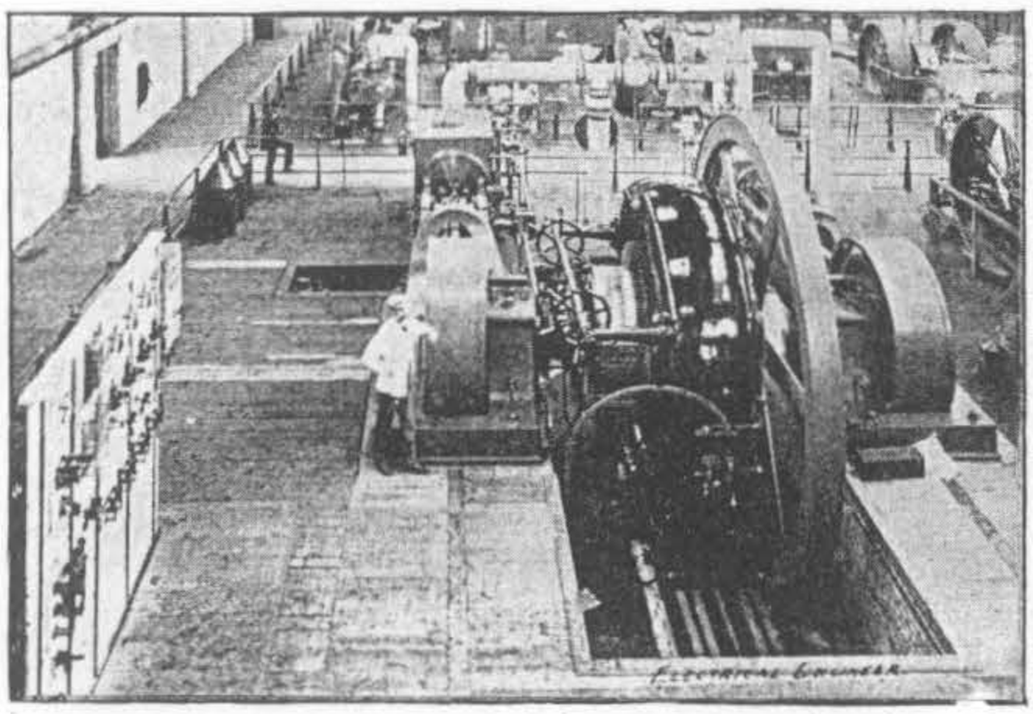

FIG. 3.—WESTINGHOUSE RAILWAY GENERATOR WITH ALLIS ENGINE.

the Transportation Building there is a Lamokin 18-foot car with two 30 h. p. Westinghouse single reduction motors and a series multiple controller, etc.; on an exhibition track near the north end of the Terminal Station is a 20-foot Laclede car similarly equipped, and in Machinery Hall has just been completed a 750 h. p. railway generator, the armature of which is mounted directly upon the shaft of an Allis engine running at only 90 revolutions a minute. This machine is unique. It has never before been assembled, as the armature, after being wound, was sent to Milwaukee, where it was fixed to the engine shaft. The illustration, Fig. 3, gives an excellent idea of the peculiar construction and the arrangement of engine and generator. A detailed account of the latter will be forthcoming as soon as it has been run and tested.

Apparatus for arc and incandescent lighting are shown in the Electricity Building just east of the railway exhibit, and include standard alternators of various sizes including the field casting of one of 450 kilowatts, showing the Westinghouse method of casting the laminated poles into the cast iron frame. Here are standard converters and transformers, special converters with non-arcing metal lightning arresters, direct current motors and generators of the horizontal, multipolar and Manchester types, alternating current arc light dynamos, Shallenberger meters complete and in operation, and also in parts to show the interior mechanism, Wurts non-arcing metal lightning arresters in operation, other types of arresters for direct currents, and a great variety of well-known styles of switches, ammeters and voltmeters for direct and alternating currents. In the southwest corner of the space is a dark room for special exhibits of high potential and high frequency phenomena, where exhibitions are given daily. Some of Mr. Tesla's early apparatus is also shown as well as some of that with which he has obtained such remarkable results in the use of high frequency alternating currents.

Nearly everyone is now familiar with the great Columbus mural decoration occupying the entire wall space above the south gallery of the Electricity Building and forming a conspicuous part of the Westinghouse display, where the lettering and decorative work is all outlined with Sawyer-Man stopper lamps supplied with current from the central station in Machinery Hall. The machinery in the Mines and Mining Building, or so much of it as is in operation, is run by two 150 h. p. 500 volt direct current Westinghouse motors, and a 20 h. p. motor of the same make operates an elevator in the New South Wales exhibit in the Transportation Building. The Yale & Towne crane in Machinery Hall, described in our last issue, is also equipped with Westinghouse motors of the Manchester type.

EXHIBIT OF TESLA POLYPHASE SYSTEM AT THE WORLD'S FAIR.

BY C. F. SCOTT, OF PITTSBURG, PA.

An exhibit of power transmission at the World's Fair which is of exceptional interest, is the Tesla polyphase system which constitutes a part of the exhibit of the Westinghouse Electric and Manufacturing Company, in Electricity Building. The exhibit includes generators, motors, transformers, and other apparatus of various sizes and types. The system itself is not new in its general plan. There are but few features of novelty in the electrical system which have not been the subjects of publications of patents. The purpose of the exhibit is not so much to bring out what is novel in electrical invention as it is to give a complete exhibit of commercial machinery constituting the elements of a power system on a large scale. The exhibit will attract practical electrical engineers rather than those who are interested only in electrical inventions.

The purpose of the exhibit is therefore to show a complete working system for generating, transmitting, and distributing power on a large commercial scale: The system includes,

I. A prime mover.

II. A generating dynamo.

III. Raising converters and transmission line and reducing converters.

IV. Motors and rotary transformers for general power and electrical service.

The prime mover in general practice is water power, but in the present plant a 500 h. p. two-phase Tesla motor of the rotary

field type serves as a prime mover. The current for this motor is received from one of the 750 K. W. two-phase Westinghouse generators of the lighting plant in Machinery Hall. The number of alternations is 7200, and the pressure is reduced from 2000 volts to 200 volts before being delivered to the motor. The current is delivered to the rotating element of the motor through brushes resting on four collecting rings. The winding is a drum-winding laid in small slots in the surface. The stationary element of the motor is of laminated iron set in an outside casting. Large copper rods are run through holes in the iron plates near the inner surface and are suitably connected at the ends. Resistances are put in circuit with this winding for starting the motor, and when speed is attained, these resistances are short-circuited, leaving this winding completely closed on itself.

The motor drives a 500 H. P. two-phase alternating current generator. This machine is of ordinary type of railway generator. There is a field of six poles which is exhibited by a small direct current machine driven by a 5 H. P. two-phase Tesla motor of the rotary field type. The exciter in general practice would be driven by a water wheel. The large generator delivers from four collecting rings, two currents differing in phase 90 degrees. The number of alternations is about 4,000 per minute, or 33⅓ periods per second, at a potential of 360 volts on each circuit. The machine is also provided with a direct current commutator connected with the same winding, delivering current at 500 volts. This commutator would not be used when the machine is intended as an alternating current generator only. The current from this machine is delivered to a marble switch-board where it is regulated and connected with the various transmission circuits, as desired. This board will afford facilities for connecting various circuits with any one of the several generators which may be placed in a large generating station. The current from the switch-board is received by alternate current converters, or transformers by which the potential is raised in the present plant to 1,200 volts. In practice, the transformation would be to a much higher voltage, depending upon the distance of transmission. The transmission circuit conveys the current to the receiving station, where it is reduced by transformers to electro motive forces appropriate to the machines to be supplied. The current passes through a marble switch-board in which there are suitable provisions for operating the various machines in the receiving station.

The largest machine in this station is a 500 H. P. two-phase Tesla motor and rotary transformer. This machine is similar in general construction to the generator above described. The alternating current at 360 volts is passed into four collecting rings on the armature. Special connections of the field circuit are made for starting the machine, and when the motor has attained full speed, a switch is turned giving the final connections and running the machine as a self-exciting synchronous motor, which maintains the exact speed of the generator by which it is driven except in cases of extreme overload. The armature of this machine is provided with a double pulley with belts driving a Worthington pump and a 40 light Westinghouse alternating current arc light dynamo. The armature is supplied with a direct current commutator, connected with the same winding which receives the alternating current, and delivers direct current at a potential of 500 volts. This current is utilized for operating two 30 H. P. street railway motors mounted upon a standard Dorner & Dutton truck, and also a 60 H. P. direct current motor mounted upon an Ingersoll-Sergeant air compressor. The direct current also supplies a series of direct current constant potential arc lamps. The current from the switch-board is also carried directly to a 60 H. P. two-phase motor and rotary transformer, which receives the current at 36 volts and delivers direct current at 50 volts adapted to electrolytic work, charging of storage batteries, and is at present used for operating the large Schuckert search light in an adjoining space. The current from the switch-board also operates a 60 H. P. two-phase Tesla motor of the synchronous type, which is adapted for any kind of constant speed work. In the present exhibit, it is direct coupled to a 45 K. W. slow speed alternator of the constant potential type used for incandescent lighting. Current from the switch-board is also directly utilized for supplying incandescent lamps.

It is commonly recognized that the mechanical design and workmanship upon electrical apparatus has fully as important a bearing upon its successful operation as the electrical design. In fact, in actual experience, it is found that electrical enterprises which have failed or have been unsuccessful have been deficient usually in mechanical rather than in electrical elements. It is therefore of especial importance to note the mechanical features of a new system and to observe whether simplicity and strength and durability are insured. Visitors to the present exhibit are

struck with the general similarity in construction of the machines employed for widely different electrical purposes. The general form and construction of the large Tesla motor of the rotating field type, the alternate current generator, the alternate current motors, the rotary transformers, the alternating current arc machine, and the constant potential alternator have the appearance of general similarity.

The main castings are two in number. The lower one contains half of the field magnets and the bearings for the armature shaft. This simple form insures rigid bearings for the armature. The upper casting contains the remaining field magnets. The field magnets are made of laminated soft steel plates of high permeability, which are cast into the yoke of the machine. The armature is built up of thin disks of soft steel with grooves in the surface for receiving the windings. The armatures are drum wound with, in general, large conductors, placed in special heavy insulating tubes through the slots. This construction affords excellent insulation and protection of the wires, and the strains upon the wires, which in case of sudden heavy loads or short-circuits, may be very great, are transmitted directly to the iron core without chance for slipping or abrasion. In general, no band wires are required. The winding and connections af the armature of the multipolar machines for delivering direct current are such that there are always two and only two parts of the winding in multiple. This insures electrical symmetry which prevents the improper distribution of current in the armature conductors which would result if there were a greater number of armature circuits in multiple and the armature should get slightly out of center from excessive wear in the bearings, or other cause.

Attention is called to these points of simplicity and solidity of construction because they are so vital to the success of electrical working, and because the general improvement which is constantly being made in the mechanical development of electrical apparatus has been fully utilized in the design of this system. It is much to the credit of the system, and confidence in its success is assured for the very reason that it uses and makes but slight modification in types of machines which have been worked out in practice in other lines of service.

This system possesses characteristics which adapt it to a wide field of service, as it combines the requisites for transmitting power over long distances and for transforming it into suitable

forms for distribution and application to a wide range of uses. The employment of the alternate current transformer permits the use of low potential machines securing greater cheapness, efficiency, and a higher factor of safety, than is possible with high potential machines. By the use of alternating current the difficulties in construction and operation, which are inherent to commutators, are avoided on generators and motors. The low pressure of the machines is readily tranformed to potentials adapted to great distances. The alternating current supplies two-phase motors of either the rotary field non-synchronous type of the synchronous type, and the rotary transformer transforms alternating into direct current. The work of this machine is equivalent to that of an alternating current motor driving a direct current generator. The two armatures, however, have been combined in one and placed in one field, and not only is the second machine eliminated, but the output of the single machine is greater than that of the two machines together, and the efficiency is increased and the commutation of a greater current is readily effected.

The alternating current circuits can supply therefore constant potential direct current at any voltage and is available for all kinds of work in which direct current is necessary or is preferable to alternating current. Incandescent lighting may be supplied from the alternating current circuits, and arc lamps may be supplied by direct current from the rotary transformer or from arc machines driven by synchronous motors.

It should be noted that the idea of complication from the grouping of several applications of the system with the transmission system proper. The transmission system proper ends with the switch board and rotary transformer in the receiving station. Other apparatus would be located where it may be required for use—distributed over a city or through mills and mines.

The alternating and direct current at various potentials for these various lines of service are secured from one generator and one transmission line. This is of practical importance both in small plants where it would be impracticable to install different kinds of service, and also in large plants where there are numerous generators. In such plants similarity and interchangeability of machines and circuits is of great economy and value in practical service.

Electrical inventors have done their part well in discovering principles and laws which form the basis for a complete electri-

cal system. Designers and mechanics have taken up these inventions and have developed them and constructed apparatus for practical working, which is now presented for the electrical engineer for adaptation to the various demands for the transmission and distribution of power. He may take up the work with full assurance, as plants are already in operation which place beyond question the practibility not only of general distribution and service but also of transmission over long distances and at high potentials. The successful installation and operation of lighting a plant for over 100 H. P. using 10,000 volts over a 28 mile circuit in southern California is an initial step which covers a distance greater than is required in a majority of the cases in which power transmission is proposed.

This exhibit of the Tesla polyphase system is the mechanical realization of one of the most unique and beautiful discoveries in electricity in recent years.

At the conclusion of Dr. Scott's paper, which was warmly applauded, the Chairman introduced Mr. W. F. C. Hasson, of San Francisco, who made the following remarks:

Mr. Chairman, I wish to say that it is a matter of great satisfaction to me to see that we have come down to the present time. I was very much afraid I was going back to California with the idea that I had only been indulging in reminiscences of successful failures, but now we have got down to date.

We are discussing a subject that is really of vital importance in electricity to-day. As a consulting engineer I represent a variety of companies in California who desire to transmit power electrically. The aggregate will amount to some 40,000 horse power, the distance running from 10 to 40 miles. Notwithstanding the fact that Mr. Scott has referred to the successful transmission of power for lighting purposes at San Antonio for 28 miles, the electrical transmission of power for long distances in California is a failure. Over a year ago the first contract for a definite transmission of power was closed. I see to-day an unhappy superintendent of a mine in eastern California up in the mountains, looking at his burnt out field coils after this generator had been in operation for less than thirteen days. Although this whole plant is very beautiful on paper; although it is all logical, the mere fact of the establishment of a small plant for operation in an exposition as we have here at Chicago and saying what may be done, does not establish the commercial success of long distance transmission of power. The points that are necessary in such machinery are first, that it shall from its inception and from its installation operate successfully; the second, that it shall continue to operate. The machinery must be so built that it will run not only a day or an hour, but for weeks and months. It must be borne in mind that power transmission is required almost invariably in places that are distant from railways, where repairs are impossible, and the machinery must be of such a nature, not only in its simplicity of construction but in its lasting qualities that accidents are almost impossible.

I believe in the transmission of power. I have been the apostle of it for a year in California, but we must definitely establish the fact to investors and others. No transmission machinery is of any use unless it will stand high voltages; we must overcome the list of defects and arrive at the correct manner of handling it. I wish to say definitely that to the investor in California to-day the successful machine for long distance transmission of power electrically exists only in the minds of the inventors and promotors, or in some beautiful advertisement.

I wish further to state that some four or five months ago I was called upon to decide upon certain plans for the transmission of 3,000 horse power some 20 miles. Most elaborate, most beautiful detailed descriptions of the methods arriving at these results were put before me, but not a single working drawing of any kind was presented by any one of the three companies that were competing for this installation. It must be recognized that these experiments are so extensive that they can only be carried out by companies. I have waited and waited for information, and all that I can arrive at is that one company says that 800 volts is the limit of multiphase generation. Another company says with equal positiveness that it does not hesitate to install 2,500 or 3,000 volts initially. Which is right? How are we to determine until these plants are installed and carefully operated. Again, we have been promised a long while a three-phase transmission in southern California. I understand that it is going out there now under special guard, and I trust that it will be taken care of and that it will arrive safely without any accident happening to it.

THE CHAIRMAN:—We should all like to hear from Dr. Louis Bell, who has given the subject of Power Transmission very careful study.

DR. BELL:—Mr. Chairman and Gentlemen: My friend, Mr. Scott, has so well described the characteristics of a typical polyphase system that as regards the general features of it I myself would have very little to add. I would only say that I am very glad that he has referred to the two-phase system as a polyphase system, because it gives us one word instead of two, and that all which applies to the two-phase system applies in varying degrees to all other numbers of phases. The general methods in the two forms of apparatus are the same in principle, and differ in such details as inventors have found desirable to introduce, so that all the polyphase systems are capable of doing practically about the

same work. The differences, it is only fair to state, are differences in degree which are far less than the differences between the polyphase system and any other system of power transmission. There are in general three methods which are at present offered and proposed for power transmission. That of the direct current, which Professor Crocker has been championing before us this morning; that of single phase currents and that of polyphase currents. Of the first I have only to say that in this country, at least, it has not been altogether a shining success. The experiments have mostly resulted in failures. I hope that M. Thury will be able to give us a far more encouraging report from the other side of the water. The great difficulty seems to be that which was suggested by Professor Crocker, that when the current becomes considerable we begin to get into trouble. Voltages which are perfectly practicable in a five horse power machine or in perhaps a 60 or 70 horse power arc dynamo, become difficult when you want to have 500 kilowatts or more in single units, and the cases of power transmission are frequent where there is a call and a very imperative call for units as large as 1,000 horse power. I am afraid that for these big units we need even more experience than Mr. Hasson has thought necessary for the solution of the general problem, before we get a successful direct current machine.

Second, we come to alternating currents, and we have to ask ourselves the very pertinent question, why do we want them? We want them for the reason which has been very well set forth by Mr. Scott, that when we get an alternate current we can do something with it. We can twist it around in an almost infinite variety of ways and set it to almost any application. Where we are dealing with a direct current, it is a direct current from start to finish, except as we transform it at the cost of more complication and an initial expense into alternate currents. Furthermore, we do not need the direct current for motors nowadays, and that is a sufficient reason why we should consider the alternating current as the coming thing in power transmission. So long as the direct current had a grinding monopoly of all the motor service, it was direct current or nothing. To-day that is changed. The single phase system, with which we have all been familiar in lighting for some years is, as we know now, largely through the experiments of our foreign friends, applicable to motor service also; not as well, however, I am sorry to say, as the polyphase system, nor is it as well adapted to the operation of the beautiful rotary transformers which are an essential feature, as Dr. Duncan has suggested, of the coming power transmission by polyphase currents. We know from experience that the single phase rotary transformer is less desirable in many ways than the polyphase one. As for the single phase motor, such as has been exploited abroad, I can say as a result both of what we have heard from other experimenters and from what I know myself from personal experiments, that the single phase motor in its present stage of development can be considered as nothing else than a rather poor polyphase motor. It starts on the polyphase principle every time and with the objection that the rotary field established is not a circular rotary field but an elliptical one, consequently less efficient as a rotary field, and giving less efficiency in the motor. If we wish to start a single phase machine we have to use some method of commutation run by a synchronized motor, which has its well known limitations, or else some non-synchronous motor of the type which we have recently been hearing about, which, as I have just stated, is not as good as a good polyphase motor. If you are building an induction motor of any kind and set out to secure a single phase motor, you will have a most phenomenally good polyphase motor before you are through with the machine.

Then finally we come to the polyphase system. Essentially they operate on the same principle. We may, however, divide them into two classes, polyphase systems having two wires per phase, that is, having an independent circuit, and polyphase systems having non-independent circuits. In this latter case we get some simplification in the wires. A two-phase system with four wires one may fairly call practical. With three wires, by combining two of the conductors, it is somewhat simpler. The three phase system operated on separate circuits would require six wires, which I think we are all agreed is prohibited. Operated with combined circuits it requires but three wires, as few, in other words, as are required by any polyphase system. Furthermore, in all of the non-independent circuits, polyphase systems save copper over the direct current, the simple alternating or the polyphase systems with separate circuits. They save copper in varying degrees, the two phase about 72 or 73 per cent., the three phase about 25 per cent., and those systems which have more phases as a rule save less than either of those mentioned, the saving lessening with the number of phases. We need not concern ourselves with more than three phases, on account of the prohibitive number of wires required, even with composite circuits. We therefore have, as distinguished from the independent circuit system, which is so well exemplified in Mr. Scott's diagrams, a second kind of polyphase system with dependent circuits, interlocked circuits, which possess the valuable property of saving almost 25 per cent. of the copper, and also giving less self-induction and capacity on the line than simple alternating currents, so that for very long transmissions, they save both in copper and in that intolerable nuisance, line inductance. Line inductance I trust in the future will not be as serious a matter as it is now, or has been in the past, thanks to the suggestion of my friend Mr. Steinmetz in his paper yesterday.

As regards the general differences between the independent circuit polyphase and the dependent circuit polyphase system, one can only say that the independent circuit requires at least four wires. The dependent circuit requires at least three wires. This in the case of installing lights is a comparatively slight difference, because we must split circuits, anyhow, for lighting. In the matter of motors, the three wires are somewhat more convenient than the four. The great objection which has been raised against the polyphase system with dependent circuits such as the two or three phase system with three wires is that it does not regulate well, and the principle thing that I wish to put before you is that that criticism is absolutely ill-founded, as we know from positive experiments. In the first place, it is quite possible to arrange a dependent circuit polyphase system so that the difference between the different branches of the circuit, even under extreme conditions, will be almost unnoticeable. That, too, was pointed out by Mr. Steinmetz in his paper yesterday. The means of doing this are not always simple, and it is therefore well to state as a result of actual experiments that without any complicated means of compensation whatever, it is possible to obtain closely constant voltages in each branch of a polyphase system, independent of their operations in the other branches. If you cut off all the branches but one you will obtain a perceptible variation. If you cut off one of the three branches of a three phase system, you will obtain a variation which is scarcely visible to the eye.

With respect to the motors on the polyphase systems, I think we can readily appreciate from what Dr. Duncan has said that between 2, 3, 4 or n phase motors there is no very wide difference in principle, nor is there any very wide difference or any perceptible difference, one may say, in their operation on independent circuits or dependent circuits. The whole point of the matter is this, that if you are going to obtain equal results, whatever the number of phases, you must practically have a motor of about equal classification. In other words, for equally good results, the four phase motor would have to be just about the same sort of a machine as regards complication, winding, etc., as the three phase, and the two phase would have to be just about as complicated as the three phase. They would have to be nearly alike if you are going to get precisely the same results, but when those motors are properly designed I do not hesitate to say as the result of experience that they are decidedly superior to any direct current machine, and that is one of the strong reasons for using the polyphase system. In the first place these machines have no commutators, and in the second place it is almost impossible to burn them out. I have been experimenting with motors of this type for a long time. and I never yet succeeded, even under the strain of the toughest kind of experimentation in burning out a single machine in any way whatever, and I do not think that is a record

that could be well made with any sort of direct current motor. If they are overloaded they stop and will not burn out for a pretty long period. Under any ordinary circumstances they simply stand up to business without any commutation, without any complicated connections. They start quite well, as well as any ordinary direct current motor, and I beg leave to correct Dr. Duncan in his statement that 8 or 10 times the running current is needed to get a good start. The motors in respect to currents taken, start just about as a shunt motor starts. Furthermore the speed of these motors can be varied. It is non-synchronous, and when it is non-synchronous I do not mean to say that it is non-synchronous in the sense that a single phase motor is, but that it is non-synchronous in the sense that a series motor is. It is possible to run a polyphase motor at a widely varying range of speed, keeping up practically constant torque. The range of speed is practically variable from $\frac{1}{10}$ speed up to full speed, keeping constant torque all the time. This I think, escapes one of the objections which has been raised against polyphase motors.

One further thing I would say and then I am through. I want to defend the polyphase machine against the accusation of the lagging current; against the accusation that it will spoil the regulation of every dynamo that the mind of man has been able to invent. It is simply not so. If a polyphase motor gives a big lagging current at or anywhere near full load, it is proof conclusive that that machine has been badly designed; that the man who made it did not know how to tilize his magnetic circuit intelligently. There is no necessity of having more than ten per cent lagging current in any polyphase motor, and indeed one that shows much more than this I should consider badly designed. As an example of what is perfectly feasible and practicable in the way of reducing lagging current, I would say that I have experimented with motors of sizes up to 20 horse power, where the power factor is from 85 to 95 per cent. I also recently experimented with a five horse power motor, and I wish to deny once for all, the statement that the polyphase motors require an enormous lagging current. And more than this, suppose the current does lag 5 or 10 or 15 per cent. It is perfectly feasible to compensate the dynamo by very simple means against the lagging current, even where there is a considerable difference in phase. I recently tried such a compensating device of an exceedingly simple and practical decsription, with the result of holding the voltage of the dynamo practically constant from no load up to full load, when the load itself was of the worst possible inductive character. The machine itself was a little experimental affair, one of the 30 kilowatts, constructed out of an old alternator frame, it being the worst machine which I could pick for the purpose and selected intentionally, but the machine required two and one-quarter times the exciting current at full load that it did at no load. In other words, it is possible to automatically regulate the voltage of a

polyphase generator in spite of even a severe lag in the line due to the operation of motors, and finally this lag due to the operation of motors become evanescent when the motor is properly designed. I am satisfied if I have been able to defend the polyphase motor against this false accusation, and the polyphase systems, whatever the number of phases, against the accusations of insufficient regulation.

THE CHAIRMAN:—I will call on Mr. A. B. Stillwell of Pittsburg, to continue the discussion.

MR. STILLWELL:—I have not come here with any paper, and have no speech prepared; In fact, I just arrived and have only listened to the remarks of the last two speakers, so that I should be afraid to go into any elaborate or detailed discussion of the polyphase system as I see them for fear that I might be taking your time in simply repeating what has already been said.

I would like to call your attention, however, to the exhibit which has been described by Mr. Scott. I believe that exhibit marks an advance in polyphase work, and I know that it will enable those who examine it to ascertain for themselves what is practicable by this system on a scale that has not hitherto been attempted. In preparing this exhibit of the Westinghouse Company we have not shown small machines. It is no exhibit of toys or models or drawings. We have simply shown what we believe to be the best development of the polyphase system. Now, what have we accomplished in that system? We have one generator and one transmission circuit. At the receiving end of the line we have direct current and alternating current at various potentials, performing every kind of work to which electricity is applicable. I think that it is sufficient to show that the system is well worthy of careful examination and study. I have no doubt that further advances will be made, but we have here machines which mechanically are very excellent and electrically are capable of a very good performance. I think it would be interesting, if time permitted, to begin at the receiving end of the station and work back to the generating end from each kind of work that we perform; that is, begin with the incandescent lighting, and see how many lights and how many applications we have. If you will work that out for yourselves you will find that the efficiency is in all cases very high, and in all except arc lighting we have introduced the minimum number of machines and of transformations of energy.

We are aiming, of course, not at a partial solution of the problem of transmission, but at a broad and general solution, the door to which was opened by the invention of the polyphase system. There have been very many partial solutions, and we have as the result of such the direct current systems of limited applicapability, and the single phase systems. We have here a system which performs all kinds of service over a single transmission circuit, and from a single generator. Of course, in a large station, we would use several generators and as many circuits as might be demanded by the amount of power needed.

Now, I have one thing to say in regard to the evolution of this business. The parties interested are the manufacturers and those who propose to buy—users, and lately we have an intermediate class, consulting engineers, as yet less numerous on this side of the water than they are on the other. We are very glad to welcome them in their work, as they certainly have their place in protecting the interests of the customer, and also in explaining to the customer what the manufacturer is trying to sell him, to assist the manufacturer in convincing the customer that he is warranted in putting in the necessary investment to accomplish the result.

We have spent a large amount of money in putting in a very large and expensive exhibit of our machines and will be glad to exhibit it to those who may be interested and to whom we may properly extend that courtesy to make such tests as will, we think, satisfy them as to the performance of the apparatus. We have not attempted to show the insulation of our circuits for long distance transmission, although we might have run a circuit around the city of Chicago and come back to the switch-board, and carried our potential at 10,000 volts and operated it. That has been demonstrated in Germany over a longer distance and over a higher potential, and very high potentials are in commercial and successful operation in this country. Now, it seems to me that the consulting engineer is the man who must put two and two together, and solve this problem for us. He is the man to stand up to the customer and to the world and say, this thing is practicable and it is a success. It is not for the manufacturer to pay for the apparatus and install it and operate it and guarantee dividends as has sometimes been proposed

THE CHAIRMAN:—I see a gentleman here who is familiar with long distance transmission, Dr. Otto Frick. I will ask him to make a few remarks on the subject.

MR. FRICK:—I have heard here speakers recommend to you the polyphase and also the direct current. I should like to say that no system is the best. I think the direct current system is a very good one, the polyphase system is a very good one, and the single phase system is a very good one for the transmission of power. For the purpose of demonstration I should like to give you some instances from the other side of the water. I will not speak of Genoa, as I suppose M. Thury will tell you himself of the transmission of power there, where they are operating with 6,000 volts and a perfect system of dynamos, etc.

We had in Germany two years ago a long transmission of 100 miles by a circuit up to 30,000 volts, but people seem to be incredulous when I tell them of it. They said it is very good for an experiment, but we should like to see such a system working for a long time. Well, gentlemen, I can tell you I was at

the works of Oerlikon two or three months ago and I saw there a transmission of power working which had been in operation for, I suppose, 15 months, at 13,000 volts. It was a three-phase current transmission on the same plan as the transmission from Lauffen to Frankfurt, the work being perfectly satisfactory all the time. Their motor was 300 horse power, constructed in the same manner as the generator.

Now, of the single phase system I said it was also good. I saw in Switzerland a 100 horse power transmission. It was lighting a mill. It was not a self-starting 100 horse power motor, but had a very good device for the purpose. There is a small single phase self-starting motor of two horse power to put in motion the big one. As soon as the big one was in phase it was connected in circuit and worked well as a motor. This little single phase motor is now constructed by Messrs. Brown, Boveri & Co., the well known builders, up to I believe 10 horse power, and I have seen these motors in perfect condition. They are put in action as a two phase motor, and as soon as it is running and synchronized with the generator, it is put on the main circuit as a single phase motor and runs in synchronism, and does not stop at an overload of 50 to 100 per cent. These motors we have in use in a little town near Munich and I can say that of the 15 motors they have there, there is not one that has given any trouble, and the people that use them are all well satisfied with the work they are doing.

I might conclude by repeating that no system is the best. One system may be the best for some special work, but there is no single *best* system.

THE CHAIRMAN:—It gives me great pleasure to call on Prof. Silvanus P. Thompson, of England, who is too well known to need any introduction.

PROF. THOMPSON:—Mr. Chairman and Gentlemen: May I first speak for M. Thury. He has asked me to place before you the following points: There is at Geneva a transmission of power at constant potential of 1,200 volts, with a simple continuous current, the motors being shunt wound. There is another at Stanzerhorn, working with a generator of 150 horse power at 1,500 volts and about 70 amperes. This works three motors, each of about 60 horse power nominally. There is another case of distribution with continuous current, but with excitation, with the generating plant consisting of dynamos in series. This is from Biberist to Rondchatel, a distance of 29 kilometers, about 20 miles. Two generators of 200 horse power each, current of 40 amperes, running at 3,500 volts and tried up to 4,500. A fourth installation is at Genoa in Italy. There is a continuous current of 45 amperes, eight dynamos as generators, all joined in series, each nominally about 1,000 volts and each being about 60 horse power, but these eight do not run quite at 1,000 volts each, the line being 6,000 volts is ordinary work,

because if you keep the current constant the volts will vary according to the demand at the other end. There are two circuits feeding motors, varying from five horse power to 100 horse power, and from 100 volts to 2,000 volts, and these are all examples of practical installations for which M. Thury makes himself responsible.

Now, to speak for myself, first of all let me deal with the continuous current problem. Let me point out that for other purposes than the mere furnishing of arc lights continuous current machines have been constructed to work at high voltages. In London Mr. Esson has designed various dynamos, working at from 1,000 to 2,000 volts, using commutators of the ordinary kind, but when I say commutators of the ordinary kind I mean that they were the ordinary straight bars of hard copper or something of that kind, but they were especially insulated and they took special precautions against sparking. In one machine they adopted the plan of wiping out any ordinary spark that might occur upon the commutator by imbedding the whole thing in a mass of asbestos, which wiped out any spark which might be formed under the brush. It was a rough and ready device, but it "got there."

Again, in Germany Mr. Lavier (?) has carried out many examples of transmission of power with continuous currents at 1,000 volts. The difficulty does not seem to arise so much from the sparking at the commutator as from the inherent difficulty which is met with everywhere when you begin to apply with continuous currents any high voltage, namely, that of electrolysis of your insulating surfaces or insulating materials that may occur in any place exposed to moisture. We know that electrically caused fires from leaks in mains more often occur with the continous current than with the alternate, no doubt because the continous current causes electrolysis in the moisture and the alternating current does not do so; at least not in the same way.

May I point out that in the old fashioned university town of Oxford in England—I must not claim for it that it is a long distance transmission of power, but it is a transmission of power by continuous currents at high voltage. The town is supplied from a lighting station something like a mile and a third—over a mile and a quarter—the current is brought in at something over 1,000 volts, and in the city of Oxford this current is transferred by continuous current transformers, that is to say, motor-dynamos, to the low pressure of 100 volts, and conveyed about the neighborhood from house to house, and that installation has been working now for many months, and gives no trouble. These rotating and continuous current transformers have a very high efficiency, and so far as my information goes, there is no trouble from the spark at the commutators.

Now, let me pass to the alternate current work. I would invite every electrical engineer who is interested in this subject to

study carefully the installation at Rome, which is fed by the power of a water-fall 14 miles away, wheret here is a station erected by the firm of Ganz and Company, of Buda-Pesth, where the water-fall works drive turbines and drive alternate current machines which supply current at from 5,000 or 6,000 volts, carried across 14 miles over the Campagna until you arrive outside the gates of the city of Rome, where there is a transformer station which brings the current down from 5,000 or 6,000 volts, to about 1,000 volts, at which it flows over lines in to the city to be again transformed down to 100 volts for actual use.

I have listened with great pleasure to the discussion originated by Dr. Duncan and carried on so ably by the engineers of the Westinghouse Company upon the question of the polyphase transmission. I have studied that polyphase transmission at Frankfurt, where there were some 8 or 10 different systems, all rivals of one another, from the various houses of Germany. We had the great houses of Schuckert, Siemens and Halske, Lahmeyer and several others, each of them showing their own way of carrying out a polyphase system, and we could compare the one with the other, and it was very interesting to see how they all had solved in their own way that problem to which so much attention has been drawn here, namely, making a rotary transformer convert a continuous current into a simple alternate current. No doubt their rotary transformers will be of service in the industry, but I imagine they will be of service rather in particular instances than in any kind of general way. Let me entirely endorse the remarks of Mr. Frick, that there is no "best" system; that each system is the best for its own purpose. What would you think of an engineer who would stand on the platform here, and say that he had invented or that any man alive had invented, the best steam engine, and that there was no other. You would want to know what that steam engine was best for, whether it was suited for a mill or a threshing machine or a large factory or a steamboat or a locomotive. There is no best steam engine. There is no best dynamo and there is no best motor and there is no best system. They are all right. They are all best.

Well, then, what is the polyphase system capable of and what is the simple alternate system capable of? I am not going to prophecy. I do not know what ten years may bring forth, but I will give you my own personal opinion as to how the thing stands at present. I do not love the complication of three phase transformers and three phase switch-boards and three phase lines. I love the three phase or the two phase alternate current dynamos and motors. They are very beautiful. We can do a great many things with them, but I do not love the complications of switch-boards and transformers. For all distribution systems—distribution, I say, not transmission systems—where you have not only to transmit but to distribute to this and that and the other consumer, I believe you will abandon all the complications of polyphase work and that you will return to simple alternate current methods, and I believe you will find that the bugbears that have been raised, the ghosts that have been put up to frighten you off the simple alternate current system will disappear in practical work, and that the motors can be made as highly efficient and as comfortable with simple alternate currents as with any polyphase system. As I said before, I do not desire to prophecy, but I venture to merely giving you my personal opinion, that the simple alternate current work will be the thing which ten years hence will be found to be effective for all long distance transmission where you want to distribute to a number of consumers.

One final word in conclusion. We in England are trying to get our stations—I am speaking mainly of lighting stations—whether they work by high voltage or low, down to the utmost simplicity of engineering. We shall have one type of engine suitable for its purpose, not half a dozen different scratch lots in the same station, and one type of generator. We have two simple conductors, or at most three, if you are working on a three wire distribution. Everything is tending in the direction of simplicity, and the results are excellent.

If I had come over here expecting to go back to England and say, apparatus has got down to such a beautiful stage of simplicity in the States that you will have to give up everything you have got in the old country and adopt the polyphase system, I should think that I would have been very effectively disillusioned, but the complications of those two diagrams which I see before me, although they represent a most enormous amount of research, of invention, of instruction and of capital fearlessly placed at the disposal of the inventors, are sufficient evidence to my mind of the correctness of my views. I admire what has been done, but while admiring it I cannot help thinking that there is something simpler which will be the successful machine of the future.

Prof. Thompson's remarks were greeted with great applause, and at the conclusion the Chairman introduced Professor George Forbes, F. R. S., of London, who addressed the Section as follows:

PROF. FORBES:—Nothing. Mr. Chairman and gentlemen, could give me greater pleasure than to be told that I am to be limited to five minutes. I have half an hour ago landed from the cars, and I have only just been able to manage to come into the tail end of your discussion. I had expected to arrive early this morning and to be here on time, and I traveled in order to be present at this discussion. I labor under the disadvantage of not having heard the papers read, of not knowing what the subject under discussion is, of only having heard the last part of Professor Thompson's remarks, and being suddenly called upon to address you on the subject under discussion. I know that the subject under discussion is the subject which has been continually occupying my mind for many years back, for which I have been mak-

ing journeys to the United States year after year, and to every part of Europe where I thought work in this direction was being done. It is a work which during the last year and a half has been the incessant occupant of my mind, and not one-quarter of my time, awake and asleep, has been taken away from this subject, and it is impossible to compress into five minutes all the things I would wish to say to you on this subject. Briefly let me take up the points which Professor Thompson was alluding to, and say a few words on some of them.

The first question that arises in this matter is the relative importance of direct and alternating currents. Professor Thompson has wisely said, with regard to the different systems, that each has its own sphere of action. He is perfectly right, and everybody who has gone thoroughly into the question will agree with him. The grandest work in connection with the use of the continuous current for transmission to distances is that which I have seen at Genoa constructed by the Companie Générale d'Electricité of Geneva, a representative of which, M. Thury, I believe is present here now. They have done a splendid work in putting that down, working at the high voltage. They have worked even up to 6,000 or 8,000 volts. They are now doing other work in the same direction. The continuous current can be used for transmission to a distance, and in many ways it is extremely convenient, but it has none of the beauty, none of the diverse applications of the alternating current. The trouble which exists in the commutator is a very serious one, and I will not dilate upon it further, as it has often been spoken of. The trouble in insulating the armature is a very serious one, largely because in continuous current machines the armature must be the revolving part. In the alternating current we may have the armature as the fixed part. In that case the armature is just as easy to insulate as the high tension side of a transformer. You may put oil into it if you wish to carry off the heat, but if you trust in any way, and it is dangerous to trust far, to its extra insulating properties, it is perfectly suitable. You may place the wires so that they are not acted upon by the mechanical action of the magnetic field. Professor Thompson has said it is best to connect the generators in series, and you get your best insulation. At the receiving end it is necessary to do the same. You cannot have a 5,000 or 10,000 horse power motor in every work shop and you must put them in series, and the complications are manifold. I will not go further into this question. I have stated the general points and I will now devote the remaining two minutes to another subject.

The great charm and beauty of the alternating current lies in the flexibility introduced by means of the transformers. It is impossible to overrate the advantages of the transformer. A continuous current introducing rotating motor-transformers has no comparison with the simplicity and the practicability of the alternating current transformer. I was pleased to hear Professor Thompson speak about the single phase. The single phase is a great thing at present and has great possibilities in the future. I have had a very long experience of synchronizing alternating machines used as motors, and I have the very highest opinion of them, but they are only applicable in such cases where the motive power is required constantly to be running. For electrical deposition works the synchronous motor is admirably adapted, and also to motor mills, but for all appliances where we have to start, stop and reverse our motors, it is practically out of the question to put in the synchronizing system. I have watched in the work shops of the greatest practical electricians in the world the progress that they have been making in the last three or four years in the evolving of an alternating current motor which shall stop and reverse with facility. Until quite lately there were none of those which were thoroughly suitable and applicable to ordinary lighting circuits. Now, however, we are able to use, as Prof. Thompson has said, a polyphase system for starting the motor, and use it synchronously afterwards, or nearly synchronously. That is a very great advance, and I personally have great hopes that the single phase is going to play a very important part in the future.

On the subject of the best means to adopt, my tongue has been considerably tied in the past, and with regard to the relative advantages of the three phase and two phase systems, on a late occasion, at the convention of the National Electric Light Association at St. Louis, when I was asked to speak, for reasons which were readily appreciated I was not able to speak on that subject. Those reasons no longer exist. I beg to say that as far as I have studied the two, and I have given a great deal of personal and practical study to it, my opinion is that they are both very good, both very excellent; that the three phase is an attractive one from its theoretical beauty, but in practical execution the two phase is better. The reasons why I have a dislike to using the three phase is first the complications caused by having three conductors, all inter-connected. This introduces trouble in regulating the circuit. It introduces troubles in testing and it introduces troubles in correcting a fault which has arisen. I can imagine the perplexity of an ordinary central station attendant when he is told that there is a fault in the line, in his endeavors to find it; if it is a three wire system where that fault is, it increases the labor enormously, but with two phase the wires may be inter-connected or they may be separated. I prefer to have a two phase system with separate independent circuits, and then they are more easily managed and more easily tested and more easily regulated. Moreover, when the three circuits are interconnected each one has an influence on the other. If you overload one circuit and underload another circuit, the underloaded circuit has a pressure much higher than the overloaded circuit.

That is a fact which is generally known. It is not generally known that if you have three circuits, A, B and C on the three phase system, that if A is overloaded and B and C are not loaded, then B may have a higher voltage than A, but C has a higher voltage than either of them. That is a fact that is not generally known, and has to be known to be appreciated. It is a very serious drawback to the use of the three phase system. For lighting purposes it condemns it. I have advised the officers of the Cataract Construction Company to reject the three phase and to built their first dynamos with two phases, because in so doing my honest conviction is that we are preparing the way to utilize those dynamos in every direction in which alternating current transmission is going to be developed in the next ten years. The two phase system has not only the advantage of being able to work the two phase motors, but it has the enormous advantage that it gives you two single phase circuits. You are able to work each of those with the synchronizing motor and with all the single phase machinery which is going to be invented in the next ten years, and at the same time you have all the advantage of the splendid work which is being done on the two phase system, and I wish that we should be able to have both of these advantages. The dynamos which are going to be put down at Niagara are capable of generating either single phase or two phases. A dynamo so constructed will give you the single phase cheaper than if it were constructed with one circuit; that is to say, there is a larger output with two single phases from one generator than from one single phase circuit from a single phased generator of the same dimensions.

Mr. Chairman and Gentlemen, I feel that I have occupied a little more than five minutes, and in that time it is quite impossible to say one tithe of what I feel is due to the importance of the subject. I have tried briefly to summarize the results which have been arrived at by myself, and which I think all those who have been investigating with the same care have also arrived at.

The Chairman then introduced Mr. C. P. Steinmetz of Lynn, Mass., stating that he would close the discussion.

MR. STEINMETZ:—Mr. Chairman, ladies and gentlemen: We have heard quite a number of able discussions on the different methods of power transmission and distribution. The largest amount of power which is distributed and used in the United States to-day is distributed by continuous current. I am speaking of the hundreds of thousands of horse power used to propel our street cars. That shows that the continuous current is not dead yet, and the very fact that the rotary transformer is recommended as a machine to transform polyphase currents into continuous currents shows that even the advocates of the polyphase current still concede that they cannot get along without the old continuous current.

Now, with regard to the polyphase and the single alternating current, it makes no difference how many phases you use, because any system of polyphase currents can be transformed into any other system of polyphase currents, by using two transformers only. Furthermore, the motors of the different polphase systems are essentially the same, worked by the same principles, and the differences which are found are rather mechanical in their nature but not electrical. If I may be permitted to take a look into the future, although we do not know what to-morrow will bring, I think the system of the future will be the single phase system. Where the power is transmitted over a long distance by an overhead wire, the ground can be used as the return conductor. There is no danger to life, because no one would touch a 20,000 volt line, whether it is grounded or not, or if he did he would have no chance to do it again. But if we use a single phase current in the power transmission of the future then we will have to learn many things. We will not be troubled any more with self-induction, with capacity, but proper appliances will eliminate the effect of self-induction and capacity, so that they are entirely anihilated in their effect on the line, and even the loss of energy and resistance will not be carried any more by a less potential. In a continuous, constant current for arc lighting or for any other use, perhaps we are nearer to this ideal condition than we all think.

The Chairman then introduced Dr. Charles A. Pollak, who read the following paper on "The Conversion of Alternating into Continuous Currents," at the close of which the meeting adjourned to August 25, 1893, at 10 A. M.

MR. TESLA'S LECTURE ON MECHANICAL AND ELECTRICAL OSCILLATORS.

On the evening of Friday, August 25, Mr. Tesla delivered a lecture before the members of the Electrical Congress, bearing the title given above, in the hall adjoining the Agricultural Building. Besides the apparatus in the room, he employed an air compressor, which was driven by an electric motor, furnished through the courtesy of the General Electric Company.

Mr. Tesla was introduced by Dr. Gray, and began by stating that the problem he had set out to solve was to construct, first, a mechanism which would produce oscillations of a perfectly constant period independent of the pressure of steam or air applied, within the widest limits, and also independent of frictional losses and load. Secondly, to produce electric currents of a perfectly constant period independently of the working conditions, and to produce these currents with mechanism which should be reliable and positive in its action without resorting to spark gaps and breaks. This he has successfully accomplished in his apparatus, and with this apparatus, now scientific men will be provided with the necessaries for carrying on investigations with alternating currents with great precision. These two inventions Mr. Tesla calls, quite appropriately, a mechanical and an electrical oscillator, respectively.

The former is substantially constructed in the following way. There is a piston in a cylinder made to automatically reciprocate by proper disposition of parts, similar to a reciprocating tool. Mr. Tesla pointed out that he had done a great deal of work in perfecting his apparatus so that it would work efficiently at such high frequency of reciprocation as he contemplated, but did not dwell on the many difficulties encountered. He exhibited, however, the pieces of a steel arbor which had been actually torn apart while vibrating against a minute air cushion.

With the piston above referred to there is associated in one of his models in an independent chamber an air spring, or dash pot, or else he obtains the spring within the chambers of the oscillator itself. To appreciate the beauty of this it is only necessary to say that in that disposition, as he showed it, no matter what the rigidity of the spring and no matter what the weight of the moving parts, in other words, no matter what the period of vibrations, the vibrations of the spring are always isochronous with the applied pressure. Owing to this, the results obtained with these vibrations are truly wonderful. Mr. Tesla provides for an air spring of tremendous rigidity, and he is enabled to vibrate big weights at an enormous rate, considering the inertia, owing to the recoil of the spring. Thus, for instance, in one of these experiments, he vibrates a weight of approximately 20 pounds at the rate of about 80 per second and with a stroke of about $\frac{7}{8}$ inch, but by shortening the stroke the weight could be vibrated many hundred times, and has been in other experiments.

To start the vibrations, a powerful blow is struck, but the adjustment can be so made that only a minute effort is required to start, and, even without any special provision it will start by merely turning on the pressure suddenly. The vibration being, of course, isochronous, any change of pressure merely produces a shortening or lengthening of the stroke. Mr. Tesla showed a number of very clear drawings, illustrating the construction of the apparatus from which its working was plainly discernable. Special provisions are provided so as to equalize the pressure within the dash pot and the outer atmosphere. For this purpose the inside chambers of the dash pot are arranged to communicate with the outer atmosphere so that no matter how the temperature of the inclosed air might vary, it still retains the same mean density as the outer atmosphere, and by this means a spring of constant rigidity is obtained. Now, of course, the pressure of the atmosphere may vary, and this would vary the rigidity of the spring, and consequently the period of vibration, and this feature constitutes one of the great beauties of the apparatus, for, as Mr. Tesla pointed out, this mechanical system acts exactly like a string tightly stretched between two points, and with fixed nodes so that slight changes of the tension do not in the least alter the period of oscillation.

The applications of such an apparatus are, of course, numerous and obvious. The first is, of course, to produce electric currents, and in a number of models and apparatus on the lecture platform, Mr. Tesla showed how this could be carried out in practice by combining an electric generator with his oscillator. He pointed out what conditions must be observed in order that the period of vibration of the electrical system might not disturb the mechanical oscillation in such a way as to alter the periodicty, but merely to shorten the stroke. He combines a condenser with a self-induction, and gives to the electrical system the same period at which the machine itself oscillates, so that both together then fall in step and electrical and mechanical resonance is obtained, and maintained absolutely unvaried.

Next he showed a model of a motor with delicate wheelwork, which was driven by these currents at a constant speed, no matter what the air pressure applied was, so that this motor could be employed as a clock. He also showed a clock so constructed that it could be attached to one of the oscillators, and which kept absolutely correct time. Unfortunately the clock had suffered in transportation, so that its actual operation could not be observed. Another curious and interesting feature which Mr. Tesla pointed out was that, instead of controlling the motion of the reciprocating piston, by means of a spring so as to obtain isochronous vibration, he was actually able to control the mechanical motion by the natural vibration of the electro-magnetic system, and he said that the case was a very simple one, and was quite analogous to that of a pendulum. Thus, supposing we had a pendulum of great weight, preferably, which would be maintained in vibration by force periodically applied; now that force, no matter how it might vary, although it would oscillate the pendulum, would have no control over its period. Mr. Telsa also described a very interesting phenomenon which he illustrated by an experiment. By means of this new appparatus, he is able to produce an alternating current in which the E. M. F. of the impulses in one direction preponderates over that of those in the other, so that there is produced the effect of a direct current. In fact he expressed the hope that these currents would be capable of application in many instances, serving as direct currents. The principle involved in this preponderating E. M. F. he explains in this way: Suppose a conductor is moved into the the magnetic field and then suddenly withdrawn. If the current is not retarded, then the work performed will be a mere fractional one; but if the current is retarded, then the magnetic field acts as a spring. Imagine that the motion of the conductor is arrested by the current generated, and that at the instant when it stops to move into the field, there is still the maximum current flowing in the conductor; then this current will, according to Lenz's law, drive the conductor out of the field again, and if the conductor had no resistance, then it would leave the field with the velocity it entered it. Now it is clear that if, instead of simply depending on the current to drive the conductor out of the field, the mechanically applied force is so timed that it helps the conductor to get out of the field, then it might leave the field with the higher velocity than it entered it, and thus one impulse is made to preponderate in E. M. F. over the other. With the current of this nature, Mr. Tesla energized magnets strongly, and performed many interesting experiments, bearing out the fact that one of the current impulses preponderates. Among them was one in which he attached to his oscillator a ring magnet with a small air gap between the poles. This magnet was oscillated up and down 80 times a second. A copper disc, when inserted within the air-gap of the ring magnet, was brought into rapid rotation. Mr. Tesla remarked that this experiment also seemed to demonstrate that the lines of flow of current through a metallic mass are disturbed by the presence of a magnet in a manner quite independently of the so-called Hall effect. He showed also a very interesting method of making a connection with the oscillating magnet. This was accomplished by attaching to the magnet small insulated steel rods, and connecting to these rods the ends of the energizing coil. As the magnet was vibrated, stationary nodes were produced in the steel rods, and at these points the terminals of a direct current source were attached. Mr. Tesla also pointed out that one of the uses of currents such as those produced in his apparatus, would be to select any given one of a numb r of devices connected to the same circuit by picking out the vibration by resonance; and he referred in a complimentary way to the work of Dr. Gray in harmonic telegraphy. There is indeed little doubt that with Mr. Tesla's devices, harmonic and synchronous telegraphy will receive a fresh impetus, and vast possibilities are again opened up.

Mr. Tesla was very much elated over his latest achievements, and said that he hoped that in the hands of practical, as well as scientific men, the devices described by him would yield important results. He laid special stress on the facility now afforded for investigating the effect of mechanical vibration in all directions, and also showed that he had observed a number of facts in connection with iron cores. Mr. Tesla's enthusiastic belief in the usefulness and success of the practical applications of his latest devices appears to be fully justified. Although but briefly outlined by him, what he showed was sufficient to indicate that this latest work of his would transcend in importance, probably, all of his previous brilliant work, not excepting even his alternating current motor. We had heretofore been accustomed to look upon Mr. Tesla as an electrician of the highest type, but the work which he has accomplished in this new field of mechanical oscillators entitles him to rank equally high as an engineer.

IMPORTANT RUMORS.

We are informed that on the recommendation of Prof. George Forbes, the Cataract Construction Co. have adopted Mr. Tesla's multiphase system as the sole method of distribution at Niagara Falls.

Rumors of serious differences between the General Electric and Fort Wayne Electric Companies seem to be well founded. We are credibly informed that their relations are severely strained and that an open rupture is feared. It is believed that the General Electric Co. owns less than a controlling interest in the Fort Wayne Co., and that Mr. R. T. McDonald and his directors are in a position to declare their independence if and when they want to.

Tesla Out-Tesla'ed.—We are waiting with some degree of impatience the receipt of information with respect to a wonderful performance that was announced to take place at Cleveland, Ohio, a fortnight ago. Mr. J. E. de Leon—styled "the young electrician of Buffalo, and possible rival of Edison" (!!)—was, on the 13th ult., to give a notable exhibition at Forest City Park. A modest advertisement sets forth that he "handles the current with perfect ease and safety, walking on a bare wire charged from the arc lighting circuit, which is powerful enough to kill an ordinary man, his body meanwhile being brilliantly illuminated by the current which is conducted through it." Mr de Leon—who might safely be called Cœur de Leon—is a dangerous man, unless his morals are of the highest order, for evidently the electrocution system would fail in his case, and he might kill, murder, or slay with impunity. Stay, though; they are said to give morphine first, and that is possibly an antidote to Mr. de Leon's "apparatus, entirely of his own invention and construction, exhibiting inventive genius of a high order."

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1884	"	82	"	"	1891	"	325	" "
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The Tesla Lecture.

THE lecture delivered by Mr. Tesla at Chicago on Friday evening of last week was a disappointment to those who expected to be entertained with brilliant experiments in luminous discharges, transmissions without wires, and other like subjects with which the name of Tesla is so intimately associated. In place of these experiments, his audience soon found out, what perhaps many of them did not know before, that the subject of the lecture was mechanical and electrical oscillators, a purely technical subject, involving but a few experiments, and these of little interest except to technical men; those of his audience who were not technical men were therefore disappointed; instead of being entertained they were being instructed with some matters not easily grasped by them. The apparatus forming the subject of his lecture was a true Tesla surprise, as will be seen from our brief report of the lecture. It consisted of a pneumatic oscillator, the underlying principle of which is analogous to that of the Leyden jar, the result accomplished being that it produced short, rapid, mechanical oscillations; but it differed in that these oscillations were of an absolutely constant frequency, as constant as that of a tuning fork, a feature which may make the apparatus quite a valuable one. He uses this to generate alternating currents, simply by oscillating a wire to and fro in a magnetic field; that is, instead of a rotary motion in an alternating field, he uses an oscillating motion in a constant bipolar field. While the currents thus produced at the lecture were quite small, still it is interesting to know that alternating currents of high frequency and of absolutely constant frequency can thus be produced, and that, according to Mr. Tesla, both the output per weight and the efficiency are very good.

THE TESLA MECHANICAL AND ELECTRICAL OSCILLATORS.*

On the evening of Friday, August 25, Mr. Tesla delivered a lecture on his mechanical and electrical oscillators, before the members of the Electrical Congress, in the hall adjoining the Agricultural Building, at the World's Fair Grounds. Besides the apparatus in the room, he employed an air compressor, which was driven by an electric motor.

Mr. Tesla was introduced by Dr. Elisha Gray, and began by stating that the problem he had set out to solve was to construct, first, a mechanism which would produce oscillations of a perfectly constant period independent of the pressure of steam or air applied, within the widest limits, and also independent of frictional losses and load. Secondly, to produce electric currents of a perfectly constant period independently of the working conditions, and to produce these currents with mechanism which should be reliable and positive in its action without resorting to spark gaps and breaks. This he successfully accomplished in his apparatus, and with this apparatus, now, scientific men will be provided with the necessaries for carrying on investigations with alternating currents with great precision. These two inventions Mr. Tesla called, quite appropriately, a mechanical and an electrical oscillator, respectively.

The former is substantially constructed in the following way. There is a piston in a cylinder made to reciprocate automatically by proper dispositions of parts, similar to a reciprocating tool. Mr. Tesla pointed out that he had done a great deal of work in

* Reprinted from "The Inventions, Researches and Writings of Nikola Tesla." By T. C. Martin.

perfecting his apparatus so that it would work efficiently at such high frequency of reciprocation as he contemplated, but he did not dwell on the many difficulties encountered. He exhibited, however, the pieces of a steel arbor which had been actually torn apart while vibrating against a minute air cushion.

With the piston above referred to there is associated in one of his models in an independent chamber an air spring, or dash pot, or else he obtains the spring within the chambers of the oscillator itself. To appreciate the beauty of this it is only necessary to say that in that disposition, as he showed it, no matter what the rigidity of the spring and no matter what the weight of the moving parts, in other words, no matter what the period of vibrations, the vibrations of the spring are always isochronous with the applied pressure. Owing to this, the results obtained with these vibrations are truly wonderful. Mr. Tesla provides for an air spring of tremendous rigidity, and he is enabled to vibrate big weights at an enormous rate, considering the inertia, owing to the recoil of the spring. Thus, for instance, in one of these experiments, he vibrates a weight of approximately 20 pounds at the rate of about 80 per second and with a stroke of about $\frac{7}{8}$ inch, but by shortening the stroke the weight could be vibrated many hundred times, and has been, in other experiments.

To start the vibrations, a powerful blow is struck, but the adjustment can be so made that only a minute effort is required to start, and, even without any special provision, it will start by merely turning on the pressure suddenly. The vibration being, of course, isochronous, any change of pressure merely produces a shortening or lengthening of the stroke. Mr. Tesla showed a number of very clear drawings, illustrating the construction of the apparatus from which its working was plainly discernible. Special provisions are made so as to equalize the pressure within the dash pot and the outer atmosphere. For this purpose the inside chambers of the dash pot are arranged to communicate with the outer atmosphere so that no matter how the temperature of the enclosed air might vary, it still retains the same mean density as the outer atmosphere, and by this method a spring of constant rigidity is obtained. Now, of course, the pressure of the atmosphere may vary, and this would vary the rigidity of the spring, and consequently the period of vibration, and this feature constitutes one of the great beauties of the apparatus; for, as Mr. Tesla pointed out, this mechanical system acts exactly like a

string tightly stretched between two points, and with fixed nodes, so that slight changes of the tension do not in the least alter the period of oscillation.

The applications of such an apparatus are, of course, numerous and obvious. The first is, of course, to produce electric currents, and by a number of models and apparatus on the lecture platform, Mr. Tesla showed how this could be carried out in practice by combining an electric generator with his oscillator. He pointed out what conditions must be observed in order that the period of vibration of the electrical system might not disturb the mechanical oscillation in such a way as to alter the periodicity, but merely to shorten the stroke. He combines a condenser with a self-induction, and gives to the electrical system the same period as that at which the machine itself oscillates, so that both together then fall in step and electrical and mechanical resonance is obtained, and maintained absolutely unvaried.

Next he showed a model of a motor with delicate wheelwork, which was driven by these currents at a constant speed, no matter what the air pressure applied was, so that this motor could be employed as a clock. He also showed a clock so constructed that it could be attached to one of the oscillators, and would keep absolutely correct time. Another curious and interesting feature which Mr. Tesla pointed out was that, instead of controlling the motion of the reciprocating piston by means of a spring, so as to obtain isochronous vibration, he was actually able to control the mechanical motion by the natural vibration of the electro-magnetic system, and he said that the case was a very simple one, and was quite analogous to that of a pendulum. Thus, supposing we had a pendulum of great weight, preferably, which would be maintained in vibration by force, periodically applied; now that force, no matter how it might vary, although it would oscillate the pendulum, would have no control over its period.

Mr. Tesla also described a very interesting phenomenon which he illustrated by an experiment. By means of this new apparatus, he is able to produce an alternating current in which the E. M. F. of the impulses in one direction preponderates over that of those in the other, so that there is produced the effect of a direct current. In fact, he expressed the hope that these currents would be capable of application in many instances, serving as direct currents. The principle involved in this preponderat-

ing E. M. F. he explains in this way: Suppose a conductor is moved into the magnetic field and then suddenly withdrawn. If the current is not retarded, then the work performed will be a mere fractional one; but if the current is retarded, then the magnetic field acts as a spring. Imagine that the motion of the conductor is arrested by the current generated, and that at the instant when it stops to move into the field, there is still the maximum current flowing in the conductor; then this current will, according to Lenz's law, drive the conductor out of the field again, and if the conductor has no resistance, then it would leave the field with the velocity it entered it. Now it is clear that if, instead of simply depending on the current to drive the conductor out of the field, the mechanically applied force is so timed that it helps the conductor to get out of the field, then it might leave the field with higher velocity than it entered it, and thus one impulse is made to preponderate in E. M. F. over the other.

With a current of this nature, Mr. Tesla energized magnets strongly, and performed many interesting experiments bearing out the fact that one of the current impulses preponderates. Among them was one in which he attached to his oscillator a ring magnet with a small air gap between the poles. This magnet was oscillated up and down 80 times a second. A copper disk, when inserted within the air gap of the ring magnet, was brought into rapid rotation. Mr. Tesla remarked that this experiment also seemed to demonstrate that the lines of flow of current through a metallic mass are disturbed by the presence of a magnet in a manner quite independently of the so-called Hall effect. He showed also a very interesting method of making a connection with the oscillating magnet. This was accomplished by attaching to the magnet small insulated steel rods, and connecting to these rods the ends of the energizing coil. As the magnet was vibrated, stationary nodes were produced in the steel rods, and at these points the terminals of a direct current source were attached. Mr. Tesla also pointed out that one of the uses of currents, such as those produced in his apparatus, would be to select any given one of a number of devices connected to the same circuit by picking out the vibration by resonance. There is indeed little doubt that with Mr. Tesla's devices, harmonic and synchronous telegraphy will receive a fresh impetus, and vast possibilities are again opened up.

Mr. Tesla was very much elated over his latest achievements, and said that he hoped that in the hands of practical, as well as scientific men, the devices described by him would yield important results. He laid special stress on the facility now afforded for investigating the effect of mechanical vibration in all directions, and also showed that he had observed a number of facts in connection with iron cores.

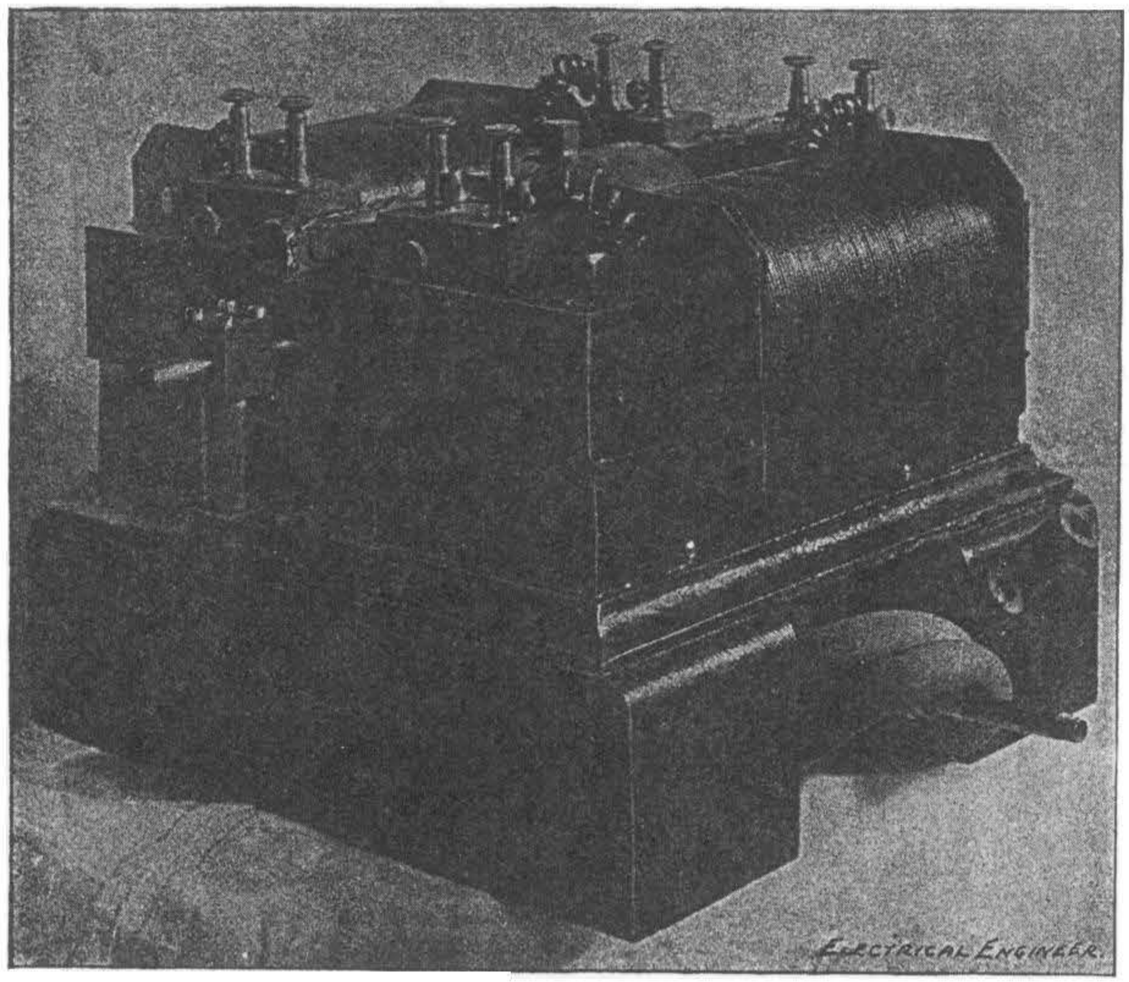


FIG. 1.

The engraving, Fig. 1, shows, in perspective, one of the forms of apparatus used by Mr. Tesla in his earlier investigations in this field of work, and its interior construction is made plain by the sectional view shown in Fig. 2. It will be noted that the piston P is fitted into the hollow of a cylinder C which is provided with channel ports O O, and I, extending all around the inside surface. In this particular apparatus there are two channels O O

for the outlet of the working fluid and one, I, for the inlet. The piston P is provided with two slots s s′ at a carefully determined distance, one from the other. The tubes T T which are screwed into the holes drilled into the piston, establish communication between the slots s s′ and chambers on each side of the piston, each of these chambers connecting with the slot which is remote from it. The piston P is screwed tightly on a shaft A which passes through fitting boxes at the end of the cylinder C. The boxes project to a carefully determined distance into the hollow of the cylinder C, thus determining the length of the stroke.

Surrounding the whole is a jacket J. This jacket acts chiefly to diminish the sound produced by the oscillator and as a jacket when

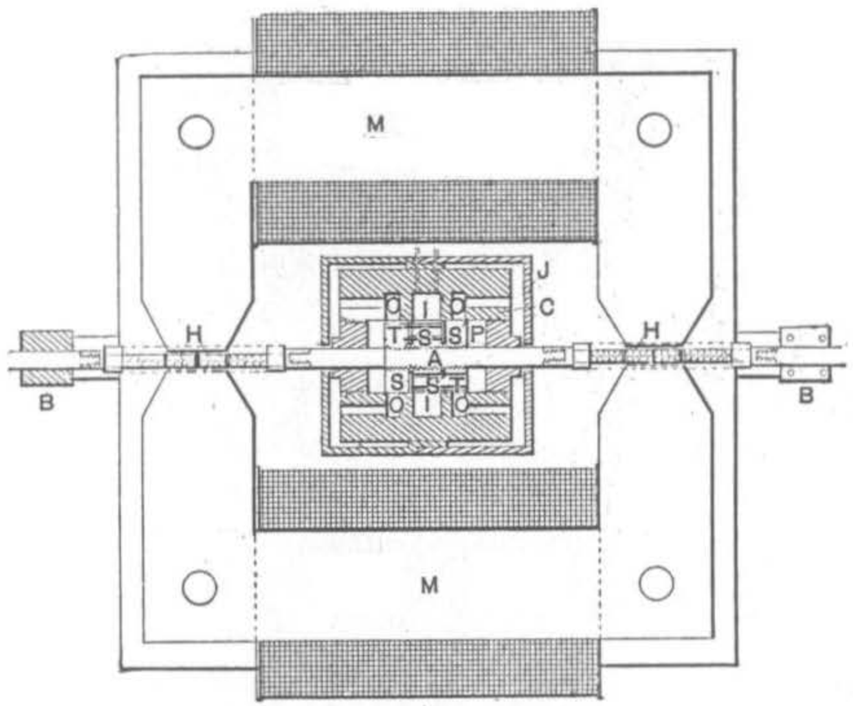


FIG. 2.

the oscillator is driven by steam, in which case a somewhat different arrangement of the magnets is employed. The apparatus here illustrated was intended for demonstration purposes, air being used as most convenient for this purpose.

A magnetic frame M. M. is fastened so as to closely surround the oscillator and is provided with energizing coils which establish two strong magnetic fields on opposite sides. The magnetic frame is made up of thin sheet iron. In the intensely concentrated field thus produced, there are arranged two pair of coils H H supported in metallic frames which are screwed on the shaft A of

the piston and have additional bearings in the boxes B B on each side. The whole is mounted on a metallic base resting on two wooden blocks.

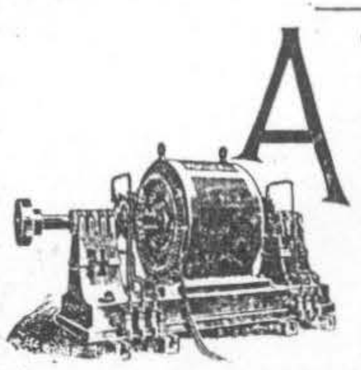
The operation of the device is as follows: The working fluid being admitted through an inlet pipe to the slot I and the piston being supposed to be in the position indicated, it is sufficient, though not necessary, to give a gentle tap on one of the shaft ends protruding from the boxes B. Assume that the motion imparted be such as to move the piston to the left (when looking at the diagram) then the air rushes through the slot s′ and tube T into the chamber to the left. The pressure now drives the piston towards the right and owing to its inertia, it overshoots the position of equilibrium and allows the air to rush through the slot s and tube T into the chamber to the right, while the communication to the left hand chamber is cut off, the air of the latter chamber escaping through the outlet O on the left. On the return stroke a similar operation takes place on the right hand side. This oscillation is maintained continuously and the apparatus performs vibrations from a scarcely perceptible quiver amounting to more than $\frac{1}{10}$ of an inch, up to the vibrations of a little over $\frac{3}{8}$ of an inch, according to the air pressure and load. It is indeed interesting to see how an incandescent lamp is kept burning with the apparatus showing a scarcely perceptible quiver.

To perfect the mechanical part of the apparatus so that oscillations are maintained economically was one thing, and Mr. Tesla hinted in his lecture at the great difficulties he had first encountered to accomplish this. But to produce oscillations which would be of constant period was another task of no mean proportions. As already pointed out, Mr. Tesla obtains the constancy of period in three distinct ways. Thus, he provides properly calculated chambers, as in the case illustrated, in the oscillator itself; or he associates with the oscillator an air spring of constant resilience. But the most interesting of all, perhaps, is the maintenance of the constancy of oscillation by the reaction of the electromagnetic part of the combination. Mr. Tesla winds his coils, by preference, for high tension and associates with them a condenser, making the natural period of the combination fairly approximating to the average period at which the piston would oscillate without any particular provision being made for the constancy of period under varying pressure and load. As the piston with the coils is perfectly free to move, it is extremely susceptible to the influence of the natural vibra-

tion set up in the circuits of the coils H H. The mechanical efficiency of the apparatus is very high owing to the fact that friction is reduced to a minimum and the weights which are moved are small; the output of the oscillator is therefore a very large one.

Theoretically considered, when the various advantages which Mr. Tesla holds out are examined, it is surprising, considering the simplicity of the arrangement, that nothing was done in this direction before. No doubt many inventors, at one time or other, have entertained the idea of generating currents by attaching a coil or a magnetic core to the piston of a steam engine, or generating currents by the vibrations of a tuning fork, or similar devices, but the disadvantages of such arrangements from an engineering standpoint must be obvious. Mr. Tesla, however, in the introductory remarks of his lecture, pointed out how by a series of conclusions he was driven to take up this new line of work by the necessity of producing currents of constant period and as a result of his endeavors to maintain electrical oscillation in the most simple and economical manner.

Multiphase Motors and the Transmission of Power



A QUESTION so important as the long distance transmission of power had been apparently overlooked in the preparations for the recent International Electrical Congress, as no papers on this subject appeared in the programme, and this fact excited more or less comment. When it was understood that the matter would come up for consideration in the section of Pure Practice, over which Prof. E. J. Houston presided, it was evident that the discussion would be followed with great interest, and that the attendance in Section B during that time would be very large. The idea, it is stated, originated with Dr. Louis Duncan, of Johns Hopkins University, who has always taken an active interest in this question, and is regarded as one of the leading exponents of the transmission of power by alternating currents in this country.

On Thursday forenoon the chairman of Section B accordingly called upon Dr. Duncan to open the discussion, and as many points of great value and interest were brought out it is given below in more detail than the brief synopsis which appeared in the report of the proceedings of the congress in the last issue of The Electrical World.



Dr. Louis Duncan.

Dr. Duncan first explained why the discussion had arisen; it was found that there were no papers on the list of those to be read before the congress which touched upon the subject, and as a great many men, who had a large amount of practical experience, and who probably knew a great deal more about multiphase systems than any one in this country were present at the congress, it was desirable, if possible, to get hold of their knowledge and experience.

Dr. Duncan then briefly described the theory of the multiphase motor, and showed that the distribution of E. M. F. was such as to give a higher efficiency than is possible in direct current machines. Taking the case of two independent alternating currents with a difference of phase of 90 degrees, one is at zero when the other is at maximum, and if these are led around the magnets of a four-pole dynamo it is evident that a maximum E. M. F. is induced in each wire when it is placed in the best possible position in the field of natural strength. There is, then, a distribution of electrical force in the conductors about the armature, such that the highest electrical force is obtained exactly where it is desired. The distribution is such that the current is obtained exactly where we want it, and for that reason the conditions are better than in a continuous current machine. It has been found in the first place in working up the problem that the electrical efficiency of such a motor is a very simple expression, equal to the angular velocity of the armature divided by the angular velocity of the field. Such a motor would start up just like a continuous current motor, and would have an efficiency greater than a continuous current motor, provided there were no lagging of the current. The starting of the motors is the most serious question which has to be dealt with; if we have a motor where the drop of potential is 10 per cent. or something like that, and if the machine when starting has a current of many times the normal current, the whole distribution is disarranged. It is just as if a continuous current motor were started with the brushes shifted almost 90 degrees from the neutral point of the commutator: The question is, How is it possible to get rid of this trouble? The first thing to do would be to decrease the self-induction; this has been done by the Stanley company by placing short-circuited coils near the armature coils; but this is done at the expense of a good deal of space which could otherwise be filled with iron, and it is questionable whether it would not be just as well to utilize that space by putting more iron into it. Another way is to increase the armature resistance of the motor. There has been a great deal of trouble with multiphase motors, and one of the reasons for it is this: Suppose that a wave is applied that is not a sine curve, but is a positive and fundamental wave, a number of upper harmonics; suppose we have the E. M. F. together with the same harmonics, then the efficiency of the motor would be greatly reduced. If the motor were revolving at 900 revolutions and the field at 1,000 the electrical efficiency would be 90 per cent., but if more waves are there, say, the third or fifth harmonics, then the efficiency is greatly decreased. It is a very difficult thing to experiment on these armature currents because any ordinary means for obtaining the curve will not work. Another piece of machinery which Dr. Duncan considered of great importance, and which he hoped would be discussed, was the rotary transformer. He illustrated by diagrams upon the board the theory of operation of such a machine, and pointed out some of the inherent difficulties. He called attention to the fact that all the current does not pass through the armature, and that this is a very important point, because the question comes up as to how much energy can be transformed with one of these machines. Another question which he hoped would be discussed was that, with a given machine, say, of 100 h. p., can more energy be transformed with a three-phase than with a two-phase machine; and, if so, in what proportion. He closed his discussion by remarking that he hoped that those present who had practical experience in this line would not hesitate to speak, and that the discussion would be simple and straightforward.

Mr. C. F. Scott called attention to the Tesla polyphase system which constitutes a part of the exhibit of the Westinghouse Electric and Manufacturing Company in Electricity Building. The purpose of the exhibit is to show a complete working system for generating, transmitting and distributing power on a large commercial scale. The system includes:

I. A prime mover. II. A generating dynamo. III. Raising converters and transmission line and reducing converters. IV. Motors and rotary transformers for general power and electrical service.

The prime mover in general practice is water power, but in the present plant a 500-h. p. two-phase Tesla motor of the rotary field type serves as prime mover. The current for this motor is received from one of the 750-kw. two-phase Westinghouse generators of the lighting plant in Machinery Hall. The number of alternations is 7,200, and the pressure is reduced from 2,000 volts to 200 volts before being delivered to the motor. The current is delivered to the rotating element of the motor through brushes resting on four collecting rings. The winding is a drum winding laid in small slots in the surface. The stationary element of the motor is of laminated iron set in an outside casting. Large copper rods are run through holes in the iron plates near the inner surface, and are suitably connected at the ends. Resistances are put in circuit with this winding for starting the motor, and when speed is attained these resistances are short-circuited, leaving this winding completely closed on itself.

This motor drives a 500-h. p. two-phase alternating current generator. This machine is of the ordinary type of railway generator. There is a field of six poles which is excited by a small direct current machine driven by a 5-h. p. two-phase Tesla motor of the rotary field type. The exciter in general practice would be driven by a water-wheel. The large generator delivers from four collecting rings two currents differing in phase 90 degrees. The number of alternations is about 4,000 per minute, or 33⅓ periods per second at a potential of 300 volts on each circuit. The machine is also provided with a direct current commutator connected with the same winding, delivering current at 500 volts. This commutator would not be used when the machine is intended as an alternating current generator only. The current from this machine is delivered to a marble switchboard, where it is regulated and connected with the various transmission circuits, as desired. This board will afford facilities for connecting various circuits with any one of the several generators which may be placed in a large generating station. The current from the switchboard is received by alternating current converters or transformers by which the potential is raised in the present plant to 1,200 volts. In practice, the transformation would be to a much higher voltage, depending upon the distance of transmission. The transmission circuit conveys the current to the receiving station, where it is reduced by transformers to electromotive forces appropriate to the machines to be supplied. The current passes through a marble switchboard in which there are suitable provisions for operating the various machines in the receiving station.

The largest machine in this station is a 500-h. p. two-phase Tesla motor and rotary transformer. This machine is similar in general construction to the generator above described. The alternating current at 360 volts is passed into four collecting rings on the armature. Special connections of the field circuit are made for starting the machine, and when the motor has attained full speed a switch is turned giving the final connections and running the machine as a self-exciting synchronous motor, which maintains the exact speed of the generator by which it is driven except in cases of extreme overload. The armature of this machine is provided with a double pulley with belts driving a Worthington pump and a 40-light Westinghouse alternating current arc-light dynamo. The armature is supplied with a direct current commutator connected with the same winding which receives the alternating current, and delivers direct current at a potential of 500 volts. This current is utilized for operating two 30-h. p. street railway motors mounted upon a standard Dorner & Dutton truck, and also a 60-h. p. direct current motor mounted upon an Ingersoll-Sergeant air compressor. The direct current also supplies a series of direct current constant potential arc lamps. The current from the switchboard is also carried directly to a 60-h. p. two-phase motor and rotary transformer, which receives the current at 30 volts and delivers direct current at 50 volts adapted to electrolytic work, charging of storage batteries, and is at present used for operating the large Schuckert search light in an adjoining space. The current from the switchboard also operates a 60-h. p. two-phase Tesla motor of the synchronous type, which is adapted for any kind of constant speed work. In the present exhibit it is direct coupled to a 45-kw. slow-speed alternator of the constant potential type used for incandescent lighting. Current from the switchboard is also directly utilized for supplying incandescent lamps. Mr. Scott then called attention to the excellent mechanical design of the machines and the necessity of such work to insure success and economy in the practical operation of a plant. He described briefly the construction of the machines, and showed their fitness for the work for which they were designed. Attention was also called to the simplicity and solidity of the whole system and to its great flexibility. Mention was made of the successful installation and operation of a lighting plant for over 100 h. p. using 10,000 volts over a 28-mile circuit in southern California is an initial step which covers a distance greater than is required in a majority of the cases in which power transmission is proposed.

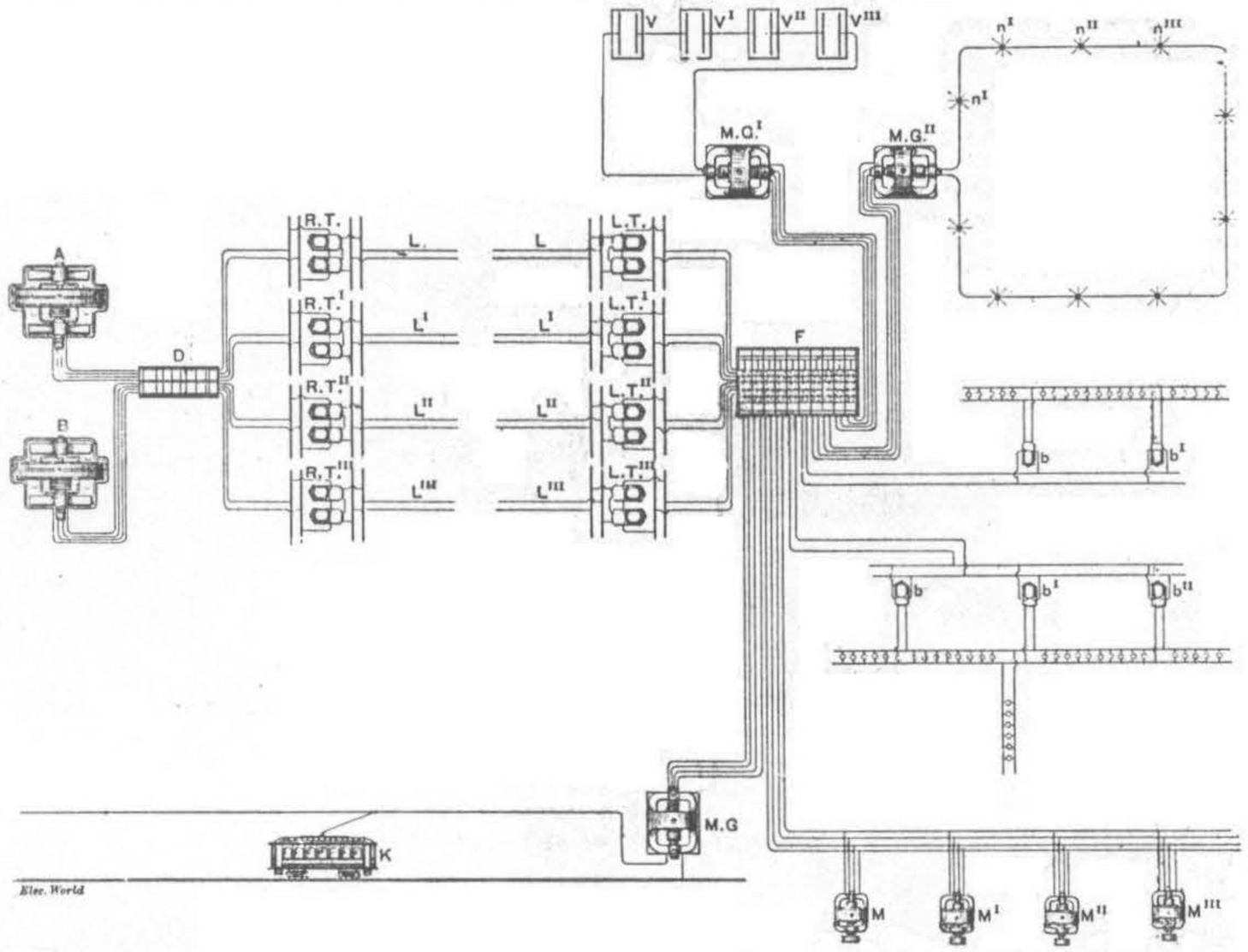


DIAGRAM OF MULTIPHASE OR TESLA SYSTEM OF TRANSMISSION AND DISTRIBUTION.

Mr. W. F. C. Hasson, of San Francisco, was then

called upon to continue the discussion. He stated that, as consulting engineer, he represented a variety of companies in California who desired to transmit power electrically to the aggregate amount of some 40,000 h. p. over distances ranging from 10 to 44 miles. Notwithstanding the fact that Mr. Scott had referred to the successful transmission of power for lighting purposes at San Antonio over 28 miles, the transmission of power electrically over long distances in California was a failure. Over a year ago the first contract for a definite transmission of power was closed, and to-day the superintendent of the mine in which the installation was made in eastern California is looking at his burned-out field coils after the generator has been in operation for less than thirteen days. The whole system just described is logical, and very beautiful on paper, but it does not establish the commercial success of long distance transmission of power. The machinery must be so built that it will not run for hours or days, but for weeks and months. Installations of this kind are almost invariably in places which are distant from railways, and where repairs are impossible, and the machinery must be of such a kind that it will be practically impossible for accidents to happen. Mr. Hasson stated that he believed in the transmission of power, and had been an apostle of it for some time in California, but that he was obliged to definitely state that as far as California was concerned the results had been failures, at least from the standpoint of the investor. Some months ago he was called upon to decide upon certain plans for the transmission of 3,000 h. p. for 20 miles; mose elaborate and beautiful descriptions of methods arriving at the results were placed before him, but not a single working drawing of any kind.

Dr. Louis Bell then took up the subject and first expressed satisfaction that a previous speaker had referred to the two-phase system as a polyphase system, because he thought that all which applies to the two-phase system applies in varying degrees to all other numbers of phases. He stated that there are in general three methods which are usually proposed for power transmission—that of the direct current, which Prof. Crocker had been championing in his paper before the Congress; that of single-phase currents and that of polyphase currents. In regard to the first, it could only be said that in this country, at least, it had not been altogether a success; the great difficulty seems to be that when the current increases to any considerable extent difficulties are at once to be met with. As for alternating currents, the reason why they are preferable is that they can be utilized in so many different ways. So long as the direct current had a monopoly of all motor service there was no choice, but at the present day that is changed; the single-phase system is now applicable to motor service, though not as well as the polyphase system, nor is it as well adapted to the operation of the rotary transformer, which is destined to play an important part in the future transmission by polyphase currents. The single-phase motor in its present state of development can be considered as nothing else than a rather poor polyphase motor; it starts on the polyphase principle, but with the objection that the rotary field established is not a circular rotary field but an elliptical one, and, consequently, gives less efficiency in the motor. Coming finally to the polyphase systems, they may be divided into two classes, those having two wires per phase or independent circuits, and those having non-independent circuits. A two-phase system with three wires is somewhat simpler than the two-phase independent circuit system; the three-phase system, operated on separate circuits, requires six wires, but with combined circuits requires only three wires—as few as are required by any polyphase system. Furthermore, in all the polyphase non-independent circuits polyphase systems save copper, as over the direct current, the simple alternating and the polyphase system with separate circuits, and this saving varies in degree from 12 or 13 per cent. in the two-phase to 25 per cent. in the three-phase. Another important feature of the three-phase dependent circuit system is that there is less self-induction and capacity on the line than in single or two-phase systems. For the installation of lights the difference between a dependent circuit system with three wires and an independent circuit system with at least four wires is very little because it is necessary to split the cur cuits in any case, but in most cases three wires are more convenient than four. The great objection which has been raised against the polyphase system with dependent circuits is that it does not regulate well, but this criticism is ill founded, as we know from experiments. In the first place it is quite possible to arrange such a system so that the difference between the different branches of the circuit will be almost unnoticeable. The means of doing this are simple, and therefore it is well to state as the result of positive experiments that without any complicated means of compensation whatever it is possible to obtain closely concordant voltages in all branches of polyphase system.

In regard to polyphase motors, there is no very wide difference in principle or in operation between two, three, four, or *m* phase motors or in their action on dependent or independent circuits. When such motors are properly designed there is no doubt that they are decidedly superior to any direct current machine, and that is one of the strong reasons for using the polyphase systems.

Dr. Bell stated that he had been experimenting with motors of this type for a long time, and that he had never yet succeeded, even under the most adverse conditions, in burning out a single machine in any way whatever, a record which could hardly have been made with any kind of a direct current motor. If overloaded they will stop, and not burn out for a pretty long period; they start quite well, as well as any ordinary direct current motor; and in regard to the current required, they start just about as a shunt motor does. It is possible to run a polyphase motor at a widely varying range of speed (say, from 1-10th speed up to full speed), keeping a practically constant torque. Dr. Bell, in closing, defended the polyphase machine against the accusation of a large lagging current.

Prof. S. P. Thompson, first speaking for M. Thury, briefly described the transmission plant at Genoa, where a direct curernt of 1,200 volts was employed and no difficulties were experienced. Another interesting continuous current plant is that operating between Biberist and Rondchatel, a distance of about 20 miles. Forty amperes of current at 3,500 volts are there transmitted. At Genoa eight dynamos, all joined in series, each running at nominally about 1,000 volts, supply generators. These are all samples of practical installations for which M. Thury makes himself responsible.

In speaking for himself, Prof. Thompson first touched upon the continuous current problem, stating that many continuous current machines of high voltage had been successfully operated, and citing cases as illustrations. Coming to the question of alternating current work, he caled particular attention to the installation at Rome, where the source of power was a waterfall some fourteen miles distant. He had studied the polyphase transmission at Frankfort, where there were eight or ten different systems on exhibition, from all the great firms in the world; he did not believe that there was any best system, but that each one was best for its own purposes. He did not care to prophesy, but would give his personal opinion as to what would be the general system in use ten years from date. He did not like the complication of three-phase transformers, and three-phase switchboards and other apparatus, although he did like three-phase and two-phase alternating current dynamos and motors. The system recently described by a previous speaker was very beautiful, but he did not like its complications. In the future he thought that all the applications of polyphase work would be abandoned, and that engineers would return to simple alternating current motors; in other words, that the simple alternating current will be the one thing which ten years hence will be found to be effective for all long distance transmission.

Mr. C. P. Steinmetz remarked that out of justice he would be obliged to take the part of the continuous current; the largest amount of power distributed in the United States to-day is distributed by continuous currents; this shows that the continuous current is not dead yet, and the many references to rotary transformers showed that even the advocates of the polyphase systems still consider that they cannot get along without the old continuous current. With regard to the polyphase and single-phase systems, it makes little difference how many phases there are, because any system of polyphase currents can be transformed into any other system of polyphase currents by using two transformers only; furthermore the motors of the different polyphase systems are essentially the same. Mr. Steinmetz thought that the system of the future would be the single-phase system. There would be no longer any trouble with self-induction or capacity, for proper appliances would eliminate their effects entirely.

Prof. George Forbes stated that he was informed that there had been an organized conspiracy among the American engineers, led by no less a man than Dr. Louis Duncan, to draw out the foreign engineers on the subject of transmission of power and multiphase motors; he did not think that this referred to him, as he has ceased to look upon himself as a foreign engineer. Prof. Forbes then proceeded to outline the methods which had been adopted for the great transmission plant at Niagara Falls. The subject had been investigated most thoroughly by himself and others connected with the enterprise, in order that the best system might be selected. The first step taken was the decision that there should be central stations established at Niagara Falls to transmit power to places at greater or less distances away, as opposed to the proposition of locating all the mills directly at the Falls. It was decided that the whole of the transmission should be done by means of electricity. In 1890 a number of plans were invited from different engineers and engineering firms as to the best means of utilizing the large power of the Falls, and these plans were submitted to an engineering congress, which met in London at the beginning of 1891. Prof. Forbes in his report at that time, stated that he regarded the best means to be that of transmission by means of alternating currents of electricity; that the two-phase system should be employed with two separate circuits of high voltage; that transformers should be used for reducing the pressure down to a safe limit; that in the mills and works synchronizing alternating current motors should be used in some cases, and in others two-phase motors should be employed, and that in cases where direct current was necessary alternating motors should be used to drive continuous current machines. During the three years since that time hardly a change has been made in the system proposed.

After the congress referred to had closed, bids were asked from all the greatest firms in the world. The greatest difficulty was experienced in nearly every case by those who proposed to use continuous currents, and in every case the cost was largely in excess of that of the alternating system. Another thing which had been decided upon was to use the same system for both short and long transmission. The advantages, however, in the use of high potentials for short distances are the same as for long, and it was found that the amount of copper which would be neccessary to transmit 50,000 h. p. at a potential of 1,000 volts over even a short distance would almost completely fill a subway large enough for a man to walk through, and the cost would, of course, be prohibitive.

Prof. Forbes hardly agreed with Prof. Thompson that the multiphase motors would disappear from general use, and that single-phase motors with a multiphase means of starting would be more universally adopted; this he regarded as only one of the possibilities of the applicable to almost every class of work.

For continuous work, such as will be found in mills, the synchronous motor would be employed in the Niagara plant, but in all ordinary workshop practice where it is necessary to stop, start and reverse continually, the multiphase motor would be employed. One reason why the two-phase independent circuit transmission was chosen for the Niagara plant was that it was likely to take care of all developments which would be made for the next few years in alternating current apparatus; even if single-phase machines alone should be used the single-phase currents can be developed more cheaply by a two-phase machine than by the ordinary single-phase generator. This was appreciated as early as 1879, when Mr. Gramme built his first alternating current dynamo with two phases, having eight poles, a revolving field and a fixed armature. The water of the Niagara River, as is well known, is taken off one mile above the Falls by a large canal, which has been built; it is then taken by tunnels into the wheel pits and sent down on penstocks to the depth of 140 feet to the turbines below. These turbines have been designed by a firm of Geneva, of world-wide reputation, and have been constructed by the I. P. Morris, of Philadelphia, and will be delivered shortly. The water, after passing through the turbines, is carried down through the tunnels, which have been built to the river below the falls. On the top of the turbines is a vertical shaft coming to the surface of the ground, and rotating at 250 revolutions per minute, which enables the large dynamos to be directly connected to the shaft without gearing. Prof. Forbes then took up the question of whether step-up transformers should be used or dynamos generating a current of very high potential. He estimated that, with a loss of 3 per cent. in the transformers in the 5,000-h. p. units, $3,000 per year would be saved per unit. With stationary armatures it was as easy to build a dynamo for very high potentials, as it was a transformer itself. Overhead lines, subways or conduits were the three means by which the current could be transmitted, and it was a very serious question as to which should be used. The subway was obviously the most satisfactory, but the pole line was the cheapest. It had been decided that the work would be done either by bare overhead conductors or by bare wires carried in a subway. The transmission of power to considerable distances from Niagara Falls would confront the company in the immediate future, and it was possible that electricity would be used to propel the canal boats on the Erie Canal, in which case a line of several hundred miles in length would be required; at any rate the transmission of power to Buffalo was a possibility of the near future; the expense of a subway over such distances would be of course, very large. Experiments would be carried out with the pole system to determine its real merits. In the meantime a subway had been started which would carry conductors from the power station at least as far as the Pittsburgh Reduction Works, about half a mile distant.

Prof. H. A. Rowland did not agree with Prof. Forbes that dynamos of very high potential could be constructed without much difficulty. He was inclined to favor the use of step-up transformers. The small loss would not be of much consequence where the source of energy was a water power of such capacity. The difficulties that would be encountered in the construction of a dynamo of 10,000 to 20,000 volts would be very great. He did not know of any such in the world, and did not believe that it was practicable to build one. In the case of the transformer it was built in sections, so that there might not be more than 1,000 volts difference of potential between any adjacent wires. Then again, as the potential increases, the amount of coper which can be got into the groove in the armature becomes less and less. The matter of frequency was also

an important point, and the lower limit has never been thoroughly investigated. The first effect of reducing the frequency is to diminish the poles in the dynamo, and if we go down far enough it is necessary to slow up the machine until we have a dynamo running at a small speed, and its output is not what is desired. Again, if in a multiphase system the two sides are not perfectly balanced with a very low frequency, a tremor occurs which may produce a very great vibration of the machine, and this applies to both dynamos and motors. Further, the decrease of frequency necessitates increasing the size of the transformers in a ratio something like five to one. If it is desired to have motors running at 1,000 revolutions per minute the limit of the number of periods is somewhere about 20.

Dr. Louis Bell then considered some further points in addition to the remarks he had already made. He assured Dr. Duncan that the effects of the wave shape on the operation of single or polyphase motors was an experimental fact, but that in practice the effect on the efficiency was not likely to be great with well designed machines. In regard to the regulation of interconnected circuit polyphase systems, he had found it quite easy to satisfactorily regulate the triphase inter-dependent circuit system. It was much the same question that had arisen when the three-wire direct current system had been introduced, and the same objections were made against it. As to rotary transformers, he was not as hopeful as Prof. Forbes that any more simple form of commutator would come into general use in the near future. The rotary transformer has an efficiency from 90 to 95 or 96 per cent., and is a thoroughly reliable and comparatively simple piece of apparatus. He favored the use of step-up transformers rather than dynamos of very high potential on the ground that there was no experimental knowledge in the latter case; for extremely large machines he thought, however, that they might be built for very high voltages. In considering the line two important factors were the inductance and the frequency. As regards the inductance, the triphase or polyphase interconnected systems, for the same energy transmitted at the same voltages, give a lower induction on the line. With the triphase interconnected system the inductance is a little less than .6 of what it is on the single-phase or independent circuit multiphase system. As to frequency, the upper practical limit would probably be somewhat less than the frequency now ordinarily used, that is, 125 to 130 cycles. The lower limit would be determined in the ordinary distribution plant by the necessities of incandescent lighting; below 30 periods, or, in fact, below 33 periods, incandescent lamps do not work well. Arc lamps with the best soft cored carbons work fairly well at 45 to 50 cycles. The practical limit, then, is probably from 30 to 35 cycles. The keeping up of an overhead line is a most serious problem. The subway is, on the other hand, in most cases absolutely prohibitive from a commercial point of view. He thought that in most of the overhead work bare overhead wires must be employed, and, if they were dangerous, that people must learn to keep away from them. The limit of distance to which power could be transmitted practically depends almost entirely upon the conditions. Given the price of coal high enough power can be transmitted to almost any distance. It is absolutely necessary, however, not to economize in the matter of insulation.

Dr. Louis Duncan, in closing the discussion, stated that the tendency of most of the foreign engineers and those of the American speakers wha had had no practical experience was in the direction of the single-phase system; but that those among the Americans who had had considerable experience, and had seen the advantages of the multiphase system, were in favor of it; certainly the multiphase system at present was the only practical system for general distribution. The question of frequency was one of vast importance. If it is intended to do arc or incandescent lighting, then 50 periods per second must be used; if lower periods are used, the lag of the current is greatly increased.

Western Electrician.

EVERY SATURDAY.

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Electricity at the World's Fair.

Aside from several distinguished members of the congress who remained to see the exposition, two notable figures attracted attention in the electricity building last week—Thomas A. Edison and Nikola Tesla. Mr. Edison paid several visits to the building, strictly in the capacity of a spectator, and greatly enjoyed his inspection of the exhibits. Mr. Tesla gave a number of experiments before invited guests and the general public. On Tuesday afternoon he repeated, at the agricultural assembly hall, the substance of his lecture on "Mechanical and Electrical Oscillators," which was delivered before the members of the congress on the preceding Friday. On this occasion he had for an audience von Helmholtz and a number of other scientists who had been unable to attend the first lecture. On Tuesday evening Mr. Telsa repeated his beautiful and interesting high tension and high frequency experiments in the dark pavilion of the Westinghouse company in electricity building before a number of foreign engineers, including W. H. Preece, H. D. Wilkinson, MM. Mascart and de la Touanne, Dr. Lobach, F. W. Tischendoerfer and others. He also instructed and entertained other parties of visitors at intervals during the week at the same place by similar demonstrations. In conversation with a representative of the WESTERN ELECTRICIAN, however, Mr. Telsa said that he considered his researches into oscillatory phenomena, and the results that he had already obtained in that direction, his greatest work, and that he hoped to continue his investigations until he could present the world a system of mechanical and electrical vibration of commercial utility.

The German historical exhibit of electrical apparatus which is illustrated on this page can be found in the central portion of the eastern gallery of the electricity building, and the collection, which has only lately been opened to the public, will well repay a visit, as it is alike instructive to the student and interesting to the casual visitor. Here are shown devices which are claimed to substantiate the assertion that three of the great applications of electricity —the electric telegraph, the electric speaking telephone and long-distance power transmission—were first made in Germany. The articles shown were contributed largely by Siemens & Halske, of Berlin, although a number were obtained from the Imperial German Postoffice Department and other sources. The central feature of the display, at the back of the exhibit, is a bust of Werner von Siemens, the great German electrician, of heroic size, conspicuously placed under a large canopy. To the right, on a pedestal, is a life-sized bust of Sömmerring, for whom is claimed the honor of inventing the electric telegraph. On the left is a bust of Philip Reis, who is undoubtedly entitled to the distinction of having invented the first electric speaking telephone, crude though it undoubtedly was, the date being 1861. On either side of these busts are bas-relief heads of Gauss and Weber, all of the sculptured figures being outlined against a background of dark crimson cloth, which conceals the side of the building. On this background is also arranged a series of framed photographs showing the primary and secondary stations of the three-phase installation used in the Lauffen-Frankfort power transmission experiment, with pictures of the line construction and of the work accomplished by this electrically transmitted power at the Frankfort electrical exposition. One of the oil insulators used is also shown. It will be remembered that the Germans succeeded in transmitting 300 horse power over 100 miles at a pressure

of 30,000 volts, and of this achievement they are naturally not a little proud. Arranged in front of the busts are a number of interesting relics. An effort was made to secure the apparatus used by Sömmerring in his first experiments with the galvanic telegraph, some eighty years ago, but without success, as the descendents of the noted physicist, who reside in Frankfort, would not consent to the removal of the instruments to America, even temporarily. Models of the Reis telephone instruments are shown, however. One of the most interesting features of the collection is the electro-magnetic telegraphic apparatus of Gauss and Weber, which was devised about 1833. It is big and clumsy, and the signals were recorded by means of a reading telescope and a mirror. A piece of the wire used in the first telegraph line in Goettingen in the year mentioned is shown, with printed copies of some interesting letters written at that time to the mayor of the town by Prof. Weber. Appropriately placed near the central bust is the first machine built in Germany on the dynamo-electric principle. It was invented by Werner von Siemens, and brought out in 1866. This interesting exhibit has but one armature winding. It is carefully preserved. Among the other Siemens & Halske appliances is the first dynamo with a von Hefner-Alteneck drum armature, which dates from 1872, and a Gramme ring machine produced between '75 and '80. The latter was a commercial machine, with commutator and brushes that do not differ greatly from the type of to-day. Another machine that excites attention is an old flat ring dynamo, with an armature that also serves as a commutator by placing the brushes on the outside winding, as is done in the large Siemens & Halske generator in machinery hall. The Siemens & Halske display also includes the oldest unipolar dynamo, an old electric drill, an interesting collection of historical lamps, including the first differential arc lamp of von Hefner-Alteneck and the standard amyl-acetate lamp, and many measuring instruments, among which is a selenium photometer made by Werner von Siemens in 1877. The first electric locomotive built by Siemens & Halske, which was produced in 1879, is accorded a prominent position in the middle of the space, and it appears curious and antiquated when compared with the electric railway motors of the present day. In the northern portion of the space are many old instruments that are worthy of inspection. These include a number of the telegraphic appliances used by Siemens in the '40's, the original machine for pressing gutta percha for insulation, old resistance boxes, galvanometers and the like.

A number of the gallery exhibitors in the electricity building have united in issuing a neat little souvenir for presentation to visitors. This memento consists of a booklet containing a portrait of Chief Barrett and views of the exhibits of the Ansonia Electric company, W. R. Brixey, Bates Manufacturing company, Commercial Cable company, North American Phonograph company, Edison Manufacturing company, Caldwell electric cloth cutter, Electrical Engraving company, Electric Appliance company, Electric Heat Alarm company, Eureka Tempered Copper company, Chas. F. Hall, Gamewell Fire Alarm & Telegraph company, McNeil-Tinder Electric company, Newman Clock & Manufacturing company, Reliance Gauge company, Weston Electrical Instrument company and others. The idea of this souvenir originated with George B. Clark, who displayed much energy in pushing the plan to completion.

Luther Stieringer, the designer of the electric fountains at the World's Fair, left for New York on Saturday. The evidence of Mr. Stieringer's second visit to the fair since the opening can be seen in the greatly improved operation of the fountains, which are now taking their rightful position among the great popular attractions on the grounds. Mr. Stieringer hopes to return before the close of the fair to inspect the exposition as a spectator.

Of the four exhibit spaces in electricity building occupied by the Westinghouse Electric & Manufacturing company, the two most prominent, which are located in the nave of the building, are shown in Figs 2 and 3. This company has about 15,000 square feet of space in this building in addition to its great alternating incandescent plant in machinery hall. In the exhibit particular attention is paid to the transmission of power by the Tesla polyphase system. The space illustrated in Fig. 2 is that in the northern portion of the building. It contains the beautiful Westinghouse golden pavilion and also the Tesla generating station, although the machinery of the latter is not shown in the picture. The current is carried from this section by an overhead pole line, shown in Fig 2, to a receiving station, Fig. 3, where it is utilized for various purposes. A very complete account of this system is given in Mr. Scott's paper, which is presented on page 126 of this issue, and it is therefore unnecessary to dwell further on it here. The exhibit of street railway apparatus is principally contained in the space illustrated in Fig. 3. It includes one 270 horse power multipolar generator directly connected to a Westinghouse compound engine; one 400 horse power multipolar generator of the belt-driven type; several Westinghouse street railway motors—single reduction—of 20, 25 and 30 horse power capacity; one Brownell 20 foot car equipped with two 30 horse power Westinghouse motors—single reduction—series multiple controller, etc.; one Stephenson 16 foot car equipped with two 30 horse power Westinghouse motors—single reduction—series multiple controller, etc. There is also a complete line of switches, ammeters, voltmeters, automatic circuit breakers, lightning arresters, switchboard fittings and connections and motor details illustrating construction. In addition the Westinghouse company exhibits a Lamokin car in the transportation building. This car is 18 feet long and is equipped with two 30 horse power single reduction motors and a series multiple controller. The company also shows a Laclede car similarly equipped on the exhibition tracks near the terminal station. The cars in electricity building are placed over a pit, so that visitors can inspect the motors and connections from beneath. The company also makes a large exhibit of arc and incandescent lighting apparatus and of general electrical supplies. Included in this list may be mentioned standard Westinghouse alternators of various sizes, including a field casting of a 450 kilowatt belt-driven alternator, showing the Westinghouse method of casting laminated poles into cast iron frame; standard Westinghouse converters and transformers; special converters equipped with non-arcing metal lightning arresters; direct current motors and generators of the horizontal type; direct current generators and motors of the "letter" type; direct current generators of the multipolar type; direct current motors of the Manchester type; alternating current arc light dynamos; Shallenberger alternating current meters, complete and in operation, also parts illustrating construction; Wurts non-arcing metal lightning arresters for alternating current circuits, in operation; lightning arresters of various types for direct current circuits; switches for alternating and direct current work; ammeters and voltmeters for direct and alternating currents. One of the most interesting sections of the display is B 1, in the southeastern portion of the building. Here, in addition to Shallenberger meters and Wurts non-arcing metal lightning arresters, is the personal exhibit of Nikola Tesla and the dark room in which the Tesla experiments are shown. Some of the early motors designed by Mr. Tesla are shown, and also the parts of a small machine built in an attempt to produce a self-exciting alternator. The head of Columbus, occupying the large wall space at the south end of the building, together with the decorative scrolls and letters, and which is made up of Sawyer-Man stopper incandescent lamps lighted by current from the circuits of the Exposition company, which are supplied by the Westinghouse central station plant in machinery hall, completes the display in electricity building.

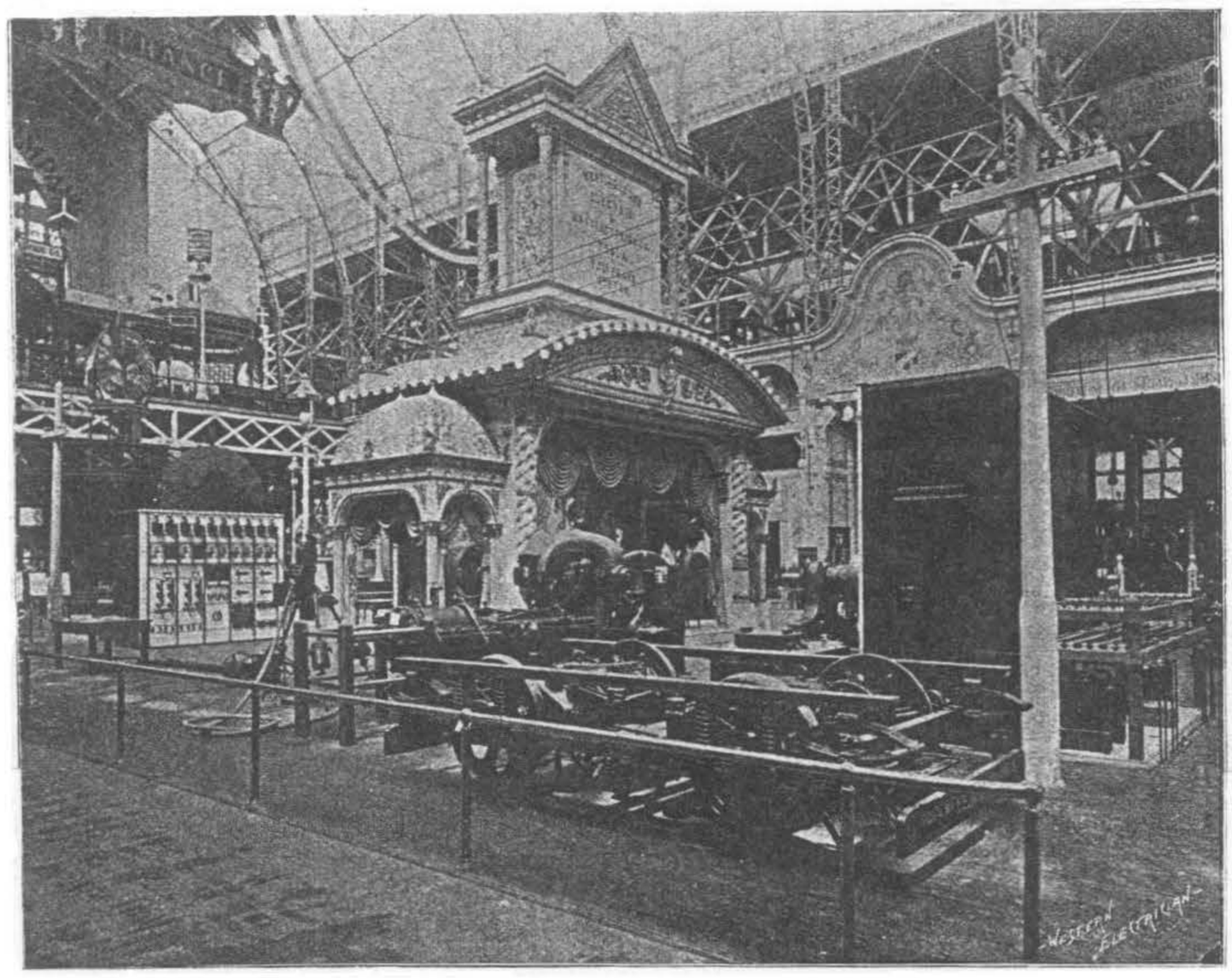

FIG. 2. ELECTRICITY AT THE WORLD'S FAIR.—EXHIBIT OF THE WESTINGHOUSE COMPANY, ELECTRICITY BUILDING.

The *Street Railway Gazette* has issued in pamphlet form its "Directory of Street Railway Exhibits at the World's Fair." The compilation has been carefully made and should be of great assistance to all particularly interested in the appliances used in street railway work.

The Turin jubilee pole for arc lamps, which was illustrated in the WESTERN ELECTRICIAN of April 22d last, has at last arrived on the World's Fair grounds. It has been erected in the General Electric company's space in the electricity building, near the tower of light, instead of in the rear of the administration building, as was originally, intended.

The General Electric company's five-foot projector, which is claimed to equal the largest Schuckert searchlight on the manufactures building in power, has been erected on the colonnade between the machinery and agricultural buildings. This huge lamp stands about 10 feet 6 inches high to the upper side of the ventilator on the top of the drum, and the total weight is about 5,500 pounds. The reflecting lens mirror used in this projector is 60 inches in diameter. It is a concave spherical mirror of the Mangin type, and was manufactured especially for this projector in Paris. It is a fine specimen of optical work, 3¼ inches thick at the edges and 1 1-16 inch thick at the center, weighing about 700 pounds. This mirror is mounted at one end of the big drum, the other end of which is furnished with a door consisting of a metal rim in which are fixed a number of plate-glass strips 5-16 inch thick by 6 inches wide. Inside this drum, and sliding upon ways arranged on the bottom, is placed the arc lamp, which is entirely automatic in its action, is 6 feet high, and weighs about 400 pounds. The upper or positive carbon is 1¼ inches in diameter and 22½ inches long, with a 5-16 inch core of soft carbon running from end to end through its center. The lower or negative carbon is 1¼ inches in diameter, 15 inches long, and also has a core of soft carbon running through it. In addition, its outer surface is heavily coated with copper. The positive carbon is set a little in front of the negative, and thus almost all the intense light of the incandescent crater is cast upon the reflector. The maximum current at which this lamp operates is 200 amperes, and at this current the lamp is calculated to have a luminous intensity of about 90,000 to 100,000 candles, which is multiplied many times by the mirror. Ventilators at the top and sides allow a constant current of air to pass through the drum and dissipate the heat generated by the arc lamp; and they are so arranged that no light can escape through them. All the connections for adjusting the positions of the carbons and the lamp are brought through the drum to the outside, and are arranged in close proximity to one another at one side, so that all may be manipulated by the operator

without moving from his position. The drum is supported by trunnions in bearings at the top of a Y-shaped fork, set in a base-plate, and the whole is supported on a system of friction wheels, forming a turntable resting upon the top of a massive pedestal, supporting the whole structure. The drum, fork and base plate may be rotated horizontally on the turntable either by hand or by gearing provided for this purpose. The drum may also be raised or lowered in a vertical plane.

The thirty-ton electric locomotive exhibited by the General Electric company on the tracks near the terminal station is now operated at 11 A. M. and 3 and 8 P. M. daily.

R. H. Pierce, the electrical engineer of the exposition, and L. S. Boggs, the assistant engineer for electrical power, have prepared a table showing the number, distribution and capacity of the electric motors in the service plant at the World's Fair. This table, which gives an excellent idea of the extended use of electrically transmitted power at Jackson Park, is given below:

MOTORS IN USE AT THE WORLD'S FAIR.

Location.	Exposition.		Exhibitors.		Total	
	No. of Motors	H.P.	No. of Motors	H.P.	No. of Motors	H.P.
Illinois Bldg	..	...	1	5	1	5
Transportation	1	1/8	36	140 3/4	37	140 3/8
Mines and Mining	7	368 1/2	18	69	25	437 1/2
Agricultural	7	237	26	21 2/3	33	258 2/3
Manufactures	..	...	61	45 1/2	61	45 1/2
Machinery Hall	45	595	23	69 1/2	68	664 1/2
Horticultural	..	...	6	11 1/4	6	11 1/4
Anthropological	..	...	1	1	1	1
Government	..	...	6	36 3/8	6	36 3/8
Weather Bureau	.	....	1	2 1/2	1	2 1/2
Terminal Station	..	...	1	2	1	2
Administration	12	208	2	1/4	14	208 1/4
Fisheries	2	10	1	1	3	11
Clam Bake	..	...	2	5	2	5
Costa Rica	..	...	1	5	1	5
Leather	5	145	1	1	6	146
Choral Building	..	...	4	12	4	12
Kansas State	..	..	1	1	1	1
German Kitchen	..	...	1	1	1	1
New York State	..	...	1	20	1	20
White Star Line	..	...	1	1/2	1	1/2
Stereotype	..	...	1	10	1	10
Puck	..	...	1	15	1	15
Woman's Building	2	40	1	1	3	41
Midway Plaisance	1	14	14	60	15	74
Dairy Building	3	83 1/2	..	...	3	83 1/2
Dairy Barn No. 6	1	6	..	...	1	6
Service Building	8	17 1/3	..	...	8	17 1/3
New Service Bldg	1	1 1/2	..	...	1	1 1/2
Sewerage Cleansing Works	1	24	..	...	1	24
Crematory	1	14	..	..	1	14
Carpenter Shop	1	9	..	...	1	9
Paint Shop	1	3	.	...	1	3
Mechanical Dept. Blacksmith Shop	1	14	..	...	1	14
Blacksmith Shop	1	9	..	...	1	9
Pump House	1	6	..	...	1	6
Bet. Pump House & Machinery Hall	1	6	..	...	1	6
Total	103	1,810 23/24	212	537 19/24	315	2,348 3/4

As will be seen, 315 motors, with an aggregate capacity of 2,348 3/4 horse power, are connected with the exposition circuits. This does not include the large number of motors in electricity building for which the exhibitors themselves supply current from machinery hall, and which are not operated by the Exposition company. The following is a list of the names of the different varieties of motors operated on exposition circuits: Eddy, Crocker-Wheeler Edison, Thomson-Houston, Diehl, Lundell, Jenney, Westinghouse, Perret, Sprague, Sperry, Card, Ford & Washburn, Keystone, Dunderdale, Eickemeyer, C. & C., Holtzer-Cabot, Western Electric, Kester, Wagner, Detroit, Mather, Emerson, Mayo, Waddell-Entz, Brush, Simpson.

Additional details in relation to the elevated electric railway plant at the World's Fair are always interesting, and so no apology is necessary for supplementing the general articles on the road that have appeared in this journal by further particulars. Electrical engineers will find the sectional drawing of the 1500 kilowatt generator in the power house, Fig. 4, of particular interest. The machine has twelve poles, is compound wound, and is carefully insulated from the ground. The air space between the faces of the poles and the face of the armature is 7-16 of an inch. The armature is built up of sheet iron punchings set around a spider shrunk on the hub. The outer face of the spider is slotted as are the inner faces of the armature punchings, so that they dove tail together. Each circle of sheet iron is carefully insulated from the preceding one, except at one point, and this results in giving to the armature a spiral construction. Not less than 17,200 pieces of sheet iron, weighing 25 tons, were used to build up the nine sheet iron sections, separated from each other by eight brass open rings, resembling spoked wheels, which serve for ventilating purposes. Two four ton cast iron washers held together by bolts, complete the material composing the armature core. The winding of the armature consists of copper strips 3 1/4 inches wide by 1/4 inch thick, two turns to the coil. These are carefully insulated from each other by mica, and each couple is inserted in one of the 348 slots in the laminated armature body each of which is itself lined with a mica tube. The strips are held in place by means of a wooden wedge. The side connections are then riveted and soldered to the strips and are brought down to the massive copper commutator. There are twelve brushes, which are manipulated by means of a hand wheel actuating a gearing concealed beneath the floor of the power house. The switchboard, Fig. 5, is made of enameled slate framed in mahogany, and is a striking feature in the installation. It is composed of five panels, one for each machine, each panel containing all the instruments necessary for the control of the machine to which it belongs, *i. e.*, triple pole switches, shunt rheostats, ammeters, automatic circuit breakers, lightning arresters, lightning switches, etc. The circuit breakers are of the new design of the General Electric company, and are provided with automatic resetting devices which close them electrically. With this electrical reset, all or any desired number of circuit breakers in the station can be reset at once. The generators are adjusted so to run in perfect harmony as exactly to divide the load in proportion to their relative capacities—a nice problem with generators of such varied sizes and types. The transportation service is effected by trains running at four minute intervals, each train consisting of a motor car and three trailers; the trains weighing 63 tons each, seating 280 people and the cars being of the same length as those generally used on elevated roads—about forty-five feet from end to end. The weight of these trains, as compared with a train drawn in the usual way by a locomotive, shows a saving of about 20 tons dead weight. The motor cars are equipped with four General Electric motors of the single reduction four pole type, one on each axle. These machines, one of which is shown in Fig. 6, are the most powerful railway motors yet constructed, developing 133 horse power each. They are geared for a speed of 30 miles an hour. Current is taken from the conductor rails by means of a sliding shoe contact, Fig. 7. The motors are controlled by a series parallel controller of special type, operated by an ingenious compressed air mechanism. The motors are connected up in a novel way. When the car is started the four motors are in series, then two in series and two short-circuited then, the four in series of two pairs of motors each in multiple, then two in multiple and two short-circuited and finally all in multiple. By this method the trains are started smoothly and without jerk, and the speed is imperceptibly increased. Air is furnished to the controller and to the air brakes, which are fitted to each train, by an air compressor pump, similar to that used on locomotives, but operated by an electric motor.

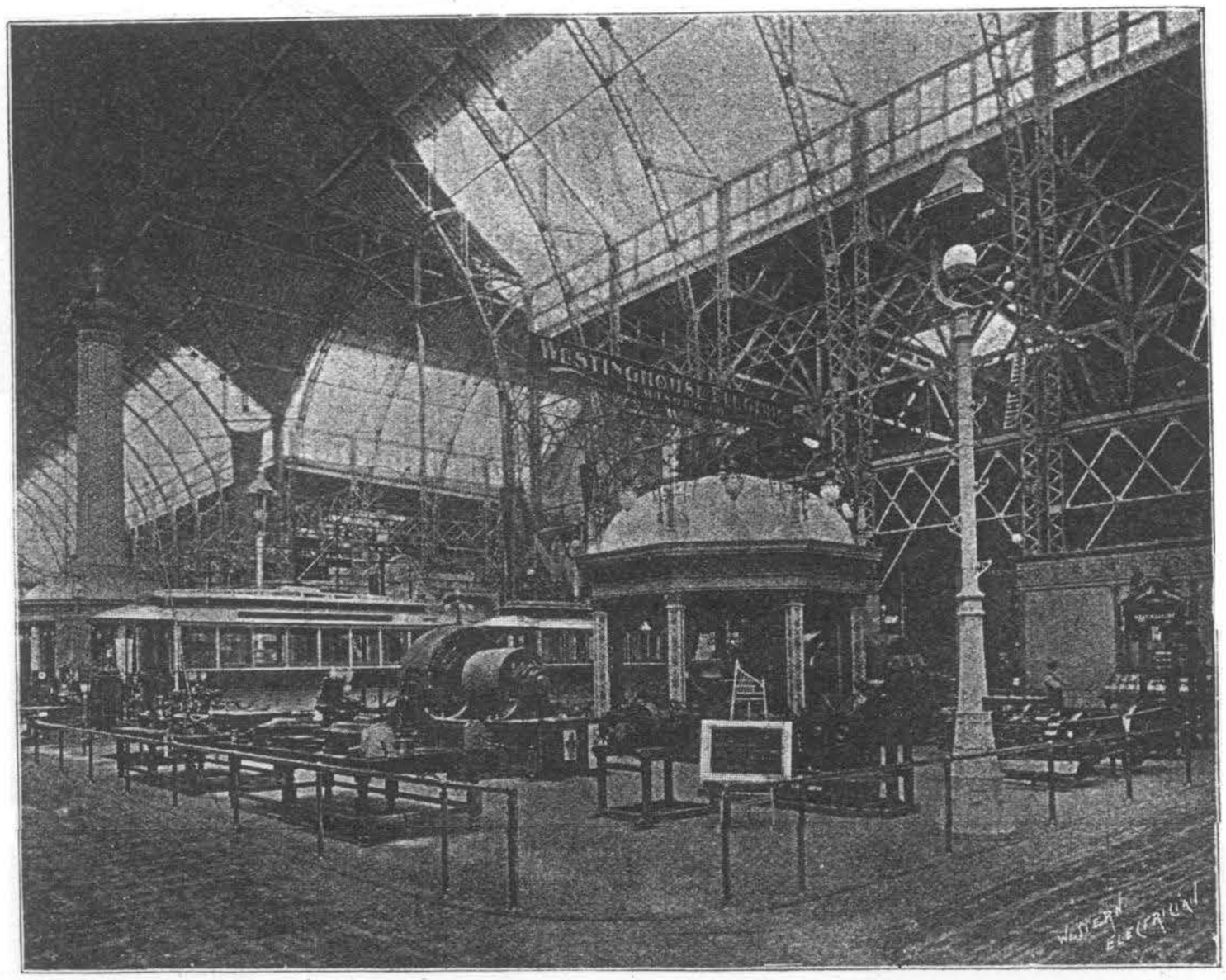

FIG. 3. ELECTRICITY AT THE WORLD'S FAIR.—EXHIBIT OF THE WESTINGHOUSE COMPANY, ELECTRICITY BUILDING.

Exhibit of Tesla's Polyphase System at the World's Fair.[1]

By C. F. Scott.

An exhibition of power transmission at the World's Fair which is of exceptional interest, is the Tesla polyphase system which constitutes a part of the exhibit of the Westinghouse Electric & Manufacturing company in electricity building. The exhibit includes generators, motors, transformers and other apparatus of various sizes and types. The system itself is not new in its general plan. There are but few features of novelty in the electrical system which have not been the subjects of publications or patents. The purpose of the exhibit is not so much to bring out what is novel in electrical invention as it is to give a complete exhibit of commercial machinery constituting the elements of a power system on a large scale. The exhibit will attract practical electrical engineers rather than those who are interested only in electrical inventions.

The purpose of the exhibit is therefore to show a complete working system for generating, transmitting and distributing power on a large commercial scale. The system includes:

1. A prime mover.
2. A generating dynamo.
3. Raising converters and transmission line and reducing converters.
4. Motors and rotary transformers for general power and electrical service.

The prime mover in general practice is water power, but in the present plant a 500-horse power two-phase Tesla motor of the rotary field type serves as prime mover. The current for this motor is received from one of the 750 kilowatt, two-phase Westinghouse generators of the lighting plant in machinery hall. The number of alternations is 7 200, and the pressure is reduced from 2,000 to 200 volts before being delivered to the motor. The current is delivered to the rotating element of the motor through brushes resting on four collecting rings. The winding is a drum winding laid in small slots in the surface. The stationary element of the motor is of laminated iron, set in an outside casting. Large copper rods are run through holes in the iron plates near the inner surface, and are suitably connected at the ends. Resistances are put in circuit with this winding for starting the motor, and when speed is attained, these resistances are short circuited, leaving this winding completely closed on itself.

This motor drives a 500 horse power two-phase alternating current generator. This machine is of the ordinary type of railway generator. There is a field of six poles which is excited by a small direct current machine driven by a 5 horse power two-phase Tesla motor of the rotary field type. The exciter in general practice would be driven by a water wheel. The large generator delivers from four collecting rings two currents differing in phase ninety degrees. The number of alternations is about 4000 per minute, or 33 1-3 periods per second at a potential of 360 volts on each circuit. The machine is also provided with a direct current commutator connected with the same winding, delivering current at 500 volts. This commutator would not be used when the machine is intended as an alternating current generator only. The current from this machine is delivered to a marble switch-board where it is regulated and connected with the various transmission circuits, as desired. This board will afford facilities for connecting various circuits with any one of the several generators which may be placed in a large generating station. The current from the switch-board is received by alternate current convertors or transformers, by which the potential is raised in the present plant to 1200 volts. In practice, the transformation would be to a much higher voltage, depending upon the distance of transmission. The transmission circuit conveys the current to the receiving station, where it is reduced by transformers to electromotive forces appropriate to the machines to be supplied. The current passes throngh a marble switch-board in which there are suitable provisions for operating the various machines in the receiving station.

The largest machine in this station is a 500 horse-power

1. Read before the World's Electrical Congress, August 24, 1893.

two-phase Tesla motor and rotary transformer. This machine is similar in general construction to the generator described. The alternating current at 360 volts is passed into four collecting rings on the armature. Special connections of the field circuit are made for starting the machine, and when the motor has attained full speed, a switch is turned giving the final connections and running the machine at a self-exciting synchronous motor,

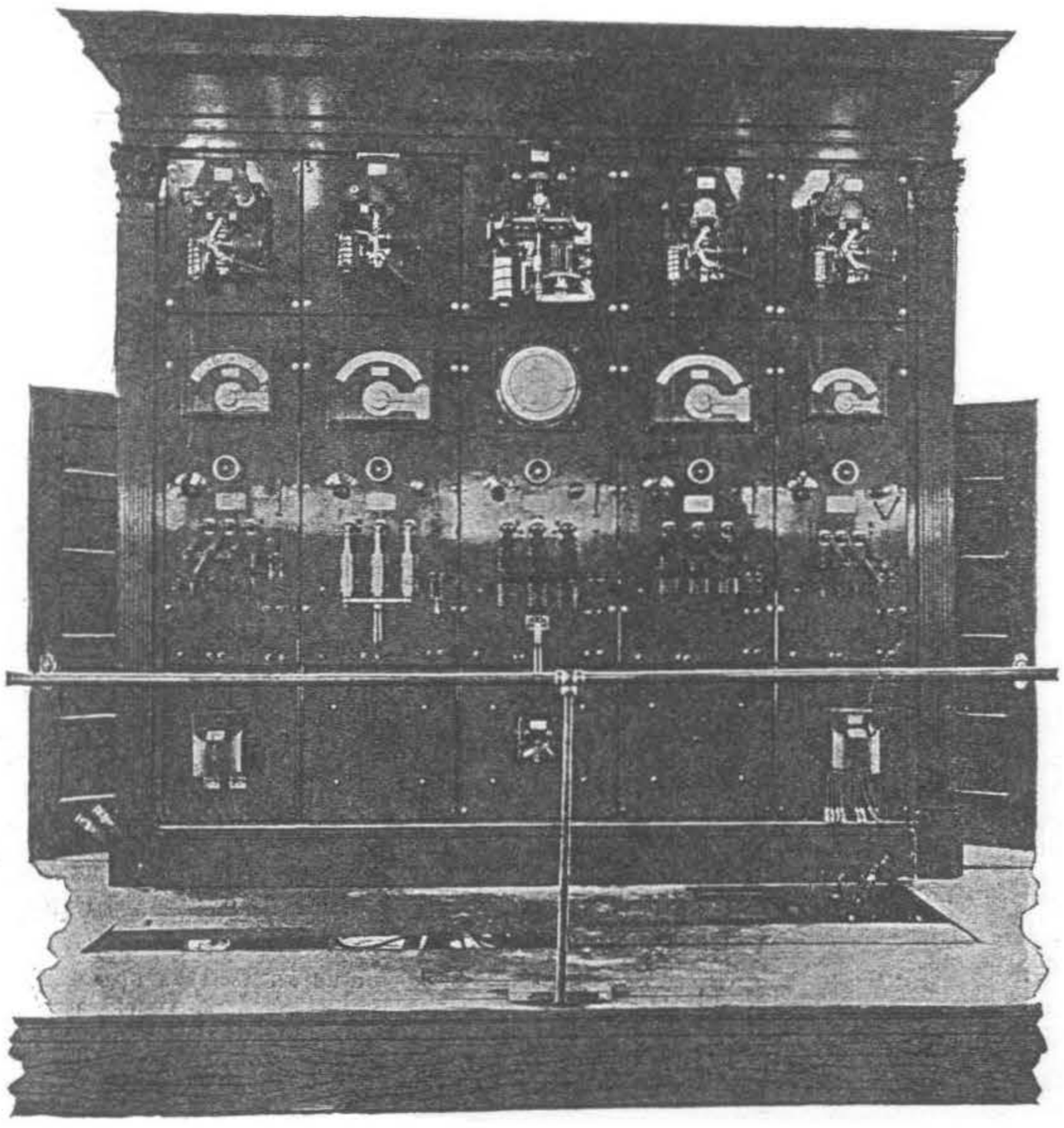

FIG. 5. ELECTRICITY AT THE WORLD'S FAIR.—SWITCHBOARD, INTRAMUAL POWER STATION.

which maintains the exact speed of the generator by which it is driven, except in cases of extreme overload. The armature of this machine is provided with a double pulley with belts driving a Worthington pump and a 40-light Westinghouse alternating current arc light dynamo. The armature is supplied with a direct current commutator connected with the same winding which receives the alternating current, and delivers direct current at a potential of 500 volts. This current is utilized for operating two 30 horse power street railway motors mounted upon a standard Dorner & Dutton truck, and also a 60 horse power direct current motor mounted upon an Ingersoll-Sergeant air compressor. This direct current also supplies a series of direct current constant potential arc lamps. The current from the switchboard is also carried directly to a 60 horse power two phase motor and rotary transformer, which receives the current at 36 volts and delivers direct current at 50 volts adapted to electrolytic work, charging of storage batteries, and is at present used for operating the large Schuckert search light in an adjoining space. The current from the switchboard also operates a 60 horse power two-phase Tesla motor of the synchronous type, which is adapted for any kind of constant speed work. In the present exhibit, it is direct coupled to a 45 kilowatt slow speed alternator of the constant potential type used for incandescent lighting. Current from the switchboard is also directly utilized for supplying incandescent lamps.

It is commonly recognized that the mechanical design and workmanship upon electrical apparatus has fully as important a bearing upon its successful operation as the electrical design. In fact, in actual experience it is found that electrical enterprises which have failed or have been unsuccessful have been deficient usually in mechanical rather in electrical elements. It is, therefore, of especial importance to note the mechanical features of a new system, and to observe whether simplicity and strength and durability are insured. Visitors to the present exhibit are struck with the general similarity in construction of the machines employed for widely different electrical purposes. The general form and construction of the large Tesla motor of the rotating field type, the alternate current generator, the alternate current motors, the rotary transformers, the alternating current arc machine and the constant potential alternator have an appearance of general similarity.

The main castings are two in number. The lower one contains half of the field magnets and the bearings for the armature shaft. This simple form insures rigid bearings for the armature. The upper casting contains the remaining field magnets. The field magnets are made of laminated soft steel plates of high permeability, which are cast into the yoke of the machine. The armature is built up of thin disks of soft steel with grooves in the surface for receiving the windings. The armatures are drum wound with, in general, large conductors placed in special heavy insulating tubes through the slots. This construction affords excellent insulation and protection of the wires, and the strains upon the wires, which in case of sudden heavy loads or short circuits may be very great, are transmitted directly to the iron core without chance for slipping or abrasion. In general, no band wires are required. The winding and connection of the armature of the multipolar machines for delivering direct current are such that there are always two and only two parts of the winding in multiple. This insures electrical symmetry, which prevents the improper distribution of current in the armature conductors, which would result if there were a greater number of armature circuits in multiple and the armature should get slightly out of center from excessive wear in the bearings, or other cause.

Attention is called to these points of simplicity and solidity of construction because they are so vital to the success of electrical working, and because the general improvement which is constantly being made in the mechanical development of electrical apparatus has been fully utilized in the design of this system. It is much to the credit of the system, and confidence in its success is assured, for the very reason that it uses and makes but slight modification in types of machines which have been worked out in practice in other lines of service.

This system possesses characteristics which adapt it to a wide field of service, as it combines the requisites for transmitting power over long distances and for transforming it into suitable forms for distribution and application to a wide range of uses. The employment of the alternate current transformer permits the use of low potential machines securing greater cheapness, efficiency and a higher factor of safety than is possible with high potential machines. By the use of alternating current the difficulties in construction and operation, which are inherent to commutators, are avoided on generators and motors. The low pressure of the machine is readily transformed to potentials adapted to great distances. The alternating current supplies two-phase motors of either the rotary field non-synchronous type or of the synchronous type, and the rotary transformer transforms alternating into direct current. The work of this machine is equivalent to that of an alternating current motor driving a direct current generator. The two armatures, however, have been combined in one and placed in one field, and not only is the second machine eliminated but the output of the single machine is greater than that of the two machines together, and the efficiency is increased and the commutation of a greater current is readily effected. The alternating current circuit can supply, therefore, constant potential direct current at any voltage, and is available for all kinds of work in which direct current is necessary or is preferable to alternating current. Incandescent lighting may be supplied from the alternating current circuits, and arc lamps may be supplied by direct current from the rotary transformer or from arc machines driven by synchronous motors.

It should be noted that the idea of complication may result from the grouping of several applications of the system with the transmission system proper. The transmission system proper ends with the switchboard and rotary transformer in the receiving station. Other apparatus would be located where it may be required for use, distributed over a city or through mills and mines.

The alternating and direct current at various potentials for these various lines of service are secured from one generator and one transmission line. This is of practical

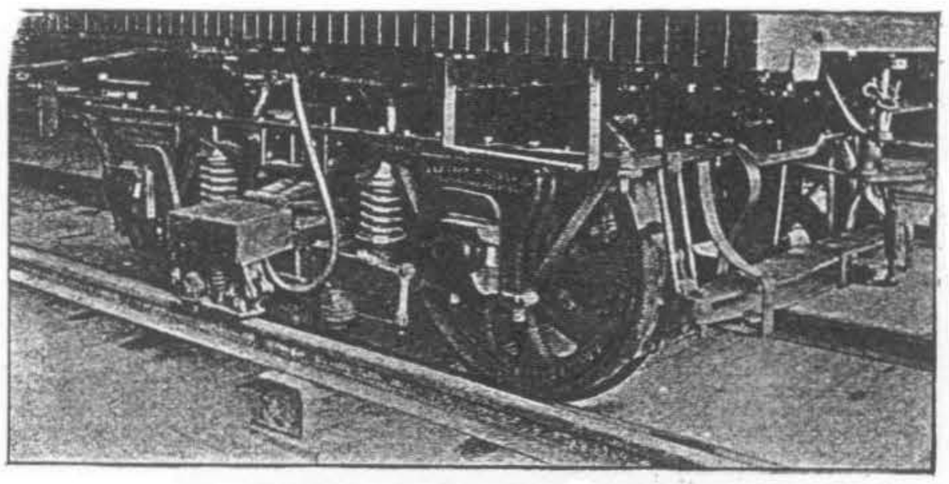

FIG. 7. ELECTRICITY AT THE WORLD'S FAIR.—TROLLEY SHOE, INTRAMURAL RAILWAY.

importance, both in small plants where it would be impracticable to install different generators and circuits for different kinds of service, and also in large plants where there are numerous generators. In such plants similarity and interchangeability of machines and circuits is of great economy and value in practical service.

Electrical inventors have done their part well in discovering the principles and laws which form the basis for a complete electrical system. Designers and mechanics have taken up these inventions and have developed them and constructed apparatus for practical working which is now presented to the electrical engineer for adaptation to the various demands for the transmission and distribution of power. He may take up the work with full assurance, as plants are already in operation which place beyond question the practicability not only of general distribution and service, but also of transmission over long distances and at high potentials, The successful installation and operation of a lighting plant for over 100 horse power using 10,000 volts over a 28-mile circuit in southern California is an initial step which covers a distance greater than is required in a majority of the cases in which power transmission is proposed.

This exhibit of the Tesla polyphase system is the mechanical realization of one of the most unique and beautiful discoveries in electricity in recent years.

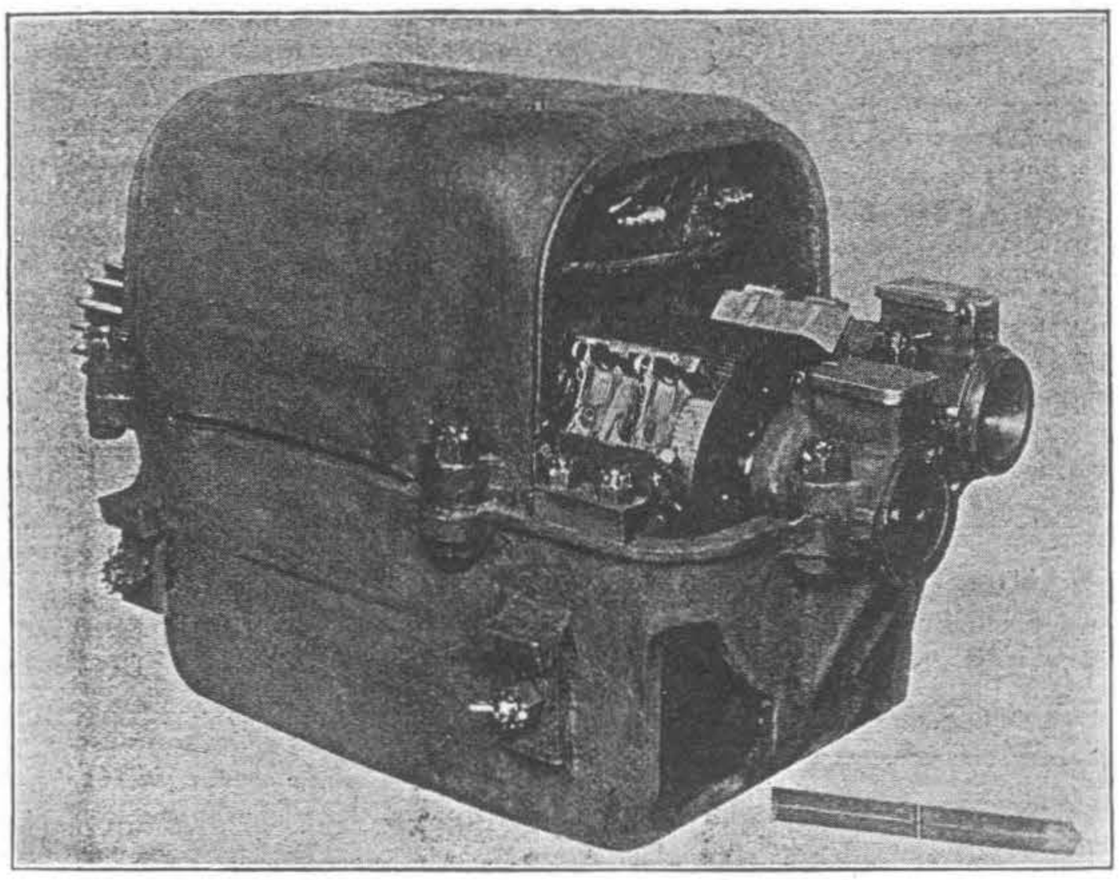

FIG. 6. ELECTRICITY AT THE WORLD'S FAIR.—133 HORSE POWER MOTOR USED ON INTRAMURAL RAILWAY.

WORLD'S FAIR NOTES.

Mr. Tesla is expected to return to Chicago the later part of this week and will then conduct in person some of the high frequency experiments which have made him so famous. The Westinghouse dark room will be used for the displays, but no definite time has yet been fixed.

The Hertz reflectors, which have been promised some time, are now shown in operation in the exhibit of Queen & Co. The reflectors are parabolic in form and when an oscilatory discharge of a high potential current takes place at the focus of one, the effect is reproduced at the focus of the other.

The Westinghouse company has placed a glass floor in one of the cars exhibited in the railway department so that the operation of the motor can be easily seen from above. The Columbus egg, which has proven such an attraction to the Westinghouse space, is now shown the first fifteen minutes of every hour from 3 until 10 p. m.

Visitors to the Electricity Building have found a new attraction in the Hoggson time stamp which has recently been placed in the exhibit of the E. S. Greeley Co. The stamp shows the date and time of day and the machine is electrically connected with a clock so as to change the time indicated every minute. On account of its many commercial uses the device is attracting considerable attention.

American Institute Of Electrical Engineers - Transactions
September 20, 1893

ALTERNATING CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY, VIZ.: TESLA'S APPARATUS AND CURRENTS. "RAPIDLY ALTERNATING ELECTROSTATIC STRESSES."

It is characteristic of alternating currents, that their energy is manifested, not so much *in* the wire, as in the space surrounding it, and the greater the frequency and the potential, the more extensive do some of the phenomena outside of the wire become. In this space, energized by the alternating current traversing the wire, may be exhibited by the aid of proper devices arranged to capture and transform the electric energy, light, heat, mechanical motion and chemical action; lamps glow, metals fuse, motors are caused to spin, and chemicals to combine. And this space around the current conveying wire is not narrowed to minute fractions of an inch, but may be measured in yards. Here is a field of force within whose influence a patient may be readily brought. Such a field would be termed an alternating electrostatic field; it is most marked around the terminals of a secondary coil whose primary is conveying an alternating current. It is the same field as that associated with the spark discharges of electrostatic machines, and even in a lesser degree with our best constructed medical induction coils, as I have shown by glow lamp tests applied to them.

The electrostatic field was indeed familiar to all; but in a feeble and minor degree. In medicine it has been a prominent feature of administrations from the influence machine in both simple insulation of the patient, in the spark, and more particularly in my own method of the static induced or interrupted current, and has been in medical use in connection with that machine. But so far as relates to induction coils, little or no account has been taken of the electrostatic properties of the current. Our attention has been wholly occupied, as has been that of the electrical engineers, with the current in the wire, and not with properties of this current—the electrostatic field outside of it.

But in induction coils affording high frequency, high potential currents, for instance, from hand to hand, it must now be noted that we have to deal with two effects—1st. The effect of the direct passage of the current through the body, and: 2nd, the lateral, surging, wave impulses spreading out in every direction from the passing current. The former of these effects alone has hitherto claimed attention. That the latter effects now

claim attention alike in the industries and in medicine is due to the wonderful experiments of Nikola Tesla. We have, as he modestly says, the same apparatus, the induction coil, and the same phenomena, only the apparatus is operated differently, and the phenomena are presented in a different aspect. So different indeed is the aspect of the phenomena that the entire scientific world hails their presentation as a revelation.

Mr. Tesla's first publication was in the *Electrical World*, of Feb. 21, 1891, under the title of "Phenomena of Alternating Currents of very High Frequency." Referring to effects upon the human body he writes, "the discharge of even a very large coil cannot produce seriously injurious effects, whereas, if the same coil were operated with a current of lower frequency, though the E. M. F. would be much smaller, the discharge would be most certainly injurious." The writer's experiences tend to show that the higher the frequency the greater the amount of electrical energy which may be passed through the body without serious discomfort."

The Tesla Apparatus.—Mr. Tesla obtains the high frequency mechanically, and by the aid of a well known natural phenomenon—mechanically by a specially constructed dynamo machine giving a frequency of about 10,000 per second, and naturally, by aid of the intensely rapid alternating or oscillating discharge of Leyden jars or condensers. The latter carry the frequency up to anywhere from 500,000 to 1,500,000 alternations per second. Low frequency may, however, be employed when the condensers are in the secondary circuit.

How important an element the Leyden jar may be in increasing frequency both in the electrostatic phenomena of the influence machine already in medical use, and in the Tesla apparatus, may be judged of from a calculation of Dr. Oliver J. Lodge that a common pint Leyden jar discharged through an ordinary discharging rod will possess a rate of oscillation equal to about ten million per second.

Mr. Tesla's high potential is due to the frequency and to "step up" transformation by coils. It consists practically of a high frequency dynamo whose current enters a primary wire, a secondary wire within whose circuit is included a condenser and discharging rods, and again a coil to which a part of the secondary wire acts as a primary.

The Tesla effects, as they are now frequently termed, are obtained:

a. By direct connection with both terminals.

b. In the space intervening between the terminals, or in the space about either one singly.

Using the apparatus above described with alternating current dynamos of low or high frequency, Tesla obtains remarkable effects. Among them may be noted:

a. The brush discharge.

With two cotton covered wires arranged parallel and near to one another, the wires are strongly illuminated by streams of flame, spreading from one to the other. The brush led from a circle of wire, 30 centimetres in diameter, to a small brass sphere, is formed into a beautiful cone of light, or again, concentrated upon small, thin wires, greatly intensifies the light.

With two circles of wire, respectively 30 and 80 centimetres in diameter, a continuous circular luminous sheet is produced.

An increase of the molecular or atomic vibration changes the color of the discharges from purplish to white.

In these experiments, the molecules of air about the terminals are intensely agitated, and give rise to the light.

b. Rotation of a motor connected to one terminal wire only of the coil.

c. Illumination of exhausted bulbs or lamps containing a refractory substance sealed within them, and when attached only to one terminal of the coil, the molecular bombardment within the bulb incandescenses the refractory substance, and emits light. Such substances are fused, disintegrated and dissipated by the intense electric bombardment.

Buttons of carbon, diamond, pumice-stone and carborundum were used. To protect the leading-in wire from the effects of the bombardment, a screen aluminium tube may be used, which acts electrostatically by reason of its conductivity, and also mechanically; the screen, becoming charged, economizes the energy supplied to the bulb by not taking it up after it is once charged. Again, the same exhausted bulbs are illuminated without the aid of a leading-in wire, the energy required being transmitted through the glass.

d. To excite vacuum tubes throughout the whole extent of a room, lighting up the tube wherever it is held in space, and at a distance from the conductor, the intense electrostatic field is set up by converting the oscillatory current of a condenser to a higher potential. Such a field Mr. Tesla establishes between two sheets of metal several yards in area and several yards apart. A vacuum tube held within the space between the metal sheets, glows intensely.

It becomes an interesting question to determine to what extent high potential, high frequency currents may be of value in medicine. The shock from the secondary coils above described are very light and can be taken without inconvenience. This to many has seemed remarkable on account of the very high voltage. Much speculation has been indulged in as to why these currents do not produce great muscular contraction, and great pain, and dangerous results. It has been suggested that the rapidity of the alternations is too great to excite the nerves, or again, that the current thus generated does not penetrate the conductor, but traverses only its surface. An explanation would seem to me to be that the current strength of what seems to be a killing current is comparatively small, since it is reduced enormously by each "step up" transformation. But other explanations are advanced.

In the immunity from pain and muscular contraction observed by D'Arsonval with a low frequency and a current strength of 5 amperes, another explanation must be sought for, and this is the comparatively gradual rise and fall of potential characteristic of the sinusoidal current, and physiologically vastly different in its effects from the impulsive rush of the condenser currents of Tesla and myself. D'Arsonval's high rate of frequency is obtained from an alternator and from induction coils, and condensers.

Whatever effects are to be obtained from Tesla currents must be obtained:

a. By the direct passage of the current through the person.

b. By this means, and by taking into account the lateral electrostatic surgings outward from this direct current.

c. By interposing the patient within the rapidly alternating electrostatic stresses constituting the field between the terminals, and yet not in contact with them.

Electro-dynamic induction effects need not probably be taken into account.

The extended physiological effects of the Tesla currents have yet to be investigated, since no apparatus has been available to

physicians or physiologists, but judging from the powerful effects upon human beings of the currents of electrostatic machines whose output is more feeble in total energy, even if equal in potential, these currents seem to me to promise most interesting and most fruitful results.

We can in our imagination picture a future group of patients pursuing any agreeable occupation, reading, conversing, playing games, and so on, in a room whose two opposite walls are of metal connected to the two terminals of a Tesla apparatus, and thus submitted to a furious molecular bombardment in the intervening space. We can imagine the surprise of the new comers, as they see the vacuum tubes carried in their hands burst into a glow of light when they are brought within the influence of the magical and invisible stream. We know that their temperatures would be raised by the bombardment, and we cannot help believing, though awaiting the proof, that profound alterations in their nutritional processes would be produced, whose influence would be far reaching in the cure of disease, particularly of the functional type.

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We present to our readers on page 68 of this issue a brief sketch of Mr. Tesla's latest achievements. Figures are not given, because the apparatus has not reached that state of mechanical perfection at which it is expected, sooner or later, to arrive. Sufficient to say, however, that with one of his oscillators and generators, each weighing but a few pounds, he has brought to bursting a 50 candle-power standard incandescent lamp. He has furnished us with a means of obtaining great outputs with almost minimum masses of metal. The oscillators have a promising future before them, and we await with interest their development.

THE MECHANICAL AND ELECTRICAL OSCILLATORS OF NIKOLA TESLA.

"Obedience,
Bane of all genius, virtue, freedom, truth,
Makes slaves of men and of the human frame
A mechanized automaton."—*Shelley.*

Thus has it been with nearly all projectors. Pioneers into the unknown have felt their power when they saw the unlimited stretch before them.

A great man upon being asked how he managed to accomplish more than others, replied, "I just do a little bit more than anybody else has done."

It has been said that a genius is one who takes infinite pains, and that he is born, not made. These statements hardly seem to reconcile themselves to each other, unless it be, the power of intense concentration and of almost limitless energy is a divine gift.

Incidents amount to nothing unless they are recognized and appreciated. The humming tea-kettle with its latent power was the vision on the wall to him who first recognized its importance. The frog legs of Galvani was but an accepted hint to those who laid the foundation of our grand and growing science. As in the life of man, where his advent is a bright spot in his history, so these pioneer discoveries were the beacons which showed the way to higher and more useful things.

We are almost tempted to change the words of the wise and worldly Solomon, who said, "There is nothing new under the sun," to, "There is nothing old under the sun." All fields present vast possibilities in their cultivation. The fruits to be obtained from these rich and generous soils are only to be procured by those who work to gather them.

Launched as we are into the realms of imaginative science, we cannot help but realize that it is the severely practical which, in the end, advances us most. Progress, strong and steady progress, having the inertia of a master mind, is full of possibilities. He who is free, untrammeled and backed with a store of the essentials that have gone before; he who lives in a world of his own and has a strong mind in a strong body, is bound to produce that which will startle plodders in the beaten paths well worn by those, the multitude gone before.

Few are they who can say: "I am as free as Nature's first made man."

He then who profits by the experience of others and follows his own line of thought approaches a certain state of freedom; but it is merely comparative.

"On their own merits modest men are dumb."

Some men have said that while Nikola Tesla has produced wonderful results, he has given the world but little of practical value. Those who have been careless enough to make this statement have evidently not realized that of which they spoke. Was the voltaic pile the dynamo of to-day? Was the æolipile the steam engine of the present? A little reflection will show us that Mr. Tesla is a pioneer; but above all, that he is essentially a practical and efficient economist. He has eagerly and unceasingly searched for radical defects in existing machines. He has patiently sought for losses in efficiencies, which, to the ordinary experimenter, were considered a matter of course. His work during the last few years, as the public has imagined, was in the line of effects due to currents of high frequencies, and a method of transmitting intelligence by means of electrical waves to almost limitless distances on the earth. And the public have been right; but little did they imagine what this man had in store for them.

A few sceptics may raise their eye-brows and say, "What does all this amount to?" These few may be quickly silenced by showing to them results. Could anyone ask for more? But to those who are impatiently waiting and who have a sincere belief, based upon previous experiences, that "the mountain will not bring forth a mouse, but that out of it a greater mountain shall spring forth," I will say: Listen to a simple tale which we will call "The History of an Invention."

On Friday evening, August 25, Nikola Tesla startled the assembled scientists at the World's Fair with what he chose to call his mechanical and electrical oscillators. None knew what he was going to see when he read the title of this lecture. None knew of the possibilities which would be presented by this radical departure in the twin sciences, steam and electrical engineering. And here is the way in which this last child of Mr. Tesla's brain was conceived.

While Mr. Tesla was working on his motor he realized the need for absolute synchronism, and this we will call Necessity No. 1.

In his extensive and varied work in high frequency currents, he obtained exceedingly small efficiencies, due to the fact that the north and south poles of his magnets were, in many cases, as close as one-sixteenth of an inch apart, and the wires which wrapped them were one-thirty-second of an inch in diameter. Magnify these conditions and the practical electrician will readily see how the efficiency will be reduced to a minimum. This led Mr. Tesla to think that the remedy for this defect would be the discarding of iron, thus making his armature entirely of copper; and to this we will give the name, Necessity No. 2.

His thoughts were not alone on electrical engineering. The losses from the furnace to the dynamo stood out in bold relief in the intricacies of his thoughts.

One of the most useful devices to mankind is the crank, that means of changing a reciprocating motion to a motion of revolution. But in that change, oh what a loss is there! That ponderous thing—the flywheel of the steam engine—melted into thin air over 50 per cent. of the power from the piston. We have a maximum resistance, practically an infinite resistance, at two points, each co-incident with the axis of the piston head, and this resistance diminishes until we obtain two points which have a minimum resistance, and in this passage from the infinitely great to the almost infinitely small we recognize our loss.

In our mammoth engines it requires special buildings to construct the separate parts, and then think of the huge masses of metal—necessary evils to the heretofore existing steam engines. Advances have been made, it is true, and a 12 per cent. loss due to belting has been saved by the direct coupled dynamos. But before the advent of the oscillator few attempts were made to reduce this sinful waste from the piston to the flywheel, and this we will call Necessity No. 3.

Here then are three great necessities, and if we may believe the old adage, we should expect great children from these great mothers; nor have we any cause to be disappointed.

Although Mr. Tesla's mechanical and electrical oscillators are not, as yet, practically perfect, the theories stand and they are obviously reasonable and correct.

We first will deal with the mechanical oscillator. We shall see how this device does away completely with those accessories called the flywheels, regulators and governors. We shall see how the ponderous pile of metal to be moved may be reduced to one-fortieth its original bulk, and still have its efficiency maintained.

The mechanical oscillator briefly described may be pictured by imagining an exceedingly short stroke piston, and port valves which extend completely around the cylinder. The oscillations of this short stroke piston may be varied in frequency by the resistance encountered. In practice these oscillations need not be more than from 40 to about 90 per second, and since the length of the movement of the piston is slight, its lineal velocity is hardly more, if equal, to that of an ordinary Corliss engine. Here though is where the beauty of the oscillator is apparent. It is perfectly regular in its movements.

To give a better idea of its method of motion we can compare it to a swinging pendulum which, though we may increase its velocity at any point of its swing, its time of oscillation is not varied a thousandth of a second, provided, of course, that nothing but gravity and the uniform surrounding medium, the air, affects it. This is exactly the case with the oscillator; if it is resisted at any point of its path, or if the steam pressure is varied, it makes no difference in the time of its "swing," and we thus have an oscillator which may be made absolutely synchronous with other oscillators, by the addition or subtraction of definite weights. Necessity number one is thus filled.

It will be seen also that necessity number three is here done away with, for our motion is simply a reciprocating one, and we need no conversion to a motion of revolution. Instead of having a generator whose armature revolves, we have one which accommodates itself to this reciprocating motion, and whose armature or field magnets, as the case may be, oscillates in a straight line. Some, perhaps, will say that this is nothing new. Nothing new is claimed for it; it is simply an improvement—an improvement which accommodated itself to the existing conditions required by the mechanical oscillator.

Let us take, for instance, the case where the armature is directly and rigidly connected with the oscillating piston. A simple form of the field magnets would be represented by two iron tubes placed concentrically—the inside diameter of one twice the outside diameter of the other—and imagine both these tubes to have such thick walls that the inside tube becomes practically a rod, the outside tube having the same thickness. Let the farther end of these two tubes be covered by a mass of iron, and immediately underneath this covering, around the inside tube, be wrapped the field magnet coils. Upon the passage of a current an intense field will be produced, and backwards and forwards in this field, near the other extremity of the two tubes, does a simple coil of wire oscillate with a clearance of but a hundredth of an inch on each side. This coil of wire is the armature, whose axis is co-incident with the axis of the mechanical oscillator. Thus we see flywheel and governor are thrown aside; a simple efficient steam engine is produced and hardly a simpler dynamo could be conceived. Delicate and absolutely accurate mechanical construction is not so necesssary as in the case of other machinery of its kind. No larger tool than a six inch lathe is necessary to turn out a 100 horse-power oscillator. Owing to its small size the losses due to heating large masses of iron are entirely done away with.

Here we have two new devices constructed on sound scientific principles. It rests with the mechanical engineer to perfect the minor details of the mechanical construction of the mechanical oscillator, and with the electrical engineer to give the finishing touches to the electrical oscillator. There is a great future before them.

Who shall they or he be?

It needs no vivid imagination to hear the answering echo of this question as it resounds in the minds of the true lovers of Nature and Progress; for who can possibly know more about this great improvement in steam and electrical construction than he, the father, who has given life to and tended these oscillators with most intense solicitude through the progress of the invention? And although the most prominent quality which all have observed in Nikola Tesla is his true modesty, his apostles should be allowed to place his name alongside of those of Franklin, Faraday and Henry. JULIAN A. MOSES.

Mr. Tesla's Lecture at the Congress.

Mr. Tesla has succeeded in constructing a new, and what seems to be a perfect, mechanism for producing electrical oscillations of a constant period, independent of the driving force, of frictional losses, and the load. At his lecture on "Mechanical and Electrical Oscillators," at Chicago, he mentioned, among other things, that he was able, by this new apparatus, to produce an alternating current in which the E.M.F. of the impulses in one direction preponderates over that of those in the other, so that there is produced the effect of a direct current. In fact, he expressed the hope that these currents would be capable of application in many instances, serving as direct currents. The New York *Electrical Engineer* describes the machine, but only very scantily. The principle involved in this preponderating E.M.F. is explained by Mr. Tesla as follows: suppose a conductor is moved into the magnetic field and then suddenly withdrawn; if the current is not retarded, then the work performed will be a mere fractional one, but, if the current is retarded, then the magnetic field acts as a spring. Imagine that the motion of the conductor is arrested by the current generated, and, at the instant when it stops, there is still the maximum current flowing in the conductor; then this current will, according to Lenz's law, drive the conductor out of the field again, and, if the conductor had no resistance, then it would leave the field with the velocity at which it entered it. Now, it is clear that if, instead of simply depending on the current to drive the conductor out of the field, a mechanically applied force is so timed that it helps the conductor to get out of the field, then it might leave the field with a higher velocity than that at which it entered it, and thus one impulse is made to preponderate in E.M.F. over the other. With a current of this nature Mr. Tesla energised magnets strongly and performed many interesting experiments, bearing out the fact that one of the current impulses preponderates. We hope to see more of Mr. Tesla's apparatus when he next honours us by bringing it to England.

Western Electrician.

EVERY SATURDAY.

Vol. XIII. CHICAGO, OCTOBER 7, 1893. No. 15

Electricity at the World's Fair.

Awards formed the principal topic of discussion among the electrical exhibitors at the World's Fair last week. The exclusive publication of the list in the WESTERN ELECTRICIAN excited much interest, and the paper was in great demand. The comments were many and varied. Some exhibitors were jubilant; others were angry and disgusted, while not a few professed indifference, with the remark, "What do the awards amount to, anyway?" It was noticeable, however, that all seemed eager to secure the diplomas and medals before the list was posted. Many, also, were puzzled by the fact that several awards, in a number of cases, were given on one class of apparatus. This is explained by the fact that the judges did not consider the comparative merits of exhibits in making awards. They examined each exhibit entered for an award separately, and if, in their judgment, the article or group was found to be worthy of commendation an award was given it, the specific points of excellence being detailed in the diploma. It thus happened that on the commoner sorts of apparatus, such as arc lamps, for instance, a number of awards were given on the same class of exhibits, although the exact language of the awards, specifying the points of excellence, will not be alike on any two diplomas. In effect, the judges, by making an award, say that the exhibit, while perhaps not better than another, is excellent, and as such entitled to recommendation to the public. No effort was made to single out the best exhibit in each class for a solitary award. By bearing this distinction in mind a better understanding of the work of the judges will be had.

Some of the awards were based on tests and some were not, according to circumstances. The awards on storage batteries, incandescent lamps, insulated wires for electric lighting, standard cells and some of the transformers, however, were not included in the list published last week because tests on them were not completed. Some of these were announced later in the week, but it will be some time before the list is entirely complete. There were 183 awards in the list of September 26th, and it is expected that the total will reach 210. In the list published last week the General Electric company's award numbered 18, for "alternating current dynamos for series arc lighting," should have been omitted, and under the head of Germany "Gemelzen, Nuremburg," should read "C. Schmelzer, Nuremberg." Otherwise the list is correct—a gratifying result when consideration is taken of the haste that Prof. W. E. Anderson was obliged to make in preparing it, owing to the pressure of other duties. Additional awards have been announced as follows:

United States.

American Battery company, Chicago.—Storage batteries.

General Electric company, New York.—(30) Incandescent lights used in the decoration of rooms and other structures.

Elisha Gray, Highland Park, Ill.—The telautograph.

Westinghouse Electric & Manufacturing company, Pittsburg.—(13) High tension experimental apparatus.

Germany.

Gas Motoren Fabrik Deutz, Cologne.—Gas motor directly connected to dynamo.

Charles Pollak, Frankfort.—Storage batteries.

Great Britain.

Epstein Electric Accumulator company, London.—Storage batteries.

Austria.

Schindler & Jenny, Kemmelbach.—Electrical cooking apparatus.

The judges authorize the statement that the Allgemeine Elektricitaets Gesellschaft of Berlin received no award because its exhibit was *hors concours*, owing to the fact that Herr Rathenau, the managing director of the company, was a member of the committee of electrical judges. For a similar reason no award was given to the "Transactions of the American Institute of Electrical Engineers," the secretary of the Institute being a judge and many of the other judges being members of the Institute.

The illustration presented on this page gives an excellent idea of a portion of the Westinghouse incandescent lighting plant in machinery hall. The features of thi

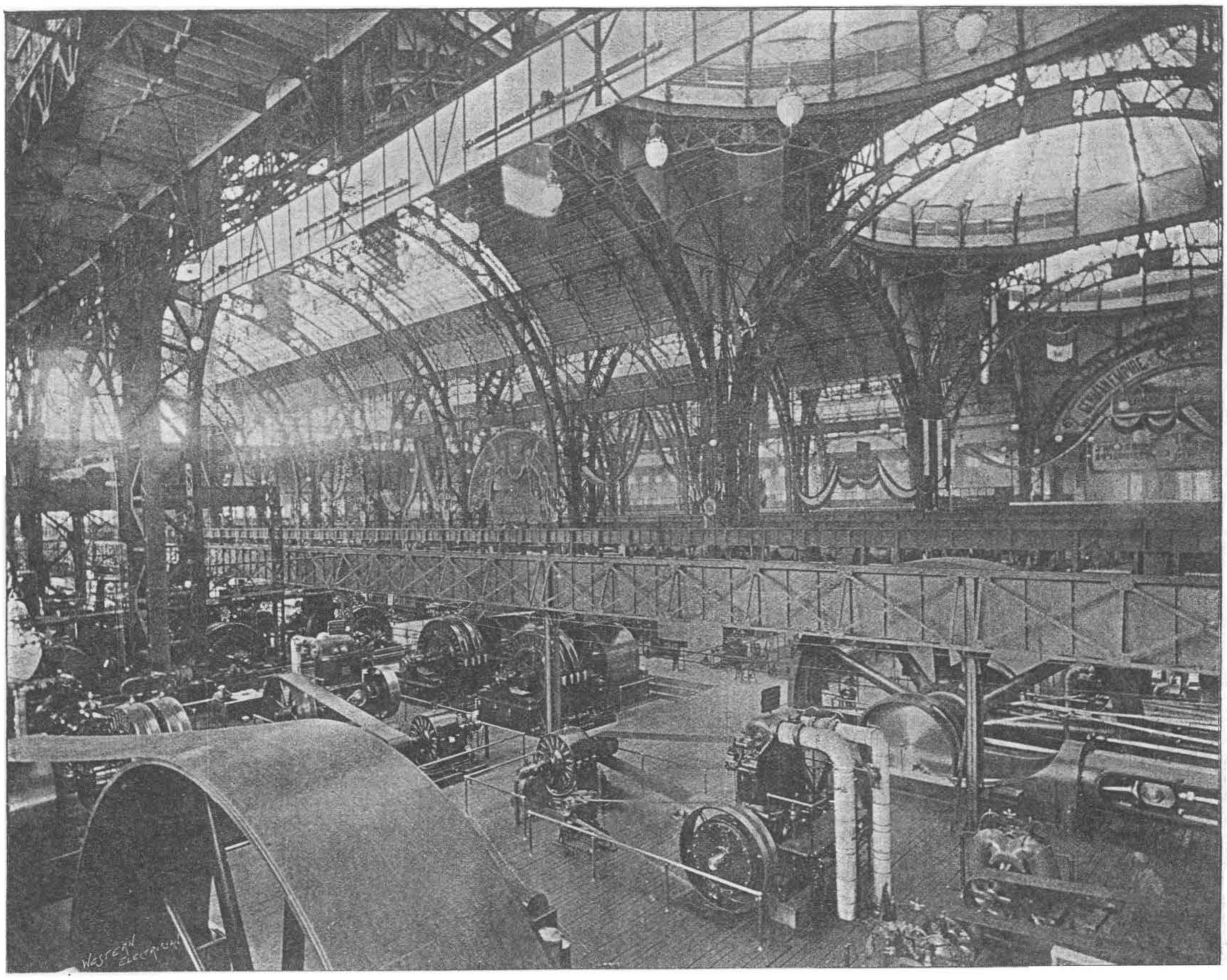

FIG. I. ELECTRICITY AT THE WORLD'S FAIR.—WESTINGHOUSE INCANDESCENT LIGHTING PLANT, MACHINERY HALL.

large and interesting installation have been before described in this journal. The picture was taken from the second gallery of the Westinghouse switchboard. The two 10,000 light alternators belt-driven by the Allis 2,000 horse power engine are shown and also a general view of the plant. The fly-wheel shown prominently in the foreground is that of the Fraser & Chalmers 1,000 horse power engine. Fig. 2 shows the row of four directly connected Westinghouse engines and alternators. It is interesting for comparison with the belt-connected sets.

On a recent busy Saturday the Elektron company carried 3,111 persons in its electric elevator in electricity building.

The incandescent lamp test is proceeding satisfactorily. The General Electric company of London has submitted a number of 16 candle power, 100 volt lamps for alternating current, and these are being tested with the others. Several 32 candle power lamps are also being tested.

Among the floats to appear in the parade on Chicago day is one which will be furnished jointly by the General Electric company and the Chicago Edison company. The float will be 38 feet long, 28 feet high and 9 feet wide. The design chosen is that of an immense dragon made of papier mache. Not a sign of the latter material will be seen, for every spot on the dragon will be covered by miniature incandescent lamps, of which over 1,000 will be

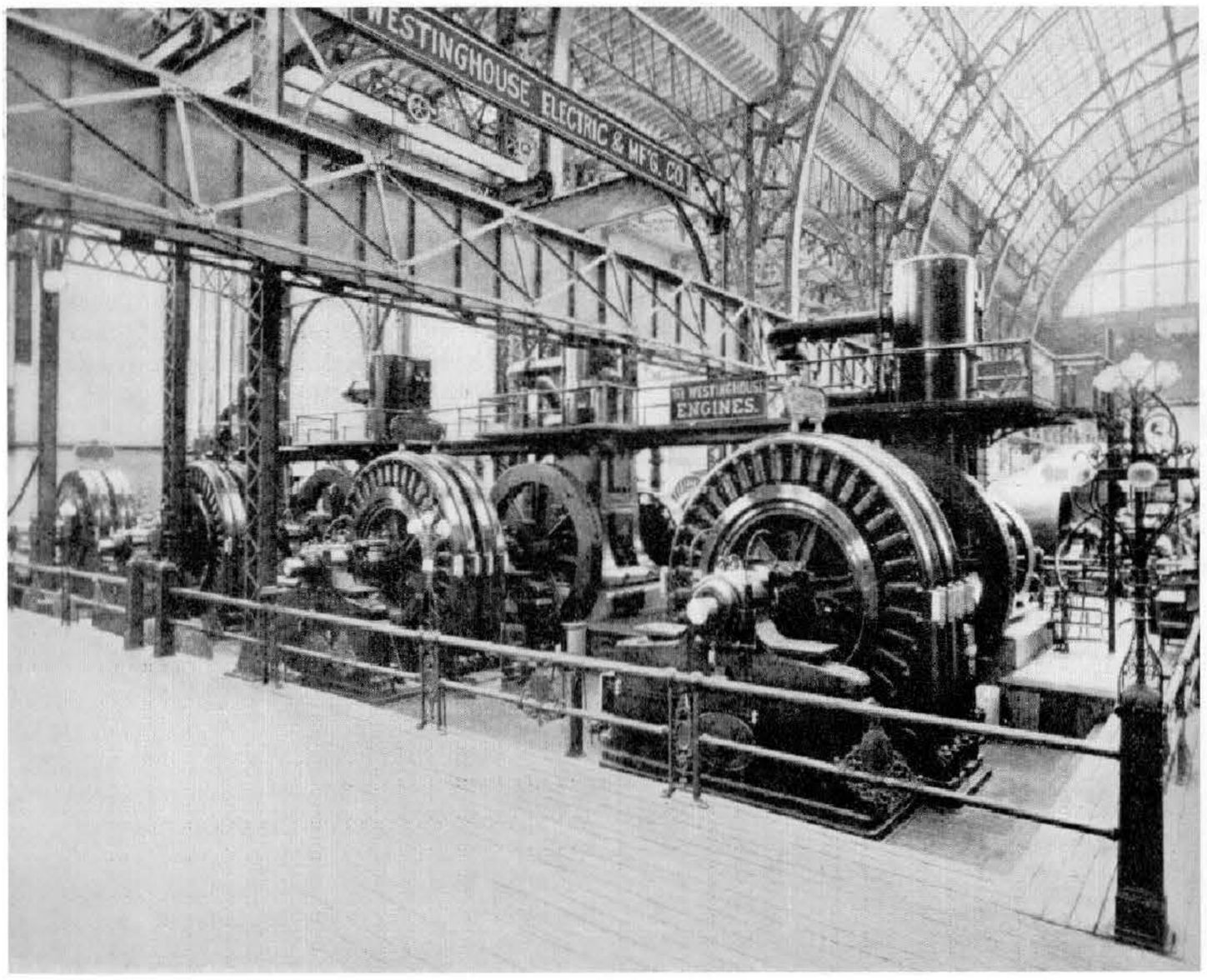

FIG. 2. ELECTRICITY AT THE WORLD'S FAIR.—WESTINGHOUSE ENGINE-DYNAMOS, MACHINERY HALL.

used. Beneath the truck a directly connected marine lighting set of 15 kilowatts capacity and wound for 80 volts will be placed, out of the sight of the spectator. By a switching arrangement the color of the dragon will be changed at intervals from green to red. The flaming breath and steaming nostrils will be supplied in a simple manner. The exhaust steam will be conducted through the throat and nostrils of the gleaming papier mache dragon. Dazzling lights will extend along the wings to the tips, which will be twenty-eight feet above the truck. Eight horses will draw this flaming creature, with its blazing red eyes and its chameleon-like hide. Immediately in front of the horses will be another truck, on which will stand the genius of electricity in the form of a woman. She will hold a fairy wand in her hand, at the tip of which will be placed a brilliant white light, supplied by a current from the dragon behind. The cost of the float will be more than $2 000.

Fig. 3 shows the exhibit of the firm of Schuckert & Co., of Nuremberg, Germany. The display is located in the northeastern portion of electricity building, on the ground floor, and is devoted mainly to marine work and search-lights. Three projectors are exhibited, the largest, which is prominently shown in the illustration, being erected on a platform in the front of the exhibit space and seven feet above the floor. This search-light is operated every evening and has a mirror diameter of 90 centimeters. It has double dispersing lenses and is the largest type used in the German and other navies. Two projectors of this size and character are installed on the cruiser Kaiserin Augusta, which attracted much attention at the naval review in New York harbor last spring. The movement of the drum is accompanied by two motors in the base of the projector, which are controlled from a wall governor, which, on shipboard, can be located at any point desired. The lamp consumes 120 amperes of current, the potential at the carbons being 55 volts. Current is supplied from the adjacent Westinghouse exhibit. This projector is provided with a jalousie signaling apparatus consisting of an iron screen in front of the lenses which can be rapidly opened and closed and by which messages can be telegraphed through the atmosphere by dots and dashes of light. Back of the large elevated search-light are two others, each having a mirror diameter of 60 centimeters. The one on the north side of the space is intended for naval use, while the other, shown at the right in the picture, is intended for fortifications. Between the two smaller search-lights is an ingenious electric signaling device for naval use, designed as a means of communication between the commanding officer on the bridge and the engine room. By moving the handle of the instrument until a corresponding pointer rests on that portion of the dial marked with the order desired to be given, the officer causes a similar movement on the dial of a duplicate instrument in the engine room. The instrument is made double, so that the engineer can signal back the order, which is repeated on a second dial, thus preventing mistakes. An engine-dynamo for use on shipboard is shown in the center of the exhibit space. The combination is compact and strong and is said to have high efficiency. The engine runs at 450 revolutions per minute, and the dynamo has a capacity of 170 amperes at 70 volts. The latter has four poles and a Gramme armature. Two copper brushes set at an angle of 90° on the commutator are used. The machine is designed with the idea of supplying current for either search-lights or incandescent lamps. It is used to a considerable extent in the German navy. On a table is shown the horizontal arc lamp used for projectors, with a differential magnet for establishing the arc and a feeding magnet. A number of measuring instruments are shown, including a recording wattmeter and Hummel ammeters and voltmeters. The improved Pilsen arc lamp is exhibited in several forms, some of the fixtures, as shown by the illustration, being highly ornamental. About the walls of the booth are a number of photographs of central stations equipped by Schuckert & Co., as well as large diagrams showing the useful angles of light of the Mangin and Schuckert mirrors for search-lights, greatly to the advantage of the latter. An interesting automatic cut-out switch and a display of electrolytic zinc complete the exhibits. The latter display includes a plate of zinc four feet long and two feet wide produced by the Dieffenbach-Kittler electrolytic process at zinc mines in Westphalia. Granulated zinc is also shown. Both are produced directly from the ore. A display of carbons made by C. Schmelzer, of Nuremberg, is also made in this space.

In addition to the exhibit in electricity building Schuckert & Co. have four large search-lights on the roof of the manufactures building, supply the arc lights in the German government building and show drawings of electric lighting stations in the German engineering exhibit in transportation building. In machinery hall there is a Deutz gas engine directly connected to a Schuckert dynamo, which supplies current for arc and incandescent lamps.

The Washburn & Moen Manufacturing company has three exhibits at the World's Fair—a general exhibit in manufactures building, a display of wire ropes, etc., in the mines building, and an exhibit of electrical wires and cables in electricity building. The first and last named are illustrated in Figs. 4 and 5. In the general display copper wire is shown in all stages, including ore, ingots, rods and all sizes of wire down to the finest that can be drawn, half the thickness of a human hair. This exhibit also includes piano wire, iron and steel wires, watch and clock springs, chains, tacks, nails, spikes, bale ties, bicycle spokes and many other kinds of hardware. Indeed it is asserted that there is hardly a house in the United States that does not include in its furnishings and fittings some article made by this company, which employs nearly 6,000 men in good times and possesses the oldest wire factory in the country. The electrical exhibit, Fig. 5, can be found near the center of the eastern gallery of electricity building. It consists of a large central show-case, apparatus for testing the "salamander" fire-proof wire and samples of all kinds of wire for electrical purposes. An interesting feature is a section of the largest insulated cable ever made, having a cross-section of copper of 2,500,000 circular mils. Feeders for electric railway lines having an area of 500,000 circular mils are also shown. An order for 145 miles of this feeder cable for the Brooklyn City Railway company has just been completed by the Washburn & Moen company. Smaller sizes of feeder cables are also shown and all sizes of weather-proof wire, ranging from No. 0000 to No. 20, rubber covered and both taped and braided. Magnet wires, both round and flat, are displayed. It is claimed that copper of a higher conductivity than any other is used for this wire. A complete exhibit of "salamander" insulated fire-proof wire, "salamander" lamp cord and "salamander" switch-board wire is made. A remarkable test of the fire-proof qualities of this insulation is shown. A sample is put in circuit with a piece of lead-covered cable at the testing table before alluded to. A current of 150 amperes from accumulators is then passed through the wires until the insulation and lead covering of the other wire are melted. The "salamander" wire is then taken out uninjured. A similar test is made with underwriters' wire and "salamander," heating the wire to a red heat and destroying the insulation on the underwriters' wire without affecting the fire-proof wire. The exhibit also comprises lead-encased cables, office and annunciator wire, hard drawn trolley wire, iron signal strand wire for electric railways, coils of tinned copper wire and rubber covered wire arranged in seven pyramids. The large central case contains a pyramid of "salamander" lamp cord in different colors, samples of all sizes of wire, bare and insulated, and coils of hard drawn and annealed copper wire, one of which is 35 miles long. A curiousity is a copper rod drawn from No. 0 size to No. 40, presenting the appearance of a metal whip. The electrical exhibit is a comprehensive and instructive one and is well worth a visit. Herbert Smith is in charge of all the exhibits of the Washburn & Moen company, while C. T. Snedekor has supervision of the display in electricity building.

The Action of the Eye.*

NIKOLA TESLA.

It can be taken as a fact, which the theory of the action of the eye implies, that for each external impression, that is, for each image produced on the retina, the ends of the visual nerves concerned in the conveyance of the impression to the mind must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distant reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and, therefore, upon the retina. Will it ever be within human power to analyze the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science, in the solution of which many if not the majority of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he was able to *see*, in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

Another fact having a bearing on this subject which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation, is that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, observable even in broad daylight.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting that the very conception of that which is perfect, or seems so to him, has been gained through this same instrument. First, the eye is, as far as our positive knowledge goes, the only organ which is *directly* affected by that subtile medium which, as science teaches us, must fill all space; secondly, it is the most sensitive of our organs, incomparably more sensitive to external impressions than any other.

This divine organ of sight, this indispensable instrument for thought and all intellectual enjoyment, which lays open to us the marvels of this universe, through which we have acquired what knowledge we possess, and which prompts us to and controls all our physical and mental activity—by what is it affected? By light! What is light?

It is beyond the scope of my lecture to dwell upon the subject of light in general, my object being merely to bring presently to your notice a certain class of light effects and a number of phenomena observed in pursuing the study of these effects. But to be consistent in my remarks it is necessary to state that according to the idea now accepted by the majority of scientific men as a positive result of theoretical and experimental investigation, the various forms of manifestation of energy which were generally designated as "electric," or more precisely "electro-magnetic," are energy manifestations of the same nature as those of radiant heat and light. Therefore the phenomena of light and heat, and others besides these, may be called electrical phenomena. Thus electrical science has become the mother science of all, and its study has become all-important. The day when we shall know exactly what "electricity" is, will chronicle an event probably greater and more important than any other recorded in the history of the human race.

* Extract from paper on the "Action of the Eye," read before Franklin Institute.

The Action of the Eye.—It can be taken as a fact, which the theory of the action of the eye implies, that for each external impression, that is, for each image produced on the retina, the ends of the visual nerves concerned in the conveyance of the impression to the mind must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distant reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and, therefore, upon the retina. Will it ever be within human power to analyze the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science, in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he was able to *see*, in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain-action, as it were.—*Nikola Tesla, in Scientific American, New York.*

Nikola Tesla's Lecture.

Mr. Tesla's lecture on "Mechanical and Electrical Oscillators" was delivered in Assembly Hall at the southwest corner of the Agricultural Building at the World's Fair grounds on Friday evening as announced in the program. Every member of the congress with one or two exceptions was present and the greatest interest was manifested in the experiments that were shown.

It was twelve minutes after eight when Prof. Elisha Gray introduced Mr. Tesla to the audience in the following words: "I came down here to-night for the purpose of introducing to you a gentleman whose name needs no introduction as it is a household word with all electricians, but I wanted to do him the compliment of coming here as the official head of the World's International Congress of Electricians and to extend to him the compliment of an introduction for them as well as for myself. This compliment loses none of its force when I tell you that I have another official duty to perform to-night and it will be necessary for me to leave immediately, but if I should follow my inclinations I should stay, for no one wants to hear and see these experiments more than myself. I have the honor, ladies and gentlemen, of introducing to you Nikola Tesla. I wish to add one word, inasmuch as I have to leave; I am going to ask Dr. T. C. Mendenhall to do the honors for the rest of the evening."

Immediately the hearty applause subsided Mr. Tesla said: "Ladies and Gentlemen: We are told in a delightful anecdote how, many years ago, when science was still in its infancy, a man to whom the world is largely indebted for the discovery of a great truth was meditating in his garden when the idea came to him, and how on that occasion he was carried away by his enthusiasm. Be that an actual fact or not it is certain that the search for truth through the centuries that have elapsed has exercised an immense power on the imagination of man. It seems as though we are actual witnesses of the researches and experiments made by the discoverers and inventors of ages gone by, and that we are almost in a condition to know how they felt at the moment of sublime inspiration.

"I am sure in this audience there are many who have felt this most exquisite pleasure and whose presence here will forever fix the recollection of this evening upon my mind To feel this pleasure is accorded to but few; however, I can say myself that I have felt it and am still under the impression of the pleasure which the accomplishment of a few insignificant thoughts that have come to me and the speculation on the possibilities of their future development have caused. In these results I am, inventor like, quite taken up, and I hardly dare hope to be able to develop them as I wish, but I feel that I must explore them; and again I have doubted my ability to present them satisfactorily. Yet I am sure of the practicability of investigations in this manner from the few results I have so far obtained.

"I can best tell you what I have attempted if I comply with the scientific duty and tell you exactly the history of these inventions. It was at a time when I was strenuously endeavoring to solve a question or two which was considered insolvable, first, Was it possible to operate a motor without sliding contact, and second; was it possible to develop constant currents in a certain direction? I found the solution to the one problem and produced dynamos without commutators and that success emboldened me to go ahead and apply whatever of knowledge and experience I possessed to the solution of the other problem.

"On the occasion of my first visit to this country I stepped into the exposition at Philadelphia and I saw there a very thick copper washer provided with handles that visitors would move within a magnetic field. That day it occured to me that when the plate was moved slowly in the field there was experienced resistance, and that when the plate was suddenly pressed in there was a rebound as though it struck against something solid. After returning from the exposition the thought occurred to me that if I took a conductor and moved it into the field and then rapidly withdrew it, Icould in this way obtain whatever of electro-motive force there was. In the first place I was impressed with the analogy of this device to the induction coil, in which the same process takes place. When we impart current to the primary circuit we put lines of force slowly into the field and when we break the current we take the force swiftly away. I began to think of a mechanism which would be capable of fulfilling these conditions.

"During my work with induction coils and motors which succeeded I became familiar with currents of high frequency, and then I clearly realized the problem before me. I convinced myself that in alternating distributions we must induce currents of more thad one phase and that we must have a better organization and a perfected mechanism capable of rendering the current into steady oscillations before we could obtain the desired results. Here then I was confronted with this difficulty. I constructed small machines of the ordinary type which enabled me to investigate, but when I endeavored to construct machines with a

greater number of alternations for higher frequency I found that I met insurmountable mechanical difficulties.

"And then the idea came up and I asked, how it would be if I took a very strong field and reciprocated very rapidly a conductor in that field, would I not have a similar machine and one which would not involve loss in the iron? And now I began to consider this matter very seriously and later I considered this question, knowing what has been done in the field of harmonic telegraphy and supposing that instead of the ordinary dynamo we take dynamos constructed like the pendulum of a clock and on a harmonic vibration principle, would we not then obtain alternating currents of a perfectly defined and absolutely constant period, which it is impossible to accomplish with an ordinary machine because it possesses so great inertia? And then again I thought like this, with such powerful machines there is a possibility of transmitting energy through the air and by means of this energy of transmitting messages. This, then, is one of the mainsprings which has driven me into this work."

Here by means of diagrams Mr. Tesla described the construction of the engine which he has invented for producing these absolutely constant oscillations and which is operated by compressed air under 100 pounds pressure and delivered at the rate of 40 cubic feet per minute. One of these engines having a diameter of about two inches and a half and of about that length operated a small motor and has a capacity of nearly one-half horse power. After this Mr. Tesla showed the operation of the lârger engine having a piston and plunger weighing 20 pounds which was oscillated at the rate of 78 times a second, and stated that 5,000 or 10,000 oscillations per second could be as readily produced. The next experiment was made by attaching a horse shoe magnet having a wire about two feet in length inserted through it to show the vibration to the plunger of the engine. The engine was then set in motion, a current communicated to the magnet through wires attached to the nodes of the magnet wire. A copper disc revolving on an axis was then introduced by Mr. Tesla between the poles of the magnet while the same was being oscillated by the engine. The result of the experiment was that the copper disc began slowly to revolve, thus disproving the theory that there is no electro-magnetic force at work in the disc and that the force was simply one produced by induction as has been believed universally heretofore.

Mr. Tesla next attempted to show an experiment with what might be called a three coil generator, but the apparatus had been damaged in some way and refused to work. The next experiment was one with a large engine similar to that last described, having attached to the plunger of the oscillator a core of iron which played through four field magnets excited with a current at 5,000 volts from the Westinghouse plant. A current was generated by the apparatus, and was used to run a small registering motor, thus proving that generators can be constructed on the ideas evolved by Mr. Tesla in accordance with these more recent experiments, and having an absolutely constant current. It should be added that one of the claims made by Tesla for these oscillators is that the period will not be varied after the machine is started, whether the pressure be 10 pounds or 100 pounds, and that the electrical currents produced from small units will oscillate just as as the pendulum oscillates, and be unaffected by the circuit load or any imaginable condition. The oscillators are so constructed that they can be adjusted so as to run with practically no noise, and with the entire absence of any pounding effect.

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WESTINGHOUSE APPARATUS AND THE TESLA SYSTEM ADOPTED AT NIAGARA FALLS.

THE CATARACT CONSTRUCTION COMPANY, has finally, after a long and thorough investigation of all the means submitted for transmitting power at Niagara, awarded the contract to the Westinghouse Company who will employ the Tesla multiphase system. The introduction of multiphase currents was some time since determined upon, but after protracted examination the Cataract Company settled upon the two-phase plan, this being recognized as the most flexible and remunerative in commercial exploitation.

The contract primarily calls for three generators of 5,000 h. p. each with corresponding motors and accessories. The revolving fields of the generators will be constructed with inwardly projecting poles and will revolve in a horizontal plane, being mounted upon the vertical shafts of the turbines. The weight of the shafts, turbines and armatures is to be carried by the upward pressure of the water-columns producing the heads for the turbines. The E. M. F. generated will be 2,000 to 2,400 volts and will be increased by step-up transformers for long-distance transmission and lowered by reducing transformers for distribution. The motors will be the two-phase Tesla. The system adapts itself readily to the use of motor generators or rotary transformers so that it is possible to develop either single-phase alternating currents or continuous currents of any desired E. M. F. as may be required for the uses of individual customers. It is expected that a large amount of power will be employed for manufacturing purposes, arc and incandescent lighting, electrolytic work and power purposes generally. It is also understood that the company contemplates sending current at high electromotive forces to Buffalo and greater distances to be used for lighting and power purposes. The work upon the apparatus has already been begun and it will be installed at the earliest possible date.

This is a high tribute to the Westinghouse Company, and not less so to the merits of the multiphase system.

Trade Notes and Novelties

THE
Electrical Engineer.

Vol. XVI. NOVEMBER 8, 1893. No. 288.

THE TESLA ELECTRICAL OSCILLATOR.

OUR readers will recall our short résumé of Mr. Tesla's lecture before the International Electrical Congress in Chicago,[1] which gave in brief outline the results accomplished in the search for an apparatus which would enable the electrical engineer to obtain currents or electrical oscillations economically without engines with rotating parts. The subject was an entirely novel one and came rather unexpectedly, and perhaps the majority of technical men have not even yet fully realized the full scope and far reaching effects of Mr. Tesla's novel work. We believe, therefore, that many will be interested in additional details relating to this work, and it is with this object in view that we give here a description of one form of Mr. Tesla's apparatus which he used in the lecture above referred to. Mr. Tesla, at that time, in compliance with a generally expressed desire left one of his oscillators in his personal exhibit at Chicago, until the end of the Exposition, and also, for fully a week, allowed all of his lecture apparatus to remain in the annex to the Agricultural Building where the lecture was held, and where it was inspected by numerous interested visitors.

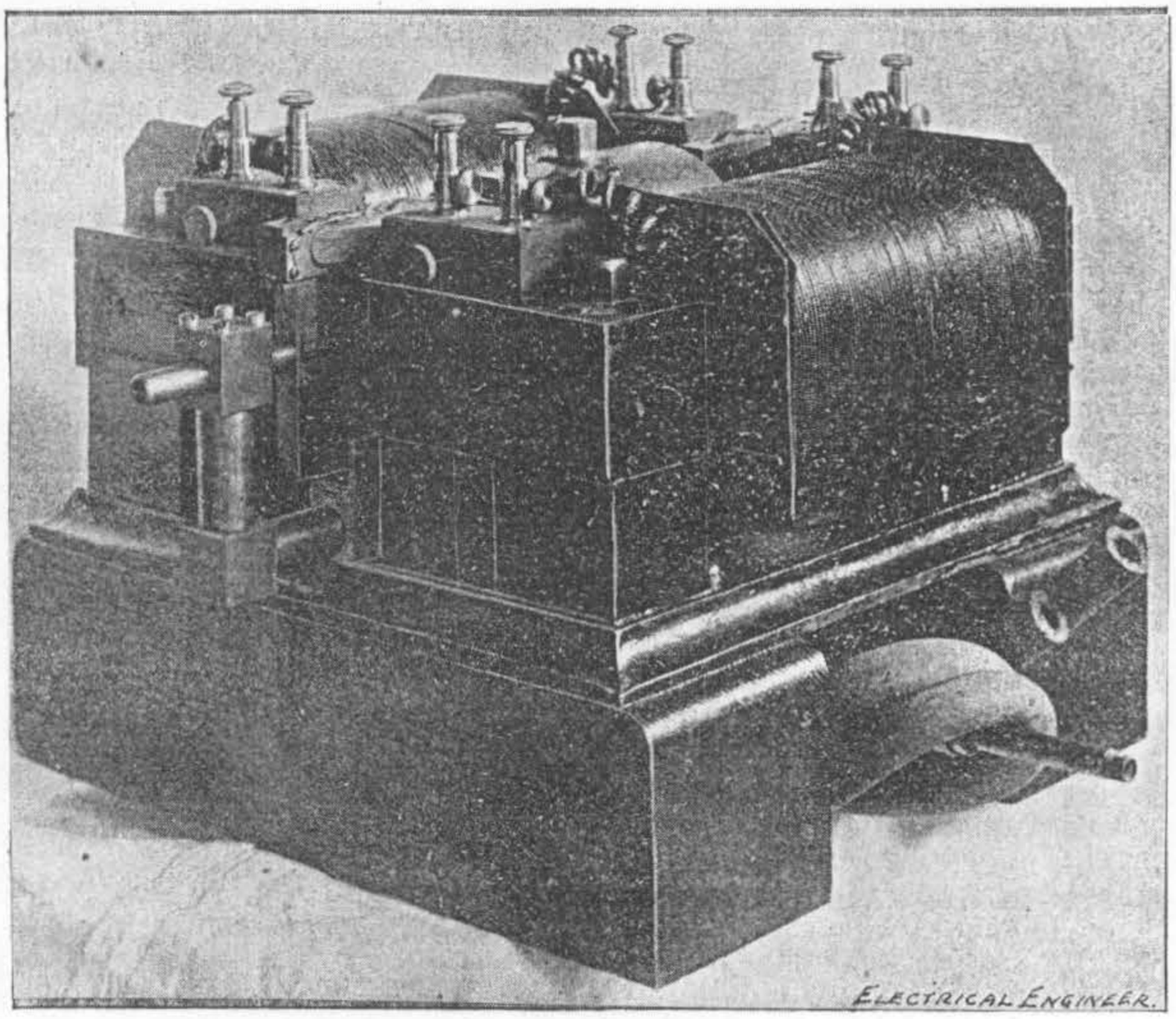

FIG. 1.—THE TESLA ELECTRICAL OSCILLATOR.

As we stated in our brief account, in these oscillators a freely movable piston, which is not connected to any rotating parts possessing inertia, as in ordinary engines, but which oscillates directly a coil or magnet and so generates electric current. Mr. Tesla pointed out in his lecture the great difficulty he had encountered in obtaining mechanical oscillation; he explained how he was guided first, in his earlier attempts, to imitate the process in a Leyden jar, in which electrical oscillations follow from an inadequate rate of supply, as compared with the rate of consumption. He exhibited a number of drawings showing apparatus in which he first employed compressed air passing through an opening, the section of which was properly calculated so that the rate at which the air was supplied was not sufficient to keep up a steady pressure; the latter would therefore suffer a sudden diminution upon a plunger being pushed to certain distance. By applying the simple laws of mechanical oscillation, determining, namely, the rigidity of the air spring and the weight of the movable parts, he was able to maintain oscillations ranging from small numbers to the most rapid mechanical vibration. He then devoted his energies to the perfection of the many varieties of apparatus of this kind with a special object of using steam as the working fluid, and getting the greatest mechanical and thermal efficiency out of the apparatus. Mr. Tesla was very sanguine in his expectations and from his remarks on that occasion we gathered that a vast field is opened up which will yield important practical results.

Our engraving Fig. 1 shows, in perspective, one of the forms of apparatus used by Mr. Tesla in his earlier investigations, and its interior construction is made plain by a sectional view shown in Fig. 2. It will be noted that the a piston P is fitted into the hollow of a cylinder C which is provided with channel ports O, O, and I, extending all around the inside surface. In this particular apparatus there are two channels O O for the outlet of the working fluid and one, I, for the inlet. The piston P is provided with two slots S S′ at a carefully determined distance, one from the other. The tubes T T which are screwed into the holes drilled into the piston establish communication between the slots S S′ and chambers on each side of the piston, each of these chambers connecting with the slot which is remote from it. The piston P is screwed tightly on a shaft A which passes through fitting boxes at the end of the cylinder C. The boxes project to a carefully determined distance into the hollow of the cylinder C, thus determining the length of the stroke.

Surrounding the whole is a jacket J. This jacket acts chiefly to diminish the sound produced by the oscillator and as a jacket when the oscillator is driven by steam, in which case a somewhat different arrangement of the mag-

2. See THE ELECTRICAL ENGINEER, Aug. 30, 1893.

nets is employed. The apparatus here illustrated was intended for demonstration purposes, air being used as most convenient for this purpose.

A magnetic frame M M is fastened so as to closely surround the oscillator and is provided with energizing coils which establish two strong magnetic fields on opposite sides. The magnetic frame is made up of thin sheet iron. In the intensely concentrated field thus produced, there are

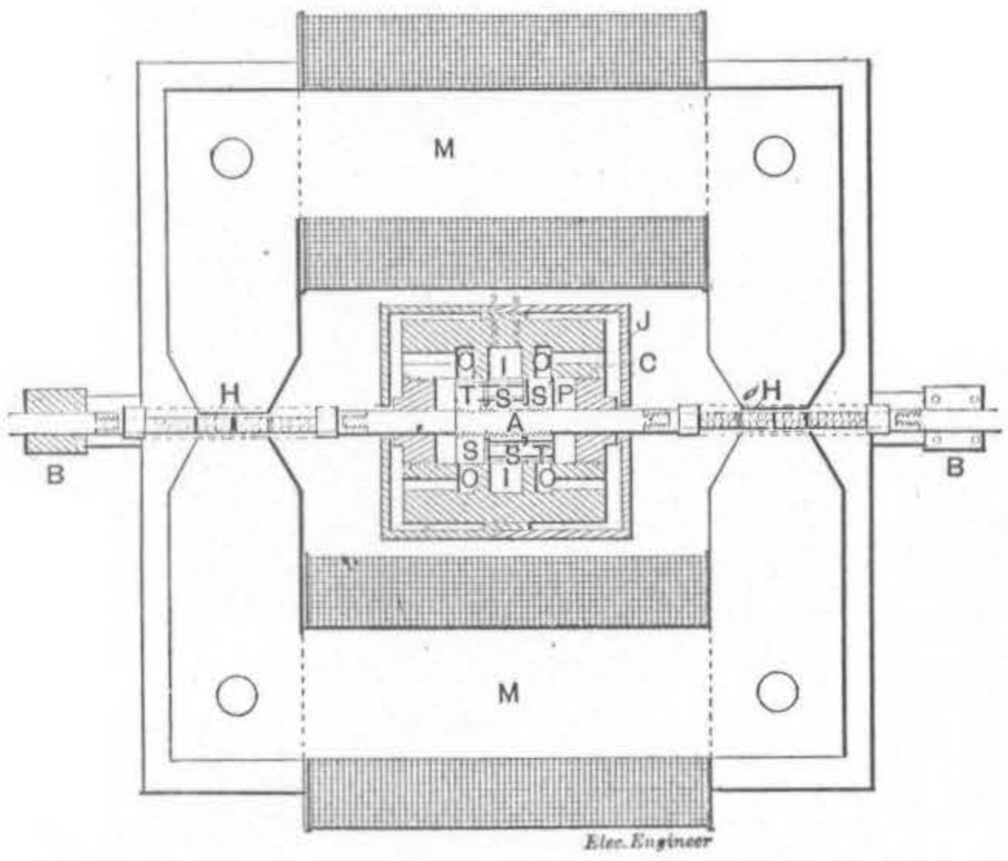

FIG. 2.—THE TESLA OSCILLATOR.—SECTIONAL VIEW.

arranged two pairs of coils H H supported in metallic frames which are screwed on the shaft A of the piston and have additional bearings in the boxes B B on each side. The whole is mounted on a metallic base resting on two wooden blocks.

The operation of the device is as follows: The working fluid being admitted through an inlet pipe to the slot I and the piston being supposed to be in the position indicated, it is sufficient, though not necessary, to give a gentle tap on one of the shaft ends protruding from the boxes B. Assuming that the motion imparted be such as to move the piston to the left (when looking at the diagram), then the air rushes through the slot s′ and tube T into the chamber to the left. The pressure now drives the piston towards the right and, owing to its inertia, it overshoots the position of equilibrium and allows the air to rush through the slot s and tube T into the chamber to the right, while the communication to the left hand chamber is cut off, the air of the latter chamber escaping through the outlet O on the left. On the return stroke a similar operation takes place on the right hand side. This oscillation is maintained continuously and the apparatus performs vibrations from a scarcely perceptible quiver amounting to no more than $\frac{1}{64}$ of an inch, to vibrations of a little over $\frac{3}{8}$ of an inch, according to the air pressure and load. It is indeed interesting to see how an incandescent lamp is kept burning with the apparatus showing a scarcely perceptible quiver.

To perfect the mechanical part of the apparatus so that oscillations are maintained economically was one thing, and Mr. Tesla hinted in his lecture at the great difficulties he had first encountered to accomplish this. But to produce oscillations which would be of constant period was another task of no mean proportions. As we pointed out, in the article before referred to, Mr. Tesla obtains the constancy of period in three distinct ways. Thus, he provides properly calculated chambers, as in the case illustrated, in the oscillator itself; or he associates with the oscillator an air spring of constant resilience. But the most interesting of all, perhaps, is the maintenance of the constancy of oscillation by the reaction of the electromagnetic part of the combination. Mr. Tesla winds his coils, by preference, for high tension and associates with it a condenser, making the natural period of the combination fairly approximating to the average period at which the piston would oscillate without any particular provision being made for the constancy of period under varying pressure and load. As the piston with the coils is perfectly free to move, it is extremely susceptible to the influence of the natural vibration set up in the circuits of the coils H H. The mechanical efficiency of the apparatus is very high owing to the fact that friction is reduced to a minimum and the weights which are moved are small; the output of the oscillator is therefor a very large one.

Theroretically considered, when the various advantages which Mr. Tesla holds out are examined, it is surprising, considering the simplicity of the arrangement, that nothing was done in this direction before. No doubt many inventors, at one time or other, have entertained the idea of generating currents by attaching a coil or a magnetic core to the piston of a steam engine, or generating currents by the vibrations of a tuning fork, or similar devices, but the disadvantages of such arrangements from an engineering standpoint must be obvious. Mr. Tesla, however, in the introductory remarks of his lecture, pointed out how by a series of conclusions he was driven to enter this line of work because of the necessity of producing currents of constant period and his endeavors to maintain electrical oscillation in the most simple and economical manner. A further development of this work will no doubt be watched with great interest.

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VOL. XVI. NEW YORK, NOVEMBER 8, 1893. No. 288.

THE LESSON OF THE INTRAMURAL.

THE best facilities for travel within the World's Fair grounds were those furnished by the Intramural elevated electric railway, winding around just inside the palings, from one end to the other, very much like a big "C" with a curl at each extremity. The line consisted of close upon 15,000 feet of double track and nearly 2,000 feet of single track. Trains ran ordinarily at 4 minute intervals and usually consisted of the motor car and three trailers, all four carrying passengers. All the cars were open, and all the seats were placed across the car, back to back, entrance being made by low doors which slid open or shut, all at the same time. The heaviest train loads were taken up or discharged with wonderful rapidity. As is well known, current was supplied to the motor cars by third rail.

The record of such a road as this is surely of interest to every large city in the country, and we are glad to be able to record the fact that the service was from first to last an enormous success. No fewer than 6,000,000 paying passengers were carried, and there was not a single accident. On Chicago day the total ran up to 125,000 passengers for the single day; and there were many other days when the figures reached 70,000 or 80,000. The service was smooth, regular and punctual, and the capacity of the road could easily have been increased had it proved necessary. The figures of operation are being carefully worked out, but they will show an economy beyond dispute. After such a brilliant demonstration, it is impossible for any man to declare that elevated electric roads will not work; and it is high time that such roads were availed of to relieve the congestion of passenger traffic that now prevails in every large American city, morning and evening and holidays all the year around. Moreover, it is high time that steam locomotives on elevated roads within city limits were arbitrarily ruled off the track. One could always sit in the Intramural cars and enjoy the fresh, free air without any stain to clothing or any soot or smoke flying in one's face; yet only a few yards away the open cars of the Illinois Central were crowded with passengers approaching or leaving the Fair, who were often harassed beyond endurance by the sulphurous, sooty clouds from the locomotives. The New York Elevated to-day is similarly a nuisance, chiefly, perhaps solely, on account of the smoke, soot, oil, ashes, drippings, etc., that it distributes lavishly all the way from the Battery to the Baseball grounds; and there is no longer any reason or any excuse for it. We watched personally the Intramural, day in and day out for six months together, riding sometimes half a dozen times in a single day, and never once did we see the slightest accident, trouble, confusion, or annoyance to any passenger. The motion of the cars was pleasant, and the motive power gave absolutely no sign of its presence. There were probably details to be improved, and that will be improved when new roads are equipped as they are soon to be; but the system as a whole is an unqualified success.

We could wish, as loyal New Yorkers, that this city or Brooklyn were the first to adopt the new method, but once again Chicago seems to be ahead, for news comes that the Northwestern Elevated Railroad Company has been formed, with a capital of $15,000,000, to operate such a road from Chicago out Evanston way. The directorate includes Mr. Frederick Sargent, recently the electrical and mechanical engineer of the Fair, and we understand that he will have a large share in the work of construction. Is New York never to have any of these modern conveniences and blessings that Chicago and Liverpool find within such easy reach?

THE TESLA ELECTRICAL OSCILLATOR.

ON another page we give a brief description of one form of Mr. Tesla's mechanico-electric oscillator, which formed part of his exhibit in Chicago. It would be hardly possible at this moment to foresee the ultimate effect which this latest work of Mr. Tesla will have upon the practical development of the electrical industry. Mr. Tesla is very sanguine, and if only part of his hopes are realized, its importance will not be long in making itself felt. The production of electrical currents in general with simpler apparatus than heretofore employed, and to all appearances with a more economical one, is certainly an achievement to be hailed by all who have the welfare of the industry at heart; while the maintenance of oscillations of constant period which may now be obtained by Mr. Tesla's apparatus in a positive manner, without the objectionable, older methods, is a result which scientific men certainly cannot fail to appreciate. We are now on the eve of witnessing the carrying out of some of Mr. Tesla's ideas on a grand scale in the work at Niagara—ideas advanced more than five years ago—and we have cause to feel certain that practical results will shortly come of this latest work. We are thus strengthened in our conviction, long since expressed, that practical results will also follow in the line of economical light production, now that Mr. Tesla has provided more perfect apparatus for the investigation of the phenomena which are associated with his name.

Western Electrician.

EVERY SATURDAY.

Vol. XIII. CHICAGO, NOVEMBER 11, 1893. No. 20

Electricity at the World's Fair.

A more marked change than that presented by the appearance of Jackson Park before and after October 31st would be difficult to imagine. The gala existence of the exposition came to an end with absolute abruptness, and the World's Fair is now in truth a "vanishing city." In common with all the other exhibitors, those in charge of the electrical machinery and appliances in machinery hall and electricity building are packing up and getting away as fast as possible, and many exhibits have already disappeared. The great central station plant in machinery hall is being rapidly dismantled. All arc lights except those used for patrol lighting have been cut out, and it is probable that this service, which will last until next spring, will be thrown on the block of Standard machines entirely. The Westinghouse company is supplying incandescent lighting to the administration, woman's and service buildings only, while all the power circuits except those supplied from one C. & C. generator will soon be cut out.

In all directions the electrical activity at the fair has ceased entirely or is only feebly existent. The electrical fountains were stopped in the middle of last week for lack of water and current; the searchlight apparatus has been removed from the roof of the manufactures building; the electric launches are not running, and the electricity building contains a confused mass of exhibits in various stages of packing and removal. On the intramural railway trains of two cars each, instead of four or five, are running, but at less frequent intervals and carrying but few passengers. The process of dismantling the plant in the intramural station has already been begun, and the 2,000 horse power generator is being taken apart for shipment to Brooklyn. The road is run by the Lake Erie upright engine, with plenty of power to spare. General Manager Baker furnishes the following interesting figures, showing the number of passengers carried on the intramural during the six months of the fair:

May	151,550
June	784 756
July	854,107
August	992,958
September	1,447,882
October	1,580.980
Total	5,812,233

The line complete is said to have cost between $800,000 and $1,000,000, and adding the anticipated proceeds of the sale of the material to the receipts from fares it is believed that the company will come out about even—a much better result than was anticipated early in the season.

Especial interest attached to the Fort Wayne plant in electricity building during the closing days of the fair by reason of the fact that it furnished current for the incandescent lamp test, which attracted much attention. Fig. 1 shows this plant as run during this period, with the members of the Fort Wayne Electric company's World's Fair staff grouped about the machines. The young men shown in the picture are E. A. Barnes, who had charge of the exhibit, E. H. Belden, W. Dudley, F. Dudley and O. Shepard. One of the far-famed Columbian Guards also lend his dignified presence to the scene. E. Waterman was connected with the exhibit, but is not shown in the illustration. Mr. Barnes left for Fort Wayne on Monday.

In the *Chicago Tribune's* excellent World's Fair souvenir edition of November 1st the following epitome of the results of the electrical display at the exposition was contributed by Chief Barrett:

I wish to comply with your request for a parting thought on the results attained in this department of the exposition. I wish to do so primarily because it is your request, as I recognize the fact that the newspapers of Chicago have been the most powerful forces at work in behalf of the fair. No other combined influences, or, indeed, all others,

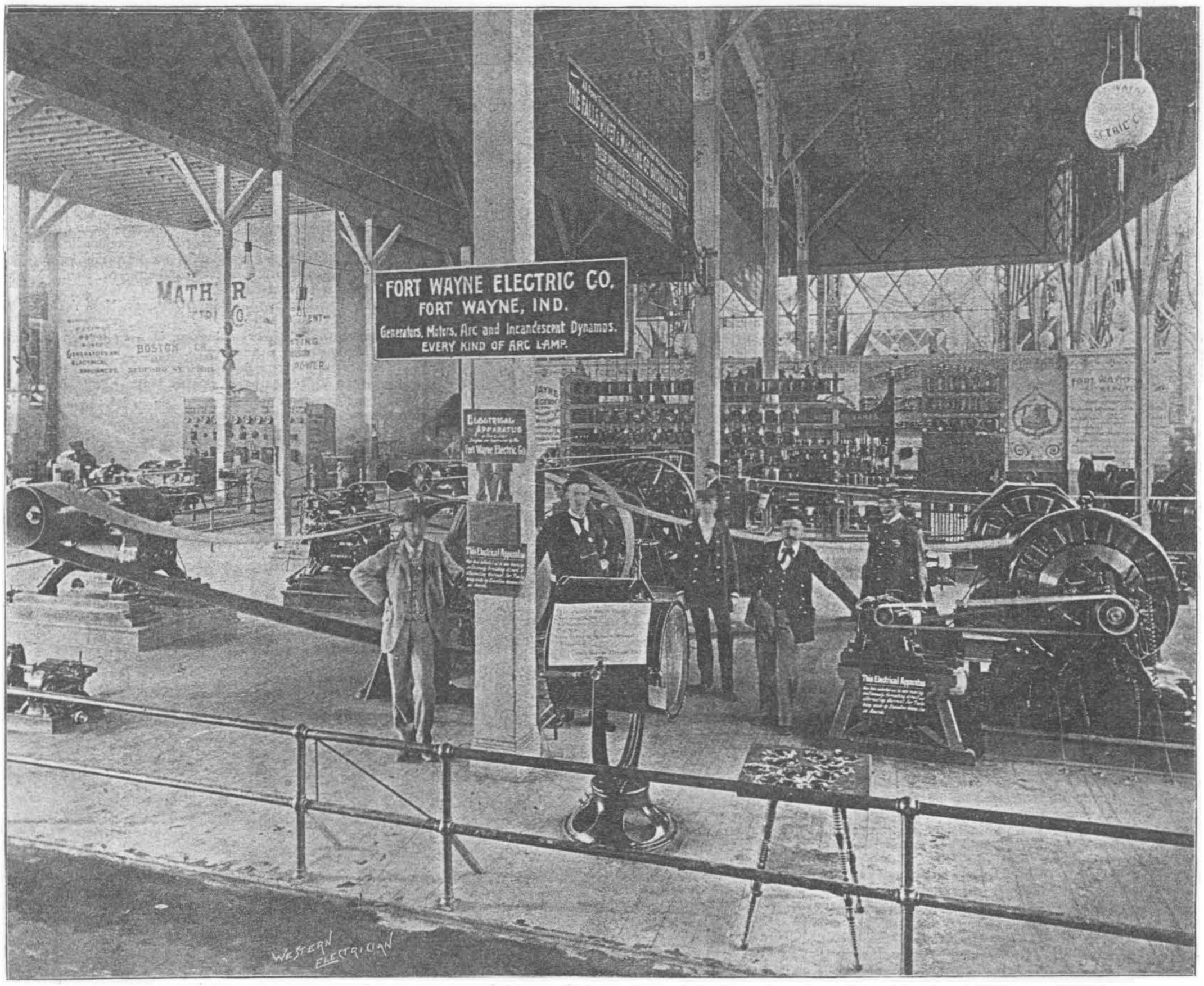


FIG. 1. ELECTRICITY AT THE WORLD'S FAIR.—EXHIBIT AND EXPOSITION STAFF OF THE FORT WAYNE ELECTRIC COMPANY, ELECTRICITY BUILDING.

have done so much to bring about whatever success has been achieved. They have been, as it were, guiding and protecting genii, or, like an approving or protecting conscience, they have held up our hands when we were right, and in a spirit of friendship have reproved us when their judgment was against us. While we may differ from the judgment passed by the Chicago papers many times, we nave never impugned their motives nor respected them the less because of those differences.

Speaking of the department, I desire to say that we have accomplished the highest aim which the well posted man could have set. We have not been the instrument for bringing out any great new principle, like the arc or incandescent light, telephone or dynamo. It seems that this is not an epoch of radical inventions. What we have done, though, is to demonstrate beyond question the commercial applicability of electricity in lines not heretofore mastered. The incandescent plant in service at the Fair is not alone the most extensive but the most economical—to the contractor—and the most efficient ever constructed, leaving out of consideration the perfection attained in decoration. Its chief merit, of course, apart from careful mechanical construction of the machinery, lies in the fact that it employs what is known as the alternating system of transmission, which means to the financier a saving of immense sums in copper and the further possibility of lighting territory at long distances from the source of supply of power.

One of the most powerful strides in electricity is in the adoption at the fair for the first time of very large units in machines and in their operation by what is known as the multiphase system of transmission. These large machines, especially those doing away with shafting and belting, by being directly coupled to their engines, open really a new epoch in the direction of economy and efficiency. Saving in friction, saving in the expenses of operation, and saving in first cost are among the advantages. Nearly all the large companies are going into this class of machine construction, and business competition will do the rest for perfection and progress.

Motors for power service have been demonstrated in greater variety than ever before. Beginning with the operation of the sawmills used in the period of construction, and ending with the tiny motors operated by exhibitors in an infinite variety of ways, we have some of the possibilities of the future.

The electric launches have demonstrated that this class of service is cheaper than by any other power. These boats have earned more money with less outlay in cost and maintenance than would have been possible with steam or any other power. Moreover, they are cleanly, rapid and in every way enjoyable.

Cooking by electricity and its application for domestic purposes is also henceforth commercial if it had not been before. It may not be uninteresting to the public to know that electric cooking and other domestic applications of the current have been commercial for a good while and that the lack of success hitherto in these directions has been due almost entirely to fights over patents.

I think these few words will indicate a train of thought for the intelligent reader to follow as an indication of the ends intended to be reached by me in the organization and execution of the work for this department.

Following Prof. Barrett's article the *Tribune* prints the following interesting personal gossip of the assistants in the office of the department:

Prof. Barrett's first assistant in the department, Dr. J. Allan Hornsby, has been in the work from its inception, having been appointed secretary of the department on the day that Prof. Barrett's commission was approved by the directors. Mr. Hornsby has done the actual work of the department under Prof. Barrett's direction, consulting with the chief on all matters at all times. Prof. Barrett's position as city electrician has made it impossible for him to give all his time to the work, hence the necessity to have a man with him in whom he had perfect confidence. John W. Blaisdell, general superintendent, is best known before the footlights, having been on the stage for some years and having become famous in theatrical work with the best actors of the day. He was for some years manager of Hooley's theater, and was with the best companies at all times. Mr. Blaisdell has had the thankless task of passing upon applications for passes for those in business with the department. W. W. Primm, engineer for the department, is a West Point man, and has been the brains of more than one large engineering project for which some famous engineer got the credit. He has been with Prof. Barrett for nearly two years, and is in no small degree to be credited with the success of the department. Willis Hawley, one of the assistants, came to the department from the active management of a large station at Urbana, O. He is an expert in every branch of the business, having secured his early training in the factory of the Western Electric company of this city. He can do anything from winding an armature to building a station from his own designs. George J. Henry is an inspector of electrical service. Largely to his efforts is due the magnificent fire protection of the building, which has in it concentrated power enough to burn a hole in Lake Michigan. Mr. Henry is also an expert amateur photographer, and has been taking the photographs for Prof. Barrett's report to the director-general. Orlando Shepard came to the department as Mr. Henry's co-laborer in the inspection department from one of Prof. Barrett's city lighting plants. Frank J. Sullivan and Stacey Butler are two young men through whose hands has passed every piece of apparatus exhibited in the building. They have kept all the records of the receipts of goods and have delivered every piece, not one case having been lost. They have relieved each other for night duty, one or the other being in service during the whole twenty-four hours of every day since the fair opened. Last but by no means of least importance in the department is the stenographer, George E. Moore. When the work of the office became too severe to be done by two young ladies Mr. Moore was employed in their stead. In closing it may be stated that Prof. Barrett's men have been paid salaries, as a rule, in excess of those paid in any other department. He has insisted on the best men he could find and has likewise insisted that they be paid for their services. One of the secrets of Prof. Barrett's success as an executive lies in the fact that every man in the department has specific duties to perform and is held to a strict personal account for their proper and prompt execution.

The exhibit of electrical and mechanical watchmen's clocks illustrated in Fig. 2 was made in the gallery of electricity building by the Newman Clock & Manufacturing company of Chicago. Mr. Newman was personally in charge, and succeeded in impressing the merits of his apparatus on many visitors.



FIG. 2. ELECTRICITY AT THE WORLD'S FAIR.—EXHIBIT OF THE NEWMAN CLOCK & MANUFACTURING COMPANY, ELECTRICITY BUILDING.

Portions of the personal exhibit of Nikola Tesla in electricity building, in connection with the Westinghouse display, are illustrated in Figs. 3 and 4. In the former is shown, on the right, a curious experiment with the alternating current. A current of 100 volts with 7,200 alternations was transformed to a potential of 15,000 volts and the frequency also greatly increased by a spark-gap and Leyden jars. A ∩-shaped bar of copper three-quarters of an inch in diameter was placed in the circuit thus created, and three lamps connected across at intervals, as shown in the illustration. When the current was turned on the lowest lamp burned about up to candle power, the next above burned dimly and the highest showed a slight red glow, demonstrating that the current took the path of high resistance through the lamps rather than the infinitely slight resistance of the copper bar, and that this seeming resistance of the thick copper decreased toward the top, allowing more and more of the current to pass through it instead of the lamp. This curious effect is explained by the theory that the extremely high frequency of the current set up local or eddy currents in the copper bar, and that this impedance was sufficient to divert the current through the small conducting medium and high resistance of the lamps. In approaching the top of the bar the impedance grew less and a greater proportion of the current passed through the mass of copper, lighting the lamps but feebly in consequence. With a direct or ordinary alternating current this apparent contradiction of the laws of electricity would not occur.

On the left in Fig. 3 are shown the transformers, circuit breaker and Leyden jars used in producing the high potentials and high frequencies used in the Tesla experiments in the Westinghouse "dark room." A 100 volt alternating current was first transformed to 100,000 volts by two 50,000 volt transformers in series. By the use of the wheel shaped circuit-breaker and Leyden jars shown on the table in the illustration the rate of alternation was multiplied many times and an additional transformer raised the pressure to about a million volts. This was the current used for the Tesla vacuum tube experiments.

The experimental apparatus used by Tesla in developing his polyphase system was shown on a table near the "dark room," and is represented in Fig. 4. Here are all sorts of fields and armatures for motors, and the whole made an extremely interesting collection. In the center was shown the "Columbus egg" of the Westinghouse company, embodying the principles of the Tesla system. In the rear of this table were shown small two and three-phase motors of the latest Tesla type. In the space illustrated the Shallenberger meter, Wurts non-arcing and "Keystone" lightning arresters were exploited on display boards.

Electrical men will find much of interest and importance in the following list of awards in group 69 (comprising motors and apparatus for the generation and transmission of power, hydraulic and pneumatic apparatus), department of machinery:

United States.

Abendroth & Root Manufacturing company, New York, N. Y.—Special riveted pipes; (2) sectional water tube boiler.
Aermotor company, Chicago, Ill.—Pneumatic pump.
Alexander Bros., Philadelphia, Pa.—Leather belting.
American Hoist & Derrick company, St. Paul, Minn.—Contractors' machinery.
American Leather Link Belt company, New York, N. Y.—Leather link belting.
American Well Works, Aurora, Ill.—Collection of pumping and well appliances.
Andrews, Johnson & Co., Chicago, Ill.—Fan engines.
Ashton Valve company, Boston Mass.—Pop safety valves.

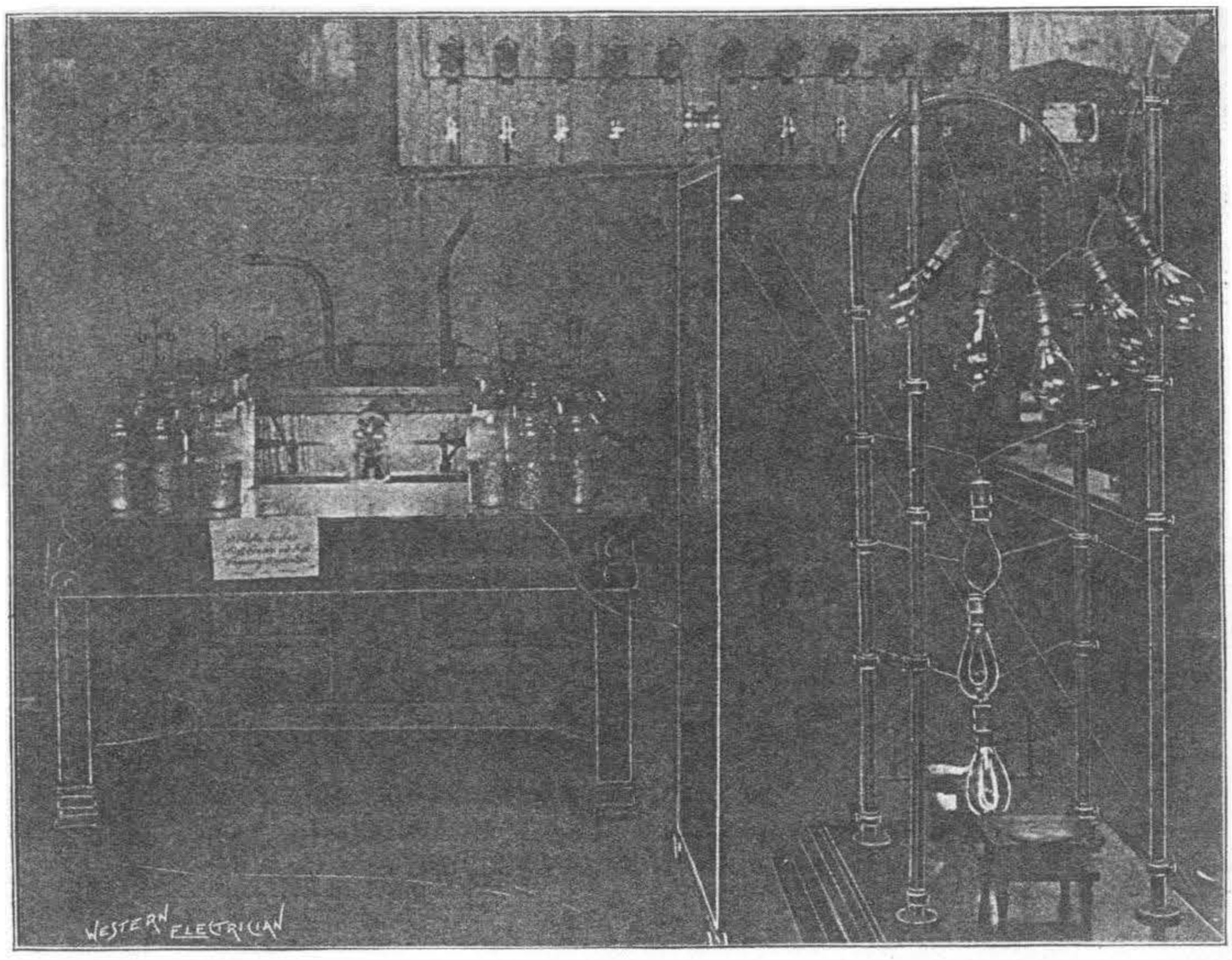


FIG 3. ELECTRICITY AT THE WORLD'S FAIR.—TESLA EXPERIMENTAL APPARATUS, ELECTRICITY BUILDING.

Atlas Engine Works, Indianapolis, Ind.—Tandem compound steam engine.
Babcock & Wilcox company, New York, N. Y.—Model water tube boilers and details.
Ball Engine company, Erie, Pa.—500 horse power cross high speed compound condensing engine.
Ball & Wood company, New York, N. Y.—High speed engines.
Baragwanath, Wm. & Son, Chicago, Ill.—Steam jacket feed and water heater.
Bates Machine company, Joliet, Ill.—Bates' Corliss engines.
Battle Creek Machinery company, Battle Creek, Mich.—Marsh steam pump.
Bilgram, Hugo, Philadelphia, Pa.—Smooth running gears

MR. TESLA'S PERSONAL EXHIBIT AT THE WORLD'S FAIR.

WHILE the exhibits of firms engaged in the manufacture of electrical apparatus of every description, at the Fair, afforded the visitor ample opportunity for gaining an excellent knowledge of the state of the art, there were also numbers of exhibits which brought out into strong relief the work of the individual inventor, which lies at the foundation of much, if not all, of our present achievement. Prominent among such personal exhibits was that of Mr. Nikola Tesla, whose apparatus occupied part of the space of the Westinghouse Company.

This apparatus represents the results of work and thought covering a period of ten years. It embraces a large number of different alternating motors and Mr. Tesla's earlier high frequency apparatus. The motor exhibit consisted of a variety of fields and armatures for two, three and multiphase circuits, and gave a fair idea of the gradual evolution of the fundamental idea of the rotating magnetic field. The high frequency exhibit included Mr. Tesla's earlier machines and disruptive discharge coils and high frequency transformers, which he used in his investigations and some of which are referred to in his published papers.

Our engraving, Fig. 1, shows a view of part of the exhibits containing the motor apparatus. Among these there is shown at A a large ring which is intended to exhibit the phenomena of the rotating magnetic field. The field produced was very powerful and exhibited striking effects, revolving copper balls and eggs and bodies of various shapes at considerable distances and at great speeds. This ring was wound for two-phase circuits, and the winding was so distributed that a practically uniform field was obtained. This ring was prepared for Mr. Tesla's exhibit by Mr. C. F. Scott, electrician of the Westinghouse Electric and Manufacturing Company.

A smaller ring, shown at B, was arranged like the one exhibited at A but designed specially to exhibit the rotation of an armature in a rotating field. In connection with these two rings there was an interesting exhibit shown by Mr. Tesla which consisted of a magnet with a coil, the magnet being arranged to rotate in bearings. With this magnet he first demonstrated the identity between a rotating field and a rotating magnet, the latter, when rotated, exhibiting the same phenomena as the rings when they were energized by currents of differing phase. Another prominent exhibit is a model illustrated at C which is a two-phase motor, as well as an induction motor and transformer. It consists of a large outer ring of laminated iron wound with two superimposed, separated windings which can be connected in a variety of ways. This is one of the first models used by Mr. Tesla as an induction motor and rotating transformer. The armature was either a steel or wrought iron disc with a closed coil. When the motor was operated from a two phase generator the windings were connected in two groups, as usual. When used as an induction motor then the current induced in one of the windings of the ring was passed through the other winding on the ring and so the motor operated with only two wires. When used as a transformer the outer winding served, for instance, as a secondary and the inner as a primary. The model shown at D is one of the earliest rotating field motors, consisting of a thin iron ring wound with two sets of coils and an armature consisting of a series of steel discs partly cut away and arranged on a small arbor.

At E is shown one of the first rotating field or induction motors used for the regulation of an arc lamp and for other purposes. It comprises a ring of discs with two sets of coils having different self-inductions, one set being of German silver and the other of copper wire. The armature is wound with two closed circuited coils at right angles to each other. To the armature shaft are fastened levers and other devices to effect the regulation. At F is shown a model of a magnetic lag motor; this embodies a casting with pole projections protruding from two coils between which is arranged to rotate a smooth iron body. When an alternating current is sent through the two coils the

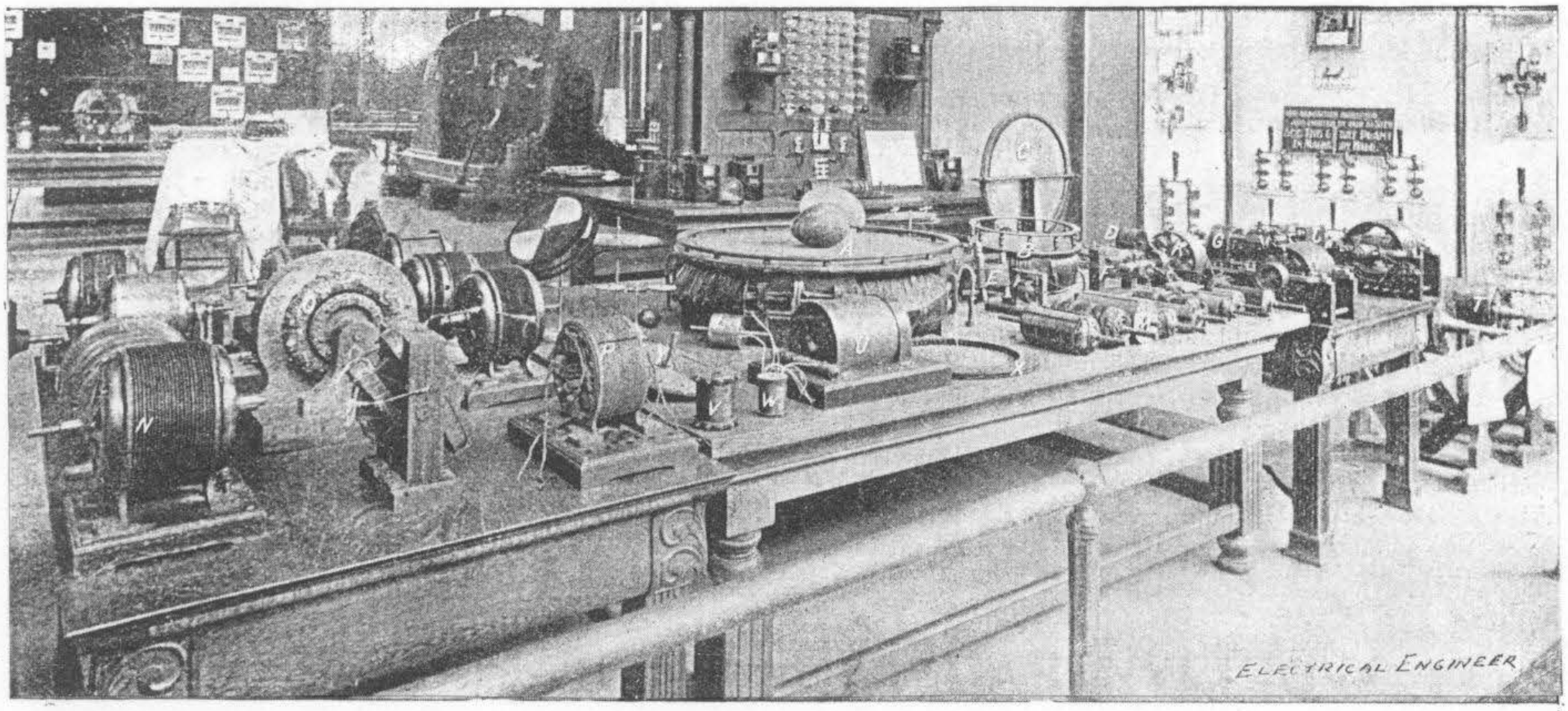


FIG. 1.—MR. TESLA'S PERSONAL EXHIBIT AT THE WORLD'S FAIR.

pole projections of the field and armature within it are similarly magnetized, and upon the cessation or reversal of the current the armature and field repel each other and rotation is produced in this way. Another interesting exhibit, shown at G, is an early model of a two field motor energized by currents of different phase. There are two independent fields of laminated iron joined by brass bolts; in each field is mounted an armature, both armatures being on the same shaft. The armatures were originally so arranged as to be placed in any position relatively to each other and the fields also were arranged to be connected in a number of ways. The motor has served for the exhibition of a number of features; among other things, it has been used as a dynamo for the production of currents of any frequency between wide limits. In this case the field, instead of being energized by direct current was energized by currents differing in phase, which produced a rotation of the field; the armature was then rotated in the same or in opposite direction to the movement of the field and so any number of alternations of the currents induced in the armature, from a small to a high number, determined by the frequency of the energizing field coils and the speed of the armature, was obtained.

The models H, I, J, represent a variety of rotating field synchronous motors which are of special value in long distance transmission work. The principle embodied in these motors was enunciated by Mr. Tesla in his lecture before the American Institute of Electrical Engineers, in May, 1888. It involves the production of the rotating field in one of the elements of the motor by currents differing in phase and energizing the other element by direct currents. The armatures are of the two and three phase type. K is a model of a motor shown in an enlarged view in Fig. 2. This machine together with that shown in Fig. 3 were models exhibited at the same lecture, in May, 1888. They were the first rotating field motors which were independently tested, having for that purpose been placed in the hands of Prof. Anthony in the winter of 1887–88. From these tests it was shown that the efficiency and output of these motors was quite satisfactory in every respect.



FIGS. 4, 5 AND 6.

It was intended to exhibit the model shown in Fig. 3 but it was unavailable for that purpose owing to the fact that it was some time ago handed over to the care of Prof. Ayrton in England. This model was originally provided with twelve independent coils; this number, as Mr. Tesla pointed out in his first lecture, being divisible by two and three, was selected in order to make various connections for 2 and 3-phase operations, and during Mr. Tesla's experiments was used in many ways with from 2 to 6 phases.



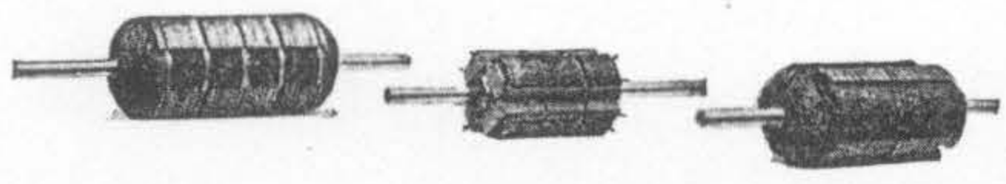
FIGS. 7, 8 AND 9.

The model, Fig. 2, consists of a magnetic frame of laminated iron with four polar projections between which an armature is supported on brass bolts passing through the frame. A great variety of armatures was used in connection with these two and other fields. Some of the armatures are shown in front on the table, Fig. 1, and several are also shown enlarged in Figs. 4 to 14. An interesting exhibit is that shown at I, Fig. 1. This is an armature of hardened steel which was used in a demonstration before the Society of Arts in Boston, by Prof. Anthony. Another curious exhibit is shown enlarged in Fig. 5. This consists of thick discs of wrought iron placed lengthwise, with a mass of copper cast around them. The discs were arranged longitudinally to afford an easier starting by reason of the induced current formed in the iron discs, which differed in phase from those in the copper. This armature would start with a single circuit and run in synchronism, and represents one of the earliest types of such an armature. Fig. 9 is another striking exhibit. This is one of the earliest types of an armature with holes beneath the periphery, in which copper conductors are embedded. The armature has eight closed circuits and was used in many different ways. Fig. 8 is a type of synchronous armature consisting of a block of soft steel wound with a coil closed upon itself. This armature was used in connection with the field shown in Fig. 2 and gave excellent results.

FIGS. 2 AND 3.—TESLA ROTATING FIELD MOTORS EXHIBITED IN HIS LECTURE BEFORE THE A. I. E. E., MAY, 1888.

Fig. 6 represents a synchronous armature with a large coil around a body of iron. There is another very small coil at right angles to the first. This small coil was used for the purpose of increasing the starting torque and was found very effective in this connection. Figs. 10 and 12 show a favorite construction of armature; the iron body is made up of two sets of discs cut away and placed at right angles to each other, the interstices being wound with coils. The one shown in Fig. 12 is provided with an additional groove on each of the projections formed by the discs, for the purpose of increasing the starting torque by a wire wound in these projections. Fig. 11 is a form of armature similarly constructed, but with four independent coils wound upon the four projections. This armature was

used to reduce the speed of the motor with reference to that of the generator. Fig. 4 is still another armature with a great number of independent circuits closed upon themselves, so that all the dead points on the armature are done away with and the armature has a large starting torque. Fig. 7 is another type of armature for a four-pole motor but with coils wound upon a smooth surface. A number



FIGS. 10, 11 AND 12.

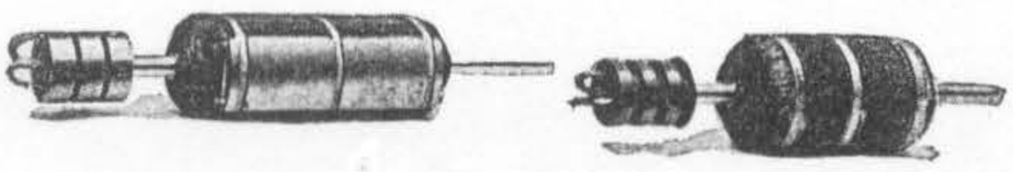
of these armatures have hollow shafts, as they have been used in many ways. Figs. 13 and 14 represent armatures to which either alternating or direct current was conveyed by means of sliding rings. Fig. 13 consists of a soft iron body with a single coil wound around it, the ends of the coil being connected to two sliding rings to which usually direct current was conveyed. The armature shown in Fig. 14 has three insulated rings on a shaft and was used in connection with two or three phase circuits.

All these models shown represent early work, and the enlarged engravings are made from photographs taken early in 1888. There is a great number of other models which were exhibited, but which are not sharply brought out in the engraving Fig. 1. For example at M is a model of a motor comprising an armature with a hollow shaft wound with two or three coils for 2 or 3-phase circuits; the armature was arranged to be stationary and the generating circuits were connected directly to the generator. Around the armature is arranged to rotate on its shaft a casting forming six closed circuits. On the outside this casting was turned smooth and the belt was placed on it for driving with any desired appliance. This also is a very early model.

On the left side of the table there is shown a large variety of models, N, O, P, etc., with fields of various shapes. Each of these models involves some distinct idea and they all represent the gradual development chiefly interesting as showing Mr. Tesla's efforts to adapt his sysem to the existing high frequencies.

On the right side of the table, at S, T, are shown, on separate supports, larger and more perfected armatures of commercial motors, and in the space around the table a variety of motors and generators supplying current to them was exhibited.

The high frequency exhibit embraced Mr. Tesla's first original apparatus used in his investigations. There was exhibited a glass tube with one layer of silk covered wire wound at the top and a copper ribbon on the inside. This was the first disruptive discharge coil constructed by him. At U is shown the disruptive discharge coil exhibited by him in his lecture before the American Institute of Electrical Engineers, in May, 1891. At V and W are shown some of the first high frequency transformers. A number



FIGS. 13 AND 14.

of various fields and armatures of small models of high frequency apparatus is shown at X and Y and others not visible in the picture were exhibited. In the annexed space the dynamo used by Mr. Tesla at Columbia College was exhibited; also another form of high frequency dynamo used.

In this space also was arranged a battery of Leyden jars and his large disruptive discharge coil which was used for exhibiting the light phenomena in the dark room. The coil was operated at only a small fraction of its capacity as the necessary condensers and transformers could not be had and as Mr. Tesla's stay was limited to one week; notwithstanding, the phenomena were of a striking character. In the room were arranged two large plates placed at a distance of about eighteen feet from each other. Between them were placed two long tables with all sorts of phosphorescent bulbs and tubes; many of these were prepared with great care and marked legibly with the names which would shine with phosphorescent glow. Among them we noted some with the names of Helmholtz, Faraday, Maxwell, Henry, Franklin, etc. Mr. Tesla had also not forgotten the greatest living poet of his own country Zmaj Jovan; two or three were prepared with inscriptions, like "Welcome Electricians," and produced a beautiful effect. Each represented some phase of this work and stood for some individual experiment of importance. Outside the room was the small battery seen in Fig. 15, for the exhibition of some of the impedance and other phenomena of interest. Thus, for instance, a thick copper bar bent in arched form was provided with clamps for the attachment of lamps, and a number of lamps were kept at incandescence on the bar; there was also a little motor shown on the table operated by the disruptive discharge.

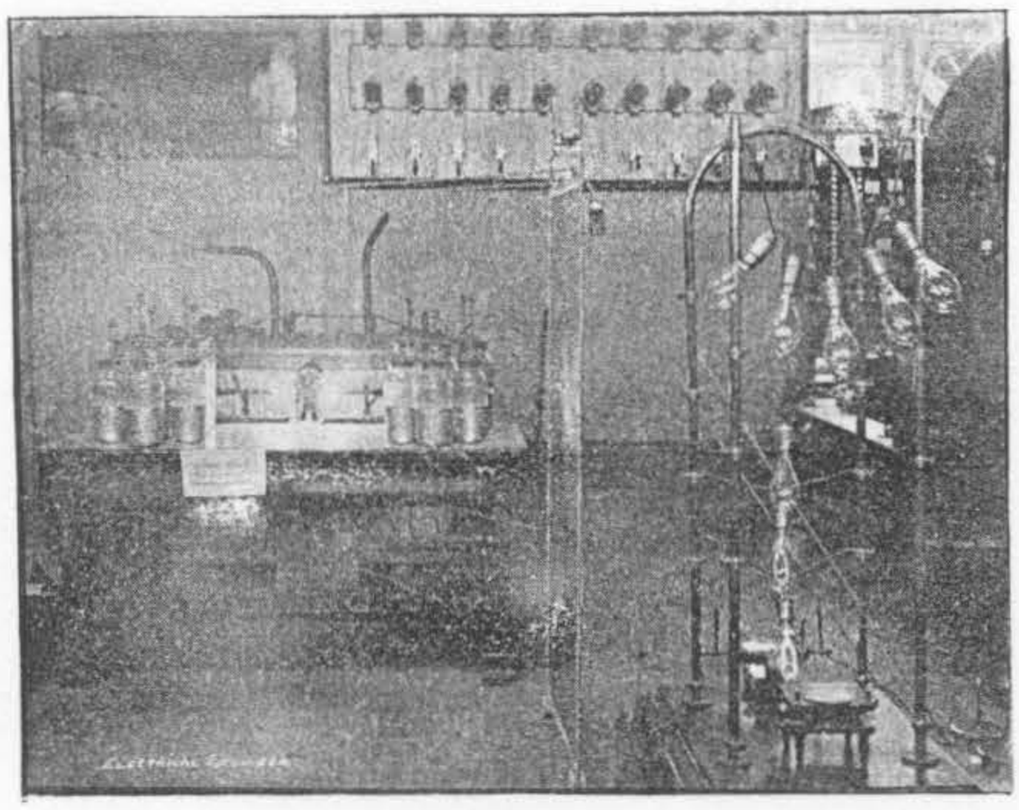


FIG. 15.

As will be remembered the Westinghouse Company made a fine exhibit of the various commercial motors of the Tesla system and also the twelve generators in Machinery Hall were of the two-phase type constructed for distributing light and power. Mr. Tesla, as is also known, exhibited some models of his oscillators. It was Mr. Tesla's intention to exhibit his motor and high frequency apparatus only during the Congress week, but it was allowed to remain on exhibition on account of a generally expressed desire. Furthermore as Mr. Tesla had only a week's notice to prepare his lecture all his time was taken up for this purpose, otherwise his motor, and especially his high frequency, exhibit would have been more complete.

THE FAIR IN '94.

THE South Park Board of Commissioners of Chicago held a joint meeting with the executive committee of the World's Fair directory recently and decided to accept the Fair buildings and a sum of money sufficient to keep them in repair for some time. The state buildings and many of the foreign buildings will be removed. The park will be improved, and next season there will be electric displays, fireworks, etc. All the buildings will be open and the walks and roadways will be kept in perfect condition.

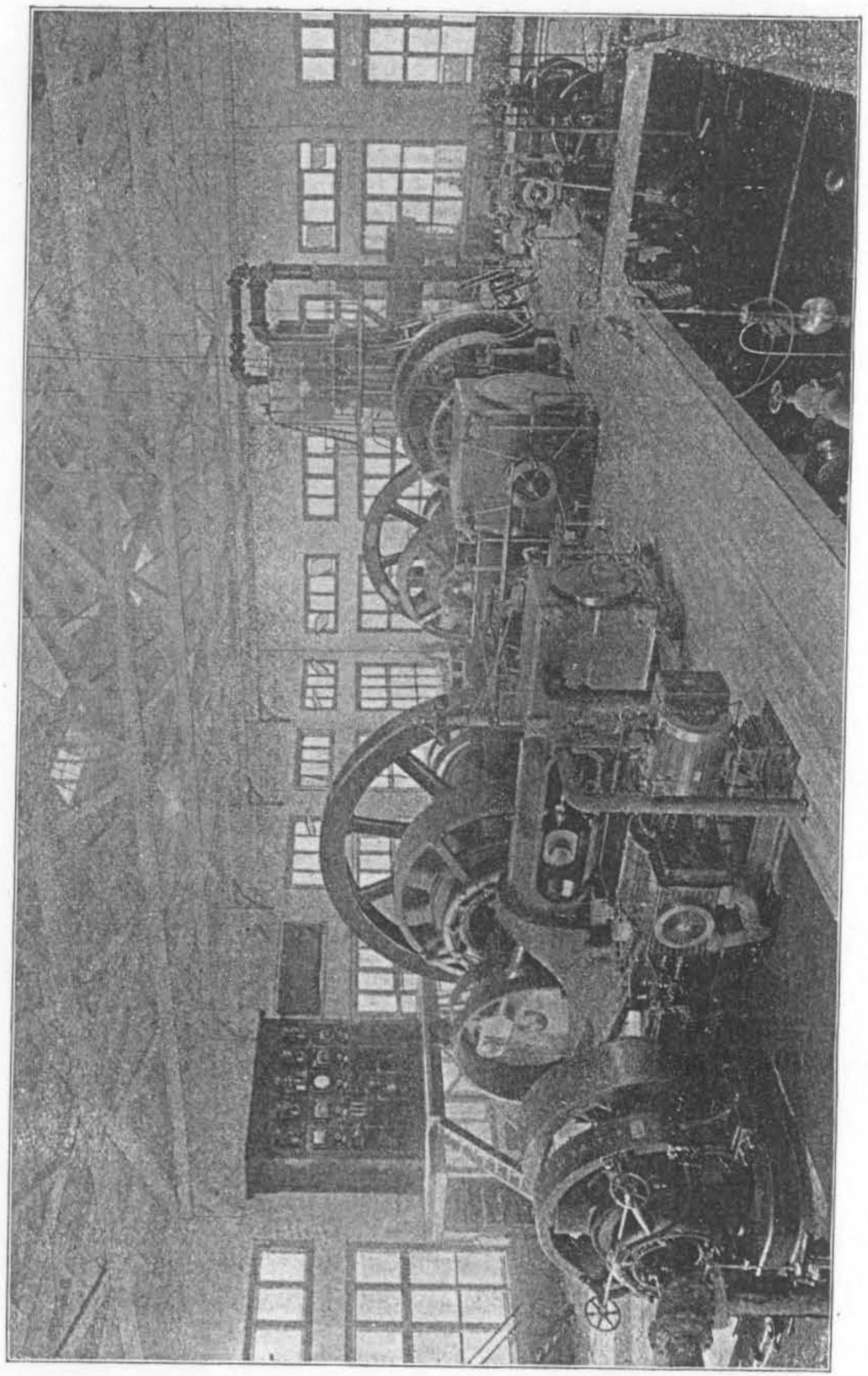
ELECTRIC POWER AT THE WORLD'S FAIR.

By Nelson W. Perry, E. M.

MACHINERY in motion has a charm that is lacking in the mechanism when at rest, yet to the student or specialist the latter may have a special interest akin to that which the corpse has for the anatomist. But the masses are not anatomists and are interested only in the moving wheels. Therefore, because much of the machinery in the Electricity building at the World's Fair was not in motion, many visitors criticised the display. "Separating the motive power from the tool," they said "is like divorcing the breath of life from the body." The exigencies of the case were such, however, that it would have been impracticable to furnish steam throughout the grounds, and it was properly confined in its uses to the Machinery Hall. Upon electricity therefore devolved the duty of transmitting power to the various buildings where it was to be used, and how well it performed the task there are millions who can attest.

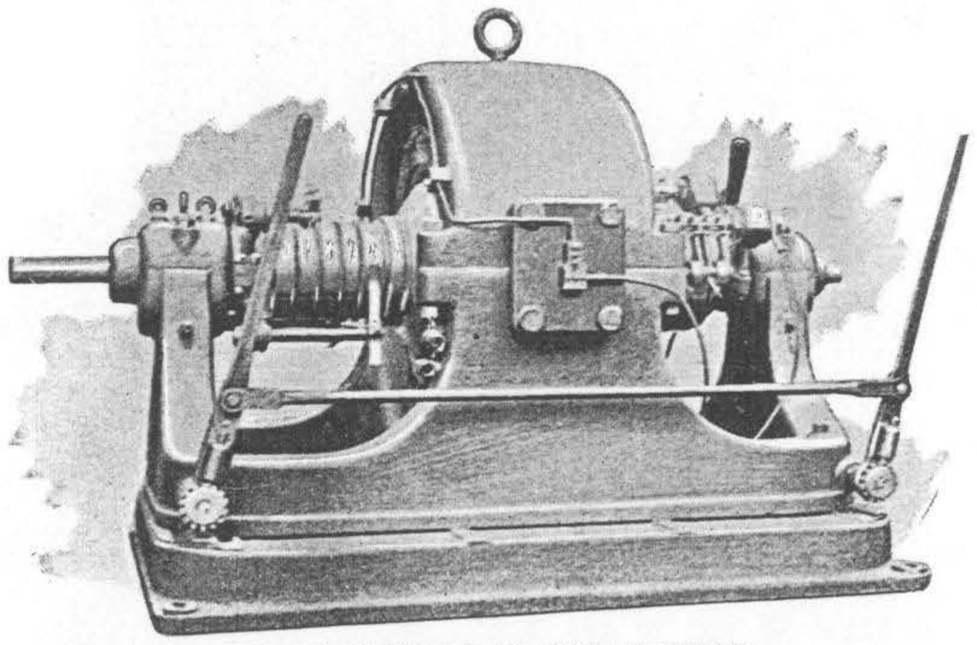
The fact that in some cases the energy thus transmitted had to undergo several transformations to adapt it to the desired use was a source of annoyance and expense which some exhibitors were unwilling to bear. The excessive demand for current which could be met by the supply only in part, and sometimes only at exorbitant charges for wiring and service, furnished a cause for many more idle wheels, but when it has been stated that all the machinery in motion at the Fair outside of Machinery Hall, as well as some of that within, was moved through the agency of electricity, enough has been said to indicate in a general way the extent to which it was thus used. Two exceptions must be made, however, to the statement regarding power outside of Machinery Hall: the power-house of the Intramural railway had its own boiler and engine-plant, and a portion of the power in the Mining building was furnished direct by steam.

Exactly how much energy was transmitted electrically for power purposes it is impossible to tell, but as a basis for an estimate it may be mentioned that in the great power-plant in Machinery Hall the generators catalogued on page 332 were employed for power purposes alone:



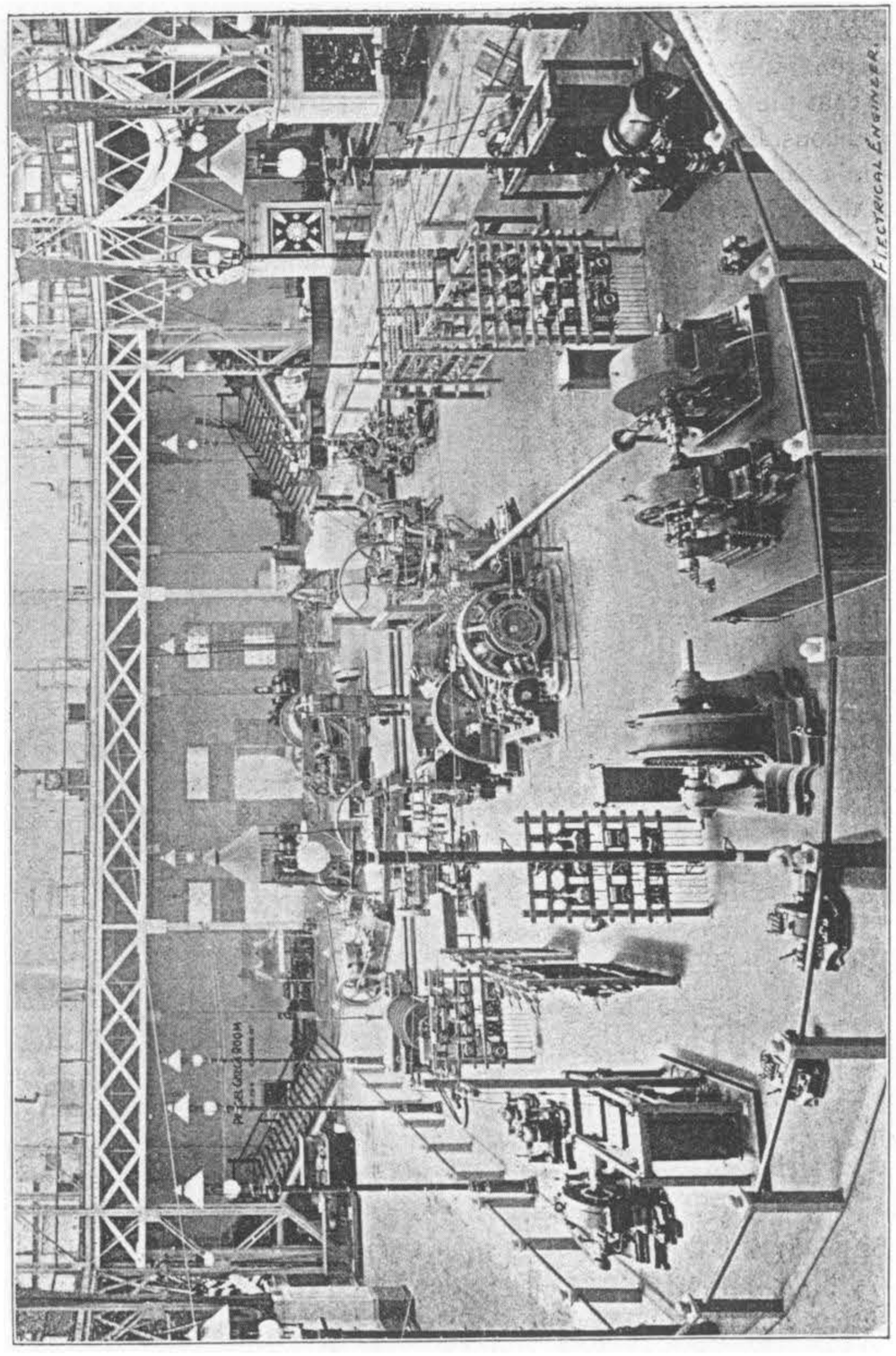
INTRAMURAL RAILWAY POWER-PLANT AT THE WORLD'S FAIR.

Makers.	No. of Generators.	Kilowatts.	Voltage.	Total Kilowatts.
Exposition :				
Mather	2	225	550	450
Mather	2	120	550	240
C & C	4	80	550	320
C & C	2	80	250	160
Eddy	4	186½	550	746
Westinghouse	1	373	550	373
Exhibitors :				
National	1	80	500	80
Jenney	1	40	500	40
Western Electric	2	137½	250	275
Wood	1	500	550	120
Total kilowatts				2,804
Capacity of Intramural power-plant				3,700
Grand total, kilowatts				6,504



TESLA TWO-PHASE MOTOR AND MOTOR TRANSFORMER.

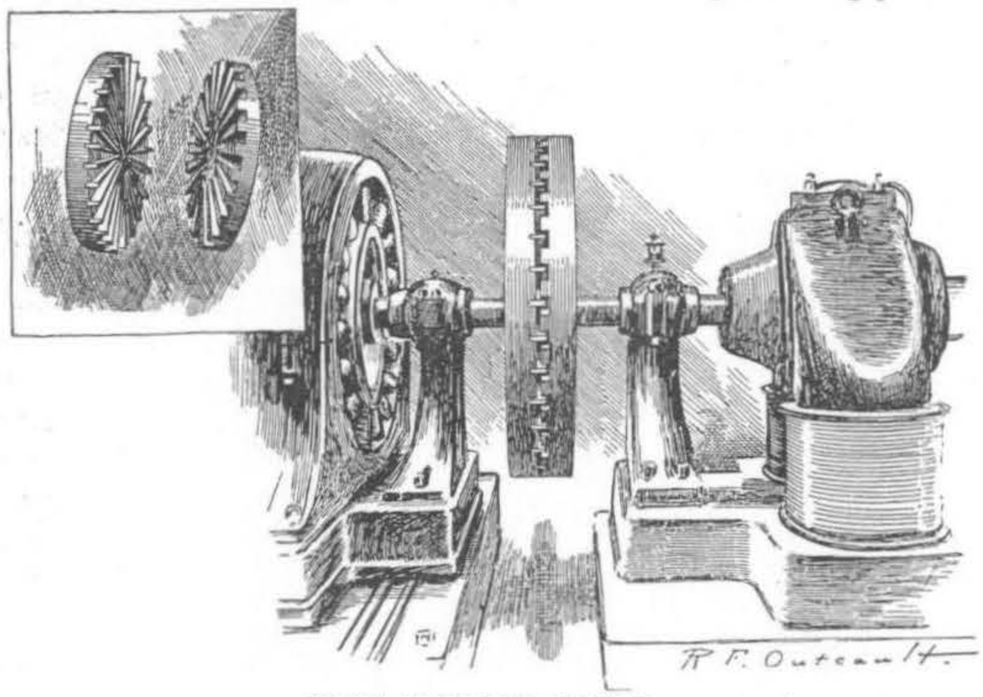
To this may properly be added the power generated more especially for lighting purposes, but which was employed in part by exhibitors or concessionaires for other purposes, and here is where the figures may become uncertain. As an illustration may be cited the four 150-kilowatt Edison generators primarily intended to supply current to the electrical fountains, but which after 10 o'clock at night were employed to charge the storage-batteries in the electric launches. There were fifty-eight of these launches, each equipped with a 4-horse-power motor. The Westinghouse com-



THREE-PHASE POWER-TRANSMISSION PLANT OF THE GENERAL ELECTRIC COMPANY.

pany used two of their single-phase lighting circuits to supply current to their polyphase power-plant, the central figure of their display in Electricity building, and other lighting as well as power currents were transformed by other exhibitors for power purposes, so that the actual horse-power of motors in operation at the Fair was considerably in excess of that indicated by the table. Certainly the rated capacity of electric machinery actually doing work at the Fair did not fall far short of 9000 horse-power, and the work performed embraced almost every variety known to the arts.

Owing to the fact that no steam was permitted in the Electricity building, all generators there shown in operation were driven by electric motors deriving current from the main generating plant in

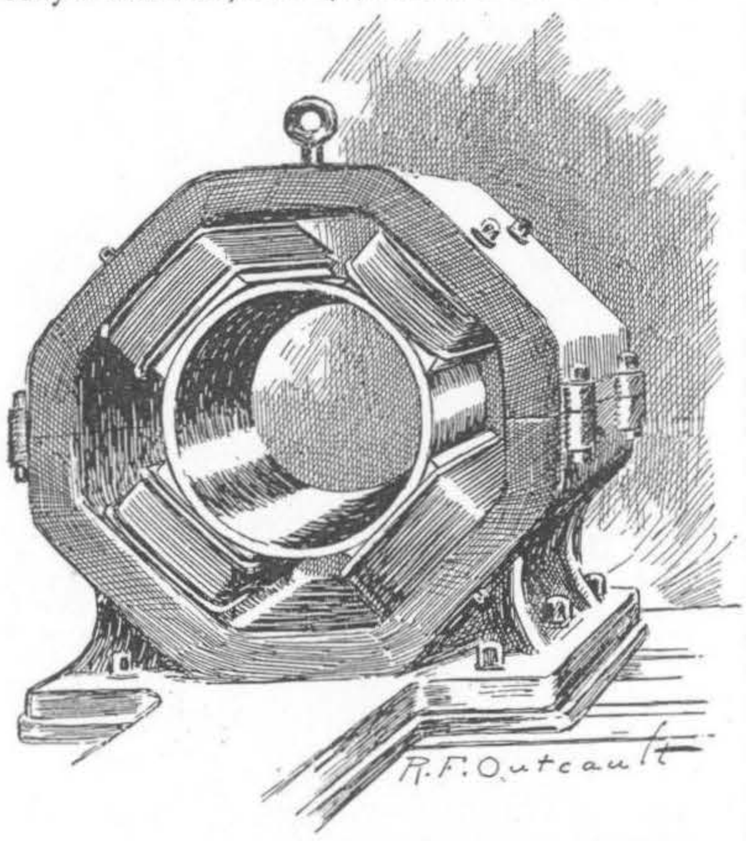


CLUTCH, OR COUPLING, IN DETAIL.

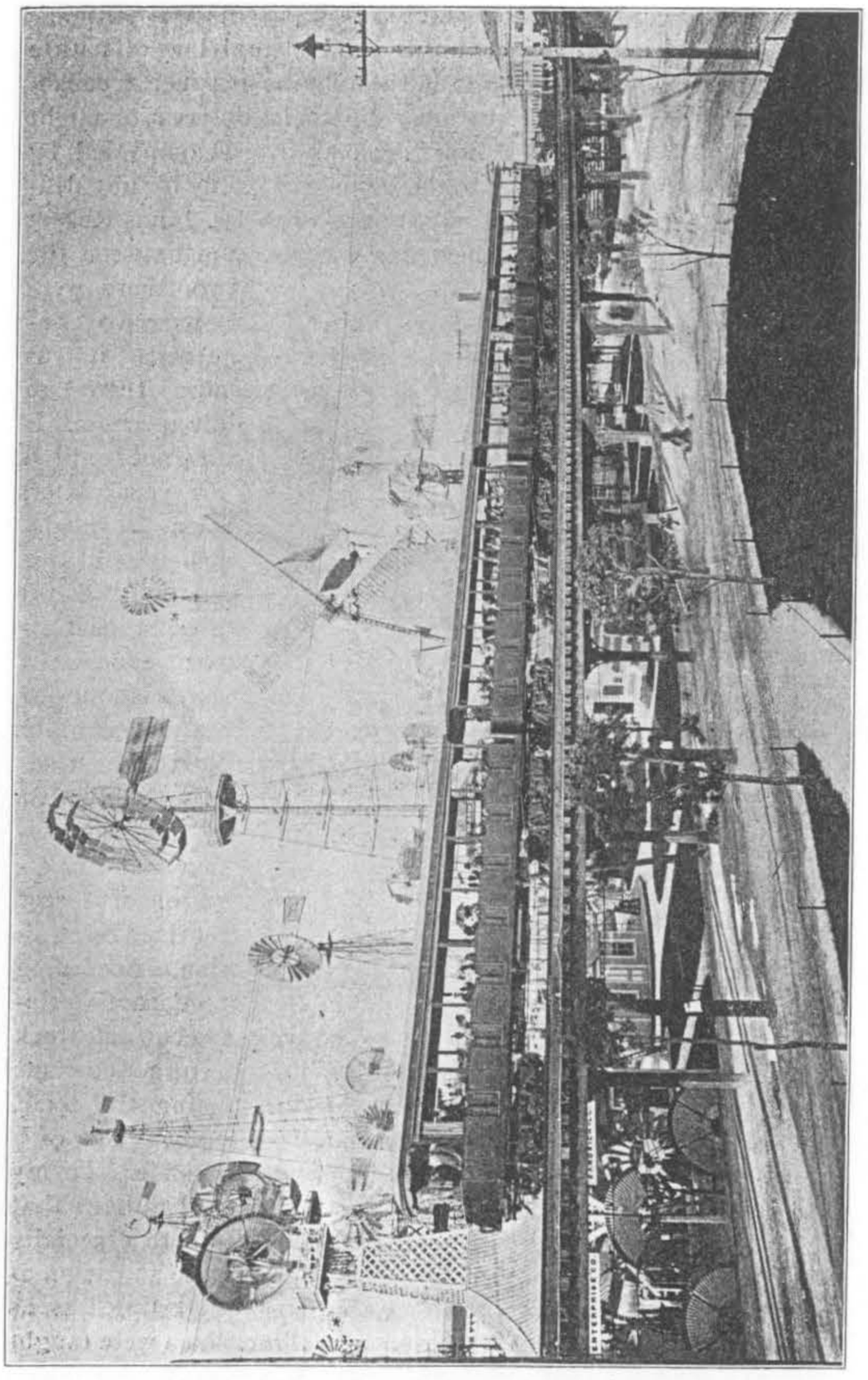
Machinery Hall, and these generators, in order to give them a load, not infrequently supplied current to other motors, besides furnishing the individual lighting supply of the various exhibitors. In this way such an exhibit became a subordinate central-station, itself operated by electricity, and which, in the cases of the Western Electric Co. and the Fort Wayne Electric Co., supplied current for power and light at a stipulated rate to other exhibitors. All of the direct-current incandescent lighting in Electricity building, as well as a considerable portion of the alternating-current incandescent and direct-current arc-lighting of individual exhibitors, was thus provided, constituting this by long odds the most extensive

illustration on a practical commercial scale of the principle of the correlation and conservation of energy.

It seems a little strange that this fundamental law of nature should have been first discovered in the relation between mechanical work and heat, for while the most superficial observation might have taught that mechanical work was always accompanied by heat, it was not so apparent that there could possibly be any definite relation between the two. Therefore when Dr. Julius Robert Mayer asserted, in 1842, that there was a connection between the two, there were few who regarded it as more than an idle assertion. It was not until a few years later, when Joule demonstrated this relation, and still later, when Carnot enunciated the principle of the reversibility of the heat engine, that the law of the correlation and conservation of forces received recognition. According to Carnot's principle, it was theoretically possible to convert mechanical work into heat and by utilizing that resulting heat perform the same amount of mechanical work again, thus completing the cycle. This having become an accepted dogma, it was not much of a step to conceive that other cycles might be possible. To my mind the greatest object lesson of modern times has been that furnished by the facility with which electricity—more especially in the form of alternating currents—lends itself to the extension of the radius of cyclic changes. To me the most interesting lessons of the World's Columbian Exposition were those which were taught by the exhibits showing a few of the possibilities in this line.



FIELD-MAGNETS WITH POLAR RING, IN THE GERMAN EXHIBIT.



A VIEW OF THE INTRAMURAL ELECTRIC RAILWAY.

When, in 1891, the experiment was tried of transmitting power derived from the falls of the Neckar to Frankfort by electrical means, crowds flocked to see the falls pumping water after their energy had passed through a cycle of six changes. To be sure, the problems of chief interest to engineers were those of insulation against high pressures and the practicability of the three-phased current in power transmissions, then first prominently brought forward, but the principle upon which these problems ultimately depended was that first enunciated by Joule and Carnot.

It will be remembered that in the Lauffen-Frankfort experiment some 300 horse-power were transmitted a distance of 108 miles at 30,000 volts with an efficiency in transmission of about 70 per cent. and utilized at the Frankfort exhibition in part in lighting a bank of lights and in pumping water for an artificial waterfall. This experiment was epoch-making and has lent an unusual interest to the methods there employed. One of the most interesting power exhibits at Chicago, therefore, was that of the Allgemeine Electricitäts-Gesellschaft, the company which built and installed the transmission plant above referred to. In this exhibit were shown all the parts involved in the experiment, including the three-phased generator, step-up and step-down transformers, and three-phased motors. The machines shown were not exact duplicates of those originally employed, but embraced such improvements as later experience had suggested.

The foreign displays of electrical apparatus were looked forward to by American electricians with the keenest interest, as it was hoped that they would abundantly illustrate electrical practice, so far as it might be said to be typical, of competing companies abroad, in order that a comparison might be drawn between their machinery and our own. These anticipations, so far as generators and motors were concerned, were only fulfilled partially by Germany alone. England showed absolutely nothing, and France only a few generators, alternating current and direct, which performed no functions of a useful or instructive nature.

The two great houses of Germany—Siemens & Halske and the Algemeine Electricitäts-Gesellschaft—had interesting though small displays. The latter was especially interesting, not only for the reason already assigned, but because it contained several features entirely new to this country. One of these novelties was the adoption of what has been termed the "polar ring" for the fields of direct-current motors and generators. This consists of a cylinder

of soft iron about an inch thick, enveloping the armature and connecting the pole-pieces of the field magnets. This was claimed to have advantages in prevention of sparking, for which purpose it was employed, which more than compensated for the magnetic short-circuiting which it must inevitably have produced.

This polar ring is strongly advocated by Dobrowolski, to whom I believe it is due, but it requires great effort on our part to believe the remedy is not worse than the disease. Certain types of field magnets have heretofore been so universally condemned by electricians simply because their shape has been such as to conduce to magnetic leakage that they have almost, if not quite, disappeared from the market. A deliberate short-circuiting of the magnetic field such as was illustrated in these machines was therefore astonishing, especially in view of the fact that sparking has been remedied in what would seem to be more rational and more economical ways. But *any* remedy is expensive that does not alleviate the disease, if one has to pay for the prescription, and I believe this is an expensive remedy, both because we pay for it in the lines of force short-circuited through the polar ring and because these machines *do* spark quite as much as well-constructed machines not employing the polar ring.

Another novelty in this exhibit which had real merit was the flexible coupling for directly connecting two shafts in approximate alignment, which consisted of two heavy iron disks, upon the face of one of which were a series of radial slots and upon the face of the other a similar series of brush-like rays of a number of thicknesses of thin sheet-iron, so arranged as to take into the slots on the opposite disk. Considerable play is allowed, permitting the two disks to gear easily, even if their shafts be perceptibly out of alignment, and the flexibility of the brushes is such as to take up the sudden strains, if moderate, or to permit them to slip a cog or two if excessive.

Siemens & Halske also showed three-phase motors and transformers. Of the latter there were two of 50,000 watts capacity each. In these air alone was used as insulation.

Until recently it has been urged by some practical men as an argument against the adoption of electricity in their business that, although it might accomplish some things better than agencies already in use, it was not sufficiently elastic to accomplish *all*, and that its adoption only meant an additional plant capable of doing one or two things a little better than existing plants, making of

electricity a luxury. This was undoubtedly true, and in no direction more so than in the field of mining. For this reason the application of electricity in mining has not kept pace with its applications in other industries.

The two largest electrical companies of America made displays side by side which must forever remove from the popular mind all idea of the lack of flexibility of electricity. The electrical exhibit at the World's Fair would have been a marked success had nothing else been shown than what were called "the transmission of power" schemes of the General Electric Company and of the Westinghouse Electric and Manufacturing Company. These two rivals presented each its own choice of methods—both well known to the electrical fraternity in each of their several parts, but neither of them ever before so completely illustrated on a working commercial scale. Additional significance was given to these two displays because it was generally believed that they represented between them, in all essentials, the system that would be employed in the Niagara Falls transmission-plant.

The General Electric Company followed the lines of the Frankfort-Lauffen experiment in so far as it employed the three-phase system, while the Westinghouse company employed the two-phase or Tesla system, but in each the most prominent feature was the flexibility of the system in hand. Each of these displays will be best illustrated by following the current from its point of entrance to the exhibit through its various transformations and translating devices which were selected so as to illustrate how, from a single source, energy could be transmitted and distributed on a large commercial scale for almost every conceivable practical use. Both of these exhibits assumed a waterfall as the source of energy, but they obtained their water-power in different ways. The General Electric Company employed a deep-mine triplex pump capable of raising water against a head of 650 feet, to furnish the water-power. This was operated by a 100 horse-power 220-volt direct-current motor, receiving current from Machinery Hall by the Edison three-wire system. The water from the pump was directed against the buckets of a Pelton water-wheel, which was directly connected with a 35-kilowatt three-phase generator, whence the currents passed to step-up transformers having a ratio of 20 to 1. They were thence transmitted at the higher potential on three No. 18 wires a short distance to what was called the Mining exhibit. Here they were transformed down again to 110 volts and carried to a

distributing switchboard whence lighting- and motor-circuits radiated. On one of the former a bank of incandescent lamps constituted the load ; on another, arc-lamps, and on a third, a series of small three-phased motors were operated, thus repeating all the links in the chain which bound Lauffen and Frankfort in the memorable experiments of 1891. The extreme potentials, long distance, and volume of power, however, were lacking.

The General Electric Company also showed both here and on the battle ship *Illinois* motor-transformers, the latter being fed from the Intramural railway trolley-wire, transforming the 500-volt current down to one of 80 volts. The secondary armature of this was compounded for the usual percentage of loss. As the current was to be used for lighting purposes, which required that its voltage be maintained constant between very narrow limits, it became a very pretty problem to compensate for the wide fluctuation in the primary. This was partially accomplished by commutating the field windings on the motor and further by inserting in parallel with the shunt winding of the generator a storage-battery which absorbed energy when the E. M. F. was too high, and gave it out when it was below normal.

The Westinghouse transmission-plant received its energy from two alternating currents in quadrature, derived from the two armatures of one of their 750-kilowatt generators in Machinery Hall. These currents at 2000 volts and 7200 alternations were transformed down to 200 volts in the building and then led to a 500-horse-power two-phase Tesla alternating current motor. Upon the same shaft, to simulate a prime mover, was a Pelton water-wheel, but this was merely a dummy operated by, instead of driving the motor. This latter, however, drove a 500-horse-power alternating-current generator. On one side of this generator, from four collecting rings, there were taken two alternating currents in quadrature with each other of about 4000 alternations and at a potential of 360 volts. On the other side was a direct-current commutator connected with the same winding, from which could be delivered a direct current at 500 volts. All three of these circuits were led to appropriate terminals on a switchboard for the distribution and control of their currents. By the alternating currents there was operated a 500-horse-power two-phase Tesla motor similar to the generator just described. This was also connected as a rotary transformer.

By means of special field connections this could be started as a

two-phase motor, and after it had gained its speed, by means of a switch, changed over to a self-exciting synchronous motor. As a motor it was employed to drive a Worthington pump and a 40-light Westinghouse alternating-current arc-light dynamo, and as a direct-current generator it furnished current at 500 volts to two 30-horse-power street-railway motors, to a 60-horse-power motor driving an Ingersoll-Sargeant air-compressor, and to a series of constant potential arc-lamps.

Another circuit from the switchboard was connected to a 60-horse-power two-phase motor and transformer, which, receiving alternating current at 360 volts, delivered a direct current at 50 volts, which was used in operating a large Shuckert search-light and which was suitable for electrolytic and other work. Still another circuit from the switchboard supplied current to a 60-horse-power two-phase Tesla motor of the synchronous type directly connected to a 45-kilowatt constant-potential alternator employed for incandescent lighting, and another circuit furnished current without further transformation to incandescent lamps. All of the transformations and all of the uses indicated in the above-mentioned applications were at different times, and when not incompatible with one another, simultaneously exhibited, and, being in every case on a commercial scale, constituted the crowning triumph of the electrical display. It was an object-lesson which must have satisfied those who had questioned the flexibility of the electrical method of transmission of power and transformation of energy. It was a realization of the theory of the correlation of forces such as neither Mayer nor Joule could have dreamed of when they first announced it.

But perhaps the part which electricity played in the transportation problem at the World's Fair came more nearly home to the masses. Within the enclosure there were three principal means of conveyance, viz. : the electric launches on the lagoons, the Intramural electric railway, extending around something more than three sides of the grounds, and the movable sidewalk, extending along the steamboat pier from the Casino to the further end. Subsidiary means of transportation were furnished by the three large traveling cranes, of 20 tons capacity each, in Machinery Hall, which ran the whole length of the building, and which, after having done duty in installing the heavy machinery, were pressed into service to give visitors a bird's-eye view of the great mechanical exhibit, the numerous elevators in the several buildings, and the

roller-chairs. All of these, except the last, were electrically propelled, and in the aggregate carried many millions of passengers.

The movable sidewalk was interesting as pointing a wide departure from established methods in transporting passengers. In this, a continuously moving carrying platform, supported upon and propelled by the periphery of the wheels of the trucks and therefore having double the speed of the latter, receives and discharges passengers while in motion by means of an intermediate slowly moving platform supported upon the axles of the trucks running upon an endless track. The relative speeds of the faster and slower platforms and the absolute speed of the latter are such as to render passage from one to the other, while motion is maintained, safe even for women and children. Since both platforms are continuous and run in closed paths, there is as much up hill as down hill and the path is therefore reduced to a plane. Since there is neither starting nor stopping, the element of the overcoming of inertia is likewise eliminated, and on theoretical grounds, at least, ideal economies should be maintained. Just what the economy was in this case can only be told when the final figures are published, but it will undoubtedly be large. In some careful experiments made by Frank J. Sprague some years ago on the Third-avenue Elevated railroad in New York, it was found that 83 per cent. of all the power utilized was consumed in overcoming gravity and the inertia of trains and that but 17 per cent. was required to maintain them in motion. It may be mentioned that the movable sidewalk was the most formidable competitor for the franchise which was finally granted to the Intramural railway, and that it has been seriously proposed as a solution of the congested transportation facilities in New York city, but it would appear to be of questionable availability for the latter purpose. The electric launches were a success financially, electrically, and popularly,—upon this all are agreed.*

Although the route pursued by the electric launches was almost an ideal one, bringing into direct communication with one another all the principal points of interest within the grounds, it was not used as a *convenience* by the masses, because of the exorbitant fares charged which made the use of the launches a luxury. In strong contrast with the launch route was that followed by the line of the Intramural railway. This led *from* nowhere *to* nowhere, and al-

* Some figures presented in the Department of "Electricity" this month give an idea of the work performed by these launches and of the cost.—THE EDITOR.

though the charges were fairly reasonable, no one thought of patronizing its cars for convenience. The concessionaries, however, were not responsible for the bad location, as they were obliged to content themselves with what they could get. That it carried without serious hitch or accident nearly six million passengers during the term of the Fair speaks volumes for the success of the experiment.

The General Electric Company, who under the name of the Western Dummy Company were the successful competitors for the franchise, have in the Intramural railway apparently solved in a satisfactory manner one of the burning questions of the day, viz.: electrical traction for elevated lines and others having their own right of way. Whether or not all of the technical and financial details have been satisfactorily solved, no one but the General Electric Company yet knows, but the public were satisfied with the service which was maintained without interruption, and this must be counted a long step in its favor.

From one point of view, the Intramural railway experiment is the most important that has ever been tried in the practical application of electricity. It has demonstrated to the public the entire practicability (from their point of view) of the application of electricity in large units to the traction problem. It has furnished to its projectors the first authentic data upon which to base future estimates, and if mistakes have been made it will enable them to correct them in future installations. In brief the system employed was as follows: Trains were made up of three trail cars and a motor car upon which latter were placed four motors—one to each axle. The method of control was what is known as the "series parallel," by which the four motors, each of 133 horse-power capacity, are thrown at starting in series of four, followed by a parallel arrangement of two in series and finally of all four in parallel. By this arrangement the required maximum torque at starting is obtained with a minimum flow of current and a more uniform consumption is maintained at all speeds. The current is carried to the motors by means of two overrunning trolley shoes running upon a third or trolley rail to one side of the track and is returned to the generator by means of the track and the iron girders of the elevated structure. A fourth rail, extending about three-fifths of the length of the structure and connected at frequent intervals with the trolley rail, does service as a feeder. The actual length of the road is 14,800 feet of double track and 1900 feet of single track, and in this dis-

tance grades of from 0.42 per cent. to 2 per cent. are encountered and numerous curves down to 100 feet radius.

All of the cars are 50 feet in' length and weigh, the trailers 20 tons and the motor cars 30 tons, when filled with passengers. Thus it will be seen that the conditions met with in the elevated roads of New York and elsewhere were in all points fairly duplicated. The maximum number of trains in service was fifteen, and these were run at a five minutes headway.

The Intramural power-plant, which comprised by far the largest part of the generating apparatus intended for power purposes at the Fair, did double duty. First it served as an exhibit for the General Electric Company of their largest sized railway and power generators and the various methods in vogue of hanging the armature and of driving it. There were in all five enormous generators shown—one 500 kilowatts four pole generator, driven by belt, and one 250 kilowatts, six pole, one 400 kilowatts, twelve pole, one 750 kilowatts, twelve pole, and one 1500 kilowatts, 12-pole generator —all directly connected to various makes of engines. The last is the largest dynamo thus far constructed, but so rapidly are large units growing in favor that there are already several others exceeding this in output either under way or contracted for. The capacity of this plant was of course far in excess of the demands made upon it by the Intramural railway, so that the various generators took turn either singly or in multiple in supplying these wants.

The enormous outlay required for this magnificent exhibit precludes the possibility of its having made in dollars and cents an adequate return to the exhibitors. They evidently relied for reimbursement upon the experience and prestige it would give them in this hitherto practically untouched field of electric traction, and the renewed consideration which electricity is receiving in our larger centers of population on urban elevated and interurban routes gives promise that their confidence was not misplaced. For obvious reasons the General Electric Company have declined to make public the technical results of the experiment, but however much this may be regretted from a professional point of view, there are few who in their hearts will blame them.

Engineering Magazine December 1893

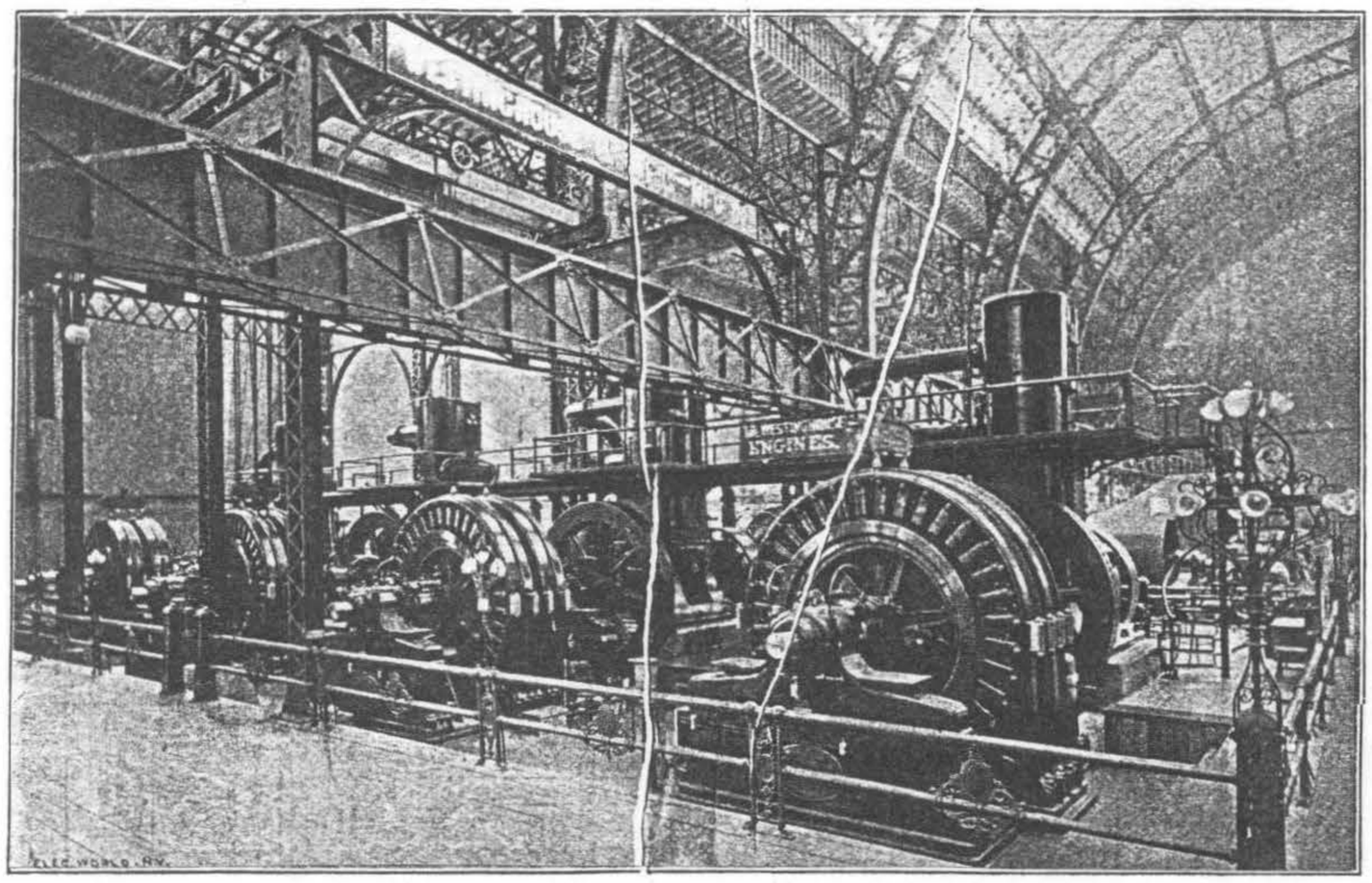
ELECTRICITY

Conducted by Franklin L. Pope.

A LARGE contract for electrical machinery for the Niagara plant has been awarded to the Westinghouse Company, of Pittsburgh. The system which has been adopted is known as the Tesla polyphase. The present contract calls for three 5000-horse-power generators, with a corresponding equipment of motors, switches, etc. The rotating fields are carried on the upper ends of vertical shafts, and are thus coupled direct to the turbines. The upward pressure of the water supports the entire weight of the turbines, shafts, and rotating parts of the generators, thus doing away with nearly all the step-friction. The electromotive force of the dynamos will be from 2000 to 2400 volts, which will be raised and lowered by transformers at different points as required. The system adopted would seem to provide for every possible requirement of an electric service, either in the way of illumination or power.



Among the many and varied scenic effects produced at the World's Columbian Exposition there was probably none which more impressed the observer or was more universally admired than the Court of Honor electrically lighted The lagoons fringed with innumerable lights. the buildings with their cornices aglow and, most picturesque, the great dome of the Administration Building outlined by incandescent lamps, all combined to produce a picture which has probably never been equaled, and which cannot be reproduced in either its novelty or uniqueness.



AN INTERESTING SECTION OF MACHINERY HALL.

It will probably be remembered that when the contract for lighting the World's Fair was awarded to the Westinghouse Electric and Manufacturing Company, its competitors were very pronounced in the expression of their opinion as to the ability of the Westinghouse company to carry out its contract, especially in the face of the decision of the long contested lamp suit which was rendered about that time. The successful performance of the contract, and the artistic illumination of the Court of Honor, as well as the incandescent lighting of the grounds and buildings of the Exposition, have been so satisfactorily carried out that an illustration and description, not only of the machinery and apparatus of the great plant furnishing the light, but also of the instructive electric exhibits made by the Westinghouse Electric and Manufacturing Company, have been deemed of interest.

To carry out the contract which had been secured only after long continued and keen competition, the Westinghouse company installed in Machinery Hall a complete alternating current central station equipment. This station was by far the largest plant in existence, and illustrated on a very large scale the high degree of excellence to which alternating current machinery, adapted to power purposes as well as to arc and incandescent lighting, has been brought by this company. The plant was located adjacent to the south wall of Machinery Hall and about the centre of the building, occupying a space of some 31,000 square feet. The general arrangement of the apparatus is shown in the accompanying ground plan illustration.

The installation comprised the following apparatus: Two 750-kw. two phase alternators, belt driven by a 3,000-h. p. quadruple expansion engine built by the E. P. Allis Company, Milwaukee, Wis.; one 750-kw. two-phase alternator, belt driven by a 1,000-h. p Fraser & Chalmers engine of the Corliss type; one 750-kw. two-phase alternator, belt driven by a 1,000 h. p. McIntosh & Seymour engine; one 750-kw. two-phase alternator, belt driven by a 1,000-h. p. Buckeye engine; one 750-kw. two-phase alternator, belt driven by a 1,000-h. p. Atlas engine; six 750-kw. two-phase alternators, each driven direct by a 1,000-h. p. Westinghouse Columbian steeple engine; two 240-kw. single-phase alternators, each belt driven by a 350-h. p. Westinghouse compound engine; three 75-kw. exciters each driven direct by a Westinghouse 100-h. p. comound engine; a complete marble switchboard for 12 two-phase alternators, 2 single-phase alternators, 4 exciters and 40 circuits.

The total output of the plant was 9,480 kw. The records of readings of the current and potential, which were taken at the switchboard every half hour from the time the Exposition was thrown open to the public, showed that about 55 watts at the generator terminals were required for each 16-c. p lamp connected to the circuit. The station, therefore, was capable of simultaneously supplying about 172,000 16-c. p. lamps.

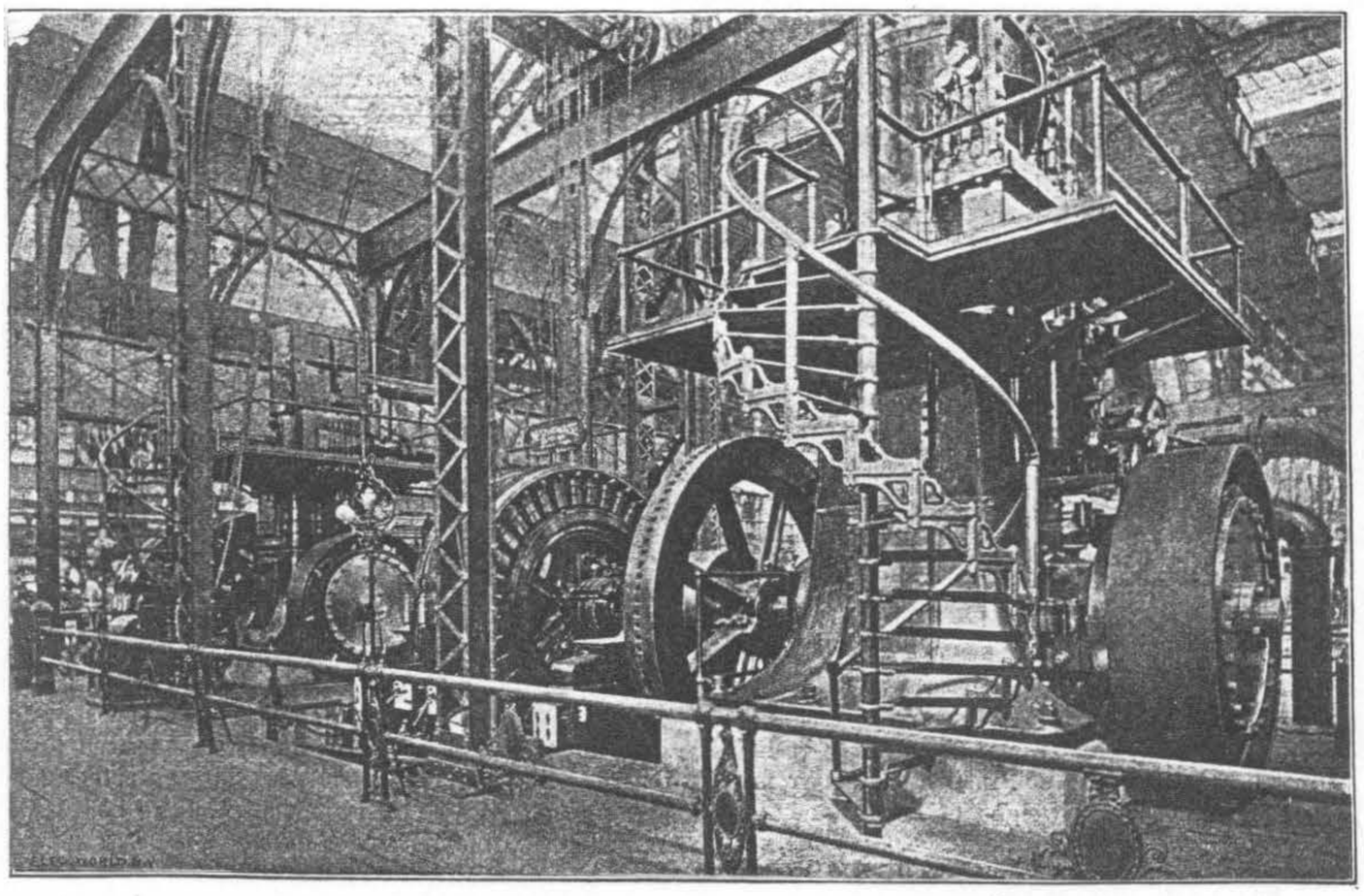
The accompanying plan indicates the location of each engine, alternator, exciter and the switchboard. Alternators numbered 1, 2, 6, 7, 8 and 9 were direct driven by Westinghouse engines. Nos. 3, 4, 5 and 10 were respectively belt driven by Buckeye, Atlas Corliss, McIntosh & Seymour, and Fraser & Chalmers engines, while machines numbered 11 and 12 were driven by tandem belts from the 3,000-h. p. engine of the E. P. Allis Company. Alternators numbered 13 and 14 were 240-kw., high speed, standard single-phase machines, belt driven by Westinghouse engines. The Kodak exciters, direct coupled to 100-h. p. Westinghouse engines, are shown at *A*, *B* and *C*, while the plan view of the feeder and dynamo switchboard will be noted in the space adjacent to the Fraser & Chalmers engine and alternator No. 10. All of the engines and dynamos were erected upon massive foundations, installed under the supervision of the mechanical engineers of the Exposition. In the case of alternators Nos. 6, 7, 8 and 9, with their engines, a single concrete foundation was used.

The plant illustrated on a very large scale the methods of driving by direct coupling of engine shaft to the dynamo shaft, and by the use of belting. The two alternators belted to the large Allis engine—the engine started by President Cleveland when he opened the Exposition—were tandem driven by belts 72 inches in width; the distance from the centre of the engine shaft to the centre of the shaft of its nearest dynamo was 47 feet; that to the centre of the more distant dynamo, 65 feet. To foreign engineers, who are unaccustomed to our high grade belting, these large and fine quality belts, furnished by the Page Belting Company, of Concord, N. H., proved to be an extremely interesting feature of the installation.

The advantage of the direct connected over a belt driven machine, as regards the saving in floor space, is well illustrated by a comparison of the space occupied by one of the 1,000-h. p. "engine-dynamos," as they are called, consisting of a 1,000-h. p. Westinghouse Columbian steeple engine and a 750-kw. alternator, with that occupied by belted engines and alternators. The outside measurement of the direct connected unit was 31 feet 8½ inches by 13 feet. The space occupied by the smallest belt connected engine and alternator was greatly in excess of this, being about 65 feet by 27 feet.

THE DYNAMOS.

Each alternator, electrically considered, is a double machine which delivers to its circuits two-phase currents, the difference between the phases being almost exactly 90 degrees. The frequency is 60 periods per second, or 7,200 alternations per minute, and the potential at the terminals of the machine varies from 2,000 volts to about 2,300 volts, depending upon the load, drop in primary circuits and transformers, secondary wire, and upon the potential required by the lamps. The speeds of the alternators, both belt driven and direct connected, are 200 revolutions per minute. Each machine has two armatures which are mounted upon the same shaft and are magnetized by two fields electrically and mechanically independent of each other,



LARGE DIRECT CONNECTED ENGINES AND DYNAMOS.

This construction is shown in the double page illustration, in the centre of which a direct connected alternator and Westinghouse engine will be noticed, while the belt driven machine is illustrated at the top.

The fields are of the circular or ring type, having 36 inwardly projecting poles built up of mild steel, laminated, and cast solid into the yoke. Lathe-wound coils are slipped upon the poles and securely fastened in position by bolts. The armatures are of the toothed type, generally employed by the Westinghouse company for alternating current work. The armature coils are lathe-wound and any one of them may be readily removed and replaced without disturbing the other coils upon the same armature. Each armature has 36 teeth, to correspond with the same number of poles on each field. The armature shafts are of forged steel, in self-aligning ball bearings, equipped with automatic oilers. The armature shaft carries at each end, between the armatures and bearings, two ring collectors which serve to receive the alternating current from each armature. The shaft also carries two commutators from which a rectified current is conveyed to the auxiliary winding of the field coils. The excitation of the field is chiefly derived from separate exciters, hereinafter described, but the auxiliary excitation is employed to secure automatic increase of the magnetic field proportioned to the reaction due to the currents flowing in the armature.

The current for the auxiliary excitation is derived from small transformers carried in the spider of the armature. The main current of the armature traverses the primary of the transformers, while the secondary current of the transformers is rectified by the commutators. In this manner the automatic compounding of the field is attained without the introduction of high potential current into the field coils.

In the belt driven machines provision was made for adjustment of the belt by sliding the machine as a whole upon foundation rails. The connection between the Westinghouse engines and their alternators was made by a rigid coupling. The size of the alternators is well shown in the illustrations; they stood 15 feet 1 inch in height from the top to the foundation. The weight of a machine of the belt driven type was a little over 140,000 pounds, while that of a direct connected alternator was 106,000 pounds.

THE EXCITERS.

Current for exciting the fields of the alternators was obtained from three 75-kw. continuous current machines, of multipolar type, direct driven by Westinghouse automatic engines. These exciters made 300 revolutions per minute, and delivered current at 250 volts. Two of them furnished current to excite 10 alternators, and the third was held in reserve. At the close of the Exposition, one of these machines had been running continuously for about three months, and in that time made over 37,000,000 revolutions.

THE SWITCHBOARD.

A switchboard was erected upon a double gallery against the south wall of Machinery Hall. This board has been fully described in THE ELECTRICAL WORLD of May 20, 1893, but a general résumé will not be out of place here. The floor of the first gallery was about 10 feet above the level of the space occupied by the engines and alternators, while the floor of the second gallery was 8 feet higher. The board was made up of marble panels, which were supported by an iron framework, consisting of angle iron supported upon floor beams of the galleries, and securely braced. The uniform width of all panels was 20 inches. The panels, most of which, themselves, constituted the bases upon which the instruments were mounted, extended into the framework of angle iron and were secured by bolts and vertical metal strips. These nickel plated strips were of semi-circular section, and extended from the floor line to the top of each board, covering the abutting edges of the marble panels, and assisting to hold the panels in position. A narrow frieze of marble was carried along the top of each board, and a vertical strip 5 inches wide at each end served as a decorative finish.

The board on the lower gallery was the dynamo and exciter board; that on the upper gallery was the supply circuit or feeder board. The circuits from the alternators were carried to the lower board through lead covered cables, and thence through switching devices to the upper board. Instruments for measuring the current and potential of each set of the two-phase alternators and of the two single-phase machines were provided on 13 panels, one panel being allotted to each of the 12 double machines, and the thirteenth panel being provided for the two single-phase machines. Provision was made for quickly substituting a relay or reserve dynamo for any one of those in operation. Two-way switches were used for each dynamo circuit, and the terminals at one end of these switches were always kept charged by the reserve alternator, so that by simply throwing the switch of the machine which was in difficulty, or which for any reason it was desired to shut down, the load was easily and instantly transferred from any alternator to the reserve machine. The board was so arranged as to make it impossible for a careless attendant to accidentally throw two alternators together. Multiple arcing the machines was considered inadvisable, and the board was so designed as to make this practically impossible. Four panels were provided in the lower board for exciters and the fifth for instruments measuring the combined output of the exciters when in multiple. One of these panels was not in use, as three exciters proved ample for the number of machines required.

The upper board comprised 40 panels and provided for a like number of supply circuits. Each panel contained a switchboard converter, a compensator, voltmeter, ammeter, Stillwell regulator, switch, fuses and plug receptacles for the connection of the supply circuit to any of the 14 alternators. Each circuit was protected from lightning by the Wurts non-arcing arrester.

The specifications under which the contract was awarded made it necessary to provide for supplying any circuit from any alternator, and inasmuch as the two-phase type of dynamo was selected, it became necessary to design a board which would permit any one of several hundred combinations to be made. The generating plant was equivalent to 26 single-phase machines, and provision was made for supplying each of the 40 distributing circuits from any one of these 26 sources; at the same time the arrangement was such that mistakes were impossible and the wiring of the board symmetrical and comparatively simple.

The panels were each lighted by etched lamps suspended from goosenecks from the top of the board, and in addition to these, four highly ornamental arc lamps, of the constant potential, alternating current type, were hung from arching wrought iron posts at the ends of the boards. Access to the lower board was secured by an artistic spiral stairway of iron. The upper platform was reached by means of two stairways from the lower gallery. Handsome ornamental railing of wrought iron inclosed the front and ends of both galleries.

The operation of this board proved satisfactory in the highest degree. The distributing circuits throughout the grounds of the Exposition were limited to 200 kw. each, and it is worthy of note that a board capable of distributing five or even ten times as much energy—that is to say 40,000 or 80,000 kw.—embodying the sectional features of this board, can be constructed to occupy practically the same space. This board, which was probably the largest ever constructed, measured in the upper gallery 71 feet in length and 9 feet 6½ inches in height. The lower part was 32 feet 6 inches long, and 11 feet 3½ inches high. The claims made by the Westinghouse company for this most interesting piece of electrical apparatus are as follows: 1. Safety against fire risk, being built entirely of non-combustible material. 2. Safety as against possible injury to attendants, as no high tension circuit or terminal is exposed on the front of the board, hence contact with dangerous circuits is impossible. 3. Safety as against accidental connection of two alternators, secured by the arrangement of the board itself. 4. Flexibility, in that any machine can be made to supply any circuit or set of circuits. 5. Capability of extension; the sectional construction adopted renders it easy to extend the board to accommodate additional machines without materially changing the wiring. 6. Sectional construction; the entire face of the board being built up of small units, transportation and erection are facilitated. 7. Accessibility, as all the wires are exposed and terminals readily accessible back of the board. 8. Uniformity and simplicity. Though there is a large amount of wiring on the board, the panels are alike and hence uniformity and simplicity are secured.

THE LAMPS.

It is a noteworthy fact that for all the incandescent lighting at the Exposition the new Sawyer-Man stopper lamp was used. Burned out lamps were periodically returned to the factory in Pittsburgh and there taken apart and supplied with new carbon burners and returned to be again used. The lighting of the Exposition has therefore afforded the Westinghouse company an excellent opportunity to test the value of the two-part lamp, of which the globe, stopper and leading-in wires can be used over and over again. The percentage broken in shipment was very small, and the success of this form of construction was claimed to have been demonstrated.

Above the gallery covering the entire eastern wall of the Electricity Building, the Westinghouse company made a very handsome exhibit by the use of the new stopper lamp. The photograph in the upper right-hand corner of the large illustration reproduces the design, but cannot accurately portray the beautiful effects produced by the various colored lamps.

EXHIBIT OF STREET RAILWAY APPARATUS.

In preparing the exhibit of street railway apparatus, and indeed in all of its exhibits in the Electricity Building, the Westinghouse company adopted the policy of selecting only apparatus illustrating new and valuable features. Duplication of exhibits was avoided wherever practicable. Therefore the railway exhibit was not as extensive as it might have been made, but it clearly illustrated the methods used by the Westinghouse company in the construction of railway generators and motors, and the method of mounting motors upon car trucks. The principal exhibit was located in Section H, Space 1, just south of the centre of Electricity Building and north of the exhibit of the Bell Telephone Company. The apparatus shown comprised one 270-h. p. generator direct driven by a Westinghouse automatic compound engine, to which it was connected by a flexible coupling, constituting what is known as the "Westinghouse Kodak Outfit." This arrangement is extremely compact and substantial. A general view of the space containing railway apparatus is shown in the lower left hand corner of the double page illustration. Beyond the handsome octagonal pavilion shown in the centre of the space was located a 400-h. p. multipolar railway generator, of the belt driven type. Several armatures such as are employed in these generators were exhibited, and were specially noteworthy for the simplicity and mechanical excellence of their construction. The fields are composed of four pole pieces, projecting radially inward from a circular yoke. The pole pieces are built up of hundreds of plates of sheet steel manufactured to a certain formula adopted by the Westinghouse company, which it is claimed secures magnetic qualities superior to anything hitherto obtained. The plates are pressed tightly together and secured by iron rods riveted to cast-iron end plates. The pole pieces thus constructed are then cast into the yoke, or field ring, which is of high grade cast iron. A distinctive feature of these generators as compared with others of corresponding size is the use of the single casting constituting the lower half of the field and the supports for the bearings; a construction which secures great rigidity of form. We have already said the armatures shown were examples of high class mechanical design and workmanship. The conductors pass through insulating tubes placed in slots about the periphery of the armature core. These insulating tubes are threaded through from one end of the armature core to the other, the slot in the core being of such a form that it is impossible to slide the tube out of place radially. It is thus impossible for the conductors and tubes to be thrown out by centrifugal force, and no band wires are required to hold them in place, as they are absolutely secured by the iron core.

The Westinghouse street railway motors of the single reduction type were fully exhibited. They were shown complete on trucks, dismounted, and with their fields thrown back. An extremely valuable characteristic of the Westinghouse motors resulting from the multipolar construction and method of armature winding employed, lies in the fact that the proper distribution of current in the armature conductors does not depend upon the uniformity of magnetization of the pole pieces, nor in the clearance of the armature, as measured from different poles of the field. If the bearings become worn and the armature is consequently decentralized, there results no unbalancing of the work which the armature conductors are called upon to perform. These points were well illustrated by the rotation of the armature of a motor which had the upper half of its field thrown back and only the lower half magnetized. The armature rotated at any desired speed, being controlled by the rheostat in its circuit, without sparking at the brushes and without abnormal heating of the armature conductors.

Complete lines of switches, ammeters, voltmeters, circuit breakers, both hand and automatic, lightning arresters of the Keystone and Tank type, as well as the smaller details, such as trolley wheels, fuse boxes, brushes, etc., were all fully shown.

A Three Rivers truck, built by the Sheffield Velocipede Car Company, of Three Rivers, Mich., was fully equipped with two 25 h. p. motors, controllers, diverter, etc., and shown in operation. A handsome 20-foot "accelerator" car of the Brownell company, St. Louis, Mo., was shown, equipped with two 30-h. p. motors, series multiple controllers, etc. The John Stephenson Company, Limited, loaned an 18 foot car with the new Tackaberry truck, which the Westinghouse company also electrically equipped and furnished with a glass floor, which allowed satisfactory inspection of the motors in operation, the car being raised from the track.

In addition to the exhibits of railway apparatus in Electricity Building, the Lamokin Car Works, of Chester, Pa., had an 18-foot car equipped with two 30-h. p. Westinghouse motors of the single reduction type shown in the Transportation Building, Section L-N, Spaces 9 to 11, and on the outside exhibition track, near the north end of the Terminal station, was a 20 foot car of the Laclede Car Company, St. Louis, Mo., completely equipped with Westinghouse apparatus.

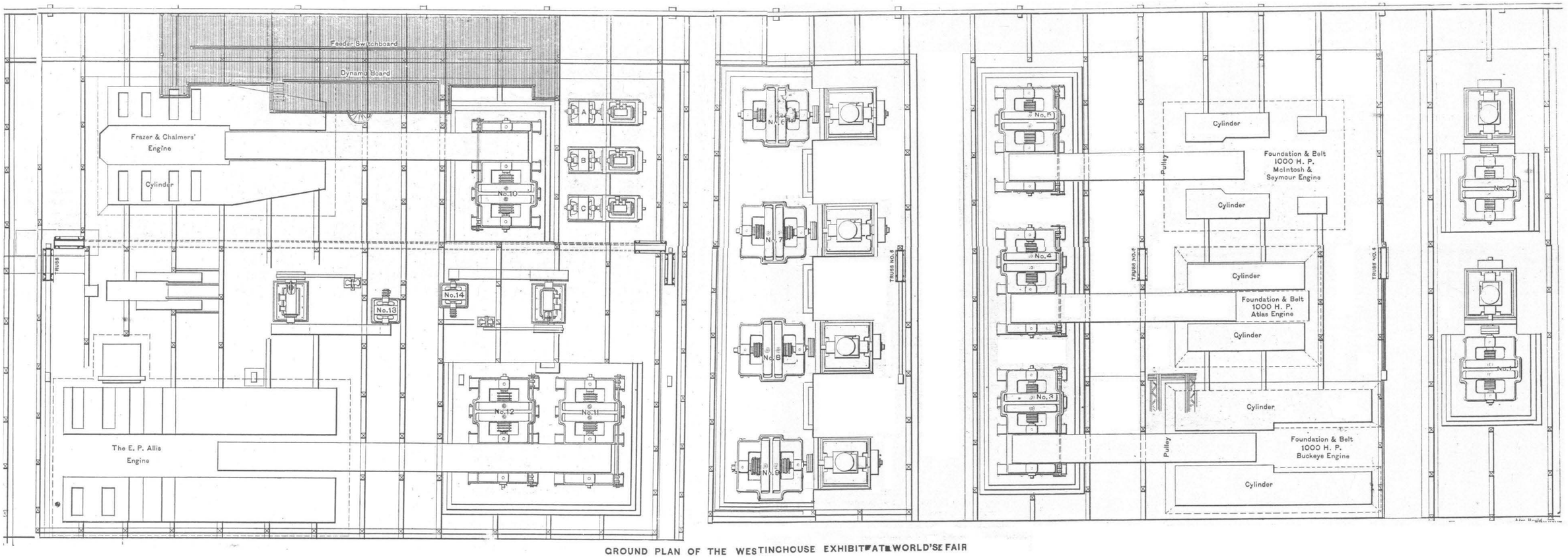
In Machinery Hall a 600-h. p. six pole railway generator, of the direct connected type, was in operation, supplying current for the power circuits of the Exposition. The armature of the generator was carried on the shaft of a Corliss compound engine, which operated at the extremely low speed of 90 revolutions per minute. The construction of this machine was massive in a noteworthy degree. As an illustration of this it may be mentioned that the radial depth of the commutator bars was four inches. The field poles were of mild steel, and the armature winding similar to that of the multipolar generators in Electricity Building.

Some idea of the size of this machine can be gained from our reproduction in the upper part of the large illustration. The generator rested in a pit in order that the armature shaft might be on a proper level for the engine. A very heavy flywheel served to maintain the momentum of the armature. The six sets of brushes were so connected that three of them supplied current to one terminal and the other three to the other terminal. The brushes were all controlled by a single holder that was operated by a handwheel. In connection with this generator was a complete marble switchboard, equipped for one generator and four supply circuits.

The Westinghouse Electric and Manufacturing Company did not deem it necessary to make an exhibition of railway motors in service, inasmuch as their apparatus is exclusively used by the South Chicago Street Railway Company and the Chicago City Railway Company. Upon these two roads there were daily carried thousands of passengers to and from the Exposition. The Chicago City Railway Company very kindly offered the judges on the National Commission the opportunity of carrying out tests with the apparatus on these cars, which the Westinghouse company very much desired them to do, but on account of scarcity of funds appropriated for testing purposes the judges were unable to make what would have been a very interesting and valuable test.

EXHIBIT OF POWER TRANSMISSION APPARATUS.

In Section J, Space 2, north of the centre of Electricity Building, and south of the French section, the Westinghouse Electric and Manufacturing Company showed in operation the most extensive plant of the Tesla polyphase type which has been erected up to the present time, either for exhibition purposes or for practical work. The question has frequently been asked, "Why cannot the electric companies show any polyphase plants in practical operation?" and the Westinghouse company here showed its



GROUND PLAN OF THE WESTINGHOUSE EXHIBIT AT WORLD'S FAIR

faith in its apparatus constructed under Tesla patents by building and installing an operative plant on a very large scale.

The centre of the space was occupied by a handsome gilt pavilion, shown in the upper left hand corner of the large illustration. This booth served at once for ornament, advertisement and office; chairs and tables being provided for visitors and representatives of the company.

The power for operating the machinery was obtained from the lighting circuits supplied by the Westinghouse plant in Machinery Hall. Two-phase currents from this source were employed to operate two Tesla motors, one a 500-h. p. machine, which took the place of the turbine or engine which would be used in practical operation to drive the generator, the other a 5-h. p. motor, direct connected to a small continuous current machine, which furnished the field excitation for the generator. Neither of the Tesla motors were intended to constitute a part of the exhibit proper, but served to furnish the power necessary for the plant, and proved that the two phase alternating current of 60 periods per second, supplied by the large installation in Machinery Hall, was adapted, not only to supplying incandescent lamps and arc lights, but also to the operation of motors.

The transmission exhibit proper consisted of a complete generating station north of the pavilion, an overhead transmission circuit, and a receiving and distributing station south of the pavilion. The apparatus in the generating station comprised one 500-h. p. two-phase alternating current generator; one 5-h. p. direct current exciter; marble switchboard, with instruments, and raising or step-up transformers, which received alternating current at a potential of 400 volts from the generator and delivered current at 1,200 volts to the transmission circuit. The generator was a six-pole machine making 600 revolutions per minute, the frequency employed being 30 periods per second, or 3,600 alternations per minute. The machines were of the multipolar type and similar in general appearance to the railway generators manufactured by this company, except that in addition to the commutator there were four collecting rings provided, which were carried upon the opposite end of the shaft. The machine as here used served simply as a generator of alternating current, but the construction permitted its being used as a rotary transformer, as a direct current generator, or as a motor operated by either direct or alternating current. The step-up transformers were located behind the switchboard, and, as before noted, they delivered current to the transmission circuit at a potential of about 1,200 volts. In practical transmission over very great distances much higher potentials would, of course, be employed, but it was not considered advisable to introduce extremely high voltages in an exhibit.

The line was carried to the pole located near the step up transformers, and thence to another pole located near the switchboard of the receiving and distributing station. The wires were supported upon special glass insulators designed by the Westinghouse company. No oil was used in these insulators, which were similar to those in successful use in transmitting energy from the power station in the San Antonio Canyon to the city of San Bernardino in south California, a distance of 28 miles. The step-down transformers were located behind the switchboard in the receiving and distributing station south of the pavilion, where the potential was reduced to 400 volts. The switchboard, like that in the generating station north of the pavilion, was non-combustible, consisting of marble panels on which the switches and instruments were mounted. These panels were fitted into skeleton frames of angle iron, similar to the big switchboard in Machinery Hall. All terminals charged with high potential were behind the board, and only accessible to the attendant, who, in order to reach them, had first to unlock a door and go behind the board; it was impossible from the front of the board to receive a discharge shock by contact with any part of an instrument or switch.

From the distributing switchboard in the receiving and distributing station, alternating current was conveyed to the 500-h. p. rotary transformer, a 60-h. p. motor of the two phase synchronous type, and a 60-h. p. rotary transformer delivering direct current at a potential of about 50 volts, intended for electrolytic purposes.

The 500-h. p. rotary transformer, like the generator north of the pavilion, was provided with a commutator at one end, and a four ring collector on the other end of the shaft. Alternating current was supplied to the armature through the collectors, and continuous current was delivered from the commutator, and used to operate a Dorner & cuit, and it was identical in every respect save one with the system which has been adopted by the Cataract Construction Company for its large installation at Niagara Falls. The one difference between the two is the frequency employed, which, instead of being 30 periods, has been reduced to 25 periods per second.

EXHIBIT OF ARC AND INCANDESCENT LIGHTING APPARATUS.

In Spaces 1 and 2, Section B, Electricity Building, were shown very complete lines of Westinghouse lightning arresters, switches, ammeters, voltmeters and transformers, both complete and dismounted, illustrating very clearly the method of construction. The new features shown in this exhibit of particular interest were the non-arcing metal lightning arresters introduced into converters, the new Sawyer-Man stopper lamp in various processes of manufacture, and converters in the various stages of construction, showing clearly the method of building up the iron, and the use of entirely separate and thoroughly insulated primary and secondary coils.

As the machines used for lighting purposes were to be seen in actual operation in the large plant in Machinery Hall, the company did not make any extensive exhibit of such machinery in Electricity Building: but here was shown a standard 450-kw. alternator field casting which very clearly illustrated the Westinghouse method of casting laminated poles into a cast iron frame. There were also shown, complete, two of the smaller alternators, viz., of 40-kw. and 60-kw. capacity, and one 25 light alternating arc machine. Supported in backets, to permit thorough inspection, the Westinghouse toothed armatures were exhibited, both complete and partially dismounted, disclosing very clearly the advantages and simplicity of this method of armature winding. The direct current lighting apparatus was well represented by various sizes of the letter type and Horizontal type machines. The Manchester motor, which seems to be commanding considerable attention and commendation for use with cranes, was shown complete and dismounted A 60-h. p. multipolar Dutton railway truck equipped with two 30-h. p. single reduction motors. Direct current from the same source was also employed to drive a 60-h. p. direct current motor mounted upon an 18-inch Ingersoll-Sergeant air compressor, shown at the bottom of the large illustration; and also to supply direct current arc lamps of the constant potential type, arranged in sets of nine across the 500-volt circuit. The rotary transformer was also used as a motor, and by means of belts was made to drive a Worthington pump and an alternating current arc light machine.

The power transmission proper, it will be noted, did not include the 500-h. p. motor which was used to drive the generator, nor the 5-h. p. motor which was directly connected to the exciter in the generating station. It began properly with the two-phase generator, which was driven by a motor supplied with current from the lighting cir- generator of low voltage and very large current was no the least attractive of the exhibits in this space. One curiosity shown in this exhibit, probably overlooked by many on account of its size, was a small dynamo and steam engine. The dynamo stood $\frac{5}{16}$ inch in height, and yet was so perfect in every detail as to be capable of operation. The engine matched the dynamo, and was run by compressed air.

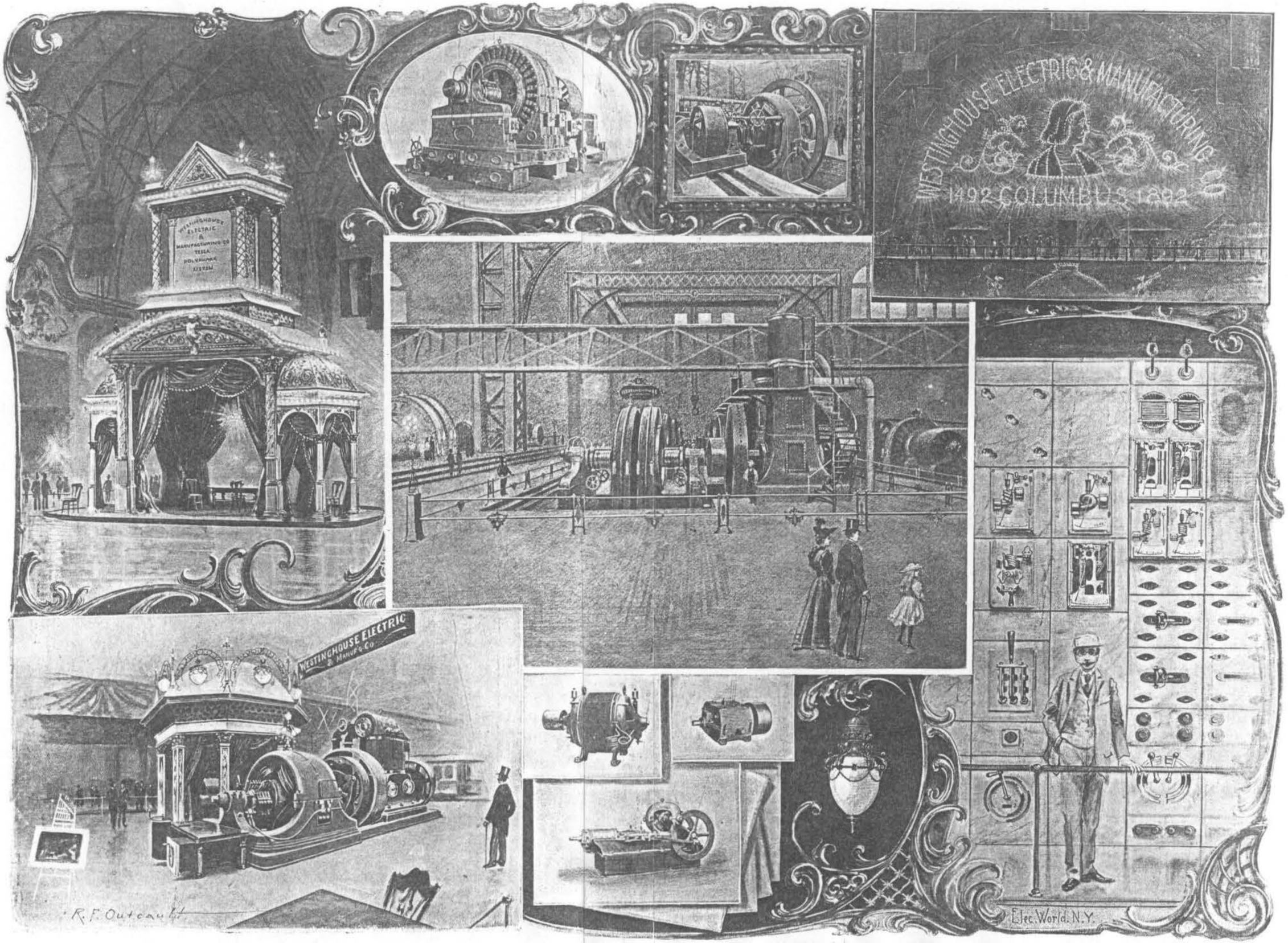
EXHIBIT OF TESLA APPARATUS AND HIGH POTENTIAL, HIGH FREQUENCY PHENOMENA.

In one corner of Space B-1 was erected a room, perhaps 30-feet square, in which were daily shown experiments illustrating the remarkable results obtained by Mr. Tesla by the use of high frequency high potential currents. Current was taken from the lighting circuits connected with the plant in Machinery Hall, and transformed up to perhaps 1,000,000 volts by oil transformers situated back of the room The rate of alternation was increased from 7,200 alternations per minute to about 400,000 per second by the use of condensers and an arc breaking device. Within the room were suspended two hard rubber plates covered with tinfoil; these were about 15 feet apart and served as terminals of the wires leading from the transformers. When the current was turned on, the condition in the vicinity of the plates was made such as to render luminous vacuum bulbs which had no wires connected to them, but lay on a table between the plates, or which might be held in the hand in almost any part of the room. These were the same experiments and same apparatus shown by Mr. Tesla in London about two years ago, where they produced so much wonder and astonishment.

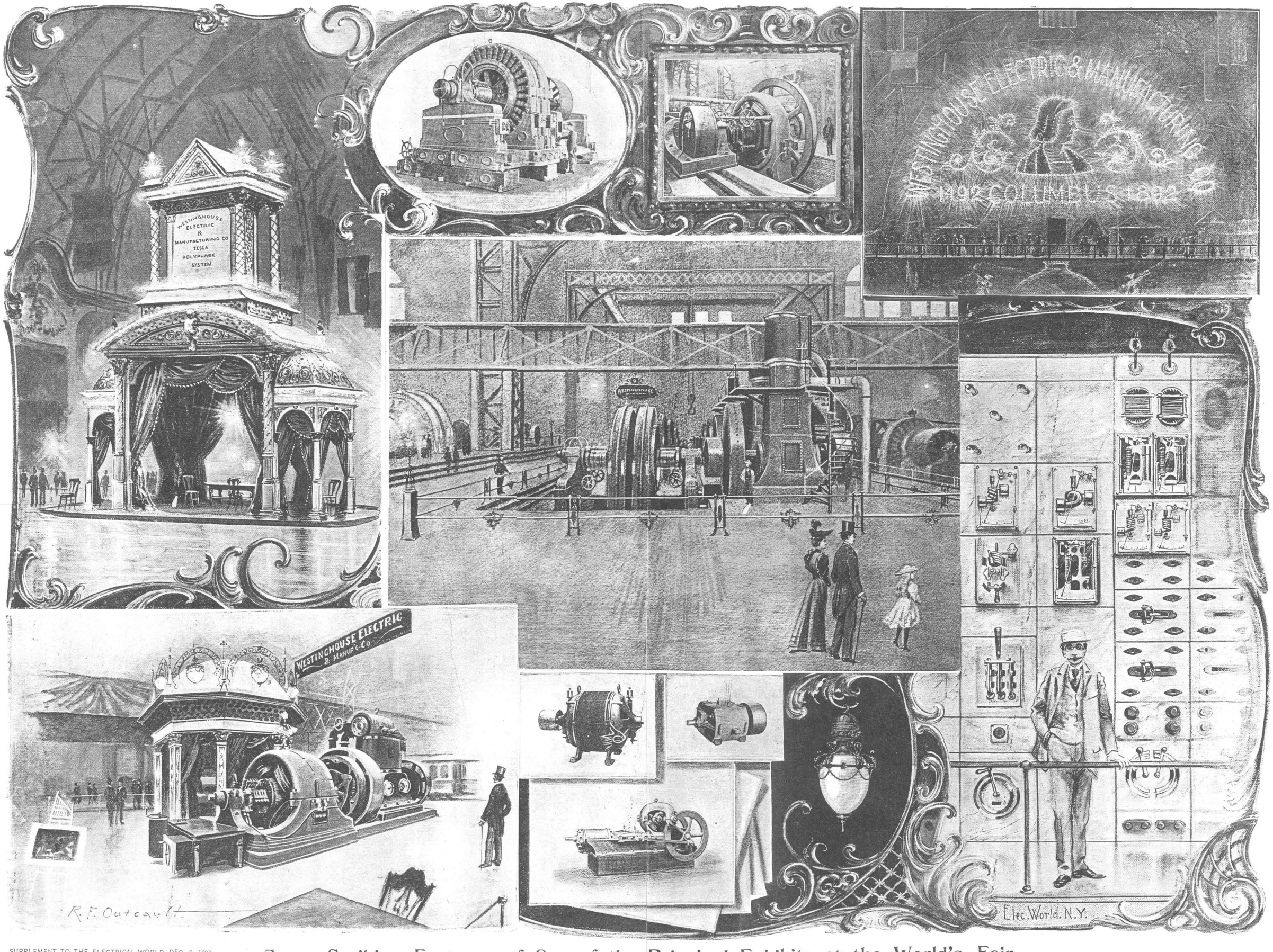
Over the entrance to this room was a glass sign bearing in its centre the name "Westinghouse." Current of high potential was led from one transformer terminal to the letters by means of invisible wires; the other terminal was connected to tinfoil on the back of the glass plate. When current was turned on the electricity would discharge across the surface of the plate, and over its edge to the tinfoil on the back, producing the effect of a modified lightning discharge, and accompanied by a similar deafening noise. This was probably one of the most novel and interesting attractions in a sensational way seen in the building, as the noise could be heard several hundred feet away, and the miniature lightning flash was very brilliant and startling.

Outside of the booth was exhibited a collection of the various forms of motors and other apparatus employed by Mr. Tesla in the discovery and development of his polyphase system. Here were to be seen also the oscillators, the subject of a lecture by Mr. Tesla before the American Institute of Electrical Engineers at the World's Fair, in August last, which attracted so much scientific interest. On a table was a Tesla ring which illustrated the principle of the rotary magnetic field. The ring consisted of an iron core wrapped with two coils of wire, through which a two-phase current was passed. The effect produced upon metallic bodies placed within the influence of this field was practically the same as though a magnet were rapidly carried along the axes of the coils.

Altogether, from a scientific as well as a popular standpoint, the Westinghouse Electric Manufacturing Company made an exhibit which was not only a great credit to themselves, but was one of the most interesting features of the Columbian Exposition.



Some Striking Features of One of the Principal Exhibits at the World's Fair.

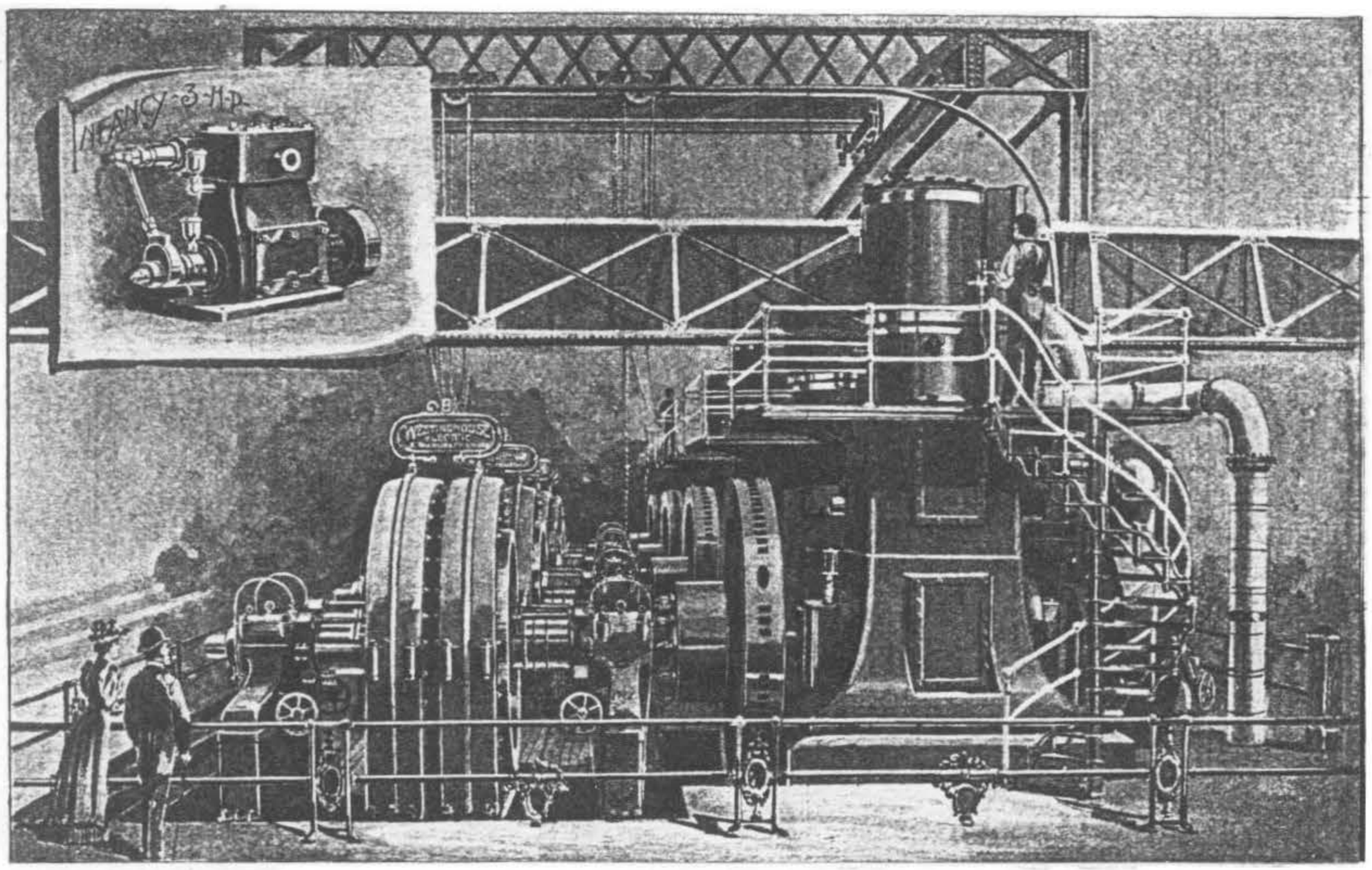


SUPPLEMENT TO THE ELECTRICAL WORLD, DEC. 2, 1893.

Some Striking Features of One of the Principal Exhibits at the World's Fair.

Westinghouse Engines at the World's Fair.

The exhibit of Westinghouse engines attracted much attention among engineers and the public in general, through its size and varied character. The main exhibit of six 1,000-h. p. engines, direct connected to Westinghouse



EARLIEST AND LATEST TYPES OF WESTINGHOUSE ENGINES.

alternating current dynamos, was the most noticeable feature, but in addition to this there were eight of smaller sizes, making in all 14 engines, aggregating 7,695 h. p., being by far the largest exhibit of this kind ever made at any exposition. The accompanying cut illustrates the development of 12 years of practice in this line, the small figure being the first engine constructed and the large one an excellent view of the row of four engines which place 4,000 h. p. developed and utilized within a smaller space than has ever before been attempted on land. The other two engines of 1,000 h. p. were in an adjacent block, similarly connected to dynamos of the same pattern. The history of the construction of these six engines indicates the constructive development which a shop can reach, for they were built from new designs and patterns within four months—in fact seven were built in this time—without losing a casting or spoiling a part. The seventh engine was provided to insure against delay through possible accident in shipment or erection, and upon the successful starting of the six engines at Chicago, the seventh was sold to the Missouri Electric Light Company, of St. Louis, where it is now in operation. This type, while a departure from the regular Westinghouse pattern, involves most of the salient features which have become so well known, and contains various new ones, especially the pneumatic inertia balance which relieves the governor of all weight and inertia of valve parts, and which by the simple turn of a valve is immediately transformed into a steam starting gear. It is believed that this type of compound engine will come into favor rapidly where large units are required, as it combines a high steam efficiency with various approved features of the Westinghouse design. A fact not generally known, but of some interest regarding the operation of these

engines, is their relation to the practical service of the Exposition lighting, for, while many lights were carried by other engines on exhibit, operating during Exposition hours, the Westinghouse engines carried lights not only during the regular hours, but all night, Sundays and various odd hours, thus rendering more extended service than is usual in the operation of exhibits.

The two 400-h. p. compound engines of the regular Westinghouse type, in operation in the central block, between the two large Corliss engines, were sold to the Exposition. and will continue to operate through such time as lighting is required. These engines were the first placed in operation last year, furnishing power for incandescent lights previous to the starting of the main exhibits. In the Electricity Building a 270-h. p. Kodak outfit of the regular type, shown in the small cut, was operated in a rather novel way. It being inconvenient to obtain steam in that location, the generator was operated as a motor. driving the engine, the latter being piped to give all the appearance of running under steam. It was difficult to perceive that it was not operated in the usual way, although a few of the more curious would investigate and easily ascertain the facts. This outfit was sold to the Lehigh Traction Company, of Hazleton, Pa.

A somewhat obscurely located though interesting and fine running set of engines were the three 125-h. p. Westinghouse compounds direct connected to three small Westinghouse multipolar dynamos, operating as exciters for the large alternating current machines. These were kept in practically continuous operation, and on Aug. 8 the engineers in charge started the one nearest the aisle for a run which should be absolutely continuous throughout the rest of the Exposition. It was operated for 85 consecutive days and nights, making in that time over 35,000,000 revolutions, and when shut down at the close of the Fair was running with perfect smoothness. Engines of this type have frequently been operated throughout longer periods, but this, so far as known, is the longest run ever made by any engine in a public place. A neighboring blackboard on which hourly records of time and revolutions were kept attracted much attention. Two Standard engines of 125 h. p. each were loaned to the Chicago Paper Trade Club to operate its paper making exhibit, and were sold to the Boone Street Railway Company, of Boone, Ia.

The display of steam engines generally at the Exposition was, on the whole, highly creditable and representative, but no exhibit was more characteristic of the product and magnitude of the interests represented than the above.

The First Three-Phase Transmission Plant in the United States.

The first water power in Southern California to be utilized for the distribution of power, as well as lights, is that situated at the mouth of Mill Creek Canon, nine miles from the city of Redlands, one of the most flourishing of the younger cities of the State. Less than two years ago a few of the public spirited citizens of Redlands saw the chance of utilizing the fine Mill Creek power and organized a company, and the enterprise was rapidly pushed forward and about nine months ago a contract was closed with the General Electric Company for the necessary apparatus.

Mill Creek is a fine and unusually reliable mountain stream that springs from the slopes of mountains San Bernardino and Grayback, the two loftiest of the Sierra Madre range. The main body of the stream and a convenient intake were found near the mouth of the canyon and, by a comparatively small deflecting dam of masonry 40 feet long and head works it was possible to turn the water into a tunnel 160 feet in length, cut through the rock, and thence into a heavy steel pipe line, which was brought down the stream a distance of 7,250 feet, where was obtained a convenient site for a power house. At the end of the tunnel is a sand box 75 feet long by 25 feet wide to catch any sediment before the water can enter the pipe line. At this point the fall is in the neighborhood of 353 feet, giving exactly 160 pounds pressure to the square inch in the receiver that terminates the pipe line, which can deliver 2,400 cubic feet of water per minute.

The power house is for the most part an excavation not far from the bank of the creek. The roof is erected on very low side walls and under the lean-to, on the right, is the wheel pit with the receiver and Pelton wheels. The wheel shafts extend through iron shutters, set in windows in a massive rubble retaining wall that bounds the wheel pit into the dynamo room, where they are directly coupled to several machines. This dynamo room contains the following apparatus, as may be seen from the cut, which gives an excellent view of its interior: Two 250-kw. ten-pole three-phase generators delivering current directly to the lines at 2,500 volts between lines; two D-10 exciters, each capable of energizing the fields of both generators, and one 50-light, 2,000-c. p., Thomson-Houston arc dynamo. With the stream at its lowest 800 h. p. is developed at the generators. Room is left and foundations are in place for a third three-phase generator and a second similar arc machine. The large generators run at 600 revolutions, give 6,000 alternations per minute, and have a rated output of 100 amperes at 2,500 volts. The general arrangement of the station was planned before the contract for the apparatus was let (and in fact, before the character of the machinery was determined) substantially according to the designs of the late A. W. Decker, whose recent death was a serious loss to the electrical interest of the Pacific Coast.

To each of these large machines just mentioned a Pelton wheel is directly coupled, the three-phase generators being supplied with 200-h. p. double wheels, each operated by a double nozzle.

The regulation of the hydraulic power is by the ordinary differential nozzle operated by Pelton differential governors driven from one of the exciter shafts. A second small differential governor, driven from the other exciter shaft, steadies the action of the first by regulating the exciter wheels. The water having done its work is discharged into a ditch and utilized for irrigation purposes.

On the side of the dynamo room opposite the dynamos are located the switchboards. The chief interest of these lies in the three-phase switchboard for the two big

generators. This is elaborately devised to meet every condition or combination that it might be desired to make with the two machines, and the two circuits that run from the power house. Either machine can be thrown on either circuit and both machines in parallel on either or both circuits. At present the parallel connection is chiefly used in shifting over the load to obtain perfect continuity of service. A six-ton traveling crane permits ready handling of any of the machinery.

The interior of the station is a model of its kind. Particularly to be noted are the excellent foundations, and a result is an excellent alignment of shafts, the large generators running without even a tremor at the bearings.

From the power house are run two three-phase circuits, each composed of three 00 B. & S. wires. One of these runs to the company's office at Redlands, a distance of seven and a half miles, and from thence is distributed over the city for lighting and power purposes. On a substantially built pole line the other extends to Mentone, four and a half miles, where is located the artificial ice plant of the Union Ice Company.

In this plant is installed a self-starting 150-kw., triphase, 750-revolution, 6,000-alternation synchronous motor, belted through the medium of a countershaft to two large compressors for the ammonia, a circulating pump for the compressor jackets, a force pump to supply water for the ice, and a small elevator for handling the ice. In order to ascertain the point of synchronism, a Thomson acoustic synchronizer is employed, and gives unqualified success. The ice plant is of the so-called "pipe" type, and the freezing room and condenser contain nearly 20 miles of three-quarter inch iron pipe, in testing which the motor was stopped and started at short intervals for several weeks. The operation of the ice plant is continuous, the load being on the motor 24 hours a day, and, barring accidents, 365 days a year, The motor plant at this point is likely soon to be increased to keep up with an increase in the plant.

From the main Redlands circuit a number of lines are taken off from the ice plant and also for the neighboring town of Mentone. There are now in operation 30 arc lamps, besides over 1,000 16-c. p. incandescent lamps distributed over three legs of the circuit. A number of small induction motors without commutators or collecting rings are to be installed before the beginning of next year, to meet the demand already created by the success of the plant. The transformers are very similar to the ordinary General Electric type of transformer, except that they are designed for 50 cycles per second, and to reduce the pressure from 2,200 to 110 volts. So far as possible rather large transformers are used with comparatively long secondaries. These are used only directly at the point where light and power are delivered.

No trouble whatever has been experienced from any unbalancing of the lighting lines. In fact, shortly after the plant was started up the largest single block of lighting in the city, wired for three circuits, had these circuits worked for several nights on two legs of the triphase generators pending the setting up of the third transformer; and, although the lights from these two legs were set in adjacent rooms where both would be seen at once, not the slightest trouble from unbalancing was evident.

The first generator reached Redlands Sept. 1, and Sept. 7 incandescent lamps were turned on in Redlands, where arc lamps had been previously working since the latter part of July. Sept. 13 the motor at the ice plant went into commercial operation. The whole plant has been running steadily and doing good service ever since.

SOCIETY AND CLUB NOTES.

THE NEW YORK ELECTRICAL SOCIETY'S WORLD'S FAIR SYMPOSIUM.—I.

ON Wednesday Nov. 29 the New York Electrical Society meeting at Columbia College, held a "symposium," the subject being "Electricity at the World's Fair." Brief addresses had been announced by a number of gentlemen, but lack of time necessitated the postponement of some of them until the next meeting of the Society. Interest in the subject was shown by the fact that the room was filled to overflowing.

The meeting was presided over by the vice-president, MR. C. O. MAILLOUX who introduced the speakers in a very happy style, and who himself opened the evening's discourses by giving an account of the

STORAGE BATTERIES AT THE FAIR.

The only interesting feature involving storage batteries at the World's Fair, said Mr. Mailloux, were the electric launches, and these involved more attention to detail than a high order of engineering. The exhibits of various types of batteries was very meagre, including only three foreign exhibits. Among these the portable battery of Wladimiroff[1] exhibited in the Russian section of Machinery Hall, presented some interesting features. Some three or four American batteries were exhibited with which most of us were familiar. The speaker also referred to the storage batteries exhibited by Mr. Ch. Pollak of Frankfort, Germany, and to his ingenious device for commutating alternating currents into continuous for the purpose of charging storage batteries.[2] According to Mr. Mailloux there still remained the necessity of making the apparatus give an alternating from a continuous battery current. Reference was also made to storage batteries used on the floats in the Chicago Day procession and on the self-propelling electric carriage at the Fair. Mr. Mailloux also drew attention to the fact that we had not yet made as much progress in the application of storage batteries as was to be found abroad, and also to the large sizes of cells used there.

DR. CHARLES E. EMERY then being introduced spoke on

THE ELECTRIC LIGHT AND POWER ENGINES AT THE FAIR.

While there was nothing specially new there, progress was shown in the perfection of detail, increase of size and adaptability to special purposes. The Corliss type was shown in many forms. Views of the principal engines exhibited at the Fair were thrown on the screen and commented on by the speaker. Among them was the Edison 2,800 kilowatt generator; the Westinghouse engine driving the 10,000-light alternators; the Schichau engine coupled direct to the large Siemens and Halske generator and having a Ryder valve. The Lake Erie Iron Works engine which drove the 750 k. w. generator in the Intramural Railway power station and which had made a remarkable record. This engine was the first to be started and was a little to small for its work, but worked very well and he thought this feature would be copied as it was a safeguard against using too much current all at once.

Among the other engines shown was the Willans[3], the large 2,000 h. p. Allis engine and the Williams and also a number of views of other interesting mechanical subjects.

PROF. F. B. CROCKER then spoke on

ELECTRIC CONGRESSES.

In three respects the Electrical Congress at Chicago had been unique. First, it had given final values and names to electrical units; secondly, it had given official sanction to the use of the henry, in honor of an American, and which thus constituted a recognition of America in electrical science; and third, on account of the importance of the papers read and the eminence of the men who read them. The presence of most of the prominent electricians at Chicago, must also be considered an extraordinary result. The speaker thought that the somewhat lax business management apparent at the Congress was an insignificant matter, and did not in any way interfere with its success. PROF. CROCKER did not agree with Prof. Rowland in the view that there never would be occasion to hold another electrical congress, and he suggested as work for a future congress the fixing of magnetic units and names for them, a standard of light, and an international nomenclature for electrical terms and quantities.

MR. NIKOLA TESLA, then being introduced, spoke, as follows on his

ELECTRICAL OSCILLATOR.

You may perhaps know, at least those of you who have followed the electrical development more closely, that the subject about which I am to say something is one which I recently presented before the Electrical Congress. During the past two years or so I have been gathering results and preparing a work which I had the intention to present before the last annual meeting of the American Institute as one of its members. Now, as a matter of fact, at that time I had gone considerably into the study of the practical aspects of the work which I was completing and my notion was that I was touching upon something very important, which would lay the foundations of a novel industry, perhaps of more than one industry. But to speak in that strain before such a gathering as I had the honor to address at the Chicago Congress would have required a nerve which I did not possess; or if I did possess it, it would be sure to leave me when I wanted to use it; and so I dwelt chiefly on those features which possessed a purely scientific interest, my desire being to present the subject very modestly, as I was not quite sure of the practical side of some of the questions involved. Right after the lecture I asked one of my friends what he thought of it. He said it was good enough but it could have been better. A prominent engineer came to me and said "Mr. Tesla, I want to tell you something but I fear it may offend you." I knew what was coming and so I asked what it was. He said "Well, don't you work on steam engines. You have done some work in electricity. If you stick to it you will do some good work, but if you work on steam engines you are bound to fail." (Laughter.) All these men that I mention are some of the most prominent men in the profession. Another said, "I wonder what Tesla is going to do with his blessed engine." Another, to whom I showed the advantage of doing away with complicated mechanism and generating electricity directly, said, after he had watched for a long time an apparatus running some incandescent lamps, "Couldn't you apply this to *rotating* motion?" Now this is the way in which my work was received. (Laughter.) But I was quite prepared for that because for fully two years I had myself rejected these ideas again and again, though I had in my mind the construction of the apparatus in many details; but it was not until I overcame experimentally some difficulties which at first seemed to me insuperable that I gained faith in the principle, that I finally resolved myself to this work.

One of the first impulses which have guided me was to produce an absolutely constant oscillation which would be independent of friction losses, or gravity, or temperature changes within very wide limits. Now, we can employ a pendulum, a clock work or a vibrating spring, or some such device as that, But they are very unreliable. I wanted to produce a positive motion, so that I might operate what I called some time ago a disruptive discharge coil. I may assume that some of you know that some time ago I advanced a method of producing currents of high frequency from direct or alternating currents. The method consists in charging condensers, discharging them either through a primary and then inducing in coils of the secondary, or in its own, currents of high potential. The lamp to be operated with such coils is already perfected. A nearly exhausted vessel would be good enough for the purpose. But the devices themselves are inefficient in the production of these currents, and one reason is that these devices do not yield a perfectly constant vibration. I had to depend on a disruptive gap and I used in connection an air blast or oil stream or a mechanical interrupter. Now with this device which I invented subsequently I was able to maintain a vibration with perfect constancy. This device consisted of a powerful spring which required several tons of force to spring it a certain distance and which was constantly kept in vibration by steam or air pressure. In the beginning I used springs of tempered steel. These steel springs would break, though they had a section of two or three square inches. So I resorted to air springs. The air springs would not break, but the air springs had no constant resilience. Then I made the chambers of the air springs communicate with the outer air. This gives a vibration constant enough, but the temperature of the air in the chambers can be maintained quite constant as by boiling water in the jacket surrounding them. The device yields a constant vibration, and as the force which is driving it is many tons and the friction but a very small matter, it is unaffected by the variations of the steam or air pressure. This was one of the chief features I wanted to present.

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1. See THE ELECTRICAL ENGINEER, Sept. 27, 1893.
2. See THE ELECTRICAL ENGINEER, Sept. 13, 1893.
3. See THE ELECTRICAL ENGINEER Oct. 25, 1893.

The Calculations of Alternating Current Motors.—IV.

BY E. ARNOLD.

It has only now been possible for me to continue the communications which appeared in THE ELECTRICAL WORLD of May 13, 1893. In that section there are a few typographical errors which I wish to correct.

The last three equations should read :

$$I_2 = \frac{3}{2} \cdot \frac{p_1 M I_1}{\sqrt{R_2^2 + p_1^2 L_2^2}} \qquad (31)$$

$$A_2 = \frac{9}{8} \cdot \frac{p_1^2 M^2 I_1^2 \cdot s_2 \cdot R_2}{R_2^2 + p_1^2 L_2^2} \qquad (32)$$

$$D = \frac{A_2}{p_1} = \frac{9}{8} \cdot \frac{p_1 M^2 I_1^2 \cdot s_2 \cdot R_2}{R_2^2 + p_1^2 L_2^2} \qquad (33)$$

Also in Fig. 6 the side $B\,c = \frac{3}{2} \cdot p_1 L_1 I$, instead of $p_1 L_1 I_1$.

We will now make the assumption that there is present only one primary and only one secondary phase, and that both coils are in the relative position of maximum mutual induction. The energy induced in the secondary coil by the first will then be :

$$A_0 = \frac{1}{2} \cdot \frac{p_1^2 M^2 I_1^2 R_2}{R_2^2 + p_1^2 L_2^2} \qquad (33a)$$

Now in order to determine for this case the relation between the work A_0 and the primary E. M. F. we calculate the energy A_0 in functions of E_1.

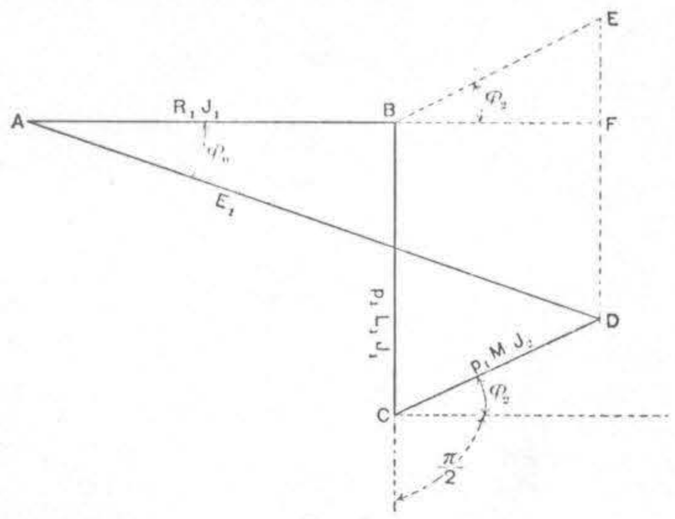


FIG. 7.

Then in Fig. 7 we make $A\,B = R_1\ I_1$, perpendicular to it.

$B\,C = p_1\ L\ I_1$ and at an angle $= \frac{\pi}{2} + \varphi_2$.

$C\,D = p_1\ M\ I_2$; then $A\,D = E_1$.

From the figure $E_1^2 = \overline{A\,F}^2 + \overline{F\,D}^2$, or

$$E_1^2 (R_1\ I_1 - p_1\ M\ I_2 \cdot \cos\varphi_2)^2 + (p_1\ L_1\ I_1 - p_1\ M\ I_2 \sin\varphi_2)^2 \qquad (34)$$

where

$$\cos\varphi_2 = \frac{R_2}{\sqrt{R_2^2 + p_1^2 L_2^2}} \qquad (35)$$

$$\sin\varphi_2 = \frac{p_1 L_2}{\sqrt{R_2^2 + p_1^2 L_2^2}} \qquad (36)$$

$$I_2 = \frac{p_1 M I_1}{\sqrt{R_2^2 + p_1^2 L_2^2}} \qquad (37)$$

and thus

$$E_1^2 = I_1^2 \left[\left(R_1 + \frac{p_1^2 M^2 R_2}{R_2^2 + p_1^2 L_2^2} \right)^2 + p_1^2 \left(L_1 - \frac{p_1^2 M^2 L_2}{R_2^2 + p_1^2 L_2^2} \right)^2 \right] \qquad (38)$$

If to abreviate we make

$$q = \frac{p_1^2 M^2}{R_2^2 + p_1^2 L_2^2}$$

and put the value of I_1^2 from equation (38) in equation (33a), then

$$A = \frac{1}{2} \cdot \frac{p_1^2 M^2 E_1^2 R_2}{(R_2^2 + p_1^2 L_2^2)[(R_1 + q R_2)^2 + p_1^2 (L_1 - q L_2)^2]} \qquad (39)$$

Also

$$q = \frac{M^2}{\left(\frac{R_2}{p_1}\right)^2 + L_2^2}.$$

The number $R_2 : p_1$ being small can be neglected in practice. Then

$$q = \frac{M^2}{L_2^2}.$$

But $M : L_2$ indicates the transforming ratio between a phase in the inducing and a phase in the induced current winding, assuming that every line of force of the primary system cuts the secondary system. For instance, if the induced circuit consists of s_2 coils (instead of simple windings, as are considered in Fig. 5), and every coil consists of z short circuited windings in series, then

$$\frac{M}{L_2} = \frac{s_2}{z}$$

R_2 thus represents the resistance of the z windings.

But as the primary and secondary windings are on separate iron cores, between which there is an air space, there will be a considerable leakage of lines of force. While the armature is at rest when the motor is being started the leakage reaches its maximum, as the excitation of the field is then many times what it is when the motor is running at normal load.

The leakage is also greatly dependent upon whether drum or ring winding is chosen, and increases with the increase of air space between field and armature, with the increase of induction of the iron of the magnet and armature and the air.

If there were no scattering of lines of force then would

$$M^2 = L_1 L_2.$$

Considering the leakage, we make

$$b^2 M^2 = L_1 L_2 \qquad (40)$$

b representing the coefficient of magnetic leakage, and $b < 1$; and, furthermore,

$$L_1 = \frac{4\pi \cdot s_1^2}{10^9 \cdot \rho} \qquad (41)$$

$$L_2 = \frac{4\pi z^2}{10^9 \cdot \rho} \qquad (42)$$

where ρ stands for the resistance of the magnetic circuit; and so we find that

$$q = \frac{b^2 L_1 L_2}{L_2^2} = b^2 \cdot \frac{s_1^2}{z^2} \qquad (43)$$

If we now divide numerator and denominator in equation (39) by p_1^2, and neglect the member $R_2 : p_1$,

$$A_0 = \frac{1}{2} \cdot \frac{b^2 \cdot E_1^2 \cdot \frac{s_1^2}{z^2} \cdot R_2}{\left(R_1 + b^2 \frac{s_1^2}{z^2} R_2\right)^2 + p_1^2 \left(L_1 - b^2 \frac{s_1^2}{z^2} L_2\right)^2} \qquad (44)$$

for $b = 1$; that is, when there is no magnetic leakage the second member of the denominator becomes zero. As this member is proportional to the square of p_1, and as we have b^2 in the numerator, this equation shows us that the energy A_0, and therefore also the torque, is greatly diminished by the magnetic leakage. This equation also shows us that the torque is proportional to the square of the primary tension E_1, that it is dependent upon the grouping of the armature windings (the total number of which $= s_2 \cdot z$), the sum of the armature resistances, $s_2 \cdot R_2$, and the transforming ratio $s_1 : z$.

The equation (38) can also be written in the following form :

$$I_1^2 = \frac{E_1^2 (R_2^2 + p_1^2 L_2^2)}{p_1^2 (R_2^2 L_2^2 + R_2^2 L_1^2 + 2 M^2 R_1 R_2) + p^4 (L_1 L_2 - M^2)^2 + R_1^2 R_2^2}. \qquad (45)$$

If we now substitute this value of I_1 in equation (33a), and neglect $R_1^2\ R_2^2$, which is small,

$$A_0 = \frac{1}{2} \cdot \frac{b^2 \cdot E_1^2 \cdot R_2}{\left(R_1^2 \frac{L_2}{L_1} + R_2^2 \frac{L_1}{L_2} + 2 b^2 R_1 R_2\right) + p_1^2 L_1 L_2 (1 - b^2)^2}. \qquad (46)$$

For $b = 1$, in case of no leakage, the second member of the denominator $= 0$; the member

$$R_1^2 \frac{L_2}{L_1} + R_2^2 \frac{L_1}{L_2} + 2 R_1 R_2$$

becomes a maximum for a particular relation of $L_1 : L_2$, namely, for

$$\frac{L_1}{L_2} = \frac{R_1}{R_2},$$

or for a transforming ratio,

$$\frac{s_1}{z} = \sqrt{\frac{R_1}{R_2}}, \qquad (47)$$

or for

$$R_2 = R_1 \cdot \frac{z^2}{s_1^2}. \qquad (47a)$$

Thus if we make the assumption that b nearly equals 1, so that the second member of the denominator can be neglected, then for the above transforming ratio or for the resistance R_2 given in equation (47a), the torque at the starting of the motor becomes a maximum. Now as s_1 depends upon the primary E. M. F., and, supposing the dimensions of the core to remain the same, increases with E_1, then the rational construction of the closed circuited armature becomes dependent upon the primary winding.

The dependence of the torque upon R_2 and the transforming ratio $s_1 : z$ can be best shown graphically. If we consider in equation (46) the quantities R_2 and $L_1 : L_2$ as the only variables, and let $b = 1$, then naturally A_0 becomes the torque.

$$D_0 = \frac{a_1 R_2}{R_1^2 \frac{L_2}{L_1} + R_2^2 \frac{L_1}{L_2} + 2 R_1 R_2}$$

where a is a constant.

For $R_1 = 0.1$; $\frac{L_1}{L_2} = 10$; $\frac{s_1}{z} = \sqrt{10}$

we obtain with different values of R_2 the curve A, Fig. 8;

for $R_1 = 0.1$; $\frac{L_1}{L} = 100$; $\frac{s_1}{z} = 10$, the curve B.

As R_2 increases the torque increases and reaches a maximum for a particular value of R_2 given by equation (47a). The resistance R_2 which corresponds to the maximum torque becomes smaller, the greater the transforming ratio $s_1 : z$; or with a constant resistance R_2, the torque increases with the increase of transforming ratio.

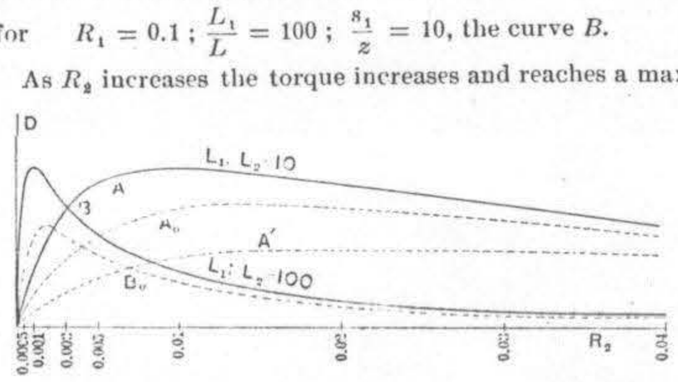


FIG. 8.

The magnetic leakage makes itself perceptible, as the torque is thereby lessened and the resistance R_2, which corresponds to the maximum torque, is increased. If we consider the leakage we will obtain instead of A and B the curves A_0 and B_0; or with heavy leakage A'. It is difficult to determine the exact form of these curves by calculation, as the value of the coefficient of leakage b is very variable. The smaller the armature resistance R_2, that is as we increase the amount of copper with which the surface of the armature is covered, the fewer will be the number of lines of force which penetrate the core of the armature, and consequently the smaller b becomes. Therefore the curves A and A_0 and B and B_0 respectively come nearer each other as R_2 increases.

Now to obtain an expression for the total torque produced by m primary and s_2 secondary phases, we make use of Fig. 9. As was done before in Fig. 6, we here make

$A\,B = R_1\ I_1$, and perpendicular to it

$$B\,C = \frac{m}{2} \cdot p_1\ L_1\ I_1,$$

$$C\,D = \frac{s_2}{2} \cdot p_1\ M\ I_1.$$

Then $A\,B = E_1$.

Furthermore in Fig. 10,

$A\,B = R_2\ I_2$,

$$A\,C = \frac{s_2}{2} p_1\ L_2\ I_2,$$

$B\,C = E_2$.

It follows that

$$\left.\begin{aligned} \cos\varphi_2 &= \frac{R_2}{\sqrt{R_2^2 + \frac{s_2^2}{4} \cdot p_1^2 L_2^2}} \\ \sin\varphi_2 &= \frac{s_2}{2} \cdot \frac{p_1 L_2}{\sqrt{R_2^2 + \frac{s_2^2}{4} \cdot p_1^2 L_2^2}} \\ I_2 &= \frac{m}{2} \cdot \frac{p_1 M I_1}{\sqrt{R_2^2 + \frac{s_2^2}{4} \cdot p_1^2 L_2^2}} \end{aligned}\right\} \qquad (48)$$

From Fig. 9 we deduce the value

$$E_1^2 = \left(R_1\ I_1 + \frac{s_2}{2} \cdot p_1\ M\ I_2 \cos\varphi_2\right)^2 + \left(\frac{m}{2} \cdot p_1 L_1\ I_1 - \frac{s_2}{2} \cdot p_1\ M\ I_2 \sin\varphi_2\right)^2 \qquad (49)$$

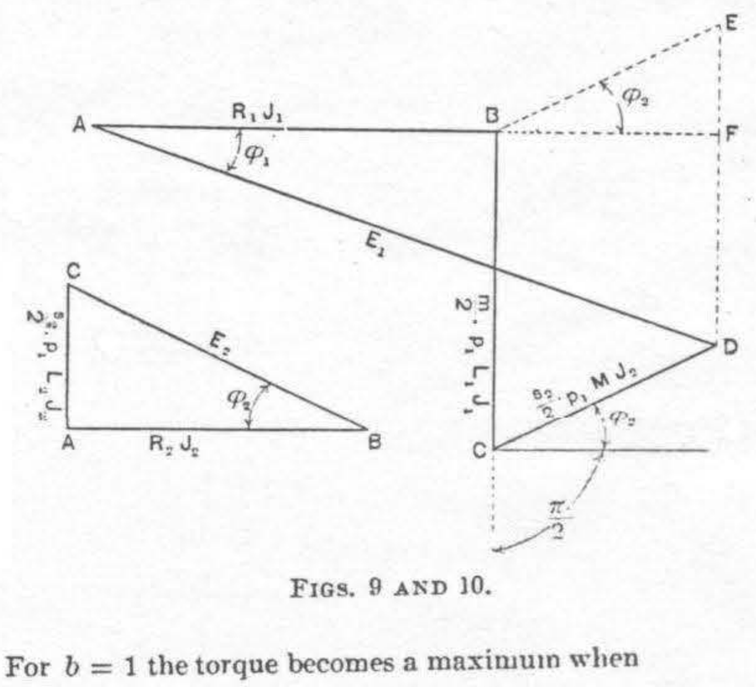
and

$$D = \frac{R_2 \cdot I_2^2 \cdot s_2}{2 p_1} = \frac{m^2}{8} \cdot \frac{p_1 M^2 I_1^2 s_2 R_2}{R_2^2 + \left(\frac{s_2}{2} \cdot p_1 L_2\right)^2}. \qquad (50)$$

Putting the value obtained in equation (48) in equation (49), and calculating I_1^2, it follows from equation (50):

$$D = \frac{m}{2} \cdot \frac{b^2 \cdot E_1^2 R_2}{p_1 \left(R_1^2 \cdot \frac{s_2 L_2}{m L_1} + R_2^2 \cdot \frac{m L_1}{s_2 L_2} + 2 b^2 R_1 R_2\right) + \frac{m \cdot s_2}{4} \cdot p_1^3 L_1 L_2 (1 - b^2)^2} \qquad (51)$$

This equation is constituted similarly to equation (46).



FIGS. 9 AND 10.

For $b = 1$ the torque becomes a maximum when

$$\frac{m L}{s_2 L_2} = \frac{R_1}{R_2} \qquad (51a)$$

or for

$$R_2 = R_1 \cdot \frac{s_2 L_2}{m L_1} = R_1 \cdot \frac{s_2 z^2}{m \cdot s_1^2}. \qquad (52)$$

(To be continued.)

Meeting of the New York Electrical Society.

The meeting of the New York Electrical Society on Wednesday, Nov. 29, was one of the most interesting which has taken place during its long career, the subject being "Electricity at the World's Fair and Its Lessons." The speakers were so well known and so eminently qualified to deliver addresses upon the subjects assigned to them that, as was expected, the attendance was large.

In the absence of the president the meeting was called to order by Mr. C. O. Mailloux. As Mr. Mailloux was on the programme for a brief address on "Storage Batteries," he opened the meeting with a few remarks on that subject. He stated that little had been done with storage batteries at the World's Fair, in fact the one interesting feature in which the storage battery played a part was the electric launches on the lagoons. But this application of the storage battery

did not involve any extraordinary features, and the conditions were not those which make the storage battery problem usually so difficult. The exhibits of storage batteries were rather meagre. There were three foreign displays, but with one exception they were little more than samples. This exception was an interesting battery in the Mechanic Arts Building, in the Russian section, which attracted attention on account of the peculiarity of construction rather than the results which it gave. In the French section a battery made on the Plante principle presented some features of interest. Among American exhibits there were three or four types of batteries which are already quite familiar. The exhibit of Mr. Pollak, of Frankfort, was instructive not only on account of the construction of the storage batteries themselves, but from the fact that it was shown in connection with a very ingenious device for commutating alternating currents for the purpose of charging storage batteries. This apparatus performs its work quite satisfactorily, and is not as complicated as one would expect. It consists merely of a system of rectifying the impulses. This was perhaps the most interesting exhibit relative to storage batteries shown at the Fair, as it suggested a new line of progress. It is in Europe that the most progress has been made in storage batteries, and while American manufacturers have been content to make batteries of two, three or perhaps four hundred ampere hours, in Europe it is current practice to use batteries of three, four and even five thousand ampere hours, weighing as much as two or three thousand pounds per cell. Another interesting feature at the Fair was an electric carriage, which suggested what we may expect in that line in the future.

Dr. Charles Emery was then introduced by the chairman and spoke briefly on "Electric Light Engines." He stated that there was nothing particularly new at the Exposition in this line; there was progress shown, but as a general rule it was more in the line of perfection in detail, increase in size and adaptability to special purposes. A large number of lantern slides were shown, and Dr. Emery described the salient features of each type.

Prof. F. B. Crocker was then called upon for remarks upon electrical congresses. He said that the recent International Electrical Congress at Chicago was remarkable in at least three respects. In the first place it gave final names and values to the electrical units. It is a fact that these definitions and values have been used before, but they had never been internationally accepted. The adoption of the name "henry" for the unit of self-induction is also another important result of the congress and a recognition both of the service of Prof. Henry and the work of Americans in general in this field. The third respect in which this congress equaled and perhaps surpassed all previous ones was in the importance of the papers and discussions brought forward there. The most important electricians of Europe as well as of this country were present, and this fact greatly added to the value of the work of the congress. As to future congresses, there was little left to be done; Prof. Rowland had said that he thought there would never be occasion to hold another congress, but this was perhaps going a little too far. Prof. Crocker thought that magnetic units and names for them, a standard of light and an international nomenclature for electrical terms and quantities would have to be taken up by some future congress.

The chairman here mentioned the fact that Prof. Crocker first suggested that the name "henry" be given to the unit of self-induction.

Mr. Nikola Tesla was then gracefully introduced by the chairman and spoke as follows, being allowed to exceed the 10-minute limit:

I have with great reluctance accepted these compliments, because I had no right to interrupt the flow of speech of our chairman. You may perhaps know, at least those of you who have followed the electrical development more closely, that the subject about which I am to say something is one which I recently presented before the Electrical Congress. During the past two years or so I have been gathering results and preparing work which I had in mind to present before the annual meeting of the American Institute as one of its members. But, as the date grew near, I found that the problems became so complicated and difficult that I could not do justice to the subject in this limited time, and so I made up my mind to drop the work for a little while, and go to the Exhibition and learn what I could, as any reasonable man would do. But the pressure at that time exerted upon me was so great that I could not resist when a number of scientific men urged me on to do something—deliver a lecture. A great many promised that they would come, but at the last moment they became ill, and when the programme was sifted down I was the only healthy man left, who had the time to deliver a lecture; and so I managed to take some of my apparatus, and through the courtesy of some officials of the American Express Company—especially Mr. Sherman, to whom I am indebted—was able to arrive in time, pretty nearly losing my opportunity by the impoliteness of one of the officials of the Fair; and so I gave a brief outline of this work.

Now, as a matter of fact, at that time I had gone considerably into the study of the practical aspects of the work which I was to present, and my notion was that I was touching upon something very important, something which would lead perhaps—so I thought in my enthusiasm—something which would lay the foundations of a novel industry, perhaps of more than one industry. But to speak in that strain before such a gathering as I had the honor to address there would have required a nerve which I did not possess, or if I did possess it it would be sure to leave me when I wanted to use it; and so I dwelt chiefly on those features which possessed a purely scientific interest, my desire being to present the subject very modestly, as I was not quite sure of some of the questions involved. Right after the lecture I asked one of my friends what he thought of it. He said it was well enough, but it could have been better. A prominent engineer came to me and said, "Mr. Tesla, I want to tell you something, but I fear it may offend you." I knew what was coming and so I asked what it was. He said: "Well, don't you work on steam engines. You have done some work in electricity. If you stick to it you will do some good work, but if you work on steam engines you are bound to fail." All these men that I mention are the most prominent men in the profession. Another said, "I wonder what Tesla is going to do with his blessed engine." Another, to whom I showed the advantage of doing away with complicated mechanism and generating electricity directly, said, after he had watched it for a long time, "Couldn't you apply this to rotating motion?" Now this is the way that my work was received. But I was quite prepared for that because for fully two years I had had these ideas in my mind. I rejected them and rejected them again and again, until I got in my mind the construction of the apparatus, until I overcame some difficulties which at first seemed to me insuperable, and finally I devoted myself to this work. One of the first impulses which guided me was to produce an absolutely constant motion, which would be independent of any friction losses, or gravity, or temperature changes within very minute limits. Now, you can employ a pendulum, you can employ a clockwork of a vibrating spring, or some such device as that. But they are very unreliable. I wanted to produce a positive motion, so that I might operate what I called some time ago a disruptive discharge coil. I may assume that some of you know that some time ago I advanced a method of producing currents of high frequency from direct or alternating currents. The method consists of charging condensers, discharging them either through a primary and then introduce devices in coils of the secondary or in its own current of high potential. Now the lamp to be operated with such coils is perfect enough. A nearly exhausted vessel would be good enough. But the devices themselves are inefficient in the production of these currents, and one reason was that these devices did not yield a perfectly constant vibration. I had to depend on a disruptive gap. I used air blasts, or oil streams, or a mechanical interrupter. Now with this device which I invented subsequently I was able to maintain a vibration with perfect constancy. This device consisted of a spring, which required several tons of force to spring a certain distance, and which was constantly kept in vibration by steam pressure or air pressure. In the beginning I used springs of tempered steel. These steel springs would break, though they had a section of two or three square inches. So I resorted to air springs. The air springs would not break, but they had no constant resilience. Then I made the chambers of the hair springs communicate with the outer air. Then I maintained boiler water around the jacket. Now you know this device yields a constant vibration, and as the force which is driving it is many tons and the friction but a very small matter, it is unaffected by the pressure, and so I have a constant vibration. This was one of the chief features I wanted to present. This is the device which I believe will be used for many purposes, for instance, governing all sorts of mechanism, engines and so on. This was one of the features which had interest for scientific men, because with this I am now enabled to produce currents of perfectly constant frequency. But this was merely the tail of the work which I have been doing. You have seen a few designs of engines described by the eminent speaker who is one of the most competent to talk on the subject, and who has shown us a great many complicated mechanisms. They are exactly adapted to illustrating what I have to say, and I would ask whether it is not worth while to attempt to simplify those mechanisms, which we have been using heretofore for the production of electric currents. When we look at a steam engine and inquire where the power comes from that drives the steam engine, we will always find that the power comes from a little box—a cylinder with a piston in it—and all the other appurtenances are really but to keep it going. You may do away with the flywheel, with the cross-heads, with the eccentrics, with all the appliances provided that you can in some other simple way govern the motion of the mechanism. So then my first idea was to apply the motion of the piston, which is freely movable, to a magnetic field, to move a magnet or a coil in a magnetic field and so generate currents by this direct motion. Now let us see what we can do in that respect. First, we reduce the weight of the engine for the same pressure and the same piston speed to one-thirtieth or one-fortieth if not one-fiftieth of its weight. Furthermore, we do away with all mechanical frictions. The engine designed according to my ideas has a mechanical efficiency of 99¾ per cent. Now that is in itself a very big item and renders it worth while endeavoring to make this mechanism a commercial success. But there are other far greater things. You will find that engineers often say what an advantage it is to apply the direct motion of the steam piston to a pump. In reality the advantage in a pump is but a very minute one. The water column has got an enormous inertia, and what we do gain in the direct acting pump is merely a matter of overcoming some additional frictions which we have in the ordinary engine. We may take the mechanical efficiency—I gather the data from various works—we may take the efficiency as say 81 to 82 per cent. at the full load. But the efficiency is much less on a varying load. Then, furthermore, we have got these variously estimated. I take the figures which I have found to be fair, giving this as the efficiency. Now the dynamo again has got mechanical losses due to friction, and, furthermore, the wire is never utilized fully in the dynamo. In my construction the dynamo may consist of a simple coil of the magnet, and a simpler coil which is all immersed in the magnetic field. There is no useless wire. Consequently dynamo and engine, if they are reduced considerably in weight, increase in efficiency. There is only one engine which can equal it in output, and that is the turbine. With the steam turbine we can obtain an enormous output, and that is the reason why the steam turbine, in my opinion, may be found a valuable adaptation for driving dynamos; and then convert the motion by means of alternating dynamos; and I think the steam turbine has in itself a physical cause why it cannot surpass a certain efficiency, and that is that we drive turbines by impact. A turbine might be very efficient if the medium which propels it were incompressible and homogeneous. But it cannot be efficient if we drive it by means of isolated shocks. Furthermore, we cannot in a turbine gain all the expansion. These causes, I think, will limit the efficiency obtained in turbines. But in reciprocating mechanisms we can, provided we obtain a sufficient high speed of the piston, expand the steam at an enormous rate. It is perfectly practicable in these mechanisms which I have been working up to obtain, if you want, a speed of 100 metres a second, and while I do not contemplate producing such speeds yet it is quite possible to do it. But since we can produce higher speeds we might as well increase the speed two or three times, and so augment the activity of the mechanism and raise the efficiency. Furthermore, as I am enabled now to work without a packing, I found that in these mechanisms the packing is actually objectionable, the expansion occurring at an enormous rate, and the engine being of such character that the exhaust can be reduced to pretty nearly the atmospheric pressure very easily. The mechanical friction is reduced to such a small figure that we can raise the temperature of the steam very considerably. You know that in high pressure steam engines one of the greatest troubles is the lubrication. We can go so far with the mineral oil, we can go so far with ordinary oil, but then we reach a point at which we cannot go any further, the lubricant will not work; and I am informed by very able practical engineers that about 250 pounds per square inch of steam pressure is as high as we practically go. With this engine we can go much higher. I am now preparing a boiler which will give me up to 350 pounds pressure. It is very important, of course, to get the pressure very high. In these mechanisms we are confronted with two things. For what are they going to be used—for light or for power? If we want to drive motors we must have a long stroke and a slow frequency. If we want to operate lamps then we want a very short stroke and a very rapid motion. To have a high speed with short stroke we must have a great initial pressure, because you know the number of vibrations increase only as the square root of the pressure. So if we want to have twice the number of vibrations we must have four times the pressure. But, on the other hand, four times the pressure and twice the number of vibrations means eight times the output. So it is very important in this mechanism in which the power depends on the square to obtain as high a pressure as possible. It is on this line now that I am working.

We have had such reciprocating engines as far back as 1868 or 1870, and it would be a very erroneous idea to think that I had evolved something radically novel in that part of the mechanism.

It is more economical to produce rapid vibrations than low vibrations. But so far as the economy of the dynamo is concerned, and so far as the economy of the engine in general is concerned, it is better to

produce a long stroke, because a long stroke means a high velocity.

I have an apparatus which runs lights in the laboratory, and shortly I think I will have something which will be ready for practical application. I think I am not mistaken in believing that we are going to have very shortly a means at hand of producing twice as much electricity from coal as we can produce at the present time—provided I am not mistaken. This is subject, of course, to a test, but I am quite confident that it can be done. This is not, however, a subject which occupies me altogether. There are also other subjects.

Mr. J. J. Carty was the next speaker, and his subject "The Telephone." He said that to give a proper idea of the telephone exhibit at the World's Fair would mean a review of the present state of the art of telephony, and this he did not propose to undertake. The foreign manufacturers had little to show of interest or novelty. The general features of the display were interesting more from the tendencies which they exhibited than from any details of structure, and the latter work in this line has been confined more to doing things which we know how to do, and doing them well, than trying to find out things which we do not know. The long distance line from Chicago to New York was perhaps the most striking exception presented. The movement has lately been away from series work toward multiple arc work. The exhibition of American underground cables was particularly complete, and in this respect this country may be said to excel; the material generally used is paper put loosely upon the wires so that the dielectric is really a mixture of paper and air. This gives a very low capacity, and is specially suited for telephonic purposes.

Mr. James Hamblet next spoke upon the subject of "Electric Clocks." About 10 years ago the first decade of standard time in this country was completed. Electric clocks were first exhibited in the exposition of 1851, but with small success. The kind of clock then used was driven entirely by electricity, but within a few years inventions have been brought out by which the clock is simply wound by electricity at stated intervals. The Self-Winding Clock Company is making arrangements with the Western Union Telegraph Company to introduce these clocks to all the large cities of the United States, and they have something like 20,000 already in operation. An elaborate exhibit of these clocks was made at the Exposition. They were scattered all over the grounds, many of the buildings containing a number; they were all wound once an hour and corrected every hour by a fine standard clock, which in turn was corrected daily by a signal from Washington. One of the newest features in the exhibit was the tower clock in the middle of the Manufactures and Liberal Arts Building. Such a clock makes it possible to dispense with the cumbersome weights and mechanism of the ordinary tower clock.

A motion to postpone remainder of programme until some future date was made and carried.

Mr. Hamblet then exhibited a collection of views showing the principal features of the World's Fair.

Dr. Emery also made a few remarks supplementing his address earlier in the evening, in which he called attention to a steam turbine exhibited in the Danish section, which ran as high as 20,000 to 30,000 revolutions per minute, and delivered 20 h. p. with a wheel about four inches in diameter at an efficiency of perhaps 80 per cent.

Mr. Tesla then stated that he did not mean to say that the turbine is mechanically inefficient, but what he meant was thermic inefficiency.

Before the adjournment a vote of thanks to the gentlemen who had favored the Society with remarks was unanimously passed.

THE TESLA OSCILLATOR.

THIS apparatus, exhibited by Tesla at the World's Fair, Chicago, attracted some attention. From a description in the *Electrical Engineer*, of New York, we take a sectional view, fig. 1, of the apparatus, and our readers may gather some notion of its construction from that and the description.

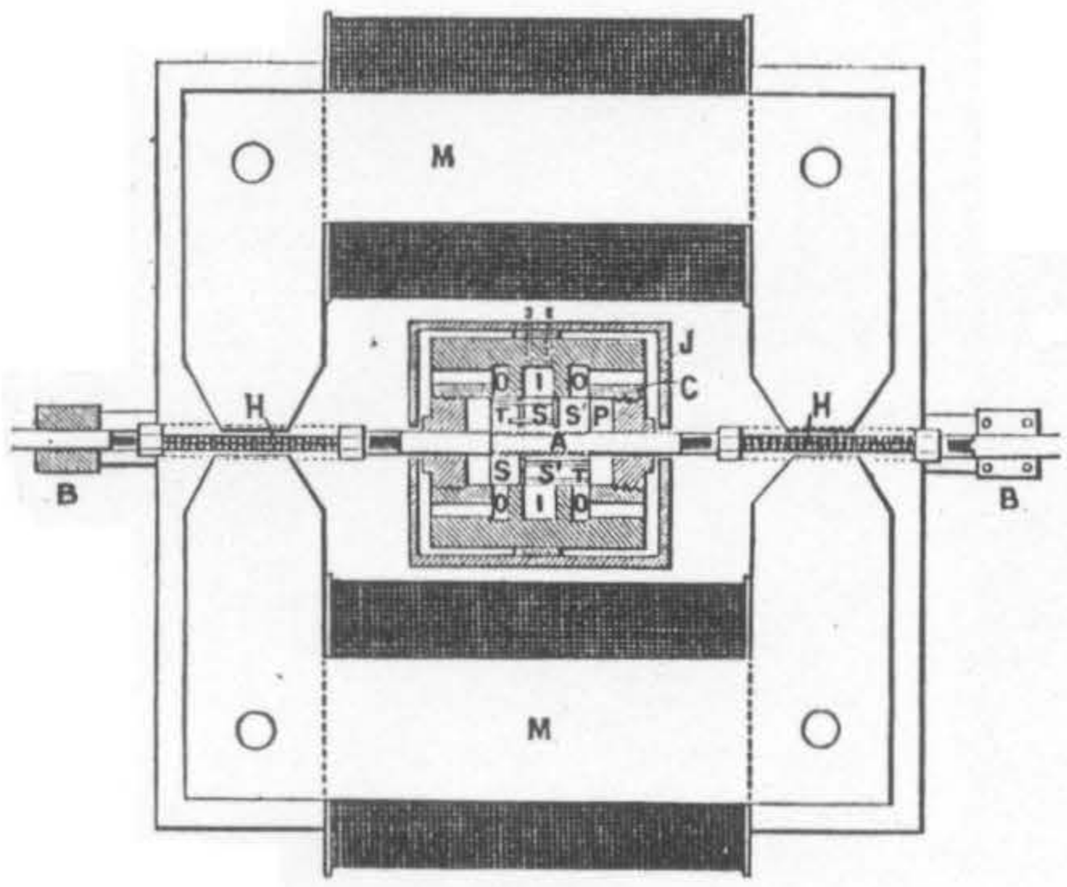


FIG. 1.

Just what this apparatus accomplishes is not made clear; no figures are given upon which one could calculate. It seems to be a kind of alternator designed to give very high frequency by imparting a rapid to and fro motion to two pairs of coils in a very strong magnetic field. The greatest frequency thus obtained is not stated, so that we are unable to compare it with rotary alternators; in that respect it would be interesting to compare it with Prof. Ewing's oscillator or alternator for high frequency, consisting of a Parsons steam turbine and a multipolar alternator.

In the sectional view a piston, P, is seen fitted into the hollow of a cylinder, C, which is provided with channel posts, O, O, and I, extending all round the inside surface. In this particular apparatus there are two channels, O, O, for the outlet of the steam or air used to drive the piston to and fro; I, being the inlet for the air or steam. The piston, P, is provided with two slots, S, S′, at a carefully determined distance, one from the other. The tubes, T, T, which are screwed into the holes drilled into the piston, establish communication between the slots, S, S′, and chambers on each side of the piston, each of these chambers connecting with the slot which is remote from it. The piston, P, is screwed tightly on a shaft, A, which passes through fitting boxes at the end of the cylinder, C. The boxes project to a carefully determined distance into the hollow of the cylinder, C, thus determining the length of the stroke. Surrounding the whole is a jacket, J, to deaden the sound produced by the action of the oscillator.

A magnetic frame, M, M, is fastened so as to closely surround the oscillator and is provided with energising coils which establish two strong magnetic fields on opposite sides. The magnetic frame is made up of thin sheet iron. In the intensely concentrated field thus produced, there are arranged two pairs of coils, H, H, supported in metallic frames which are screwed on the shaft, A, of the piston and have additional bearings in the boxes, B, B, on each side. The whole is mounted on a metallic base resting on two wooden blocks.

The operation of the device is as follows: The working fluid being admitted through an inlet pipe to the slot, I, and the piston being supposed to be in the position indicated, it is sufficient, though not necessary, to give a gentle tap on one of the shaft ends protruding from the boxes, B. Assuming that the motion imparted be such as to move the piston to the left (when looking at the diagram), then the air rushes through the slot, S′, and tube, T, into the chamber to the left. The pressure now drives the piston towards the right and, owing to its inertia, it overshoots the position of equilibrium and allows the air to rush through the slot, S, and tube, T, into the chamber to the right, while the communication to the left hand chamber is cut off, the air of the latter chamber escaping through the outlet, O, on the left. On the return stroke a similar operation takes place on the right hand side. The oscillation is maintained continuously and the apparatus performs vibrations from a scarcely perceptible quiver amounting to no more than $\frac{1}{64}$th of an inch, to vibrations of a little over $\frac{3}{8}$ths of an inch, according to the air pressure and load. It is, indeed, interesting to see how an incandescent lamp is kept burning with the apparatus showing a scarcely perceptible quiver.

The piston cushions against the enclosed air in the cylinder so that even at high velocities it is stopped and reversed without shock. As an apparatus for experimental research on high frequency alternating currents this alternator or oscillator may have the advantages claimed for it, but it does not possess any recommendations as a practical alternator.

As to the novelty of the air or steam oscillator for producing the rapid to and fro motions there is none; a common stone-cutting or engraving tool has long been in use in which this very same idea has been worked out in a thoroughly efficient manner, a piston and cylinder working a small chisel to and fro at a speed of 20,000 per minute by means of compressed air.

NOTES.

The Tesla Engine.—Speaking at a meeting of the New York Electrical Society, Mr. Nikola Tesla referred to his improved engine, which is to do away with fly-wheels, cross-heads, and eccentrics; everything, in fact, but the piston and cylinder, all the control mechanism being electro-magnetic. Mr. Tesla's address is reported in the N.Y. *Electrical Review*, December 6th.

NEW BOOKS.

Light and Other High-Frequency Phenomena. By NIKOLA TESLA.

Introduction. — Mr. Tesla introduces his lecture about as follows: — In our study of the physical universe we find that our sense of sight is superior to all other senses, because it enables us to penetrate much deeper into the fathomless depths of Nature's mysterious activities. The activity by means of which Nature reveals herself to us through our organ of sight, the activity which we call light, deserves our closest attention. What is light? It is an electromagnetic activity, according to most advanced views; hence the importance of investigating those forms of electromagnetic activities which approach the phenomena of light as near as experimental possibilities of the present day will permit.

The introduction might lead one to expect that Mr. Tesla intends to describe a novel class of high-frequency electrical oscillations for the purpose of illustrating and giving new evidence in favor of the electromagnetic theory of light. In that case one would perhaps feel somewhat disappointed to find that Mr. Tesla's experiments are simply Hertz's experiments in a modified form, a form by which it can be shown that in the first place the Hertzian oscillations enable us to transmit a considerable amount of energy along a single wire, and in the second place that novel vacuum tube effects can be produced by rapid alternations of the electromagnetic field.

But this feeling of disappointment, if it should occur at all, would be soon dispelled and quickly give way to a feeling of admiration for the patient work of an enthusiastic inventor who has brought all the ingenuity of his remarkable engineering skill to bear upon the problem before him, and that problem is contained in the question: — What immediate benefits can modern electrotechnics derive from Hertzian oscillations? This problem Mr. Tesla handles with extraordinary ability.

Method of Conversion. — To produce the oscillations Mr. Tesla connects a direct or alternating current dynamo to an oscillatory transformer. The primary of this transformer, consisting of a small number of turns of stranded wire, corresponds to the Hertzian exciter, and the secondary, consisting of an appropriate number of turns of wire surrounding the primary, corresponds to the Hertzian resonator. Hertz worked with oscillations of about 10^8 periods per second. Mr. Tesla is satisfied with a

frequency of 10^6 or even smaller, hence his primary and secondary coils have a much larger self-induction than that of the Hertzian exciters and oscillators. By a suitable arrangement of the ratio of the turns in the primary and secondary, the oscillatory transformer can be an up or a down transformer. The primary spark space is similarly located as in the Hertzian experiments. Capacity is generally added to both the primary and the secondary coils.

Precautions which must be observed in order to render the Primary Impulses very Powerful. — No arc formation should be allowed in the primary spark space. Four different devices for this purpose are described, the purpose of each being to blow out the arc as soon as it begins to form.

1. Spark space is placed between the poles of a sufficiently powerful magnet.

2. Current of hot air sweeps continually through the spark space (especially when dielectrically weak air is required between the discharge knobs).

3. Spark space is placed in a partially exhausted glass tube, the tube being placed between the poles of a strong magnet to prevent arc formation.

4. Two objections against a spark space through a gaseous medium are pointed out: (*a*) the discharges are not sufficiently disruptive; (*b*) there is too much dissipation. To improve both, a liquid dielectric was tried. A hollow pulley was partially filled with oil (the quality of oil not mentioned); the pulley being rotated rapidly, the oil was thrown out centrifugally and compressed against the rim; discharge through oil improved the disruptive character of the primary sparks and diminished losses. These discharges were effective for producing great spark length, but not for luminous effects, since for these, according to Mr. Tesla, a harmonically varying electromagnetic force is preferable.

The best form of generator is then discussed; it is pointed out that the most convenient method is to use a low-tension dyna-motor, to transform direct currents into low frequency alternating currents of low voltage. The low-voltage alternating current thus obtained is then transformed into high tension alternating by a stationary transformer, and this high-tension current is then employed to feed the oscillatory transformer.

Phenomena produced by Electrostatic Force. — In the introduction to these phenomena, Mr. Tesla makes the following statement concerning electrostatic force: "It is the force which governs the motion of the atoms, which causes them to collide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an infinite variety of ways according to Nature's fanciful designs, and to form all these wondrous structures we perceive around us. . . ."

Evidently Mr. Tesla makes even a broader claim for the electrostatic

force than Professor J. J. Thomson does for Faraday's tubes of electrostatic induction. (Compare also H. von Helmholtz's lecture on Faraday.[1])

Experiment 1. — One pole of the oscillatory transformer is touched with one hand, and the other hand approaches the other pole. A brush discharge passes from the free hand to the free pole. The frequency of the current is said to be a million, and the electromotive force $= 2 \times 10^5$ volts. Mr. Tesla calculates that, with four times the frequency, and a potential of 3×10^6 volts, his whole body would be surrounded by a flame, but the current would do him no harm, because the body offers a large cross-section to the high-frequency current, and the current *in its passage through the body distributes itself uniformly*, so that the current density is small at any point. This interpretation takes it for granted that Hertzian oscillations pass through the human body just the same as an ordinary direct current would pass through a good conductor.

Experiment 2. — Illustrates difference between discharges at high and low frequency. Two circular brass plates, each connected to a pole of an oscillatory transformer, are placed at a distance of 12 inches. At high frequency the luminosity of the discharge between the plates is steady and perfectly uniform; at low frequency, the discharge is in the form of numerous, quivering, and noisy spark filaments. Mr. Tesla admits the impossibility of disruption at high-frequency; he observes the powerful chemical action of the high-frequency discharge; he seems, however, to fail to recognize in the difference of the two discharges a confirmation of the generally accepted dissociation theory of electrical conduction through gases.

Experiment 3. — An incandescent lamp bulb with a single straight carbon filament is attached to one pole of the oscillatory transformer. An apparently unipolar discharge takes place. (The luminosity in the immediate neighborhood of the external surface of the lamp is evidently due to the varying condenser charges of that surface. If that surface has any sharp points, the current density there will be large, and the point will be heated.[2]) A bulb drawn out into a point is (therefore) heated and is ultimately broken at that point. Mr. Tesla ascribes this heating to molecular bombardment which, according to his opinion, will take place in *heterogeneous media like gases*, because *the molecules* or atoms in such bodies are free to move under the impulse of electrical forces. Mr. Tesla does not seem to be aware of the fact that nobody has succeeded yet in electrifying the molecules of a perfect gas. Several experiments are then described in support of the bombardment theory, but they do not seem to be convincing.

[1] Vorträge und Reden, Vol. 2, p. 302, 1884.

[2] The reviewer is responsible for the opinion enclosed in parentheses in this paragraph.

On Currents or Dynamic Electricity Phenomena. — In these experiments it is shown that electrical energy can be transmitted along a single open-circuited wire. The *modus operandi* is the following: — One end of a wire is attached to one of the poles of the secondary of an oscillatory transformer; the other end is attached to a large plate. An adjustable coil is also inserted in this circuit. The plate gives this open circuit its principal capacity, the adjustable coil, which the reviewer calls the inertia coil, enables the experimenter to regulate its self-induction or inertia. When the frequency is very high, the capacity of the plate can be dispensed with, the capacity of the remaining part of the circuit being sufficient to bring the circuit in resonance with the impressed electromotive force.

Two methods are then employed to demonstrate the flow in the open circuit and its dependence on the constants of the circuit; namely, capacity, self-induction, and frequency.

Method I. — The circuit of several turns of wire surrounding the auxiliary inertia coil is closed by a 50-volt, 16-C.P. lamp, and the flow studied by the intensity of the glow of this lamp.

Method II. — The flow in the open circuit is transformed in various ways, and various simple devices are then employed to cause a disc to rotate under the electromagnetic or electrodynamic action of the oscillatory currents thus employed. The first method points out the possibility of a distribution of oscillatory currents for electric lighting; the second method demonstrates in a certain way the feasibility of employing such currents for operating electromotors. The difficulties which would necessarily attend such an employment of oscillatory currents might have been discussed a little more fully, in order to prevent a misconception on the part of those who are not familiar with the subject. To show the effects of impedance (a wave distribution of potential energy along a short, stout wire), Mr. Tesla employs Lecher's well-known and generally adopted method of producing very rapid Hertzian oscillations. He devotes, then, twelve pages to a discussion of electrical resonance, and particularly of the bearing of electrical resonance upon the problem of transmitting signals all over the earth by causing the electrical charge of the earth to oscillate.

This discussion is evidently introduced to relieve somewhat the serious character of the rest of the lecture, and seems to bear the same relation to the rest of the lecture as the amusing gravediggers' dialogue in "Hamlet" bears to the rest of the play. In the reviewer's opinion, Mr. Tesla does not wish to be taken *au serieux* in this part of his lecture.

Vacuum Tube Effects produced by Hertzian Oscillations.

1. *Incandescence of a Solid.* — It was observed a long time ago that the electrodes of a Geissler tube, especially the cathode, become very hot, although the current through the tube may be exceedingly small.

Mr. Crookes, it seems, was the first to suggest that this heating was due to molecular bombardment. Mr. Tesla shows that by means of this property of the vacuum-tube discharge carbon filaments and carbon buttons, when enclosed in the vacuum of an incandescent lamp, can be rendered incandescent by an exceedingly small current, provided that the potential of these carbons is very high and the frequency considerable; the higher the frequency, the slower will be the process of disintegration of the carbons. He also ascribes this heating to molecular bombardment, but his arguments in favor of this view are open to the same objections which were brought, long ago, against the molecular bombardment theory of Crookes. Some of the heating in such tubes is very probably due to molecular, or rather atomic, bombardment, but according to the splendid investigations of E. Wiedemann, Schuster, Elster and Geitel, J. J. Thomson, Giese, and others, the chemical process going on in such tubes owing to the action of the electrical forces will account easily for a very large part of the heat. It should also be remembered that the spectrum of an incandescent gas is very rich in ultra-violet light, which part of the luminous energy of the gas never leaves the bulb, being absorbed by the same and transformed into heat. To ascribe all the various heat phenomena in a vacuum tube simply to molecular bombardment means to turn a sharp corner, in order to get out of the way of difficulties instead of forcing the difficulties themselves to get out of the way. The same criticism applies to Mr. Tesla's view of the cause which produces phosphorescence and fluorescence in vacuum tubes. It is, of course, a well-known fact that mechanical shocks can produce phosphorescence and fluorescence; but it is equally well known that no agent is as powerful as ultra-violet light and purely chemical processes to produce these phenomena. Why, then, refer these phenomena in vacuum tubes to molecular bombardment and to nothing else?

It must be observed, however, that the value of Mr. Tesla's work is, of course, independent of the view which he may have formed of the causes of all these various phenomena which he investigated by means of extremely powerful electrical oscillations. The real value of Mr. Tesla's work is due to the fact that he was the first to succeed in constructing a magnificent array of physical apparatus, by means of which these exceedingly powerful Hertzian oscillations can be produced, and to point out a way of attacking old but still puzzling phenomena by weapons with which the refinements of modern electrotechnics can furnish us. It is a work which, for some time to come, will be consulted by the electrical engineer who wishes to become acquainted with the tendencies of recent advances in electricity, and it will be consulted by the physicist who wishes to make himself familiar with the practical bearing of these advances. In the per-

formance of this work Mr. Tesla has, therefore, rendered invaluable service to all those who are interested in the science of electricity.

M. I. PUPIN.

COLUMBIA COLLEGE, New York, Oct. 15, 1893.

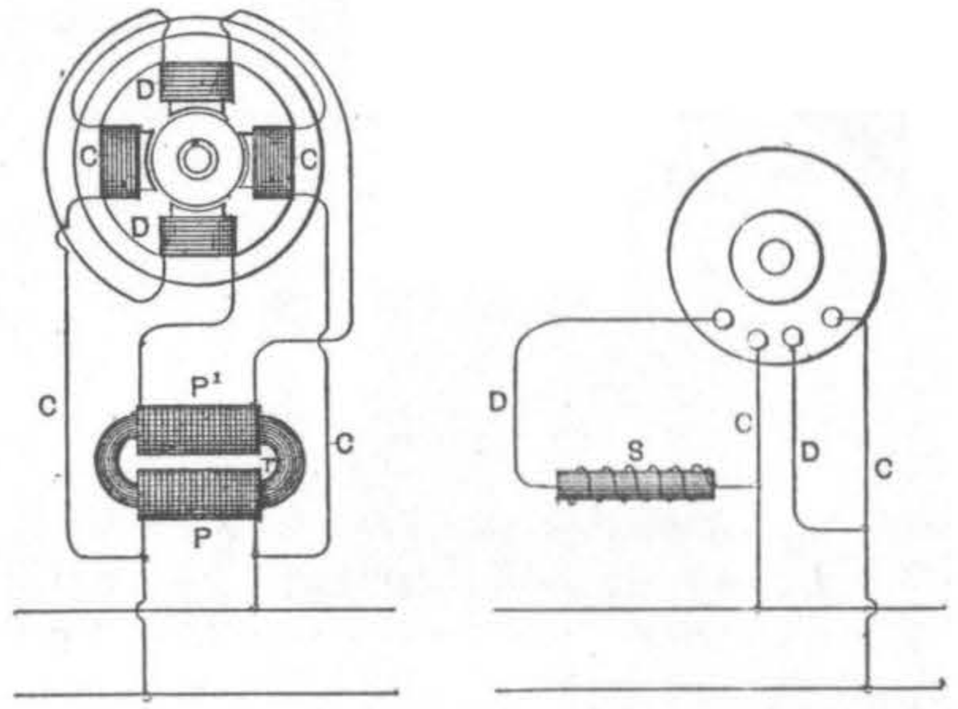
TESLA MOTORS OPERATED FROM SINGLE PHASE TWO-WIRE ALTERNATING CIRCUITS.

THOSE who have followed Mr. Tesla's work in alternating motors will recall that in 1888 he first drew public attention to his new multiphase system of operating alternating current motors, in a paper read before the American Institute of Electrical Engineers, in which he laid down the principles which have since been practically applied in many ways. In this system, it will be remembered, each motor contains two or more independent energizing circuits through which are passed alternating currents, having in each circuit such a difference of phase that by their combined or resultant action they produce a rotary progression of the poles or points of maximum magnetic effect of the motor and thereby maintain the rotation of the armature.

A multiphase system of this kind, however, requires at least three wires for its successful operation, to convey the currents differing in phase, and Mr. Tesla, therefore, early set about to devise means for operating phase motors from the ordinary single-phase alternating circuit, by creating the difference of phase locally at and in the motor. The various ways in which this can be done are described in two patents just granted to Mr. Tesla, which are of special interest at this time.

In all the methods described below, the fundamental idea involved is to pass a single alternating current through both of the energizing circuits of the motor, and to retard the phase of the current in one circuit to a greater or less extent than in the other. The distribution of current between the two motor circuits is effected either by induction or by derivation.

The diagram Fig. 1 shows a motor with two energizing circuits, C and D. One of these circuits, C, is connected directly with the line circuit, while the other set of coils D, is connected up in the secondary circuit of a transformer T. The primary coil P of this transformer, is connected to the line circuit. The alternations of current in the line tend to establish in their passage through the coils C, a polarity opposed to that set up in the coils D, and if the currents in the two sets of coils coincided in their phases, no rotary effect would be produced. But the secondary current developed in the coil P' of the transformer, will lag



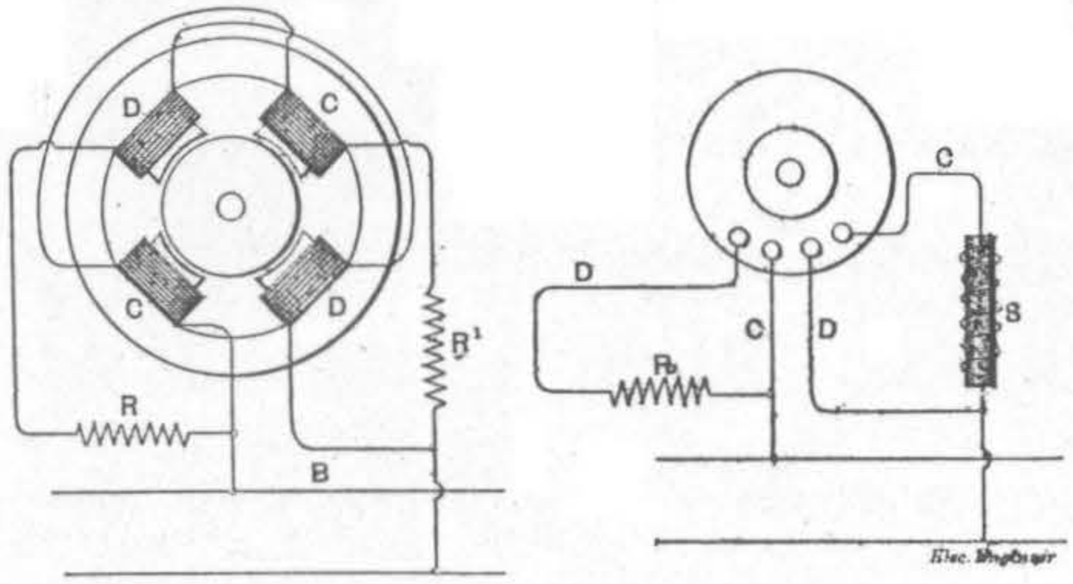
FIGS. 1 AND 2.

behind that in the primary, which lag may be increased to a sufficient extent to practically obtain the same result as though two independent currents were used to energize the motor.

In another form, shown in Fig. 2, the arrangement of the parts is similar to that shown in Fig. 6, except that a self-induction coil S, is introduced into one energizing circuit of the motor. The effect of thus increasing the self-induction in one of the circuits is to retard the phases of the current passing therein to a greater extent than in the other circuit, and in this way to secure the necessary difference in phase

between the two energizing currents to produce the rotation of the motor.

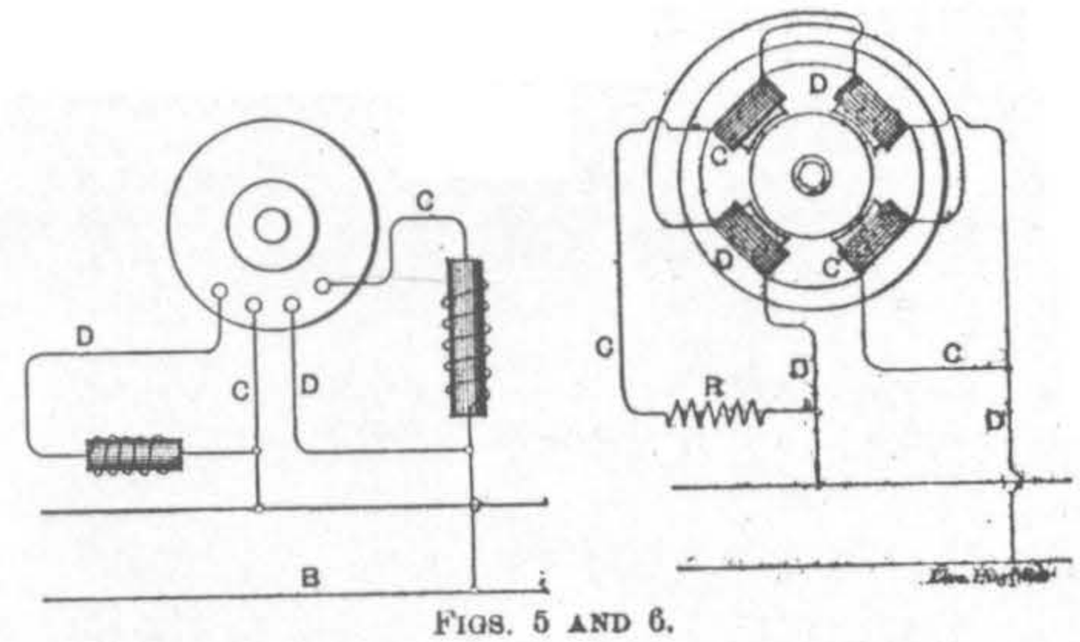
In Fig. 3 there is shown diagrammatically a type of motor in which two dead resistances R R′ are included respectively in the energizing coils of the motor. No rotary effect will be produced as long as the resistances are equal, but by varying the resistance in one circuit the retardation of the current in that circuit will be varied and correspond-



FIGS. 3 AND 4.

ing effects produced. For example, a reduction of the resistance in one circuit imparts to the motor rotation in one direction while a reduction of the resistance in the other circuit will produce a rotation in the opposite direction. By means of the two resistances, therefore, capable of variation or of being bodily withdrawn from or inserted in the circuits by simple means, rotation of the motor is secured.

In Fig. 4 a self-induction coil S is included in one of the motor circuits and a dead resistance R in the other. The increased self-induction in one circuit thus produced acts to increase the difference of phase between the current in that motor circuit and the unretarded current in the line circuit. On the other hand, the introduction of the dead resistance in the other motor circuit reduces the retardation and brings the phases of the current in it more closely in accord with those of the unretarded current, thus producing a correspondingly greater difference of phase between the two currents in the energizing circuits C and D.



FIGS. 5 AND 6.

In Fig. 5, two self-induction coils are shown, one in each motor or energizing circuit. One of these coils is much smaller than the other and has less self-induction or counter-E. M. F. than the other, so that the phases of current will be retarded to a less extent than in the other.

In Fig. 6 the two energizing circuits of the motor are shown connected in multiple arc to the line circuit and in one of these circuits is a resistance R. Assuming the two motor circuits to have the same degree of self-induction no rotary effect will be produced by the passage through them of an alternating current from the line. But if one of the motor circuits, as C, be varied or modified by the introduction of a dead resistance R, the self-induction of that circuit or branch is reduced, and the phases of current therein retarded to a correspondingly less extent. The relative degrees of retardation of the phases of the current in the two motor circuits with respect to those of the unretarded current in the circuit B thus produced, will set up a rotation of the motor.

Finally we may mention another type in which one set of energizing coils is of finer wire than the other or has a greater number of convolutions; or each circuit may contain the same number of convolutions, but composed of different conductors, as, for instance, one of copper, and the other of German silver.

Mr. Tesla has devised still other methods for accomplishing the same purpose, but those described will give a fair idea of the wonderful flexibility of the system.

Tesla Motors Operated from Single Phase Two Wire Alternating Circuits.

The reader who has followed up the line of work in which Mr. Tesla has been recently engaged will, no doubt, be interested to hear of some results which have been crystallized into two patents recently granted to Mr. Tesla.

As early as 1888 a paper was read before the American Institute of Electrical Engineers, in which Mr. Tesla first publicly described his new multiphase system of operating alternating current motors. As an outgrowth of this, results have been obtained by others working in the same direction, and valuable and interesting have been the observations and practical devices obtained.

In the system above mentioned, each motor is supplied with two or more energizing circuits, through which are passed alternating currents, having in each circuit such a difference of phase, that by their combined or resultant action they produce a rotary progression of the poles or points of maximum magnetic effect of the motor, and thereby maintain the rotation of the armature.

Three wires are necessary in a system of this kind, but in order to avoid this, Mr. Tesla set to work to devise a means whereby the phase motors could be operated from the ordinary single phase alternating circuit by creating a difference of phase locally at and in the motor.

The patents below referred to had this object in view, and it will be noticed that

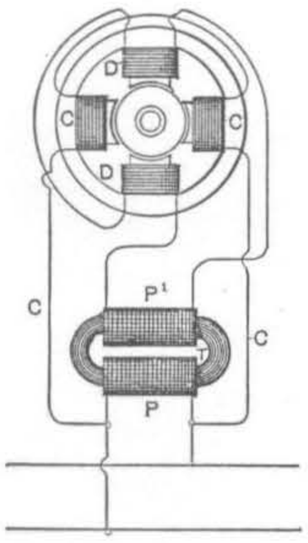


FIG. 1.—TESLA MOTOR WITH TWO ENERGIZING CIRCUITS.

the fundamental idea involved is to pass a single alternating current through both of the energizing circuits of the motor, and to retard the phase of the current in one circuit to a greater or less extent than in the other, either by induction or by derivation, is the distribution of current between the two motor circuits.

The diagram Fig. 1 shows a motor with two energizing circuits, C and D. One of these circuits, C, is connected directly with the line circuit, while the other set of coils D, is connected up in the secondary circuit of a transformer T. The primary coil P of this transformer is connected to the line circuit. The alternations of current in the line tend to establish in their passage through the coils C, a polarity opposed to that set up in the coils D, and if the currents in the two sets of coils accorded in their phases, no rotary effect would be produced. But the secondary current developed in the coil P' of the transformer will lag behind that in the primary, which lag may be increased to a *sufficient extent* to practically obtain the same result as though two independent currents were used to energize the motor.

In another form, shown in Fig. 2, the arrangement of the parts is similar to that shown in Fig. 6, except that a self-induction coil S is introduced into one energizing circuit of the motor. The effect of thus increasing the self-induction in one of the circuits is to retard the phases of the current passing therein to a greater extent than in the other circuit, and in this way to secure the necessary difference in phase between the two energizing currents to produce the rotation of the motor.

Shown diagrammatically in Fig. 3 is a type of motor in which two dead resistances R R'are included, respectively, in the energizing coils of the motor. No rotary effect will be produced as long as the resistances are equal, but by varying the resistance in one circuit the retardation of the current in that circuit will be varied and corresponding effects produced. For example, a reduction of the resistance in one circuit imparts to the motor rotation in one direction, while a reduction of the resistance in the other circuit will produce a rotation in the opposite direction. By means of the two resistances,

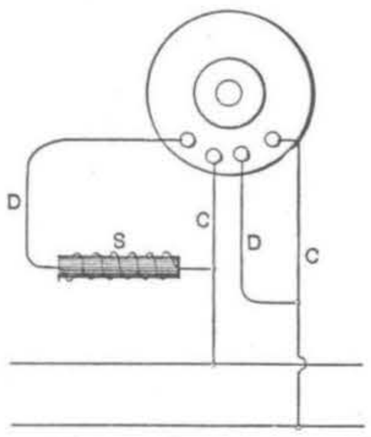


FIG. 2.—TESLA MOTOR WITH SELF-INDUCTION COIL.

therefore, capable of variation or of being bodily withdrawn from or inserted in the circuits by simple means, rotation of the motor is secured.

In Fig. 4 a self-induction coil S is included in one of the motor circuits and a dead resistance R in the other. The increased self-induction in one circuit thus produced acts to increase the difference of phase between the current in that motor circuit and the unretarded current in the line circuit. On the other hand, the introduction of the dead resistance in the other motor circuit reduces the retardation and brings the phases of the current in it more closely in accord with those of the unretarded current, thus producing a correspondingly greater difference of phase between the two currents in the energizing circuits C and D.

Two self-induction coils are shown in Fig. 5, one in each motor or energizing circuit. One of these coils, is much smaller than the other, and has less self-induction or counter electro-motive force than the other, so that the phases of current will be retarded to a less extent than in the other.

The two energizing circuits of the motor are shown in Fig. 6, connected in multiple arc to the line circuit, and in one of these circuits is a resistance R. Assuming the two motor circuits to have the same degree of self-induction, no rotary effect will be produced by the passage through them of an alternating current from the line. But if one of the motor circuits, as C, be varied or modified by the introduction of a dead resistance R, the self-induction of that circuit or branch is reduced, and the phases of current therein retarded to a correspondingly less extent. The relative degrees of retarda-

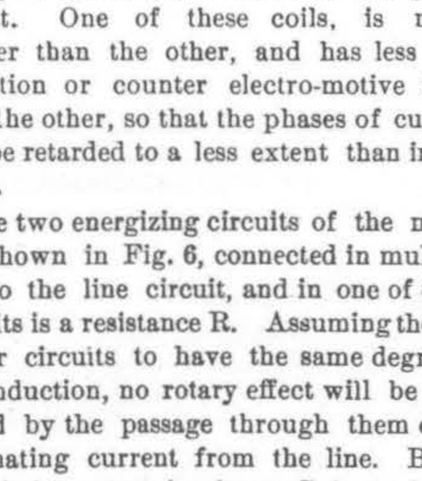


FIG. 3.—TESLA MOTOR WITH TWO DEAD RESISTANCES.

tion of the phases of the current in the two motor circuits with respect to those of the unretarded current in the circuit B thus produced will set up a rotation of the motor. Another type may be mentioned in which one set of energizing coils is of finer wire than the other or has a greater number of convolutions; or each circuit may contain the same number of convolutions, but composed of different conductors, as, for instance, one of copper and the other of German silver.

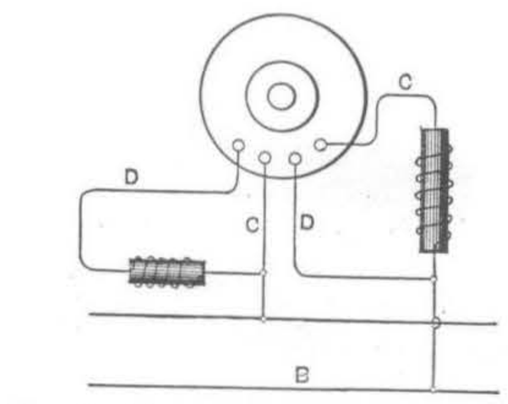


FIG. 5.—TESLA MOTOR WITH TWO SELF-INDUCTION COILS.

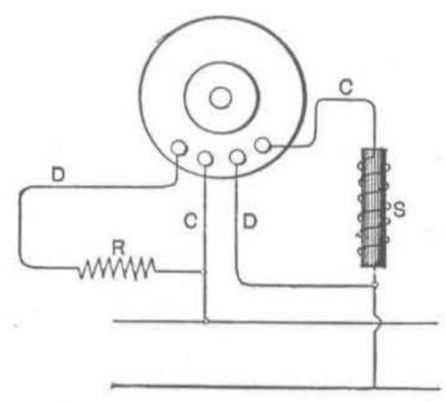


FIG. 4.—TESLA MOTOR WITH SELF-INDUCTION COIL AND DEAD RESISTANCE.

FIG. 6.—TESLA MOTOR WITH ENERGIZING CIRCUITS IN MULTIPLE ARC.

Electricity.

Nikola Tesla.

Perhaps the most daring of the experimenters of the latest decade of the nineteenth century is Nikola Tesla, who was unknown to the scientific world five or six years ago, but who to-day is regarded as a second Edison, and who has achieved more magnificent results than any half-dozen of his contemporaries combined.

To sum up his achievements in a few words is impossible, says *Paper and Press*. He has discovered, or, rather, demonstrated, the possibility of illumination without wires or globules in almost exact imitation of daylight. This lot he can vary to order, and although he has not been able to bring it to what he termed a commercial basis, he has advanced so far in the direction that comparatively little remains to be done before the public can buy daylight by the room instead of by the lamp or light. And this is but one of his marvels. He has produced a flame which does not consume and which gives out no heat whatever, and has thus laid the foundation for untold developments in every phase of electrical work. In the production of ozone by electricity he has also scored a distinct triumph. He has shown that nearly all sanitary problems can be solved by the aid of electricity, and he has also made immense strides in the direction of solving the problem of parceling out electrical force and enabling it to be applied to manual labor in every possible direction.

He was invited to visit London and explain his experiments on the very spot made immortal by Faraday. He went, and was received by the Royal Institution with due honors. The moment his fingers grasped his long glass tubes they glowed with a softened splendor, and when he waved them over his head they gleamed with a radiance which was described as weird, if not ghostly. He manufactured flames which appeared dangerous in the extreme, and then placed them in a wooden box, which was absolutely unaffected by them. He repeated these experiments, with several others, while the guest of the National Electric Convention in St. Louis, at the end of February, and he also explained the details somewhat more fully.

THE

Electrical Engineer.

Vol. XVII. JANUARY 10, 1894. No. 297.

THE TESLA ELECTRICAL OSCILLATOR.

IN the lecture delivered before the Chicago Electrical Congress, Mr. Nikola Tesla first drew attention[1] to the method and means which he had devised for the continuous production of alternating currents of constant period in which all rotating parts are avoided by the employment of his oscillating engine directly to the movement of the generating coil in the magnetic field.

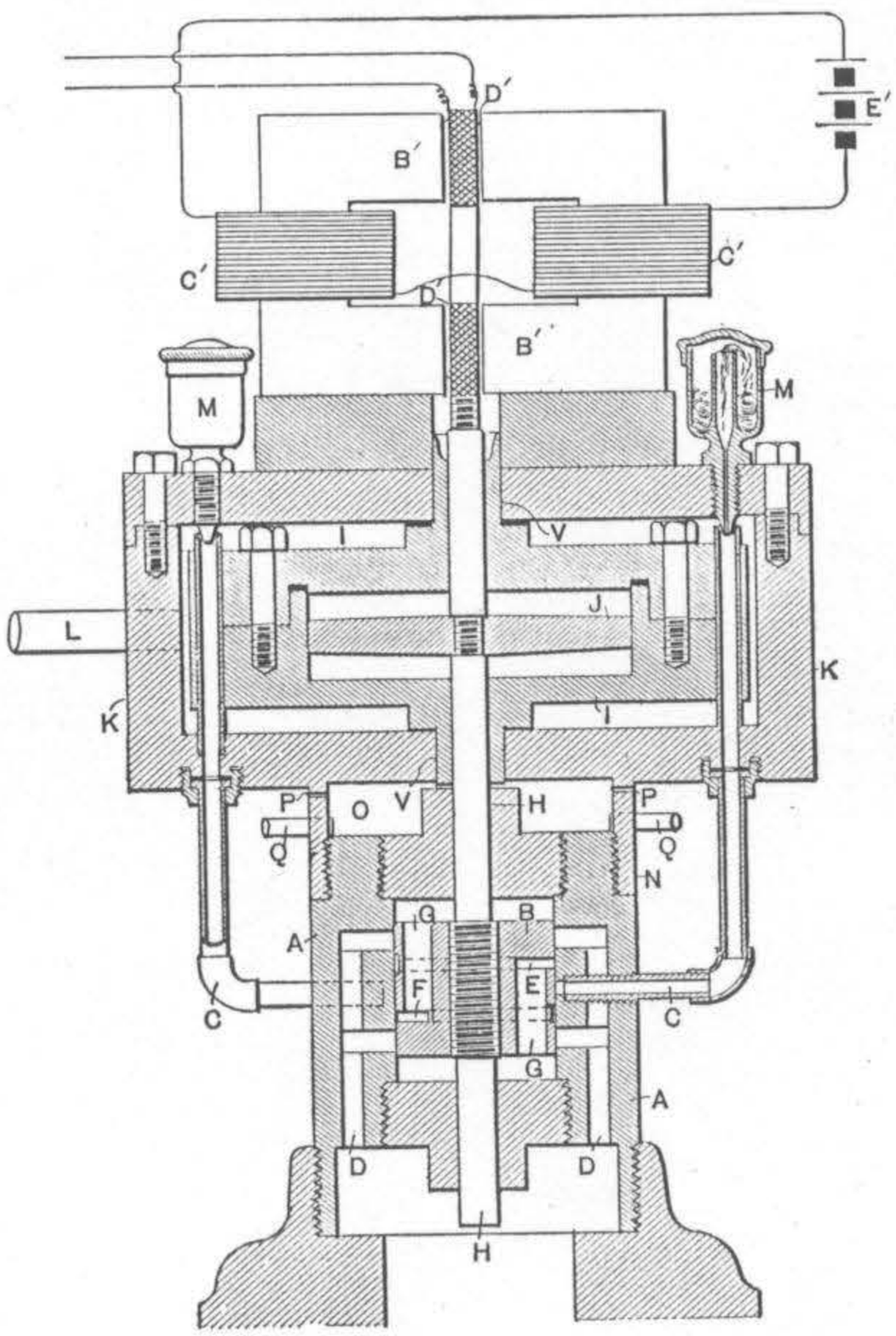
The main reason why no engine heretofore has been capable of producing results of this nature is that it has been customary to connect with the reciprocating parts a heavy fly-wheel or some equivalent rotary system of relatively very great inertia, or in other cases where no rotary system was employed, as in certain reciprocating engines or tools, no regard has been paid to the obtainment of the conditions essential to the end which Mr. Tesla had in view.

In applying the Tesla oscillator for the generation of currents of constant period certain conditions are encountered which must be taken into consideration in order to satisfactorily secure the desired result. When a conductor is moved in a magnetic field and a current caused to circulate therein, the electromagnetic reaction between it and the field might disturb the mechanical oscillation to such an extent as to throw it out of isochronism. This, for instance, might occur when the electromagnetic reaction is very great in comparison with the power of the engine, and there is a retardation of the current so that the electromagnetic reaction might have an effect similar to that which would result from a variation of the tension of the spring; but if the circuit of the generator be adjusted so that the phases of the electromotive force and current coincide in time, that is to say, when the current is not retarded, then the generator driven by the engine acts merely as a frictional resistance and will not, as a rule, alter the period of the mechanical vibration, although it may alter its amplitude. This condition may be readily secured by properly proportioning the self induction and capacity of the circuit including the generator.

Mr. Tesla has, however, observed the further fact in connection with the use of such engines as a means for running a generator, that it is advantageous that the period of the engine and the natural period of electrical vibration of the generator should be the same, as in such case the best conditions for electrical resonance are established and the possibility of disturbing the period of mechanical vibrations is reduced to a minimum. Mr. Tesla has found that even if the theoretical conditions necessary for maintaining a constant period in the engine itself are not exactly maintained, still the engine and generator combined will vibrate at a constant period. For example, if instead of using in the engine an independent cylinder and plunger, as an air spring of practically constant rigidity, the piston may impinge upon air cushions at the ends of its own cylinder. Although the rigidity of such cushions or springs might be considerably affected and varied by the variations of pressure within the cylinder, still by combining with such an engine a generator which has a period of its own, approximately that of the engine, constant vibration may be maintained even through a considerable range of varying pressure, owing to the controlling action of the electromagnetic system.

Indeed Mr. Tesla has even found that under certain conditions the influence of the electromagnetic system may be made so great as to entirely control the period of the mechanical vibration within wide limits of varying pressure. This is likely to occur in those instances where the power of the engine, while fully capable of maintaining a vibration once started, is not sufficient to change its rate.

In our issue of November 8, 1893, we gave the details of construction of the Tesla oscillator and a patent just issued



Elec. Engineer

FIG. 1.—TESLA ELECTRICAL OSCILLATOR.

to Mr. Tesla now enables us to supplement our previous descriptions with those of other types employed by him in this work. The accompanying engraving, Fig. 1, is a sectional view of an oscillator fulfilling the conditions laid down above.

Referring to Fig. 1, A is the main cylinder in which works a piston B. Inlet ports C C pass through the sides of the cylinder opening at the middle and on opposite sides. Exhaust ports D D extend through the walls of the cylinder and are formed with branches that open into the interior of the cylinder on each side of the inlet ports and on opposite sides of the cylinder. The piston B has two circumfer-

1. See THE ELECTRICAL ENGINEER, August 30, 1893.

ential grooves E F which communicate through openings G in the piston with the cylinder on opposite sides of the piston respectively.

The particular construction of the cylinder, the piston and the ports controlling it may be very much varied, and is not in itself material, except that in the special case under consideration it is desirable that all the ports, and more especially the exhaust ports, should be made very much larger than is usually the case so that no force due to the action of the steam or compressed air will tend to retard or affect the return of the piston in either direction.

The piston B is secured to a piston rod H which works in suitable stuffing boxes in the heads of the cylinder A. This rod is prolonged on one side and extends through bearings V in a cylinder I mounted in line with the first, and within which is a disc or plunger J carried by the rod H. The cylinder I is without parts of any kind and is airtight except as a small leakage may occur through the bearings V, which experience has shown need not be fitted with any very considerable accuracy.

The cylinder I is surrounded by a jacket K which leaves an open space or chamber around it. The bearings V in the cylinder, extend through the jacket to the outside air and the chamber between the cylinder and jacket is made steam or air-tight by a suitable packing. The main supply pipe L for steam or compressed air leads into this chamber, and the two pipes that lead to cylinder A run from this chamber, oil cups M being conveniently arranged to deliver oil into the pipes for lubricating the piston.

In the particular form of engine shown, the jacket K which contains the cylinder I is provided with a flange N by which it is screwed to the end of the cylinder A. A small chamber O is thus formed which has air vents P in its sides and drip pipes Q leading out from it through which the oil which collects in it is carried off.

In the position of the parts shown, or when the piston is at the middle point of its stroke, the plunger J is at the centre of the cylinder I and the air on both sides of the same is at the normal pressure of the outside atmosphere. If a source of steam or compressed air be then connected to the inlet ports C-C of the cylinder A and a movement be imparted to the piston as by a sudden blow, the latter begins to reciprocate in the well-known way.

The movements of the piston compress and rarefy the air in the cylinder I at opposite ends, alternately. A forward stroke compresses the air ahead of the plunger J which acts as a spring to return it; similarly, on the back stroke the air is compressed on the opposite side of the plunger J and tends to drive it forward.

The compressions of the air in the cylinder I and the consequent loss of energy due mainly to the imperfect elasticity of the air, give rise to a very considerable amount of heat. This heat is utilized by conducting the steam or compressed air to the engine cylinder through the chamber formed by the jacket surrounding the air-spring cylinder, the heat thus taken up and used to raise the temperature of the steam or air acting upon the piston is availed of to increase the efficiency of the engine.

In any given engine of this kind the normal pressure will produce a stroke of determined length, and this will be increased or diminished according to the increase of pressure above, or the reduction of pressure below, the normal. In constructing the apparatus proper allowance is made for a variation in the length of stroke by giving to the confining cylinder I of the air spring properly determined dimensions. The greater the pressuse upon the piston, the higher will be the degree of compression of the air-spring, and the consequent counteracting force upon the plunger.

The rate or period of reciprocation of the piston, however, is mainly determined by the rigidity of the air spring and the inertia of the moving system, and any period of oscillation within very wide limits may be secured by properly proportioning these factors, as by varying the dimensions of the air chamber, which is equivalent to varying the rigidity of the spring, or by adjusting the weight of the moving parts. These conditions are all readily determinable, and an engine constructed as above described maintains a perfectly uniform period through very wide limits of pressure.

The pressure of the air confined in the cylinder when the plunger I is in its central position will always be practically that of the surrounding atmosphere, for while the cylinder is so constructed as not to permit such sudden escape of air as to sensibly impair or modify the action of the air-spring, there will still be a slow leakage of air into or out of it around the piston rod, according to the pressure therein, so that the pressure of the air on opposite sides of the plunger will always tend to remain at that of the outside atmosphere.

To the piston rod H is secured a coil D′ which, by the

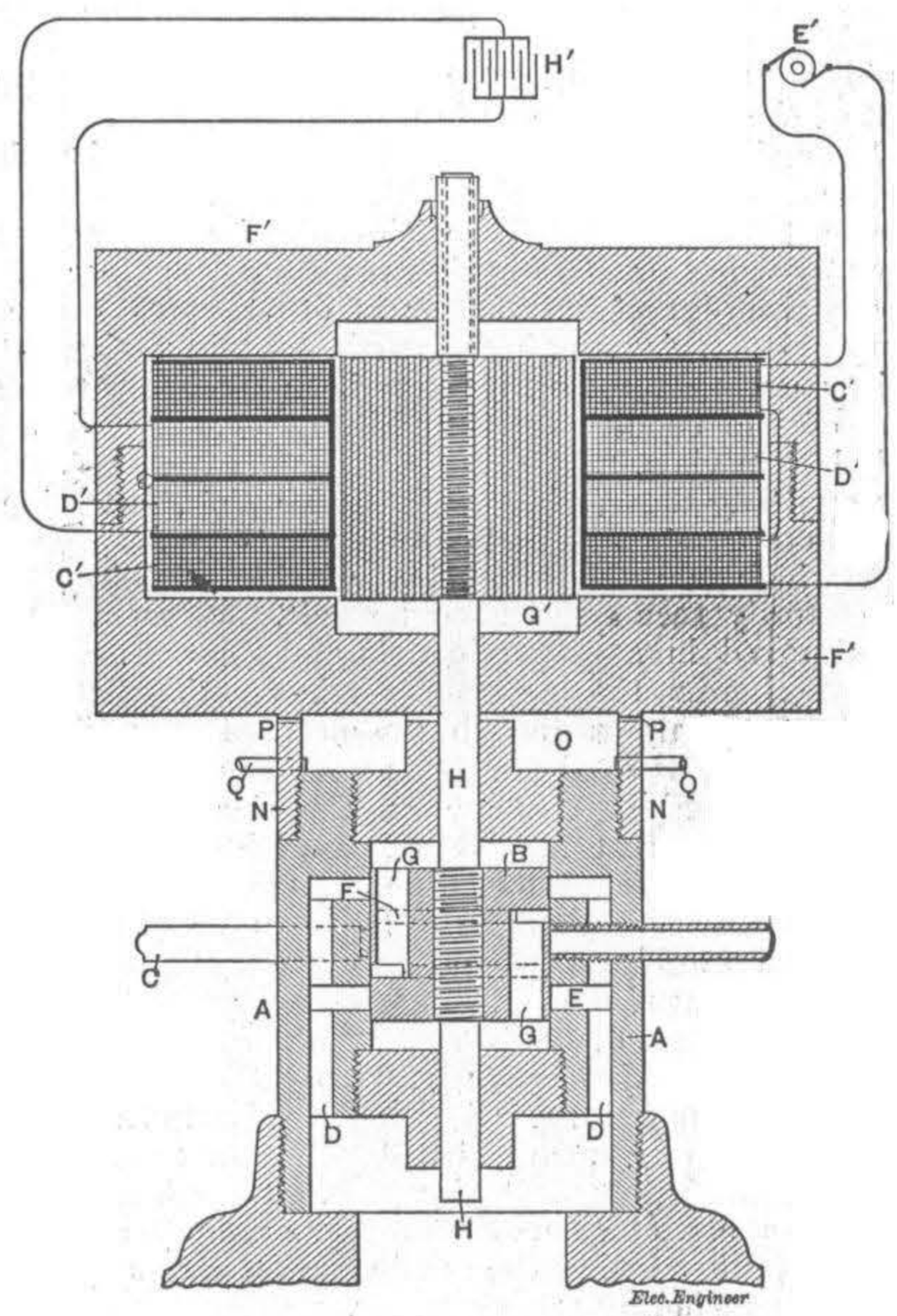


FIG. 2.—TESLA ELECTRICAL OSCILLATOR.

movements of the piston, is oscillated in the magnetic field produced by two magnets B′ B′ which may be permanent magnets or energized by coils C′ C′ connected with a source of continuous current E′. The movement of the coil D′ across the lines of force established by the magnets gives rise to alternating currents in the coil. These currents, if the period of mechanical oscillation be constant will be of constant period.

In the case under consideration it is assumed as a necessary condition that the inertia of the movable element of the generator and the electromagnetic reaction which it exerts will not be of such a character as to materially disturb the action of the engine.

Fig. 2 is an example of a combination in which the engine is not of itself capable of determining entirely the period of oscillation, but in which the generator contributes to this end. In this figure the engine is the same as that shown in Fig. 1. The exterior air spring is however omitted and the air spaces at the ends of the cylinder A

relied on for accomplishing the same purpose. As the pressure in these spaces is liable to variations from variations in the steam or gas used in impelling the piston they might affect the period of oscillation, and the conditions are not as stable and certain as in the case of an engine constructed as in Fig. 1. But if the natural period of vibration of the electric system be made to approximately accord with the average period of the engine such tendencies to variation are very largely overcome and the engine will preserve its period even through a considerable range of variation of pressure.

The generator in this case is composed of a magnetic casing F′ in which a laminated core G′ secured to the piston rod H is caused to vibrate. Surrounding the plunger are two exciting coils C′ C′, and one or more induced coils D′ D′. The coils C′ C′ are connected with a generator of continuous currents E′ and are wound to produce consequent poles in the core G′. Any movement of the latter will therefore shift the lines of force through coils D′ D′ and produce currents therein.

In the circuit of coils D′ is shown a condenser H′. By the use of a proper condenser the self-induction of this circuit may be neutralized. Such a circuit will have a certain natural period of vibration, and, as this depends upon the capacity and self induction, the period may be varied to approximately accord with the period of the engine.

In case the power of the engine be comparatively small, as when the pressure is applied through a very small fraction of the total stroke, the electrical vibration will tend to control the period, and it is clear that if the character of such vibration be not very widely different from the average period of vibration of the engine under ordinary working conditions that such control may be entirely adequate to produce the desired results.

THE WESTINGHOUSE PLANS FOR THE NIAGARA CONTRACT.

THE work now being done in connection with the electrical utilization of Niagara is attracting universal attention, and public interest has again been greatly stimulated by the paper read before the English Institution of Electrical Engineers, by Prof. George Forbes, and reprinted and discussed in our pages. We now have the pleasure of printing a very important communication on the subject from Mr. L. B. Stillwell, electrical engineer of the Westinghouse Electric and Manufacturing Company, signed by him on behalf of the company.

"We have read the leading editorial on 'The Niagara Project' in THE ELECTRICAL ENGINEER of December 20th, and note with interest the following:

> It was hardly to be expected that the promoters of the Niagara enterprise would accept the individual opinion of any one man on the various points of prominent importance, which had to be considered, and Prof. Forbes' paper may therefore be looked upon as a fair representation of the views of the most advanced electrical engineers, as well as the results of Prof. Forbes' own careful study of the literature on the subject and information gained from other sources. The paper may thus be considered not less an expression of the author's personal opinion than an epitome of the views of a large number of prominent electrical and mechanical engineers, and, as such, it will be of interest to determine in how far these views have been applied at Niagara.

"The fact that the engineers and electricians of the Westinghouse Electric and Manufacturing Company have for several years devoted much attention to the subject of power transmission is well known, as is also the fact that our company has received from the Cataract Construction Company the order for the initial installation of electrical apparatus at Niagara. It seems, therefore, a fair inference that you intend to include the engineers of this company among the electrical engineers of whose views you assume that Prof. Forbes' paper is a fair representation.

"The system which has been adopted for the installation at Niagara Falls is simply the Tesla polyphase system as developed by the technical staff of the Westinghouse Electric and Manufacturing Company. It has not been modified in any particular by the engineers of the Cataract Construction Company or of the Niagara Falls Power Company. It is fully described in publications of this company and was demonstrated on a large scale by one of our exhibits in the Electricity Building at the recent Columbian Exposition in Chicago. In developing and perfecting the system, we have not only been guided by a wide experience in the design, manufacture and use of electrical machinery but we have carried out a large amount of experimental work, much of it on an extensive scale, and have made a careful, theoretical and practical study of the subject. Prof. Forbes' views, as stated in his paper, are naturally in accord with ours upon many points. In others, his paper fails to fully state the facts as we see them, and, in others still, we think his views are incorrect. We cannot, therefore, in justice to our company, consent to the assumption that his paper be accepted as a "fair representation" of our views.

"Some of the technical journals have apparently received the impression that the generator described in Prof. Forbes' paper under the heading "General Description of a 5,000 H. P. Alternator" is that which has been adopted by the Cataract Construction Company. This is not the case. The drawings and specifications of the generator, which Prof. Forbes describes were laid before us in August last, and were fully explained by Dr. Coleman Sellers and Prof. Forbes. After careful consideration, we accepted the general mechanical features of the construction proposed as excellent, but, in the opinion of our electricians and engineers, the electrical features—the method of winding, the insulation, etc.—were impracticable, and realizing that we could not undertake the construction of such a machine with credit to our company, we declined to submit proposals. We were thereupon requested by the officers of the Cataract Construction Company to submit our own plans and specifications and this was done early in August. We followed closely the mechanical features approved by Dr. Sellers but the electrical features are wholly our own. These plans were accepted by the Cataract Construction Company and are those under which the generators for Niagara are now being constructed.

"Prof. Forbes is undoubtedly qualified to speak with authority as to the assumptions and reasoning which have led him to agree with other engineers of the Cataract Construction Company in recommending to his Board of Directors the adoption of the system, which has been selected, but the premises and the reasoning which guided the engineers of the Westinghouse Electric and Manufacturing Company in the development of the Tesla polyphase system, as it will be used at Niagara, differ widely in some respects from those which are set forth in the paper to which your editorial refers.

"We trust that you will give to this explanation suitable prominence as we are unwilling, for the reasons stated, to have Prof. Forbes' paper accepted by your readers as a statement of our views."

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THE WESTINGHOUSE COMPANY AND THE NIAGARA CONTRACT.

WE print elsewhere in this issue an important communication from Mr. L. B. Stillwell, on behalf of the Westinghouse Co., which sheds a strong side light on the information embodied in Prof. Forbes' paper on the electrical features of the Niagara transmission plant. This communication, taken in connection with Prof. Forbes' own statements, would make it appear that so far as essential features are concerned; the promoters of the Niagara scheme deemed it wise to accept the advice of experienced constructors in preference to that of their consulting electrical engineer. And this brings us back to the old question of the relation between these two frequently antagonistic elements. The consulting electrical engineer's services have from the very outset been little availed of in this country, purchasers of electrical plants having in the large majority of cases left matters entirely in the hands of the contracting companies, which practice has, it must be admitted, given rise to but few conflicts. In the case of the work at Niagara, it would appear that the consulting electrical engineer, instead of confining himself to laying down the conditions and leaving to the contractors to devise the best methods of carrying out the specifications, actually entered into competition with them, with the result that might have been foreseen. According to Mr. Stillwell it would also seem that while the engineers of the Westinghouse Co., are in accord with Prof. Forbes on the selection of the methods adopted, they differ from him radically in the assumptions and reasoning which led them to advocate the final plans adopted.

It would be interesting to know the details of these differences and it is to be hoped that the electrical profession will not be kept in ignorance of them. For this reason it is perhaps a pity that Prof. Forbes' paper could not have been read and discussed on this side of the water also. Probably an early opportunity may be afforded by the Institute for such a timely discussion.

THE TESLA ELECTRICAL OSCILLATOR.

WHILE Mr. Tesla has until the last year or two confined himself to purely electrical work,his most recent labors have been devoted to the solution of a mechanical problem intimately connected with the generation of electric currents, the outcome being his electrical oscillators, of which we describe two additional types in this week's issue. Aside from the numerous possibilities in other fields it would seem that if the "oscillator" fulfills the expectations of its inventor, it is destined to create little short of a revolution in our present methods of power generation and distribution. It must be confessed that in spite of the numerous obvious cases in which the application of motors to the driving of machines and line shafting would prove a gain over the present methods, and despite even the successful working of such plants, the conservative factory owner and machinist still looks with a doubtful glance at these innovations of the last ten years. But, if, as Mr. Tesla claims, he will be able to furnish electric current by means of his oscillator, at anything like one half the cost for fuel now required and with much simpler apparatus, the aspect becomes quite a

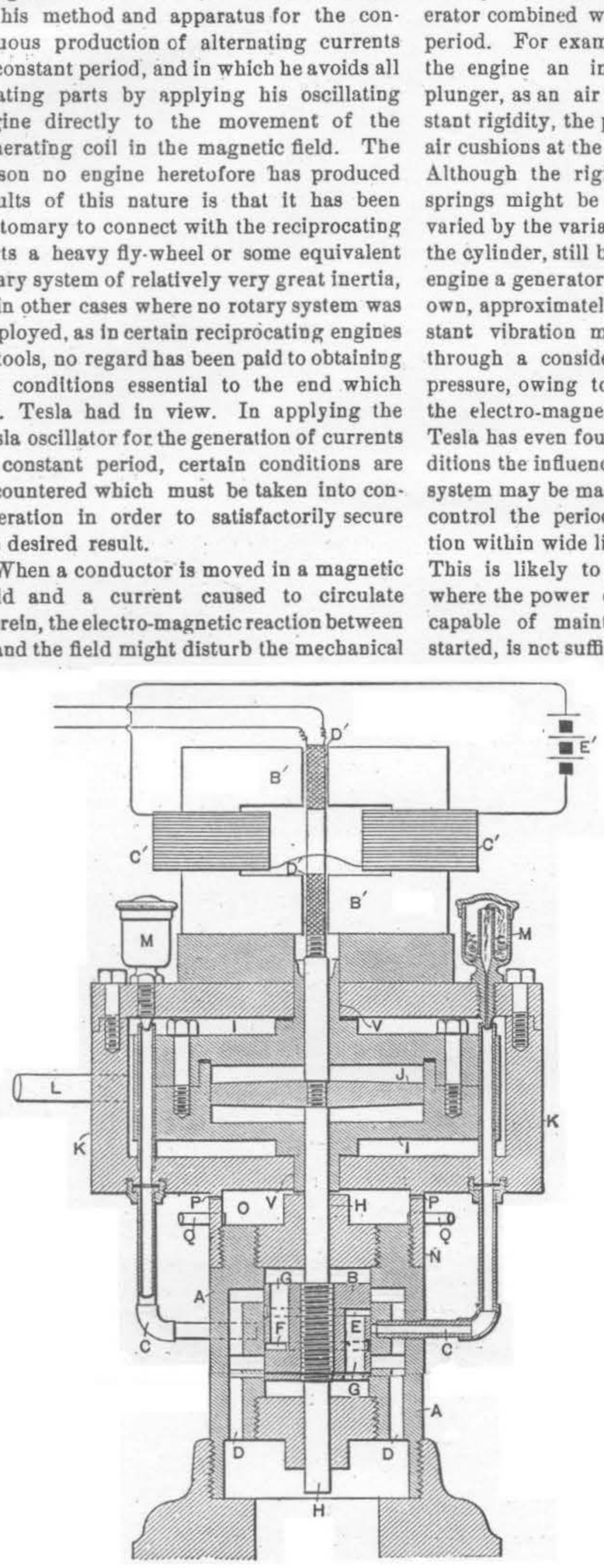
different one. Such an accomplishment would immediately appeal to every power user and would at once determine the direction of future methods of local power transmission. Indeed it might not be inapt to inquire here also into the probable effect of such an achievement on long distance electrical transmission. With the potentials which have been practically handled up to date, the size of conductors required has not permitted of the extension of power transmission plants utilizing water power, to the distances hoped for, although we note small but constant gains in this respect. With the initial source of energy in the shape of fuel reduced to one half the present cost, it would indeed require an exceptional set of conditions such for example, as those existing at Niagara or in regions far remote from fuel supply to make the utilization of water-powers worth considering for any considerable distance from the fall. Already the cost of water power even locally distributed has in numerous conspicuous instances proved less economical in competition with modern steam engines and a still further improvement in the latter added to the benefits to be derived from electric motors must still further tend to decrease the comparative margin of economy with water power. It seems strange indeed that a power available on the spot should not be able to compete in economy with another form of energy hauled frequently for a distance of hundreds of miles, but experience bears out the conclusions just stated. While the above remarks refer merely to power distribution they are equally applicable to the question of electric lighting and current distribution in general. From Mr. Tesla's observations before the recent meeting of the New York Electrical Society (see THE ELECTRICAL ENGINEER, Dec. 6 and 13, 1893) we infer that he has so far gone into the study of the methods he advocates that we shall not have to wait long for their practical realization.

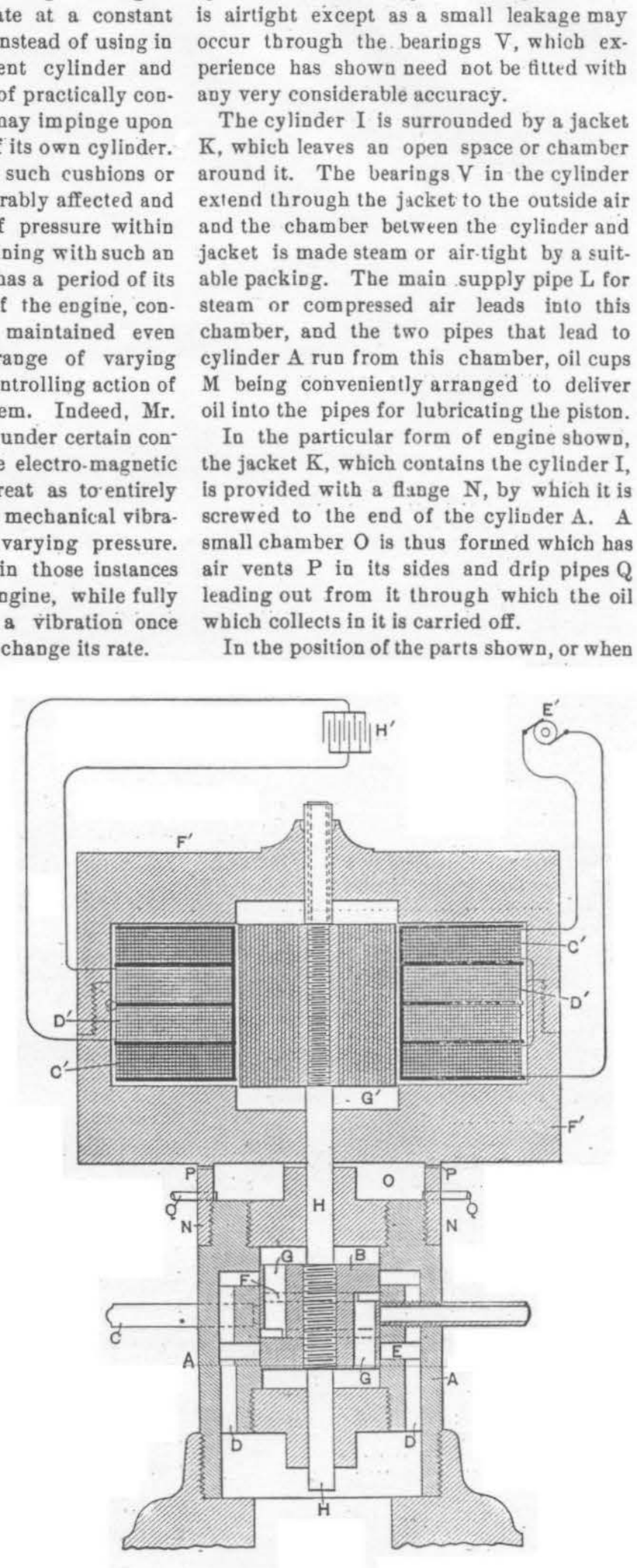
Tesla's Electrical Oscillators.

Mr. Nikola Tesla, at the World's Fair Congress of Electricians, first drew attention to his method and apparatus for the continuous production of alternating currents of constant period, and in which he avoids all rotating parts by applying his oscillating engine directly to the movement of the generating coil in the magnetic field. The reason no engine heretofore has produced results of this nature is that it has been customary to connect with the reciprocating parts a heavy fly-wheel or some equivalent rotary system of relatively very great inertia, or in other cases where no rotary system was employed, as in certain reciprocating engines or tools, no regard has been paid to obtaining the conditions essential to the end which Mr. Tesla had in view. In applying the Tesla oscillator for the generation of currents of constant period, certain conditions are encountered which must be taken into consideration in order to satisfactorily secure the desired result.

When a conductor is moved in a magnetic field and a current caused to circulate therein, the electro-magnetic reaction between it and the field might disturb the mechanical oscillation to such an extent as to throw it out of isochronism. This, for instance, might occur when the electro magnetic reaction is very great in comparison to the power of the engine, and there is a retardation of the current so that the electro-magnetic reaction might have an effect similar to that which would result from a variation of the tension of the spring; but if the circuit of the generator be adjusted so that the phases of the electro-motive force and current coincide in time, that is to say, when the current is not retarded, then the generator driven by the engine acts merely as a fractional resistance and will not, as a rule, alter the period of the mechanical vibration, although it may its amplitude. This condition may be readily secured by properly proportioning the self-induction and capacity of the circuit including the generator. Mr. Tesla has, however, observed the further fact in connection with the use of such engines as a means for running a generator, that it is advantageous that the period of the engine and the natural period of electrical vibration of the generator should be the same, as in such case the best conditions for electrical resonance are established, and the possibility of disturbing the period of mechanical vibrations is reduced to a minimum.

Mr. Tesla has found that even if the theoretical conditions necessary for maintaining a constant period in the engine itself are not exactly maintained, still the engine and generator combined will vibrate at a constant period. For example, if instead of using in the engine an independent cylinder and plunger, as an air spring of practically constant rigidity, the piston may impinge upon air cushions at the ends of its own cylinder. Although the rigidity of such cushions or springs might be considerably affected and varied by the variations of pressure within the cylinder, still by combining with such an engine a generator which has a period of its own, approximately that of the engine, constant vibration may be maintained even through a considerable range of varying pressure, owing to the controlling action of the electro-magnetic system. Indeed, Mr. Tesla has even found that under certain conditions the influence of the electro-magnetic system may be made so great as to entirely control the period of the mechanical vibration within wide limits of varying pressure. This is likely to occur in those instances where the power of the engine, while fully capable of maintaining a vibration once started, is not sufficient to change its rate.





FIGS. 1 AND 2.—NIKOLA TESLA'S ELECTRICAL OSCILLATORS.

The accompanying illustration, Fig. 1, is a sectional view of an oscillator fulfilling the conditions laid down above. Referring to Fig. 1, A is the main cylinder in which works a piston B. Inlet ports C C pass through the sides of the cylinder opening at the middle and on opposite sides. Exhaust ports D D extend through the walls of the cylinder and are formed with branches that open into the interior of the cylinder on each side of the inlet ports and on opposite sides of the cylinder. The piston B has two circumferential grooves E F, which communicate through openings G in the piston with the cylinder on opposite sides of the piston respectively.

The particular construction of the cylinder, the piston and the ports controlling it may be greatly varied, and is not in itself material, except that in the special case under consideration it is desirable that all the ports, and more especially the exhaust ports, should be made very much larger than is usually the case, so that no force due to the action of the steam or compressed air will tend to retard or affect the return of the piston in either direction.

The piston B is secured to a piston rod H, which works in suitable stuffing boxes in the heads of cylinder A. This rod is prolonged on one side and extends through bearings V in a cylinder I, mounted in line with the first, and within which is a disk or plunger J carried by the rod H. The cylinder I is without parts of any kind and is airtight except as a small leakage may occur through the bearings V, which experience has shown need not be fitted with any very considerable accuracy.

The cylinder I is surrounded by a jacket K, which leaves an open space or chamber around it. The bearings V in the cylinder extend through the jacket to the outside air and the chamber between the cylinder and jacket is made steam or air-tight by a suitable packing. The main supply pipe L for steam or compressed air leads into this chamber, and the two pipes that lead to cylinder A run from this chamber, oil cups M being conveniently arranged to deliver oil into the pipes for lubricating the piston.

In the particular form of engine shown, the jacket K, which contains the cylinder I, is provided with a flange N, by which it is screwed to the end of the cylinder A. A small chamber O is thus formed which has air vents P in its sides and drip pipes Q leading out from it through which the oil which collects in it is carried off.

In the position of the parts shown, or when the piston is at the middle point of its stroke, the plunger J is at the center of the cylinder I, and the air on both sides of the same is at the normal pressure of the outside atmosphere. If a source of steam or compressed air be then connected to the inlet ports C C of the cylinder A, and a movement be imparted to the piston as by a sudden blow, the latter begins to reciprocate in the well-known way.

The movements of the piston compress and rarefy the air in the cylinder I at opposite ends, alternately. A forward stroke compresses the air ahead of the plunger J, which acts as a spring to return it; similarly, on the back stroke the air is compressed on the opposite side of the plunger J and tends to drive it forward.

The compressions of the air in the cylinder I and the consequent loss of energy due mainly to the imperfect elasticity of the air, give rise to a very considerable amount of heat. This heat is utilized by conducting the steam or compressed air to the engine cylinder through the chamber formed by the jacket surrounding the air spring cylinder, the heat thus taken up and used to raise the temperature of the steam or air acting upon the piston is availed of to increase the efficiency of the engine.

In any given engine of this kind the normal pressure will produce a stroke of determined length, and this will be increased or diminished according to the increase of pressure above, or the reduction of pressure below, the normal. In constructing the apparatus proper allowance is made for a variation in the length of stroke by giving to the confining cylinder I of the air spring properly determined dimensions. The greater the pressure upon the piston, the higher will be the degree of compression of the air spring, and the consequent counter-acting force upon the plunger.

The rate or period of reciprocation of the piston, however, is mainly determined by the rigidity of the air spring and the inertia of the moving system, and any period of oscillation within very wide limits may be secured by properly portioning these factors, as by varying the dimensions of the air chamber, which is equivalent to varying the rigidity of the spring, or by adjusting the weight of the moving parts. These conditions are all readily determinable, and an engine constructed as above described maintains a perfectly uniform period through very wide limits of pressure.

The pressure of the air confined in the cylinder when the plunger I is in its central position will always be practically that of the surrounding atmosphere, for while the cylinder is so constructed as not to permit such sudden escape of air as to sensibly impair or modify the action of the air spring, there will still be a slow leakage of air into or out of it around the piston rod according to the pressure therein, so that the pressure of the air on opposite sides of the plunger will always tend to remain at that of the outside atmosphere. To the piston rod H is secured a coil D′ which, by the movements of the piston, is oscillated in the magnetic field produced by two magnets B′ B′, which may be permanent magnets or energized by coils C′ C′ connected with a source of continuous current E′. The movement of the coil D′ across the lines of force established by the magnets gives rise to alternating currents in the coil. These currents, if the period of mechanical oscillation be constant, will be of constant period. In the case under consideration it is assumed as a necessary condition that the inertia of the movable element of the generator and the electro-magnetic reaction which it exerts will not be of such a character as to materially disturb the action of the engine.

In Fig. 2 is shown an example of a combination in which the engine is not of itself capable of determining entirely the period of oscillation, but in which the generator contributes to this end. In this figure the engine is the same as that shown in Fig. 1. The exterior air spring is, however, omitted, and the air spaces at the ends of the cylinder A relied on for accomplishing the same purpose. As the pressure in these spaces is liable to variations from variations in the steam or gas used in impelling the piston, they might affect the period of oscillation, and the conditions are not as stable and certain as in the case of an engine constructed as in Fig. 1. But if the natural period of vibration of the elastic system be made to approximately accord with the average period of the engine, such tendencies to variation are very largely overcome and the engine will preserve its period even through a considerable range of variation of pressure.

The generator in this case is composed of a magnetic casing F′, in which a laminated core G′, secured to the piston rod H, is caused to vibrate. Surrounding the plunger are two exciting coils C′ C′, and one or more induced coils D′ D′. The coils C′ C′ are connected with a generator of continuous currents E′ and are wound to produce consequent poles in the core G′. Any movement of the latter will, therefore, shift the lines of force through coils D′ D′ and produce currents therein.

In the circuit of coils D′ is shown a condenser H′. By the use of a proper condenser the self-induction of this circuit may be neutralized. Such a circuit will have a certain natural period of vibration, and, as this depends upon the capacity and self-induction, the period may be varied to approximately accord with the period of the engine. In case the power of the engine be comparatively small, as when the pressure is applied through a very small fraction of the total stroke, the electrical vibration will tend to control the period, and it is clear that if the character of such vibration be not very widely different from the average period of vibration of the engine under ordinary working conditions, that such control may be entirely adequate to produce the desired results.

ELECTRICAL PATENTS.

Issued December 26, 1893.

511,559. Electrical Transmission of Power. Nikola Tesla, New York, N. Y.

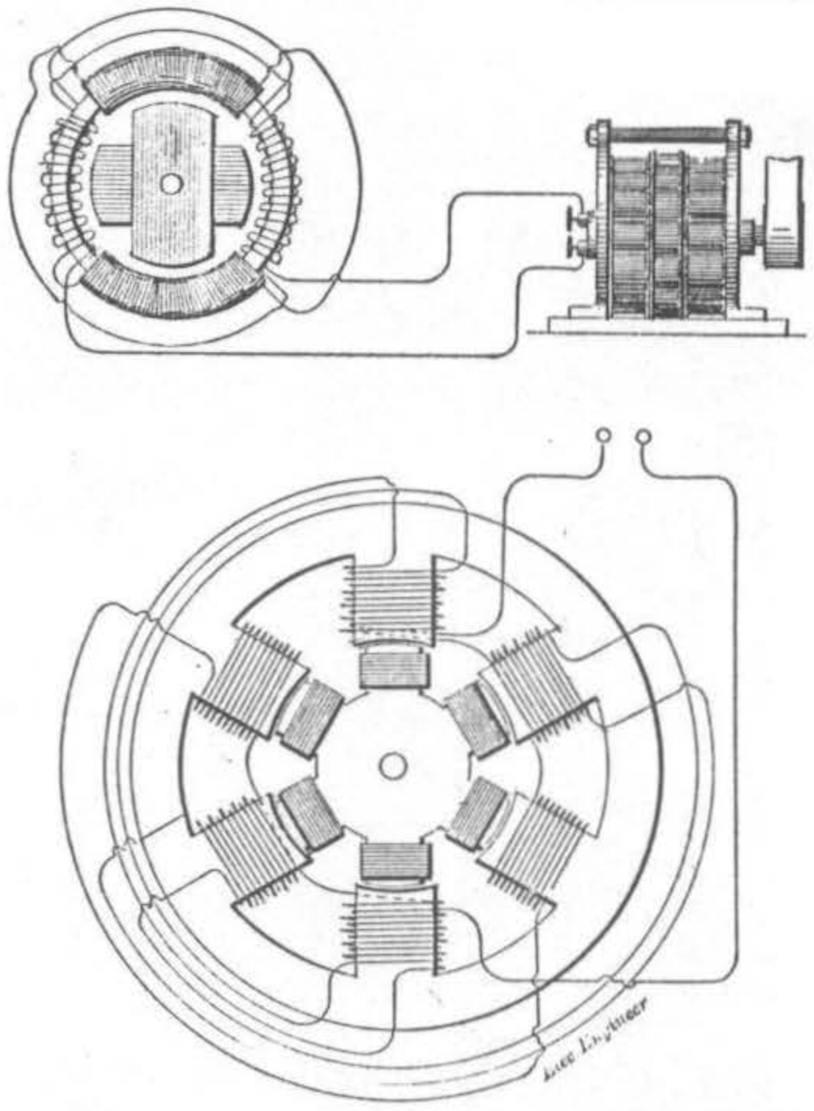
The invention relates to the operation of motors having independent energizing circuits; alternating currents are passed through both of the circuits, the phase in one being retarded to a greater or less extent than in the other.

511,560. System of Electrical Power Transmission. Nikola Tesla, New York, N. Y.

PATENT NOTES.

TESLA SINGLE CIRCUIT ALTERNATING MOTOR.

IN a patent issued to Mr. Nikola Tesla, on Jan. 2, entitled "Electrical Transmission of Power," No. 311,915 originally filed

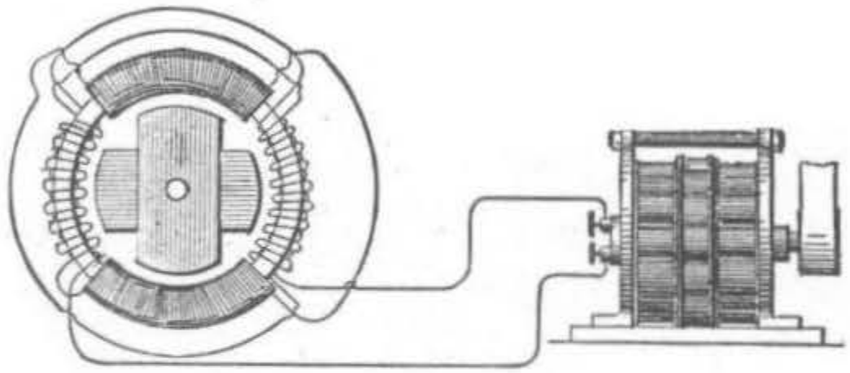


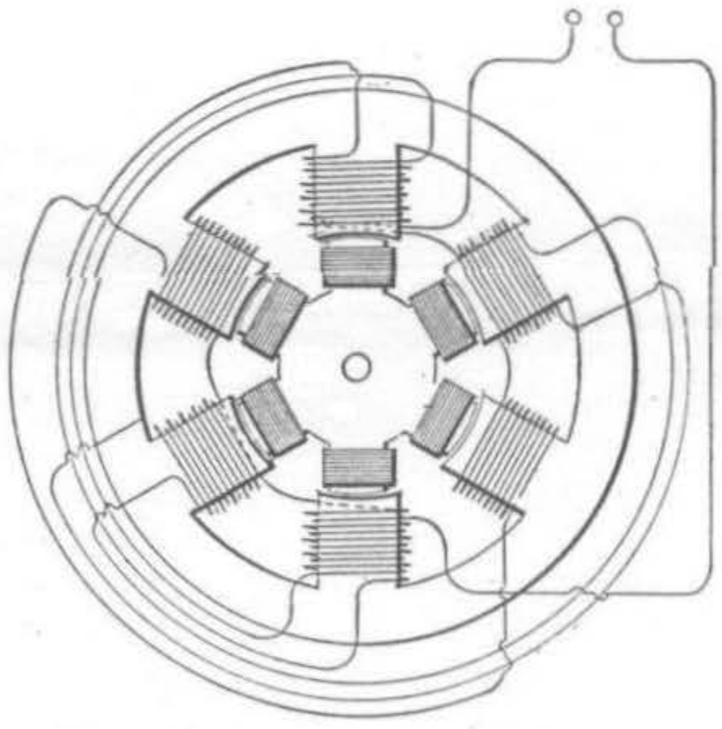
TESLA SINGLE CIRCUIT ALTERNATING MOTOR.

May 15, 1888, that inventor describes a method of operating motors from a two-wire alternating circuit. The method employed is set forth in the two claims of the patent which we give below :

1. The method of operating electro-magnetic motors having independent energizing circuits, as herein described, which consists in passing an alternating current through one of the energizing circuits and inducing by such current the current in the other energizing circuit of the motor, as set forth.

2. The method of operating electro-magnetic motors having independent energizing circuits as herein described, which consists in developing an alternating current in one of said energizing circuits and inducing thereby currents in the other energizing circuit or circuits, as herein set forth.





TESLA SINGLE CIRCUIT ALTERNATING MOTOR.

Tesla Single Circuit Alternating Motor.

In a patent issued to Mr. Nikola Tesla on January 2, entitled, "Electrical Transmission of Power, No. 311,915, originally filed May 15, 1888," is described a method of operating motors from a two-wire alternating circuit. The method employed is set forth in the two claims of the patent as follows:

1. The method of operating electro-magnetic motors having independent energizing circuits, as herein described, which consists in passing an alternating current through one of the energizing circuits and inducing by such current the current in the other energizing circuit of the motor, as set forth.

2. The method of operating electro-magnetic motors having independent energizing circuits, as herein described, which consists in developing an alternating current in one of said energizing circuits, and inducing thereby currents in the other energizing circuit or circuits, as herein set forth.

THE TESLA ELECTRICAL OSCILLATOR.*

In the lecture delivered before the Chicago Electrical Congress, Mr. Nikola Tesla first drew attention to the method and means which he had devised for the continuous production of alternating currents of constant period, and in which all rotating parts are avoided by the employment of his oscillating engine directly to the movement of the generating coil in the magnetic field.

The main reason why no engine heretofore has been capable of producing results of this nature is that it has been customary to connect with the reciprocating parts a heavy flywheel, or some equivalent rotary system of relatively very great inertia, or in other cases where no rotary

* From an advance proof of the *Electrical Engineer* (New York).

system was employed, as in certain reciprocating engines or tools, no regard has been paid to the obtainment of the conditions essential to the end which Mr. Tesla had in view.

In applying the Tesla oscillator for the generation of currents of constant period, certain conditions are encountered which must be taken into consideration in order to satisfactorily secure the desired result. When a conductor is moved in a magnetic field and a current caused to circulate therein, the electromagnetic reaction between it and the field might disturb the mechanical oscillation to such an extent as to throw it out of isochronism. This, for instance, might occur when the electromagnetic reaction is very great in comparison to the power of the engine, and there is a retardation of the current, so that the electromagnetic reaction might have an effect similar to that which would result from a variation of the tension of the spring; but if the circuit of the generator be adjusted so that the phases of the E.M.F. and current coincide in time—that is to say, when the current is not retarded—then the generator driven by the engine acts merely as a fractional resistance, and will not, as a rule, alter the period of the mechanical vibration, although it may its amplitude. This condition may be readily secured by properly proportioning the self-induction and capacity of the circuit, including the generator.

Mr. Tesla has, however, observed the further fact in connection with the use of such engines as a means for running a generator, that it is advantageous that the period of the engine and the natural period of electrical vibration of the generator should be the same, as in such case the best conditions for electrical resonance are established, and the possibility of disturbing the period of mechanical vibrations is reduced to a minimum. Mr. Tesla has found that even if the theoretical conditions necessary for maintaining a constant period in the engine itself are not exactly maintained, still the engine and generator combined will vibrate at a constant period. For example, if instead of using in the engine an independent cylinder and plunger, as an air spring of practically constant rigidity, the piston may impinge upon air cushions at the ends of its own cylinder. Although the rigidity of such cushions or springs might be considerably affected and varied by the variations of pressure within the cylinder, still by combining with such an engine a generator which has a period of its own, approximately that of the engine, constant vibration may be maintained even through a considerable range of varying pressure, owing to the controlling action of the electromagnetic system.

Indeed, Mr. Tesla has even found that under certain conditions the influence of the electromagnetic system may be made so great as to entirely control the period of the mechanical vibration within wide limits of varying pressure. This is likely to occur in those instances where the power of the engine, while fully capable of maintaining a vibration once started, is not sufficient to change its rate.

In our issue of November 8, 1893, we gave the details of construction of the Tesla oscillator, and a patent just issued to Mr. Tesla now enables us to supplement our previous descriptions with those of other types employed by him in this work. The accompanying engraving, Fig. 1, is a sectional view of an oscillator fulfilling the conditions laid down above.

Referring to Fig. 1, A is the main cylinder in which works a piston, B. Inlet ports, C C, pass through the sides of the cylinder opening at the middle and on opposite sides. Exhaust ports, D D, extend through the walls of the cylinder, and are formed with branches that open into the interior of the cylinder on each side of the inlet ports and on opposite sides of the cylinder. The piston, B, has two circumferential grooves, E F, which communicate through openings, G, in the piston with the cylinder on opposite sides of the piston respectively. The particular construction of the cylinder, the piston, and the ports controlling it may be very much varied, and is not in itself material, except that in the special case under consideration it is desirable that all the ports, and more especially the exhaust ports, should be made very much larger than is usually the case, so that no force due to the action of the steam or compressed air will tend to retard or affect the return of the piston in either direction. The piston, B, is secured to a piston-rod, H, which works in suitable stuffing-boxes in the heads of the cylinder A. This rod is prolonged on one side and extends through bearings, V, in a cylinder, I, mounted in line with the first, and within which is a disc or plunger, J, carried by the rod, H. The cylinder, I, is without parts of any kind, and is airtight except as a small leakage may occur through the bearings, V, which experience has shown need not be fitted with any very considerable accuracy. The cylinder I is surrounded by a jacket, K, which leaves an open space or chamber around it. The bearings, V, in the cylinder, extend through the jacket to the outside air, and the chamber between the cylinder and jacket is made steam or air tight by a suitable packing. The main supply pipe, L, for steam or compressed air leads into this chamber, and the two pipes that lead to cylinder A run from this chamber, oil-cups, M, being conveniently arranged to deliver oil into the pipes for lubricating the piston.

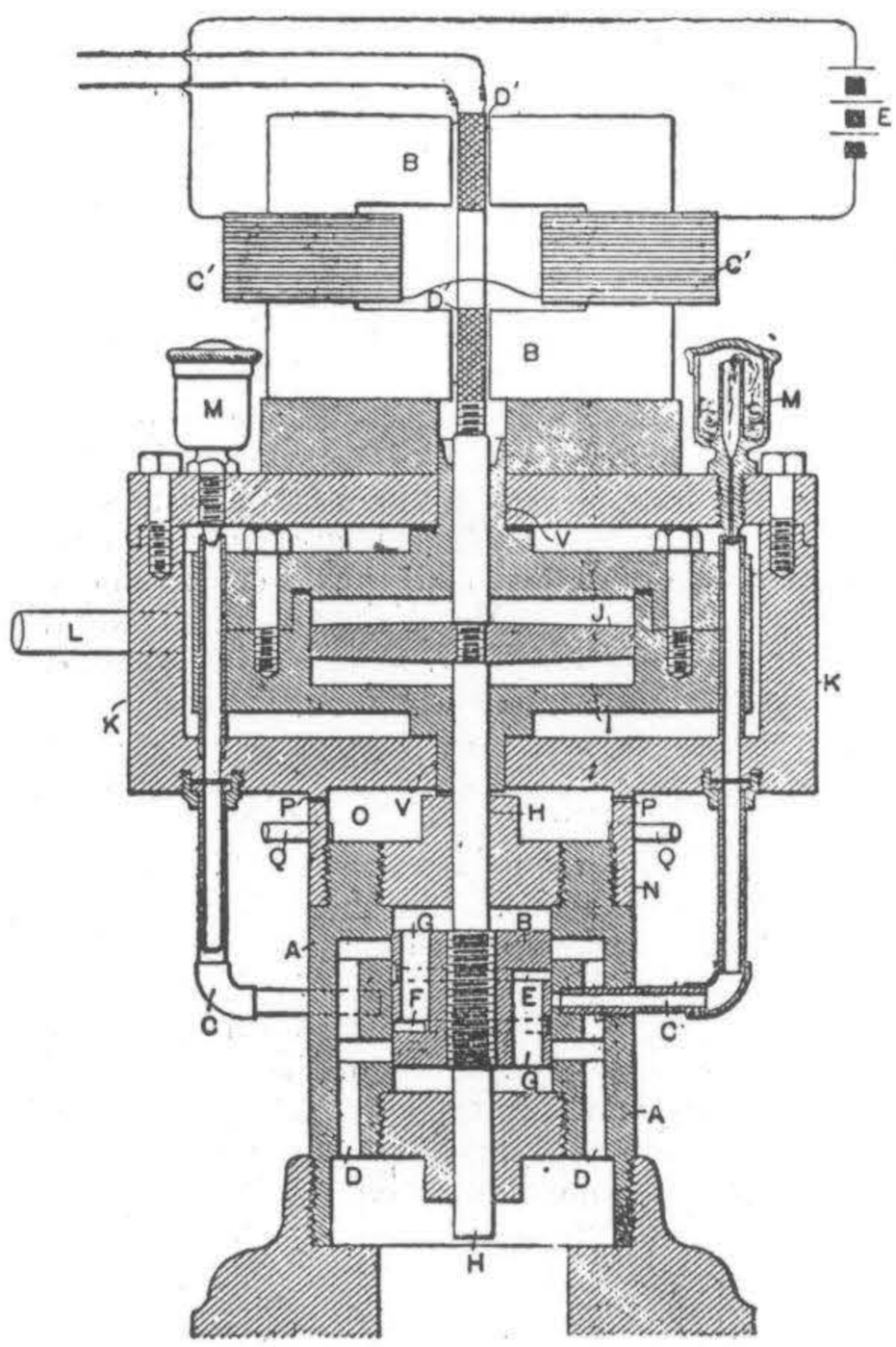


FIG. 1.

In the particular form of engine shown, the jacket, K, which contains the cylinder I is provided with a flange, N, by which it is screwed to the end of the cylinder A. A small chamber, O, is thus formed which has air-vents, P, in its sides, and drip pipes, Q, leading out from it through which the oil which collects in it is carried off. In the position of the parts shown, or when the piston is at the middle point of its stroke, the plunger, J, is at the centre of the cylinder I, and the air on both sides of the same is at the normal pressure of the outside atmosphere. If a source of steam or compressed air be then connected to the inlet ports, C C, of the cylinder A, and a movement be imparted to the piston as by a sudden blow, the latter begins to reciprocate in the well-known way. The movements of the piston compress and rarefy the air in the cylinder I at opposite ends, alternately. A forward stroke compresses the air ahead of the plunger, J, which acts as a spring to return it; similarly, on the back stroke the air is compressed on the opposite side of the plunger, J, and tends to drive it forward. The compressions of the air in the cylinder, I, and the consequent loss of energy due mainly to the imperfect elasticity of the air, gave rise to a very considerable amount of heat. This heat is utilised by conducting the steam or com-

pressed air to the engine cylinder through the chamber formed by the jacket surrounding the air-spring cylinder, the heat thus taken up and used to raise the temperature of the steam or air acting upon the piston is availed of to increase the efficiency of the engine.

In any given engine of this kind the normal pressure will produce a stroke of determined length, and this will be increased or diminished according to the increase of pressure above, or the reduction of pressure below, the normal. In constructing the apparatus proper allowance is made for a variation in the length of stroke by giving to the confining cylinder, I, of the air spring properly determined dimensions. The greater the pressure upon the piston, the higher will be the degree of compression of the air spring, and the consequent counteracting force upon the plunger. The rate or period of reciprocation of the piston, however, is mainly determined by the rigidity of the air spring and the inertia of the moving system, and any period of oscillation within very wide limits may be secured by properly portioning these factors, as by varying

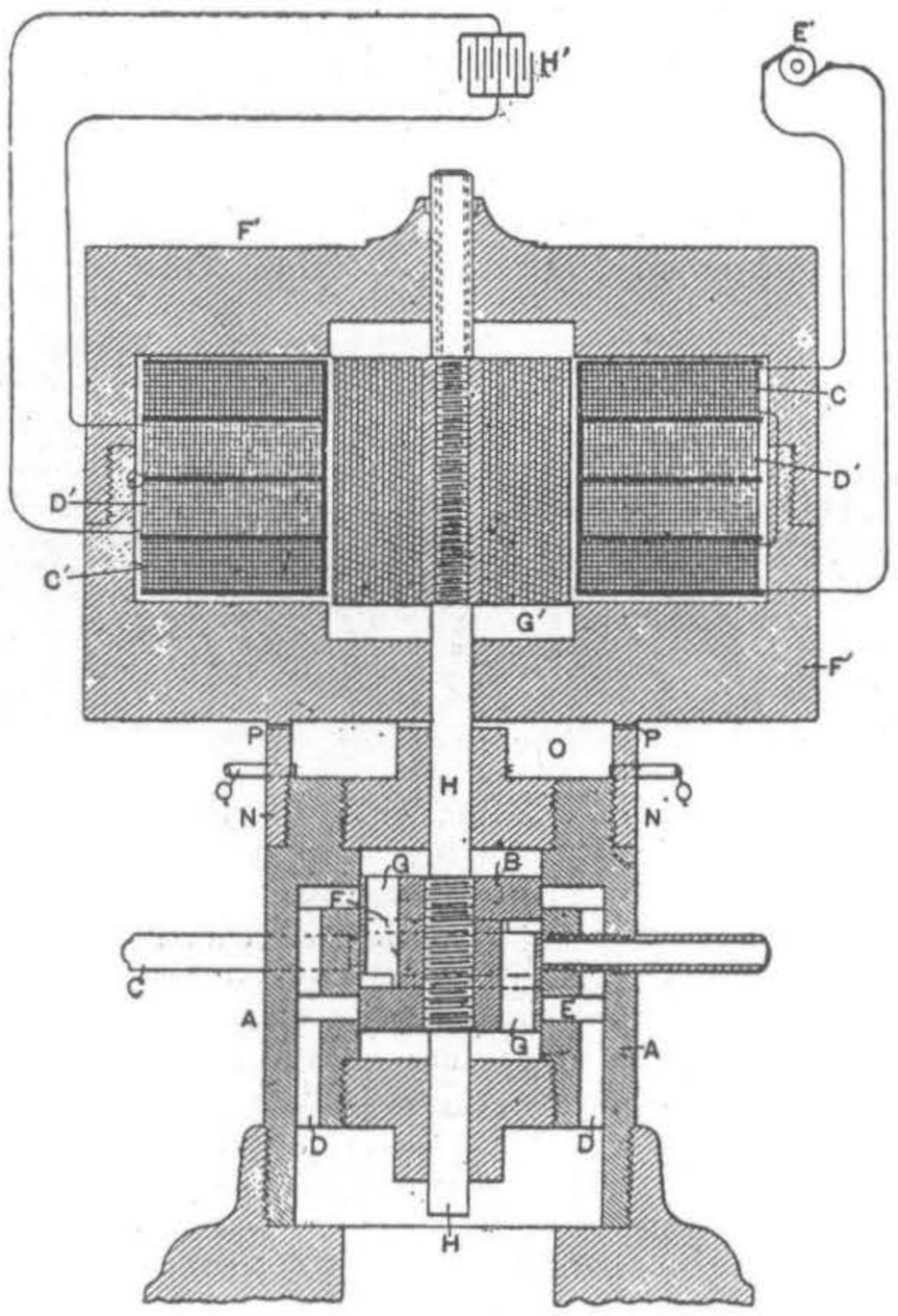


FIG. 2.

the dimensions of the air-chamber, which is equivalent to varying the rigidity of the spring, or by adjusting the weight of the moving parts. These conditions are all readily determinable, and an engine constructed as above described maintains a perfectly uniform period through very wide limits of pressure. The pressure of the air confined in the cylinder when the plunger, I, is in its central position will always be practically that of the surrounding atmosphere, for while the cylinder is so constructed as not to permit such sudden escape of air as to sensibly impair or modify the action of the air spring there will still be a slow leakage of air into or out of it around the piston-rod according to the pressure therein, so that the pressure of air on opposite sides of the plunger will always tend to remain at that of the outside atmosphere. To the piston-rod, H, is secured a coil, D', which, by the movements of the piston, is oscillated in the magnetic field produced by two magnets, B' B', which may be permanent magnets or energised by coils, C' C', connected with a source of continuous current, E'. The movement of the coil D' across the lines of force established by the magnets gives rise to alternating currents in the coil. These currents, if the period of mechanical oscillation be constant, will be of constant period. In the case under consideration it is assumed as a necessary condition that the inertia of the movable element of the generator and the electro magnetic reaction which it exerts will not be of such a character as to materially disturb the action of the engine.

Fig. 2 is an example of a combination in which the engine is not of itself capable of determining entirely the period of oscillation, but in which the generator contributes to this end. In this figure the engine is the same as that shown in Fig. 1. The exterior air spring is, however, omitted, and the air-spaces at the ends of the cylinder, A, relied on for accomplishing the same purpose. As the pressure in these spaces is liable to variations from variations in the steam or gas used in impelling the piston they might affect the period of oscillations, and the conditions are not as stable and certain as in the case of an engine constructed as in Fig. 1. But if the natural period of vibration of the elastic system be made to approximately accord with the average period of the engine, such tendencies to variation are very largely overcome, and the engine will preserve its period even through a considerable range of variation of pressure. The generator in this case is composed of a magnetic casing, F', in which a laminated core, G', secured to the piston-rod, H, is caused to vibrate. Surrounding the plunger are two exciting coils, C' C', and one or more induced coils, D' D'. The coils C' C' are connected with a generator of continuous currents, E', and are wound to produce consequent poles in the core, G'. Any movement of the latter will therefore shift the lines of force through coils D' D', and produce currents therein. In the circuit of coils D' is shown a condenser, H'. By the use of a proper condenser the self-induction of this circuit may be neutralised. Such a circuit will have a certain natural period of vibration, and, as this depends upon the capacity and self-induction, the period may be varied to approximately accord with the period of the engine.

In case the power of the engine be comparatively small, as when the pressure is applied through a very small fraction of the total stroke, the electrical vibration will tend to control the period, and it is clear that if the character of such vibration be not very widely different from the average period of vibration of the engine under ordinary working conditions, that such control may be entirely adequate to produce the desired results.

THE TESLA ELECTRICAL OSCILLATOR.

WE are indebted to the editors of the *Electrical Engineer*, of New York, for an advance proof of the following article :—

In the lecture delivered before the Chicago Electrical Congress, Mr. Nikola Tesla first drew attention * to the method and means which he had devised for the continuous production of alternating currents of constant period and in which all rotating parts are avoided by the employment of his oscillating engine directly to the movement of the generating coil in the magnetic field.

The main reason why no engine heretofore has been capable of producing results of this nature, is that it has been customary to connect with the reciprocating parts a heavy fly-wheel, or some equivalent rotary system of relatively very great inertia, or in other cases where no rotary system was employed, as in certain reciprocating engines or tools, no regard has been paid to the obtainment of the conditions essential to the end which Mr. Tesla had in view.

In applying the Tesla oscillator for the generation of currents of constant period, certain conditions are encountered which must be taken into consideration in order to satisfactorily secure the desired result. When a conductor is moved in a magnetic field and a current caused to circulate therein, the electro-magnetic reaction between it and the field might disturb the mechanical oscillation to such an extent as to throw it out of isochronism. This, for instance, might occur when the electro-magnetic reaction is very great in comparison to the power of the engine, and there is a retardation of the current so that the electro-magnetic reaction might have an effect similar to that which would result from a variation of the tension of the spring, but if the circuit of the generator be adjusted so that the phases of the electromotive force and current coincide in time, that is to say, when the current is not retarded, then the generator driven by the engine acts merely as a fractional resistance and will not, as a

* See the New York *Electrical Engineer*, August 30th, 1893; and the ELECTRICAL REVIEW, December 29th, 1893.

rule, alter the period of the mechanical vibration, although it may its amplitude. This condition may be readily secured by properly proportioning the self-induction and capacity of the circuit, including the generator.

Mr. Tesla, has however, observed the further fact in connection with the use of such engines as a means for running a generator, that it is advantageous that the period of the engine and the natural period of electrical vibration of the generator should be the same, as in such case the best conditions for electrical resonance are established and the possibility of disturbing the period of mechanical vibrations is reduced to a minimum. Mr. Tesla has found that even if the theoretical conditions necessary for maintaining a constant period in the engine itself are not exactly maintained, still the engine and generator combined will vibrate at a constant period. For example, if instead of using in the engine an independent cylinder and plunger, as an air spring of practically constant rigidity, the piston may impinge upon air cushions at the ends of its own cylinder. Although the rigidity of such cushions or springs might be considerably affected and varied by the variations of pressure within the cylinder, still by combining with such an engine a generator which has a period of its own, approximately that of the engine, constant vibration may be maintained even through a considerable range of varying pressure, owing to the controlling action of the electro-magnetic system.

Indeed, Mr. Tesla has even found that under certain conditions the influence of the electro-magnetic system may be made so great as to entirely control the period of the mechanical vibration within wide limits of varying pressure. This is likely to occur in those instances where the power of the engine while fully capable of maintaining a vibration once started, is not sufficient to change its rate.

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Referring to fig. 1, A is the main cylinder in which works a piston, B. Inlet ports, C, C, pass through the sides of the cylinder opening at the middle and on opposite sides. Exhaust ports, D, D, extend through the walls of the cylinder and are formed with branches that open into the interior of the cylinder on each side of the inlet ports and on opposite sides of the cylinder. The piston, B, has two circumferential grooves, E, F, which communicate through openings, G, in the piston with the cylinder on opposite sides of the piston respectively.

The particular construction of the cylinder, the piston and the ports controlling it, may be very much varied, and is not in itself material, except that in the special case under consideration it is desirable that all the ports, and more especially the exhaust ports, should be made very much larger than is usually the case, so that no force due to the action of the steam or compressed air will tend to retard or affect the return of the piston in either direction.

The piston, B, is secured to a piston rod, H, which works in suitable stuffing boxes in the heads of the cylinder, A. This rod is prolonged on one side and extends through bearing, V, in a cylinder, I, mounted in line with the first, and within

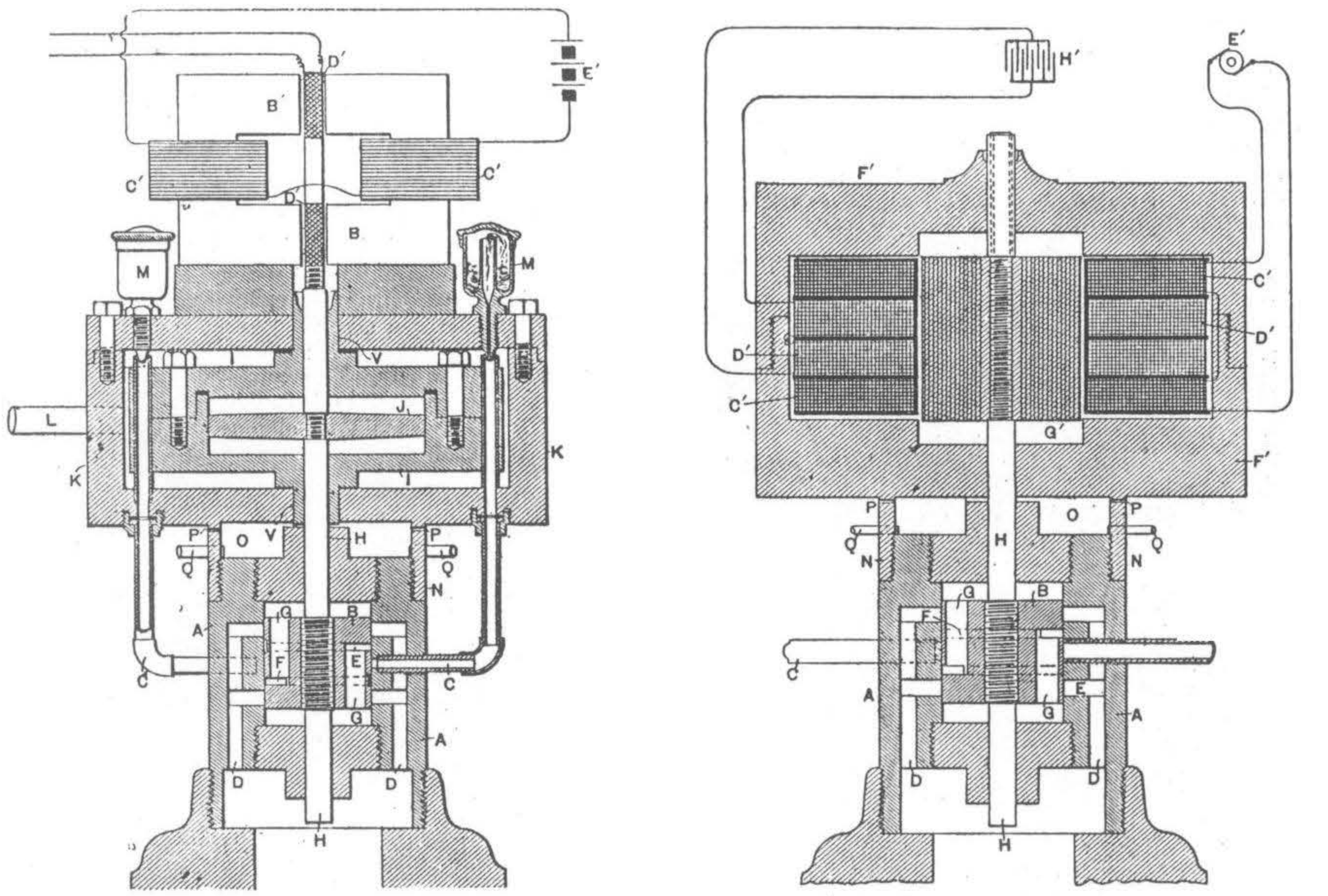

FIG. 1.

which is a disc or plunger, J, carried by the rod, H. The cylinder, I, is without parts of any kind and is airtight, except as a small leakage may occur through the bearings, V, which experience has shown need not be fitted with any very considerable accuracy.

The cylinder, I, is surrounded by a jacket, K, which leaves an open space or chamber around it. The bearings, V, in the cylinder, extend through the jacket to the outside air and the chamber between the cylinder and jacket is made steam or airtight by a suitable packing. The main supply pipe, L, for steam or compressed air leads into this chamber, and the two pipes that lead to cylinder, A, run from this chamber, oil cups, M, being conveniently arranged to deliver oil into the pipes for lubricating the piston.

In the particular form of engine shown, the jacket, K, which contains the cylinder, I, is provided with a flange, N, by which it is screwed to the end of the cylinder, A. A small chamber, O, is thus formed which has air vents, P, in its sides, and drip pipes, Q, leading out from it, through which the oil which collects in it is carried off.

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The movements of the piston compress and rarefy the air in the cylinder, I, at opposite ends, alternately. A forward stroke compresses the air ahead of the plunger, J, which acts as a spring to return it; similarly, on the back stroke the air is compressed on the opposite side of the plunger, J, and tends to drive it forward.

The compressions of the air in the cylinder, I, and the consequent loss of energy, due mainly to the imperfect elasticity of the air, give rise to a very considerable amount of heat. This heat is utilised by conducting the steam or compressed air to the engine cylinder through the chamber formed by the jacket surrounding the air-spring cylinder; the heat thus taken up and used to raise the temperature of the steam or air acting upon the piston is availed of to increase the efficiency of the engine.

In any given engine of this kind the normal pressure will produce a stroke of determined length, and this will be increased or diminished according to the increase of pressure above, or the reduction of pressure below, the normal. In constructing the apparatus, proper allowance is made for a variation in the length of stroke by giving to the confining cylinder, I, of the air-spring properly determined dimensions. The greater the pressure upon the piston, the higher will be the degree of compression of the air-spring, and the consequent counteracting force upon the plunger.

The rate or period of reciprocation of the piston, however, is mainly determined by the rigidity of the air spring and the inertia of the moving system, and any period of oscillation within very wide limits may be secured by properly portioning these factors, as by varying the dimensions of the air chamber, which is equivalent to varying the rigidity of the spring, or by adjusting the weight of the moving parts. These conditions are all readily determinable, and an engine constructed as above described maintains a perfectly uniform period through very wide limits of pressure.

The pressure of the air confined in the cylinder when the plunger, I, is in its central position, will always be practically that of the surrounding atmosphere, for while the cylinder is so constructed as not to permit such sudden escape of air as to sensibly impair or modify the action of the air spring, there will still be a slow leakage of air into or out of it around the piston rod according to the pressure therein, so that the pressure of the air on opposite sides of the plunger will always tend to remain at that of the outside atmosphere.

To the piston rod, H, is secured a coil, D′, which, by the movements of the piston, is oscillated in the magnetic field produced by two magnets, B′, B′, which may be permanent magnets or energised by coils, C′, C′, connected with a source of continuous current, E′. The movement of the coil, D′ across the lines of force established by the magnets gives rise to alternating currents in the coil. These currents, if the period of mechanical oscillation be constant, will be of constant period.

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The generator in this case is composed of a magnetic casing, F′, in which a laminated core, G′, secured to the piston rod, H, is caused to vibrate. Surrounding the plunger are two exciting coils, C′, C′, and one or more induced coils, D′, D′. The coils, C′, C′, are connected with a generator of continuous currents, E′, and are wound to produce consequent poles in the core, G′. Any movement of the latter will therefore shift the lines of force through coils, D′, D′, and produce currents therein.

In the circuit of coils, D′, is shown a condenser, H′. By the use of a proper condenser the self-induction of this circuit may be neutralised. Such a circuit will have a certain natural period of vibration, and, as this depends upon the capacity and self-induction, the period may be varied to approximately accord with the period of the engine.

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THERE have been, so far as we remember, only three attempts to apply simple reciprocating motion, instead of rotary movement round an axis, to the armature of a dynamo. The first of these was the "thunder-pump," a magneto device used for ringing-up in the early days of telegraphy. Perhaps this instrument ought not to be classed as a dynamo, but it was a practical success in its day. As much cannot be said for the Edison tuning-fork dynamo. Electrically, this second attempt was reasonable, but it was mechanically impossible and absurd. The third reciprocating dynamo is that of NIKOLA TESLA. This was first shown in a lecture delivered by the inventor before the Chicago Congress, and is illustrated and described elsewhere in our present issue. The account, for which we are indebted to the *Electrical Engineer* of New York does not allude to the principal object in view in designing this machine. We understand, from the reports of the lecture, that high frequency was Mr. TESLA's aim. In the *Electrical Engineer* of New York, for August 30, 1893, we find that a mass of about 20lb. was kept in vibration with a stroke of $\frac{7}{8}$in. at a frequency of about 80 per second, "but by shortening the stroke the weight could be vibrated many hundred times, and has been in other experiments." This result seems hardly sufficient to justify so complete a departure from ordinary practice, but on looking up the subject we found some more figures in the *Electrical World* of New York, for September 2, 1893. "The piston is operated by compressed air at 60lb. per square inch. . . . The compression reaches as much as 16 tons. . . . The number of oscillations used at the lecture was from 50 to 90 per second, although from 5,000 to 10,000 per second have been obtained, and as many more as desirable"!

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* Abstract from an advance proof, kindly sent by the *Electrical Engineer* of New York.

openings, G, in the piston with the cylinder on opposite sides of the piston respectively.

The particular construction of the cylinder, the piston and the ports controlling it, may be very much varied, and is not in itself material, except that in the special case under consideration it is desirable that all the ports, and more especially the exhaust ports, should be made very much larger than is usually the case so that no force due to the action of the steam or compressed air will tend to retard or affect the return of the piston in either direction.

The piston, B, is secured to a piston rod, H, which works in suitable stuffing boxes in the heads of the cylinder, A. This rod is prolonged on one side and extends through bearings V in a cylinder, I, mounted in line with the first, and within which is a disc or plunger, J, carried by the rod H. The cylinder I is without parts of any kind and is air-tight, except as a small leakage may occur through the bearings V, which experience has shown need not be fitted with any very considerable accuracy.

The cylinder I is surrounded by a jacket, K, which leaves an open space or chamber around it. The bearings V in the cylinder extend through the jacket to the outside air, and the chamber between the cylinder and the jacket is made steam or air-tight by

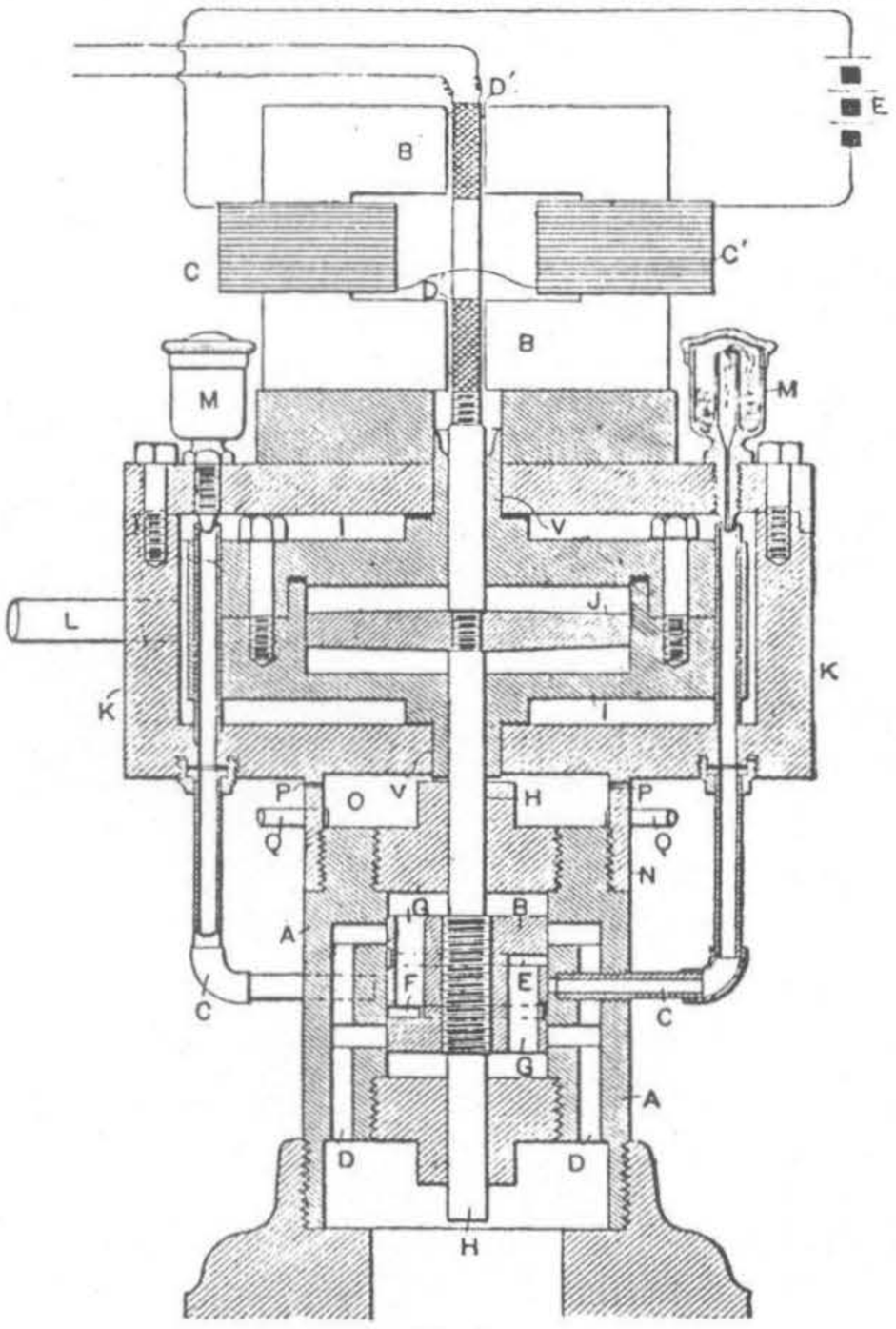


FIG. 1.

conducting the steam or compressed air to the engine cylinder through the chamber formed by the jacket surrounding the air-spring cylinder, the heat thus taken up and used to raise the temperature of the steam or air acting upon the piston is availed of to increase the efficiency of the engine.

In any given engine of this kind the normal pressure will produce a stroke of determined length, and this will be increased or diminished according to the increase of pressure above, or the reduction of pressure below, the normal. In constructing the apparatus proper allowance is made for a variation in the length of stroke by giving to the confining cylinder I of the air spring pro perly determined dimensions. The greater the pressure upon the piston the higher will be the degree of compression of the air spring, and the consequent counteracting force upon the plunger.

The rate or period of reciprocation of the piston, however, is mainly determined by the rigidity of the air spring and the inertia of the moving system, and any period of oscillation within very wide limits may be secured by properly portioning these factors, as by varying the dimensions of the air chamber, which is equivalent to varying the rigidity of the spring, or by adjusting the weight of the moving parts. These conditions are all readily

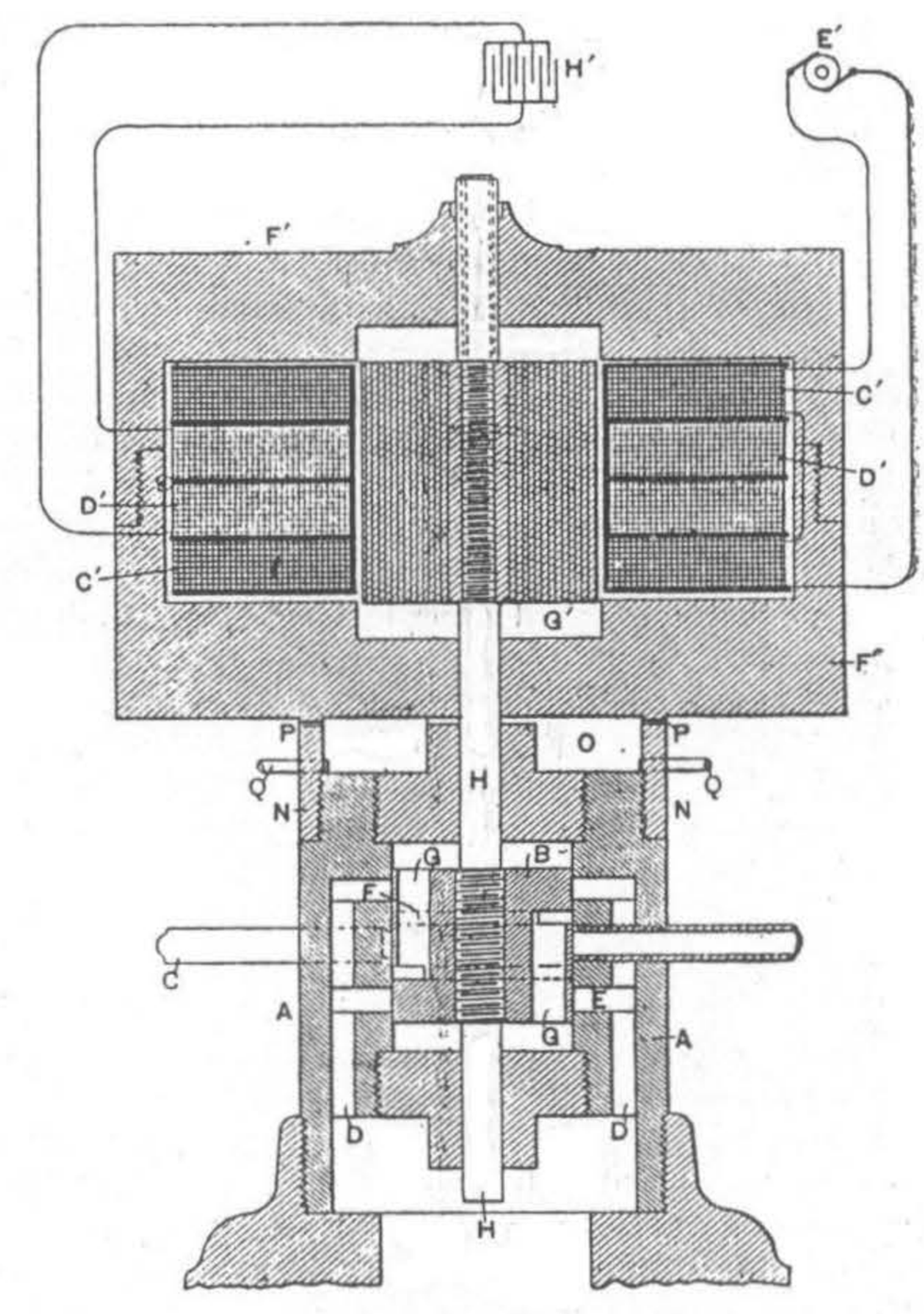


FIG. 2.

a suitable packing. The main supply pipe L, for steam or compressed air, leads into this chamber, and the two pipes that lead to cylinder A run from this chamber, oil cups M being conveniently arranged to deliver oil into the pipes for lubricating the piston.

In the particular form of engine shown, the jacket K, which contains the cylinder I is provided with a flange N, by which it is screwed to the end of the cylinder A. A small chamber O is thus formed, which has air vents, P, in its sides, and drip pipes Q leading out from it through which the oil which collects in it is carried off.

In the position of the parts shown, or when the piston is at the middle point of its stroke, the plunger J is at the centre of the cylinder I, and the air on both sides of the same is at the normal pressure of the outside atmosphere. If a source of steam or compressed air be then connected to the inlet ports C C of the cylinder A, and a movement be imparted to the piston as by a sudden blow, the latter begins to reciprocate in the well-known way.

The movements of the piston compress and rarefy the air in the cylinder I at opposite ends alternately. A forward stroke compresses the air ahead of the plunger J, which acts as a spring to return it; similarly, on the back stroke the air is compressed on the opposite side of the plunger J, and tends to drive it forward.

The compressions of the air in the cylinder I, and the consequent loss of energy due mainly to the imperfect elasticity of the air, give rise to a very considerable amount of heat. This heat is utilised by determinable, and an engine, constructed as above described, maintains a perfectly uniform period through very wide limits of pressure.

To the piston rod H is secured a coil, D', which, by the movements of the piston, is oscillated in the magnetic field produced by two magnets, B' B', which may be permanent magnets or energised by coils, C' C', connected with a source of continuous current, E'. The movement of the coil D' across the lines of force established by the magnets gives rise to alternating currents in the coil. These currents, if the period of mechanical oscillation be constant, will be of constant period.

In the case under consideration it is assumed as a necessary condition that the inertia of the movable element of the generator and the electromagnetic reaction which it exerts will not be of such a character as to materially disturb the action of the engine.

Fig. 2 is an example of a combination in which the engine is not of itself capable of determining entirely the period of oscillation, but in which the generator contributes to this end. In this figure the engine is the same as that shown in Fig. 1. The exterior air spring is, however, omitted, and the air spaces at the ends of the cylinder A relied on for accomplishing the same purpose. As the pressure in these spaces is liable to variations from variations in the steam or gas used in impelling the piston they might affect the period of oscillation, and the conditions are not as stable and cer-

tain as in the case of an engine constructed as in Fig. 1. But if the natural period of vibration of the elastic system be made to approximately accord with the average period of the engine such tendencies to variation are very largely overcome, and the engine will preserve its period even through a considerable range of variation of pressure.

The generator in this case is composed of a magnetic casing F′, in which a laminated core G′ secured to the piston rod H is caused to vibrate. Surrounding the plunger are two exciting coils, C′ C′, and one or more induced coils, D′ D′. The coils C′ C′ are connected with a generator of continuous currents, E′, and are wound to produce consequent poles in the core G′. Any movement of the latter will therefore shift the lines of force through coils D′ D′, and produce currents therein.

In the circuit of coils D′ is shown a condenser, H′. By the use of a proper condenser the self-induction of this circuit may be neutralised. Such a circuit will have a certain natural period of vibration, and as this depends upon the capacity and self-induction, the period may be varied to approximately accord with the period of the engine.

In case the power of the engine be comparatively small, as when the pressure is applied through a very small fraction of the total stroke, the electrical vibration will tend to control the period, and it is clear that if the character of such vibration be not very widely different from the average period of vibration of the engine under ordinary working conditions, that such control may be entirely adequate to produce the desired results.

After-Glow in Exhausted Bulbs.

BY H. M. MARTIN AND W. H. PALMER, JR.

Having failed to note in any communication on the subject of the phosphorescence of exhausted bulbs in a field of high potential and frequency any mention of what, for want of a better name, may be called the "after-glow," we are led to believe that a brief description of this phenomenon may be of general interest.

If an exhausted bulb having a sealed-in electrode be held in the hand and approached to a terminal of an induction coil giving moderately high potential and frequency, the whole interior of the bulb will be permeated by a phosphorescent glow; if, now, the bulb be slowly withdrawn from the field of excitation, the degree of luminosity will gradually diminish till a point is reached beyond which the intensity of the glow, now greatly attenuated, is practically unaffected by any further increase in distance from the terminal. It is this glow, entirely independent for its perpetuation of the field in which the bulb was charged, and continuing, we believe, until electrical equilibrium has been established between the rarefied gas and the electrode of the bulb, that we have called the "after-glow." That it is thus independent of the field of excitation may be proved by shutting off, after the "after-glow" has been established, the exciting current of the induction coil, when the glow will be entirely unaffected and continue, practically, for the same length of time as when the coil is in action. When the glow has become almost imperceptible it may often be stimulated into renewed life by shifting the position of the fingers on the surface of the bulb. After this has been done and the glow has again died away, a single bright flash may be obtained by touching with one finger the projecting end of the sealed-in electrode. That the hand of the experimenter is a factor in these effects may be shown by laying the glowing bulb on a table; the glow, though not extinguished, becomes very faint, especially if no object of capacity be near. The bright flash may still be obtained by again picking up the bulb and discharging as explained. We have repeatedly charged a bulb, shut off the primary current from the coil, carried the bulb to a remote part of the house, laid it on a table, and after picking it up again, obtained a flash on discharging that could be seen some yards away. Lack of apparatus has prevented us from following up these experiments, which are now some months old, but they are valuable, at least, as additional and ocular proof of the electrostatic origin of the "Tesla bulb effects."

The Electrical World's Current Technical Digest of Electrical Literature

COMPILED FROM THE PRINCIPAL FOREIGN ELECTRICAL JOURNALS.

BY CARL HERING.

Tesla's Researches.—The "Zeit. feur Elek.," Dec. 15, reprints a portion of an address by Prof. Ettingshausen, in which he gives a short description of the life and works of his countryman, Nikola Tesla.

The New York Times January 22, 1894

TESLA AND HIS RESEARCHES.

THE INVENTIONS, RESEARCHES, AND WRITINGS OF NIKOLA TESLA. With special reference to his work of Polyphase Currents and High Potential Lighting. By Thomas Commerford Martin. New-York: The Electrical Engineer.

We have not yet got at the bottom of the transmission of electrical power or of methods by means of which electrical force can be stored or distributed. But as to a motor, that may be, as Mr. Martin says, but secondary "to the radical improvement of the means and methods of illumination." Perhaps when we better appreciate the dynamo and the question is solved, we shall get to the economics of electrical lighting. To the many "who work in the domain of electrical invention, the apparatus and devices which are familiar appear cumbrous and wasteful, and subject to severe limitation." To bring this down to its simplest equation, we want a cheaper light.

Working toward this end, what has been already accomplished by Mr. Nikola Tesla is particularly worthy of attention. Mr. Tesla, having his theory by heart, has not alone inventive powers of the highest order, but possesses a practical mind. It is of no use to disparage the scientist who invents what may apparently be nothing more than an electrical toy. There are many now alive who remember when at college the electrical machine and the Leyden jar as simply sources of recreation to the Professor of Natural Sciences. No one forty years ago imagined the vast possibilities of electricity. And so it may happen that what is an electrical trick which astonishes to-day may be in the time to come of enormous practical advantage to us.

Mr. Tesla has a genius for electrical work, "with all the play and push of a vigorous and original mind." In brief biographical sketch we are told that Mr. Nikola Tesla was born in Austro-Hungary some thirty-seven years ago. He had a fair scientific education, and early devoted himself to the study of electricity and magnetism. When a school lecture was given on a dynamo, his instructor told the class that it was impossible "to operate a dynamo without commutator or brushes," and at once Mr. Tesla differed with his teacher. He had already "seen by quick intuition that a way could be found to dispense with them, and from that time he may be said to have begun work in the ideas that fructified ultimately in his rotating field motors."

His primary studies ended, Mr. Tesla found occupation at Prague and Buda-Pesth, in the Telegraph Engineering Department, and then went to Paris to enlarge his field of practical and theoretical study. In France he followed out his early idea of the rotating field principle. In coming to the United States he found his first occupation in the Edison works. To be there had been the "goal of his ambition," and for Mr. Edison Mr. Tesla always has had the strongest admiration. But the young electrician had master thoughts of his own, which required maturing. His own inventions in lighting might, too, in time be worth marketing. Mr. Tesla was right in trying to get the commercial value of his inventions, but still all through this period of earning his bread he returned unceasingly to his subject, the rotating field principle, and to-day "the application of it in motors has become known the world over."

In this volume may be found a history of the many steps taken by Mr. Tesla before arriving at his conclusions. Nothing in nature goes by jumps, and it is all wrong to believe that the man of science clears his ground at one spring. Those plodding and cautious ways which belong to true genius are essentially Mr. Tesla's. It was hard study, perhaps many failures, which led to the working out of polyphase currents.

Mr. Tesla's lectures are given here, with a description of his exhibits at Chicago. The chapter which will particularly interest those who look to a newer method of illumination, contain the lecture delivered in New-York, entitled "Experiments with Alternate Currents of Very High Frequency and Their Application to Methods of Artificial Illumination." A by no means easy task has been successfully undertaken in this volume.

THE TESLA CONDENSER-MAGNET.

In electric apparatus or systems in which alternating currents are employed, the self-induction of the coils or conductors in many cases operates disadvantageously by giving rise to false currents which often reduce the commercial efficiency of the apparatus or operate detrimentally in other respects.

The effects of such self-induction, as is well known, can be neutralized by proportioning to a proper degree the capacity of the circuit with relation to the self-induction and frequency of the currents. This has been accomplished heretofore by the use of condensers applied as separate instruments. In order to avoid the employment of condensers, which involve additional expense, Mr. Nikola Tesla has devised a method of constructing the coils themselves so as to accomplish the same object as the condensers.

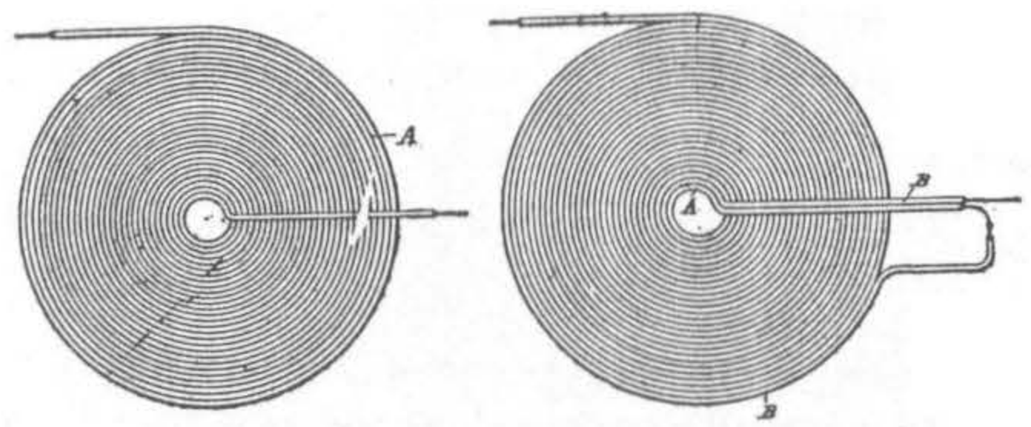
Mr. Tesla had found some years ago that in every coil there exists a certain relation between its self-induction and capacity that permits a current of given frequency and potential to pass through it with no other opposition than that of ohmic resistance, or, in other words, as though it possessed no self-induction. This is due to the mutual relations existing between the special character of the current and the self-induction and capacity of the coil, the latter quantity being just capable of neutralizing the self-induction for that frequency.

It is well known that the higher the frequency or potential difference of the current, the smaller the capacity required to counteract the self-induction; hence, in any coil, however small the capacity, it may be sufficient for the purpose stated if the proper conditions in other respects be secured. In the ordinary coils the difference of potential between adjacent turns or spires is very small, so that while they are in a sense condensers, they possess but very small capacity and the relations between the two quantities, self-induction and capacity, are not such as under any ordinary conditions satisfy the requirements contemplated by Mr. Tesla, because the capacity relatively to the self-induction is very small.

In order to attain his object and to properly increase the capacity of any given coil, Mr. Tesla winds it in such a way as to secure a greater difference of potential between its adjacent turns, and since the energy stored in the coil —considering the latter as a condenser—is proportional to the square of the potential difference between its adjacent convolutions, it is evident that in this way he may secure, by a proper disposition of these convolutions, a greatly increased capacity for a given increase in potential difference between the turns. The accompanying drawings show the general nature of the plan which he has adopted for carrying out this idea.

Fig. 1 is a diagram of a coil wound in the ordinary manner, while Fig. 2 shows the winding designed to secure the objects Mr. Tesla is aiming at.

In Fig. 1, A designates any coil the convolutions of which are wound insulated in the usual way. Let it be assumed that the terminals of this coil show a potential difference of 100 volts, and that there are 1,000 convolutions; then considering any two contiguous points on



FIGS. 1 AND 2.—THE TESLA CONDENSER-MAGNET.

adjacent convolutions let it be assumed that there will exist between them a potential difference of one-tenth of a volt.

If now, as shown in Fig. 2, a conductor B be wound parallel with the conductor A and insulated from it, and the end of A be connected with the starting point of B, the aggregate length of the two conductors being such that the assumed number of convolutions or turns is the same, viz., 1,000, then the potential difference between any two adjacent points in A and B will be 50 volts, and as the capacity effect is proportional to the square of this difference, the energy stored in the coil as a whole will now be 250,000 times as great.

Based on this principle, any given coil may be wound either in whole or in part, not only in the exact manner illustrated, but in a great variety of ways, so as to secure between adjacent convolutions such potential difference as will give the proper capacity to neutralize the self-induction for any given current that may be employed. Capacity secured in this particular way possesses an additional advantage in that it is evenly distributed, a consideration of the greatest importance in many cases, and the results both as to efficiency and economy are more readily and easily obtained as the size of the coils, the potential difference, or frequency of the currents are increased.

THE TROLLEY AND INSURANCE.

THE New York Board of Fire Underwriters' special committee on electrical hazards called upon Mayor Gilroy recently and protested against the introduction of the trolley upon Manhattan Island, also warning the Mayor that if the trolley was introduced the inevitable result would be an increase in fire insurance rates.

Century Magazine February 1894

NIKOLA TESLA.

SERVIAN poetry has so distinct a charm that Goethe is said to have learned the musical tongue in which it is written rather than lose any of its native beauty. History does not record, however, any similar instance in which the Servian language, though it be that of Boskovich, expounder of the atomic theory, has been studied for the sake of the scientific secrets that might lurk therein. The vivid imagination and ready fancy of the people have been literary in their manifestation and fruit. A great Slav orator has publicly reproached his one hundred and twenty million fellows in Eastern Europe with their utter inability to invent even a mouse-trap. They were all mere barren idealists. If this were true, to equalize matters, we might perhaps barter without loss some score of ordinary American patentees for a single singer of Illyrian love-songs. But racial conditions are hardly to be offset on any terms that do not leave genius its freedom, and once in a while Nature herself rights things by producing a man whose transcendent merit compensates his nation for the very defects to which it has long been sensitive. It does not follow that such a man shall remain in a confessedly unfavorable environment. Genius is its own passport, and has always been ready to change habitats until the natural one is found. Thus it is, perchance, that while some of our artists are impelled to set up their easels in Paris or Rome, many Europeans of mark in the fields of science and research are no less apt to adopt our nationality, of free choice. They are, indeed, Americans born in exile, and seek this country instinctively as their home, needing in reality no papers of naturalization. It was thus that we welcomed Agassiz, Ericsson, and Graham Bell. In like manner Nikola Tesla, the young Servian inventor with whose work a new age in electricity is beginning, now dwells among us in New York.

Mr. Tesla's career not only touches the two extremes of European civilization, east and west, in a very interesting way, but suggests an inquiry into the essential likeness between poet and inventor. He comes of an old Servian family whose members for centuries have kept watch and ward along the Turkish frontier, and whose blood was freely shed that our western vanguard might gain time for its advance upon these shores. Yet, remote as such people and conditions are to us, it is with apparatus based on ideas and principles originating among them that the energy from Niagara Falls is to be widely distributed by electricity, in the various forms of light, heat, and power. This, in itself, would seem enough to confer fame, but Mr. Tesla has done, and will do, much else. Could he be tamed to habits of moderation in work, it would be difficult to set limit to the solutions he might give us, through ripening years, of many deep problems; but when a man springs from a people who have a hundred words for knife and only one for bread, it is a little unreasonable to urge him to be careful even of his own life. Thirty-six years make a brief span, but when an inventor believes that creative fertility is restricted to the term of youth, it is no wonder that night and day witness his anxious activity, as of a relentless volcano, and that ideas well up like hot lava — till the crater be suddenly exhausted and hushed.

A Slav of the Slavs, with racial characteristics strongly stamped in look, speech, and action, Mr. Tesla is a notable exemplification of the outcropping in unwonted form of tendencies suppressed. I have never heard him speak of a picture or a piece of music, but his numerous inventions, and the noble lectures that embody his famous investigations with currents of high frequency and high potential, betray the poetic temperament throughout. One would expect the line separating fact from theory to fade at the altitudes of thought to which his later speculations reach; but this lithe, spare mountaineer is accustomed to the thin, dry air, and neither loses sharpness of sight nor breathes painfully. Has the Servian poet become inventor, or is the inventor a poet? Mr. Tesla has been held a visionary, deceived by the flash of casual shooting stars; but the growing conviction of his professional brethren is that because he saw farther he saw first the low lights flickering on tangible new continents of science. The perceptive and imaginative qualities of the mind are not often equally marked in the same man of genius. Overplus of imagination may argue dimness of perception; an ability to dream dreams may imply a want of skill in improving reapers. Now and then the two elements combine in the creative poet of epic and drama; occasionally they give us the prolific inventor like Tesla.

Jules Breton has spoken of the history of his life as being at the same time the genesis of his art. This is true of Nikola Tesla's evolution. His bent toward invention we may surely trace to his mother, who, as the wife of an eloquent

clergyman in the Greek Church, made looms and churns for a pastoral household while her husband preached. Tesla's electrical work started when, as a boy in the Polytechnic School at Gratz, he first saw a direct-current Gramme machine, and was told that the commutator was a vital and necessary feature in all such apparatus. His intuitive judgment or latent spirit of invention at once challenged the statement of his instructor, and that moment began the process of reasoning and experiment which led him to his discovery of the rotating magnetic field, and to the practical polyphase motors, in which the commutator and brushes, fruitful and endless source of trouble, are absolutely done away with. These perfected inventions did not come at once; they never do. The conditions that surrounded this youth in the airy fastnesses of the Dinaric Alps all made against the hopes he nursed of becoming an electrician; and not the least impediment was the fond wish of his parents at Smiljan Lika that he should maintain the priestly tradition, and benefit by the preferment likely to come through his uncle, now Metropolitan in Bosnia. But Tesla felt himself destined to serve at other altars than those of his ancient faith, with other means of approach to the invisible and unknown. He persevered in mathematical and mechanical studies, mastered incidentally half a dozen languages, and at last became an assistant in the Government Telegraph Engineering Department at Buda-Pest. His salary was small enough to please those who hold that the best endowment of genius is poverty, and he would make no appeals to his widowed mother for help. Experimenting, of course, went on all the time; at this juncture it was on telephony that he wasted his meager substance in riotous invention. Desirous of going to a fête with some friends, and anxious not to spend on clothes the money that might buy magnets and batteries, the brilliant idea occurred to him to turn his only pair of trousers inside out and to disport in them on the morrow as new. He sat up all night tailoring, but the fête came and went before he could reappear in public. This episode is quite in keeping with his boyish efforts to fly from the steep roof of the house at Smiljan, using an old umbrella as aërostat; or with the peculiar tests, stopped by the family doctor before the results could be determined, as to how long he could suspend the beating of his heart by will power.

Naturally enough for a young inventor seeking larger opportunity, Tesla soon drifted westward from Buda-Pest. He made his way to Paris, where he quickly secured employment in electric lighting, then a new art, and encountered an observant associate of Mr. Edison. Almost before he knew it, he was on his glad voyage across the Atlantic to work in one of the Edison shops, and to enter upon a new stage of development. He had profound faith in the value of the principles first meditated in the silence of the sterile mountains that border the Adriatic, and he knew that in a country where every new invention in electricity has its chance, his turn would come also, for he now had demonstrated his theories in actual apparatus.

If anything were needed to confirm Mr. Tesla in his hopes and enthusiasm, it would have been the close relation that he was thus thrown into with the robust, compelling genius who has created so many new things in electricity. Emerson has said that steam is half an Englishman; may we not, in view of what such men as Edison have done, add that electricity is half an American? The fiery zeal with which this young recruit flung himself on the most exacting tasks matched that of his chief. It went the length of a daily breakfast of Welsh rabbit, for weeks Mr. Tesla accepting as true, in spite of protesting stomach, the jocular suggestion that it was thus that his hero fortified himself successfully for renewed effort after their long vigils of toil. Mr. Edison, like most other people, had some difficulty in finding anywhere within the pale of civilization, as marked by the boundaries of maps, the isolated region of Mr. Tesla's birth, and once inquired seriously of his neophyte whether he had ever tasted human flesh. It was inevitable that a really delightful intimacy and apprenticeship should end. Even the most cometic genius has its orbit, and these two men are singularly representative of different kinds of training, different methods, and different aims. Mr. Tesla must needs draw apart; and stimulated by this powerful spirit, he went on his own way for his own work's sake.

Of late years a sharp controversy has raged in the electrical field as to the respective advantages of the continuous and the alternating current for light and power. In bitterness and frequent descent to personalities it has resembled the polemics of the old metaphysical schoolmen, and uninstructed, plain folk have mildly wondered whether it was really worth while to indulge in such terrible threatenings and slaughter over purely speculative topics. There is, however, a very practical aspect to the discussion, and from the first Mr. Tesla has been an advocate of the alternating current, not because he loved the direct current less, but because he knew that with the alternating he could achieve results otherwise impossible, especially in power transmission. Furthermore, all direct-current generators and motors have required commutators and brushes, but Mr. Tesla, who has himself perfected many inventions based on direct currents, has shown that with the ap-

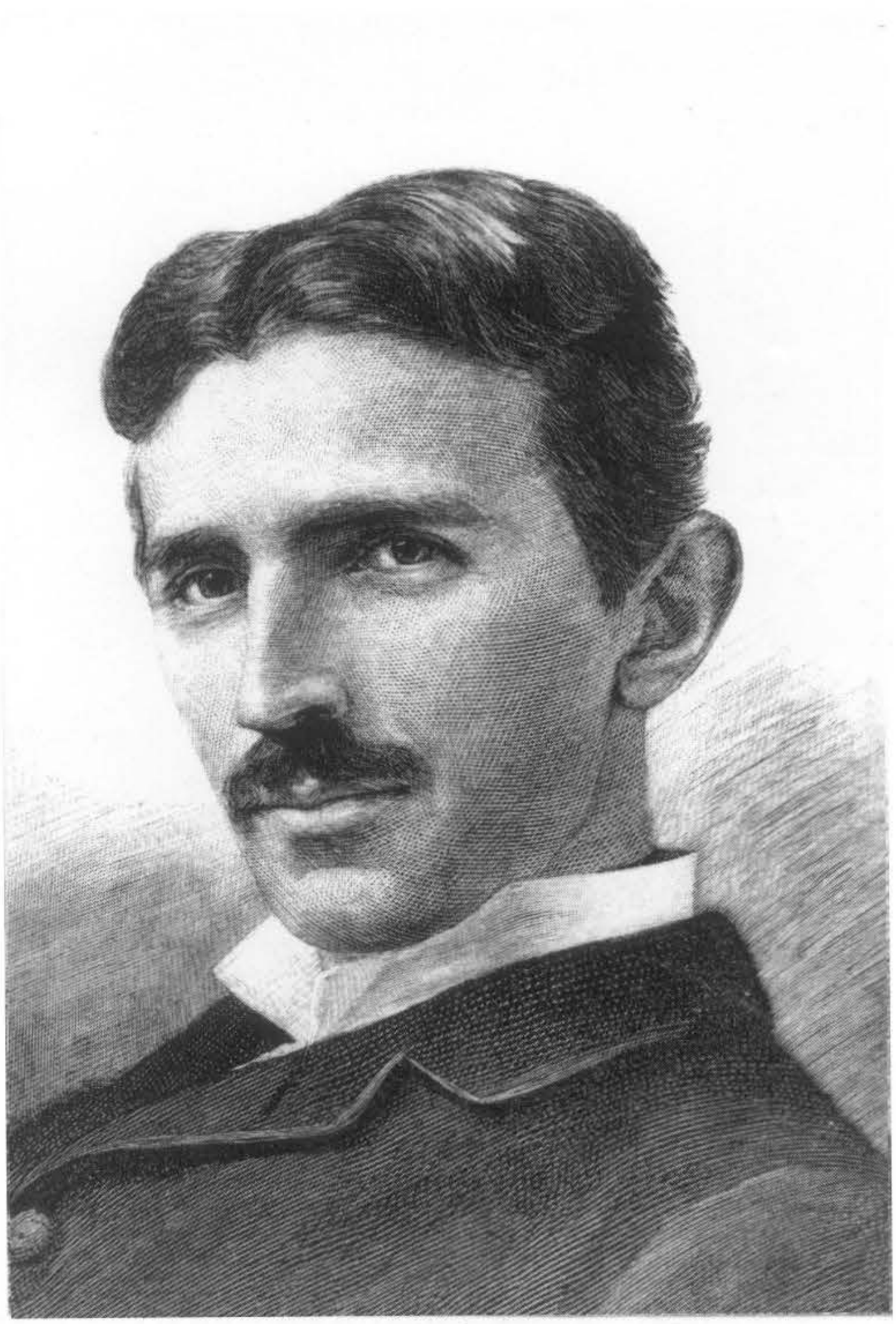
plication of the rotating-field principle these elements of complication and restriction were no longer needed. This utilization of polyphase currents was a most distinct advance, made a deep imprint on the electric arts, and has been duly signalized. In America the invention found immediate sale. From Italy came an insistent cry of priority, reminding one of the "anticipations" that have clustered thick around the telegraph, the telephone, and the incandescent lamp. In Germany, with money raised by popular and imperial subscription, apparatus on the polyphase principle was built by which large powers were transmitted electrically more than a hundred miles from Neckar-on-the Rhine to Frankfort-on-the-Main; and now by equivalent agency Niagara is to drive the wheels of Buffalo and beyond.

So thoroughly has Mr. Tesla worked out his discovery of the rotating magnetic field, or "resultant attraction," that the record of his inventions contains no fewer than twenty-four chapters on varying forms of his polyphase-current apparatus and arrangements of circuit. But ever pursuing new researches, Mr. Tesla, after the enunciation of these fundamental ideas, next brought to notice his series of even more interesting investigations on several novel groups of phenomena produced with currents of high potential and high frequency. To familiarize the American public with some of his results, he lectured upon them at Columbia College, before the American Institute of Electrical Engineers, in May, 1891. The year following, with riper results to publish, and by special invitation, he lectured twice in England, appearing before the Institution of Electrical Engineers, a distinguished scientific body of which Professor Crookes was then president, and, later, at the Royal Institution, where the immortal Faraday lived and labored. From England he was called to France to repeat his demonstrations before the Société Internationale des Electriciens and the Société Française de Physique. In Germany he received the greetings of Hertz and Von Helmholtz, and from his own country came the Order of Saint Sava, conferred by the king. Since his return to this country he has lectured before the Franklin Institute at Philadelphia and the National Electric Light Association at St. Louis. But he has an intense dislike to the platform, and has returned to his laboratory with a remorseful sense of neglected work from which long months of abandonment to unremitting research will not free him.

I can only outline the vast range of the researches that these lectures, and the apparatus connected with the demonstrations, cover. Broadly stated, Mr. Tesla has advanced the opinion, and sustained it by brilliant experiments of startling beauty and grandeur, that light and heat are produced by electrostatic forces acting between charged molecules or atoms. Perfecting a generator that would give him currents of several thousand alternations per second, and inventing his disruptive discharge coil, he has created electrostatic conditions that have already modified not a few of the accepted notions about electricity. It has been supposed that ordinary currents of one or two thousand volts' potential would surely kill, but Mr. Tesla has been seen receiving through his hands currents at a potential of more than 200,000 volts, vibrating a million times per second, and manifesting themselves in dazzling streams of light. This is not a mere *tour de force*, but illustrates the principle that while currents of lower frequency destroy life, these are harmless. After such a striking test, which, by the way, no one has displayed a hurried inclination to repeat, Mr. Tesla's body and clothing have continued for some time to emit fine glimmers or halos of splintered light. In fact, an actual flame is produced by this agitation of electrostatically charged molecules, and the curious spectacle can be seen of puissant, white, ethereal flames, that do not consume anything, bursting from the ends of an induction coil as though it were the bush on holy ground. With such vibrations as can be maintained by a potential of 3,000,000 volts, Mr. Tesla expects some day to envelop himself in a complete sheet of lambent fire that will leave him quite uninjured. Such currents as he now uses would, he says, keep a naked man warm at the North Pole, and their use in therapeutics is but one of the practical possibilities that has been taken up.

Utilizing similar currents and mechanism, Mr. Tesla has demonstrated the fact that electric lamps and motors can not only be made to operate on one wire, instead of using a second wire on the ground to complete the circuit, but that we can operate them even by omitting the circuit. Our Subway Boards are to find their wires and occupations gone. Electric vibrations set up at any point of the earth may by resonance at any other spot serve for the transmission of either intelligence or power. With these impulses or wave discharges, Mr. Tesla also opens up an entirely new field of electric lighting. His lamps have no filaments as ordinarily known, but contain a straight fiber, a refractory button, or nothing but a gas. Tubes or bulbs of this kind, in which the imprisoned ether or air beats the crystal walls, when carried into the area or room through which these unsuspected currents are silently vibrating, burst into sudden light. If coated inwardly with phosphorescent substances, they glow in all the splendors of the sunset and the aurora.

These are only a scant handful of ideas and



PHOTOGRAPHED BY SARONY. ENGRAVED BY T. JOHNSON.

NIKOLA TESLA.

discoveries from the rich mint of Mr. Tesla's laboratory, where alone, secluded, intimates or assistants shut out, he reasons from cause to effect; and with severe, patient diligence not only elaborates his theories, but tries them by the rack and thumbscrew of experiment. He is of all men most dissatisfied with things as they are in his own field of work. Recently, the high-frequency generators with which he has done so much of this advanced work have been laid aside in discontent for an oscillator, which he thinks may not only replace the steam-engine with its ponderous fly-wheels and governors, but embodies the simplest possible form of efficient mechanical generator of electricity. He may be wrong, but misdirection will only suggest new avenues to the goal.

Mr. Tesla has often been urged to assume domestic ties, settle down, and till some corner of the new domain. But shall he farm or explore? Soon enough the proprietary fences will be set up; soon enough will the dusty, beaten highway, dotted with milestones and finger-posts, run straight ahead. If we would, we cannot leash the pioneers whose yearnings are for inner Nature, whose sense is keenest to her faint voices and odors, the quest of which lures onward through the trackless woods.

Thomas Commerford Martin.

TESLA MOTORS OPERATED FROM SINGLE PHASE TWO-WIRE ALTERNATING CIRCUITS.

THE reader who has followed up the line of work in which Mr. Tesla has been recently engaged will, no doubt, be interested to hear of some results which form the subject of two patents recently granted to him. The New York *Electrical Review*

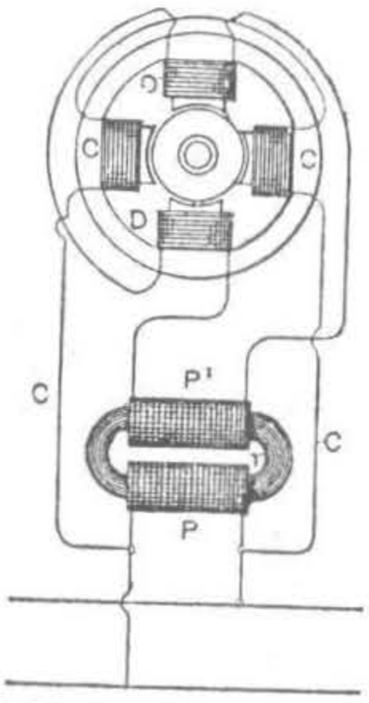


FIG. 1.—Tesla Motor with Two Energising Circuits.

says:—As early as 1888 a paper was read before the American Institute of Electrical Engineers, in which Mr. Tesla first publicly described his new multiphase system of operating alternating current motors. As an outgrowth of this, results have been obtained by others working in the same direction, and valuable and interesting have been the observations and practical devices obtained. In the system above mentioned, each motor is supplied with two or more energising circuits, through

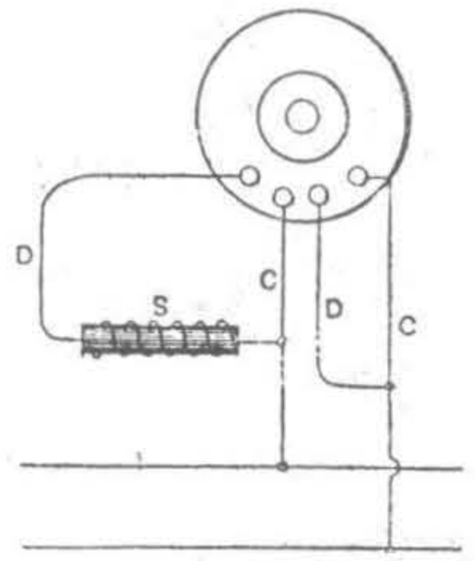


FIG. 2.—Tesla Motor with Self-Induction Coil.

which are passed alternating currents, having in each circuit such a difference of phase, that by their combined or resultant action they produce a rotary progression of the poles or points of maximum magnetic effect of the motor, and thereby maintain the rotation of the armature. Three wires are necessary in a system of this kind, but in order to avoid this Mr. Tesla set to work to devise a means whereby the phase motors could be operated from the ordinary single phase alternating circuit by creating a difference of phase locally at and in the motor. The patents below referred to had this object in view, and it will be noticed that

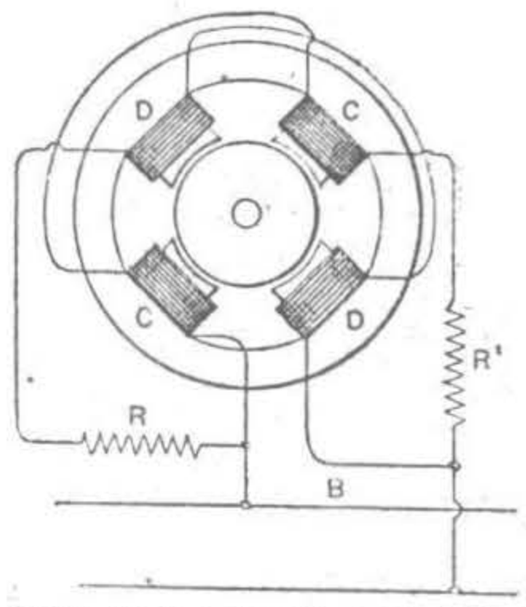


FIG. 3.—Tesla Motor with Two Dead Resistances.

the fundamental idea involved is to pass a single alternating current through both of the energising circuits of the motor, and to retard the phase of the current in one circuit to a greater or less extent than in the other, either by induction or by derivation, is the distribution of current between the two motor circuits.

The diagram, Fig. 1, shows a motor with two energising circuits, C and D. One of these circuits, C, is connected directly with the line circuit, while the other set of coils, D, is connected up in the secondary circuit of a transformer, T. The primary coil P of this transformer is connected to the line circuit. The alternations of current in the line tend

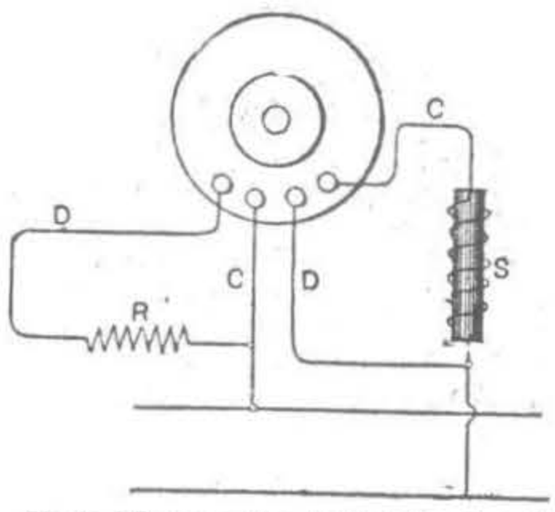


FIG. 4.—Tesla Motor with Self-Induction Coil and Dead Resistance.

to establish in their passage through the coils C a polarity opposed to that set up in the coils D, and if the currents in the two sets of coils accorded in their phases, no rotary effect would be produced. But the secondary current developed in the coil P^1 of the transformer will lag behind that in the primary, which lag may be increased to a sufficient extent to practically obtain the same result as

though two independent currents were used to energise the motor.

In another form, shown in Fig. 2, the arrangement of the parts is similar to that shown in Fig. 6, except that a self-induction coil S is introduced into one energising circuit of the motor. The effect of thus increasing the self-induction in one of the circuits is to retard the phases of the current passing therein to a greater extent than in the other circuit, and in this way to secure the necessary difference in phase between the energising currents to produce the rotation of the motor.

Shown diagrammatically in Fig. 3 is a type of motor in which two dead resistances, R R′, are included, respectively, in the energising coils of the motor. No rotary effect will be produced as long as the resistances are equal; but by varying the resistance in one circuit the retardation of the current in that circuit will be varied, and corresponding effects produced. For example, a reduction of the resistance in one circuit imparts to the motor rotation in one direction, while a reduction of the resistance in the other circuit will produce a rotation in the opposite direction. By means of the two resistances, therefore, capable of variation, or of

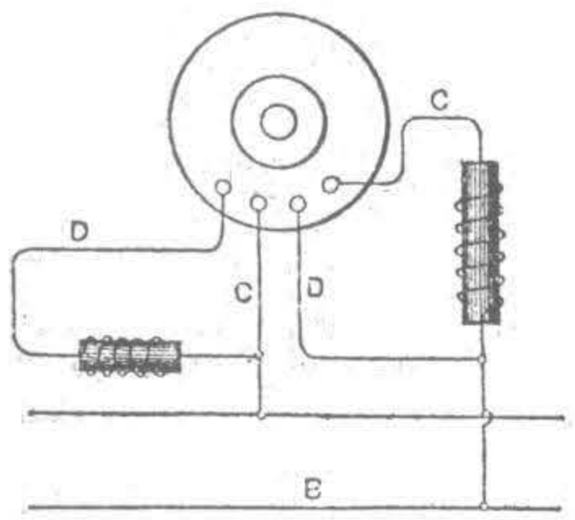


Fig. 5.—Tesla Motor with Two Self-Induction Coils.

being bodily withdrawn from, or inserted in, the circuits by simple means, rotation of the motor is secured.

In Fig. 4 a self-induction coil, S, is included in one of the motor circuits, and a dead resistance, R, in the other. The increased self-induction in one circuit thus produced acts to increase the difference of phase between the current in that motor circuit and the unretarded current in the line circuit. On the other hand, the introduction of the dead resistance in the other motor circuit reduces the retardation, and brings the phases of the current in it more closely in accord with those of the unretarded current, thus producing a correspondingly greater difference of phase between the two currents in the energising circuits C and D.

Two self-induction coils are shown in Fig. 5, one in each motor or energising circuit. One of these coils is much smaller than the other, and has less self-induction or counter electro-motive force than

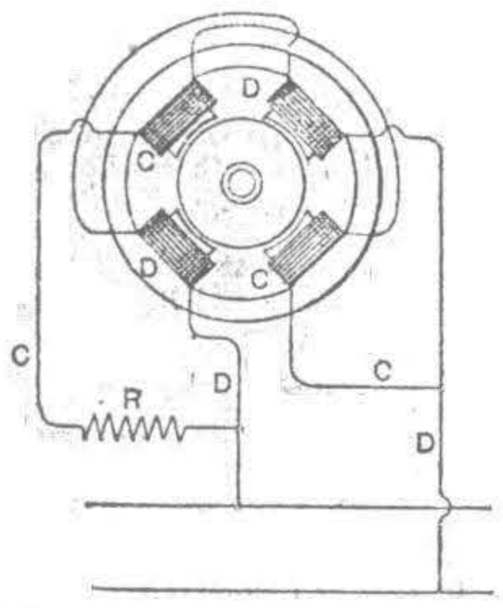


Fig. 6.—Tesla Motor with Energising Circuits in Multiple Arc.

the other, so that the phases of current will be retarded to a less extent than in the other.

The two energising circuits of the motor are shown in Fig. 6, connected in multiple arc to the line circuit, and in one of these circuits is a resistance, R. Assuming the two motor circuits to have the same degree of self-induction, no rotary effect will be produced by the passage through them of an alternating current from the line. But if one of the motor circuits, as C, be varied or modified by the introduction of a dead resistance, R, the self-induction of that circuit or branch is reduced, and the phases of current therein retarded to a correspondingly less extent. The relative degrees of retardation of the phases of the current in the two motor circuits with respect to those of the unretarded current in the circuit B thus produced will set up a rotation of the motor. Another type may be mentioned in which one set of energising coils is of finer wire than the other, or has a greater number of convolutions; or each circuit may contain the same number of convolutions, but composed of different conductors, as, for instance, one of copper and the other of German-silver.

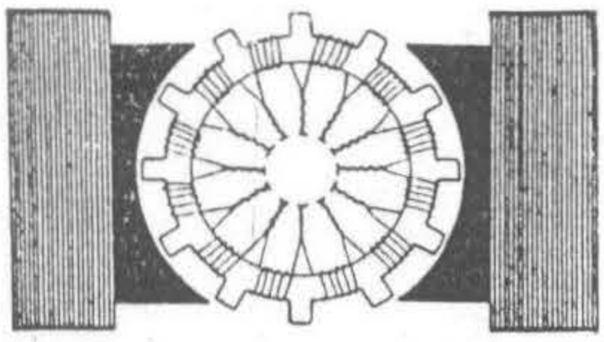
SCIENCE AND MECHANICS.

THE MULTIPHASE MOTOR.

ONE OF TESLA'S GREAT INVENTIONS.

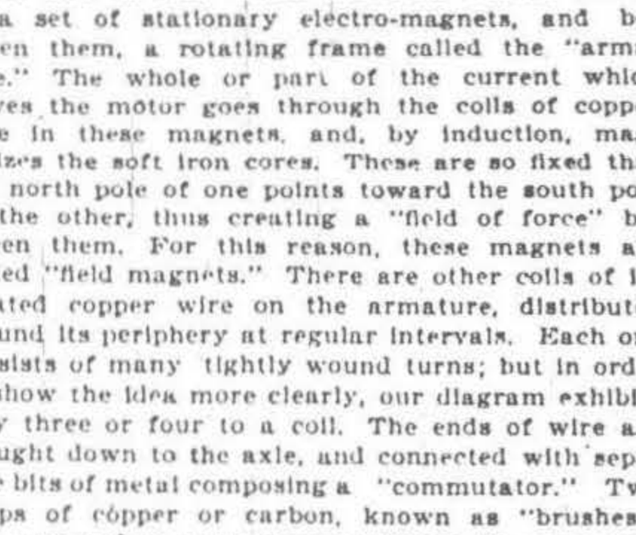
HIS RECENT IMPROVEMENT THEREIN—FEATURES OF THE HARNESS WHICH NIAGARA FALLS WILL WEAR.

In some of the accounts of that remarkable achievement in Germany nearly three years ago of transmitting 300 horse-power in the form of electricity from the waterfall at Lauffen to Frankfort, 108 miles away, we read that it was a notable illustration of the "three-phase" system. Similar expressions are used regarding a plant in Southern California, set in operation last September and furnishing the city of Redlands with electricity generated at Mill Creek Canyon, nine miles away. The equipment for like purposes at Sewall's Dam, near Concord, N. H., is of the same class. We also run across the term "two-phase." It has been announced, for instance, that the enormous dynamos soon to be set in operation by Niagara Falls are to be adapted to the distribution of power on the "two-phase" plan. "Polyphase" and "multiphase" are other words coming into increasing use by scientific periodicals in mentioning existing or proposed electrical installations. All this phraseology



relates to a new system of converting an alternating current into power, invented by our young and gifted fellow-countryman, Nikola Tesla. Ferraris, an Italian, hit upon the same idea at almost the same time, but he did not develop it in a practical way; and Shallenberger, Elihu Thomson and others in this country, as well as various foreigners, have utilized it in some form. The plan has not yet come into extensive use; but in the near future it is destined to attract wide attention.

The special features of the Tesla system will be better understood, perhaps, if the reader will first recall the general arrangement of the types of motor now in use. These machines consist chiefly of a set of stationary electro-magnets, and between them, a rotating frame called the "armature." The whole or part of the current which drives the motor goes through the coils of copper wire in these magnets, and, by induction, magnetizes the soft iron cores. These are so fixed that the north pole of one points toward the south pole of the other, thus creating a "field of force" between them. For this reason, these magnets are called "field magnets." There are other coils of insulated copper wire on the armature, distributed around its periphery at regular intervals. Each one consists of many tightly wound turns; but in order to show the idea more clearly, our diagram exhibits only three or four to a coil. The ends of wire are brought down to the axle, and connected with separate bits of metal composing a "commutator." Two strips of copper or carbon, known as "brushes," and mounted so as to press gently on the commutator as the armature revolves, are the terminals of the wires which conduct the electricity generated at a distance, first into one and then to another of the armature coils. That is, one brush leads it in and the other leads it out. It will be seen that so long as the motor is running the field magnets are constantly energized; but the armature coils are only momentarily and successively influenced. A magnet will attract a wire or coil of wire which bears an electric current if that current be flowing in one direction; but it will repel that wire or coil if the current goes in the other direction. Now, in a motor the current is so guided into the armature coils that the latter are, in succession, drawn toward the poles of the field magnets; but as soon as each coil approaches as nearly as possible the current in it is reversed by the commutator, and



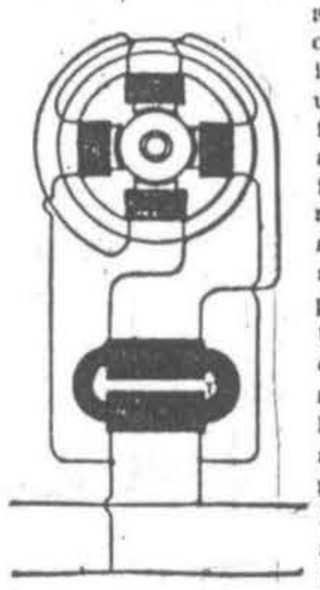
then the coil is driven away. Both attraction and repulsion are so timed as to give motion to the revolving armature in the same direction. Meantime, the other magnet, on the other side of the machine, is co-operating in a similar manner. The armature, by the way, is a ring, not solid usually, but a lot of thin iron plates insulated from each other, often perforated to allow ventilation, and bound into one by the encircling coils.

The principle which Mr. Tesla uses in his polyphase motor is quite different. In its simplest form, his armature is a mere bar or plate of magnetic iron, like A in our second diagram, mounted on a spindle so as to rotate. His "field of force," instead of being stationary, is made to go around in a circle, dragging the armature along as it goes. The field magnets do not actually move, however, but act in such a manner as to keep the centre of attraction shifting, progressively. In a "two-phase" motor, for instance, the current from the dynamo is divided so as to come in and go out first by one route, which is designated as B in our diagram, and then by another, marked C. The magnets D and E are included in the first circuit, and are simultaneously energized; and then, while the wave-like impulse is subsiding another comes in by the second circuit and acts upon the other pair of magnets. Let us suppose that at starting the current first comes in by the route B, and makes the end of D facing the centre of our circle a "north" pole, and the corresponding end of E a "south" pole. We will also suppose that the armature has a slight magnetic predisposition of its own, which impels the end that is uppermost in our diagram to seek a north pole, wherever it can find one. At the outset, then, it will be drawn to D, while E will similarly attract the other end. If, now, the current is let into the circuit C, and makes a north pole at F, the armature will feel two attractions, and swing so as to be half way between those magnets. But the wave in D is dying out, and that in F is rising; so that the latter magnet is soon in supreme control, and the armature moves to a position at a right angle with its first one. Meantime, G has a "south" polarity, and attracts the other end of the armature. When the current next flows through the wires at B, its direction has been reversed, as it is an "alternating" current; so that D is a "south" pole, and E is a "north" pole. Hence E coaxes the arrow-marked end of the armature at first part of the way and then all of the way from F; and we have secured half a rotation. The other half is obtained by the same general method; and the armature is soon spinning at great speed. In a three-phase motor of this pattern there are six magnets instead of four; and there are three separate circuits instead of two.

Mr. Tesla found, after a little, that a circular disk would retain its polarity as well as a bar, and hence ceased to slice off the sides of his armature, as he did at first. He and his imitators have also tried many modifications of form for the field magnets, while retaining the principle of moving the field around in a circle. In its latest form the armature is a cylinder, not a disk. A few turns of heavy copper wire are distributed about it, wound from end to end, to intensify the magnetism of the iron inside.

It was not long before this ingenious inventor discovered that three wires would do the work of four for a two-phase motor. It seemed necessary to have two separate ones for supply purposes, but not two for the return currents. The three-phase motor is also, at present, operated by three wires, two of which are made to carry the three sets of inflowing waves, since no two circuits are in full service at once. Mr. Tesla has even devised a way —several ways, in fact—by which the two (or three) currents may be separated, not at the dynamo which generates them, but close to the motor; so that the latter may, if desirable, be used on an ordinary two-wire circuit. It has been intimated, however, that the Niagara electrical output will be distributed by the four-wire system.

One of Mr. Tesla's means for effecting separation on the site of the motor is a transformer, or induction coil. This piece of apparatus consists of two coils of copper wire so insulated and combined that the primary current passing through one excites a



secondary current in the other. It should be borne in mind that the current used with polyphase motors is not a continuous but an alternating one; that is, it is made up of a series of minute oscillations in opposite directions. Thence the secondary, as well as the primary, alternates. But the impulses of the secondary lag an exceedingly small fraction of time behind those of the primary; and that lag can be magnified if desired. Thence, Mr. Tesla is able to energize one coil of his two-phase motor with the primary current and the other with the secondary. Our third diagram indicates the arrangement of the apparatus. He has devised several other schemes for dividing the current, at the place where it is used, instead of where it is generated.

Almost all the electric motors running to-day, on trolley cars, in workshops and mines and to operate elevators, are driven by a direct or continuous current, by a system similar to that described in the first part of this article. There are plenty of alternating current dynamos, which generate electricity for lighting and other purposes, but very few alternating current motors. Various difficulties have stood in the way of making one which would work as satisfactorily as those of the other type. There are several reasons, however, why it is desirable to have a good motor capable of being operated by an alternating current. A plant generating the latter for lighting purposes, for instance, could then supply electricity for power also. And in the application of this form of force to a vast variety of industries, in the near future, adaptability to all uses will be an important economic factor. Furthermore, the alternating current has advantages over the direct when it comes to production on a large scale and transmission to great distances.

One serious objection to the alternating motor, when run by a single current, has been that it was not self-starting. Other power was required to give the rotations of the armature a frequency equivalent to that of the waves of the energizing current before it would run alone. Possibly this may be overcome, some day, with a "singlephase" machine; but the multiphase motor is already a self-starter. The polyphase plan also gets rid of the commutator and brushes, which, in motors (as in dynamos), are liable to emit dangerous sparks. A disadvantage attaching to other motors, including those of the "direct" type, is that the armature coils become overheated, and "burn out," when more work than the machine is adapted to perform is imposed upon it. No such ruinous effect is experienced by the multiphase motor; if overloaded, it merely stops. For this reason and for others, it is said, less skilful workmen are needed to operate such motors.

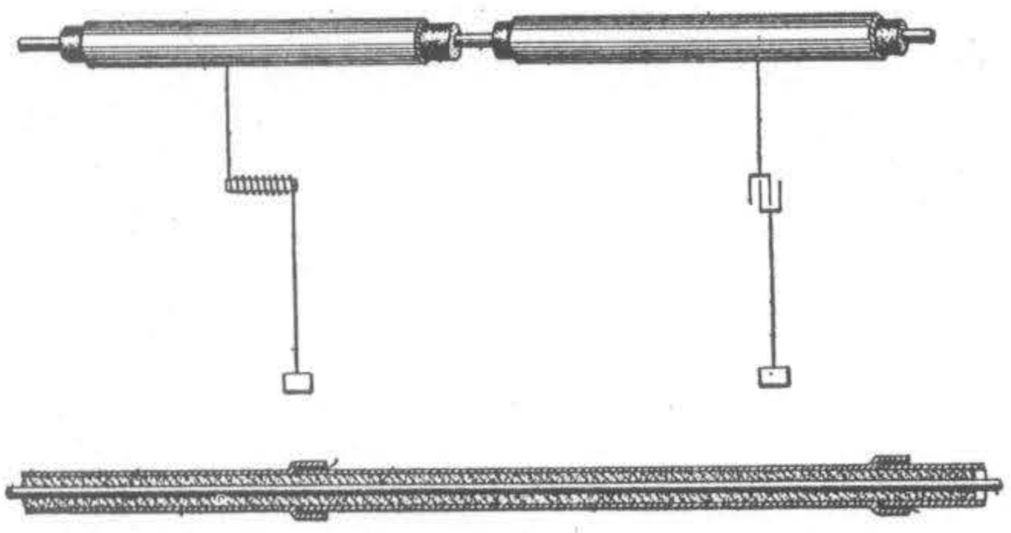
SCIENCE IN THE MAGAZINES.

The *Century* contains a biographical sketch of Mr. Nikola Tesla, by Mr. T. C. Martin, illustrated by an excellent portrait of that investigator. Mr. Tesla comes of an old Servian stock, and is but thirty-six years of age. His electrical work began in the Polytechnic School at Gratz, where he distinguished himself in experimentation. He afterwards became an assistant in the Government Telegraph Engineering Department at Buda-Pest, from which he passed into an electric-lighting establishment in Paris. A little later he crossed the Atlantic, and entered one of Mr. Edison's workshops. When his term of apprenticeship there had ended, he struck out for himself, his investigations eventually leading him to the brilliant phenomena produced with currents of high potential and high frequency. "Recently," says Mr. Martin, "the high-frequency generators with which he had done so much of this advanced work have been laid aside in discontent for an oscillator, which he thinks may not only replace the steam-engine with its ponderous fly-wheels and governors, but embodies the simplest possible form of efficient mechanical generator of electricity."

THE TESLA HIGH POTENTIAL CONDUCTOR.

In order to prevent loss by dissipation or interference by induction on line conductors carrying high potential alternating currents they have in some instances, such as at Deptford, London, been insulated and inclosed in a continuous conducting sheathing which is connected with the ground by a good conducting path.

While conducing to the safety of the system, Mr. Tesla has found that the use of a conducting sheath or screen around the line conductors and well grounded, or even brought into proximity to external conductors or large bodies is attended by an actual, and generally a serious, loss of energy which is the greater, the greater the number of alternations and the higher the potential. He therefore maintains the sheath either entirely isolated or connected directly or inductively to the ground, through a path which will practically prevent the passage of currents over it. He has also found that when a continuous isolated sheath or screen is employed, there is greater liability to loss of energy by inductive action; for, unless the sheath or screen be considerably shorter than the current waves passing in the conductor, electromotive forces will be set up between different points in the sheath, which will result in the passage between such points of induced currents. Mr. Tesla therefore, divides up the sheath or screen into short lengths, very much shorter than the wave lengths of the current used, so that the grounding of any one of such lengths or the approach thereto of a large body will result in an inappreciable loss, or at most a small local draining of the energy, while the tendency of currents to flow between different points in the sheath is effectually overcome. The function of the sheath as a static screen for preventing the dissipation of the electric energy, however, requires for its complete effectiveness an uninterrupted conducting partition or screen around the conductor. In the case of a sectional screen, this is obtained, by causing the ends of the insulated divisions or



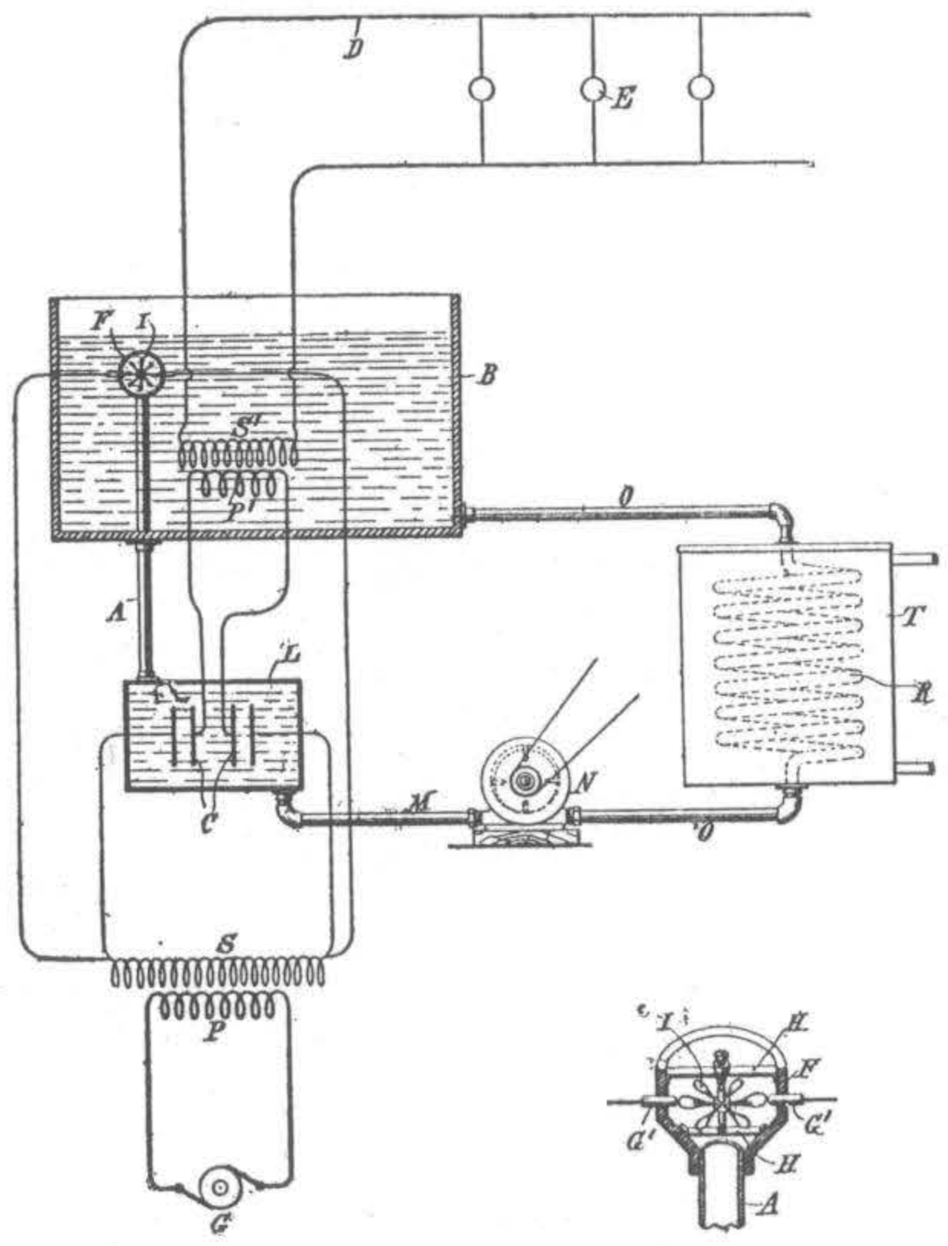
FIGS. 1 AND 2.—THE TESLA HIGH POTENTIAL CONDUCTOR.

sections to overlap, and interposing insulating material between the overlapping portions.

For transmitting currents of very high potential and very high frequency, Mr. Tesla provides between the sheath and the ground a path of very high ohmic resistance, or one containing a self-induction coil properly determined with respect to the existing conditions so that it will effect the desired result, or a condenser of very small capacity, as shown in Fig. 1. In such cases the sheathing or screen for practical purposes may be regarded as isolated from the ground, since by the character of the connection employed no appreciable loss results from the passage of current from the sheath to the ground. Fig. 2 shows the construction of an actual conductor of embodying the idea.

TESLA'S AUTOMATIC FLUID INTERRUPTED FOR PRODUCING HIGH FREQUENCY CURRENTS.

The Tesla system of lighting and power transmission with high frequency and high potential currents, as is now well known, involves the maintenance of an intermittent or oscillatory discharge



TESLA'S AUTOMATIC FLUID INTERRUPTER.

of a condenser or circuit of suitable capacity into a working circuit containing lamps or other devices. In systems of this character when the high frequency of the currents employed is due to the action of a disruptive or intermittent discharge across an air gap or break at some point of the circuit, Mr. Tesla has found it to be of advantage not only to destroy the least tendency to continuity of the arc, but to control the period of its re-establishment, and from investigations made with this object in view he has found that greatly improved results are secured by causing the discharge to take place in and through an insulating liquid, such as oil, and, instead of allowing the terminal points of the break to remain at a uniform distance from each other, to vary the distance by bringing them periodically in actual contact or sufficiently near to establish the discharge and then separating them, or what is the equivalent of this, throwing in and out of the gap or break a conducting bridge at predetermined intervals. To obtain the best results, moreover, Mr. Tesla finds it essential to maintain at the point of discharge a flow of the insulating medium, or, in general, such a circulation of the same as will constantly operate to cut off or break up the discharge as fast as it is established. The accomplishment of this latter result involves the employment of some mechanism for maintaining the flow or circulation of the insulating medium past the points of discharge, and he takes advantage of the presence of the same device to maintain the circulation of the insulating liquid in which the converter for raising the potential and the condenser plates are immersed; by this means the liquid is prevented from heating.

All this is accomplished by a pumping arrangement shown in Fig. 1, the spark gap being controlled by a small turbine which is shown enlarged in Fig. 2. When the pump is started up and the turbine I revolves, the blades bridge the space between the two terminals, nearly or quite touching the terminals in their movement. If now the tank B be filled with oil and the latter permitted to flow off through the tube A, the turbine will be rotated by the flow, the rate of rotation being dependent upon the rate of flow. By this means the arc or discharge is periodically established through a flow of oil, which secures in the most satisfactory manner the conditions best adapted for practical results. The flow of oil is regulated by the speed at which the pump N is driven, and by this means the period of re-establishment of the arc is controlled. A cooling tank T may be provided if necessary.

Recent Inventions of Nikola Tesla.

In conducting his experiments with alternating currents of high frequency and high potential Mr. Tesla has found it necessary to devise new forms of apparatus to produce and control the current with which he has achieved such interesting results. Three of the latest improvements of this description, all patented, are illustrated by the accompanying cuts.

In Fig. 1 is shown a new device for producing the

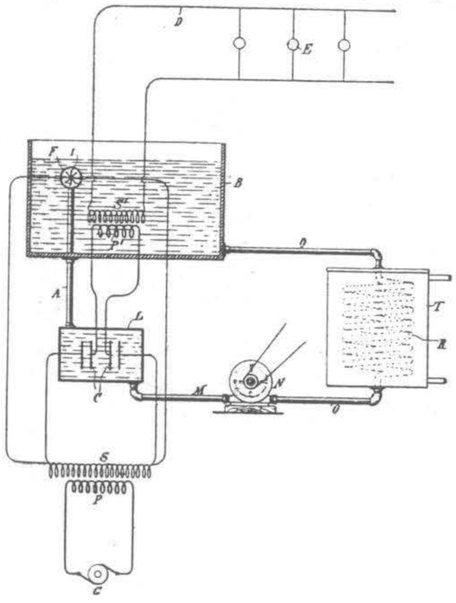
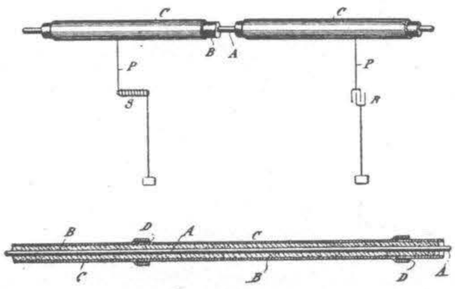


FIG. 1. RECENT INVENTIONS OF NIKOLA TESLA.

intermittent discharge across a break in the circuit, designed to replace the air gap in the production of alternating currents of high frequency. The advantages of this method lie in the fact that the disruptive discharge takes place in oil insulation and that the rate of discharge is under absolute control, obviating any tendency to a continuity of the arc or discharge. The inventor also takes advantage of the presence of the oil to secure a more effective insulation for the converter coils and condenser plates which are necessary in apparatus of this character. By reference to the diagram the method of operation will be readily understood. *G* is an ordinary alternator, connected to the primary winding *P* of a transformer, of which *S* is the secondary. To the latter are connected the plates of a condenser *C*, and at *F* is a break in the circuit at which occurs the disruptive discharge. In the secondary circuit, in series with the condenser, is a primary coil *P'* with which is associated a secondary *S'*, the latter constituting the ultimate source of current for the working circuit *D*, with which are connected translating devices *E*. By the disruptive discharge between the terminals at *I* the condenser is charged and discharged, producing a current of enormous frequency. The unique feature of the apparatus is the means by which the disruptive discharge is accomplished by interposing a series of rotating conductors *I* between the terminals. *A* is a pipe that leads into a tank *B*. To the end of this tube is secured an extension *F* of insulating material and the two terminals are caused to project through it. Within the extension are two cross-bars which afford bearings for the spindle of a small metallic turbine *I*, the blades of which, as the turbine revolves, bridge the space between the two terminals, nearly or quite touching the terminals in their movement. If the tank *B* be filled with oil and the latter is drawn off or permitted to flow off through the tube *A*, the turbine will be rotated by the flow, the rate of rotation being dependent upon the rate of flow. By this means the arc or discharge is periodically established through a flow of oil, which secures the object sought to be attained. A glance at the cut will show the manner of insulating in oil the second transformer *P' S'* in the tank *B* and the condenser in a receptacle *L*. A small rotary pump *N* causes the oil to circulate, and, of course, the rate of the disruptive discharge is regulated by the speed of this pump. The jacket *T* and coil *R* provide a means for cooling the oil if necessary.

A simple plan to prevent the dissipation of current on electrical conductors carrying excessively high potentials is shown in Figs. 2 and 3. Mr. Tesla has found that the use of grounded conducting sheaths is usually attended by a serious loss of energy. He therefore maintains the sheath either entirely isolated or connected directly or inductively to the ground through a path which will practically prevent the passage of current over it. He divides the screen into short lengths, much shorter than the wave lengths of the current used, so that the grounding of any one of such lengths or the approach thereto of a large body will result in an inappreciable loss, or at most a small local draining of the energy, while the tendency of currents to flow between different points in the sheath is effectually overcome. The function of the sheath as a static screen for preventing the dissipation of the electric energy, however, requires for its complete effectiveness an uninterrupted conducting partition or screen around the conductor. This requirement is met by causing the ends of the insulated sections to overlap, interposing a suitable insulating material between the overlapping portions. In the cuts *A* is the conductor, *B* the insulation, *C* the sheathing divided into overlapping sections insulated from one another by the material *D*. The ground connections are illustrated in Fig. 2. Mr. Tesla obtains the beneficial results of an earth connection, while preventing the generally serious loss that would occur in the use of such currents, by providing between the sheath and the ground a path *P* of very high ohmic resistance or one containing a self-induction coil *S* properly determined with respect to the existing conditions, so that it will effect the described result, or a condenser of very small capacity as shown at *R*. In such cases the sheathing or screen for practical purposes may be regarded as isolated from the ground, since by the character of the connection employed no appreciable loss results from the passage of current from the sheath to the ground.

An improved incandescent lamp for use on circuits carrying alternating currents of high potential and frequency is the third invention, the object of which is to prevent dissipation from the conductors in the lamp. This is accomplished by surrounding the leading-in and supporting conductors with a conductor which acts as a static screen. By this means the light-giving body or button which lies beyond the influence of the screen is quickly and efficiently brought to and maintained at higher incandescence, by reason of the fact that the electrical action to which the incandescence is due is confined mainly to the button. *A* is a glass globe of the usual form, in the base of which is sealed a very thin conducting wire *B*, passing up through a stem of glass or other refractory insulator *C*. To the upper or inner end of this



FIGS 2 AND 3. RECENT INVENTIONS OF NIKOLA TESLA.

wire is united, as by means of a mass of carbon paste *D*, a carbon or other refractory stem *E*, that supports or carries a small button of carbon or other suitable substance *F*. Over the stem *C* is passed a metallic tube *G*. Mr. Tesla recommends for this purpose a very thin cylinder or tube of aluminum, and it should entirely surround all parts of the conductor within the globe except the button itself, extending to or nearly up to the point of union of the stem *E* with the button *F*. Such a device, by reason of its electrostatic action, reduces the loss of energy supplied to the bulb, preventing its radiation or dissipation into space except through the exposed or unprotected button. The tube or screen *G* is entirely insulated from the conductors within the globe and from all external conductors or bodies.

A NEW EDISON ON THE HORIZON.

IN the February *Century* Mr. T. C. Martin tells of the young Servian, Nikola Tesla, who has come to the New World to make what amounts to a revolution in many world-important departments of electrical invention. Mr. Tesla is only thirty-six years old, and, like Edison, has achieved his triumphs in the face of extreme poverty and other adverse influences. One of the most important of his inventions has had to do with the polyphase currents, on the principle of which large powers are "transmitted electrically more than a hundred miles from Neckar-on-the-Rhine to Frankfort-on-the-Main; and now, by equivalent agency, Niagara is to drive the wheels of Buffalo and beyond."

Mr. Martin tells of other marvelous discoveries of the young Servian:

"Broadly stated, Mr. Tesla has advanced the opinion, and sustained it by brilliant experiments of startling beauty and grandeur, that light and heat are produced by electrostatic forces acting between charged molecules or atoms. Perfecting a generator that would give him currents of several thousand alternations per second, and inventing his disruptive discharge coil, he has created electrostatic conditions that have already modified not a few of the accepted notions about electricity. It has been supposed that ordinary currents of one or two thousand volts' potential would surely kill, but Mr. Tesla has been seen receiving through his hands currents at a potential of more than 200,000 volts, vibrating a million times per second, and manifesting themselves in dazzling streams of light. This is not a mere *tour de force*, but illustrates the principle that while currents of lower frequency destroy life, these are harmless. After such a striking test, which by the way, no one has displayed a hurried inclination to repeat, Mr. Tesla's body and clothing have continued for some time to emit fine glimmers or halos of splintered light. In fact, an actual flame is produced by the agitation of electrostatically charged molecules, and the curious spectacle can be seen of puissant, white, ethereal flames that do not consume anything, bursting from the ends of an induction coil as though it were the bush on holy ground. With such vibrations as can be maintained by a potential of 3,000,000 volts, Mr. Tesla expects some day to envelop himself in a complete sheet of lambent fire that will leave him quite uninjured. Such currents as he now uses would, he says, keep a naked man warm at the North Pole, and their use in therapeutics is but one of the practical possibilities that has been taken up.

'Utilizing similar currents and mechanism, Mr. Tesla has demonstrated the fact that electric lamps and motors can not only be made to operate on one wire, instead of using a second wire on the ground to complete the circuit, but that we can operate them even by omitting the circuit. Our subway boards are to find their wires and occupations gone. Electric vibrations set up at any point of the earth may by resonance at any other spot serve for the transmission of either intelligence or power. With these impulses or wave discharges, Mr. Tesla also opens up an entirely new field of electric lighting. His lamps have no filaments as ordinarily known, but contain a straight fiber, a refractory button, or nothing but a gas. Tubes or bulbs of this kind, in which the imprisoned ether or air beats the crystal walls, when carried into the area or room through which these unsuspected currents are silently vibrating, burst into sudden light. If coated inwardly with phosphorescent substances, they glow in all the splendors of the sunset and the aurora."

The Tesla High-Potential Conductor.—In order to prevent loss by dissipation or interference by induction on line conductors carrying high-potential alternating currents, they have in some instances, such as at Deptford, London, been insulated and enclosed in a continuous conducting sheathing, which is connected with the ground by a good conducting path. The *Electrical Engineer* of New York states that, while conducing to the safety of the system, Mr. Tesla has found that the use of a conducting sheath or screen around the line conductors and well grounded, or even brought into proximity to external conductors or large bodies, is attended by an actual, and generally a serious, loss of energy, which is the greater the greater the number of alternations and the higher the potential. He therefore maintains the sheath entirely isolated or connected directly or inductively to the ground, through a path which will practically prevent the passage of currents over it. He has also found that when a continuous isolated sheath or screen is employed, there is greater liability to loss of energy by inductive action; for unless the sheath or screen be considerably shorter than the current waves passing in the conductor, E.M.F.'s will be set up between different points in the sheath, which will result in the passage between such points of induced currents. Mr. Tesla therefore divides up the sheath or screen into short lengths very much shorter than the wave lengths of the current used, so that the grounding of any one of such lengths or the approach thereto of a large body will result in an inappreciable loss, or at most a small local draining of the energy, while the tendency of currents to flow between different points in the sheath is effectually overcome. The function of the sheath as a static screen for preventing the dissipation of the electric energy, however, requires for its complete effectiveness an uninterrupted conducting partition or screen around the conductor. In the case of a sectional screen this is obtained by causing the ends of the insulated divisions or sections to overlap, and interposing insulating material between the overlapping portions. For transmitting currents of very high potential and very high frequency, Mr. Tesla provides between the sheath and the ground a path of very high ohmic resistance, or one containing a self-induction coil properly determined with respect to the existing conditions so that it will effect the desired result, or a condenser of very small capacity. In such cases the sheathing or screen for practical purposes may be regarded as isolated from the ground, since by the character of the connection employed no appreciable loss results from the passage of current from the sheath to the ground.

THE TESLA HIGH POTENTIAL CONDUCTOR.*

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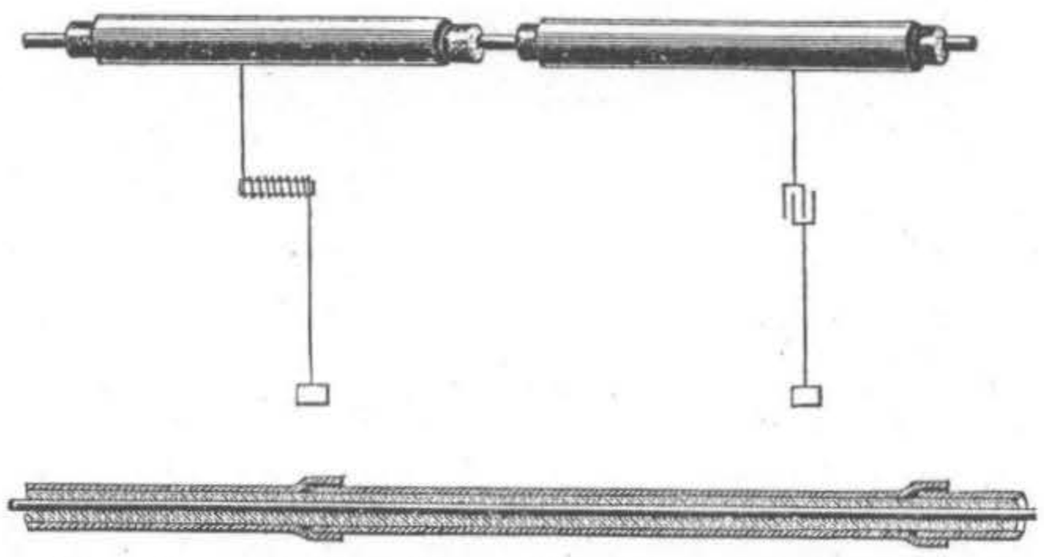


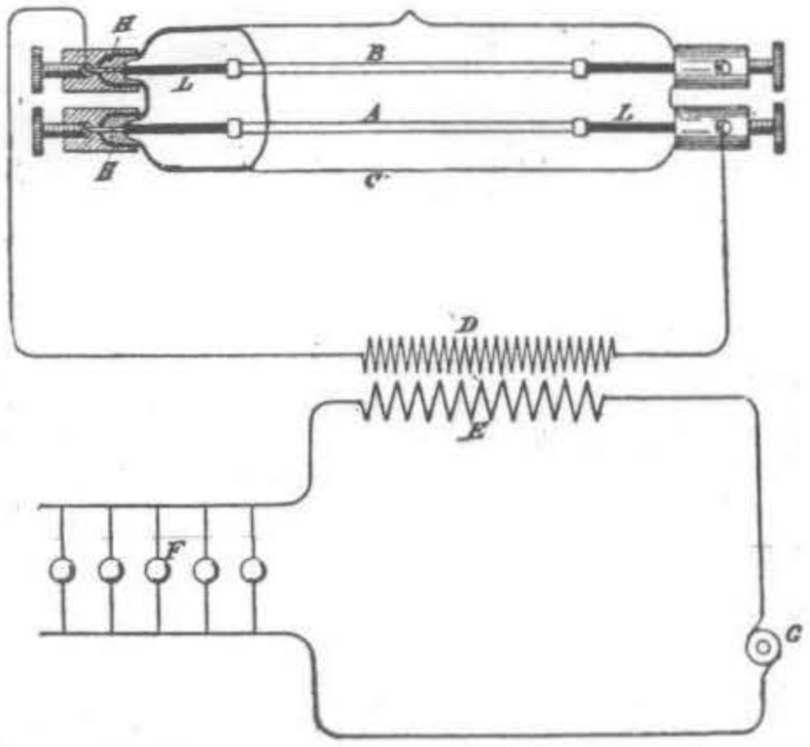
Figs. 1 and 2.—The Tesla High Potential Conductor.

For transmitting currents of very high potential and very high frequency, Mr. Tesla provides between the sheath and the ground a path of very high ohmic resistance, or one containing a self-induction coil properly determined with respect to the existing conditions so that it will effect the desired result, or a condenser of very small capacity, as shown in fig 1. In such cases the sheathing or screen for practical purposes may be regarded as isolated from the ground, since by the character of the connection employed no appreciable loss results from the passage of current from the sheath to the ground. Fig. 2 shows the construction of an actual conductor of embodying the idea.

* New York *Electrical Engineer*.

NOTES.

The Tesla Polyphase Patents.—An action has been brought by the Westinghouse Electric and Manufacturing Company against the General Electric Company for alleged infringement of the Tesla polyphase patents.



TESLA'S ALTERNATING CURRENT METER.

Tesla's Alternating Current Meter.

A novel meter for alternating currents, designed by Nikola Tesla, is illustrated in the accompanying diagram. The invention is based upon the fact that when a high tension discharge is made to pass from a conductor through rarefied gas, minute particles are thrown off from the conductor, the amount of detachment depending upon the strength of the current. In a suitable tube of glass are sealed platinum leading wires H coated inside the tube with insulating material. Sticks of carbon A, B are connected to these platinum terminals and the tube exhausted and sealed. The two carbon sticks A, B are electrically connected with the secondary of an induction coil, the primary of which is in series with the alternating circuit in which the current consumption is to be measured. For example, F represents a group of incandescent lamps, and E the primary of the induction coil. The difference of potential at the terminals of the secondary is proportionate to the primary current, and, therefore, to the current used by the lamps. The discharge from one conductor, A, to the other, as B, produces a detachment of infinitesimal particles along the entire length of the sticks, and after a period of service the latter increases in resistance. The amount of detachment is said to be proportional to the difference of potential between the two conductors. Hence, the increase of their resistance is in a definite proportion to the number of lamp hours. By measurements taken at the start and finish of any period of service the amount of energy used during such period of service may be computed. The action may be confined to confronting faces of the carbon sticks by coating the other faces with insulating material.

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NIKOLA TESLA.

In another column we print a review and estimate of the work of Nikola Tesla from the pen of Lieut. Patten, whose own work, to some extent along similar lines, well qualifies him for the undertaking. While much has been written of Tesla and his achievements, it has been almost invariably from a popular standpoint, and, as far as we know, this is the first attempt to give a critical estimate. The great beauty of the Tesla experiments, the novelty of the subjects dealt with, the charming literary style and picturesque personality of the gifted inventor himself—all those have distracted attention from the technical and commercial features which, under ordinary circumstances, are the grounds upon which judgment is based. Perhaps another reason is that only recently has the opportunity been afforded, through an exhaustive compilation of Tesla's writings, patents and of other material, to take a comprehensive view instead of only the partial one hitherto possible. One is naturally disappointed that nothing practical has as yet proceeded from the magnificent experimental investigations with which Tesla has dazzled the world, and, what is still more disappointing, that they hold out no definite hope of the realization of the great promise they were supposed to contain. On the other hand, it should be borne in mind that Tesla is not working as a commercial experimenter with only a view to the speedy coining of his results into dollars and cents. His attitude is more that of Faraday, who felt that the world would obtain most benefit from his genius if devoted to pure physical research, knowing that his discoveries would eventually have a

practical fruition. The whole hope of modern science may be said to lie in molecular physics, and it is through work like that of Hertz and Tesla that we will, if ever, penetrate its mysteries. While therefore the popular conception of Tesla as one working like Edison to achieve only practical results is wrong, the popular estimation in which he is held has nevertheless a real justification in his valuable labors, though these may not lead directly to the marvels expected.

Nikola Tesla and His Work.

BY LIEUT. F. JARVIS PATTEN.

Mr. Nikola Tesla has been prominent in the electrical field for more than ten years, and the creations that have sprung from his brain have made his name familiar to the general public. His work, however, has been of such an advanced order of electrical application that comparatively few have a clear idea as to just what he has accomplished.

Within the past three months a book has been published which tells the story and which is indeed a rather exceptional contribution to the electrical literature of the day, presenting, as it does, an elaborate description of all that Mr. Tesla has thus far given to the public in his patents and lectures.* It includes not only descriptions of his numerous inventions, but his personal writings upon the lines of thought and experiment he has advanced, and so affords the opportunity for a brief review of what he has done.

From both a literary and typographical standpoint the book is an excellent addition to the electrical library. It is tastily gotten up, and evinces care and literary skill in the editing; the illustrations, which are profuse, are good, and this is equally true of the frontispiece portrait of Mr. Tesla, which to many will largely enhance the value of the book.

With the exception of a short biographical sketch, Part I., comprising twenty-four chapters, is devoted to a rather exhaustive treatment of the many forms of rotary field motors that Mr. Tesla has from time to time invented. One of these chapters, which will meet the requirement of the average reader, is an abridgment of Mr. Tesla's well remembered lecture before the American Institute of Electrical Engineers in May, 1888, in which he gave for the first time the rotary field motor invention to the public. Most of the remaining chapters of part I. are detailed descriptions of different modifications of the general multiphased motor system, such as would likely occur to an active inventor anxious to bar with a profusion of patents every access to a broad system naturally open to many variations. In fact, many of these chapters are little else than mere transcripts from patent specifications.

Part II. is devoted to high frequency phenomena, a field of investigation that seems to be peculiarly Mr. Tesla's own. It opens with an interesting chapter that seems to be from the editor's pen, in which he gives his own resume and estimate of the matter set forth in Mr. Tesla's three lectures upon high frequency effects, lectures given in succession before the American Institute of Electrical Engineers, the Royal Institution in London, and the Franklin Institute in Philadelphia. These three lectures, reproduced verbatim and making as many long chapters, constitute, in fact, the main part of the work.

Part III., comprising seven short chapters, describes quite a variety of inventions of relatively minor importance, so far as Mr. Tesla's work is generally known, and which would probably never have seen publication beyond the patent specifications, from which they are evidently drawn, had not the exhaustive design of this book rendered their inclusion excusable. The inventions here mentioned include an arc lighting system of earlier days, some suggestions of how a unipolar machine might be built, a pyromagnetic generator, a thermomagnetic motor, an anti-sparking dynamo brush, and a method of regulation for constant current. These chapters are interesting mainly as showing how much a professed inventor must do that is not in the line of great achievement.

A short but interesting chapter describing Mr. Tesla's personal exhibit of apparatus at the World's Fair, and a brief reference to his latest surprise, the "electro-magnetic

*"Inventions, Researches and Writings of Nikola Tesla." Edited by Thomas Commerford Martin. New York. 1894. Price, $4.00.

oscillator" for producing high frequency currents by mechanical means, ends the volume.

With the exception of a few chapters by the editor, the volume is a collection of Mr. Tesla's writings, and those who have followed his work closely will find in it little that is new. Much of the subject matter in Part I., devoted to polyphased currents, is taken in a sweeping manner from patent specifications, and as such will be new to some who little know, without such a review, how thoroughly Mr. Tesla looked after the possible variations of his broad invention. The various motors described are shown in their most elementary forms by mere diagrams of the operative circuits.

While these numerous variations of the same general idea are instructive as showing the growth of the invention in the inventor's mind, and the gradual development of the mere abstract idea to different practical forms, still, in all these descriptions there is little to be found that has any practical bearing or importance to-day. The engineer will find in these chapters little that he cares to remember for practical use or application, the advocate of controversy as to priority of invention will find ample data for reference, and the student of electrical science will find in them evidence of how little the most thoughtful inventor can foresee the features of his invention that will lead to most controversy and discussion, for nowhere in these earlier writings is any importance attached to the frequency of the alternating current used. Throughout the twenty-four chapters of Part I. the charming delusion prevails by inference that all these machines are as good at one frequency as at another. One might also draw the erroneous conclusion that polyphased currents were first discovered and used by Mr. Tesla; on the other hand, no one can doubt that the biphased and triphased rotary field machines were simultaneously worked out by him as early as 1887. He did not leave the triphased machine for a follower to invent.

Following the general treatment of multiphased machines come descriptions of various devices and makeshifts (no word seems more appropriate) for working these machines by a single alternating current. The rotary field motor operated by multiphased currents, as its every feature indicates it should be, is a unique and characteristic thing and should have been left to the field of operation that its inherent simplicity must sooner or later create for it. Its birth, however, was contemporaneous with that of single alternating current working, so the genius that first showed the rotary field machine in practice must pervert his invention to meet the requirements of a system to which it was entirely unsuited. The description of these many attempts adds but little to the value of the book.

In chapter XIV. is given a description of a single alternating current motor that does not depend upon the production of two currents from one, and another chapter shows a similar motor with a condenser in circuit, which points to Mr. Tesla as one of the earliest users of this device.

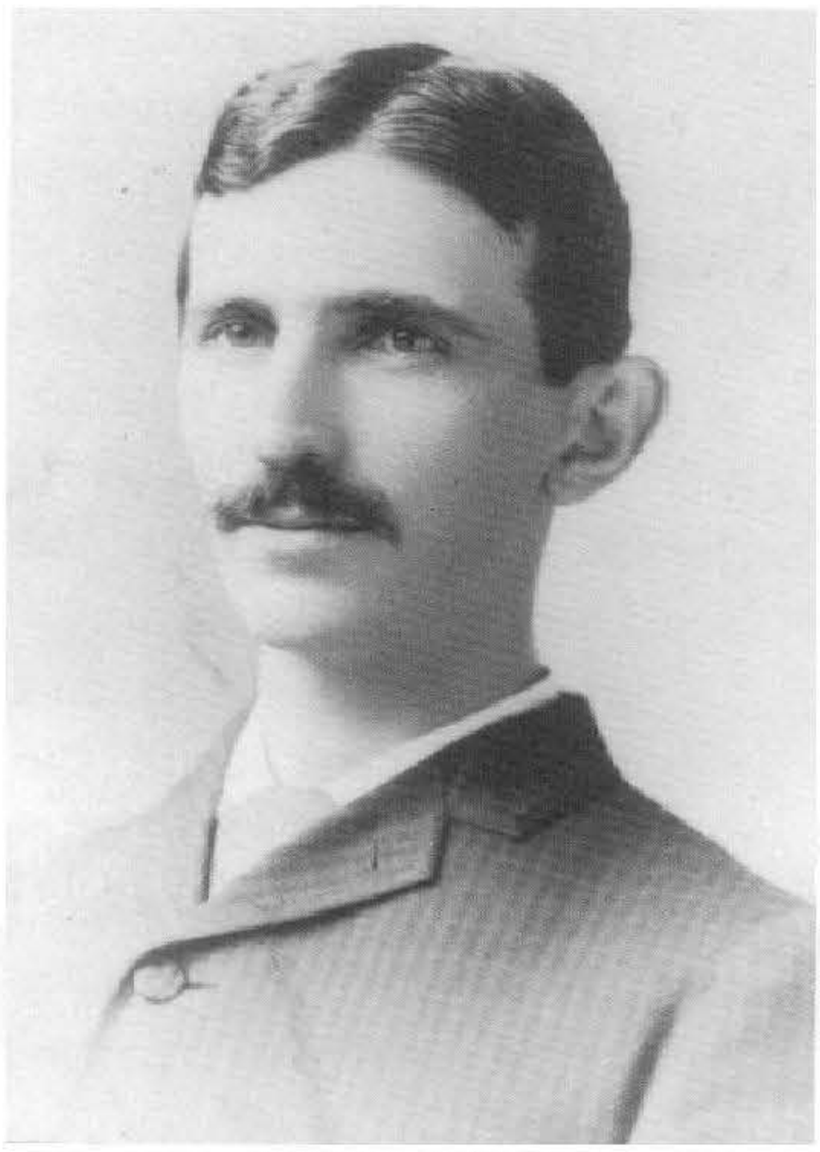
One cannot resist the conclusion, however, that this part of the work is a little padded with the only ostensible purpose of showing what a lot of inventions Mr. Tesla has made, and the reader is tempted to wish he had not invented so much.

In Part II., devoted to high frequency effects, we have to consider an entirely different order of work, which may be properly classed as pure science, for there is scarcely a practical effect described in the many pages given to the three lectures.

In this work the purpose in view has apparently been to establish by experimental process the identical character of light and some form of electrical manifestation of energy. In attempting this proof, Mr. Tesla has doubtless given new evidence in favor of the electro-magnetic theory of light, which theory, of course, preceded his work.

In his endeavor to obtain a very high frequency, Mr. Tesla doubtless started with the notion of setting matter into vibration at a rate approximating that of light, with the expectation that under such violent molecular agitation it would emit light. It is left to be inferred that so high a frequency is scarcely possible of attainment, while a much lower one under favorable conditions produces the desired effects. The investigation of these conditions constitutes a large part of the three lectures, which are sometimes tedious with exhaustive detail; though doubtless essential to a thorough investigation of the problem and invaluable as a guide to further work, these minutiae are not always interesting reading. This fact seems to be appreciated occasionally, and when it is we find a digression in the form of some purely speculative possibility—generally a suggested practical application of the effect under consideration. These are often so purely speculative in character as to be actually amusing.

Seriously speaking, the scientific world to-day believes in



NIKOLA TESLA.

the electro-magnetic theory of light which grows out of fundamental views enunciated by Faraday and elaborated in later years chiefly by Maxwell and Hertz. Mr. Tesla has not touched the mathematical side of this question, and so has added nothing to Maxwell's proof. Hertz established by experimental or physical demonstration the truth of Maxwell's deductions. So, if Mr. Tesla has added something to our scientific knowledge of this subject, it will consist in what he has added to the work of Hertz.

Broadly speaking, however, the Tesla experiments are the same in general results as those performed by Hertz, but are undertaken in a different and entirely original manner and are shown in far greater profusion and variety of effect. Indeed, Tesla's investigation of the electrostatic field, so far as variety of effect is concerned, would seem to leave but little to be desired. Tesla's labor in this direction was simply a long and painstaking investigation, the apparent purpose of which was really to determine what practical use, if any, can electrical science derive from the so-called Hertzian oscillations. If this question must be definitely answered by the Tesla experiments, we are compelled to say that no practical use for such phenomena has yet been shown.

The vacuum tube and light effects produced by rapid al-

ternations of an electro-magnetic or electrostatic field, and the transmission of energy along a single wire without a return lead, are beautiful, and mostly novel exhibitions of what can be done with electric energy under properly arranged conditions, but they are not of practical value in any use that has yet been made of them. They are simply advanced laboratory experiments of great scientific beauty and interest.

The introductory part of one lecture is given to a description of the apparatus used for producing the high frequency effects, and the precautions that must be taken in the arrangement of the parts are carefully pointed out with a view to help the experimenter who desires to follow this line of investigation.

Another is opened with a description of the best form of generator to be used, preference being given to a form of motor dynamo for transforming direct current into an alternating current of low voltage by a simple dynamo conversion. This low voltage alternating current is then changed to high tension by an ordinary converter, and this current, on being passed through the oscillatory transformer, has its frequency raised to something like a million a second.

Introducing another lecture, Mr. Tesla goes into a long digression upon the human eye that deals in nothing but generalities, having little or no bearing upon the subject.

The effects described in these three papers may be classed, for sake of arrangement, as phenomena produced by electrostatic force, dynamic electricity phenomena, and vacuum tube effects. We will consider some of these briefly.

Mr. Tesla claims that all electric and magnetic effects can be traced to the action of electrostatic molecular forces. In fact, he goes much further in one of his speculative digressions and refers everything among Nature's fanciful designs to the action of electrostatic force. His first claim finds some confirmation in a beautiful experiment he describes, in which he produces a veritable flame by the action of electrostatically charged molecules. A flame is thus produced by which, however, no material is consumed. He thinks this experiment gives us a further insight into the nature of an ordinary flame, which he attributes to the electrostatic effects produced by the chemical changes going on.

The experiments in which vacuum tubes are shown glowing brightly by simply being placed in a rapidly alternating electrostatic field are beautiful, but the practical application suggested—of lighting an apartment by simply creating an electrostatic field in the space between the walls and using detached vacuum tubes for lamps that will always be aglow when between the walls—is far from realization, and the reading public should not be left with the impression that anything of the sort has ever been accomplished.

Another very interesting experiment consists in the operation of lamps and motor devices by the discharge from condensers, and he points out methods of transforming or changing the voltage of direct as well as alternating currents by means of condensers, and expresses the hope in this connection of perfecting apparatus by which electricity of high tension may be obtained directly from heat energy itself. No suggestion is, however, given as to what the method is or how the transformation is to be effected. This hazy suggestiveness of great practical ends just in view but never reached becomes at times somewhat unsatisfactory.

Among the most beautiful of this array of experiments is one that illustrates the impedance of a rod or bar of practically no resistance when connected in a circuit to which a very high electromotive force and frequency is applied. Owing to the impedance the current may be shunted around it through a circuit of comparatively high resistance supplied with incandescent lamps that glow brilliantly when their terminals are connected to the bar at points only a few inches apart. It is further shown in this experiment that there are points or nodes on the bar, from which no current can be taken in the manner described, while others differently situated give a high difference of potential, and so marked is this distribution that the points can be readily selected by an ordinary voltmeter or by the lamp circuit itself.

The most surprising of the new facts elicited from these investigations is that the shock due to these very high potential and high frequency discharges can be supported by the person without serious inconvenience. This Mr. Tesla attributes to the fact that the body offers a large cross-section to the high frequency current, which distributes itself uniformly, so that the current density is small at any point of the path. The inference also follows that these currents pass through the human body in much the same manner as a direct current passes through a good conductor. The E. M. F. used in this experiment was about 2×10^5 volts and the frequency near a million a second. With this enormous potential literally in hand Tesla grasps one pole of the high tension transformer and approaches the other to the opposite pole, on nearing which a brush discharge having the appearance of a flame passes from his hand to the free pole. Enlarging upon this phenomenon in his usual style he estimates that with a frequency of four million and an E. M. F. of 3×10^6, his entire person would be enveloped in such a flame, but without danger.

In another beautiful experiment two straight wires are connected to the poles of the high tension transformer and stretched parallel to each other across the room, there being no cross connection between of any kind. When given the high tension current, these wires emit streams of light or brush discharges so profusely that light enough is produced to distinguish objects in the room. If these wires are bent into concentric circles, one inside the other in the same plane, the annular space between them is filled with streamers that make a sheet of light about a metre in area.

Perhaps the most interesting feature of these high frequency phenomena is their apparent capability of operating various sorts of electric devices—even motors of a certain description—and this with only a single wire leading to the source of energy. In one of these illustrations Mr. Tesla is led to say that he thinks it probable these experiments indicate the possibility of operating a motor at any point of the earth's surface from a central source with only an earth connection to the latter. This he hopes to accomplish by causing the electrical charge of the earth to oscillate and by the use of resonance a distant motor is made capable of picking out the current of different rate or frequency that is intended for its consumption or supply. It is probably suggestions of this character that have caused some readers to view Mr. Tesla's work as that of a visionary enthusiast.

It is more important, however, to determine just what Tesla has given in this discussion of high frequency phenomena that is of value—for its value is really quite independent of any views he may hold concerning the possible future applications of electricity.

He has built up a method of experimental investigation of physical phenomena, concerning which much remains to be learned. This method, with its vast array of beautiful experiment, is original and goes some steps beyond the point reached by previous work in this field, which may be defined as the experimental investigation of molecular physics. In all this there is little of practical interest to the electrical engineer. In going into this domain Mr. Tesla left what is commonly called electrical engineering behind and his work in this new field should therefore not be judged by its standards.

To the physicist Mr. Tesla stands a pioneer of a new and wide field of research.

To the electrical engineer he stands the inventor of the

rotary field machine, a brilliant and unique conception, which he soon left for the engineer to elaborate and figure out.

Before the general public he stands a phenomenal inventor from the Eastern World, from whom is expected little less than if he carried Aladdin's lamp in his hand, which, of course, is wrong, and an injustice both to the public and to Mr. Tesla.

Mr. Tesla is a hard and patient worker and has done enough for one decade in producing the rotary motor. He has doubtless much of importance in store for us, but the difference should never be lost sight of between the search for Nature's truths in the laboratory of the physicist and the reduction of the results attained, however great their promise, to a form suitable for commercial use.

PERSONAL

MR. NIKOLA TESLA has been awarded the Elliott-Cresson Medal by the Franklin Institute, of Philadelphia, for his Researches in High Frequency Phenomena.

NEW BOOKS.

Inventions, Researches, and Writings of Nikola Tesla. By THOMAS COMERFORD MARTIN. 8vo, 500 pp. The Electrical Engineer, New York, 1894.

This book for the first time affords the reader an opportunity to make a continuous and consecutive study of Mr. Tesla's work. Mr. Tesla has been more of a student and inventor than a writer and lecturer. He finds the laboratory more congenial than the lecture-room, and takes a much deeper interest in the prosecution of new lines of research and the development of new facts, than in the presentation to the public of the results of his work. As a consequence, Mr. Tesla's lectures and published papers have appeared at irregular and rather long intervals, and are scattered through the technical journals and in separate pamphlets.

Those interested in Mr. Tesla's work are greatly indebted to Mr. Martin for collecting as he has done into one volume all of Mr. Tesla's published papers, and especially for the connecting links and summaries that, as Mr. Tesla's intimate personal friend, he was so well qualified to supply.

The work begins with a brief biographical sketch, and we find that, as usual with great inventors, Mr. Tesla's fertile brain was even, while he was a student, developing new ideas, and it is interesting to note that the germ of the idea of the rotating field was conceived before the beginning of 1880.

Part I. deals with the rotating field apparatus, beginning with Mr. Tesla's paper read before the American Institute of Electrical Engineers in May, 1888. This paper was a revelation, to most of those present at that meeting, of an entirely new departure in alternating current work. The rotating field principle has since become familiar to electrical engineers through the published accounts of experiments conducted in this country and abroad, and numerous workers have entered the field. Simple as the principle seemed when first explained by Mr. Tesla, it was found when the attempt was made to apply it to the construction of large motors, that, contrary to the usual experience with continuous current machines,

the large motors were less efficient than the small ones, especially when operated at high frequencies. With the talent brought to bear upon the subject, sources of loss have been discovered and eliminated, and the motors improved until now they stand nearly on a par in efficiency with continuous current motors.

The chapters which follow in Part I. describe a great variety of forms of rotary field motors. In some the difference of phase is obtained on branches from a single circuit by the proper proportioning of resistance and self-induction. In others, a "magnetic lag" in peculiarly formed polar-projections serves to produce the rotary effort by the use of a single alternating current. Many of these forms could hardly be developed into efficient commercial machines, but they are curious examples of the working of alternating currents, and are especially interesting here as showing the extreme fertility of Mr. Tesla's mind.

Part II. relates to Mr. Tesla's high frequency experiments. In it are published in full Mr. Tesla's three lectures delivered respectively, at New York, May 20, 1891; at London and Paris, 1892; and at Philadelphia and St. Louis in 1893. The lectures are preceded by a review by Mr. Martin.

It is to be regretted that this review is not more discriminating. Instead of pointing out what properly belongs to Mr. Tesla, and what had already been done by other experimenters, he leaves the reader to infer that everything described is Mr. Tesla's work. The claim for novelty of the experiments seems, in some cases, to be unduly exaggerated. The operation of electrical devices by means of one wire is spoken of as though it were something before unheard of; and yet, how does it differ in principle from the old method of measuring the capacity of a condenser by charging it through a galvanometer? One wire from the battery passes through the galvanometer and terminates in the condenser. Close the key, and a current rushes through the galvanometer coil into the condenser and swings the needle. Substitute an alternating potential for the constant potential of the battery, and an alternating current would flow through the galvanometer coil.

The writer more than ten years ago showed that the needle of a galvanometer would be deflected by the rush of electricity into the coil when a glass rod charged by rubbing with a silk handkerchief was brought to one terminal, the other terminal having no connection with anything whatever. Deflection in the opposite direction was caused by charging the coil through the other terminal. Deflection was also produced by discharging the coil by one of its terminals. The coil used in this experiment was very thoroughly insulated, and held the charge given to it for some time. This was a case of an electrical device actuated through one

connection only, the generator being a glass rod and a silk handkerchief. The writer did not consider it anything wonderful; in fact, it was just what he expected would take place in a coil sufficiently well insulated, and having a sufficient number of convolutions.

How are we to understand the statement on page 120 that Mr. Tesla has demonstrated, that for the production of light-waves, "primarily," electrostatic effects must be brought into play? It does not appear that Mr. Tesla has produced light-waves *primarily*, in any way.

But the writer does not wish to be understood as finding nothing except for criticism in Mr. Martin's summary; far otherwise. The reader will find it an excellent *résumé* of the results portrayed in Mr. Tesla's lectures, and will find it very useful, even after having read the lectures themselves.

Referring to the experiments exhibited by Mr. Tesla in his three lectures, their novelty seems to the writer to consist more in the brilliancy and magnitude of the results than in the development of anything radically new. By this he does not mean in any way to belittle the value of Mr. Tesla's work. His experiments are no less a revelation if they only exhibit old phenomena in a new light, and demonstrate experimentally facts that were before only theoretically known. By means of a high frequency alternating machine, and still further by the extremely rapid Hertzian oscillations, the old induction coil is made to exhibit some wonderfully brilliant phenomena. Geissler tubes glow with unwonted brilliancy. In Crookes' tubes, in place of heating to redness only a tiny piece of platinum, a whole lamp filament or a block of carbon is rendered incandescent. In consequence of the high frequency, great differences in the phenomena are produced by exceedingly small changes in capacity, and many of the experiments strikingly illustrate this fact.

In the title to Mr. Tesla's New York lecture we find that he proposes to deal with high frequency phenomena "and their application to methods of artificial illumination." It is in this last that the practical engineer is specially interested; and the first question that occurs to him is, what is the efficiency of the methods hinted at by Mr. Tesla? [We do not find the methods more than hinted at in these lectures, and there is nowhere any light thrown upon the question of efficiency.] Knowing as we do the losses that accompany the use of high frequencies and high potentials, such as those due to disturbances in surrounding media, and currents in conductors due to their capacity, it would be interesting to learn what method Mr. Tesla may have in view for eliminating these. Mr. Tesla speaks of using an electrostatic screen for a conducting wire, and remarks that such a screen would have the same effect as removing all objects to an infinite distance. The writer does not know of any such screen.

A metallic sheath would serve as a screen only if its own potential were

maintained constant, and that could only be if it were in perfect conducting communication with the earth. The effect of any such sheath, whether connected to earth or not, would increase the capacity of the conductor.

The scheme of lighting by means of isolated vacuum tubes in a rapidly alternating electrostatic field is an attractive one, but the plates forming the boundaries of such a field would have considerable capacity. To charge them to a potential of a hundred thousand volts would require a considerable quantity of electricity, and if this charge were reversed many thousand times per second, the transfer of that quantity of electricity would mean a considerable current, and this current would be continually flowing whether any work were being done or not.

To be efficient it would be necessary that the capacity of the system when the lights were not in use should be extremely small, and should be largely increased by bringing them into action. Is it likely that such a relation could be achieved?

In the single wire distribution about which so much is said in the lectures, the result is only reached by a very accurate adjustment of frequency, potential, and capacity. Supposing the question of efficiency settled, would not such a system still be inapplicable for an extended distribution where lamps are to be turned on and off, on account of the nicety of the adjustments required? Would not the balance be destroyed with every lamp turned off or on. Is it not true that in any system involving the use of very high potentials and high frequencies capacity becomes a most important factor, and that small changes in capacity may interfere seriously with the working of the system?

In closing his London lecture Mr. Tesla tells us that his screened cables will not be made, "for ere long intelligence — transmitted without wires — will throb through the earth like a pulse through a living organism." But how many people could use the earth at once? Would not the telephone girls' frequent answer, "line in use," have to be accepted in that case as at least plausible?

In the Franklin Institute lecture a number of pages are given to the subject of resonance. The writer is not sure that he understands fully the statements and illustrations in that part of the lecture, and will only refer to one or two points.

The statement that "pure" resonance effects are impossible in nature evidently means simply that motion as we have to deal with it cannot be maintained without the constant consumption of energy. This is a fact perfectly well known, and is, of course, true of vibratory motion as well as of any other.

A body acted on by a force ceases to increase in velocity when the

resistances it meets with equal the force applied. A vibrating body kept in motion by successive small impulses derived from another body which vibrates in unison with it, which is all there is of resonance, ceases to increase in vibration when the resistances it meets with equal the impulses, or, in other words, when the loss of energy during each vibration is equal to the energy received during the same time. If the energy of the receiver is employed for some useful purpose, it must, of course, receive from the original vibrating body as much energy as is used; otherwise it will cease to vibrate.

When Mr. Tesla says that in "electrical vibration it is of enormous importance to arrange the conditions so that the vibration is effected with the greatest freedom," it is the same as saying that the waste of energy must be reduced to a minimum, and this is just as true when electrical energy is transferred in other ways.

It is also just as important that the transfer should be efficiently effected.

The case of the resonant tuning-forks, where one is sounded and imparts its vibrations to all the surrounding air, a small portion of which air imparts its vibration to the other fork, is an example of a very inefficient way of transferring energy. The energy of the first fork is mainly frittered away in imparting useless vibration to the surrounding air. If the energy of the first fork could be efficiently transferred, the vibration of the second might be maintained in mercury, and if agitation of the mercury were the object to be attained, it might be efficiently effected; and yet the means of transferring the energy from one fork to the other might be such that no effective vibration could be imparted unless the two forks were tuned to unison.

In short, when energy is to be transmitted by means of periodic motions, it may be desirable or convenient to use receivers having a definite vibration period of their own, in which case they must be adjusted to unison with the generator; but the use of such receivers does not increase or diminish the necessity of observing the other conditions of efficient transformation; viz. that as little energy as possible should be used outside of the receivers, and that in the receivers as little energy as possible should be consumed except for the useful purpose. In any case the use of resonant receivers introduces a new difficulty, that of adjusting them to unison, and maintaining unison under the varying demands for energy by the consumers.

Now it seems to the writer that in the transmission of energy electrically by means of high frequency and high potential currents the difficulties in preventing losses are greatly increased; and although, by the use of such high potentials, light may be obtained by means of discharges through

rarefied gases without the accompaniment of so large a proportion of energy in the form of dark heat, yet the losses in the use of electrical energy in this form, and applied in this way, seem to much more than counterbalance the efficiency of the luminous source itself.

As has been already said, Mr. Tesla has devised some wonderfully brilliant and striking experiments illustrative of the action of high potential and high frequency currents, but when it comes to the application of these to artificial illumination he is silent upon the all-important question of efficiency, and from such information as we have, it would seem that very little progress had been made toward any reasonable result in that direction.

Part III. treats of miscellaneous inventions. These are of interest as showing the diversified character of Mr. Tesla's work. Some of them show great ingenuity, but probably there are few of them to which Mr. Tesla would to-day attach any practical value.

Part IV. relates to Mr. Tesla's World's Fair exhibit, and to the oscillator, which was made the subject of the lecture before the members of the Electrical Congress.

The personal exhibit was itself a very interesting one, showing as it did, the progress of Mr. Tesla's work, especially in the development of the rotating field apparatus. The reader will be glad to find embodied here brief but excellent descriptions of the separate pieces of apparatus there exhibited.

The oscillators shown by Mr. Tesla at the Congress lecture were very ingeniously designed, and would no doubt give a fairly uniform vibration under varying loads; but the claim that the vibrations would be so uniform under all conditions, that a clock actuated by the apparatus "would keep absolutely correct time" is probably not intended to be taken literally. The apparatus appears to be an excellent one for the production of alternating currents whose frequency can be accurately known, and it may serve an excellent purpose in experiments and investigations, and perhaps for telegraphy, but the writer is unable to feel that confidence in the great future of this apparatus that he felt in that of the rotating field motors when they were first explained to him in Mr. Tesla's laboratory.

The chapter devoted to the oscillators in this volume is very brief, and does not describe very fully the oscillators themselves, or the apparatus used in connection with them.

The work of Mr. Tesla described in this volume covers a period of hardly eight years. In that time the rotating field principle was developed, and a multitude of different forms of motors embodying the principle were built. The high frequency alternators, induction coils, condensers, lamps, vacuum tubes, etc., etc., have all been developed through successive

experimental failures, and the immense variety of apparatus shown in successful operation on the occasion of the three lectures on high frequency phenomena are only a tithe of the instruments and apparatus built. All this shows not only Mr. Tesla's wonderful fertility, but his industry and perseverance as well. The writer understands that it is wholly his own work; the few assistants employed by him in his laboratory being only mechanics who could give him no help in the development of the apparatus. Few men can point to more work accomplished in so short a time.

WILLIAM A. ANTHONY.

Century Magazine May 1894

ZMAI IOVAN IOVANOVICH.

THE CHIEF SERVIAN POET.

HARDLY is there a nation which has met with a sadder fate than the Servian. From the height of its splendor, when the empire embraced almost the entire northern part of the Balkan peninsula and a large portion of the territory now belonging to Austria, the Servian nation was plunged into abject slavery, after the fatal battle of 1389 at the Kosovo Polje, against the overwhelming Asiatic hordes. Europe can never repay the great debt it owes to the Servians for checking, by the sacrifice of their own liberty, the barbarian influx. The Poles at Vienna, under Sobieski, finished what the Servians attempted, and were similarly rewarded for their service to civilization.

It was at the Kosovo Polje that Milosh Obilich, the noblest of Servian heroes, fell, after killing the sultan Murat II. in the very midst of his great army. Were it not that it is a historical fact, one would be apt to consider this episode a myth, evolved by contact with the Latin and Greek races. For in Milosh we see both Mucius and Leonidas, and, more than this, a martyr, for he does not die an easy death on the battle-field like the Greek, but pays for his daring deed with a death of fearful torture. It is not astonishing that the poetry of a nation capable of producing such heroes should be pervaded with a spirit of nobility and chivalry. Even the indomitable Marko Kraljevich, the later incarnation of Servian heroism, when vanquishing Musa, the Moslem chief, exclaims, "Woe unto me, for I have killed a better man than myself!"

From that fatal battle until a recent period, it has been black night for the Servians, with but a single star in the firmament — Montenegro. In this gloom there was no hope for science, commerce, art, or industry. What could they do, this brave people, save to keep up the weary fight against the oppressor? And this they did unceasingly, though the odds were twenty to one. Yet fighting merely satisfied their wilder instincts. There was one more thing they could do, and did: the noble feats of their ancestors, the brave deeds of those who fell in the struggle for liberty, they embodied in immortal song. Thus circumstances and innate qualities made the Servians a nation of thinkers and poets, and thus, gradually, were evolved their magnificent national poems, which were first collected by their most prolific writer, Vuk Stefanovich Karajich, who also compiled the first dictionary of the Servian tongue, containing more than 60,000 words. These national poems Goethe considered fit to match the finest productions of the Greeks and Romans. What would he have thought of them had he been a Servian?

While the Servians have been distinguished in national poetry, they have also had many individual poets who attained greatness. Of contemporaries, there is none who has grown so dear to the younger generation as Zmai Iovan Iovanovich. He was born in Novi Sad (Neusatz), a city at the southern border of Hungary, on November 24, 1833. He comes from an old and noble family, which is related to the Servian royal house. In his earliest childhood he showed a great desire to learn by heart the Servian national songs which were recited to him, and even as a child he began to compose poems. His father, who was a highly cultivated and wealthy gentleman, gave him his first education in his native city. After this he went to Budapest, Prague, and Vienna, and in these cities he finished his studies in law. This was the wish of his father, but his own inclinations prompted him to take up the study of medicine. He then returned to his native city, where a prominent official position was offered him, which he accepted, but so strong were his poetical instincts that a year later he abandoned the post to devote himself entirely to literary work.

His literary career began in 1849, his first poem being printed in 1852, in a journal called "Srbski Letopis" ("Servian Annual Review"); to this, and to other journals, notably "Neven" and "Sedmica," he contributed his early productions. From that period until 1870, besides his original poems, he made many beautiful translations from Petefy and Arany, the two greatest of the Hungarian poets, and from the Russian of Lermontof, as well as from German and other poets. In 1861 he edited the comic journal, "Komarac" ("The Mosquito"), and in the same year he started the literary journal, "Javor," and to these papers he contributed many beautiful poems. He had married in 1861, and during the few happy years that followed he produced his admirable series of lyrical poems called "Giulichi," which probably remain his masterpiece. In 1862, greatly to his regret, he discontinued his beloved jour-

nal, "Javor"—a sacrifice which was asked of him by the great Servian patriot, Miletich, who was then active on a political journal, in order to insure the success of the latter.

In 1863 he was elected director of an educational institution, called the Tekelianum, at Budapest. He now ardently renewed the study of medicine at the university, and took the degree of doctor of medicine. Meanwhile he did not relax his literary labors. Yet, for his countrymen, more valuable even than his splendid productions were his noble and unselfish efforts to nourish the enthusiasm of Servian youth. During his stay in Budapest he founded the literary society Preodnica, of which he was president, and to which he devoted a large portion of his energies.

In 1864 he started his famous satirical journal, "Zmai" ("The Dragon"), which was so popular that the name became a part of his own. In 1866 his comic play "Sharan" was given with great success. In 1872 he had the great pain of losing his wife and, shortly after, his only child. How much these misfortunes affected him is plainly perceptible from the deeply sad tone of the poems which immediately followed. In 1873 he started another comic journal, the "Ziza." During the year 1877 he began an illustrated chronicle of the Russo-Turkish war, and in 1878 appeared his popular comic journal, "Starmali." During all this period, he wrote not only poems, but much prose, including short novels, often under an assumed name. The best of these is probably "Vidosava Brankovicheva." In recent years he has published a great many charming little poems for children.

Since 1870 Zmai has pursued his profession as a physician. He is an earnest advocate of cremation, and has devoted much time to the furtherance of that cause. Until recently he was a resident of Vienna, but now he is domiciled in Belgrade. There he lives the life of a true poet, loving all and beloved by everybody. In recognition of his merit, the nation has voted him a subvention.

The poems of Zmai are so essentially Servian that to translate them into another tongue appears next to impossible. In keen satire free from Voltairian venom, in good-hearted and spontaneous humor, in delicacy and depth of expression, they are remarkable. Mr. Johnson has undertaken the task of versifying a few of the shorter ones after my literal and inadequate readings. Close translation being often out of the question, he has had to paraphrase, following as nearly as possible the original motives and ideas. In some instances he has expanded in order to complete a picture or to add a touch of his own. The four poems which follow will give some idea of the versatility of the Servian poet, but come far short of indicating his range.

Nikola Tesla

PARAPHRASES FROM THE SERVIAN.[1]

AFTER ZMAI IOVAN IOVANOVICH.

THE THREE GIAOURS.

IN the midst of the dark and stormy night
Feruz Pacha awakes in fright,
And springs from out his curtained bed.
The candle trembles as though it read
Upon his pallid face the theme
And terror of his nightly dream.

He calls to his startled favorite:
"The keys! the keys of the dungeon pit!
Cannot those cursèd Giaours stay
There in their own dark, rotting away,
Where I gave them leave three years ago?
Had I but buried their bones! — but, no!
They come at midnight to clatter and creep,
And haunt and threaten me in my sleep."

"Pacha, wait till the morning light!
Do not go down that fearful flight
Where every step is a dead man's moan!
Mujo to-morrow will gather each bone
And bury it deep. Let the Giaours freeze
If thy bed be warm."

"Nay, give me the keys.
Girl, you talk like a wrinkled dame
That shudders at whisper of a name.
When they were living, their curses made
A thousand cowards: was I afraid?
Now they are dead, shall my fear begin
With the Giaour's curse, or the skeleton's grin?
No, I must see them face to face
In the very midst of their dwelling-place;
And ask what need they have of me
That they call my name eternally."

As groping along to the stair he goes
The light of the shaking candle shows
A face like a white and faded rose;
But if this be fear, it is fear to stay,
For something urges him on his way —
Though the steps are cold and the echoes mock —
Till the right key screams in the rusted lock.

Ugh! what a blast from the dungeon dank! —
From the place where Hunger and Death were wed;
Whence even the snakes by instinct fled,
While the very lizards crouched and shrank
In a chill of terror. 'T is inky black,

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And icy cold, but he cannot go back,
For there, as though the darkness flowers —
There sit the skeletons of three Giaours
Ghost-white in the flickering candle-gleam! —
(Or is it the remnant of his dream?)
About a stone that is green with mold
They sit in a group, and their fingers hold
Full glasses, and as the glasses clink
The first Giaour beckons him to drink.

"Pacha, here is a glass for thee!
When last on me the sunlight shone
I had a wife who was dear to me.
She was alone — no, not alone;
The blade in her hand was her comrade true,
As she came to your castle, seeking you.

"And when she came to your castle gate
She dared you forth, but you would not go.
Fiend and coward, you could not wait
For a woman's wrath, but shot her, so.
Her heart fell down in a piteous flood.
This glass is filled with her precious blood.

"See how fine as I hold it up!
Drink, Feruz Pacha, the brimming cup!"

Spellbound the Pacha now draws nigh;
He empties the glass with a sudden cry:
The skeletons drink with a laugh and toss,
And they make the sign of the holy cross.

Then speaks the second of the dead:

"When to this darkness I was led,
My mother asked, 'What sum will give
Your prisoner back to the sun?' You said,
'Three measures of gold, and the dog shall live.'
Through pinching toil by noon and night
She saved and saved till her hope grew bright.

"But when she brought you the yellow hoard,
You mocked at the drops on her tired brow,
And said, 'Toward the pay for his wholesome board
Of good round stones I will this allow.'
She died while her face with toil was wet.
This glass is filled with her faithful sweat.

"See how fine as I hold it up!
Drink, Feruz Pacha, the brimming cup!"

Haggard the Pacha now stands by;
He drains the glass with a stifled cry:
Again they drink with a laugh and toss,
And the third one says, as his comrades cross:

"When this black shadow on me fell,
There sang within my mountain home
My one pale lad. Bethought him well
That he would to my rescue come;
But when he tried to lift the gun
He tottered till the tears would run.

"Though vengeance sped his weary feet,
Too late he came. Then back he crept,—
Forgot to drink, forgot to eat,—
And no slow moment went unwept.
He died of grief at his meager years —
This glass is laden with his tears.

"See how fine as I hold it up!
Drink, Feruz Pacha, the brimming cup!"

The Pacha staggers; he holds it high;
He drinks; he falls with a moan and cry:
They laugh, they cross, but they drink no more —
For the dead in the dungeon-cave are four.

THE GIPSY PRAISES HIS HORSE.

You 're admiring my horse, sir, I see.
He 's so light that you 'd think it 's a bird,
Say a swallow. Ah, me!
He 's a prize!
It 's absurd
To suppose you can take him all in as he passes
With the best pair of eyes,
Or the powerful aid
Of your best pair of glasses:
Take 'em off, and let 's trade.

What! "Is Selim as good as he seems?"
Never fear,
Uncle dear,
He 's as good as the best of your dreams,
And as sound as your sleep.
It 's only that kind that a gipsy would keep.
The emperor's stables can't furnish his mate.
But his grit and his gait,
And his wind and his ways,
A gipsy like me does n't know how to praise.
But (if truth must be told)
Although you should cover him over with gold
He 'd be worth one more sovereign still.

"Is he old?"
Oh, don't look at his teeth, my dear sir!
I never have seen 'em myself.
Age has nothing to do with an elf;
So it 's fair to infer
My fairy can never grow old.
Oh, don't look — (Here, my friend,
Will you do me the kindness to hold
For a moment these reins while I 'tend
To that fly on his shanks?) . . .
As I said — (Ah — now — thanks!)
The longer you drive
The better he 'll thrive.
He 'll never be laid on the shelf!
The older that colt is, the younger he 'll grow.
I 've tried him for years, and I know.

"Eat? Eat?" do you say?
Oh, that nag is n't nice
About eating! Whatever you have will suffice.
He takes everything raw —
Some oats or some hay,
Or a small wisp of straw,
If you have it. If not, never mind —
Selim won't even neigh.
What kind of a feeder is he? That 's the kind!

"Is he clever at jumping a fence?"
What a question to ask! He 's immense
At a leap!
How absurd!
Why, the trouble 's to keep
Such a Pegasus down to the ground.
He takes every fence at a bound
With the grace of a bird;
And so great is his strength,
And so keen is his sense,
He goes over a fence
Not across, but the way of its length!

"Under saddle?" No saddle for Selim!
Why, you 've only to mount him, and feel him
Fly level and steady, to see
What disgrace that would be.
No, you could n't more deeply insult him, unless
You attempted to guess
And pry into his pedigree.

Now why should you speak of his eyes?
Does he seem like a horse that would need
An eye-glass to add to his speed

Or, perchance, to look wise?
No, indeed.
Why, not only 's the night to that steed
Just the same as the day,
But he knows all that passes —
Both before and behind, either way.
Oh, he does n't need glasses!

"Has he any defect?" What a question, my friend!
That is why, my dear sir, I am willing to sell.
You know very well
It is only the horse that you give or you lend
That has glanders, or springhalt, or something to mend:
'T is because not a breath
Of defect or of death
Can be found on my Selim that he 's at your pleasure.
Alas! not for gipsies the care of such treasure.

And now about speed. "Is he fast?" I should say!
Just listen — I 'll tell you.

One equinox day,
Coming home from Erdout in the usual way,
A terrible storm overtook us. 'T was plain
There was nothing to do but to run for it. Rain,
Like the blackness of night, gave us chase. But that nag,
Though he 'd had a hard day, did n't tremble or sag.
Then the lightning would flash,
And the thunder would crash
With a terrible din.
They were eager to catch him; but he would just neigh,
Squint back to make sure, and then gallop away.
Well, this made the storm the more furious yet,
And we raced and we raced, but he was n't upset
And he would n't give in!
At last when we got to the foot of the hill
At the end of the trail,
By the stream where our white gipsy castle was set,
And the boys from the camp came a-waving their caps,
At a word he stood still,
To be hugged by the girls and be praised by the chaps.
We had beaten the gale,
And Selim was dry as a bone — well, perhaps,
Just a little bit damp on the tip of his tail.[1]

MYSTERIOUS LOVE.

INTO the air I breathed a sigh;
She, afar, another breathed —
Sighs that, like a butterfly,
Each went wandering low and high
Till the air with sighs was wreathed.

When each other long they sought,
On a star-o'er-twinkled hill
Jasmine, trembling with the thought,
Both within her chalice caught,
A lover's potion to distil.

Drank of this a nightingale,
Guided by the starlight wan —
Drank and sang from dale to dale,
Till every streamlet did exhale
Incense to the waking dawn.

Like the dawn, the maiden heard;
While, afar, I felt the fire
In the bosom of the bird;
Forth our sighs again were stirred
With a sevenfold desire.

These we followed till we learned
Where they trysted; there erelong
Their fond nightingale returned.
Deeper then our longings burned,
Deeper the delights of song.

Now, when at the wakening hour,
Sigh to sigh, we greet his lay,
Well we know its mystic power —
Feeling dawn and bird and flower
Pouring meaning into May.

Jasmine, perfume every grove!
Nightingale, forever sing
To the brightening dawn above
Of the mystery of love
In the mystery of spring!

TWO DREAMS.

DEEP on the bosom of Jeel-Begzad
(Darling daughter of stern Bidar)
Sleeps the rose of her lover lad.
It brings this word: When the zenith-star
Melts in the full moon's rising light,
Then shall her Giaour come — to-night.

What is the odor that fills her room?
Ah! 't is the dream of the sleeping rose:
To feel his lips near its velvet bloom
In the secret shadow no moonbeam knows,
Till the maiden passion within her breast
Kindles to flame where the kisses rest.

By the stealthy fingers of old Bidar
(Savage father of Jeel-Begzad)
Never bloodless in peace or war
Was a handjar sheathed; and each one had
Graved on its handle a Koran prayer —
He can feel it now, in his ambush there!

The moon rides pale in the quiet night;
It puts out the stars, but never the gleam
Of the waiting blade's foreboding light,
Astir in its sheath in a horrid dream
Of pain, of blood, and of gasping breath,
Of the thirst of vengeance drenched in death.

. . .

The dawn did the dream of the rose undo,
But the dream of the sleeping blade came true.

Robert Underwood Johnson.

[1] Readers will be reminded by this conclusion of Mark Twain's story of the fast horse as told to him by Oudinot, of the Sandwich Islands, and recorded in "The Galaxy" for April, 1871. In that veracious narrative it is related that not a single drop fell on the driver, but the dog was swimming behind the wagon all the way.



PERSONAL

MR. NIKOLA TESLA had the degree of LL.D. conferred upon him by Columbia College at the commencement exercises on June 13th. It will be remembered that it was at Columbia College, in 1891, before the American Institute of Electrical Engineers, that Mr. Tesla delivered the first of his brilliant series of lectures on his remarkable experiments with currents of high potential and high frequency.

NIKOLA TESLA AND HIS WORKS.

By Lieut. F. Jarvis Patten.

In this age of practical endeavor, when everything is turned to its immediate use with the least delay possible, a life like that of Tesla, devoted to scientific research for the love of it, stands out in peculiar and interesting prominence. Such a character, however, is the natural outcome of the rapid advance in all material investigation, which has become so broad, and goes into so many different fields of research, that few workers attain to general prominence.

The last decade pays tribute to two names that have added something to our knowledge and better comprehension of nature's methods. These names are Hertz and Tesla. Hertz gave promise of showing the ultimate law that connects matter separated by space. The work so well begun was ended by his untimely death. Maxwell had shown that all of nature's reacting forces can be expressed by methods of mathematical analysis, and clearly formulated by the terms of an equation. By purely empirical methods Hertz gave physical proof of the truth of Maxwell's theoretical deductions, and so connected pure theory to practical fact.

Out of both pure theory and physical research came the general conclusion, that all manifestations of energy are but the different tangible or apparent evidences of one and the same force; that all energy, whatever its form of manifestation, is simply molecular agitation of greater or less degree. If that be true, then heat and light are merely the results of molecular agitation, and could this agitation be set up by purely mechanical means, heat or light would result.

Tesla conceived the bold idea that, by causing matter to pass to the stage of luminous vibration, without remaining for any appreciable time in the stage of heat vibration, it would produce light without heat; and so near has he come to the practical accomplishment of this conception that he

has set the scientific minds of all Europe thinking, and placed his name beside that of Hertz.

Tesla comes from Herzegovina, near the Western borderland of Turkey, and in early youth was a pupil of the government schools where he lived. Later, he held government office as a collector of statistics. His twenty-third year found him in Paris, whither he had come to study engineering at the École Polytechnique. From this school he went to the Edison Station in Paris as an engineer, where his ability was quickly recognized, and he was soon persuaded to come to this country. Here a place was found for him in the celebrated Edison laboratory. He remained in this position a few years, but, having many ideas that he wished to develop independently, he left that employ, and has since conducted a laboratory of his own in New York City, which has been devoted purely to physical research and scientific investigation.

Thirteen years' residence in this country has not deprived Tesla of his cosmopolitan character and disposition. Master of five or six languages and a devotee to broad science, he is truly a citizen of the world, a genial host and charming companion. What first brought him into prominence and gave him the means to go further, was his discovery of the "Rotary Field Motor," an invention of marked originality and beauty, but not appreciated at its full value at the time of its discovery. Announced by him and commercially disposed of in 1888, it is now just coming into general use. Simple and beautiful as it seemed, our knowledge of electrical engineering was not then equal to the task of making the machine electrically right. European engineers, however, held to the work, and, following in their footsteps, we now understand the rotary field motor, and the largest electrical enterprise in the world, the fifty thousand horse-power plant for sending the power of Niagara to light Buffalo and other distant towns, will use the multiphase system that Tesla first gave to the engineering world six years ago.

An apt illustration of the difference between the purely theoretical or scientific mind, and the semi-practical mind

guided by scientific training, suggests itself here. Professor Ferraris, of Turin, independently discovered and announced the principle and operation of the rotary field motor at about the time that Tesla did the same thing in this country. The professor's announcement was in the form of a paper to a scientific society. Tesla made many forms of the machine, reduced his theory to a practical operative device, and, having protected his invention by many patents, he exhibited his machines to the American Institute of Electrical Engineers in May, 1888. Professor Ferraris's description, however, antedates Tesla's exhibition by some months. It is worthy of remark in passing, that three of the epoch making inventions in electrical advance are of Italian origin. I refer to the chemical element, or Volta's pile; the first direct current generator invented by Pacinotti, and left in obscurity for years; and last, but greatest of all for the coming era of long distance power transmission, the rotary field engine of Ferraris and Tesla.

Before considering Tesla's more recent work, it seems appropriate to describe briefly the salient features of this machine, which can be best done by comparing it with the ordinary type of electric motor. This, in general terms, is an engine having a fixed and a revolving part, of which the latter, turning about its spindle, communicates motion to other machinery. The moving part is always provided with commutating devices that constantly shift the magnetic axis backward, in the same measure and degree that the moving part turns forward. These devices are always intricate and complex. They are, in fact, the weak point of all electric engines. The Tesla rotary field machine, being entirely free from them, is a marvel of simplicity and ingenuity. To understand this machine, one must picture a circular iron ring, and conceive it to be magnetized along a vertical diameter, North Pole at the top; then, a moment later, along a horizontal diameter, with the North Pole at the right; again along the vertical diameter, but North Pole at the bottom; and lastly on the horizontal line again, with North Pole at the left, thus completing a revolution of the North Pole around

the ring. Such an effect is called a rotating magnetic field, and can be perfectly produced by the simultaneous use of two independent alternating currents, which follow each other periodically in such a way that one has always a maximum value or strength when the other is zero, and conversely. If now the iron ring is wound all around with a coil of wire closed on itself, and one such current be introduced to this winding at the extremities of a vertical diameter, while another is simultaneously introduced to the same winding at the extremities of a horizontal diameter, they will jointly produce a revolving magnetic field that turns continuously around the ring, while the latter remains fixed in space. We then have a fixed magnet, but the magnetism itself, or magnetic axis, is in motion. A compass or magnetic needle suspended freely inside the ring would spin around in its endeavor to follow the revolving magnetism or the shifting magnetic axis of the ring.

Tesla delights in surprises for the public. He generally brings a new line of development to fair completion before giving it any public exhibition. The rotary field motor was a genuine surprise to the world of electrical engineering in 1888. Nothing more was heard from him for two years, and his motor—talked of awhile as a sort of nine days' wonder—was practically forgotten, while he was at work on other problems, of which no hint was given until his celebrated lecture at Columbia College, in the spring of 1890. In this lecture he exhibited for the first time his wonderful "high frequency effects," and certainly gave the scientific world some promise of obtaining light without heat, although this accomplishment was far from fruition at the time, and I believe is now abandoned as hopeless on the lines attempted. Still, his researches developed many new and surprising effects, which, aside from their purely laboratory interest, may have a certain commercial value. In these researches, which constitute an investigation of what have now come to be known as "The Tesla Effects," it was his aim and purpose to establish by experimental process the identity of light and some form of electrical manifestation ot

energy, and he gave to science much evidence of the electro-magnetic theory of light that was new, though the theory, of course, had preceded his work, having been enunciated by Maxwell from purely theoretical deductions, and proven by Hertz by empirical methods.

Mr. Tesla started with the idea of setting matter into vibration at a rate approximating that of light (some two and a half millions a second), with the expectation that under such violent molecular agitation it would emit light. He has not as yet succeeded in obtaining so high a rate, but a much lower one produced some very surprising luminous effects. The general plan at first was this: To construct an alternating current dynamo that would produce this high rate of current alternation or pulsation. This current, now known as the "high frequency" current, will cause luminous effects in different media. Thus, in a darkened room, a bare copper wire conveying such a current will be seen to glow, and vacuum tubes will shine brightly, as a result of a molecular bombardment or agitation of the ether atoms, when such a current is sent through them under very high pressure—the very high electro-motive force of several hundred thousands of volts being used in most of his experiments of this character. The dynamo method for getting very high frequencies was soon abandoned as inadequate, and the oscillatory discharge of a Leyden jar or plate condensers was substituted. This answered much better, although the frequency was then an unknown quantity and quite beyond control; and this departure led to the discovery of some very beautiful electro-static effects, which are still being pushed by many investigators with the hope of arriving at some result of commercial value.

As soon as news of Tesla's first lecture, and the experiments there shown, reached the other side of the Atlantic, he was at once invited by various scientific societies of Europe to deliver his lecture and perform his experiments before them. This he soon did; and the scientific minds of Europe were quickly at work investigating the so-called Tesla effects, the result being that the electro-magnetic theory of light may

be regarded as proven, while it seems equally well-established that light without heat is not to be looked for as an outcome of the Tesla effects. A beautiful and startling exhibition of what can be done with electric energy, under properly arranged conditions, is that of causing vacuum tubes or partially exhausted bulbs to glow by merely holding them between two metallic plates (about four feet square, and two or three yards apart), which are made the terminal poles of a circuit conveying a high frequency and high voltage current. It was hoped that rooms could be lighted in this way by placing the plates in the walls, where such tubes would glow without any material connection whatever with the source of energy.

Mr. Tesla claims that all electric and magnetic effects are traceable to the action of electro-static molecular forces, and in confirmation of this theory he produces what appears to be a veritable flame by the action of electro-statically charged molecules of gas. A flame is actually shown issuing from the tip of a wand, or from the ends of his fingers, which flame is devoid of heat, and by it no material is consumed. Perhaps the most surprising of the new facts elicited from his investigations is that the shock due to these very high voltage and high frequency currents can be supported by a person without any serious inconvenience. He passes a current of two hundred thousand volts through his body with perfect impunity, whereas one of two thousand volts will produce almost certain death from even a momentary shock. In one experiment, two wires are stretched parallel to each other across the room. When given the high tension current they emit streams of light, or brush discharges so profusely that light enough is produced to distinguish objects in the room. If the wires are bent into concentric hoops, one inside the other in the same plane, the annular space between them is filled with streamers that make a sheet of flame a yard or more in area.

Mr. Tesla is viewed by some as an impractical inventor—a mere visionary enthusiast—but this is hardly fair to one who has built up an entirely novel method for the experimental investigation of physical phenomena. This method, with its vast array of beautiful experiments, is original, and goes

some steps beyond any point reached by previous work in the same line. There seems to be little of practical value in it for the electrical engineer. So we may say, that to the physicist Mr. Tesla stands as the pioneer of a new and wide field of research, while before the practical man of electricity he stands as the inventor of the "rotary field machine," a beautiful and unique conception, which he soon left for the practical man to figure out.

Before the general public he stands as a phenomenal inventor from the Eastern World, from whom is expected little less than if he carried Aladdin's lamp in his hand. This view of the matter, of course, is wrong, and is an injustice both to the public and the inventor. Mr. Tesla is a hard and patient worker, and did enough for one decade in producing the rotary motor. He has doubtless much yet in store for us, but the difference should never be lost sight of between the work of the empirical physicist searching for nature's truths, and the reduction of a single result to a form for commercial use.

College Notes.

YALE UNIVERSITY.

At the commencement exercises on June 27th, Yale Uuiversity conferred on Mr. Nikola Tesla the honorary degree of M.A. It will ba remembered that Columbia College made Mr. Tesla an LL.D. two weeks ago.

THE WORLD.

NEW YORK, SUNDAY, JULY 22, 1894.

OUR FOREMOST ELECTRICIAN

The Wonderful Discoveries and Daring Theories of Nikola Tesla, as Told by Him to The World.

GREATER EVEN THAN EDISON.

Hard at Work Experimenting with a New Kind of Light and Promises Wonders That Are Now Undreamed Of by Scientists.

THE ELECTRICITY OF THE FUTURE.

He Predicts It Will Be the Great Labor Saver—Picturesque Personality of a Man Who Is Toying with the Secrets of the Universe.

There is a small country in Europe called Lika, and in that country there is a village of forty houses, called Smiljan.

You have probably never heard of either, but you and many others will live to know about a baby that was born in the village of Smiljan in the country called Lika thirty-seven years ago.

It was probably the usual Slavonic baby, very dark, very nervous and doomed in advance to a dull and wasted life. Lika is really a part of Servia, and Servia had her day long ago. Her men gained fame by fighting and helping the Hungarians to keep Asia out of Europe. Huxley, who thinks seriously, and Oscar Wilde, who is foolish, can enjoy life and London now because those old fighters fought so hard.

Most of Servia's modern babies might as well have avoided the annoyance of birth for all they can ever do in the world, but this baby is an exception.

He was visible yesterday, in his grown-up condition, at Delmonico's. His name is Nikola Tesla. He is the best electrician living, if men who know about electricity may be believed. He is to the average electrician as Horace Greeley is to Bill Nye. He is serious, he is earnest, and in all ways he commands respect.

Every scientist knows his work and every foolish person included in the category of New York society knows his face. He dines at Delmonico's every day. He sits each night at a table near a window. When Ward McAllister, that strange contradiction of the theory that nature abhors a vacuum, wanders in, he sees Nikola Tesla with his head buried in an evening paper.

Every foolish young man who cares for the law of gravitation only because it interferes with jumping fences, every foolish young woman who thinks that there is something new about her two-cent love affair, has seen this serious, owl-faced Servian eating his dinner and thinking about electrical vibrations.

Nikola Tesla is almost the tallest, almost the thinnest and certainly the most serious man who goes to Delmonico's regularly.

VERY THIN, AND VERY TALL.

He has eyes set very far back in his head. They are rather light. I asked him how he could have such light eyes and be a Slav. He told me that his eyes were once much darker, but that using his mind a great deal had made them many shades lighter. I have often heard it said that using the brain makes the eyes lighter in color. Tesla's confirmation of the theory, through his personal experience is important.

He is very thin, is more than six feet tall and weighs less than a hundred and forty pounds. He has very big hands. Many able men do—Lincoln is one instance. His thumbs are remarkably big, even for such big hands. They are extraordinarily big. This is a good sign. The thumb is the intellectual part of the hand. The apes have very small thumbs. Study them and you will notice this.

Nikola Tesla has a head that spreads out at the top like a fan. His head is shaped like a wedge. His chin is as pointed as an ice-pick. His mouth is too small. His chin, though not weak, is not strong enough. His face cannot be studied and judged like the faces of other men, for he is not a worker in practical fields. He lives his life up in the top of his head, where ideas are born, and up there he has plenty of room. His hair is jet black and curly. He stoops—most men do when they have no peacock blood in them. He lives inside of himself. He takes a profound interest in his own work. He has that supply of self-love and self-confidence which usually goes with success. And he differs from most of the men who are written and talked about in the fact that he has something to tell.

WONDERS OF THE FLY.

It is most pleasing to hear this wise man talk about figures that tire the usual brain. Mr. Delmonico and an aged friend were talking to Mr. Tesla when I saw him night before last. Mr. Tesla having had his supper was discussing, by way of relaxation, the number of vibrations of the wing of a certain fly. The fly, of which Mr. Tesla did not know the name, is a fly that flies straight ahead so fast that you can't see him, and flies back in a straight line without any apparent effort.

"That," said Mr. Tesla, "is the strongest living animal, in proportion to his size. He moves his wings about twenty-five thousand times to the second." The aged man who had consented to take a drink with Mr. Delmonico mopped his forehead worriedly, for it was a hot night.

"And that is nothing, from the ordinary point of view," mused the distinguished Mr. Tesla. "You see, if you move your hand ten times in a second and then try to move it one hundred times to the second, it will take a hundred times as much strength to move it ten times as fast. The fly that moves its wings twenty-five times to the second requires twenty-five thousand multiplied by twenty-five thousand times as much force as he would to move them once in a second. That makes him use up about six hundred million times as much force as you might think to move his wings like that." Mr. Delmonico's aged friend said: "Don't talk of such exertion in this weather," and wearily mopped himself out of the place.

When the aged man had gone Mr. Tesla said he could go to sleep floating on the water, and Mr. Delmonico, who is a very handsome young man with a pointed black beard, said that he did not believe sharks ever ate any one up. Mr. Tesla said that was nonsense, for in the lower Danube pikes sometimes had seized men and dragged them beneath the surface. The pikes were four feet long, and became so dangerous that swimming about there was prevented. Mr. Delmonico said he was going to Sharon Springs, and started for the Springs at once.

Mr. Nikola Tesla then talked, at my urgent request, about electricity and the things that he hopes to do.

There is no intention here to give a technical account of Mr. Tesla's past achievements and future ambitions. It would be much too hard to write to begin with, and utterly incomprehensible to almost every one after being written. The idea is to discover the new great electrician thoroughly; to interest Americans in the Smiljan baby's personality, so that they may study his future achievements with proper care.

TESLA'S THEORY OF LIGHT.

Mr. Tesla's biggest undertaking at present—that to which he is devoting his most earnest efforts—is the production of light by the vibrations of the atmosphere. He has no intention of heating a bit of cinder red hot and letting it glow by incandescence. The present incandescent system, compared to the Tesla idea, is as primitive as an ox cart with two solid wooden wheels compared to modern railroading.

The light of the sun, according to Mr. Tesla, is the result of vibrations in 94,000,000 miles of ether which separate us from the centre of this solar system. Mr. Tesla's idea is to produce here on earth vibrations similar to those which cause the sunlight, and thus to give us a light as good as that of the sun, with no danger from clouds or other obstructions. Mr. Tesla has already achieved decided success in this line. He takes in his hand a long bar of glass, which, by vibration alone, lights up into most amazing brilliancy. He himself comes out of his experiments a most radiant creature, with light flaming at every pore of his skin, from the tips of his fingers and from the end of every hair on his head.

In explaining his experiments, Mr. Tesla uses figures calculated to pulverize an ordinary mind.

"It is difficult for me," he said, "to give you an idea that you will readily grasp about this question of vibration. In ordinary life our minds do not deal with the figures that come up in such investigations, but take a 5 and put after it fourteen zeroes; then you will have the number of vibrations which occur in the ether every second and which produce light."

I carried out Mr. Tesla's suggestion, with the following result—500,000,000,000,000.

"All I have to do," said Mr. Tesla, "to duplicate the sunlight is to get this number of vibrations to the second with my machinery on earth. I have succeeded up to a certain point, but am still at work on the task."

THE POWER OF VIBRATION.

I tried in various ways to present in cold writing some notion of what five hundred trillions of vibrations to the second might mean. I didn't succeed very well. The nearest I could was to mention, at Mr. Tesla's suggestion, the following fact: If a mass of metal as big as the Delmonico restaurant, in which we sat, possessing 10,000 times the resisting force of the most finely tempered steel, should be caused to vibrate with one millionth of the rapidity of the light-producing electric vibrations in ether, that mass of metal, 10,000 times harder than steel, would simply vanish into the air like smoke. It would disappear into separate atoms too small to be seen and would never be heard of again.

Electricity in its vibrations, according to Mr. Tesla, has a great advantage over all other things, such as flies' wings and other material bodies. Electricity has no weight, and therefore no opposition is offered to its moving backward and forward freely any number of times to the second.

"It is perfectly easy to prove that electricity weighs nothing," said Mr. Tesla. "I will load you so full of electricity that you can't hold any more and then put you on the finest weighing machine, and you will not find one-thousandth part of an ounce added to your weight."

I ventured to suggest to Mr. Tesla that as a vibrator electricity might meet with serious competition among modern statesmen, but his mind was so serious that he only said: "No statesman could vibrate fast enough to be of any value scientifically."

Before deciding to give Mr. Tesla unlimited space in the greatest newspaper that was ever heard of, I had heard from a dozen reliable sources that there was not the slightest doubt about his being a very great man. Authorities unite in declaring him the very greatest man living in the line of abstract electrical research.

One able electrician told me that there never was such a man for working out purely intellectual problems. Another said he could conceive of nothing more extraordinary than the devotion and admiration for Tesla entertained by all of the young electrical engineers. It is a pitiful thing for a morbidly conscientious writer to find himself booming one not altogether worthy of his periods and climaxes, but I am certain in the case of Mr. Tesla that it is safe to go ahead.

ONE OF HIS DISCOVERIES.

Mr. Tesla discovered the rotating magnetic field. That seems to me, next to his idea of getting light by vibration, the best thing he ever did. The rotating magnetic field is a thing which may be described but not understood. Everybody knows that a magnet will seize a piece of iron and hold it firmly; everybody knows that the magnet must use up force in holding that iron, but of course as long as it holds the iron perfectly still the force is wasted. The piece of iron if left alone would stand still. There is no use in getting a magnet to make it stand still. But Mr. Tesla found that he could get a magnet to use its force in such a way as to cause the piece of iron to spin violently round and round. He can make a wheel at a distance from the source of electro-magnetic force spin round with 10,000 horse-power. He expects to apply this principle in employing the strength of the Niagara Falls electric current. The fact may be mentioned that the Niagara Falls people who have relied upon Tesla to tell them how they may use their power at a distance have adopted his scheme.

This rotating magnetic field struck me as a most impressive discovery. I asked Mr. Tesla whether he didn't think it possible that the spinning, rotary motion of the earth and her fellow planets, commonly attributed to some unexplained primary propulsive force, might be due to the application on a grand scale of his rotating magnetic field idea. I suggested that the sun might be a great magnet, that the five hundred trillion vibrations per second which he spoke of showed considerable electrical power somewhere; that there was a great deal of iron and a powerful lot of electricity in the earth. Mr. Tesla observed that he thought it was dangerous to jump at such conclusions, but he treated my enthusiasm, born of complete ignorance, with a kind toleration, which did much to convince me of his true greatness.

THE SECRET OF ELECTRICITY.

Electricians in general think that Tesla's best work thus far is a machine which has industrial value as a new and more direct agent for producing electrical force. I didn't care much about that compared with the rotating magnetic field, but I asked Mr. Tesla to tell me in as few words as possible just how we get electricity, and why we get it when we do get it. Said Mr. Tesla:

"We get electricity by causing a wire to revolve near a magnet. The stronger the magnet the faster the revolutions of the wire, and the bigger the wire the more electricity.

"Why we get electricity in this way, and what electricity is, are different questions. Every electrician has his theory. I have one which I think I can demonstrate mathematically. There is no accepted explanation of the most extraordinary phenomenon in nature."

Mr. Tesla does not care to see in cold print an account of those things which he hopes to accomplish, or to see accomplished, by means of electricity.

"You would think me a dreamer and very far gone," he said, "if I should tell you what I really hope for. But I can tell you that I look forward with absolute confidence to sending messages through the earth without any wires. I have also great hopes of transmitting electric force in the same way without waste. Concerning the transmission of messages through the earth I have no hesitation in predicting success. I must first ascertain exactly how many vibrations to the second are caused by disturbing the mass of electricity which the earth contains. My machine for transmitting must vibrate as often to put itself in accord with the electricity in the earth."

TOOK 250,000 VOLTS HIMSELF.

Mr. Tesla is the interesting person who, in Philadelphia, before a large gathering, allowed a quarter of a million volts of electricity to go through his body. Having seen Carlyle Harris and one other unfortunate individual instantly killed by the application of less than 2,000 volts, I asked Mr. Tesla if he didn't feel a little worried about taking a current of a quarter of a million volts. Said he:

"I did at first feel apprehensive. I had reasoned the thing out absolutely, nevertheless there is always a certain doubt about the practical demonstration of a perfectly satisfactory theory. My idea of letting this current go through me was to demonstrate conclusively the folly of popular impressions concerning the alternating current. The experiment had no value for scientific men. A great deal of nonsense is talked and believed about 'volts,' &c. A million volts would not kill you or hurt you if the current vibrated quickly enough—say half a million times to the second. Under such conditions the nerves wouldn't respond quickly enough to feel pain."

"You see, voltage has nothing to do with the size and power of the current. It is simply the calculation of the force applied at a given point. It corresponds to the actual pressure per square inch at the end of a water pipe, whether the volume of the water be great or small. A million volts going through you doesn't mean much under proper conditions. Imagine a needle so small that the hole it would make in going through your body would not allow the blood to escape. Imagine it so small that you couldn't even feel it. If you had it put through your arm slowly, that would be, electrically speaking, a very small voltage. If you had it stuck through your arm with great rapidity, going, say, at the rate of a hundred miles a second, that would be very high voltage. Voltage is speed, pressure at a given point. It wouldn't do you any more harm to have a needle shot through your arm very rapidly—that is to say, with high voltage—than it would to put it through slowly. In fact, if it hurt you at all, the slow operation would probably hurt more than the other. The question of danger is simply the size of current, and yet if a big enough current should be turned against you and broken with sufficient rapidity—if it should, so to speak, jerk back and forth an inconceivable number of times to the second—it wouldn't kill you. Whereas, if applied continuously, it would simply burn you up."

ELECTRICITY OF THE FUTURE.

When Mr. Tesla talks about the electrical problems upon which he is really working he becomes a most fascinating person. Not a single word that he says can be understood. He divides time up into billionths of seconds, and supplies power enough from nothing apparently to do all the work in the United States. He believes that electricity will solve the labor problem. That is something for Mr. Debs to ponder while he languishes in his dungeon. It is certain, according to Mr. Tesla's theories, that the hard work of the future will be the pressing of electric buttons. A few centuries from now the criminal instead of working a treadmill or picking oakum will be sentenced to press fifteen electric buttons every day. His fellows, long since disused to work, will look upon his toil with pity and horror.

Mr. Nikola Tesla is to be envied. He owns one of those rare minds which do not absorb trivialities. A computation of the vibrations of a fly's wing is to him what croquet would be to Grover Cleveland—it is play. He can play when he wants to, but he doesn't do it very often.

Mr. Delmonico lowers his voice when he speaks of Mr. Tesla, as Boston cabdrivers used to lower their voices in speaking of John L. Sullivan. He said:

"That Tesla can do anything. We managed to make him play pool one night. He had never played, but he had watched us for a little while. He was very indignant when he found that we meant to give him fifteen points. But it didn't matter much, for he beat us all even and got all the money. There are just a few of us who play for 25 cents, so it wasn't the money we cared about, but the way he studied out pool in his head, and then beat us, after we had practised for years, surprised us."

I talked to this Mr. Tesla of Smiljan until all but one of the lights had gone out and until the feeble daylight found Mr. Delmonico's scrub-ladies scrubbing his marble floor. All that he said was interesting, both the electrical things and the others.

HARD WORK HIS PLEASURE.

He is very proud of his Slavonic race. He believes that the poetry of the Slavs written in Servian and Croatian would surprise the civilized world if it could be presented in widely known languages.

He says that the thin man relies constantly on the food which he eats at the moment. He looks upon good food as most important and feels the strengthening effects of it within twenty minutes. He believes that work never hurts, but that play does.

Nobody, he thinks, can work enough to hurt him.

He thinks that marriage and love interfere with success.

That suppers are very bad for one in New York, but all right in Paris.

He does not believe in telepathy, which is, according to its exponents, a sort of psychical electricity enabling one mind to communicate ideas to another without words. He considers that what is usually taken as an evidence of the existence of telepathy is mere coincidence. But the working of the human mind through observation and reason interests and amazes him, as it well may.

"Suppose I made up my mind to murder you," he said, "in a second you would know it. Now, isn't that wonderful? By what process does the mind get at all this?"

One wise man whom I knew used to say that the scientists with their jumble of laws governing the universe were ignoramuses, and that there weren't more than half a dozen fundamental laws all told. I asked Mr. Tesla what he thought about that.

"I think," said he, "that they could all be reduced to one."

ARTHUR BRISBANE.



NIKOLA TESLA.

Showing the Inventor in the Effulgent Glory of Myriad Tongues of Electric Flame After He Has Saturated Himself with Electricity.

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TESLA AND THE REPORTER.

Nikola Tesla fell under the pen of Arthur Brisbane in last Sunday's New York *World*. Mr. Brisbane is a keen and astute observer and after admitting the uselessness of attempting to describe Tesla's work turned himself to the scarcely less easy task of critically analyzing the man. He assures his readers that he first satisfied himself that Tesla was worth "booming" and then proceeds to do it in characteristic fashion. Mr. Brisbane, who is a young man said to be deep in Joseph Pulitzer's confidence and esteem, is a first-class reporter and consequently sees things that other people miss. He is much given to describing character from anatomical indications and sizes up a man's worth from the color of his eyes, the contour of his chin, the size of his nose, the width of his mouth, the length of his thumbs. Tesla appears to Brisbane so:

He has eyes set very far back in his head. They are rather light. I asked him how he could have such light eyes and be a Slav. He told me that his eyes were once much darker, but that using his mind a great deal had made them many shades lighter. I have often heard it said that using the brain makes the eyes lighter in color. Tesla's confirmation of the theory through his personal experience is important.

He is very thin, is more than six feet tall and weighs less than 140 pounds. He has very big hands. Many able men do—Lincoln is one instance. His thumbs are remarkably big, even for such big hands. They are extraordinarily big. This is a good sign. The thumb is the intellectual part of the hand. The apes have very small thumbs. Study them and you will notice this.

Nikola Tesla has a head that spreads out at the top like a fan. His head is shaped like a wedge. His chin is as pointed as an ice-pick. His mouth is too small. His chin, though not weak, is not strong enough. His face cannot be studied and judged like the faces of other men, for he is not a worker in practical fields. He lives his life up in the top of his head, where ideas are born, and up there he has plenty of room. His hair is jet black and curly. He stoops—most men do when they have no peacock blood in them. He lives inside of himself. He takes a profound interest in his own work. He has that supply of self-love and self-confidence which usually goes with success. And he differs from most of the men who are written and talked about in the fact that he has something to tell.

Tesla has been written about by all sorts of writers, from heavy scientists to young and enthusiastic reporters for the electrical journals. But it doubtless gave him a new and unusual sensation to read Mr. Brisbane's critical and worldly analysis, the data for which he acquired in a conversation at Delmonico's where Tesla usually eats. It is a long jump from the scientifically accurate and tastefully written biography by Thomas Commerford Martin to the surgical dissection of Tesla by Arthur Brisbane. And yet both are interesting.

NIKOLA TESLA AND HIS WORK.*

By Nelson W. Perry, E. M.

IT is not often that it is in good taste to estimate the character of a man while he is living, or safe to weigh his works or to estimate their proper place in any science while it is still in an embryotic state. There are exceptions, however, as in the case of political and other celebrities who, by reason of their eminence, have become in a sense public characters, or whose work has already revolutionized the science in the interest of which it has been undertaken. Under both of these exceptions it seems altogether proper to speak of Mr. Nikola Tesla, for if a man by taking two continents by storm may be called a public character in the sense in which the expression is here used, Mr. Tesla is one, and if the discovery of a new system such as the rotary magnetic field which in a few years has largely revolutionized our methods of conversion of electrical into mechanical energy, and which has formed the basis of the greatest attempt at power-transmission ever made, partakes of the nature of a revolution of the science, then for this reason may Mr. Tesla's work be reviewed with propriety while their author is still in the flesh.

Mr. Tesla was born in 1857, and therefore is still quite a young man, but he has crowded within his thirty-seven years of life an experience that would be considered ripe for any one of a dozen other men if it were divided equally among them. While foreign-born (at Smiljan-Lika on the borderland of Austro-Hungary), he is an American by adoption. Though proud of his adopted country he is not so intensely American as some foreigners become who adopt this country as their home.

The one discovery of Mr. Tesla which among practical men stands out most prominently to-day, because of the practical results already obtained, is his discovery of what is generally known as the rotating magnetic field. The alternating current, as the name would imply, means a current which changes its direction periodically. It possesses many characteristics peculiar to itself. The distinct advantage of an alternat-

* In the publisher's announcement, some months ago, of a series of papers on "Electrical Science up to Date," was included the promise of a paper in this volume of THE ENGINEERING MAGAZINE, by Mr. Nikola Tesla, on "Electric-Lighting Without Heat." Only the unfortunate condition of the health of Mr. Tesla has postponed his compliance with his engagement in this connection. In order to keep faith, so far as possible, with the readers of the Magazine, there is presented herewith a paper by an electrical engineer who enjoys the acquaintance of Mr. Tesla, reviewing the discoveries of the latter gentleman which it was hoped that the inventor himself would be able to describe for us. The paper thus prepared has received the approval of Mr. Tesla, who, indeed, furnished personally some of the suggestions upon which it is based.—THE EDITOR.

ing or undulating current over a steady current such as heretofore used in arc-lighting is, that one is able to dispense with a large resistance in the dynamos and lamps which are necessary in order to obtain a steady light. This produces a greater economy in the circuit all along. For transmission purposes its advantages so far outweigh its disadvantages as to make it the method *par excellence*. Alternating-current motors enable us to obtain results which are not possible with motors heretofore used, namely: the motor may be made to run in perfect synchronism with the generators. In the ordinary motors the speed as is known falls below this increase, but not so in the motors just mentioned. But if one desires it is possible also to exactly imitate an ordinary direct-current motor and produce a machine which will have a great effort on the start.

Mr. Tesla conceived an idea which has entirely overcome the shortcomings of the alternating current as applied to motors. Every one knows—or at least is easy of demonstration—that if the north and south poles of a small horseshoe magnet be suspended over a bar of soft iron free to revolve in a horizontal plane, or be placed over an ordinary compass-needle, the latter will be attracted at either end by the poles of the magnet and take up a position parallel to a straight line drawn between the two poles of the magnet. Now if the latter be revolved through any angle the soft iron or needle will follow, being dragged around by the magnet, and if the magnet be caused to revolve regularly the iron will also revolve, being pulled around by the full force of the magnet. It was not feasible, however, to cause the magnet to revolve in this way, and Tesla's invention consisted in obviating this trouble and, in fact, in greatly simplifying the problem. He conceived the idea that if he took an iron ring and used two alternating currents, one of which had its maximum value at the instant that the other had a zero value—or, in other words, two currents whose periods were such that one waned as the other increased—he could produce in that iron ring by winding these circuits in alternate coils surfaces that without any mechanical movement of the parts would travel around that ring with a rapidity equal to the number of changes of direction of the currents employed. He thus had a ring, the north and south poles of which were rapidly revolving just as would the poles of the horseshoe magnet were it tied at its middle to a twisted string and allowed to revolve. A piece of iron pivoted at its middle placed concentric with this ring would therefore be dragged around by the changing poles of the ring. He had thus discovered what is somewhat awkwardly expressed by the expression, "the rotary magnetic field," and also the use of what have been termed "polyphased currents"—the one referring to the magnetism and the other

to the combination of currents by which this changing magnetism was produced. This discovery is undoubtedly one of the most important that has ever been made within the domain of alternating currents, and marks a most important step in applied electricity; in fact, it may be said to have been epoch-making, for without this method the experiment of transmitting 100 horse-power, 108 miles from Lauffen on the falls of the Neckar to the Frankfort Exposition grounds, in 1891, would have been impracticable.

If two separate currents are employed as Tesla employs them, we have what is called a "diphased" system; if three are employed it is called a "triphased" system; but in speaking of the employment of more than one current the generic term "polyphased" is used. Tesla's discovery is the basis of them all. The Frankfort-Lauffen experiment referred to was operated on the three-phased system. The great scheme of transmitting Niagara's power to distant points, which in magnitude far surpasses the former experiment, will employ the original Tesla diphased system.

His first successful experiment was in 1883, but the first practical motor that showed good efficiency was only obtained in 1887. Ferraris published a pamphlet bearing on the broad principles and some features of the discovery in May, 1888, but six months prior to this, that is in October, 1887, Tesla's first fundamental applications were filed in the Patent Office in Washington.

There is no conflict between Ferraris and Tesla, each according to the other full honor and credit for the work individually done.

As before stated, the discovery of the rotary field has nearly revolutionized the practice of tranmission of energy by alternating currents and the practical value of the invention is fully attested by the adoption by the most eminent experts in the world of the Tesla system for the Niagara electrical plant, by which it is proposed to transmit eventually at least 100,000 horse-power from the falls to various points along the Erie canal, as far as such transmission may prove economical. This invention at once attracted the eyes of the scientific world to Mr. Tesla, who was until then comparatively unknown. He has, however, been an indefatigable worker and has made many inventions which have attracted little attention, often only because of their lesser importance. Mr. T. Commerford Martin, in his exhaustive work on the "Inventions, Researches, and Writings of Nikola Tesla," catalogues 137 inventions or discoveries made by this man. There is not room here for even this catalogue and in discussing his work it will be necessary for me to confine myself strictly to a few of his accomplishments upon which his fame chiefly depends.

Mr. Tesla early turned his attention to phenomena of alternating

currents of high frequency and high potential. These brilliant effects which have so much interested scientific men are obtained in his experiments by a peculiar arrangement of condensers and coils, which enables him to obtain enormous potentials of a million volts or more which are alternated in direction many million times a second, if necessary. In the reports of his lectures his apparatus is minutely described, but limited space does not permit me to dwell upon it here. Others had experimented with currents of several thousand volts and as many reversals or more per minute. The phenomena thereby produced were so interesting as to lead Mr. Tesla to explore the field further. He employed currents of hundreds of thousands of volts and having more than 2,000,000 reversals per minute. With these elements at hand he possessed the key with which he unlocked entirely unexplored avenues and produced effects, especially of light, that literally dazzled the scientific world.

Maxwell had taught the world to believe that ordinary light was due to electromagnetic waves of the ether, having a frequency per second of 5 with 14 ciphers after it. He did not prove this, but arrived at his conclusions through mathematical logic. Later Heinrich Hertz proved the truth of these deductions experimentally. This meant that if, by any possible means, we could artificially produce ether waves of this frequency, we would have light without heat and a useful efficiency for the energy expended of about 99 per cent. instead of an efficiency of less than 1 per cent. as obtained in our best gas-burners. We can readily produce etheric waves of a frequency of some hundreds of thousands and even millions, but these fall far short of the requirements in the case, and there were practical obstacles in the way preventing the slightest hope of our ever being able to produce the required frequency or to transmit them if we could produce them. It was Tesla's idea that the desired results were possible of attainment by means of powerful electro-static effects which, by the way, he was able to produce by his peculiar methods and apparatus invented for this purpose and high potentials.

Of course the general bearing of these experiments is upon the problem of an efficient production of light, but in his lectures many scientific facts are pointed out, which contributed to a radical change in scientific opinion in regard to a number of phenomena. So for instance it was demonstrated that a gaseous medium like air, when electric stress of great intensity and frequency were made to act through it, becomes rigid. The agitation produced by the stress in the molecules of the air is such as to render the air luminous, and he produced in some experiments streams of light by merely charging the body. In fact it appears possible from some experiments that a flame might be produced which would appear to be ordinary gas-flame and yet it would be a solid. The phenomenon of the aurora borealis and of the electric storms are usually attributed to the changes of the potential of the sun. A very important fact was demonstrated that in an electrical condenser and in any insulating material, the air must be kept away. As long as this fact was not known it was not possible to properly insulate parts of high tension.

I give here a paragraph on this subject in his own words: *

> But powerful electro-static effects are a *sine qua non* of light-production on the lines indicated by theory. Electromagnetic effects are primarily unavailable, for the reason that to produce the required effects we would have to pass current impulses through a conductor, which, long before the required frequency of the impulses could be reached, would cease to transmit them. On the other hand, electromagnetic waves many times longer than those of light, and producible by sudden discharge of a condenser, could not be utilized. . . . . We could not affect by means of such waves the static molecular or atomic charges of a gas, cause them to vibrate and emit light.
>
> *To produce such luminous effects, straight electro-static thrusts are required; these, whatever be their frequency, may disturb the molecular charges and produce light.*

It is to be regretted that lack of space here prevents the elucidation of the terms used, but the fact will be well understood without this, that the production of light practically without heat is within the bounds of possibility. This was Tesla's grand discovery and it was this that dazzled the mental vision of the scientific world. It only remained for him to illustrate his theory by experiments that the physical vision of the world should also be dazzled. He further says:

> It has occurred to me, however, that electro-static effects are in many ways available for the production of light. For instance, we may place a body of some refractory material in a closed, and preferably more or less exhausted globe, connect it to a source of high, rapidly-alternating potential, causing the molecules of the gas to strike it many times a second at enormous speeds, and in this manner, with trillions of invisible hammers, pound it until it gets incandescent; or we may place a body in a very highly exhausted globe, in a non-striking vacuum, and by employing very high frequencies and potentials, transfer sufficient energy from it to other bodies in the vicinity, or in general to the surroundings, to maintain it at any degree of incandescence, or we may, by means of such rapidly alternating high potentials, disturb the ether carried by the molecules of a gas or their static charges, causing them to vibrate and to emit light.

Here are clearly enunciated three distinct methods of producing light by electro-static action, any one of which would have startled the scientific world if founded solely on hypothesis. Tesla's announcement was based on no such unstable basis as this, however; it was based on experimental data which he reproduced before his audiences. Some of these effects had in fact been produced in a feeble way by previous investigators in a somewhat different manner, but it remained for Tesla to bring them out in a far more brilliant way than any of his predecessors and thereby to call attention to their importance that they had not previously attracted. In regard to this, he says:

* Tesla's lecture before the American Institute of Electrical Engineers, delivered at the School of Mines, Columbia College, May 20, 1891.

But electro-static effects being dependent upon the potential *and* frequency, to produce the most powerful action it is desirable to increase both as far as practicable. [Tesla was the first to realize and practise this.] It may be possible to obtain quite fair results by keeping either of these factors small provided the other is sufficiently great; but we are limited in both directions. My experience demonstrates that we cannot go below a certain frequency, for, first the potential then becomes so great that it is dangerous; and secondly, the light production is less efficient.

Speaking of what has been termed the bombardment method (the first of the three above mentioned), he says:

There is no difficulty in reaching such high degrees of incandescence *that ordinary carbon is to all appearance melted and volatilized.* If the vacuum could be made absolutely perfect, such a lamp, although inoperative with apparatus ordinarily used, would, if operated with currents of the required character, afford an illuminant which would never be destroyed, and which would be far more efficient than an ordinary incandescent lamp.

In lamps constructed on this principle, the filament or button of refractory material was connected to but one terminal of the circuit instead of to both as necessary in present practice.

In regard to the second method, Mr. Tesla says:

The use of alternating currents of very high frequency makes it possible to transfer, by electro-static or electromagnetic induction through the glass of the lamp, sufficient energy to keep a filament at incandescence and *so do* away with the leading in wires. Many forms of lamps on this principle with continuous and broken filaments have been constructed by me and experimented upon.

Thus far he had used in the first case a single connection to the source of energy and in the second no connection at all, but in both cases some refractory material within the globe was brought to incandescence and served as the light-giving body. In the third method, however, he used neither connections nor filaments or buttons, but merely exhausted tubes having no electrodes whatever. Such tubes when grasped in the hands of the experimenter standing near an induction coil became luminous themselves. This seems to be a most remarkable phenomenon, as there is nothing from which the light can emanate. It would seem that the tubes were filled with a luminous substance which was light itself. Speaking of this phenomenon he says:

In all cases, then, when we excite luminosity in exhausted tubes by means of such a coil, the effect is due to the rapidly alternating electro-static potential and furthermore it must be attributed to the harmonic alternation produced by the machine and not to any superposed vibration which might be thought to exist.....In all the last-described experiments, tubes devoid of any electrodes may be used and there is no difficulty in producing by their means sufficient light to read by. The light effect is, however, considerably increased by the use of phosphorescent bodies such as yttria, uranium glass, etc.

But he caps the climax of this brilliant series of experiments by producing conditions whereby a vacuum tube without electrodes may be moved anywhere within the room and, with no connection whatever to the walls, still remain luminous. He says:

For this purpose I suspend a sheet of metal a distance from the ceiling on insulating cords and connect it to one terminal of the induction coil, the other terminal being preferably connected with the ground; or else I suspend two sheets, each being connected to one terminal of the coil, and their size being carefully determined. An exhausted tube may then be carried in the hand anywhere between the sheets or placed anywhere, even a certain distance beyond them; it remains always luminous.

During this lecture Mr. Tesla performed all of the experiments referred to and many more before his audience and then, summing up his own belief as to their value, he said:

How far the results here borne out are capable of practical applications will be decided in the future. As regards the production of light, some results already reached are encouraging and make me confident in asserting that the practical solution of the problem lies in the direction I have endeavored to indicate. Still, whatever may be the immediate outcome of these experiments I am hopeful that they will only prove a step in further development towards the ideal and final perfection. The possibilities which are opened by modern research are so vast that even the most reserved must feel sanguine of the future. Eminent scientists consider the problem of utilizing one kind of radiation without the others a rational one. In an apparatus designed for the production of light by conversion from any form of energy into that of light, such a result can never be reached, for no matter what the process of producing the required vibrations, be it electrical, chemical, or any other, it will not be possible to obtain the higher light vibrations without going through the lower heat vibrations. It is the problem of imparting to a body a certain velocity without passing through all lower velocities. But there is a possibility of obtaining energy not only in the form of light, but motive power, and energy of any other form, in some more direct way from the medium. The time will be when this will be accomplished, and the time has come when one may utter such words before an enlightened audience without being considered a visionary. We are whirling through endless space with an inconceivable speed; all around us everything is spinning, everything is moving, everywhere is energy. There *must* be some way of availing ourselves of this energy more directly. Then, with the light obtained from the medium, with the power derived from it, with every form of energy obtained without effort, from the store forever inexhaustible, humanity will advance with giant strides. The mere contemplation of these magnificent possibilities expands our minds, strengthens our hopes, and fills our hearts with supreme delight.

While none of these experiments on light have developed into practical processes, they constitute one of the most remarkable contributions to physical science since the days of Faraday. In the brilliancy of their conception and the beauty of the results obtained we are apt to lose sight of the great inventive genius that was required to devise and prepare apparatus suitable for their public production. Nowhere has the genius of Tesla been displayed to better advantage than in the production of suitable means to the desired ends, and the last public announcement he has made was a description of a mechanical and electrical oscillator by which his investigations of alternating currents would be facilitated.

His lecture of May 20, 1891, echoed around the world and attracted the attention of the gray-haired savants of Europe. He was at once besieged by invitations to repeat his lecture abroad and, on

February 3, 1892, he delivered his lecture with some additions before the most learned men of England, and received at their hands an ovation such as has perhaps never before been accorded to a scientific man. The last public appearance of Mr. Tesla was in a lecture during the Electrical Congress at the World's Fair, which was attended by the principal savants of Europe and America.

But Mr. Tesla is having the experience of all pioneers whose work does not show immediate practical results. One of the leading savants of Europe said to me after Tesla's last lecture: "His work is brilliant, but of what use is it? I would rather see him devote his energies to something more practical."

At this lecture Mr. Tesla exhibited and described a mechanical oscillator in which he had great confidence. He believed that its future possibilities in a practical way were great. He is still of that opinion and, notwithstanding the criticism just quoted, Mr. Tesla says that this invention contains the germ of the most practical work he has ever done. He probably knows best about this and we shall await the outcome with great interest. We are not at liberty to speak freely concerning this invention at this time, but when Mr. Tesla is ready to make an announcement we may hear something startling.

I believe that this sentiment finds considerable response among the scientists abroad. Faraday was constantly met with the question, *cui bono?* and Tesla cannot hope to escape the same experience. Faraday's minute electric spark obtained by electromagnetic induction was his baby. The question was reiterated, *cui bono?* That baby has now grown to man's estate and appears in the form of the 5000 horse-power Tesla generators now nearly completed for the great Niagara Falls transmission plant. The experiments in light, a few of which I have briefly referred to, are Tesla's babies. Who knows how they may appear in mature development?

My own estimate of Tesla is that his is one of the most vigorous and original minds the world has ever produced. Whether he will ever rank with Faraday, whom he resembles in many ways, I do not know, but there is no one in history whose work and character so closely resembles Faraday's to my mind as Tesla's. But Tesla's work is not finished. He is now engaged on something which he tells me he regards as the best work that he has ever done. What it may be the near future will disclose. It is unfair to write one's eulogium until his work is done. Tesla's work, perhaps, has only commenced.

NIKOLA TESLA AND HIS WORKS.

IN the *New Science Review* Lieut. F. Jarvis Patten gives a sketch of Nikola Tesla, together with a short account of what this distinguished young scientific investigator and inventor has accomplished. Before the advent of Tesla into the scientific field, we learn from Lieutenant Patten that out of both pure theory and physical research the general conclusion had been arrived at "that all manifestations of energy are but the different tangible or apparent evidences of one and the same force; that all energy, whatever its form of manifestation, is simply molecular agitation of greater or less degree." This being true, it follows that heat and light are merely the results of molecular agitation, and could this agitation be set up by purely mechanical means, heat or light would result. Tesla conceived the bold idea that by causing matter to pass to the stage of luminous vibration, without remaining for any appreciable time in the stage of heat vibration, it would produce light without heat; and, says Lieutenant Patten, "so near has he come to the practical acccomplishment of this conception that he has set the scientific minds of all Europe thinking, and placed his name beside that of Hertz."

HIS BEGINNINGS.

Tesla was born in Herzegovina, near the western borderland of Turkey, and in early youth was a pupil of the government schools where he lived. His twenty-third year found him in Paris, whither he had come to study engineering at the Ecole Polytechnique. From this school he went to the Edison Station in Paris as an engineer, and later to the celebrated laboratory near Orange, N. J. He remained with Mr. Edison for several years, but having many ideas that he wished to develop independently, he left that employ, and has since conducted a laboratory of his own in New York, which has been devoted purely to physical research and scientific investigation.

"Mr. Tesla started with the idea of setting matter into vibration at a rate approximating that of light (some two and a half millions a second), with the expectation that under such violent molecular agitation it would emit light. He has not as yet succeeded in obtaining so high a rate, but a much lower one produced some very surprising luminous effects. The general plan at first was this: To construct an alternating current dynamo that would produce this high rate of current alternation or pulsation. This current, now known as the 'high frequency' current, will cause luminous effects in different media. Thus, in a darkened room, a bare copper wire conveying such a current will be seen to glow, and vacuum tubes will shine brightly, as a result of a molecular bombardment or agitation of the ether atoms, when such a current is sent through them under very high pressure—the very high electro-motive force of several hundred thousands of volts being used in most of his experiments of this character. The dynamo method for getting very high frequencies was soon abandoned as inadequate, and the oscillatory discharge of a Leyden jar or plate condensers was substituted. This answered much better, although the frequency was then an unknown quantity and quite beyond control; and this departure led to the discovery of some very beautiful electro-static effects, which are still being pushed by many investigators with the hope of arriving at some result of commercial value."

HIS INVESTIGATIONS.

"Mr. Tesla claims that all electric and magnetic effects are traceable to the action of electro-static molecular forces, and in confirmation of this theory he produces what appears to be a veritable flame by the action of electro-statically charged molecules of gas. A flame is actually shown issuing from the tip of a wand, or from the ends of his fingers, which flame is devoid of heat, and by it no material is consumed. Perhaps the most surprising of the new facts elicited from his investigations is that the shock due to these very high voltage and high frequency currents can be supported by a person without any serious inconvenience. He passes a current of 200,000 volts through his body with perfect impunity, whereas one of 2,000 volts will produce almost certain death from even a momentary shock. In one experiment, two wires are stretched parallel to each other across the room. When given the high tension current they emit streams of light, or brush discharges so profusely that light enough is produced to distinguish objects in the room. If the wires are bent into concentric hoops, one inside the other in the same plane, the annular space between them is filled with streamers that make a sheet of flame a yard or more in area.

"Mr. Tesla is viewed by some as an impractical inventor—a mere visionary enthusiast—but this is hardly fair to one who has built up an entirely novel method for the experimental investigation of physical phenomena. This method, with its vast array of beautiful experiments, is original, and goes some steps beyond any point reached by previous work in the same line. There seems to be little of practical value in it for the electrical engineer."

To the practical man of electricity Mr. Tesla stands as the inventor of the rotary field motor, which he brought forth in 1888. Some idea of the importance of this discovery may be had when it is known that the largest electrical enterprise in the world, the 50,000 horse-power plant for sending the Niagara water power to Buffalo and other distant towns, will use the multiphase system that Tesla announced to the world through this motor.

Nikola Tesla.

The Sunday World of July 22 prints an interesting half-page article on Nikola Tesla, written by Mr. Arthur Brisbane, and accompanied by a portrait which we reproduce, without, however, the full caption which was as follows: "Nikola Tesla. Showing the Inventor in the Effulgent Glory of Myriad Tongues of Electric Flame After He Has Saturated Himself with Electricity." In deference to the well-known modesty of Mr. Tesla, we will not reproduce the newspaper writer's highly complimentary description of his personality and achievements, but confine ourselves to the following extracts, containing his remarks on the future of electricity and on the effects on the human body of high voltages coupled with high frequencies.

In answer to a question from the interviewer as to what he hoped to see accomplished by means of electricity, Mr. Tesla replied: "You would think me a dreamer and very far gone if I should tell you what I really hope for. But I can tell you that I look forward with absolute confidence to sending messages through the earth without any wires. I have also great hopes of transmitting electric force in the same way without waste. Concerning the transmission of messages through the earth, I have no hesitation in predicting success. I must first ascertain exactly how many vibrations to the second are caused by disturbing the mass of electricity which the earth contains. My machine for transmitting must vibrate as often to put itself in accord with the electricity in the earth."

When asked if he did not feel a little worried about taking a current of a quarter of a million volts, Mr. Tesla said, "I did at first feel apprehensive. I had reasoned the thing out absolutely; nevertheless, there is always a certain doubt about the practical demonstration of a perfectly satisfactory theory. My idea of letting this current go through me was to demonstrate conclusively the folly of popular impressions concerning the alternating current. The experiment had no value for scientific men. A great deal of nonsense is talked and believed about 'volts,' etc. A million volts would not kill you or hurt you if the current vibrated quickly enough—say half a million times to the second. Under such conditions the nerves wouldn't respond quickly enough to feel pain. You see, voltage has nothing to do with the size and power of the current. It is simply the calculation of the force applied at a given point. It corresponds to the actual pressure per square inch at the end of a water pipe, whether the volume of the water be great or small. A million volts going through you doesn't mean much under proper conditions. Imagine a needle so small that the hole it would make in going through your body would not allow the blood to escape. Imagine it so small that you couldn't even feel it. If you had it put through your arm slowly, that would be, electrically speaking, a very small voltage. If you had it stuck through your arm with great rapidity, going, say, at the rate of a hundred miles a second, that would be very high voltage. Voltage is speed pressure at a given point. It wouldn't do you any more harm to have a needle shot through your arm very rapidly—that is to say, with high voltage—than it would to put it through slowly. In fact, if it hurt you at all, the slow operation would probably hurt more than the other. The question of danger is simply the size of current, and yet if a big enough current should be turned against you and broken with sufficient rapidity—if it should, so to speak, jerk back and forth an inconceivable number of times to the second—it wouldn't kill you. Whereas, if applied continuously, it would simply burn you up."



NIKOLA TESLA.

NIKOLA TESLA AND HIS WORK.

LIEUT. F. JARVIS PATTEN contributes to *The New Science Review*, New York, July, an interesting account of the work of the young electrician Nikola Tesla, whose inventions have already been mentioned frequently in these columns. He says:

"Tesla conceived the bold idea that by causing matter to pass to the stage of luminous vibration without remaining for any appreciable time in the stage of heat vibration, it would produce light without heat; and so near has he come to the practical accomplishment of this conception that he has set the scientific minds of all Europe thinking. . . .

"What first brought him into prominence, and gave him the means to go farther, was his discovery of the 'Rotary-Field Motor,' an invention of marked originality and beauty, but not appreciated at its full value at the time of its discovery. Announced by him and commercially disposed of in 1888, it is now just coming into general use. Simple and beautiful as it seemed, our knowledge of electrical engineering was not then equal to the task of making the machine electrically right. European engineers, however, held to the work, and, following in their footsteps, we now understand the rotary-field motor; and the largest electrical enterprise in the world, the fifty thousand horse-power plant for sending the power of Niagara to light Buffalo and other distant towns, will use the multiphase system that Tesla first gave to the engineering world six years ago.

"An apt illustration of the difference between the purely theoretical or scientific mind and the semi-practical mind guided by scientific training suggests itself here. Professor Ferraris of Turin independently discovered and announced the principle and operation of the rotary-field motor at about the time that Tesla did the same thing in this country. The professor's announcement was in the form of a paper to a scientific society. Tesla made many forms of the machine, reduced his theory to a practical operative device, and having protected his invention by many patents he exhibited his machines to the American Institute of Electrical Engineers in May, 1888. Professor Ferraris' description, however, antedates Tesla's exhibition by some months. . . .

"Before considering Tesla's more recent work, it seems appropriate to describe briefly the salient features of this machine, which can be best done by comparing it with the ordinary type of electric motor. This in general terms is an engine having a fixed and a revolving part, of which the latter, turning about its spindle, communicates motion to other machinery. The moving part is always provided with commutating devices that constantly shift the magnetic axis backward, in the same measure and degree that the moving part turns forward. These devices are always intricate and complex. They are in fact the weak part of all electric engines. The Tesla rotary-field machine, being entirely free from them, is a marvel of simplicity and ingenuity. To understand this machine one must picture an iron-ring and conceive it to be magnetized along a vertical diameter, the North Pole being at the top; then a moment later along a horizontal diameter with the North Pole at the right; again along the vertical diameter but North Pole at the bottom, and lastly on the horizontal line again with North Pole at the left, thus completing a revolution of the North Pole around the ring. Such an effect is called a rotating magnetic field, and can be perfectly produced by the simultaneous use of two independent alternating currents, which follow each other periodically in such a way that one has always a maximum value or strength when the other is zero, and conversely. If now the iron ring is wound all around with a coil

of wire closed on itself, and one such current be introduced to this winding at the extremities of a vertical diameter, while another is simultaneously introduced to the same winding at the extremities of a horizontal diameter, they will jointly produce a revolving magnetic field that turns continuously around the ring, while the latter remains fixed in space. We then have a fixed magnet, but the magnetism itself, or magnetic axis, is in motion. A compass or magnetic needle suspended freely inside the ring would spin around in its endeavor to follow the revolving magnetism or the shifting magnetic axis of the ring. . . .

"Having disposed of his motor Mr. Tesla devoted himself to the establishment, by experimental process, of the identity of light and some form of electrical manifestation of energy. . . .

"Mr. Tesla started with the idea of setting matter into vibration at a rate approximating that of light (some two and a half millions a second) with the expectation that under such violent molecular agitation it would emit light. He has not yet succeeded in producing so high a rate, but a much lower one produced some very surprising luminous effects by currents of high frequency. In these experiments the dynamo was abandoned as inadequate and the Leyden-jar substituted. . . . The scientific minds of Europe were quickly at work investigating the so-called Tesla effects, the result being that the electromagnetic theory of light may be regarded as proven, while it seems equally well established that light without heat is not to be looked for as one of the Tesla effects.

"Mr. Tesla claims that all electric and magnetic effects are traceable to the action of electrostatic molecular forces, and in confirmation of this theory he produces what appears to be a veritable flame by the action of electrostatically charged molecules of gas. A flame is actually shown issuing from the tip of a wand, or from the ends of his fingers, which flame is devoid of heat, and by it no material is consumed. Perhaps the most surprising of the new facts elicited from his investigations is that the shock due to these very high voltage and high frequency currents can be supported by a person without any serious inconvenience. He passes a current of two hundred thousand volts through his body with perfect impunity, whereas one of two thousand volts will produce almost certain death from even a momentary shock. In one experiment, two wires are stretched parallel to each other across the room. When given the high tension current they emit streams of light, or brush discharges, so profusely that light enough is produced to distinguish objects in the room. If the wires are bent into concentric hoops, one inside the other in the same plane, the annular space between them is filled with streamers that make a sheet of flame a yard or more in area. . . .

"There seems to be little of practical value in this for the electrical engineer. So we may say that to the physicist Mr. Tesla stands as the pioneer of a new and wide field of research, while before the practical man of electricity he stands as the inventor of the 'rotary-field machine,' a beautiful and unique conception, which he soon left for the practical man to figure out."

Tesla Effects with Simple Apparatus.

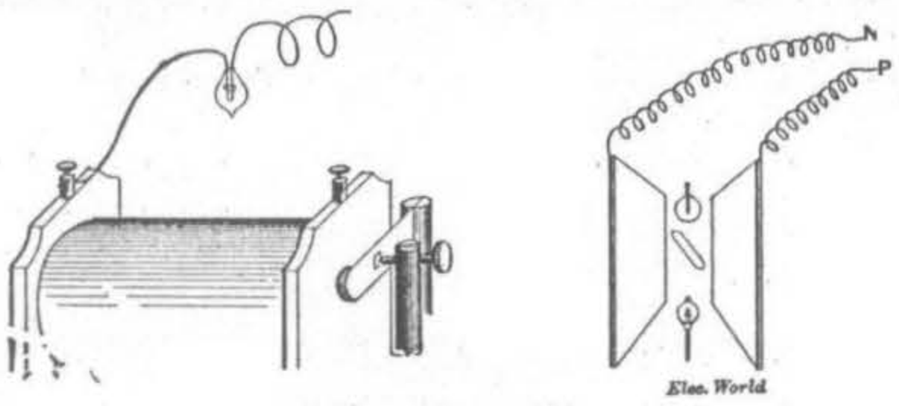
BY H. M. MARTIN AND W. H. PALMER, JR.

All who visited the room in the Electricity Building at the World's Fair in which Mr. Tesla's high frequency apparatus was exhibited must have brought away with them a lively desire to repeat at their leisure the beautiful and interesting experiments there shown; but a recollection of the many expensive appliances used in obtaining the effects has doubtless deterred many from entering upon what must prove a valuable and absorbing line of study. It is the object of this paper to show that no one need fear failure in this field who has at his command the simple apparatus to be found in the most unpretentious laboratory; nor should it be thought that results are less instructive or of smaller scientific value when obtained in this way than when obtained by the use of more powerful apparatus.

Some years ago the writers, while testing a small Ruhmkorff coil, connected up a burnt-out miniature incandescent lamp between the secondary terminals. On closing the primary circuit the usual violent discharge was set up between the broken ends of the carbon. While the current was on one of the connections became unfastened, leaving the lamp joined to only one of the coil terminals, as in Fig. 1; and the discharge instead of being extinguished, changed to a soft glow that filled the whole interior of the lamp. This was, on a small scale, identical with the experiment performed so brilliantly by Mr. Tesla during his London lecture, when he lighted an exhausted bulb, having a sealed-in electrode, through a single lead from a source of high potential and frequency.

Although this experiment was often repeated, its significance was not realized until Mr. Tesla made known the results of the researches which have entitled him to rank among the foremost investigators of our times. But the published report of the lecture placed the previous experiment in its true light, and inspired a hope that other effects might be duplicated with the feeble apparatus at hand. The results have more than fulfilled our expectations.

The necessary potential and frequency were obtained from a small



FIGS. 1 AND 2.

Ruhmkorff coil capable of giving a quarter-inch spark when operated by three Bunsen cells.

Two insulated metallic plates 12"x12" in size were placed about three inches apart and connected with the terminals N and P (see Fig. 2). Exhausted bulbs, miniature incandescent lamps, Geissler tubes, etc., were then introduced between the plates, and glowed brightly without any direct connection with the plates or coil. Actual photometric measurements of the maximum light emitted by this arrangement show it to be greater than that obtainable by using the current directly in an incandescent lamp. This is significant as showing the poor economy of the present methods of electric lighting, and leads us to believe that molecular bombardment electrostatically sustained contains great possibilities in this connection.

A slight modification of this arrangement makes it possible to dispense with one of the two plates. In all these experiments the battery cells act as a species of reservoir or condenser, so that tubes and bulbs lying in their vicinity are often seen to glow brightly and fade, in proportion as the capacity of the apparatus is changed.

Incandescent lamps may be lighted through a single lead from one of the secondary terminals; this effect is greatly heightened if the hand or some other object of capacity is placed near the lamp bulb. The small 6 c. p. lamps are peculiarly adapted for use in these experiments, their shape seeming to concentrate the molecular bombardment upon the carbon filament.

If a good mercurial air-pump is not accessible, vacuum tubes that will serve for want of better may be obtained by heating mercury in a piece of tubing, and sealing the end after the mercury has reached the boiling point. A pretty experiment may be performed by holding the exhausted tube in one hand, with one end near the coil terminal, and then passing the other hand down the length of the tube, extinguishing the glow and giving the effect, as a friend expressed it, of "wiping the moonshine off."

Many other combinations will suggest themselves to the investigator, but there is one experiment which, since it depends upon a principle that has not, to the writer's knowledge, received as yet any published explanation, should be of special interest.

This phenomenon, a description of which has already appeared in

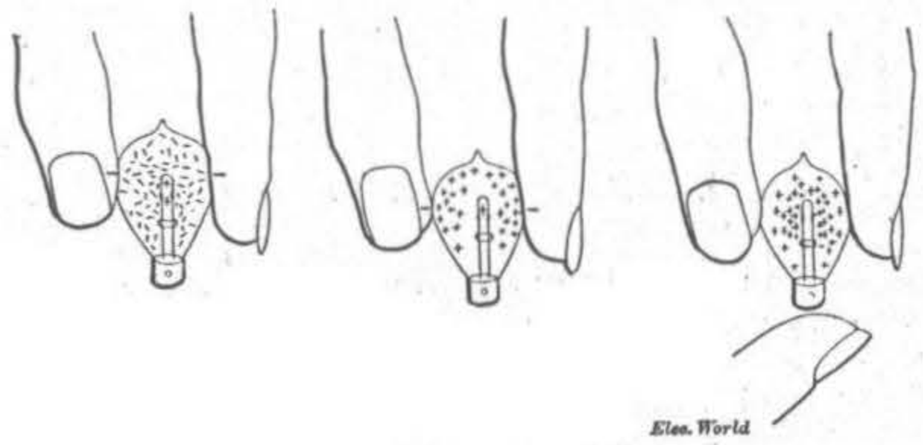


FIG. 3.

these columns,* may be satisfactorily observed with the small induction coil by proceeding as follows:

Holding the bulb of a miniature incandescent lamp in the hand, bring the leading-in wire into contact with the coil terminal; the bulb will be filled with the usual phosphorescent glow. If, now, the lamp is slowly withdrawn from contact with the terminal, this light will gradually fade, as the confines of the field are approached, and concentrate itself around the interior carbon. Soon a point will be reached beyond which the glow does not diminish through further removal from the coil. It is now quite self-sustained, and cutting the current off from the coil will not effect it in any perceptible way. This phenomenon we have called the "afterglow."

When obtained in this way, the afterglow will continue for from one to two minutes after the coil is shut off. The lamp may be carried glowing from room to room; if put down out of the hand the light becomes fainter, but is not extinguished. After some minutes, when the glow has faded quite away, a sudden flash may be observed if the leading-in wire is touched with the finger. Several of these flashes may sometimes be obtained before the bulb is entirely discharged.

It must not be supposed that this glow is due to heat remaining in the lamp carbon, the heating effect of so weak a coil being quite insignificant. A consideration of the accompanying figures will show the purely electrostatic nature of this phenomenon.

When the lamp is withdrawn from the alternating field, the interior electrode retains a charge differing in sign or intensity from that of the rarefied gas in the bulb and that induced in the fingers of the experimenter, Fig. 3. The natural consequences of this state of unequal charge are molecular bombardments and collisions more violent in the immediate neighborhood of the electrode, because of the small surface over which its charge is distributed. When electrical equilibrium has been established between the gas molecules and the electrode, this interchange of charge ceases, and the glow dies away. The condition of affairs at this moment is shown in Fig. 4.

Discharging the electrode will now cause a sudden rush of molecules toward it to re-establish equilibrium (see Fig. 5), giving rise to the momentary flash observed, and this may be repeated until no charge remains in the lamp.

This is, perhaps, the simplest arrangement ever devised for obtaining light from electricity, and it may not be extravagant to say that it embodies the fundamental principles of an economical system of artificial illumination.

*"The Afterglow in Exhausted Bulbs," The Electrical World, Jan. 20, 1894.

jars 16 cm. in diameter and 42 cm. high, three lamps could be made to glow, hung over each other, one a 65-volt lamp at the bottom, then a 16-volt lamp in the middle and a 2-volt lamp at the top.

If the middle of the glass bulb of such a lamp is filed off it will either not glow or glow very little. Tesla explains this by the different bombardment of the molecules of the glass in the bulb, while the author ascribes the result to the different heat conducting power of the air which entered.

If the incandescent body is a platinum wire of 0.05 to 0.1 mm. diameter, it will oscillate rapidly while glowing, taking the form of a zigzag line, not in a single plane like a stretched string, but in all possible planes, thus representing a model of a ray of natural light. A condition for the success of the experiments is the use of an interrupter which operates with certainty, as also in the use of a proper spark micrometer. He recommends the Foucault interrupter with tough zinc amalgam instead of mercury, covered with machine oil. The spheres of the micrometer are best made of zinc.

A Tesla transformer was constructed as follows: On a glass cylinder of 4 cm. diameter he wound 10 turns of a 4 mm. wire, with a distance between the windings of 1 cm., over which a thick glass cylinder, or better, a hard rubber cylinder of 6 mm. thickness, was placed, and on it were wound 200 windings of a 1 mm. wire. In order that the distance between the windings may be made 1 mm. two similar wires were wound next to each other, after which one of them was again unwound. The transformer was placed horizontally in an earthenware vessel filled with machine oil, and supported on hard rubber, and the secondary winding ended in two metallic balls on hard rubber pillars. The primary winding was connected with the Leyden jars in place of the above mentioned U form wire. When the interrupter is in action, brush discharges will appear at the knobs; if a conductor is placed near them, bright sparks will pass to it. Between two parallel wires connected to these knobs, a bright band of light of three to four metres in length will be formed.

If one pole is connected to earth and the other to a thin wire 15 to 20 cm. long which hangs freely suspended, it will begin to move and describe a cone-shaped figure which is distinctly visible in the dark on account of the brush discharges which take place from it.

If a person takes hold of one pole of such a coil, bundles of rays can be drawn out from any part of his body near which a conductor is approached. If the person is standing on a metallic plate a prickling sensation will be produced in the feet; in the dark, discharges will be seen to pass out of the shoes. If several persons are connected together the first taking hold of one pole of the transformer, while the last holds a Geissler tube with or without electrodes, this tube will be brightly illuminated, although none of the persons will feel the discharges.

If one pole is connected to earth and the other to a large metal sphere, 60 cm. in diameter, Geissler tubes will be brightly illuminated at distances of from three to four metres from this sphere.

An incandescent lamp connected with the pole which is not connected to earth shows only the pale light of a Geissler tube. But if a large metallic disc is connected to the glass bulb, the lamp will glow brightly. The filament will, in that case, oscillate so that it soon breaks. If a conductor be approached to the point of the lamp this point will be immediately pierced by the current and a continual bright stream of sparks will pass through the opening, and the filament will at once begin to glow until it is consumed.

In the second part of his paper the author states that a Tesla coil is quite different in its actions from an ordinary induction coil. A Geissler tube connected in any way with the pole of a Tesla coil shows cathode light at both electrodes, an anode light in the middle. A commutation of the primary current or a reversal of the pole has no effect. An electroscope is always charged positively when it is approached with a pole terminating in a point. Both poles produce only positive Lichtenberg figures, never negative.

Researches with different gases show that this preponderance of the positive discharges from the pole of a Tesla coil depends on the surrounding medium. Air or oxygen promote positive discharges; hydrogen, illuminating gas, nitrogen, carbonic acid gas and ammonia, promote negative discharges.

If two points are connected with one pole, one in air and the other in hydrogen, positive and negative electricity will be discharged simultaneously from the same pole, depending on the surrounding gas. If one of the points is in oxygen, and if gradually more and more nitrogen is added, an electroscope opposite the point will at first show a moderate positive charge; with increasing quantities of nitrogen this will increase; when the mixture corresponds to that of air the positive charge will reach a maximum; if the nitrogen is

Tesla Currents with Simple Apparatus.

Mr. F. Himstedt publishes in Wiedemann's Annalen, vol. 52, page 473, some interesting researches with Tesla currents, produced by means of rather simple apparatus. We give below a translation of an abstract of this paper as published in the Elektrotechnische Zeitschrift, July 12.

The reason why the researches of Tesla have not been reproduced in Germany is probably due to the fact that the apparatus which he used was not at hand. It is very interesting to note that the author succeeded in reproducing most of the results with exceedingly simple apparatus. He at first used Lecher's arrangement for the production of Hertzian waves, but afterward used still better known apparatus, namely, Leyden jars.

He connected the pole of a powerful Ruhmkorff coil (50 cm. long and 20 cm. diameter, using from 5 to 6 accumulators) with the inner coatings of two moderately large Leyden jars, insulated from each other by being placed on paraffine; he also used a spark micrometer. The outer coatings of the jars were connected with a 4 mm. wire, 150 cm. long and bent in the shape of a U. A 16-volt incandescent lamp connected in parallel to this wire was brought to a white heat by proper adjustment of the micrometer. By using

in excess the charge will be reversed and will become negative. The process is similar if it is begun with nitrogen and the oxygen gradually added. With an ordinary induction coil the charge of an electroscope will be reversed when the primary current is reversed.

DIGEST OF CURRENT TECHNICAL ELECTRICAL LITERATURE

COMPILED FROM PRINCIPAL FOREIGN ELECTRICAL JOURNALS

BY CARL HERING

ELECTRO-PHYSICS.

Researches with Tesla Currents.—An abstract of a paper by Mr. Himstedt, published in the *Elek. Zeit.*, July 12, will be found translated in full in another column of the present issue.

TESLA EFFECTS WITH SIMPLE APPARATUS.*

ALL who visited the room in the Electricity Building at the World's Fair in which Mr. Tesla's high-frequency apparatus was exhibited must have brought away with them a lively desire to repeat at their leisure the beautiful and interesting experiments there shown; but a recollection of the many expensive appliances used in obtaining the effects has doubtless deterred many from entering upon what must prove a valuable and absorbing line of study. It is the object of this paper to show that no one need fear failure in this field who has at his command the simple apparatus to be found in the most unpretentious laboratory; nor should it be thought that results are less instructive or of smaller scientific value when obtained in this way than when obtained by the use of more powerful apparatus.

Some years ago the writers, while testing a small Ruhmkorff coil, connected up a burnt-out miniature incandescent lamp between the secondary terminals. On closing the primary circuit, the usual violent discharge was set up between the broken ends of the carbon. While the current was on one of the connections became unfastened, leaving the lamp joined to only one of the coil terminals, as in Fig. 1, and the discharge, instead of being extinguished, changed to a soft glow that filled the whole interior of the lamp. This was, on a small scale, identical with the experiment performed so brilliantly by Mr. Tesla during his London lecture, when he lighted an exhausted bulb, having a sealed-in electrode, through a single lead from a source of high potential and frequency.

Although this experiment was often repeated, its significance was not realised until Mr. Tesla made known the results of the researches which have entitled him to rank among the foremost investigators of our times. But the published report of the lecture placed the previous experiment in its true light, and inspired a hope that other effects might be duplicated with the feeble apparatus at hand. The results have more than fulfilled our expectations.

The necessary potential and frequency were obtained from a small Ruhmkorff coil capable of giving a ½in. spark when operated by three Bunsen cells.

Two insulated metal plates, 12in. by 12in. in size, were placed about 3in. apart and connected with the terminals N and P (see Fig. 2). Exhausted bulbs, miniature incandescent lamps, Geissler tubes, &c., were then introduced between the plates, and glowed brightly without any direct connection with the plates or coil. Actual photometric measurements of the maximum light emitted by this arrangement show it to be greater than that obtainable by using the current directly in an incandescent lamp.

Fig. 1.

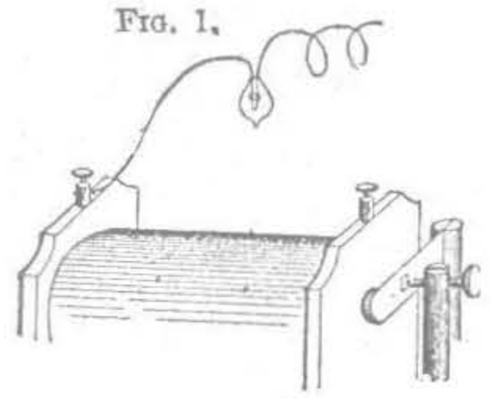
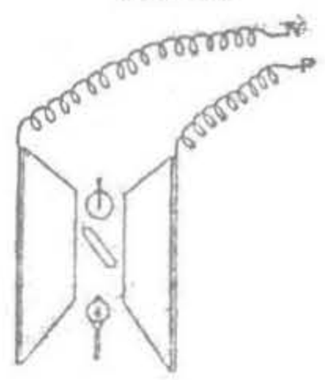


Fig. 2.



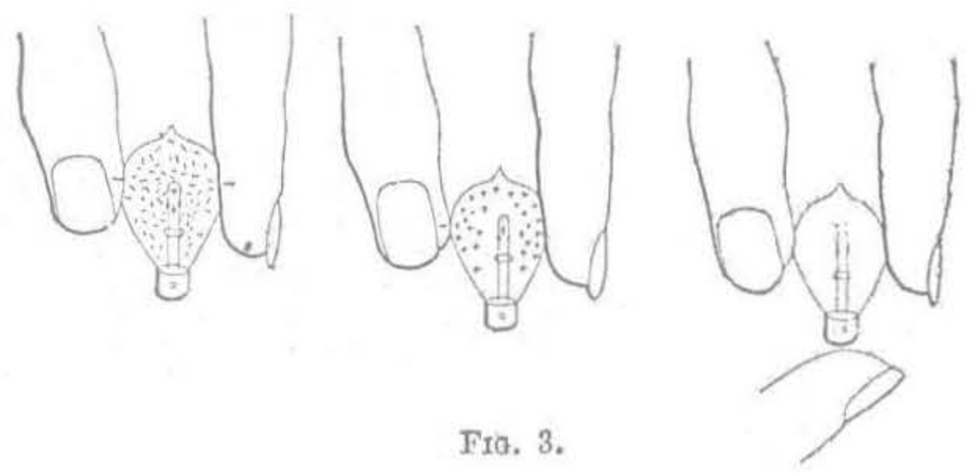


Fig. 3.

This is significant as showing the poor economy of the present methods of electric lighting, and leads us to believe that molecular bombardment electrostatically sustained contains great possibilities in this connection.

A slight modification of this arrangement makes it possible to dispense with one of the two plates. In all these experiments the battery cells act as a species of reservoir or condenser, so that tubes and bulbs lying in their vicinity are often seen to glow brightly and fade, in proportion as the capacity of the apparatus is changed.

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* By H. M. Martin and W. H. Palmer, Jr., in the *Electrical World*, N.Y.

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Holding the bulb of a miniature incandescent lamp in the hand, bring the leading-in wire into contact with the coil terminal; the bulb will be filled with the usual phosphorescent glow. If, now, the lamp is slowly withdrawn from contact with the terminal, this light will gradually fade as the confines of the field are approached, and concentrate itself around the interior carbon. Soon a point will be reached beyond which the glow does not diminish through further removal of the coil. It is now quite self-sustained, and cutting the current off from the coil will not affect it in any perceptible way. This phenomenon we have called the "afterglow."

When obtained in this way, the afterglow will continue for from one to two minutes after the coil is shut off. The lamp may be carried glowing from room to room. If put down out of the hand the light becomes fainter, but is not extinguished. After some minutes, when the glow has faded quite away, a sudden flash may be observed if the leading-in wire is touched with the finger. Several of these flashes may sometimes be obtained before the bulb is entirely discharged.

It must not be supposed that this glow is due to heat remaining in the lamp carbon, the heating effect of so weak a coil being quite insignificant. A consideration of the accompanying figures will show the purely electrostatic nature of this phenomenon.

When the lamp is withdrawn from the alternating field, the interior electrode retains a charge differing in sign or intensity from that of the rarefied gas in the bulb and that induced in the fingers of the experimenter, Fig. 3. The natural consequences of this state of unequal charge are molecular bombardments and collisions more violent in the immediate neighbourhood of the electrode, because of the small surface over which its charge is distributed. When electrical equilibrium has been established between the gas molecules and the electrode, this interchange of charge ceases, and the glow dies away. The condition of affairs at this moment is shown in Fig. 4. Discharging the electrode will now cause a sudden rush of molecules towards it to re-establish equilibrium (see Fig. 5), giving rise to the momentary flash observed, and this may be repeated until no charge remains in the lamp. This is, perhaps, the simplest arrangement ever devised for obtaining light from electricity, and it may not be extravagant to say that it embodies the fundamental principles of an economical system of artificial illumination.

NIKOLA TESLA AND HIS WORK

ADVANCING WITH CERTAINTY TO GREATEST TRIUMPHS.

Amazing Force Wasted in Making Electric Light—Economical Conversion of Available Energy—The Oscillator, Which Will Give to Most Machines the Value of Old Metal Only—Power of the Medium in Motion Around Us.

"Of the energy that goes to the making of electric light over 90 per cent. is wasted."

The statement is made on the authority of Nikola Tesla, and will be disputed by but few competent electricians. To explain the grounds on which it is made would be to elucidate some of the most elusive problems in physics, and to mark out the path of success for some of the most daring achievements of applied science. For, be it noted, it is electrical energy only of which Mr. Tesla speaks. No account is taken of the waste in combustion and in the many of the processes preceding the transformation of caloric into mechanical and mechanical into electrical energy.

Accepting Mr. Tesla's startling assertion in all its breadth, what a preposterous dissipation there must be of the energy stored in a lump of coal between its first liberation by combustion and its final appearance in its form of electric light! The waste of heat-

Nikola Tesla.

energy begins in the furnace, and is continued in every step of the process of generation, transmission, and conversion of the steam, so that it is one of the oldest and most stubborn commonplaces of mechanical engineering that a practical engine does not utilize more than 16 per cent. and sometimes not even as much as 5 per cent. of the heat energy employed to generate it. Besides, there is the loss by mechanical friction, in most cases equal to 35 per cent. on an average load of the engine, and the loss by belt friction, often equals 15 per cent. more—or 50 per cent. in all used up in the working of the engine itself, and in the transfer of the energy which it communicates to a piece of shafting. Even should that shaft be directly connected with an electric dynamo of good construction for conversion, there will be a further waste of certainly 20 per cent. in the dynamo itself. If the dynamo be worked in connection with an arc-lighting system, the loss will be high as 20 per cent., because of the unsteadiness of the electrical energy developed. And, between the dynamo and the carbon filament, or pencil, which is made the centre of an electric light, there ensues, as has been said, a loss of the potential energy conveyed to it of at least 90 per cent. To speak of the fluidity of scientific achievement in presence of waste on a scale like this is more than absurd.

Science and Invention to Save Energy.

In point of fact, science and her handmaid Invention are advancing by deliberate but perfectly confident strides toward a much more economical conversion of available energy. In the case of electric light, one may accept the correctness of the statement that it is not conceivable that the incandescent lamp can be much improved, and yet be forced to acknowledge that by a simple addition of purely mechanical application, the cost of producing the light may be reduced by one-half or even more. Suppose the steam engine and the electrical generator or dynamo, instead of being separate, should be combined in one. Suppose that the average 35 per cent. of loss by mechanical friction in the working of the engine should be saved, likewise the 15 per cent. of loss by belt friction and the 10 per cent. wasted in the dynamo, there would clearly be an addition of 60 per cent. to the available energy obtained from the steam for the purpose of producing electricity. Suppose, further, that the consolidated machine is much simpler, smaller, and lighter than the two which, which it is to replace; suppose it to be absolutely constant in its action, automatically regulated, and therefore available to the least possible amount of wear and tear, its advent would certainly mark a revolution, not only in the equipment of electric-light stations, but in many other fields of applied energy. These requirements Mr. Tesla seems to have met in the invention of the "oscillator." The essential characteristics of this very remarkable appliance may be briefly described to be the application of the pressure of steam to produce an extremely rapid vibration of a bar of steel or piston, which, in turn, is so adapted to a set of magnets that the mechanical energy of the vibrating bar is converted into electricity. Moreover, under certain conditions, the electrical vibration entirely governs the motion of the bar of piston, and, finally, by means of this appliance, the extraordinary result is reached that to all intents and purposes an absolutely constant vibration is established.

For reasons difficult to make plain without recourse to technical language, the great rapidity of this piston action admits of the use of steam at very high pressure, indeed, and lends itself to the development in this simply and economically constructed machine of power much in excess of that obtainable in the most costly expansion engines using a similar amount of steam. The primary purpose of the "oscillator" is to convert by a process as direct as possible the energy of steam into that of electricity. If the no rotary motion, because for its purpose rotary motion is not only unnecessary, but wasteful. If it be a question of generating electricity, for the production of light, all rotary motion in the mechanism is merely so much dissipation of energy. Dynamos and other reasons there can be no doubt about the impression which the "oscillator" will make in the lighting business. But if the machine does all that its inventor believes it can and will, it is also destined to have a very profound influence indeed on all the great branches of production and transportation. The fact is already recognized by all progressive men that the cheapest way of distributing power is by means of electricity. To say nothing about the enormous frictional losses due to the employment of extended systems of shafting and belting, account must be taken of the power wasted in moving long lines of shafting for the purpose of operating the small part which may be actually in use. When the transmission of power is made by electric energy, it is used only when and where it is needed.

Now, how it is recognized that it is most economical to convert the energy of the steam first into electricity, and then reconvert it into any form of motion that may be required, it is clear that the most successful signature of power production adapted to modern needs will be the one best fitted for the generation and economical generation of electricity. Mr. Tesla has done what may be called the core of a steam engine and the core of an electrical dynamo, given them a harmonious mechanical adjustment, and produced a machine which has in it the potentiality of reducing to a rate of waste of metal half the machinery at present moving on the face of the globe. It may come to do the work of the engines of an ocean steamship within a small part of the space they occupy and at a fraction of their cost, both of construction and operation. It will do the work, if all, without jar or pounding, and will reduce to a minimum the risk of derangement or breakage. There is nothing in the whole range of mechanical construction, from railway locomotives to stamp mills, which such an invention may not revolutionize.

Paradoxes in Tesla's Machine Involved.

It will be perceived that what has been outlined in regard to the construction of the "oscillator" involves some paradoxes in mechanics. If it is not to wear out, it must be destitute of friction, and must, therefore, present the anomaly of a steam cylinder and piston without packing, and yet admitting of no escape of steam. Still further, to bear out the claim of practical imperishability, the motion of the piston must be such as to produce molecular change in the metal calculated to weaken it, and the whole machine must be extremely simple in its adjustments and mode of operation in comparison with the highly complicated engines of to-day. There are engineers who will pronounce the attainment of these conditions to be impossible. But scientific men are becoming very cautious about the use of the word "impossible." It is less than twenty-five years since a man who had already won some reputation, then engaged in the construction of the present five-arch system of New-York, said to the writer that it would pay to use electricity as a motive power when we could get no feed steam boiler furnaces with piano frames. A steel rod vibrating without appreciable loss of energy, and without loss directly transforming the energy of its vibrations into electrical energy, may appear to be as much of a dream to the practical engineer of to-day, even on the eve of its realization, but when the genius of a scientific investigator of the first rank is combined with the genius of the inventor, humdrum people simply prepare to wait and watch.

They doubtless will be when Mr. Tesla's machine is sufficiently perfected to be introduced to the public, and it may surprise people who are hundreds of years in the future if this very beautiful piece of mechanical adaptation derives its chief value in the eyes of its inventor from the fact that it will enable him to pursue with new confidence some very far-reaching scientific investigations. It has given him a new tool, which promises to solve indispensable difficulties of certainty and uniformity of action hitherto lacking. This is by no means the only case in Tesla's scientific career in which he has demonstrated that practical achievements are simply the result of long speculative advance at the very outset of the path of investigation. He has already led him to a position of distinguished eminence, but even now the principle of the rotating magnetic field could be so applied as to reduce to a few hundred dollars the enormous and costly form of armature employed in the construction of motors. Scores of patents have been taken out by other men on inventions based on principles not his, which he has freely made for the guidance of his fellow-workers. But, brilliant as have been his practical achievements which directly or indirectly stand to Tesla's credit, he is only in the beginning of them, because he aims so extremely high. Electricians have an enormous respect for the man who applied the alternating current to motors, dispensed with brushes and commutators, and made an effective armature, formerly about as big as a cart wheel, not much larger than its hub. But these were relatively small things for the man whose goal of effort can be thus outlined: "We are whirling through space at an inconceivable speed all around us everything is spinning, everything is moving, everything is energy. There must be some way of availing ourselves of this energy directly. Then, with the light obtained from the medium, with the power derived from it, with every form of energy obtained without effort from the ever-flowing inexhaustible, humanity will advance with giant strides." This was said before the American Institute of Electrical Engineers at Columbia College in 1891. It was only the other day that Tesla repeated the same idea to the writer in a more confident form. "I expect to be able to set a machine in the middle of this room and move it by no other agency than the energy of the medium in motion around us." The three years which have elapsed since the delivery of this address have served only to deepen his conviction that the consummation hardly hoped for then is neither impracticable nor visionary.

Oscillator a Tool of Larger Problems.

When the key is found to the elimination of the chief waste of energy incidental to the production of electric light, then that consummation will not be far from our grasp. But, let it be noted that, however efficient the machine may be, it may prove impossible to be reducing the cost of generating the electricity that goes to the production of light, it marks only the first step toward the solution of greater problems in the working out of which it is to serve as a tool. The scientific as distinguished from the commercial value of the new machine, consists, as its inventor has pointed out, in its capacity for practically verifying theorizing currents of electricity whose frequency, i. e., rate of oscillation, whether high or low, is absolutely constant. Further progress in the direction whither Mr. Tesla's experiments are leading was all but impossible while the latter requirement was lacking. Some of the most perplexing problem which Tesla has set out to solve study popular fallacies, and even, indeed, almost transcend comprehension. But when it is stated that light is the result of etheric vibration of very high period and of a definite kind, much higher than the heat-producing vibrations, the same group of ideas that light production must be wasteful while it continues to be impossible to obtain the higher light vibrations without passing through the lower heat vibrations. No apparatus yet designed for the production of light, by any other form of energy, whether the process be electrical, chemical, or other has been able to avoid that necessity. Escape from it seems to be as impossible as from that of imparting to a body a certain velocity without passing through all lesser velocities.

But We Shall Not Be Able to Follow Very Far in the Path which the Advanced Guard of Modern Science Is Treading.

But we shall not be able to follow very far in the path which the advanced guard of modern science is treading if the laws of what we have been accustomed to call matter are regarded as the measure of the universe. Matter is a term whose significance science has greatly enlarged. It has become a scientific postulate that what is commonly called the void of space is filled with a medium which, though imperceptible to any human sense, has yet material properties. That is to say, the all-enveloping, all-pervading ether—the etheric ocean without a shore, in whose immensity suns and planets are but bubbles of varying size and hue—is the carrier and transmitter of all primary forms of energy, and perhaps is the material from which the tangible and visible universe has come. The question of the schoolbooks is relevant here: "If light is motion, what moves?" Beyond that which we call the earth's atmosphere, there are the depths of interplanetary space, through which must be communicated to us the form of energy known as light. But as the science primers again remark, "empty space can neither receive nor communicate motion." And we come to the only hypothesis that accords with the facts, that of the etheric ocean, namely, expectations to which that theory has given birth. The immensities of space, the ultra-tenuity of the universe's structure, is tossed about," as Tesla says, "in space eternally, a play to external influences, like a boat in a troubled sea." It moves, it vibrates, and that, too, with almost marvelous rapidity, and by the very necessity of its existence, as the postulate of the dead matter—quite an inconceivable thing, in spite of the popular impression to the contrary.

Possibilities in Appalling Figures.

Science says that light must travel at the rate of 186,000 miles a second; and that light is the product of an etheric vibration whose rate is about 500,000,000,000,000 a second, but science has hardly stopped to consider what profound possibilities there are in the forces which such appalling figures convey. Even now we know very little of what electricity is, but it has been one of the triumphs of modern investigation to identify electro-magnetic manifestations of energy with those of light and heat. Out of this identification has been born the demand which the world could be operated with one wire only, or without any connecting wire at all. The latter formula: "It is not necessary to have even a single connection between the motor and the generator, except, perhaps, through the ground; for not only is an insulated plate capable of giving off energy into space, but it is likewise capable of deriving it from an alternating electrostatic field, though in the latter case the available energy is much smaller." Now, from this demonstration of the possibility of working a motor without connecting wires by currents passed through the earth or by air, a dazzling possibility is revealed. For, "alternate currents, especially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. To reach a number of miles into space requires the overcoming of difficulties of a merely mechanical nature. Once into space, there is little or otherw

THE CAPTURE OF. NIAGARA.

By E. Jay Edwards.

CAPITAL is not always timid, though such is the repute it bears. No finer display of business courage was ever made than that exhibited by Peter Cooper, Cyrus W. Field, and a few others, when they staked millions on the experiment of the first Atlantic cable. In a few weeks there will have been completed another enterprise having the commercial use of electricity as its end, which, involving the expenditure of a very great sum of money, furnishes a new illustration that capital can be courageous, at least on occasion; for that work which has been in progress alongside the Niagara waterfall for some four years is, after all, experimental, and the capitalists cannot know until the plant is finished, the tests are made, and the electric power is furnished, whether the undertaking is going to bring them profit, or whether they have paid dearly for their faith

THE PURPOSE OF THE PLANT.

The power-producing plant now near completion at Niagara Falls is an experiment, however, only as regards the commercial availability of the electric current to be generated. The use of some portion of the power captured from the Niagara cataract as a direct force brought to bear upon turbine wheels, so that they may move the machinery of immense mills, and as many mills as can be erected within the territory controlled by the company, is not experimental. None of the experts doubted the ability of the engineers, mechanical and hydrographic, to construct a plant that would furnish a water-power equivalent to all of the power used in the city of Buffalo for every commercial purpose. The driving of the greatest paper-making machine in the world by this water-power has not

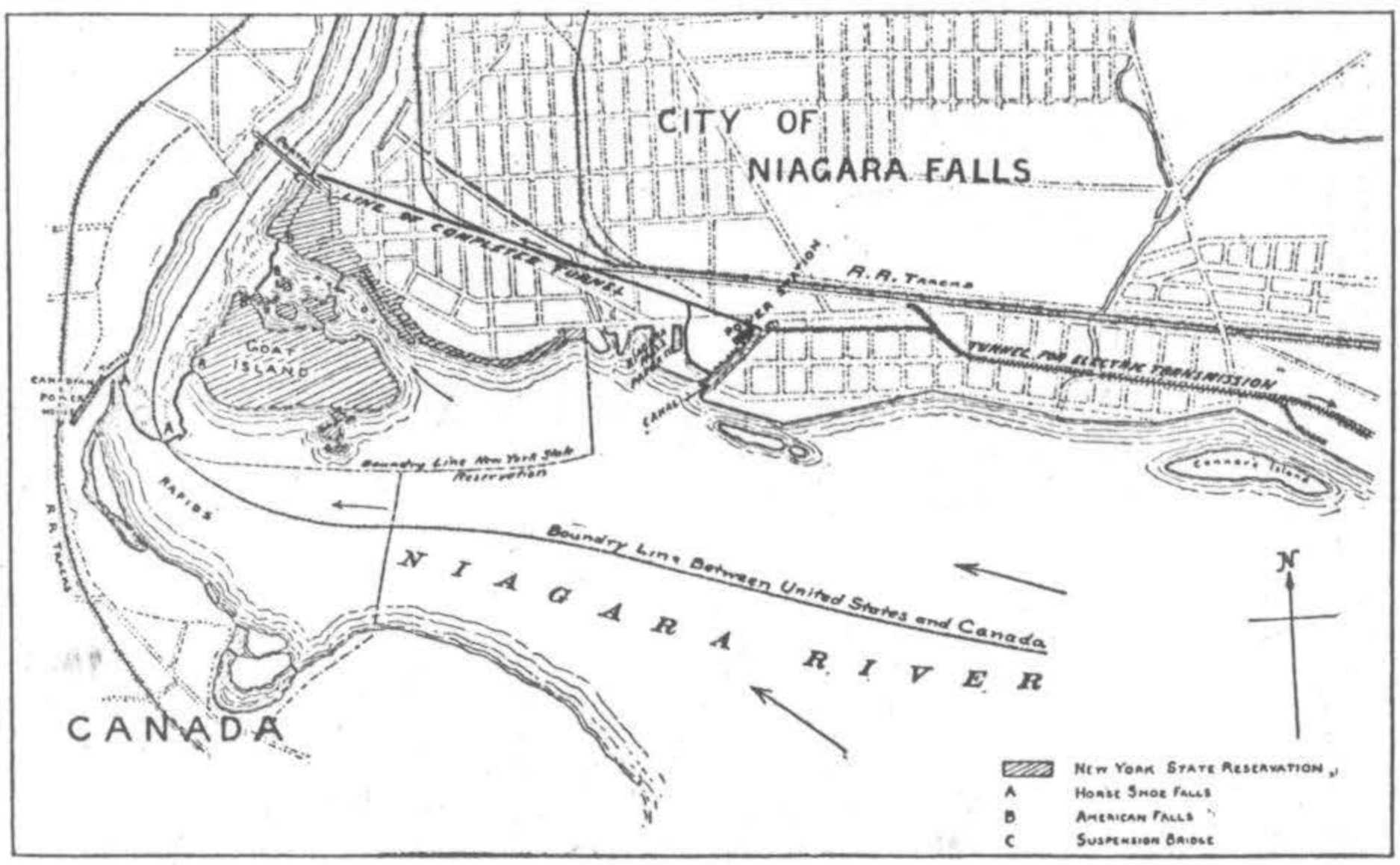


SEAL OF THE CATARACT CONSTRUCTION COMPANY. PHOTOGRAPHED FROM THE ORIGINAL, WHICH WAS MODELLED IN CLAY BY McMONNIES.

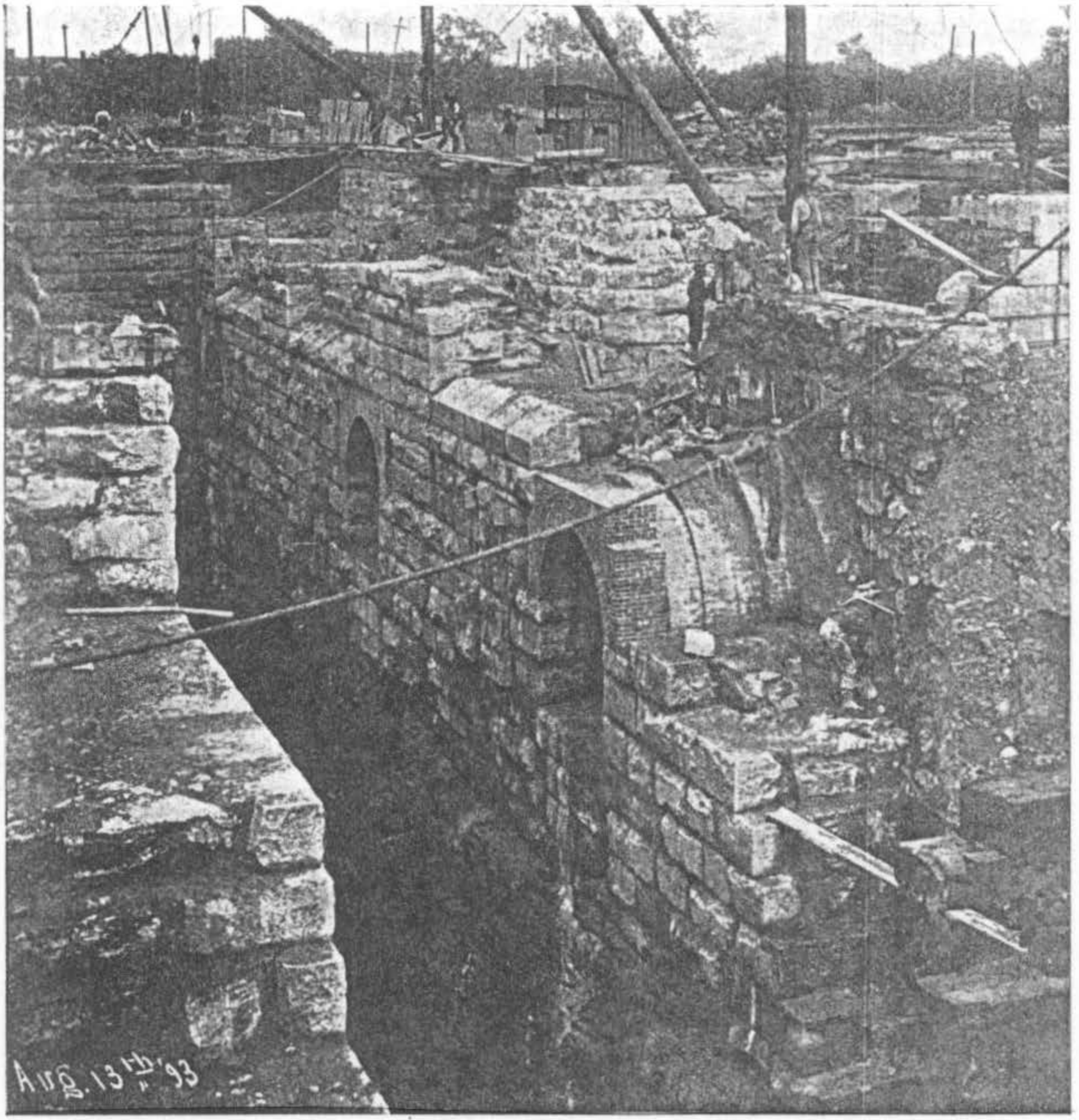
only been proved possible by practice, but it was proved possible even before the first stone was blasted from those rocky banks to make place for the foundations of the mill. To-day this colossal machine, dragon-like in its length and suggestion, the longest single piece of machinery in operation in any of the factories in the world, runs as smoothly, and delivers its finished product as perfectly, as the most exacting of mechanics or manufacturers could demand. To effect this only a little over three thousand horse-power is diverted from the Niagara current, and the amount of water is as inappreciable, almost, in its effect upon the Rapids, as would be the withdrawal of a hogshead of water from the ocean.

It is the design to secure perhaps as much as fifty thousand horse-power from the force of the Niagara current, by diverting it into turbine wheels for direct application. This of itself would create one of the greatest water-power plants in the world, and, if cost, transportation facilities, and other conveniences of manufacture are found to be satisfactory to the manufacturers, would be sure to rear upon the banks of the Niagara, before many years, a city rivalling Lowell, or Lawrence, or any of the great manufacturing towns in New England which have sprung into flourishing existence because water-power was near.

But it was not the development of water-power as a direct agent chiefly that led capitalists to put their money into the development of a power-producing plant. Their plan contemplated the conversion of some portion of the force of the Niagara current into electric power, and the delivery of that power to communities at least fifty, probably a hundred, and possibly five hundred miles or more away. Of course the mechanical engineers have long been aware that the power which goes to waste over



the Niagara precipice is sufficient to turn the wheels of probably every manufactory in the United States, if it could be communicated to them. For years a little of the Niagara force has been utilized at the Falls; paper-mills and other manufactories have long been established there. But the expense of utilizing the power on any large scale by the diversion of it to water wheels has been too great to tempt capitalists to make much of an investment for such purpose. Not until after the invention of dynamos and the development of electricity into a commercially available force, even when carried to some distance, did the capture of the Niagara River, and its subjection to honest labor on a large scale, command the serious thought of capitalists.



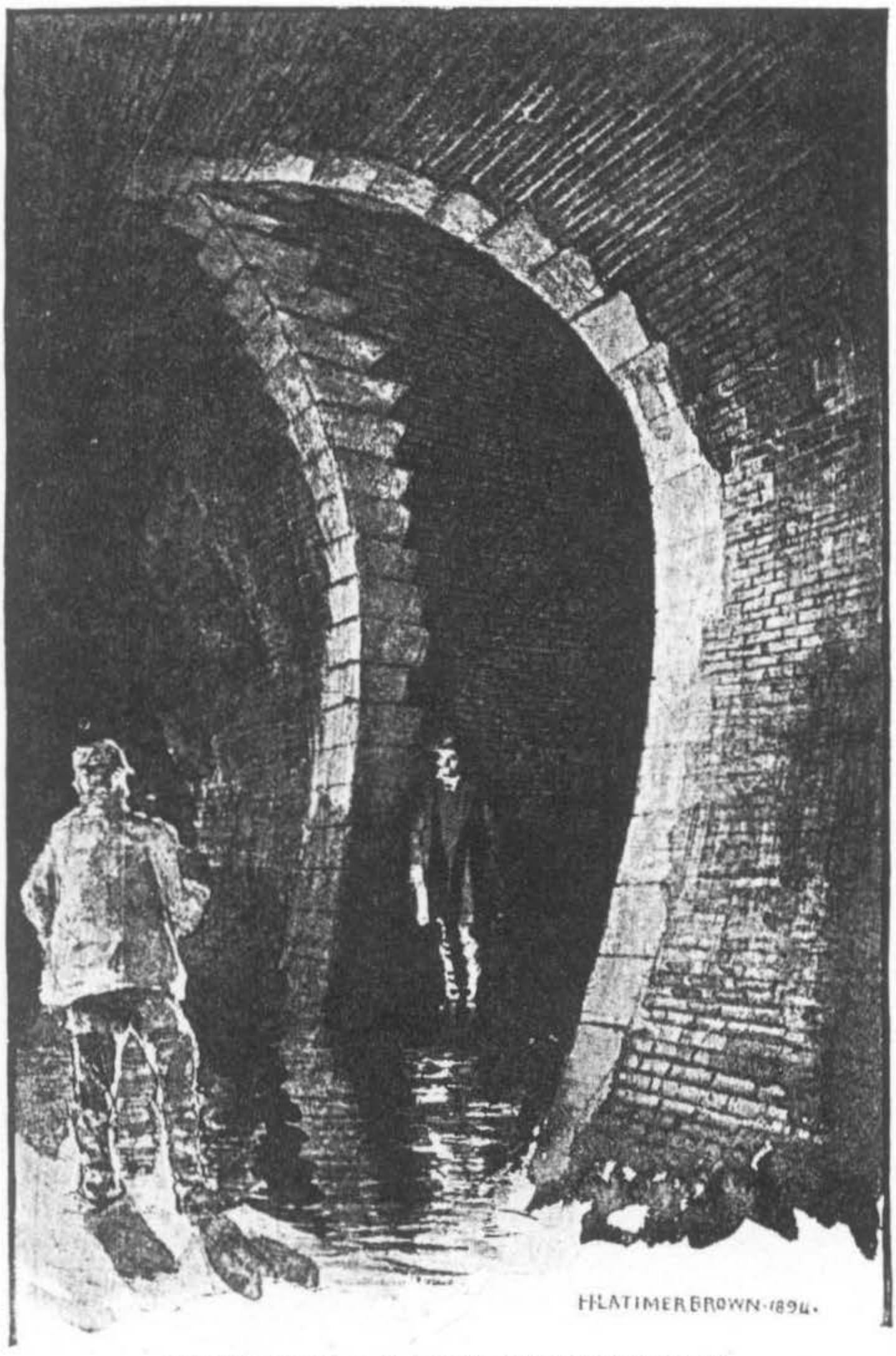
THE GREAT WHEEL-PITS IN COURSE OF CONSTRUCTION.

THE ORGANIZATION OF THE COMPANY.

It is now nearly five years since a few of the citizens of Niagara Falls determined to attempt the organization of a company to develop the Niagara water power and supply from it electrical power to near-by manufactories, and perhaps to the city of Buffalo. They met with the usual discouragements. The patience and aggressive faith of Mr. W. P. Rankine, a young lawyer of Niagara Falls, were all that stood between the original project and failure. Repulsed here and laughed at there, Mr. Rankine at last turned to Mr. Francis Lynde Stetson, a lawyer of New York City, who, having a large practice and intimate relations with some of the greater capitalists, might, Mr. Rankine thought, be disposed

to try and interest them, if he were once interested himself.

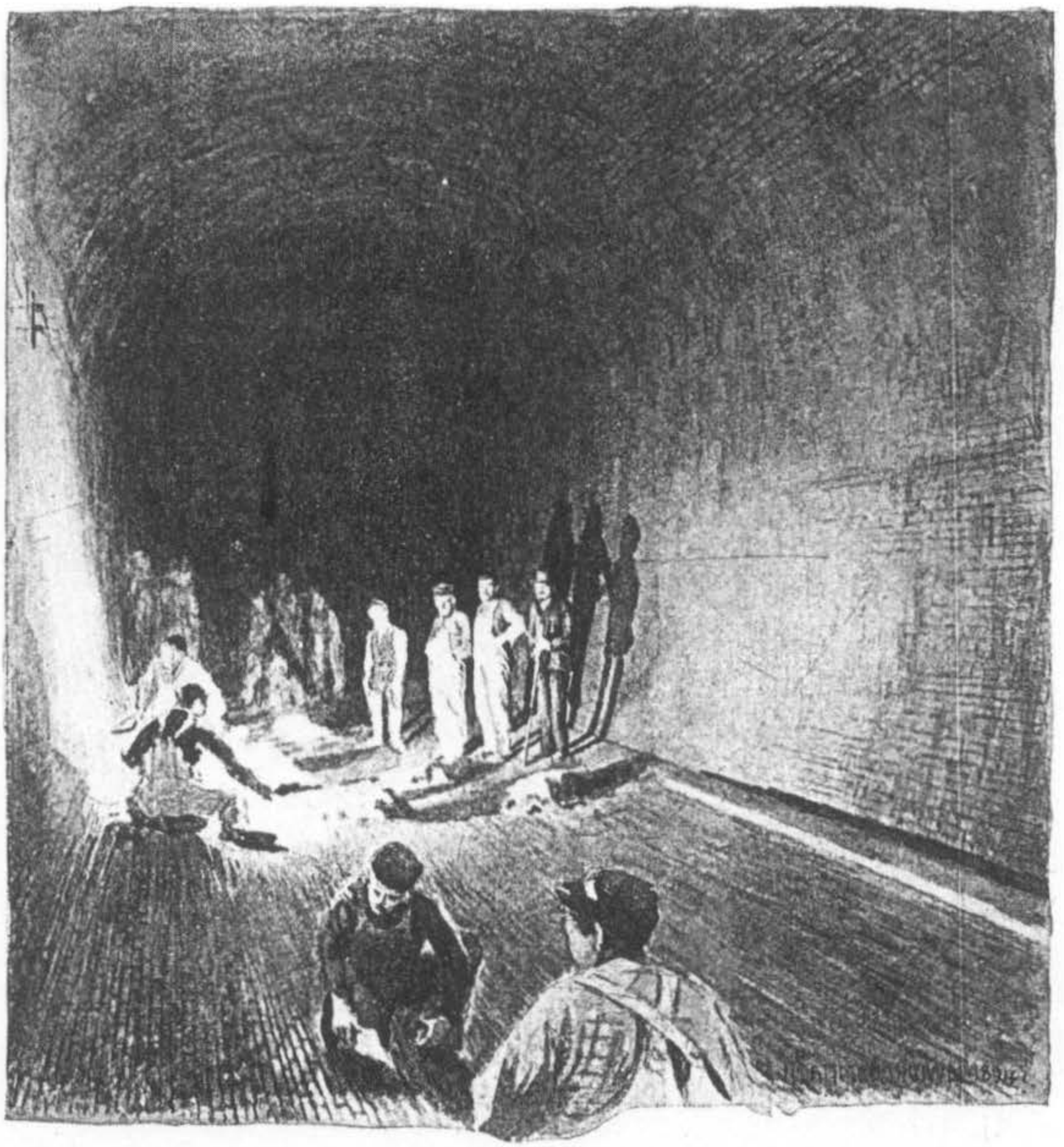
Mr. Stetson is a very busy lawyer. He is not a constructor, but a critic. It has not been his business to conceive and execute any of those plans which have developed into the greater business establishments of these years, but it has been his vocation to criticise, to view with the lawyer's eyes, to satisfy the statutes, and to show those who do plan what their rights and responsibilities are under the law. Therefore it was natural that, when the proposition to capture and control for the market some portion of Niagara's water power was made to him, he should be little disposed to listen. Perhaps, had the suggestion been made by one who was not an old and valued friend, he would have closed his ears to it entirely. As it was, it seemed to him too magnificent, almost too sublime, a scheme. However, he was at last persuaded, and upon his enlistment followed, under his influence, the enlistment of other important people. The company was organized, the needful money provided, the contracts given out, and upon a beautiful day in the spring of 1891, with appropriate and impressive ceremonies, the first spadeful of earth was turned.



JUNCTION OF THE MAIN TUNNEL AND THE WHEEL-PITS.

A WORK OF THE LARGEST DIFFICULTIES.

The enterprise so fraught with difficulties in the mere getting organized, involved in its execution yet more trying problems. It was necessary to determine not only the mechanical possibilities contained in the plan of construction, but also whether the expense entailed would be reasonable or would be so great as to make it prohibitive. And back of all others lay the ever-perplexing question whether the electric current, having been produced, could also be made available for delivery at considerable distances from the plant. On this the opinions of some engineers were discouraging. The reports of others had something of hope in them; but it was the splendid confidence of so great an engineer as Dr. Coleman Sellers, supplemented by that of Lord Kelvin, Mr. Clemmens Herschel, and one or two others, upon which the faith of the capitalists was based. The problem was, perhaps, not wholly solved in theoretical demonstration until Nicola Tesla, that illuminating wizard of electricity, persuaded these capitalists that he had discovered and, in great measure, perfected mechanical appliances which would make it possible to deliver the electric current, under complete control, and



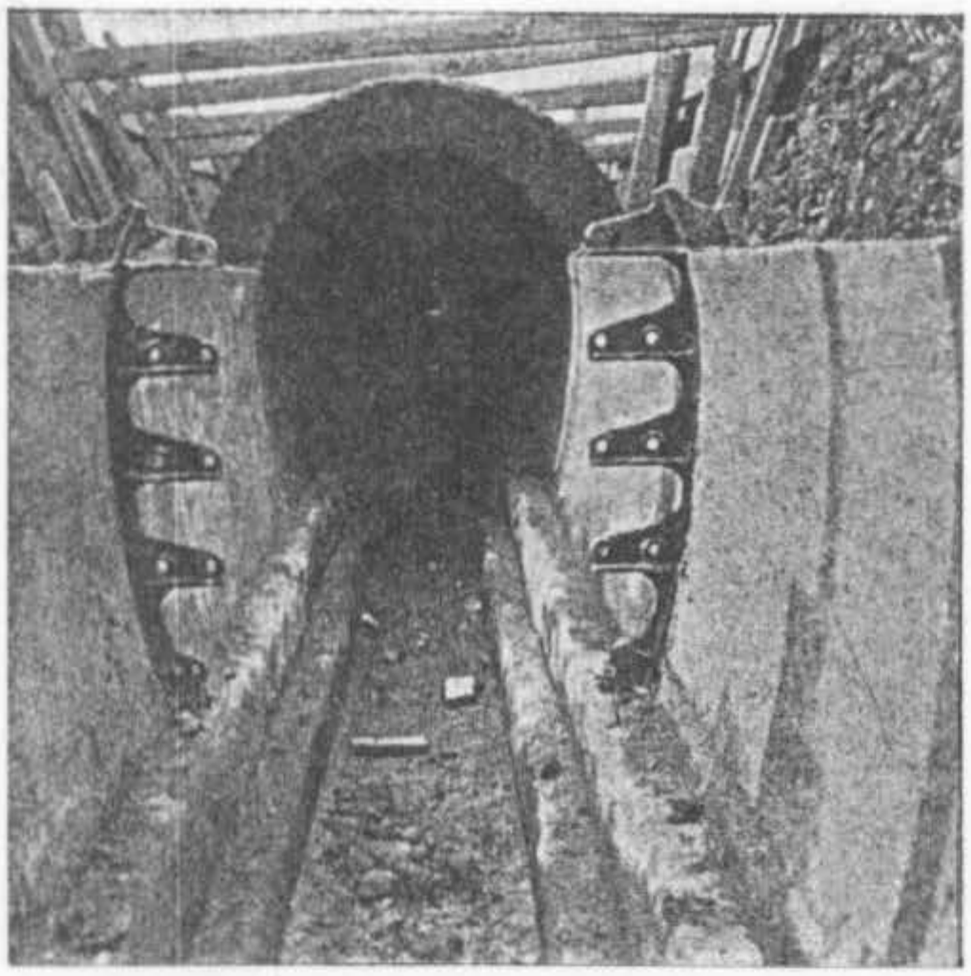
INTERIOR OF THE MAIN TUNNEL.

without costly loss from waste, a long distance; certainly as far as Buffalo and Rochester, and, as he himself firmly believed, as far as Albany, three hundred miles away. Mr. Tesla also has faith that, with the improvements suggested by experience, it will be possible by and by to deliver the current at fairly competitive prices as far away as New York City on the east, and as Cleveland and other of the greater towns in Ohio on the west.

Whether Mr. Tesla's views are correct, is something that is yet to be tested. We cannot know, in fact, whether the electric current can be delivered with commercial profit to any considerable distance from the plant until (which will be a few weeks hence) the turbine wheels are actually started, their colossal power is delivered to the dynamos, and, after being by them converted into electricity, is conveyed thence to the testing points. The scientific world is awaiting these experimental tests as it awaited the first flashing of the message through the Atlantic cable; and the world of commerce and manufacture is awaiting them with no less interest. In Great Britain, lacking any colossal water power like Niagara, it is already proposed to set up sufficient plants at the coal mines for the local conversion of the coal into electricity, to be delivered all over England and Scotland; and this will surely be done if the Niagara enterprise succeeds.

THE FEEDING CANAL.

The power plant proper consists first of an inlet canal situated about a mile and a half up the river from the American Falls. This canal is really a great reservoir into which the water backs. The opening, or great, gates, are placed not at the upper but at the lower end, the end nearest the Falls. That was done because the engineers believed that the current would be too strong if the water was admitted directly from the river. It therefore goes in by



THE SUBWAY CONDUIT, WITH BRACKETS FOR CARRYING THE ELECTRIC WIRES. THE CONDUIT WAS ABANDONED ON ACCOUNT OF THE HEAVY COST OF CONSTRUCTION.

a back flow. The canal will always be full. No drought, no frost of winter, has ever occurred so severe as to interfere materially with the flow of water over Niagara's brink. Into the canal are cut gateways of massive masonry, each controlled by a heavy gate, and connected with enormous shafts, or penstocks, of iron and steel, some of them of a diameter as great as seven feet. Through each shaft may be delivered a continuous force of water equivalent to from two thousand to five thousand horse-power. Those that turn the turbine wheels which keep the massive machinery of the paper-mill in motion, deliver three thousand six hundred horse-power. The total capacity of the canal is one hundred thousand horse-power; and it will be possible to so increase the capacity of this and other plants controlled by the parent and allied companies that ultimately there may be captured from Niagara Falls as much as four hundred and fifty thousand horse-power.

Some sense of the full significance of these figures can be had by bearing in mind that the city of Buffalo, one of the great manufacturing centres of the country, employs at present a force equivalent to only fifty thousand horse-power for all of its manufacturing plants. Four hundred and fifty thousand horse-power would serve to turn the wheels of every manufactory in central New York, to light and heat the cities and towns, and to provide propulsive power for the boats employed in traffic on the Erie canal. Yet even this is but a small fraction of the power which now goes to waste over the Niagara precipice. It has been estimated that when the plant is run to its full capacity, it will absorb only so much water from the river as would cause it to recede less than seven inches from its present mark upon the banks.

THE GREAT WHEEL-PITS.

Next to the canal or reservoir to be observed, are the great and gloomy pits at the bottom of which the turbine wheels are placed. Standing in the power-house of the paper-mill and looking down into the pit, it seems almost as though we were gazing into the mouth of the infernal regions. The workmen light a piece of tow saturated with oil, and when it has flamed up into a huge torch, let it down by a rope to the bottom of the pit. Then the visitor may see by the ghastly light of this torch the rushing of the water as it escapes from the wheel, and, coming up from the depths, he hears an infernal diapason. The force of the water is so great that if a man received it upon his body he would be crushed and shattered as though blown from the mouth of a cannon. The power is so great that turbine wheels of almost perfect resisting tensile strength have had to be made in order to receive the force with safety. Some of them are so large that it is possible for a man to stand between the blades, and one photograph has been taken in which Mr. Stetson and some of the officers of the company are pictured thus framed by these bronze blades. The pits are cut out of the solid rock, and the work was very expensive



THE MAIN TUNNEL WHILE UNDER CONSTRUCTION.



NIAGARA FALLS.

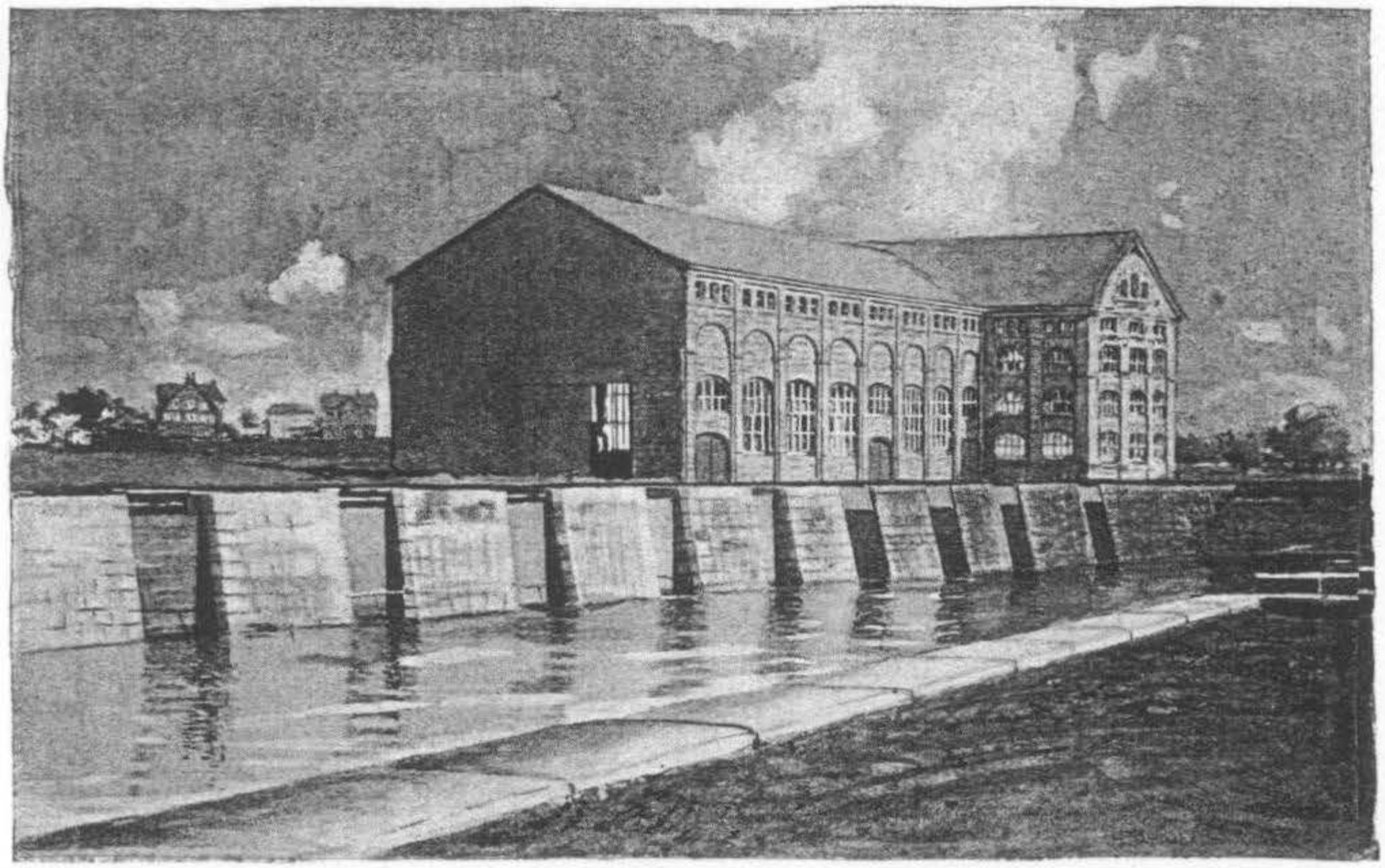
and difficult, consuming more time than the engineers had estimated it would.

THE ELECTRICAL POWER-HOUSE.

Over the greater of these pits is built the electrical power-house, a building designed by Stanford White, and suggesting in its unique and impressive architecture the enormous power to be generated within, and giving in itself some hint of the capacity of man to master the forces of nature. As it now stands it is one hundred and forty feet long, but the company designs ultimately to extend it three hundred feet. At the same time the main wheel-pit will be extended until it is large enough to contain ten turbine wheels, flying ten dynamos, each of five thousand horse-power. The water wheels at the bottom of the pit are connected by steel shafts to the dynamos, which are upon the main floor; so that the power of the water falling nearly two hundred feet upon the wheels is conveyed back to the surface and transformed by the dynamos into electricity. The dynamos are probably the finest and largest of all the mechanical implements now employed for the development of electrical power. They are built after the designs of the Westinghouse Company, and embody the very latest improvements in works of their class. For the present only enough of them are to be set up to produce electricity equivalent to fifteen thousand horse-power, and it is the design to deliver the greater part of this to the city of Buffalo.

THE GREAT TUNNEL.

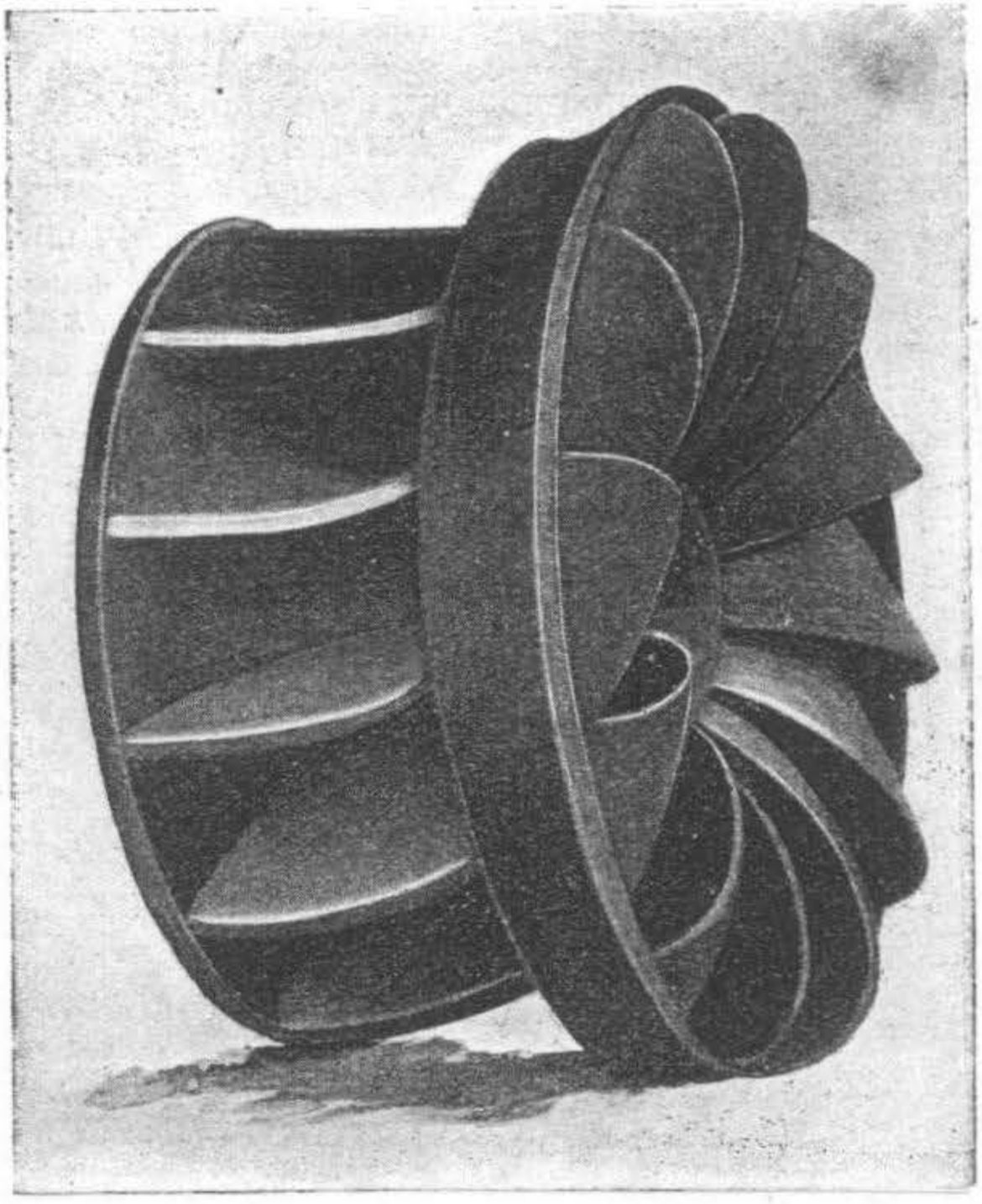
The most difficult to construct, perhaps, and the most impressive to view, of the several parts of this huge piant, is an artificial waterway, cut through the solid rock, two hundred feet beneath the surface. It is seven thousand feet in length, and as smooth and perfect as the boring of a great war gun. This is the main tunnel. It has no other function than to receive and discharge the water which has served its purpose and spent its force upon the turbine wheels. One section of it is almost directly beneath the heart of the town of Niagara Falls. When the passenger alights



THE POWER-HOUSE AND THE FEEDING-CANAL.

at the railway station he stands just over it. It is probably the most perfect piece of continuous rock boring to be found anywhere in the world. It is large enough to drive through, being eighteen feet and ten inches wide at its greatest diameter and fourteen feet and five inches wide at the bottom, and twenty-one feet high. It has a grade of from four to seven feet to the thousand, or sufficient to carry off the water swiftly, and yet with the least friction possible. The great boring is shaped like a horseshoe. In order that it may more surely resist the action of the water, it is lined at the lower end with plates of the best steel, and for the rest of the distance it is lined with bricks burned with the particular view of enabling them to resist the friction of the water. Some idea of the amount of work necessary to bore this tunnel may be obtained from the fact that the rock excavated in making it was sufficient to fill in nearly twenty acres of land along the shore of the Niagara, thus reclaiming, or, rather, actually constructing, land which is estimated to be worth at least one hundred thousand dollars.

One of the most difficult of the problems that the engineers had to solve was the connection of the main tunnel with the wheel pits, for just there not only was the force of the water very great, but it was necessary to turn the tunnel almost at right angles. The



A TURBINE WATER WHEEL.

tunnel proper runs as straight as the arrow flies, and the outlet, situated about a quarter of a mile below the American Falls and almost exactly underneath the new suspension bridge, is of itself a very remarkable piece of engineering work, one that has been greatly discussed by engineers and in the scientific journals. It is probable that this outlet, and the inlet connecting the tunnel with the wheel-pits, made a larger demand on engineering skill, and required more of accurate and careful science, than did the entire tunnel between these two.



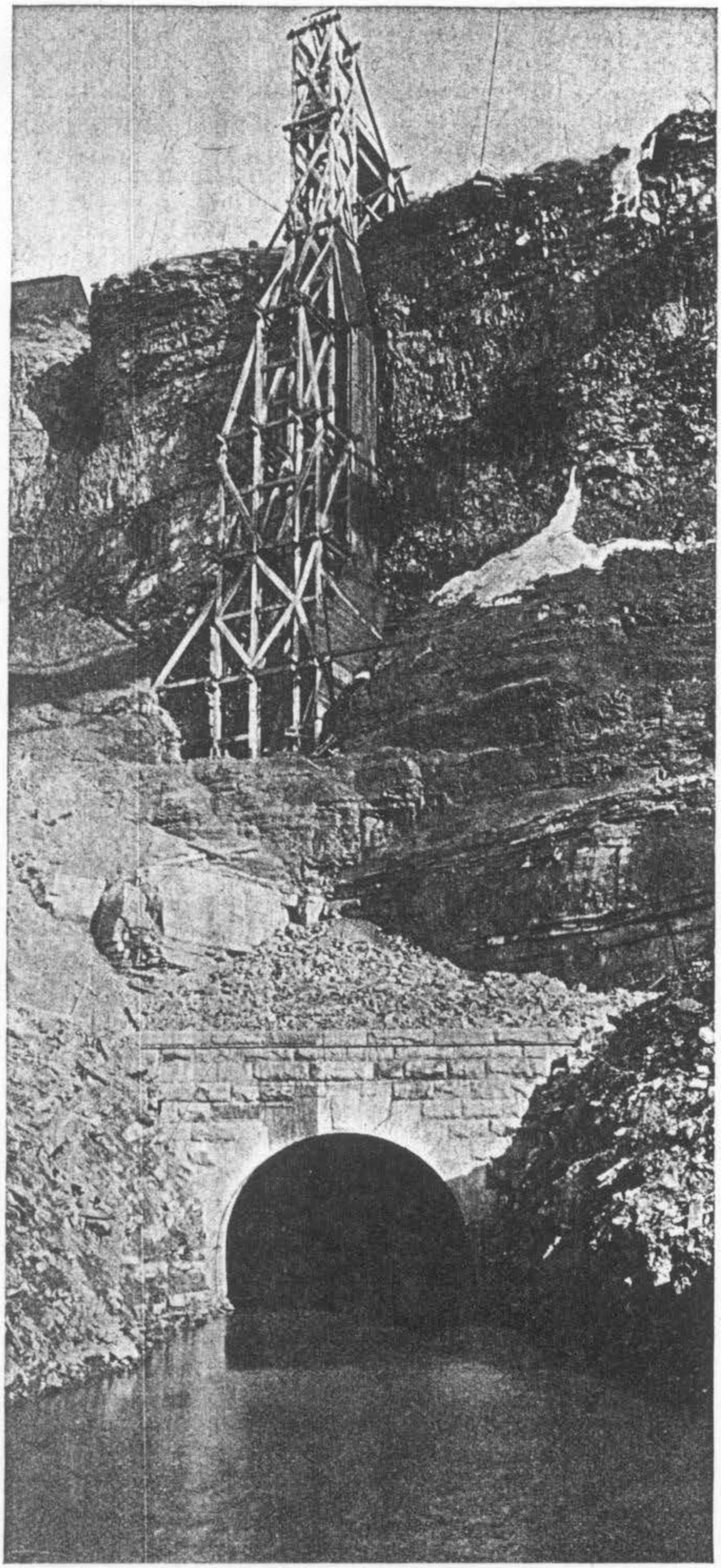
VIEW OF THE FALLS AND THE POWER-HOUSE.

THE WATER WHEELS.

The water wheels are not all of the same size. Those employed in the transmission of power to the machinery of the paper-mill were, when they were put in, the largest ever made. They were capable of generating as much as one thousand horse-power each. But they are mere pygmies in comparison with those which are to supply power to the great dynamos. Each of these has been built with the purpose of developing as much as five thousand horse-power, which is about the power required to drive an ordinary ocean steamship from twelve to fourteen knots an hour. There are to be three of these mammoth turbines, and their handmaids, the dynamos, are sympathetically colossal in their capacity to generate electricity.

THE COMMERCIAL PROBLEM.

Now that the plant itself is all finished and ready for the touching of the button which will send electricity over the wires, the next problem to be worked out in practice is the purely commercial one whether the

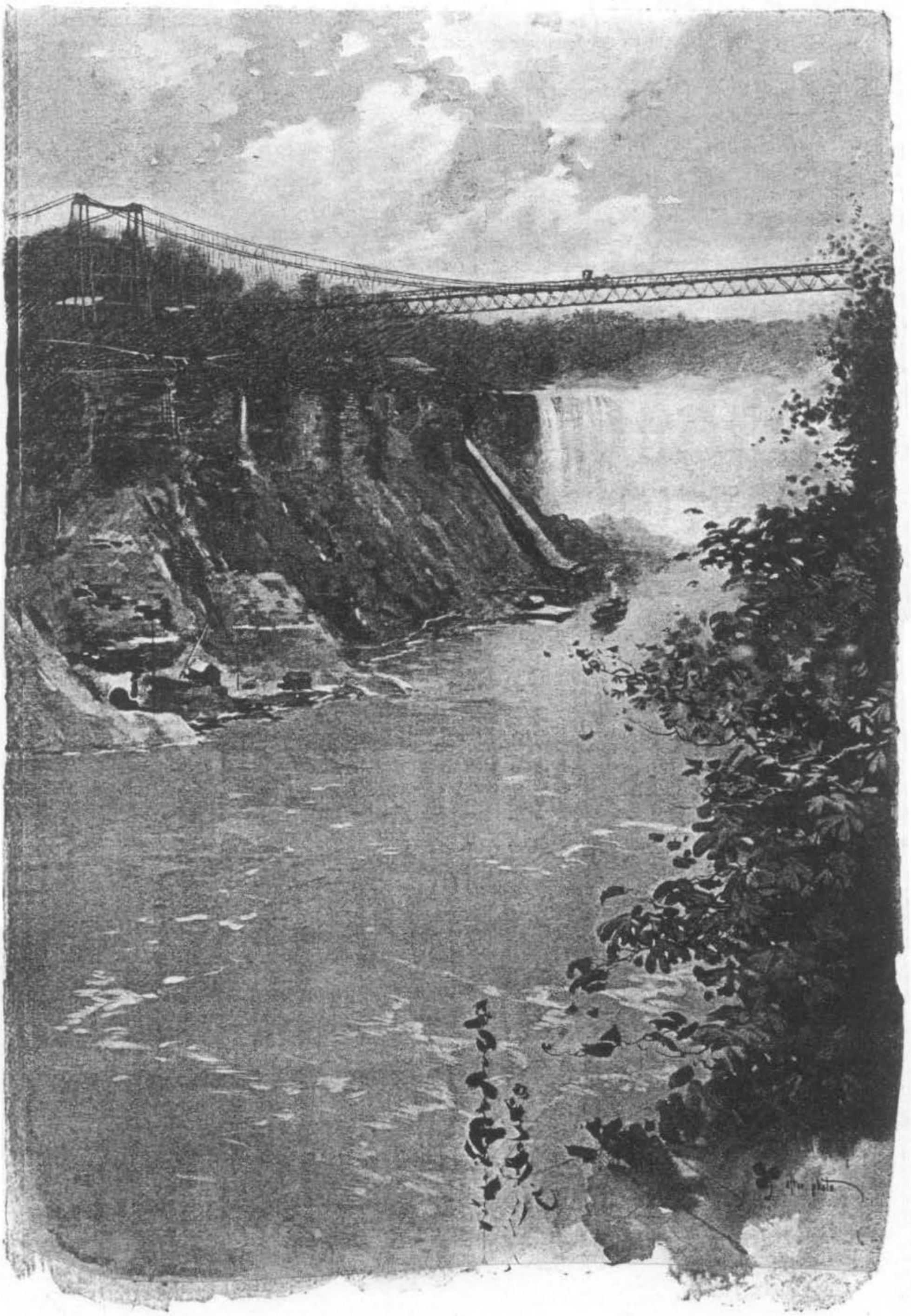


THE OUTLET OF THE TUNNEL BELOW THE FALLS.

power can be furnished to manufacturers, especially those at a considerable distance, at a price profitable to them and the company. The company itself, of course, and the able engineers and scientists who are associated with it, have no theoretical doubts about the commercial success of the undertaking. And, if it is commercially successful, it is simply the beginning of a prodigious revolution in the manner of producing and delivering power. In that case the time is probably not far distant when all of the considerable mills, all of the lighting, much of the traction power of the region within three hundred or four hundred miles of Niagara Falls will be furnished with this living energy which has been captured from the Niagara cataract. There will be created a considerable city at Niagara Falls, and there will be a great development of Buffalo as a manufacturing centre. Then considerable water powers in other sections of the country will be utilized so that the force of them can be converted into an electric current and delivered for commercial purposes to the towns within a considerable radius.

THE TRANSMISSION OF THE ELECTRICITY.

It was the first intention of the engineers to carry the electric current from the power-house by means of wires stretched through a subway conduit, whose beginnings may now be seen at a point near the power-house. But it has been discovered that the construction of such a conduit will be too costly, and the electricity is to be transmitted by overhead wires. This is the part of the undertaking which Mr. Tesla has devoted much thought to for several years. He has assured the company that, by means of inventions and the scientific application of newly-discovered principles which he has

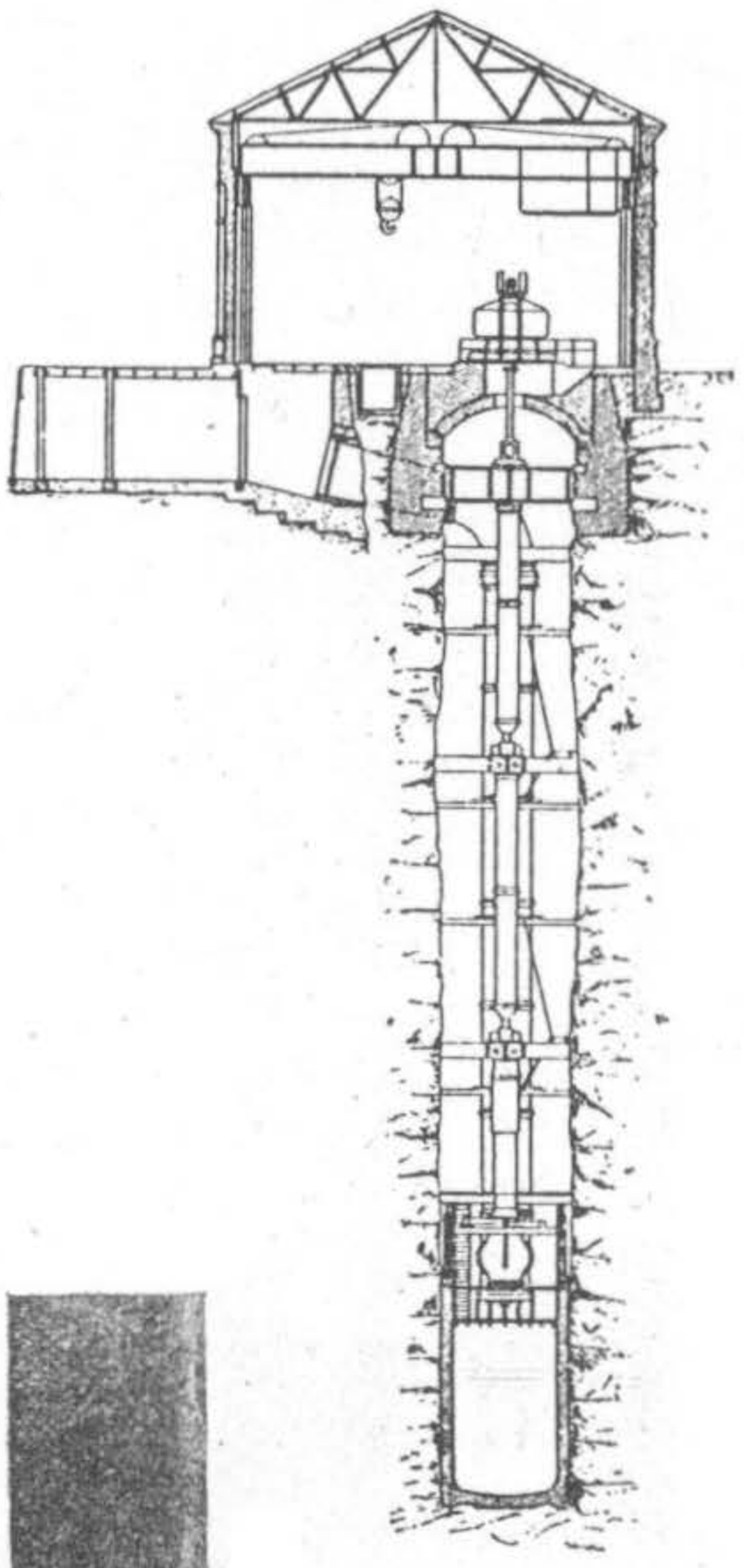


THE SUSPENSION BRIDGE, SHOWING THE OUTLET OF THE TUNNEL AT THE LEFT.

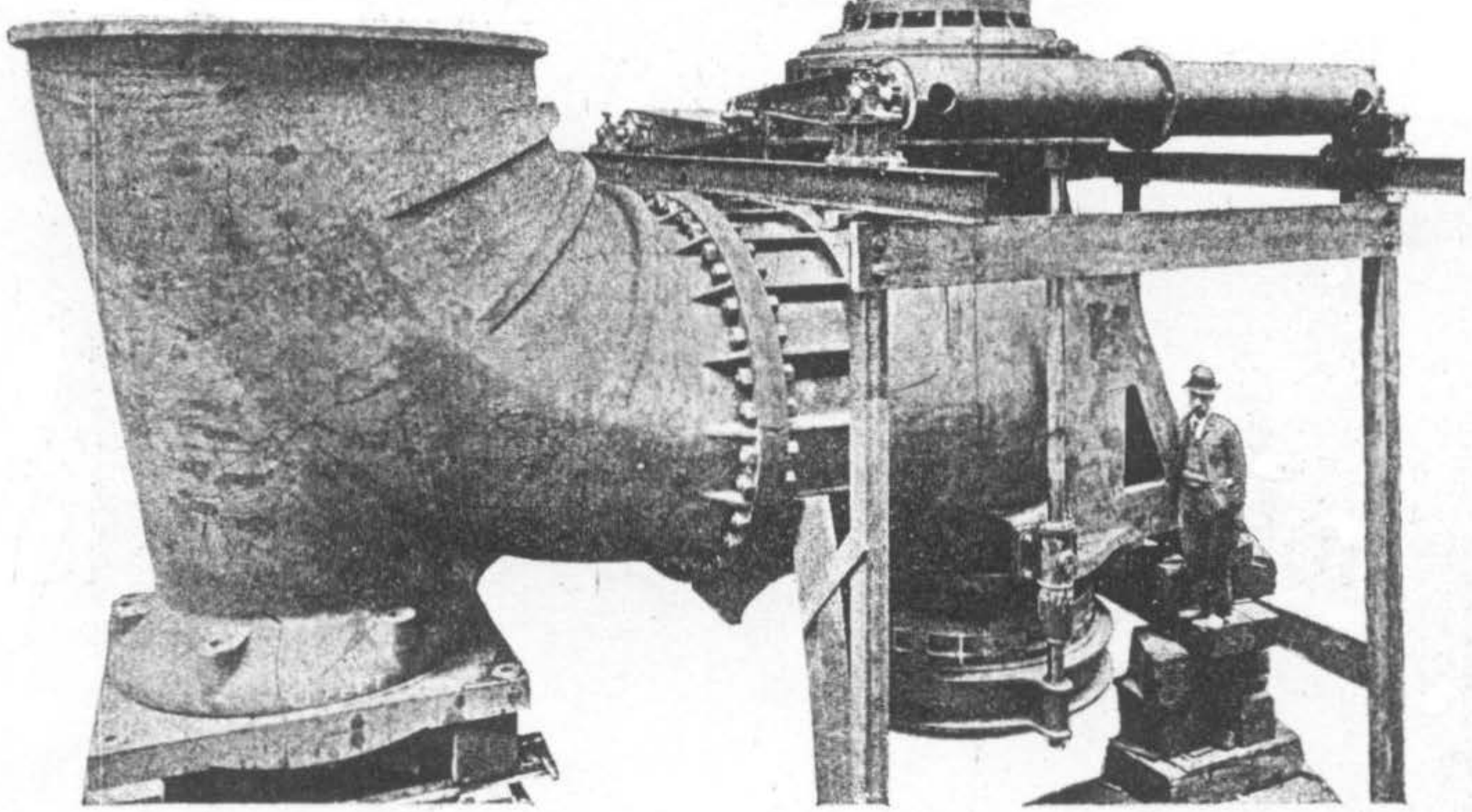
been able to make, it will be possible to convey the current without very great loss by induction or leakage, and under absolute control, by the use of certain transformers, as far east as Albany. It is Mr. Tesla's opinion that this current can be sufficiently utilized even to propel vessels from Albany to New York. The capitalists have faith in him. The scientists believe that he is right. The city of Buffalo is persuaded that it is so, and already contracts for the delivery of as much as ten thousand horse-power to that city have been made. In a general way it has been estimated that the power can be delivered to any town within a distance of three hundred miles, at a cost of about fourteen dollars a year per horse-power, and for twenty-four hours a day, while it is estimated that the cost to the city of Buffalo will be considerably less.

THE SEVERAL COMPANIES.

In the enterprise are several companies, each independent as a corporation, but all mutually dependent upon the parent company. There is the Niagara Construction Company, the Niagara Falls Power Company, the railway company (for they have built a railway some five miles in length), and the land company, which controls the new village of Echotah, a community which promises to be a model one. Then there are the Canadian companies, which will ultimately build two tunnels on the Canadian side, each of them representing a power-producing capacity of one hundred and twenty-five thousand horse-power, and work upon one of which is to be begun in a short time. It is also probable that in each of the towns in which electric power is furnished there will be organized



PENSTOCK AND SHAFTING. SIDE VIEW.



PENSTOCK AND CASING OF A FIVE THOUSAND HORSE-POWER TURBINE WATER WHEEL.

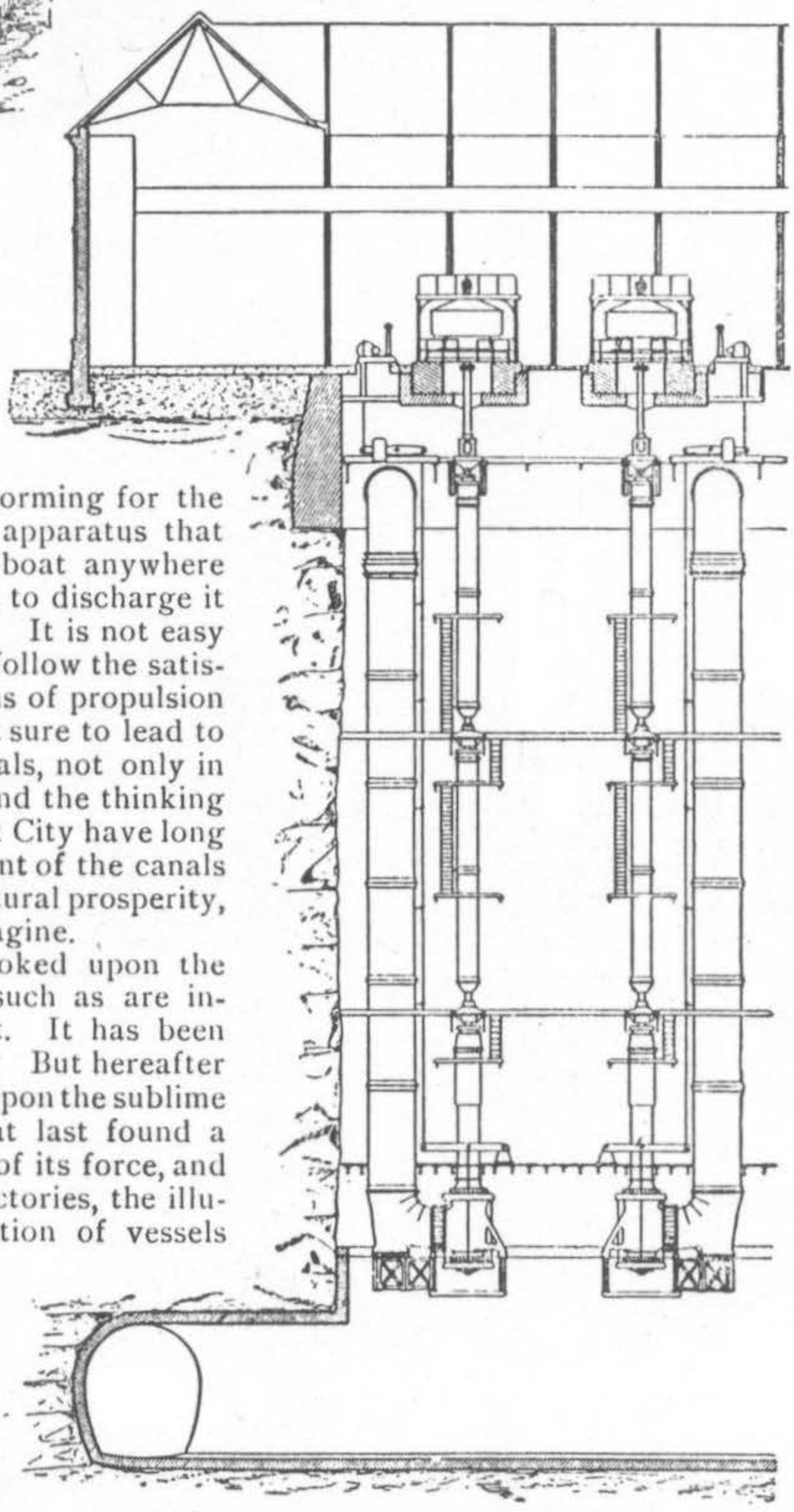
local companies for the control of it, independent in one respect, and yet practically controlled by the parent company.

One of the most important of the undertakings in contemplation is that of furnishing electricity for the propulsion of canal-boats. That the electric current can satisfactorily propel a heavily laden canal-boat was demonstrated by experiments made near Rochester last fall under the direction of Mr. Frank Hawley, who, while associated with the parent company indirectly, is more especially interested in the development of electric power for canal purposes. Already projects are forming for the equipment of the Erie canal with apparatus that will make it possible for a canal-boat anywhere to take up the electric current, and to discharge it again wherever the owner pleases. It is not easy to estimate the results that would follow the satisfactory use of electricity as a means of propulsion upon our water-ways. It is almost sure to lead to a greater development of the canals, not only in New York State, but elsewhere; and the thinking men of the exchanges in New York City have long said that with a greater development of the canals will come a commercial and agricultural prosperity, the limits of which no man can imagine.



A STREET IN THE NEW VILLAGE OF ECHOTAH.

Thousands of people have looked upon the Niagara cataract with emotions such as are inspired by no other natural object. It has been pronounced "nature's finest epic." But hereafter when the visitor who goes to look upon the sublime cataract discerns how men have at last found a way to take from it some portion of its force, and how the whirl of the wheels of factories, the illumination of cities, the steady motion of vessels upon the artificial waterways are all but responsive throbbings to the thunder of the cataract, perhaps he will consider that a yet finer epic has been written by the energy of those who have been engaged in subduing the forces of nature that they may serve mankind.



PENSTOCK AND SHAFTING—REAR VIEW.

McClures Magazine October 1894

NIAGARA.*

SINCE the first dawn, thro' vague and unknown ways,
  Between the icy north and where I fall,
  From lands beyond the pole, from where brooks call,
And sing responsive to the cold birds' lays,
I glide, I leap, I bound, thro' nights and days;
  I rush, I rave, I roar, and I appal—
  Ay! to the very heights of heaven's wall—
The hosts that reverential glances raise.

And puny men who walk the earth ne'er dream
  Of the great force beneath my glassy face;
    And, so, from my brown bed up to the sod,
I seem in all my majesty supreme
  Defying time and earth, and fate and space,
    To be the tumult of the tears of God!

AN EVENING IN TESLA'S LABORATORY.

WHILE the American Electro-Therapeutic Association was accorded a great honor in being the first body to receive an invitation to visit the Tesla Laboratory, and showed its appreciation by a large muster, it must be said that to engineers present the demonstrations made were even more interesting than to the physicians. The feature of the reception on Thursday evening was the exhibition of a recent form of Mr. Tesla's new machine, the oscillator, which was running beautifully and with which the experiments were performed. Some of these experiments were certainly quite remarkable. The oscillator was run at 350 pounds steam pressure, and in the course of his conversational remarks Mr. Tesla said that he did not anticipate any difficulty in running at much higher pressure with such a machine. There were two pistons in the machine vibrating in opposite phase 80 times a second. The vibrations of these pistons developed an electric current which was led to a bank of lamps, and some 50 incandescents were lit up by the current. Arc lights were also shown in operation, and Mr. Tesla pointed out the curious fact that when arcs were operated from this new type of machine, the oscillations of the pistons were but a fraction of the time of the oscillation of the carbon rod; and hence the lamps instead of pumping or jumping as they so often do when fed from the ordinary rotating machines, were as absolutely steady as though they were on a battery circuit. The ordinary rotating dynamo has inertia which requires time to respond, and hence considerable resistance, ohmic or inductive, must be provided in the ordinary arc armature; otherwise the amount of arc lights or variable load on the machine must be comparatively small in proportion to the steady load of incandescent lights.

Mr. Tesla repeated also what he said, as to another feature of advantage in the oscillator, at the time he first brought it to notice before the Chicago Electrical Congress, namely, the production of currents of constant period and the perfect maintenance of the regime once established. This enables him to perform experiments remarkable for the small amount of energy they take as compared with ordinary alternators. Mr. Tesla expressed the belief that by further perfecting such machines he will have at hand the means for transmitting intelligence to a distance without wires, as already pointed out in one of his recent lectures. He asserted that this problem depended solely on the perfection of this machine.

One of the very interesting and striking experiments shown was the following: Mr. Tesla had a circle or cylinder frame about 4 feet in diameter in a room about 40 feet by 80. This circle was composed of a number of turns of copper wire, and was entirely unconnected with anything and remote from anything, being in the centre of the open space. It was adjusted to the vibration of a current which passed through a wire stretched around the room; and vacuum tubes and small incandescent lamps were lighted by proper adjustments of the capacity of the circuit.

Another curious and suggestive experiment was the following. A small hoop or circle, about 3 feet in diameter was shown wound

with fine wire. Mr. Tesla explained that he had adjusted the wire to the ordinary average "capacity" of plain citizens, in such a way that the maximum current would flow through the wire. The ends of the wire were connected to two handles which could be grasped so as to allow the circle to be held out. The current induced in the wire sprang through the small air gap shunted by the handles, and powerful shocks were felt all around in the room, by means of this exploring instrument. When the area of the circle was compared with the area enclosed by the distant wire around the room, the effects were really remarkable.

Several motors were also on view, of the rotating field type, and single phase. There was one, of small dimensions, which served to count the oscillations, and which had been exhibited also at the World's Fair. Mr. Tesla touched incidentally on the advantages of the current curves employed in these machines, which are proportioned to the squares of the sines of the time. There are two such sine square curves superimposed in quadrature and Mr. Tesla commented on certain benefits obtained with such curves.

A great many other experiments were performed with static and electro dynamic induction, closing with the display of the vacuum tubes and phosphorescent bulbs lit up in the charged free spaces. Mr. Tesla frequently repeated the remark, which was obviously true to those who had seen his earlier experiments, that his oscillator is already proving of great value as a means of prosecuting further experiments and researches in the new field which he has opened up; while its promise of yielding great practical economy in the production of electricity is daily nearer realization. Among the advantages referred to were the ability of the machine to demonstrate the electro-magnetic theory of light, and its value as affording a crucial test of the Hertzian experiments and other investigations in that line. It may be added that besides the feature of running at almost any pressure, being, so to speak, frictionless, the most noteworthy fact to be appreciated by engineers is that when the piston vibrates at this great speed, and in spite of the high steam pressure, there is no packing on the piston whatever, and there is no leaking of the steam. As one watched the oscillator on Thursday evening, there was nothing to indicate that steam was present or was being used, except the steam gauge and its indication. The small boiler used by Mr. Tesla is one specially built for him by the Babcock & Wilcox Co., of their regular sectional type and tested up to 550 pounds. Mr. Tesla was really enthusiastic in praise of its working. The four arc lamps were of the Helios Company's make.

A MAN OF THE FUTURE.

A Genius Who Loves America and Has Added to Its Greatness.

How Nikola Tesla Looks at Work—The Day When We Can Telegraph Messages Without Wires—Niagara Power in New York—Electricity, Generated by Flying Atoms, Will be Pumped Out of the Earth for Use Anywhere. Tesla's Early Days and His Wonderful Experiments—His Latest Invention.

New York, Oct. 20.—It is a most difficult thing to interview Nikola Tesla, but to sit down and talk with him, man to man, ah, that is a different matter, and if one has had that privilege he will be glad to remember it in years to come, and to tell his grand-children about it, for it is quite likely that they will know very well who Nikola Tesla was.

This brilliant young electrician, who undoubtedly is the foremost thinker of the world in his chosen field is honestly and sincerely modest. No writer who has tried to get him to talk for publication has any doubts on that score. "It is an embarrassment to me," he says, "that my work has attracted much public attention, not only because I believe that an earnest man who loves science more than all should let his work speak for him if it will, but because I am afraid that some of the scientists whose friendship I value very much suspect me of encouraging newspaper notoriety." Mr. Tesla reverted to this matter several times in the course of two conversations and is evidently sensitive about it. Therefore, the portions of this article that come from him should be regarded as a spesial concession, particularly as he has never talked so freely before. Bogus interviews with him have been published of late, but this is genuine.



Nikola Tesla.

Mr. Tesla spends his days on the fourth floor of a machine shop at No. 33 South Fifth avenue. His name does not appear anywhere on the building, and there is nothing about the place to indicate that it is one of the world's centers of electrical interest. The whole floor is occupied by Mr. Tesla's laboratory, except that one corner is partitioned off into the plainest of little offices containing principally a modest desk for the inventor a more modest desk for his bookkeeper; a book case largely devoted to the "Official Gazette of the patent Office," and a small black board which hangs on the wall and bears evidence of hard usage. The black is worn from this board in several spots, and the rest of it is covered with figures and cabalistic signs. No doubt the science of electricity would have been notably poorer but for some of the problems worked out on that shabby black board, for when the inventor is puzzled he goes to it and works on it nervously with a stubby piece of chalk.

The laboratory itself looks commonplace to the uninitiated. It is filled with machinery and electrical appliances, and a stranger prowling about the building at will would surely mistake its fourth floor for a part of the machine shops below. One who is not an electrician would find in the Tesla workshop none of the marvels that make Edison's laboratory better than a circus for the sight-seer. An electrician, however, would find secrets there with which he could make and break colossal fortunes on the stock market, for the reasons that will appear further on.

But Mr. Telsa's half-dozen employes are tried and trusted men, and the would-be visitor would find it an extremely difficult matter to get into this laboratory. If he did get in he would be more than likely to find the inventor there, working over some bit of machinery, with a handkerchief tied about his throat in lieu of a collar, yet dressed in clothes of fashionable cut, and generally looking very neat and clean. Unlike Mr. Edison, the younger inventor has some regard for his personal appearance.

One rarely meets a man more free from affectations and self-consciousness than Nikola Tesla. He does not like to talk of himself, and when that subject comes up he is sure to steer away from it as quickly as possible. He has bachelor quarters at the Gerlach, on West Twenty-seventh street, but he can be found at Delmonico's nearly always at breakfast and dinner time.

With due apologies to Mr. Tesla for so much personality, it may be said that he has the same cast of countenance as Ignace Jan Paderewski—long and thin, with fine, clean-cut features, low forehead, and a certain gleam of the eye that denotes what might be called spirituality. He is an idealist and one who has created an ideal of him from the fame that he has won, will not be disappointed in him upon seeing him for the first time. He is fully 6 feet tall, very slender, very dark of complexion, nervous and wiry. Impressionable maidens would fall in love with him at sight, but he has no time to think of impressionable maidens. Day and night he is working away at deep problems that fascinate him, and any one who talks with him for even a few minuntes will get the impression that science is his only mistress and that he cares more for her than for money or fame.

Any one who has met Paderewski and has been able to speak German or French with sufficient fluency to enjoy a conversation with him, and who has also had the pleasure of a talk with Tesla across one of Delmonico's tables, will feel instinctively that the Polish pianist and the Servian electrican have much in common, and that it is a great pity they have never met. Some philanthropist could do both of them a service by bringing them together when Paderewski comes to this country again next December. They could at least find a common ground of interest in Slavic literature, with which both have a wide acquaintance.

Speaking of love for science, Mr. Tesla said the other day in one of the rare moments when he could be induced to talk of himself: "Wherever I am, I cannot help working at problems that present themselves to me and seem so important that I cannot help but try to solve them. I spend so many hours at my laboratory at times that my friends become alarmed and threaten to lock the place up and hide the key. Seriously," he continued, with earnest face and eyes fairly ablaze, "seriously, if they tried to do that I should shoot them. I would indeed. It makes no difference to a man's health how long he works as long as he loves his work, for his affection is like the oil in the lamp which keeps the wick burning without consuming the wick itself. When the oil is gone, then it is that the wick goes fast. If at any moment I lost my eagerness and enthusiasm, then very likely I would go to pieces.

"That was what would have happened to me if I had continued to be a journalist. You never knew that I was once a member of your profession? Well, I was. The trouble with me was that I wrote too carefully, and, as it seems to me, too thoughtfully. When I wrote an article of which I was particularly proud, my friends would say: 'Tesla, that was a masterpiece.' But the editor would say: 'Why don't you write something more lively? Not a half a dozen people would read that stuff.' No, journalism is the hardest work in the world for the man who wishes to be thoughtful. My heart was not in it, and it would have worn me out soon, like the wick without any oil. Even as it is now I get worn out sometimes, but it is a great comfort to be one's own master and to feel that there is nothing to prevent one's dropping all work at any moment and starting for Europe or elsewhere for as long a rest as one wants.

"I have noticed a queer thing about my mental operation, and that is that my mind seems to work in two halves, each independently of the other, so that when I talk, or even when I sleep, only one half of my mind appears to be thus engaged, the other half goes on steadily with whatever I have on my mind, or may be I ought to say with whatever it has on its mind. My friends say, 'You will kill yourself.' I say, 'Nonesense.' I used to be an athlete once and I recuperate very quickly. See me now." He held up his hands as if they were trustworthy indicators of his physical condition. They were long and thin and nervous. They trembled a little and the conclusion naturally to be drawn from them was that their possessor was a man whose tremendous energy, although under good control, was likely to use him up if run at such high pressure much longer.

Mr. Tesla is only 37 years old, and he looks even younger. He was born at a town called Smiljan in Servia, on the borderland of Austro-Hungary. His family was an old one, cultured and highly respected. His father was an eloquent preacher of the Greek church, and his mother was a woman of re markable ingenuity. He had an inherited taste for mechanics and it is her blood that made Tesla what he is. His father wanted him to enter the church, but he could not be kept away from experiments in magnetism and electricity, in which he was deeply interested by the time he was 16. He was finally permittd to go to a polytchnic school with the idea of becoming a professor of mathematics and physics. He was making inventions of improvements for the telephone before he was 25 years old. He secured employment in Paris as an electrical engineer and then came to America early in the80's, not because he had any definite employment in view, but because he became convinced that the United States was the best country in the world for an inventor, because new ideas were more quickly and highly appreciated here than anywhere else.

The day he arrived he e he went to work for Mr. Edison, for whom he had, and has yet, the strongest admiration. He left the wizard of Menelo park in order to join a company organized to sell some of his inventions in arc lighting.

Much of Mr. Tesla's spare time during his first five years in this country was devoted to experiment with what is known as the rotating field for use with the alternative current. In 1887 Prof. Anthony proved that the young electrician had produced an alternating current motor of an efficiency equal to that of direct current motors, yet dispensing with the brushes and commutators which had added materially to the cost and inconvenience of manufacturing electricity.

He pushed on eagerly in the field he had opened, experimenting with alternating currents of extraordinary high potentials and frequencies. The results of his experiments were laid before the public in a lecture delivered before the American Institute of Engineers in May, 1891. Before that time he had been known only to electricians. By the hour the reports of that lecture had found their way to the public, he was famous. The brilliant gathering of scientists before whom the lecture was delivered, was taken by storm with his theories and his remarkable experiments in verification of them. Soon after,



Those Little Worlds.

another lecture was delivered before the most notable body of electricians in Europe, the Institution of Electrical Engineers in London, and his reception by them was as enthusiastic as it had been in America. A day later, by special request, he repeated his experiments before the Royal Institution, and soon afterward responded to an urgent call from the two foremost societies of engineers in France. In 1893 he delivered lectures in Philadelphia and Europe, which served to intensify public interest in him. One of his experiments on these two occasions was spectacular in the extreme. Facing an audience of some 5,000 persons, he passed through his body a current of 200,000 volts, causing streams of light to pour from his body and break forth from his finger tips, whereas a current of a hundreth part of that energy would have killed him instantly, thus proving that the amount of electric energy that may be passed into the human body depends on the strength and frequency of the current, and that the higher these are the less harm they do the body. Mr. Tesla said that at the time that the only inconvenience he felt from thus making an electric light of himself was a slight pricking as of a needle, and a burning sensation at the finger tips.

The most important work on which Mr. Tesla is now engaged, and which bids fair to bring him more fame than anything he has done before this, is a machine by which a heretofore unheard of steam pressure can be applied to the generation of electricity, reducing the waste of the current, and what is of supreme importance, reducing the cost of electricity.

It is easy to see that any device by which the cost of electric power is brought below the cost of steam power will bring a revolution in the process of manufacturing more sudden and startling than was brought about by the introduction of steam. The economical transmission of electricity generated by water power, as at Niagara Falls, has already brought a promise of this revolution, and if Mr. Tesla's machine will bring a corresponding reduction in the cost of electricity to cities too far away to derive benefit from water power like that at Niagara, then, indeed, the revolution will be complete. Electric motors will everywhere



Experimenting.

take the place of costly and wasteful shafting in mills and factories, and the day when private houses will be lighted, heated and, to some extent, run by electricity, will be brought almost as near to other cities as it now is to Buffalo, which will receive its first installment of power from Niagara Falls in a few weeks at a price promised to be somewhere near a fourth cheaper than that now paid for the work done by steam.

This much may be said positively, and the statement is here made to the public for the first time: If the wonderful machine on which Mr. Tesla is now putting the finishing touches works as well elsewhere as it has already worked in the Tesla laboratory, it will bring the extraordinary advantages suggested above. The inventor himself refuses to make any definite statement as to what his engine will do. "I know," he says, "that it will accomplish in my laboratory results that cannot but be considered important, and that certainly open up a new field for high-pressure boilers. It is now in operation and has succeeded absolutely, but of course I must not predict from laboratory results what a machine will accomplish when applied to public uses. It may take two or three years to prepare for placing it on the market. I have, of course, a pretty definite idea as to the reduction it will make in the cost of electricity, but there are many reasons why it would not be well to give the figures."

The young inventor endeavors to speak very conservatively of this new machine of his, but it is quite probable that he believes he has solved one of the most important practical problems within reach of the electrical science of the present day. Any one who is familiar with the mathematics of the steam engine will appreciate one phase of his device when it is stated that it is now run with a steam pressure of 375 pounds, the highest that was ever put to practical use. The pressure generally used is about 175 pounds. The boiler which supplies this steam pressure in the Tesla laboratory is said to be the most powerful ever constructed. It was built for the inventor by Babcock & Wilcox, and so far has responded to the amazng test to which it has been put. The machine to which this unprecedented pressure has been applied has to run almost without friction, that is the kernel of Mr. Tesla's discovery. He tells me that he would dare apply a steam pressure of 1,000 pounds to his machine, and would do so if he could get a boiler that could supply the pressure. Engineers who read this statement will conclude, unless they know Mr. Tesla personally, that he is crazy.

One technical value of this new discovery for utilising steam at high pressure is in the saving that it makes in the cost of heat for producing the steam, because it is a queer freak of nature that requires proportionately less heat to produce steam at high pressure than to produce it at low pressure. For instance, it takes an increase of only 56 degrees Fahrenheit to raise steam pressure from 125 pounds up to 250 pounds.

There are other electricians who say of Mr. Telsa that he is not a particularly great man as a practical, working electrician, and that his machines are not always as valuable in practice as they are in theory, but most of them admit willingly that he has no peer as a theorist and investigator, a dreamer of the dreams that will come true. His talk of the future is worth thinking about. He is very confident that great things are coming soon through the utilization of the electrostatic magnetic condition of the earth itself. "Sometime," he says, "electricity will be taken from all about us and used for light, heat and motive power. We will reach down to the earth and tap the current anywhere, getting all we want without expense. It is interesting to sit down somewhere, away from all interruption, and think out what that would mean. It seems hardly possible that these wonders can be far away, because the process by which they can be realized is so simple. Expressed roughly, all that would have to be done would be to set the earth's electricity to vibrating, and adjust a machine to these vibrations wherever the force was required. It is something as if the earth were a rubber bag. Shake it in one place and you feel the vibrations in another place. You and I could not feel the electrical vibrations, but I have in mind a machine that will. If nothing else is transmitted by these vibrations, intelligence surely will be. I have the best of reasons for predicting that messages will be transmitted through the earth in this way without wires, like a pulse through a human being. It seems surprising that this has not been done before.

"It is reasonable to suppose that the earth's electricity is generated by the atoms of which all things are composed. We and our world are not only whirling through space with terrific speed, but



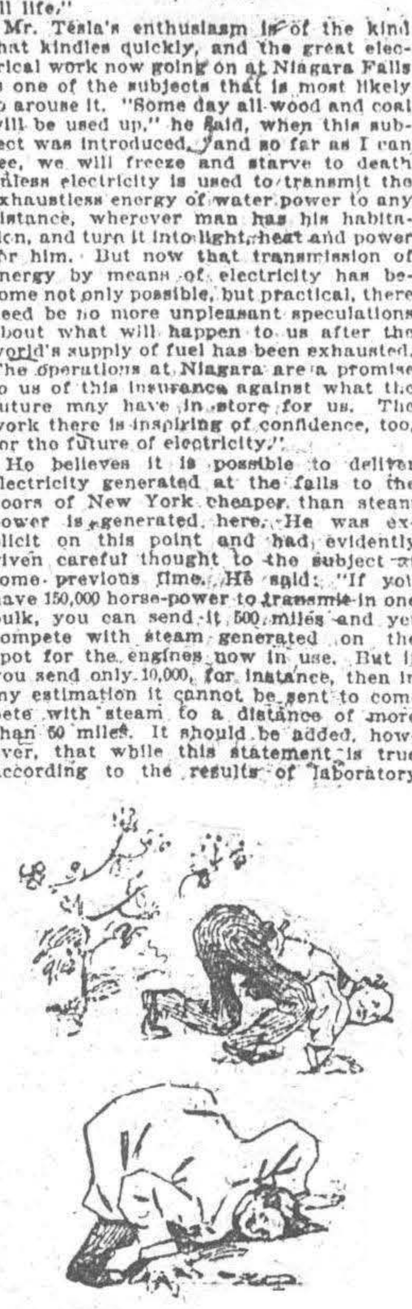
The Incondescent Human Lamp.

every little atom in the world is whirling, too. Now there is good reason to believe that the molecules and their atoms are really little worlds that revolve and move in their orbits like the stars, causing the ether about them to spin with them, thus generating electricity, or affording the conditions suitable to its generation.

"While electricity could hardly be called the ether itself, it is probable that the effects of dynamic electricity and electromagnetism are the effects of ether in motion, and the effects of static electricity are the effects of ether under a strain. The discovery of a method of utilizing this practically exhaustless force that lies so close at hand, would uncover what are surely some of the greatest secrets of the universe. It would be the greatest discovery since the creation, and would bring about a total revolution in all life."

Mr. Tesla's enthusiasm is of the kind that kindles quickly, and the great electrical work now going on at Niagara Falls is one of the subjects that is most likely to arouse it. "Some day all wood and coal will be used up," he said, when this subject was introduced, "and so far as I can see, we will freeze and starve to death unless electricity is used to transmit the exhaustless energy of water power to any distance, wherever man has his habitation, and turn it into light, heat and power for him. But now that transmission of energy by means of electricity has become not only possible, but practical, there need be no more unpleasant speculations about what will happen to us after the world's supply of fuel has been exhausted. The operations at Niagara are a promise to us of this insurance against what the future may have in store for us. The work there is inspiring of confidence, too, for the future of electricity."

He believes it is possible to deliver electricity generated at the falls to the doors of New York cheaper than steam power is generated here. He was explicit on this point and had evidently given careful thought to the subject at some previous time. He said: "If you have 150,000 horse-power to transmit in one bulk, you can send it 500 miles and yet compete with steam generated on the spot for the engines now in use. But if you send only 10,000, for instance, then in my estimation it cannot be sent to compete with steam to a distance of more than 50 miles. It should be added, however, that while this statement is true, according to the results of laboratory



Listening for the First Telegraphic Message Sent Through the Earth.

practice, it may not apply exactly to the actual operation where all the differences of condition from those in the laboratory cannot be fully discounted beforehand."

A fellow-electrician who is in a positon to judge of Mr. Tesla with friendly impartiality gives this opinion of him—and it is an opinion that will probably be found to have the approval of most of the scientists who have come in contact with this wonderful young man: "He is a scientist who is in advance of his time, a seer, a genuine poet of electricity, a man whose eye is focused to the great things of science, and whose mind is fitted by nature to deal with them better than with the commonplace things that the most of us are obliged to busy ourselves with. He has been charged with being a visionary, but it seems to me that the charge is misleading, for though Tesla undoubtedly saw visions that other scientists had not seen, some of them were based on reasoning rather than on imagination unaided by facts, as was proved by the circumstance that the other scientists saw the same visions after Tesla had pointed out the way to look for them. They were visions that opened rich new fields for scientific exploration and that will bring practical benefits to every household. Tesla is young and strong and his head is not turned. He is as eager as ever, and there is no reason to suppose that the most brilliant and useful part of his life is not yet before him."

Mr. Tesla is gong to Europe very soon, but not to stay—not by any manner of means—he is too thorough-going an American for that. He believes the United States is the most progressive,



Power Generated from Niagra Falls.

enlightened and liberal land on earth, and of all the reasons he has for satisfaction with life he holds one of the greatest to be the decision that brought him to this country ten years ago.

I said to him a week ago, on bidding him goodby: "You're sure you are thoroughly Americanized now; that you'll never hunger after any other titles than that of a citizen of the United States." And this was the memorable saying with which he made an enthusiastic answer: "You bet."

Curtis Brown.

Electric Motive Power.*

Relative Merits of Two-phase and Three-phase Currents.

BY ALBION T. SNELL.

Experts differ as to the relative merits of two a nd three phase currents. As regards the alternators and motors there is, perhaps, not much to choose between them. Machines designed for similar outputs, whether synchronous or non-synchronous, are found to have about the same efficiencies, starting torque, weight, and apparent watt consumption, the three-phase machines, however, being the better, according to experiments made by Mr. Kolbein, the chief engineer of the Oerlikon Works. As regards the winding details, perhaps the two-phase type is the simpler. The main difference between the two systems lies in the relative weight of copper required in the conductors for given conditions, and the ease with which the currents may be handled, regulated and controlled.

The first experiments with three-phase working brought to light difficulties in the regulation of pressure between the three mains at the points of supply, when the currents in the three circuits were not approximately the same, which though since overcome to some extent, are greater than those obtaining with two-phase currents—they lie chiefly with the design of alternators and transformers. Two-phase currents, if worked

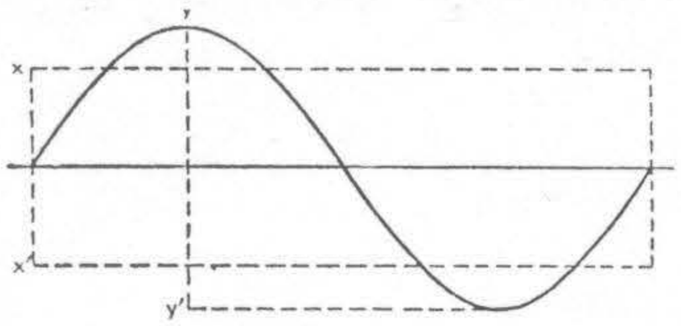


FIG. 1.

$x\,x'$ = Effective pressure of 3,550 volts.
$y\,y'$ = Maximum pressure of 5,000 volts.

with *two separate circuits* are as easily dealt with as single-phase currents, and serve readily most purposes to which single or poly phase currents are usually applied. They are specially convenient for distribution. It may be safely inferred that two-phase are better adapted for a combined service of light and power work; while the three-phase currents are specially useful for running with equally loaded circuits, and therefore are not generally so suitable for lighting work.

For simple transmission of power between two distant points, however, the requirements are different, and the three-phase current system is generally cheaper than either a continuous current or a one or two-phase current system.

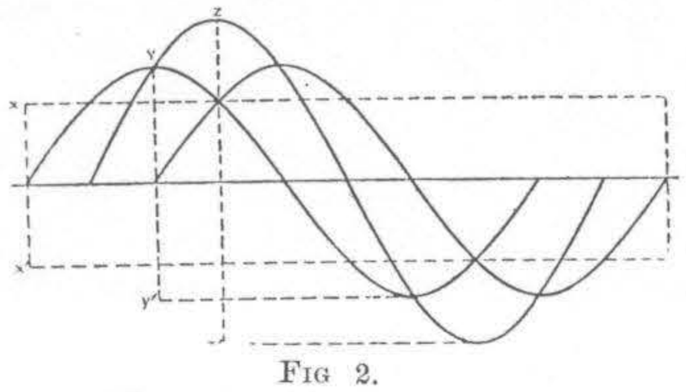


FIG 2.

$x\,x'$ = Effective working pressure of 3,550 volts.
$y\,y'$ = Maximum working pressure of 5,000 volts.
$z\,z'$ = Max'm component pressure of 7,100 volts.

This interesting and important problem may be considered from three points of view, each of practical value :

(1) On the basis of effective pressure at the distributing station (or motor terminals, perhaps).

(2) On the basis of maximum difference of pressure between conductors.

(3) When the economic law is considered.

The significance of the difference between effective and maximum pressure is at once apparent if Figs. 1, 2, 3 and 4 are examined.

In these figures the *electrical centre of gravity* is shown graphically. In any electrical circuit of good or bad insulation there is a datum pressure with reference to the variations of pressure in the circuit. For example, in a continuous current circuit the absolute pressure of the negative pole of the dynamo will have a constant ratio to that of the earth's surface at the particular site, and the difference of pressure between

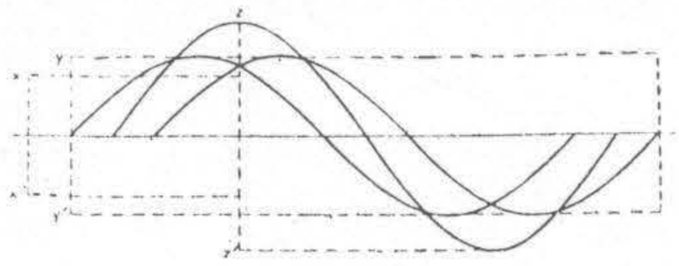


FIG. 3.

$x\,x'$ = Effective working pressure of 2,500 volts.
$y\,y'$ = Effective component pressure of 3,550 volts.
$z\,z'$ = Max'm component pressure of 5,000 volts.

it and the positive pole will simply affect the absolute pressure of the positive pole. And if the negative pole be grounded, the datum pressure will be that of the earth's surface.

Again, with an alternate circuit, with both poles insulated, the cyclical changes will alternately raise and lower the absolute pressure above and below zero pressure, which corresponds to that of the earth's surface. Thus in a circuit carrying a current of 5,000 effective volts pressure the maximum pressure between any two points of the circuit will be $5{,}000\ \sqrt{2} = 7{,}050$ volts, while the absolute pressure, i. e., that above the earth, will be only 3,525, positive or negative. The stress through the insulation to earth will, therefore, be only 3,525 volts.

But if the circuit be grounded, say, at one of the main terminals, the absolute pressure between the other terminal and earth will

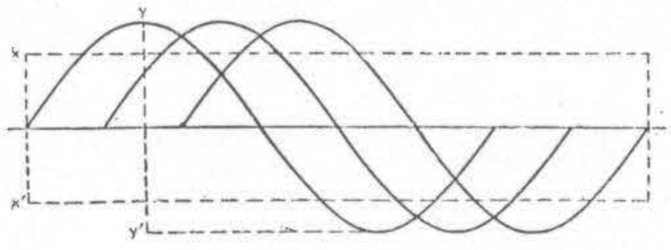


FIG. 4.

$x\,x'$ = Effective pressure of 3,550 volts.
$y\,y'$ = Maximum pressure of 5,000 volts.

be 7,050 volts, and therefore the insulation all over the high-pressure circuit will be subjected to this stress, although the effective working pressure will remain the same as before.

This possible change in the stress upon the insulation of a circuit carrying an alternate current has led to the general practice of earthing one of the primary mains, usually at both the generating and distributing circuits. The maximum stress is thus accepted and suitable precaution adopted to safeguard against accidents; and additional security is gained because a fault in the other main at any point at once blows the fuses and disconnects the faulty section.

With two-phase three-wire circuits it is permissible to earth the middle wire at the generating station, which then is at zero pressure. The same precaution is observed with the "star" coupled three-phase system. With the "triangle" three-phase system it is not permissible to earth either of the mains, since the earth would then form part of the circuit.

It appears then, from considerations affecting prime cost of line the three-phase system is cheaper for long-distance transmission than either single-phase or double-phase alternate currents. Continuous currents are the cheapest of all, but are not admissible for extra high pressures.

The selection of a system for a long distance transmission of power plant will mainly depend upon the maximum permissible pressure. If it be possible to work at such pressures as are feasible, in the engineer's judgment, for continuous-current dynamos (coupled in series or otherwise), then there can be no doubt from considerations affecting the line that this will be the cheapest and best system. But if extra high pressure be deemed advisable, then the three-phase system will generally prove the cheapest.*

In connection with this question it is important to notice that the engineers responsible for the electric transmission of power plant being laid down at Niagara, have finally, after mature consideration, decided upon a four-wire two-phase system. The reasons for their choice are given by Prof. G. Forbes, in a Paper entitled "The Electrical Transmission of Power from Niagara Falls," read before the Institution of Electrical Engineers on November 1, 1893. The details of the scheme have been strongly criticised by English experts, and the choice of the two-phase currents is open to doubt. When it is considered that Buffalo, the nearest large city, is fifteen miles distant, it is clear that the weight of copper will be a very important item in the cost of the whole plant, and in the author's judgment a three-phase system would prove more economical in first cost and give as good pressure regulation as the two-phase. For it must be recollected that there is a line difference of pressure of 20,000 volts, and hence step-down transformers will have to be used at every point from which power is taken. The *main line* drop will, therefore, be as difficult to regulate with two-phase as with three-phase currents; and variation of pressure of submains of the distributing systems can be as readily controlled by using *independent* secondary circuits from three-phase transformers as from *separate* secondary circuits of single or two phase transformers, Prof. Forbes's argument that two-phase currents are more easily *redressed* than three-phase currents is probably sound, but the fact that no form of alternate current has yet been made unidirectional in a practical manner cannot be ignored.

* The *Electrician*.

* The generating plant may perhaps be a two-phase one, with suitable step-up transformers, as proposed by Mr. Scott, of the Westinghouse Company. And it may also prove economical to transform the phase again at the receiving station. The ingenious proposals of Mr. Scott, however, have not yet been verified in practice; but there seems to be no doubt of their feasibility and usefulness.

INCORPORATIONS.

The National School of Electricity, Chicago, Ill.—to teach the principles of electrical and allied sciences and to transact all business incident thereto. Capital stock, $100,000. Promoters: Walter Clyde Jones, Geo. L. Cragg, Geo. S. Buell.

Scientific Progress.

Tesla's Oscillator.

Tesla's latest invention, the "oscillator," is one of the most remarkable appliances of the age. It is described as being the core of a steam engine and the core of a dynamo combined, making a harmonious mechanical adjustment. This combination, says an enthusiastic admirer, constitutes a machine which has in it the potentiality of reducing to the rank of old bell metal half the machinery at present moving on the face of the globe. It may come to do the entire work of the engines of an ocean steamship within a small space they occupy and at a fraction of their cost, both of construction and operation. It will do this work without jar or pounding, and will reduce to a minimum the risk of derangement or breakage. There is nothing in the whole range of mechanical construction, from railway locomotives to stamp mills, which such an invention may not revolutionize. The essential characteristic of the machine is the application of the pressure of steam to produce an extremely rapid vibration of a bar of steel or piston, which, in turn, is so adapted to a set of magnets that the mechanical energy of the vibration is converted into electricity. The extraordinary result is that practically an absolutely constant vibration is established, and a power is obtained greatly beyond that obtainable in the most costly expansion engines using a similar amount of steam.

Besides saving in mechanical friction the 35 per cent of loss in the working of the engine, the 15 per cent of loss in belt friction, and the 10 per cent of loss wasted in the dynamo, making altogether an addition of 60 per cent to the available energy obtained from the steam for the purpose of producing electricity, it is simpler, lighter and smaller than the mechanism it is designed to replace, absolutely constant in its action, automatically regulated, and subject to the least possible amount of wear and tear. The utilization of this machine in any branch of industry would result in an appreciable lowering in the cost of production, and it is quite possible that its first general employment may be in electric lighting.

In the face of this marvelous invention a recent statement of Tesla seems hardly longer visionary. The young Montenegrin said: "I expect to live to be able to see a machine in the middle of this room and move it by no other agency than the energy of the medium in motion around us."

ON THE PRODUCTION OF ROTARY MAGNETIC FIELDS BY A SINGLE ALTERNATING CURRENT.

READ BEFORE THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS DECEMBER 19, 1894, BY LUDWIG GUTMANN.

Since the first announcements of Professor Ferraris and Mr. Tesla that rotation can be accomplished by employing two or more alternating currents of displaced phase, the question has been raised by many an engineer as to the possibility of producing a rotary magnetic field by the use of a single circuit, carrying the ordinary alternating current, instead of requiring three or more wires or several independent circuits. So far it has been necessary to construct a special generator armature, the windings of which were rotated in a field of constant polarity, to produce two or more currents lagging in phase behind each other. To use the currents generated for establishing a progressive or rotary field it was necessary to carry as many wires to the place of consumption as currents were employed differing in phase. Six years have passed, and quite rapid progress has been made in various directions. I wish now to bring to your notice a method of generating a rotary magnetic field by a single alternating current or its field without condensers or choking coils. This is accomplished by a device brought out by me some three years ago. Its fundamental principle is hardly as yet appreciated. However, the World's Fair exhibits, as well as literature of late, show that the device has attracted attention, and that several engineers have approached the principle involved.

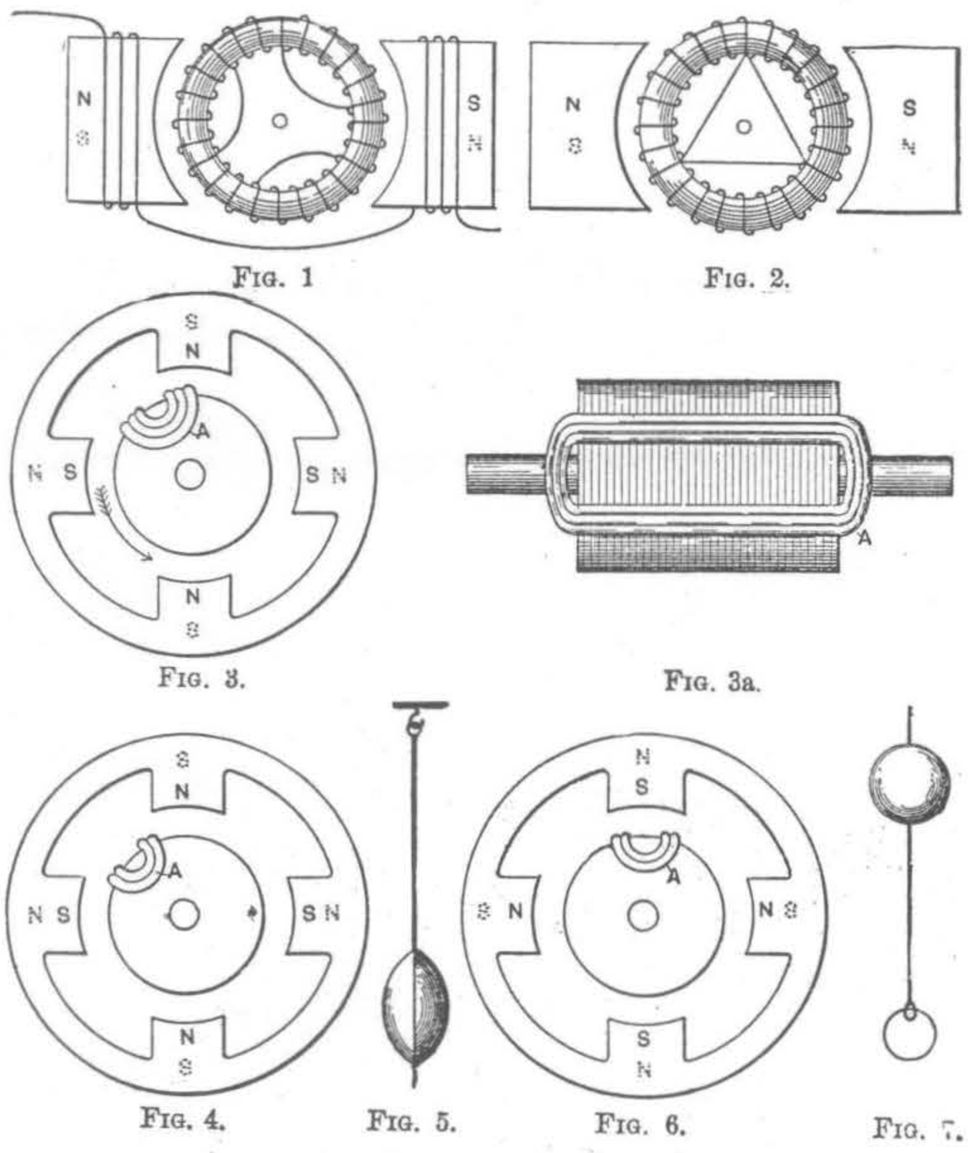


FIG. 1 FIG. 2. FIG. 3. FIG. 3a. FIG. 4. FIG. 5. FIG. 6. FIG. 7.

FIGS. 1–7.—ON THE PRODUCTION OF ROTARY MAGNETIC FIELDS BY A SINGLE ALTERNATING CURRENT.

I wish to refer to my motor and especially to its armature, described in 1891. Figs. 1 and 2 show the device. The former is principally used in the American patents, while the latter is given in the English patent of the same year. The novelty of the armature construction lies in a winding containing closed sub-circuits, and another point is that the closed circuits do not coincide in number with the poles of the field magnet. Before going into the action of this device I will mention two simple experiments which are essential in order to understand the operation of this rotary magnetic field system.

If we have a closed coil moving in an alternating magnetic field, or better, between the poles of a field magnet, as illustrated in Figs. 3 and 3*a*, energized by alternating currents, then the coil A will be repelled from the pole, owing to the secondary field which it establishes, so long as it cuts, or is threaded by the lines of the force of the field. The consequence is that it will rotate and place itself between the north and south pole, Fig. 4, where it reaches a stable magnetic equilibrium, as I like to term it, because in this position it acts like a pendulum properly suspended (Fig. 5). Any motion imparted causes the pendulum to make a few oscillations and come to rest, and similarly any attempt made to move the coil into an energized field will cause it to be repelled, and after a few oscillations it will remain at rest between the poles. It is repelled in either direction, because as soon as it approaches a strong magnetic flux, currents are induced in its windings and create an opposing field. The same coil can be in unstable magnetic equilibrium (Fig. 6), if it stands just in front of a pole, in which position it would act like a pendulum which is balanced with the weight above the point of the support (Fig. 7). Both are in unstable equilibrium; the least motion to the left or right imparted to either will cause them to accelerate in the direction of the impulse, and to assume a position of stability (Figs. 4 and 5). In this position, Fig 4, the coil is therefore currentless. This stable position is the natural position of synchronous motors in operation.

If such a synchronous motor is held behind the phase when rotating under load, a heavier current is induced in the spools which accelerate the armature and keep it in step. If, however, the motor runs in harmony, and suddenly a great deal of the load is taken off, then the armature has a tendency to go more quickly, but in this case opposing currents are generated in the windings, which retard the speed of the armature and keep it back, to remain in step or in stability.

Let us look into the device before us and consider first its quality as a motor. Returning to Figs. 1 or 2, preferably the latter, which is simpler and easier to explain, we find that if we send into the field magnet coil an alternating current, the armature will turn through a certain angle and stop. This motion depends upon the position of the three closed coils with respect to the two poles. This same device can itself be self-starting if we make the poles far enough apart and the energizing current sufficiently strong, so that at the initial speed the armature is repelled at a certain rate. This initial speed changes with the number of poles, closed circuits and alternations. Let us take the first case and examine it. If we try to rotate the armature (as I shall call it hereafter) in a field of alternating polarity, we induce currents in the closed circuits, which establish poles, but these poles are alternating in nature, and owing to the motion imparted, and owing further to the permanent connections in the winding, the poles move or travel with the latter. This accounts for the fact that if the field poles are close together the armature consumes power during its rotation through the alternating field; it acts as a dynamo and does not start from a state of rest. If we impart by mechanical means an impulse to the armature, currents are generated whose sum has a variable

and principally negative value. The armature makes a few revolutions and places itself in a stable magnetic equilibrium; viz., in such a position, symmetrical if possible, as not to generate any currents, and hence not to induce any reactionary* poles in the core. If, however, we impart to this armature a certain initial speed, which I shall call the critical speed, then it will continue to rotate, with a tendency to reach a certain fixed higher speed. This initial impulse may be given by mechanical or electrical means. I shall not state the results as yet, but prefer to explore the action first, so that the same may be before us in various diagrams, and enable us to make any deduction desirable. First, let us assume that the armature rotates synchronously: it is evident that in order to have an armature with three close-circuited coils, interconnected as shown, rotate in one direction, we must have currents induced whose sum has a positive value; viz., two of the coils must do work, in the same sense, while the third coil is either without a current, or has a smaller current in opposite direction, so that the value still remains positive. For true synchronism a close-circuited coil reaches within a half-period the opposite pole, and consequently our diagram for one revolution would look as follows: (See Fig. 8.)

The three diagrams, *a*, *b*, *c*, show the flow of currents and resultant poles. The close-circuited coil 2, diagram *a*, is at this moment generating opposing currents to the others; coil 1 is passing just in front of a pole. All three induced currents combined are developing poles as indicated, and rotating the armature in counter clockwise direction. The rotation being synchronous, diagram *b* shows the position of the armature when the polarity in the field has reversed; diagram *c* gives the position of the coils after the polarity has changed again. It will be noticed that the original position, as shown at *a*, has been reached again and that the cycle will repeat itself. Without explaining these diagrams at this point, I wish to bring before you several other conditions, all of which will assist in reaching definite conclusions. Looking at the armature we see that it has a symmetrical winding, and as long as these closed circuits do not coincide with the number of poles of the field magnet (contrary to all synchrous motors built heretofore), other working positions are possible. The operation will take place as long as the sum of the armature currents have a positive value, since as far as the rotation is concerned it is indifferent which of the coils are doing the work. Let us assume that the armature does not run at a synchronous rate, but at another fixed speed which may have a certain commensurable relation to the periods of the exciting field current, which speed I shall call the harmonic speed. Instead of showing the diagram with windings as in the first set, I have simplified them. In the following sets of diagrams, Fig. 9, I assume that the armature, on account of the load or other reasons, cannot reach synchronism, and that at each field reversal the position of the armature with respect to the field is the same, only the coils have changed places as indicated. You will notice that in this set of diagrams the armature, for each half-period, makes one-third of a revolution only; namely, coils 1, 3 and 2 exchange positions with the change of polarity. Let us step at once to another speed (Fig. 10), which you will no doubt admit as possible; viz., let us assume that coils 1, 2 and 3 cannot arrive at synchronous speed, and that coil 2 reaches the position which 1 ought to occupy, it will be seen that owing to the symmetrical position, it is quite indifferent which of these coils arrives at a given position required for harmonic operation. This will be clear to you by referring to the third set of diagrams, Fig. 10.

We are now enabled to compare three sets of diagrams, Figs. 8, 9 and 10. The first set shows for this new type of synchronous motor that at synchronous speed the pole positions in the armature are practically stationary relatively to the coils and core, and rotate with it. The second set shows that during a complete revolution of the armature, the field has reversed three times, that is, an odd number of times, hence, when the armature returns to its original position, after a complete revolution, it finds the field magnetization of reversed polarity. The magnetic field of the armature rotates in the opposite sense, one and a half times per revolution. In the third set, the armature makes but one-sixth of a revolution per half-period, and the magnetic field of the armature in a complete revolution rotates three times in the opposite direction. This statement may be startling, and my argument, so far, may not be entirely convincing, as on close inspection it will be found that the armature poles have to do considerable jumping. I will now explain the performance of the rotary magnetic field of this armature in a four-pole field, where the changes occur far more gradually, leaving no doubt whatever as to the assertion made. Fig. 11 shows diagrams illustrating synchronous speed. By the aid of these four diagrams we can more easily follow the pole position in the armature core, and find them stationary in it. Inspecting now Fig. 12, in which the armature speed is reduced, we are able to obtain a clear picture of the main subject under consideration.

In this set of five diagrams we see five positions, which coil 1, for instance, occupies before it has made one-third of a revolution. Nevertheless, if we now look at the changing pole positions we can readily detect that they are progressively shifting, and we also see that they have made one whole revolution and that in opposite direction to the mechanical rotation, or, in other words, the magnetic field would travel three times around the armature core during one revolution. In all armature diagrams described and to be described the resultant of the magneto-motive forces of the armature currents is given only. To complete the picture showing every one of the component magneto-motive forces acting, it becomes desirable to plot a diagram of force (Fig. 13). These components act like three variable concurrent forces, including an angle of 120 degrees with each other. These forces we may represent as equal, for the sake of convenience, as it does not influence the idea which we wish to illustrate. However, those two forces which are acting in the same direction are indicated by heavier lines.

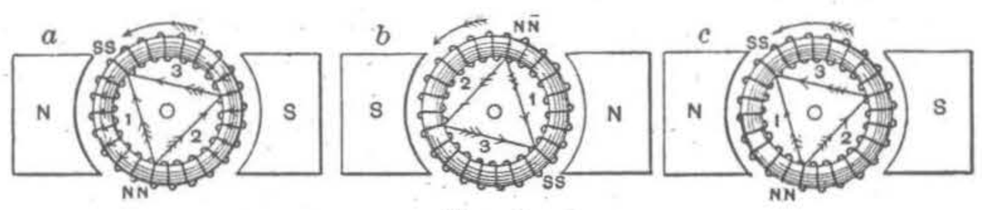


FIG. 8.

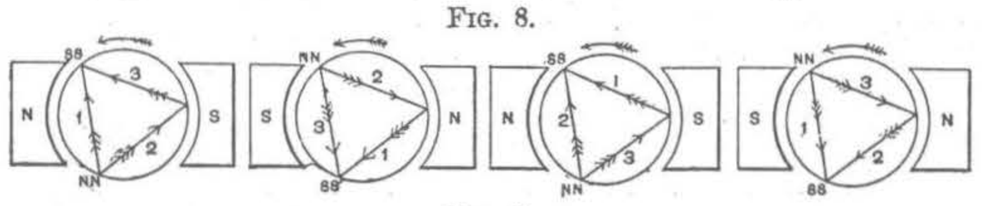


FIG. 9.

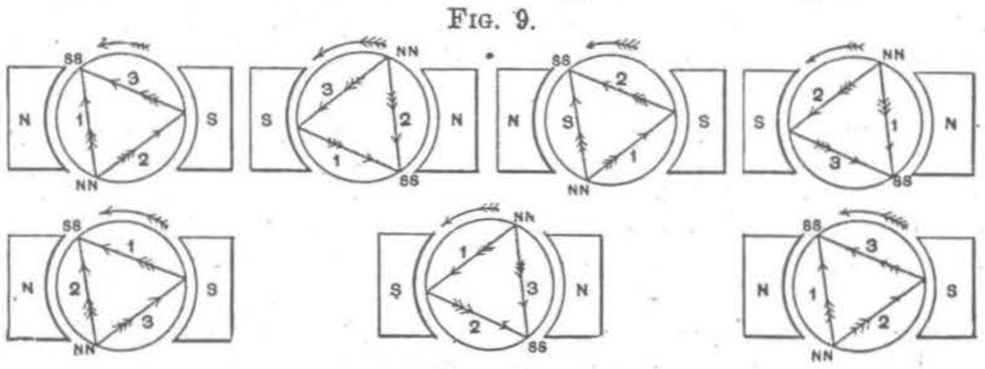


FIG. 10.

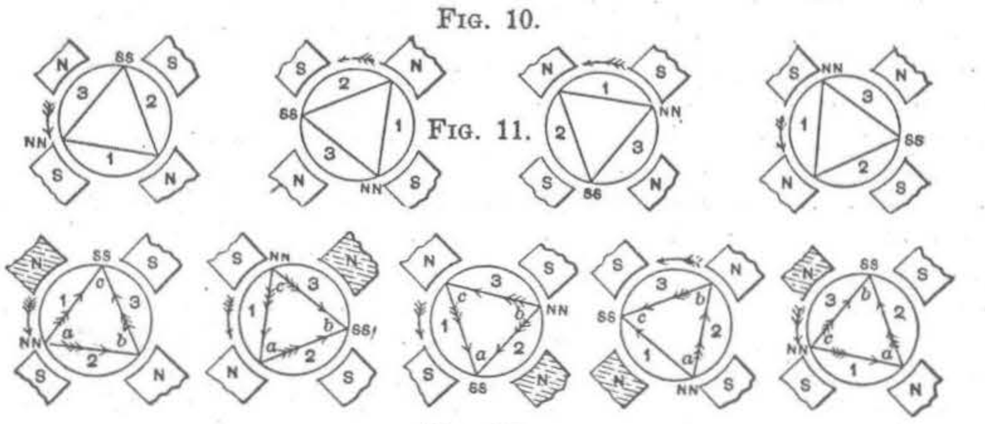


FIG. 11.

FIG. 12.

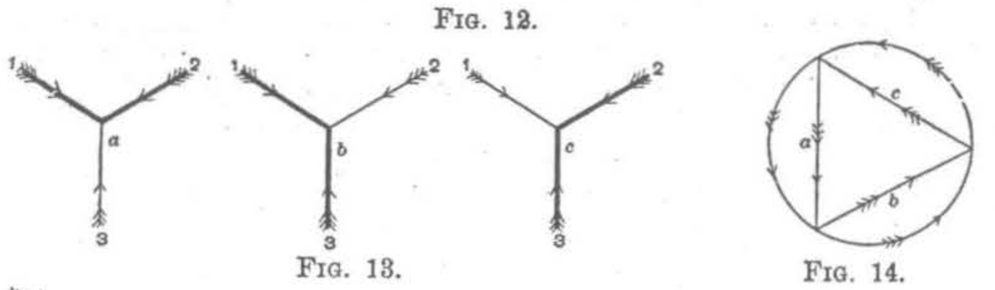


FIG. 13.

FIG. 14.

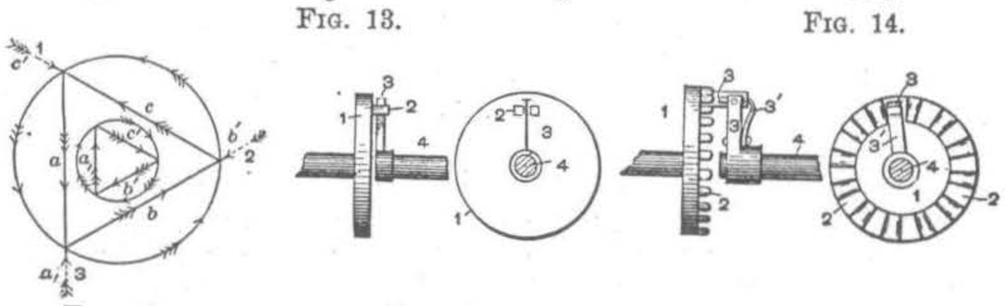


FIG. 15.

FIG. 15a.

FIG. 15b.

FIGS 8-15b.—ON THE PRODUCTION OF ROTARY MAGNETIC FIELDS BY A SINGLE ALTERNATING CURRENT.

Plotting the direction of the forces in order, as, for instance, in the last named set of diagrams (Fig. 12), where the coils act in the order 1, 2 against 3; 3, 1 against 2, and 2, 3 against 1, we obtain Fig. 13 for one cycle. The three figures marked *a*, *b* and *c* indicate the direction in which the three forces are acting in the three positions of one cycle or revolution.

By drawing the resultant diagram of force from the predominating forces of each position, we obtain the accompanying figure (Fig. 14). These forces form a triangle, and the rotation resulting may be seen from the direction of arrows on the circumference of the surrounding circle. However, the reactive forces should be considered and represented separately to obtain the true picture, and we have to add them to find the total force applied and the manner in which all the forces are acting. We therefore repeat the resultant diagram (Fig. 14), and add the opposing forces at their proper places. This diagram (Fig. 15) shows that the reactive forces, shown by dotted arrows, also have a common center, and that as regards time of maximum effect, they succeed each other in the direction of rotation of the armature, while they are acting in the opposite direction of the main force. If we now plot a diagram of these reactive forces alone, we obtain the smaller triangle shown (Fig. 15) inside the larger. It will be noticed that rotation is in the opposite direction; or, in other words, that in reality we have, with this disposition, to deal with two rotary magnetic fields in opposite direction; the useful work done will depend on the difference of the angular velocity of these two rotating fields and their relative intensity.

Looking now at the device as a generator (Fig. 12), we can account for the rotary magnetic field because we generate polyphased currents in the coils 1, 2 and 3. They operate together in the following order: 1, 2; 3, 1; 2, 3; 1, 2, etc. If rotated as shown the coils will distribute three-phased currents over the armature, and this will be understood when examining into the flow of currents of the close-circuiting conductors which are here provided with arrows. At this particular harmonic speed it will be further noticed that the simple alternating field of force has the identical qualities as a polyphase energizing field, as the poles in front of the close-circuited coil seem to be traveling (for the armature) in clockwise direction. This is indicated by the shading of the pole of the same sign in front of the coil most powerfully acted upon in the five positions, representing one revolution for the field. The currents displaced in phase cause the armature to rotate harmoniously with the alterations, and prevent the armature from being easily thrown out of step.

(To be concluded.)

*It is well to call the armature poles, due to the armature currents, reactionary poles. The other armature poles are induced directly by the field poles, and contribute nothing to the torque.

ON THE PRODUCTION OF ROTARY MAGNETIC FIELDS BY A SINGLE ALTERNATING CURRENT.

READ BEFORE THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS DECEMBER 19, 1894, BY LUDWIG GUTMANN.

(*Concluded from page 313.*)

Returning once more to the earlier diagrams, Figs. 9 and 10, we see that below synchronism there are two other speeds that are entitled to be called synchronous, because a certain fixed relation exists between the periods of field excitation and armature rotation.

It will be evident that the greater the number of closed circuits, the greater is the number of harmonic or synchronous speeds in which the armature can operate. If the armature contains ten closed circuits, and rotates in a two-pole field, it will be able to generate five currents, lagging 72 degrees behind one another in phase, and would have at least five speeds which are synchronous, and the armature, owing to its peculiar construction, can operate at a slower speed than the synchronous speed as interpreted heretofore.

Looking at the device from a general standpoint, it will be clear that this particular armature construction embodies all the weak points of a synchronous and all the strong points of a polyphase motor. The weak points are :

1. That the machine will not start from state of rest in the form shown, because in Figs. 1, 2 and 12, the coils act on one another differentially and have a variable and negative value ; they are in magnetic stability when at rest, hence no rotation can result.

2. The device has a small starting torque when rotated, owing to the differential action of the coils, which cause, with a small number of closed circuits, strongly oscillating or jumping poles until a harmonic speed is reached.

3. The device, when in rotation, is not reversible by simply changing circuit connections.

The strong points are :

1. That the motor develops polyphased currents in its own windings.

2. That, therefore, it is more difficult to pull it out of step, as it has the capacity to stand, what I would term, magnetic slippage.

Let us assume that a certain coil, which should reach a given point to run harmonically, remains behind owing to a slower motion of the armature; in this event the coil ahead has to perform the function at the expense of a heavier current. The loss of revolutions due to this action may be comparable to the slipping of a belt over a pulley. However, there is also a limit to the slipping. The armature should have some harmonic speed with respect to the alternations. Should it fall below the lowest harmonic speed, then it will come to a standstill just like any other overworked synchronous machine.

Synchronism in a motor means nothing more nor less than a magnetic flexible clutch, which may be represented mechanically as follows :

The old fashioned non-starting synchronous machine having equal armature coils and field poles, can be compared with the arrangement shown in Fig. 15*a*, giving side view and elevation. The disk 1 is provided with two projections; 2, imparts rotation to shaft 4 by means of the flexible arm, or spring 3, which enables the shaft 4 to be slightly behind or ahead of disk 1. However, if the work put on shaft 4 is in excess of the strength of spring 3, then it will break, and shaft 4 will speedily come to a standstill.

In contrast to this older form of synchronous motors stands the new one, which forms the subject of this paper and the machines operated by bi- or polyphased currents. The mechanism for showing magnetic coupling for these latter types may be represented by Fig. 15*b*. In this case, 1 represents a crown wheel the teeth marked 2 ; into these teeth meshes a catch 3 in a flexible manner, which catch is connected rigidly to shaft 4. Within the range of normal work, catch 3 would remain fixed between the two given teeth, but if the shaft 4 is overloaded, the flexibility of catch 3 will cause it to yield, and pull out of its position, drop in between some other two teeth, and continue to operate, but at a slower speed. The greater the excess of work the greater will be the slippage and the more

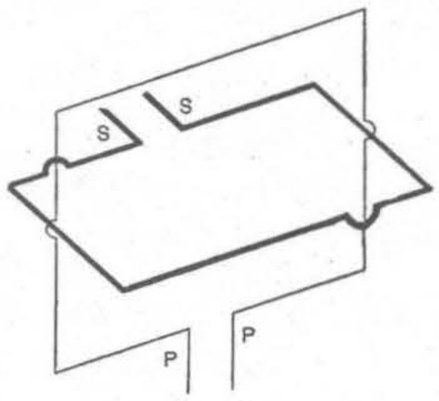


FIG. 16.

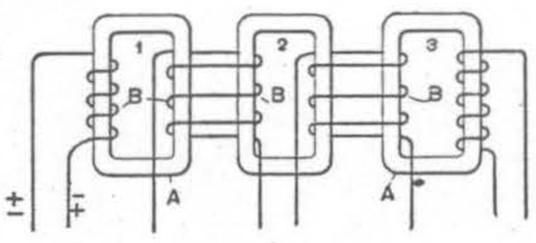


FIG. 17.

teeth will be jumped by the catch 3 in every revolution of disk 1. For the synchronous motor herein described, the overloading to the extent that it cannot reach the lowest harmonic speed would be equivalent to the breaking of spring 3^1.

It will be remembered that Prof. Ferraris obtained a rotary magnetic field and rotation by influencing one coil carrying a primary current, by another at right angles thereto carrying secondary currents. Here we have two phases from a single source, Fig. 16. To obtain a multiple of phases we may take two or three iron cores A and surround them with coils B, like the links of a chain, Fig. 17, so that the secondary coil of transformer 1 is the primary of transformer 3, and so on ; or we may design a special core for a transformer, and create a rotary magnetic field by applying to one coil a primary current from the line, and to another coil a secondary current from a transformer, whereupon by the rotary field obtained, polyphased currents may be taken through other coils on the transformer. These methods have, however, one drawback, and that is that the phase will change more or less in lag with difference in load, while for many purposes it is most essential that for efficient working the phase should remain at the same constant angle. This desideratum has been accomplished by the device under consideration, and any suitable number of currents lagging in phase may be obtained from a single alternating current.

To obtain a rotary magnetic field in or by a stationary body, at least two electric or electro-magnetic forces of definite phase relations, acting at an angle to one another and changing at periods harmoniously, are essential requirements.

If, however, we allow the body, or part of the same, to be movable, we may substitute mechanical rotation primarily as an adjuster of the periodicity and phase of one of the two forces ; the fundamental relation between the two forces must in this case also be the same as in the other ; namely, they must work in harmony and the periodicity and phase determines the periodicity and phase of the other of one force. If the second force is a current, it must be one of the same period or some harmonic of that period ; if it is rotation, it has also to be synchronous or harmonic. We can now clearly understand why, when rotating the armature, Figs. 1 and 2, in an ordinary alternating current field, we have no system of polyphased currents and no rotary field, simply because the armature rotation does not stand in any relationship whatever to the alternations ; but as soon as the speed does so, there are generated polyphased currents lagging in phase at a fixed angle, and a rotary magnetic field.

There is a difference whether the armature is influenced by a single alternating current, or by several, causing themselves a rotating energizing field. Nevertheless, in either condition the armature is in magnetic stability, and this state is the reason that it remains stationary in the first case and that it rotates in the second.

The reason that the motor starts in the second case is evidently because the inducing magnetic field is itself rotating in the stationary field magnet core. As said before, it is considered necessary for the proper operation of the armature for giving maximum torque, that if placed in an alternating current field of force the armature rotation should have a definite relation to the alternations. Up to the publication of this device, some three years ago, synchronous motors had as many armature coils as field coils, and hence to obtain the value of the synchronous speed, all that was necessary was to divide the alternations of the armature current n by the number of field poles p of the magnet employed. But if the number of armature coils are not the same as the field poles, then the speed may vary from this synchronous speed and

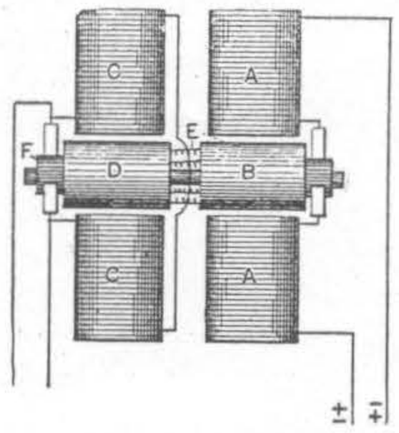


FIG. 18.

a modification is thought to be necessary. We would have to find the smallest common factor between the field poles p and armature coils p^1, with which we have to divide the number of alternations to obtain the value of the lowest synchronous speed, while the condition of slippage may allow for the lowest harmonic, the value $\frac{n}{p\,p^1}$.

It will now be clear that motors can be designed having any desired variation of speed and have defined synchronous speeds or approach the indifferent relation. I wish it understood that I do not intend to treat the subject in all its details, and I am especially reluctant on the ground of having carried on but few experiments.

The few diagrams presented do not disclose many conditions of those possible. They show only one or two facts of conditions which frequently are of a complex nature. Evidently the rotary magnetic fields in the device under consideration may have altogether different speeds from those shown in the diagrams; also, that the magnetic field may rotate with and ahead of the armature, and lastly, the speed of rotation of the rotary field of the armature may be synchronous, and opposite in direction to its rotation.

The device has been given in the form of a diagram, and as it has been described as not self-starting, I wish now to state that it becomes self-starting as a series, a shunt or an induction motor in a field of single phase or polyphased alternating currents. Fig. 18 represents one of the earliest forms, which have since been simplified to a considerable extent. The part A B represents here a simple series motor whose armature B may be any drum or ring type, open or closed coil winding ; the part C D may be similarly constructed. Both armature windings B and D are connected electrically by four wires E at points of equal distance, which number of conductors E may be reduced or increased, depending on the number of phase currents desired. Now send an alternating current into the series motor, part A B*, then the armature will start from state of rest and will send current impulses into the D part winding, which becomes the more regular the more the armature has approached synchronous speed, where biphase currents will be established therein ; these react on the field magnet core C, and for the purpose of maintaining the armature in this synchronous speed, the commutator F is applied to rectify the polyphase currents, which continuous current may be used to energize the magnet C.

The fundamental principle disclosed opens to us a very wide field for work. Not only are we enabled to construct motors almost as cheap and simple as continuous current motors, but there is in this principle involved the germ for the ideal distribution of power, inasmuch as we are enabled to collect the polyphased currents generated, or commutate them immediately at will.

Finally, I wish to call your attention to the fact that the last figure is in reality a motor-generator, and it is, therefore, evident that the electrical energy supplied need not all be transformed into mechanical power, but that a portion may be utilized in one of the modified forms named above.

Nikola Tesla as Viewed by a Layman.

A familiar figure at Delmonico's in the evening is that of a tall, well-knit, well-groomed man, swarthy, eagle-eyed, with a long nose, high cheek bones and a firm jaw, and with the air of being intensely interested in everything at which he looks. This is Nikola Tesla, man among men in the electrical world, a giant of discoverers, bold, original—a pathfinder whose every step is now being watched by all the scientific societies of the world. Where others have followed old theories and been hedged in by trammels of tradition, he has struck out at right angles, and startled the know-alls by showing that the laws of electrical force are still unwritten and unknown. His dynamo is radically different in construction and operation from any in use; his currents, while of vastly greater voltage, are innocuous; his system of lighting needs no filament of carbon or platinum, and gives out no heat; he can clothe himself in radiance like Phœbus, like Ajax; he can defy true thunderbolts, for he has tamed them while leaving their strength unshorn. All this and more has already been done, and yet the man has but little more than passed his thirtieth year, looks like a student, and has the unaffected simplicity of one whose thoughts never turn to self.—*Major Moses P. Handy in the "Mail and Express."*

ELECTICAL WORLD December 29, 1896

DIGEST OF CURRENT TECHNICAL ELECTRICAL LITERATURE

COMPILED FROM PRINCIPAL FOREIGN ELECTRICAL JOURNALS

BY CARL HERING

ELECTRO-PHYSICS.

Tesla Effects With Influence Machine.—The first part of an abstract of a lecture by Dr. Toepler (inventor of the Toepler-Holtz machine) is published in the "Zeit. fuer Elek.," Dec. 1. He describes a number of experiments made with his multiple plate machines, and shows the advantages of using such a machine with 20 plates for making researches with high frequency currents; the machine itself is well known, but was improved slightly to increase the self-excitation and the intensity of the current for a very high voltage. He shows its application for produing some of the Hertz effects and states that it gives two different kinds of primary sparks. With this machine the fundamental experiments of Tesla can be demonstrated, although it consumes only 1-16 to 1-18-hp; better results were obtained with a 60-plate machine requiring ⅛-hp. The connections are the same as usual, the machine discharging through a spark-gap, the poles of which are connected to condensers whose outer coatings discharge through the primary of a transformer, the secondary current of which is used to produce the effects; with a large machine he obtains 100 sparks per second 3 mm. long; one of the chief advantages of using influence machines is that it gives the high tension and high frequency alternating currents directly; also that a better symmetry is obtained, for with an unsymmetrical system, discharges in one direction are obtained which are disturbing; no air-blast or magnetic field is in this case necessary to rupture the current in the spark-gap and to this he attributes, in part, the success of the results. A Geissler tube in this circuit shows the cathode light at both poles which proves that the current is an oscillating one, while with a Ruhmkorff coil the cathode light is produced at only one pole. The article is to be continued.

ELECTRO-PHYSICS AND MAGNETISM.

Tesla Effects With Influence Machines.—The conclusion of the lecture by Dr. Toepler (see Digest Dec. 29) is contained in the "Zeit. f. Elek.," Dec. 15. He showed the experiment in which an incandescent lamp was brilliantly illuminated, although shunted by a thick wire bent in the form of a loop, and to show that it was due to surface conduction he added a thin but wide sheet of metal bent like the wire and connected to it, which, therefore, greatly increased the surface but scarcely affected the cross section, the lamp in this case diminished greatly in candle power. With such high frequency currents iron has the opposite effects in a transformer than with the usual currents, which he showed with the aid of a lamp run from a high frequency transformer in which the iron could be introduced or withdrawn; a core of insulated copper wires produced no effect but a glass rod covered with tin foil almost extinguished the lamp. He gives the data for 4 coils and describes various experiments with them; he showed that there was a very appreciable repulsion between the coils of a transformer; by transforming the high frequency current to another of lower voltage and greater current, iron wires were melted and a sort of arc light consisting of a point of carbon resting on another could be lighted; other experiments were shown by transforming the high tension currents still higher. He performed the experiment of illuminating a Tesla single pole lamp, in which case, however, the glass opposite the filament soon became very hot; in one case the voltage was so high that the whole transformer was surrounded with light in the form of a brush discharge; he estimates that the voltage was 500,000; although of considerable intensity, these high tension currents give off comparatively little heat. Geissler tubes placed near two condensor plates, but not in contact, were so brightly illuminated that the experiment could readily be shown in daylight. In conclusion he states that almost all the Tesla experiments can be shown with his large 60 plate machine, but perhaps not on such a brilliant scale, the difference, however, is not as great as would appear from the difference in the amount of power used (concerning which, however, he unfortunately gives no data).

Tesla's Researches.—A lecture of Dr. Tuma on Tesla's researches is briefly abstracted in the "Elek. Zeit.," Dec. 20. According to Prof. Puluj there are two chief drawbacks against the use of this "light of the future," one being that with such high tension currents there is a generation of ozone which is as dangerous to breathe as chlorine gas; and the second is that a sufficiently durable insulation cannot be obtained; he also stated that Prof. Puluj showed similar lamps as early as 1880; they were run from a Ruhmkorff coil, and are said to have had a greater candle power than those of Tesla; references to the description are given; he states that long ago, in the eighties, Mr. Von Marxow showed experimentally that the physiological action of alternating currents is less, the higher the frequency.

Century Magazine February 1895

LUKA FILIPOV.

(AN INCIDENT OF THE MONTENEGRIN WAR OF 1874.)

PARAPHRASED FROM THE SERVIAN OF ZMAI IOVAN IOVANOVICH, AFTER LITERAL TRANSLATION BY NIKOLA TESLA.

ONE more hero to be part
Of the Servians' glory!
Lute to lute and heart to heart
Tell the homely story:
Let the Moslem hide for shame,
Trembling like the falcon's game,
Thinking on the falcon's name —
Luka Filipov.

When he fought with sword and gun
Doughty was he reckoned;
When *he* was the foremost, none
Blushed to be the second.
But he tired of the taint
Of the Turk's blood, learned restraint
From his sated sword — the quaint
Luka Filipov.

Thus he reasoned: Though they fall
Like the grass in mowing,
Yet the dead Turks, after all,
Make a sorry showing.
Foes that die remember not
How our Montenegrins bought
Our unbroken freedom — thought
Luka Filipov.

So, in last year's battle storm
Swooped our Servian falcon,
Chose the sleekest of the swarm
From beyond the Balkan:
Plucked a pasha from his horse,
Carried him away by force,
While we cheered along his course
"Luka!" "Filipov!"

To the Prince his prize he bore
Just as he had won him —
Laid him at the Prince's door,
Not a scratch upon him.
"Prince, a present! And for fear
He should find it lonely here,
I will fetch his mate," said queer
Luka Filipov.

Back into the fight he rushed
Where the Turks were flying,
Past his kinsmen boldly brushed,
Leaping dead and dying:
Seized a stalwart infidel,
Wrenched his gun and, like a spell,
Marched him back — him heeding well
Luka Filipov.

But the Moslems, catching breath
'Mid their helter-skelter,
Poured upon him hail of death
From a rocky shelter,
Till a devil-guided ball
Striking one yet wounded all:
For there staggered, nigh to fall,
Luka Filipov!

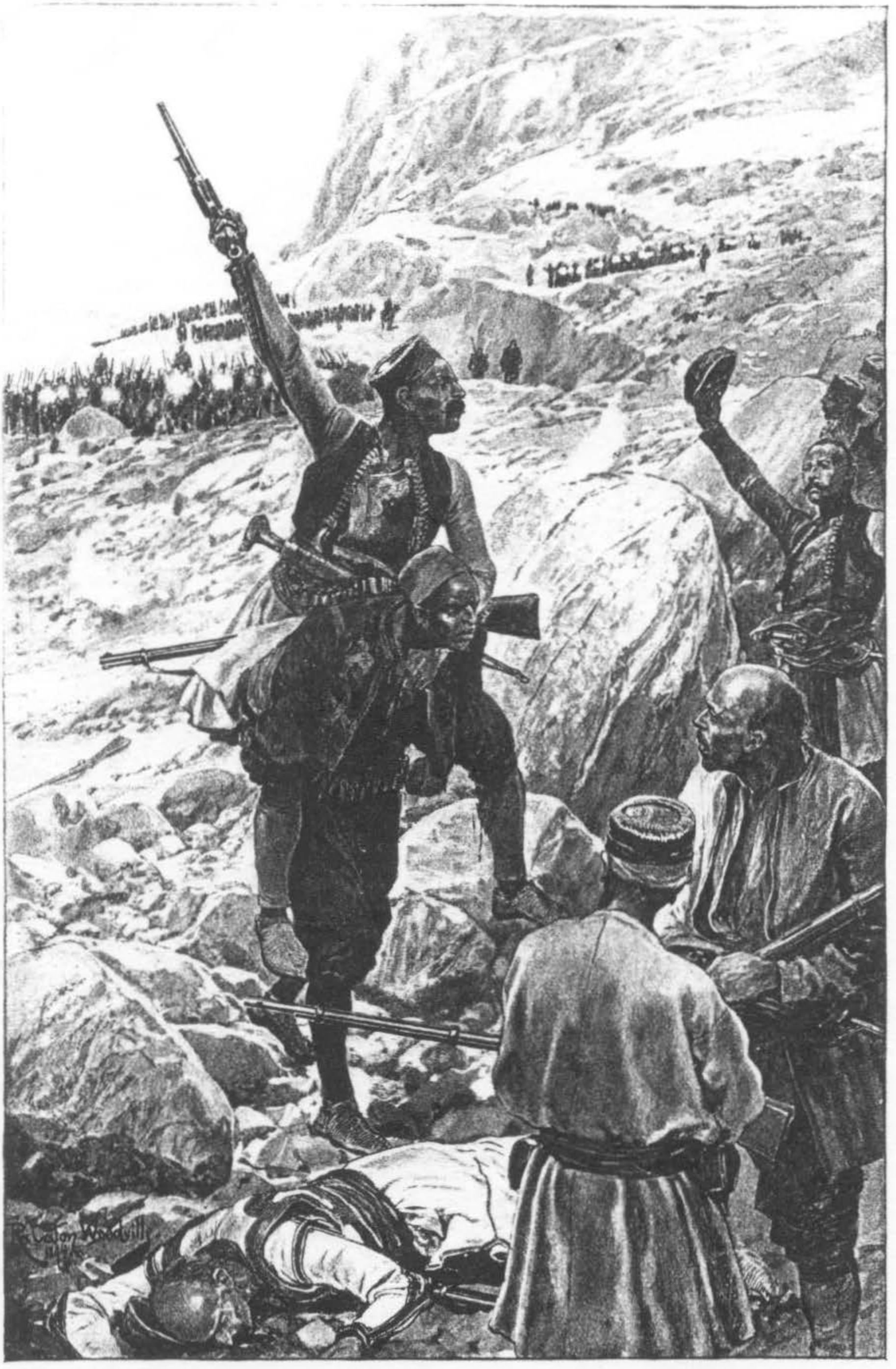
Paused the conflict — all intent
On the two before us;
And the Turkish regiment
Cheered in hideous chorus
As the prisoner, half afraid,
Turned and started up the glade,
Thinking — dullard! — to evade
Luka Filipov.

We 'd have fired, but Luka's hand
Rose in protestation,
While his pistol's mute command
Needed no translation:
For the Turk retraced his track,
Knelt, and took upon his back
(As a peddler lifts his pack)
Luka Filipov!

How we cheered him as he passed
Through the line, a-swinging
Gun and pistol — bleeding fast —
Grim — but loudly singing:
"Lucky me to find a steed
Fit to give the Prince for speed!
Rein or saddle ne'er shall need
Luka Filipov!"

So he urged him to the tent
Where the Prince was resting —
Brought his captive, shamed and spent,
To make true his jesting.
And as couriers came to say
That our friends had won the day,
Who should up and faint away?
Luka Filipov.

Robert Underwood Johnson.



DRAWN BY R. CATON WOODVILLE.

LUKA FILIPOV.

NIKOLA TESLA.

NIKOLA TESLA was born in 1857, at Smiljan, Lika, a region bordering on Austro-Hungary. His unquestionable genius was in part inherited from his mother, who took pleasure in constructing mechanical appliances, to be used in the household and for agricultural purposes. Having gone through the preparatory schools, he entered the polytechnic school at Gratz, where he began to prepare for the profestion of teacher in mathematics and physics. It was here that he saw a gramme dynamo, and although the instructor in charge stated that the commutator and brushes were absolutely necessary adjuncts, he saw a means whereby these could be dispensed with.

After this he conducted some experiments and became so fascinated by the work that he decided to take up the course in engineering. Having finished this he began to study languages, in order to be more fully fitted for the profession. He has undoubtedly found that this was a wise move, as it has often smoothed the way in his many dealings with foreigners.

During all this time he was constantly at work on his rotating field principle, and it was in 1882, when in Paris, while in the employ of one of the large illuminating companies, that he began in earnest to adopt it to commercial apparatus.

Believing America to have more field for inventors, he made up his mind to come, and fortunately secured a position in Mr. Edison's laboratory, which was then situated on Goerck street, New York city, in a building formerly known

as the Etna Iron Works. Here he endeared himself to all, both by the many instances of his genius and by his unostentatious manner.

But being influenced by the desire to advance his rotating field idea, he concluded it best to relinquish his position in the laboratory, although it was a very pleasant one. After joining a company for the manufacture and sale of arc-lighting apparatus, and this being successfully started, he began experiments with alternating currents and motors. In 1887 Mr. Tesla submitted to Prof. Anthony the results of his endeavors, and the ensuing test proved his motors to have a very high efficiency, as high in fact as those operated by direct current. This result was contrary to the expectations of the scientific world, as the alternating current had as yet won for itself but little confidence. Encouraged by these results, Mr. Tesla read a paper before the American Institute of Electrical Engineers in May, 1888, on high frequency and high potential currents, and exhibited his motors in operation, thereby demonstrating his first idea that a motor could be constructed without resorting to the use of complicated and expensive commutators and accessories.

Having opened up this new field in such a degree, he redoubled his efforts and obtained some very interesting results, which formed the basis of another lecture delivered by him in May, 1891, before the same Institute to which his first lecture was read. This decisively marked the beginning of a new era in the theory and practice of alternating currents. Three lectures followed, one in London, in 1892, and one in Philadelphia and St. Louis, respectively, in the subsequent year, each one being more advanced and treating of many beautiful things in the high-frequency and potential line.

The Tesla motor patents for the United States were secured by the Westinghouse company and have come largely into commercial use, and have proved to be very satisfactory from their simplicity. The Niagara Falls Power Company anticipate employing these motors, wound for the two-phase current, for the development of power in Buffalo and neighboring towns transmitted from Niagara.

In addition to Mr. Tesla's work in the foregoing subjects, he has been devoting himself recently to his "oscillator." Of late years the problem of generating electrical currents without passing from horizontal to rotary motion has been one of special interest to inventors. This had hitherto remained unsolved until Mr. Tesla brought out his oscillator, which is acknowledged to be a practical solution of the case in question. In this device the steam is let into a cylinder, the shaft of whose piston protrudes from one end in the early types, but, in the later forms, from both ends, sufficiently far to allow of field magnets being placed around it. This shaft is caused to vibrate very rapidly, producing currents in the surrounding coils, one hundred times a second being the number of vibrations obtained by an oscillator now used in Mr. Tesla's laboratory. The construction of the cylinder permits of using very high steam pressures, even as high as one thousand pounds to the square inch, and although there is no packing whatever, one is unable to hear or see the slightest trace of escaping steam. An unchanging frequency of vibration is established by means of an air spring, attached to the shaft, and should the pressure vary between wide limits, the number of vibrations per second remain unchanged, as any variation in pressure only causes a difference in amplitude, causing, however, a decrease in electrical power generated.

The capacity of these machines, then, depend, within reasonable limits, upon the steam pressure supplied, and as the cylinders may be made of very great strength, as stated above, a surprising amount of power may be produced from a machine occupying but comparatively little space.

Friction is conspicuous by its absence, there being but few bearings, thereby making the life of the apparatus one of unusual length, increasing efficiency and decreasing cost of maintenance as compared with the usual steam engine.

This mode of generation certainly bids fair to come into universal use, not only from the very nature of its simplicity and practicability, but from its high efficiency and cheapness.

Mr. Tesla is acknowledged to be one of the greatest living scientists, because of his ability in mathematics, physics and experimentation, his wonderful creative genius and his untiring application to his work.

The hope is sincerely felt by all that he may be spared to continue his labors which have been so favorably begun and have been productive of so much good.

ERNEST K. ADAMS.

Electrical Progress.

Tesla's "Oscillator."

Tesla's latest invention, the "Oscillator," is described as one of the most remarkable appliances of the age, consisting of "the core of a steam engine and the core of a dynamo combined, making a harmonious mechanical adjustment." This combination, says an enthusiastic admirer, constitutes a machine which has in it the potentiality of reducing to the rank of old bell metal half the machinery at present moving on the face of the globe. It may come to do the entire work of the engines of an ocean steamship within the small space they occupy and at a fraction of their cost, both of construction and operation. It will do this work without jar or pounding, and will reduce to a minimum the risk of derangement or breakage. There is nothing in the whole range of mechanical construction, from railway locomotives to stamp mills, which such an invention may not revolutionize. The essential characteristic of the machine is the application of the pressure of steam to produce the extremely rapid vibration of a bar of steel, or piston, which, in turn, is so adapted to a set of magnets that the mechanical energy of the vibration is converted into electricity. The extraordinary result is that practically an absolutely constant vibration is established, and a power is obtained greatly beyond that obtainable in the most costly expansion engines using a similar amount of steam.

Besides, it is said, saving in mechanical friction the thirty-five per cent of loss in the working of the engine, the fifteen per cent of loss in belt friction, and the ten per cent of loss wasted in the dynamo, making altogether an addition of sixty per cent to the available energy obtained from the steam for the purpose of producing electricity, it is simpler, lighter and smaller than the mechanism it is designed to replace, absolutely constant in its action, automatically regulated and subject to the least possible amount of wear and tear. The utilization of this machine in any branch of industry would, it is claimed, result in an appreciable lowering in the cost of production, and it is thought quite possible that its first general employment may be in electric lighting.

THIRD EDITION OF "THE INVENTIONS, RESEARCHES AND WRITINGS OF NIKOLA TESLA."

"The Inventions, Researches and Writings of Nikola Tesla," by Thomas Commerford Martin, published by THE ELECTRICAL ENGINEER, N. Y., has met with remarkable success. The first edition appeared during January, 1894, and the second was completely exhausted before the close of the year, several orders now being in hand for the third, which is expected this month. It is rarely that technical books have such a reception, The welcome accorded to the work abroad has also been most cordial. It har been favorably reviewed by the technical press of England, Gesmany, France, Russia, Italy and other countries; and an authorized German translation is now being brought out by the well known house of W. Knapp, of Halle. The book embraces all Mr. Tesla's inventions and researches made known up to date, and includes his oscillator, or new electrical generator, which he is rapidly bringing to a high pitch of efficiency and economy. The more important parts of the book have had the benefit of Mr. Tesla's personal revision.

Trade Notes and Novelties

AND MECHANICAL DEPARTMENT.

THE NIKOLA TESLA COMPANY.

The Nikola Tesla Company has been incorporated in New York City, to manufacture and sell machinery, generators, motors, electrical apparatus, &c., capital $5,000. The directors are Edward D. Adams, Ernest K. Adams, Alfred S. Brown and William B. Rankine of New York City, and Charles F. Coaney of Summit, N. J.

ILLUSTRATED

ELECTRICAL REVIEW

A Journal of Scientific and Electrical Progress.

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VIEWS, NEWS AND INTERVIEWS.

Mr. Nikola Tesla is generally regarded as an unusually modest man, and one who doesn't go in for ostentatious display. This was exemplified at the time the New York *World* printed an interview with him, written by Arthur Brisbane and accompanied by that truly marvelous picture of Tesla, showing him standing erect with lightning flashes glancing out from every portion of his body. Mr. Tesla had gone to a well-known health resort for a brief vacation a few days prior to the publication of the interview. He had been at the hotel just long enough to make a few acquaintances, and to become pretty well known himself. On the Sunday that the interview was published, the papers containing it reached the hotel at 10 o'clock. Mr. Tesla, in walking about the hotel lobby, observed many people who glanced at a paper in their hands, then looked up at him with an expression of awe, and finally put their heads together and discussed something in whispers. He finally discovered the cause to be that wonderful picture. At 11 o'clock Sunday morning Mr. Tesla was on the first train bound for New York.

Mechanical Progress.

Tesla's Steam Engine.

Much has appeared in technical journals concerning this engine, and considerable speculation has been indulged in regarding its practicability. The engine is a vibratory direct-generating one, or steam dynamo. The scheme is to produce electric current without rotary movement, friction or moving joints even, except of a steam piston, which directly vibrates or reciprocates—an armature between magnets. Mr. Tesla gives out the following particulars of his direct steam engine:

"I had gone considerably into the study of the practical aspects of the work which I was to present, and my notion was that I was touching upon something which would lay the foundations of a novel industry, perhaps of more than one industry. I dwelt chiefly on those features which possessed a purely scientific interest, my desire being to present the subject very modestly, as I was not quite sure of some of the questions involved. A prominent engineer came to me and said: 'Mr. Tesla, I want to tell you something, but I fear I may offend you.' I knew what was coming, and so I asked what it was. He said: 'Well, don't you work on steam engines. You have done some work in electricity. If you stick to it you will do some good work, but if you work on steam engines you are bound to fail.' Another, to whom I showed the advantage of doing away with complicated mechanism, and generating electricity directly, said, after he had watched it for a long time, 'Couldn't you apply this to rotating motion?'

"One of the first impulses which guided me was to produce an absolutely constant motion, which would be independent of any friction losses, or gravity, or temperature changes within very minute limits. I wanted to produce a positive motion, so that I might operate what I called a disruptive discharge coil. With a device which I invented, I was able to maintain a vibration with perfect constancy. The device consisted of a spring which required several tons of force to spring a certain distance, and which was constantly kept in vibration by steam pressure or air pressure. In the beginning I used springs of tempered steel. These steel springs would break, though they had a section of two or three square inches. So I resorted to air springs. The air springs would not break, but they had no constant resistance. Then I made the chambers of the air springs communicate with the outer air. This device yields a constant vibration; and as the force which is driving it is many tons, and the friction but a very small matter, it is unaffected by the pressure, so I have a constant vibration. This is the device which I believe will be used for many purposes—for instance, for governing all sorts of mechanisms, engines and so on. It contains much of interest for scientific men, because with it I am now able to produce currents of perfectly constant frequency.

"When we look at a steam engine, and inquire where the power comes from that drives the steam engine, we will always find that the power comes from a little box, a cylinder with a piston in it, and all the other appurtenances are really but to keep it going. My first idea was to apply the motion of the piston, which is freely movable, to a magnetic field, to move a magnet or coil in a magnetic field, and so generate currents by this direct motion. We can reduce the weight of the engine for the same pressure and the same piston speed to $\frac{1}{30}$ or $\frac{1}{40}$ if not $\frac{1}{50}$ of its weight. We do away with all mechanical frictions.

"The engine designed according to my ideas has a mechanical efficiency of 99¾ per cent. In my construction the dynamo may consist of a simple coil of the magnet and a simpler coil, which is all immersed in the magnetic field. There is no useless wire, consequently dynamo and engine, if they are reduced considerably in weight, increase in efficiency. There is only one engine that can equal it in output, and that is the turbine. With the steam turbine we can obtain an enormous output, and that is the reason why the steam turbine, in my opinion, may be found a valuable adaptation for driving dynamos. In reciprocating mechanisms we can expand the steam at an enormous rate. It is perfectly practicable in these mechanisms, which I have been working up to obtain, if you want, a speed of 100 metres a second; and while I do not contemplate producing such speeds, yet it is quite possible to do it. As I am enabled now to work without a packing, the expansion occurs at an enormous rate; and the engine being of such character that the exhaust can be readily reduced to pretty nearly the atmospheric pressure and the mechanical friction is reduced to such a small figure that we can raise the temperature of the steam very considerably.

"I am now preparing a boiler which will give me up to 350 pounds pressure. If we want to drive motors we must have a long stroke and a slow frequency; if we want to light lamps then we want a very short stroke and a very rapid motion. It is very important in this mechanism, in which the power depends on the square, to obtain as high a pressure as possible. It is more economical to produce rapid vibrations than low vibrations. But, so far as the economy of the dynamo and of the engine is concerned, it is better to produce a long stroke, because a long stroke means a high velocity. I think I am not mistaken in believing that we are going very shortly to have a means at hand of producing twice as much electricity from coal as we can produce at the present time. This is subject, of course, to a test, but I am quite confident it can be done."

ON EXPERIMENTS WITH TESLA CURRENTS.

BY F. HIMSTEDT IN "WIEDEMANN'S ANNALEN."

The author has succeeded in reproducing most of Tesla's experiments with very simple apparatus. He utilized at first the Lecher method of producing electrical oscillation, but later on used the still more common Leyden jar. The pole of a powerful Rubenkorff coil, 50 centimeters long and 20 centimeters in diameter, and used with five or six accumulator cells, was connected to the inner coatings of two medium-sized Leyden jars insulated from one another by standing on paraffine blocks, and also to a spark micrometer. The outer coatings of the jars were connected together by a copper wire four millimeters thick and 120 centimeters long, bent into U shape. A 16-volt glow lamp put in parallel with this wire was soon brought to incandescence when the spark micrometer was suitably adjusted. When jars 16 centimeters in diameter and 42 centimeters high were used, as many as three lamps could be made to glow —a 65-volt lamp below, a 16-volt lamp in the middle and a 2-volt lamp at the top. If the nipple of such a lamp be filed off it ceases almost entirely to glow. Tesla ascribes this fact to the alteration in the molecular bombardment in the lamp; but the author considers that it is due to the connection of heat by the air admitted.

If the incandescent body be a platinum of 0.05 to 0.1 millimeter diameter, it oscillates violently while glowing, not in one plane like a string under tension, but in every possible plane, becoming a model of a beam of natural light. It is essential to the success of this experiment to use a proper interruptor and a suitable spark micrometer. As interruptor the author used the Foucault form, with tough zinc amalgam in the place of mercury, and covered with machine oil. The balls of the micrometer are best made of zinc.

The Tesla transformer was made as follows: A glass tube of four centimeters diameter was taken, and on it were wound 10 turns, one centimeter apart, of a wire four millimeters thick. Over this was pushed an ebonite tube, six millimeters thick, on which were 200 turns of wire one millimeter thick and spaced with one millimeter between each. The whole transformer was placed in an earthenware container filled with machine oil, the secondary terminals being two metal balls on ebonite pillars. The primary was put in the place of the U-shaped wire, between the outsides of the Leyden jars. When the interruptor begins working, brush discharges start from these balls, and sparks spring to a conductor put near. Two parallel wires starting from the balls have between them a broad band of light three to four meters long. If one pole be put to earth, and to the other be connected a wire 15 to 20 centimeters long, hanging freely downwards, it begins to move when the interruptor is started and describes the surface of a cone, which is easily seen in a dark room by the brush discharge, which renders it luminous.

If anyone takes hold of the pole of such a transformer with the hand, rays of light start from any part of his body when a conductor is held near. If he stands on a metal plate he feels a pricking sensation in his feet, and in the dark the rays coming out of the soles of his shoes may easily be seen. If several persons form a chain, and the first touches one pole of the transformer, while the last holds in his hand a vacuum tube with or without electrodes, the tube glows brilliantly. None of the persons feel any symptom of the electrical phenomena.

If one pole of the transformer be earthed and the other connected to a metal sphere 60 centimeters in diameter, vacuum tubes glow brightly up to 15 feet away. A glow lamp connected to the unearthed pole glows faintly in a phosphorescent manner; but if a large metal reflector be placed over the lamp it glows brilliantly, while the filament oscillates so violently that it soon breaks. If a conductor be held near the point of the lamp, the glass is immediately punctured by the current, a continuous and brilliant stream of sparks passes through the opening, and the filament glows until it burns away.

In the second portion of the article the author remarks that a Tesla transformer differs in important particulars from an ordinary Ruhmkorff coil. A vacuum tube connected in any manner to the transformer shows kathode light at both electrodes, and evenly distributed anode light in the center. An alteration of direction of the primary current, or alteration of pole, has no effect in altering this phenomenon. An electroscope is always charged positively if held to either pole, and both poles give positive Lichtenberg figures only. It was found that this effect depended on the nature of the surrounding medium. Air and oxygen produce positive discharge; hydrogen, illuminating gas, nitrogen, carbon dioxide and ammonia give negative discharges. If a pole have two points immersed in air and hydrogen, respectively, positive and negative discharges take place simultaneously, according to the medium. If a pole be in oxygen, and nitrogen be gradually added; an electroscope shows first a positive charge, first increasing, reaching a maximum at the mixture corresponding to air, and then diminishing, and ultimately becoming negative. With a Ruhmkorff coil the charge in the electroscope changes sign if the primary current be reversed.

NIAGARA WILL DO IT.

Electricity from the Great Cataract May Supplant Engines, Cables and Locomotives.

STEAM WILL BE OBSOLETE.

Some of Bellamy's Brightest Dreams May Soon Be Realized in This City.

NEW YORK IS NOT TOO FAR.

Nicola Tesla Says the Problem of Long Distance Transmission Is Solved.

IN an article in the HERALD some time ago on electrical possibilities in New York I quoted the remark of Nicola Tesla that "the labor of the future will largely consist in pressing electric buttons." In a little talk I had with Mr. Tesla a few evenings ago he disclosed to me that he is now engaged upon important experiments looking toward a very material realization of his prophecy right here in New York city.

Mr. Tesla is now completing experiments, in which he has been engaged for the last four years, upon means of transmitting great electrical power long distances. Just the immediate means and mechanical devices which he has adopted for this purpose Mr. Tesla does not care at the present time to disclose. He, however, gave me a glimpse of his method. It is, in brief, that he believes that while it would probably be too expensive and too wasteful to attempt to transmit large electrical power by ordinary alternating currents, the feat may be achieved by means of what he terms "electrical waves." The phrase is one which an electrician will understand, but which would involve technical explanation of little interest to the lay reader.

What is more to the point is that the feasibility of utilizing Niagara Falls to do the mechanical work of New York city is not only now assured, but that the attempt will very shortly be made.

It is probable that within a month the actual work of construction looking toward this great end will have been begun.

A BIG PROBLEM SOLVED.

The officers of the Niagara Falls Power Company, which has in hand the great feat of "harnessing Niagara," are as yet reticent to speak upon the subject, inasmuch as their plans are not fully developed and the right of way has not yet been secured. When I saw him at his home, at No. 453 Madison avenue, yesterday, President Edward D. Adams said:—

"It has been the policy of this company to say nothing of what it is going to do and to speak only of what it has done. I must, therefore, decline to enter into any discussion of the company's plans. We might have a great many things in mind which another month would give an entirely different face to. We have been compelled to change our plans many times, at least in important details, and it would, therefore, be premature to attempt to speak now upon what the company has in mind with regard to bringing power to New York city."

Mr. Adams expressed himself, however, as firmly of the belief that the problem of long distance transmission has been practically solved. Upon this point he has the backing of most advanced electrical experts, in addition to Tesla.

Whatever doubts may have been entertained hitherto as to the possibility of successful transmission for long distances, it may be set down that the question is no longer open. For comparatively small distances, ranging from ten to fifty miles, the question has not only been solved, but the process is now being successfully employed at many points throughout the country.

Some time ago a company was formed for the purpose of utilizing the power of the beautiful Snoqualmie Falls, in the State of Washington. This famous cataract, the most imposing and most beautiful on the continent, except Niagara, lies about twenty-three miles directly east of the cities of Seattle and Tacoma, on Puget Sound. It is 268 feet in height, or more than one hundred feet higher than Niagara. Its total realizable energy is estimated at 51,000 horse power. What this means may be gathered from the fact that the total horse power employed in all the manufacturing enterprises of the industrial city of Buffalo, with a quarter of a million inhabitants, is only equivalent to about this single fall.

It is the design of the Snoqualmie Company to transmit the power acquired from the cataract and by electricity do all the mechanical work of Seattle and Tacoma.

Before undertaking the construction of their plan, the company looked carefully into similar enterprises now in operation. They found several successful examples. The San Antonio Electric Light Company of California transmits light and power thirty miles to San Bernardino, and recently tested its ability to employ a ninety mile circuit with perfect success. The Portland (Ore.) plant transmits power from the Willamette Falls to Portland, a distance of fifteen miles. A Mexican enterprise at the falls of Juanacatlan transmits power a distance of seventeen miles. In Montana, Idaho, California, Colorado and Utah plants are in operation successfully transmitting power all the way from four to thirteen miles. All of these have been in successful operation from two to five years.

MORE THAN MERE DREAMS.

It will be seen, therefore, that there is nothing particularly new or hazardous in the attempts of the Niagara Falls Company to turn the machinery of Buffalo by electricity from a distance of twenty-two miles. But this enterprise, great as it is, shrinks into insignificance before the definite dreams which this company has of practically furnishing energy for the whole machinery of New York State.

Several years ago it was officially estimated that the entire power employed to run all the machinery in New York State is equivalent to about 450,000 horse power.

The plans of the Niagara Company look to the generation of half a million horse power.

The question of transmission is practically the whole of the difficulty. Although the work of constructing a plant capable of generating this stupendous amount of energy has been a great one, it has practically been nothing more than a question of the application of capital and hard work along the lines of approved hydraulic engineering. The element of difficulty lies in the fact that electricity is of such an elusive character that, to speak untechnically, it leaks off the wires. Power that can be sold at a profit at Niagara Falls at $15 per year per horse power will at a certain distance reach a price equal to that of steam, owing to the loss from leakage and the expense of installation. Electricians are cautious about making predictions as to whether this distance is 100 miles or 1,000 miles. Dr. Coleman Sellers—no relative of Colonel Sellers—is president of the Niagara Falls Power Company, and a most conservative and experienced engineer. On this point he writes:—

It is absolutely certain, from what has already been done elsewhere, that profitable transmission to a distance of 150 miles is only within the existing practice of distributed power. This 150 miles from Niagara Falls, in a straight line, brings us to within ninety miles of the city of New York. And if we assume as probable economical transmission to a distance of 320 miles, we have an area including the very densest population. It would take in Columbus, Ohio, the cities of Washington, Philadelphia and New York; would include the whole of Pennsylvania, New York, two-thirds of Ohio, three-quarters of Michigan, besides reaching to Montreal, in Canada.

Thus the situation of Niagara Falls is phenomenal in its ability to distribute the power over an area that furnishes the most desirable market for its profitable development. If in the near future, as now seems entirely probable, Chicago can receive its power from Niagara Falls, then the whole of New England, as far as Maine, will come within the reach of this cyclops of energy.

This opinion of Dr. Sellers has the indorsement of no less a personage than Lord Kelvin, formerly Sir William Thompson, who ranks as the greatest electrical authority in the world.

TESLA'S BOLD DECLARATION.

The problem was, perhaps, not wholly solved in theoretical demonstration, however, until Nicola Tesla, that daring wizard of electricity, assured the company that he had discovered, and in great measure perfected, mechanical appliances which would make it possible to deliver the electrical current under complete control, and without costly loss from waste, at long distances. Mr. Tesla has faith that he has now devised the means to deliver the current, at fairly competitive prices, as far as New York city on the east, and as Cleveland and other great towns of Ohio on the west.

It yet remains to be seen whether Mr. Tesla's audacious views are entirely practicable. But no one who has watched the achievements of this wonderful genius can doubt for a moment that he is able to do everything that he promises. It was by a simple invention, of his alone, that it was possible to light the grounds of the World's Fair Exposition at Chicago in the dazzling fashion that made them almost as light as day. But for Mr. Tesla's invention the cost would have been absolutely prohibitive. It is this same simple device, too, that makes it possible to run a main current of electricity and tap it at a thousand points, exactly as we tap a water main. Before that each lamp had to have its separate current, and the use of electricity for house lighting, warming and a hundred other little purposes was economically impossible.

It was the first intention of the engineers to carry the electrical current from Niagara out over the country by means of wires stretched through a subway conduit. It was found however, that the cost would be very great. Mr. Tesla has therefore been engaged for some time in experimenting and devising means to bring the current by overhead wires. He has assured the company that, by invention and the scientific application of newly discovered principles, which he has made, it will be possible to convey the current without very great loss by induction or leakage, and under absolute control, by the use of certain transformance. Mr. Tesla believes not only that this current will be employed upon the Erie Canal, but even to propel vessels from Albany to New York.



PORTRAIT OF J. F. RAFFAELLI, THE PAINTER, BY HIS FRIEND, E. A. ABBEY.

WHAT WILL THE ELECTRICITY COST?

It yet remains to be seen whether the companies can bring electricity to New York city at a price sufficiently low to drive out steam, and practically abolish coal used for power purposes. In a general way, it has been estimated that the power can be delivered here at a cost of about fourteen dollars per year per horse power. If this can be done, it is safe to say that within one year after its introduction the use of coal will have very largely disappeared in New York city. We should have no more smoke and no more gas.

This means a great deal. Roughly speaking, New York pays out every year from $15,000,000 to $20,000,000 for gas alone. It spends upward of $30,000,000 a year for coal. In other words, if we could abolish coal and gas at a stroke, it would involve an item of from $40,000,000 to $50,000,000. Add to this the sums paid out for coal and gas in the additional area of greater New York and the neighboring cities of New Jersey, and this sum would be nearly doubled. The Niagara Company is therefore planning big things.

But even this does not begin to represent the actual saving that would be effected.

Take, for example. At the present time to run the big cable roads of this city there are required immense power houses, employing a large number of workmen, besides truckmen and horses used to transport the necessary coal to run the engines. If these roads were run by an underground trolley, all these power houses would be useless.

This fairly suggests the saving that would be effected all over the city. Steam engines would disappear, engineers would be out of employment and the number of truckmen and horses would be greatly reduced.

We are already dealing with an item of a hundred millions or so. But the prospect stretches still further. If electricity can be brought to New York, as Mr. Tesla declares, at such a price, we should have a Bellamyized metropolis. We should have no noisy, dirty elevated railroads, throwing clouds of hot cinders into the eyes of passengers or passers by upon the streets below. We should have no clumsy, unreliable cable which leaves us stranded half way from our destination about every third time we board a car.

REAL RAPID TRANSIT.

If the municipality under the lead of the Rapid Transit Commission constructs the underground railway, it will probably be from Niagara Falls that it will obtain the power required for the operation of the system. The elevated railroads are a demonstration of the costliness, noise, soot, smoke, gas, cinders, and every conceivable annoyance involved in the use of steam.

The elevated railroads, even if they could obtain cheap electrical power at about the figures indicated, could abolish their steam engines, operate their cars by electricity, make trains of one or two cars each, run them very much faster than they do now, and at a two or three cent fare, probably make as large a profit, if not larger, than they do at the present time. If a cheap, odorless, smokeless, non-heating motive power would be of advantage to the elevated railroads, it would be doubly so, in fact, almost a prerequisite, to the comfortable and successful operation of the underground lines. In the latter, traversing a long and slightly ventilated vault, the presence of smoke, soot and cinders, would be simply unbearable. It is the hope, too, of the projectors of the underground road to not only run the trains at such a speed, but to so reduce fares as to make it feasible for the workers of the downtown districts to have homes in the annexed districts, and still not lose more time going to and fro than they probably do now. This end could only be achieved through cheap electrical power.

HOW THE BIG PROJECT WAS BEGUN.

While the project of transmitting electricity a long distance has been of late years only the dream of daring innovators, yet its use as a motor power has been practically demonstrated for a considerable time. So it is rather strange than otherwise that the tremendous energy of Niagara should have so long remained unharnessed. The energy of the falls is so great that the mind can hardly grasp it. It is so great that the deflection of enough water to turn all the machinery for five hundred miles around—that is to say, to do all the mechanical work for New England and the Middle States—will not make an appreciable decrease in the volume of the water which goes over the falls.

Up to 1885 its enormous power remained practically unused. There were hundreds of engineers or men of a mechanical turn of mind who lay awake o' nights thinking of the fortunes that could be made by turning millwheels with this mighty stream. Finally one of them evolved a plan for a system of wheel pits a mile and a half above the falls, to which water would be carried by lateral canals and from which it would be taken to the river below the falls by a tunnel.

Capitalists were induced to take hold of the project, and the Niagara Falls Power Company was chartered in 1886. The first work was begun in October, 1890, four years ago. The main wheel pit was completed last year, and probably within another month the first of the giant dynamos will be ready. The work has cost, so far, some $4,000,000 and, incidentally, twenty-eight human lives. The device for applying the little portion of Niagara's strength which it is designed to utilize would be simple if one could see it on a small scale. From a point a mile and a half above the American Fall a broad, deep inlet leads back from the river. The heavy masonry with which it is lined at the upper end is pierced by a score of gateways, through which the inflowing water is admitted by short canals to pits, pouring down through huge steel pipes—engineers call them penstocks. The water strikes the bronze turbine wheels at the bottom and then whirls on through the subterranean passage ways that connect each pit with the main tunnel. This tunnel carries the water underneath the heart of the city to the portal just below what is known as the new Suspension Bridge.

A $1,250,000 TUNNEL.

The penstocks are brought down under the turbines and made to discharge upward into the wheels, an ingenious contrivance by which the pressure of the water is made to bear up the entire weight of the heavy wheels and 140 feet of shafting. Three of these turbines form practically an independent plant from which it is expected to cap 5,000 horse power. This will gradually be extended to a capacity of 50,000 horse power. In addition, another 50,000 horse power will be developed in various smaller pits adjacent. The tunnel which will carry away the water used in developing this 100,000 horse power is 1½ miles long, 21 feet high and shaped like a horseshoe. It was cut in a straight line through the rock 200 feet below the surface of the city. It cost $1,250,000, being lined its entire length with from four to six layers of hard brick.

The mouth of the tunnel is nearly 50 feet lower than the head, and the water tears through it at a furious rate. A marked piece of wood dropped in the water near the head of the tunnel is whisked out at the portal, 6,700 feet distant, exactly three minutes later.

Over the big pits is the power house, in which are the giant dynamos. Like almost everything else connected with this enterprise, the three dynamos in the central power station are far and away the most powerful ever constructed, each being expected to transform the 5,000 horse power received from its turbine shaft into an equivalent of electrical force. The most ambitious dynamos hitherto constructed sent out a little more than 2,000 horse power.

Some idea may be obtained of the force of the water in the big wheel pits when it is stated that if the stream injected into the turbines were directed at a man's body it would crush him like a triphammer. These big turbines, too, are so large that a man may stand between the blades.

When the company's entire plant is complete it will generate 450,000 horse power. In addition to this company, there is a second—the Niagara Falls Hydraulic Company—which, until the development of the more remarkable work up the river, possessed the largest water power plant in existence. While a much smaller enterprise than its great rival above, it still expects to compete with the latter in the generation and distribution of electrical power. It has the right of way for a canal 100 feet in width and has made arrangements to enlarge its plant at an early date.

THE CANADIAN ENTERPRISE.

Meanwhile, and in the face of these stupendous operations, a yet greater plant is under way on the Canadian side of the falls. Permission to build this plant was obtained from the Canadian government on condition that the work be begun by May 1, 1897. It is the intention to generate 250,000 horse power eventually on the Canadian side.

All the power generated on the Canadian side will be transformed into electricity and sent to a distance, as mills could not be built adjacent to the plant without disfiguring the scenery of the beautiful Victoria Park.

Those who have studied the question assure us that no one visiting Niagara Falls five or six years from now, when all these great enterprises are fully developed, will find any outward and visible sign of them except the mills along the hydraulic canal basin, which for years have formed a part of the view from Victoria Park.

There is little danger to the falls themselves. The vast mass of water speeding over the precipice will suffer but little diminution—not enough to even make it apparent to the naked eye. The official report of State Engineer Bogart in 1890 estimates that the diversion of enough water to produce a hundred thousand horse power would reduce the depth of the water at the crest of the American Fall about an inch and a half. So that the half a million horse power called for by the present plans of both companies will scarcely reduce the height of the falls three-quarters of a foot—hardly enough to make a noticeable difference in the appearance of this mighty cataract, whose sources of power come from half way across the continent, and whose strength, ceaselessly put forth, is more than twice as great as the combined energy of every steam engine in North America. Niagara will still be the monarch of waterfalls.

Nikola Tesla and the Electric Light of the Future

By Walter T. Stephenson

EXACTLY ten years ago Nikola Tesla, who, in June, 1894, received high honorary degrees from the Colleges of Yale and Columbia, came to this country, poor and unknown, to enter an Edison shop in New York City. For two years previous he had served as engineer in one of the new electric-lighting companies in Paris, and, having become an ardent and appreciative admirer of the splendid genius of Thomas A. Edison, whose fame in those days had only recently flashed throughout Europe, he was, naturally, eager to accept an opportunity of meeting the "wizard" face to face.

Tesla had already patented several minor inventions of his own, but, what was of more importance, his brain was then literally teeming with great ideas, as yet, perhaps, chaotic, but which must some day evolve into definite shape for revelation, and of all countries he firmly believed the United States offered the best encouragement to the inventor who could show practical results. Since New York has continued to be Mr. Tesla's home, we may reasonably infer that he has not been disappointed in his early expectations.

The young Servian electrician derived a fresh stimulus and lasting benefit from his association with Thomas A. Edison. Nevertheless, he soon realized that it would be far wiser for him to continue his special investigations alone, unhampered by other work. Therefore, after a few months of delightful intimacy, the two men of genius separated with mutual expressions of good will.



Nikola Tesla

Mr. Tesla now threw himself with redoubled ardor and energy into the study and analysis of alternating or polyphase currents, which had long been his chosen field of electrical investigation. In 1887 he exploited his wonderful invention of the rotating magnetic field for the economic transmission of power. This simple statement means that, after thirteen years of indomitable effort, embittered by sore disappointments and fierce controversies, a substantial success was at last assured, while scientists everywhere began now to await with keenest interest succeeding developments of the potentialities undoubtedly latent in these hitherto neglected alternating currents.

The majority of us probably are aware that the principal electricians of the world have long been struggling vainly towards the solution of a tremendous problem—the improvement of the electric light. When we are told, for one thing, that fully ninety-nine per cent. of energy is wasted every time such artificial illumination is produced under existing conditions, we begin to realize the crying need there is for a radical change in industrial methods. Now, the goal which some electricians declare to be already in sight means nothing less than the recovery of fully one-third of this wasted energy, thereby rendering possible an illumination many times brighter than at present and at a notable reduction of expense. The question is, which one of the few leaders in the race will outstrip the others and win an immortal name?

Rumors have reached the public ear with increasing frequency of late that Nikola Tesla was working slowly but surely in his own way towards the accomplishment of some such magnificent end.

We know that in May, 1891, Mr. Tesla emerged from the seclusion of his laboratory to deliver an address before the American Institute of Electrical Engineers, at Columbia College, on polyphase currents as applied to artificial illumination. Having in this lecture created a marked impression by the lucid exposition of his peculiar theories, he was soon urged by some of the prominent scientists of Europe to favor them in like manner. So it was that in February, 1892, he crossed the ocean and lectured before numerous audiences in England and on the Continent. It is not too much to say that the name of Nikola Tesla now commanded universal attention in the world of science, but still the man himself was beginning to chafe sadly already under his prolonged absence from the distant laboratory. In the fall of 1892, therefore, he gladly returned to New York to resume his interrupted labors in behalf of science.

In view of all this, even the hardiest of interviewers would be apt to think twice before intruding upon such an individual in his privacy. It will be enough, perhaps, for me to say that the forbearance and kindliness of Nikola Tesla are by no means his least distinguishing traits. Not very far from Washington Square, in the heart of that picturesque neighborhood known as the French quarter, teeming with cheap restaurants, wine-shops, and weather-beaten tenements, the observant passer-by will notice a huge yellowish brick building of some half-dozen stories apparently devoted to manufacturing purposes.

If such a one should undertake to explore the murky interior of this uninviting-looking pile, say to the extent of climbing three or four flights of stairs, and warily threading a signless path through successive mazes of vociferous machinery, his perseverance might be rewarded, as in my own case, by discovering the retreat of a modern wizard. While awaiting my opportunity in an anteroom, I caught glimpses through the adjoining office and library of the mystic laboratory itself, which, as I ascertained later, opened into an immense machine-room.

I may candidly state that I was a trifle shocked the first time I saw Nikola Tesla as he suddenly appeared before me in the library and sank into a chair seemingly in a state of utter dejection. Tall, straight, gaunt, and sinewy of frame like a true Slav, with clear blue eyes and small, mobile mouth fringed with a boyish mustache, he looked younger than his thirty-seven years. But what arrested my attention chiefly at the moment was the pallid, drawn, and haggard appearance of the face. While scanning it closely I plainly read a tale of overwork and of tremendous mental strain that must soon reach the limits of human endurance.

"I would like to talk with you, my dear sir," he said, "but I feel far from well to-day. I am completely worn out, in fact, and yet I cannot stop my work. These experiments of mine are so important, so beautiful, so fascinating, that I can hardly tear myself away from them to eat, and when I try to sleep I think about them constantly. I expect I shall go on until I break down altogether. So you would really like to see some of my experiments in electric lighting," he added. "I shall endeavor to accommodate you, my friend, if you will come with me into the laboratory. Be prepared, though, for a surprise or two."

Mr. Tesla then ushered me into a room some twenty-five feet square, lighted on one side by two broad windows, partially covered by heavy black curtains. Directly opposite was an open door leading into the machine-room, which seemed to be fairly alive with grimy figures flitting to and fro. The whole scene, to my unaccustomed eyes, suggested a veritable magician's den.

The laboratory was literally filled with curious mechanical appliances of every description. Wires innumerable, from the smallest size to cables three-quarters of an inch

thick, ran along the walls, ceiling, and even the floor. In the center was what appeared to be a large circular table covered with thick strips of black woolen cloth; snakelike cables running up underneath were connected at the other end with an adjacent dynamo, thereby establishing a possible center of electro-dynamic vibration. Between the table and the windows two large brownish globes, eighteen inches in diameter, depended from the ceiling by cords. These balls were composed of brass coated with two inches of wax to render them non-injurious, and served the purpose of spreading the electrostatic field.

So much for my surroundings as I glanced about in some bewilderment after hearing Mr. Tesla say that he had a surprise in store for me. Promptly suiting the action to the word, he called in several employees from the workshop and issued a succession of hurried orders which I followed but vaguely. Presently, however, the doors were shut and the curtains closely drawn until every chink or crevice for the admission of light was concealed, and the laboratory bathed in absolutely impenetrable gloom. I awaited developments with intense interest.

The next minute exquisitely beautiful luminous signs and devices of mystic origin began to flash about me with startling frequency. Sometimes they seemed iridescent, while again a dazzling white light prevailed.

"Take hold," said a voice, and I felt a sort of handle thrust into my hand. Then I was gently led forward and told to wave it. On complying, I spelled the word "Welcome" flaming before my eyes. Unfortunately, I was totally unable at the time to appreciate the kindly sentiment implied.

A hand approached mine ere I had quite recovered, and I felt the tips of my fingers lightly brushed. Fancy my dire dismay when I immediately experienced an acute tingling sensation, accompanied by a brief pyrotechnic display that was surprising, to say the least. When the daylight as well as my equanimity was in a measure restored, I learned something of the meaning of these wondrous experiments, which may be said to foreshadow in a way the electric light of the future. What impressed me most of all, perhaps, was the simple but cheerful fact that I remained unscathed while electrical bombardments were taking place on every side. Curiously enough, the polyphase currents of high frequency and high potential, of say 200,000 volts, have, as Mr. Tesla has demonstrated repeatedly on the platform, no harmful effect whatever on the human body, although a like energy exerted in indirect currents would prove instantaneously fatal.

Over two and a half years ago Mr. Tesla made this striking observation in one of his lectures: "The ideal way of lighting a hall or room would, however, be to produce such a condition in it that an illuminating device could be moved and put anywhere, and that it should be lighted no matter where it is put, and without being electrically connected to anything."

To return to my own experience in the darkened laboratory, it seems that the entire room was actually filled with electric vibrations through the agency of these same currents, styled alternating (that is, with direction perpetually changing). The strange devices I had seen were nothing more than nearly exhausted glass tubes bent into various shapes and analogous to lamps, excepting that they were devoid of filament or button.

These tubes being carried into the area where the electrical agitation was strongest, the remaining molecules of ether or air within all the while pressing against the crystal confines, a molecular bombardment followed, produced by the collision of two forces, and the bulbs simultaneously became luminous. Those which were made to glow with the colors of the rainbow were coated on the inside with phosphorescent substances.

I have attempted nothing more than a very imperfect outline of Mr. Tesla's novel and interesting scheme, which is to be regarded as still in a state of embryo. It cannot be denied, too, that there are many scientists to-day who shake their heads dubiously at the brilliant Servian's unequivocal attitude towards the electric light.

Meanwhile Mr. Tesla makes no boasts, but is willing to abide his time. Throughout the interview I was constantly impressed with the man's loftiness of purpose, innate modesty, and utter indifference to public applause. "I should much prefer not to be written about at all," he remarked; "but if it must be done, I trust you will take due pains to quote me correctly."

Speaking of the scientific status of the United States as compared with that of older nations, he said: "English scientists are the greatest in theory, perhaps, although, as far as practical results go, America may well claim to lead the world. That is why I like to stay here."

Mr. Tesla speaks our language with the idiomatic range and choice diction of a native who is also a scholar and a trained speaker, the guttural accent of the Slav, of course, being slightly noticeable. He told me that he felt equally at home in six languages, not to mention the same number of dialects.

Though simple, self-contained, and undemonstrative in manner, when he is especially pleased or absorbed in enthusiastic description of electrical wonders, the intellectual animation of his frank blue eyes, combined with a rarely winning smile, exercises a charm that is irresistible. I have noticed the same unconscious quality of personal magnetism in Mr. Edison, though in almost every other respect these two remarkable individuals are totally dissimilar.

Edison may be more truly the man of genius. He works out his intricate problems by intuition. He peers into the future like a seer of old, and receives, as it were, lightning flashes of inspiration to guide him to the goal. In a word, the illiterate train boy of thirty-odd years ago has come to be regarded as little less than a wizard; and yet, assuredly, he is neither a thinker nor a student in the true sense.

Now, how is it with the Servian, who has acquired fame much less rapidly? What was his life before he came among us? Let me say at the outset that eighteen years of exhaustive, patient study were accomplished before Nikola Tesla deemed himself adequately prepared to embark upon the career which he had planned from childhood.

Born in 1857 at Smiljan Lika, a remote village in Austro-Hungary, he is the descendant of a sturdy line of Servian patriots, who for centuries had taken a prominent part in the protracted struggle against the domineering Turk.

The young Nikola commenced his studies in the public school of Gospich when five years of age. Not long afterwards the marvels of electricity and magnetism began to dawn upon the boy's receptive soul. Fascinated and stirred until he scarcely thought of anything else, he resolved thenceforth to devote his life to research and investigation in this noble field of knowledge. In 1873, against the wishes of his father, who, being a clergyman in the Greek Church, had hoped that his son would discover a theological bent, Nikola entered the Polytechnic school at Gratz. It was at this institution, while puzzling over the complexities of a direct current Gramme machine, that his alert mind was led to conceive of a rotating magnetic field, which discovery was destined to deal the death-blow to those troublous contrivances the commutator and brushes. After completing the technical course at Gratz, Mr. Tesla removed to Vienna, where for several years he attended philosophical lectures, read omnivorously on many subjects, continued his special studies, and incidentally found time to master five or six languages. Verily, an intellectual training of this sort, in the face, too, of untold trials and difficulties, would have far exceeded the scope of any ordinary student.

Before I bade a regretful farewell to this kindly wizard of Washington Square he confided to me that he was engaged on several secret experiments of most abundant promise, but their nature cannot be hinted at here. However, I have Mr. Tesla's permission to say that some day he proposes to transmit electric vibrations through the earth; in other words, that it will be possible to send a message from an ocean steamer to a city, however distant, without the use of any wire.

To those who would gain a complete technical knowledge of the Servian's manifold labors since he came to the United

States I would recommend a careful study of the volume recently issued by Mr. T. C. Martin, of the "Electrical Engineer," entitled "The Inventions, Researches, and Writings of Nikola Tesla." How strange it is, indeed, that, though electricity has so long been partially controlled by mankind, yet we are utterly unable to define it! As Mr. Tesla has said: "The day when we know what electricity is will chronicle an event probably greater than any other recorded in the history of the human race."

A Mother of Bosnia

By Robert Underwood Johnson

From the Servian of Zmai, after Literal Translation by Nikola Tesla

I.

Three sons she has of Servian mold
  As balsam for her widow's grief,
While in her Danka all behold
  A treasure precious past belief.

Oh, lovely Danka! happy she,
  More fortunate than all beside,
To be the pride of brothers three,
  Themselves of Bosnia the pride!

In her they glory: she inspires
  To freedom's never-ending fight,
And in their hearts burn patriot fires,
  As stars upon the Turkish night.

And often at the mother's door
  Tears mingle with the words that bless:
"O gods of battle! guard my four—
  My falcons and my falconess."

II.

Her radiant beauty nothing hides—
  What wonder that the Turk has seen,
And as before her door he rides
  The Raven-Aga calls her queen!

For three nights has he lain awake—
  To call on Allah? Nay, till dawn
Calling on Danka, for whose sake
  His heart is sore, his brow is wan.

He gathers warriors ere the sun;
  They gallop quickly through the murk;
And Danka, at the signal gun,
  Cries, "Save me, brothers!—'tis the Turk!"

Now flash the rifles, speeds the fight,
  Till, shamed, the Raven-Aga flies.
Alas for Danka! in her sight
  One lion-hearted brother dies.

. . . . . .

Again the infidel appears,
  And at his heels ride forty guns;
But at the voice of Danka's fears
  Red many a Turkish stirrup runs.

But, oh, at vespers, when once more
  The baffled Raven back has fled,
Across the sill of Danka's door
  There lies another brother, dead.

. . . . . .

The Turkish devil once again
  Summons each savage wedding-guest,
And half a hundred to be slain
  Go forth at midnight toward the west.

Once more the stealthy Moslems ride,
  Once more the Servians gather fast,
As Danka summons to her side
  Her brother—and her last.

The fight grows fiercer, till the dead
  Fill the dim street from wall to wall.
Call on thy mother, Battle-wed,
  Thou hast no brother left to call!

The Raven seizes her and croaks:
  "At last thou art my bride, proud maid"
"Not thine—my yataghan's!" Two strong
  Her warm heart weds the loyal blade.

III.

Dark is the night as on the slopes
  Of that deserted battle-ground
The mother, crazed with sorrow, gropes
  Until her sons' three swords are found

And as she roams through Servian lands
  (Her mirth more piteous than her tears
She bears a blade in her thin hands
  To right the wrongs of many years.

And offering Danka's plighted knife
  Or one of those three patriot swords,
She calls the coldest rock to strife,—
  "Take, and repel the Turkish hordes

And as the rock no word replies,
  She asks, "Are you not Servian too?
Why are you silent then?" she cries;
  "Is there no living heart in you?"

She treads the dreary night alone;
There is no echo to her moan. . . .
Is every heart a heart of stone?

FRUITS OF GENIUS WERE SWEPT AWAY.

By a Fire the Noted Electrician, Nicola Tesla, Loses Mechanisms of Inestimable Value.

INVENTIONS IN THE RUINS.

The Workshop Where He Evolved Ideas That Startled Electricians Entirely Destroyed.

YEARS OF LABOR LOST.

Utterly disheartened and broken in spirit, Nicola Tesla, one of the world's greatest electricians, returned to his rooms in the Gerlach yesterday morning and took to his bed. He has not arisen since. He lies there, half sleeping, half waking. He is completely prostrated.

In a single night the fruits of ten years of toil and research were swept away. The web of a thousand wires which at his bidding thrilled with life had been twisted by fire into a tangled skein. Machines, to the perfection of which he gave all that was best of a master mind are now shapeless things, and vessels which contained the results of patient experiment are heaps of pot sherds.

By the fire which swept through the building at Nos. 33 and 35 South Fifth avenue in the early hours of yesterday morning one of the most valuable laboratories in the world was destroyed. It was that of Nicola Tesla, the Servian electrician. In those upper lofts were apparatus and appliances which meant a revolution in electrical science.

There were materials which he could shape to fetter the lightning and to call into action the most subtle of forces. Early and late he toiled there. He was on the eve of making known scientific discoveries which would have added new lustre to his name when all was swept away. He had worked day in and day out, and far into many a night over the work bench and the forge in those upper rooms.

THERE HE HAD TOILED.

Time spent in sleep he considered almost wasted. A man can never injure himself by working too much, was the maxim on which he shaped his life. He drove himself to tasks which would have seemed superhuman to the man of ordinary mind. He evolved theories upon which the power of Niagara was harnessed to work. He constructed mechanisms which converted simple materials into mighty electric currents.

In these lofts, above the dust and rattle of the elevated road and the din of the factory wheel, steam heaters were made. This man discovered principles in physics which have revised many a page in the great book of science.

Nicola Tesla came to this country about ten years ago from Servia. He was twenty-seven years old then, yet his name was already one of the foremost in the world of electrical research.

He was for a time associated with Thomas Edison. He and Mr. Edison parted after a few months and went their separate ways. They were friends, yet rivals.

The young Servian devoted all his best energies to the study of electrical phenomena. In addition to his work as controlling electrician for some of the largest companies using electrical power, he perfected several appliances for the production of electricity.

His discovery, in 1887, of the rotating magnetic field for the economic transmission of power, attracted the attention of the entire scientific world to him. His theory of the production of light by the vibration of the atmosphere, and his proposal to transmit messages without the use of wires, amazed the older scientists.

It was to perfect such theories as these that the young Servian toiled so unremittingly in his South Fifth avenue laboratory. The experiments which he has been carrying on there in the last few months were conducted with secrecy. He would say but little about them beyond the the fact that he hoped soon to solve a vexed electrical problem.

His strength was overtaxed by the strains placed upon it. For weeks those who knew him knew that he was bordering on a state of nervous exhaustion. Yet so firm was his will that few would have suspected how worn he was with toil.

"I am completely worn out," he said the other day to a friend, "yet I cannot stop my work. These experiments are so beautiful, so fascinating, so important, that I can hardly tear myself away from them to eat, and when I try to sleep I think about them constantly. I expect that I shall go on until I break down altogether."

THEN HE SUCCUMBED.

When the fire took away that which sustained him in spite of his exhaustion, the iron will was broken, and Nicola Tesla became as other men, whom work and care have worn.

The man who had, in the course of one of his experiments, withstood, under peculiar conditions, the polyphase currents of electricity to thousands of volts, is lying on his bed, clasping his nerveless hands and speaking no word.

The laboratory where he worked was situated over Gillis & Geoghegan's factory, in South Fifth avenue. The fire was discovered at half-past two o'clock yesterday morning. The building is now four cracked and blackened walls.

Hundreds of workmen were thrown out of employment, and the loss will be many thousands of dollars. It is easy to replace all that. Money will do it. But the loss which Nicola Tesla has sustained gold cannot make good.

The actual amount invested by him there was between $80,000 and $100,000. What he has lost and what the scientific world has lost cannot be estimated that way.

The New York Sun March 14, 1895

INVENTOR TESLA'S LOSS.

HIS LABORATORY AND WORK RUINED BY FIRE.

Gillis & Geoghegan Also Burned Out—The Six-story Building at 33 and 35 South Fifth Avenue Gutted—Years of Labor Gone for the Inventor—He Was Too Much Overcome by His Loss to Talk of It.

By a fire which almost completely gutted the six-story and basement building at 33 and 35 South Fifth avenue early yesterday morning Nicola Tesla, the electrician, lost all of the apparatus with which he has been carrying on his professional experiments. Among the things destroyed were several nearly completed inventions which were intended to revolutionize electric lighting.

Mr. Tesla occupied the entire fourth floor. When the floor gave way his apparatus fell to the second floor where it lies in unrecognizable ruin. It was not insured.

Gillis & Geoghegan, manufacturers of steam fitters' supplies, who occupied the rest of the building, lost their entire stock, valued at $63,000. They are insured for $60,000. The building, which belongs to Mrs. Matilda W. Bruce, was damaged to the extent of $40,000, which is also covered by insurance.

The fire was discovered at 2:30 o'clock. John Mahoney, the watchman employed by Gillis & Geoghegan, had left the office on the ground floor just before that hour to bank the fires in the subcellar, leaving a single gas jet burning. In about ten minutes he returned and found flames running along the floor and up the sides of the partition of the office. Mahoney yelled for a policeman.

Policeman Haggerty ran to the watchman's assistance. Mahoney had closed the office door and was pouring buckets of water on the flames. Seeing that this did no good he told the policeman to turn in an alarm. A moment later he was driven into the street by great tongues of flame which shot up through the floor.

Before Chief Reilly with Engine 33 reached the fire the flames had spread to the first and second floors, and were shooting to the top of the building through the stairways, airshaft, and elevator well. From top to bottom the building was saturated with machine oils, and this ignited with great rapidity. Chief Reilly at once sent in a third alarm. Chief Bonner was soon on the scene with about a dozen engines and trucks.

The Laurens lodging house stands next door at 37 South Fifth avenue. The firemen turned its 150 men occupants into the street and carried their hose to the roof of the building. The occupants of the Italian tenement houses in the vicinity were also turned out of their homes. The firemen fought the flames for fully three hours before they were under control. The Sixth avenue elevated road was blocked in the mean time, the firemen using its structure to work from.

It was not until 8 o'clock that the recall for the engines was sounded. The walls and framework of the building were still standing, but the north side of the structure was so badly cracked that the tenants of the nearest houses were ordered out again for fear that it would fall.

Inventor Tesla, who lives at the Gerlach Hotel, was almost prostrated when he heard the news, shortly before breakfast time. He has been for some time in a state of nervousness bordering on exhaustion because of overwork. He would not at first believe the messenger who brought the news. When convinced of its truth he slammed the door of his room shut and remained buried in thought for an hour. Then he dashed down stairs and went to the scene of the conflagration, where he gazed mournfully up at the fourth floor of the building. Later, in company with a fireman, he went up to the second floor and looked at the ruins of his work. He came out of the building much affected. He paid hardly any attention to the sympathy expressed by his fellow tenants, so absorbed was he in the thought of his loss.

After a light lunch at Delmonico's he retired to his apartments and denied himself to all callers, saying that he felt too bad to see anybody. The clerk would not even send up notes from the many friends of the inventor who called.

Tesla is a Servian. He came to this country ten years ago, and was associated for a short time with Thomas A. Edison. He has received honorary degrees from Yale and Columbia Colleges, and is the controlling electrical engineer to the Niagara Power Company and many other concerns.

Since he has been in the building in South Fifth avenue he has worked with about a dozen assistants in a very secretive manner. It was understood that he was working on inventions intended to save much of the energy now lost in electric lighting. It is well known to electricians that about 90 per cent. of the energy used to produce incandescent lights now goes to waste, and he has said that he hopes to save one-third of the loss.

The New York Sun March 14, 1895

The destruction of NIKOLA TESLA'S workshop, with its wonderful contents, is something more than a private calamity. It is a misfortune to the whole world. It is not in any degree an exaggeration to say that the men living at this time who are more important to the human race than this young gentleman, can be counted on the fingers of one hand; perhaps on the thumb of one hand.

MR. TESLA'S GREAT LOSS

All of the Electrician's Valuable Instruments Burned.

WORK OF HALF A LIFETIME GONE

Firemen Unable to Save His Laboratory in South Fifth Avenue—He Loses $50,000; Gillis & Geoghegan $80,000.

"I am in too much grief to talk. What can I say? The work of half my lifetime, very nearly; all my mechanical instruments and scientific apparatus, that it has taken years to perfect, swept away in a fire that lasted only an hour or two. How can I estimate the loss in mere dollars and cents? Everything is gone. I must begin over again."

That is all that Nikola Tesla, the renowned electrician, had to say about a fire that utterly wiped out his laboratory at 35 South Fifth Avenue yesterday and destroyed instruments on which he has made experiments in advanced electricity that have astonished the world. Tears were in his eyes when he spoke.



Nikola Tesla,
Whose Electric Works Were Burned Yesterday.

Ever since Mr. Tesla came to this country from Servia, about ten years ago and became for a time associated with Mr. Edison in his laboratory, at Menlo Park, N. J., his experiments have been watched with increasing solicitude by almost everybody interested in the progress of electrical science. He has attracted almost as much attention as "Wizard" Edison himself. The two men are scarcely rivals, for they conducted their investigations on substantially different lines. Personally, they are warm friends. Mr. Tesla never cared to talk much about his work. Few people knew what was going on in the rooms that were destroyed by fire yesterday. About fifteen men were at work there nearly every day, experimenting under Tesla's personal direction. He worked as hard as his men did. He had a little office with a roll-top desk and a rug but he seldom went near it except to talk to visitors. Most of his workaday hours were spent bustling about in his shirt sleeves among his instruments.

Outside of his shop he is something of a Sybarite. He dines at Delmonico's almost invariably, and lounges about the café during the evening. Habitués of the place know him well. He is very tall and very thin. His dark eyes are perhaps his most noticeable feature. They are large and brilliant, showing with the zeal of an enthusiast.

Lectures given by Mr. Tesla from time to time give the best idea of his hopes and aims. Of course, he does a great deal of practical work all the time, aside from his experiments. He is controlling engineer of the Niagara Power Company and consulting engineer to other corporations interested in electrical supply. But his experiments took up most of his time. One thing that Mr. Tesla was striving to accomplish was to prevent the enormous waste of force in the manufacture of electricity. He has contended that about 99 per cent. of the energy now goes to waste. His experiments have been devoted to saving at least one-third of the energy, which would make it possible to obtain a much greater illumination than can be procured at present, and at a great decrease in cost.

"The ideal way of lighting a room would be," he said in one of his lectures before a scientific society two years ago, "to produce such a condition in it that an illuminating device could be moved and put anywhere, and that it should be lighted no matter where put, without being electrically connected with anything."

Mr. Tesla has demonstrated in his experiments that the polyphase currents of high potency, even to 250,000 volts, have no hurtful effect on the human body. He allowed that number of volts to pass through his own body without harm. Through his discovery of the means of transmitting electricity without a wire, Mr. Tesla expected to produce a light as powerful as sunshine as soon as he had discovered how to care safely for the 8,000,000 volts necessary for the purpose.

Gillis & Geoghegan, manufacturers of steamfitters' supplies, occupied the lower floors of the building in which Mr. Tesla had his laboratory. Night Watchman Mahoney was employed to look after the building. He said that he was making his rounds as usual just before 3 o'clock yesterday morning when he discovered the fire. It had started on the ground floor, but from precisely what cause is not known. He tried in vain to put it out with pails of water.

The building was saturated with oils necessary in the manufacture of fittings, and it burned like a tinder-box. Before a line of hose could be put down it was evident that the place was doomed. Chief Bonner and his men could make little headway against the terrific heat. It was so intense that at one time the elevated railway structure caught fire. There was a box factory next door, filled with inflammable material, and every endeavor was made to keep that from going, too. It took three hours to get the flames under control. There are so many ramshackle buildings in that locality that if the box factory had once caught fire there is no telling where the fire would have ended.

Mr. Tesla's employes were dismayed when they appeared on the scene for work in the morning and found their occupation gone. Not one of them had the courage to go and tell their employer of his terrible loss. He appeared, as usual, about 10 o'clock, and found it out for himself. At first he was simply dazed.

"It cannot be true!" he exclaimed, pacing up and down before the ruins in hopeless despair. He told a fireman that he had no insurance, and that, so far as he knew, the money loss would probably represent $50,000. The loss to the building itself is estimated at $25,000, and the loss to Gillis & Geoghegan is estimated at $80,000. This is covered by insurance.

Mr. Tesla's Works Destroyed by Fire.—A Reuter's telegram, reproduced in yesterday's *Western Mail*, states that Mr. Tesla's works have been destroyed by fire. The whole of his extensive plant, and all his specially-designed apparatus for conducting experiments were destroyed. The damage is estimated at $100,000, but the greatest loss is the physical collapse of the inventor from the shock caused by the disaster.

TESLA AGAIN AT WORK.

He Says that a Million Dollars Would Not Pay for What Was Burned.

Nikola Tesla, the electrician, whose workrooms and apparatus were destroyed by fire on Wednesday morning, was at work again yesterday. Although not yet recovered from the shock occasioned by his loss, he spent several hours in drawing up the plans of a new invention. When seen at his apartment in the Gerlach Hotel Mr. Tesla was walking nervously up and down his room, dictating to a typewriter.

"Yes, I am at work again," said he, in reply to the reporter's question. "I have already begun work on a new set of plans. I shall now be obliged to work doubly hard to make up for the most unfortunate loss I have sustained."

When asked if he could give an estimate of his loss, Mr. Tesla said:

"No, that would be very difficult. In a case like this the loss cannot be estimated in dollars and cents. If it could be, I might say that a million of dollars would not pay for what has been destroyed."

"But you will doubtless be able to replace everything in time," said the reporter.

"I don't know," replied the inventor wearily. "Some things can never be replaced. A painter may have commenced a masterpiece which is destroyed while in process of completion. In that case the painter may begin all over again, inspired by his misfortune, as is sometimes the case. Nerved up by his loss, he may produce another masterpiece which will make him famous.

"In the case of an inventor it is different. When, at one blow, all his apparatus, his machinery, the work of months of careful study, are swept away, it is no easy matter to replace the loss. As I said before, I can give no estimate of my loss as most persons would reckon it. A man may spend $100,000 in fitting out a laboratory, which another man would not give $10,000 for. Some of my models," he continued, "were boxed up ready for shipment. There were a few which had already been sent away. The larger part of my work, however, was a total loss. I did not insure it, as no insurance could cover its true value."

Mr. Tesla said that his electrical apparatus, with which he hoped to improve the electric light had been destroyed with the rest. There were also other half-completed inventions of which he did not care to speak.

"All my friends have been very kind to me," said he. "I have received a letter from Mr. Edison offering me the use of his workshops in which to continue my experiments. He has shown me the greatest kindness and consideration. I do not think, however, that I will accept the offer. I shall probably within a short time secure other quarters in the city and begin my work anew. I have not as yet recovered sufficiently from the shock of my loss to make any definite plans.

"One thing in particular has cheered me up a good deal. It was the kind editorial which appeared about me in this morning's SUN. I am deeply grateful."

It is estimated that Mr. Tesla's loss, aside from the contingent damage, will amount to between $80,000 and $100,000, as much valuable apparatus and complicated machinery were destroyed.

THE destruction of Mr. Tesla's laboratory by a fire due to the carelessness of a lazy or stupid watchman is a very serious loss to the inventor and to the world; but it takes more than a fire to set back an inventor of such dauntless courage and such indefatigable originality.

DESTRUCTION OF THE TESLA LABORATORY BY FIRE.

By a fire which almost completely gutted the six-story and basement building at 33 and 35 South Fifth avenue, this city, on March 13, Mr. Nikola Tesla, the electrician, lost all of the apparatus with which he has been carrying on his professional experiments. He occupied the entire fourth floor. When the floor gave way his apparatus fell to the second story where it lay in unrecognizable ruin. It was not insured.

Gillis & Geoghegan, manufacturers of steam fitters' supplies, occupied the rest of the building. The fire was discovered at 2:30 a. m. John Mahoney, the watchman employed by Gillis & Geoghegan, had, he says, left the office on the ground floor just before that hour to bank the fires in the subcellar, leaving a single gas jet burning. In about ten minutes he returned and found flames running along the floor and up the sides of the partition of the office. Mahoney yelled for a policeman. Policeman Haggerty ran to the watchman's assistance. Mahoney had closed the office door and was pouring buckets of water on the flames. Seeing that this did no good he told the policeman to turn in an alarm. A moment later he was driven into the street by great tongues of flames which shot up from the floor.

Before Chief Reilly with Engine 33 reached the fire the flames had spread to the first and second floors, and were shooting to the top of the building through the stairways, airshaft and elevator well. From top to bottom the building was saturated with machine oils, used in cutting steam pipe, and this ignited with great rapidity. The firemen fought the flames for fully three hours before they were under control. The Sixth avenue elevated road was blocked in the mean time, the firemen using its structure to work from. It was not until 8 o'clock that the recall for the engines was sounded. The walls and framework of the building were still standing, but the north side of the structure was so badly cracked that the tenants of the nearest houses were ordered out again for fear that it would fall.

Mr. Tesla was at first very much affected by the news of his loss, but sustained the blow stoically, and within 6 hours was busily engaged making and giving out designs for the reconstruction of his latest type of oscillator, which has now been running successfully for some time past, lighting the laboratory and supplying current for a number of new and novel experiments. It is needless to add that Mr. Tesla has received innumerable expressions of sympathy and regret not only from friends and acquaintances but from total strangers.

TESLA'S LABORATORY BURNED.

THE DISTINGUISHED INVENTOR'S HEAVY LOSS BY FIRE OF APPARATUS AND RECORDS.

By a fire which almost completely destroyed the six-story and basement building at 33 and 35 South Fifth avenue, New York city, March 13, Nikola Tesla, the electrician, lost all of the apparatus with which he has been carrying on his professional experiments. Mr. Tesla occupied the entire fourth floor. When the floor gave way his apparatus fell to the second floor, where it remained in an unrecognizable ruin. It was not insured.

Mr. Tesla was naturally considerably affected by this sudden and most disastrous loss, but with true grit at once began preparations to resume his work elsewhere. In an interview he says :

I am congratulating myself all the time it is no worse. I begin all over again, but I have the knowledge and experience of what has gone before, and fortunately I was able to show with completed apparatus that my ideas and theories are correct. Had the fire occurred a few months ago, I should have been robbed of the opportunity of many highly successful demonstrations. Take my oscillator, for example, that combines the steam engine and dynamo. Last Fall, for example, I had there a gathering of medical and other professional men—perhaps 200—and they all saw the machine running, lighting up my laboratory with plenty of lights and furnishing current for a series of novel experiments. The machine is gone. But suppose the fire had happened before that or before others had seen it running? My statements about it would not have been half so convincing. Everything is destroyed—practically all—although, of course, where some of it has passed into commercial operation the interest in that part was of an historic and personal nature. I had a cabinet containing many of the earlier inventions, over which I have brooded and worked days and nights. To-day the ideas there embodied are utilized in the big 5,000 horse-power generators at Niagara and in kindred motors in a great many parts of the world ; but I prized the old models and trial apparatus, and would not have taken any money for them. Some of them were shown in the Electricity building at the World's Fair, where also some of the new principles I have discovered were illustrated by operative devices. These devices I had in my laboratory, and they have gone down in the wreck, too. Moreover, I had there some records, books and papers, such as every industrious experimenter is likely to get around him in time, and they have vanished. Happily, a good deal of my work has appeared in book form now, or in the technical journals, and that much is secure. The rest, he added, with just a little note of sadness in his voice, I shall try to jot down as soon as I can get time from more pressing matters. You know an inventor while making experiments often gets a few spare minutes between whiles, and I had been employing some of these spells lately in getting my data in better order. Part of that work has gone also.

I was engaged on four main lines of work and investigation. One of these was the oscillator, which I cannot but regard as a practically perfected machine, but which, of course, suggests many new lines of thought every day. Another was improved methods of electric lighting. Another was the transmission of intelligence any distance without wires. A fourth, which is an ever present problem for every thinking electrician, touches the nature of electricity. Each of these questions and many others I shall follow up, and somehow I cannot help feeling that this disaster will sharpen my intuition as to the best lines of work, so that good will come out of evil. With so much on my mind and hands I need not excuse myself for being brief with you. I have been overwhelmed with generosity and sympathy this week, and feel the kindness deeply, even if I can make no response. But I must carve my way through or over the mountain suddenly planted in front of me, and so you see me preoccupied. I am glad to add to-day that by last reports from the scene of the fire some of the debris is in better shape than I dared hope, and I may yet see some valuable salvage. But my men are meantime busy as though none of the old were left.

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NIKOLA TESLA.

Tesla's loss by fire, while a serious one, has not prostrated the talented inventor, as the accounts in the daily press imply. Instead he goes to work with renewed vigor, replying to a friend, who suggested that he take a long rest before starting in again, that "I might have followed your advice and taken a rest if this had not occurred, but now I feel that it is about time to stop idling." Tesla never was an idler, and if he works any harder now than before, he will have to find the way to live without stopping to eat or sleep. The kindly tone of the great dailies in speaking of the young inventor's loss is particularly noticeable. We do not remember ever having seen a higher compliment paid anyone than the following from the *Sun* of this city, evidently by Mr. Chas. A. Dana:

> The destruction of Nikola Tesla's workshop, with its wonderful contents, is something more than a private calamity. It is a misfortune to the whole world. It is not in any degree an exaggeration to say that the men living at this time who are more important to the human race than this young gentleman can be counted on the fingers of one hand; perhaps on the thumb of one hand.

The ELECTRICAL REVIEW extends to Mr. Tesla its regrets over his most exasperating loss, but with everyone else interested in scientific progress is glad to note his resolution to at once take up his work so near completion. May health and strength and greater success and honor be his!

PUBLIC OPINION

A WEEKLY JOURNAL

Volume XVIII, Number 12 Thursday, 21 March, 1895

***The aim of this journal is to reflect public opinion. The utmost care is taken to treat each question upon which extracts are given in a perfectly fair, non-partisan and unbiased manner. The editors do not assume to determine the politics of any paper quoted, the political credits being taken from the publishers' own statements.

***Unless otherwise indicated, the condensed extracts printed in these columns are not rewritten, but are in the language of the original article.



The destruction of Nicola Tesla's electrical workshop in New York City is commented upon as a loss that distinctly sets back the hand upon the dial of progress in electrical discovery and invention, both theoretical and practical. It is hoped, however, that the lost apparatus may be replaced in the course of time, and that Mr. Tesla's genius and energy may yet produce the results delayed by this calamity.

Nicola Tesla's Loss

Baltimore *Herald*

A disposition prevails to view the destruction of Nicola Tesla's electrical laboratory in New York as a great calamity. The wizard himself is described as being very much cast down over the loss, which involves the fruits of a lifetime of labor, and particularly so because he thought he was on the eve of making discoveries which would have revolutionized electrical science. It is stated that delicate instruments and much intricate apparatus were ruined which could not be replaced. There seems to be no reason, however, for taking such a gloomy view, nor for viewing the loss incurred as irreparable. Mr. Tesla's capacity for technical research remains undiminished. He was said to be on the eve of mental breakdown previous to the fire on account of incessant pursuit of his experiments. By the time he fits up a new workshop he will have had an opportunity to recuperate, and can go to work with new strength. It ought not to be so very difficult, at least not impossible, to replace the apparatus. The brain that created it should be able to construct it anew. To Mr. Tesla the world already owes some wonderful inventions, and latterly he was pursuing a course of investigation which promised still more startling results. Transmission of electrical power over long distances, telegraphing without wires, light without heat, utilization of electricity for heating purposes, to the exclusion of coal, were some of the problems which engaged his attention. Several had already reached a partial solution, and it remained only to make them practical. A loss infinitely greater than the destruction of the workshop would have been the failure of the workman. As it is, we can afford to wait until the damage has been repaired.

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NOTES.

We are glad to learn by special cablegram that the somewhat sensational Reuter's despatch, which came to hand last week, announcing not only the burning out of Mr. Nikola Tesla's laboratory, but his mental collapse, was inaccurate in several respects. A fire began, it seems, early on Wednesday morning, the 13th inst., in the office of a steam-fitting concern situated on the ground-floor of the building in which Mr. Tesla carries on his work. The watchman reports that the mischief was started by a gas flame. Mr. Tesla's laboratory, on the fourth floor, was almost entirely destroyed. The contents included the whole of his polyphase models, most of his papers, the records of his experiments, the apparatus exhibited at Chicago, his original and latest form of oscillator, and all the apparatus with which he performed so many striking experiments when in London. None of the property was insured. Mr. Tesla, instead of being in a state of collapse as alleged, actively recommenced, on the very day of the fire, the building of a new oscillator. It is unnecessary to add that great sympathy has been expressed for this enthusiastic experimenter in the land of his adoption; an expression of feeling which we feel sure will find an echo in this country where he has made so many friends.

Tesla's Laboratory Destroyed.

A fire in the building at 35 South Fifth avenue on the morning of March 13 utterly destroyed the laboratory of Nikola Tesla, which occupied the two upper floors. The destruction was most complete, nothing having been saved from the wreck. Mr. Tesla had occupied this laboratory for several years and in it were gathered all of the results of his labors for years in many lines of work, notably in the utilization of electrical currents of high frequency and voltage. All of the magnificent apparatus which he used to illustrate his lectures on high frequency effects was destroyed, with the latest forms of his new type of dynamo, which was approaching commercial completion, besides scores of pieces of experimental apparatus employed by Mr. Tesla in researches, extending to every department of electrical science.

INVENTOR TESLA'S LOSS.

By a fire which occurred at 33 and 35 South Fifth Avenue, New York City, on the morning of March 13, Nikola Tesla, the inventor and scientist, sustained a severe loss in the total destruction of his laboratory, in which were several nearly completed inventions which, it is said, were intended to revolutionize electric lighting. The loss cannot unfortunately be reckoned in dollars, and it is feared may seriously affect Mr. Tesla's health, as for some time he has been in a state of nervousness bordering on exhaustion, on account of overwork occasioned by the approach to completion of some of his great inventions.

Dr. Tesla was for a time associated with Edison. The attention of the scientific world first centered upon Tesla in 1887 through his invention of the rotating magnetic field for the economic transmission of power. It is believed that Mr. Tesla's experiments were made with a view to saving at least one-third of the energy now wasted in electric lighting. He has been working in his laboratory with a number of assistants, and the results which he has actually obtained have been kept a profound secret. Mr. Tesla has lectured before scientific bodies, both in Europe and America, and he has recently received honorary degrees from Yale and Columbia Colleges. He is at present controlling electrical engineer of the Niagara Falls Power Company. Some of Mr. Tesla's remarkable experiments have been reproduced lately in Berlin. The Illustrirte Zeitung of recent date gives an engraving, which we copy, together with the following account:

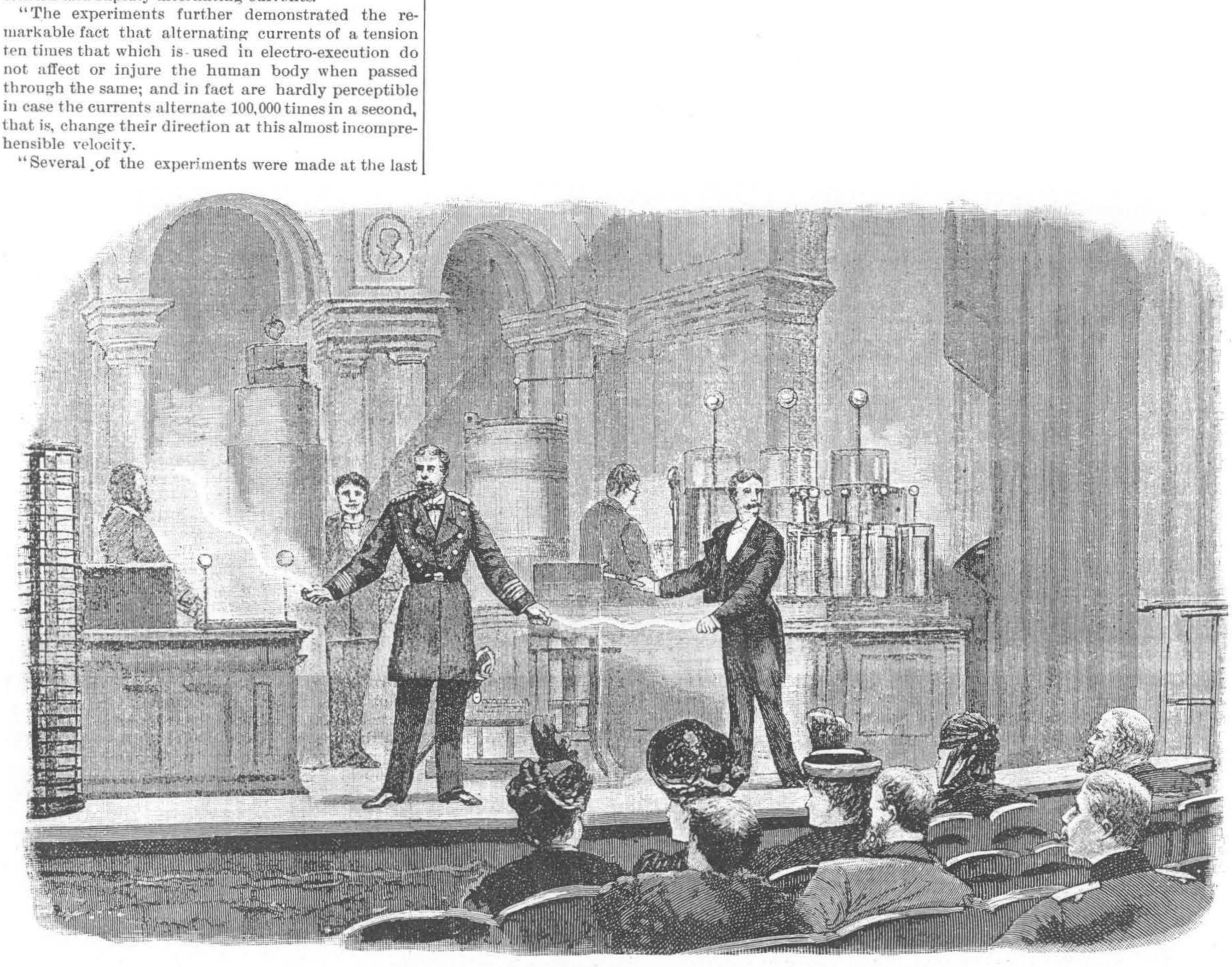
'About twenty years have passed since Edison produced the incandescent lamps under the proud name of the 'light of the future,' and which lamps slightly modified are now the 'light of to-day.'

"A new 'light of the future,' is again promised from the United States, and should it materialize in practical form will have the great advantage over the incandescent and arc lamps that for its production no conducting wires are required, and which for this reason alone would be sufficient to produce a complete revolution in the electrical world.

"Nikola Tesla, the inventor of the new light, obtained by his experiments surprising results. In following up certain discoveries of Prof. Herz, of Bonn, relative to electrical waves, he succeeded in lighting a freely suspended incandescent lamp by the use of high tension and rapidly alternating currents.

"The experiments further demonstrated the remarkable fact that alternating currents of a tension ten times that which is used in electro-execution do not affect or injure the human body when passed through the same; and in fact are hardly perceptible in case the currents alternate 100,000 times in a second, that is, change their direction at this almost incomprehensible velocity.

"Several of the experiments were made at the last annual meeting of scientists in Vienna, but through Prof. Spies, one of the members of the Berlin 'Urania,' the experiments were made publicly, and were attended by the German Emperor's brother, Prince Henry, who, as the cut shows, served as a conductor for the high voltage currents. By reference to the illustration, it will be seen that the connection between two persons is made by Geissler tubes, which show the light produced by the currents. In another experiment a number of connected wires were arranged in the auditorium and connected with the electric current, whereby an electrical wave was produced in the room, and noticed by some of the audience through the lighting of Geissler tubes held in their hands, and without these persons being in direct connection with the wires."



RECENT TESLA EXPERIMENTS IN BERLIN.

Various Topics

New York Sun: The destruction of Nikola Tesla's workshop, with its wonderful contents, is something more than a private calamity. It is a misfortune to the whole world. It is not in any degree an exaggeration to say that the men living at this time who are more important to the human race than this young gentleman can be counted on the fingers of one hand; perhaps on the thumb of one hand.

NIKOLA TESLA.

His Discoveries in Electricity.

In a brief but pregnant comment on the destruction by fire of the workshop of Nikola Tesla, the New York "Sun" remarked: "It is not in any degree an exaggeration to say that the men living at this time who are more important to the human race than this young gentlemen can be counted on the fingers of one hand; perhaps on the thumb of one hand." There is perhaps no man now writing for newspapers whose culture is so many-sided and whose accomplishments range over so wide a field of human effort as those of the editor of the "Sun." The brevet rank of immortality conferred by an authority so competent challenges attention to the work of the man whom he deems worthy of placing on the pinnacle of fame. Reference to the practical aspect of that work has been made from time to time in these columns. But public curiosity about it has only begun to demand some intelligible exposition of its scope and purpose. Even among electricians it is but imperfectly understood, and there are the most widely divergent opinions as to its character and significance.

It is about ten to one that the mention of the name of Nikola Tesla in a company of ordinary intelligence will merely elicit the inquiry, "What has he done?" This question Mr. Thomas Commerford Martin essays to answer in the April number of the "Century," and brings to the task a felicity and accuracy of expository method well calculated to adorn and illumine the subject. Mr. Martin's richly illustrated and carefully digested study of Tesla will render it somewhat easier to put in popular language a reply to the popular question, but it suggests also the conclusion that for some time to come the greatest electrician of our time must continue to be an enigma to those whose only intelligible measure of achievement is that of tangible results and commercial valuation. The more distant an object is from the eye the more difficult is it to realize the rapidity of its movement, and the researches of Tesla are so far removed beyond the ken of most of us that we may watch him with a sensation such as that with which we regard bodies moving with prodigious velocity through interstellar pace, but whose apparent position remains unchanged.

Two years ago Mr. Tesla publicly declared that he was becoming daily more convinced of the practicability of transmitting intelligible signals or perhaps even power to any distance without the use of wires. He had already demonstrated that electric vibration might be transmitted through a single conductor, that is, that there was no necessity to employ a wire as a conductor of the return current. But if the earth may serve for one purpose, why not for both? Treating the earth in common with the air simply as a conductor of electrical vibration, and remembering the tremendous rapidity with which an electric disturbance may be propagated through the earth, there is nothing visionary in the claim that alternating currents might be passed through it from one source of electrical energy to another. The pendulous swing of the wave-like action of electricity might, in short, be indefinitely diffused by a series of sources of alternating currents working in perfect synchronism, that is, giving out electric energy of precisely the same period of vibration. This would be like moving a pendulum over a given arc of space by the application at either side of exactly the force needed to send it to the end of its swing on the other.

But if the earth, in addition to being a conductor of electricity, has itself a fixed electric charge, the possibility of using it as a vehicle for the transmission of electric energy becomes much more impressive and brilliant. For, as electricity behaves like an incompressible but elastic fluid, the slightest pressure applied to it at one point must be felt at all other points over which it is diffused. But pressure cannot be applied to the subtle and occult form of energy which we call electricity except by a similar phase of the same force. In other words, if the earth be an electrically charged body insulated in space, its charge can be disturbed only by an oppositely electrified system or known circuit whose period of vibration corresponds in some way with that of the charge of the earth. It is not enough to pump electricity into the earth to excite a reflex action in the electricity already there. The period of vibration of the energy pumped in must in certain essential respects correspond to the period of that with which the earth is charged to send the latter oscillating so as to produce in some perceptible degree what the electricians call "resonance."

This is the work to which Mr. Tesla has given most of the last few years of his life. The elusive difficulty of the task can be but imperfectly conceived even by those who know something of the scientific conditions of the problem. If the earth were a great tuning fork which would vibrate in unison with but one unknown note, it would be a comparatively simple problem to run up and down the gamut of tone to discover the precise combination of sound waves to which the globe would thrill in responsive music. But the gamut of electric vibration is so vast, and in the range of its period from low to high there is such an infinite series of combinations, that the attempt to find what may be called the fundamental note of the cosmic charge of electricity sounds like the effort of a dreamer. It has, nevertheless, been conducted in a very practical way, and has already begun to yield some highly practical results. If the true note has not yet been struck, some notes to which it is partially responsive have been. The electrical charge of the earth is no longer an inert force to human touch; under the wonder-working hands of Tesla it has moved and stirred, and in the purple streamers of lambent lightning which leaped at its impulse from the apex of the return wire in the now vanished laboratory there was the promise of such achievement as will cast into the shade all that science has yet accomplished for man.

Tesla is deeply impressed with the idea that all that man has yet done toward bending the forces of nature to his service is but feeble and tentative compared with what there is left for him to do. To have two electrical instruments move in unison though unconnected by wires and divided by half the globe, seems a marvellous not to say incredible achievement. But a much more marvellous thing than that is witnessed when simultaneously with the appearance of a white spot on the face of the sun there ensues a general disturbance of magnetic needles, and telegraphy is greatly interrupted by "earth currents" on this little globe of whose distances we make so much. If distance is an element in the problem, telegraphy without wires across an interval of ninety-two millions of miles must surely be less conceivable than a similar process over a distance of six thousand miles. To say that we cannot reduplicate the gigantic forces of nature is to beg the whole question, for all the scientific achievements of men have been merely the subjugation of the forces of nature to their service. An ordinary flame gives light and heat no less than the sun, and the light produced by both is equally the result of vibrations so inconceivably rapid that the force which they represent would, mechanically measured, be equivalent to a pressure of thousands of tons per square inch. Man can liberate by the simplest effort forces truly gigantic, but he is only beginning to learn how to employ them. Above all, he is only beginning to discover that his empire over nature is to be found in the co-ordination of forces in nature's own way.

It is in this direction that it will be reckoned the crowning glory of Tesla to have led his generation. A bolder or more original inquirer science has never numbered among her votaries; a man combining in a higher degree the patience of the investigator, the modesty of the student and the intuitive perception of genius the world has not seen. What other men have regarded as the limit of human attainment has been to him merely the beginning of a new domain of scientific conquest. Since he startled the electrical world with the principle of the rotating magnetic field his advance has been swift, continuous, irresistible. The world at large will better appreciate this when a scientific tool of his—the oscillator—invented in response to the necessity of producing electric vibrations of absolute constancy, becomes a commercial factor in cheapening by one-half the cost of light and increasing fourfold the effective energy of steam. But the interpretation of the secrets of nature which is destined to make his name immortal, will go on consuming years of a life dominated by an intensity of effort beyond that of which most men are capable, and people may go on asking, "what has he done?" forgetful how long may be the journey of one who has set his goal beyond the limit of achievement dreamed of by the most daring and farsighted of his contemporaries.

JOHN FOORD.

—*The Century* builded better than it knew when it engaged an article by T. C. Martin, editor of *The Electrical Engineer*, on "Tesla's Oscillator and Other Inventions," which will appear in its April number. Since this article was written, Mr. Tesla's laboratory, with all its contents, including machinery and records, was destroyed by fire, leaving the text and illustrations of Mr. Martin's paper absolutely the only record of some of the inventor's most important discoveries. Not the least interesting parts of this article are the reproductions of the first photographs taken by phosphorescent light, being portraits of Mark Twain, Joseph Jefferson and Marion Crawford.

[FROM THE OUTLOOK.]

NIKOLA TESLA AND THE ELECTRIC LIGHT OF THE FUTURE.

By WALTER T. STEPHENSON.

EXACTLY ten years ago Nikola Tesla, who, in June, 1894, received high honorary degrees from the colleges of Yale and Columbia, came to this country, poor and unknown, to enter an Edison shop in New York City. For two years previous he had served as engineer in one of the new electric lighting companies in Paris, and, having become an ardent and appreciative admirer of the splendid genius of Thomas A. Edison, whose fame in those days had only recently flashed throughout Europe, he was, naturally, eager to accept an opportunity of meeting the "wizard" face to face.

Tesla had already patented several minor inventions of his own, but, what was of more importance, his brain was then literally teeming with great ideas, as yet, perhaps, chaotic, but which must some day evolve into definite shape for revelation, and of all countries he firmly believed the United States offered the best encouragement to the inventor who could show practical results. Since New York has continued to be Mr. Tesla's home, we may reasonably infer that he has not been disappointed in his early expectations.

The young Servian electrician derived a fresh stimulus and lasting benefit from his association with Thomas A. Edison. Nevertheless, he soon realized that it would be far wiser for him to continue his special investigations alone, unhampered by other work. Therefore, after a few months of delightful intimacy, the two men of genius separated with mutual expressions of good will.

Mr. Tesla now threw himself with redoubled ardor and energy into the study and analysis of alternating or polyphase currents, which had long been his chosen field of electrical investigation. In 1887 he exploited his wonderful invention of the rotating magnetic field for the economic transmission of power. This simple statement means that, after thirteen years of indomitable effort, embittered by sore disappointments and fierce controversies, a substantial success was at last assured, while scientists everywhere began now to await with keenest interest succeeding developments of the potentialities undoubtedly latent in these hitherto neglected alternating currents.

The majority of us probably are aware that the principal electricians of the world have long been struggling vainly toward the solution of a tremendous problem—the improvement of the electric light. When we are told, for one thing, that fully ninety-nine per cent. of energy is wasted every time such artificial illumination is produced under existing conditions, we begin to realize the crying need there is for a radical change in industrial methods. Now, the goal which some electricians declare to be already in sight means nothing less than the recovery of fully one-third of this wasted energy, thereby rendering possible an illumination many times brighter than at present and at a notable reduction of expense. The question is, Which one of the few leaders in the race will outstrip the others and win an immortal name?

Rumors have reached the public ear with increasing frequency of late that Nikola Tesla was working slowly but surely in his own way toward the accomplishment of some such magnificent end.

We know that in May, 1891, Mr. Tesla emerged from the seclusion of his laboratory to deliver an address before the American Institute of Electrical Engineers, at Columbia College, on polyphase currents as applied to artificial illumination. Having in this lecture created a marked impression by the lucid exposition of his peculiar theories, he was soon urged by some of the prominent scientists of Europe to favor them in like manner. So it was that in February, 1892, he crossed the ocean and lectured before numerous audiences in England and on the Continent. It is not too much to say that the name of Nikola Tesla now commanded universal attention in the world of science, but still the man himself was beginning to chafe sadly already under his prolonged absence from the distant laboratory. In the fall of 1892, therefore, he gladly returned to New York to resume his interrupted labors in behalf of science.

In view of all this, even the hardiest of interviewers would be apt to think twice before intruding upon such an individual in his privacy. It will be enough, perhaps, for me to say that the forbearance and kindliness of Nikola Tesla are by no means his least distinguishing traits. Not very far from Washington Square, in the heart of that picturesque neighborhood known as the French quarter, teeming with cheap restaurants, wine shops, and weather-beaten tenements, the observant passer-by will notice a huge yellowish brick building of some half-dozen stories apparently devoted to manufacturing purposes.

If such a one should undertake to explore the murky interior of this uninviting looking pile, say to the extent of climbing three or four flights of stairs, and warily threading a signless path through successive mazes of vociferous machinery, his perserverance might be rewarded, as in my own case, by discovering the retreat of a modern wizard. While awaiting my opportunity in an anteroom, I caugh glimpses through the adjoining office and library of the mystic laboratory itself, which, as I ascertained later, opened into an immense machine room.

I may candidly state that I was a trifle shocked the first time I saw Nikola Tesla as he suddenly appeared before me in the library and sank into a chair seemingly in a state of utter dejection. Tall, straight, gaunt, and sinewy of frame like a true Slav, with clear blue eyes and small, mobile mouth fringed with a boyish mustache, he looked younger than his thirty-seven years. But what arrested my attention chiefly at the moment was the pallid, drawn and haggard appearance of the face. While scanning it closely I plainly read a tale of overwork and of tremendous mental strain that must soon reach the limits of human endurance.

"I would like to talk with you, my dear sir," he said, "but I feel far from well to-day. I am completely worn out, in fact, and yet I cannot stop my work. These experiments of mine are so important, so beautiful, so fascinating, that I can hardly tear myself away from them to eat, and when I try to sleep I think about them constantly. I expect I shall go on until I break down altogether. So you would really like to see some of my experiments in electric lighting," he added. "I shall endeavor to accommodate you, my friend, if you will come with me into the laboratory. Be prepared, though, for a surprise or two."

Mr. Tesla then ushered me into a room some twenty-five feet square, lighted on one side by two broad windows, partially covered by heavy black curtains. Directly opposite was an open door leading into the machine room, which seemed to be fairly alive with grimy figures flitting to and fro. The whole scene, to my unaccustomed eyes, suggested a veritable magician's den.

The laboratory was literally filled with curious mechanical appliances of every description. Wires innumerable, from the smallest size to cables three-quarters of an inch thick, ran along the walls, ceiling, and even the floor. In the center was what appeared to be a large circular table covered with thick strips of black woolen cloth; snakelike cables running up underneath were connected at the other end with an adjacent dynamo, thereby establishing a possible center of electro-dynamic vibration. Between the table and the windows two large brownish globes, eighteen inches in diameter, depended from the ceiling by cords. These balls were composed of brass, coated with two inches of wax to render them non-injurious, and served the purpose of spreading the electrostatic field.

So much for my surroundings, as I glanced about in some bewilderment after hearing Mr. Tesla say that he had a surprise in store for me. Promptly suiting the action to the word, he called in several employes from the workshop and issued a succession of hurried orders which I followed but vaguely. Presently, however, the doors were shut and the curtains closely drawn until every chink or crevice for the admission of light was concealed and the laboratory bathed in absolutely impenetrable gloom. I awaited developments with intense interest.

The next minute exquisitely beautiful luminous signs and devices of mystic origin began to flash about me with startling frequency. Sometimes they seemed iridescent, while again a dazzling white light prevailed.

"Take hold," said a voice, and I felt a sort of handle thrust into my hand. Then I was gently led forward and told to wave it. On complying, I spelled the word "Welcome" flaming before my eyes. Unfortunately, I was totally unable at the time to appreciate the kindly sentiment implied.

A hand approached mine ere I had quite recovered, and I felt the tips of my fingers lightly brushed. Fancy my dire dismay when I immediately experienced an acute tingling sensation, accompanied by a brief pyrotechnic display that was surprising, to say the least. When the daylight, as well as my equanimity, was in a measure restored, I learned something of the meaning of these wondrous experiments, which may be said to foreshadow in a way the electric light of the future. What impressed me most of all, perhaps, was the simple but cheerful fact that I remained unscathed while

electrical bombardments were taking place on every side. Curiously enough, the polyphase currents of high frequency and high potential, of say 200,000 volts, have, as Mr. Tesla has demonstrated repeatedly on the platform, no harmful effect whatever on the human body, although a like energy exerted in indirect currents would prove instantaneously fatal.

Over two and a half years ago Mr Tesla made this striking observation in one of his lectures: "The ideal way of lighting a hall or room would, however, be to produce such a condition in it that an illuminating device could be moved and put anywhere, and that it should be lighted no matter where it is put, and without being electrically connected to anything."

To return to my own experience in the darkened laboratory, it seems that the entire room was actually filled with electric vibrations through the agency of these same currents, styled alternating (that is, with direction perpetually changing). The strange devices I had seen were nothing more than nearly exhausted glass tubes bent into various shapes and analogous to lamps, excepting that they were devoid of filament or button.

These tubes being carried into the area where the electrical agitation was strongest, the remaining molecules of ether or air within all the while pressing against the crystal confines, a molecular bombardment followed, produced by the collision of two forces, and the bulbs simultaneously became luminous. Those which were made to glow with the colors of the rainbow were coated on the inside with phosphorescent substances.

I have attempted nothing more than a very imperfect outline of Mr. Tesla's novel and interesting scheme, which is to be regarded as still in a state of embryo. It cannot be denied too, that there are many scientists to-day who shake their heads dubiously at the brilliant Servian's unequivocal attitude toward the electric light.

Meanwhile Mr. Tesla makes no boasts, but is willing to abide his time. Throughout the interview I was constantly impressed with the man's loftiness of purpose, innate modesty and utter indifference to public applause. "I should much prefer not to be written about at all," he remarked; "but if it must be done, I trust you will take due pains to quote me correctly."

Speaking of the scientific status of the United States as compared with that of older nations, he said: "English scientists are the greatest in theory, perhaps, although, as far as practical results go, America may well claim to lead the world. That is why I like to stay here."

Mr. Tesla speaks our language with the idiomatic range and choice diction of a native who is also a scholar and a trained speaker, the guttural accent of the Slav, of course, being slightly noticeable. He told me that he felt equally at home in six languages, not to mention the same number of dialects.

Though simple, self-contained and undemonstrative in manner, when he is especially pleased or absorbed in enthusiastic description of electrical wonders, the intellectual animation of his frank blue eyes, combined with a rarely winning smile, exercises a charm that is irresistible. I have noticed the same unconscious quality of personal magnetism in Mr. Edison, though in almost every other respect these two remarkable individuals are totally dissimilar.

Edison may be more truly the man of genius. He works out his intricate problems by intuition. He peers into the future like a seer of old, and receives, as it were, lightning flashes of inspiration to guide him to the goal. In a word, the illiterate train boy of thirty-odd years ago has come to be regarded as little less than a wizard; and yet, assuredly, he is neither a thinker nor a student in the true sense.

Now, how is it with the Servian, who has acquired fame much less rapidly? What was his life before he came among us? Let me say, at the outset, that eighteen years of exhaustive, patient study were accomplished before Nikola Tesla deemed himself adequately prepared to embark upon the career which he had planned from childhood.

Born in 1857 at Smiljan Lika, a remote village in Austro-Hungary, he is the descendant of a sturdy line of Servian patriots, who for centuries had taken a prominent part in the protracted struggle against the domineering Turk.

The young Nikola commenced his studies in the public school of Gospich when five years of age. Not long afterward the marvels of electricity and magnetism began to dawn upon the boy's receptive soul. Fascinated and stirred until he scarcely thought of anything else, he resolved thenceforth to devote his life to research and investigation in this noble field of knowledge. In 1873, against the wishes of his father, who, being a clergyman in the Greek Church, had hoped that his son would discover a theological bent, Nikola entered the Polytechnic School at Gratz. It was at this institution, while puzzling over the complexities of a direct current Gramme machine, that his alert mind was led to conceive of a rotating magnetic field, which discovery was destined to deal the deathblow to those troublous contrivances the commutator and brushes. After completing the technical course at Gratz, Mr. Tesla removed to Vienna, where for several years he attended philosophical lectures, read omnivorously on many subjects, continued his special studies, and incidentally found time to master five or six languages. Verily, an intellectual training of this sort, in the face, too, of untold trials and difficulties, would have far exceeded the scope of any ordinary student.

Before I bade a regretful farewell to this kindly wizard of Washington Square he confided to me that he was engaged on several secret experiments of most abundant promise, but their nature cannot be hinted at here. However, I have Mr. Tesla's permission to say that some day he proposes to transmit electric vibrations through the earth; in other words, that it will be possible to send a message from an ocean steamer to a city, however distant, without the use of any wire.

To those who would gain a complete technical knowledge of the Servian's manifold labors since he came to the United States I would recommend a careful study of the volume recently issued by Mr. T. C. Martin, of the Electrical Engineer, entitled "The Inventions, Researches and Writings of Nikola Tesla." How strange it is, indeed, that, though electricity has so long been partially controlled by mankind, yet we are utterly unable to define it! As Mr. Tesla has said: "The day when we know what electricity is will chronicle an event probably greater than any other recorded in the history of the human race."

TESLA, MAN AND INVENTOR.

He Might be Called the Flower of a Mountaineering Clan.

HAS FACULTY OF RUSHING INTUITION

Achievements with the Neglected Alternating Current—A Man Who Dwells Apart—His Latest Problem Enormous.

Nicola Tesla is peculiarly fortunate to have taken up the cause and exploitation of the alternating current at a time when others cared to have little to do with it, when others scarcely appreciated its value and importance. Now that the rapid march of events in electrical development has



Recent Tesla Experiments in Berlin.

brought the art abreast of the times, Tesla finds himself lifted into prominence, not so much because of what he is to-day but because of the hard and now well-nigh unparalleled work that he has done during the last decade.

Tesla is a foreigner, but is not exceptional in that respect. It is curious how many of the great electricians who have made America the foremost country in electrical appliances have been born outside its borders. Bell, Thomson, and Weston were born under the English flag, and Edison himself hardly escaped being a Canadian; Sprague, the man who did more, perhaps, than any other to make the electrical railway an actuality, is of straight American blood, but Van Depoele and Daft, colaborers, were both aliens. It is not a matter of surprise, therefore, that Tesla, with so many others, should find a home and welcome and all the facilities for the fruition of his ideas on American soil.

There are many things to differentiate Tesla from his distinguished colleagues, and many which will make him a man apart to the end of the chapter. He is hardly the representative of any European nationality; perhaps he might be better spoken of as a flower of a mountaineering clan. Just as the Highlanders in Scotland have beaten back the tide of invasion, so his people, in the highlands of the Adriatic, have fought, cursed, and slaughtered the Turks ever since the turban invaded Europe.

His people are a rural people, and willing to be peaceful, but ever ready to turn their shepherds' crooks into spears and their scythes into bloody blades. They have been planted from time immemorial in the Adriatic mountains, but it was, perhaps, a happy caance that took thither in the turbulent First Napoleon days an officer of the victorious French legions, who intermarried and thus gave to the aboriginal stock the blood of which Tesla is the latest and best producer.

When Tesla, as a youth, found his tastes and inclinations turning to mechanics and electricity, expatriation became not a choice, but a necessity. Moreover, he had heard in those dim uplands, overshadowed by the Turkish mist of cruelty and oppression, the magic name of Edison, and he felt as though he could not live or die happily until he had found out for himself what the country was like that owned such men, and had there sought for himself an opportunity for his tastes and his genius. When Tesla came to this country he began, as almost every other emigrant does, at the "foot of the ladder."

He was willing to do so. No task that was given him was too heavy or difficult. But he soon found that it was easier and better to carry out some of his own seething and tumultuous schemes than to try to give shape to those of others, which he understood and solved even before the proposition was stated to him.

A notable faculty of Tesla's mind is that of rushing intuition. As with Edison, you begin to state a question or proposition to him, and before you have half formulated it he has suggested six ways of dealing with it and ten of getting around it.

Tesla said once to a friend: "If I were to try every crude idea when it first came into my mind I could bust two banks every day. That is the trouble with many inventors; they lack patience. They lack the willingness to work a thing out slowly and clearly and sharply in their mind, so that they can actually feel it work. They want to try their first idea right off; and the result is they use up lots of money and lots of good material, only to find eventually that they are working in the wrong direction. We all make mistakes, and it is better to make them before we begin."

As soon as Tesla began practical work he found that everybody in the electrical field of lighting and power was trying to work with the continuous current, which, with all its inherent advantages, has a great many drawbacks and complications. He felt that if electricity was to reach out into the fields awaiting it, it must have greater flexibility than could be secured with the continuous current, and he saw in the alternating current a means to a great many ends.

With that idea in his mind as a starting point, his career and his work may be regarded as a striking and sequential evolution. Even as a boy he thought it was necessary to abolish the commutator in electrical dynamos and motors, as that had always been the weakest part of these machines. In all his earlier work this idea haunted him, and, although he went through the usual experience in developing continuous current apparatus for incandescent and arc lighting, he felt that there was another goal to reach.

He startled the electrical public about eight years ago by bringing before the American Institute of Electrical Engineers a class of motors in which there were neither commutators nor brushes, and in which by the use of "phase" currents of shifting polarity, alternating currents are used in terms of the highest economy, flexibility, and range. From that moment may be said to begin the use of polyphase currents in this country and in Europe.

This is the chief line on which electrical work for light and power is advancing to-day. In this direction there has already been evolved what are known as single-phase, two-phase, tri-phase, and monocycle current apparatus, and it will readily be seen that these all can be grouped under the one idea of "polyphase currents," the nomenclature adopted by Mr. Tesla very early in his work.

It is impossible for the public to understand these things, even if they sit up all night for weeks; but, as illustrative of what Tesla polyphase system has been adopted for the enormous transmission of power at Niagara Falls.

All the twenty generators of 5,000 horse power each which are now being set up in the power house at Niagara are of the Tesla two-phase type. The radical advantage of this method is that it allows the power to be transmitted a long distance with small loss, and that it permits the employment at the consumption end of the line of devices which insure the best conditions of economy and efficiency.

It has been impossible to use the continuous current over long distances in any built, and it may be questioned whether any continuous current power transmission has ever exceeded 100 horse power over ten miles with the faintest success. The Rothschilds settled in France the transmission by high voltage continuous currents of less than 100 horse power between Paris and Creil, a distance of thirty-four miles, and the attempt was an ignominious failure.

But at Niagara Tesla has contemplated the transmission to Buffalo, a distance of over twenty miles, by the Tesla plan, of at least 50,000 horse power when the plant is in full operation.

Expert calculations show that the practical outcome of all this work is that power can be transmitted with economy at least 100 miles in every direction from Niagara Falls, while, if it were found expedient, it could easily be transmitted to New-York and Chicago. About this there is little question.

The condition that has to be met is whether it would not be cheaper to generate power in New-York from coal and in Chicago from natural gas, but this does not in any wise diminish the magnitude and brilliancy of the invention which renders such things feasible. Coal fields can be dug empty and gas fields even piped dry, but Niagara runs on forever.

Granted there are the coal fields in apparently inexhaustible abundance, Mr. Tesla has naturally felt that it would be well, incidentally, to get a little more power out of the coal than has been possible heretofore. To this conception is due his oscillator, in which he has endeavored to combine at one stroke the dynamo and the steam engine.

Even allowing for the natural and invincible optimism of an inventor, it is evident that if one can devise a dynamo reduced to its essential elements, and a steam engine which is governed by the dynamo, and not by its own cumbrous gear, one has an apparatus which should give up electrical current an output far above that which is now obtained from the dynamo as one unit and from the engine as another unit, each working, practically, on an independent basis, and each with its counteracting conditions that make against economy.

Mr. Tesla's latest oscillator was consumed in the fire the other day, and the few score who have visited the laboratory had the opportunity to see it in full operation, supplying a large number of incandescent lights, current for arc lights, and the means of conducting a large variety of curious and novel experiments demonstrative of entirely new phenomena.

This machine, which one could apparently pick up and walk away with comfortably under one's arm, was doing work which, under ordinary conditions, would require a machine that a cart and team of horses could with difficulty haul around town. The current was developed by a machine combining dynamo and steam engine which could stand on an office chair.

Among the experiments shown were those of lighting lamps in free space, the illumination of phosphorescent bulbs, the demonstration of the innocuous effects of currents of high potentiality and high frequency, and the ability of a plain, every-day mortal to take a million volts. All this apparatus was consumed in the fire; but the handful who saw it will never forget it.

They are only longing for a chance to see it again as soon as Tesla, with his indomitable courage and perseverance, has rebuilt it.

The man is an indefatigable, tireless worker. The day after the fire which wiped out his laboratory he worked until 3 in the morning, and at 9 o'clock he was up again and eager to get his men at work on reconstruction. Naturally, he felt his loss; but never was a sudden, staggering blow sustained with greater courage.

It is a curious and typical incident in the disaster that a few nights after, when he dropped, for sheer respite, into an up-town club, he found there a gathering of well-known actors, musicians, and artists. Some of these he knew well, for there is always a bon camaraderie among men of this stamp.

With quick and kind sympathy they immediately organized an impromptu "benefit concert," for his sole gratification, with an aggregation of talent that, had the public only known of it, would have given a substantial endowment for his new laboratory.

He seems to be a man who dwells apart. He has no kith or kin in this country, and only a few friends who share his confidences. Even in moments of closest social intercourse he will become abstracted, and never a time when he would not prefer his laboratory to any other spot on earth. One of his few recreations is billiards, another is literature.

He has taken not a little pride in endeavoring to introduce to the American literary public, with the assistance of Robert Underwood Johnson of The Century, the charming work of the national poet, Zmai Jovan, and it is not unlikely that the readers of this sketch will have noticed some admirable renderings from the Servian in that magazine, as well as in The Outlook, The Independent, and other periodicals.

An evening in Mr. Tesla's laboratory was something to remember. He rarely invited anybody there, but would sometimes yield to pressure, and once or twice entertained select and professional bodies with demonstrations that would be of interest and value. In the course of his experiments, Mr. Tesla had collected some very curious apparatus, and other novel pieces had been made to illustrate his lectures in this country and in England and France.

Much of this was glassware, in the shape of lamps and bulbs. Entering a wide, lofty room with these lamps or bulbs held in the hand, one would be surprised to see them light up brilliantly. Curious streams of luminosity would surge and twist in these empty glass tubes, milky white in glowing turbidity.

These tubes were of different lengths and dimneters, the larger ones as long as a broomstick and as thick, the smaller ones, as thin as wheat straws and as long. Whether held singly or in sheaves, their illumination was equally brilliant and pure.

In some lamps Mr. Tesla had placed substances that phosphoresced, under the stimulation of the currents reaching them across many feet of space, and the light was red or blue or yellow, according to the ingredients. Other lamps or tubes had been twisted into odd and interesting shapes.

One, for instance, was like a veritable handful of lightning, when the streams of luminescent ether rushed through its strange zags. Many were shown for their novelty and beauty, but Mr. Tesla had a great variety of phenomena to explain with their help, and, seeing them, it was impossible not to believe that the era of practical phosphorescent lighting is very close.

Mr. Tesla has lectured once in New-York, once in Philadelphia, once in St. Louis, twice in London, and twice in Paris. He is not a successful elocutionist, and is prone to forget himself in the pleasure of demonstrating one novel phenomenon after another, regardless of his audience; but experts have never found his addresses long enough.

The experience in St. Louis in 1893 was rather disturbing. The National Electric Light Association was meeting in the city, and had indeed made Tesla's show it what might be expected among developments in the near future. Somehow it got hinted around the city that the effects would be novel and strange, as well as of technical interest, and the local committee was swamped with applications for tickets.

Finally, the great hall in the Exhibition Building was taken, somewhat reluctantly; but on the night of the lecture the rush was so great that people had to fight for admission, and Tesla, to his dismay, found himself facing a jammed house of probably 5,000 auditors. He had expected a little gathering of expert electricians, and, though he went through the ordeal bravely, no power on earth would induce him to try anything like it again.

After the lecture was over the crowd insisted on meeting at close quarters the man who had dazzled and puzzled them, and thronged to an offhand reception, from which there was no escaping.

It was a funny episode, also, of the World's Fair, that while Mr. Tesla was attending the Electrical Congress, by special invitation, to explain the principle of his oscillator, a shrewd Westerner, who had seen the exhibit of Tesla's apparatus in Electricity Building, hunted him up and nearly killed him with ceaseless propositions for a long lecturing tour at rates that would make a modern prima donna die of envy. But Tesla does not lecture for pay.

The way in which Tesla does his work is rather interesting. Unlike most inventors, he has practically no associates, so that he is not subject to such a sharp controversy as arose between Morse and Vail as to the origin of certain features of the telegraph.

He has an intelligent staff of workmen, who carry out his orders implicitly; but beyond that the directing brain power of his laboratory is solely and wholly his own. He begins work early in the day, and will very often work until late into the night, after which he can sometimes be found eating his dinner at Delmonico's at the time when people are dropping in from the theatre.

His thoughts are given entirely to his own work; but his growing fame has brought around him a persecuting host of small fry inventors and men with schemes, who want him to work out impossibilities for them and make millions in the feat. His judgment is remarkably quick and sound on all kinds of engineering, with which he has the most intimate acquaintance; but he rarely can be invited out of his way to express his opinion about it. In short, he is intensely absorbed with the problems which he has set himself, and which deal with the fundamental conditions of being upon this little planet.

More than this: It is not generally known that of late Mr. Tesla has carried his ideas and work to a height of audacity which can only be spoken of as unparalleled. It has generally been supposed and assumed that this earth has a natural electrical charge of its own.

Accepting this theory as true, Mr. Tesla argued that it should be within the power of mankind, with suitable apparatus, to disturb this electrical contrast, and in some of his later inventions he has directed his energies to that enormous problem, which, if successfully solved, would represent in science the material conquest of the world by a Napoleon or a Cæsar.

Mr. Tesla now thinks he has succeeded in his object, and has, with his own eyes, seen the electricity of the earth reach out its arms of ethereal and vocal flame to heaven. This, seems incredible; but Mr. Tesla is one of the most secretive and cautious of men, and has not yet been known to speak of a thing as being possible until he had already accomplished it in his laboratory.

Of course, this achievement, which is among his latest, has many bearings and aspects. With suitable mechanism, properly adjusted, it will be possible to talk from one part of this earth to another without wires. But this is a detail. If this earth has an electrical charge, and all the other heavenly bodies have, as they undoubtedly have, an electrical charge, we have at once facilities of interplanetary communication, should there be beings who have yearnings across the chasms of space.

GEORGE HELI GUY.

TESLA'S OSCILLATOR AND OTHER INVENTIONS.

AN AUTHORITATIVE ACCOUNT OF SOME OF HIS RECENT ELECTRICAL WORK.[1]

SKOBELEFF, the great Russian general, once said of the political conditions in Central Asia, that they changed every moment; hence the necessity for vigilance, no less the price of empire than of liberty. Thus changeful, also, is the aspect of that vast new electrical domain which the thought and invention of our age have subdued. They who would inform themselves expertly about it, in whatever respect, must ever keep up an attitude of strained attention. Its theoretical problems assume novel phases daily. Its old appliances ceaselessly give way to successors. Its methods of production, distribution, and utilization vary from year to year. Its influence on the times is ever deeper, yet one can never be quite sure into what part of the social or industrial system it is next to thrust a revolutionary force. Its fanciful dreams of yesterday are the magnificent triumphs of to-morrow, and its advance toward domination in the twentieth century is as irresistible as that of steam in the nineteenth.

Throughout this change there has prevailed a consistency of purpose: a steady aim has been leveled at definite goals; while useful arts in multitude attest the solidity of the work done. If, therefore, we find a tremendous outburst of activity at the very moment when, after twenty-five years of superlative productiveness, electricians were ready, with the reforming English statesman, to rest and be thankful, we may safely assume that electricity has reached another of those crucial points at which it becomes worth the while of the casual outside observer to glance at what is going on. To the timid and the conservative, even to many initiated, these new departures have indeed become exasperating. They demand the unlearning of established facts, and insist on right-about-faces that disregard philosophical dignity. The sensations of a dog attempting to drink sea-water after a lifetime spent on inland lakes are feeble compared with those of men who discover that electricity is quite other than the fluid which they have believed it to be from their youth up, and that actually there is no such thing as electricity or an electric current.

Electricity has, indeed, taken distinctively new ground of late years; and its present state of unrest — unsurpassed, perhaps, in other regions of research — is due to recent theory and practice, blended in a striking manner in the discoveries of Mr. Nikola Tesla,[2] who, though not altogether alone, has come to be a foremost and typical figure of the era now begun. He invites attention to-day, whether for profound investigations into the nature of electricity, or for beautiful inventions in which is offered a concrete embodiment of the latest means for attaining the ends most sought after in the distribution of light, heat, and power, and in the distant communication of intelli-

[1] The photographs reproduced in this article were taken, under the special direction of the inventor, by Tonnele & Co.

[2] A biographical sketch of Mr. Tesla, by the present writer, with portrait, appeared in THE CENTURY for February, 1894.—EDITOR.

gence. Any one desirous of understanding the trend and scope of modern electrical advance will find many clues in the work of this inventor. The present article discloses a few of the more important results which he has attained, some of the methods and apparatus which he employs, and one or two of the theories to which he resorts for an explanation of what is accomplished.

By a brief preliminary survey, we may determine our historical longitude and latitude, and thus ascertain a little more precisely where we are. It is necessary to recapitulate facts known and accepted. Let it, then, be remarked that aside from the theories and interpretations that have beset the science, electricity as an art has for three hundred years been directed chiefly to securing an abundant, cheap, efficient, and economical supply of the protean agency, be it what it may. Frictional machine, Leyden jar, coil, battery, magnet, dynamo, oscillator,— these are but the steps in a process as regular and well-defined as those which take us from the aboriginal cradling of gold out of river sands up to the refining of ore with all the appliances of modern mechanism and chemistry. Each stage in electrical evolution has seen the conquest of some hitherto unknown art — electrotherapy, telegraphy, telephony, electric lighting, electric heating, power transmission; yet each has had limitations set on it by the conditions prevailing. With a mere battery much can be done; with a magnet, still more; with a dynamo, we touch possibilities of all kinds, for we compel the streams, the coal-fields, and the winds to do us service: but with Mr. Tesla's new oscillator we may enlist even the ether-waves, and turn our wayward recruits into resistless trained forces, sweeping across continents of unimagined opportunity.

The dynamo, slowly perfected these fifty years, has rendered enormous benefits, and is destined to much further usefulness. But all that we learn now about it of any intrinsic value is to build it bigger, or to specialize it; and the moment a device reaches that condition of development, the human intellect casts about for something else in which the elements are to be subtler and less gross. Based upon currents furnished by modern dynamo-electric machines, the arc-light and the trolley-car seek to monopolize street illumination and transportation, while the incandescent lamp has pre-empted for exclusive occupancy the interiors of our halls and homes. Yet the abandonment of gas, horses, and sails is slow, because the dynamo and its auxiliaries have narrow boundaries, trespassing which, they cease to offer any advantage. We can all remember the high hopes with which, for example, incandescent lighting was introduced some fifteen years ago. Even the most cynical detractor of it will admit that its adoption has been quick and widespread; but as a simple matter of fact, to-day, all the lamps and all the lighting dynamos in the country would barely meet the needs of New York and Chicago if the two cities were to use no other illuminant than electricity. In all England there are only 1,750,000 incandescent lamps contesting for supremacy with probably 75,000,000 gas-burners, and the rate of increase is small, if indeed it exceeds that of gas. Evidently, some factor is wanting, and a new point of departure, even in mere commercial work, is to be sought, so that with longer circuits, better current-generating apparatus, and lamps that will not burn out, the popular demand for a pure and perfect light can be met. In power transmission, also, unsatisfied problems of equal magnitude crop up. "Is there any load that water cannot lift?" asked Emerson. "If there be, try steam; or if not that, try electricity. Is there any exhausting of these means?" None, provided that our mechanics be right.

It must not be supposed that the new electricity is iconoclastic. In the minds of a great many people of culture the idea prevails that invention is as largely a process of pulling down as of building up; and electricity, in spreading from one branch of industry to another, encounters the prejudice that always rebuffs the innovator. The assumption is false. It may be true that in the gladiatorial arena where the principles of science contend, one party or the other always succumbs and drags out its dead; but in the arts long survival is the law for all the appliances that have been found of any notable utility. It simply becomes a question of the contracting sphere within which the old apparatus is hedged by the advent of the new; and that relation once established by processes complex and long continued, capable even of mathematical determination, the two go on together, complementary in their adjustment to specific human needs. In its latest outgrowths, electrical application exemplifies this. After many years' use of dynamo-electric machinery giving what is known as a "continuous current," the art has reached the conclusion that only with the "alternating current" can it fulfil the later duties laid upon it, and accomplish the earlier tasks that remain untouched. With the continuous current we have learned the rudiments of lighting and power distribution. With the alternating current, manipulated and coaxed to yield its highest efficiency, we may solve the problems of aërial and marine navigation by electricity, operate large railway systems, transmit the energy of Niagara hundreds of miles, and, in Mr. Tesla's own phrase, "hook our machinery directly to that of Nature."

THE GENERATION OF CURRENT.

LET us see wherein lies the difference between these two kinds of currents. In all dynamos the generation of what we call electric current is effected by the whirling of coils of wire in front of magnets, or conversely. The wires that lead away from the machine and back to it to complete the necessary circuit, may be compared to a circle of troughs or to a pipe-line; the coils and magnets are comparable to pump mechanism; and the lamps or motors driven by the current, to fountains or faucets spaced out on the trough circle. This comparison is crudity itself, but it gives a fairly exact idea. The current travels along the surface of the wire rather than inside, its magnetic or ether whorls resembling rubber bands sliding along a lead-pencil. A machine that produces continuous current, dipping its wire coils or buckets into the magnetic field of force, has all its jets, as they come around to discharge themselves, headed one way, and complicated devices called "commutators" have been unavoidable for the purpose of "rectifying" them. A machine that produces alternating currents, on the contrary, has its jets thrown first into one end of the trough system, and then into the other, and therefore dispenses with the rectifying or commutating valves. On the other hand, it requires peculiar adjustment of its fountains and faucets to the streams rushing in either way. It is an inherent disadvantage of the continuous-current system that it cannot deliver energy successfully at any great distance at high pressure, and that therefore the pipe-line must be relatively as bulky as were the hollow wooden logs which were once employed for water-conduits in New York. The advantage of the alternating current is that it can be delivered at exceedingly high pressures over very slender wires, and used either at that pressure or at lower or higher ones, obtained by means of a "transformer," which, according to its use, answers both to the idea of a magnetic reducing valve, and to that of a spring-board accelerating the rapidity of motion of any object alighting on it. Obviously a transformer cannot return more than is put into it, so that it gives out the current received with less pressure but in greater volume, or raised in pressure but diminished in the volume of the stream. In some like manner a regiment of soldiers may be brought by express to any wharf, and transferred, Indian file, to a sailing barge or an ocean liner indifferently; but throughout the trip the soldiers will constitute the same regiment, and when picked up by another train across the ferry, the body, though there be loss by desertion and sickness, will retain its identity, even if the ranks are broken in filling the cars, and are reformed four abreast at the end of the journey.

ALTERNATING CURRENTS.

LET us, still recapitulating familiar facts, make the next step in our review of what is involved in the resort to alternating currents. It was stated above that the current-consuming devices such as motors, likened to fountains, needed peculiar adjustments to the inflow first from one side and then from the other. Not to put it at all too strongly, they would not work, and have largely remained inoperative to the present time. Lamps would burn, but motors would not run, and this fact limited seriously the adoption and range of the otherwise flexible and useful alternating current until Mr. Tesla discovered a beautiful and unsuspected solution of the problem, and thus embarked on one part of the work now revealing grander possibilities every day. The transmission of the power of Niagara has become possible since the discovery of the method. In his so-called "rotating magnetic field," a pulley mounted upon a shaft is perpetually running after a magnetic "pole" without ever being able to catch it. The fundamental idea is to produce magnetism shifting circularly, in contrast with the old and known phenomenon of magnetism in a fixed position. Those who have seen the patient animal inside the treadmill wheel of the well at Carisbrooke Castle can form an idea of the ingenuity of Mr. Tesla's plan.

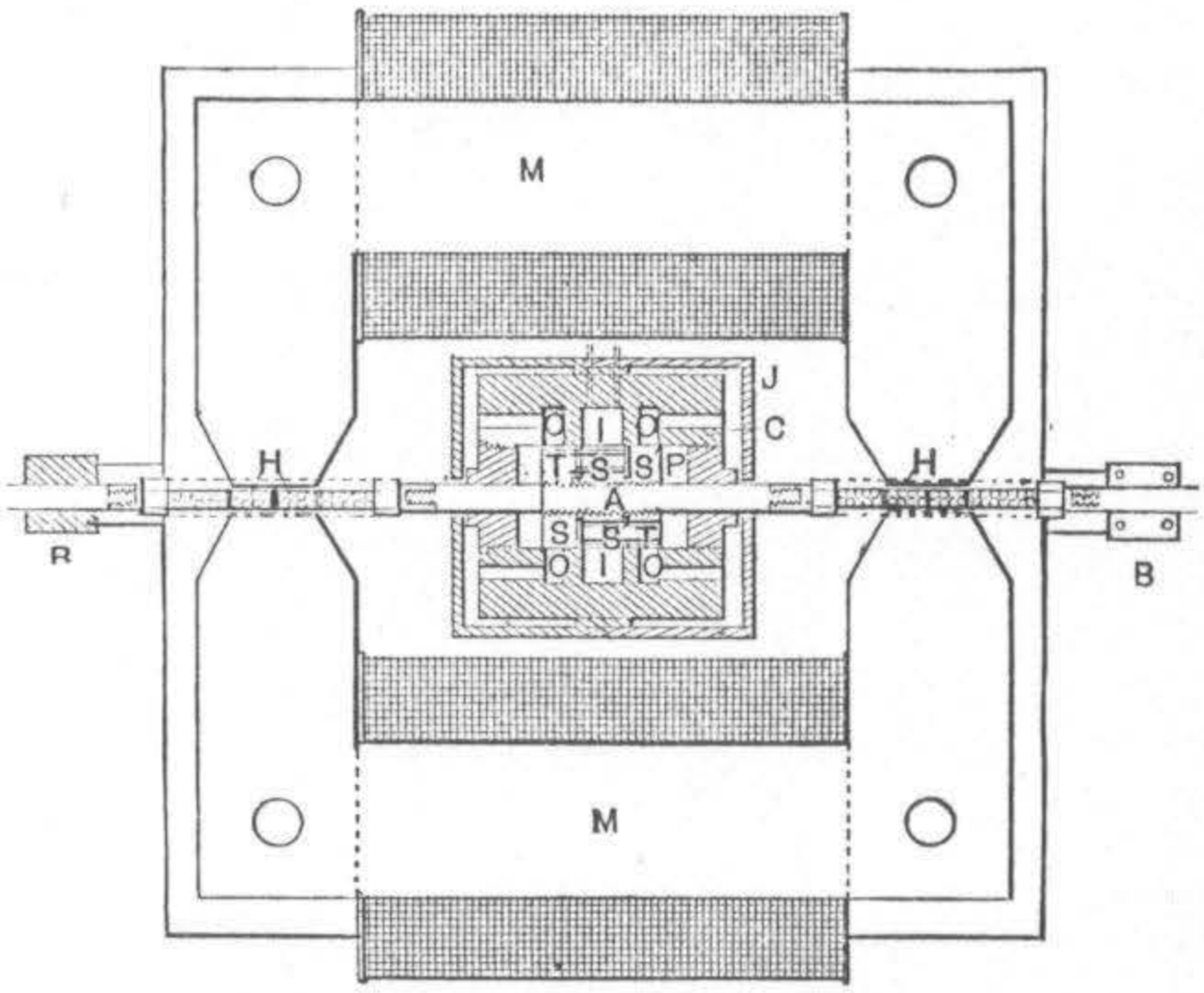
Ordinarily, alternating-current generators, such as are now in common use, have a great number of projecting poles to cause the alternations of current, and hence their "frequency" is high — that is, the current makes a great many to-and-fro motions per second, and each ebb-and-flow in the circuit is termed the "period" or "frequency," one alternation being the rise from zero to maximum value and down to nothing again, and the other the same thing backward. If we ruled a horizontal straight line, and then drew a round-bellied Hogarth curve of beauty across it, the half of the curve above the line would be illustrative of the positive flow, the lower half of the negative flow; the top of one oval and the bottom of the other oval would be the positive and negative maxima respectively; and the point where the curve crossed the straight line would mark the instant when the current changes its direction. A swinging pendulum is an analogy favored by scientists in their endeavors to illustrate popularly the process of the generation of the alternating current. Each time the copper wire in the coils on the dynamo armature is rotated past the pole of the dynamo field, the currents in each coil follow this rise and fall; so that the number

of the magnets and coils determines the period or frequency, as stated. The more numerous the magnets, and the faster the rotation of the coils, the quicker will be the ebbs and flows of current. But the character of the work to be done, and existing conditions, govern the rate at which the current is thus to be set vibrating; and no small amount of skill and knowledge enters here. The men who can predicate the right thing to do are still few and far between. The field has as yet been little explored. Moreover, in one of the deepest problems now engaging the thought of electrical engineers,—namely, the production of cheap light and cheap power by these new means,—opposite conditions pull different ways. Mr. Tesla made up his mind some time ago that for motor work it was better to have few frequencies; and the whole drift of power transmission is on that path, the frequency adopted for the work at Niagara being only twenty-five. But, as was natural, he ran through the whole scale of low and high frequencies, and soon discovered that for obtaining light, one great secret lay in the utilization of currents of high frequency and high potential. Some years ago, after dealing with the power problem as above described, Mr. Tesla attacked the light problem by building a number of novel alternating-current generators for the purpose, and attained with them alternations up to 30,000 per second. These machines transcended anything theretofore known in the art, and their currents were further raised in pressure by "step up" transformers and condensers. But these dynamos had their shortcomings. The number of the poles and coils could not be indefinitely increased, and there was a limit to the speed. To go to the higher frequencies, therefore, Mr. Tesla next invented his "disruptive discharge coil," which permitted him to reach remarkably high frequency and high pressure, and, what is more, to obtain these qualities from any ordinary current, whether alternating or continuous. With this apparatus he surprised the scientists both of this country and of Europe in a series of most interesting demonstrations. It is not too much to say that these experiments marked an epoch in electricity, yielding results which lie at the root of his later work with the oscillator in an inconceivably wider range of phenomena.

THE TESLA OSCILLATOR.

Up to this point we have been considering both continuous-current and alternating-current dynamos as driven by the ordinary steam-engine. Perhaps nine tenths of all the hundreds of thousands of dynamos in the world to-day are so operated, the remainder being driven by water-wheels, gas-engines, and compressed air. Now, each step from consuming the coal under the boilers that deliver steam to the engines, up to the glow of the filament in an incandescent lamp, is attended with loss. As in every other cycle that has to do with heat transformation, the energy is more or less frittered away, just as in July the load in an iceman's cart crumbles and melts in transit along the street. Actual tests prove that the energy manifesting itself as light in an incandescent lamp is barely five per cent. of that received as current. In the luminosity of a gas flame the efficiency is even smaller. Professor Tyndall puts the useful light-waves of a gas flame at less than one per cent. of all the waves caused by the combustion going on in it. If we were dealing with a corrupt city government, such wretched waste and inefficiency would not be tolerated; and in sad reality the extravagance is but on a par with the wanton destruction of whole forests for the sake of a few sticks of lumber. Armies of inventors have flung themselves on the difficulties involved in these barbaric losses occurring at every stage of the calorific, mechanical, and electric processes; and it is indeed likely that many lines of improvement have already been compelled to yield their utmost, reaching terminal forms. A moment's thought will show that one main object must be the elimination of certain steps in the transfer of the energy; and obviously, if engine and dynamo both have large losses, it will be a gain to merge the two pieces of apparatus. The old-fashioned electric-light station or street-railway power-house is a giddy maze of belts and shafting; in the later plants engine and dynamo are coupled directly together on one base. This is a notable stride, but it still leaves us with a dynamo in which some part of the wire wound on it is not utilized at every instant, and with an engine of complicated mechanism. The steam-cylinder, with its piston, is the only thing actually doing work, and all the rest of the imposing collection of fly-wheel, governor-balls, eccentrics, valves, and what not, is for the purpose of control and regulation.

In his oscillator Mr. Tesla, to begin with, has stripped the engine of all this governing mechanism. By giving also to the coils in which the current is created as they cut the "lines of force" of the magnets, a to-and-fro or reciprocating motion, so that the influence on them is equal in every direction, he has overcome the loss of the idle part of the wire experienced in rotating armatures; and, moreover, greatest achievement of all, he has made the currents regulate the mechanical motions. No matter how close the governing of the engine that drives the ordinary dynamo, with revolving armature, there is some irregularity in the generation of current. In the Tesla oscillator, if its inventor and the evidence of one's eyes may be



This form of oscillator has been used for experimental purposes, with air as the propelling force. It illustrates the principle of operation further developed in the machine shown in perspective in Fig. 2, in which steam is used as the propelling force. Outermost of all is seen the magnetic frame M M, built up of thin sheet-iron. This frame is wound with energizing coils of wire (indicated in hatchwork), as in ordinary electromagnets, and thus an intense magnetic "field of force" is concentrated on each side in the vicinity of H H, where are seen in dotted line two pairs of armature coils moving between the jaws of the inclosing electromagnets formed by M M. These armature coils, at H H, are supported on the shaft A, which runs through the piston P, and they, with the shaft, have additional bearings in the boxes B B at each end of the mechanism. The piston P is fitted into the hollow of the cylinder C, which in turn is inclosed by a jacket J, the latter serving chiefly to deaden the sound caused in working. The piston P is provided with channel-ports O O and I, which extend all around its inside surface. I is the inlet for the propelling compressed air, and O O are the outlets for the expanded air after its work is done at each stroke. In the piston P there are also two slots S S', while tubes T T are screwed into holes drilled in the piston. These tubes T T establish communication between the slots S S' and the chambers seen on each side of the piston, each chamber being thus connected with the slot which is remote from it. Now, the compressed air being brought through a delivery-pipe to the inlet I, with the piston P in the position it occupies in the diagram, and the shaft A being slightly touched so as to slide it a little to the left, the compressed air rushes through the slot S' and its communicating tube T, out into the chamber on the left of the piston. The pressure thus encountered by the piston on the left, from the expanding air, drives it back toward the right. Owing to its inertia, the piston thus impelled overshoots the position of equilibrium, allowing in this way the next supply of compressed air to rush from the inlet I into slot S and its tube T, and from them into the chamber on the right of the piston. Meantime the communication to the left-hand chamber is cut off, and the now expanded air there, having instantly done its work, escapes through the channel-port outlet O. As the piston now travels back from the right on the return stroke, a precisely similar operation takes place on the right-hand side of it, due to the expanding of the compressed air there and its subsequent quick escape as exhaust. In this manner, so long as compressed air is supplied, oscillation of the piston P is maintained at a very high rate, and with highest accuracy. The coils of fine wire mounted on shaft A, to which the piston P is firmly attached, are thus rapidly thrust to and fro by the shaft across the faces of, and in the space inclosed by, the jaws of the electromagnets at H H. In this manner they cut the so-called "lines" of the intense "field of force" at those two points, and currents are thus engendered in them, which are led off to the exterior circuit for use. These currents are "alternating" in their character, and are of high regularity. The maintenance of constancy of oscillation on the part of the piston P is also due to the reaction and steadying effect of this electromagnetic part of the combination. The "fitting-boxes" at the ends of the cylinder C inclosing the piston project a carefully determined distance into the cylinder, thus setting limits to the length of the stroke. It will be obvious to those familiar with such matters that steam could also be used in this type of oscillator, with slight adjustments.

FIG. 1. DIAGRAM OF WORKING PARTS OF EARLY FORM OF TESLA OSCILLATOR, AS IF SEEN FROM ABOVE, IN SECTION. (FROM "THE ELECTRICAL ENGINEER," BY PERMISSION.)

believed, the vibrations of the current are absolutely steady and uniform, so that one could keep the time o' day with the machine about as well as with a clock. It was this superlative steadiness of the vibration or frequency that Mr. Tesla aimed at, for one thing. The variations caused by the older apparatus might be slight, but minute errors multiplied by high rates of occurrence soon become perceptible, and militate against desirable uniformity and precision of action. Back of the tendencies to irregularity in the old-fashioned electrical apparatus were the equal or greater tendencies in the steam-engine; and over and above all were the frightful losses due to the inefficient conversion in both of the power released from the fuel under the boiler generating the steam.

Gain in one direction with a radical innovation usually means gain in many others, through a growing series. I confess I do not know which of the advantages of the oscillator to place first; and I doubt whether its inventor has yet been able to sit down and sum up all the realities and possibilities to which it is a key. One thing he does: he presses forward. Our illustration, Fig. 2, shows one of his latest forms of oscillator in perspective, while the diagram, Fig. 1, exhibits the internal mechanism of one of the early forms. Fig. 2 will serve as a text for the subsequent heads of discourse. The steam-chest is situated on the bed-plate between the two electromagnetic systems, each of which consists of field coils between which is to move the armature or coil of wire. There are two pistons to receive the impetus of the incoming steam in the chest, and in the present instance steam is supplied at a pressure of 350 pounds, although as low as 80 is also used in like oscillators, where steam of the higher pressure is not obtainable. We note immediately the absence of all the governing appliances of the ordinary engine. They are non-existent. The steam-chest *is* the engine, bared to the skin like a prize-fighter, with every ounce counting. Besides easily utilizing steam at a remarkably high pressure, the oscillator holds it under no less remarkable control, and, strangest of all, needs no packing to prevent leak. It is a fair inference, too, that, denuded in this way of superfluous weight and driven at high pressure, the engine must have an economy far beyond the common. With an absence of friction due to the automatic cushioning of the light working parts, it is also practically indestructible. Moreover, for the same pressure and the same piston speed the engine has about one thirtieth or one fortieth of the usual weight, and occupies a proportionately smaller space. This diminution of bulk and area is equally true of the electrical part. The engine-pistons carry at their ends the armature coils, and these they thrust reciprocatively in and out of the magnetic field of the field coils, thus generating current by their action.

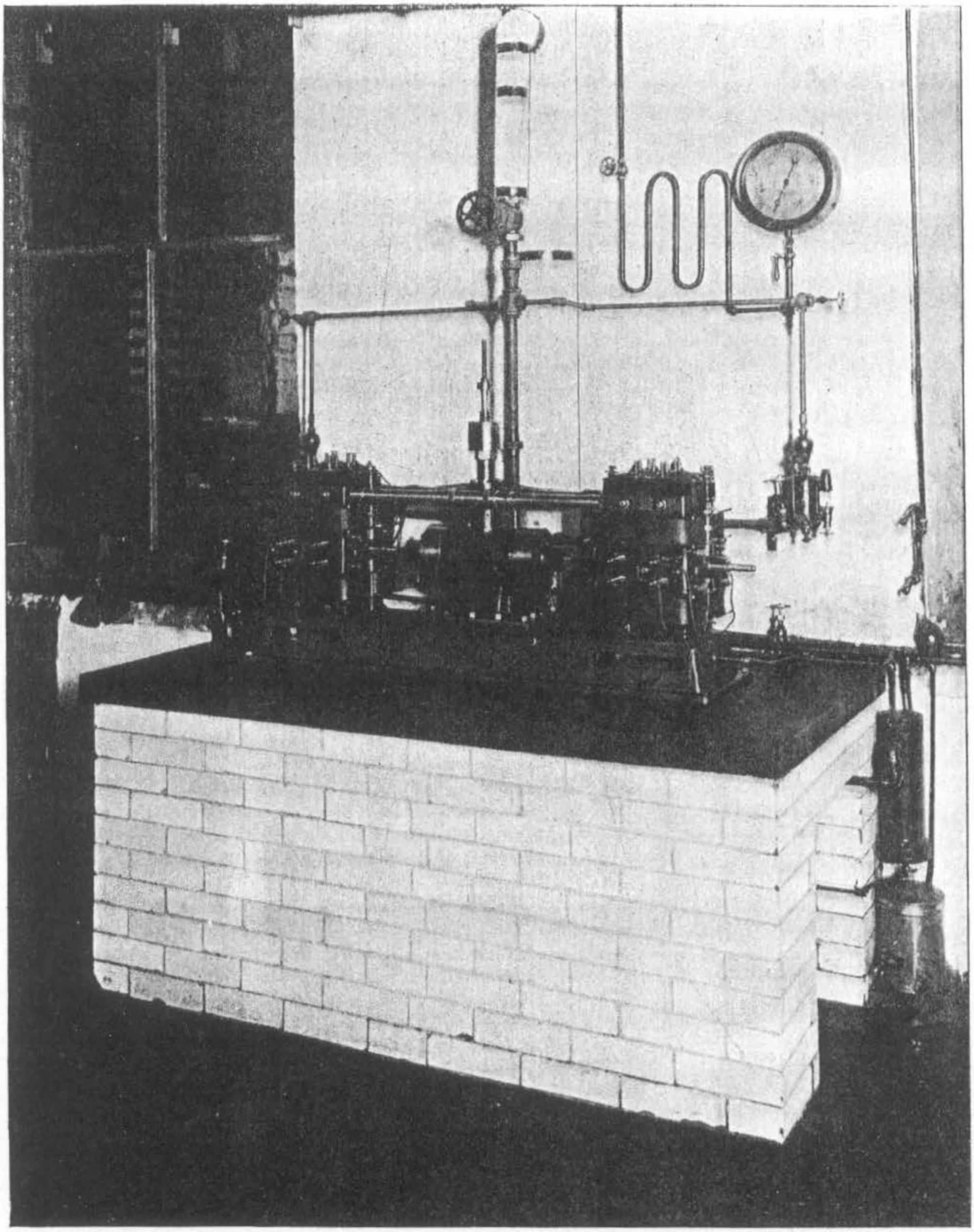


FIG. 2. LATEST FORM OF TESLA OSCILLATOR, COMBINING IN ONE MECHANISM DYNAMO AND STEAM-ENGINE.

If one watches any dynamo, it will be seen that the coils constituting the "armature" are swung around in front of magnets, very much as a turnstile revolves inside the barricading posts; and the current that goes out to do work on the line circuit is generated inductively in the coils, because they cut lines of influence emanating from the ends of the magnets, and forming what has been known since Faraday's time as the "field of force." In the Tesla oscillator, the rotary motion of the coils is entirely abandoned, and they are simply darted to and fro at a high speed in front of the magnets, thus cutting the lines of the "field of force" by shooting in and out of them very rapidly, shuttle-fashion. The great object of cutting as many lines of an intense field of force as swiftly, smoothly, regularly, and economically as possible is thus accomplished in a new and, Mr. Tesla believes, altogether better way. The following description of remarkable new phenomena in electricity will justify him in regard-

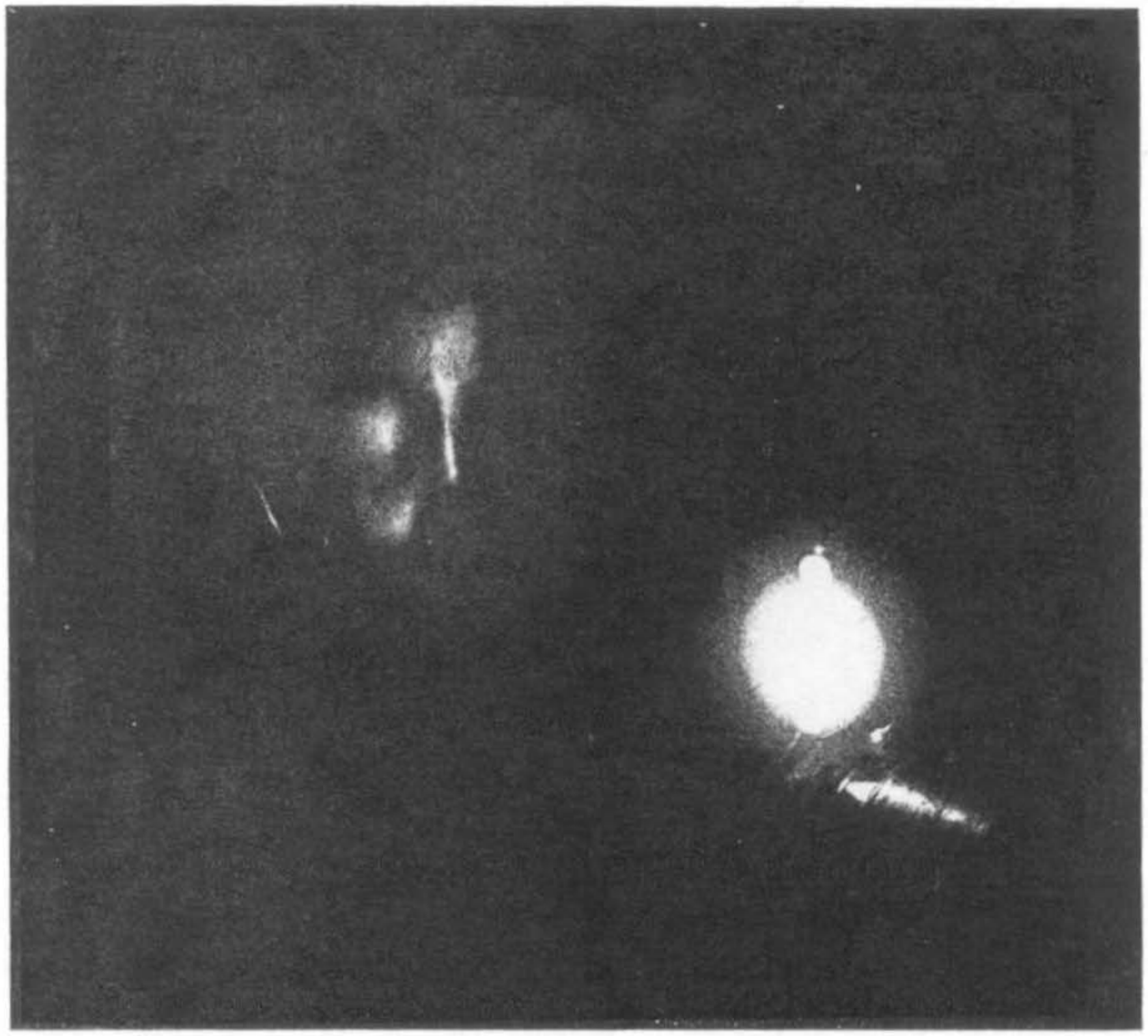


FIG. 3. FIRST PHOTOGRAPH EVER TAKEN BY PHOSPHORESCENT LIGHT. THE FACE IS THAT OF MR. TESLA, AND THE SOURCE OF LIGHT IS ONE OF HIS PHOSPHORESCENT BULBS. TIME OF EXPOSURE, EIGHT MINUTES. DATE OF PHOTOGRAPH JANUARY, 1894.

ing the oscillator as an extremely valuable instrument of research, while time will demonstrate its various commercial and industrial benefits.

Incidentally it may be remarked that the crude idea of obtaining currents by means of a coil or a magnetic core attached to the piston of a reciprocating steam-engine, is not in itself an entire novelty. It may also be noted that steam-turbines of extremely high rotative velocity are sometimes used instead of slow-moving engines to drive dynamos. But in the first class of long-abandoned experiments no practical result of any kind was ever reached before by any sort of device; and in the second class there is the objection that the turbine is driven by means of isolated shocks that cannot be overcome by any design of the blades, and which frustrate any attempts to perform work of the kind now under survey. What we are dealing with here is a dual, interacting machine, half mechanical, half electrical, of smallest bulk, extremely simple, utilizing steam under conditions unquestionably of the highest efficiency, its vibrations independent of load and pressure, delivering currents of the greatest regularity ever known for practical work or research. That such a combination should produce electricity for half the consumption of steam previously necessary with familiar apparatus in equivalent results, need not surprise us; yet think how much a saving of that kind would mean in well-nigh every industry consuming power!

THE OSCILLATOR AND THE PRODUCTION OF LIGHT.

HAVING obtained with the oscillator currents of high potential, high frequency, and high regularity, what shall be done with them? Mr. Tesla having already grappled successfully with the great difficulties of long distance power transmission, as narrated above, has first answered that question by boldly assailing the problem of the production of light in a manner nearer, perhaps, to that which gives us sunshine than was ever attempted before. Between us and the sun stretches the tenuous, sensitive ether, and every sensation of light that the eye experiences is caused by the effect of five hundred trillions of waves every second impressed on the ether by the molecular energy of the sun traveling along it rhythmically. If

the waves have a lower frequency than this 500,000,000,000,000, they will chiefly engender heat. In our artificial methods of getting light we imitatively agitate the ether so poorly that the waves our bonfires set up rarely get above the rate at which they become sensible to us in heat, and only a few waves attain the right pitch or rapidity to cause the sensation of light. At the upper end of the keyboard of vibration of the ether is a high, shrill, and yet inaudible out energy-waves on the ether, which will be conveyed to us through the glass of the bulb by the ether as light rather than as heat. The glass is as unconfining to the ether as a coarse sieve is to water.

Now Mr. Tesla takes his currents of high frequency and high potential, subjects the incandescent lamp to them, and, skipping some of those intermediate wasteful heat stages of lower wave vibration experienced in the old

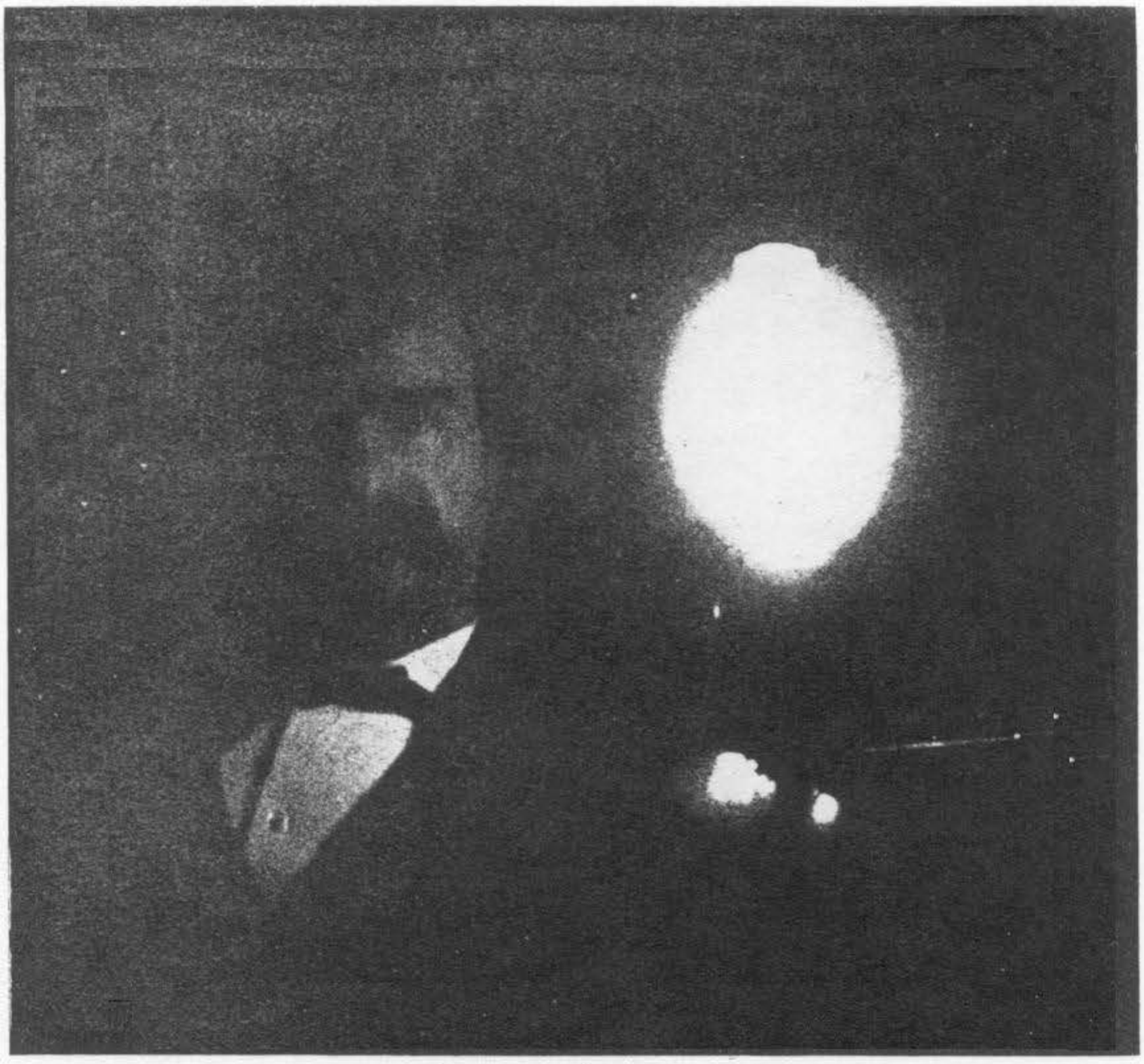


FIG. 4. PHOSPHOGRAPH OF MR. CLEMENS (MARK TWAIN), TAKEN IN THE TESLA LABORATORY JANUARY, 1894. TIME OF EXPOSURE, TEN MINUTES.

note,—"light,"—which we want to strike and to keep on striking; but we fumble at the lower, bass end of the instrument all the time, and never touch that topmost note without wasting the largest part of our energy on the intermediate ones, which we do not at all wish to touch. Light (the high note) without heat (the lower notes) is the desideratum. The inefficiency of the gas flame has been mentioned. In the ordinary incandescent lamp the waste is not so great; but even there the net efficiency of any one hundred units of energy put into it as electric current is at the most five or six of light, the waste occurring in the process of setting the molecules of the filament and the little air left in the bulb into the state of vibration under which they must work before they can throw methods, gets the ether-charged molecules more quickly into the intensely agitated condition necessary to yield light. Using his currents, produced electromagnetically, as we have seen, to load each fugitive molecule with its charge, which it receives and exercises electrostatically, he gets the ether medium into a state of excitement in which it seems to become capable of almost anything. In one of his first lectures, Mr. Tesla said:

> Electrostatic effects are in many ways available for the production of light. For instance, we may place a body of some refractory material in a closed, and preferably in a more or less air-exhausted, globe, connect it to a source of high, rapidly alternating potential, causing the molecules of the gas to strike it many times a second

at enormous speeds, and in this way, with trillions of invisible hammers, pound it until it gets incandescent. Or we may place a body in a very highly exhausted globe, and by employing very high frequencies and potentials maintain it at any degree of incandescence. Or we may disturb the ether carried by the molecules of a gas, or their static charges, causing them to vibrate or emit light.

These anticipatory statements are confirmed to-day by what Mr. Tesla has actually done in one old way revolutionized, and in three new ways: (1) the incandescence of a solid; (2) phosphorescence; (3) incandescence or phosphorescence of a rarefied gas; and (4) luminosity produced in a gas at ordinary pressure.

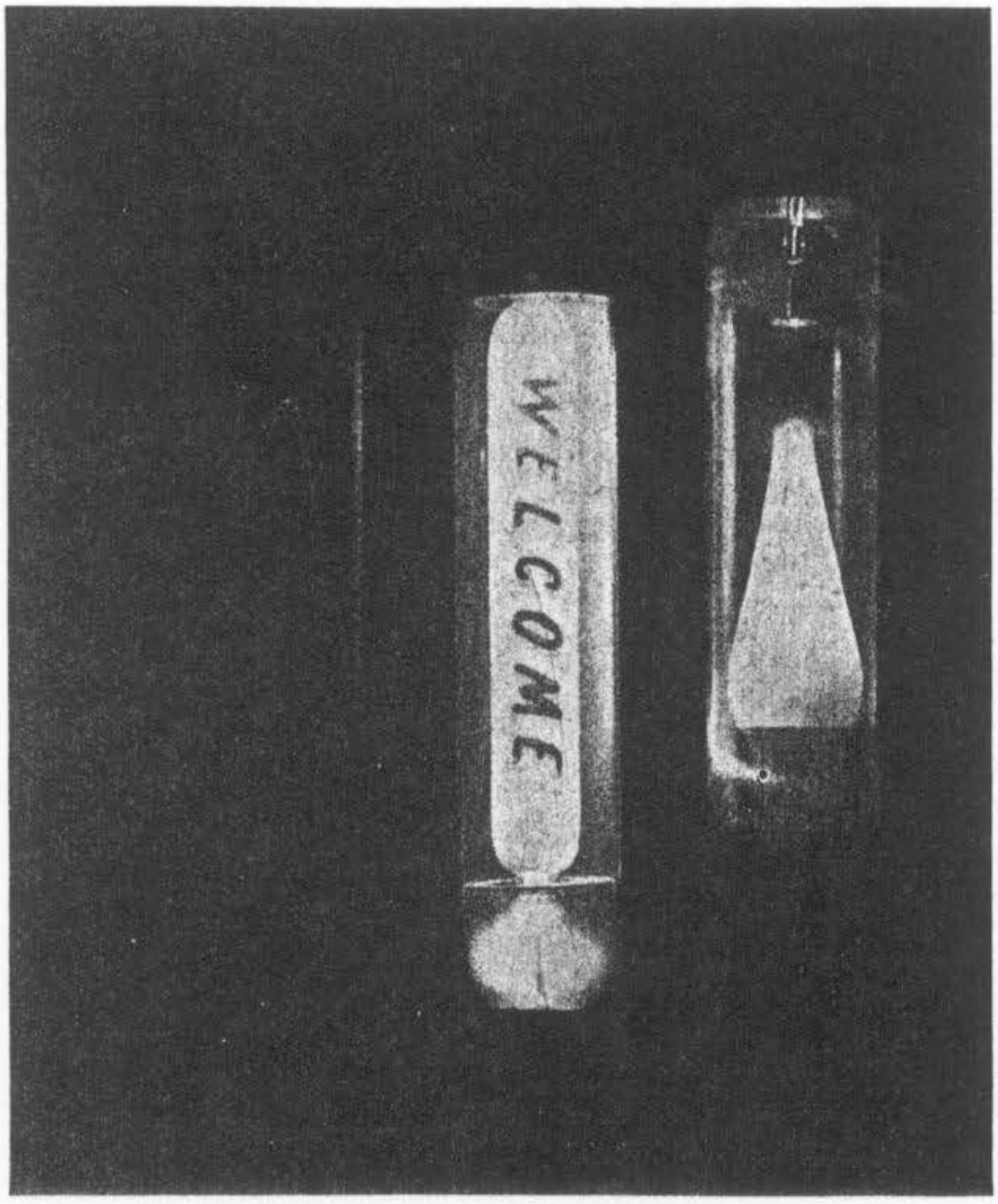


FIG. 5. THREE PHOSPHORESCENT BULBS UNDER TEST FOR ACTINIC VALUE. PHOTOGRAPHED BY THEIR OWN LIGHT.

LAMPS WITH BUTTONS OR BARS IN PLACE OF FILAMENTS.

TAKING lamps in the first category, it may be stated that it had been commonly supposed that the light-giving conductor in the lamp, to be efficient and practical, should be fine; hence the name "filament" given to the carbon loop in such lamps. But with the Teslaic currents the resistance or friction of the filament to the flow of current does not count for anything: the filament may just as well be short and thick, for it will rapidly reach and steadily maintain proper incandescence by the passage of a small current of the right high frequency and potential. An action is set up as the result of which the filament is hit millions of times a second by the bombardment of the molecules around it in a merciless ring of tormentors. The vibrations of the current in similar manner will cause the infinite jostling of the molecules of solid and gas against a small polished carbon or metallic button or bar in a lamp, and brilliant light is also obtainable in this way.

LIGHT AND PHOTOGRAPHS WITH TESLA PHOSPHORESCENT BULBS.

IN the field of lighting by phosphorescence we reach hitherto untrodden ground. Phosphorescent light has been associated with the idea of "cold light," or the property of becoming luminous with the omission of the intermediate step of combustion, as commonly understood. As a physical action, we know it in the light of the firefly, which Professor S. P. Langley rates at an efficiency of 100 per cent., all its radiations lying within the limits of the visible spectrum. By means of the Teslaic currents phosphorescent light strong enough even to photograph by has been obtained; and Fig. 3, representing the inventor himself, is the first portrait or photograph of any kind ever taken by phosphorescent light. A bulb whose light-giving member is coated with sulphide of zinc treated in a special way was rendered phosphorescent by means of current obtained from a high-frequency transformer coil. The current used was alternated or oscillated about 10,000 times per second. The exposure was about eight minutes.

Fig. 4, of Mr. Clemens (Mark Twain), was taken a few weeks later — early in 1894 — with the aid of the same bulb, and with an exposure of about ten minutes. In order to test more closely the actinic value of phosphorescent light, some bulbs subject to high-frequency currents were photographed, or, if we may coin a new word, "phosphographed," with a somewhat longer exposure. They are shown in Fig. 5. The right-hand, bright pair utilize sulphide of zinc in some form for luminosity. The third bulb, seen faintly to the left of them, has a coating of sulphide of calcium. Although, judged by the eye, it glowed with a brightness fully equal to that of the other two, the actinic value was

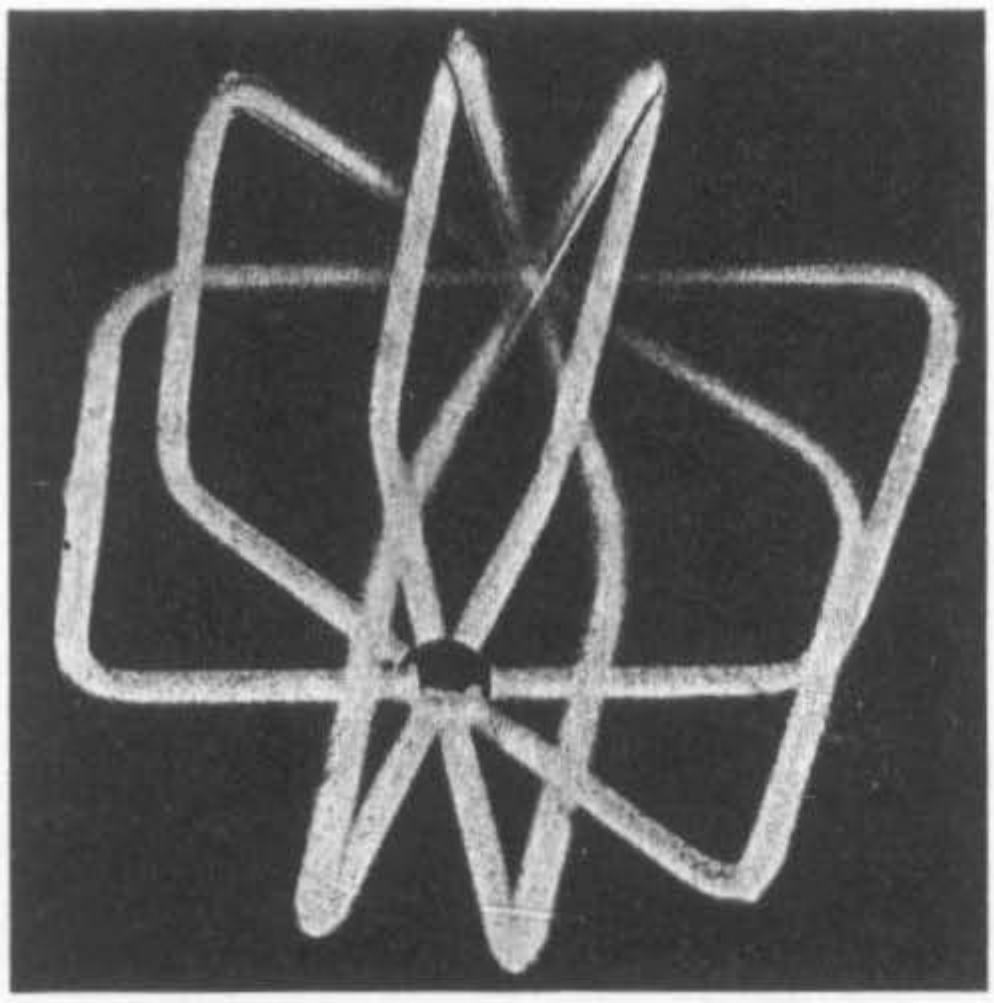


FIG. 6.

FIGS. 6, 7, AND 8 ARE TESLA TUBES OF DIFFERENT FORMS IN WHICH LIGHT IS OBTAINED WITHOUT FILAMENT OR COMBUSTION. (PHOTOGRAPHED BY THEIR OWN LIGHT.)

evidently much less. It is, perhaps, needless to say that these demonstrations invite to an endless variety of experiments, in which investigators will find a host of novel phenomena awaiting them as to phosphorescence and fluorescence produced with electrical currents.

LIGHT FROM EMPTY BULBS IN FREE SPACE.

THE third and fourth classes of lighting enumerated above as obtained by Teslaic currents are those caused by the incandescence or phosphorescence of a rarefied gas and the luminosity of a gas at ordinary pressure. We get pure, beautiful light without any filament or any combustion. In Figs. 6, 7, and 8 we have tubes or bulbs by means of which some of these interesting phenomena are obtained and illustrated. The bulbs shown are more or less exhausted of air. In the case of Figs. 6 and 7 the glass of the tubes is the ordinary German glass. In Fig. 8, uranium glass—green—was employed. This last was held in the hand while a photograph was taken of it by its own light; whence the unsteadiness of the negative. To obtain the beautiful illumination seen in all three, the bulbs were simply approached within a few inches of the terminal of a high-frequency coil or transformer. Just here it may be pointed out that the lamps are spoken of as unattached, in free space. Ordinary incandescent lighting is done, as everybody knows, with the lamps' bases firmly attached to the two current-bearing wires. Even where the lamps have been used on the ordinary alternating circuits in which the transformer is employed to "step down," or reduce, for safe use, the higher-tension current brought to it by the wire from the dynamo, the lamps have to be attached to the "secondary" wires of the coil so as to make a closed circuit for



FIG. 8.

them. But as we rise in the frequency of the current, as we leave behind the electrodynamic conditions for the electrostatic ones, so we free ourselves from the restrictions and limitations of solid wires for the conveyance of the effects sought, until at last we reach a point where all the old ideas of the necessity of a tangible circuit vanish. It is all circuit if we can properly direct the right kind of impulses through it. As Mr. Tesla long ago pointed out, most of the experiments usually performed with a static machine of glass plates can also be performed with an induction-coil of wire if the currents are alternated rapidly enough; and it is in reality here that Mr. Tesla parts company with other distinguished workers who have fixed their attention merely on the results attainable with electrodynamic apparatus. Before passing on, let us quote the inventor himself:

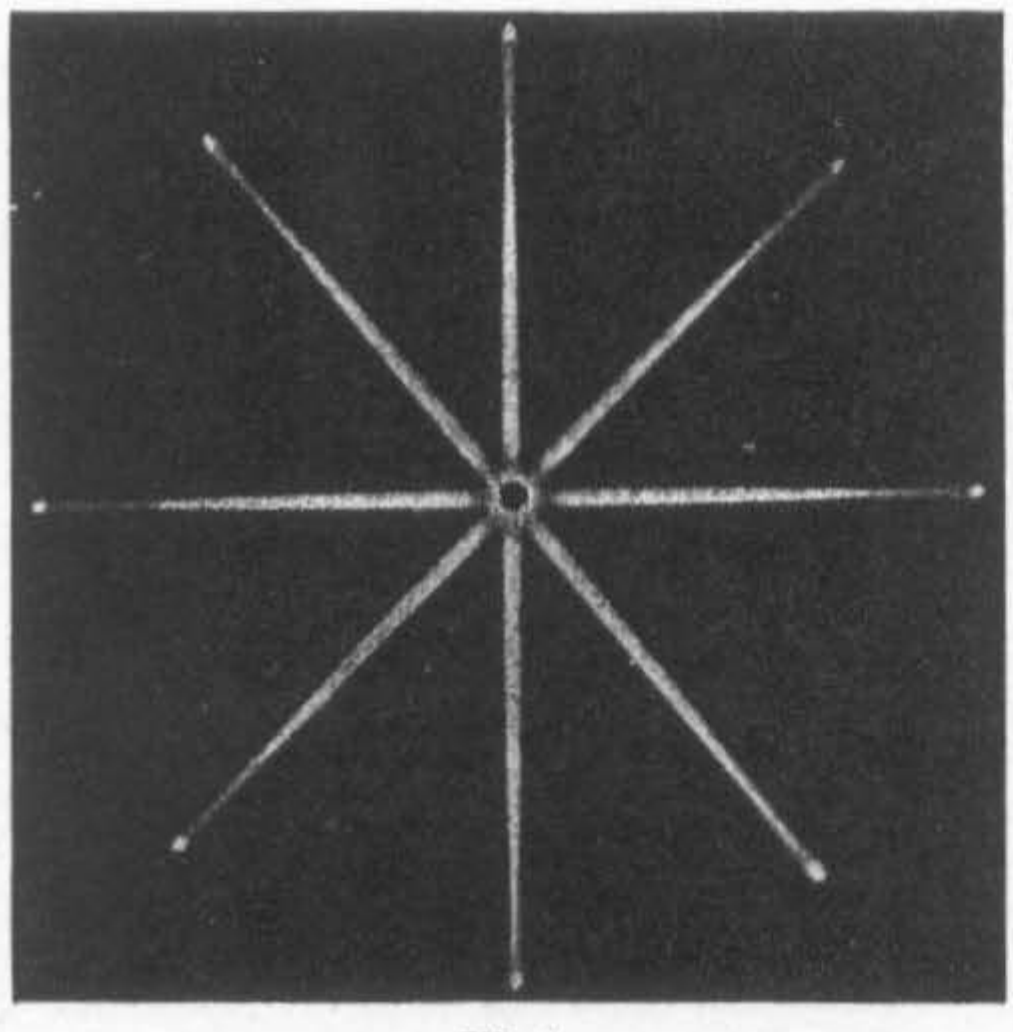


FIG. 7.

Powerful electrostatic effects are a *sine quâ non* of light production on the lines indicated by theory. Electromagnetic effects are primarily unavailable, for the reason that to produce the required effects

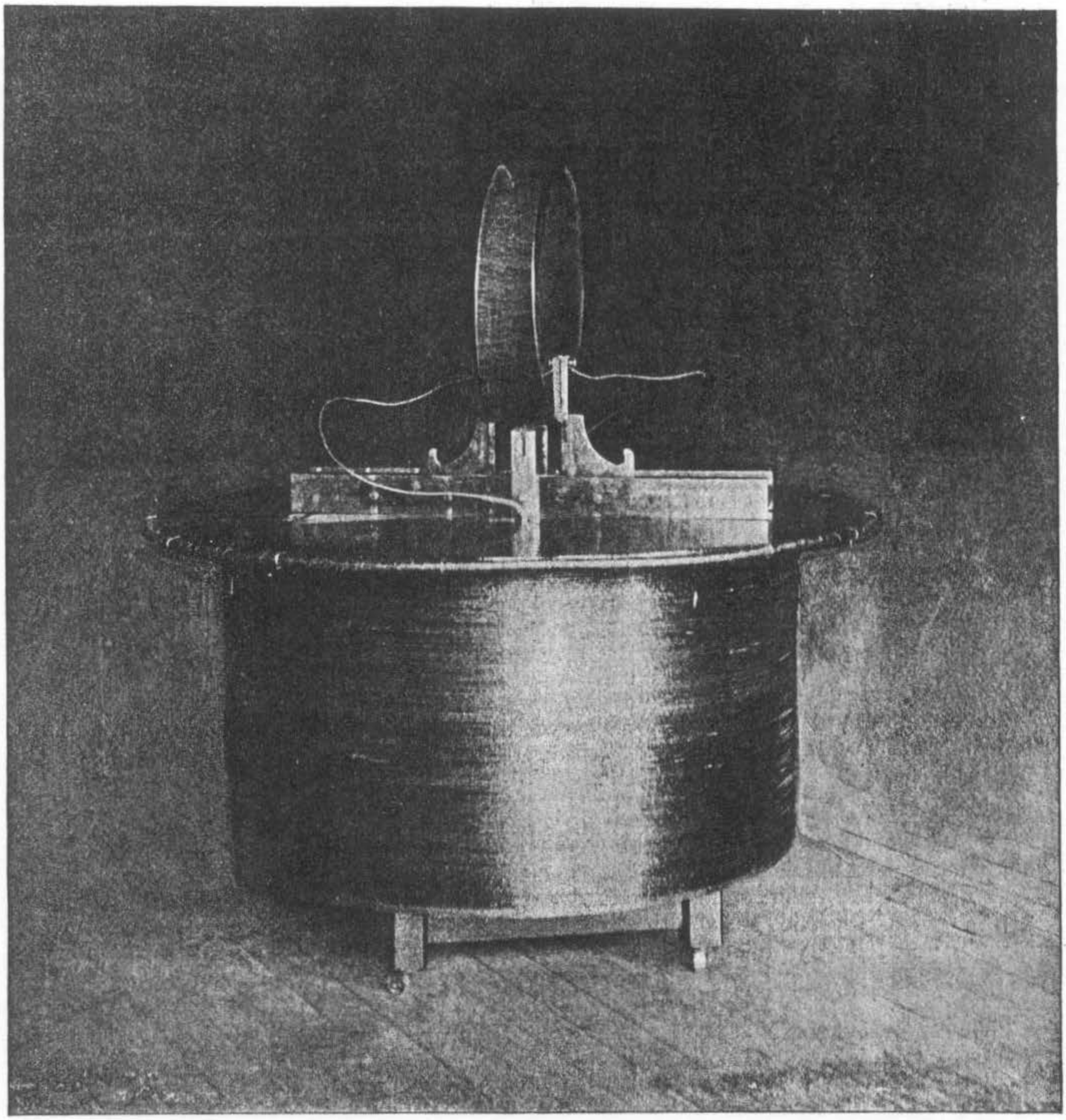


FIG. 9. EXPERIMENT SHOWING PLAY OF ELECTRIC SPARKS BETWEEN CONDENSER PLATES, PRODUCED BY ELECTRIC CHARGE. THE COIL, STANDING IN THE CENTER OF A LARGE ROOM, IS UNCONNECTED WITH THE ENERGIZING CIRCUIT. (FROM FLASH-LIGHT PHOTOGRAPH.)

we would have to pass the current impulses through a conductor which, long before the required frequency of the impulses could be reached, would cease to transmit them. On the other hand, electromagnetic waves many times longer than those of light, and producible by sudden discharge of a condenser, could not be utilized, it would seem, unless we availed ourselves of their effect upon conductors as in the present methods, which are wasteful. We could not affect by means of such waves the static molecular or atomic charges of a gas, and cause them to vibrate and to emit light. Long transverse waves cannot, apparently, produce such effects, since excessively small electromagnetic disturbances may pass readily through miles of air. Such dark waves, unless they are of the length of true light-waves, cannot, it would seem, excite luminous radiation in a Geissler tube, and the luminous effects which are producible by induction in a tube devoid of electrodes, I am inclined to consider as being of an electrostatic nature. To produce such luminous effects straight electrostatic thrusts are required; these, whatever be their frequency, may disturb the molecular charges and produce light.

EFFECTS WITH ATTUNED BUT WIDELY SEPARATED CIRCUITS.

A FEW experiments performed in Mr. Tesla's laboratory workshop afford an idea of the flexibility of the methods by which powerful electrostatic effects are produced across many feet of intervening space. The workshop is a room about forty by eighty feet, and ten or twelve feet

high. A circuit of small cable is carried around it from the terminals of the oscillator. In the center of the clear, open space is placed a coil, wound drum fashion, three or four feet high, and unconnected with the current source save through the medium of the atmosphere. The coil is provided, as shown in the picture, with two condenser plates for adjustment, standing up like cymbals. The plates act after the manner of a spring, and the coil is comparable to an electromagnetic weight. The system of apparatus in the middle of the room has therefore a certain period of vibration, just as though it were a tuning-fork, or a sheet of thin resonant glass. Around the room, over the cable, there are sent from the oscillator electrical current vibrations. By carefully adjusting the condenser plates so that the periodicity or swing of the induced current is brought into step with that of the cable currents, powerful sparks are made to pour across between the plates in the dense streams shown in Fig. 9. In this manner it is easy to reach tensions as high as 200,000 and 300,000 volts.

No one who has witnessed these significant experiments can fail to be impressed with the evidence of the actuality of a medium, call it ether or what you will, which in spite of its wonderful tenuity is as capable of transmitting energy as though it were air or water. Still more impressive to a layman, perhaps, is the confidence and easy precision with which these fine adjustments are brought about.

In Fig. 10 there is a similar coil, in the middle of the same room, which has been so adjusted to the vibrations sent around the shop that an ordinary sixteen-candle-power incandescent lamp is well lighted up.

Fig. 11 pursues this a little further. Above the coil a circle of wire is held by an observer, and an incandescent lamp is attached to the circle. As before, the vibration of the ether in the coil is brought into harmony with the vibrations emitted from the cable. The inductive effect upon the circle held loosely in free space by the observer is so pronounced that the lamp is immediately lighted up, though it may be connected with but one terminal wire, or with two. A 100-volt lamp is used, requiring when employed ordinarily more than one tenth of a horse-power right off the connecting circuit wires direct from the dynamo to bring it up to proper illuminating value. Hence, as will be seen, there is actual proof here of the transmission of at least that amount of energy across a space of some twenty feet and into the bulb by actually no wire at all. This need not surprise us when we remember that on a bright day the ether delivers steadily from the sun a horse-power of energy to every seven square feet of the earth's

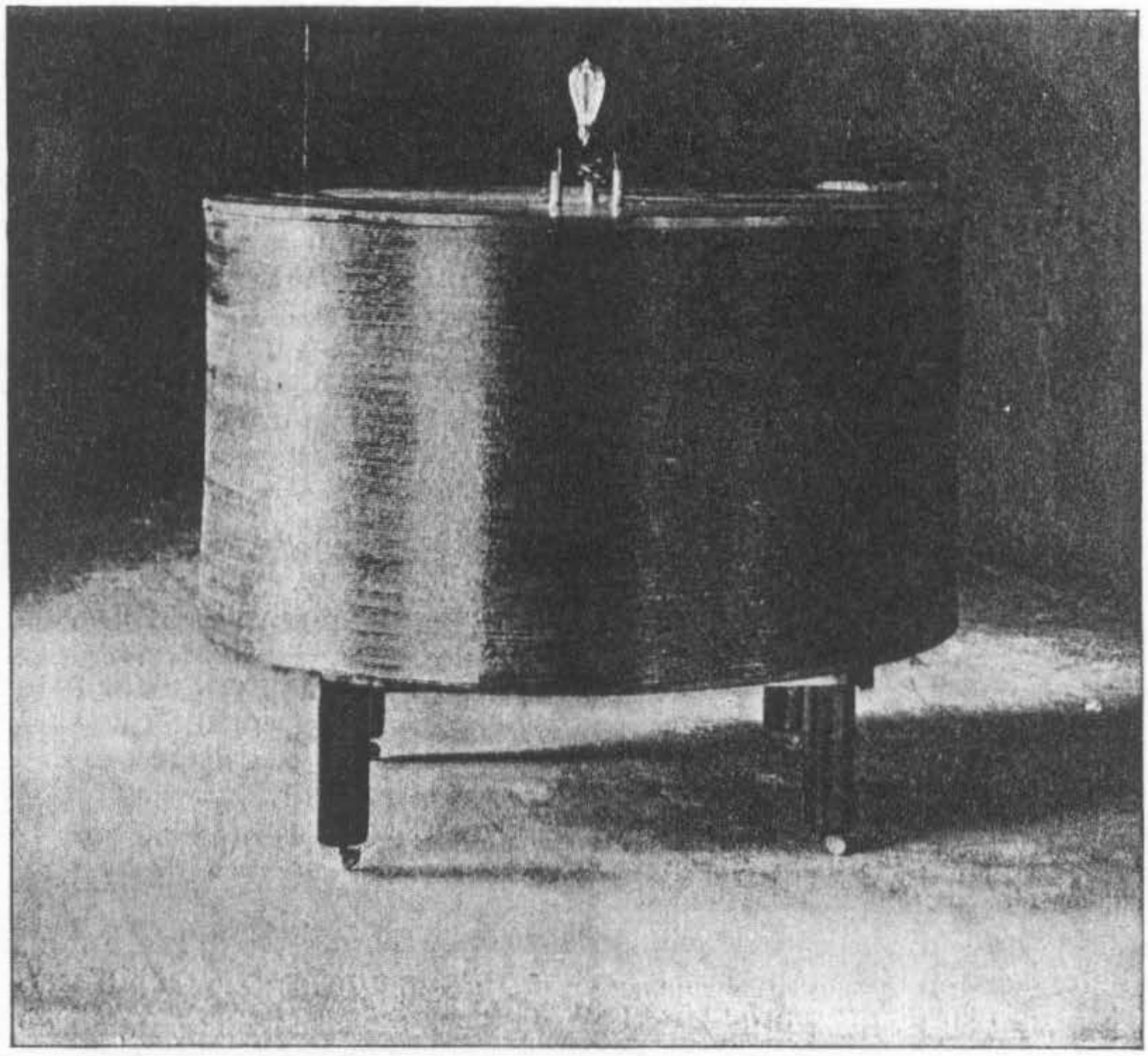


FIG. 10. EXPERIMENT SHOWING THE LIGHTING UP OF AN ORDINARY INCANDESCENT LAMP, AT A DISTANCE, THROUGH THE INFLUENCE OF ELECTRIFIED ETHER-WAVES. (FROM FLASH-LIGHT PHOTOGRAPH.)

surface toward it: so great is its capacity for transmitting energy. Mr. Tesla with his "electrostatic thrusts" has simply learned the knack of loading electrically on the good-natured ether a little of the protean energy of which no amount has yet sufficed to break it down or put it out of temper. We may assume either an enormous speed in what may be called the transmitting wheelwork of the ether, since the weight is inconceivably small; or else that the ether is a mere transmitter of energy by its well-nigh absolute incompressibility.

CURIOUS "IMPEDANCE" PHENOMENON.

IN Fig. 12 we have another remarkable experiment illustrated. Standing over the coil in the center of the room, the observer holds a hoop of stout wire in his hand. One or more lamps are connected with two points on the wire, so that the lamps are "short-circuited" by the short bar of wire. The vibrations are, however, so extremely rapid that in spite of the opposite terminals being united in this way, the current does not flow past them neglectfully, in the apparently easier path, as it should, but brings them to a bright incandescence. We have here an example of what is known as "impedance" phenomena, in which the current is oddly choked back at certain points and not at others. Under the conditions of "impedance," the best electrical conductor loses its property of conducting, and behaves like a highly resisting substance. Elaborating further these experimental results, Mr. Tesla shows that a gas — a perfect non-conductor under ordinary circumstances — may be more conductive than the best copper wire, provided the currents vibrate rapidly enough. The fantastic side of this phenomenon he touched on playfully once by suggesting that perchance in such wise we might some day utilize gas to convey electricity, and the old gas-pipe to insulate it.

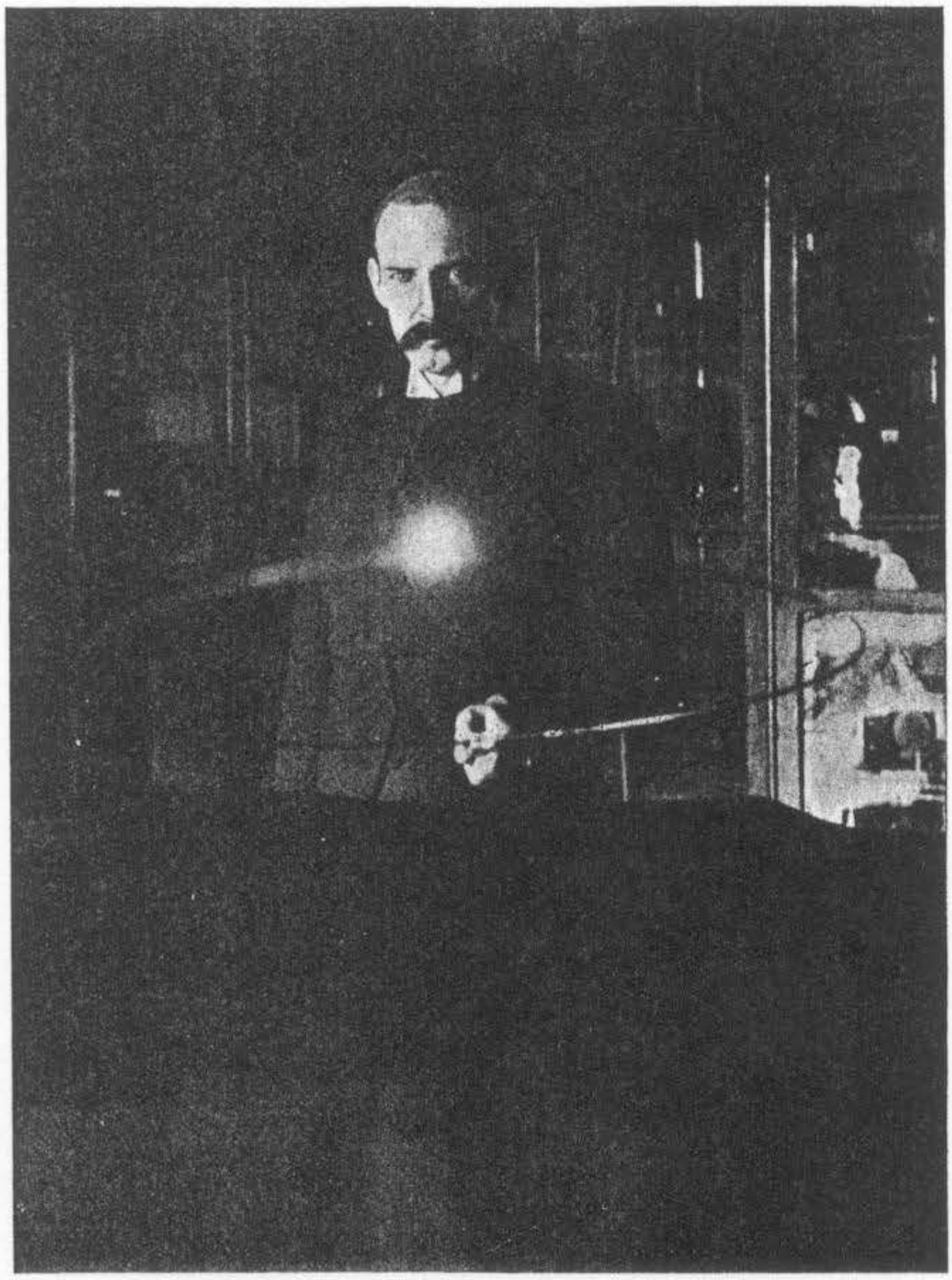


FIG. 11. EXPERIMENT ILLUSTRATING THE LIGHTING OF AN INCANDESCENT LAMP IN FREE SPACE BY INDUCTION FROM COIL BELOW, ENERGIZED BY DISTANT CIRCUIT AROUND THE ROOM. THE LOOP OF WIRE CARRYING THE LAMP IS HELD BY MR. MARION CRAWFORD. (FROM FLASH-LIGHT PHOTOGRAPH.)

LAMPS LIGHTED BY CURRENTS PASSED THROUGH THE HUMAN BODY.

IN Fig. 13 a most curious and weird phenomenon is illustrated. A few years ago electricians would have considered it quite remarkable, if indeed they do not now. The observer holds a loop of bare wire in his hands. The currents induced in the loop by means of the "resonating" coil over which it is held, traverse the body of the observer, and at the same time, as they pass between his bare hands, they bring two or three lamps held there to bright incandescence. Strange as it may seem, these currents, of a voltage one or two hundred times as high as that employed in electrocution, do not inconvenience the experimenter in the slightest. The extremely high tension of the currents which Mr. Clemens is seen receiving prevents them from doing any harm to him.

TRANSMISSION OF INTELLIGENCE BY ATTUNED OR "RESONATING" CURRENTS.

REFERENCE has been made to the "resonating" quality of the circuits and coils. It would be

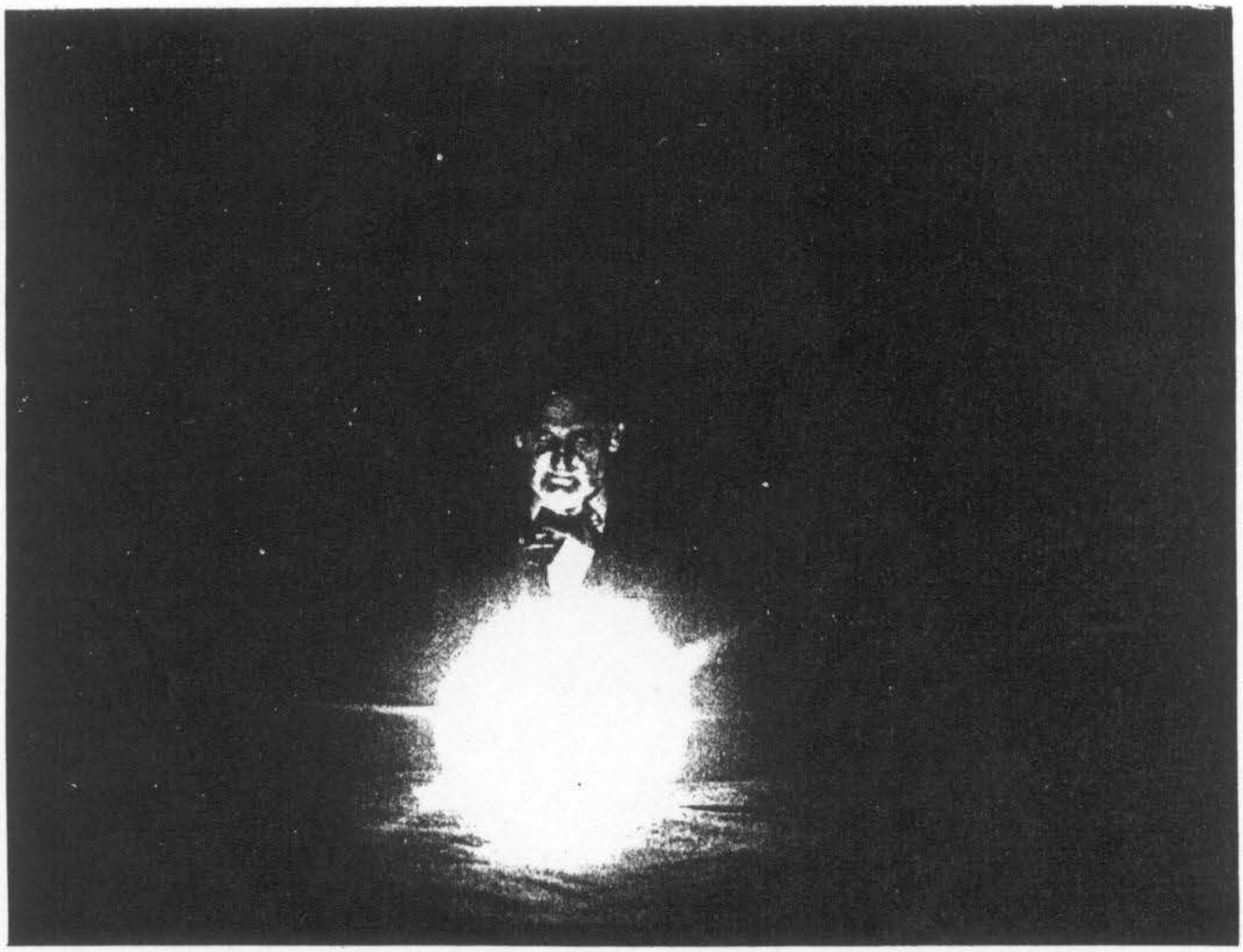


FIG. 12. SIMILAR EXPERIMENT, ILLUSTRATING THE PHENOMENON OF IMPEDANCE. THE LOOP OF WIRE, CARRYING TWO LAMPS, IS HELD BY MR. JOSEPH JEFFERSON. (FROM FLASH-LIGHT PHOTOGRAPH.)

wearisome, and indeed is not necessary, here to dwell on the difficulty often experienced in establishing the relation of "resonance," and the instantaneity with which it can be disturbed. It may be stated, in order to give some idea of the conditions to be observed in these experiments, that when an electric circuit is traversed by a rapidly oscillating current which sets up waves in the ether around the wire, the effect of these waves upon another circuit situated at some distance from the first can be largely varied by proper adjustments. The effect is most pronounced when the second circuit is so adjusted that its period of vibration is the same as that of the first. This harmonizing is deftly accomplished by varying either of the two elements which chiefly govern the rapidity of the vibration, viz., the so-called "capacity" and the "self-induction." Whatever the exact process may be, it is clear that these two quantities in their effect answer almost directly to what are known in mechanics as pliability and as weight or inertia. Attach to a spring a weight, and it will vibrate at a certain rate. By changing the weight, or modifying the pliability of the spring, any period of vibration is obtainable. In very exact adjustments, minute changes will completely upset the balance, and the very last straw of fine wire, for example, in the induction-coil which gives the self-induction will break the spell. As Mr. Tesla has said, it is really a lucky thing that pure resonance is not obtainable; for if it were, all kinds of dangers might lie in store for us by the increasing oscillations of every kind that would be set up. It will, however, have been gathered that if one electrical circuit can be tuned to another effectively, we shall need no return wire, as heretofore, for motors or for lights, the one wire being, if anything, better than two, provided we have vibration of the right value; and if we have that, we might get along without any wires or any "currents." Here again we must quote Mr. Tesla:

In connection with resonance effects and the problem of transmission of energy over a single conductor, I would say a few words on a subject which constantly fills my thoughts, and which concerns the welfare of all. I mean the transmission of intelligible signals, or perhaps even power, to any distance without the use of wires. I am becoming daily more convinced of the practicability of the scheme; and though I know full well that the majority of scientific men will not believe that such results can be practically and immediately realized, yet I think that all consider the develop-

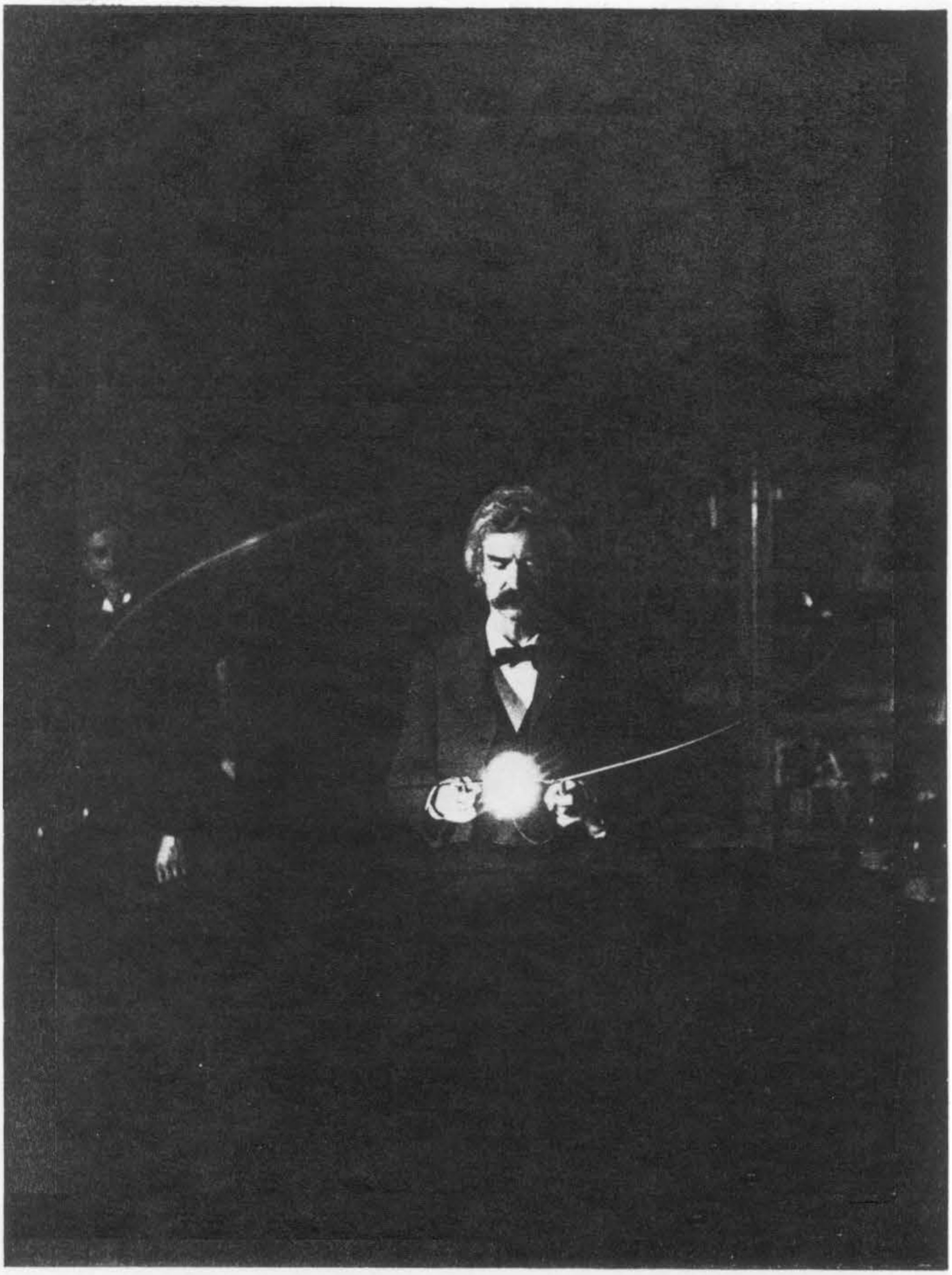


FIG. 13. SIMILAR EXPERIMENT, THE HIGH-TENSION CURRENT BEING PASSED THROUGH THE BODY BEFORE IT BRINGS THE LAMPS TO INCANDESCENCE. THE LOOP IS HELD OVER THE RESONATING COIL BY MR. CLEMENS (MARK TWAIN). (FROM A FLASH-LIGHT PHOTOGRAPH.)

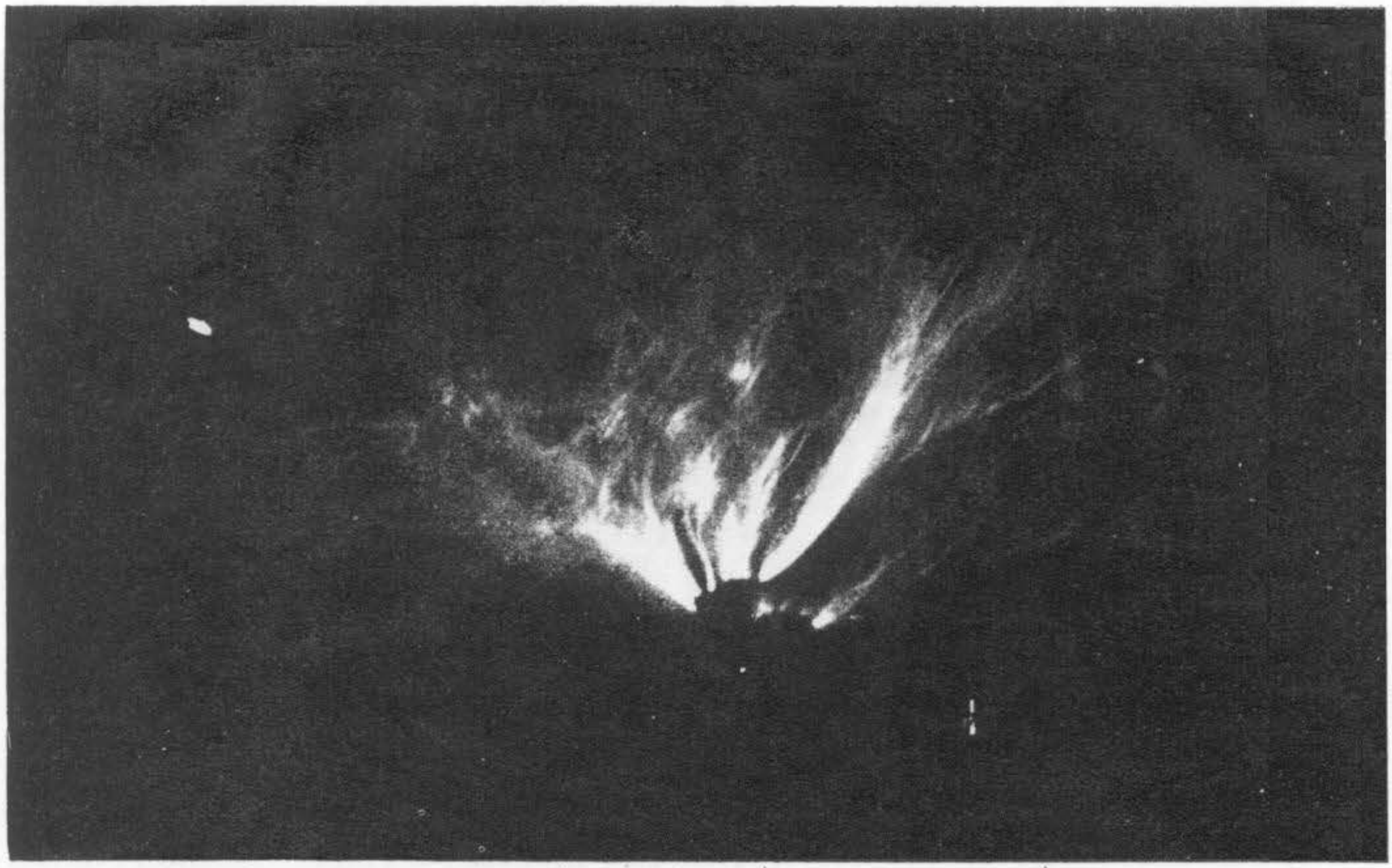


FIG. 14. EFFECT OF ELECTRICAL DISCHARGE FROM THE EARTH BY TESLA COIL. (PHOTOGRAPHED BY ITS OWN LIGHT.)

ments of recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering which must be carried out some day. The idea of transmitting intelligence without wire is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far; but I do firmly believe that it is practicable to disturb by means of powerful machines the electrostatic condition of the earth, and thus transmit intelligible signals and perhaps power. In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why, then, not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile-posts the earth may appear very large; but to that happiest of all men, the astronomer, who gazes at the heavens, and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician; for when he considers the speed with which an electric disturbance is propagated through the earth, all his ideas of distance must completely vanish. A point of great importance would be first to know what is the capacity of the earth, and what charge does it contain of electricity.

DISTURBANCE AND DEMONSTRATION OF THE EARTH'S ELECTRICAL CHARGE.

PART of Mr. Tesla's more recent work has been in the direction here indicated; for in his oscillator he has not simply a new practical device, but a new implement of scientific research. With the oscillator, if he has not as yet actually determined the earth's electrical charge or "capacity," he has obtained striking effects which conclusively demonstrate that he has succeeded in disturbing it. He connects to the earth, by one of its ends, a coil (see Fig. 15) in which rapidly vibrating currents are produced, the other end being free in space. With this coil he does actually what one would be doing with a pump forcing air into an elastic football. At each alternate stroke the ball would expand and contract. But it is evident that such a ball, if filled with air, would, when suddenly expanded or contracted, vibrate at its own rate. Now if the strokes of the pump be so timed that they are in harmony with the individual vibrations of the ball, an intense vibration or surging will be obtained. The purple streamers of electricity thus elicited from the earth and pouring out to the ambient air are marvelous. Such a display is seen in Fig. 14, where the crown of the coil, tapering upward in a Peak of Teneriffe, flames with the outburst of a solar photosphere.

The currents which are made to pass in and out of the earth by means of this coil can also be directed upon the human body. An observer mounted on a chair, and touching the coil with a metal rod, can, by careful adjustments, divert enough of it upon himself to cause its manifestation from and around him in splinters of light. This halo effect, obtained by sending the electricity of the earth through a human being,—the highest charge positively ever given in safety,—

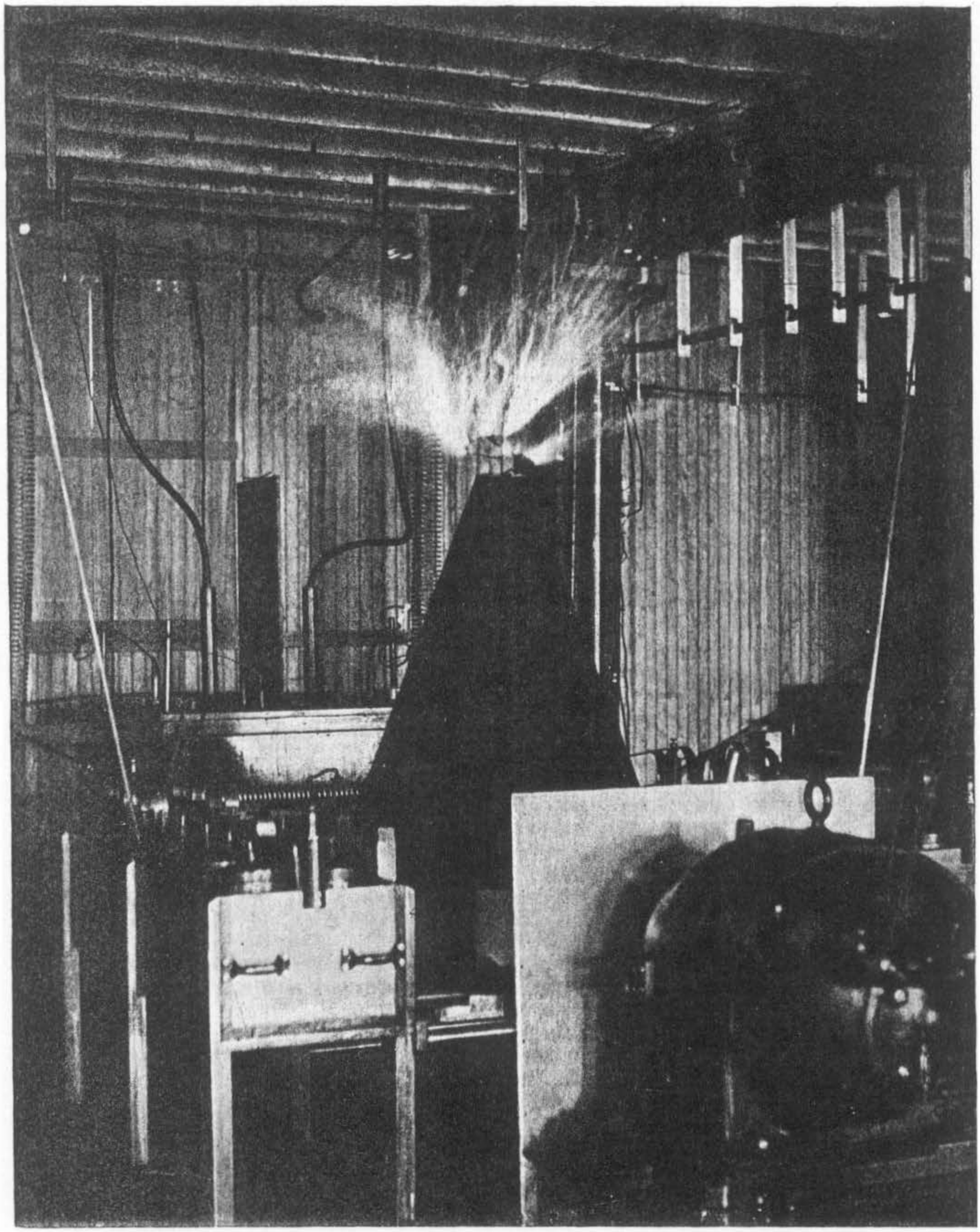


FIG. 15. TESLA COIL FOR ASCERTAINING AND DISCHARGING THE ELECTRICITY OF THE EARTH. THE STREAMERS AT TOP OF COIL ARE OF PURPLE HUE, AND IN FORM RESEMBLE FILAMENTS OF SEAWEED, THE EFFECT OF MASS BEING CAUSED BY PROLONGED EXPOSURE OF FLASH-LIGHT NEGATIVE.

is, to say the least, curious, and deeply suggestive. Mr. Tesla's temerity in trying the effect first upon his own person can be justified only by his close and accurate calculation of what the amount of the discharge from the earth would be.

Considering that in the adjustments necessary here, a small length of wire or a small body of any kind added to the coil or brought into its vicinity may destroy entirely all effect, one can imagine the pleasure which the investigator feels when thus rewarded by unique phenomena. After searching with patient toil for two or three years after a result calculated in advance, he is compensated by being able to wit-

ness a most magnificent display of fiery streams and lightning discharges breaking out from the tip of the wire with the roar of a gas-well. Aside from their deep scientific import and their wondrous fascination as a spectacle, such effects point to many new realizations making for the higher welfare of the human race. The transmission of power and intelligence is but one thing; the modification of climatic conditions may be another. Perchance we shall "call up" Mars in this way some day, the electrical charge of both planets being utilized in signals.

Here are great results, lofty aims, and noble ideas; and yet they are but a beggarly few of all those with which Mr. Tesla, by his simple, modest work, has associated his name during recent years. He is not an impracticable visionary, but a worker who, with solid achievements behind him, seeks larger and better ones that lie before, as well as fuller knowledge. I have ventured to supplement data as to his late inventions by some of his views as to the ether, which throughout this presentation of his work has been treated familiarly as the maid-of-all-work of the universe. All our explanations of things are but half-way houses to the ultimate facts. It may be said, then, in conclusion, that while Mr. Tesla does not hold Professor Oliver Lodge's ingenious but intricate notion of two electricities and two ethers, and of the ether as itself electricity, he does belong to what Lord Kelvin has spoken of as the nineteenth-century school of plenum, accepting one ether for light, heat, electricity, and magnetism, outward manifestations of an inward unity whose secret we shall some day learn.

Thomas Commerford Martin.

IN TESLA'S LABORATORY.

HERE in the dark what ghostly figures press!—
No phantom of the Past, or grim or sad;
No wailing spirit of woe; no specter, clad
In white and wandering cloud, whose dumb distress
Is that its crime it never may confess;
No shape from the strewn sea; nor they that add
The link of Life and Death—the tearless mad,
That live nor die in dreary nothingness:

But blessèd spirits waiting to be born—
Thoughts, to unlock the fettering chains of Things;
The Better Time; the Universal Good.
Their smile is like the joyous break of morn;
How fair, how near, how wistfully they brood!
Listen! that murmur is of angels' wings.

Robert Underwood Johnson.

Tesla's Laboratory Burned.

The laboratory of Nikola Tesla was burned on March 13th with its entire contents. The building in which his laboratory was located was at 33 and 35 South Fifth Ave., New York. The entire building was consumed, and the contents are a total loss. The fire was discovered between two and three o'clock in the morning. The fire gained such headway that it was soon beyond control. The experimental apparatus, models, plans, etc., in the laboratory, whose value can not be estimated in dollars and cents, were destroyed. The loss is felt not only by the wonderful investigator and inventor himself, but by the world at large. The work which was being done by Tesla, received the attention of all scientific and technical persons. A new laboratory is being fitted up and the work taken up again.

Engineering Magazine April 1895

THE BURNING OF TESLA'S LABORATORY.

By Thomas Commerford Martin.

OF Tycho Brahe's famous observatory at Uraniburg remain to-day but a mound of earth and a couple of holes. The same inventory would aptly apply to all that is left of the upper floor where Nikola Tesla has of late years been carrying on his suggestive and beautiful demonstrations in electricity. Two tottering brick walls and the yawning jaws of a sombre cavity aswim with black water and oil were all that could be seen on the morning of March 13 of a laboratory which to all who had visited it was one of the most interesting spots on earth. Beset by the squalor and clamor of plebeian South Fifth Avenue, the building was unpretentious, and its lower stories were given up to the prosaic details of an iron-pipe cutting business. Commonplace also was the origin of the disaster. A flaring gas jet, oil-soaked floors, and a "watchman" have been heard of before as an effective combination for midnight fires.

It has been curiously pathetic to note how universal was the expression of sympathy with Mr. Tesla in his loss. The newspaper dealers in the marvelous had been so relentlessly active in attempting to describe what they imagined to be going on in the laboratory that they experienced no difficulty in arousing regret as to the magnitude of the loss. But even now, if the average citizen were asked to explain definitely what he was grieving about, he would hesitate to answer. Impressions as to the laboratory have been mixed and weird. For example, one vivid young lady of the press, in her anxiety to be instructive, went so far as to depict herself undergoing a brilliant electrical ordeal that is possible only with the body entirely naked. This grotesque kind of misrepresentation has had vastly more terrors for Mr. Tesla than even the grim episode of last month. Nothing is so absurd as to suppose that inventors of his stamp relish the derogatory *persiflage* of the highly-colored articles that purport to reveal them and their work to the lay public. On the contrary, if it were not all so puerile, it would agonize men striving simply after scientific results and appreciative solely of scientific approval thus to be depicted in the *rôle* of charlatans,—that of a

> Katerfelto, with his hair on end,
> At his own wonders wondering for his bread.

Happily, the Tesla laboratory was visited not alone by irresponsible purveyors of popular misinformation, eager for a new topic to be handled with exhaustive inaccuracy. Happily, the selfish lion-hunters

of society have not been the only other class to which Mr. Tesla had an opportunity of presenting, with his unwearied good nature, new theories, new phenomena, and new apparatus. Happily, before the copper, glass, and insulation melted, physicists, electricians, and representative men in art and literature were able to see and judge for themselves what was forward. Indeed the pressure to secure an *entrée* to the laboratory had of recent months been extreme; and, now that the fire has occurred, perhaps it is as well that Mr. Tesla's imperative refusals once and again had their edges turned. The occasions are certainly rare when an inventor draws general notice to himself; and this is natural, for inventions deal chiefly with outward, material things. A poet or an artist can enter by his work into the life-blood of a people, and becomes part of their soul and growth. An ordinary inventor is more often like a man cutting his initials high up in the young bark of a sapling. The stem rises and expands, but the notches harden and stay ever at the same height, and are foreign to the tree's vital processes. At rare intervals the public becomes dimly conscious of new inventions that touch the arteries of social being; and then it is vaguely, but deeply, stirred. These inventions are generically such as affect and change our methods of obtaining light, heat, and power, our modes of travel, and the transmission of intelligence. The public had learned, more by intuition than knowledge, that Mr. Tesla was at work in each of these fields.

The Tesla laboratory was, in a sense, a private museum. The owner kept in it many souvenirs of bygone toil and experiment, and an important part of his records. During the past ten years Mr. Tesla has done an enormous amount of original experimentation, and it was all represented in the contents of the laboratory. His priority and preeminence in the polyphase current domain, which has been created by the development of his principle of the "rotating field," was richly exemplified by models and parts of single, two, three, and multiphase motors of all kinds. Some of the pieces showed how careful of his material the inventor always was. A close observer could discern that he had used it sometimes a dozen ways in a dozen forms. Readers of the ENGINEERING MAGAZINE may remember to have seen these relics in Electricity Building at the World's Fair, as well as the curious ring wound for two-phase circuits over a smooth disc upon which copper balls revolved at wild speed, or near which other bodies could be set spinning rapidly. This illustrated graphically the manner in which Mr. Tesla was able in his motors to dispense with commutators and brushes. Another notable class of apparatus in the laboratory was that employed for researches into the qualities and effects of currents of high potential and high frequency. Mr. Tesla's name is peculiarly associated with this work, and his too infrequent lectures have described a wide range of results obtained in lighting novel electric lamps, or empty bulbs, in free space, without any connection with the distant wires or machinery. In this group may be included his early dynamos for generating high-frequency currents, one of them giving as high as thirty thousand alternations per second; and of equal interest were the disruptive discharge coils designed and built specially to demonstrate a number of recondite and startling discharge phenomena. There were also several unique appliances with which novel conditions could be studied in insulation, induction, impedance, and resonance.

But that which was of largest interest to everybody was the group of oscillators. In the new machine to which he gave quite appropriately the name of "oscillator," Mr. Tesla had blended or merged the dynamo and steam engine, seeking thereby to secure a far higher efficiency than both could give individually at their best. It is curiously typical of the man that he had no sooner placed in the hands of electricians the means for the economical long-distance transmission of water powers—his system being adopted widely, for example, at Niagara—than he threw himself on the problems of getting electrical current more cheaply from steam; and that, while lavishly generous in personal intercourse, he is ever fighting savagely the waste that goes on in our utilization of Nature's resources. It is something to have rendered the waterfalls more useful, but one's sympathies must equally go out to work that is aimed at greater economy of coal. If each 10 hours' work of 1 h. p. from a steam engine requires a total of 6 tons of coal every year, and if that is subject to further tremendous losses when turned into electric current, it is worth the effort to aim at less wasteful processes. This is the goal of Mr. Tesla's oscillator, and he is sanguine enough to believe that he has reached it.

The oscillator is simply a steam chest dissociated from all the orthodox governing mechanism, and joined in a new partnership with sets of electro-magnetic coils, into whose fields of force it thrusts reciprocatively armatures carried by its pistons, the regulation being subtly accomplished by the currents that are thus set up. The reduction in bulk is very striking, but obvious; while the reduction in steam consumption and the higher value of the currents are both elements that Mr. Tesla believes he has insured to a significant degree. He makes few mistakes.

Only one oscillator had ever been shown in public,—that, namely, which Mr. Tesla used in his lecture before the Electrical Congress at Chicago, in August, 1893, employing compressed air as the working fluid, for convenience. That machine and later types were all to be seen at the laboratory. The most advanced form shown to visitors

was a very neat mechanism, entirely practical and successful, by means of which the laboratory had been lighted for months as well as furnished with current for the work done with the high-frequency apparatus alluded to above. It was run at 350 lbs. steam pressure; but, although there was no packing, no leakage of steam could be detected. Two pistons vibrated in opposite phase eighty times per second. The vibrations of these pistons past two sets of electromagnets developed current that was led to a bank of fifty or sixty incandescent lamps, which were lighted up to full candle-power and were steadiness itself in illumination. Current was also furnished by the machine to four arc lamps and to motors, as well as to devices of a fascinating nature, by means of which Mr. Tesla would light up tubes or ordinary incandescent lamps in the centre of the laboratory,—a room perhaps 40 feet by 80. He also used the current to experiment boldly with the electrical charge of the earth itself. One cannot but regret that all these first fruits of penetrative investigation have gone down in the wreck at South Fifth Avenue. They are being swiftly reproduced by incessant labor on the part of the dauntless inventor, but as the first, and, for awhile, the only exemplars of their kind, they are now touched with a sentimental interest unworthy neither of those who feel it or of the objects themselves.

Perhaps the most painful loss of all is the destruction of Mr. Tesla's notes and papers. His memory is all right, and flashes on any experiment of the past with the revealing power of a search-light; but when can leisure now be won to jot things down that, marking achievement on one hand, might also save other experimenters years of toil, and that would show to capital as well the doors open as the paths that are blind. The loss falls least heavily on the loser. Like many another tireless experimenter, he hoped to give the world with due rapidity the report of his failures as well as of his discoveries, but he had not counted on casual destruction of memorabilia by fire as one of the obstacles in his way. Mr. Tesla had taken the papers to his laboratory so that he might work on them in brief leisure spells, and was thus the victim of his own conscientious endeavor to be of use to his fellow-electricians. There seems to be a fate about such things. Galileo's own son, from filial religious motives, destroyed some of his father's dearest manuscripts; and it was no less a friend than John Stuart Mill who burnt up for poor Carlyle the first volume of the unprinted "French Revolution." It took Carlyle four weeks, and heaps of the trashiest novels, to quiet his mind after the miserable accident. Tesla was at work again with clenched determination while the ashes of his hopes lay hot.

THE

Electrical Engineer.

Vol. XIX. APRIL 3, 1895. No. 361.

STAGES AND TYPES OF THE TESLA OSCILLATOR.



Tesla Coil Demonstrating Earth's Electrical Charge (Sketched from April Century). Fig. 9.

THE recent destruction by fire of the building in New York City in which Mr. Tesla's laboratory was situated, and the consequent wreck of all his valuable apparatus, lends special value to the illustrations herewith, never before shown, of a number of Tesla oscillators. It will interest our readers to know that the engravings were made about a year ago, but were laid aside awaiting the completion of other and later work, all of which Mr. Tesla proposed to bring in rounded shape before one or other of the scientific societies, accompanied by actual demonstrations with the machinery. Fate has willed otherwise, and these pictures are practically all that can now be shown, except the engraving secured by the *Century Magazine* of the latest "double oscillator" and printed by that publication in its April issue. In view of the fire, it becomes proper and desirable to bring these machines to general notice, and we have obtained Mr. Tesla's consent to our doing so at this juncture.

In order to render the series of Tesla oscillators in some degree complete and consecutive, we have reproduced here from THE ELECTRICAL ENGINEER of Nov. 8, 1893, the cut of one of the machines shown before the Electrical Congress, at Chicago, using compressed air as the working fluid (Fig. 1.) It will be remembered that the principle involved in the oscillator is that of oscillating a coil or magnet, with great economy of energy, in an intense field, and thus generating current on terms of very high efficiency and regularity, as well as with marked diminution in size and weight of apparatus. The engine resolves itself down to a chest or cylinder for the working fluid and the piston for carrying the armature. The article in the ENGINEER to which we have referred above gives a number of details, with a diagram, and other data will be found in Mr. Martin's work on Mr. Tesla's inventions.

Fig. 2 was one of the oscillators shown at Chicago in August, 1893. It was actuated by compressed air there during the lecture delivered by Mr. Tesla. The machine consists of an engine mounted on an ornamental column, carrying on top a generator similar to that shown in E of Fig. 7.

An analogous form is shown in Fig. 3, without the generator. In the box on top of the column there is a

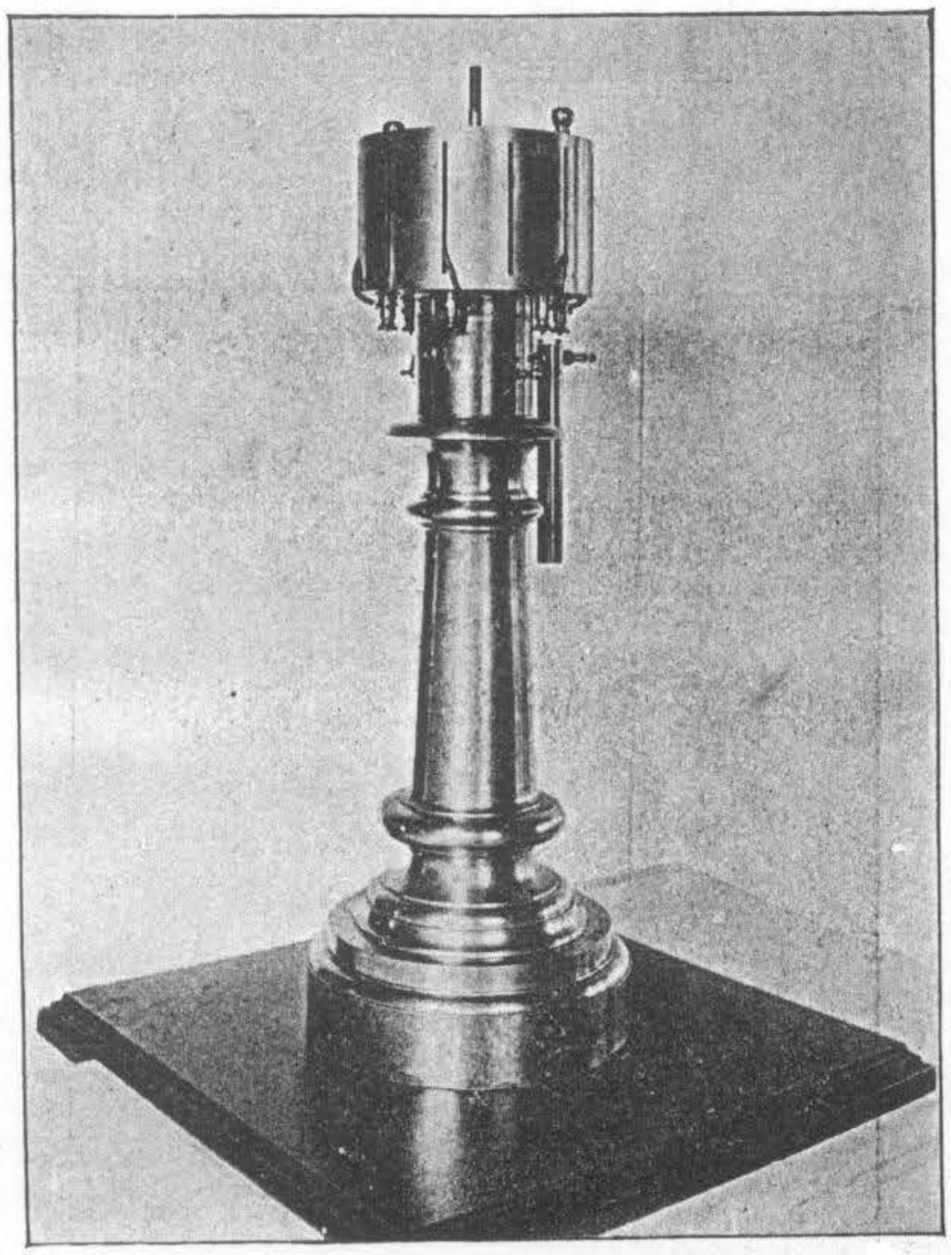


FIG. 2.

TYPES OF TESLA OSCILLATOR.

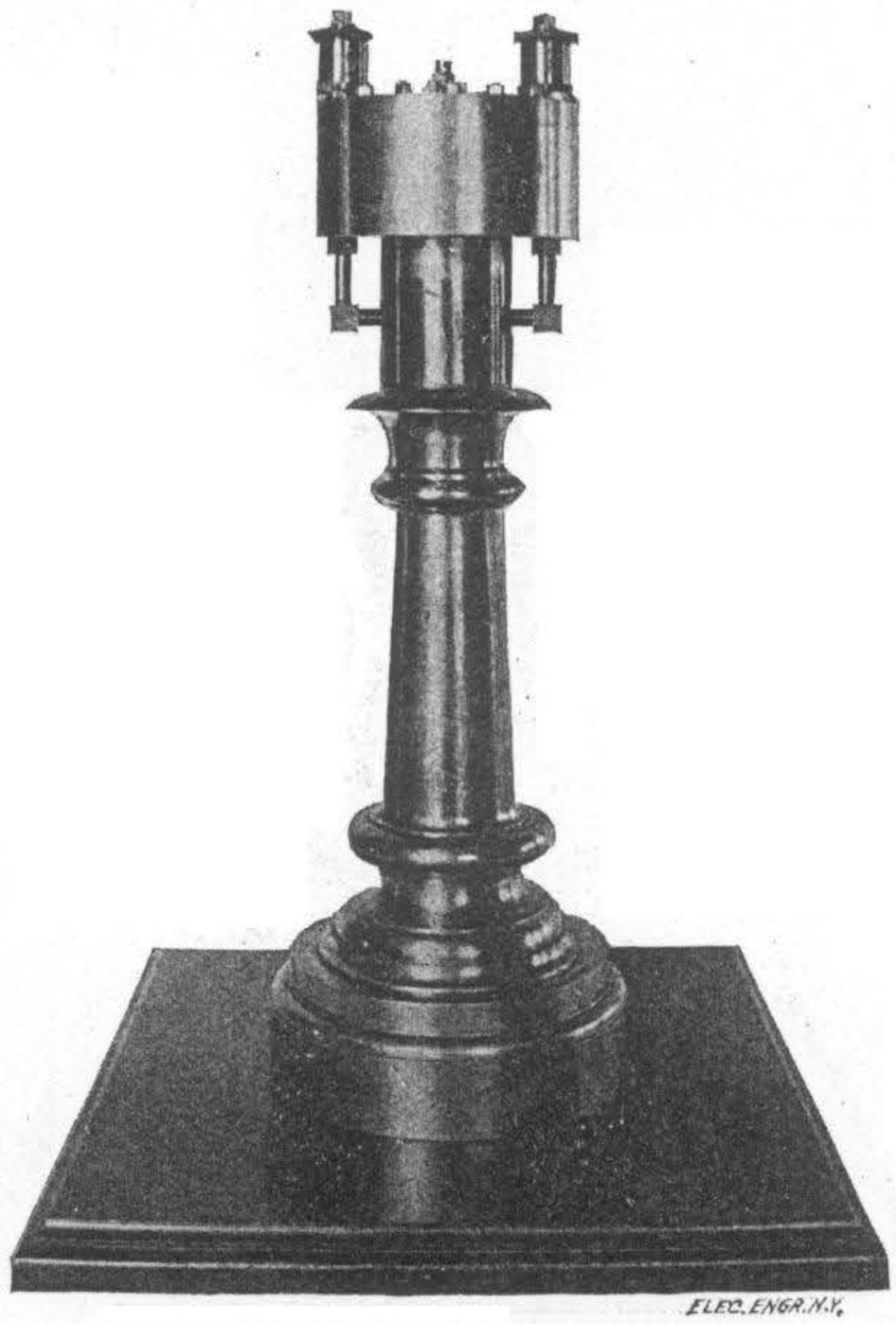


FIG. 3.

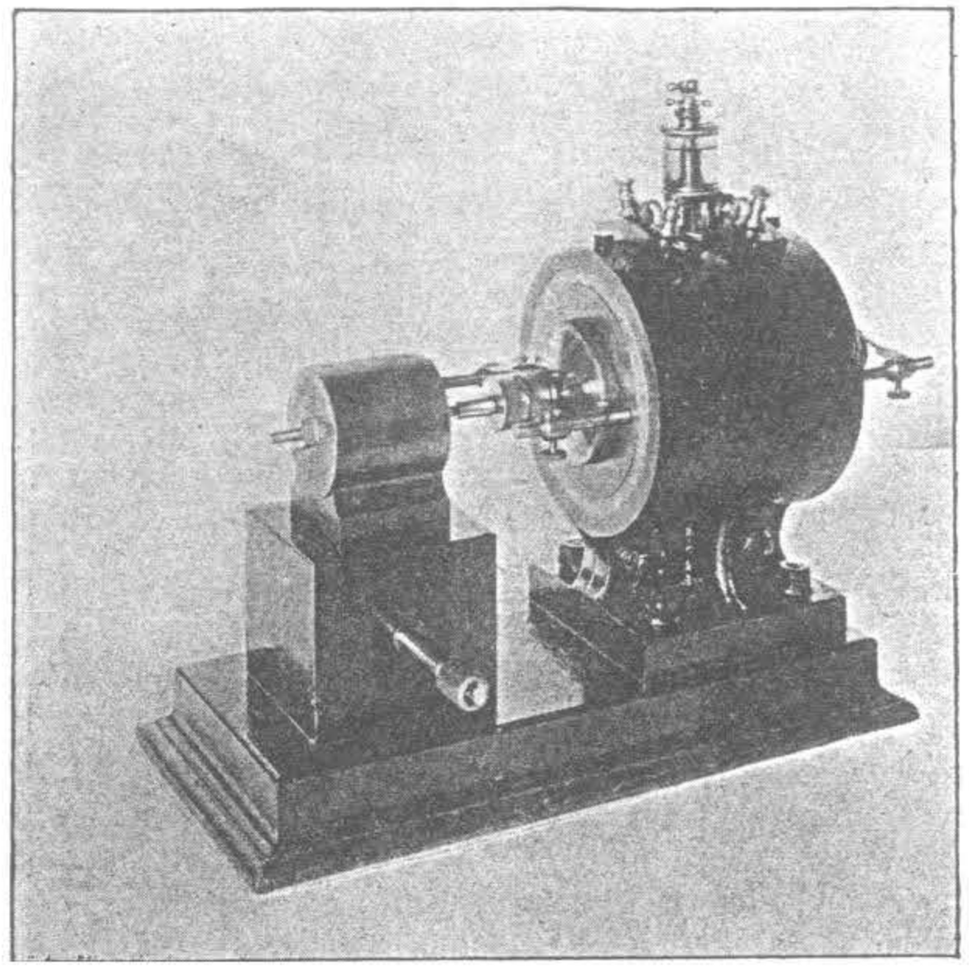


FIG. 4.

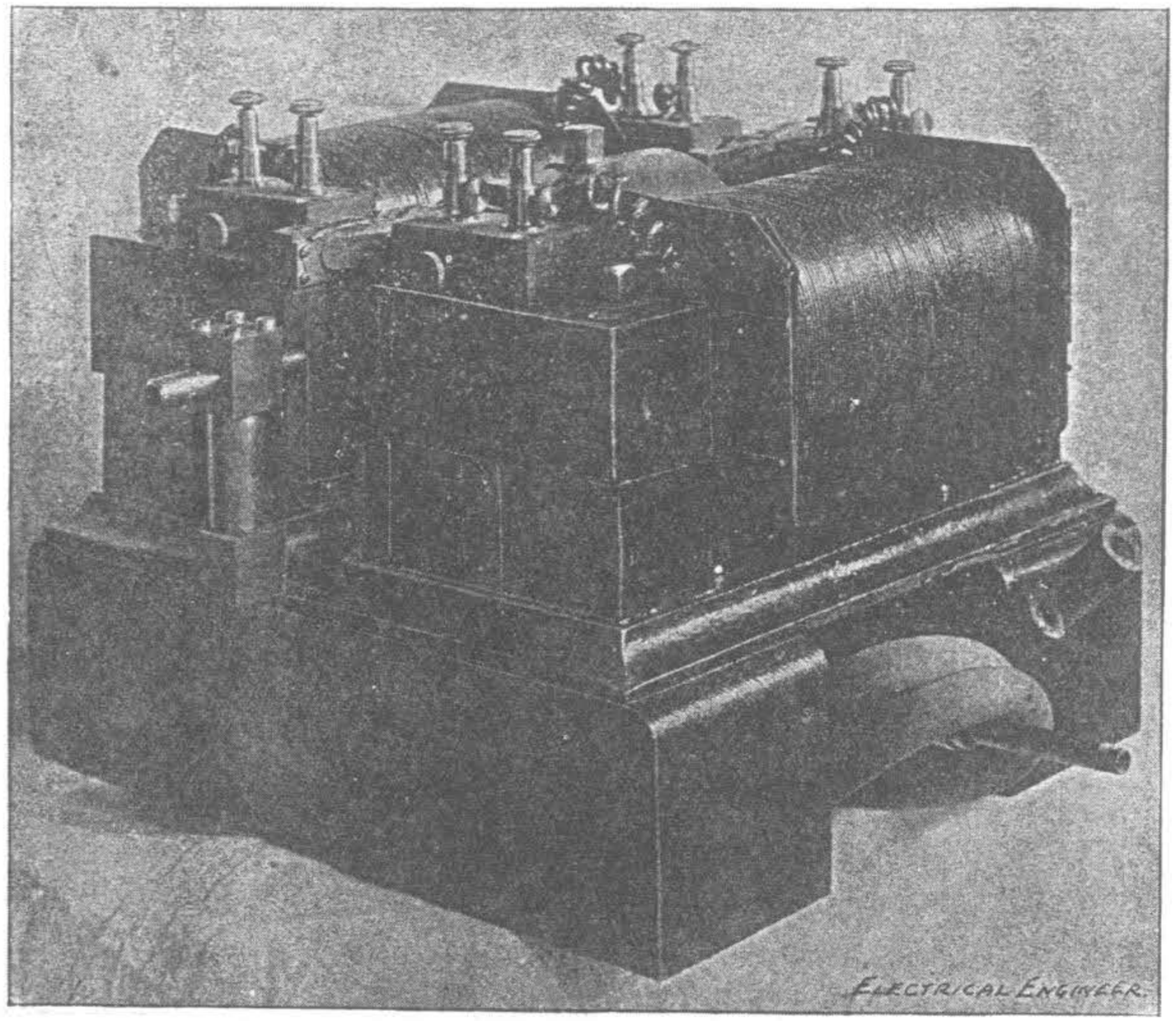


FIG. 1.

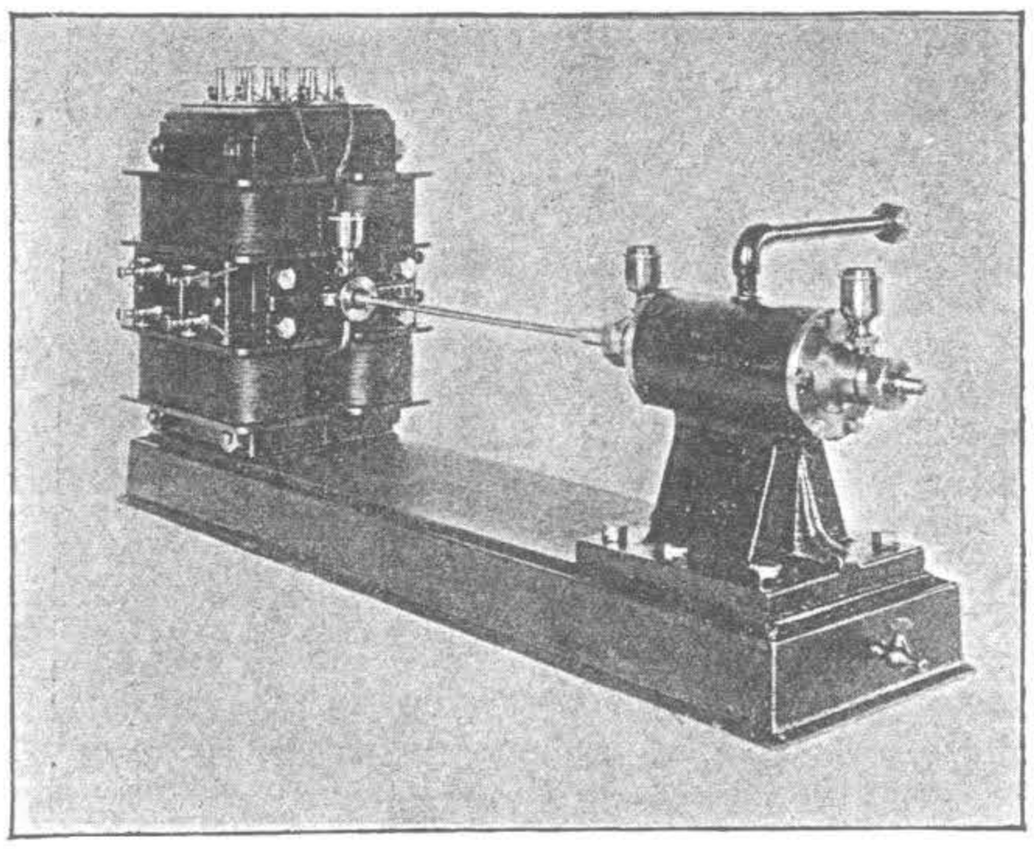


FIG. 5.

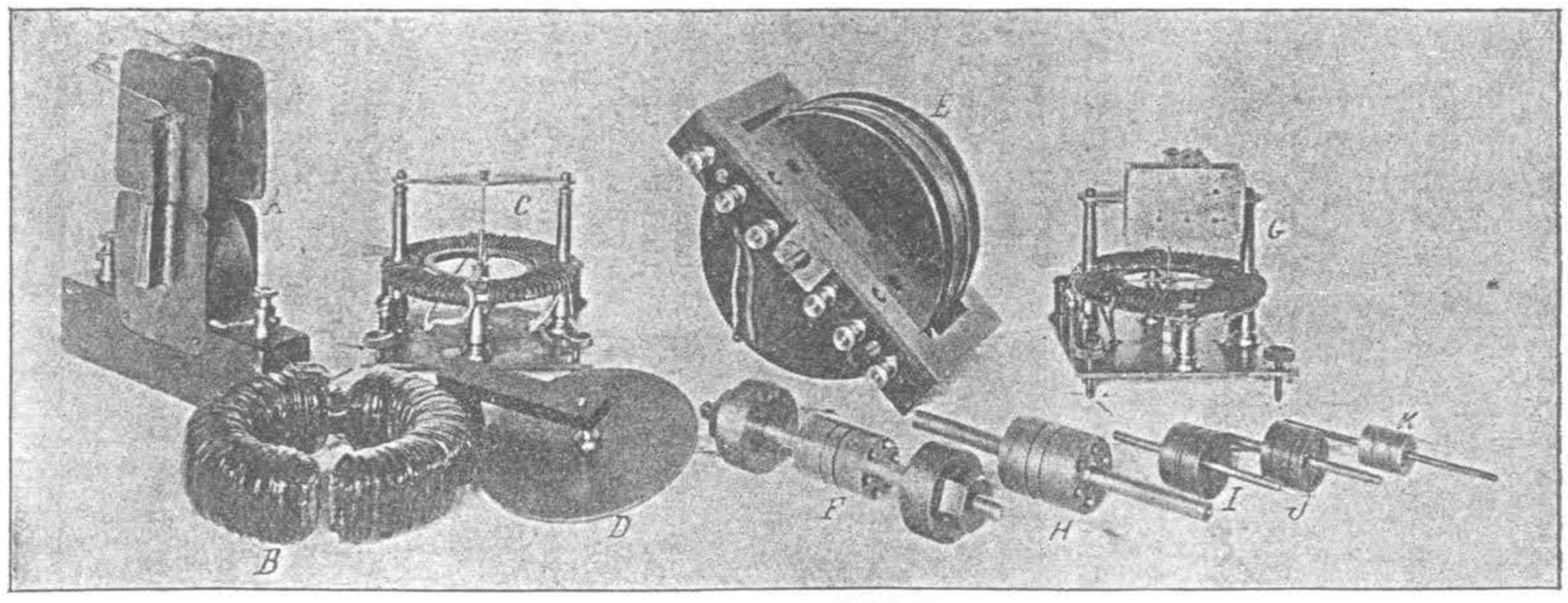
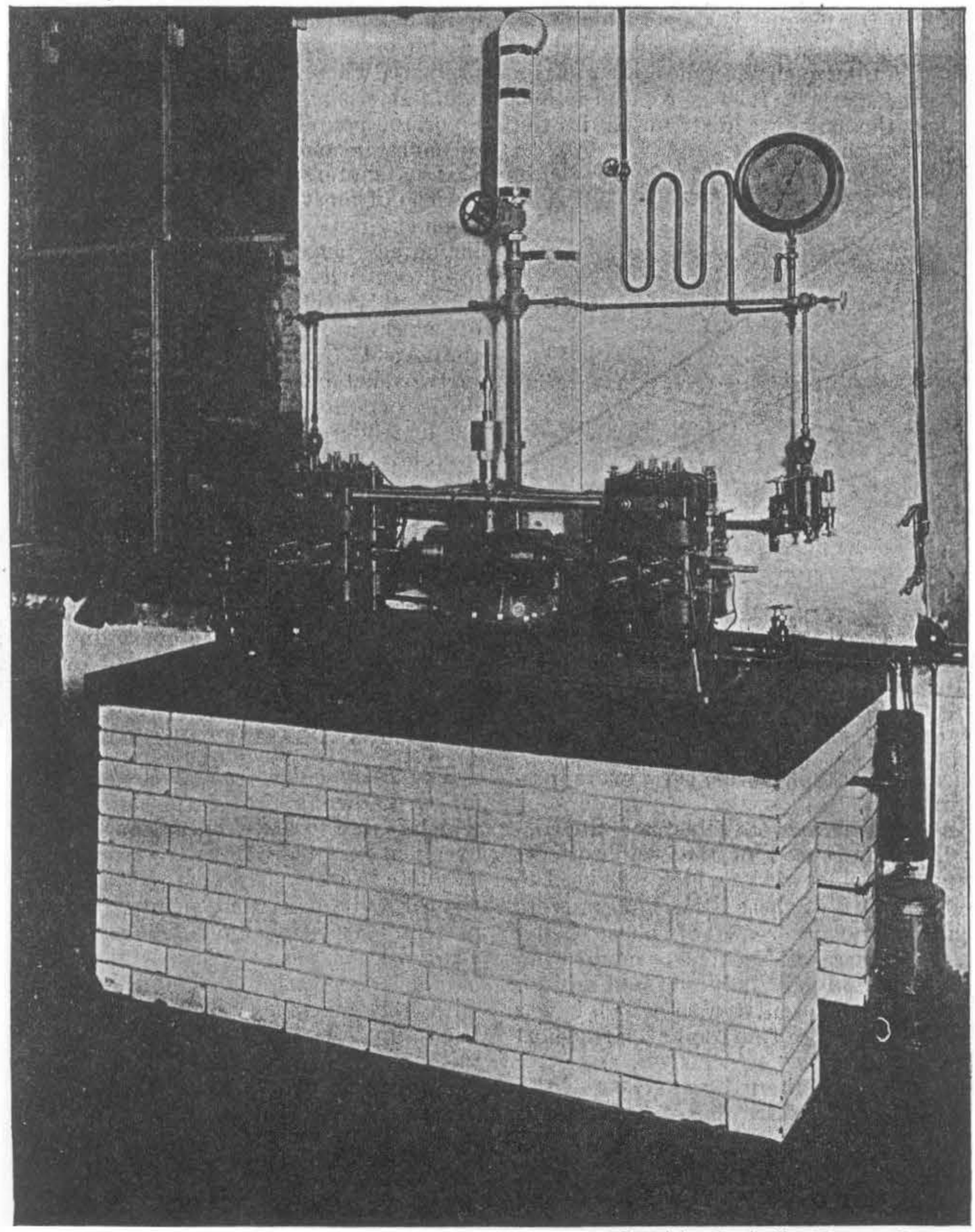


FIG. 7.

TYPES AND DETAILS OF TESLA OSCILLATORS.

Lent by THE CENTURY CO.



Copyright, 1895, by THE CENTURY CO.

FIG. 8.—RECENT FORM OF TESLA OSCILLATOR.

very strong air spring. The construction is such that the engine is always in exact synchronism with the vibrations of this spring. The engine can do nothing else but keep the spring vibrating, and eventually will alter the amplitude of the vibration, but the period remains the same, i. e., it is the natural period of vibration of the system. The recoil of the spring is, of course, incomparably greater than the impulse received each time from the engine. There is a chamber around the spring which can be maintained at a constant temperature by any usual means. As the frictional losses are vanishingly small compared with the enormous elastic force, the isochronism is perfect.

In Fig. 4, another quite distinct type is shown. A small oscillator is mounted on a stand with a dynamo of somewhat unconventional form. This dynamo comprises a circular field magnet in which are arranged to move on each side circular coils. The coils are carried by an arbor which is connected directly to the little engine; and the currents are produced by vibrating the coils within the field of the magnet. In this form, Mr. Tesla says, there is absolutely no useless wire, as all of it is within the field and all equally active.

In Fig. 5, a more advanced form of oscillator is shown, operated by steam and freely used for laboratory purposes. This minute machine had a capacity of 12 lights. It consisted of a small oscillator and a dynamo, the latter comprising a field magnet with its exciting coils and an armature merely of iron. The magnet had on its inside a number of pole projections upon which the induced coils were wound. The armature had projections of lesser number than those of the field. In this way the output of the dynamo was increased, by the number of teeth.

In Fig. 6 we have an interesting experimental apparatus consisting of a field magnet within which there is arranged to vibrate a tongue of steel carrying on its end a coil. This tongue and coil were vibrated in the strong field. There were adjusting screws on each side which allowed the attainment of any periodicity, within wide limits. This apparatus was used for scientific research solely.

Fig. 7 comprises a most interesting group of parts which were shown by Mr. Tesla in his demonstrations. Several of the instruments were used for the exemplification of novel features. The magnets in A, for example, were used to elucidate the principle of the preponderance of one impulse over the other in the current produced by

the oscillator and creating virtually the effect of a direct or continuous current. In B a magnet is shown which was vibrated. When the copper disc D, arranged to rotate freely in bearings, was held between the poles, i. e., in the field of the vibrating ring magnet, it was rotated in one direction, showing that the currents distributed in the

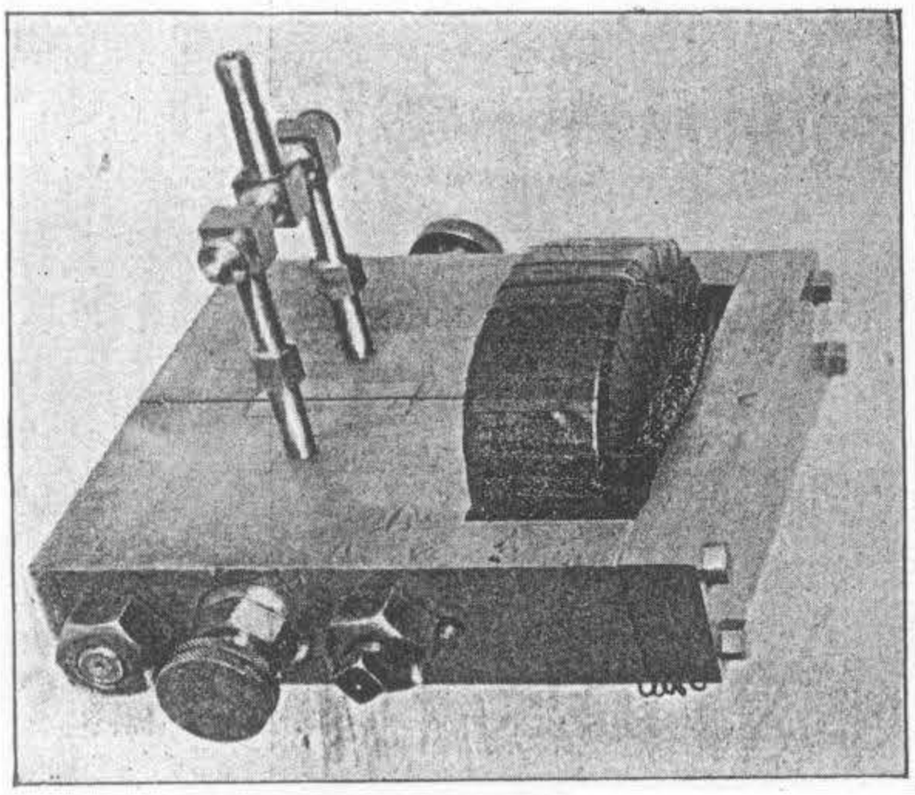
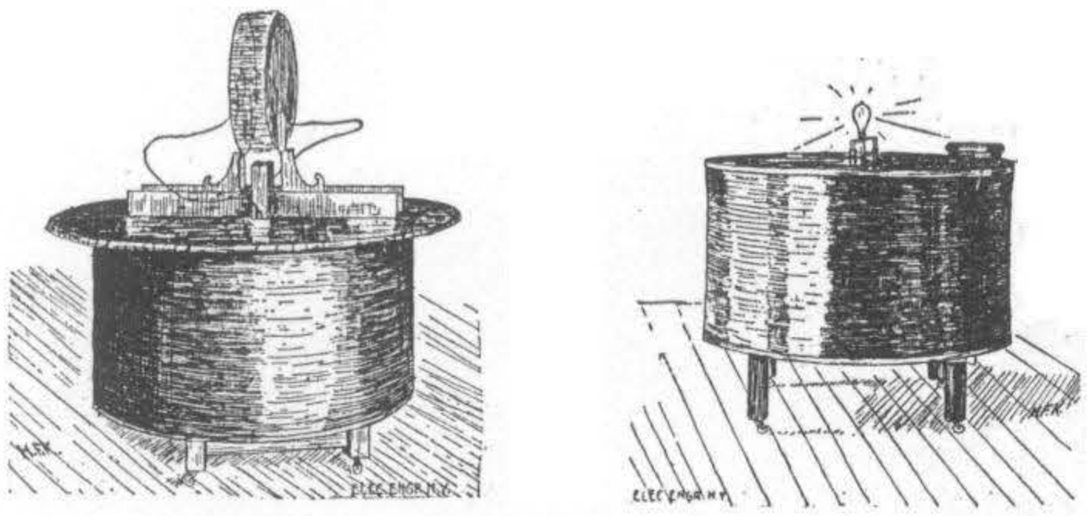


FIG. 6.

disc were asymmetrical. In other words, they were preponderating in one direction.

C, in Fig. 7, is a little motor used to illustrate the constancy or invariability of the speed of the oscillator. G was also a little motor with clockwork, which was used to count the revolutions. Both of these little motors were driven from one circuit, the difference of phase being obtained artificially. E was a little generator comprising three coils, two inducing and one induced; and an iron coil which was vibrated by the oscillator to which it was attached. F, H, I, J, K, are parts of an oscillator for short and long stroke respectively.

In Fig. 8, which we reproduce here by courtesy of the *Century Magazine*, is seen one of the latest types of the Tesla oscillator. It is a steam mechanism, but the "engine" part may be said to have disappeared, so far as that word implies an aggregation of fly wheel, governors, etc. On the one base were mounted two dynamos, or electro-magnetic generating systems and a small steam chest. There were two pistons which were vibrated by the



FIGS. 10 AND 11.—TESLA EXPERIMENTS.
(*Sketched from April Century.*)

steam 80 to 100 times a second. Each of the pistons carried an armature which was plunged reciprocatively into the field of the magnets. Normally the engine was run with the two pistons in opposite phase; but they could be set by an independent device in any phase. Above the chest was mounted an independent little oscillator, which in some experiments controlled the steam admission, and made the vibration of the engine quite independent of the load.

This oscillator was operated with steam at 350 pounds pressure, when it needed no packing, as there was no leakage. It was also used at pressures down to the ordinary 80 or 100 pounds. It was used to light up a bank of 50 or more incandescent lamps, some arc lamps, and to run various motors; while it also furnished current for a variety of most interesting and novel experiments, all of them suggestive of new departures in the electrical arts, including phosphorescent lighting, the transmission of intelligence long distances without wires, the utilization the earth's electrical charge, etc. Some of these branches of work are touched on, in a popular manner, in the April *Century*, from which we have made one or two sketches, in Figs. 9, 10 and 11, illustrative of the devices employed in connection with the oscillator.

Our readers will be glad to know that although, in the fire, Mr. Tesla's apparatus which we have shown above was practically wiped out of existence, the inventor has been most indefatigably at work ever since and will soon have reproduced his oscillator in its latest and most perfect form. There can be no doubt that in this appliance we have a mechanism for the simultaneous utilization of steam and generation of current under conditions that must effect large economies in every direction; while it should also prove a powerful instrument for exhaustive research.

TESLA EXPERIMENTS IN BERLIN.

THE latest addition to the repertoire of the Berlin "Urania," or scientific theatre, is a complete demonstration of the celebrated Tesla experiments with currents of high frequency and high potential. This lecture has been arranged by Prof. Spies and on a recent occasion he was assisted by no less a personage than Prince Henry, brother of the German Emperor. Prince Henry interposed his body between the high tension terminals, and held exhausted tubes glowing under the influence of the Tesla currents.

THE PRACTICAL TESLA OSCILLATOR.

When that notable assemblage of electricians, from whose ranks death has already removed one of its most shining lights, went forth from the lecture delivered by Mr. Tesla at the International Electrical Congress, in Chicago, in 1893, it is not too much to say that many came away with but a vague understanding of what the lecturer had sought to bring to their attention. At that lecture Mr. Tesla was too much engrossed in the description and the operation of his electrical and mechanical oscillator, to bring out clearly and sharply all the possibilities of this type of machine. Even since that time Mr. Tesla has been so absorbed in its development that he has had little time to elaborate on the facts which he brought out on that occasion. The late destruction by fire of practically all of Mr. Tesla's models has, fortunately, not deprived the world of the record of his work.

Thanks to the art of photography, we are enabled to present to our readers the article appearing on another page. The study of the evolution of a concept or machine must always prove instructive, and in the present instance the development of Mr. Tesla's oscillator from its original form constitutes a most valuable record of the origin and growth of an idea, the embodiment of which, in the opinion of its author, will make possible much that has heretofore been relegated to the realm of conjecture. Looking first at the most immediate application of the Tesla oscillator from the point of the steam engineer, a machine which permits of the employment of steam pressures of 300 pounds, or over, per square inch, practically without packing at the joints and without lubrication, at once gives the oscillator an advantage over the present type of steam engine, which a century has failed to secure for any type of the latter. If to this be added the absolute isochronous character of the oscillator over the widest ranges of load, there is gained another advantage which the highest skill of the steam engine builder has yet failed to accomplish fully in the most modern rotary steam engine. It is this absolute regularity of motion which is also destined to play an important part in the utilization of the currents generated through the medium of the oscillator in the attainment of those effects which Mr. Tesla deems essential to the accomplishment of one great problem of modern times, light without heat. While the theories on this point put forward by Mr. Tesla as the result of his experimental work have been called into question in some quarters, he is still as firmly convinced as ever of the correctness of his views. It is not to be denied, of course, that vacuum glow lighting effects can be obtained by other means, but Mr. Tesla is firmly convinced, we believe, that for the economical production of light without heat high potentials and high frequencies are indispensable elements, and that to obtain the highest perfection in this class of apparatus, practically absolute regularity in the production of the primary electrical impulses, which cannot be obtained by the ordinary forms of machinery, is necessary; and this is now made possible. The accomplishment of these immediate results made possible with the oscillator, both as a steam engine and as an electric generator, will, of itself, stamp it as a device of the first order of importance; and we may well leave to the future the working out of the problems which lie beyond and which Mr. Tesla holds forth as tangible possibilities of not distant years.

NIKOLA TESLA'S LOST APPARATUS

ILLUSTRATIONS AND DESCRIPTIONS OF SOME OF THE INVENTOR'S DEVICES DESTROYED BY FIRE—HIS GOOD FORTUNE IN HAVING HAD PHOTOGRAPHS MADE OF THIS APPARATUS MORE THAN A YEAR AGO—THE "OSCILLATOR" AND ITS WONDERFUL EFFICIENCY.

Nikola Tesla some time since established his right to be known as the most promising electrical inventor of to-day. When on March 13 last his laboratory, his workshop and all its contents, and most of his important records were totally destroyed by fire, the loss was felt by every one familiar with recent electrical developments.

Tesla, although an extremely modest man, is very widely known through his achievements in pure electrical science and through the many articles that have been written about him and his work by lay and technical writers. The loss which he recently sustained was a most serious one and called forth expressions of sympathy from every side. It resulted in his receiving one of the highest compliments ever paid to any man. This was from the pen of Charles A. Dana, editor of the New York *Sun*, and a warm admirer of Tesla. Mr. Dana wrote as follows:

> The destruction of Nikola Tesla's workshop, with its wonderful contents, is something more than a private calamity. It is a misfortune to the whole world. It is not in any degree an exaggeration to say that the men living at this time who are more important to the human race than this young gentleman can be counted on the fingers of one hand; perhaps on the thumb of one hand.

Immediately following the fire Mr. Tesla, instead of being prostrated by his misfortune, as reported in several daily newspapers, secured new quarters in which he began all over again the labor of years in the hope of reconstructing what had been totally wiped out. He is now busily engaged at this herculean task.

In view of the fact that Mr. Tesla's most important records were burned, it is extremely fortunate that the persuasions of Mr. Thomas Commerford Martin resulted in securing photographs of a number of pieces of apparatus which Mr. Tesla had developed and constructed more than a year ago. The illustrations which accompany this article were made from the photographs referred to. The half-tone plates were engraved at the time the photographs were taken, another fortunate circumstance, as the original prints were burned with everything else the Tesla laboratory contained.

Naturally, Mr. Tesla does not wish to have complete technical evidence of his work published abroad while he is in his present crippled condition, yet it is by his permission that these particulars are given here.

In the course of lectures, all too few in number, Mr. Tesla has at different times demonstrated before technical societies in this country and abroad a number of experiments wonderful in themselves and yet puny in comparison with the deep work of which they were but a feeble outgrowth. It has come to be pretty generally understood that the principal objects of Mr. Tesla's labors were the more efficient production of light, heat and power by electricity and the transmission of energy over long distances. His name is especially associated with the discovery of new phenomena resulting from his researches into the qualities and effects of high potential and high frequency currents. His first public lecture was based on these discoveries.

Since Tesla's discovery of the "rotating magnetic field" the long-distance transmission of alternating current from Niagara Falls has become possible. The basic idea of this discovery is to produce a circularly shifting magnetism instead of the well-known phenomenon of magnetism in a fixed position.

To the lay mind the most wonderful of all Tesla's experiments was the lighting of electric lamps or empty glass bulbs in free space, without any connection with the wires or generating apparatus. The light from these Tesla tubes is so intense that photographs taken by their illumination have been made with exposures of eight to 10 minutes.

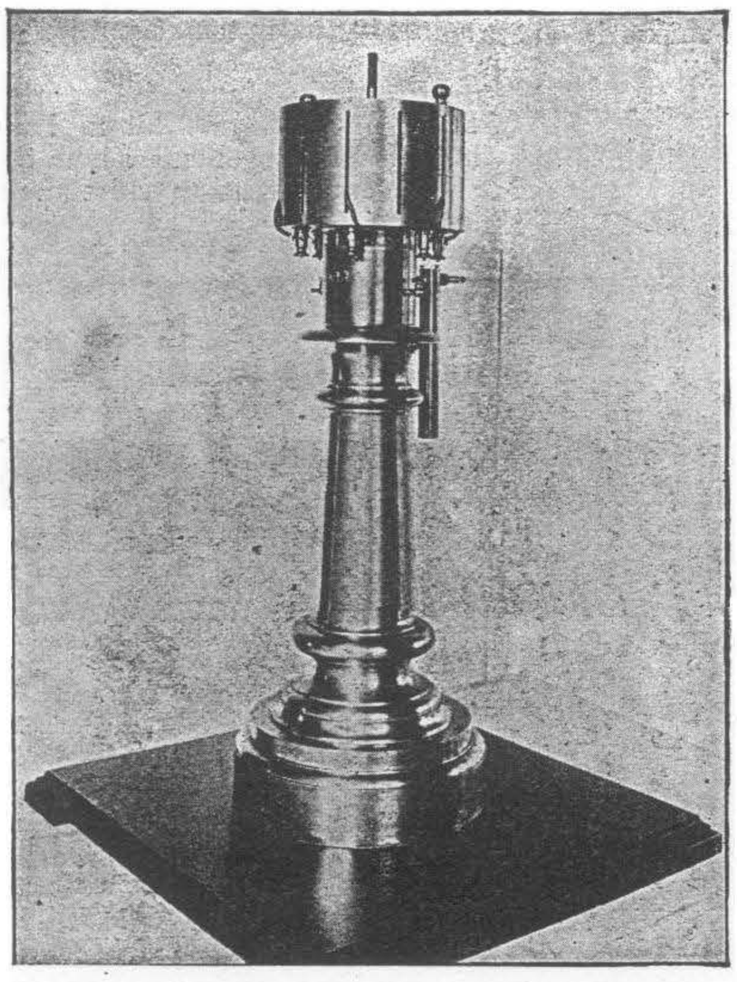


FIG. 1.—THE TESLA OSCILLATOR SHOWN AT CHICAGO IN 1893.

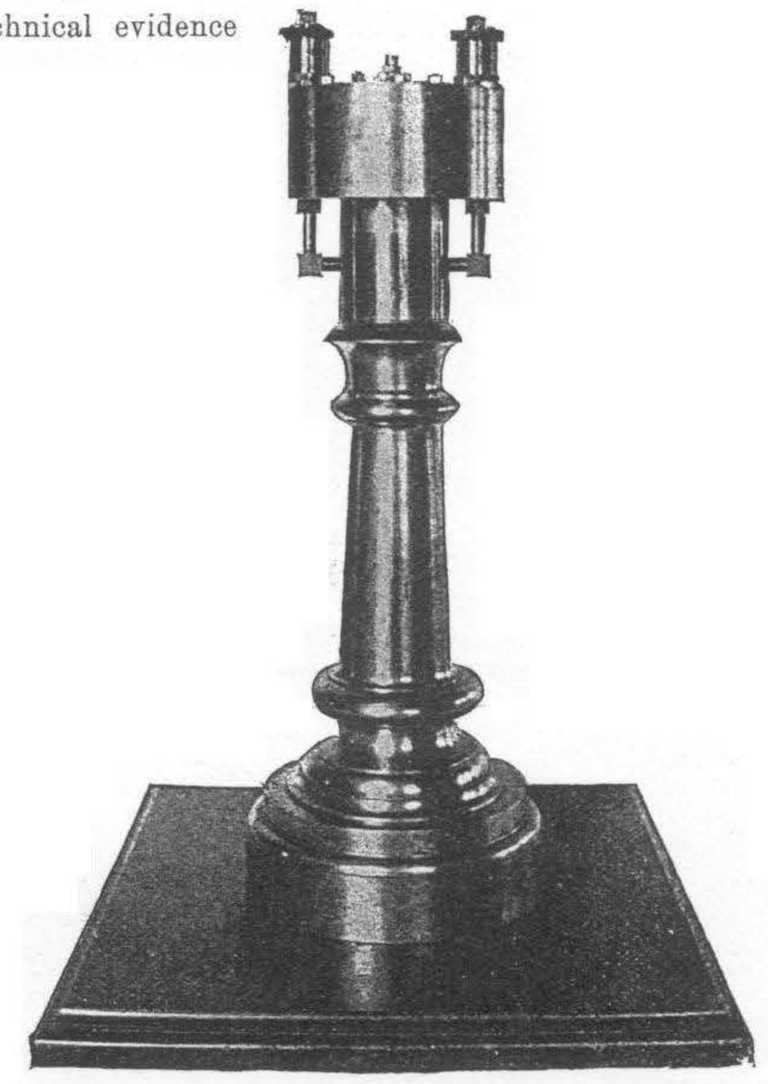


FIG. 2.—A SIMILAR FORM OF OSCILLATOR.

The wide field for improvement open to Mr. Tesla in his efforts to discover more efficient means of generating electrical energy may be better appreciated when it is stated that actual tests have shown that the energy manifesting itself as light in an incandescent lamp is less than five per cent of that received as current. The other 95 per cent is lost between the coal pile and the lamp. An important step in Mr. Tesla's labors to reduce this tremendous loss was the invention of his "oscillator." He reasoned that if large losses occurred in the steam engine and other large losses in the dynamo, it would minimize the combined losses if both machines were blended in one. And in the crudest terms this is what an oscillator is—an engine-dynamo.

In generating current by a revolving armature there is always some part of the wire winding which is doing no work, just as in the steam engine the steam cylinder and its

piston are the only parts doing any work, all the other complex mechanism being used for control or regulation. In brief and popular terms, the Tesla oscillator consists of a bedplate, in the middle of which is located

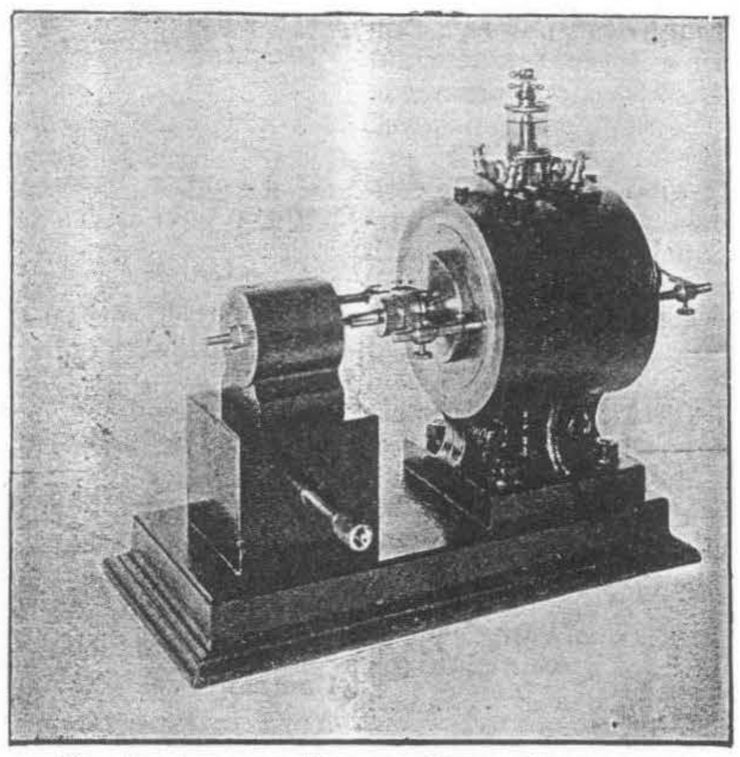


FIG. 3.—ANOTHER TYPE OF TESLA OSCILLATOR.

a steam chest. On each side of the steam chest is an electro-magnetic system consisting of field coils, between which the armatures move.

Two pistons are worked by the steam entering the chest. In one case steam at 350 pounds pressure is used, although as low as 80 pounds is used in other oscillators. At the ends of the pistons are the armature coils, which are thrust in and out of the magnetic fields with a reciprocating motion, thus generating current.

Here, then, is a steam engine stripped of every inefficient complication, and at the same time it is an electrical generator in which every part is doing steady work. The oscillator keeps the high pressure steam under such control that no packing is required to prevent leakage. For the same pressure and the same piston speed the engine part of the oscillator has but one-thirtieth to one-fortieth of the usual weight and consequently occupies a proportionately smaller space. The reduction of bulk and space occupied is also true of the electrical portion of the oscillator. Mr. Tesla believes that in the development of this apparatus he has reached a long way in advance in the reduction of the wasteful processes now present in the generation of electric current from coal.

The most highly developed form of oscillator, and one that was entirely practical and successful, had been used for many months in Tesla's laboratory. It was used to light the rooms with incandescent lamps and also furnished current for four arc lamps, for motors, for experiments with the high frequency apparatus and for other investigations. Many visitors to the laboratory have witnessed this oscillator in successful operation.

The oscillator which Mr. Tesla used in his lecture before the International Electrical Congress, during the World's Fair at Chicago, in August, 1893, is the only one that has ever been exhibited in public. This is shown in the accompanying illustration, Fig. 1. For convenience, compressed air instead of steam was used to operate this oscillator during Mr. Tesla's lecture. The machine consists of an engine mounted on an ornamental column, on top of which is a generator much like that shown at E in Fig. 6. In Fig. 2 is illustrated a similar form without the generator. A very strong air spring is contained in the box on top of the column. The apparatus is so constructed that the vibrations of this spring and the engine are always in perfect synchronism. The only possible function of the engine is to keep the spring vibrating. Eventually the amplitude of the vibration will be altered, but the period will remain the same; that is, it is the natural period of vibration of the system. The recoil of the spring is, of course, very much greater than the impulse received each time from the engine. Around the spring is a chamber which can be maintained at a constant temperature by any usual means. The isochronism is perfect because the frictional losses are infinitesimally small compared with the enormous elastic force.

Another quite distinct type is illustrated in Fig. 3. On a stand with a dynamo of somewhat unusual form is mounted a small oscillator. The dynamo includes a circular field magnet in which circular coils are arranged to move on each side. An arbor directly connected to the small engine carries the coils, and currents are produced by vibrating the coils within the field of the magnet. Mr. Tesla says that in this form there is absolutely no useless wire. All of it is within the field and all is equally active.

An oscillator of more advanced form, operated by steam and freely used for laboratory purposes, is shown in Fig. 4. This extremely small machine had a capacity of 12 incandescent lights. The combination was made up of a small oscillator and a dynamo having a field magnet with exciting coils and an armature simply of iron. The induced coils were wound on a number of pole projections extending from the inside of the magnet. The armature had fewer projections than the field and in this way the output of the dynamo was increased by the number of teeth.

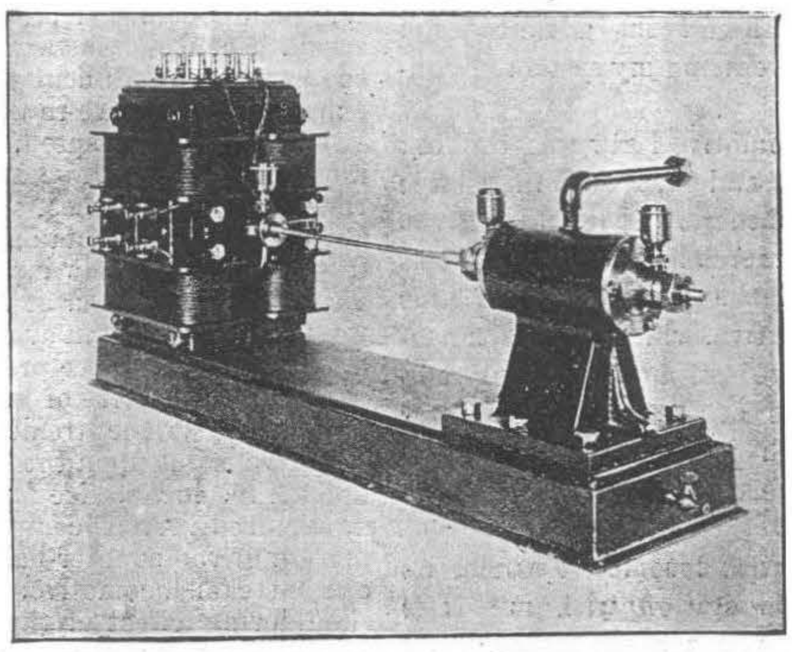


FIG. 4.—OSCILLATOR USED FOR LABORATORY PURPOSES.

An extremely interesting piece of experimental apparatus, used solely for scientific research, is shown in Fig. 5. It consisted of a field magnet within which there was arranged to vibrate a tongue of steel carrying at its end a coil. Both the tongue and coil were vibrated in the strong field, adjusting screws on each side allowed the attainment of any periodicity within a wide range.

A most interesting group of parts used by Mr. Tesla in his demonstrations is illustrated in Fig. 6. Novel features were exemplified by the use of several of the instruments shown. As an example, the magnets in A served to make clear the principle of the preponderance of one impulse over the other in the current produced by the oscillator and creating virtually the effect of a direct or continuous current. A magnet which was vibrated is shown in R. The copper disk D was arranged to rotate freely in bearings. When the disk was held between the poles, that is, in the field of the vibrating ring magnet, it was rotated in one direction. This showed that the currents distributed in the disk were asymmetrical, or in other words, they were preponderating in one direction.

The constancy or invariability of the speed of the oscillator was illustrated by the use of the little motor shown at C in Fig. 6. Another little motor with clockwork attached, shown in G, was used to count the revolutions of the oscillator. Both of these little motors were driven from one circuit, the difference of phase being obtained by artificial means. E was a little generator comprising three coils, two inducing and one induced, and an iron coil which was vibrated by the oscillator to which it was attached. The parts of an oscillator for short and long strokes, respectively, are shown in Fig. 6 at F, H, I, J and K.

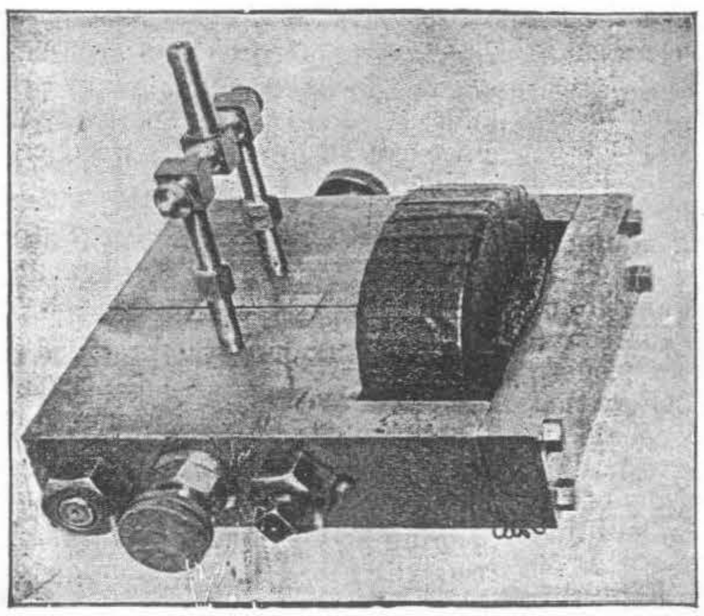


FIG. 5.—TESLA APPARATUS USED FOR SCIENTIFIC RESEARCH.

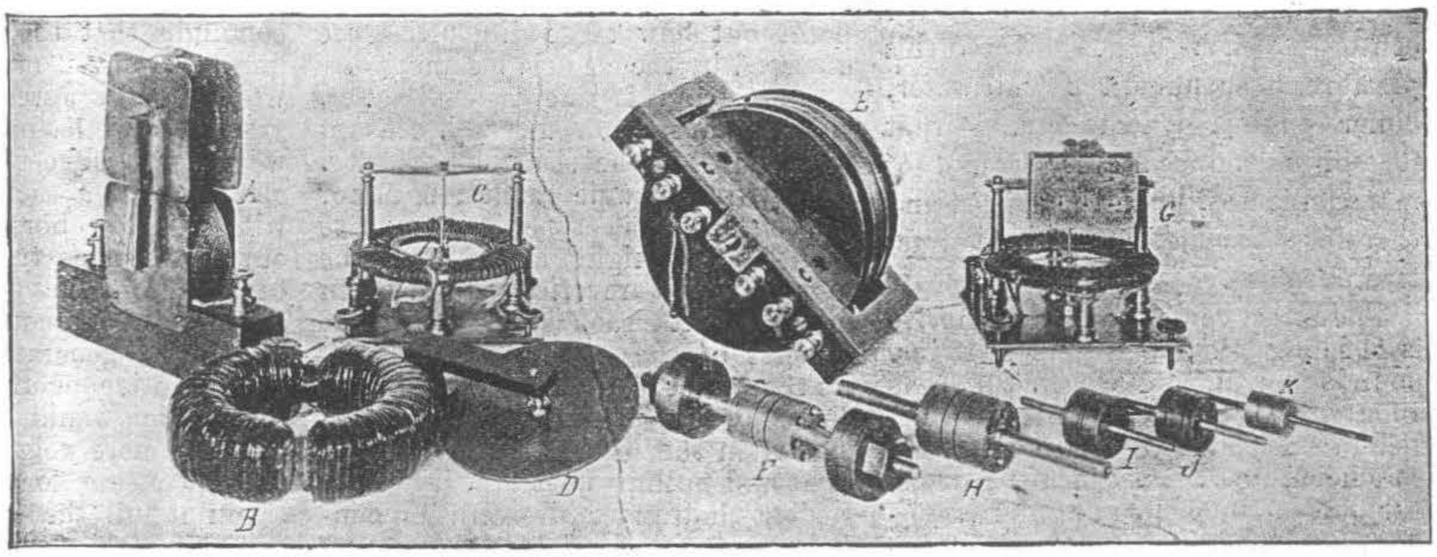


FIG. 6.—A GROUP OF PARTS OF TESLA APPARATUS.

These are only a very few of the Tesla devices which are now blackened ruins; yet they will serve to give a faint idea of the great and interesting achievements which this inventor has been accomplishing. Mr. Tesla is successfully at work reproducing his lost records and apparatus. The sympathy and encouragement he has received since his misfortune occurred will doubtless result in spurring him on to still greater and more brilliant efforts which an appreciative public will not be slow to recognize.

April 3, 1895

ELECTRICAL REVIEW

IN TESLA'S LABORATORY.

BY ROBERT UNDERWOOD JOHNSON.

[*From the Century Magazine.*]

Here in the dark what ghostly figures press !—
No phantom of the Past, or grim or sad ;
No wailing spirit of woe ; no specter, clad
In white and wandering cloud, whose dumb distress
Is that its crime it never may confess ;
No shape from the strewn sea ; nor they that add
The link of Life and Death—the tearless mad,
That live nor die in dreary nothingness.

But blessed spirits waiting to be born—
Thoughts, to unlock the fettering chains of Things ;
The Better Time ; the Universal Go d.
Their smile is like the joyous break of morn ;
How fair, how near, how wistfully they brood !
Listen ! that murmur is of angels' wings.

THE TESLA OSCILLATOR.

In view of the recent destruction by fire of Mr. Nikola Tesla's laboratory, with all the apparatus therein contained, some of the mechanism most nearly completed and perfected that has gone has been given an additional interest. There is probably no device of Mr. Tesla's of recent date around which more interest has centered than the electrical oscillator, which he first exhibited before a select audience at the World's Fair during the occasion of the Electrical Congress.

Since those instruments were exhibited the mechanism has undergone a considerable change, not in principle but in detail, which has tended to make it more compact, more efficient and in every way better adapted to the peculiar requirements of experimentation in which Mr. Tesla has been engaged as well as to the everyday requirements of the commercial machine. To such an extent had his work been carried in this line that Mr. Tesla was about ready to put the apparatus on the market, and did in fact for some time previous to the fire have his oscillator in practical service in his laboratory.

Through the courtesy of the *Century Magazine* we are enabled to reproduce here an engraving of the latest type of this machine, made from the last photograph taken of it, which, now that the machine itself has been destroyed, will have additional interest for our readers. This picture was made to accompany an exceedingly well written article by Mr. T. C. Martin which appears in the April number of the *Century*, to which our readers are referred. Mr. Martin, as is well known, is Mr. Tesla's historian, and any statements coming from him in regard to Tesla's work are therefore authoritative.

The Tesla oscillator is a steam mechanism, but the "engine" part may be said to have disappeared, so far as that word implies an aggregation of fly wheel, governors, etc. On the one base were mounted two dynamos, or electro-magnetic generating systems, and a small steam chest. There were two pistons, which were vibrated by the steam 80 to 100 times a second. Each of the pistons carried an armature which was plunged reciprocally into the field of the magnets. Normally the engine was run with the two pistons in opposite phase, but they could be set by an independent device in any phase. Above the chest was mounted an independent little oscillator, which in some experiments controlled the steam admission, and made the vibration of the engine quite independent of the load.

This oscillator was operated with steam at 350 pounds pressure, when it needed no packing, as there was no leakage. It was also used at pressures down to the ordinary 80 or 100 pounds. It was used to light up a bank of 50 or more incandescent lamps, some arc lamps, and to run various motors, while it also furnished current for a variety of most interesting and novel experiments, all of them suggestive of new departures in the electrical arts, including phosphorescent lighting, the transmission of intelligence long distances without wires, the utilization of the earth's electrical charge, etc.

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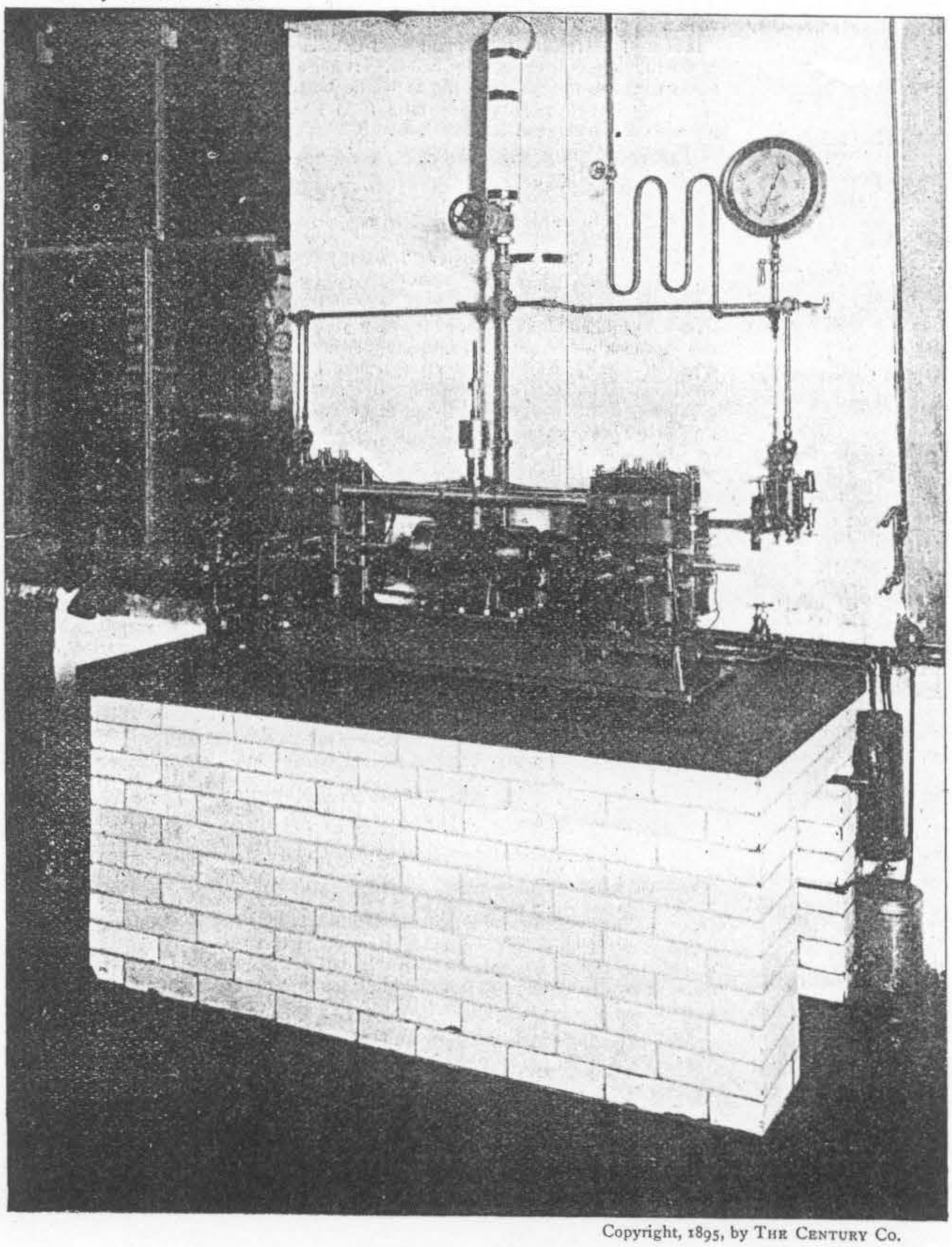

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The Tesla Oscillator.

MISCELLANEA.

WE read with regret that on the 13th ult. Mr. Nikola Tesla sustained a severe loss in the total destruction of his laboratory by fire. It is said that several instruments embodying nearly completed inventions were destroyed.

NOTES AND NEWS.

Dr. Nikola Tesla suffered a serious loss in the destruction of his laboratory by fire on March 13th.

The April Magazines

"The Century Magazine"

FIRST IN IMPORTANCE among the contents of this number is the article on "The Latest Electrical Inventions and Discoveries of Nikola Tesla," by T. C. Martin, editor of *The Electrical Engineer*. It is a survey of all the electrical advances of the last fifty years, and a forecast of the work of the next fifty. Text and illustrations deal with lighting, power transmission, telegraphy without wires, means for obtaining illumination by phosphorescence, the feasibility of using lamps without life-giving members and in free space, the disturbance and manipulation of the earth's electrical charge, and a variety of unclassified phenomena. Of great importance among these discoveries is the "oscillator," which is "not simply a new practical device, but a new implement of scientific research." With it Mr. Tesla, "if he has not as yet actually determined the earth's electrical charge or 'capacity,' has obtained striking effects, which conclusively demonstrate that he has succeeded in disturbing it." The great inventor has aimed at manipulating this electrical charge of the earth itself, and, says Mr. Martin, "aside from their deep scientific import and their wondrous fascination as a spectacle, such effects point to many new realizations making for the higher welfare of the human race. The transmission of power and intelligence is but one thing; the modification of climatic conditions may be another. Perchance we shall 'call up' Mars in this way some day, the electrical charge of both planets being utilized in signals." Among the illustrations accompanying the article are several photographs, of Tesla himself, Mark Twain, Marion Crawford and Joseph Jefferson, taken by phosphorescent light. As is well known, Mr. Tesla's laboratory was destroyed in March, and this article is the only record of some of his most important discoveries. Mr. Tesla has gone to work undismayed to reconstruct his lost appliances and machinery.——Besides Prof. Sloane's "Life of Napoleon," there is another historical paper, on "Lincoln's Reëlection," by Noah Brooks, whose recent work in this field, we think, is now so widely and well known that it requires no further praise or recommendation.——A third deals with Paul Jones, and is from the pen of Molly Elliot Seawell, who has taken our naval heroes under her special charge, and is making old and young America—especially the latter—better acquainted with the details of their lives.——Dr. Lyman Abbott in his essay on "Religious Teaching in the Public Schools" reviews again the mooted question, indicating, as many have done before him, what education in a democracy should be, and expressing his conviction that some day the ideal will be attained.——In the meanwhile, S. W. Powell discusses another important educational question, "Should Higher Education be Provided for the Negro?" This higher education of a few gifted Negroes seems to Mr. Powell of more immediate importance than the common education of the masses of the race; or, rather, he thinks that the latter will be accelerated and made more effective by the former. His reasons are sound and clearly stated, but—funds are low.——Our readers remember, of course, that only a short while ago Paul Griggs the novelist visited New York and was intimate with the Lauderdale clan, and especially with Katharine Ralston. He now makes his appearance in Italy, in Mr. Crawford's "Casa Braccio," which interesting tale glides here into a period of calmness.——Among the rest of the contents we can only mention, *en passant*, an excellent full-page portrait of Mme. Réjane, with a short appreciation by Justin Huntly McCarthy, short stories by Mrs. Roger A. Pryor, George I. Putnam and Alice Turner, a biographical sketch of Bernhard Stavenhagen, by Henry T. Finck, and several poems, among them an unsigned sonnet on "Robert Louis Stevenson," and another, "Resurrection," by Maurice Francis Egan.

Tesla's Laboratory.—In a short article in the "Eng. Mag." for April Mr. Martin discusses the nature and significance of the event of the burning of Tesla's laboratory; he mentions briefly that the most advanced form of the oscillator had been used to light the laboratory for months.

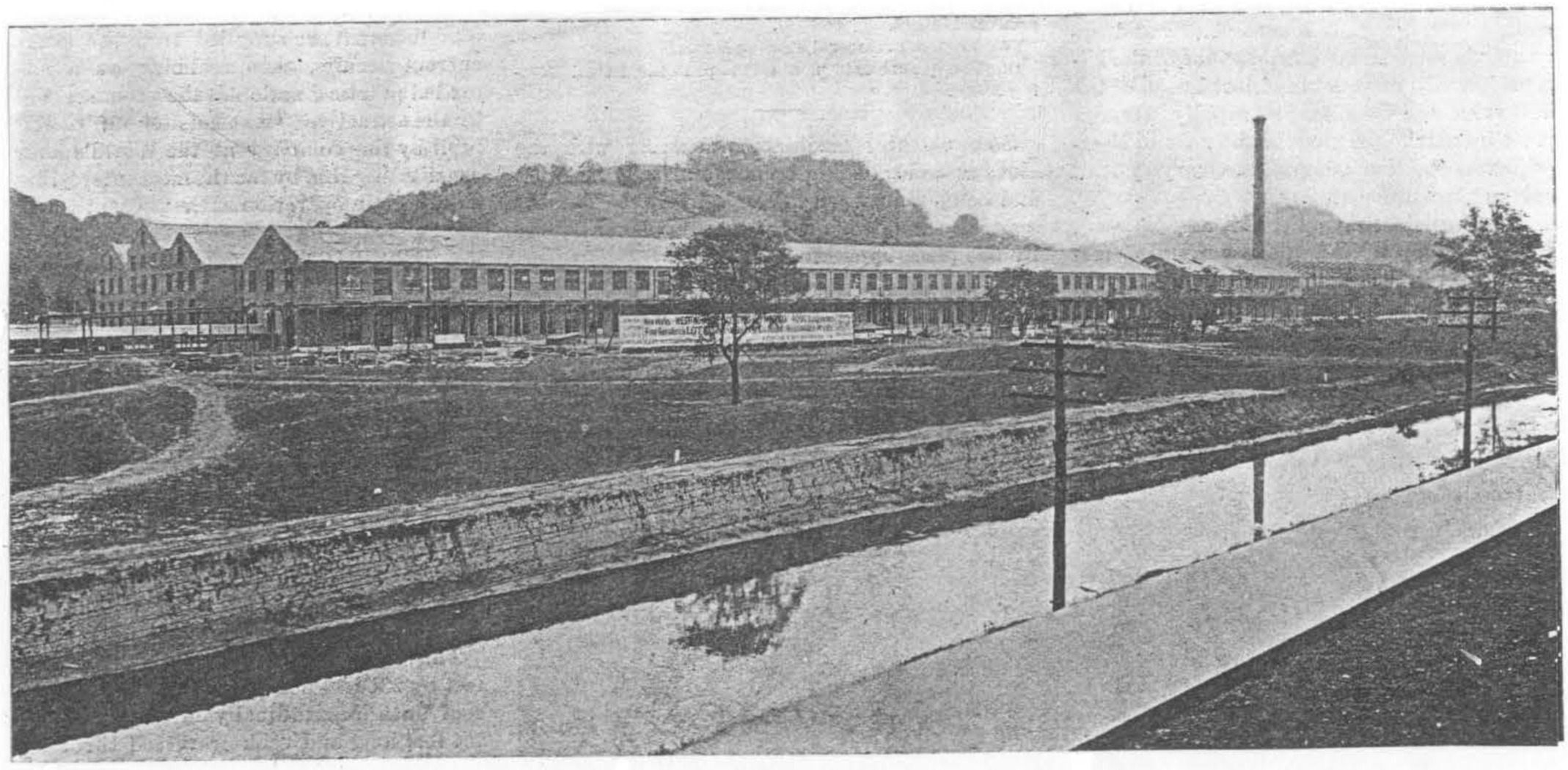


FIG. 1.—WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY'S PLANT, BRINTON, PA.

The Tesla Two-Phase System.

Extensive Use at the Westinghouse Works, Brinton.

The New Plant Fully Equipped with Alternating-Current Apparatus—The Most Important Installation Thus Far Attempted.

BY NELSON W. PERRY, E. M.

For many years it was a matter of reproach to the electrical industry that the manufacturers of electrical apparatus who zealously urged its adoption in all other industries failed to use it in their own. While recommending their wares to others they used them not themselves, except in a few isolated cases where small electrical apparatus was erected in the works to show to prospective purchasers that it would run under favorable circumstances. On the conservative business man the claims of superior economy, efficiency and convenience made for electrical methods produced rather the opposite effect to that intended when he saw in these great establishments the same methods in vogue which their proprietors were urging him to discard in his own.

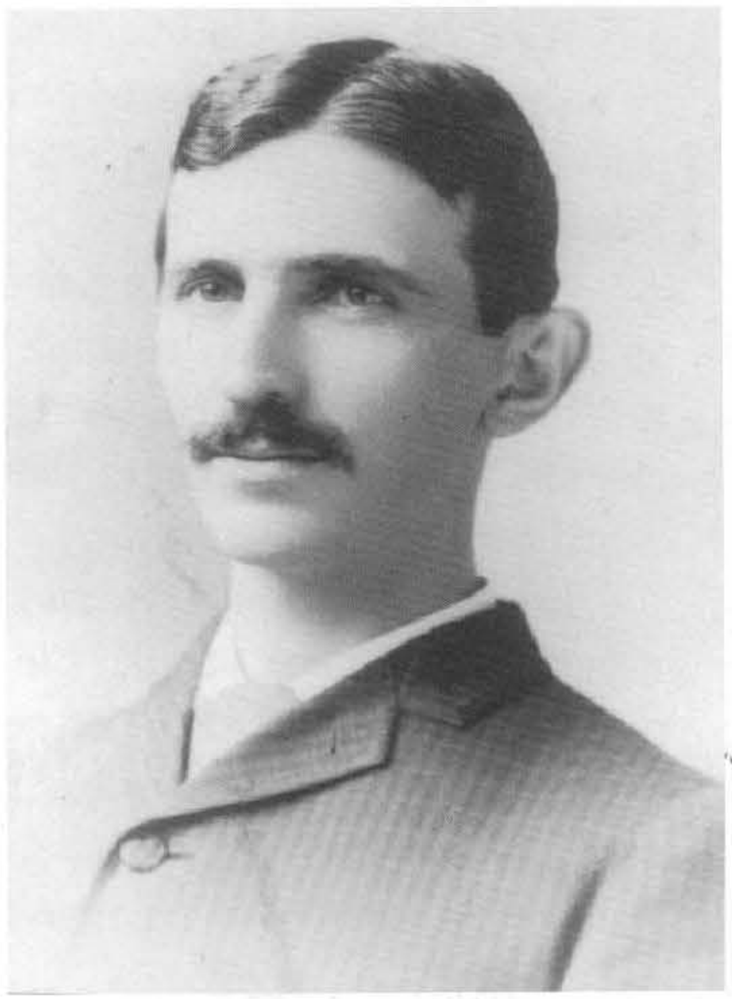
Gradually, however, things changed, and the electrical manufacturer began himself to follow the advice which he had so long been giving to others.

Direct current methods are the oldest, commercially speaking at least, and first reached a perfection leaving little to be desired; and for some years past several of our largest electrical companies have been distributing power throughout their works by electrical means instead of by long belts and shafting, and have driven almost all of their tools either directly from direct current motors or from short lines of shafting driven locally in the same way.

Next in point of time came the simple alternating current which seemed to present possibilities for the future which would relegate direct current practice to the rear. For incandescent lighting purposes and long distance transmission *per se* it seemed all-sufficient almost from the invention of Gaulard and Gibbs, but for motor service it proved inadequate to the demands. Early in the history of the art alternating current motors of good efficiency had been constructed, which, when once brought up to speed, would do good work, but from that day to this, notwithstanding the persistent efforts of the best talent, a simple alternating current motor that could be started and stopped and reversed while under load, and thus fulfil all the requirements of commercial practice, has not been built.

From time to time claims have been made that this has been accomplished, but the test has never verified the promise. Not until the invention of the polyphase motor by Nikola Tesla, in which two or more simple alternating currents differing in phase were employed, was the alternating current adapted to the demands of commercial power practice.

Although Tesla's seven earliest patents were issued on May 1, 1888, followed by four others during the same year, the value of the polyphase system was not generally realized until 1891, when the Frankfort-Lauffen experiment attracted world-wide attention to its merits. Both before and since that date, however, many modifications of Tesla's method had sprung into existence



NIKOLA TESLA.

whose claims for utility were strongly urged by their respective promoters, and the history of the direct current method from the manufacturer's standpoint was repeated. Although extraordinary claims were advanced for these systems, and latterly numerous successful installations had been made, the manufacturer himself neglected them in the equipment of his own shop. With one or two exceptions, while the manufacturer of alternating current apparatus equipped his factory with electrical power apparatus, it was of the direct current type, which his own wares were professedly intended to supplant by reason of their superiority.

There were often more or less valid reasons for this seeming inconsistency, but the public knew them not, and from this circumstance, perhaps, more than any other has looked upon polyphase systems with lack of confidence, if not suspicion.

The greatest difficulty that the manufacturer has had to contend with in replacing an established system by a new one, has been to adapt the speeds of the new motors to the old pulley relations—either this had to be done or the pulley relations had to be adapted to the new motor speeds, either of which would involve an expense scarcely warranted by the results.

But when the Westinghouse Electric and Manufacturing Company began equipping their magnificent new works at East Pittsburg they were hampered by neither of these considerations, and were left entirely free to choose that system which they thought promised the best results. This company being the owners of all the Tesla polyphase patents, had for years been recommending the system to their patrons as universally applicable for general power distribution; and they have given evidence of their faith in the system by equipping their new works throughout with it.

This plant, which is now described for the first time, though not yet complete, forms the most interesting installation of polyphase apparatus thus far made, for several reasons. In the first place, the same type of apparatus, the same method of distribution and the same frequency of alternation of current (3,000 per minute) are employed as are to be used at Niagara. Its sufficiency for all the multifarious demands of these large works is therefore a demonstration of its sufficiency for all the demands that can be made upon it at Niagara. Furthermore, it is the first practical demonstration of this on a sufficiently extended scale to settle the matter beyond question. In the second place it is the first demonstration

on a practical scale of the system to machinery and work of the greatest heterogeneity and severity of exactions and as a forerunner of the Niagara project will serve as an object lesson of the greatest value and do more to rapidly advance the great industrial progress in and around Niagara, which has to depend upon this very system, than almost any other agency.

Although anticipating a little, it may be well, in order to convey an idea of the variety of service that this system is supplying in the Westinghouse works, to catalogue the apparatus it is now driving.

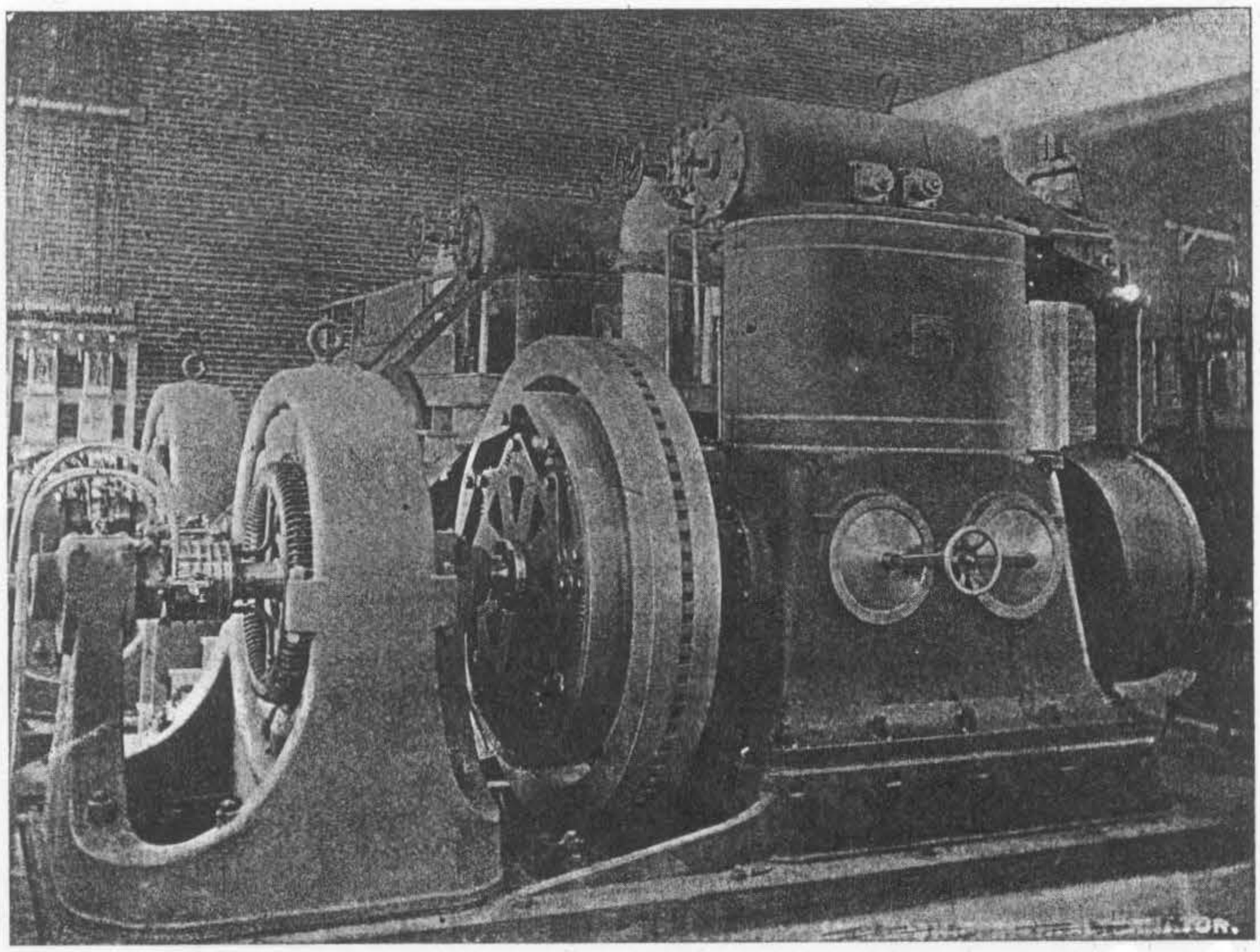


FIG. 2.—TWO-PHASE GENERATORS FURNISHING POWER AND LIGHT TO THE WESTINGHOUSE SHOPS. 500 H. P. UNITS.

PRESENT INSTALLATION.

Main Machinery Building, 754 feet long by 235 feet wide.

SMALL GENERATOR DEPARTMENT—MACHINES BELOW 100 H. P.

Ground Floor—

Two 40 h. p. motors each, driving planers, drill presses, lathes, etc., to the number of about 100 machines.

Galleries—

One 30 h. p., driving about 40 screw machines of various sizes.

Two 20 h. p. each driving 40 tools of various kinds in Too Department.

One 40 h. p. driving about 40 tools of various sizes in Commutator Department.

One 20 h. p. driving about 25 or 30 tools in Brush-holder Department.

One 30 h. p. driving about 60 tools in Controller Department.

One 20 h. p. driving about 15 tools in Converter Department.

One 20 h. p. driving 15 punches and various tools in Mica Department.

Four 20 h. p. driving 200 winding lathes.

Six 40 h. p. driving fans for heating.

Making 20 motors of an aggregate of 620 h. p. already installed in this building.

There still remain to be installed in this building the following motors:

One 30 h. p. to drive 3 Ingersoll milling machines.

Two 30 h. p. in Railway Motor Armature Department, each of which will drive some 40 tools, lathes, etc.

One 15 h. p. in Motor Armature Winding Department.

Two 30 h. p. in Motor Machinery Department, each driving some 30 heavy tools, boring mills, lathes, drills, etc.

One 30 h. p. to drive 3 boring mills, one 122 inch by 35 inch lathe, two 72 inch radial drills, two large planers.

One 30 h. p. to operate planers, boring mills and drill presses.

Three 20 h. p. to drive large planers, boring mills, drill press and lathes.

Two 500 h. p. in General Testing Room.

One 75 h. p., one 60 h. p., one 40 h. p. in the Detail Testing Room.

Some of this machinery, together with the elevator and traveling cranes, is already installed and being temporarily driven by direct current apparatus, but it is intended to supplant all these by two-phase apparatus.

WAREHOUSE, 76 FEET X 754 FEET.

Motors already installed—

Four 20 h. p., each driving some 40 tools.

Two 30 h. p., each driving some 45 tools.

Two 40 h. p., each driving fans for heating purposes.

Making 8 motors of 220 h. p.

CARPENTER AND CABINET SHOP, 102 FEET X 60 FEET.

100 h. p. in small units, all direct current at present, but to be replaced with two-phase motors.

BLACKSMITH SHOP, 242 FEET X 82.6 FEET.

Two 20 h. p., on exhaust fans.

Two 10 h. p., on pressure fans.

One 20 h. p., driving two large shears and punches and 5 smaller tools.

Total—5 motors of 80 h. p.

POWER HOUSE, 206 FEET X 76 FEET.

At present this contains—

Two 500 h. p. direct connected alternating current (two-phase) and two 500 h. p. direct connected direct current machines.

The full complement will be 3 units of 500 h. p. each of each kind.

PUNCH SHOP, 258 FEET X 76 FEET.

Two 80 h. p., each driving 40 odd punching machines.

Recapitulating, we find that there are at present installed and in operation 37 alternating current motors of an aggregate capacity of 980 h. p. There are yet to be installed 16 more of a capacity of 1,390 h. p., besides several hundred horsepower direct current motors now installed to be replaced by two-phase alternate current motors.

It will be seen from this catalogue that the new plant constitutes by far the largest installation of polyphase motors that has heretofore ever been attempted and that these motors are doing almost every conceivable class of service except electrolytic work. In addition to this, all of the lights, both arc and incandescent, for the whole establishment are supplied from the alternating current circuits, thus realizing on a most extended practical scale all the promises held out by the attractive "transmission of power" exhibit by this company at the World's Fair, and constituting this by far the most interesting plant anywhere in operation at the present time.

DESCRIPTION OF THE PLANT.

The site of the Westinghouse Electric & Manufacturing Company's new shops, which has been christened East Pittsburg, is 12 miles from Pittsburg, on the Pennsylvania Railroad. The buildings at present erected and occupied are seven in number, and in the order of size are the main machine shop, warehouse, punch shop, blacksmith shop, power house, carpenter shop, and temporary brass foundry. All of these are substantial brick buildings except the carpenter shop and the brass foundry, which are of corrugated iron.

THE MAIN MACHINE SHOP.

This, by far the largest, covers an area of 754 feet by 231 feet 6 inches, and is divided by the roof lines longitudinally into three aisles, each 754 feet long and each traversed throughout its whole length by railroad tracks connecting with the main line of the Pennsylvania Railroad. The main aisle is unbroken from floor to roof and traversed throughout its length by a 30-ton electric crane. Here all the heavy machine work and large generator erecting is carried on. The side aisles are both divided midway of their height by floors, under which in each case is a 10-ton electric crane with a 754-foot runway.

On the ground floor of the north aisle are located the motor armature winding, fitting, and assembling departments and storerooms, and in the south aisle are found the small generator department, small generator armature winding and assembling departments and more storerooms, and the entire eastern quarter of the three aisles as general testing rooms for the classes of work done in their respective western portions.

On the second floor of the north wing, beginning at the west and going east, are the screw department, tool and storeroom, brush-holder department and railway equipment rooms, and similarly situated in the south wing are the wire storeroom, winding and insulation department, mica department, detail testing room and converter department.

Each of these longitudinal sections of the building is traversed by line shafting divided

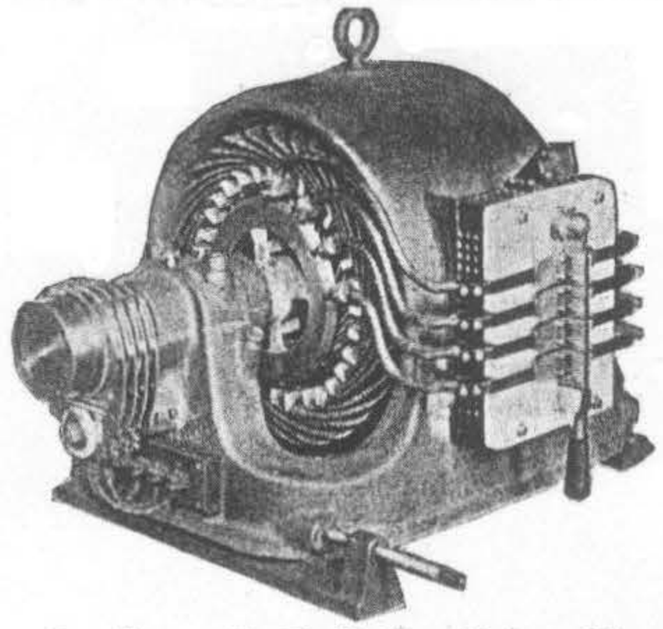


FIG. 3.—TESLA 50 H. P. TWO-PHASE MOTOR. OLD STYLE SWITCH. NEW STYLE COLLECTOR BRUSHES.

into numerous sections, each of which is belted to an individual two-phase motor situated on the floor, and from which are belted the various tools and machines already enumerated. This plan of transmission from motor to tool is observed throughout the various buildings and need not be again referred to. It may also be stated here that with the exception of three small steam

hammers for copper forging, in the blacksmith shop, every piece of machinery in the establishment is electrically driven.

THE WAREHOUSE.

Directly south of the machine shop is a building of equal length, but only 76 feet 2 inches broad, whose entire first floor is occupied as a warehouse, in which all finished and returned material is stored for further disposal. For the

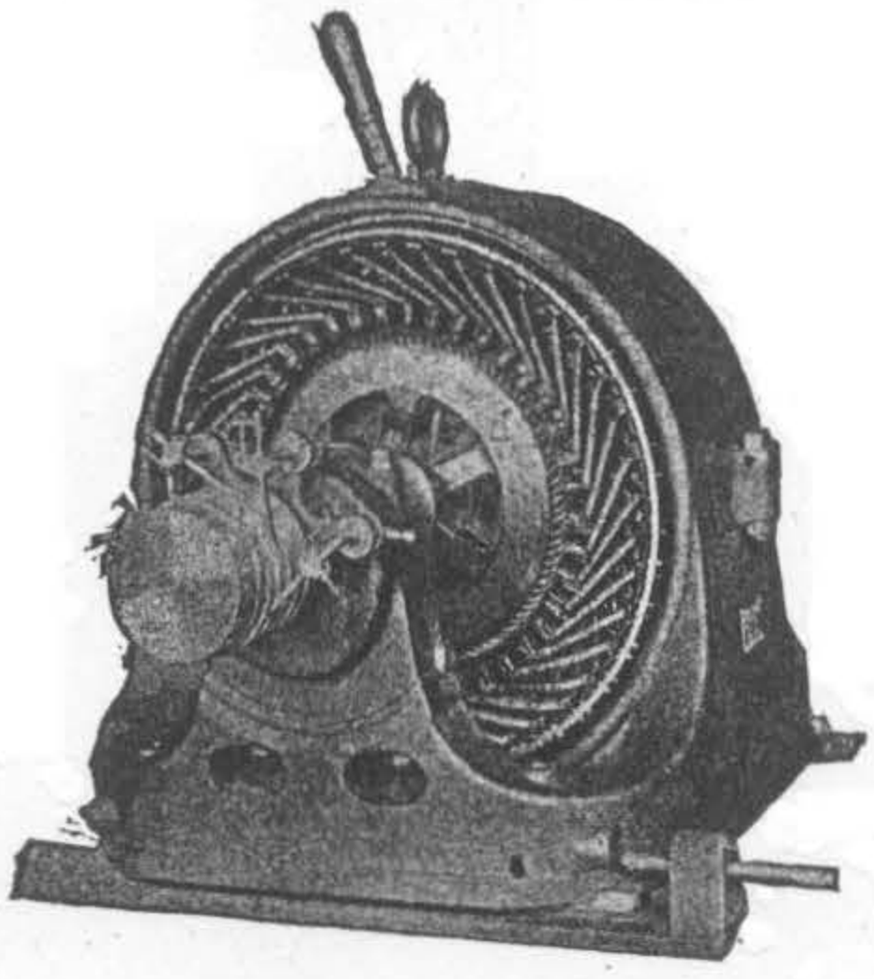


FIG. 4.—TESLA 50 H. P. TWO-PHASE MOTOR. NEW STYLE SWITCH RING. OLD STYLE COLLECTOR BRUSHES.

handling of this material there are two 10 ton electric cranes with runways extending the entire length of the building.

The second floor is connected by five bridges with the second floor of the south wing of the machine shop thus practically making the two one. The west end of this floor is devoted to the general offices of the administrative, engineering and draughting departments and the eastern end to the instrument department, including meter, arc lamp and switchboard equipments.

THE POWER HOUSE.

East of the warehouse, and separated from it by a passageway 52 feet wide, is the power house. This is 206 feet long by 76 feet 2 inches wide, and devoted in its western part to the engines and dynamos and two hand-operated overhead cranes and in its eastern part to the boilers. The latter are Pierpoint boilers of 2,500 h. p., and there is room for an equal number more. These boilers are equipped with the Roney mechanical stoker. The fuel is delivered from cars on an elevated track direct into large iron hoppers from which it descends as needed to the grates without manual handling of any sort. The present engine and dynamo equipment consists of two 500 h. p. Westinghouse compound engines directly connected by means of two standard Westinghouse flexible couplings to two 500 h. p. two-phase Tesla generators, and two similar engines connected in the same way to two 500 volt



FIG. 5.—TESLA 10 H. P. MOTOR. ROTATING PRIMARY.

multipolar direct current generators. The foundations are all ready for one more 500 h. p. unit of each kind.

PUNCH SHOP.

Fifty feet to the east of the power house and on the same lines is the punch shop, 258 feet long by 76 feet 2 inches wide. Upon the ground floor are the shearing and heavy punching machines, and storage for sheet iron. In the extreme east end are the annealing ovens. The second story is devoted exclusively to the machines for punching armature disks, converter and other shapes for laminated structures.

Running along the north fronts of the warehouse, power house and punch shop is a surface railroad track connecting with the Pennsylvania Railroad's main line, and along the south walls an elevated track by which shipments to and from the second stories of the buildings are made.

TEMPORARY BRASS FOUNDRY.

Just north of the punch shop is a one-story corrugated iron building, 40 feet by 242 feet, used as a brass foundry, and north of this is the

BLACKSMITH SHOP.

This is a substantial brick building covering an area of 242 feet by 82 feet 6 inches. These last three buildings complete the extreme eastern tier of buildings, as do the machine shop and warehouse the western.

Through the center of the building runs a track for local transportation purposes. There are already erected and in operation within this building twenty-five forge fires, and there are fifteen more to be installed. The blast for these forges is supplied by two 10 h. p. two-phase motors. Over each fire is suspended a large sheet-iron hood to collect the smoke and other products of combustion, and these are connected with a system of flues in which a strong draft is created by exhaust fans operated by two 20 h. p. Tesla motors. There are also two large Allstatter combined shears and punches and some smaller tools operated by one 20 h. p. motor. Besides these there are three small steam hammers for forging copper bars of the largest size used in dynamo construction.

CARPENTER SHOP.

The carpenter shop, 60 by 192 feet, lying east of the machine shop, is a one-story corrugated iron building, fully equipped for the purpose. In

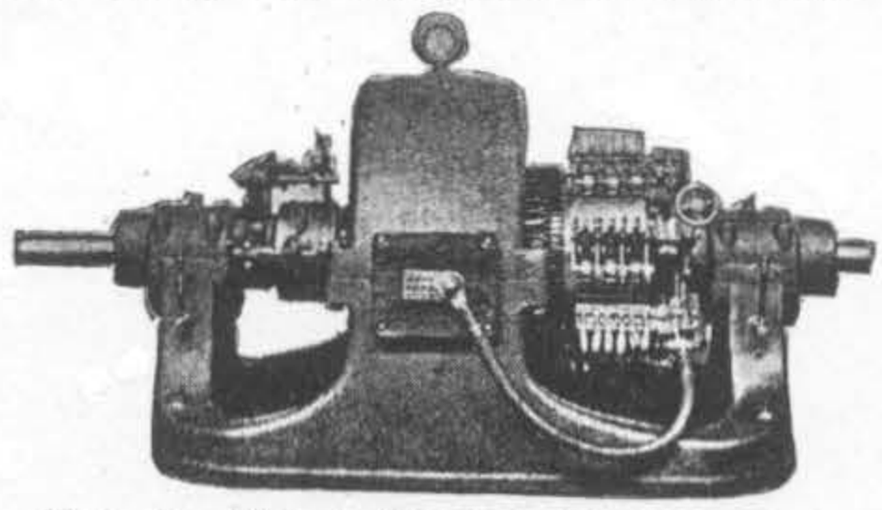


FIG. 6.—TESLA ROTARY TRANSFORMER.

the 65 feet space separating the machine shop from the warehouse is located the

COIL-BAKING AND OIL STORAGE HOUSE,

which is a small brick building, 182 feet 10 inches long by 27 feet 4 inches wide, devoted to the purposes indicated in its name. On the roof of this has been constructed a light, airy room in which the thousands of blue prints used by this great establishment are prepared.

(To be continued.)

The Tesla Two-Phase System.

II.

EXTENSIVE USE AT THE WESTINGHOUSE WORKS, BRINTON.

The New Plant Fully Equipped with Alternating-Current Apparatus—The Most Important Installation Thus Far Attempted.

BY NELSON W. PERRY, E. M.

Returning to the power-house we find, as already stated, two 500 H. P. direct connected direct current units furnishing current at 500 volts. These are used for testing the direct current apparatus manufactured by the company and are at present operating the five electric traveling cranes, the elevators and several large direct current motors, all of which it is intended to replace as soon as possible with alternating two-phase motors. As these generators are of the standard street railway type with which all are familiar, they need not take more of our attention at this time.

Turning now to the alternating current machines on the other side of the building, we find them very different from the two-phase apparatus employed for lighting purposes at the World's Fair. In those machines, it will be remembered, there were practically two armatures revolving in a common field. The windings of these two armatures were in such relation to each other that the phases of the two currents were in quadrature with each other. In fact the World's Fair generators were really two separate machines operated on the same shaft and in a common field. The frequency of the currents was 7,200 and their voltage approximately 2,000. The present machines, which are admirably illustrated in Fig. 2 (page 170 of last issue), in many respects resemble multipolar direct current machines, except that four collecting rings replace the familiar commutator. The field magnet yoke is of massive cast-iron with inwardly projecting laminated pole-pieces, fourteen in number. The armature is single instead of double and resembles very closely in outward appearance a Gramme ring. The winding is continuous and connections are brought out at four points, 90° from each other, to collecting rings, as represented in diagram, Fig. 7, the two terminals of each diameter forming the terminals of a different circuit the phases of which differ also by 90°.

In the diagram A and B represent the collector rings of one circuit and their connections, and C and D those for the other circuit.

In three of these wires are placed automatic circuit breakers, so that in case of a short circuit between any two of the wires the circuits involved will be opened.

The windings of the armature are carried in slots in its cylindrical surface and held against centrifugal force by vulcanized fiber rods slipped into grooves in the slots just over the conductors. No binding wire is therefore employed on the cylindrical surface of the armature as is necessary when the conductors lie upon the surface.

The pole-pieces are fourteen in number and consist of laminated iron inserted into the yoke at time of casting. This insures the most perfect continuity between the two and obviates the reluctance factors due to mechanical joints. The magnetic circuit of the yoke is of high conductivity by reason of its massiveness, and the high permeability required of the pole pieces is obtained by the soft iron, and the prevention of foucault currents where they are most likely to occur is obtained by its lamination.

In the machines under discussion the fields are separately excited from a Tesla rotary transformer, illustrated in Fig. 6 (page 171).

This receives the alternating currents at the collector ring end, running as an alternating current motor and transforming them to direct currents which are taken off the commutator end for field excitation.

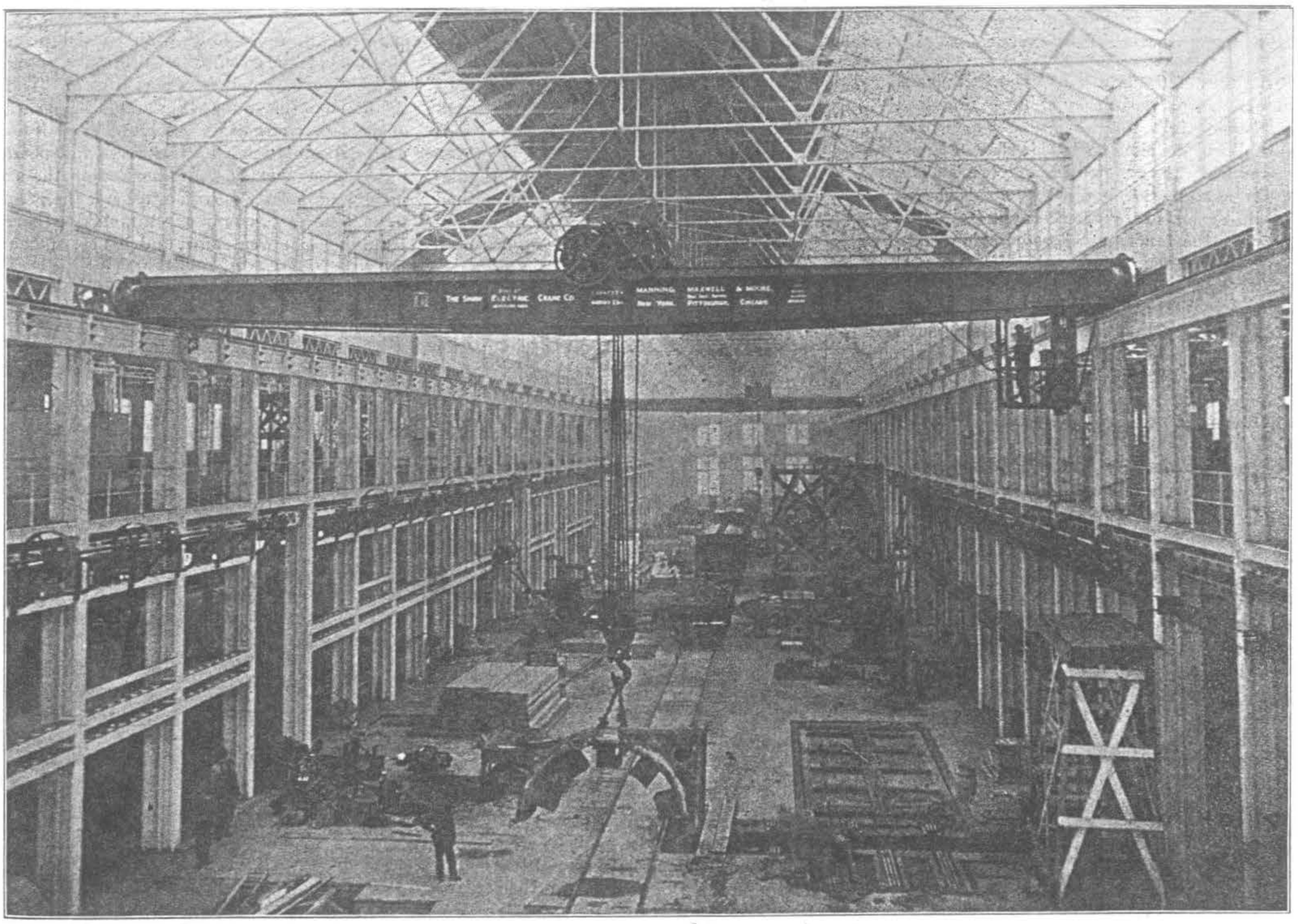
The two generators run at 220 revolutions, giving currents of 3,000 alternations—the same frequency as is to be employed at Niagara. Since in this installation the greatest distance of transmission is but about 1,100 feet, high potentials were not necessary nor desirable. The voltage employed is therefore only 230 at the generator terminals or about 220 at the motors.

Much has been written about the practicability of coupling alternators in multiple, and while it has been successfully done in a number of cases it has also failed in a sufficient number to give rise in the popular mind to a question as to its practicability. It is of the utmost importance to the central station man that he have the ability to throw units in and out of action, in multiple, as his load changes, for without this ability he must drop out in the race for supremacy. One of the points which the Westinghouse Company wished to emphasize, therefore, was that their two-phase generators could be operated in multiple, and upon their ability to operate in this way they staked the entire success of the new plant. It had not been a question with them, for it had already been demonstrated to their entire satisfaction, but the public required assurance on this point, and the object lesson which these works was intended to afford would have been incomplete had the two generators been employed on separate sets of circuits. They are therefore coupled up in multiple, and during the days when the writer saw them operating were giving a combined output of more than 400 amperes on each of the two circuits. The variation between the two machines was practically negligible, and they seemed to work in parallel in every respect as well as two direct current machines similarly connected are accustomed to do.

Where longer distances are concerned, machines giving higher potentials would be employed and step-down transformers used at the point of distribution to bring the voltage down to that suitable for motor work or lighting; or if very long distances were involved, requiring higher potentials than it would be desirable to generate directly in the armature, these same machines generating 230 volts could be used, step-up transformers employed at the power station to raise the voltage to that required for economical transmission, and step-down transformers at the point of distribution employed as before to reduce the pressure to the requirements of service.

The simplicity and efficiency of the closed magnetic circuit transformer are too well known to require remark here further than to say that they are the most efficient transformers of energy known to man. So high has this efficiency been for several years past that little improvement seemed possible or even desirable in this direction. There has been room for improvement, however, in methods of insulation against the increasingly high potentials now being used and in the dissipation of the heat energy which constitutes inevitable losses in the transformer. Theoretically a transformer working with a hot core and a cool coil would be the most efficient, but these two conditions are incompatible. They have been partially realized, however, in the Westinghouse transformer, which is illustrated in Fig. 8. This photograph shows very clearly the method of building up the laminated core around the coils adopted by this company, but the main feature to which it is desired to call attention at this time is the spreading of the ends of the coils after they come out of the iron, which affords a much better opportunity for the dissipation of the heat energy developed in the coils than any other method thus far suggested which does not at the same time dissipate the heat from the iron as well.

Still another essential to a good transformer or converter, as the Westinghouse people call it, is that it shall be proof against the breaking down of the dielectric. Where comparatively low potentials are concerned, it is not difficult to insulate against them, but when extreme pressures such as long-distance transmissions require are used, the insulation against these pressures becomes a question of the utmost importance. Tesla has shown that the air itself is a most fruitful cause of discharge across either from static or dynamic charges, and that if this be removed many of the difficulties of transformer insulation are also removed. The Westinghouse Company, therefore, exclude the air from the transformer chamber by utilizing a fluid dielectric, which has the further quality, not possessed by solid dielectrics, of repairing itself in case it does at any instant break down. The transformer shown is the latest type of the oil transformer now manufactured and used on high-potential circuits. As will be observed, no attempt is made at high insulation in the winding of the coils, they being simply wrapped in untreated cotton tape. The transformer, however, when ready for use is simply immersed in an oil



VIEW CENTRAL AISLE OF MACHINE SHOP. 30 TON ELECTRIC CRANE.

bath, the air driven out as far as possible and then connected up for service.

The Westinghouse Company was the first to appreciate the possibilities of the alternating current in long-distance transmission, and when

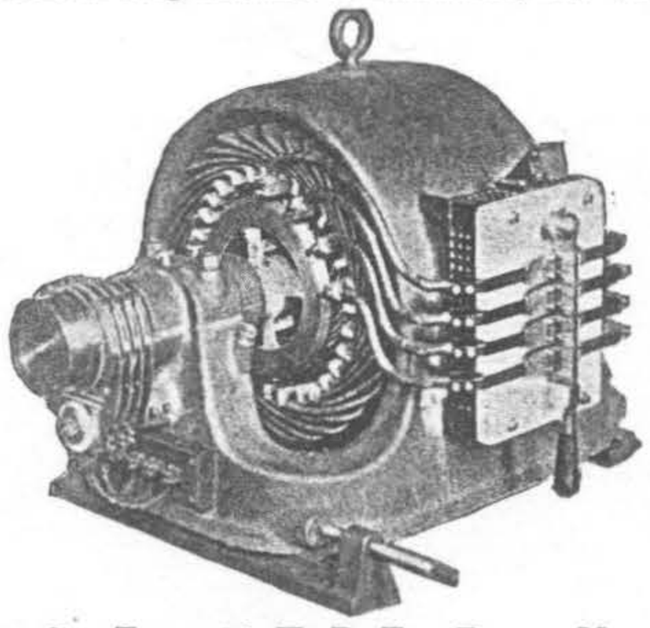


FIG. 3.—TESLA 50 H. P. TWO-PHASE MOTOR. OLD STYLE SWITCH. NEW STYLE COLLECTOR BRUSHES.

the inventions of Gaulard and Gibbs had placed it on a commercial basis, they at once procured the exclusive right to their use. They have therefore been the pioneers in this class of apparatus, and while the system of to-day bears little resemblance to that elaborated by Gaulard and Gibbs, the system of transformation is based primarily upon the fundamental patents issued to those two gentlemen. Many other fundamental patents bearing upon this important field were also early acquired, among the most important of which are the Tesla polyphase patents, which it is claimed completely cover the whole field of polyphase transmission and distribution and which will find their highest and most extensive application in the great Niagara scheme.

The Tesla polyphase patents upon which the Westinghouse Company base their claims of ownership in this field are the following:

May 1, 1888, Nos. 381,968—381,969—381,970—382,279—382,280—382,281, 382,282.
October 2, 1888, Nos. 390,413—390,414.
October 9, 1888, Nos. 390,721—390,820.
April 16, 1889, No. 401,520.
June 25, 1889, No. 405,858—405,859.
December 3, 1889, Nos. 416,191--416,192—416,-193—416,194—416,195.
December 31, 1889, No. 418,248.
March 25, 1890, No. 424,036.
August 5, 1890, Nos. 433,700—433,701—433,702—433,703.
January 27, 1891, No. 445,207.
June 30, 1891, No. 445,067.
September 22, 1891, No. 459,772.
December 8, 1891, No. 464,666.

Making twenty-nine patents all told, which

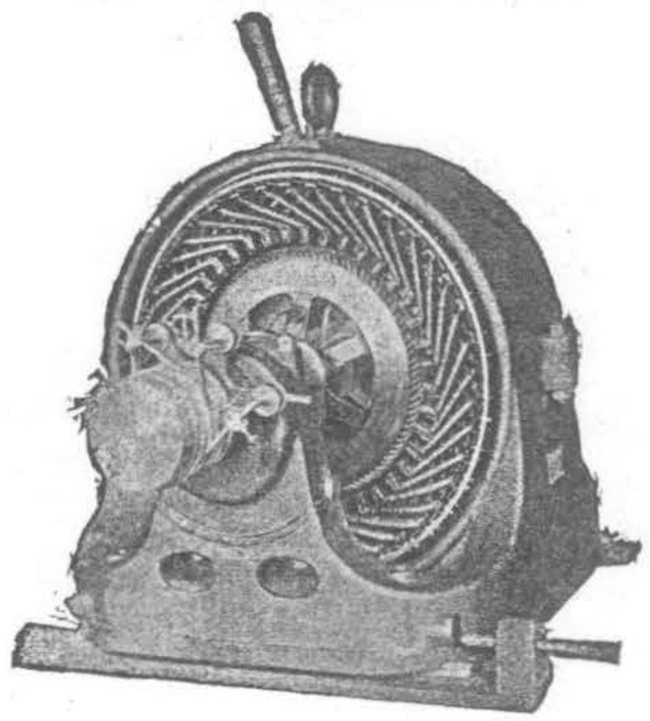
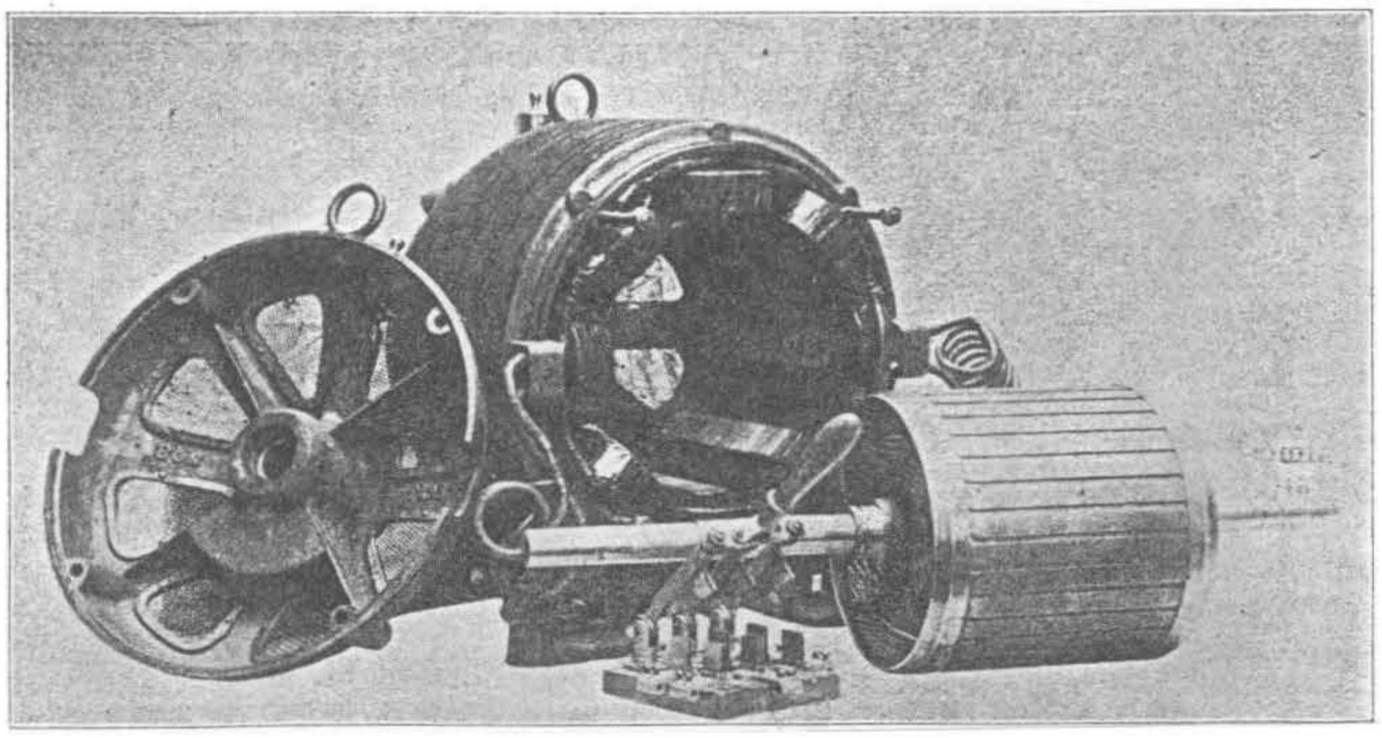


FIG. 4.—TESLA 50 H. P. TWO-PHASE MOTOR. NEW STYLE SWITCH RING. OLD STYLE COLLECTOR BRUSHES.

the company believe completely cover the polyphase field so far at least as it has been developed.

It is not to be supposed, however, that any one mind has contributed all that goes to make up the completed commercial system of to-day. Many minds indeed have contributed to the perfected system as exemplified in the plant under discussion, and while, if we were to confine ourselves strictly to this particular plant, we would necessarily pass lightly over some of these features, or not mention them at all, the description of the system as a whole would be incomplete. At the risk, therefore, of seeming a little prolix some of the more important accessories will be referred to.

Where lights are to be supplied as well as power, it is of the utmost importance to have means at hand by which the potential on the various circuits may be regulated so as to compensate for the change of losses due to variations in load. The voltmeter as usually employed in the generating station indicates only the pressure at the generator terminals and not that at the point of consumption where the variable effects of drop are encountered. In ordinary practice it has been customary to bring back small *pressure* wires from the points of distribution, by which means the pressures at those points were indicated and the proper regulation indicated to the station manager. A method of equalizing the pressures among a number of distribution points, often resorted to, has been



TESLA 5 H. P. MOTOR, OLD TYPE.

that of connecting them all together with equalizing wires. Both of these methods are cumbersome and expensive, and have been discarded by the Westinghouse Company. In their places have been substituted the following arrangements:

The voltmeter is supplied by the secondary of a small converter, usually reducing in the ratio of 30 to 1 where the initial voltage is 3,300, or in a greater ratio if higher. In the voltmeter circuit there is placed a compensator. This is shown in Fig. 9, and consists of a small transformer with its primary in series with the main circuit and its secondary in series with the voltmeter circuit, and connected in such a way that the compensator pressure to the main current opposes the voltmeter pressure to an extent proportional to the loss in the conductors. The voltmeter by this arrangement, therefore, indicates the potential--not at the station, but at the point of distribution.

Now as this pressure varies it becomes necessary to have some means of correspondingly varying the station pressure. If there were but one circuit extending from each generator, this would easily be accomplished either by varying the field excitation or the speed of the armature, but in practice there are usually a number of circuits extending from each machine in each of which a different compensation is required, and the methods referred to would not be applicable. To meet such cases resort is had to the Stillwell Regulator, represented in diagram in Fig. 10.

THE STILLWELL REGULATOR.

The great value and importance of this instrument as a part of the modern complete central station equipment has been demonstrated beyond question. The principle of the instrument—as beautiful as it is simple—is that of induction. For this reason no similar device can by operated from a direct current system. It consists primarily of a converter, suitably designed, with secondary coil adjustable in length, i. e., with connections brought out from different parts of the secondary coil to a multipoint switch. By means of this switch the whole or any part of the secondary coil may be thrown in series with the main circuit, thus adding to the initial primary potential of the circuit the additional potential of the secondary coil, or a part thereof. Within the limits of the voltage thus added the potential of the supply circuit is, therefore, subject to the most delicately shaded adjustment, independent of whatever may be the potential at the alternator terminals. Consequently, it is the practice to have several supply circuits taking current from the same generator, and hence, of course, they are at absolutely the same potential. Although each circuit may be operated at a different percentage of loss, by the use of the Stillwell Regulator all lamps will be maintained at a uniform voltage and brilliancy. The attachment of a double-throw switch makes it practicable to reverse the action of the regulator and decrease instead of increase the initial potential. This may

FIG. 6.—ARMATURE ROTARY TRANSFORMER.

be frequently done to meet local conditions, and is an additional convenience.

It will be noted that this instrument simply increases the electromotive force in the circuit by a few volts. To do this it is necessary to transform but a small portion of the electrical energy passing through the regulator. The

efficiency of conversion of this fraction of energy is easily 95 per cent., and it is therefore evident that the loss of energy in the regulator will be but an extremely small percentage of the total energy of the circuit. For example, at full load a 100 ampere regulator, designed to raise the initial potential 10 per cent., would receive at the

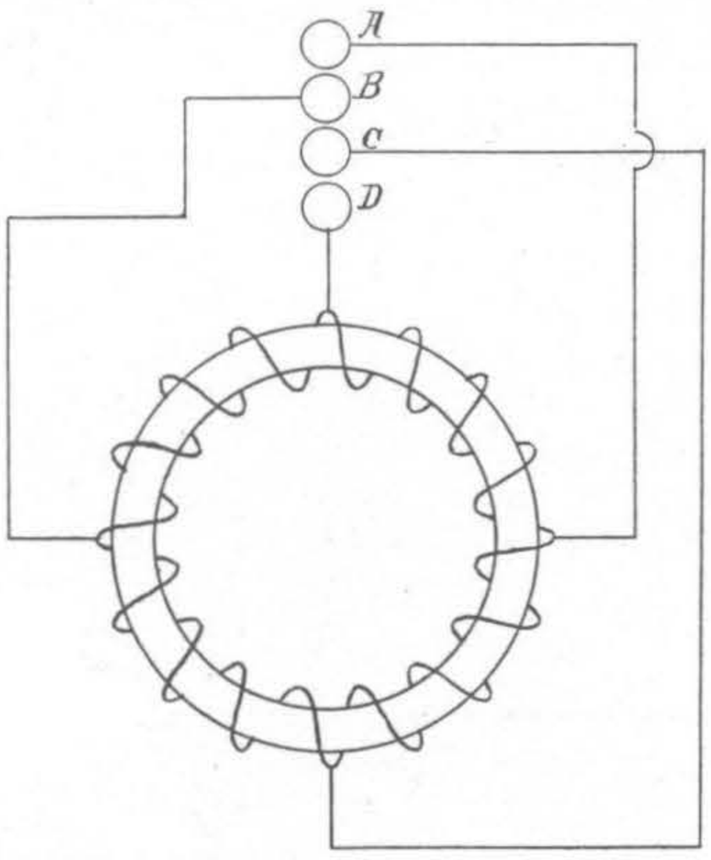


FIG. 7.—DIAGRAM OF GENERATOR ARMATURE CONNECTIONS.

terminals of its primary coil 10 amperes at 1,000 volts, and at the terminals of its secondary coil would deliver 100 amperes at 100 volts, less any losses suffered in conversion. These losses, being the same as those of a standard converter of equal capacity, aggregate not to exceed 5 per cent., i. e., 500 watts. The total energy supplied to the circuit by the generator being 110 amperes at 1,000 volts, i. e., 110,000 watts, the percentage of loss is therefore .00455, or less than $\frac{1}{2}$ per cent.

The extreme flexibility supplied by the use of the regulator is illustrated by an example which occurs almost daily in practice. Let us assume a small station operating under ordinary conditions with, say, a loss of $2\frac{1}{2}$ per cent. in its feeders and 1 per cent in its mains, the territory supplied being within a radius of one mile from the station. Let us further assume that there is

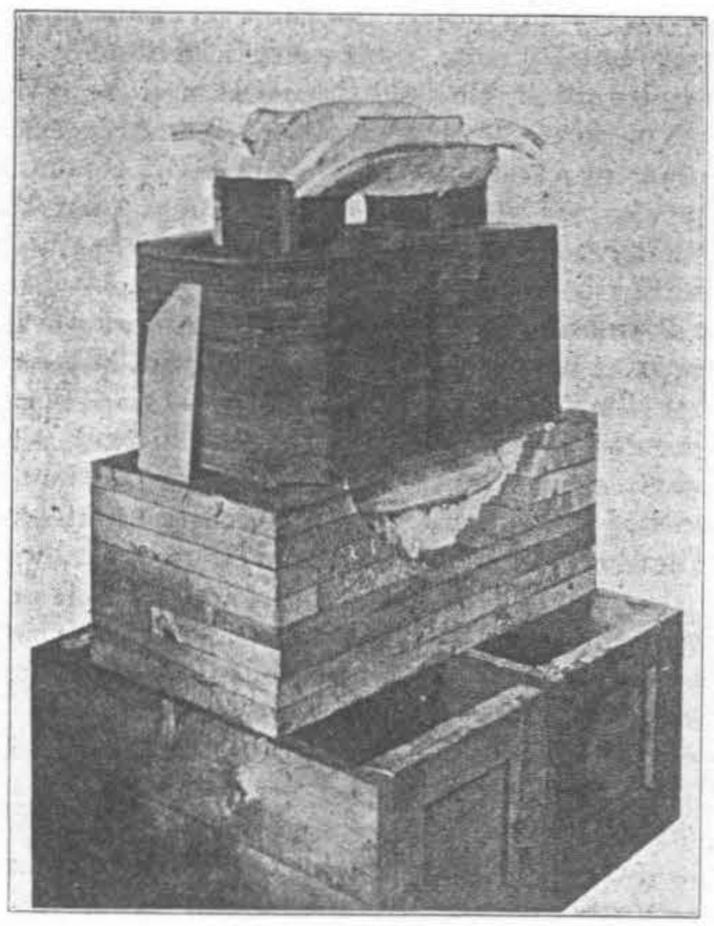
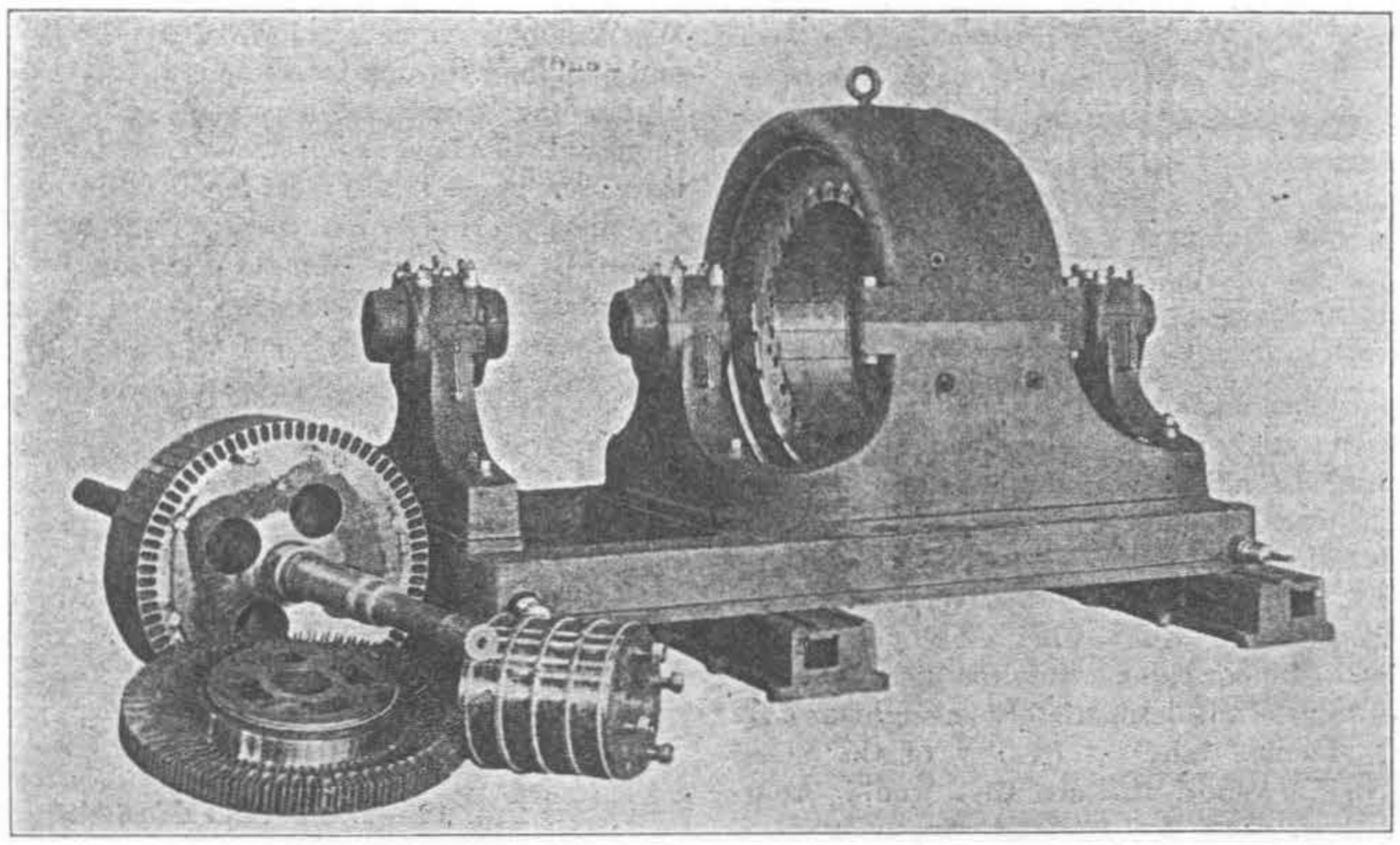


FIG. 8.—OIL TRANSFORMER PARTLY BUILT UP.

a point two and one-half miles distant where an additional 500 lights can be secured. It would evidently not pay to erect a special alternator to supply this number of lights, and yet to supply them from the same alternator sufficient additional copper must be put into the new circuits to reduce the losses over the greater distance to those already incurred in the shorter circuits. This also would prove uneconomical and the station manager would find himself confined to a choice of three undesirable methods: 1st, to install a new alternator for the 500 lights; 2d, put in a sufficiently heavy wire to maintain the same loss at the greater distance, and 3d, abandon the idea entirely of supplying the new customers. I do not know whether dilemmas usually have three horns, but this one seems to have and they all promise to be equally uncomfortable to sit upon. The regulator, however, comes to the station manager's assistance in this way: Assuming an average of $\frac{1}{20}$ ampere in the primary line for every 16 C. P. lamp on the secondary circuits and a 10 per cent. Stillwell Regulator to be attached to the new circuit, it is immediataly possible to raise the initial electromotive force 10 per cent. above the electromotive force of the other circuits supplied from the same dynamo, and to therefore allow an additional loss of the same amount on the line. The line cost for supplying these lights by this means (including the cost of the regulator) would be only about one-third what it would were the extra copper otherwise required employed. It also effects economies in operation and renders possible much better service by placing in the hands of the station manager a most perfect means of independent regulation of the various circuits extending from the same dynamo.

In the regulators as now put on the market, the secondary is divided into small sections, each of which has an electromotive force equal to 1 per cent. of the primary. Any number of these sections may be placed in series with the supply circuit, and thus with standard apparatus the variations in pressure at the point of distribution may be compensated for through all variations in load within less than 1 per cent.

All long lines of overhead wire, and particularly such as traverse mountainous sections, are subject to violent atmospheric conditions which if not provided against in some efficient manner are liable to result in the destruction of the machinery at both ends of the line. The popular belief is that these destructive effects are due to lightning, but while they are apt to occur most frequently in sections of country where severe thunder-storms prevail it is doubtful if the lightning itself ever, or at least frequently, actually strikes the wires. The so-called lightning strokes on circuits are now known to be chiefly inductive effects, due to sudden changes of potential of the earth or clouds due to lightning flashes occurring not necessarily in the immediate proximity of the circuits, but which by inductive effects set up electrical surgings in the wires. These surgings if they reach the transformer or dynamos are liable to cause disruptive discharges across the insulation which may lead to its destruction. It is not the disruptive discharge, however, that does so much damage, as it is the dynamo current which, having had this path opened to it by the disruptive discharge, follows it. An effective lightning arrester, therefore, has two distinct offices to fill: 1st, to offer an easier path for the surgings than that through the coils of the machinery whereby it may be drawn off the line, and second, to prevent the passage of the dynamo current over the same path that the disruptive discharge has opened for it. The old idea was that the first of these functions was fulfilled



TESLA 300 K. W. MOTOR, WORLD'S FAIR TYPE.

when a grounded conductor was separated by a short air-gap from the circuits to be protected, and the second by providing some mechanism, either mechanical or magnetic, by which the arc which followed might be broken instantaneously and the normal air gap re-established for subsequent protection. Experience has taught, however, that these electrical surgings do not seek to

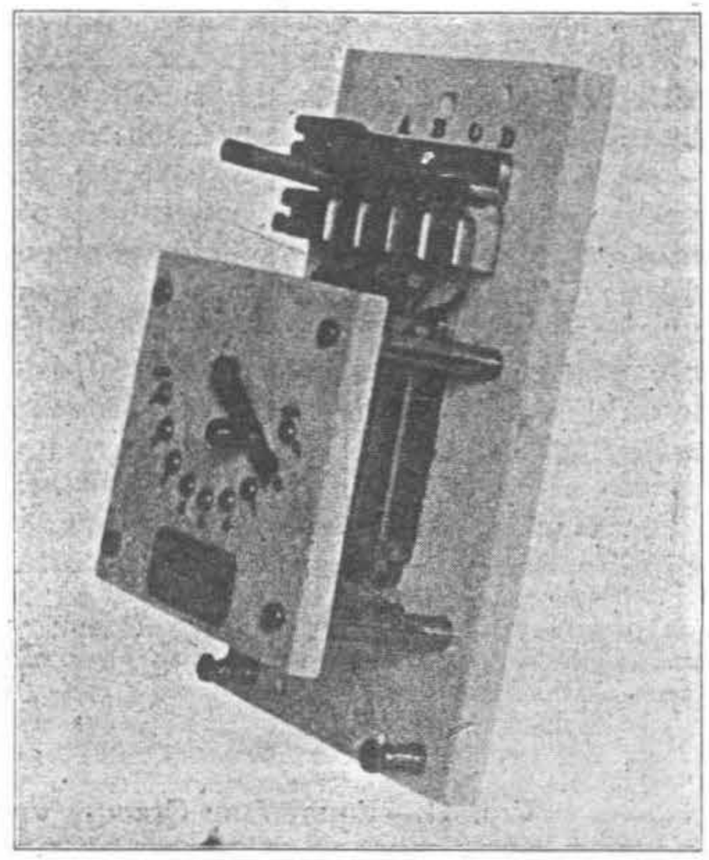


FIG. 9.—COMPENSATOR.

leave the wires with equal force at all points and that they will frequently pass by a number of short air gaps and then find the ground through a much longer and apparently more difficult path. The reason for this is now well understood and is implied by the name by which I have

described them, viz., surgings. If an air gap be provided where the crest of the wave happens to be, a discharge will take place, whereas similar air-gaps, or even shorter ones, would be passed by by the same surging if they happened to be situated at any other point than where the crest happened to be found.

Mr. Alexander Jay Wurtz of the Westinghouse

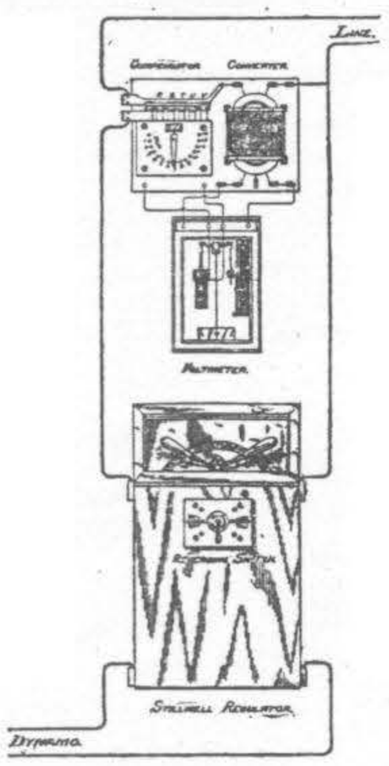


FIG. 10.—STILLWELL REGULATOR.

Company has made, under their auspices, a very exhaustive study of the phenomena of so-called lightning discharges on overhead circuits, and has discovered a method by which the lines are afforded almost absolute protection from these dangers. The basis of this discovery is that of a non-arcing metal which, when employed as the terminals of an air gap, permits the disruptive discharge to pass but immediately extinguishes, by virtue of some inherent quality of the metal itself or its vapor, the arc that would otherwise follow. In his completed arrester he employs seven cylinders of the metal—each one inch in diameter, and three inches long. These are mounted side by side, separated from one another by $\frac{1}{64}$ of an inch. The central one is connected to the ground while the two outside ones are connected to the two sides of the circuit. With these metals and this arrangement it has been found impossible to start and maintain an arc when they are separated by an air gap of this size, but strange to say, where the gap is longer—say half an inch—the arcing is said to be very vicious. In recognition of the value of this discovery of non-arcing metals and their application to the protection of circuits, the Franklin Institute of Philadelphia awarded to Mr. Wurtz the John Scott Legacy premium and medal. These lightning arresters are placed at such frequent intervals along the line that some one or more of them is sure to be in the proper position to draw off the charge at the crest of the wave. The arresters are also placed in the stations at both ends of the line. As showing the frequency of these discharges in some localities, an instance is cited in the experience of a line at Telluride, Colorado, when forty-two discharges of the lightning arresters were observed in as many minutes, any one of which might, if not thus provided for, have damaged or destroyed the machinery at one or the other end of the line.

The above digression has been indulged in to call attention to some of the accessories to a transmission plant installed on the Westinghouse system. This is scarcely pertinent to the subject in hand, but we may consider that the Westinghouse shops are located at the further end of a long line of transmission, and that the high voltage transmission currents of 5, 10 or 20 thousand volts have been transformed down in the power house to 230 volts for distribution, the dynamos previously described being simply replaced by step-down transformers, and we have the conditions exactly as they would be if the shops were actually hitched on to Niagara or

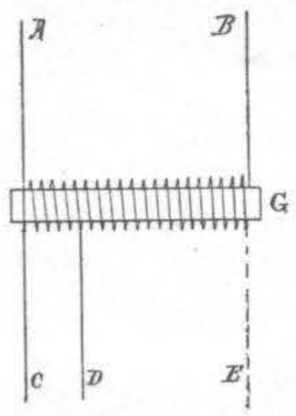


FIG. 12.—BALANCING COIL.

any other distant source of power. The switchboard would remain as it is, and from it would run, as they do now, the four circuits—two for each of the two-phase currents.

At Pittsburg these wires are carried overhead on insulators to the various buildings where power and light are required.

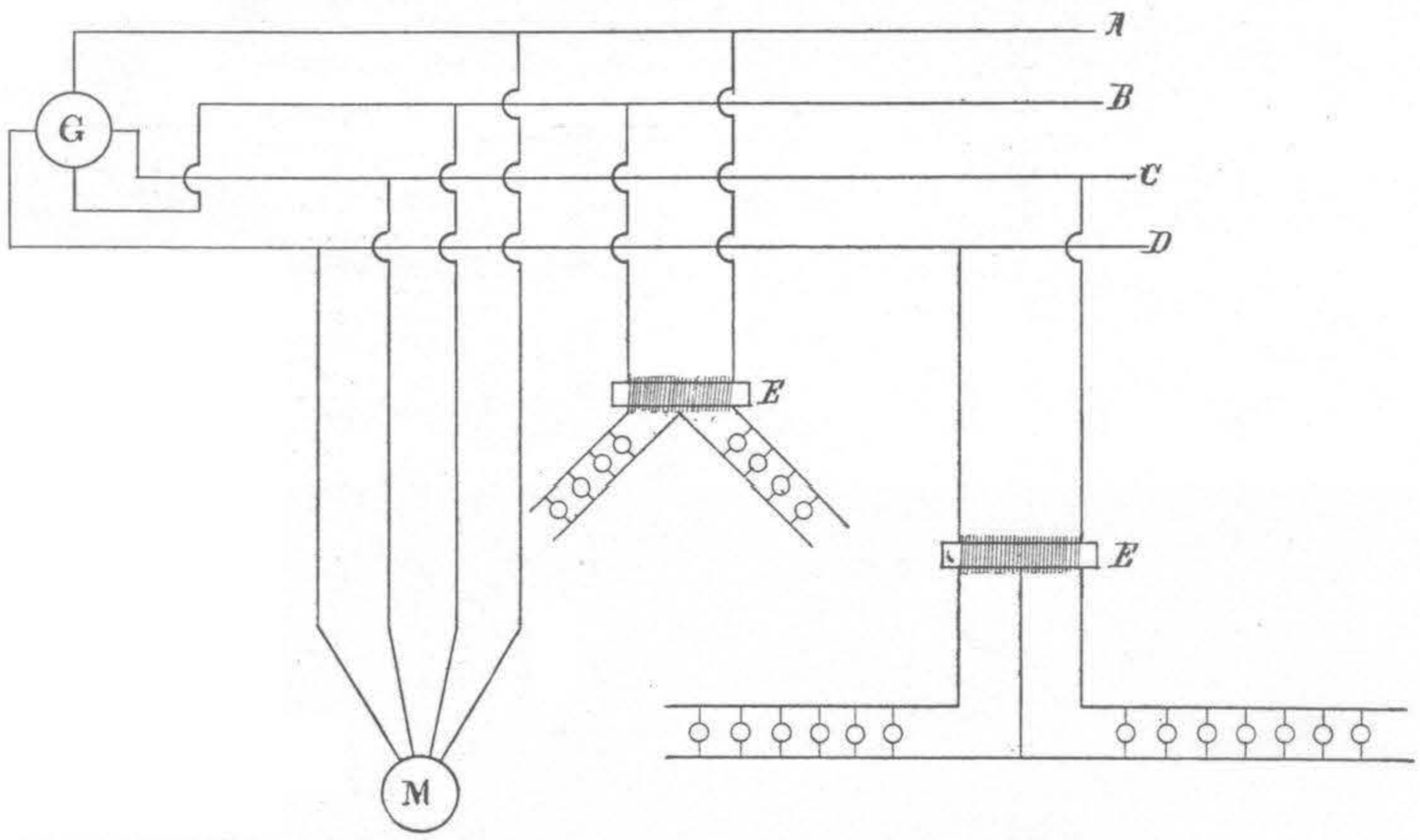


FIG. 11.—FOUR-WIRE CIRCUIT WITH MOTOR AND LIGHT CONNECTIONS.

Fig. 11 shows the methods of distribution and the manner of taking current off from the circuits both for motors and light. It will be observed that the lights are taken off of both circuits indiscriminately. Usually, it would be better to divide the lights about equally between the two circuits, for the reason that where all the motors used are two-phased motors, as in this establishment, the only chance for unbalancing the circuits is by overloading one circuit with lights at the expense of the other. Some writers have held that this unbalancing of the circuit would

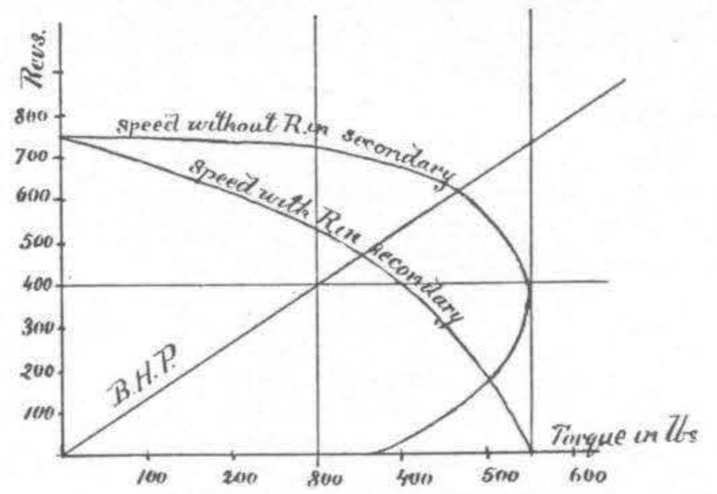


FIG. 13.—CURVE OF TORQUE.

introduce undesirable complications in the operation of the apparatus. There seems to have been no foundation for these fears, for the irregularities do not develop in practice. The Westinghouse Company have put the system to the severest test of fully loading one side with lamps and

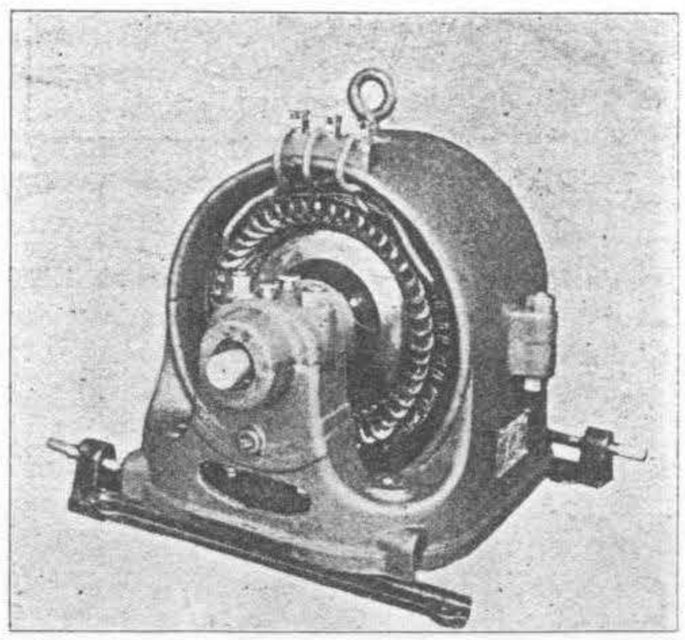


FIG. 14.—TESLA THREE-PHASE MOTOR.

operating them with no load on the other side. The difference observed under these conditions between the two sides was only 4 per cent.

THE BALANCING COILS.

It will be observed in the diagram (Fig. 11), that the lights are taken off of either circuit, between which there is a difference of potential at this point of about 220 volts. The lamps require but 110 volts. The usual method would require either that the lamps should be wired two in series or that the potential be reduced by means of a transformer. Instead of the usual transformer with separate primary and secondary windings, the balancing coil is here used. While the functions of this coil are doubtless well understood by many of the readers of this paper, it may be well for the benefit of others to describe it in detail. In Fig. 11 this coil is represented by E, and in Fig. 12 on a larger scale by G. In the latter figure, A and B are the two sides of the 220 volt circuit connected to the terminals of a coil with iron core G. If there were no secondary coil, or if the secondary coil were open, this coil would act by self-induction as a choking coil, and no current could pass from A to B. For the purposes of illustration I have represented this coil as having twenty complete turns. If to one end the wire C were attached, and another one D were attached to the fifth turn, then the twenty turns would act as a primary and the five as a secondary—the currents in the two being in opposite phase, and the reduction of potential between these two wires would be from 220 volts to 55. If now a third wire E were attached to the other end of the coil, the whole coil would again act as a primary to that portion of the coil between D and E as

a secondary—in this case fifteen turns—and the potential between these two wires would be $\frac{15}{20}$ of the primary voltage, or 165 volts. By this means it is possible with a single coil to divide up the voltage into two or more parts by including between the secondary wires the proper proportions of the coils to effect the desired reduction. It is in fact a transformer, but one of exceedingly simple and economical construction, and for distributing a 220 volt current to 110 volt lamps is made use of by connecting a neutral wire into the center of the coil, and from this elementary three-wire circuit taking off the two-wire circuits at convenient points. Since the coil is equally divided between the two circuits, the electromotive force of the primary is also equally divided between the two branches, and there is obtained 110 volts in each branch. If it were desired to take off four circuits of 55 volts each, for arc lamps or other purposes, the coil would be divided into four equal portions, or any other portion of the primary voltage could be obtained in the secondary by simply including between the two wires of the secondary the proper proportion of the primary coils.

The advantage of this arrangement over the two-coil transformer for this purpose is its simplicity and the economy both of copper and of attendant copper losses.

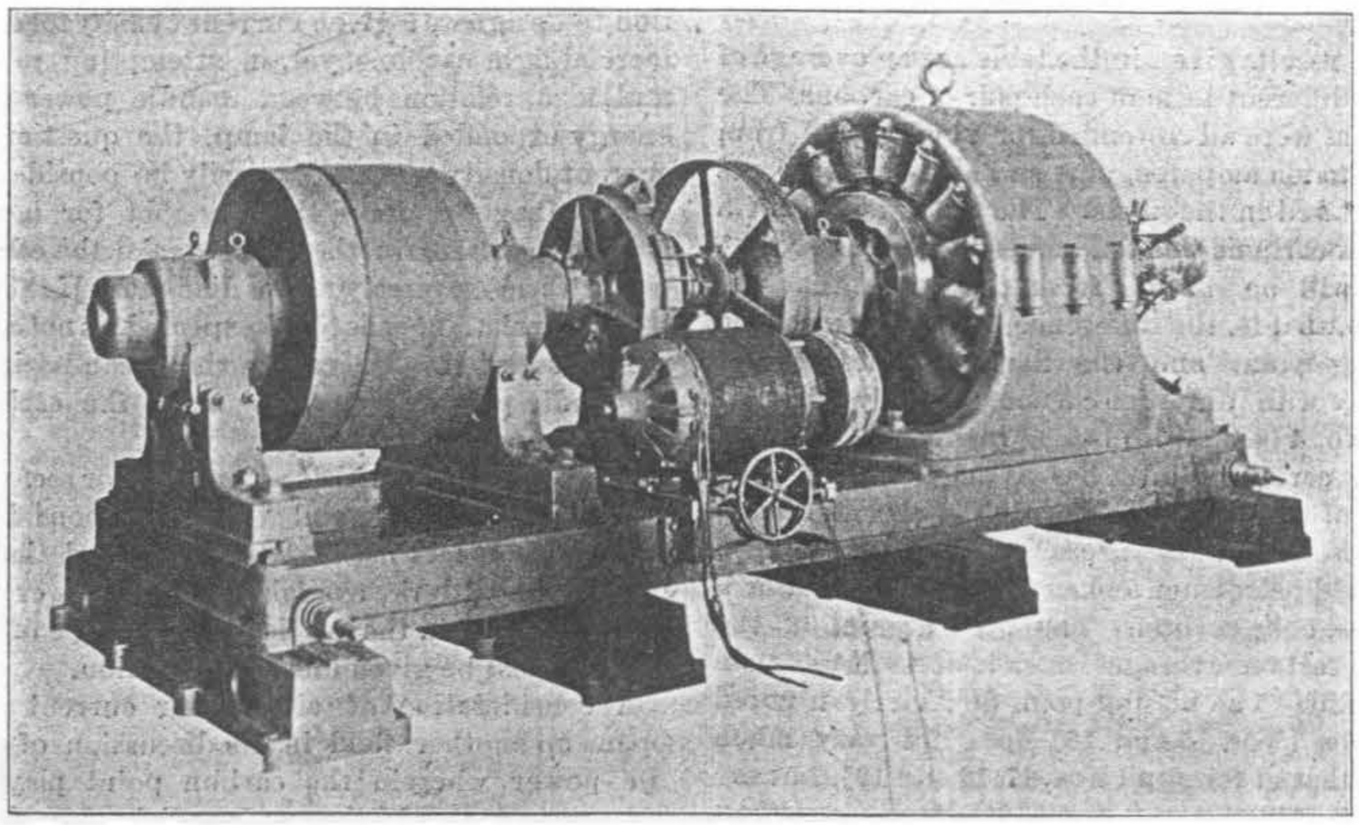


FIG. 15.—250 H. P. SYNCHRONOUS AND STARTING MOTOR.

TWO-PHASED MOTORS.

The motors' currents are taken off the two circuits as shown in Fig. 11, the connections being made as shown at M. The alternating current motor is in reality a transformer so constructed as to permit of relative motion between the primary and secondary coils. If either one of these be fixed in position, the other becomes the rotating part, and from one point of view it is entirely immaterial which is made the stationary and which the rotating part. Carelessness in the use of language has accustomed us to refer to the rotating member of a motor as the armature, but strict scientific accuracy forbids such indiscriminate use of the term. The Westinghouse Company are therefore to be commended for introducing a more accurate nomenclature, which is bound to find general acceptance as soon as it is better known. At the Westinghouse Works the word "armature" is no longer used when speaking of the two-phased motor, but it is described as the "rotating primary" or rotating secondary" as the impressed E. M. F.'s are led into the rotating or the stationary part. There is nothing in direct current practice to indicate the advisability of introducing resistances into the armature circuit, and they are avoided as far as possible except for starting purposes, when their function is simply prevent too great a rush of current. These resistances are not only wasteful, but actually cut down the starting torque of the motor by the exact amount by which they cut down the current. The starting resistance in a direct current motor is therefore the lesser of two evils, because nothing could be worse for the motor than to have its armature burn out, as it most surely would do if started under heavy load without the resistance. It has been found, however, that in the polyphase motor the starting resistance has performed a valuable service, viz., it *increases* the starting torque of the motor.

For the purpose of illustration the diagram, Fig. 13, is given. These curves are not intended to be correct, but merely to illustrate the point which it is desired to emphasize. If a polyphase motor were started without a resistance in its secondary, the curve determined by torque and speed would be something like the upper one. The torque would be comparatively low at start, but reach a maximum in this case when the speed had reached 400 revolutions per minute.

Now the torque of that particular motor can never exceed this maximum, but the position of the maximum may be made to come anywhere on the vertical line passing through this point desired and will descend as the resistance in the secondary increases. If this resistance be just right, the point will be brought down to the intersection of this vertical line with the line of no speed, or in other words, the motor will have its maximum torque at starting. Under these conditions the curve will take the form shown in the lower of the two curves, which is an actual curve taken from a 40 H. P. 220 volt two-phase motor with old style switch.

The resistance which performed this valuable function of giving the motor its maximum torque at starting in addition to preventing a too great rush of current at that time, will, after speed has been attained, be a detriment, so that means are provided by which it can be then cut out. To facilitate the cutting in and out of the starting resistances the larger sized motors which are likely to be called upon to exert a heavy starting torque are usually made with a stationary secondary—the current from the line being led to the revolving part by means of brushes bearing upon four rings on the shaft. Fig. 3 represents a motor of this kind. In this the brushes are of an improved type, but the switch is one that, although still used, is being superseded by another to be described later. In the old style, Fig. 3, all of the windings of the secondary are in series with each other, and when the switch is open are also in series with the starting resistances. When speed is attained these resistances are simply short-circuited by closing the switch, as shown in the engraving. The new style switch shown in Fig. 4, is considered a great improvement on this and is arranged as follows: At starting each conductor of the secondary is in series with a small resistance and with every other conductor. By means of a closed copper ring and sliding contacts connected with it, by a movement of the controlling switch, not only are the starting resistances thrown out of circuit but all of the conductors of the secondary are thrown from a series arrangement into a parallel one, being short-circuited on this ring. This not only greatly reduces the internal resistance of the secondary windings over that which is possible by the previously described arrangement, where at best they are in series, but leaves each of the short conductors free to act independently irrespective of the disturbing influences which the others might have upon it were they all in series. In Fig. 4 the brushes are of the old style. No photograph has yet been taken of the improved type motor, and it cannot therefore be shown here, but if the brushes shown in Fig. 3 were substituted for those shown in Fig. 4 the latter would then accurately represent the latest development of the Tesla two-phase motor with revolving primary.

For the smaller sizes, where a starting torque is not so essential, the primary coil is made the stationary part and the secondary coil the revolving part. The primary is a continuous winding of the drum type with connections brought out to binding posts from the points 90° apart. The secondary consists of a laminated iron cylinder into whose surface are sunk copper bars of large section, forming elements of the cylindrical surface. These copper bars, which form the windings of the secondary, are simply short-circuited at both ends on heavy copper rings, as is the case in Fig. 4 when the latter has reached speed. There are no collecting rings, brushes or other means of connection between the rotating part and the outside circuit on motors of this type, and although they do not attain a maximum torque until considerable speed is reached, they still have an initial torque sufficient to start under a very considerable load.

While the two-phase motor is the only kind at present in use in these shops, the company also makes several other types, one of which, the three-phase motor, similar to those employed in the Lauffen-Frankfort experiment, is shown in Fig. 14. Another type is the single-phase synchronous motor, such as has been in successful use for about four years in the long mining transmission plant at Telluride, Col. This latter type will not start under load, but when brought up to a speed synchronous with the generator it will then take the load and maintain it without further attention. In this motor the fields are excited by a direct current derived from a second winding parallel with the main coils around the teeth of the armature. This is commutated and led to the field coils.

A motor of the synchronous type requires an auxiliary device for starting, however, which is usually a small motor—a special modification of the Tesla type. Fig. 15 is a photograph of a 250 H. P. synchronous motor, with the Tesla starting motor and friction clutch, installed at Telluride some years ago and still in successful operation.

With this somewhat hasty and necessarily incomplete description of the New Westinghouse Works this paper must be brought to a close. Much that would be of interest has been passed over lightly or omitted entirely, but enough has been said probably to verify the opinion expressed in the beginning, that this is the most interesting, and from many points of view the most important, electrical installation thus far attempted.

Tesla's Inventions.—The "Century Mag." for April contains a long well illustrated article on "Tesla's Oscillator and Other Inventions" by Mr. Martin; it is written in a popular style describing the oscillator and a number of light effects, which latter are well illustrated, some of them by means of photographs made by their own light; among the light effects are those of the incandescence of a solid, phosphorescence, incandescence or phosphorescence of a rarefied gas and luminosity produced in a gas at ordinary pressure. He describes also effects with widely separated resonating circuits in one of which it is claimed that at least one-tenth of a horse power was transmitted across a space of some 20 feet into the bulb of a lamp without using any wires at all; other experiments show how lamps were lighted by currents passed through the human body; an experiment is described showing the disturbance of the earth's electrical charge.

Some other illustrations of the oscillators are reproduced with a brief description in the "Elec. Eng." and "Elec. Rev.," April 3, and one of them in "El'ty," April 3. In the former it is stated that the principle involved in the oscillator is that of "oscillating a coil or magnet with great economy of energy in an intense field and thus generating current on terms of very high efficiency and regularity as well as with marked diminution in size and weight of apparatus. The engine resolves itself down to a chest or cylinder for the working fluid and the piston for carrying the armature." There is a strong air spring in the top of the apparatus and the construction is such "that the engine is always in exact synchronism with the vibrations of this spring;" the engine varies the amplitude of the vibration but the period remains always the same; "the recoil of the spring is of course incomparably greater than the impulse received by it from the engine." Several distinct types are shown and briefly described, that of the more advanced form being as follows: "this minute machine had a capacity of 12 lights. It consisted of a small oscillator and a dynamo, the latter comprising a field magnet with its exciting coils and an armature merely of iron. The magnet had on its inside a number of pole projections upon which the induced coils were wound. The armature had projections of lesser number than those of the field. In this way the output of the dynamo was increased, by the number of teeth." It is stated that there is a preponderance of one impulse over the other creating virtually the effect of a direct or continuous current, but this is not described. With the latest form of oscillator which is illustrated, the frequency is 80 to 100 and the steam pressure 350 pounds, the steam admission being controlled by a small independent oscillator. In conclusion it is stated that "there can be no doubt that in this appliance we have a mechanism for the simultaneous utilization of steam and generation of current under conditions that must effect large economies in every direction; while it should also prove a powerful instrument for exhaustive research."

SCIENCE AND MECHANICS.

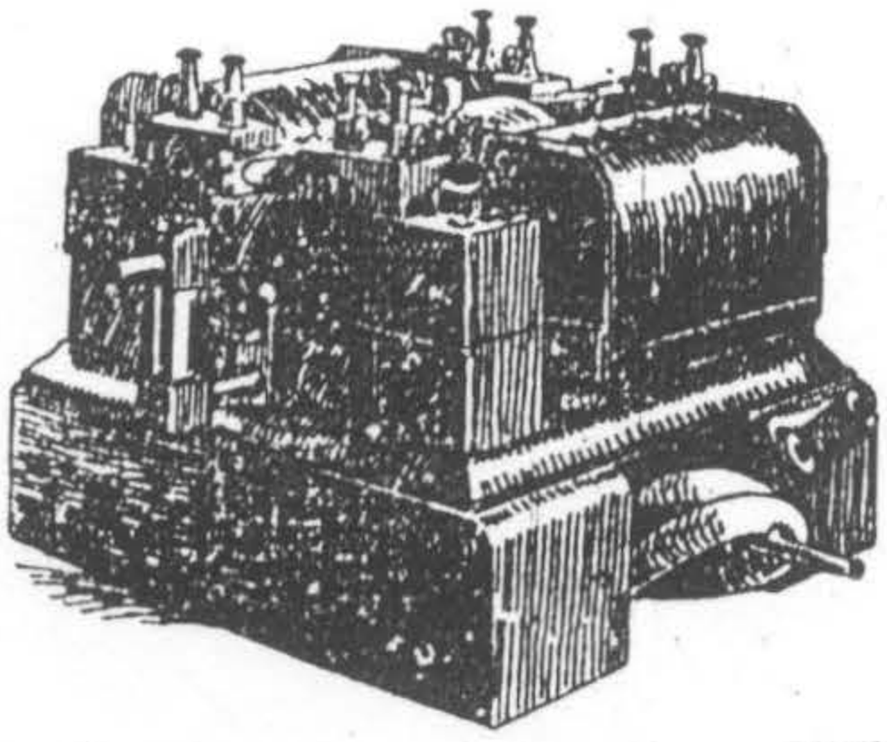
(From The Weekly Tribune).

MR. TESLA'S OSCILLATOR.

A GREAT AND RECENT INVENTION.

GENERATING ELECTRICITY WITH MUCH MORE SIMPLE AND ECONOMICAL APPARATUS THAN THAT NOW IN USE.

Countless are the directions in which Nikola Tesla, the greatest living genius now at work in the electrical field, has experimented, but there are four things with which, in the minds of people familiar with his labors, he is particularly identified. He has introduced an entirely new system into the operation of dynamos and motors, by causing what is called the "magnetic field" to revolve and drag the armature along with it. This is an improvement of immense practical importance in the transmission and use of alternating currents for power purposes, and is alone sufficient to render him famous for generations. He has shown that alternating currents of tremendously high potentials may be handled with practical impunity under certain circumstances—an exceedingly brilliant achievement, although of less practical value than some others. Then he has very nearly, if not quite, solved the problem of producing electric light without heat—an object which numerous scientists have eagerly sought with little result so far, but which is highly desirable in the interests of economy, to say nothing of safety and beauty. Finally, he has invented a combination of steam engine and dynamo, called an "oscillator," which is designed greatly to simplify the mechanism necessary in

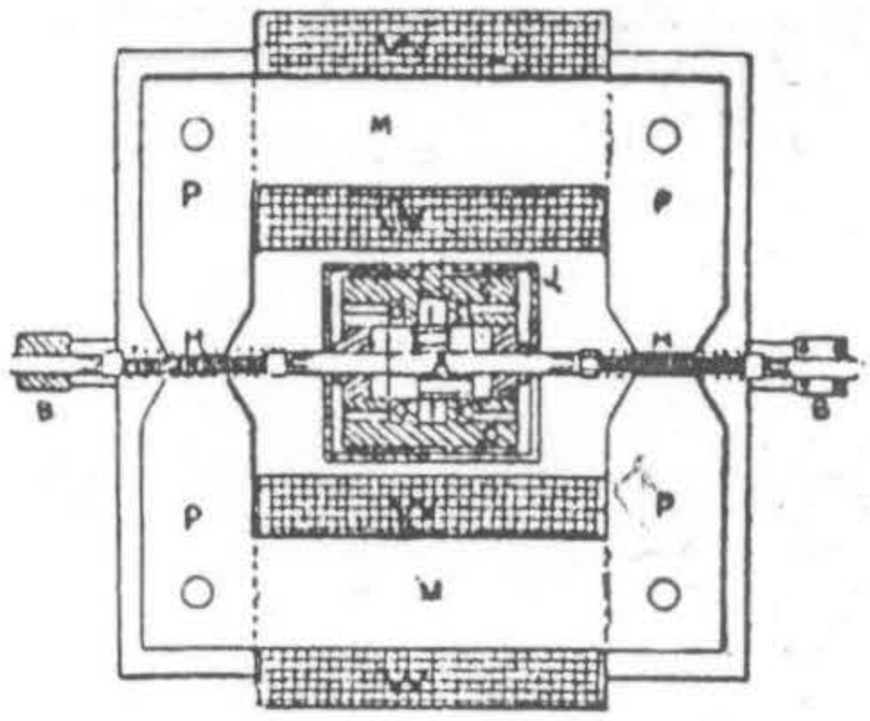


generating electricity, and hence to revolutionize that art. Several specimens of this device, differing among themselves in form but not in principle, were publicly exhibited and explained by Mr. Tesla nearly two years ago. He has since improved it in detail, with a view to still greater simplicity and efficiency, and it is said that just before the fire which destroyed his laboratory a few weeks ago this invention had reached such a degree of perfection that it was ready for the commercial stage of its career. Although some of its less important features are still kept private, and while it is impossible yet to measure with accuracy the possibilities of its usefulness, the oscillator is just now attracting renewed attention and provoking much enthusiasm among electrical engineers.

The fundamental idea of this machine is that the coils of wire in which a current is excited are moved to and fro horizontally, instead of being whirled around by a rotating shaft. What electricians call the "field" is the area in front of the poles or pole pieces of a magnet. Out into that space there extend invisible "lines of force." If a piece of soft iron be moved transversely past these poles, and near them, cutting the lines of force, it is momentarily magnetized by induction; and in any coil of insulated copper wire surrounding it there is induced, for the same brief instant, an electric impulse. In the ordinary dynamo a ring of soft iron is used instead of a bar, a number of connected coils are wound on it, and the whole "armature" is revolved between and in very close proximity to the field magnets; but Mr. Tesla winds his coils on a straight bar, and oscillates the latter between his magnets. By this change of method, he is able to accomplish several things not secured by the ordinary dynamo. He reduces the size of the apparatus greatly. The steam engine is said to weigh from one-thirtieth to one-fortieth as much as any standard type of stationary engine having the same steam pressure and piston speed; he gets rid of governor, fly-wheel, eccentrics, cutoffs, packing and other "jig-a-ma-rees"; and with the same amount of steam he generates about twice the current obtained from the old, cumbrous, complicated and more costly machinery.

The outward appearance of one of the early oscillators is shown in the first illustration, and the general arrangement of parts in the second. The cores of the big field magnets are indicated at MM, and the insulated copper wires wound around them at W W W W. The pole pieces, P P P P, attached to the ends of the cores, extend the magnetic fields to the narrow gaps, H H. At these points are placed small armature coils wound upon the shaft A, which latter slides in the bearings B B, under the influence of a piston screwed on to it. The walls of the cylinder C C, the jacket J and the inlets I I tell their own story; and the further details need not be explained. In the model here represented, compressed air was used instead of steam; but the latter is to be employed in the perfected oscillator. The motive fluid, whatever it be, smites the two sides of the piston alternately. A very short stroke results. In some of Mr. Tesla's models this ranged from one-sixty-fourth to three-eighths of an inch. But this movement is enough to excite a brief electric impulse in the coils at H H, whence, the alternating current is led off to its work, without the intervention of a commutator. This last improvement is in itself a great gain, to say nothing of the other merits already mentioned. Besides, Mr. Tesla claims that in his machine there is no idle wire, as in the rotating system.

One of the most exquisitely beautiful, as well as essential, features of the oscillator is yet to be mentioned. It is desirable that the frequency of the alternations in a current—its "period," as the experts call it—shall remain constant in the face of all



variations of "load," or work demanded of it. This can be regulated with a spring of the proper stiffness attached to the oscillating rod. An "air-spring," consisting of a piston inside an air-tight cylinder, may be made to perform this office, and the supplementary cylinder may be situated either close to the working cylinder or at some distance away, both pistons, however, being secured to the same rod. Again, proper air chambers at the end of the working cylinder may be made to serve as springs. By proportioning the size of the chamber of the air spring to the weight of the moving parts, the desired period is produced. Greater or less pressure of steam and any fluctuation in load may affect the length of the stroke, but not the frequency. There is still another mode of regulating the vibrations. It has been shown that electrical currents exhibit certain phenomena resembling those of sound. A circuit of a given "capacity" and "potential" is more favorable to vibrations of one frequency than any other. An instrument known as the "condenser" can be introduced into an electrical circuit to "tune" the latter to the desired frequency of oscillation—thirty, fifty, eighty or any other number per second. Mr. Tesla has applied this principle of "resonance" to some of his experimental oscillators, and thus imparted to his apparatus a selective affinity for whatever rate of vibration he wants. This is an automatic governor, which corrects any tendency to fall below or exceed the required speed. With such precision will this period be maintained that a clock may be driven with an oscillator and keep good time.

The illustrations are modified reproductions of two given in "The Electrical Engineer."

SCIENTIFIC

The Work of Nikola Tesla

THOMAS C. MARTIN, in the *Century* Magazine for April. Condensed for PUBLIC OPINION

Perhaps nine-tenths of all the hundreds of thousands of dynamos in the world to-day are operated by means of the ordinary steam engine, the remainder being driven by water-wheels, gas engines, and compressed air. Now, each step from consuming the coal under the boilers that deliver steam to the engines, up to the glow of the filament in an incandescent lamp, is attended with loss. In his oscillator Mr. Tesla, to begin with, has stripped the engine of all governing mechanism. By giving also to the coils in which the current is created as they cut the "lines of force" of the magnets, a to-and-fro or reciprocating motion, so that the influence on them is equal in every direction, he has overcome the loss of the idle part of the wire experienced in rotating armatures; and, moreover, greatest achievement of all, he has made the currents regulate the mechanical motions. In one of his latest forms of oscillator the steam-chest is situated on the bed-plate between the two electromagnetic systems, each of which consists of field coils between which is to move the armature or coil of wire. There are two pistons to receive the impetus of the incoming steam in the chest, and in the present instance steam is supplied at a pressure of 350 pounds, although as low as 80 is also used in like oscillators, where steam of the higher pressure is not obtainable. We note immediately the absence of all the governing appliances of the ordinary engine. They are non-existent. The steam-chest *is* the engine, bared to the skin like a prize-fighter, with every ounce counting.

Mr. Tesla has boldly assailed the problem of the production of light in a manner nearer, perhaps, to that which gives us sunshine than was ever attempted before. He takes his currents of high frequency and high potential, subjects the incandescent lamp to them, and, skipping some of those intermediate wasteful heat stages of lower wave vibration experienced in the old methods, gets the ether-charged molecules more quickly into the intensely agitated condition necessary to yield light. Ordinary incandescent lighting is done, as everybody knows, with the lamps' bases firmly attached to the two current-bearing wires. But as we rise in the frequency of the current, as we leave behind the electrodynamic conditions for the electrostatic ones, so we free ourselves from the restrictions and limitations of solid wires for the conveyance of the effects sought, until at last we reach a point where all the old ideas of the necessity of a tangible circuit vanish. It is all circuit if we can properly direct the right kind of impulses through it. As Mr. Tesla long ago pointed out, most of the experiments usually performed with a static machine of glass plates can also be performed with an induction coil of wire if the currents are alternated rapidly enough; and it is in reality here that Mr. Tesla parts company with other distinguished workers who have fixed their attention merely on the results attainable with electrodynamic apparatus.

A few experiments performed in Mr. Tesla's laboratory workshop afford an idea of the flexibility of the methods by which powerful electrostatic effects are produced across many feet of intervening space. The workshop is a room about 40 by 80 ft., and 10 or 12 ft. high. A circuit of small cable is carried around it from the terminals of the oscillator. In the center of the clear, open space is placed a coil, wound drum fashion, three or four feet high, and unconnected with the current source save through the medium of the atmosphere. The coil is provided with two condenser plates for adjustment, standing up like cymbals. The system of apparatus in the middle of the room has a certain period of vibration, just as though it were a tuning-fork, or a sheet of thin resonant glass. Around the room, over the cable, there are sent from the oscillator electrical current vibrations. By carefully adjusting the condenser plates so that the periodicity or

swing of the induced current is brought into step with that of the cable currents, powerful sparks are made to pour across between the plates in dense streams. In this manner it is easy to reach tensions as high as 200,000 and 300,000 volts. There is a similar coil in the middle of the same room which has been so adjusted to the vibrations sent around the shop that an ordinary sixteen-candle-power incandescent lamp is well lighted up.

In another experiment a most curious and weird phenomenon is illustrated. The observer holds a loop of bare wire in his hands. The currents induced in the loop by means of the "resonating" coil over which it is held, traverse the body of the observer, and at the same time, as they pass between his bare hands, they bring two or three lamps held there to bright incandescence. Strange as it may seem, these currents, of a voltage one or two hundred times as high as that employed in electrocution, do not inconvenience the experimenter in the slightest.

Mr. Tesla belongs to what Lord Kelvin has spoken of as the nineteenth century school of plenum, accepting one ether for light, heat, electricity, and magnetism, outward manifestations of an inward unity whose secret we shall some day learn.

Electrical Progress.

Tesla's Oscillator.

Countless are the directions in which Nikola Tesla has experimented, but there are four things with which, in the minds of people familiar with his labors, he is particularly identified. He has introduced an entirely new system into the operation of dynamos and motors by causing what is called the "magnetic field" to revolve and drag the armature along with it. This is an improvement of immense practical importance in the transmission and use of alternating currents for power purposes, and is alone sufficient to render him famous for generations. He has shown that alternating currents of tremendously high potentials may be handled with practical impunity under certain circumstances—an exceedingly brilliant achievement, although of less practical value than some others. Then he has very nearly, if not quite, solved the problem of producing electric light without heat—an object which numerous scientists have eagerly sought with little result so far, but which is highly desirable in the interests of economy, to say nothing of safety and beauty. Finally, he has invented a combination of steam engine and dynamo, called an "oscillator," which is designed greatly to simplify the mechanism necessary in generating electricity, and hence to revolutionize that art. Several specimens of this device, differing among themselves in form but not in principle, were publicly exhibited and explained by Mr. Tesla nearly two years ago. He has since improved it in detail, with a view to still greater simplicity and efficiency, and it is said that just before the fire which destroyed his laboratory, a few weeks ago, this invention had reached such a degree of perfection that it was ready for the commercial stage of its career. Although some of its less important features are still kept private, and while it is impossible yet to measure with accuracy the possibilities of its usefulness, the oscillator is just now attracting renewed attention and provoking much enthusiasm among electrical engineers.

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One of the most exquisitely beautiful, as well as essential, features of the oscillator is yet to be mentioned. It is desirable that the frequency of the alternations in a current—its "period," as the experts call it—shall remain constant in the face of all variations of "load," or work demanded of it. This can be regulated with a spring of the proper stiffness attached to the oscillating rod. An "air spring," consisting of a piston inside an air-tight cylinder, may be made to perform this office, and the supplementary cylinder may be situated either close to the working cylinder or at some distance away, both pistons, however, being secured to the same rod. Again, proper air chambers at the end of the working cylinder may be made to serve as springs. By proportioning the size of the chamber of the air spring to the weight of the moving parts, the desired period is produced. Greater or less pressure of steam and any fluctuation in load may affect the length of the stroke, but not the frequency. There is still another mode of regulating the vibrations. It has been shown that electrical currents exhibit certain phenomena resembling those of sound. A circuit of a given "capacity" and "potential" is more favorable to vibrations of one frequency than any other. An instrument known as the "condenser" can be introduced into an electrical circuit to "tune" the latter to the desired frequency of oscillation—thirty, fifty, eighty or any other number per second. Mr. Tesla has applied this principle of "resonance" to some of his experimental oscillators, and thus imparted to his apparatus a selective affinity for whatever rate of vibration he wants. This is an automatic governor which corrects any tendency to fall below or exceed the required speed. With such precision will this period be maintained that a clock may be driven with an oscillator and keep good time.

TESLA CURRENT TUBES.

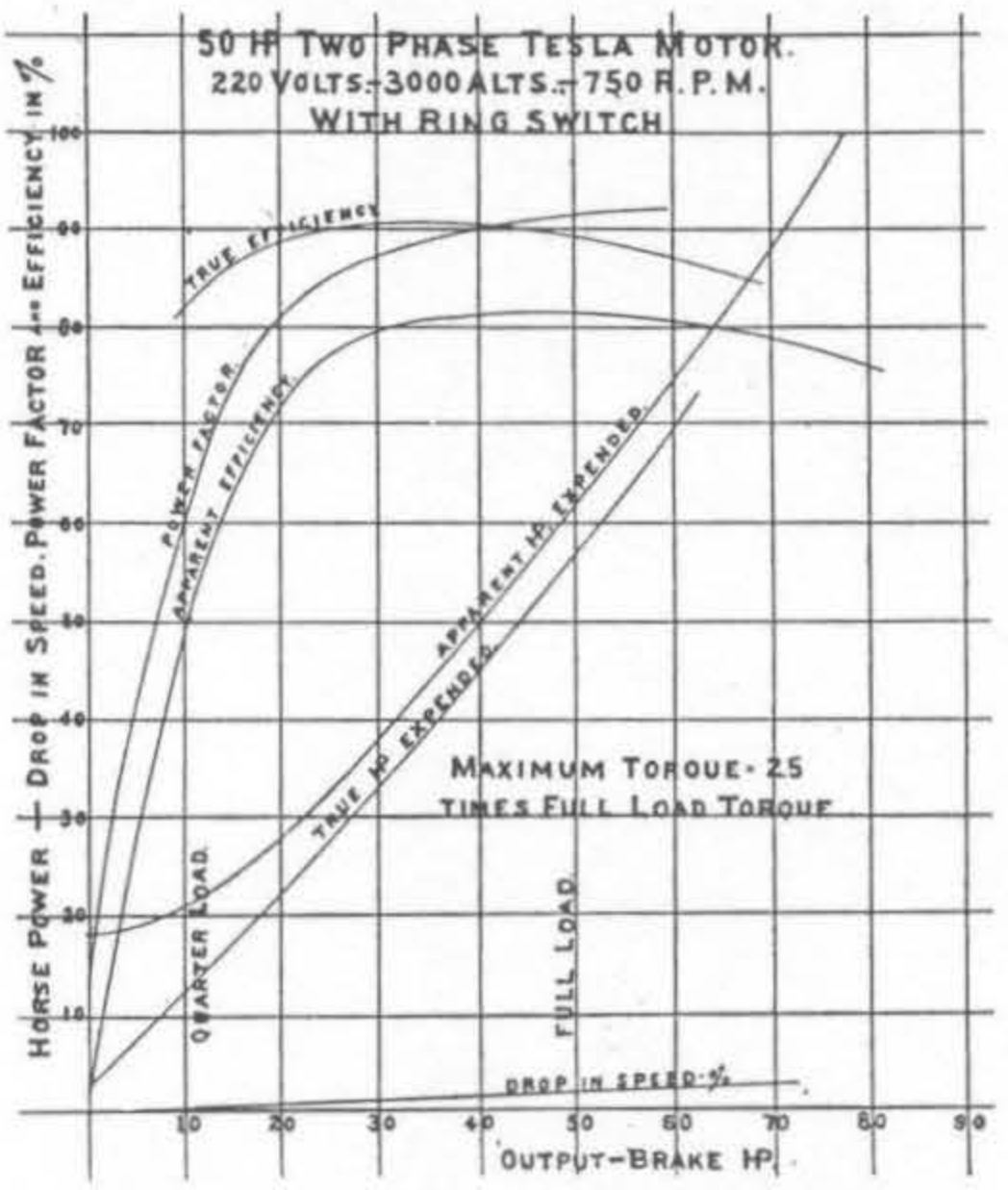
The *Buffalo Express* of April 21, favors the public with the following, which, to say the least, is interesting, if rather mixed and confused:—"It was stated here to-night that Nikola Tesla had lately made further improvements in his method of transmitting electricity by fluid and had declared that he was more certain than ever that the current could be sent from Niagara Falls to New Orleans and Chicago and delivered there at less than it would cost to generate power on the spot by steam. The fluid he uses in the tubes costs scarcely more than water, and loses so little electricity in transit that the cost of transmission is little more than the cost of putting up the poles and tubes. It is asserted that the Niagara Falls Power Company, having at last obtained all the consents for the right of way from the Falls to Buffalo along the shore (the Grand Island route having been given up) will prepare at once to supply power for the trolley line between the two cities, and every one else along the route who will pay the price. What the price will be cannot be determined until the line for transmission has been actually completed and the loss of power in transit has been determined. If Mr. Tesla's predictions about his tubes are fulfilled, it is believed that the company will agree to the maximum price insisted upon in Buffalo." The tube method is also described as "a solution of some metallic salt contained in a metal tube surrounded by rubber."

THE PERFORMANCE OF THE TESLA MOTOR.

Supplementary to Mr. Perry's article on the new Westinghouse Electrical Works at East Pittsburg, which appeared in our issues for April 10th and 17th, we give the following curves of performance made especially for this purpose but completed too late for insertion with the rest of the matter. The motor under test was one of those referred to in the article rated at 50 H. P. It is running on the regular shop two-phase currents, 220 volts—3,000 alternations, 750 revolutions per minute. The switch for throwing in and out the starting resistances was of the ring or most recent type, and was illustrated in Fig. 4 on page 176.

The curves will sufficiently explain themselves, but it seems worth while to draw particular attention to several points in the performance of the motor.

The maximum starting torque of which the motor is capable is a little over 2½ times the full load running torque, but as in ordinary practice such a starting torque is not required, the starting resistance in the secondary of the motor is given such value that the torque at starting is about 1½ times the full load running torque. This is done to avoid the excessive current which is necessarily required by any motor, whether for direct or alternating currents, for the development of an



abnormal torque. With such a resistance the current taken by the motor at the instant of starting is about 50 per cent. in excess of that taken at full load. When the motor has nearly attained full speed the starting resistance is short-circuited.

The motor when running unloaded takes only 18 apparent H. P., or 36 per cent. of the full load output.

The falling off of speed from no load to full load is less than 2 per cent.

The apparent and true efficiencies rise very rapidly as the load increases. At one quarter load the apparent efficiency is 57 per cent. and true efficiency 84 per cent. At full load the apparent efficiency is 81.5 per cent. and the true 89.5 per cent. The full load efficiency is better than is ordinarily attained by direct current machines of the same output, and the light load efficiencies are much better. Such a motor as this will have, therefore, a much higher all-day efficiency than a direct current motor of the same output in places where the power required is variable. It is claimed for this type of motor that, in addition to its electrical superiority, the simplicity and durability of construction and the consequent freedom from breakdowns, its ability to carry severe overloads without any harm resulting, and the ease with which it can be controlled both as to speed and as to direction of rotation, make such a machine as this much superior to any direct current motor for all ordinary purposes for which an electric motor can be used.

The Burning of Tesla's Laboratory.—Now that a little time has elapsed since the disaster which overwhelmed Nikola Tesla's laboratory, it is possible to sum up the significance of the event. Our sympathies have been with this unfortunate physicist from the first, and for good reasons. But the average newspaper man, who, by the way, was mostly extravagant with his commiseration, would probably hesitate to venture upon an answer were he asked to explain definitely what he was grieving about. The thing was terribly overdone at the time it happened, and, in illustration of this, we believe it to be a fact that one vivid young lady of the trans-Atlantic press, in her anxiety to be instructive as well as "alive" in her descriptions, went so far as to depict herself undergoing a brilliant electrical ordeal, that is possible only with the body *in puris naturalibus!* For Tesla's future we have no fear. He is young and indomitable. It took Thomas Carlyle four weeks to quiet his mind after that miserable accident in which John Stuart Mill was concerned, which entailed the destruction of the first volume of the unprinted "French Revolution." But, in spite of sensational reports, we know it to be a fact that Tesla was at work again with clenched determination while the ashes of his hopes were still hot. No! The loss falls least heavily upon the loser. Like many another tireless experimenter, he hoped to give the scientific world the report of his failures as well as of his discoveries: he had not counted upon the casual destruction of his memorabilia and apparatus by fire. The loss falls most heavily upon those scientists who are at work upon the phenomena of high-frequency currents, of insulation, induction, impedance, and resonance, and the problems of obtaining cheap electricity by means of oscillators. In time, Tesla will doubtless reproduce all that was of value in those unfortunate notes and papers. In his own immediate work their loss will scarcely be felt, for his memory is all right, and flashes upon any experience of the past with the revealing power of a search light. But the years of toil which his work might have saved experimenters by indicating the paths which are open as well as those which are blind, are gone for ever.



Performance of the Tesla Motor.—"El'ty," May 15, publishes a number of curves of the performance of a 50-hp motor which is running at the Westinghouse works, on the regular two-phase circuits at 220 volts, 3,000 alternations and 750 revolutions. The maximum starting torque of which the motor is capable, is a little over 2.5 times the full load running torque but this starting torque is not required in ordinary practice, as a resistance in the secondary of the motor has such a value that the starting torque is about 1.5 times the full load running torque; with this resistance the current taken by the motor at starting is about 50 per cent. more than that at full load; when running unloaded the motor takes 18 apparent horse-power; the speed falls less than 2 per cent. from no load to full load; the apparent and true efficiencies rise very rapidly as the load increases; at one quarter load the former is 57 per cent. and the latter 84 and at full load they are 81.5 and 89.5, respectively; the latter is said to be better than that ordinarily attained by direct current machines of the same output, and the light load efficiency is much better; the all-day efficiency will therefore be higher than that of a direct current motor if the power required is variable; the ease with which it can be controlled both "as to speed" and as to direction of rotation make it superior to the ordinary motor.

LITERATURE.

Nikola Tesla's Untersuchungen ueber Mehrphasenströme und ueber Wechselströme hoher Spannung und Frequenz. By Thomas Commerford Martin. Authorized German edition, Translated by H. Maser. Halle, a. S.: 1895. Wilhelm Knapp. 508 pages, 6½ x 9½ inches. Paper.

MR. MARTIN'S book is too well known to English readers to require any review at our hands, but it is interesting to note that the demand for information relating to Mr. Tesla's work has so soon called for a German edition. The translator, Herr Maser, has done the work in an admirable manner, so that German readers are now placed on the same footing as English in the facilities at their command for following the researches of Mr. Tesla. The book is admirably printed in good type on good paper, and the cuts are the same as in the American editions.

The Burning of Tesla's Laboratory.

Now that a little time has elapsed since the disaster which overwhelmed Nikola Tesla's laboratory, it is possible to sum up the significance of the event. Our sympathies have been with this unfortunate physicist from the first, and for good reasons. But the average newspaper man, who, by the way, was mostly extravagant with his commisseration, would probably hesitate to venture upon an answer were he asked to explain definitely what he was grieving about. The thing was terribly overdone at the time it happened, and, in illustration of this, we believe it to be a fact that one vivid young lady of the transatlantic press, in her anxiety to be instructive as well as "alive" in her descriptions, went so far as to depict herself undergoing a brilliant electrical ordeal, that is possible only with the body *in puris naturalibus!* For Tesla's future we have no fear. He is young and indomitable. It took Thomas Carlyle four weeks to quiet his mind after that miserable accident in which John Stuart Mill was concerned, which entailed the destruction of the first volume of the unprinted "French Revolution." But, in spite of sensational reports, we know it to be a fact that Tesla was at work again with clenched determination while the ashes of his hopes are still hot. No! The loss falls least heavily upon the loser. Like many another tireless experimenter, he hoped to give the scientific world the report of his failures as well as of his discoveries; he had not counted upon the casual distruction of his memorabilia and apparatus by fire. The loss falls most heavily upon those scientists who are at work upon the phenomena of high-frequency currents, of insulation, induction, impedance, and resonance, and the problems of obtaining cheap electricity by means of oscillators. In time, Tesla will doubtless reproduce all that was of value in those unfortunate notes and papers. In his own immediate work their loss will scarcely be felt, for his memory is all right, and flashes upon any experience of the past with the revealing power of a search-light. But the years of toil which his work might have saved experimenters by indicating the paths which are open as well as those which are blind, are gone forever.--*London Electrical Review.*

NO DELAY IN THE TESLA PATENT SUITS.

In the suit of the Westinghouse Co., against the General Electric Co., for infringement of the Tesla multiphase patents, Judge Townsend of the U. S. Circuit Court at Hartford, Conn., has handed down an order requiring the General Electric Co., to complete its proofs by October 7 next.

The Electrician.

(The Oldest Electrical Journal, 1861—1878.)

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SPECIAL NOTICE.

Owing to the growth of the electrical and allied industries the demands for space in "THE ELECTRICIAN" are, for the greater part of the year, so pressing that a permanent increase in the size of the journal has become necessary. To meet the increased cost involved by this step, and by other improvements, such as heavier paper and more numerous illustrations, the price of "THE ELECTRICIAN" has from May 3rd been advanced to 6d.

The Subscription to "THE ELECTRICIAN," commencing with Vol. XXXV. (May 3, 1895), is as follows:—

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POLYPHASE PATENT LITIGATION.

It has often been asked, Why has the transmission of power by polyphase currents made so little progress in this country, in comparison with its use on the Continent and in America? This difference cannot be wholly attributed to ignorance on the part of British manufacturing firms, nor even to a natural conservatism tinged with the feeling that the advantages of polyphase motors have been somewhat overstated. The cause of the delay in this country has, we think, to a large extent been due to the uncertainty that exists as to what claims would be made by the owners of certain patents, and as to the ground that they considered covered by those patents. British firms have hardly yet sufficiently recovered from the costs and expenses incurred in litigation over compound winding, over incandescent lamps, and over telephones, to wish again to embark without due consideration on the troubled waters of the law. Nor is that feeling unjustified in view of the position which affairs have now assumed in America. The Westinghouse Electric Company, which controls the patents and inventions of NIKOLA TESLA, have instituted suits against the General Electric Company of America, and against the Stanley Manufacturing Company, for alleged infringements of TESLA's patents, claiming, as their advertisements state, that these patents cover broadly any system of polyphase alternate current distribution of power. It is interesting to note, as showing how broad is the ground

claimed, that neither in the "monocyclic" system of the General Electric Company, nor in the two-phase system of the Stanley Manufacturing Company, are the motors simple rotary field motors, but modifications which have the appearance of being expressly designed to avoid any claim on behalf of the owners of TESLA's patents. The results of these actions will be regarded with interest in Europe, as it is only to be supposed that if successful in America a similar line is likely to be taken in this country and elsewhere where TESLA's patents are in force. That this question is not lightly regarded by the owners of the TESLA patents is evident from the fact, that the valuation of the TESLA patents is said to have been the point at which the recently negotiated "combine," as to patents, between the General Electric Company and the Westinghouse Company, came to a deadlock.

The ground on which the priority of TESLA's patents is likely to be contested, is probably the, till recently, forgotten rotary field motor of BAILY (1879), and the motors of FERRARIS; but these do not appear to entirely touch the issue. In the first of these the rotary field was produced by commutating a continuous current; in the second, by splitting a single-phase alternating current into two phases by proper arrangements of self-induction or condensers. This is a different thing from the reproduction in a motor of a rotating magnetic field, the image or reflection if the term may be used, of an existing rotating magnetic field, produced in a dynamo with multiple coils, connected to similar coils in the motor. This is the kernel of TESLA's inventions, and it remains to be seen whether his patents of 1888 will withstand the fire to which they will now be exposed. The Westinghouse Company, in any case, can claim little credit for the practical introduction of polyphase motors, for whilst the patents date back to 1888, for some years after this no definite information as to the results that had been obtained by their use was forthcoming, whilst even as late as 1894, the current lists of the Westinghouse Company, only described and showed their use, like FERRARIS' motors, on single-phase transmission plants for starting up synchronous motors. The credit of showing what it is possible to effect with polyphase transmission will always be connected with the names of C. E. L. BROWN and DOLIVO-DOBROWOLSKI. It is to be hoped, in the interests of all parties, that this question will be settled shortly and decisively, as until its conclusion a cloud will necessarily hang over a system which, in many cases, may prove of considerable value.

Meanwhile it is interesting to note what is the real position now to be assigned to polyphase power transmission and distribution, in what respects it is superior to continuous current systems, in what respects it is inferior. The answer in general terms is this, where the transmission or distribution is satisfied by motors running at a constant speed, and not requiring a turning moment greater than, say, 50 per cent. above the full load running moment, no system can beat the polyphase, either in economy in first outlay, simplicity of working or efficiency. But where variations of speed are required, or a largely increased turning moment is necessary, either at starting or when running, polyphase plant is not applicable. Great loss of efficiency always occurs when a polyphase motor revolves at a speed differing considerably from the speed of the revolving field, and the turning moment appears at any speed to have a maximum beyond which a reduction of speed decreases instead of increasing it, thus producing instability. These generalisations omit the consideration of the possibility of using higher pressures owing to the power of transforming alternating currents with simple apparatus. It may, therefore, be taken that with polyphase motors as at present made, they will be used for transmission of power in manufacturing, but for mining, for traction, for lifts, and analogous purposes, continuous current machinery may be expected to hold its own.

ELECTRIC POWER GENERATION AT NIAGARA.

By Lewis Buckley Stillwell, Electrical Engineer.

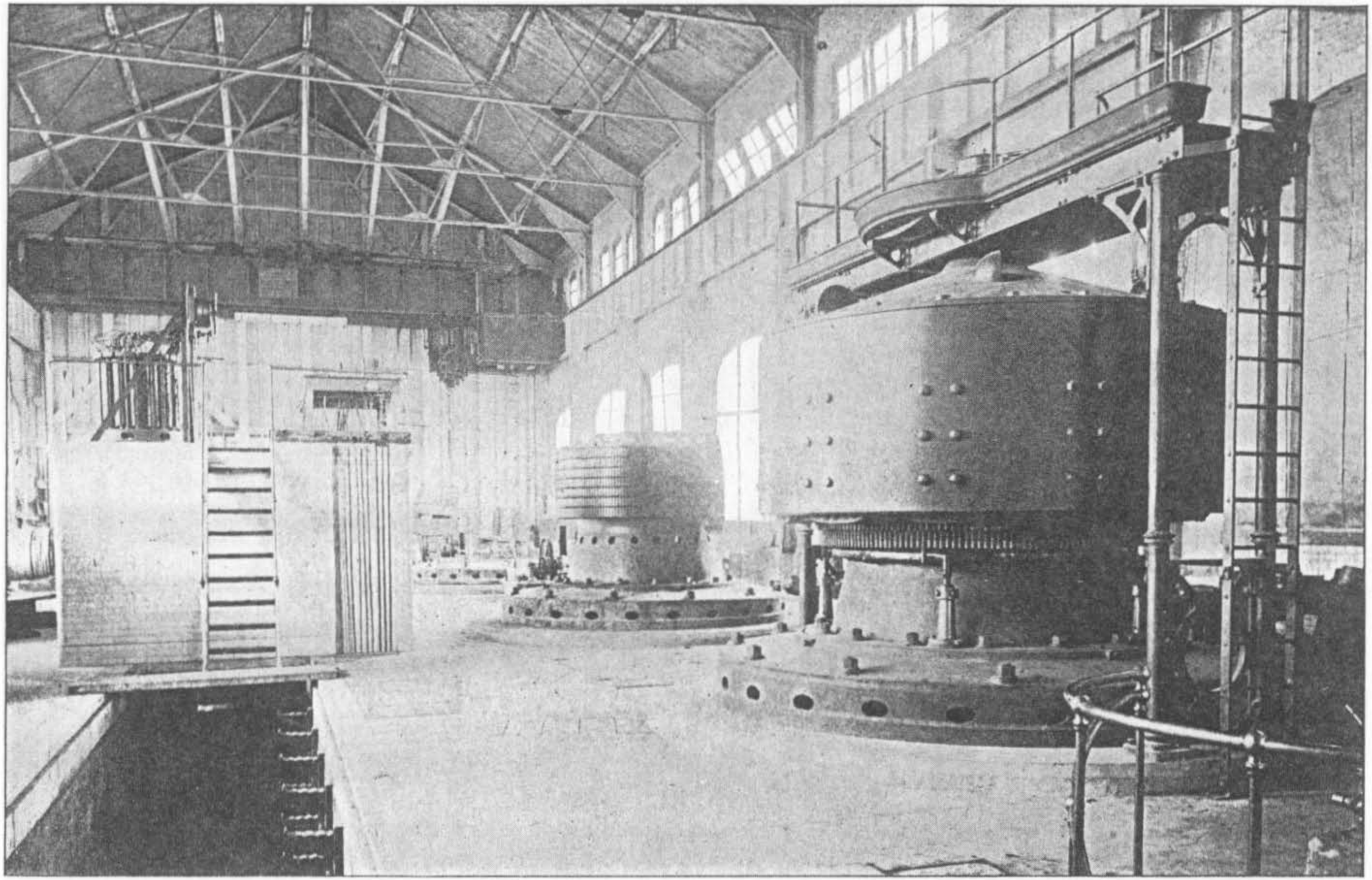


ELECTRICITY as an agent for transmitting and distributing power has received its most weighty endorsement in its adoption by the Cataract Construction Company, of New York, for their great project at Niagara. No enterprise of modern times, involving special and extraordinary engineering problems, has been more carefully, more patiently, more systematically or more intelligently studied than has the utilization of this, the greatest water power in the world. The officers and directors of the company, controlling financial means ample for their purpose, have, for five years, energetically and persistently endeavored to avail themselves of the best resources of modern engineering science. Confronting a problem without precedent in its magnitude, and almost without parallel in its significance, they have attacked it with energy and ability of the highest order, studied it with keen insight and sound judgment and, in solving it with success, have contributed a chapter of rare interest and meaning to the history of industrial progress.

The utilization of Niagara for industrial purposes imposes upon those undertaking it a responsibility far beyond that which is measured by the capital invested. Science is cosmopolitan; she recognizes no boundary of race or nation; and engineering science of the twentieth century, in passing judgment upon the methods and apparatus employed, while not failing to take into consideration the difficulties and limitations imposed by the boundaries of our present knowledge, will allow no excuse for failure to find out and use the best means known to our age.

It is, therefore, a source of profound gratification that, from the outstart, the policy of the company has been characterized by a breadth of view commensurate with the far-reaching importance of the enterprise. The directors have allowed no local or even national prejudice to bias their judgment. They early threw the lists wide open and in the original competition which they inaugurated, the international commission passed upon no less than twenty-two plans covering practically the whole known range of electric, hydraulic and pneumatic distribution of power, and originating from places as far East as the city of Buda-Pesth, and as far West as San Francisco.

It must be gratifying to Americans that under these conditions a system developed by an American company has been adopted, but for the recent rapid advancement in engineering science which has made this work possible, America is in no position to claim exclusive credit, if she would. In the plans for the hydraulic plant, Switzerland, the land of water powers, shows the way, while in the design of the great electric generators, the most powerful as yet produced, Great Britain is represented directly in the excellent general form of construction adopted, which was proposed by Prof. Geo. Forbes, and indirectly in the work of Hopkinson, Kapp, Thompson, Mordey, and others, whose careful study of the principles underlying the construction of electrical machinery has done much to make it possible to design a machine so far beyond the range of actual experience, in full confidence that the results predicted from theory would



THE INTERIOR OF THE POWER HOUSE, SHOWING ONE GENERATOR COMPLETED.

be realized in practice. Perhaps no country is more largely or more creditably represented in the great Niagara installation than Smiljan Lika, —that sturdy little province on the Adriatic, which has honoured itself by producing Mr. Nicola Telsa, and were it possible to trace to its true source each one of the great number of ideas embodied in the complete installation, it is probable that we should find nearly every civilized nation represented—England, America, Switzerland, France, Germany, Italy, some in greater degree, some in less, but all co-operating to achieve what is, beyond question, one of the most significant triumphs of nineteenth century engineering skill.

The problem in electrical engineering presented by the Cataract Construction Company, as defined by the organization of the hydraulic plant in the power house and the requirements of the proposed market for the power developed, may be stated as follows:

Given, 1st:—Four vertical shafts, direct-driven by turbines making 250 revolutions per minute and capable of delivering at the top of each shaft from 5000 to 5500 mechanical horse-power. Additional turbines and shafts to be installed as the demand for power increases. 2d:—A market for power, beginning just outside the walls of the power house and extending at least twenty miles (and as much further as possible), said power to be used for, (A) general industrial purposes, such as the operation of machinery in mills and factories; (B) the operation of street railways; (C) lighting by arc and incandescent lights; (D) electrolytic purposes; (E) heating.

Required:—The most reliable and efficient method and machinery for utilizing the power for the purposes named.

The system or organization of electric apparatus which was adopted is known as the Tesla Polyphase Alternating-Current System. Each generator delivers alternating current to each of two circuits, the currents in these circuits differing from each other in their time relation, or phase, by 90 degrees; that is to say, the current delivered to each circuit attains its maximum value at the instant when the current delivered to the other circuit is zero. The frequency is 25 cycles per second,—in other words, the direction of the current is reversed 3000 times per minute. By means of rheostats, controlling the field circuits of the generators, the potential of the current delivered is adjustable up to the limit of 2400 effective volts. In ordinary service, and until transmission over great distances is undertaken, the normal potential will approximate 2100 volts, but, to compensate for the losses incident to long distance transmission, the generators may be operated at any potential not exceeding 2400 volts.

The currents delivered by the generators are conveyed through heavily insulated cables to the switchboard. There, by means of suitable switching devices, the engineer in charge of the station may, at will, connect any one of the generators, or any combination of the generators, to the external circuits which convey the currents from the power house to the consumers. These external circuits, known as feeder or supply circuits, passing from the switchboard, are supported upon iron brackets in a brick-lined subway within the power house, as shown in the illustration on page 286. Insulated, lead-covered cables are used, and these, leaving the subway, are continued through the bridge connecting the power house with the transformer house on the east bank of the power canal. The cables conveying current, intended for the use of tenants of the company and other consumers of power within a radius of 2 or 3 miles of the power house, pass directly through the transformer house and enter a conduit leading to the works of those tenants who are, at present, the principal users of the power.

Current intended for transmission to considerable distances, as, for example, to Buffalo, will pass from the switchboard through similar lead-covered cables in the power house subway and the bridge to the transformer house. There it will enter the "step-up" transformers, and from these current at high potential (E. G. 20,000 volts) will

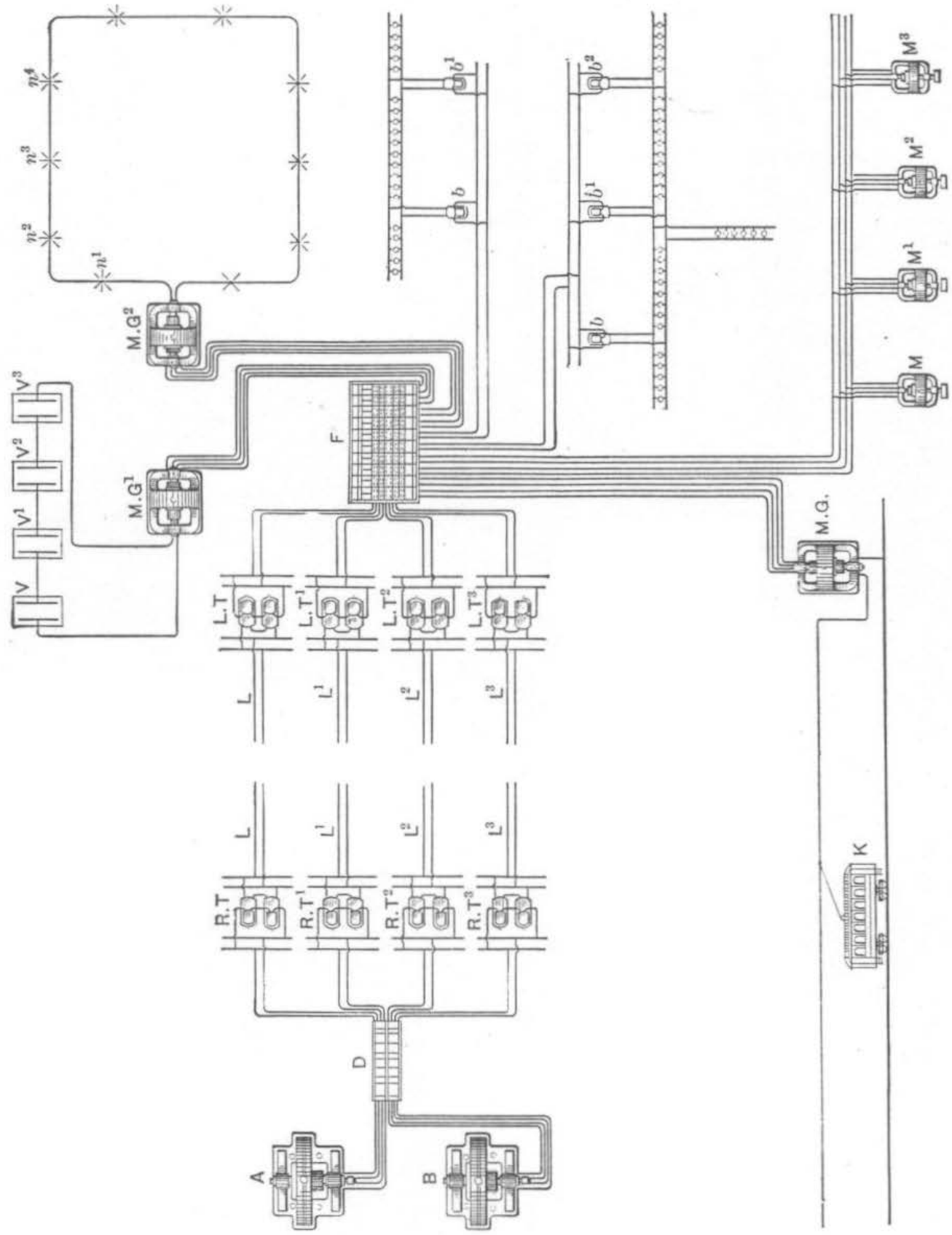
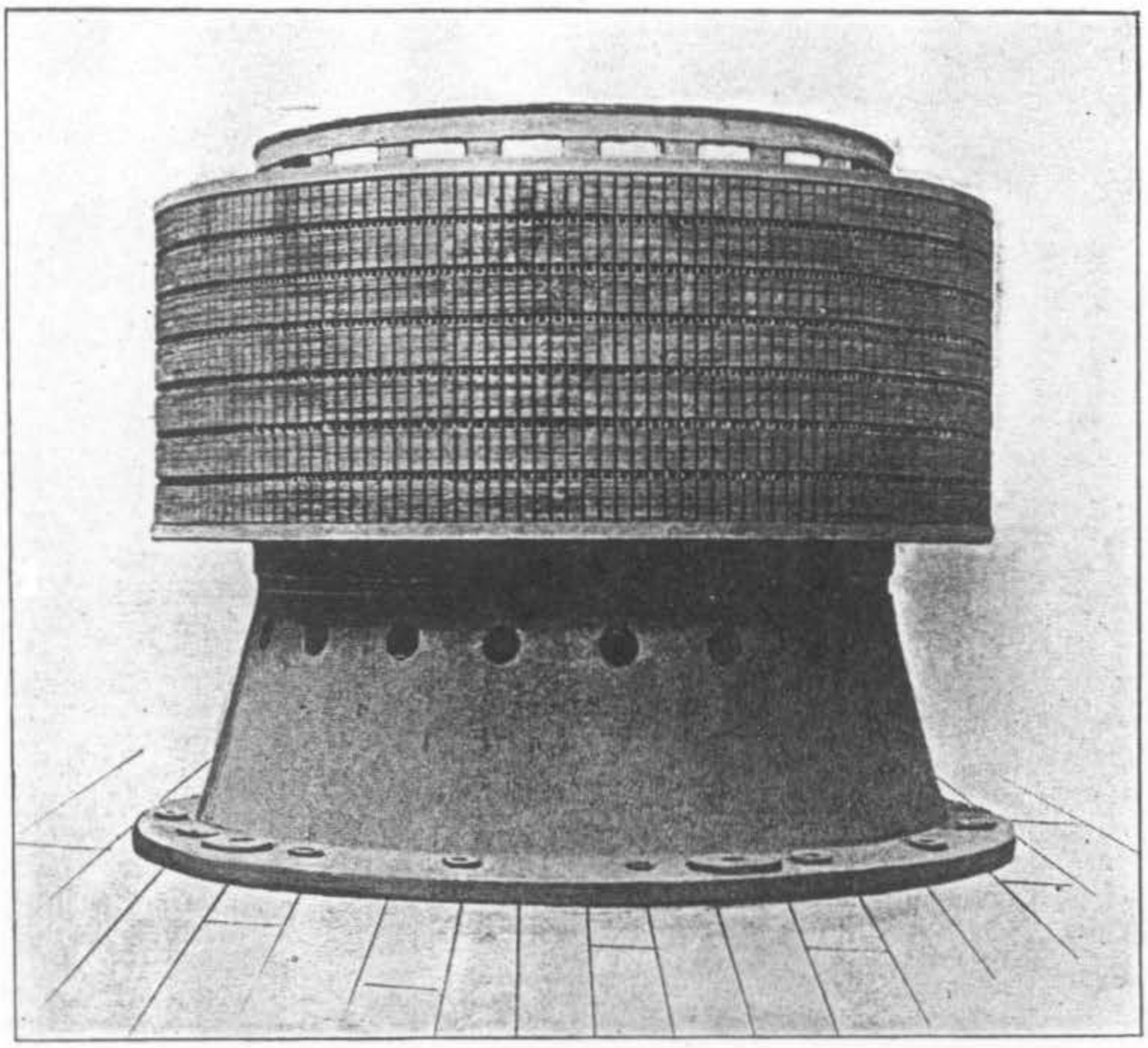


DIAGRAM OF A MULTI-PHASE SYSTEM OF ELECTRIC TRANSMISSION AND DISTRIBUTION.

be delivered to the long-distance transmitting circuits. It has not yet been determined whether these long-distance circuits shall be overhead or underground. At the distant end of the circuits "step-down" transformers will be employed to reduce the potential of the currents to an amount suitable for local distribution.

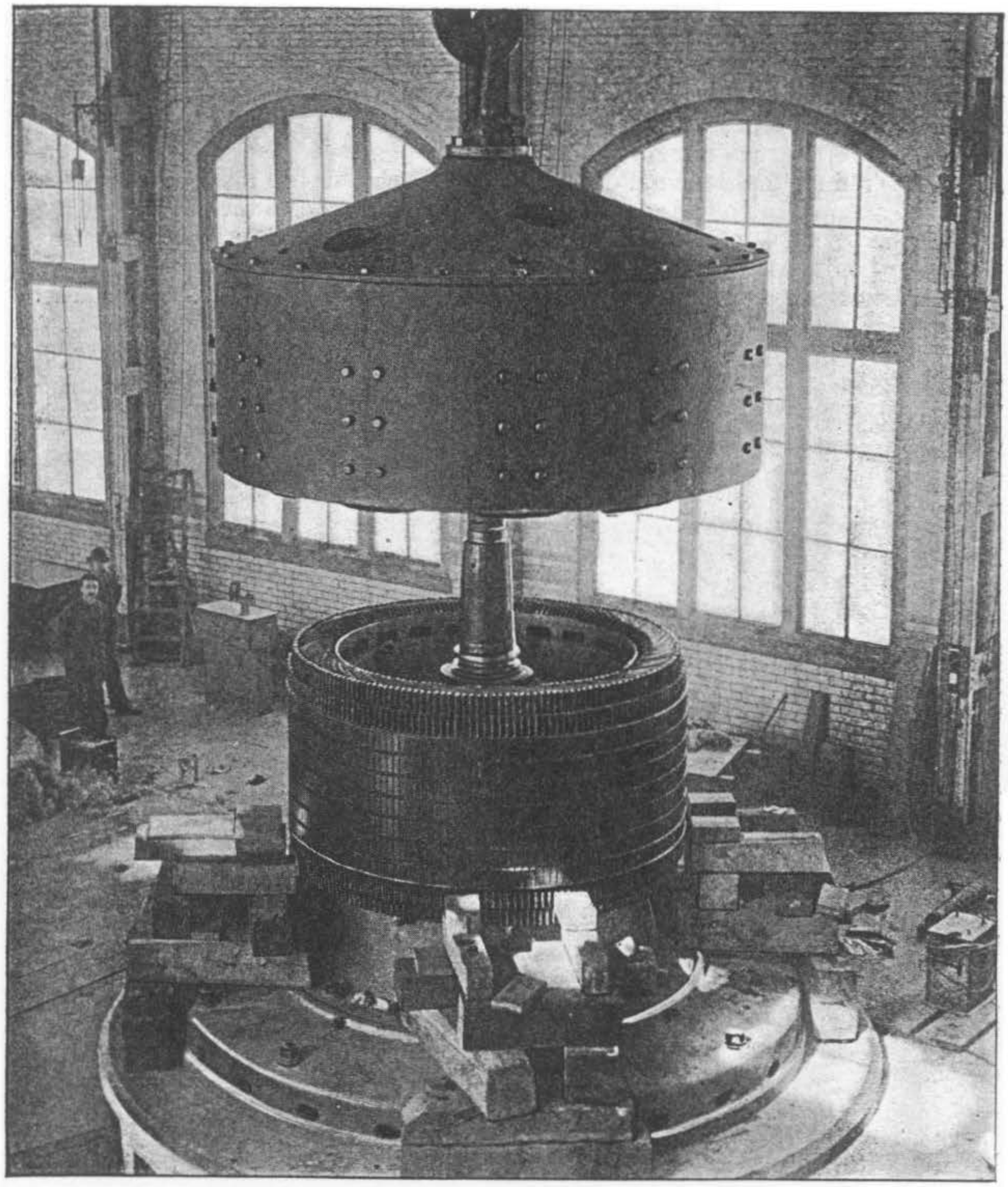
The kind and amount of apparatus which it will be necessary to install upon the premises of the users of power depends upon the kind of service required. In the case of large motors, the current delivered by the local distributing circuits at Niagara may be supplied to the machines without reduction of potential by transformers. In the case of smaller motors, and in the case of commutating machines used to supply direct current, step-down transformers will ordinarily be employed. The general organization of the system and character of the apparatus required for each of the principal types of service are illustrated in the diagram on the opposite page.



ONE OF THE 5000 HORSE-POWER ARMATURES.

Referring to this diagram, each of the generators A and B delivers two separate and distinct alternating currents to the step-up or raising transformers RT, RT^1, RT^2, and RT^3, through the switchboard D. The current, delivered by the generators at 2000 volts, is transformed by the raising transformers to a high potential suitable to long-distance transmission, say 20,000 volts, and is delivered by them to the transmission circuits L, L^1, L^2, and L^3. At a point conveniently located with reference to the district where lights and motors are to be supplied a sub-station is erected. The transmission circuits enter the station and deliver their currents to the step-down or lowering transformers LT, LT^1, LT^2, and LT^3, which, in turn, deliver currents at moderate potentials, suitable for local distribution.

The switchboard F affords means whereby the circuits coming from the various groups of lowering transformers may be readily transferred and inter-



A FIELD RING READY TO BE LOWERED ON A GENERATOR SHAFT.

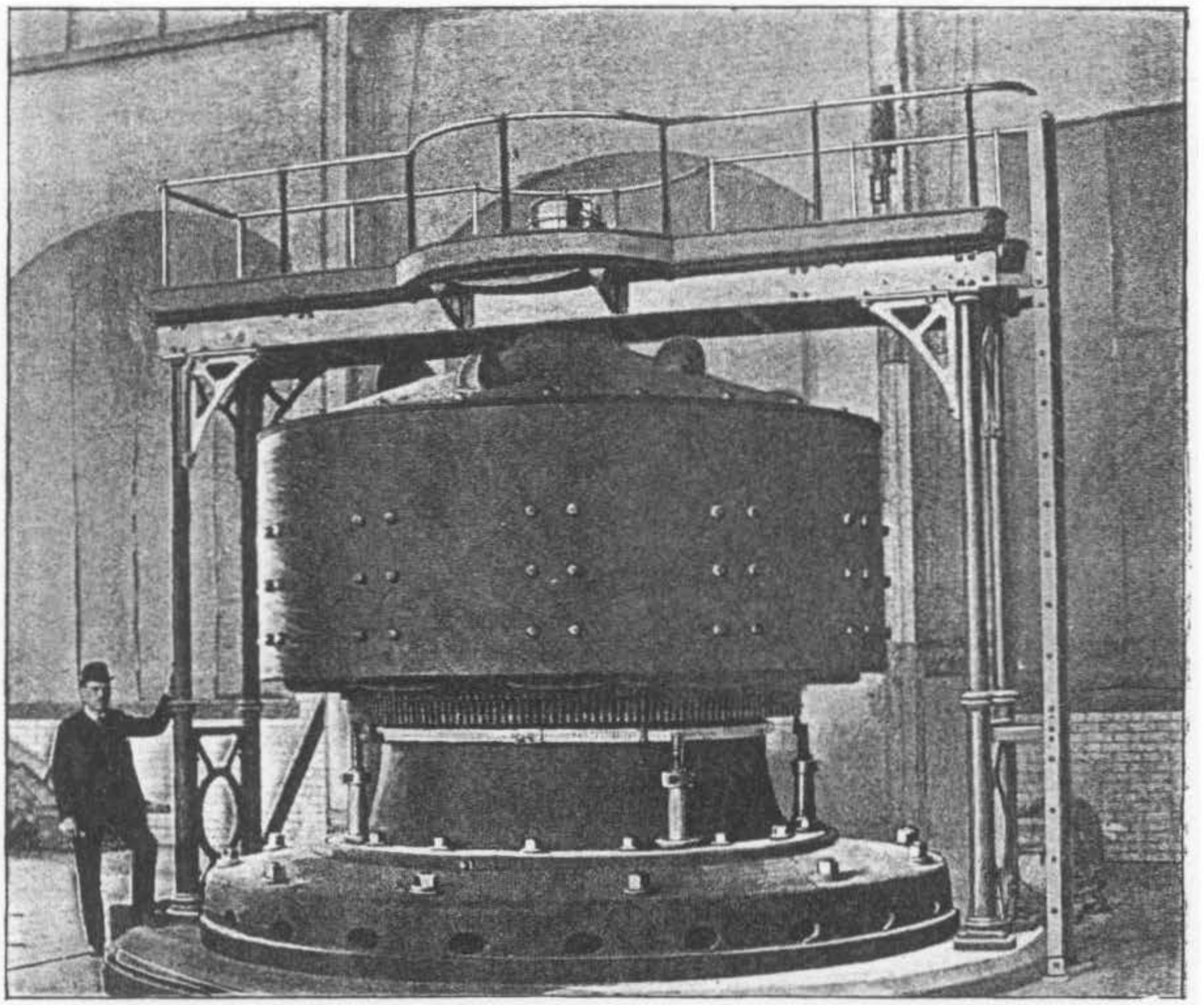
changed, so that any of the transmission circuits may be used to supply any of the local distributing circuits, as may be advantageous or convenient, or all of the local circuits may be supplied with current from bus bars to which the transmission circuits of like phase are connected in parallel.

In the diagram, beginning at the left of the switchboard, the first four-wire circuit is used to supply alternating current to the motor-generator or rotary transformer MG, which, in turn, delivers direct current at 500 volts to a trolley line, from which the street car K is supplied. The second circuit supplies the motors M, M^1, M^2, and M^3 of the two-phase, synchronous type, or of the induction type, which are adapted to general power purposes in mills, fac-

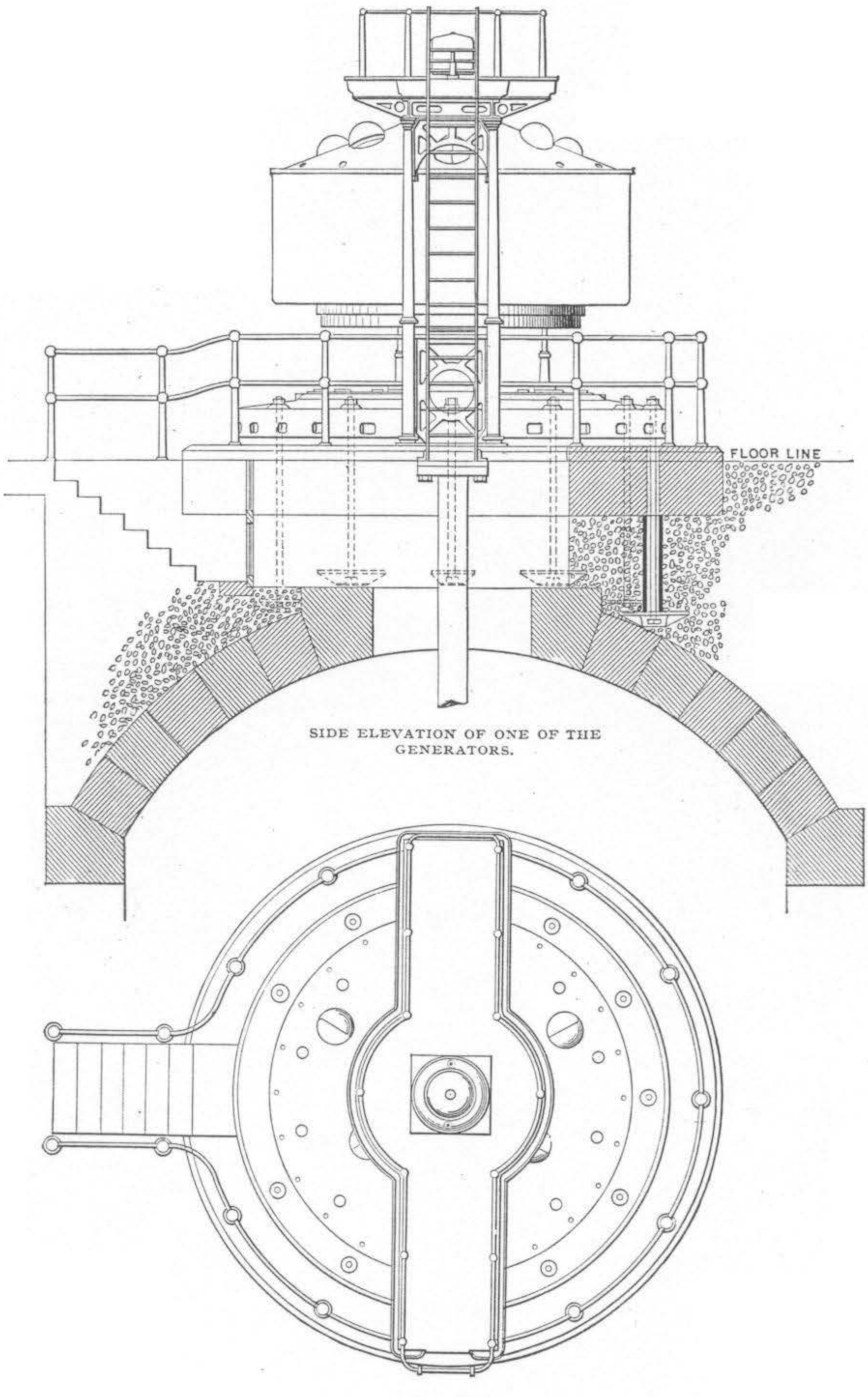
tories, etc. The next four-wire circuit is divided into two two-wire circuits, and is used to supply incandescent lamps through the transformers b, b^1, and b^2. The next circuit supplies alternating current to the motor-generator MG^2, which delivers direct current for arc lighting purposes. The last circuit shown supplies the motor-generator MG^1, which, in turn, delivers direct current at a low potential for electrolytic purposes, as indicated in the vats V, V^1, V^2, and V^3.

It is not intended to attempt the supply of incandescent lights in general in the manner indicated in the diagram, as the frequency is rather low for that purpose. At 25 cycles per second a slight wavering or variation in the intensity of the light is perceptible under certain conditions in the case of lamps having especially thin filaments, such as a 10 candle-power lamp for a 100-volt circuit. In 100-volt lamps of greater candle-power, and in 50-volt lamps, the light is entirely satisfactory. Arc lighting can, of course, be accomplished not only in the way shown in the diagram, but also by the indirect method of employing polyphase motors to drive arc light machines of the types generally in use.

The frequency selected is in every respect admirable for power purposes, and was chosen in preference to a higher frequency because the amount of energy required for lighting from Niagara will, for many years, and perhaps for all time, constitute but a comparatively small part of the energy distributed. At present the only practicable way to utilize Niagara power for lighting purposes is by substituting motors for the engines now used in arc and incandescent lighting plants in Niagara, Tonawanda, Buffalo and other cities and towns to which the circuits may be extended. When the demand for



THE FIRST GENERATOR IN POSITION IN THE POWER HOUSE AT NIAGARA.

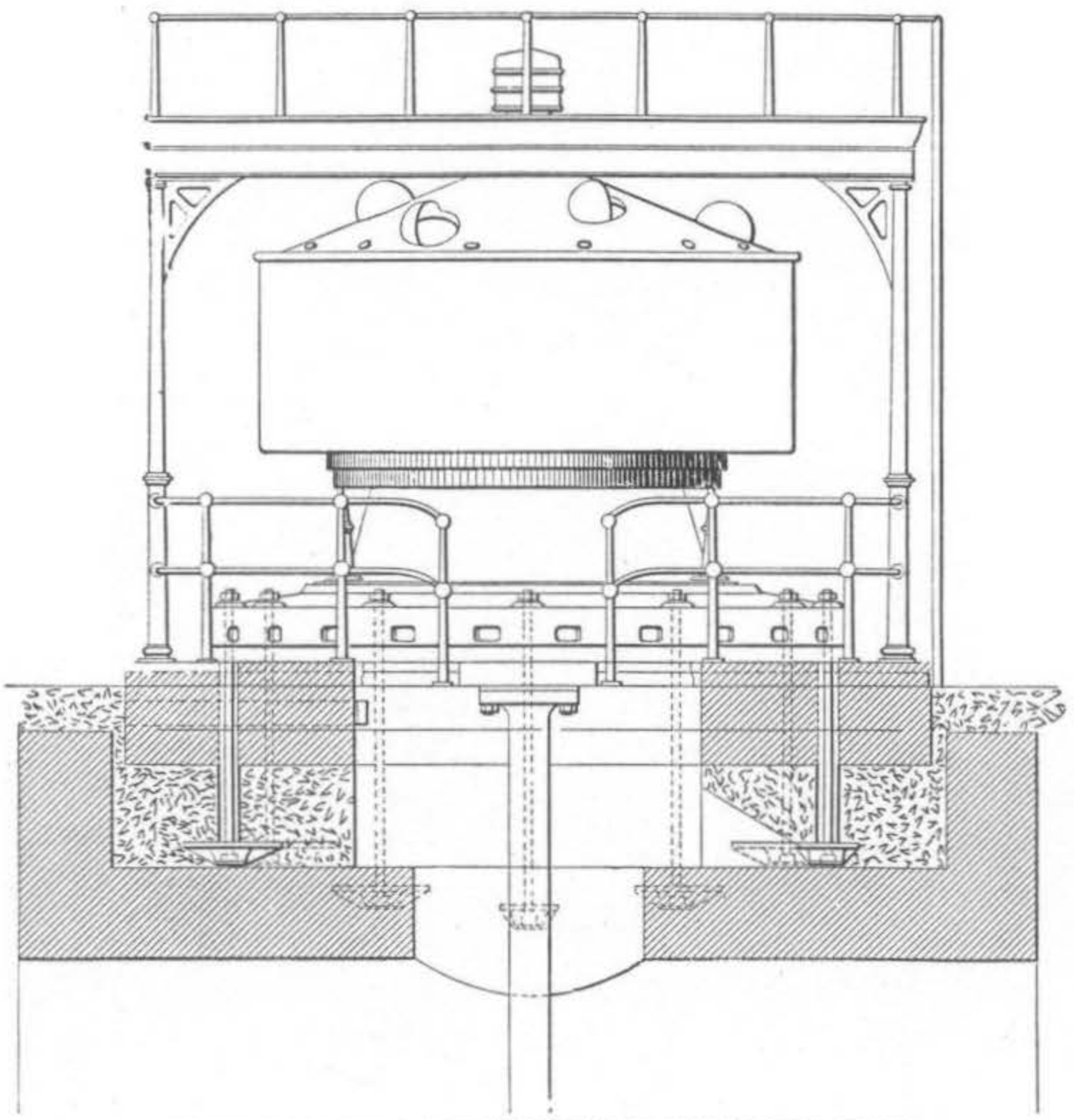


SIDE ELEVATION OF ONE OF THE GENERATORS.

A TOP VIEW.

current to be used for lighting purposes becomes sufficiently important to justify a change in the apparatus, and, perhaps, in the methods now employed for lighting the cities and towns to which the circuits may be extended, a certain number of generators of higher frequency may be installed.

The drawings reproduced on this and the opposite pages are front and side elevations and a plan, showing the relation of the generator, the bed

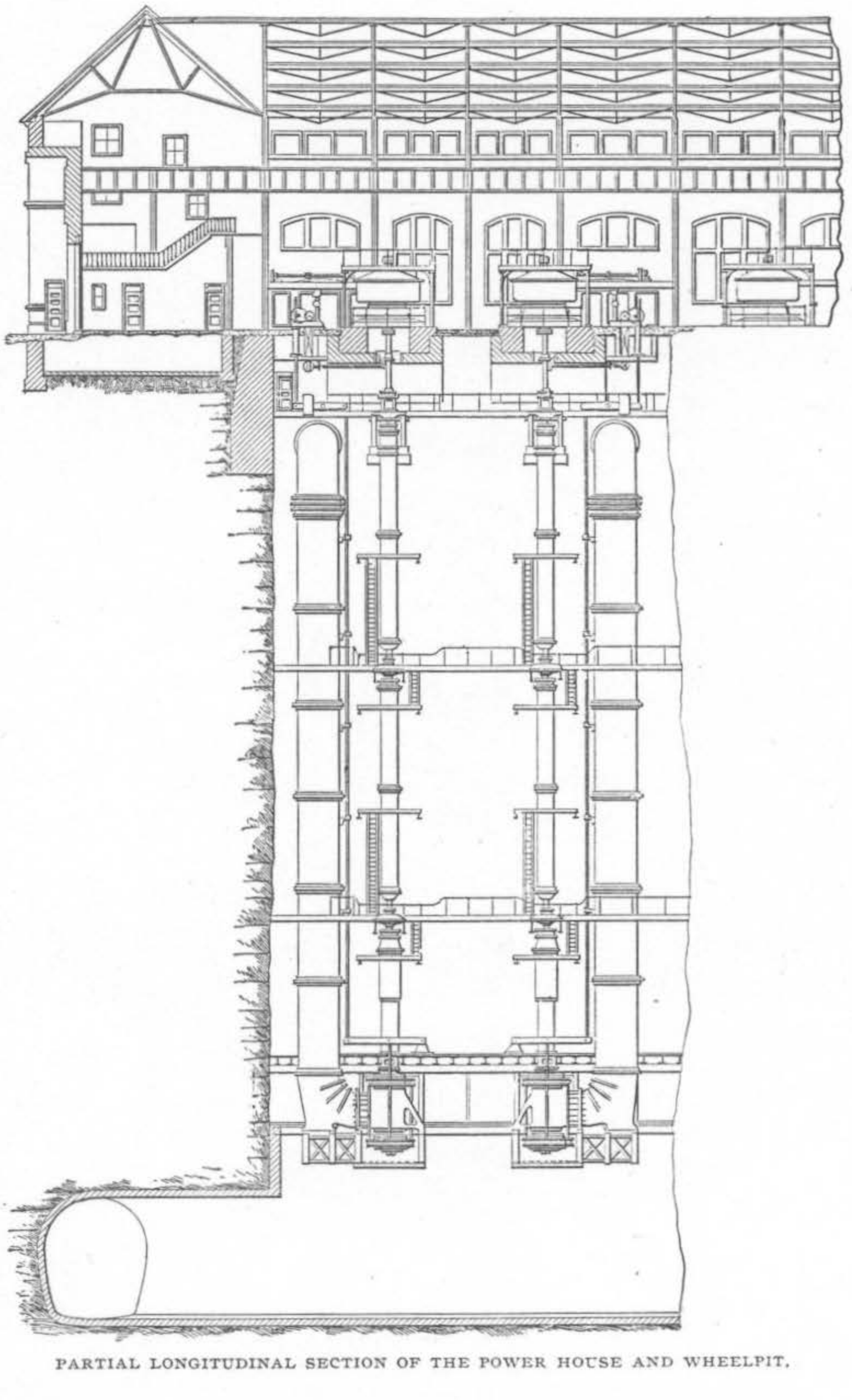


FRONT ELEVATION AND SECTION THROUGH FOUNDATION.

of concrete supporting the massive capstone and the excellently constructed arch which spans the wheel pit. On pages 262 and 263 sections through the power house and wheel pit, reproduced from the general drawings, show the generators in relation to the power house, the wheel pit and the hydraulic plant. The large scale upon which the work has been planned and carried out is graphically evident upon comparison of these sections, illustrating the relatively small space occupied by the generators, with the actual size of the machine as shown on page 258.

The height of each generator from the bottom of the bedplate to the top of the floor of the bridge is 11 ft. 6 in. The diameter of the bedplate is 14 ft., and the outside diameter of the revolving field ring is 11 ft. 7⅛ in. Each generator delivers 5000 electrical horsepower, and requires about 5150 horsepower delivered through the turbine shaft to drive it under full load. Exclusive of the bridge, which is simply used to give access to the brushes bearing upon the collecting rings at the top of the shaft, the entire machine could be placed in a room 15 ft. square and 15 ft. high.

The weight of each generator is 170,000 lbs., of which about 79,000 lbs. are in the revolving element, which is made up of the shaft, the driver to which the field ring is attached, the



PARTIAL LONGITUDINAL SECTION OF THE POWER HOUSE AND WHEELPIT.

field ring with its pole pieces and bobbins, and the collecting rings, carried upon an extension of the shaft above the driver. The speed at which the field revolves is normally 250 revolutions per minute, and the fly-wheel effect of the revolving parts of the machine, measured by the pounds multiplied by feet per second squared, is 1,274,000,000.

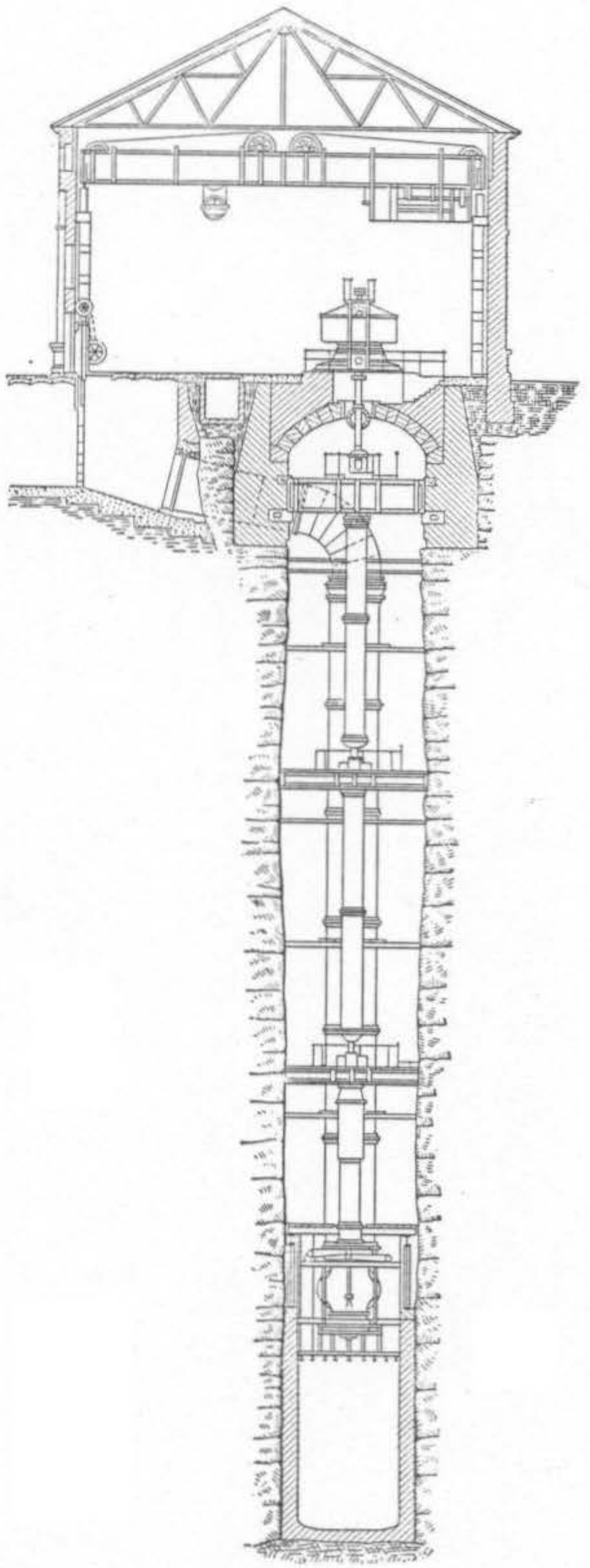
The conditions to be met in the construction of the generators, as determined by the plans adopted for the hydraulic plant, were such as to impose very considerable difficulty upon the designers and manufacturers. These conditions were, in brief, an output of 5000 electrical horse-power, a speed of 250 revolutions per minute, a weight in

the revolving element of the machine not exceeding 80,000 lbs., and a fly wheel effect of the revolving parts, measured by the pounds multiplied by feet per second squared, of not less than 1,100,000,000.

In saying that the imposition of these conditions involved difficulties, no reflection upon the wisdom of the decision which imposed these conditions is intended. It would be, perhaps, more exact to say that the general specifications laid down were such as called for the highest skill in the designers and builders of the generators. The conditions have been met successfully, and the object which the officers of the Cataract Construction Company had in view is attained. The Niagara generators represent to-day the highest state of the art of design and construction of electrical machinery.

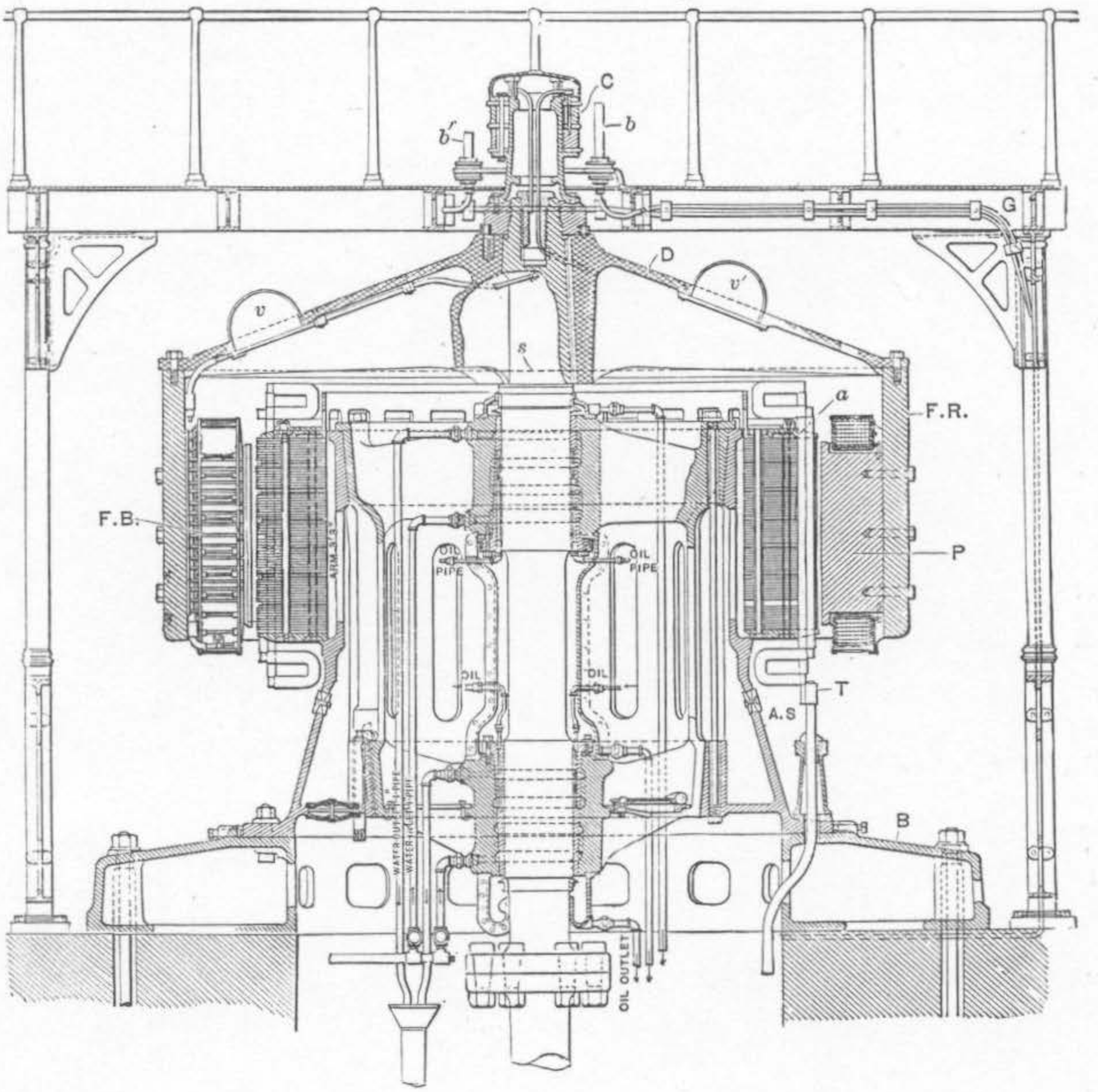
The construction of the generators is illustrated by the reproductions from the general drawings on pages 264 and 265. In the vertical section through the centre line of the shaft on page 264, *a* represents the stationary armature, secured in place by the armature support AS, which, in turn, rests upon the bedplate B. One of the four terminals at which the current from the armature is delivered to the cables leading to the switchboard, is shown at T. Of course, since the armature is stationary, no ring collectors or brushes are needed. The revolving part of the generator consists of the shaft S, carrying the driver D, the field ring FR, the steel pole pieces P, the field bobbins FB (each bobbin surrounding a pole piece), and the collector C, by means of which the current delivered from the exciters to the brush holders *b*, *b'*, is conveyed to the field bobbins. In the horizontal section through the armature and field, *a* is the armature, FR the field ring, P, P', etc., are the pole pieces and B, B', etc., the field bobbins. The clearance between the armature and the field poles is one inch.

The power house is equipped with a 50-ton electric crane, built by Messrs. Wm. Sellers & Co., of Philadelphia, which is of ample strength to handle



CROSS SECTION OF POWER HOUSE AND WHEELPIT.

any part of the electric or hydraulic machinery, and by means of this the revolving parts of the machines may be removed when necessary. In doing this the collecting rings near the top of the shaft are first removed, and the bridge is taken out of the way. The key which fixes the driver to the shaft is then withdrawn, and a special tool,



VERTICAL SECTION OF ONE OF THE 5000 HORSE-POWER GENERATORS.

which may be described as a combined eyebolt and hydraulic pump, is attached to the driver by eight heavy tap bolts. The pressure pump is then operated by hand, and, leakage of water being prevented by packing rings, a pressure of many thousand pounds, tending to lift the driver with reference to the shaft, is exerted. In this way the driver is loosened from the shaft, and, with the field, is then raised bodily by the electric crane. The bearings and the castings which support them are next lifted out, and the shaft is removed if necessary. When this has been accomplished, a clear space is left within the fixed part of the machine, that is, within the armature support, five feet in diameter, through which parts of the turbine shaft or other machinery from the wheel pit can be raised.

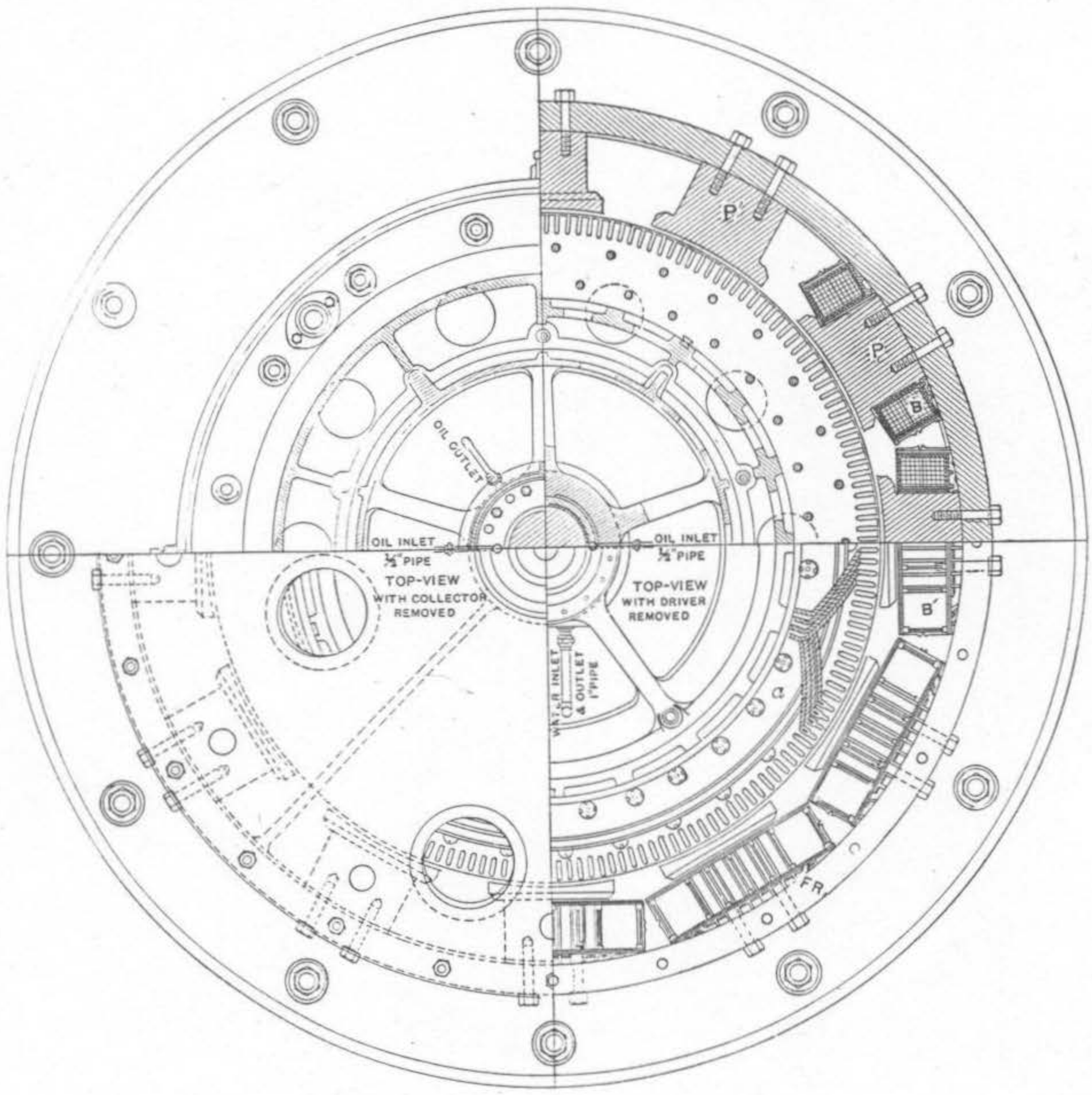
An attractive feature of the form of construction adopted is the fact that the magnetic attraction between the field poles and the armature acts against the centrifugal force. As compared with the centrifugal force at high speeds at which the ring must still be safe, the magnetic attraction is not very great, and, unless the field is charged, there is, of course, no magnetic pull between armature and field. But with normal conditions, this attraction tends to reduce the strains in the ring, due to centrifugal force, whereas, were the armature revolved inside of the field,

the magnetic pull would be added to the centrifugal force.

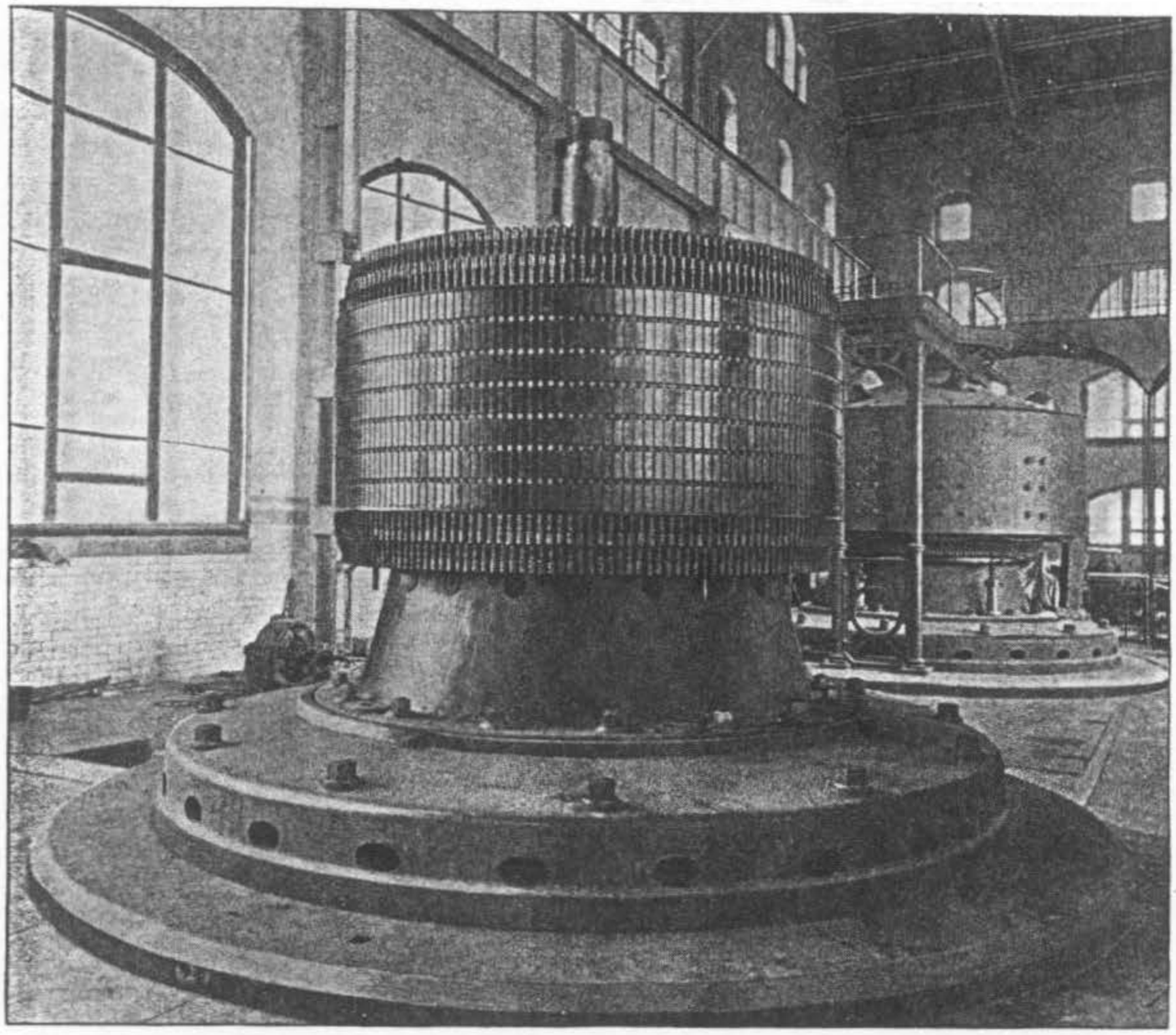
The armature and field are ventilated by means of openings in the driver, provided with special ventilators v, v', so arranged as to draw air up through the machine, and throw it out at the top. A considerable draught is necessary, since, at full load, heat equivalent to about 100 horse-power, representing the loss in the generator due to magnetization of the iron and the resistance encountered by the currents traversing the conductors, must be dissipated.

The sections on pages 260 and 261 show the method of securing the bed plate in place. Eight 2½-inch bolts are used, and, at their lower ends, are securely held by castings buried in the concrete foundation. The masonry is of the highest class, massive blocks of Queenston limestone being used for the capstone and in the construction of the arch. In the latter a cylindrical steel casting takes the place of the keystone, the turbine shaft passing through it to the dynamo shaft above.

The armature support is a single casting of cylindrical form, and is securely bolted to the bedplate, upon which it is adjusted by set screws in a flange around the circular bed, and is afterwards babbitted to secure rigidity. This cylindrical casting has on its outer periphery a series of vertical ribs, which terminate at the lower ends in a flange upon which the armature ring rests. The latter was lowered to this flange



HORIZONTAL SECTION.



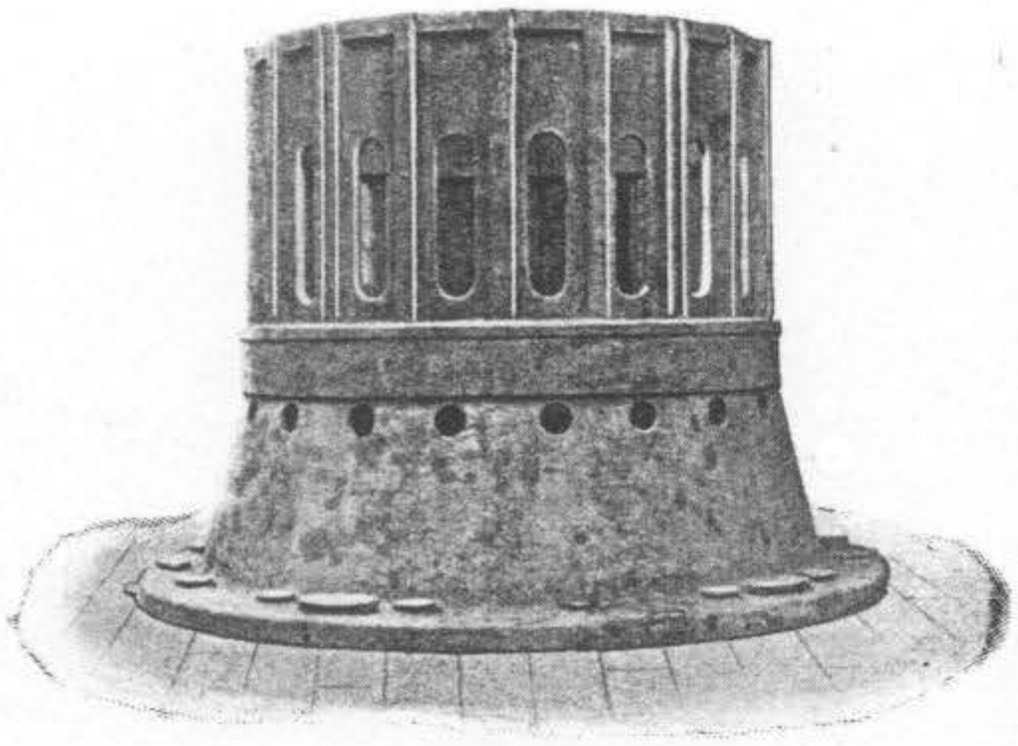
THE ARMATURE OF THE SECOND GENERATOR IN PLACE.

while heated, and then shrunk into place against the ribs on the cylindrical support. Five of these ribs are provided with dove-tailed keyways, corresponding with keyways in the armature ring. Into these, after the ring was shrunk into place, metal keys were cast. While the outer surface of this casting which supports the armature is cylindrical, its inner surfaces, at the top and bottom, form sections of two truncated cones into which fits and is securely bolted a second casting carrying two massive, five-arm spiders, which support the upper and lower bearings. The illustration on page 267 shows the armature support and armature core after the latter has been shrunk into place. The vertical slots which will be noted around the periphery of the core, are ready for the reception of the armature conductors.

The construction of the casting which carries the spiders supporting the bearings is illustrated on the same page. The end view shows the bushings in place, and these bushings are separately illustrated on page 268. The bearings, which are of the best quality of bearing metal, are in two parts, are fitted into conical bearings of iron surrounding the shaft, and are provided with set screws to assist in withdrawing or tightening when necessary. The bearings are lubricated by oil under pressure, admitted at a point midway between the top and bottom, and also at a point near the top.

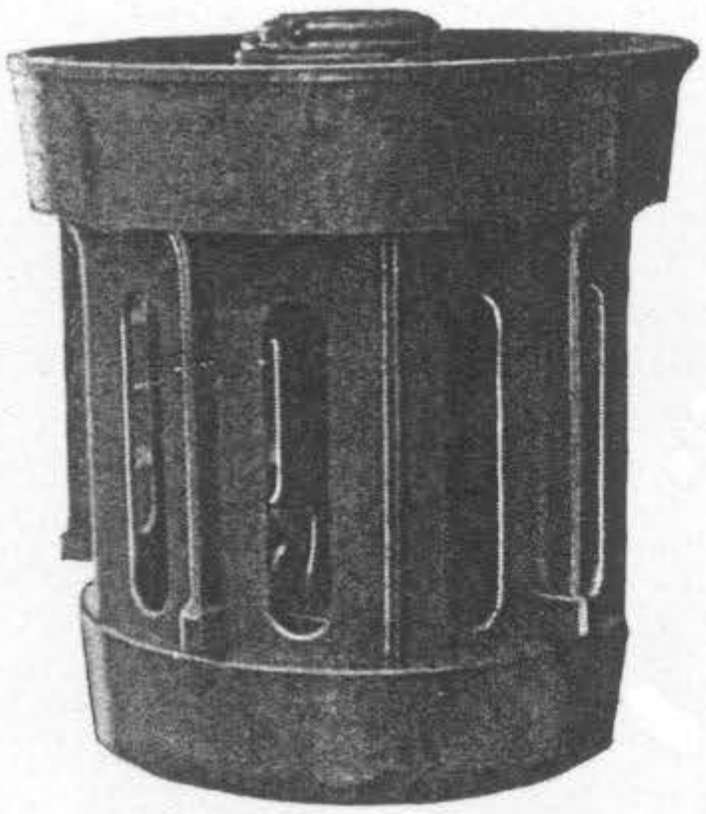
Grooves are cast in the hub of each spider, with pipes at each end, permitting the circulation of water to cool the bearings, this water being conveyed to the bearings direct from the city mains at a pressure of 60 pounds per square inch. The oil is supplied from a reservoir placed at an elevation of about 30

ft. above the upper bearing. After having passed through the bearings, it is filtered and pumped back into the reservoir. The pressure at which it is supplied to the machine is that due to gravity.



THE ARMATURE SUPPORT AND CORE.

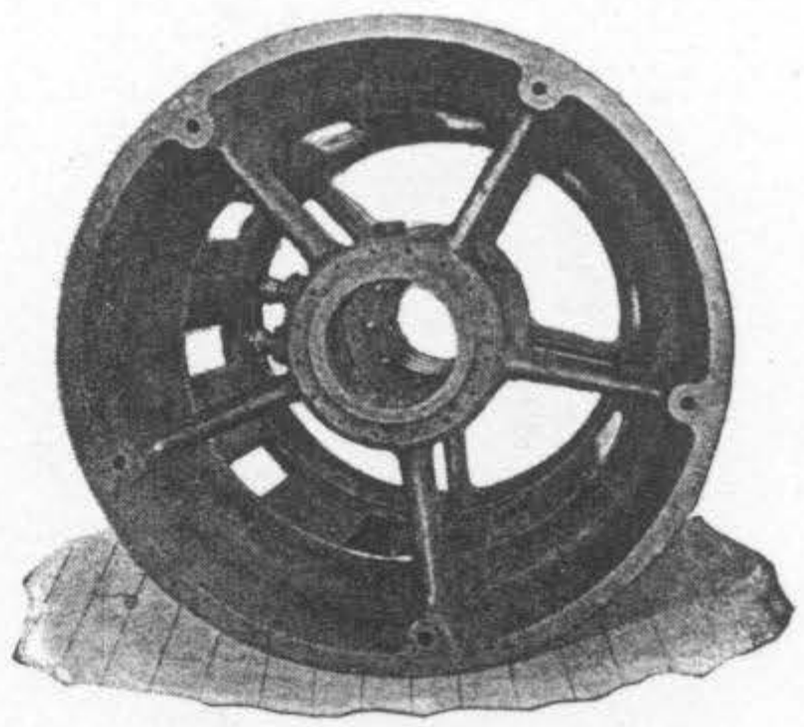
The illustrations on pages 269 and 266 show, respectively, the armature core, or ring, in place upon its support before winding, and the armature complete, with conductors in the grooves or slots around the periphery of the core. The armature core is built up of



SIDE VIEW OF CASTING CARRYING SPIDER FOR BEARINGS.

thin sheets of mild steel, No. 30 B. W., G., and, to secure free circulation of air, is divided horizontally into six equal parts, separated from one another by one-inch spaces. Each layer of the core consists of eleven segments, which are so placed that all joints in each layer are overlapped by the segments of the adjacent layers. One of the sheets of steel is shown on page 268. These pieces are punched out of large sheets of a certain predetermined quality, .015 of an inch thick, by steel dies in powerful presses. They are afterwards thoroughly annealed. In this process of annealing, the surfaces of the segments are oxidized, the oxide serving as insulation to reduce the eddy currents which are set up in the iron of the armature when the machine is in operation.

The ring thus built up is securely held together by sixty-six bolts of nickel steel, containing a high percentage of nickel which renders them practically non-magnetic. These bolts are, of course, carefully insulated from the core. The large discs, or end-plates, at the top and bottom of the armature ring are of brass. At the time of tightening the bolts, the steel plates are pressed closely together by



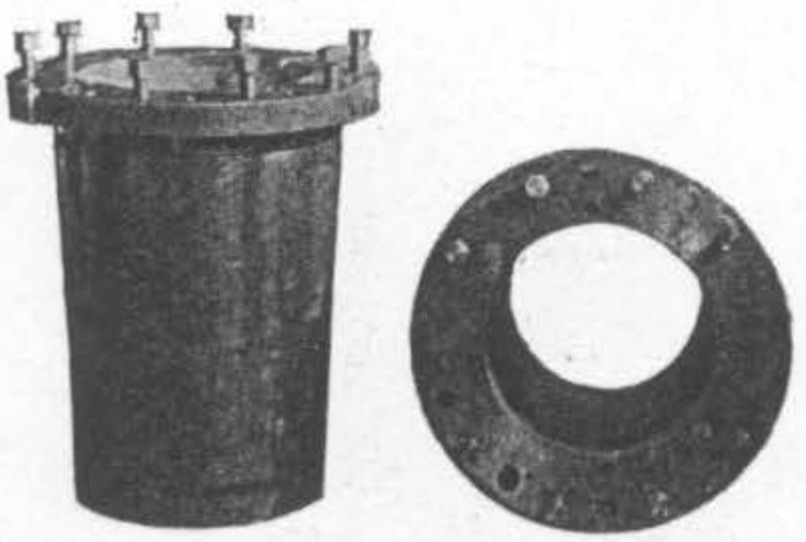
END VIEW OF THE CASTING.

powerful hand-presses. The six equal parts, or layers, into which the core of the armature is divided, are separated from one another by segments of cast brass, these segments being cast in such form that, while they have sufficient strength to withstand the pressure under which the armature core is assembled, the larger part of the spaces between the six adjacent rings or steel plates is left open for the circulation of air.

The armature ring, when finally

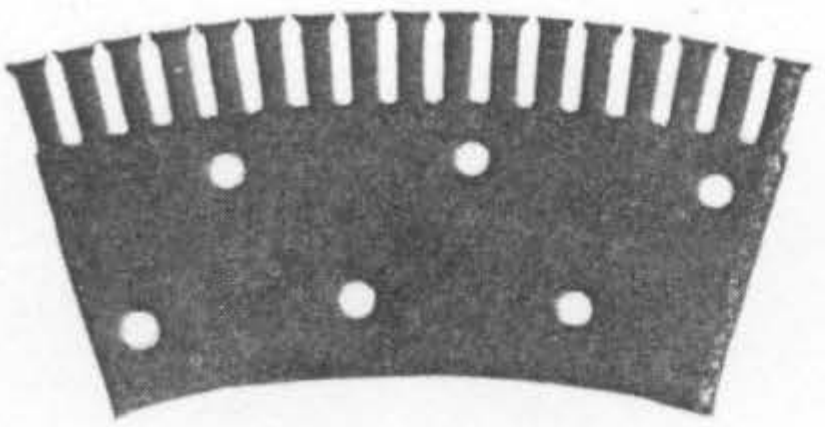
built up, is turned on the inner surface so as to accurately fit the ribs of the armature support. It is then heated, and lowered into place against the flange on the support, and, in cooling, shrinks itself tightly into place against the ribs.

The armature conductors consist of copper bars $1\frac{11}{32}$ in. by $\frac{7}{16}$ in. in section, the edges of the bars being rounded to a radius of about one-eighth of an inch to avoid cutting the insulation. Two of these bars, after being insulated, are placed in each of the 187 slots around the periphery of the armature core. The conductivity of the bars used is above 100 per cent., by



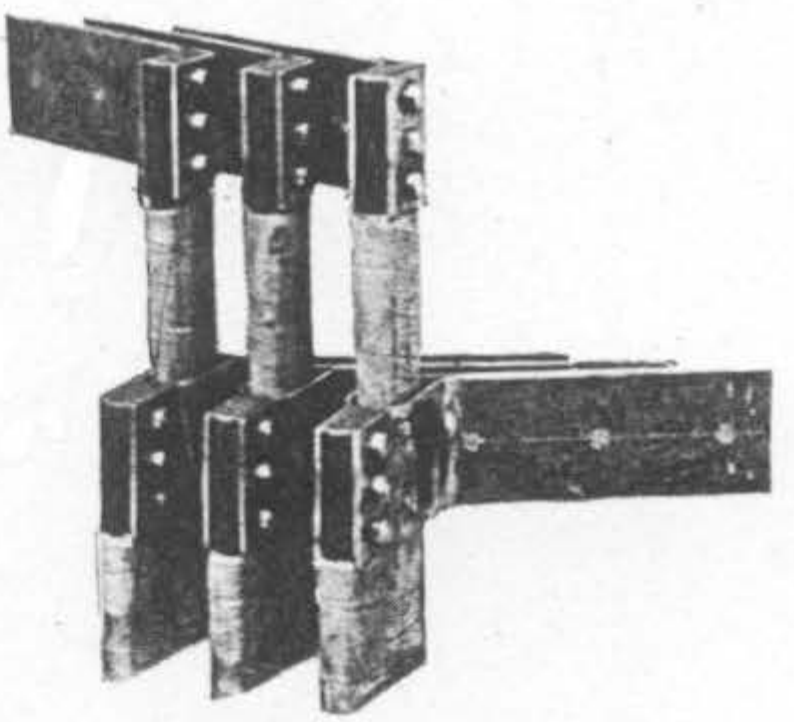
DETAILS OF ARMATURE BEARINGS.

Matthiesen's standard. In the case of the second generator the conductivity of the copper, furnished by the Washburn & Moen Mfg. Co., of Worcester, Mass., is 102.6 per cent., which strikingly illustrates the fact that what was considered pure copper when the standard referred to, and still generally used,



ONE OF THE SHEETS MAKING UP THE ARMATURE CORE.

was determined, is now inferior to certain grades of commercial copper. The proper insulation of these conductors is a matter of the greatest importance. Each conductor must be separated from its neighbors and from the iron of the armature core by insulating material which is abundantly able to withstand the potential to which it will be subjected, and in order to be sure of this, a large factor of safety is allowed; that is, the insulation is tested by apply-



JUNCTION OF ARMATURE BARS AND CONNECTORS BEFORE SOLDERING AND INSULATING.

ing a potential several times as great as any to which it will be subjected in service.

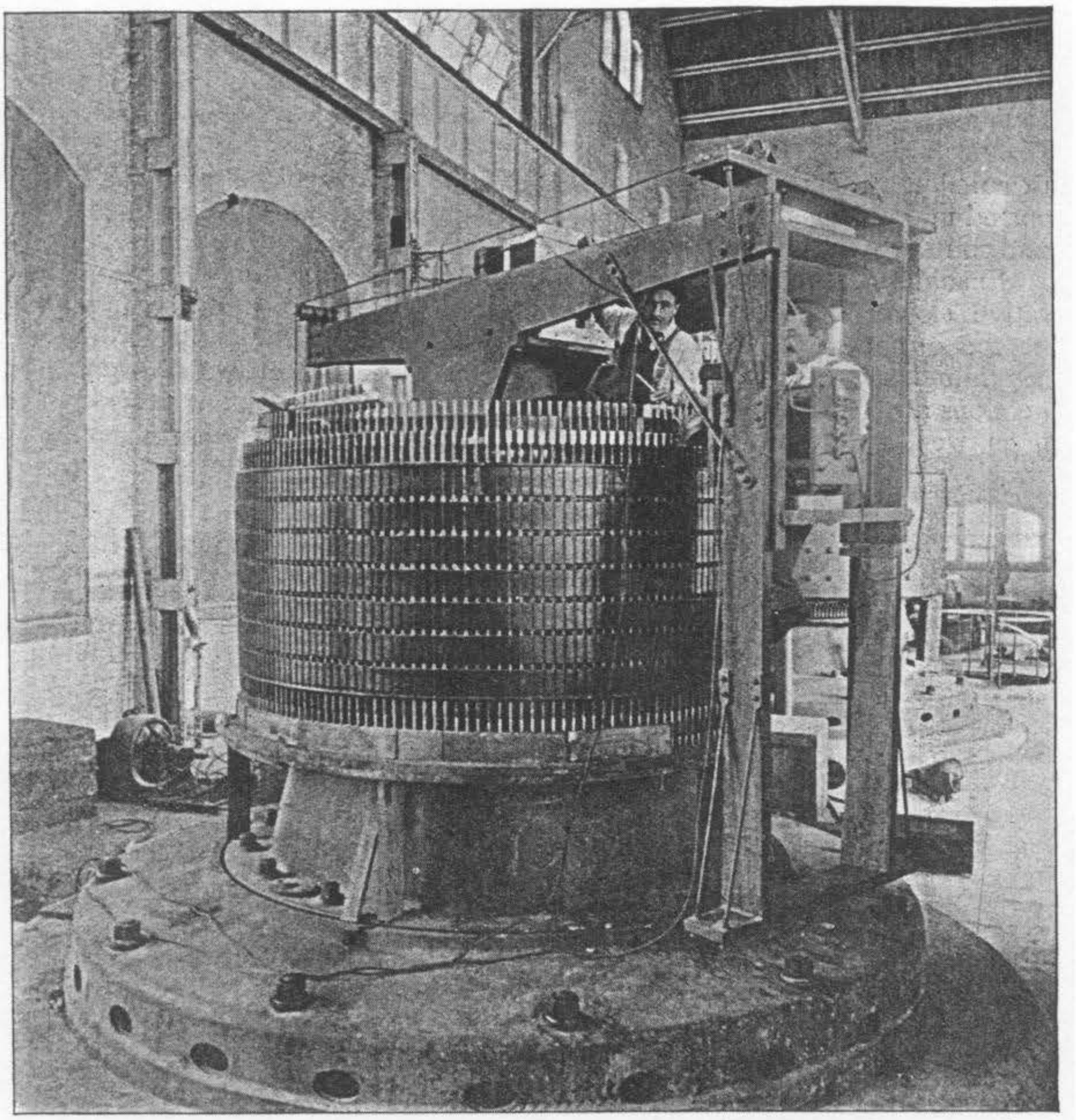
At the factory, the insulation of each bar was tested by applying a potential of 15,000 volts. One terminal of the transformer used in testing was connected to the conductor, and the other terminal was connected to a layer of tinfoil, wrapped about the outside of the insulation. During the erection of the generators at Niagara, the insulation was again tested by applying a potential of 6000 volts, one terminal of the testing transformer being connected to the conductors, while the other was connected to the armature core. An alternating potential was used in both tests, and the values given are in each case the mean or effective potential.

The material used for insulating the bars is principally mica. The armature conductors project above and below the core, as shown in the illustration on page 269, and connections are made by pieces of copper, punched from large sheets and shaped into proper form by presses and iron moulds. These connectors are insulated by mica and rubber insulating tape, the former being used only where connectors conveying

currents of considerable difference of potential are adjacent to each other.

It is very important that good electrical connection be made at the junction of connector and armature bar. The illustration on page 268 illustrates the connection before the solder is applied. Three holes drilled through the split end of the connector correspond to three holes in the end of the armature bar. The split end of the connector is fitted closely to the end of the bar, and when the holes in the connector and bar are properly aligned they are securely fixed in place by three wrought iron bolts, the holes through one side of the connector being reamed out to receive the heads of the bolts. After the nuts are tightened into place, the projecting ends of the bolts are upset; that is to say, they are split and, as it were, riveted to lock the nuts.

The joint is then thoroughly soldered, this work being greatly facilitated by the use of an electrical soldering tool. The process will be best understood by referring to the illustration on this page, which was taken during the erection of the first generator. A transformer, supplied with alternating current at a potential of about 150 volts, is so wound as to deliver a current of very large quantity but low pressure. This current is coveyed through heavy jaws, or terminals, of copper to the point of junction between the armature bar and

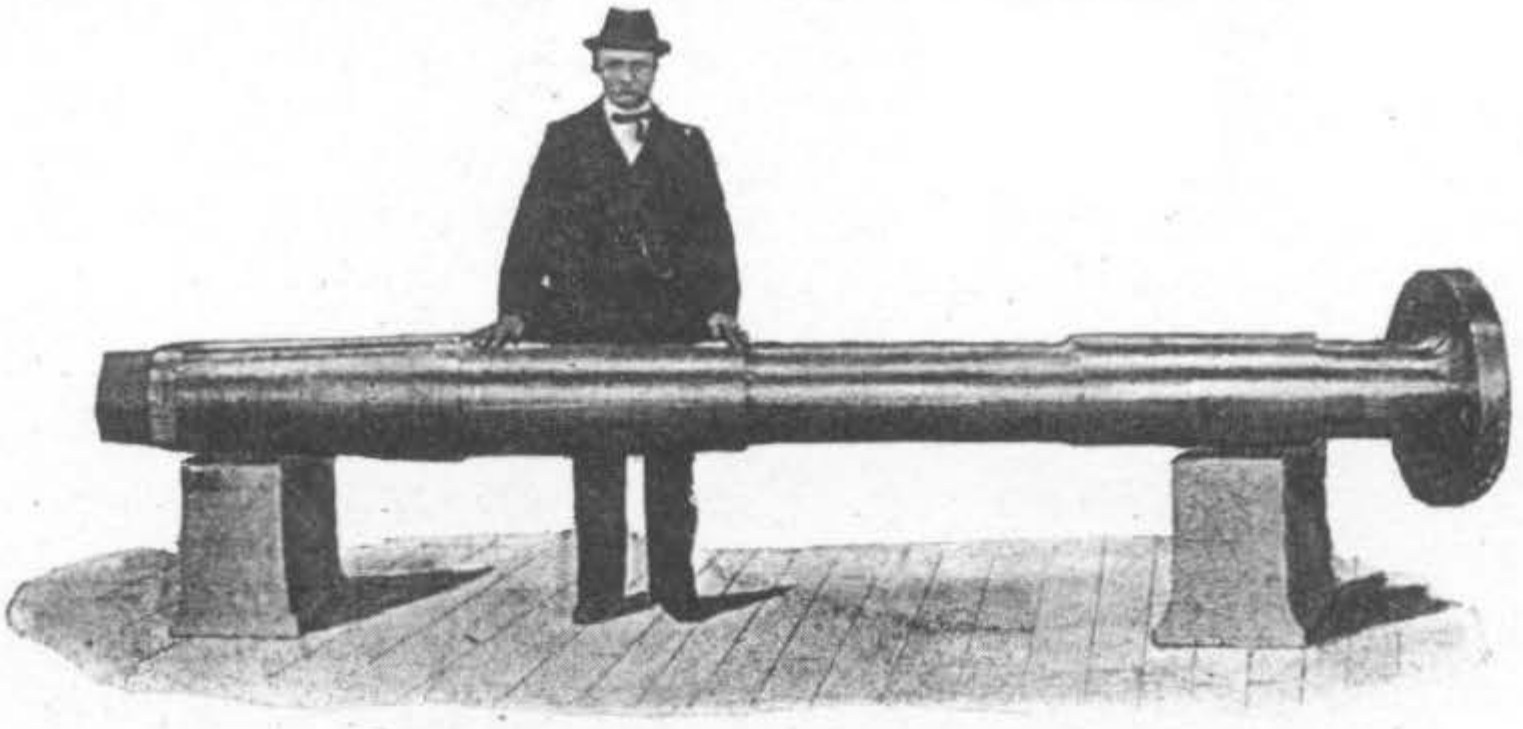


ELECTRICALLY SOLDERING THE CONNECTIONS OF AN ARMATURE WINDING.

its connector, and in a few seconds this point is heated to a high temperature. The joint is then readily flooded with solder. This is afterwards dressed up by a file, and the joint is thoroughly insulated.

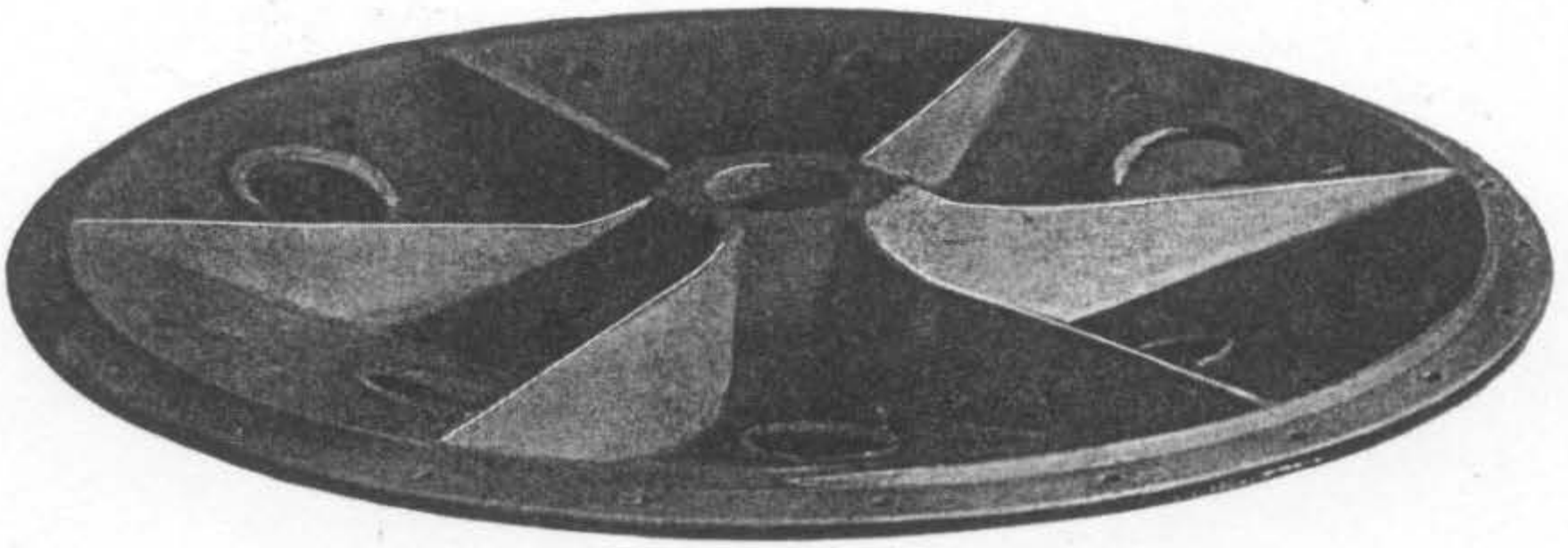
In the illustration the soldering transformer and one of the operatives are seen carried at one end of an oak frame, supported upon the shaft of the generator and counter-weighted at its opposite end. In soldering the connections the operative slowly revolves the frame about the armature. The seat which carries him is adjustable, so that the connections at the bottom of the armature, as well as at the top, can be reached, and it is provided with rails upon which the transformer is pushed forward until the copper jaws grasp the connection, or withdrawn after the soldering is completed.

When the armature is completely wound, as shown in the illustration on page 266, the conductors are so connected as to form two complete circuits, each thoroughly insulated from the other and from the steel core, and so related to each other that the electromotive forces induced in them by the revolving magnetic field are ninety degrees apart.



THE GENERATOR SHAFT.

Coming now to the revolving parts of the generator, we begin with the shaft, which is shown on this page. It is of open-hearth steel, and was forged and rough-turned by the Cleveland City Forge and Iron Company of Cleveland, Ohio. The diameter of the shaft in the bearings is $12\frac{15}{16}$ in. It is tapered at the upper end to receive the driver, and a flange, 27 in. in diameter, is forged at the lower end to provide means for connection to the flange at the top of the turbine shaft. These flanges are bolted together by eight tapered steel bolts. At its extreme upper end the shaft is threaded to provide means for securing



THE DRIVER FOR THE FIELD RING.

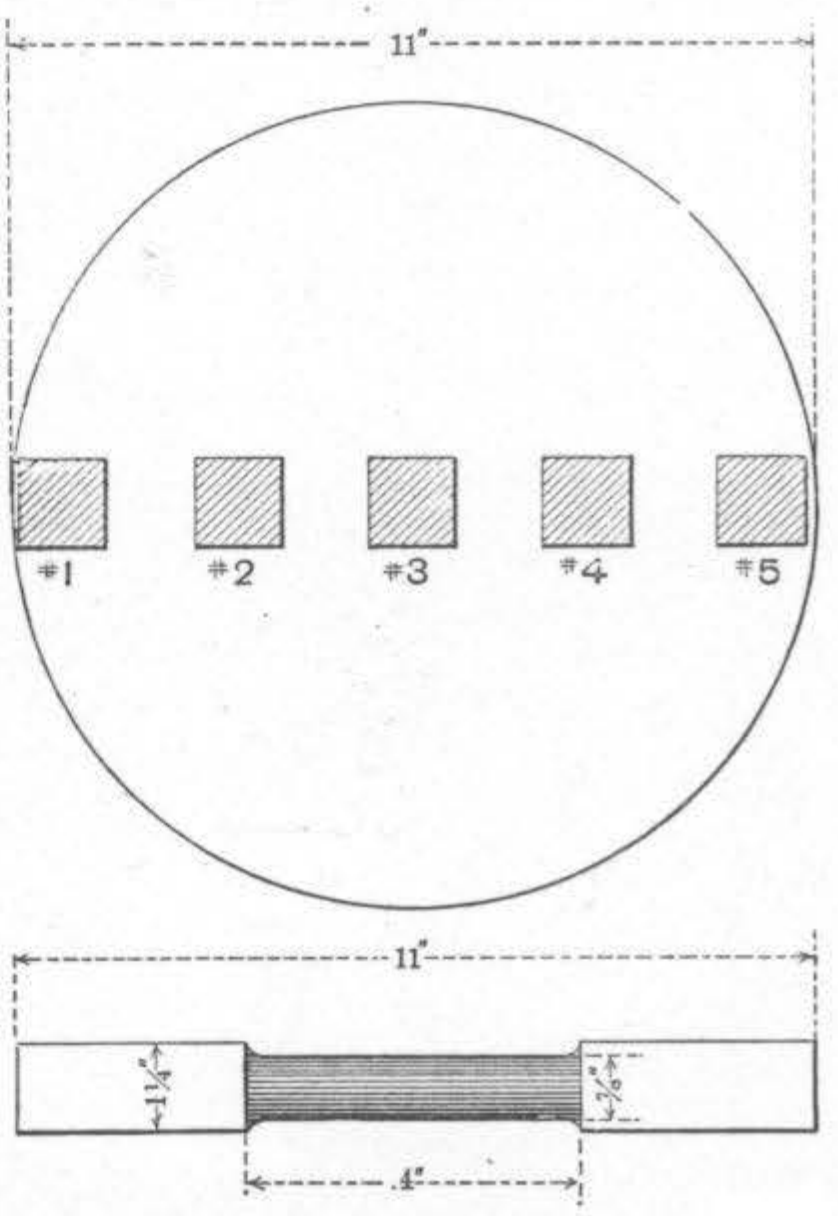
in place the revolving parts which project above the driver and carry the collecting rings.

For the purpose of securing information as to the physical properties of the steel used for the shaft, it was originally forged of extra length ; an end, several inches in length, was then cut off, and from this five samples were taken, two being cut from the periphery of the shaft at opposite ends of a diameter; one, from the centre of the shaft; and two, from points midway between the periphery and the centre, as illustrated in the cut on this page, where the numbers 1, 2, 3, 4 and 5 indicate the places in the section of the shaft from which the test samples were taken. These samples were tested by the Pittsburgh Testing Laboratory at Pittsburgh, and the fact that forged shafts are stronger near their outer surface than elsewhere is shown in an interesting manner by the results, which are set forth in the following table :

Sample No.	Tensile Strength in Pounds Per sq. in.	Elastic Limit in Pounds Per sq. in.	Reduction of Area in Percentage of Area Before Test.	Elongation in Percentage of Length Before Test.
1	63,000	35,500	53	37.5
2	59,000	29,500	51	38
3	56,000	28,500	37 5	31
4	58,500	31,500	41.5	38
5	62,500	35,000	55.5	35

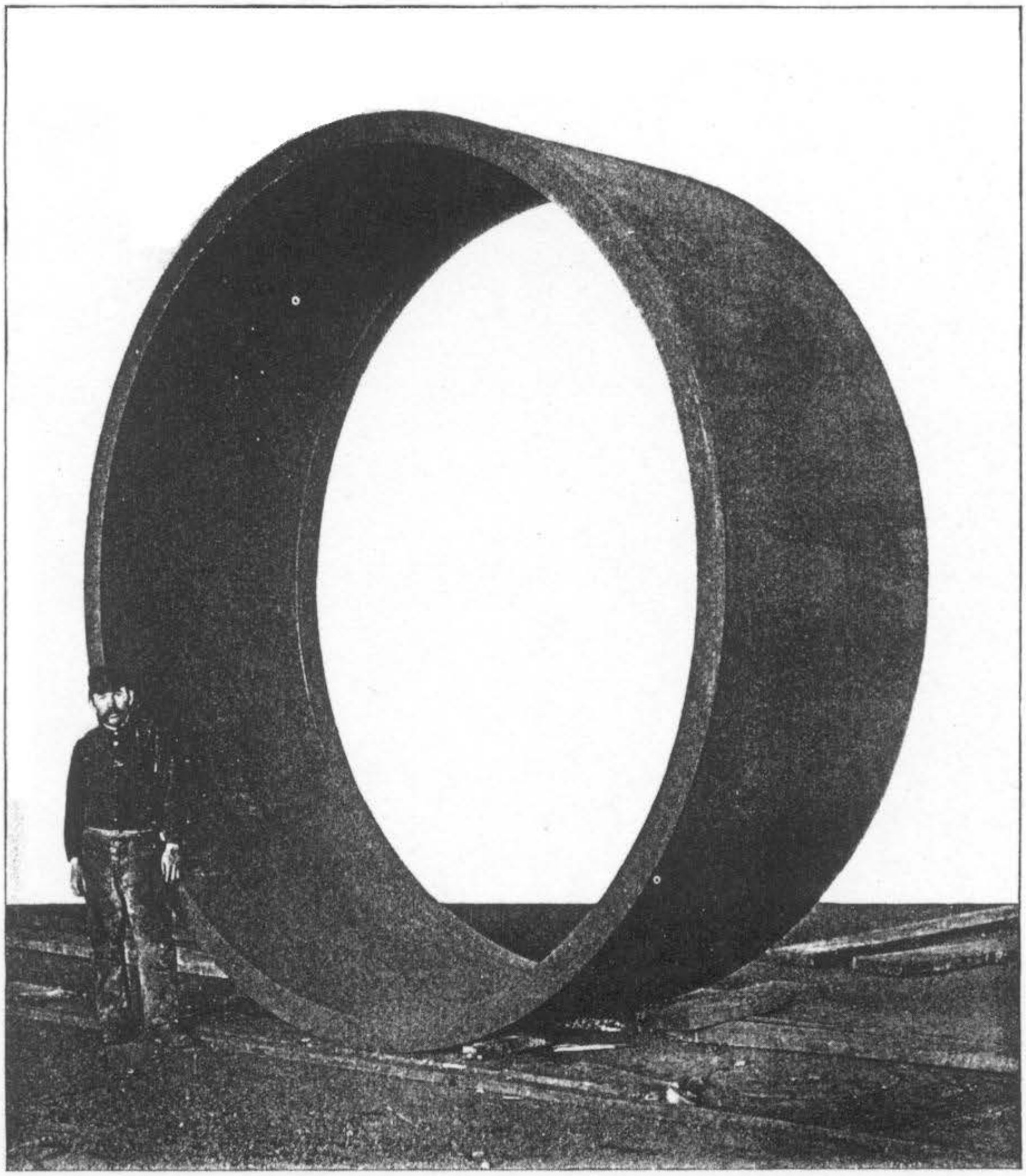
A view of the driver is given on page 270. It is 11 ft. 8 in. in diameter. As has been noted in describing the shaft, the latter is tapered at its upper end, and by referring to the illustration on page 270 it will be seen that a heavy key-way is cut into the tapered portion. The bearing in the driver which fits over this tapered end of the shaft is also provided with a key-way, and the driver and shaft are held together by a long and massive steel key. The driver is of mild cast steel, and was turned out by the Midvale Steel Company, of Philadelphia. It was guaranteed to have a tensile strength of about 60,000 lbs. per sq. in., but the tests of samples of steel, taken from the casting near the periphery of the first driver, showed a tensile strength of 74,700 lbs. per sq. in., an elastic limit of 44,590 lbs. per sq. in., an elongation of 30 per cent. in 3 in., and a reduction of area of 43 per cent. The surface of the fracture was silky and fine-grained. The drivers are turned on their outside surfaces and are strengthened by six deep ribs on the inside.

Perhaps the most interesting part of each generator is the field magnet ring, which not only illustrates the wonderful physical properties of nickel steel, but demonstrates in a most striking manner the perfection of modern forging ma-



TEST PIECES FROM THE GENERATOR SHAFT.

chinery and the skill of those who use it in the great plant of the Bethlehem Iron Company, at South Bethiehem, Pa. The ring is forged in one piece without weld, and is shown in the photographic reproduction on the following page. The Bethlehem Iron Company guaranteed that the rings for the first three generators should have a tensile strength of not less than 70,000 lbs. per sq. in., an elastic limit of 38,000 lbs. per sq. in., and an elongation of about 25 per cent. in 2 in.; but they have done much better. Three samples, cut from the first ring before



NICKEL STEEL FIELD RING, FORGED WITHOUT A WELD BY THE BETHLEHEM IRON COMPANY. DIAMETER, 11 FT. 7⅛ IN.

turning were tested with the following results :

Sample No.	Tensile Strength Measured in Pounds Per sq. in.	Elastic Limit Measured in Pounds Per sq. in	Elongation in 2" Measured in Percentage of Original Length.
1	82,915	53,560	27.05
2	81,110	47,230	25.75
3	82,140	49,280	22.5

The following brief account of the method of making the field rings is based upon notes furnished by Mr. R. W. Davenport, second vice-president of the Bethlehem Iron Company. A nickel steel ingot, 54 inches in diameter at the bottom, 197 inches long, and weighing about 120,000 lbs., was cast solid, and compressed by hydraulic pressure when fluid and during solidification. This ingot is shown in the illustration on page 274. A hole was bored through its longitudinal axis, as shown on page 275, and a block of proper weight was then cut from the ingot. The cylinder thus formed was brought

to a forging heat, and expanded on a mandril under a 14,000 ton hydraulic press. The high degree of skill, and the perfection of mechanical appliances required to expand part of the cylinder, shown on page 275, to the ring, illustrated on page 272, are evident, and reflect much credit upon the Bethlehem Iron Company. After forging, the ring was carefully treated to obtain the physical qualities desired, and was then bored and rough-turned on a large boring mill. It was finally turned true in the shops of the Westinghouse Electric & Manufacturing Company, at Pittsburg, Pa.

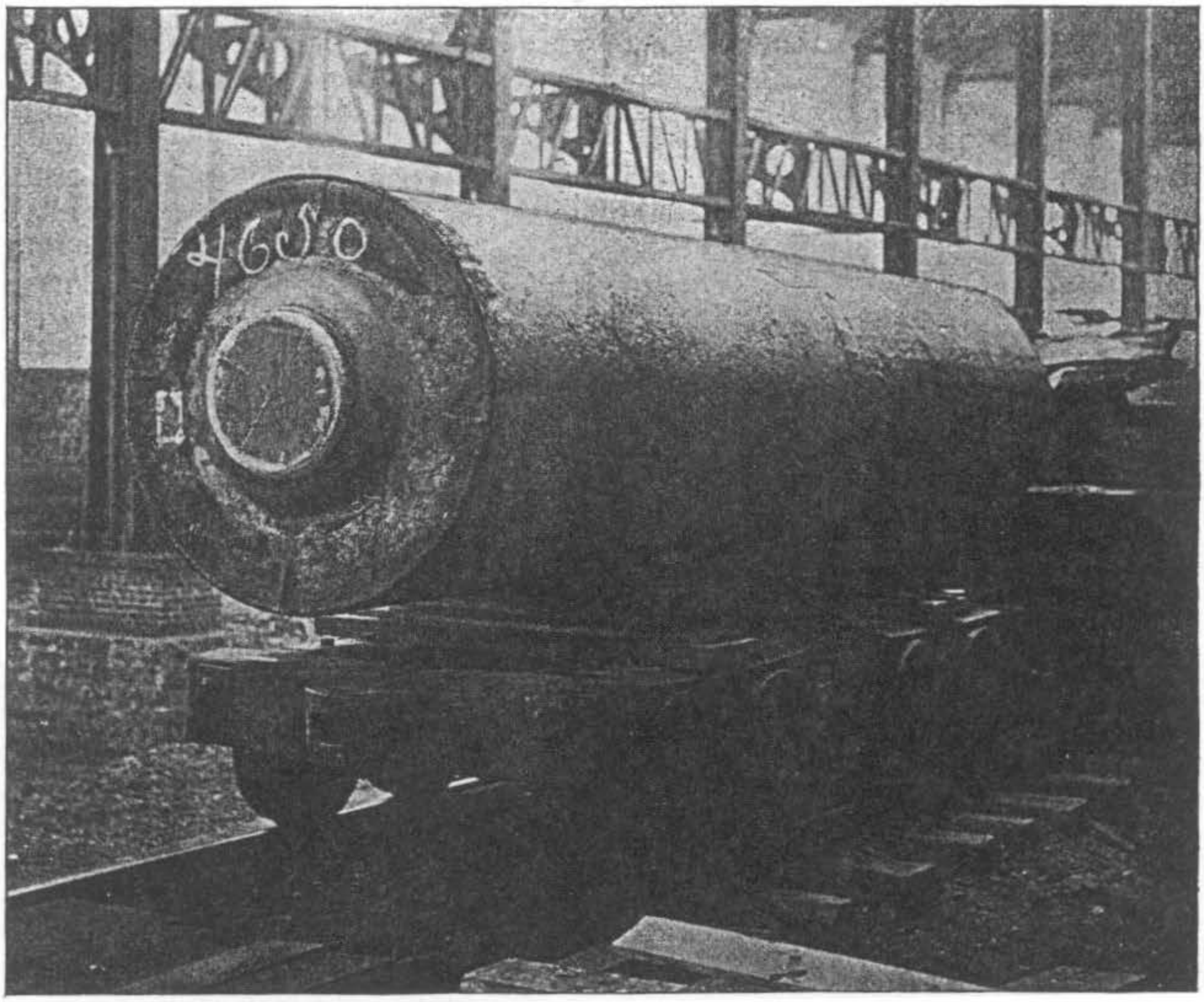
Not only are the physical properties of the ring extraordinary; in size it is without precedent, and to those interested in the recent remarkable improvement in the quality of steel, and in the methods of working it, the interest which attaches to this ring, as an example of the finished product of the Bethlehem Iron Company, is not less than that which it derives from the important part which it sustains in the Niagara installation.

Why it is necessary that these rings should be so strong, and that they should be so forged as to eliminate the possibility of weakness in any part, will be better understood when we consider the speed at which they revolve, and the weight of the pole pieces and field bobbins which they carry. The illustrations on page 276 show one of the field poles without its winding, and one of the field poles with bobbin in place. The poles are of mild open-hearth steel, and were cast by the Midvale Steel Company. Their magnetic qualities have been carefully tested by sample, and are excellent.

The field winding, which consists of copper conductor of rectangular section, thoroughly insulated, is contained in ribbed brass boxes or covers, one of which is well illustrated on page 276. The weight of each pole piece with its bobbin is 2800 lbs. The relation of the pole pieces and bobbins to the ring is shown in the illustration on page 277. The speed of the ring at its periphery is 9300 ft. per minute when making 250 revolutions per minute, and at this speed the centrifugal force, due to each field pole and bobbin, is 2727 lbs. The strain is, of course, a maximum at a point in the ring midway between each pair of adjacent poles. The strain due to the mass of the ring itself is 2325 lbs. The total maximum strain in the ring at 250 revolutions per minute is, therefore, by calculation, 5052 lbs.

It is not sufficient that the ring should be simply strong enough to withstand the centrifugal force due to the field poles, bobbins and its own mass when revolving at 250 revolutions per minute; it must be able to run safely at a much higher speed, for it is conceivable that, should anything happen to the apparatus which governs the turbines, a much higher speed may be attained. It was judged necessary, therefore, to so design the machine that it should be safe when running at a speed of 400 revolutions per minute, and at this speed the centrifugal force due to each pole piece and bobbin becomes 6500 lbs. The strains in the ring have been, as may be supposed, calculated with great care, and even at 400 revolutions per minute, equivalent to 241 feet per second at the periphery, the total strain will not exceed 13,000 lbs. per sq. in. As the elastic limit of the material used in the rings is 48,000 pounds, the factor of safety at this speed, which will probably never be realised in practice, is nearly four. At a speed of 800 revolutions per minute, which means 482 feet per second, or nearly six miles per minute at the periphery, the ring would burst. But it is, of course, impossible that any such speed could, under any circumstances, be attained; in fact, the calculations of the designers of the hydraulic machinery show that the speed could in no case exceed 400 revolutions per minute.

Above the driver in the illustration on page 254 are the collector and brushes by which the current is conveyed from the exciters to the revolving field of the generator. The conductor conveying the field current comes from the exciters through covered conduits beneath the level of the floor, passes



SOLID INGOT OF FLUID COMPRESSED STEEL USED FOR MAKING THE FORGED FIELD RING. LENGTH, 197 IN. DIAMETER, 54 IN. WEIGHT, 120,000 LBS.

through an iron pipe concealed in the capstone of the foundation, up one of the hollow iron columns supporting the bridge or platform across the machine, and thence, along the bridge, to the brushes. From the collector rings it passes under the driver through the shaft, and thence, along one of the ribs inside of the driver, to the field bobbins. The collector rings are built upon a separate cylindrical casting placed above the driver, and securely fixed to the hub of the latter by heavy screws through a flange at its base. The brush-holder rods are held in place by a heavy iron bracket encircling the casting below the collector rings. This bracket rests upon the bridge which spans the machine.

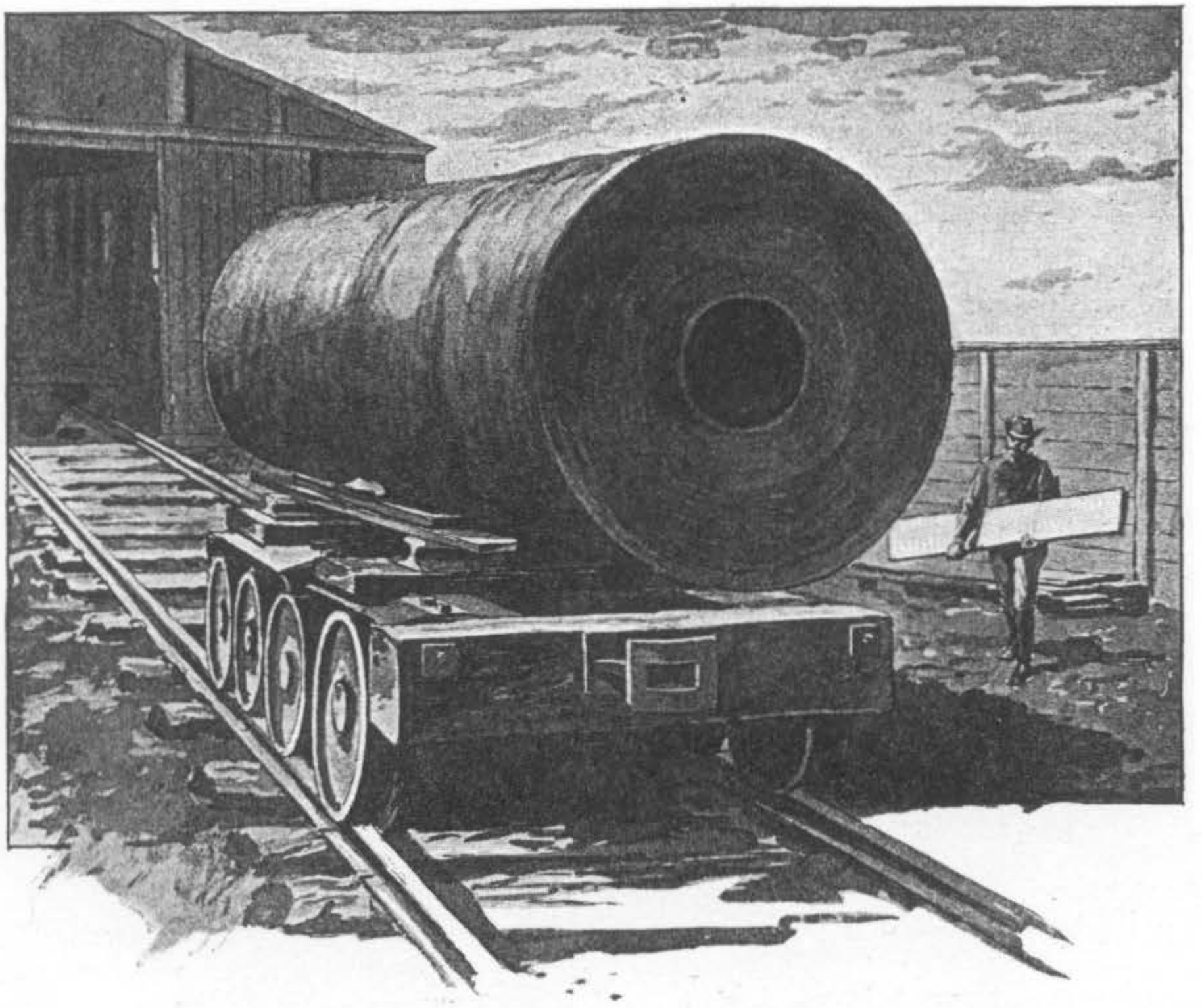
Balancing the Revolving Field.

The longitudinal and transverse sections of the power house and wheel-pit, showing turbines, shafts and generators in place, reproduced on pages 262 and 263, illustrate the relation of these elements in the plant more graphically and exactly than is possible in a mere verbal description. The turbines are so designed that they and the shaft and the revolving part of the dynamo above them are supported upon the water passing through the wheels. By calculation, the force of the water tending to lift the shaft and generator varies from about 149,000 lbs. to about 155,000 lbs., depending upon the amount of water passing through the turbines, which, in turn, depends upon the amount of current which the generator is delivering to the circuits. The weight of the shaft and revolving part of the generator is very nearly 152,000 lbs. The difference between this weight and the upward

thrust of the water is taken care of by the thrust bearing located on the third gallery above the turbines. When the upward thrust of the water exceeds 152,000 lbs., the collars on the steel shaft are pressed upward against the grooves in the bearing in which they revolve, and when the upward pressure is less than 152,000 lbs. the collars are drawn downward by gravity against the grooves in the bearing. This pressure, however, whether upward or downward, in direction, never exceeds 3500 lbs. in amount, and this, of course, puts very little work upon the bearing.

The entire revolving parts of each unit of the plant, therefore, consisting of the turbines, the dynamo field and the shaft, 166 feet in length, constitute a huge top, the weight of which is practically carried upon the water in the turbines. The bearings on the first and second galleries of the wheel pit, and the upper and lower bearings in the generator, are simply guides for the shaft, to keep it in a vertical position, while the thrust bearing on the third gallery acts as a guide, and also carries the relatively small difference between the weight of the revolving mechanism and the upward thrust of the water. The turbines, shaft, and generator field revolve at the high speed of 250 revolutions per minute, and it is obvious that all of the revolving parts, especially the heavy generator field, weighing about 70,000 lbs. and measuring nearly 12 feet in diameter, must be balanced with the utmost accuracy to prevent vibrations which might become dangerous.

The method employed in balancing the revolving element of the generators is illustrated on page 278. A special shaft was placed in the bearings of the machine, and supported at its lower end by a thrust bearing into which oil was pumped at a pressure of about 1000 lbs. per sq. in. This pressure was sufficient to lift the weight of the revolving parts,



COMPRESSED STEEL INGOT WITH HOLE THROUGH CENTER, PREPARATORY TO FORGING.

and the collars on the shaft were separated from the grooves of the thrust bearing by a thin layer or film of oil. A small piece of tool steel was set into the upper end of the shaft, a half sphere or cup being cut in its upper surface, and in this was placed a tempered steel ball,



A FIELD POLE WITH WINDING IN PLACE.
WEIGHT, 2800 LBS.

⅜ in. in diameter. A large eyebolt with a similar piece of tool steel, having in its lower surface a cup bearing similar to that at the top of the shaft, was secured in the tapered bearing of the umbrella-shaped driver, to the periphery of which the field ring is bolted. The entire weight of the driver and the ring was thus supported upon the small steel ball.

A casting, clamped to the shaft, served to rotate the driver and ring with the shaft. A section of this casting and of one of the ribs of the driver is shown in the illustration. The steel ball, as will be noted, was placed a very short distance above the centre of gravity of the field and driver, and under these conditions, the driver and ring being free to rock while rotated, a defect in balance was quickly shown. As a matter of fact, in the case of the first generator the driver at first assumed the position indicated by the dotted lines. This was corrected by riveting to the driver a wrought iron plate, the weight of this plate and the distance from the axle of rotation being experimentally determined to obtain not only exact static balance, but also exact running balance.

The driver was first balanced in this manner, independently. The ring was then bolted to the driver, and the two were balanced together as shown in the illustration. It was unnecessary to balance the combination of the driver, ring and field poles since the field poles and bobbins were separately weighed, and their weights adjusted to exact equality, while the positions in which they are bolted to the ring are exactly symmetrical with reference to each other and to the axis of rotation.

Organization of Apparatus in the Power House.

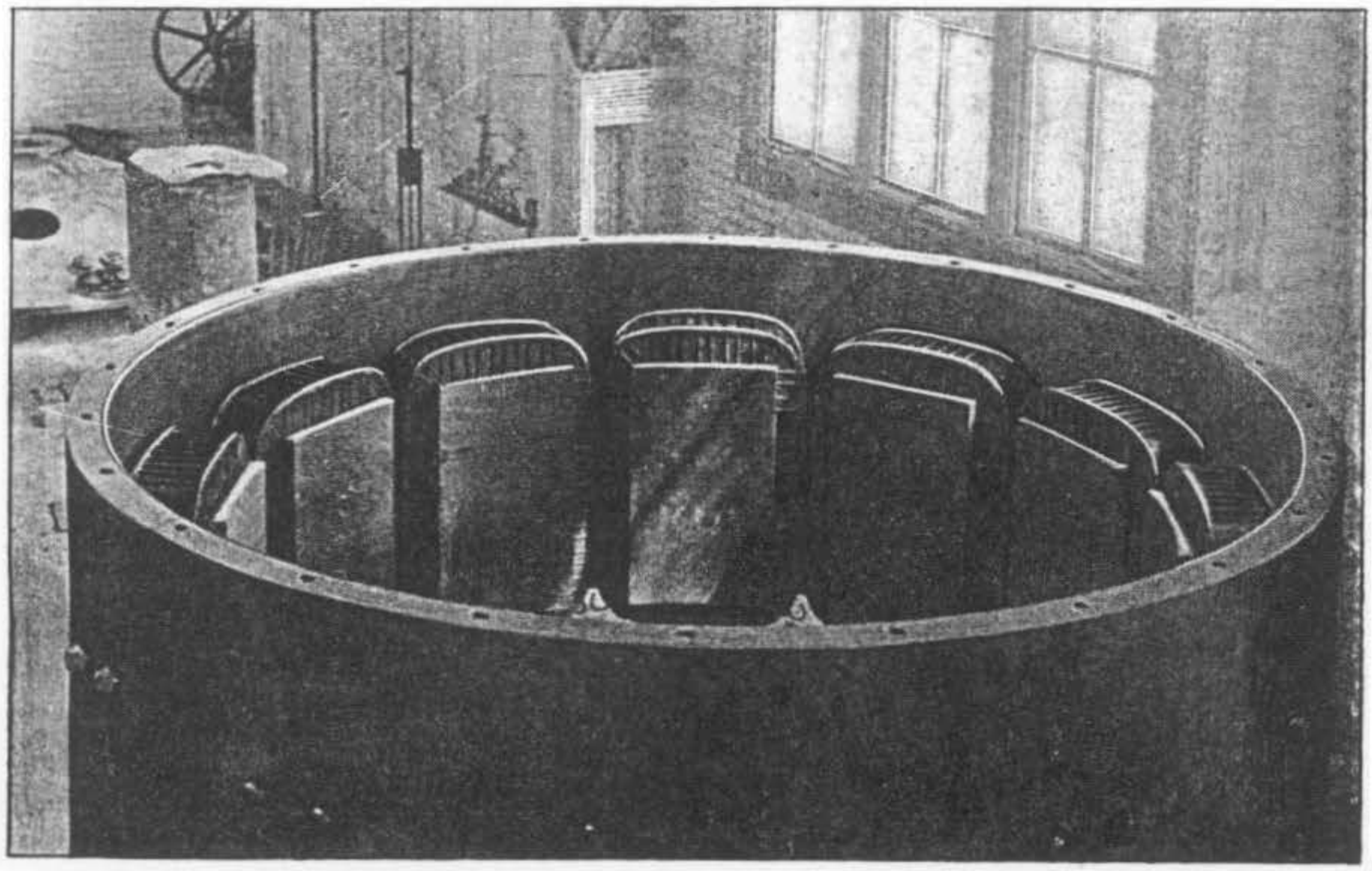
The organization of apparatus constituting the system adopted, that is,



A FIELD POLE.

the inter-relation and the functions of the generators, step-up transformers, step-down transformers, motors, commutating machines and other appa-

ratus, has been described in a general way in the early part of this article. I have also explained the construction of the generators,—the most important unit of apparatus in the plant. It remains now to describe the means adopted for controlling the heavy currents delivered by the generators, and for delivering these currents to the supply circuits which convey them from the power house to the premises of the users of power.



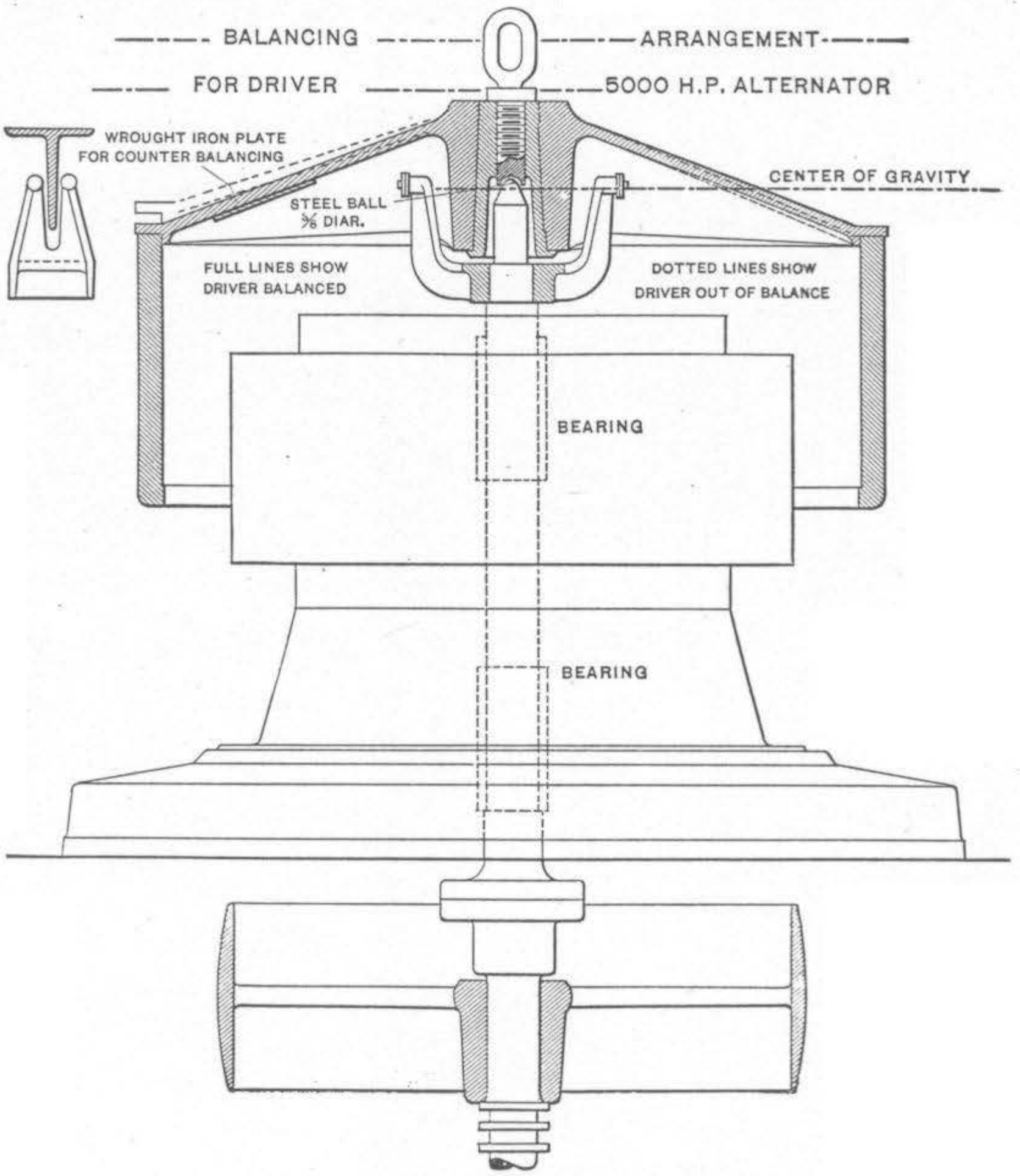
FIELD RING WITH POLES AND BOBBINS IN PLACE.

In deciding upon a plan of station organization, we face, at the outstart, two very serious conditions :—First :—The forces with which we are dealing are, in amount, far beyond the range of experience. Second :—The plan adopted must be capable of almost indefinite extension without radical modification, and without involving loss of symmetry.

We are dealing with energy in units of 5000 horse-power, developed under conditions which are, in many respects, without precedent ; and while, at the outstart, there are to be installed but three generators, the fact must be kept in mind that others will be added to the installation, and that, when the number of generators shall have increased from three to thirty or twice thirty, the organization and means provided for operating them must still be symmetrical and consistent in all its parts. The plan adopted contemplates an arrangement in groups of five generators each. The switching and regulating apparatus, and the indicating and measuring instruments, are concentrated in a swithboard centrally located with reference to each group. Provision is made for cross-connecting the several groups to be ultimately installed in this power house and in other power houses which may be erected on both the American and Canadian sides of the river in order that continuity of service may be doubly assured.

The switchboard is the centre from which the brain and hand of the operator control the mighty forces of Nature which are here compelled to do work,—it is the bridge of the ship. From it, imprisoned energy, aggregating 25,000 horse-power,—electric energy, eager to escape, seeking for the smallest pinhole in insulation, and concentrating instantly at that pinhole, if

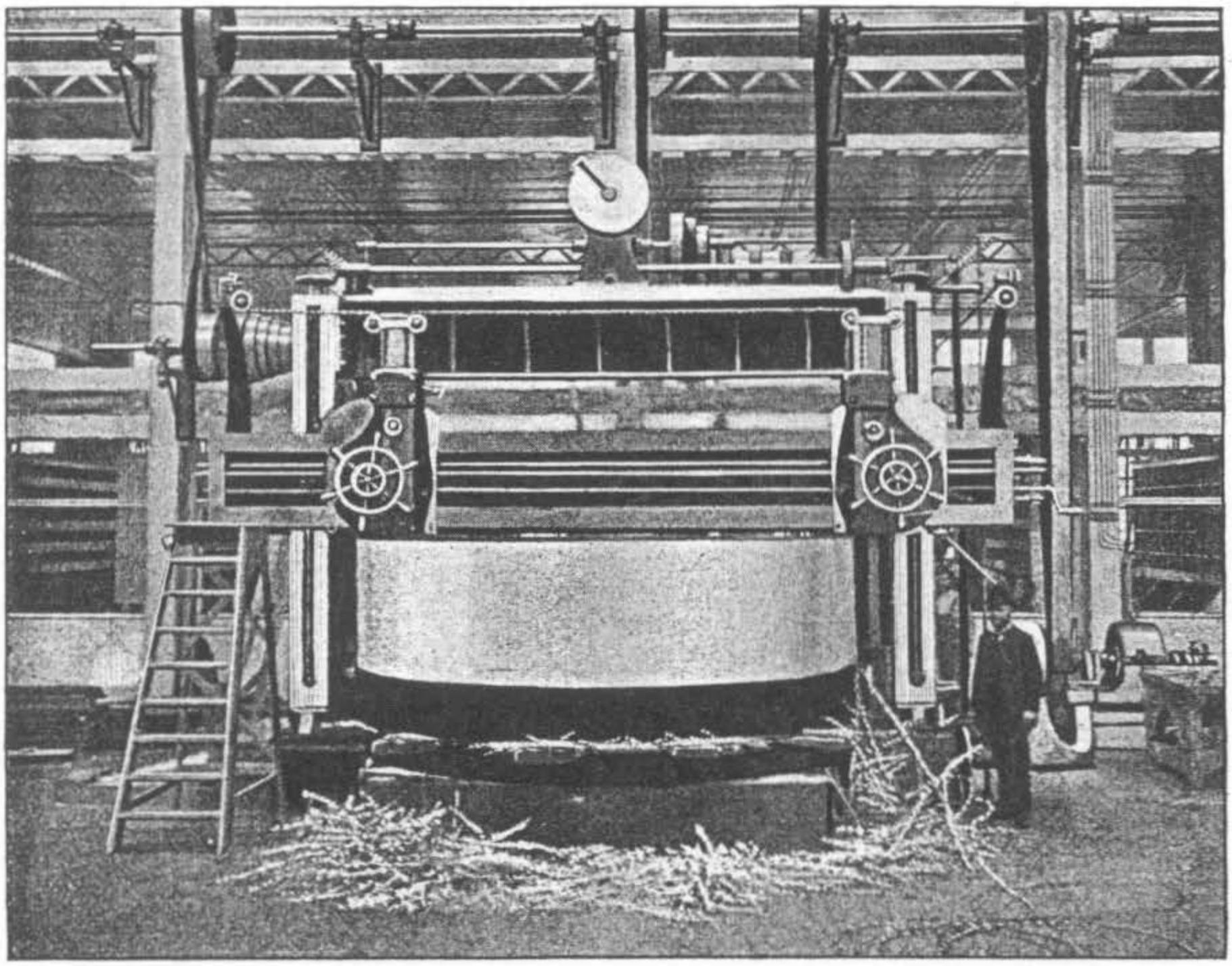
found,—must be controlled, combined, subdivided and directed. It is evidently desirable to operate the generators in parallel, this method tending to improve regulation of speed and potential, insuring continuity in the delivery of current to the users of power, and house, and the latter referring to the service which will supply consumers in Buffalo and other distant places. This consideration makes it probable that it will prove convenient and desirable to operate the generators in two sets, for the following reason :—



METHOD OF BALANCING THE DRIVER AND FIELD RING.

minimizing the necessity of opening switches conveying heavy currents of high potential in circuits of very considerable inductance and capacity. But it is also evident that the service will, in the near future, divide itself into two classes, which we may call "local service" and "long-distance service," the former referring to the service which will supply consumers within a radius of a few miles from the power

Distribution of electricity at constant potential is strictly analogous to the methods commonly employed in supplying gas and water. Each consumer has a small, independent circuit through which he draws his supply from the distributing mains, and he may open or close this circuit without in any way interfering with the supply to his neighbours, provided the potential or pressure in the network of mains is kept

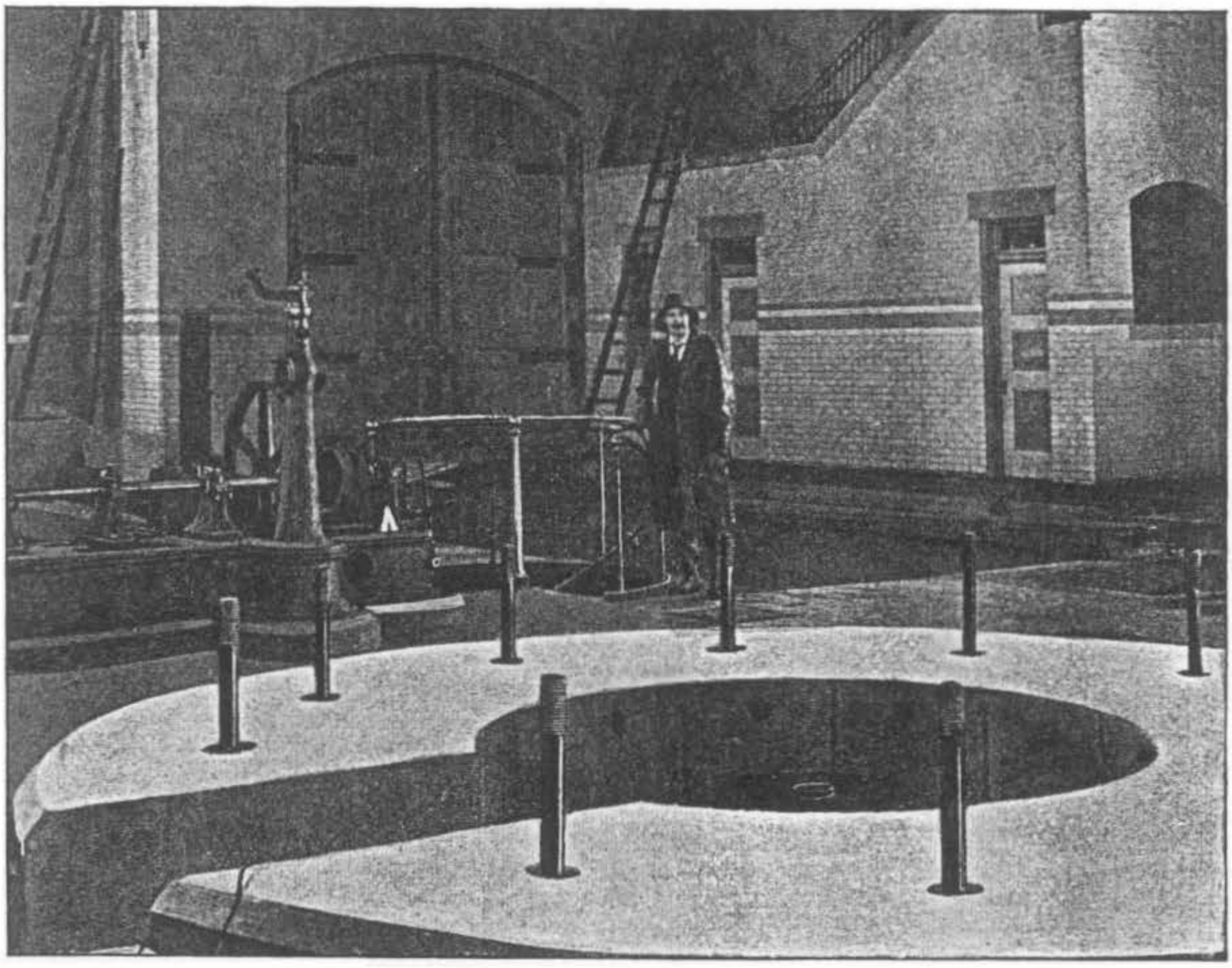


TURNING THE FIELD RING IN THE WESTINGHOUSE SHOPS.

constant. For satisfactory service, this last provision is a necessity,—the potential in the distributing mains must be constant. The local circuits at Niagara are supplied direct from the power house, through feeder or supply circuits of comparatively short length, and, consequently, the loss of potential, or drop, as it is technically called, will, in these circuits, not exceed one or two per cent.

The distributing mains in Buffalo, however, will be necessarily supplied from feeders extending from the power house, a distance of about twenty miles, and in these feeders, unless a very high potential be used, the drop will vary from a maximum of, say, five or possibly ten per cent., depending upon the amount of copper in the circuits, down to one-half, one-fourth or one-tenth of these percentages, depending upon whether the current transmitted along the feeders is the full load current for which these feeders are designed, or one-half, one-fourth or one-tenth of the full load current. It follows that at certain times during each day the potential delivered to the long-distance feeders must exceed that delivered to the local feeders by a not inconsiderable percentage, and the readiest means to meet this condition is to operate the generators in two sets or groups, the units constituting each set working in parallel.

When two or more generators work "in parallel," they are so connected that their currents are delivered to a set of large conductors, called "bus bars," just as two engines, belted to the same line shaft, deliver the power which they develop to that shaft. By suitable devices, such as friction clutches or fast and loose pulleys, either engine may be put into service, or shut down without stopping the line shaft; and, in a similar manner, any electric generator of a group may be made to add its current to that of another generator or group operating in parallel with it, or may be shut down without interfering with the



ONE OF THE GENERATOR FOUNDATIONS.

continuity of the supply of energy delivered by the group.

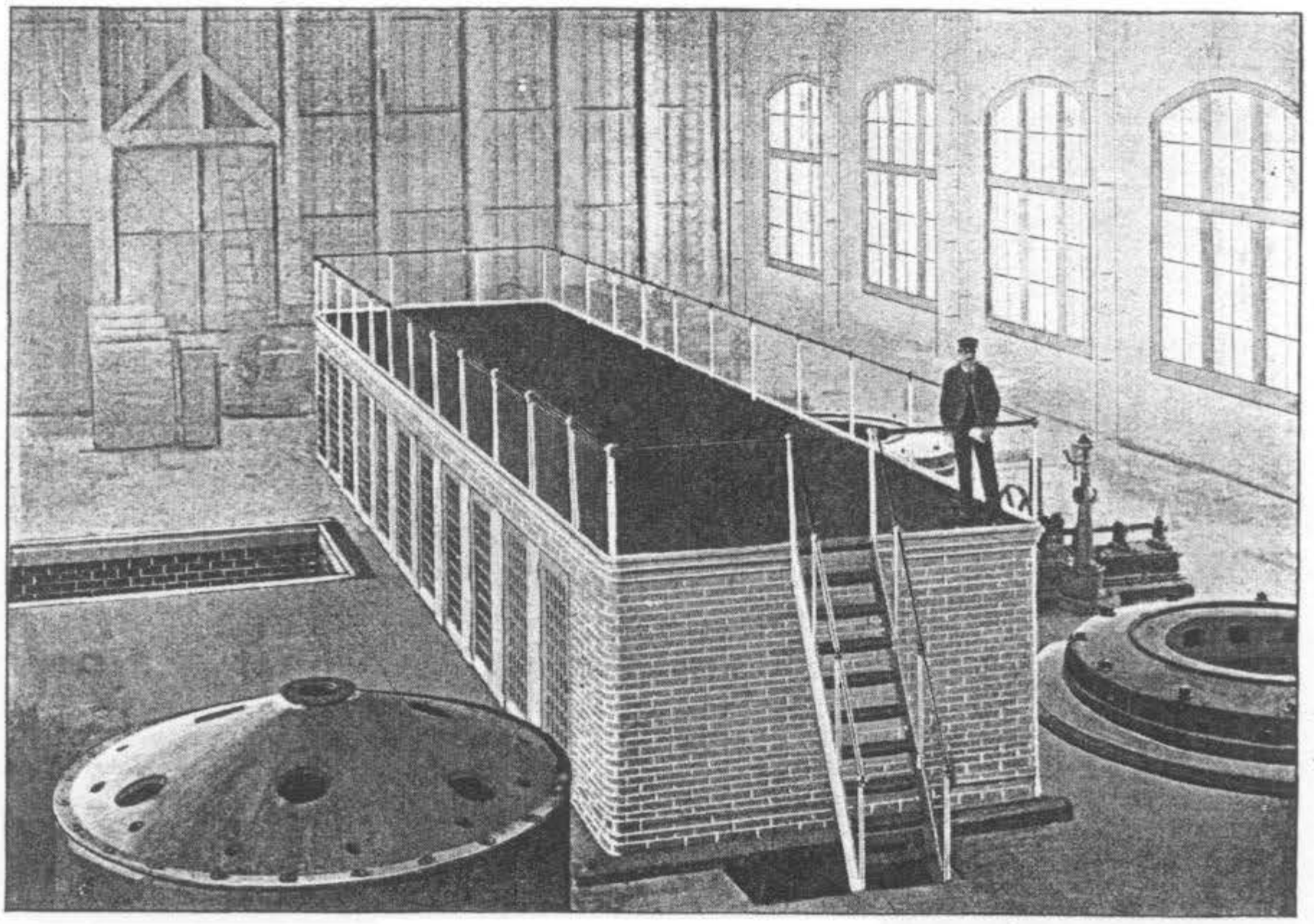
As an alternative to the plan of operating the generators in two groups, they may all be operated in one group, provision being made for adjusting the potential in either the local mains at Niagara, or the distant mains in Buffalo, by special regulating devices. For a limited number of generators this latter plan offers some advantages, but, looking forward to the time when a dozen or a score of generators will be installed, the method of operating in two groups appears preferable.

In the case of transmission to places more remote than Buffalo, it will be necessary to adopt special means for regulating potential in the distributing mains, at least until the time when improved methods of insulating circuits shall make it practicable to employ very high potentials. When that time comes, the drop in the circuits between the power house and the city of Buffalo will become so small that we may treat the Buffalo feeders as local circuits and can supply them with current from the same bus bars that are used in supplying power in the immediate vicinity of the power house; and when the practicability of commercially employing these very high patentials, *e. g.* 25,000 or even 50.000 volts, is demonstrated, transmission to places more distant than Buffalo will naturally be undertaken. Here again the second set of bus bars will be useful. The diagram on page 282 illustrates the connections of generators, generator switches, bus bars, feeder switches and local and long-distance feeder or supply circuits. To avoid complication but two generators and one long-distance and one local feeder are shown. The currents are conveyed from the generators 1 and 2, to the generator switches, S, S″, through insulated cables, each made up of 427 tinned wires. The aggregate section of copper in each cable is 1 sq. in. Through the generator switches the currents from the respective generators pass at the

will of the engineer in charge, to either of the two sets of bus bars A, B. Each set consists of four thoroughly insulated copper conductors, the construction of which will be again referred to. The switches are operated by compressed air, controlled by levers mounted on iron stands placed upon the platform above the switchboard structure within which the switches are located. By them any one of the generators, or any combination of the five generators constituting the group, may be connected to either set of bus bars.

Each switch has two separate and independent air cylinders, by which the two ends of the switch are independently controlled. The construction of the switch is shown in the illustration on page 292. To charge the bus bars A with current from the dynamo, 1, the switch is closed at one end, establishing connections between four points in the horizontal row of terminals, marked *a*, and the four points *b*. To connect the dynamo to the bus bars B, the switch is closed at the other end, establishing metallic connection between the four terminals in the row *c*, and the four terminals in the row *d*. If the two sets of bus bars are to be charged with the same potential we may supply both from the generator, 1, by closing both ends of the switch simultaneously. Similar connections are, of course, possible in the case of the other generators and the bus bars.

The feeder switch S′ is similar in



THE SWITCHBOARD STRUCTURE.

construction to the dynamo switches, but the connections are different. So far as the feeders are concerned, it is not necessary that we should be able to connect them to more than one set of bus bars. Until long-distance transmission is begun, either set of bus bars may be used, or both may be charged from the same generator or generators, in which case they will, of course, be charged with the same potential. When additional generators are installed, and long-distance as well as local service is undertaken, as I have said, it will probably be advantageous to operate the

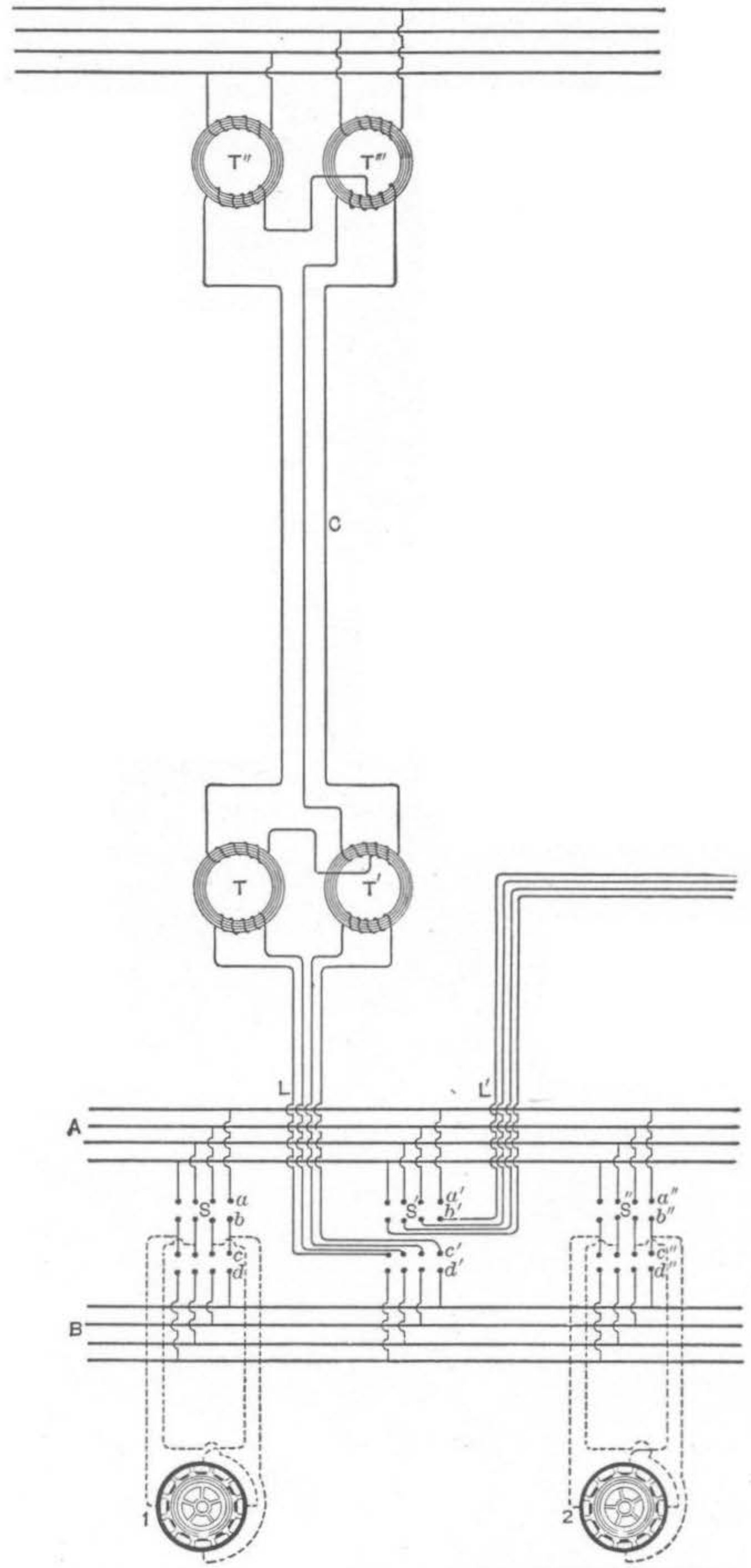
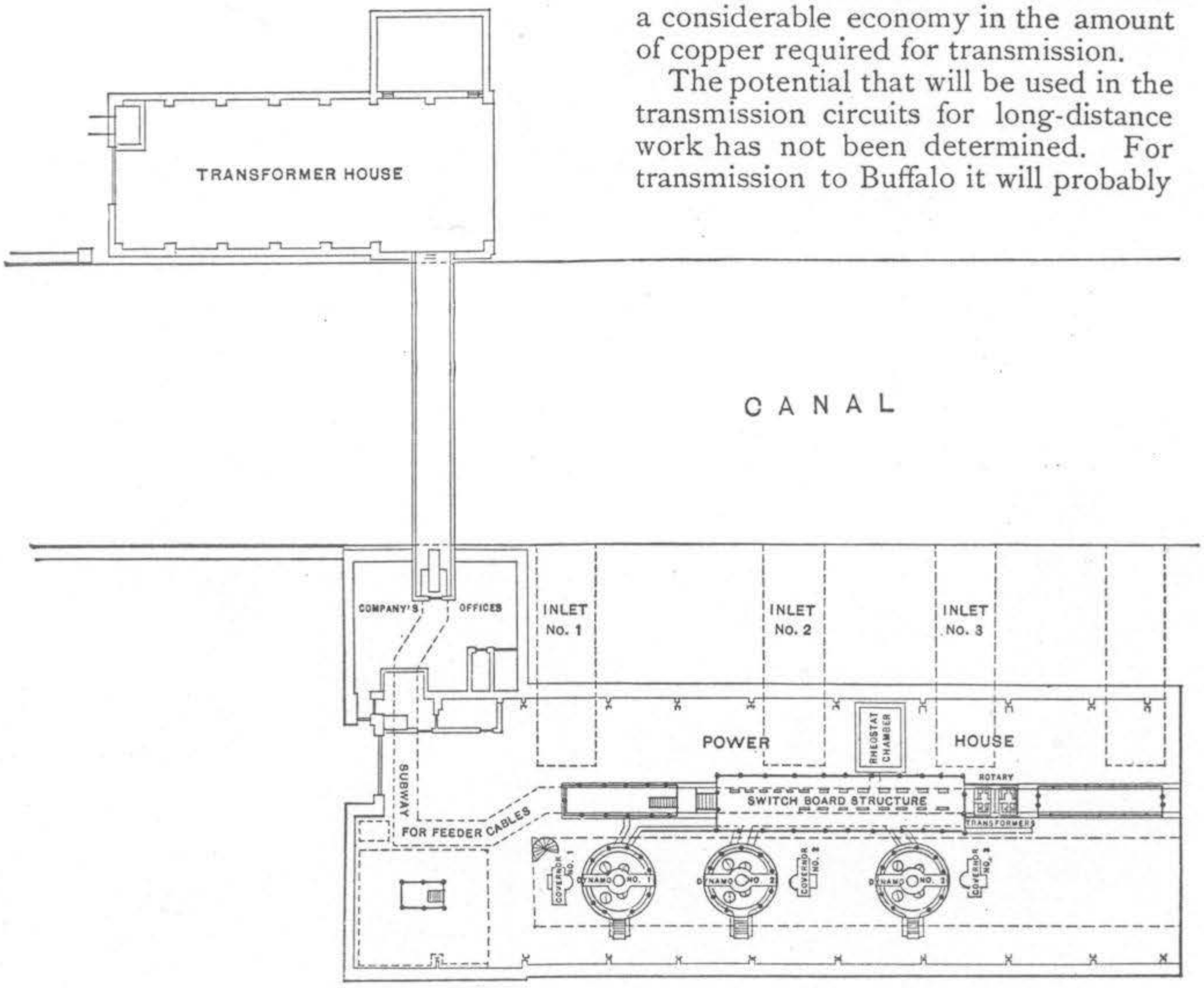


DIAGRAM SHOWING THE CONNECTIONS OF THE GENERATORS WITH LOCAL AND LONG-DISTANCE FEEDERS.

generators in two sets to permit adjustment of potential to compensate for losses in transmission. The respective local and long-distance supply circuits will then be simply arranged for connection through their switches to the local or long-distance bus bars, as desired.

In the diagram on page 282, L represents a supply circuit used for long-distance service, and L′ represents a similar circuit used for local service. In the diagram of the long-distance circuit, T and T′ are step-up transformers, used to increase the potential for transmission, while T″ and T‴ are step-down transformers, located at the distant end of the transmission circuit, for example, at Buffalo or Tonawanda. In the general diagram on page 256 is illustrated the arrangement of circuits in the case of simple two-phase transmission by four wires. The diagram on page 282 shows an arrangement of transformers by which the two-phase currents, delivered by the generators, are changed to three-phase currents in the transmitting circuits, and then changed back to two-phase currents in the local distributing circuits at a distance. This method effects a considerable economy in the amount of copper required for transmission.

The potential that will be used in the transmission circuits for long-distance work has not been determined. For transmission to Buffalo it will probably not be less than 10,000 volts, and not more than 25,000 volts. For transmission to greater distances, still higher potentials are contemplated.



PLAN OF POWER AND TRANSFORMER HOUSES.

The illustration on page 281 shows the structure erected for the switchboard apparatus. It is of white enameled brick, and is 57 ft. 10 in. long, 13 ft. wide and a little less than 8 ft. in height. It is erected directly over the sub-way, as shown in the floor plan on page 283. The top of the structure is of slate sup-

ported upon iron I-beams, and the platform thus formed is surrounded by a neat brass hand-rail. The sub-way beneath the switchboard is spanned at suitable distances by iron I-beams, to which the dynamo and feeder switches are bolted in place. The cables passing from the generators through ducts beneath the floor line are connected to the generator switches, while the outgoing cables, constituting the feeder or supply circuits, drop directly from the feeder switches into the subway. Iron standards are secured to each side of the subway by expansion bolts. They are placed at intervals of about 4 ft., and adjustable iron brackets set into these standards support the lead-sheathed cables passing through the sub-way and bridge to the transformer house on the east bank of the canal.

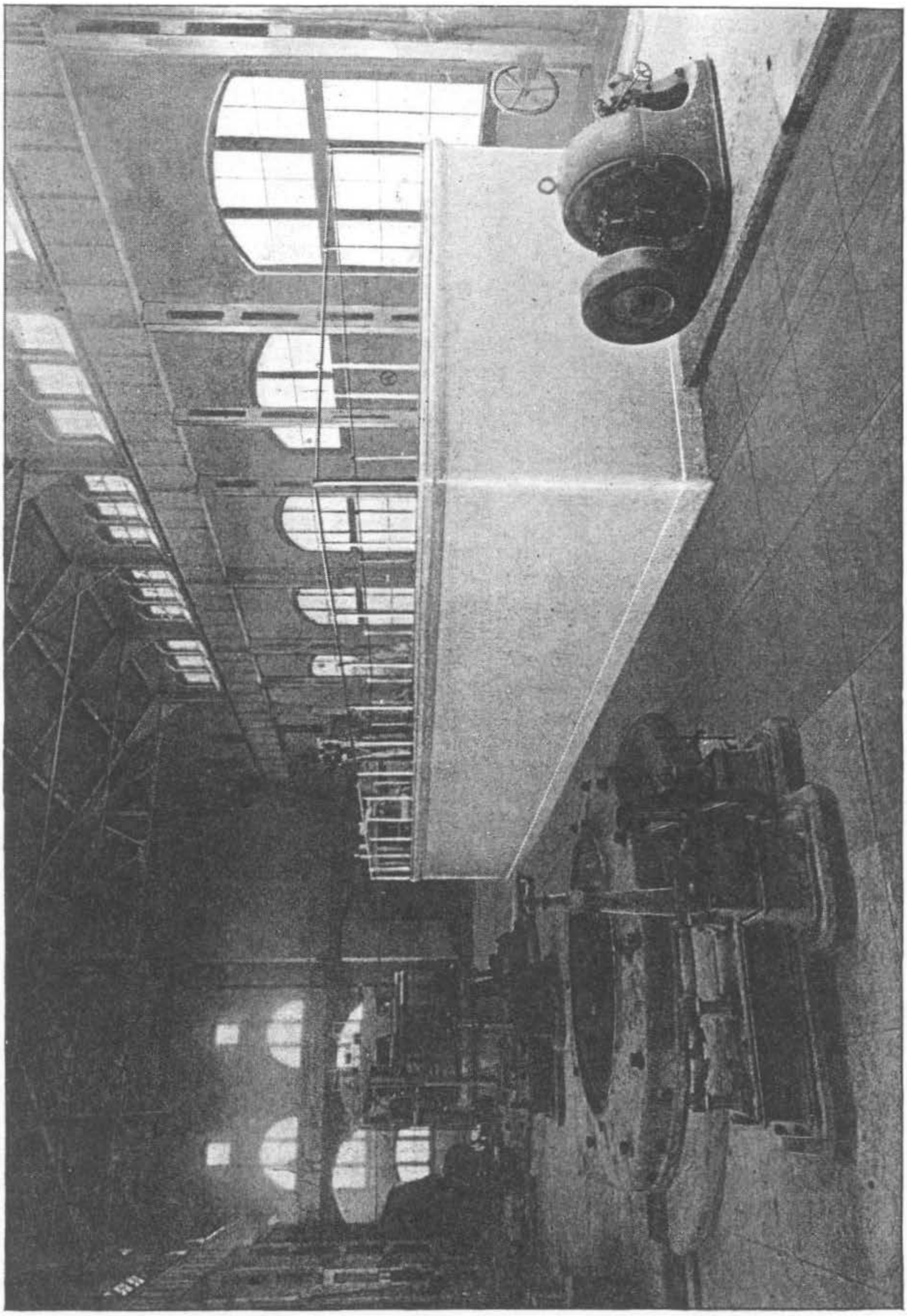
The drawing on page 283, showing the floor plan of the power house, bridge and the transformer house, will make clear the position of the switchboard structure with reference to the first three generators and the sub-way. Additional generators will, in due time, be erected in line beyond the generator marked "Dynamo, No. 3," and the switchboard structure is designed to accommodate all instruments and switches needed in connection with the first five generators.

The organization of the switchboard apparatus and the general features of the construction of the essential elements will be best understood by reference to the illustration on page 286, which is reproduced from the official drawing. The upper part of the illustration at the reader's right hand is a front elevation of the stands which carry the instruments for the several generators and for the exciters, and also shows one of the lever stands for the feeder circuits. Beneath the floor line of the switchboard platform is seen one set of bus bars in connection with an end elevation of the generator and feeder switches. A plan of the switchboard platform is also given in the illustration on page 288, a part of the platform being cut away to show a plan of one generator switch and one feeder switch. On page 286, again, is shown a plan of the rheostat chamber and sub-way for the cables, and just above this, a section through the switchboard, sub-way and rheostat chamber, at right angles to the direction of the sub-way, is given.

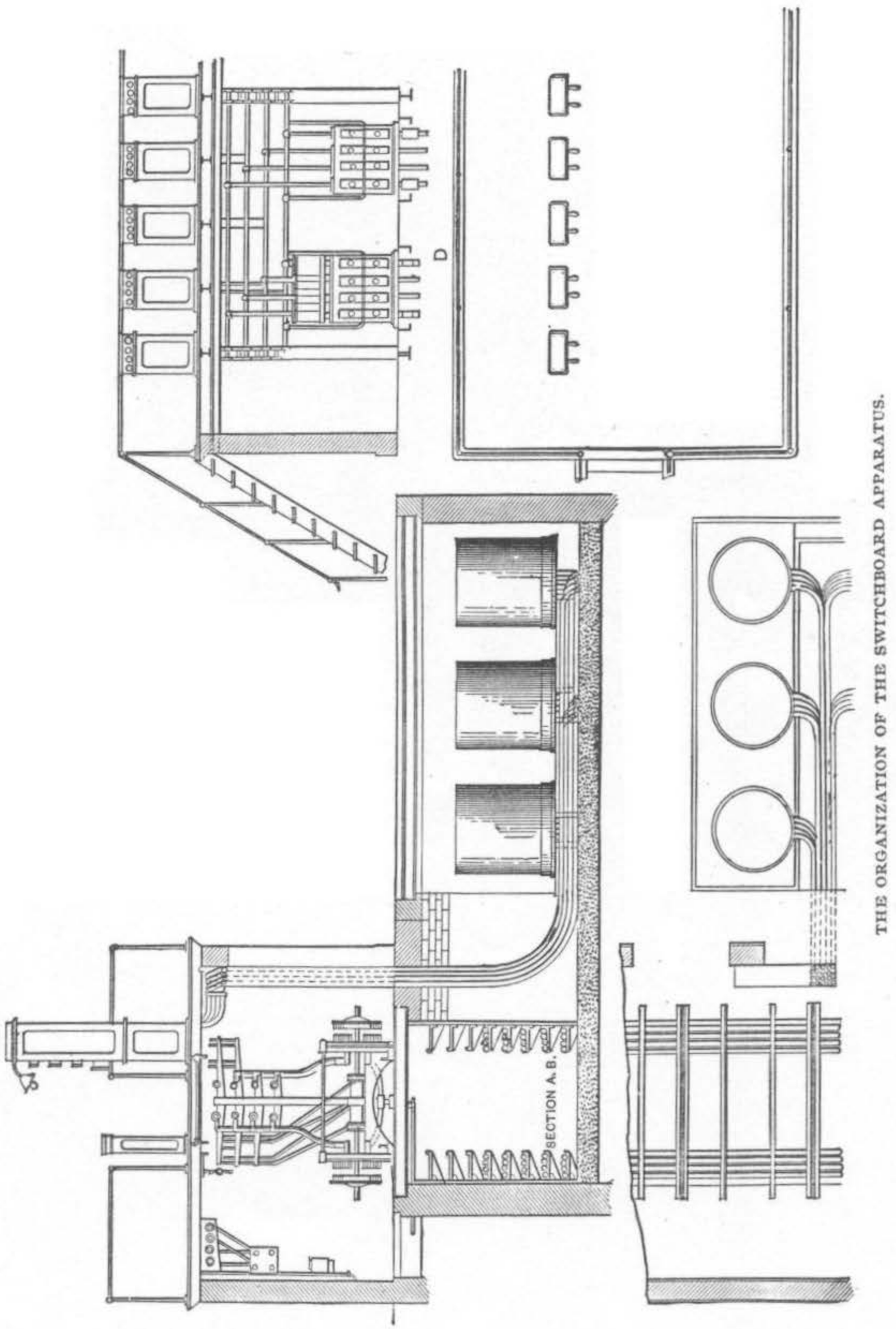
The essential elements of the switchboard apparatus are,—the generator and feeder switches, the bus bars, the switching and safety devices for the exciting currents, the rheostats for controlling the generator fields, and the indicating and measuring instruments. As shown by the plans, the switches and bus bars are located within the switchboard structure. Upon the switchboard platform are erected the instrument stands, one for each generator, two for the rotary transformers, and one for the engine-driven generator, temporarily used as an exciter, and in front of each instrument stand is placed a cast-iron stand, about 30 inches in height, carrying the levers which control the admission of air to the switch cylinders, and a wheel by means of which the rheostats are controlled.

Each of the lever stands used for controlling the large generator switches carries also levers for opening and closing the field circuit of the corresponding generator, and a hand wheel by which the rheostat resistance in the field of the generator is adjusted. The rheostats are located in a special chamber below the floor line of power house, the face-plates being located in the bases of the instrument stands. Connection between the face-plates and resistance coils of the rheostats is secured by insulated cables of suitable section. The compressed air used in operating the switches comes from a compressor direct, driven by a Worthington water motor. This compressor is located at the bottom of the wheel pit, and supplies air to a large cylindrical reservoir from which pipes are led to the various switches. The pressure used is 125 pounds per square inch.

Engineers, not familiar with the possibilities of electricity, will be impressed by the fact that the currents actually measured are not the heavy currents traversing the cables within the switch-



ONE END OF THE POWER HOUSE.



THE ORGANIZATION OF THE SWITCHBOARD APPARATUS.

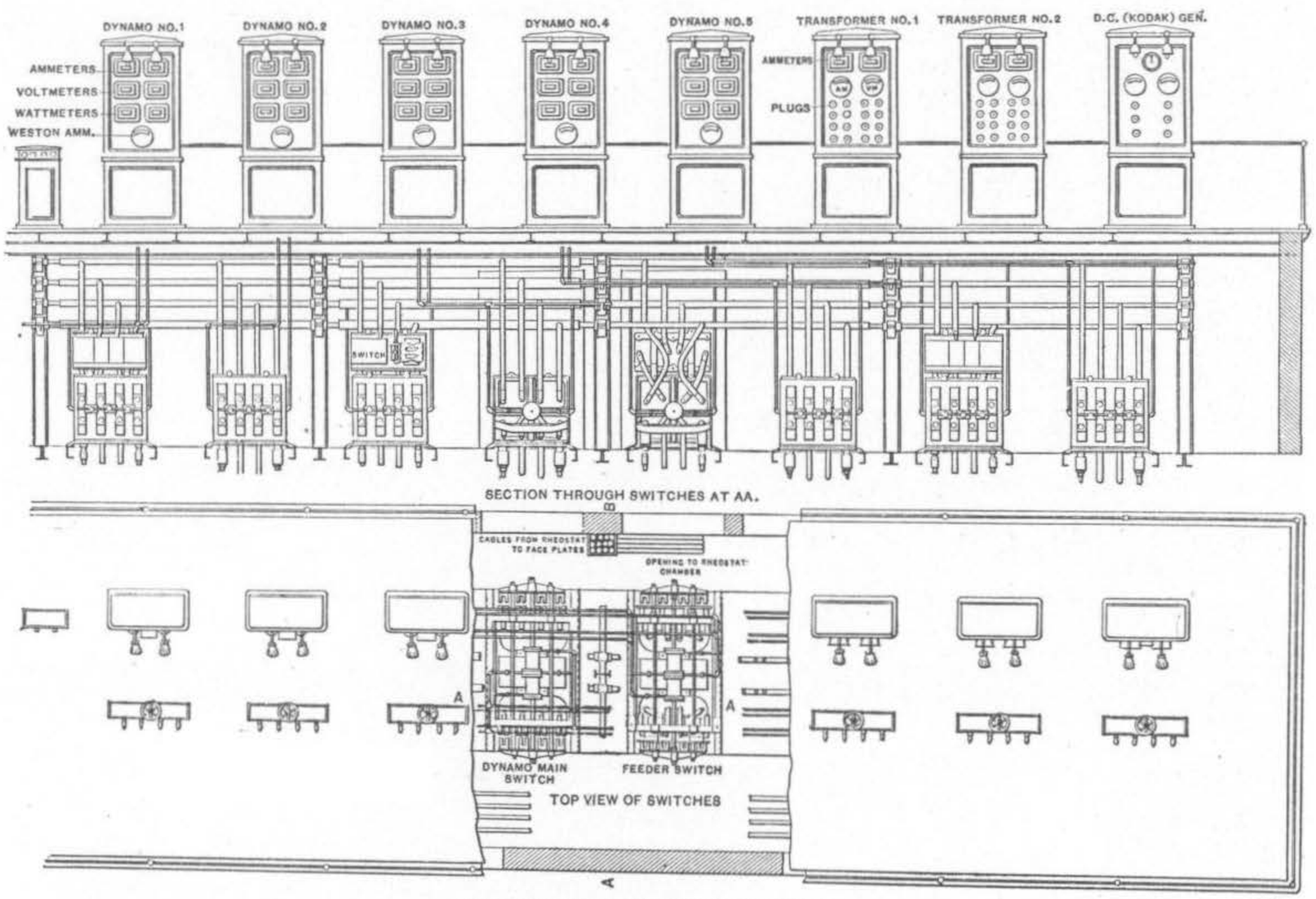
board structure, but are derived currents, bearing a known relation to the heavy currents delivered by the generators. They are small in quantity and absolutely harmless. The operator, standing upon the switchboard platform, cannot possibly touch a circuit which is in the slightest degree dangerous. The currents measured are obtained by means of transformers located inside the switchboard structure, the ratio of their winding being such that for every 50 ampères flowing in the main circuit, a current of 1 ampère is supplied from the secondary of the transformer to the measuring instruments. Currents to the respective voltmeters are supplied from transformers, the primaries of which are connected across the generator circuits. For the wattmeters both series and shunt connections from the generator circuits are needed, and these are obtained from the transformers used for the voltmeters and ammeters.

To measure energy, current and potential in each phase of each generator, two converters, an indicating wattmeter, an ammeter and a voltmeter are employed. The energy required by these devices amounts, as a maximum, to about 30 watts—that is, $\frac{1}{25}$ horse-power. It is an extraordinary illustration of the facility with which electricity is accurately measured that we should be able thus to determine energy varying from 25 horse-power to 2500 horse-power by means of measuring devices, accurate throughout their range within one per cent., and requiring for their operation not more than $\frac{1}{30}$ horse-power.

The instrument stands are boxes or cabinets, constructed of iron and marble, the front of each, above the pedestal, being formed of a single slab of polished Italian marble, 1¾ inches thick, 30 inches in width and 45 inches in height. Each stand occupies a floor space of 38 inches by 20 inches and is 7 feet in height. Sliding doors at the back give access to the measuring instruments. The marble front of the stand is pierced by six rectangular openings, and the instruments are secured to the marble in such a way that the front of each, with its scale and index, projects through the marble to the front of the stand.

The engraving on page 289 illustrates one of the alternating current ammeters, as viewed from the front. The indicating wattmeter and the voltmeter are similar in appearance. The fronts are finished in oxidised brass. These instruments, and the integrating wattmeters, used in connection with feeder circuits (not located upon the switchboard platform), comprise a remarkable group of measuring instruments recently invented and designed by Mr. Oliver B. Shallenberger, Consulting Electrician of the Westinghouse Company. As they were primarily designed with special reference to the Niagara installation, they are designated the "Niagara type" by the Westinghouse Company. Their sphere of usefulness, however, will be as wide as the applications of alternating currents. They depend for their action upon the induction of currents in a movable closed secondary circuit, and all operate to a certain extent upon the same general principles, specifically developed in each case to attain the object desired. They are extremely simple in construction, the parts are few and comparatively massive, and yet the instruments are capable of giving very accurate results. They are guaranteed by the Westinghouse Company to be correct within one per cent.

In each instrument a thin aluminium disc, stiffened by a flange around its edge, constitutes the movable element, in which eddy currents are induced by currents traversing coils placed above and below it. The relation of the induced currents in the disc and the inducing currents in the coils is such that the disc tends to rotate. In the wattmeter the tendency is proportional to a function of the energy traversing the inducing circuits, and these currents come from a converter located beneath the platform, and, in turn, are proportional to the energy in one of the gen-



SOME DETAILS OF THE SWITCHBOARD.

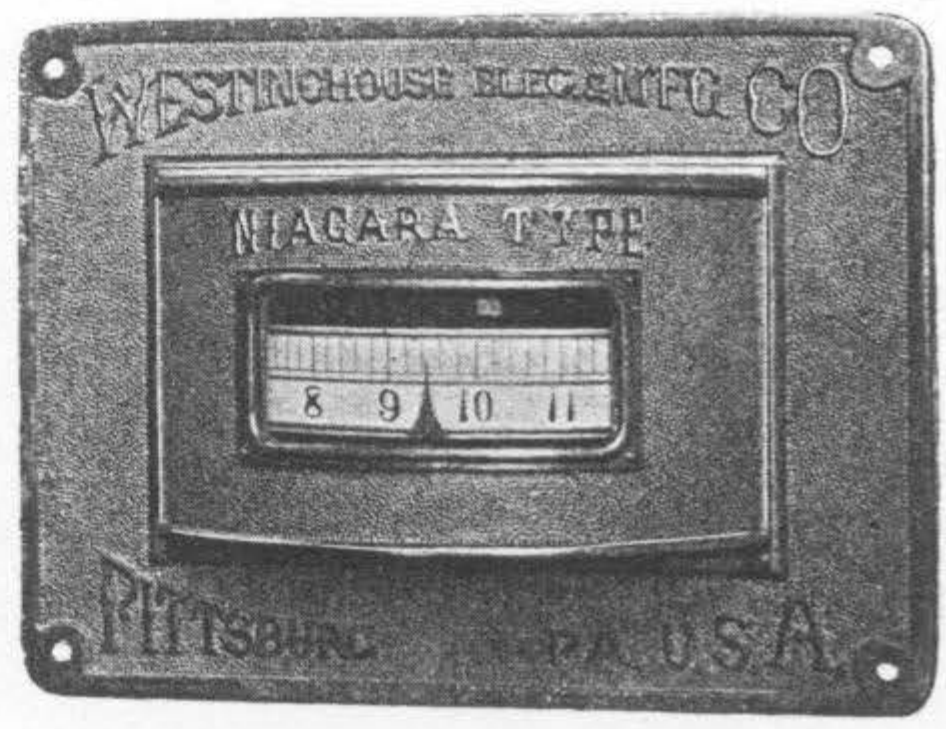
erator circuits, which is the energy to be measured. The tendency to rotate is resisted by a torsion spring, and the currents turn the disc, overcoming the resistance of the spring through a certain angle. This angle depends upon the relative strength of the twisting moment, due to the currents and the resisting force of the spring, and the position of the disc, with reference to its position when no current traverses the coils, becomes a measure of the energy. The scale is attached to the circumference of the disc, and depends from it much as the field ring of the generator depends from the driver. This scale is carried with the disc, from its zero position, through an angle depending upon the current measured, and the instrument being once carefully compared with a standard and the scale properly marked, the energy can be determined by taking the reading of this scale opposite the index, which is always fixed in position. In the illustration on this page the index will be seen in the centre of the rectangular glass window, and, immediately behind it, an arc of the circular scale.

The ammeter, which measures the strength of the current, and the voltmeter, which measures the potential, resemble the indicating wattmeter in the fact that they are based upon the same principles, and they are also similar in general features of construction. The methods employed to obtain the proper phase relations of the currents in the inducing circuits and in the disc are very ingenious and, to the electrician, interesting. But this is not the place to describe them in detail.

The ammeters, which measure the currents in the fields of the generators, were furnished by the Weston Instrument Company, of Newark, N. J., and are of their well-known type, in which the current actually measured by the instrument is that which flows through a circuit connected in shunt to a resistance which is placed in the circuit traversed by the current to be measured.

All of the currents measured by the instruments located in the instrument stand are supplied through insulated conductors of small section, which convey the small derived currents from converters or from the terminals of resistances placed beneath the switchboard platform. Each generator instrument stand carries, in addition to the instruments already described, a phase indicator, by means of which the attendant or the engineer in charge, who desires to connect a generator in parallel with another generator or group of generators, determines the proper time for closing the switch.

The instruments provided for the stands belonging to the rotary transformers used as exciters, are not the same as those provided for the generator instrument stands, and they also differ from the instruments provided for the stand belonging to the temporary engine-driven exciter. They comprise two Shallenberger alternating-current ammeters of the Niagara type and a direct-current ammeter and voltmeter made by the Weston Instrument Company. A number of plug contacts are provided, by means of which the ratio of conversion of the static transformers which supply current to the rotary transformers may be adjusted.



AN ALTERNATING CURRENT AMMETER, NIAGARA TYPE.

The construction of the bus bars is, in several respects, remarkable, the magnitude of the quantities dealt with again making it necessary to devise methods of construction outside the range of experience. As has been said, two sets of bus bars are provided, but it

is, of course, conceivable that under certain circumstances it may be desirable to cut one set out of service and control the output of five generators through the other set. By arranging the generator switches and feeder switches as shown in the illustration, in such a way that the former, through which current is delivered to the bus bars, alternate with the latter, through which current is drawn from the bus bars, the maximum current which it is necessary to convey through any section of the bus bars becomes that supplied by three generators. This is equivalent in each bar to about 3000 ampères, and, assuming a current density of 1000 ampères per sq. in., would require a section of about 3 sq. in. in the bus bar. The potential of the currents may be as high as 2400 volts.

A short-circuit might obviously be very dangerous, and this fact, in connection with the fact that at certain times the atmosphere of the power house is liable to carry a considerable amount of moisture, ready to be precipitated upon metallic surfaces, points to the desirability of insulating the bars. To insulate them in the most satisfactory manner, rounded surfaces are necessary, but in a round solid conductor, 3 square inches in section, nearly 2 inches in diameter, two other difficulties must be faced: First, the surface from which the heat, due to resistance, must be radiated, is small as compared with that obtained by using flat bars or straps of equal section; and, second, an alternating current in such a conductor will not distribute itself uniformly, but will seek the surface, leaving the copper at the centre relatively idle and ineffective.

These difficulties have been successfully overcome by the construction adopted. From the middle each bar tapers toward the ends. The middle section consists of a copper tube of about 3 inches outside diameter and 2 inches inside diameter. Into this, at either end is screwed a tube, the outside diameter of which is approximately 2 inches, while its inside diameter is about $1\frac{1}{8}$ in. Into the other ends of each of these tubes, in like manner, a copper rod $1\frac{1}{8}$ inch in diameter is screwed. The offsets or connections from which short lengths of cable convey current to or from the several switches, are clamped to the bar thus formed, all surfaces being rounded. The entire bar with offsets is then insulated with very high-class rubber insulation. These bars were constructed by the Brown & Sharpe Manufacturing Company, of Providence, R. I., U. S. A., according to the designs of the Westinghouse Company, and were insulated by the India Rubber and Gutta-Percha Insulating Company, of New York, the method employed being that covered by the Habirshaw patents. The insulation consists of alternate layers of pure Para gum and vulcanized rubber, two layers of each being used, and the outer layer of vulcanized rubber protected by a special braided covering chemically treated to make it non-combustible. Similar insulation is used for the cables between the generators and the switches and for the connections between the bus bars and switches.

A section of the Habirshaw cable is reproduced on the opposite page. The illustration is very nearly the exact size of the cable. The makers guarantee that the insulation of cables and bus bars, erected in place, shall stand an alternating current potential of 10,000 effective volts between copper and earth. Samples submitted and tested in the laboratory of the Westinghouse Company successfully resisted the application of potentials exceeding 40,000 volts.

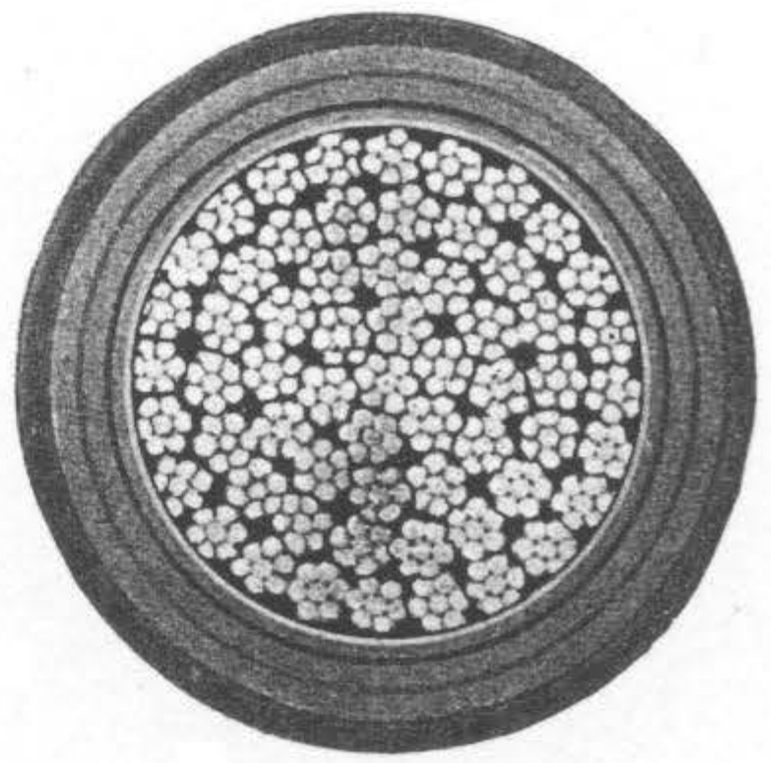
The calculated losses in a set of four bus bars conveying the full output of five generators, 25,000 electrical horse-power, are less than 10 horse-power. The radiating surface is, of course, considerably greater than it would be in the case of solid circular bars of equal section. At the ends of the bars, where the section is about 1 sq. in., the current is that coming from one generator only, and in a bar of this section the tendency of the current to seek the surface is negligible. In that part of the bar which has an outside diameter of 2 inches the current con-

veyed may be that coming from two generators, and the tendency to seek the surface would be appreciable in a solid circular conductor of equal section, while in that part of the bar which is 3 inches in diameter and which may be called upon to convey current from three dynamos, it would be very considerable. The use of the tubes instead of solid bars gets rid of the idle copper at the centre of the latter, and at the same time increases the ratio of radiating surface to section of conductor.

The construction of suitable switching devices for circuits conveying 5000 horse-power at a potential of 2000 volts is a serious problem. To be sure, the dynamos will be operated in parallel, and by proper adjustment of the field charges of the generators and the gates controlling the turbines, the current traversing the dynamo switch at the moment of opening or closing the circuit can be reduced within moderate limits. But there is always the chance that something may go wrong; the operative may make a mistake, or something else may happen, and it was, therefore, deemed necessary to construct a switch capable of opening without damage to itself or other apparatus, circuits conveying 5000 horse-power. The Westinghouse Company accordingly inaugurated a series of experiments, and detailed several expert engineers to thoroughly study the subject. The result of their work is illustrated on page 292. The opportunity has not yet been afforded to thoroughly test this switch in commercial service, but shop tests, carried out under conditions approximating to those which will be met in practical operation of the plant at Niagara, indicate that it is capable of switching very heavy currents without damage to itself, and without dangerous rise of potential.

Current for exciting the fields of the generators is obtained directly from rotary transformers, which, in turn, are supplied with alternating current from the generators, static transformers being interposed to reduce the potential. During the period of construction exciting current is also derived, when necessary, from a 75 kilowatt direct current generator driven direct by a Westinghouse compound engine. This generator and engine, together with the boiler plant for the latter, are located in a small temporary building at a distance of about 200 yards from the power house. The engraving on page 293 illustrates one of the two rotary transformers installed, and their location in the power house is indicated in the floor plan on page 283. These transformers are of 200 kilowatts output each.

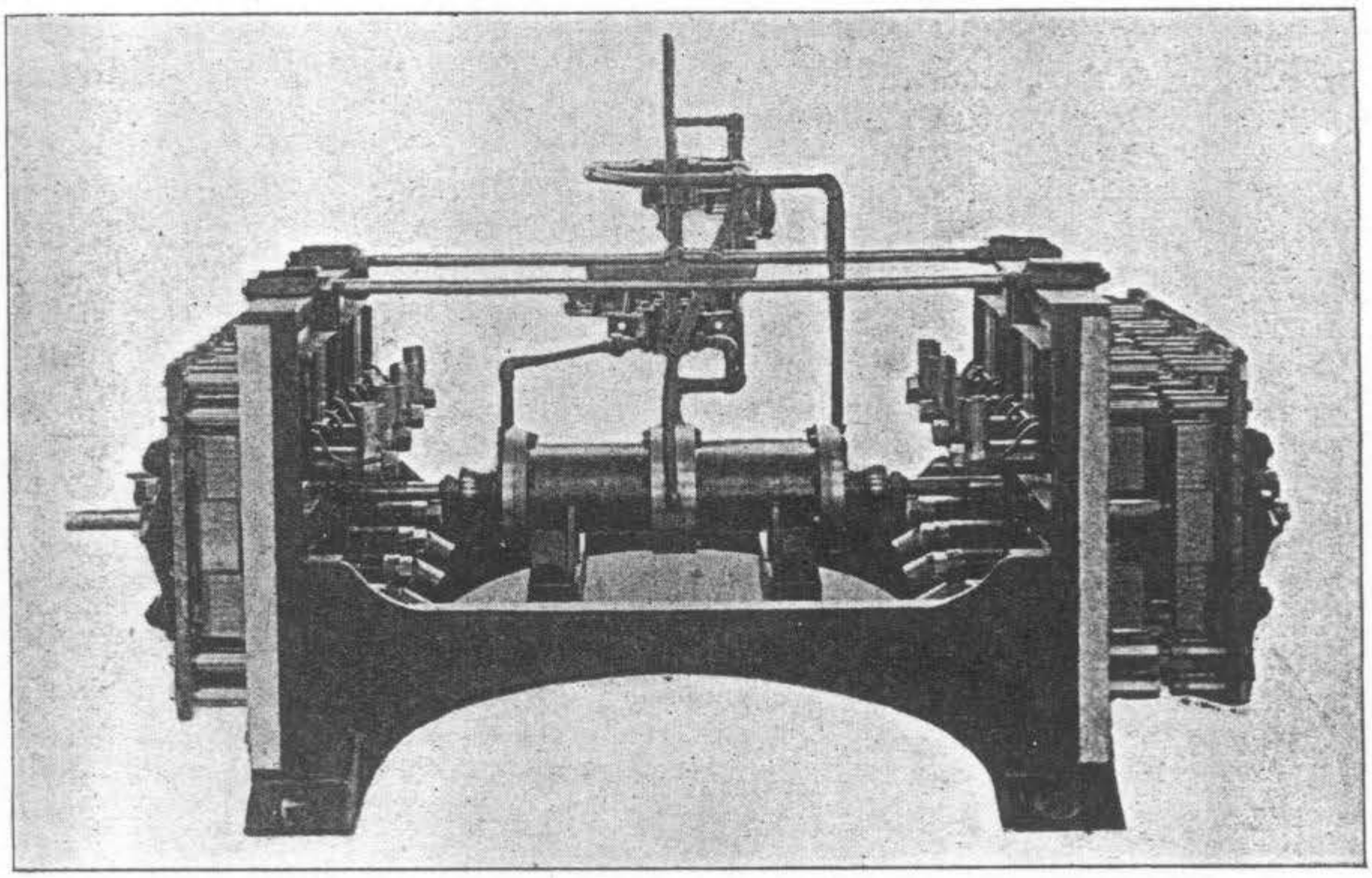
As will be seen in the illustration of the complete machine, on page 259, the shaft carries a commutator at one end of the armature and a four-ring collector at the opposite end. Alternating current, at about 125 volts potential, is delivered to the collector from the secondary terminals of the static transformers, one of which is illustrated on page 294. From the commutator end of the rotary transformer, direct current, at a potential approximating 175 volts, is delivered to the fields of the generators, the field rheostats being interposed in these circuits to permit adjustment of the current flowing in each field.



A SECTION OF THE HABIRSHAW CABLE.

The armature winding is of the closed circuit type, and each of the ring collectors is connected to a certain point in the same winding from which current is delivered to the commutator. The machine, in operation, runs as a

synchronous motor, driven by the two-phase alternating current, and delivers from the commutator continuous current, just as it would do were it driven as a generaror by a turbine or an engine. The fly-wheel at the end of the shaft is used to give steadiness of speed and to prevent what is sometimes called "pumping;" that is to say, unequal angular velocity at successive stages in a revolution of the armature, caused by the flow of idle current between the generator and the rotary transformer.



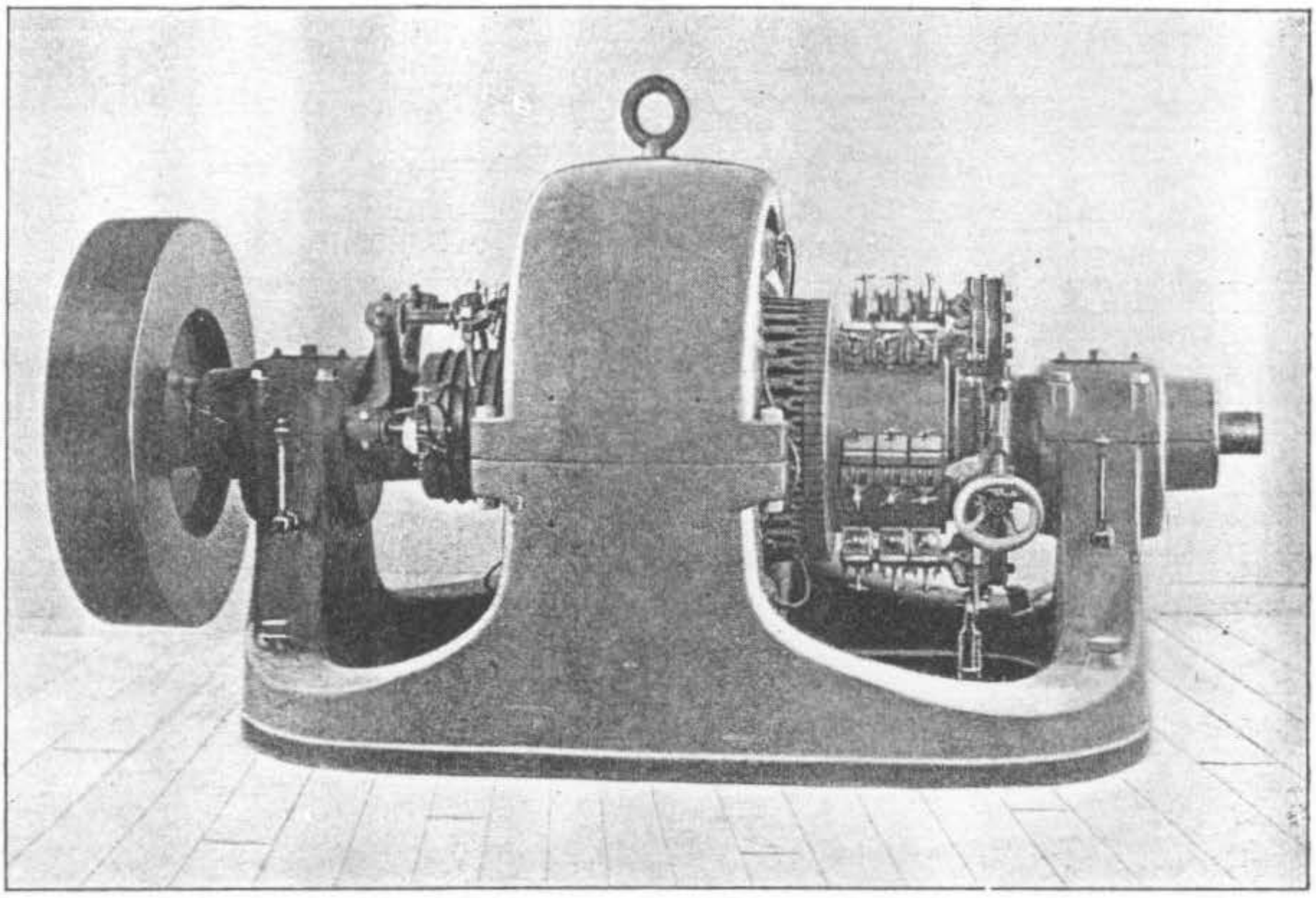
ONE OF THE MAIN SWITCHES.

Two static transformers, each capable of delivering 100 kilowatts each, are used to supply alternating current to each rotary transformer. They are placed in cylindrical boxes of boiler iron, and are immersed in oil. This secures an extremely thorough insulation. The oil is kept cool by water, which circulates through a spiral of galvanized iron pipe, fitting closely to the inside of the cylindrical box. Each box is provided with an oil gauge by which the height of oil may be determined. Provision is made for readily drawing off the oil at the bottom of the box in case of necessity. The transformer, the box, and the spiral of pipe through which the water circulates are shown on page 295.

Before the generators were erected in the shops of the Westinghouse Electric and Manufacturing Company, at Pittsburgh, careful tests were made of the materials used in the construction of the various elements of the machines. Of these, the tests of the physical properties of the shaft, field ring and driver have been referred to. The special means adopted for balancing the revolving parts of the generator have also been described. Among other tests, the following are of especial interest:

TESTS OF THE MAGNETIC QUALITIES OF THE FIELD RING.

Two samples of steel, cut from the edge of the rough-forged ring before it was turned, were tested by the permeameter method to obtain what is technically known as the B-H curve; that is, the ratio of induction to magnetizing force for various values of the latter. The B-H curve was also determined by a modification of the so-called "ring method," the entire field ring being used for this purpose. This very beautiful and interesting experiment

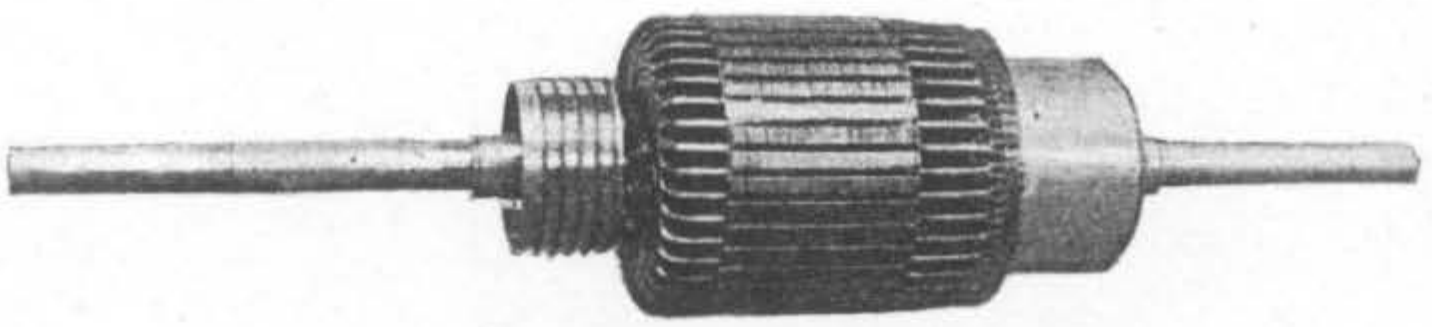


A 200 KILOWATT ROTARY TRANSFORMER USED AS AN EXCITER.

was suggested by Mr. Chas. F. Scott, electrician of the Westinghouse Electric and Manufacturing Company, and carried out under his direction.

All the measurements are illustrated graphically in the chart on page 297. Curves A and B are respectively the B-H curves for wrought-iron and cast-iron, as determined by Dr. John Hopkinson of London, and are here given for purposes of comparison. Curve C is the B-H curve for nickel, as determined by Prof. J. A. Ewing. Curves D and E are determined by permeameter from samples cut from the edge of the ring. Curve F was determined by the ring method, using the entire field ring. The very high values of the induction, for all except very low magnetizing forces, are remarkable.

The tests by the ring method indicate higher values of the induction for moderate magnetizing forces than were obtained by the permeameter. The former is the more reliable method, and curve H undoubtedly represents very closely the true relation of induction and magnetizing force in the field ring of the first generator. The permeability of the field ring is, therefore, considerably higher than that of standard wrought iron.

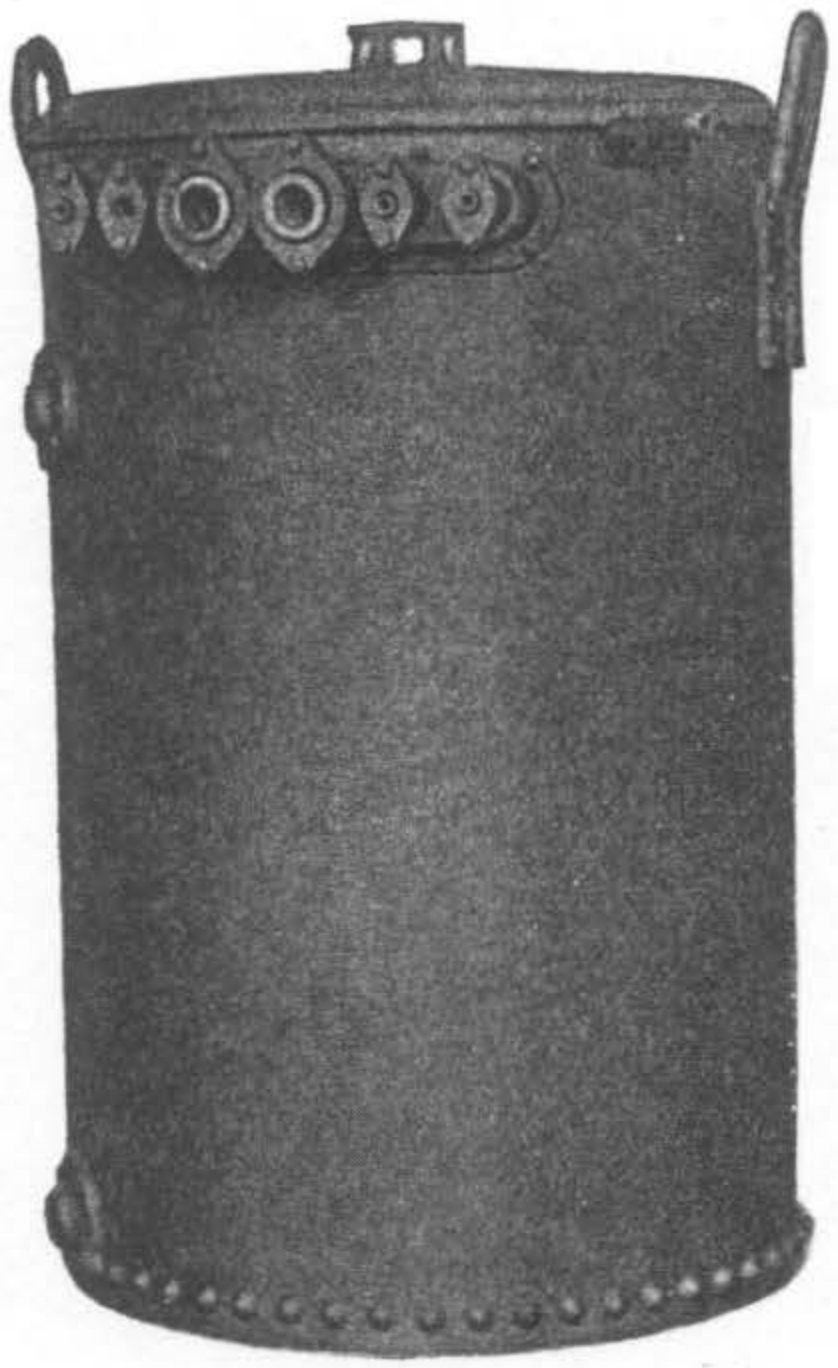


ARMATURE OF THE ROTARY TRANSFORMER.

For the purpose of balancing the driver and field ring, and to make mechanical and electrical tests as complete as was practicable in the shops where no 5000 horse-power engine was available to drive the generators under full load, each machine was erected in such a manner that the weight of the

revolving element was carried upon a collar or thrust bearing at the bottom of the shaft. Into this bearing oil was forced by a pump, at a pressure approximating 1000 pounds per square inch, the result being that the collars on the shaft and the corresponding grooves in the bearing were thoroughly lubricated. The oil was kept in circulation so that it might not become excessively heated.

That the friction in the bearing was reduced within very moderate limits was demonstrated during some of the later tests, when, the driving belt coming off the pulley suddenly when the machine was running at about 250



A 100 KILOWATT TRANSFORMER.

revolutions per minute, the field continued to revolve for thirty-nine minutes by reason of its own inertia.

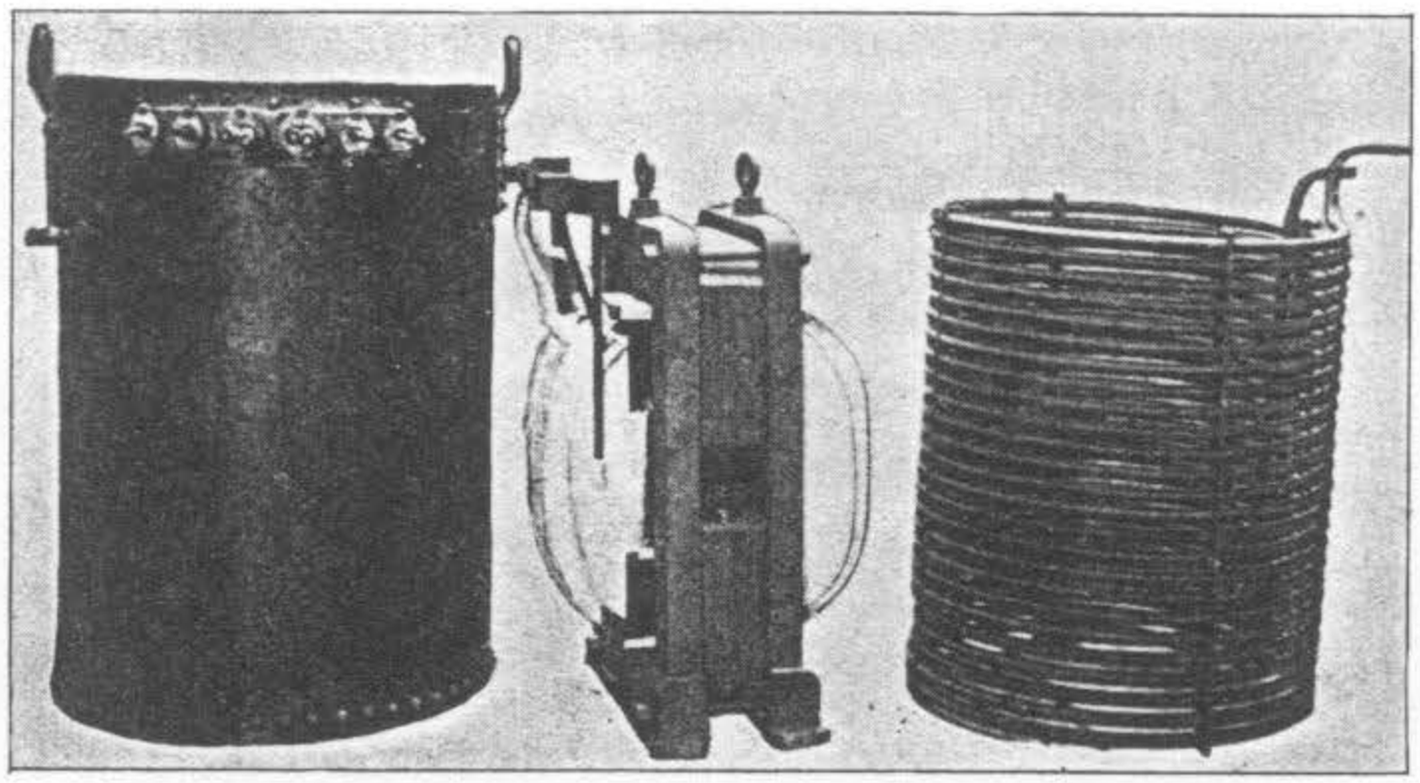
Determination of the Potential Curve.

As is now pretty well understood by those who are in any way interested in engineering, the potential at the terminals of an alternating current generator varies from zero to a positive maximum value, then to zero, then to a negative maximum value, and then to zero again, this cycle being continuously and rapidly repeated, in the case of the Niagara generators twenty-five times per second. One half of such a cycle is graphically represented by the chart on page 298, in which the solid line is the curve of potential at the terminals of the first generator, as experimentally determined. The dotted line is a sine curve, representing an electro-motive force of equal effective value. Horizontal distances, measured along the base or zero line, represent time, while the vertical distances, measured from the base line to the potential curve B, represent difference of potential at the generator terminals. At any given instant, represented by a certain point on the base line, the difference of potential is proportional to the vertical distance from that point to the curve.

In the determination of the form of the potential curve at the terminals of the first Niagara generator, a method, suggested by Mr. B. G. Lamme, of the engineering staff of the Westinghouse Electric and Manufacturing Company, was adopted, and carried out as follows: The machine being set up, as above described, a steel cable was secured to the outside of the field ring, about which it was wound to the extent of a half-dozen turns. The free end of the cable was then secured to a vertical shaft placed in a boring mill. The latter, being revolved at slow speed, the cable was wound upon the shaft, and the field of the generator was slowly revolved as the cable unwound from the field ring. In this way an extremely slow speed (about one revolution in five minutes, or one cycle in fifty seconds) was obtained.

A field charge which, at 250 revolutions per minute, would induce an electro-motive force of 2500 volts in the armature, would, at this speed, induce about 2 volts in the armature circuits. Voltmeters, capable of reading accurately to $\frac{1}{100}$ of a volt, were connected directly across the terminals of the armature, and, as the field revolved, readings were taken at intervals of three

seconds, these intervals being timed by an observer, while two others read the voltmeters, and two assistants recorded the readings. This test was repeated many times with very close agreement in the results. It is due to Mr. Scott, Mr. Lamme and Mr. McLaren, of the technical staff of the Westinghouse Company, to say that the results, when plotted to the same scale as the theo-



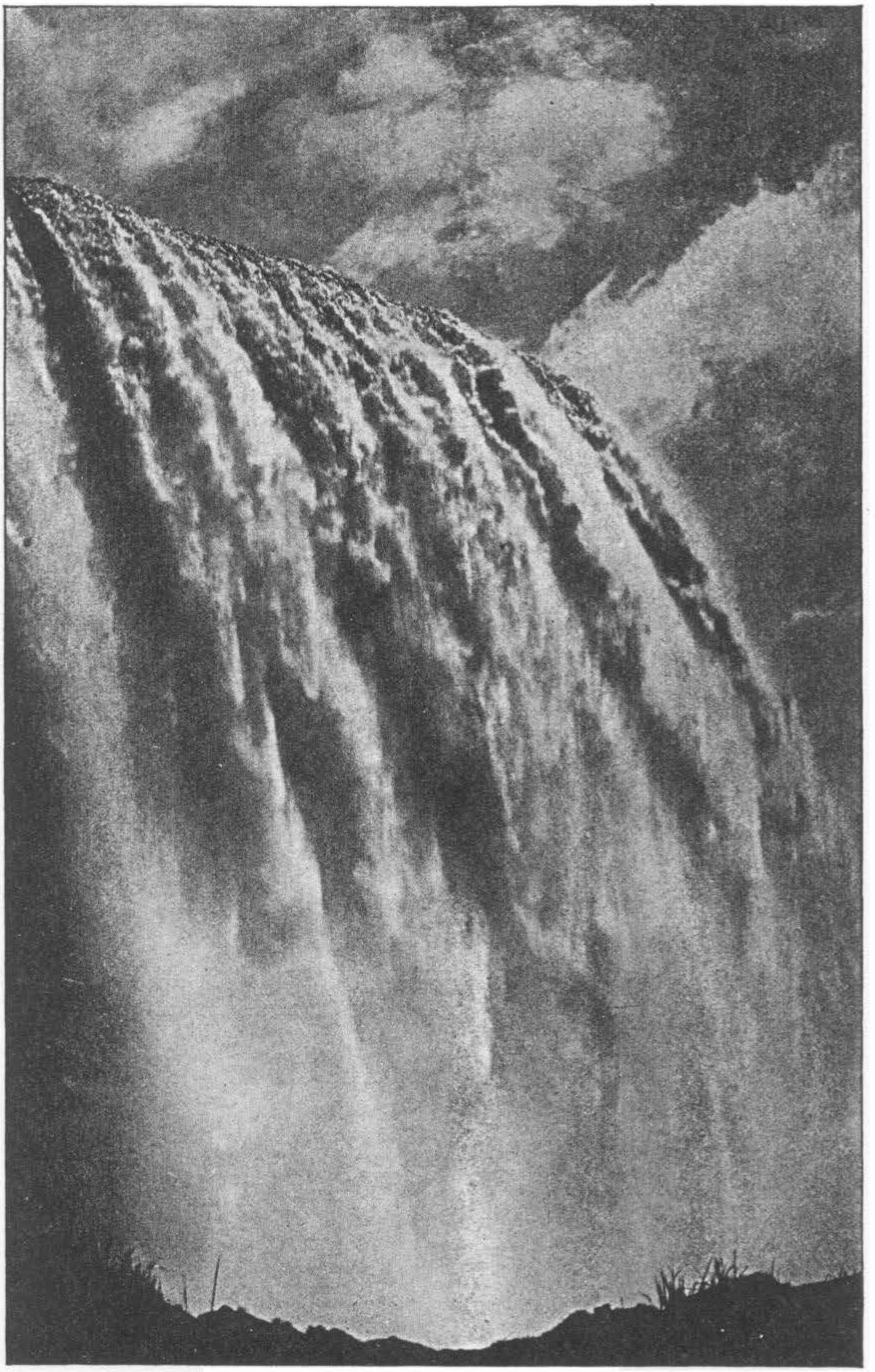
DETAILS OF THE 100 KILOWATT STEP-DOWN TRANSFORMER.

retical curve which they calculated before the test was made, can scarcely be distinguished from the actual curve determined by experiment.

By the efficiency of the generator we mean the ratio of electrical output to mechanical input; that is to say, the quotient obtained by dividing the amount of energy delivered to the circuits by the generator, by the energy delivered to the shaft of the generator at the top of the long shaft which connects the generator and the turbine. This quotient is expressed as a percentage of the input. The difierence between the input and output of energy is represented by the various losses in the generator.

These losses are mechanical, electrical and magnetic. The mechanical losses are those due to air friction of the revolving parts of the generator, and the friction of the two bearings which guide the generator shaft. The electrical losses are those due to the main or primary current traversing the armature conductors, the exciting current in the field winding, and eddy currents which may be set up in the armature conductors, in the core of the armature, in the field poles and in the field bobbins. The magnetic losses are those due to the magnetization of the core of the armature, which is, of course, alternating in sign, and to fluctuations in the magnetization of the field. Not all of these various losses can with convenience or accuracy be segregated, but fortunately, practically all that are of special importance can be measured. Tests were, therefore, made at the Westinghouse factory which determined the efficiency of each machine with a very fair degree of accuracy. They were made with great care, and in the case of the first generator all important measurements were repeated many times. This is not the place for a complete statement and discussion of the tests made, which, in itself, would be as long as this entire article, but the methods employed and the results obtained may be briefly summarized.

As the generator was erected in the shops, the revolving element was sustained, as already stated, by a collar or thrust bearing. A direct current motor, capable of delivering 200 horse-power, was used to drive the generator, the motor being turned upon its side, so that the shaft, supported upon a thrust bearing, was vertical, and, therefore,



THE AMERICAN FALLS AT NIAGARA.

parallel to the shaft of the generator. The field of the direct current motor was independently excited, and readings of the current and potential, delivered to its armature from a direct current generator, driven by an engine, were taken in a series of tests, which were repeated several times during a period of about two weeks. The results show that when the field of the generator was not charged by exciting current, it was necessary to deliver to the motor 76 horse-power to drive the generator field at a speed of 250 revolutions per minute. The belt connecting motor and generator being taken off, 26 electrical horse-power were required to drive the motor at the same speed as before. The difference between these two quantities, or 50 horse-power, represents the mechanical friction in the generator, made up of air friction, the friction of the two bearings which guide the shaft, the friction of the step-up or thrust bearing at the bottom of the shaft, and also the loss in the belt, which was necessarily kept very tight. Just what this belt friction, and the increased friction in the bearings, due to tightness of the belt, amounted to could not be easily determined, nor was any attempt made to segregate the loss in the thrust bearing from the other losses.

This loss in the thrust bearing is not properly chargeable to the generator, since the machines, as erected at Niagara, have no thrust bearing above the point in the shaft where the power is delivered to the generator. It can safely be said, therefore, that at Niagara the total mechanical losses in the generator will be less than 50 horse-power, —that is, less than one per cent. of the power required to drive them.

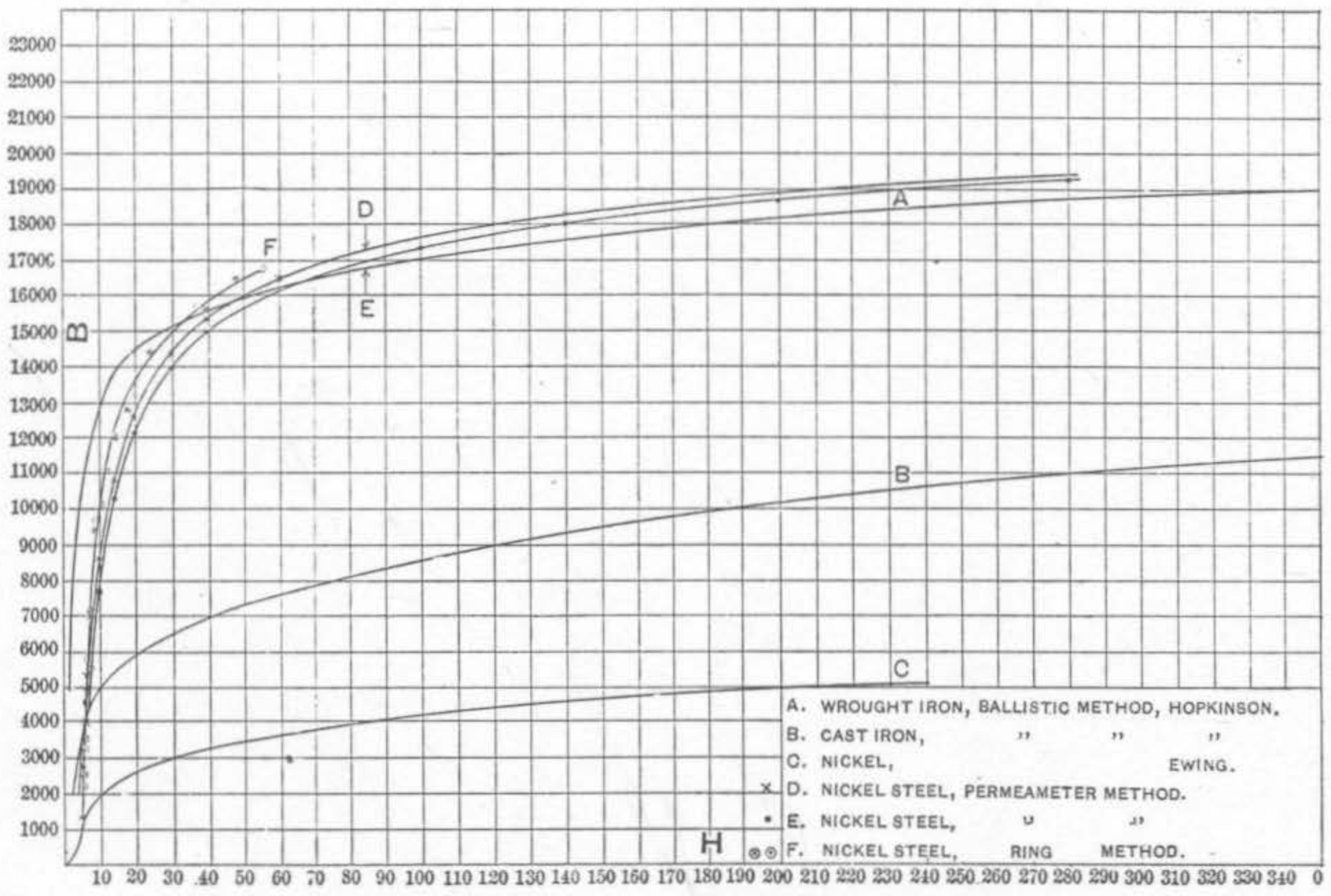


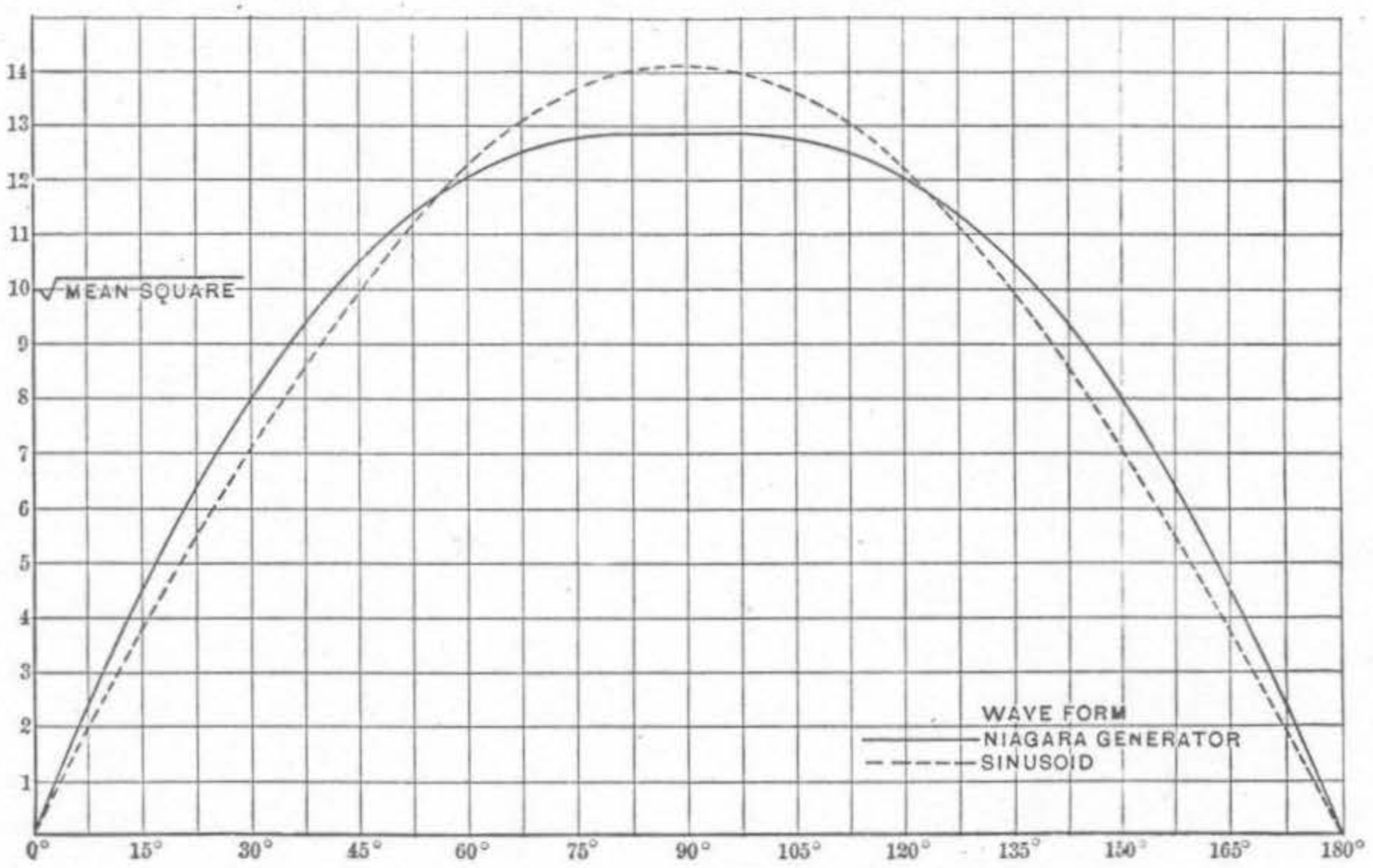
CHART SHOWING THE MAGNETIC QUALITIES OF THE FIELD RING.

The determination of the amount of energy represented by the current which excites the field of the generator is easily made. The method employed was to charge the field, beginning with a very small current, and increase this by successive steps until the potential at the terminals of the armature, at a speed of 250 revolutions per minute, approximated 3000 volts, taking at each

step simultaneous reachings of the current in the field, the potential at the field terminals, and the potential at the armature terminals. The field current was then gradually reduced, simultaneous measurements being taken as before of the current in the field, the potential at the field terminals, and the potential at the armature terminals. In this way the field current required to induce in the armature, without load, any given electromotive force not less than 500 volts and not greater than 3000 volts, was determined. From this the field current which corresponds to any armature potential when the generator is loaded,—that is, when the armature is delivering current,—can be determined with close accuracy by calculation.

With some types of machines this would not be so easily done, but in these generators the relations existing between the armature and field are similar to those which exist in many of the large generators employed in street railway service, and in making the calculation, therefore, we are not far removed from the safe basis of experimental fact. In this way it was determined that under conditions which will exist at Niagara, the field current in each generator under full load will in no case exceed 15 horsepower.

The next loss to be determined is that due to the magnetization of the armature core. This is made up of two factors, but for our purpose, these need not be differentiated from each other. The test was made as follows: The generator being driven at a speed of 250 revolutions per minute by the direct current motor, measurements of the electric energy delivered to the



THE POTENTIAL CURVE FOR ONE OF THE GENERATORS.

latter were made coincidently with measurements of the potential at the terminals of the generator armature. As the current in the field of the generator is varied, by adjusting resistance in its circuit, the magnetization of the armature, of course, varies, and the potential at its terminals is a measure of the magnetization, or, more strictly, induction in the armature core.

As the magnetization increases, more power is required to revolve the field, the difference in the power delivered by the motor to the generator for any given potential at the armature terminals (that is, for any given degree of magnetization), and the power required to drive the field at the same speed with

no magnetization being accounted for by the core loss. As already stated, the energy required to drive motor and generator, as determined in the case of the first machine, is 76 horse-power, and by subtracting this amount from the amounts required to drive the generator with any given magnetization in the core, we have a closely accurate measure of the loss.

In this way it was determined that the amounts of power delivered to the motor, corresponding to potentials at the armature terminals varying from 2000 to 2400 volts, were as follows :

2000 volts	121 − 76 = 45	horse-power
2200 "	130 − 76 = 54	"
2400 "	141 − 76 = 65	"

Were the armature in service, delivering currents representing the full output of the machine, the distribution of the magnetic lines in the armature core would be somewhat, but not very radically different, and consequently these measurements do not tell us exactly what the loss in the core will be under conditions of actual service. But, making a fair allowance for an increased loss due to this and other minor causes which may make themselves felt in the commercial operation of the generator, it would seem safe to say that the loss in the armature core, operating at 2100 volts, which is about the voltage at which those generators supplying local service will be operated, will not exceed 60 horse-power.

The loss due to the current in the armature conductors could not be accurately determined from tests in the shop. This loss, however, is easily calculated with close accuracy from measurements of the resistance of the armature conductors and the known value of the full load currents which they will carry in service. Disregarding possible eddy currents in the conductors, which, from the construction, should be almost negligible, calculations show that the loss in the armature conductors under full load will not exceed 30 horse-power. Theory indicates that other losses, with the possible exception of eddy currents in the field poles, will be so small as to be practically negligible, and including the loss in the field poles, which could not be readily determined, their amount will not be sufficient to materially affect the efficiency of the generator.

To sum up the mechanical, electric and magnetic losses, when the generator is delivering current at 2100 volts, we have roughly the following:

Maximum loss in field copper	15	horse-power
Loss in armature core	60	"
Loss in armature conductors	30	"
Total	105	"

To arrive at the actual efficiency of the generator we must add to this the losses due to air friction and friction of the bearings, but the tests do not indicate to what these amount, except that with the loss in the thrust bearing used during the shop tests they did not exceed 50 horse-power. With the losses in the thrust bearing charged against the generator (which is, of course, unfair to the machine) we have for the total mechanical, electric and magnetic losses 155 horse-power. In order that the generator shall deliver 5000 horse-power to the circuits it is, therefore, necessary that 5155 horse-power be transmitted to it through the shaft. Dividing 5000 horse-power, the output, by 5155 horse-power, the assumed input, we have almost exactly 97 per cent. From all this it appears perfectly safe to say that the generators, under the conditions of commercial service, will, at full load, operate at an efficiency exceeding 97 per cent. At the time of writing this, the tests of the generators as erected in the power house at Niagara are not yet completed.

The description of the electric generating plant in the foregoing pages is necessarily incomplete. Much that would interest scientific specialists is omitted or merely glanced at, and on the other hand, space and time have not permitted the attempt to elucidate statements which, to those not familiar with electric work, must appear more or less obscured by technical phraseology. This I cannot hope to amend.

The tests of the first 5000 horse-power unit are now in progress, and success is assured. When, on the

morning of April 4th, 1895, Mr. Rudolphe Baumann, the Swiss engineer, who has for several years devoted his skill and energy to perfect the hydraulic plant, gently moved the hand wheel which controls the first turbine, the field of the generator began to revolve, noiselessly, irresistibly, testifying to the skill and painstaking effort of the civil, hydraulic, mechanical and electrical engineers, whose combined efforts, directed by the splendid enterprise of the Cataract Construction Company, have united in producing a 5000 horse-power unit of machinery, capable of transforming the energy of falling water to electric energy, live, vibrant, needing only suitable conductors to guide it across miles of country, to places where it may turn the wheels of a thousand mills and factories.

The Niagara generators were constructed by the Westinghouse Company, following, as regards mechanical form, the type of machine proposed by the engineers of the Cataract Construction Company. This was fully described by Prof. George Forbes in a paper read in November, 1893, before the British Institution of Electrical Engineers. The auxiliary electric apparatus, including exciters, switching devices, measuring instruments, etc., were designed and constructed by the Westinghouse Company, assisted, as to the bus bars, by the Brown & Sharpe Manufacturing Company, of Providence, R. I., U. S. A., and the India Rubber and Gutta Percha Insulating Company, of New York.

Among those who have been particularly prominent in the work are: Mr. Albert Schmid, general superintendent; Mr. C. F. Scott, electrician; Mr. Philip Lange, superintendent; Mr. O. B. Shallenberger, consulting electrician; Mr. B. C. Lamme, Mr. E. C. Means, Mr. H. P. Davis; Messrs. Sigfried, Wright, Boegel, W. F. Lamme, Beinitz, Alberger, Mirault, Friedlander, Strauss, Mould and Parks. To Dr. Coleman Sellers, president and chief engineer of the Niagara Falls Power Company, and Mr. De Courcy May, late superintendent and engineer of the Cataract Construction Company, who, in consultation with Mr. Schmid and his assistants, made many valuable suggestions, the thanks of the Westinghouse Company are also due.

THE DOGMATISM OF SCIENCE.

By Mrs. Bloomfield Moore.

Henry Thomas Buckle, in a paper read at the weekly evening meeting of the Royal Institution of Great Britain, Friday, March 19th, 1858, said that "an exclusive employment of the inductive philosophy was contracting the minds of physical inquirers and gradually shutting out speculations respecting causes and entities; limiting the student to questions of distribution, and forbidding to him questions of origin; making everything hang on two sets of laws, namely, those of co-existence and of sequence; and declaring beforehand how far future knowledge can carry us. But," added this great man, "we shall not always be satisfied with seeing the laws of nature rest on this empirical basis; and the most advanced thinkers are looking to a period when we shall deal with problems of a much higher kind than any yet solved; when we shall incorporate mind and matter into a single study; when we shall seek to raise the veil and penetrate into the secret of things."

No man nor woman of intelligence, who is conversant with the writings of "the most advanced thinkers" of our age, can fail to see that this time is near at hand; and yet dogmatic science refuses to put itself in a position where it could announce that the veil is already raised, and, to quote the words of Prof. Lascelles-Scott[1], that "the door which

[1] Physicist at the Government Physical and Chemical Laboratories, Forest Gate, Essex.

prejudice has declared to be shut and bolted is even now ajar, and gleams of light are struggling over the threshold from Keely's discoveries."

Of course, new hypotheses should not meet with too ready an acceptance, and the professor, with admirable caution, takes the text of his review of "Keely and His Discoveries," from the Syracuse philosopher—Epicharnus—"The very nerves and sinews of knowledge consist in believing nothing rashly." But with such evidence as he sets before his readers (in the October number of THE NEW SCIENCE REVIEW), the determined blindness of dogmatic science should not be permitted to delay, to another century, the general promulgation of truths which have been already established by the testimony of some of the most distinguished American men of science of this age. The fact that there are, as yet, no commercial profits from Keely's discoveries is all that retards the promulgation of these truths; but the law allows no patents on new truths nor on a principle of nature. Until the vibratory circuit, operated by this costless current of force drawn direct from space, is connected with some patentable device, Keely's discovery has no more commercial value than Newton's discovery of gravity. Therefore, as science still denies the fundamental doctrines on which this new system of physics is based, the only hope lies in the prolongation of Keely's life until commerce, instead of science, is able to make the announcement; unless the press, with its gigantic power, lends itself to the efforts now being made to bring before the public the present position of Keely in his great work of evolution. Of another discoverer of unknown truths the poet Cowley wrote:

"Bacon, like Moses, led us forth at last;
The barren wilderness he passed;
Did on the very border stand
Of the blest, promised land;
And from the mountain's top of his exalted wit,
Saw it himself, and showed us it.
But life did never to one man allow
Time to discover worlds and conquer too."

Scientific caution is necessary at all times, and more especially so with discoveries which antagonize the established order of what is supposed to be scientific truth. But of quite a different nature is that stolid and contemptuous indifference manifested by those "lights of science," who consider it derogatory to their dignity to interest themselves in an examination of claims that, if proved to be true, would revolutionize the accepted dogmas of science. When Italy was disturbed by Galileo's discovery, the same thing occurred. It was a professor of the University at Padua who refused Galileo's invitation to look through his telescope and obtain proof of his assertion that "the world moves."

The world of thought moves faster than in the days of Galileo. Under the pressure of outside opinion and the gradual infiltration of new truths, men of science will, in the end, be awakened into honest and serious attention to Keely's claims. New truths pass more quickly, now than formerly, through stages of blind, unreasoning opposition. This improvement does not spring out of any change in human nature in scientific men, for their "good-fellowship," among themselves, is never extended beyond those researchers who maintain orthodox views and support each other in their claims.

The hope of Keely's life being prolonged "to conquer too" (nearly three score years and ten as he is now), would be much more likely to be realized if the certainties of the scientific value of his discoveries were made known more widely, together with the *uncertainties* of his living to complete all that is necessary before there can be any financial gain therein.

Notwithstanding the persistent denial of physicists, who have not examined into Keely's claims, the advancing wave of interest in his work cannot be kept back, for it will be sustained in its course by the ever-increasing pressure of a larger outside public of intelligent and interested minds, not wedded by long association of thought to special systems, and having no motives of self-preservation prompting them to repel what appeals to their intellectual capacity of

comprehension with much greater force than to minds educated on rigid lines of thought, as is the mind of the physicist. Such minds, says Hovenden, from the necessities of the case, are the least capable of solving a problem which can only be solved by views that are foreign to the fundamental ideas in which the physicist has been educated.

The distinguished men of science, Profs. Leidy, Brinton and Koenig, who investigated Keely's work in 1889–90, testing the current of force produced with the most sensitive galvanometer of the University of Pennsylvania, publicly asserted that it was free of electricity, magnetism or any known force—scoffing at the less than school-boy knowledge, which had, in 1876, pronounced it to be compressed air.

Ricarde-Seaver, an European electrician, who, after investigating, returned to London and gave testimony in favor of the discoverer, was asked to withdraw his name, when the balloting was about to take place for membership at the Athenæum Club, by the very man of science[1] who had proposed him sixteen years before, the only reason given being his espousal of Keely's claims as a discoverer.

Such an experience (and more notably the recent experience of Prof. Oliver J. Lodge) proves that the founder of new systems must look to the power of the press, which is greater than that of the sword, when help is needed in making known to the world the importance of newly-discovered truths not accepted in general by those whose canons they controvert.

One of the most widely-known English physicists,[2] who for more than ten years has followed Keely's progress in his experimental researches, when asked in 1891 why he was not willing to make public his views of their nature, replied: "If I am called before a bar of justice to give testimony, I am cross-questioned by judge and counsel. It is the same at the bar of science. I cannot say what I think. I must say what I know, what I believe, what I have seen."

[1] Lord Kelvin.

[2] Prof. Dewar, of The Royal Institution of Great Britain.

As long as the so-called "Lights of Science" hold the attitude that they take toward lesser lights, who are interested in Keely's work, no physicists of note can be expected to interest themselves in Keely's claims publicly.

Prof. Lodge, in closing a recent article, "Unusual Physical Phenomena," writes: "And now, finally, let me disclaim all missionary spirit in this long exposition. The business of a scientific man is the pursuit of natural knowledge and the imparting of such portion of it as has by long trial become recognized and orthodox—*i. e.*, such portion as people are willing to receive. For I need hardly remind the reader that at one time the science of nature, or physics itself, was very far from being orthodox, and that in past days promulgators of any new truth had to pass, not through the fire of a little friendly badinage and ridicule, but through fire of a much fiercer and more searching character; unless, indeed, they recanted their 'errors.' Instruction in orthodox branches of science is now permitted to youth; an unorthodox department of knowledge may have to wait many years before instruction in it can be willingly received, even by adult and experienced minds. Let it wait! The instinct of an investigator and teacher is to set forth, as best he may, such natural truth as he is able to perceive—such truth as the interworking of his era and his opportunities have revealed to him—and there he must leave it. For its reception by the human race, he is not responsible.

"The universe is not so simple a matter as men in this century have been apt to think. *All we ask for on the part of our contemporaries is an attitude of mind willing to give to new truths a chance of life. If it be of God, they cannot indeed ultimately overthrow it; but they may, by determined blindness, seriously delay its coming, and entirely prevent its reception in their own age.*

"I ask for no hasty belief. No one can usefully believe things of which he has had no experience. He may say that the statements of those who support them are or are not entitled to respect, and that, if he were forced by a pistol at his head to take sides prematurely, he would range himself

on one side or the other; but till he has had some sort of first-hand experience his belief and his disbelief are equally worthless, except in so far as they may lead him to devote some portion of his time to a study of what has been recorded on the subject, and to an unprejudiced, critical contemplation of whatever phenomena may in the progress of events unfold themselves before him."

The public is now asked in the same spirit to give attention to Keely's present position in an unorthodox department of true scientific research. The long course of experiments made by English and Continental physicists in the case of the medium Eusebia, seems to have proved nothing more than that obsession did not cease with the days of the Apostles. In fact, Mr. Keely is opposed to these mediumistic experiments with subjects possessing abnormal will power. Hypnotism, animal magnetism, suggestion, etc., he considers are so little understood in their workings, that it is like an obstruction placed on a railway track: the engine may dash it aside, or it may wreck the train. The experimental researching of Keely, in manifestations of will power, is of an entirely safe nature, made with dynamic apparatus instead of on the human brain and the physical organism.

Since the insults to which he was subjected several years ago by a professor of physics who visited his work-shop, Mr. Keely has refused to make explanations of the operations of his instruments to those physicists who have reluctantly condescended to inspect his aerial navigation machinery, preferring to wait until the propellor is able to speak for itself. At present, however, for certain business reasons, it has become necessary for him to explain the operation of the machine, and Dr. Tuttle, physicist at the U. S. Mint in Philadelphia, has been chosen to receive this instruction. The series of experiments which Mr. Keely was preparing to give (as set down on page 464 of the April number of THE NEW SCIENCE REVIEW) before an expert committee, will therefore be made before Dr. Tuttle; but no public announcement will follow on account of the business complications alluded to.

It has become evident that an authoritative public announcement of the completion of Keely's long work of evolution, in a machine adapted to navigation of the air, would facilitate stock jobbing operations. That such undesirable results may be avoided, this statement must be delayed until Mr. Keely's plan of reorganization of the old Keely Motor Company has been accepted by the shareholders of its stock, and a settlement made with them, as set down in his circular No. 1. (The circular will be found in the advertisement pages of this number of THE NEW SCIENCE REVIEW). When Mr. Keely has effected this settlement and completed his railway traction engine, then, and not before, will the stock of the Keely Motor Company possess marketable value. The expert American electricians and engineers, who were to have formed the committee of investigation, prefer to wait until this is accomplished, lest their names be used to facilitate Wall street operations in Keely Motor stock.

Mr. C. W. Baker, of *Engineering News*, upon withdrawal of the invitation that had been extended to him (in accordance with an intimation from him that he would like to pursue the subject farther than he had been able to do), expressed his regret that the plans formed for giving a wide publicity to the result of the demonstrations had been frustrated from want of coöperation on the part of the Board of Directors of the Keely Motor Company. Nikola Tesla, for reasons that need not be explained, would not have been able to serve on the committee. It is well known that he is striving to draw power from space by purely scientific methods, which Keely succeeded in doing in 1893 by "unscientific methods." An earnest effort has been put forth to induce this distinguished man of genius to acquaint himself with Keely's system of aerial navigation, in order that he may more quickly attain one of the goals he is aiming to reach—that of producing light devoid of heat.

It is now a number of years since Mr. Tesla crossed the border line of the circle in which all other electricians are working, on their treadmill round, but he still remains in the interatomic field of research, apparently unmindful of

the triple conditions that govern electricity in the relation which it sustains, in that field, to the first order of the luminous.

Tesla's great penetration may enable him eventually to attain his aims on orthodox lines of research; but, in the writer's opinion, were he to acquaint himself with Keely's system of resonance, it would be but a short time before he could induce electrical alternation of such an intense degree as to produce a light as susceptible to the retina as is solar light. Even should Tesla succeed in drawing power from space, on his own line of research, his position would still be remote from all the conditions governing magnetic and electric phenomena in the sympathetic field, where Keely has solved the problem of navigation of the air. Keely calls this realm the interetheric or celestial, in contradistinction to the terrestrial or interatomic realm, which Tesla is researching. The terrestrial sympathetic forces are subservient to the celestial sympathetic. Tesla stands as it were on the bridge which connects the primary two-thirds of the electric stream—the subdominant current with the dominant. Even should he hook on to the dominant, he would still be subserved to the terrestrial neutral; far in the rear of sympathetic union to radiating celestial outreach,[1] the connecting link of which exists in the interluminous, and remote from all the conditions that govern electricity sympathetically. Therefore Tesla is wrong when he says that "electric phenomena and ether phenomena are identical;" nor will he arrive at a true conclusion, as to the relation or association of the two, until he has brought about an alter-

[1] The sympathetic outreach of negative attraction is born of the celestial and impregnates every mass that floats in space, seeking out all magnetic or electric conditions. All these masses are subservient to celestial outreach It is the power that holds the planetary masses in their orbital ranges of oscillatory action. Magnetism is static. Sympathetic negative attraction reaches from planet to planet, but electricity does not, nor does magnetism.

All the magnets in the world could not induce rotation, no matter how differentiated, but polar negative attraction induces rotation, as exemplified scores of times in an insulated compass-needle before the professors of the Pennsylvania University in 1890. (See page 279, "Keely and his Discoveries.", The Transatlantic Publishing Company, 63 Fifth avenue, New York.)

nation of that intensity which induces light visible to the eye. Even then he will not have reached the compound interetheric—the border line to the introductory luminous.

It is evident that Tesla already comprehends the law governing transmission and dissociation in electrical alternation with regard to its reception by the physical organism, whereby an increase of the number of volts that prove fatal to life are harmless, and given without any risk to the subject. The ear is not susceptible to the vibrations of inaudible sounds; nor the eye to those of light beyond the number necessary for sight. A wheel having five spokes and making ten revolutions per minute gives fifty alternations on the spokes, which are readily counted by the eye; whereas an increase in the revolutions, to five hundred in ten minutes, increases the alternations of the spokes beyond the power of the retina to receive and count.

It is the same with electrical alternation in regard to its receptiveness by the physical organism. Phenomenal as it may seem to those ignorant of the fact, this is a standard truth in sympathetic physics, which Tesla's penetration did not fail to discover. The plane of research that he occupies in regard to electrical phenomena, is as much above that of his fellow electricians as is the plane occupied by Keely (in researching the problem of aerial navigation) beyond the realm in which those inventors are working, who are constructing balloons and flying machines on various principles, while still ignorant of a force in nature that is antagonistic to gravity and overcomes it; thus making navigation of the air, with ships of thousands of tons burthen, both possible and perfectly safe.

Electricians will no longer remain captive in their domain when Keely's system is published to the world; as it will be when he has effected the settlement that he seeks. If this settlement is not effected, without the delay of litigation, his secrets will die with him, in all probability, for no one but himself knows the process by which dead metal is sensitized so as to be operated upon, as the brain is operated upon by celestial radiation.

Were Tesla and Edison brought to a proper appreciation of Keely's methods, were they to make themselves acquainted with his system of sympathetic physics, what might not be expected of them in view of their brilliant achievements on a lower plane of research? The march of science would then be a triumphal one indeed.

Let Keely be known to Tesla and Edison as the "great discoverer" which Professor Koenig called him in 1891, and the press will then be ready to publish what has already been accomplished for science. This can be done without affecting the stock market, as long as there is no engine to base speculation upon. Why should science wait upon commerce? Is it not enough that "the whole world problem" is solved by this new system of physics, demonstrating, as it does by dynamic apparatus, the truth of Professor Ladd's words in his recent work, "Body and Mind," when he says, "The Being of the world, of which all particular beings are parts, must be so conceived of as that in it can be found the One Ground of all interrelated existencies and activities."

The cosmical law of sympathetic association, as set down in Keely's system of Vibratory Spiritual Physics, has solved this greatest of all problems—both psychical and physical—the problem of the human will.

Shall this system, founded upon knowledge known to the ancients, which has been lost out of the world for centuries, only be regained to be lost to this age because of the dogmatism of science? There is a warning in Cowley's words, which men of science will do well to heed:

> "But life did never to one man allow
> Time to discover and to conquer too."

THE TESLA OSCILLATOR.

By Lieut. F. Jarvis Patten.

The fire which, since our last issue went to press, destroyed the laboratory of Nikola Tesla in this city and reduced to ashes all the recent devices of his ingenuity, has again aroused public interest in the work of this world-renowned inventor. By the creation of the rotary field motor, which now, some six or seven years from its birth, is a commercial success, and the brilliant investigations he subsequently made in the direction of high frequency phenomena—not yet so far advanced—Tesla has established his right to be regarded as the most promising inventor in electricity that we have to-day. It is, therefore, only natural that, when without warning all his records and more recent apparatus are suddenly wiped out of existence, the public should be eager to know what he had in preparation for his next surprise.

The so-called "Oscillator" was near to a practical working form when the fire occurred, and as this machine, in a less finished shape, had been exhibited at the Chicago Exposition, and has received a large share of his attention since that time, he has considerately given the public some photographs and details of the more advanced forms of this engine. Tesla's researches and inventions have heretofore been confined to purely electrical problems, and electricians were naturally expecting a continuation of such work, but this inventor appears to delight in surprises, and when the Oscillator was announced for the first time, the general conclusion that Tesla had contrived some way of shaking the earth's electric charge, or had made some other ultra scientific step of a like character, was far from the truth.

Of all things yet produced by him the Oscillator is certainly the most thoroughly mechanical and possibly the most practical. The term "Oscillator," in fact, was evidently selected by him in order to distinguish it from other well-known forms of vibrator, and gives hardly any idea either of the

machine itself or the functions it is designed to perform. There is, indeed, no connection between this machine and his former productions, except through the fact that its purpose is to economize the work of the steam-engine and the dynamo at the same time, and so materially to increase the output of these two essentials of every large electric generating plant, the combined weight and cost of the two being greatly reduced.

The Oscillator, in fact, is an "engine dynamo," consisting of a novel form of steam engine combined with and operating on the same bed plate a novel form of dynamo. To understand how such a contrivance can have any practical value in electric generation it is necessary first to consider the essential features of any ordinary electric plant, their relations to each other, and where any losses of power seem unavoidably to enter. In plain terms, all such plants at the present time consist of two independent parts, the steam-engine and the dynamo. This the engine drives generally by indirect methods, as it would any other piece of machinery, as a lathe or a planer, through a system of shafting and belting. True, in modern plants, where large units are employed of five hundred horse-power or upward, the moving part of the dynamo is secured directly to the driven shaft of the engine. This plan is known as direct coupling, and though it introduces no small degree of economy in operation, it seems, according to Tesla, to be only a step in the right direction. It saves, for instance, at least one unnecessary line of shafting with its attendant friction; also, the work wasted in driving the belt or gearing of some kind between the engine and the dynamo, which is a far greater useless drain upon the steam-power.

Direct coupling is, therefore, all very well, so far as it goes, but we have not saved much, if anything, in floor space, or in weight, for we have still an ordinary engine and an ordinary dynamo as before. Are there not other losses equally easy to eradicate? Every engineer knows how really imperfect the steam-engine itself is in respect to work wasted in the friction of many parts that are purely auxiliary, yet appar-

ently necessary to its operation; and although the dynamo, the much younger machine of the two, is a far less wasteful engine, there is still in every reliable form a large percentage of wire that does no work, the friction resistance of sending current through which has to be overcome. Consider the steam-engine first. Here we have a steam cylinder in which is produced the reciprocating motion of the piston rod, and this motion, which represents the active power of the engine, is next converted into rotary motion through a system of auxiliary parts, namely, the connecting rod, the crank, and the attached fly-wheel. These parts all consume work by friction, but by far the greatest loss lies in the change from the reciprocating, or to and fro, piston motion to the rotary motion of the crank, the actual power of the piston working, as it does, at every point of the circle at a disadvantage, owing to the varying inclination of the crank and piston rod in all positions. Rotary motion once obtained, however, we have to reconvert a portion of it back again through further auxiliary apparatus—the eccentric with its rods and valves—to the reciprocating motion of the valve in the steam chest, which latter by its great friction, due to the steam pressure, wastes no inconsiderable amount of power. Thus we see that in the steam-engine all the apparatus except the piston and steam cylinder are auxiliary to it, and all waste, or use up without doing any work on the shaft of the engine, some of the energy delivered by the expanding steam to the piston head. In fact, it is plain that our conversion of the reciprocating motion of the piston to the rotary one of the fly-wheel is wasteful, and if done away with a considerable saving of power could be effected.

Unfortunately, however, in all the machinery for which the steam-engine has been heretofore used as a motive-power or driver, the rotary motion was required in the apparatus, and was, therefore, made in the steam-engine which drove it; all machinery, in fact, with very few exceptions, being essentially rotary.

On the other hand, if we examine the dynamo we shall find that we have made the dynamo a rotary machine only

because the steam-engine is, and to accommodate it to the latter. The dynamo had to be driven by a steam-engine, and in its evolution was naturally first made rotary in order to adapt it to existing forms of the steam-engine.

It is well known to electrical engineers that the simplest and most economical forms of dynamo have reciprocating parts only, and that the rotary form can only be contrived at a certain loss of efficiency. We may, therefore, state in general terms that the usual form of engine, rotary, is not adapted to the best form of dynamo, while the best type of engine for driving the simplest and most economical form of dynamo, that having a reciprocating motion only, has not yet been contrived or designed; not because of any inherent difficulty in the designing of such an engine, but simply because such a machine has heretofore had no particular sphere of usefulness.

The Tesla Oscillator is revolutionary in this respect, that it reverses the existing forms of engine and dynamo construction by making them both reciprocating in their action, thus coupling an efficient dynamo to a steam-engine, which, being also reciprocating, has no wasteful auxiliary parts, and no wasteful conversion of the original reciprocating motion to the rotary form of motion. Such, in general terms, is the Tesla Oscillator. It aims simply at a higher economic construction of the two essential parts of an electric generating plant, and in formulating this idea Tesla makes one machine of the two on one bed-plate, and thus again makes no little saving of space and weight.

While this construction, as described for sake of simplicity, might seem easy at first glance, a few engineering difficulties of a purely mechanical character soon become evident that render the solution of the problem one of extreme difficulty.

Briefly stated they are as follows: The dynamo to be economical requires an extremely high rate of to-and-fro motion, say at least eighty to one hundred strokes a second, while the steam-engine, on the other hand, owing to its necessarily heavy parts, requires a very slow rate for a dyna-

mo, say ten strokes a second, and these adverse requirements of the two machines must somehow be reconciled.

Again, the conversion to rotary motion in the steam-engine from the reciprocating form through the medium of the crank, serves a very useful purpose, especially in the case of heavy and powerful engines. This connection of the piston to the crank causes the piston to start up slowly under the enormous pressure of the steam, attaining its highest speed only for an instant about midway of the stroke, then slowing gradually down to the end of the stroke, where it is zero. The piston is then ready to resume its backward journey in the same manner without shock or jar to the structure. We thus see that there is at least one compensating feature in our conversion loss, for it would evidently be impossible to send the heavy piston, weighing, perhaps, a thousand pounds, at full speed from one end of the cylinder to the other, then instantly arrest its motion at the exact point and send it back again at the same rate. To do this a few times a second would be certain disaster, but to do it at a high rate of speed would be as certainly impossible. In the Oscillator the piston travels its journey to and fro a hundred times a second, and can go much faster if required, but the mechanical conditions are all different. In the first place, the parts are all small and extremely light, it being claimed that an engine of a given power on this plan can be made about one-fortieth the weight of an ordinary engine of the same power; secondly, the piston stroke is very small, being in no case more than a fraction of an inch; and, finally, automatically operated air cushions, or springs, are used, that serve to check and slow down the motion of the piston gradually at the end of the stroke.

In one form of the Oscillator two pistons are used that go out and in the opposite ends of the same cylinder at the same time, thus balancing the motion and relieving the apparatus from the rapid shock of vibration. Like the engine having two pistons the dynamo is double, or rather there are two, one for each piston, each of which carries a light armature that it rapidly thrusts into and withdraws from a very in-

tense magnetic field. The vibratory form or oscillatory form of dynamo is not essentially new. Several earlier laboratory machines having been made this way, perhaps the most remarkable of which was the Edison tuning-fork dynamo, remarkable chiefly, however, for its utter inapplicability to any use.

Perhaps the most remarkable feature about the Tesla apparatus is a novel system of steam packing introduced, which enables him to use a steam pressure of three hundred and fifty pounds without any perceptible leak. This, taken in conjunction with the very high rate of piston speed used, which, of course, only compensates for the very short stroke, should produce an engine of high economy. As for the dynamo, the type certainly admits of high economy in construction, and it is claimed that in one form there is absolutely no armature wire that is not cutting lines of force and doing work.

While it is too early to predict the eventual outcome of such revolutionary steps in both steam and electrical engineering, the developments thus far seem to have been of the most encouraging sort.

ANNUAL REPORTS.

Westinghouse Electric & Manufacturing Company.

(For the year ending March 31, 1895.)

The report of President George Westinghouse, Jr., says in part :

General.—The all-important feature of the year's business has been the creation of a magnificent workshop, having unequaled facilities for the carrying on of the business in which your company is engaged. These new works are located at East Pittsburg, about twelve miles east of Pittsburg. As was to be expected, such extensive building operations and the removal of materials from the old to the new works reduced the output for the year to about three-quarters of what it would otherwise have been. The directors earnestly invite all holders of the company's stock who may be able and desire so to do to attend in person the annual meeting on July 17 at Pittsburg, where special railway and other arrangements will be made.

So far as ascertained there was expended directly in removing the machinery and material $90,499, after deducting which from the earnings from business and from other sources there is left a net profit of $711,909.

Light and Power Properties.—Your company has for the past six years been interested in the United Electric Light & Power Company, of New York, and the Brush Electric Company, Baltimore, Md. During the past year both of these companies, with the assistance of your company, have carried through financial plans which have put them on a prosperous business basis. Their fields of operation are unusually profitable ones and it is believed by your management that the value of their securities owned by your company will, in the near future, be equal to their par value (amounting to $2,591,100); and that the final profit thereon will be a large one.

The United Electric Light & Power Co., under the plan referred to, has acquired almost all of the stock of the Brush Illuminating Company and of the United States Illuminating Company, both of New York City, and is now completing one of the most comprehensive light and power stations in the United States. It has contracted with your company for ten complete electrical outfits of 1,000 h. p. each, and for all the converters and other needed apparatus, half of these outfits having been used for the World's Fair lighting. On the completion of the above contract your company will have in securities of the United Company: 1st mortgage bonds, $913,000; preferred stock, $550,400; common stock, $411,700.

From its old stations this company is now doing a business of about $800,000 per annum, which should be more than doubled by the revenue from the output of the new station, giving it a net revenue sufficient to pay interest on its bonds and dividends on all of its stocks, there now being a demand for light and power sufficient to absorb the entire capacities of the stations of all existing companies.

Brush Electric Company of Baltimore, Md.—In the reorganization of this company your company subscribed for $40,000 first mortgage 5 per cent bonds and took in payment for machinery $170,000 first mortgage 5 per cent bonds, making your company's total holding $210,000 first mortgage 5 per cent bonds. Your company also was the owner and now holds 5,060 ($100) shares of the common stock out of a total of 7,292 shares outstanding.

The station of the Baltimore Brush Company is new and is one of the finest to be found in the country. It has three of the World's Fair 1,000-horse power engines and generators and has been supplied with a large amount of other electrical apparatus and will be hereafter, as will also the United Company, a constant purchaser of your company's apparatus and supplies.

Collateral Trust Bonds.—Your board, under the powers conferred upon it by the company's charter, has authorized the issue of $1,250,000 ten-year 5 per cent collateral trust bonds, secured by certain bonds and stocks held by the company, provision being made in the deed of trust for the sale of a portion or all of the securities, and for the cancellation of the corresponding amount of the collateral trust bonds secured thereby. It is proposed to fund out of the proceeds of this issue of collateral trust bonds an equal amount of debt, a greater part of which has been created in the building of the new works, the purchase of new machinery and the outlays in connection with the financial plans of the United and Brush Companies.

Westinghouse Electric Company, Limited.—Your company during the past year sold additional patent rights to the above company, and with the proceeds purchased the preferred and common stock of a number of English holders, so that your company now owns $782,500 preferred and $1,397,400 common stock (together $2,079,980) out of $2,332,750 outstanding, and your company will hereafter direct all of its affairs. All apparatus sold by the London company has been purchased from your company at profitable rates, and the business of the London company last year netted nearly five per cent on a valuation of $1,000,000. It is proposed to push the business in Great Britain, Continental Europe and in the various colonies in order to increase the sales of your company's product.

Patents and Litigation.—Your company has been successful in favorably terminating the litigation in respect to incandescent lamps, the feeder and main, and other important patents, and it was especially successful in the celebrated Bate Refrigerator case before the Supreme Court, in which the life of a number of patents, which were being used to influence trade by your adversaries, was finally determined.

In the McKeesport case, argued in the Supreme Court October last, involving the ownership of the carbon burner for incandescent lamps, no decision has yet been handed down, but the long delay on the part of the Court in arriving at a conclusion is regarded as not unfavorable to the sustaining of the claims of our Sawyer Man Patent.

To-day the most important inventions are those relating to the use of alternating currents, and your management believe that, with the exclusive control of the Tesla patents its position in patent matters is more favorable than that of any or all of its competitors.

Street Railways Operated by Underground Electric Circuits.—Your company has secured the controlling interest in the stock of the Electro-Magnetic Traction Co. of West Virginia, and through it the control of valuable inventions relating to the operation of street railway cars in large cities by means of underground circuits. This system has been in continuous operation in Washington during the past year, and is now in successful operation on the tracks of your company in and about the buildings at East Pittsburg, where it is to be used for moving freight cars and for general work. This arrangement appears to be a complete solution of the problem of street car propulsion in all large cities. A model of this system is now in operation at our office at No. 120 Broadway, New York City, and will be exhibited to stockholders between the hours of 10 A. M. and 4 P. M. during July.

Tesla Power Distributing Inventions.—Your company owns the exclusive right to manufacture and sell apparatus under the patents of Nikola Tesla, covering the use of multiphase alternating currents for power distribution. The rights under these patents are of great value, for developments indicate that it is only by means of Tesla's inventions that elevated and long lines of railways can be successfully operated, and that power can be most economically distributed over wide areas, and throughout workshops. The 5,000 H. P. generators contracted for by the Niagara Cataract

Construction Company have been put in successful operation, and other important installations for power transmission under the Tesla patents have been made in various parts of the country. Recently your company has fitted a short branch of the Pennsylvania Railroad with ordinary electrical apparatus for the propulsion of standard cars, and the tests have been entirely satisfactory. Your company is, however, pushing forward the manufacture of multiphase motors under the Tesla patents for practical tests in running standard cars on elevated roads and long lines, the success of which will be of especial importance, for it will insure to your company a large amount of trade for which your rivals will have no right to compete.

Suits under the Tesla patents are pending against the Stanley Electric Manufacturing Company of Pittsfield, Mass., and the Thomson-Houston Company. In the latter case, on application made by attorneys of your Company, the defendants have been limited to the 7th of October within which to close their testimony, it being the intention of counsel to push all cases of infringement. It is estimated by experts that in the near future the bulk of the business will be done by means of alternating current multiphase apparatus, involving the use of Tesla's important inventions.

BALANCE SHEET MARCH 31.

Assets.

	1895. $	1894. $
Cash in banks	202,881	325,694
Bills receivable	80,134	373,445
Accounts receivable	2,146,131	2,345,161
Material in stock and in process of manufacture (at cost of labor and material)	2,120,228	1,545,472
Advances to leased companies	149,588	109,124
Bonds (par value March, 1895, $866,2 6)	811,271	237,397
Stocks (par value March, 1895, $8,656,009)	4,092,519	3,988,992
Real estate and buildings	464,403	464,403
New factory ($1,186,350), less mortgages ($674,3 0) on land	612,450	.....
Machinery and tools	1,159,843	886,452
Miscellaneous	70,293	66,339
Charters, franchises, patents, etc.	4,404,499	4,379,831
Total assets	16,314,241	14,722,314

Liabilities.

Accounts payable	403,017	311,749
Bills payable, issued for merchandise	379,222	116,933
Discounted with collateral	1,265,000	697,300
Contract and contingent liabilities—		
Scrip dividend	194,560	194,560
Stock subscriptions	13,125	13,125
Collateral trust bonds	250,000	.....
U. S. E. Ltg. Co.'s 6 per cent 15-year bonds, $50,000 payable annually	500,000	550,000
(Bills receivable under discount, $528,550 in 1894; $396,972 in 1895.)		
Capital stock—		
Preferred	3,993,266	3,671,965
Assenting	5,188,951	5,165,481
Common	147,700	179,150
(In treasury 134·69 shares preferred; and 13,266·98 shares assenting.)		
Surplus (see below)	3,979,400	3,822,049
Total liabilities	16,314,241	14,722,314

Surplus—	1895. $	1894. $
Balance March 31 of previous year	3,822,049	2,757,649
Twelve months net earnings from business	734,699	1,610,504
From other sources	67,710	30,304
	4,624,458	4,398,458
Less amount written off, &c	301,939	271,521
	4,322,519	4,126,936
Interest on bonds	57,387	36,000
Interest on scrip	11,674	11,673
Dividends	274,059	257,213
	343,119	304,886
Surplus March 31	3,979,400	3,822,049

The New York Times July 9, 1895

NICOLA TESLA'S INVENTIONS

As time passes, Mr. Tesla's discoveries in electrical matters assume greater and greater importance. Cassier's Magazine, special Niagara number, just issued, describes at length and in detail the work that has been done at Niagara Falls for the commercial utilization of the great power that has so long gone to waste, and in connection with this work Mr. Tesla is quoted as saying that Niagara Falls power can be transmitted to New-York and Chicago and there sold in competition with steam power generated from coal.

Much has been written concerning the discoveries of Mr. Tesla in connection with the development of light in a manner that seems startling and mysterious; but it is fair to predict that his greatest inventions will prove to be those in connection with the transmission of power by alternating currents over long lines; for, without such discoveries, the cost for transmission would be so great that capitalists would be unwilling to undertake the development of great water powers.

At the present time much attention is given to the discussion of the replacing of the steam locomotive by the electric motor on standard railways. It is already apparent that such results are possible only by reason of Tesla's discoveries, for, with the continuous current apparatus, such as is used commonly by street railway companies, it would be most difficult to make such undertakings profitable.

To carry out Tesla's inventions requires generators of special construction—that is, generators capable of producing two alternating currents of electricity at the same time, in such relation to each other that one current is at its highest voltage while the other is at its lowest voltage. These currents can be produced by the generators at any required voltage, or they can be raised from a couple of thousand volts at the generator to ten, twenty, or thirty thousand volts by means of transformers, and then led out on lines of very small diameter, and consequently low cost, and can be carried any required distance. At the point of use these currents can be again transformed to the low voltage required for the safe operation of motors. Tesla's great discovery was in the form of motor for the utilization of these double, or, as they are called, two-phased currents. Prior to his time all motors required a revolving part, or armature, having a complicated device called a commutator, upon which were pressed the brushes or collectors. This armature revolved within a frame having inward projections wound with wires, which was termed the field of the generator, or motor. Tesla found that, by winding a portion of the field with wires taking currents from one of the circuits of the two-phase generator, and the other portion from the other circuit, he could cause the armature within these fields to rotate without using commutators or brushes, the armature of the motor being so wound that the appropriate currents were induced as a result of those acting through the two sets of wires in the field.

In the operation of a railway it will often happen that fully 1,000 horse power of electricity will be required to be transferred from the trolley line to the locomotive, and to transmit this 1,000 horse power a considerable distance, at 1,000 volts, which is the utmost limit for the continuous current, would take 100 times as much copper wire for the transmission lines as would be required in the Tesla system with a voltage of 10,000; and 400 times as much as would be required if Tesla carried the current on his transmission lines at 20,000 volts, which has already been proved practicable. It will be noted in reading the accounts of the work at Niagara Falls that a commission of eminent scientists was created to determine the proper method for the carrying of Niagara's power, and this commission, after two years of investigation, finally determined upon the use of the two-phase generators, which was an acknowledgment that Tesla's method was the only practicable way of distributing the electric current for commercial purposes; and, in the technical description given by the several writers in Cassier's Magazine, the induction, or Tesla motor is always referred to as the device for the utilization of the power generated at the Falls.

That much is to be heard of the Tesla inventions in the future is a foregone conclusion, because Tesla was the pioneer discoverer of the most practicable method for the transmission of electricity for power purposes. He has patented his inventions, and has sold his rights to the Westinghouse Company of Pittsburg, which concern has taken steps to enforce its exclusive rights under the Tesla patents. At the same time, the General Electric Company and the Stanley Company, in a minor way, are making Tesla motors and installing them. Litigation is already far advanced, and is bound to keep Tesla's name prominently before the public, for an unusual patent struggle must result over the exclusive right to manufacture and sell electrical apparatus which will within a short time exceed in value all other kinds of electrical machinery manufactured by the great electrical corporations of the country. If a prominent Director and official of the General Electric Company is reported correctly, he expects some arrangement to be effected which will enable his company also to manufacture legally apparatus under the Tesla inventions.

When Tesla's discoveries were first announced, the electricians of the country and the world at large conceded their novelty and pioneer character, and for several years confined themselves to the forms of apparatus operated by continuous currents, and it was only after the Cataract Construction Company had finally determined that it was by means of Tesla's inventions alone that its operations could be carried out that the actual copying of his work was begun in various quarters. There could be no better evidence of the practical quality of his inventive genius.

LEGAL NOTES.

TESLA PATENT LITIGATION.

The Suburban Electric Company of Philadelphia has filed an answer in the United States Circuit Court to the suit brought against it by the Westinghouse Electric and Manufacturing Co. and Tesla Electric Co. for alleged infringement on various patents. The Suburban Co. denies having made infringement as alleged, and claims that the patents of the complainants for electro-magnetic motors are void because the alleged inventions and improvements and all the substantial and material parts thereof were disclosed and well-known in the art long prior to any alleged inventions held by the complainants.

The New York Times July 16, 1895

TESLA'S WORK AT NIAGARA

In 1877 Sir William Siemens, who had lately been to America, in an address before the Iron and Steel Institute, says Clemens Herschel in Cassier's Magazine for July, thus outlined briefly his views as to the possible utilization of the world's great water powers:

The advantage of utilizing water power applies, however, chiefly to continental countries, with large elevated plateaux, such as Sweden and the United States of America, and it is interesting to contemplate the magnitude of power which is now for the most part lost, but which may be, sooner or later, called into requisition. Take the Falls of Niagara as a familiar example. The amount of water passing over this fall has been estimated at 100,000,000 tons per hour, and its perpendicular descent may be taken at 150 feet, without counting the rapids, which represent a further fall of 150 feet, making a total of 300 feet between lake and lake. But the force represented by the principal fall alone amounts to 6,800,000 horse power, an amount which, if it had to be produced by steam, would necessitate an expenditure of not less than millions of tons of coal per annum.

It would not be very difficult, indeed, to realize a large portion of the power so wasted by means of turbines and water wheels erected on the shores of the deep river below the falls, supplying them from races cut along the edges. But it would be impossible to utilize the power on the spot, the district being devoid of mineral wealth or other natural inducements for the establishment of factories. In order to render available the force of falling water at this and hundreds of other places similarly situated, we must devise a practicable means of transporting the power.

As regards electrical transmission, suppose water power be employed to give motion to a dynamo-electrical machine, a very powerful electrical current will be the result, which may be carried to a great distance, through a large metallic conductor, and then be made to impart motion to electro-magnetic engines, to ignite the carbon points of electric lamps, or to effect the separation of metals from their combinations. A copper rod, 3 inches in diameter, would be capable of transmitting 1,000 horse power a distance of, say, thirty miles, an amount sufficient to supply 250,000 candle power, which would suffice to illuminate a moderately sized town.

The audience smiled incredulously, and it is unlikely that a single man present, except the orator himself, gave any serious thought to the question. It was looked upon as a dream, as a permissable vagary of an accomplished scientist. But the visitor to Niagara to-day would speedily be impressed with the fact that the dream of the great German of 1877 is the accomplished reality of this year 1895.

Attracting little attention except in the scientific papers, there has been going on there for several years a work which stands completed to-day in its details, and which is the unrivaled engineering triumph of the nineteenth century.

Perhaps the most romantic part of the story of this great enterprise would be the history of the career of the man above all men who made it possible—not an American, not a Britisher, neither a Frenchman nor a German, but a Montenegrin, a man of humble birth, who has risen almost before he reached the fullness of manhood to a place in the first rank of the world's great scientists and discoverers—Nikola Tesla.

Extremely modest and retiring in disposition, he has kept himself so far in the background during his few years of brilliant and fruitful research, that it has only been within a few months that the world has come to know him at all. Even now the world is more apt to think of him as a producer of weird experimental effects than as a practical and useful inventor. Not so the scientific public, or the business men. By the latter classes Tesla is properly appreciated, honored, perhaps even envied. For he has given to the world a complete solution of the problem which has taxed the brains and occupied the time of the greatest electro-scientists of the last two decades—namely, the successful adaptation of electrical power transmitted over long distances to the varied uses demanded in commercial work.

The earliest electric lighting was by the arc system, the peculiarities of the current rendering the system totally unfit for anything else. Next came the low-tension incandescent system, which was gradually and successfully adopted for both arc lighting and motor service. But the limitations of this system were within such narrow lines that it was proved at once to be far short of perfection in a commercial sense. The distance from the station to which this low tension direct current can be profitably transmitted is not over a mile and a half. Clearly, something else was needed.

In 1887 the single-phase alternating system was first introduced in this country by the Westinghouse Company. It was a step in advance, yet not the ideal, in that only lighting could be done by the system, there being no fit motor invented for this current.

A short time after his in 1888—patents were first issued to Nikola Tesla on a complete polyphase alternating system. He labored diligently, taking out in all twenty-nine uncontested patents, all acquired by the Westinghouse Company, covering every part of the system, and it was not long before the scientific world knew that the long-hidden result was achieved—an electrical system, perfectly well adapted for use in small villages, but still so flexible that both arc and incandescent lights and power for factories or mills can be profitably furnished twenty miles or more from the dynamo. Indeed, the limit of distance over which it may practically be transmitted is not yet fully determined, and such engineers as Mr. E. H. Kennelly and Prof. Houston assert with confidence that Albany, 300 miles away, can easily be lighted and supplied with power from the great plant at Niagara Falls.

To Tesla belongs the undisputed honor of being the man whose work made this Niagara enterprise possible, for without the possibility of long-distance transmission with practical motor service no way could have been found for utilizing profitably the almost boundless power of the great waterfall. Within a few years Tesla motors will be driving tools in every manufactory in the civilized world.

PERSONAL.

DR. NIKOLA TESLA has had the Order of the Eagle conferred upon him by the Prince of Montenegro. He has already received the Order of St. Sava from the King of Servia.

NOTES.

Critical Condition of Tesla.—Our readers will be grieved to learn, on the authority of Mrs. Bloomfield Moore, in the *New Science Review*, that Mr. Tesla is in a very awkward position. It is a number of days, says this gifted woman, since Tesla crossed the border line of the circle in which other electricians are working, but he still remains in the interatomic field of research, unmindful of the triple conditions that govern electricity in the relation which it sustains to the first order of the "luminous." This is sad enough, but we have yet to tell the worst. It appears that by reason of Tesla's wicked neglect of Keely's system of resonance he has missed the chance of hobnobbing with electrical phenomena in the sympathetic field, and is standing on a bridge which connects the primary two-thirds of the electric stream—the subdominant current with the dominant. What a fearsome post is his! But the consequences of his folly will still pursue him, and even though he may hook on to the dominant, he will still be subserved to the terrestrial neutral far in the rear of sympathetic union to radiating celestial outreach, the connecting link of which exists in the interluminous. Mrs. Moore says, further, that even in the event of Tesla's salvation, he will not have reached the compound interetheric. If such be the case, we should advise Mr. Tesla to climb down at once from his supradominant hypoluminous outreachment, and no longer seek to attain the interatomic realm, but to content himself with hard pan. The sting of Mrs. Moore is, however, in her—well, our readers will understand. Given a prompt cash settlement, and Keely will plank down all his secrets, and tell us how we may make a ten thousand ton ship float like a gossamer in the summer breeze. (Our readers will kindly take notice that this last poetic vein is our own, not Mrs. Moore's.) Failing this settlement they will die with Keely. The cosmical law of sympathetic association will then be lost to an ungrateful world, and Keely will rise on his vibratory mediums into the far outreach after a life spent in over-reaching, amongst others, Mrs. Moore.

THE RESEARCHES OF TESLA.

Inventions, Researches, and Writings of Nikola Tesla. By Thomas Commerford Martin. (New York: *The Electrical Engineer*, 1894.)

WE have here an account of Nikola Tesla, his scientific inventions and work, by a devoted admirer. Mr. Martin is not a Boswell, and from the nature of the case his book could hardly have about it all that human interest which pervades the life and achievements of a veteran discoverer in science. Mr. Tesla is a young man whose career has been somewhat romantic, and whose ingenuity is such as to rank him very high indeed among the electrical workers and discoverers of the day. Born in Austro-Hungary, educated at the Realschule at Carstatt and the Polytechnic at Gratz, and professionally first in the Government Telegraph Department, and afterwards in Paris, his career as an engineer really began when he arrived in America little more than ten years ago.

In two or three years from the day on which he took off his coat in the Edison Works, Tesla motors had attracted attention, and he leaped at once to a position as a successful experimenter and inventor, which his subsequent work has only secured and made more important. His researches on the effects of alternating currents of high potential and frequency, in particular, though they had the misfortune to be made the subject of the speculations of the ordinary journalist, are of great scientific interest, and continued by Mr. Tesla himself and the army of enthusiastic workers we now have, cannot fail to yield theoretical results and practical applications which will more than fulfil the anticipations of those who took a sober and rational view of their possibilities. None of those who listened to Mr. Tesla at the Royal Institution will soon forget the almost marvellous experiments performed, their clear exposition in what was to the lecturer manifestly a foreign language, and the enthusiasm which the results displayed excited in those present who were best able to judge of their scientific interest and importance.

Mr. Martin's account of Mr. Tesla's work is interesting, and yet perhaps it might have been in some respects better than it is. He has had excellent materials, such as the various lectures delivered by Mr. Tesla on his researches generally, the papers read from time to time to scientific societies on particular inventions and points of interest, and apparently the specifications of Mr. Tesla's patents. Our complaint, if we have one, is that this material has hardly been sufficiently worked up. Many of the lectures and papers were, as was inevitable, hurriedly composed, and the expression of Mr. Tesla's theoretical views contained in them is not always so clear and complete as it might have been made by one not so rapidly carried forward by the stream of discovery. A great inventor can hardly be expected to spend time weighing words and phrases, at any rate he has a title to be excused from doing so, which others who expound him do not possess. As it is, Mr. Martin's book is on the whole a reproduction of articles which appeared from time to time in the *Electrical Engineer* (of New York), and all we wish is that he could have spared the time and trouble necessary to cast the matter into a more homogeneous and symmetrical form.

For the lectures which are reproduced we are very grateful. They give Mr. Tesla's own description of his inventions, and his views on points of theory—views, which if not always orthodox, and sometimes expressed in language which appears strange, are always fresh and suggestive. The unavoidable repetitions of the same ideas, and recurring descriptions of the same apparatus, are not without some advantage, though they interfere with the unity of Mr. Martin's book, as they enable the lecturer's meaning to be made out more completely than would otherwise be possible.

The book is divided into four parts: Polyphase currents; Tesla effects with high frequency and high potential currents; miscellaneous inventions and writings; early phase motors and the Tesla oscillators. The two first parts are of course much more interesting than the remaining two, which have to do with such things as oil condensers, anti-sparking dynamo brushes, unipolar generators, the Tesla exhibit at the World's Fair, and the Tesla mechanical and electrical oscillators.

The discussion of polyphase currents, which occupies the first 115 pages of the book, has more unity of treatment about it than the second part, which consists mainly of the lectures Mr. Tesla delivered in this country and America. After a short introductory and biographical chapter, Mr. Martin proceeds to expound the principle of the rotating magnetic field and the construction of synchronising motors. A paper by Tesla, on a "New System of Alternate Current Motors and Transformers," is reproduced in this connection, and contains the foundation on which is based the remaining twenty-one chapters which make up Part i. These contain numerous modifications of the original idea, many of them exceedingly ingenious. A motor "depending on 'magnetic lag' or hysteresis" is described in Chapter xii. The peculiarity of this is stated in an introductory paragraph to be "that in it the attractive effects or phases, while lagging behind the phases of current which produce them, are manifested simultaneously and not successively." This statement itself seems to want some little exposition, though the arrangement is really very simple. An iron disc is pivoted within a fixed coil, wound just

large enough to admit the diameter of the disc one way, and a little more than its thickness the other. The coil carries two pole-pieces, one at each end, which project from opposite sides a little way round the disc. Thus opposite poles are stretched out as it were from the coil round the disc in the same direction. An alternating current passed round the coil magnetises both these pole-pieces and the disc, and the repulsion between the adjacent similar polarities of the disc and pole-pieces produces the rotation, the polarities of both being of course reversed with the current. The disc is wound with closed coils, so that the induced currents augment the turning couple developed. This arrangement is further developed into a "multipolar motor"; but in neither case is there any clear statement of how the action depends on hysteresis.

In connection with these and similar devices it would have been interesting to have had some estimate of efficiency, but generally speaking, in no part of the book is there any discussion of this most important question. Indeed, when the word energy is used it seems to bear a somewhat peculiar sense. For example, at p. 81 we have a statement as to the "energies" of the field and the armature, and the importance of these being equal if for a given sum the motor is to have the greatest efficiency. This passage is a little difficult of interpretation, if the word energy is to be taken as it ought to be in its technical sense throughout, though it is not very hard to make out the idea intended.

By far the most interesting portion of the book to a student of electricity generally is Part ii. The alternator of high frequency which Mr. Tesla used is fully described, and the arrangements for using it explained in the first of the lectures already referred to. The phenomena produced are set forth in the remaining chapters with numerous illustrations which render the descriptions very easy to follow. The whole subject of high frequency phenomena is very intimately connected with the researches of Hertz on the one hand, and the work of Mr. Crookes on the other, and forms a most inviting field of research for experimentalists who possess the necessary equipment. Whether always the theoretical view taken by Mr. Tesla is correct, is matter for legitimate difference of opinion. For one thing, we do not think that there is any difference at all between electric force produced by what is properly called electrostatic action and that produced by electro-magnetic action. The distinction is only mathematical—the former force can be derived from a potential function, the latter cannot—and in a sense only expresses our ignorance of the mode of production of the force. But perhaps we are mistaken in supposing that Mr. Tesla regards the electric forces in these two cases as different in nature.

To every physical inquirer the perusal of these lectures cannot but be of the greatest benefit. It will again remind him that the field of research is unlimited, and quicken his scientific enthusiasm, if not to taking part in the work of this particular part of it, to at least prosecuting with renewed vigour the inquiry, whatever it is, which lies ready to his hand.

It was reported a few weeks ago that all the apparatus and machinery belonging to Mr. Tesla had been destroyed by fire. Every reader of his researches must sincerely sympathise with Mr. Tesla in his loss of valuable appliances and still more valuable time. That he at once set himself to repair the loss is only what was to be expected from his character; let us hope that it may result in such improvements of his means of experimenting as may, in some measure at least, make up for his disappointment, if it is not, what is perhaps too much to suppose, turned into a blessing.

A. GRAY.

Critical Condition of Mr. Tesla.

[*From the London Electrical Review.*]

Our readers will be grieved to learn, on the authority of Mrs. Bloomfield Moore, in the *New Science Review*, that Mr. Tesla is in a very awkward position. It is a number of days, says this gifted woman, since Tesla crossed the border line of the circle in which other electricians are working, but he still remains in the interatomic field of research, unmindful of the triple conditions that govern electricity in the relation which it sustains to the first order of the "liminous." This is sad enough, but we have yet to tell the worst. It appears that by reason of Tesla's wicked neglect of Keely's system of resonance he has missed the chance of hobnobbing with electrical phenomena in the sympathetic field, and is standing on a bridge which connects the primary two-thirds of the electric stream—the subdominant current with the dominant. What a fearsome post is his! But the consequences of his folly will still pursue him, and even though he may hook on to the dominant, he will still be subserved to the terrestrial neutral far in the rear of sympathetic union to radiating celestial outreach, the connecting link of which exists in the interluminous. Mrs. Moore says, further, that even in the event of Tesla's salvation, he will not have reached the compound interetheric. If such be the case, we should advise Mr. Tesla to climb down at once from his supradominant hypoluminous outreachment, and no longer seek to attain the interatomic realm, but to content himself with hard pan. The sting of Mrs. Moore is, however, in her—well, our readers will understand. Given a prompt cash settlement, and Keely will plank down all his secrets, and tell us how we may make a 10,000-ton ship float like a gossamer in the Summer breeze. (Our readers will kindly take notice that this last poetic vein is our own, not Mrs. Moore's.) Failing this settlement they will die with Keely. The cosmical law of sympathetic association will then be lost to an ungrateful world, and Keely will rise on his vibratory mediums into the far outreach after a life spent in overreaching, amongst others, Mrs. Moore.

TESLA'S MOTOR.

WHILE the Westinghouse Electric Company and the Baldwin Locomotive Works are combining the resources of their tremendous plants and are exerting all the energy that lies in millions upon millions of dollars to develop the possibilities of the Tesla motor, which some day will draw cars at a speed of 150 miles an hour, the inventor, Nikola Tesla, plods along in his workshop, planning and scheming and experimenting and maintaining a profound silence.

This workshop—a long, bare room at 46 East Houston Street—is fitted up with only a few electrical appliances. There Mr. Tesla is to be found every day, sitting at his desk, tinkering with figures and drawings. A Recorder reporter called upon him recently to learn something about this fabulous motor, which is going to send heavy trains rushing through space at such a terrific speed. As far as gaining any information from Mr. Tesla was concerned, the visit was fruitless.

Gently, yet very firmly—the manner was born of long experience—Mr. Tesla declined to be interviewed. The reporter, however, was allowed to see the marvelous motor, and later in the day, through the kindness of a gentleman who had devoted much time to studying the principle upon which it is constructed, was told exactly how the motor works. Truly, it is a marvelous invention The secret lies in turning the inert and seemingly lifeless force of magne ism into an active force more powerful than steam or a current from a dynamo.

If you take an ordinary magnet or a piece of iron, through which a magnetic current is passing, and hold it close to little pieces of iron or steel it will attract them and hold them motionless. This is practically all that the world has ever known of magnetic force. Now it seemed to Nikola Tesla—this was years ago, when he was a student in the Polytechnique—that this invisible force, pent up within the confines of the magnet, might, perhaps, be developed or transmitted or changed or utilized in such a manner that it would become active and quick where it had always lain passive. Upon this theory he worked for years, and its triumphant development led to the Tesla motor. The principle of the Tesla motor is this:

An electric current is passed through a circular magnet, in appearance resembling a life preserver. It consists simply of a ring of iron with copper wire bound around it. The electric current generates a strong magnetic current, which flashes around and around the circular magnet at terrific speed. Now if one holds a nail close to an ordinary electric magnet, it will be passive in the hand until it is brought close enough for the magnetic force to seize it, when it will fly out of the hand straight to the magnet. But—and here lies the wonder of it all—if one holds a nail close to this circular magnet of Tesla's, it will begin to revolve in the hand. That is, if the nail is held by the head and the point allowed to hang over the hollow center of the magnet, the point will move around in a circle, slowly at first, then faster and faster, until if it is dropped upon the table in the center of the hollow, it will spin around so rapidly that the eye cannot follow its motions.

One hears the explanation of the phenomenon—there are several magnetic currents in the iron ring, and they are chasing one another around in a furious race—and is as much mystified as ever. If one balances an iron wheel upon the nail or lets the wheel revolve upon a finger, using the finger as the axle, and holds it close to the magnet, it will fly around at a speed that will take one's breath away. It is not necessary to touch the magnet at all. All one needs do is to hold a piece of iron or steel in his hand and bring it within a foot of the magnet, and then he will feel a queer sensation as of some invisible force trying to draw the piece of metal out of his hand, and, failing in this, striving to twist it around in a circle.

If one places a wide board over the whole magnet, the force will make itself felt through the wood, for if a piece of iron shaped like an egg is dropped upon the board it will wobble around for a moment and then, as soon as it gains a little momentum, it will spin around on its narrower end like a top.

Such is the principle of the Tesla motor. In its application as a motive power on a railroad, the construction, of course, differs from that of the experimental magnet, but the idea is the same.

Here the circular magnet is attached to the bottom of the engine and the axle upon which the wheels revolve passes through the center of the magnet without touching it. When the current is turned on, the magnetic force whirling around in the hollow of the magnet catches the axle and turns it. The power for generating this magnetic current can be transmitted by underground wires for almost any distance, and there is practically no waste of power or energy.

The Westinghouse Company controls the American patents of this motor. Its application to railroads is merely one of its uses. Dozens of skilled mechanics are at work constructing machines which embody Mr. Tesla's idea in various forms and for various purposes, and electricians believe that before long it will have revolutionized electrical science.

As far as its ability to propel cars at a speed of 150 miles or more an hour is concerned, no expert whom the reporter saw has the slightest doubt of it. One electrician said:

"As far as speed is concerned, Mr. Tesla's invention contributes all that electricity can do as a motive power. There is not the faintest doubt in the world that the Tesla motor will propel a car at the rate of 150, 200—I hardly hesitate to say 300—miles an hour. Now, however, they must build engines and cars and roadbeds and tracks to stand the strain, and when they have done that rapid transit will be attained."—N. Y. Recorder.

HARNESSING NIAGARA.

THERE is no class of professional men who travel so much as engineers. Their experiences are often full of interest, and at times not devoid of excitement. Yet how seldom it is that any account of these travels is found in print. This is partly due to the fact that it all seems to the principal actor to be all in the day's work, and hardly worth committing to paper. But there is also a certain pleasure in having a store of experiences to relate to one's more intimate friends, which the vulgar crowd cannot read in a book.

At the present moment I am tempted to curb this natural reticence with the object of narrating my experiences of the last few years, which I believe are unique in our profession. Our engineers are often called upon to travel in difficult countries, and to accomplish what look like impossibilities. But it is by no means an everyday occurrence for the financial men in a great country like the United States, who are not in the habit of minimising the capabilities of their fellow-countrymen, to invite a foreigner to carry out one of the greatest works of modern times in that country. Some people say that the Americans are perhaps too much inclined to look upon their countrymen as the inventors of Electricity. It is, then, all the more surprising that the work about which the English engineer was asked to advise them was the electrical utilisation of Niagara Falls. It must, however, be remembered that this work involved entirely new problems and designs, while the American electrician has less capability of evolving entirely new plans, or designing entirely new machinery, than of adapting his past experience, exactly as it stands, to new conditions. It was for this reason that one of the ablest of American engineers said in public three years ago that it was impossible to transmit the power of the Falls to Buffalo, some twenty miles, so as to make it pay; whereas we have now established the fact that the limit of distance is to be counted by hundreds of miles.

There are two great mistakes commonly made as to Americans. One is, that they are original inventors; the other is, that they are humorous. Neither of these propositions is true. It is true that if asked to create a knitting-machine, or a type-writer, or a reaper, they will put together well-known mechanical devices to accomplish the result. But this is designing, not inventing; and the cause of so much work of this kind being done in America is the high price of labour, which must be replaced by steam and machinery. So with humour, with of course some brilliant exceptions, their periodical literature is filled with so-called wit, but it smells strongly of the midnight oil. I remember an incident related to me by an editor of a weekly journal. He said, "Yesterday a poor miserable man came into my office and laid before me some manuscript and said, 'O Mr ——, I wish you would look through these jokes and pick out any you can use. I was working at them all last night, and I need money badly to bury my poor wife.'"

Invention and humour require a gift of imagination, the same gift that shows itself in poetry and letters, in music, painting, and sculpture; and in no one of these directions has this gift of imagination been found to predominate amongst Americans.

I have given these reasons why it was perhaps natural to have recourse to a European to take hold of this great and entirely novel problem. Another reason is that all their electricians who may have had a wide practical experience are tied to manufacturing companies, and cannot be looked upon as independent either in thought or action; and since it was pretty certain that any plans that might be adopted would have much of novelty in them, and would be opposed in the first place both by scientific men and by the manufacturers, it required that the man selected should have nothing to gain or lose by the friendship or hostility of these two classes of men.

When I had finished my work at Niagara Falls the chairman (or president, as he is there called) of the company wrote me a letter, in the course of which he incidentally mentioned some of the reasons why I had been invited to carry out this work. These are given later on in this article.

Passing now from these digressions, let us come to the Falls themselves. I have no talent for pictorial description, and they are well known to a large number of my readers. I will only say that the river Niagara leaves Lake Erie at the City of Buffalo and meanders, innocently enough, through level plains for sixteen or eighteen miles, passing on the two sides of the Grand Island and then opening out into a wide lake-like expanse a mile wide, where, a mile above the Falls, the current becomes more swift. It then is parted in two by Goat Island, the narrow part dashing down by furious rapids to the American Fall, which is a straight curtain of water shooting down a perpendicular height of 160 feet. The wider branch makes a turn round Goat Island and is very wide, and the breakers dance merrily in the sunshine, until the waters concentrate themselves at the Horse-shoe, or Canadian, Fall — the greatest volume of water being at the V-shaped apex in the centre, where the depth of water at the lip is sufficient to impart a brilliant emerald colour to the water. From the Falls downwards for many miles the river runs through a precipitous gorge. For the first mile it is sluggish, but with gurgling upheavals of the water from below. Then come the terrible whirlpool rapids where Captain Webb was drowned. After that a sulky repentant river creeps to Lake Ontario.

There are three things at the Falls themselves which rivet the attention. 1. The water takes four or five seconds to fall, and in doing so it assumes the most fantastic forms of drapery. 2. The mist and spray rising from the base of either Fall is drifted by the wind, or in a calm rises in a cloud 1000 feet in height. 3. The third feature is the noise. You have not only the rushing noise of the Rapids, but also a booming, at times resembling a thunderclap, when the somewhat intermittent flow tumbles upon the water beneath, and shakes the foundations of houses half a mile away. The village or town of Niagara Falls on the American side of the river is built of wood. It is dirty, and the streets are bad. Its industry is the catering to excursionists. Cheap restaurants, merry-go-rounds, itinerant photographers, and museums of Indian and other

curiosities are the chief features. The last are mostly impostures, always excepting the world-famed "Katie & Libby's Stores," where genuine curios are to be found, and many pleasing souvenirs. This village is remarkably conducive to the concoction of lies, and the Falls lend themselves to the art. The prophets of this cult are the hackmen (cab-drivers), who earn the gratitude of the excursionist by the thrill of their narratives. I believe, however, I have reliable evidence for some remarkable statements. 1. On the 1st of April 1848 the Falls ran nearly dry owing to a stoppage by ice and a strong east wind on the lakes. 2. A drifting ship, drawing sixteen feet of water, went over the deepest part of the lip of the Horse-shoe Fall. 3. A steamer called the Maid of the Mist, built at the Falls, traversed the Whirlpool Rapids in order to escape creditors, and reached Lake Ontario in safety. I cannot, however, vouch for the generally-accepted statement that in doing so she turned a complete somersault. 4. At the Whirlpool there is a path descending to the water to a spot where they catch the bodies that float there. There is an average of one suicide a month, and they are invariably trapped by the Whirlpool. 5. There is another true story which is rather startling. A hundred yards above the brink of the American Fall a rock ten feet square projects for a foot above the water in mid-stream. One morning the inhabitants awoke and saw a man sitting on it. The noise of the Rapids prevented verbal communication. They did not, do not, and never will know how he got there. He stayed there thirty-six hours. The people telegraphed to Buffalo, and the railway company sent one excursion train after another for thirty-six hours to see the man on the rock. They painted signs and stuck them up for the man to read, saying, "We will save you." Two hundred yards above there is a bridge. From this, by ropes, they floated rafts with provisions to him. At the end of his stay a big one came for him to get on. What they were going to do with him if they got him in this seething rapid I know not. He tried and failed, and went over the Fall, and that is all!

People are differently affected by their first sight of the Falls. Some say, "How disappointing!" others, "How magnificent!" Some (Colonel Bob Ingersol was the first to say this to me, but I have heard the same from others), "How horrible!" and others say, "How seductive! I want to go over with the water."

The Falls in winter are totally different from what they are in summer. Every bush and tree is a work in silver filigree. The precipices are concealed behind icicles 60 feet long. Every rock in the river is the nucleus for a dome of frozen spray rising 150 feet it may be.

When you know the river you will love it; but to know it you must see it at every season and at every hour—at sunrise, noon, and by moonlight; in sunshine and storm; with the mist rising as a tower, or drifting away to unveil new points of beauty. You must know every corner, peaceful or violent; you must see it from above and from below, and from every point of view, and always you will hear that thundering boom that shakes the ground. It is best to live on the Canadian side at the Clifton House, open only in summer. The most impressive points of view are those that make you feel the smallest. Mr Bayard, the United States Ambassador in London, tells me that the only true way to appreciate the grandeur is in the early morning to swim across from the Canadian to the American side, just below the Falls. He has often done it, so he ought to know.

To me the great charm of the Falls is their immutability and change. The drifting spray and varying light give the changes of a kaleidoscope, but the volume of water pouring over never varies. They remind me of the face of a dear friend, always the same but never two moments alike. I suppose there is nothing to compare with them in size or grandeur except the Victoria Falls of the Zambesi; and Livingstone, who never exaggerated, said that these were the finer.

The "utilisation of Niagara" is a hateful phrase to the lover of nature. But it must be stated at the outset that what is being done does not in the least degree affect its beauty. Only a small fraction of the water is to be used, and all the works are more than a mile above the Falls.

It is time now to leave the digressions about the beauties of Niagara to explain how it is possible to make use of this power without affecting the scenery. Now, "gentle reader," do not for a moment imagine that I am going to burden you with engineering details in any part of this article. I hope to allude to them only in such a manner as to excite your interest rather than to bore you. Any one who has visited the Falls of late years knows that the land on the two sides has been appropriated by the United States and Canada respectively for national parks. The old mills which used to be in the stream above the American Fall have been removed for æsthetic purposes, and the land laid out with some attempt at good taste. On the Canadian side the same thing was done, but I regret to say that the rapacity of the Legislature of Ontario has not proved equal to withstanding the blandishments of the greedy capitalist. Two lines of rails traverse the whole of the National Park at the edge of the gorge. After the land had been confiscated by the Government, and the owners had been paid only a fraction of its true value, it is now turned into a source of revenue by the Government, and a gold mine to the capitalists, at the expense of the visitors, who can no longer enjoy the peaceful quiet which Lord Dufferin tried so hard to give them.

In spite of all that the Americans have done for preserving the beauty of the Falls, there is one terrible eyesore—a large number of mills have been erected at the edge of the precipice over the gorge. To these the water of the upper river has been led by a canal passing through the town. This water drives water-wheels or turbines in the mills, and is then shot over as waste water down the precipice. Not only is this hideous in itself, but it is repulsive to the engineer, because of the great waste. They use only a few feet of the fall, and waste over 100 feet.

Thirty years ago an American engineer of the name of Evershed proposed a plan by which the mills should not be in view of the Falls, and by which the power might be utilised without detracting from their appearance, and the fundamental idea of this plan has now been actually executed. Mr Evershed's idea was to take in the

water from the river by a long canal a mile or two above the Falls. Along the banks of the canal mills were to be placed requiring power. At each mill a hole or shaft was to be dug in the ground to a depth of about 150 feet. The bottoms of these shafts were to be all connected by a long tunnel passing from them under the town at a gradual slope, and emerging at a tunnel mouth below the Falls, on a level with the lower river. At each mill-site a water-wheel or turbine was to be placed at the bottom of the pit, which would rotate a vertical steel shaft coming to the surface. At the top this shaft would, by means of cog-wheels or belts, turn the machinery of the mill. In this way the canal was to bring water to the pit, and, having given up its power to the water-wheels, was to flow away by the tunnel into the lower river. Such a tunnel has been built, though the details of Mr Evershed's plan have been altered. The result is that the factories and mills are far distant from the Falls, and do not interfere with the views. The tunnel has been built so as to be capable of using 100,000 horse-power or more. There are not many manufacturing towns in the world whose steam-engines all combined would give so enormous an amount of power as this. As Dominie Sampson would say, "It is prodigious!" The tunnel-mouth can be seen from the Canadian side of the river, and looks like a mere speck compared with the volume of water which is pouring over the Falls. A single glance is sufficient to convince anybody that even when 100,000 horse-power, or many times that, has been used, the effect will be imperceptible. But even now the water which is being used issues from the mouth with great velocity, and sets up quite a strong current across the surface of the stream.

Probably every engineer who ever visited this spot has been struck with the vast amount of power going to waste. But I am very doubtful whether its use could have been a commercial success before the electrical art had been so much developed that it was possible to distribute power by its means for all kinds of purposes.

Nevertheless, before this question had been entered upon, some New York capitalists were found who were prepared to take the matter in hand. At that date such an action was a bold stroke; but fortune in this case favoured the bold, and the electrical work which I have carried out has been done at a cost which even now seems incredible to many.

In 1889 the Niagara Falls Power Company was formed to carry out this work, and their first act was to buy up all the land in the neighbourhood. The capital subscribed was wholly American, and amounted to £2,000,000, about one-half of which has been spent. The acting committee consisted of railway men and lawyers. The chairman, as usual, is called a president. They like giving big names to things in America. A pond is a lake, and a hill is a mountain; they never speak of the sea, it must be called the ocean; a meeting is a convention, a dictionary is a "speller and a definer," a town is a city, a chairman is a president, and so on. The only exception I know of is that the wealthy people who own those charming country residences at Tuxedo and Lennox call them cottages. But these are not average Americans, and in that country

the manners and customs, as seen by the ordinary traveller, are governed by the average man, who is not a good specimen. He is apt to be a most awful "bounder," has no taste, and does not know the meaning of the word "repose"; but you need never meet this type except in railway trains and hotels. His ideal, as one of them told me, is to spend his nights "on the cars" and his days in getting the better of his fellow-men. But the refined American is quite different. These are mostly met in Washington and the south, and, of course, Boston is a thing apart; and as you approach this town you are told that the humming you hear is the noise of people reading Browning. Tuxedo also is a great exception, where you can have congenial society. It is a large estate with woods and lakes and forty miles of well-laid roads. Country houses or cottages have been built all over it, and there is an excellent residential club—into which, however, the female element has progressed so far as to have introduced even babies into the bedrooms!

I must really ask to be excused for such digressions, but I must tell my story in my own way or leave it alone. The chairman of the company which has utilised the Falls is Mr E. D. Adams, well known as a banker and a reorganiser of railways. The first vice-president is Mr F. L. Stetson, a lawyer who has also had much experience in the finance of railway companies. Mr Cleveland, the U.S.A. President, is a partner in his law business. The second vice-president is Mr E. A. Wickes, also a railway-man. The secretary and treasurer, Mr W. B. Rankin, is one of the most able and energetic and charming men I met in the States. I only hope he will not utterly ruin his health by overwork. All these are very able business men, though not engineers, and the affairs of the company could hardly be in better hands.

In October 1889 the Niagara Falls Power Company was formed to carry out the great work of utilising the Niagara Falls on so gigantic a scale that all previous attempts to use water-power at once sank into insignificance. The Cataract Construction Company was at the same time formed by the same people to carry out the work. All that they had then settled was that they would make the tunnel proposed by Evershed for carrying away the used water. They had not settled whether the mills should be brought to the power, or the power to the mills. They had no estimates of the cost. If power were to be distributed to mills and factories, they had no notion whether it would be by means of air or water under pressure in pipes, or by wire ropes, or by electricity. None of the acting committee were engineers, but they had faith in the evolution of ideas which would culminate in success.

In order to obtain more definite ideas they invited certain engineers to prepare plans of any methods they might think best. These were to be laid before a Commission of engineers and physicists from England, France, Switzerland, and America, with Lord Kelvin as chairman.

At first I declined this invitation on the grounds that the method of competition is contrary to my professional practice, and also that with so novel a problem I would not accept any man, or combination of men, to adjudicate upon the project which I might decide upon.

Having learnt, however, accidentally, that any electrical plans to be submitted would not be of a satisfactory nature, I withdrew my refusal in order that a plan, as I conceived on proper lines, might be at least in evidence.

Up to this date there had been only one example of electric-power distribution, and that was in a small village called Oyonnaz, on the frontiers of France and Switzerland. But the problem now before me was entirely new in many ways, besides being of gigantic proportions. The object was to send *power* rather than *light* over the wires. But I found that every different user of the power would want his electricity delivered at a different pressure (it is not here necessary to understand the meaning of the words "electric pressure"). House-lighting, street-lighting, electric tramways, flour-mills, metallurgical processes, all required different "pressures." Also, if we were to carry any of this power through wires to a distance, the "pressure" must (for sake of economy) be very high during transit, and be reduced at the place where it is used.

Now let me say, without explanations, that there are two kinds of electric current—a "continuous current," always flowing in the same direction, and an "alternating current," in which the direction of flow is reversed, it may be hundreds of times in a second.

I soon realised the fact that not only could the latter current be more easily obtained at high pressures, but that it could easily, and without moving machinery, be transformed to any required pressure at any spot when it was wanted.

Up to that date, 1890, both kinds of electric current had been used for electric lighting, but the alternating current had never been used for giving mechanical power except in an experimental way. For this reason it seemed to most people absurd to suggest its use for Niagara Falls. I would have shared this view were it not that for several years I had visited the United States and the continent of Europe to study the progress that others were making in electric work. I had thus become well acquainted with the system which Nicola Tesla, a young Montenegran, was experimenting on at Pittsburg, U.S.A., called a "two-phase" system. He distributes two alternating currents, one of which attains its maximum when the other is at its zero value. With these two currents a simple form of motor could be worked to supply power to shops, factories, or mills. I also had seen many things in various parts of Europe not generally known in England. Owing to these varied experiences, I had an opportunity above all others at that date of foreseeing that the alternating current would soon be very generally applied not only to light, but also to motive power.

Acting upon this knowledge, I worked out complete plans, using only machinery which could then be got in the open market, and was able to furnish complete working plans, drawings, specifications, and estimates of cost. This laborious work when concluded left no doubt in my mind that the alternating current must be adopted.

The Commission sat upon these plans, and, as I expected, denounced the alternating current, for none of them had had the experience which I possessed of

the latest developments. How well I remember walking along Piccadilly with a member of the Commission. He told me of this decision with an air of sympathy with my supposed misfortune. He was somewhat surprised when I replied that nothing could have given me greater satisfaction than this decided expression of opinion, "for," I said, "the alternating current will certainly be adopted at Niagara."

I heard no more from the promoters of this enterprise for over a year. It took them all this time to realise that the Commission had made a mistake. Lord Kelvin was the most violent opponent of the alternating current; and for long afterwards (although he is my most esteemed and oldest scientific friend), even when I was appointed as the consulting engineer, he continued to write and cable to the company, though his opinion on this point was not asked for, telling them that they were making a "fatal mistake" if they followed my advice. His latest expression of opinion in this sense was in November 1894, when my work was practically completed. Such a line of action has hitherto been unknown among professional men. I need hardly say that this opposition on the part of so eminent a man was a stumbling-block which might well have wrecked the whole scheme; but in this and other points where my plans were at variance with the opinions of others, I was most loyally supported by the directors, and through this support alone they and I have been enabled to put the works into their present satisfactory condition.

To add to the difficulty, the highest scientific authority in the States had taken up the same position as Lord Kelvin. Fortunately, however, the year 1891 saw some great developments in the use of alternating currents for motive power in Europe over a distance of 112 miles, and our American opponent frankly confessed to a change of opinion owing to the results then attained.

Early in the year 1892 it became evident to the acting committee that the views of engineers had been undergoing a change, and that the use of alternating currents for Niagara was a necessity, thus indorsing the prophecy I had made long before. They then asked me to act as their electrical consulting engineer, and during that year and the next and the next I was almost constantly in the States. The only real rest I ever got was in my voyages across the Atlantic. I soon came to feel at home on all the large liners. The Campania, Lucania, Umbria, Etruria, Majestic, Teutonic, and many others were havens of rest; and one always feels glad to meet old friends in Captains M'Micken (now, alas! dead), Haines, Parcell, Walker, M'Kay, Murray, and many others. The misfortune is that at most seasons the only class who travel much are American bagmen, or drummers, and they are not a favourable class to judge Americans by.

Sometimes I lived in New York, where the offices were; sometimes at Niagara, to be near the works. I did not care to go much into society, but I made some very firm friends, specially the Hewitts, and our amiable Consul-General Sir William Booker and his charming American wife. My greatest friend of former days had been S. L. M. Barlow, a well-known and remarkable man. Roscoe, Conklin, and I used to dine with him

every Sunday. These two lawyers, both able men, on opposite sides in politics, and also in the great Stewart will case, amused and instructed me much by the exposition of their views on men and things. Both were dead now, and I had two friends the less to help me to pass these three years. Part of the time I lived at Tuxedo, an hour from New York, where you could have fishing, shooting, boating, bathing, and golf; and I shall never forget the cordial welcome I there received from the Potters, Bruzes, Lorillards, Delafields, Fishes, Kents, Rushmores, Prestons, Van Courtlandts, Van Nests, and from Allen Lathrop and many others. The lovely scenery and genial society of this place helped me greatly to retain health during a period of anxious and arduous work.

Now I must go on to describe what has been accomplished. The tunnel of which I spoke is 21 feet high and 19 feet broad, and is horse-shoe-shaped. It was expected that no lining would be necessary, but at the outset the roof began to fall in, and it had to be lined with four courses of bricks, increasing the cost largely and diminishing the capacity from 120,000 to 100,000 horse-power. The tunnel is 7000 feet long, mostly on a slope of 7 feet in 1000 feet. At the mouth there is a curved surface of iron for the water to flow over smoothly. The level of the water below the Falls varies a good deal. Sometimes it is far below the tunnel-mouth, at other times it is several feet above.

The plan of having a separate shaft for a mill has been adopted in only one case, the largest paper-mill in the country, where at present 3300 horse-power is being used. The paper is made out of wood-pulp, and trunks of trees have to be ground down for this purpose. This accounts for the large amount of power used.

It is intended to supply all the rest of the power from a great power-house where electricity is generated. Within this building a slot in the ground, communicating with the tunnel, has been excavated to a depth of 150 feet. It is 20 feet wide and some 150 feet long. Parallel with this slot there is a canal of great width taking in water from the river. From the canal to the slot there are water-passages from which iron pipes $7\frac{1}{2}$ feet diameter descend to the bottom of the slot. At the bottom of these the water passes into the casing of the turbines, and in passing through these develops power to the extent of 5000 horse-power for each unit. Three of these are in place. The power is given to a vertical shaft $2\frac{1}{2}$ feet in diameter except at the three bearings, where it is less. This steel shaft extends right up to the surface of the ground, and is attached at the top to the revolving part of the dynamo, which generates the electric current. Two designs of these turbines or water-wheels had been received from Swiss makers, and the selection of the best was intrusted to another English engineer, Professor W. C. Unwin. The company has, besides its powers on the American side, acquired a control of the rights on the Canadian side, rendering the undertaking international in its character, and also in the benefits to be conferred. In the autumn of 1892 Professor Unwin accompanied me to the Falls, and he then made a study for the company of the hydraulic work to be done on the Canadian side. So

that English engineering has been represented in more than one part of this great work.

In 1892, when I came to examine the plans put in by various manufacturers, I found that some of the crudest work conceivable had been submitted by the Americans. The Europeans sent some excellent designs, especially the Oerlikon Fabrik, near Zurich. But these makers were handicapped by the duty imposed on machinery imported into America. There was, however, one fatal defect in all the plans then or subsequently submitted by the manufacturers. I must explain that all the revolving parts of turbine, shaft, and dynamo have their weight supported by a hydraulic piston in the turbine—being balanced, in fact, by the water-pressure. The total weight which could be supported was thus strictly limited. Also, the designers of the turbines (Messrs Faesch & Picard of Geneva) required that there should be a certain momentum or fly-wheel effect to assist the regulation of speed. In none of the designs submitted had the revolving part of the dynamo sufficient fly-wheel effect. In every case it was necessary to add a large heavy fly-wheel; and in every case this increased the weight beyond what was permissible. The American manufacturers were entreated to alter their dynamo designs to meet this difficulty. They tried, but they were unable to do so. We were then in a most awkward dilemma, and it looked as if a serious departure from the original design of turbines must be made. Meanwhile I had been constantly working at various new designs, and at this stage I saw that, for the credit of the company, it was imperative that I should, if possible, get out a design on new lines which should have the required fly-wheel effect without too great a weight. A dynamo always consists of two main parts, a fixed and a revolving part. In every one of the many designs sent in the revolving part was central—*i.e.*, inside of the fixed part. It occurred to me that if I could make the external part revolve I should get a maximum of fly-wheel effect with a minimum of weight. By making the external part bell-shaped, I was able to attach the centre or top of the bell to the top of the vertical shaft, and the central fixed part resting on the floor could be reached from below. I proceeded to get out rough designs, and found, with the utmost satisfaction, that I could meet all the requirements of the turbine-makers. I also found that this design gave far greater mechanical strength to the revolving part of the dynamo—an important matter, with this forty tons revolving more than four times a second. Further, the magnetic attractions which in all the other designs increased the dangers from centrifugal force, in my design actually diminished them. It soon became evident that this happy idea of revolving the external parts completely extricated the company from the very awkward dilemma in which they had been placed. I then proceeded with a large staff of draughtsmen to get out the working drawings, and I secured an American patent as a protection to myself and my company. It was a matter of considerable satisfaction to all concerned that I had thus so simply got over the serious difficulty which at one time threatened us with starting afresh on all the machinery, turbines and

all. We were now able to feel quite easy about the hydraulic and electric generating plant. The only weak part in the scheme seemed to me to be the vertical steel shaft. The officials, however, were satisfied, as it had been passed by the Swiss firm who designed the turbines (though made in Philadelphia). I had always wished to put the dynamos at the bottom of the pit close to the turbines, and I still believe that this arrangement would have served us better.

The designing of a suitable dynamo was, however, only one of a number of difficulties that had to be overcome. Some of these were of an engineering character, but others savoured of "politics" in the sense in which that word is used in the States. There *politics* means intriguing, underhand dealing, and jobbery, and is always used in conversation to express that meaning. Until I went to America the manufacturers of electrical machinery never had a consulting engineer to reckon with, but dealt directly with the financiers, who knew nothing about cost or efficiency of machinery. When they knew that I was to advise the Niagara Company, they tried by every means in their power to revert to the old plan. Every game of bluff, bounce, and threats was used, but without the least effect. One of our engineers, in another department to mine, who knew nothing of electricity, was completely taken in by one of these firms. This and other intrigues hindered me a good deal in carrying out my plans. Then, again, I had at times great difficulty in keeping the president and vice-presidents in hand. One of the latter, after he had learnt a little about ohms and volts, believed himself capable of instructing me as to which tenders I ought to recommend for acceptance, and did his best to try to influence my judgment. Most of them began to think they knew something about the subject, and that they were quite capable of settling what tests the machines should be put to. All this was generally amusing enough, but became almost tragic at times when I found them endangering the whole work. On such occasions I would write to my millionaires and tell them that if they did not do what I told them they would be personally answerable to the directors and shareholders for any disaster that might occur. This always had the desired effect, and my point was carried. I fear that at times they wished me at Jericho, but after any one of these tiffs was over I think they were glad that I had taken that line.

I have said that there were many new electrical problems to attack. One of these was a new departure on my part, which involved a very heavy piece of calculating and designing before I could be perfectly certain that my conclusions were correct. It occurred to me that with the large machinery we were using (the dynamos which I designed were three or four times as powerful as any that had then been made) it would be best to make the alternating current reverse its direction as slowly as was consistent with making a good dynamo. This would not do so well for *lighting*, but for a *power* station like ours the advantages were powerful and numerous. The one objection that struck me was that the machines used for changing the electric pressure would be more expensive. This compelled me to design all these machines (they are called

transformers), and to calculate the cost of construction. I was then agreeably surprised to find that the cost was enormously less than any one had dreamt of. At the same time, out of every 100 horse-power put into such a transformer we could get out 98½ horse-power, a result which had never been approached in smaller machines. Then, again, some of the manufacturers threatened us with patent-litigation if we used certain types of machinery, so I had to get out designs of another kind of motor to drive the mills, so that in any eventuality we should be prepared and able to go on in spite of these threats. Then our first customers wanted continuous current, and I had to select a method of making the conversion. In fact, I found myself obliged, before we advanced a step, to have all the designs ready for manufacturing all kinds of machinery, even if they were not all to be used. This work, carried out under all kinds of difficulties put in my way, was chiefly done in the summer of 1893 at the Falls. I had a lovely house in parklike grounds (as the agents say) on the banks of the placid river above the upper rapids. I went to bed early and rose at five or six in the morning, and I shall never forget the delights of these glorious summer mornings at one of the most beautiful sites in the whole neighbourhood. In the afternoons I generally took a drive in a buggy on the Canadian side, where the roads were passable, and sometimes I rode. I had a nigger servant to look after the house, who differed from all his race I ever saw in his desire for work. If I did not want the gravel rolled or the grass cut, he grumbled. He always got up at five o'clock, and prepared my bath. I used to ask Jim about his previous life, and found he had been "porter" on a railway, and latterly servant in a gambling-hell in Buffalo! He was a good servant. This house belonged to one of the Porter family, who have long owned most of the property here. A Miss Porter was once travelling in Europe, and at the *table d'hôte* her neighbour said, "Oh, if you are an American I suppose you have seen Niagara Falls?" She turned to her inquirer, and fixing him with her eyes, she said, "I own them!"

An Englishman in America should always try to retain his Englishness,—otherwise in a year or two he will be reduced to the level of an average American. Where all men think themselves equal, individuality is at a premium. An American once tried to find fault with me for pitching into my servant, because, forsooth, all men were equal. I never saw the man before, and would never see him again. So I told him that if he wished to be placed on a par with my valet I would willingly acquiesce, but he must not attempt to define my place on so short an acquaintance.

I acquired quite a reputation on the New York Central Railway from a little Englishman. I had forgotten all about it when a friend at the Falls, arriving home from New York, said he had heard of me. "How is that?" I asked in the vernacular. "Well," he said, "you seem to be able to get the better of the conductors on our railways" (the most insolent class of men in the country). "I was talking to one on the cars, and when he heard I belonged to Niagara Falls he said, 'Oh then, you know Professor Forbes.' I said I did, and he said, 'Well,

there's no flies on him.' I asked him why, and he said, 'One night we were coming from New York, and in the early morning six of us conductors were in the smoking-room yarning when in comes Professor Forbes: he takes a look round and then says, "I want to smoke, but pray don't disturb yourselves, I am only a passenger;" and we all put our tails between our legs and slunk out, and then we roared with laughing to think how he had got the better of us in his quiet way.'"

These were very happy days, though I lived quite a solitary life. Of course I had anxieties and worries, but I felt quite certain of loyal support in any case where the safety of the work was threatened.

The dynamos were at last made and tested, after most annoying delays and disingenuousness on the part of the manufacturer. The makers of the transformers and machinery for getting a continuous current, on the other hand, were prompt and obliging, and the tests came out well. Then I got bids for the appliances for transmitting power to Buffalo. All the conclusions I had arrived at from my own designs were now confirmed. Their cost per horse-power, even with my low frequency, was a fifth part of those that had been used for lighting, and the efficiency guaranteed was as I had stated. I decided on all this transmission plant, and it is not now put in only because the Buffalo people want to get the power for next to nothing. There is too much "politics" in this business at Buffalo. Another triumph I have had is, that engineers all over the world have learned to appreciate my low frequency of alternations, while we ourselves have found new merits in it at every step.

I had also arranged for special apparatus for people who had set up a factory within a mile of the power-house, and who wanted 1000 horse-power, and wished to be able to vary the electric pressure during the heating of their electric furnace. Arrangements for arc-lighting, for tramways and house-lighting, had also to be arranged. When this was all completed and the first plant in place, the period of construction and design gave way to a period of dividend-earning, and my continuing to take charge would have swallowed up too much of the annual income, so I concluded my engagement with the company. In writing my farewell letter, I felt how much I had been assisted by the acting directors, and I told them so while summarising the results which we had been enabled to attain to. In this letter I said that we now had completed a work which for successful working, security against break-downs, high efficiency, and low cost, was ahead of anything that had hitherto been even dreamt of, and that I was confident of a great success from a commercial point of view.

The company, through their president, replied in cordial terms as to the satisfactory results of our co-operation, from which it may be interesting to make the following extract:—

"In our desire to secure the best theoretical results under your eminent and valuable advice, it has been most gratifying to have had your cordial co-operation up to this point, where the commercial manufacturers are ready to give us satisfactory guarantees of performance.

"When you were selected as the electrical consulting engineer of this company, we recognised that the novelty in the proposed size of units to be used in the Niagara installation, and in the character of the station proposed for the generation and distribution of power, was such that we must have the benefit of the very highest scientific advice. We further recognised that in the advocacy of the use of the alternating current and of low frequencies you were a pioneer, and we join you in the feeling of just satisfaction in the conclusion which has now been reached in respect of those features. In this, too, your independence of thought and action has been of peculiar service, while, through your original design of the stationary armature and revolving [external] field of the generators, adopted by us, you have relieved us of one most embarrassing question in connection with the relation of the generator to the turbine. Nor can we fail to recognise the value of the vast fund of information which you have brought to us concerning electrical installations in different parts of the world, and well described in your various and exhaustive reports.

"In making you this partial expression of our appreciation of your assistance during your professional connection with this company, we beg to assure you that we now part from you with the best wishes for your professional and personal success."

The letter from which I have made this extract attributes the splendid results which we attained mainly to engineering skill. I am inclined to believe that they were fully as much the result of an exercise of tact, judgment, and forbearance, combined with firmness—qualities which I do not hesitate to say that both the officers of the company and myself recognised in each other, and without which we should have found it difficult to obtain satisfaction from the manufacturers. We had the utmost difficulty in enforcing proper tests for balance of the dynamos, and the strict rule that no circuit should be suddenly opened or closed while carrying a large current. I mention these as being two matters of prime importance, the neglect of which would have been a crime. Owing to the support I obtained from the acting directors, the whole work for which I was responsible has been put in place and set agoing without a single hitch. This is not usual in a novel work of so great magnitude. I feel confidence in asserting that so long as the instructions I insisted upon are acted on, there will be no trouble with the electrical machinery.

In jotting down these personal experiences, I may have failed to give a *coup d'œil* of the whole scheme. Now there is at the Falls a small tower of observation, like Eiffel's, 300 feet high. The last time I was there I penned a letter to the 'Times,' which was published at the end of the year 1894, from which I may make an extract:—

"I am perched on the top of a small Eiffel tower, lately erected, and casting my eyes up the river, over the house-tops and beyond the town, I see a new world created. There is a wide canal leading water from the river into that gigantic tower-house where three turbines are set up to drive three dynamos of 5000 horse-power each. There is the bridge to carry cables across to the transformer house. Inside the tower-house the water is carried down pipes $7\frac{1}{2}$ feet diameter into the turbines, and thence it passes through a 7000-feet tunnel under the town, emerging below the Falls, the tunnel being capable of developing 100,000 horse-power. Far as the eye can reach extend the company's lands, with here and there a huge factory either now using the water-power, or waiting for the electric

supply. One of them uses 3300 horse-power, another 300, a third one 1500, and that unfinished one requires 1000. You can see, far away, the model village for working men, and improved sewage-works with drainage, pumps for water-supply, electric light, and well-paved streets. There again is the dock where ships from all parts of the Great Lakes can unload, and there a huge expanse of reclaimed land; while the whole is swept by the company's railway, seven miles long, connecting every factory with the great trunk lines."

Since these words were written the machinery has been set to work on its commercial task of supplying power and earning money.

The directors have no present desire to send the current to great distances. It will pay better to create a smokeless manufacturing town in the neighbourhood. If required, the power could be sent much more than a hundred miles, and still be more economical than steam, even though coal is cheap there. In countries where power is much wanted, but very costly, the electrical transmission will be successful at distances of many hundreds of miles. Such cases occur in many places where there are valuable mines but no fuel.

In conclusion, I may say that the work done at Niagara is the forerunner of much more, and already I have in hand the preparation of plans of schemes nearly as important.

I also wish to bear tribute to the kindly friendship which I almost universally experienced at the hands of American engineers. Hardly a single case occurred where any jealousy was shown at an Englishman (or rather Scotchman) being selected to carry out the work.

GEORGE FORBES.

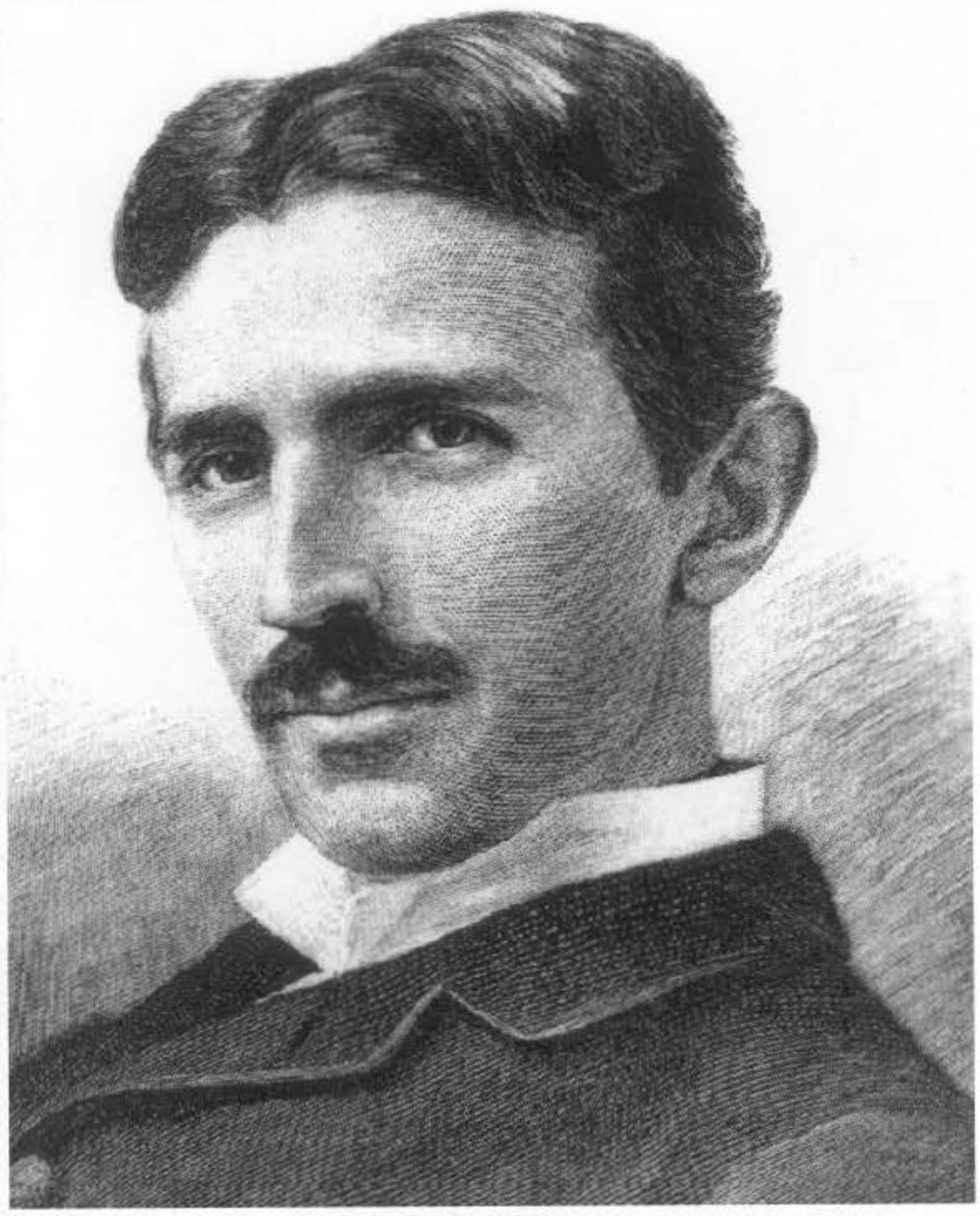
NIKOLA TESLA AND THE ELECTRICAL OUTLOOK.

THE NEW DEVELOPMENT IN POWER TRANSMISSION.

WHEN Nikola Tesla last gave to the world the results of his explorations into the field of electricity, the predictions which he ventured as to the possibilities of his discoveries were skeptically received. That was two years ago, in a lecture which he delivered before the Electrical Congress in session at the World's Fair. "His work is brilliant, but of what use is it?" said one of Europe's leading savants when Mr. Tesla had finished; and in this exclamatory interrogation the learned scientist voiced the general opinion of the whole Congress. Mr. Tesla was regarded as a theorist and his inventions as impracticable.

A few weeks ago we witnessed one of the triumphs of this industrial age, the yoking into service of old Niagara herself. While this event is yet news, there comes the announcement that one of our great electrical companies has formed a business alliance with the largest locomotive works in the country, with the view of substituting electricity for steam on our railroads. These two projects are themselves an answer to the question asked by the incredulous savant: Of what use is Mr. Tesla's brilliant work? for neither of them would at this time have been practically possible but for his discovery known as the "rotating magnetic field," which opened the way to the conversion (by means of the alternating, as against the direct current) of electrical into mechanical energy and the economical transmission of power through long distances. This discovery forms the basis of the Niagara Company's attempt to utilize on a large scale that enormous power which for centuries has been running to waste and thus to turn machinery in towns and cities so far away as Buffalo, 20 miles distant, and perhaps New York and Chicago. And it underlies the hardly less bold venture of the Westinghouse and Baldwin companies to drive a through railway express by electricity. It is not too much to say that the Tesla motor is behind all the large attempts at power transmission by electricity which are being made throughout the country, not only in the fields of manufacture and transportation, but also in mining, irrigation and farming.

The "rotating magnetic field" was discovered by Mr. Tesla over ten years ago, when the problems engaging the attention of the electrical world were the furnishing of light and the transmission of sound. The advantages of the alternating current as applied to lighting were already recognized, but no attempt had been made to adapt it to motor work if, indeed, it had been seriously thought of. The direct current then in use was difficult to transform and not practicable for long distances. Mr. Tesla was at least the first to conceive an effective method of utilizing the undulating current. As every one knows, a small piece of soft iron, when placed close to an ordinary magnet (or bar of iron around which is passing an electric current), will be drawn to the magnet and adhere motionless to it. It occurred to Mr. Tesla that if instead of a bar of iron he should take an iron ring and use two alternating currents, so regulated that one would be positive in value when the other was negative, he could, by means of wires wrapped alternately about the ring,



NIKOLA TESLA.

produce a magnetic current which would travel around the ring in accordance with the frequency of the alternations in the electric currents. His theory worked in practice and he thus had a magnet the north and south poles of which revolved while the magnet itself remained stationary. A piece of iron pivoted at its centre and placed within the magnetic field of the ring, and concentric to it, would, therefore, be revolved by the changing poles of the magnetized ring. In this way Mr. Tesla was able to convert electrical into mechanical energy much more simply, economically and effectively than it had been possible to do it by the direct current. It was now only necessary to pass alternating currents around the axle of a wheel in order to set in motion the machinery of a mill or drive a railway engine.

For transmission purposes, as well as in transforming electrical into mechanical energy, Mr. Tesla was soon able to demonstrate the superiority of the

undulating over the direct current. It will be sufficient here to say that by means of his motor, which is only a development of his ring magnet, power may be sent long distances with but small loss. The magnitude of the field opened up by the Tesla motor will be apparent when it is considered that ten years ago it was not economically possible to transmit power more than a few hundred feet away from the source of production, while to-day its transmission is no longer a question of state of the art, but one of capital only. As early as 1891, Mr. Tesla's method was successfully employed in the experiment of sending 100 horse-power 109 miles from Lauffen to the Frankfort exposition grounds. In Southern California there has been in operation for two or three years a plant which transmits power equivalent to 10,000 volts from a waterfall to a sub-station at Pomona, 13¾ miles distant, and San Bernardino, 28 miles away; and there is now being projected, also in California, an enterprise which will involve an outlay of from $2,000,000 to $3,000,000 for supplying motors in San Francisco and adjacent cities with 20,000 horse-power from the outlet of Clear Lake, 75 miles to the north. Mr. Tesla believes that it is easily possible at the present time to place 100,000 horse-power on a line at Niagara and deliver it to New York or Chicago, with a loss in energy of less than 25 per cent.; and it would seem that the Cataract Construction Company is also persuaded that this is within the limits of practical achievement.

The alliance of the Westinghouse and Baldwin companies is in line with the policy recommended by Dr. Lewis Duncan in his address on the substitution of electricity for steam in railway practice, delivered last June at the Niagara meeting of the American Institute of Electrical Engineers—that of making electricity an ally instead of an enemy of steam. This union of large railway and electric interests would seem to mark the beginning of a new era in traction, coming as it does along with the substitution of electricity for steam by the Old Colony road on its Nantucket Division out of Boston; the adoption of an electric instead of a steam engine by the Baltimore & Ohio Railroad, for use in hauling heavy express and freight trains through the long tunnel underneath the city of Baltimore, and the installation of an electric line by the Pennsylvania Road from Mt. Holly to Burlington. The purpose of the Westinghouse Baldwin combination, as officially announced, is to develop the possibilities of the Tesla motor as applied to railroad service. It is declared that with this motor, power is assured sufficient to draw cars at the rate of 150 miles an hour. This is perhaps the possible speed under favorable conditions of road and equipment rather than the rate likely to be attained in every day travel.

The method of electric traction in use on the three roads named is the trolley, the power being supplied to the motor or motor cars from the central station by means of wires. It is the same system that is in general use upon our electric street railways, except that the alternating instead of the direct current is employed, the direct, as has already been noted, not being practicable in long distance transmission. The trolley, either the overhead or the underground, is the only method that has so far been demonstrated as suitable to general railroad practice. By means of the Tesla motor it is now regarded by conservative railway men and electricians entirely possible to run trains under this system, say from New York to Philadelphia, or through multiplication of the power stations from, Boston to Washington, or even across the continent from New York to San Francisco. But whether or not it would be feasible at the present time for our large companies to change from steam to electricity, in part or throughout, is another question. These are transition days for electric traction and it is not probable that any of them is at present willing to go to the expense of equipping electrically a considerable part of its line with a system which may soon be rendered obsolete by some new method.

Perhaps we already have this new and superior method of traction in the combination steam and electrical engine upon which Mr. Tesla has been at work for many months. The invention has been taken over by the Westinghouse Company and it is probable that it is this application of the Tesla motor that the new alliance is to develop. This engine is designed to do away with the use of the unpopular and well-abused trolley. Instead of drawing its power by wire from a central station, the engine generates its own power by converting steam into electric energy and then into mechanical. By this transformation a large per cent. of the power that is now wasted in steam locomotion is conserved. From the same amount of fuel Mr. Tesla has demonstrated, experimentally, that he can easily obtain twice as much effective energy, and under favorable conditions three times as much. He effects this saving by means of a "mechanical and electrical oscillator,"—an engine which is in itself a dynamo, and which operates with small frictional losses. The principle of this mechanism rests on the law of vibrations. With the machine electrical currents may be transmitted of a perfectly constant period and at an absolutely certain rate, and so regulated as to drive with precision an engine or a watch; thus, in railroad practice, overcoming the wear and tear to which cars are now subject by the continual change in steam pressure. The Tesla "oscillator" is really a power station on wheels, instead of a locomotive designed to draw a train of cars. The power which it generates is communicated to the wheels of the cars as well as to its own. This is accomplished by applying the principle of the "rotating magnetic field" in simply passing alternating currents around each axle. Thus an even, steady motion is attained and favorable conditions afforded for a high rate of speed.

Nikola Tesla, who is thus helping so effectively to solve one of the great industrial problems of our day, the economical transmission of power, is still a young man in the very vigor of life. His work has only begun.

The Tesla Patents in France.—*L'Industrie Electrique* states that MM. Schneider et Cie, sole concessionnaires for France of the Tesla rotary-field patents, has issued writs against MM. Weyher et Richémond, who build Brown motors, MM. Guitton et Bertolus, who own the Oerlikon patents in France, and M. Joly, Lyons representative of the firm of Alioth, of Basle and of the Société Grenobloise, which makes a rotary-field motor.

LEGAL NOTES.

THE TESLA PATENTS.

THE Westinghouse Electric and Manufacturing Co. has issued a circular directing attention to its Tesla patents, under which it is suing the General Electric and Stanley Cos., and asserting that these patents control all the developments of polyphase and multiphase working, both for lighting and for power.

The Tesla Patents.

The Westinghouse Electric and Manufacturing Company have issued the following circular letter to central station men:

DEAR SIRS: In view of the great prominence given to the multiphase motors covered by the patents of Mr. Nikola Tesla, we think it right to direct your attention to the fact that this company claims the exclusive right to manufacture and sell all forms of motors operated by currents of two, three or more phases, and all forms of single phase motors where a second phase is induced so as to make the same a two phase induction motor—notably the form used for the operation of fans. Suits are now pending against the Thomson-Houston Electric Company (the General Electric Company), the Stanley Manufacturing Company of Pittsfield, Mass.; and numerous suits have been entered against the users of apparatus purchased from the above companies; it being the intention of this company to enforce its exclusive right to manufacture and sell multiphase generators and motors, the two being used in combination as a system, and such system being covered by the patents of Nikola Tesla above referred to. In the first-named suits, the General Electric Company has put in its defence, and the Court has limited it to October 7, 1895, in which to complete its testimony, so that a hearing may be had in the latter part of this year or the beginning of 1896. We are advised that the defence has been unable to produce a single working device that can in any way take from Mr. Tesla the pioneer character of his inventions.

We have been informed that the two companies named have offered to guarantee the purchaser of infringing apparatus against damage or loss, but you can well appreciate that it will be impossible for such companies to make good their guarantees to cover all losses if the courts enjoin the use of apparatus made in imitation of that covered by Tesla's patents.

We are prepared to furnish multiphase generators and motors for all classes of work, and being the owners of the patents, no contingency can arise by which the purchasers of such apparatus made by us can in any way be interfered with in its continued commercial use.

It is the opinion of those who have given the subject most careful attention that in the near future a very large proportion of electric work will be done by the multiphase system, and this together with the fact that in the main we believe men would prefer to purchase property from its rightful owners, has led us to write to you and give you an opportunity to place your orders with this company for such multiphase apparatus as you may desire to use, and thus avoid the risks incident to the purchase of apparatus from unlawful manufacturers.

The adoption by the General Electric Company of the term "Monocyclic" in connection with their use of multiphase apparatus does not free them from the charge of infringement, but on the contrary makes the case against them stronger, because of the sale of apparatus under misleading terms.

In conclusion, we wish to call your attention to the fact that with our system incandescent lights, arc lamps and alternating motors can be operated from the same circuits, and that it will be of especial advantage to companies desiring to remodel or to increase their plants to make a full and careful investigation of the Tesla apparatus as installed in our works at East Pittsburg, and you are invited to come or send a representative, to whom every facility will be given for careful inspection. Yours truly,

WESTINGHOUSE ELECTRIC AND MFG. CO.

The Tesla Multiphase System.

Mr. Lemuel Bannister, vice-president and general manager of the Westinghouse Electric and Manufacturing Company, of Pittsburgh, is sending the following letter to central stations throughout the country:

In view of the great prominence given to the multiphase motors covered by the patents of Mr. Nikola Tesla, we think it right to direct your attention to the fact that this company claims the exclusive right to manufacture and sell all forms of motors operated by currents of two, three or more phases, and all forms of single-phase motors where a second phase is induced so as to make the same a two-phase induction motor, notably the form used for the operation of fans. Suits are now pending against the Thomson Houston Electric Company (the General Electric Company), the Stanley Manufacturing Company, of Pittsfield, Mass., and numerous suits have been entered against the users of apparatus purchased from the above companies; it being the intention of this company to enforce its exclusive right to manufacture and sell multiphase generators and motors, the two being used in combination as a system, and such system being covered by the patents of Nikola Tesla above referred to. In the first named suits, the General Electric Company has put in its defense, and the court has limited it to October 7, 1895, in which to complete its testimony, so that a hearing may be had in the latter part of this year or the beginning of 1896. We are advised that the defense has been unable to produce a single working device that can in any way take from Mr. Tesla the pioneer character of his inventions.

We have been informed that the two companies named have offered to guarantee the purchaser of infringing apparatus against damage or loss, but you can well appreciate that it will be impossible for such companies to make good their guarantees to cover *all* losses if the courts enjoin the use of apparatus made in imitation of that covered by Tesla's patents.

We are prepared to furnish multiphase generators and motors for all classes of work, and being the owners of the patents, no contingency can arise by which the purchasers of such apparatus made by us can in any way be interfered with in its continued commercial use.

It is the opinion of those who have given the subject most careful attention, that in the near future a very large proportion of the electric work will be done by the multiphase system, and this, together with the fact that in the main, we believe, men would prefer to purchase property from its rightful owners, has led us to write to you and give you an opportunity to place your orders with this company for such multiphase apparatus as you may desire to use, and thus avoid the risks incident to the purchase of apparatus from unlawful manufacturers.

The adoption by the General Electric Company of the term "Monocyclic" in connection with their use of multiphase apparatus, does not free them from the charge of infringement, but on the contrary makes the case against them stronger, because of the sale of apparatus under misleading terms.

In conclusion we wish to call your attention to the fact that with our system incandescent lights, arc lamps and alternating motors can be operated from the same circuits, and that it will be of especial advantage to companies desiring to remodel or to increase their plants to make a full and careful investigation of the Tesla apparatus as installed in our works at East Pittsburgh, and you are invited to come or send a representative, to whom every facility will be given for careful inspection.

ELECTRICITY.

attention to the fact that this company claims the exclusive right to manufacture and sell all forms of single-phase motors where a second phase is induced so as to make the same a two-phase induction motor, notably the form used for the operation of fans." The advice is also given to those who are using motors of the kind named to avoid permanent injunction by arranging with the company betimes, as a decision in important suits now pending is expected early in 1896, and all indications point to a decision in favor of the owners of the Tesla patents.

Progressive Age (Oct. 11), which gives these facts with editorial comments, while regarding much of the circular as "pure advertising," to be "taken with the large modicum of salt needed by the statement of a corporation with millions at stake and whose fate is still in the hands of the courts, undecided," yet feels it a duty to present the facts on the side of the company.

"It is undoubtedly true that electrical apparatus depending upon alternating currents of two or more phases will play an important part in the electrical industry of the near future. It is still more certain that a decision of the suits in question will throw a tremendous amount of existing apparatus out of legitimate use, and a corresponding amount of new business into the hands of the victor; while rumor has it that all the points of equity, if not of law, are on the side of the aggressive corporation. So that, whichever way the proceeding turns,—and we do not presume to undertake prophecy, or legal analysis of the question,—there will be a large volume of property affected, outside of that owned by the two principal combatants."

The guarantees to purchasers under which a large number of this class of motors have been sold our contemporary regards as worthless, in case the favorable decision expected by the company shall be obtained. "The intentions of the insuring party may have been of the best, but it is now clear that the liabilities which he has thus gradually accumulated are such as will fall, if at all, in a lump, and, when they fall, are certain not only to swamp,

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The Tesla Patents.

THE company which controls the patents granted to Mr. Nikola Tesla evidently is planning to make it warm for infringers. In a circular recently sent out to persons and corporations deemed to need the warning, they say: "In view of the great prominence given to the multiphase motors covered by the patents of Mr. Nikola Tesla, we think it right to direct your

but to leave by far the greater portion of the insured without protection or protector. The questions therefore arise: Are these parties, so plainly damaged in equity, to have no recourse in law? And if so, to whom?"

It appears to us that there is no recourse. In such cases one would wish that purchasers could be protected, if possible; but we can see no way whereby a person, having accepted an insufficient security and relied upon it as a sole remedy, can be resecured; and the editorial reviewed admits the extreme difficulty of the case. "Clearly the purchasers should be protected. But by whom? It is plainly not the duty of the successful litigant, who has been merely defending his rights. It is as plainly beyond the powers of the vanquished party. So the question is not a simple one. But it would certainly seem that, if the State cannot guarantee the validity of its patents, before it issues them, or is so slow settling that validity by other means that large numbers of its citizens become involved in losses as a consequence, it cannot be regarded as clear of blame, or at least of indebtedness."

Emanations from an Egoist.

PROF. FORBES SURVEYS HIMSELF AND IS FULLY SATISFIED.

How He "Harnessed Niagara."

The pest of society is egotists. . . . In the distemper known to physicians as chorea the patient sometimes turns round and continues to spin slowly on one spot. Is egotism a metaphysical varioloid of this malady?—*Emerson.*

Prof. George Forbes, C. E., has contributed an article to the current number of *Blackwood's Magazine*, in which he settles forever a great many disputed points in regard to the Niagara transmission scheme and the work of those connected with it. There is no longer any doubt as to who did it at all. The master mind was that of Forbes. Forbes has confessed it in 9,000 words, of which 200 are personal pronouns. Kelvin, Turrettini, Mascart, Sellers, Unwin, the Westinghouse Company, and the rest were never in it from start to finish except as disturbing elements to annoy the Master Mind.

Yet the creation of the great Niagara plant is not the Professor's crowning achievement. His glory of glories must forever be the *Blackwood's* article. We print such of it as is of especial interest to Americans, with a few brief comments, which are offered in a spirit of abject humility, as becomes an editor who at one time in his life was an American bagman:

There is no class of professional men who travel so much as engineers. Their experiences are often full of interest, and at times not devoid of excitement. Yet how seldom it is that any account of these travels is found in print. This is partly due to the fact that it all seems to the principal actor to be all in the day's work, and hardly worth committing to paper. But there is also a certain pleasure in having a store of experiences to relate to one's more intimate friends, which the vulgar crowd cannot read in a book.

At the present moment I am tempted to curb this natural reticence with the object of narrating my experiences of the last few years, which I believe are unique in our profession.

How can any one curb a natural reticence?

Our engineers are often called upon to travel in difficult countries, and to accomplish what look like impossibilities. But it is by no means an everyday occurrence for the financial men in a great country like the United States, who are not in the habit of minimizing the capabilities of their fellow-countrymen, to invite a foreigner to carry out one of the greatest works of modern times in that country. Some people say that the Americans are perhaps too much inclined to look upon their countrymen as the inventors of Electricity. It is, then, all the more surprising that the work about which the English engineer was asked to advise them was the electrical utilization of Niagara Falls. It must, however, be remembered that this work involved entirely new problems and designs, while the American electrician has less capability of evolving entirely new plans, or designing entirely new machinery, than of adapting his past experience, exactly as it stands, to new conditions. It was for this reason that one of the ablest of American engineers said in public three years ago that it was impossible to transmit the power of the Falls to Buffalo, some twenty miles, so as to make it pay; whereas we have now established the fact that the limit of distance is to be counted by hundreds of miles.

The remark of the American engineer must stand as truth until the contrary is proved. Power has not yet been sent to Buffalo. The statement that "the limit of distance is to be counted by hundreds of miles" is contrary to experience.

There are two great mistakes commonly made as to Americans. One is, that they are original inventors; the other is, that they are humorous. Neither of these propositions is true.

We yield both points to Forbes; he is the greatest inventor and the most humorous humorist of the age; and thank God he is not an American.

. . . Invention and humor require a gift of imagination, the same gift that shows itself in poetry and letters, in music, painting, and sculpture; and in no one of these directions has this gift of imagination been found to predominate amongst Americans.

In no one of these directions, save perhaps in poetry, does the Anglo-Saxon race lead; and in poetry America has no cause to be ashamed of her productions. In fact, more copies of Longfellow have been sold in England than of Tennyson.

I have given these reasons why it was perhaps natural to have recourse to a European to take hold of this great and entirely novel problem. Another reason is that all their electricians who may have had a wide practical experience are tied to manufacturing companies, and cannot be looked upon as independent either in thought or action; and since it was pretty certain that any plans that might be adopted would have much of novelty in them, and would be opposed in the first place both by scientific men and by the manufacturers, it required that the man selected should have nothing to gain or lose by the friendship or hostility of these two classes of men.

When I had finished my work at Niagara Falls the chairman (or president, as he is there called) of the company wrote me a letter, in the course of which he incidentally mentioned some of the reasons why I had been invited to carry out this work. . . .

Passing now from these digressions, let us come to the Falls themselves. I have no talent for pictorial description. . . .

Forbes is too modest. His whole article is a word-picture, a living picture, and when one finishes it the image of Forbes is fixed on his mind never to be effaced.

The village or town of Niagara Falls on the American side of the river is built of wood. It is dirty, and the streets are bad. Its industry is the catering to excursionists. Cheap restaurants, merry-go-rounds, itinerant photographers, and museums of Indian and other curiosities are the chief features. The last are mostly impostures, always excepting the world-famed "Katie & Libby's Stores," where genuine curios are to be found, and many pleasing souvenirs.

Who would dream that Forbes could have been taken in by our old friends Katie and Libby?

This village is remarkably conducive to the concoction of lies, and the Falls lend themselves to the art. . . .

We fear the Professor stayed there too long.

To me the great charm of the Falls is their immutability and change.

The drifting spray and varying light give the changes of a kaleidoscope, but the volume of water pouring over never varies. They remind me of the face of a dear friend, always the same but never two moments alike. I suppose there is nothing to compare with them in size or grandeur except the Victoria Falls of the Zambesi; and Livingstone, who never exaggerated, said that these were the finer.

. . . The old mills which used to be in the stream above the American Fall have been removed for æsthetic purposes and the land laid out with some attempt at good taste.

To what æsthetic purposes have they been devoted?

On the Canadian side the same thing was done, but I regret to say that the rapacity of the Legislature of Ontario has not proved equal to withstanding the blandishments of the greedy capitalist. Two lines of rails traverse the whole of the National Park at the edge of the gorge. After the land had been confiscated by the Government, and the owners had been paid only a fraction of its true value, it is now turned into a source of revenue by the Government, and a gold mine to the capitalists, at the expense of the visitors, who can no longer enjoy the peaceful quiet which Lord Dufferin tried so hard to give them. . . .

In 1889 the Niagara Falls Power Company was formed to carry out this work, and their first act was to buy up all the land in the neighborhood. The capital subscribed was wholly American, and amounted to £2,000,000, about one-half of which has been spent. The acting committee consisted of railway men and lawyers. The chairman, as usual, is called a president. They like giving big names to things in America. A pond is a lake, and a hill is a mountain; they never speak of the sea, it must be called the ocean; a meeting is a convention, a dictionary is a "speller and a definer."

How many Americans knew this before Prof. Forbes told them?

A town is a city, a chairman is a president, and so on. The only exception I know of is that the wealthy people who own those charming country residences at Tuxedo and Lenox call them cottages. But these are not average Americans, and in that country the manners and customs, as seen by the ordinary traveller, are governed by the average man, who is not a good specimen. He is apt to be a most awful "bounder," has no taste, and does not know the meaning of the word "repose"; but you need never meet this type except in railway trains and hotels. His ideal, as one of them told me, is to spend his nights "on the cars" and his days in getting the better of his fellowmen. But the refined American is quite different. These are mostly met in Washington and the South, and, of course, Boston is a thing apart; and as you approach this town you are told that the humming you hear is the noise of the people reading Browning. Tuxedo also is a great exception, where you can have congenial society. It is a large estate with woods and lakes and forty miles of well-laid roads. Country houses or cottages have been built all over it, and there is an excellent residential club—into which, however, the female element has progressed so far as to have introduced even babies into the bedrooms!

I must really ask to be excused for such digressions, but I must tell my story in my own way or leave it alone.

And not even the "average American" would stop you, Professor. You are a peach.

The chairman of the company which has utilized the Falls is Mr. E. D. Adams, well known as a banker and a reorganizer of railways. The first vice-president is Mr. F. L. Stetson, a lawyer who has also had much experience in the finance of railway companies. Mr. Cleveland, the U. S. A. President, is a partner in his law business. The second vice-president is Mr. E. A. Wickes, also a railway-man. The secretary and treasurer, Mr. W. B. Rankine, is one of the most able and energetic and charming men I met in the States. I only hope he will not utterly ruin his health by overwork. All these are very able business men, though not engineers, and the affairs of the company could hardly be in better hands——

Unless Forbes took charge again.

In October, 1889, the Niagara Falls Power Company was formed to carry out the great work of utilizing the Niagara Falls on so gigantic a scale that all previous attempts to use water-power at once sank into insignificance. The Cataract Construction Company was at the same time formed by the same people to carry out the work. . . .

In order to obtain more definite ideas they invited certain engineers to prepare plans of any methods they might think best. These were to be laid before a Commission of engineers and physicists from England, France, Switzerland, and America, with Lord Kelvin as chairman.

At first I declined this invitation on the grounds that the method of competition is contrary to my professional practice, and also that with so novel a problem I would not accept any man, or combination of men, to adjudicate upon the project which I might decide upon.

Having learnt, however, accidentally, that any electrical plans to be submitted would not be of a satisfactory nature, I withdrew my refusal in order that a plan, as I conceived on proper lines, might be at least in evidence. . . .

Now let me say, without explanations, that there are two kinds of electric current—a "continuous current," always flowing in the same direction, and an "alternating current," in which the direction of flow is reversed, it may be hundreds of times in a second.

I soon realized the fact that not only could the latter current be more easily obtained at high pressures, but that it could easily, and without moving machinery, be transformed to any required pressure at any spot when it was wanted.

Up to that date, **1890,** both kinds of electric current had been used for electric lighting, but the alternating current had never been used for giving mechanical power except in an experimental way. For this reason it seemed to most people absurd to suggest its use for Niagara Falls. I would have shared this view were it not that for several years I had visited the United States and the continent of Europe to study the progress that others were making in electric work. I had thus become well acquainted with the system which Nicola Tesla, a young Montenegron, was experimenting on at Pittsburg, U. S. A., called a "two-phase" system. I also had seen many things in various parts of Europe not generally known in England. Owing to these varied experiences, I HAD AN OPPORTUNITY ABOVE ALL OTHERS AT THAT DATE of foreseeing that the alternating current would soon be very generally applied not only to light, but also to motive power.

Here we must digress long enough to introduce a little correspondence between Prof. Forbes and the Westinghouse Company, in **1891,** which needs no comment.*

Acting upon this knowledge, I worked out complete plans, using only machinery which could then be got in the open market, and was able to furnish complete working plans, drawings, specifications and estimates of cost. This laborious work when concluded left no doubt in my mind that the alternating current must be adopted.

The Commission sat upon these plans, and, as I expected,

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* (*Prof. Forbes to Mr. George Westinghouse, Jr.*)

34 Great George Street, London, S. W.,
September 19, 1891.

Dear Mr. Westinghouse: I am going to read a paper on alternate current motors. I want to emphasize the importance of your work on the Tesla motors. May I ask you kindly to allow me to have as full information as possible by instructing one of your staff to forward some details? I daresay you cannot give me all the facts I want, but if I indicate them generally perhaps you will give me some of the points. First, and most essential, I want a drawing to show the winding of the armatures, especially the unsymmetrical winding, which I saw last year. I should also like to have drawings of the complete machines, generator and motor, the dimensions, weight, speed of revolution, output and efficiency of any particular machine that you have made. What are the largest and smallest machines you have had giving good results? What is the period of alternations and e.m.f. you have used? What examples may I quote of their successful use in practice? I know that the development of the motor has been retarded by other than engineering difficulties. I am glad to learn that the financial difficulties of the company have been surmounted.

With kind regards I am, yours most truly,

GEORGE FORBES.

P. S.—I also want facts about the power when starting the motor.

(*Mr. George Westinghouse, Jr., to Prof. Forbes.*)

Pittsburgh, Pa., October 30, 1891.

Prof. George Forbes, 34 Great George Street,
London, S. W., England.

My Dear Sir: I desire to apologize for not having written earlier in answer to yours of September 19th. I have given the matter very full and careful attention,

denounced the alternating current, for none of them had had the experience which I possessed of the latest developments. . . .

I heard no more from the promoters of this enterprise for over a year. It took them all this time to realize that the Commission had made a mistake. Lord Kelvin was the most violent opponent of the alternating current; and for long afterwards (although he is my most esteemed and oldest scientific friend), even when I was appointed as the consulting engineer, he continued to write and cable to the company, though his opinion on this point was not asked for, telling them that they were making a "fatal mistake" if they followed my advice. . . . But in this and other points where my plans were at variance with the opinions of others, I was most loyally supported by the directors, and through this support alone they and I have been enabled to put the works into their present satisfactory condition. . . .

Early in the year 1892 it became evident to the acting committee that the views of engineers had been undergoing a change, and that the use of alternating currents for Niagara was a necessity, thus indorsing the prophecy I had made long before. They then asked me to act as their electrical consulting engineer, and during that year and the next and the next I was constantly in the States. The only real rest I ever got was in my voyages across the Atlantic. I soon came to feel at home on all the large liners. . . . The misfortune is that at most seasons the only class to travel much are the American bagmen or drummers, and they are not a favorable class to judge Americans by.

Sometimes I lived in New York where the offices were; sometimes at Niagara to be near the works. I did not care to go much into society, but I made some very firm friends, specially the Hewitts, and our amiable Consul-General Sir William Booker and his charming American wife. My greatest friend of former days had been S. L. M. Barlow, a well-known and remarkable man. Roscoe Conkling and I used to dine with him every Sunday. These two lawyers, both able men, on opposite sides in politics and also in the great Stewart will case, amused and instructed me much by the exposition of their views on men and things. Both were dead now and I had two friends the less to help me pass these three years. Part of the time I lived in Tuxedo, an hour from New York, where you could have fishing, shooting, boating, bathing and golf; and I shall never forget the cordial welcome I there received from the Potters Bruzes, Lorillards, Delafields, Fishes, Kents, Rushmores, Prestons, Van Courtlandts, Van Nests and from Allen Lathrop and many others. The lovely scenery and genial society of this place helped me greatly to retain health during a period of anxious and arduous work.

This is all of intense interest, and the Professor should not have cut it off so short. We crave for more.

In 1892 when I came to examine the plans put in by various manufacturers, I found that some of the crudest work conceivable had been submitted by the Americans. The Europeans sent some excellent designs, especially the Oerlikon Fabrik, near Zurich. But these makers were handicapped by the duty imposed on machinery imported into America. There was, however, one fatal defect in all the plans then or subsequently submitted by the manufacturers. . . . The American manufacturers were entreated to alter their dynamo designs to meet this difficulty. They tried, but they were unable to do so. . . . Meanwhile I had been constantly working at various new designs, and at this stage I saw that, for the credit of the company, it was imperative that I should, if possible, get out a design on new lines which should have the required fly-wheel effect without too great a weight. . . . It occurred to me that if I could make the external part revolve I should get a maximum of fly-wheel effect with a minimum of weight. . . . I proceeded to get out rough designs and found, with the utmost satisfaction, that I could meet all the requirements of the turbine-makers. I also found that this design gave far greater mechanical strength to the revolving part of the dynamo—an important matter, with this forty tons revolving more than four times a second. Furthermore, the magnetic attractions which in all the other designs increase the dangers from centrifugal force, in my design actually diminish them. It soon became evident that this happy idea of revolving the external parts completely extricated the company from the very awkward dilemma in which they had been placed. I then proceeded with a large staff of draughtsmen to get out the working drawings, and I secured an American patent as a protection to myself and my company. It was a matter of considerable satisfaction to all concerned that I had thus so simply got over the serious difficulty which at one time threatened us with starting afresh on all the machinery, turbines and all. . . .

The designing of a suitable dynamo was, however, only one of a number of difficulties that had to be overcome. Some of these were of an engineering character, but others savored of "politics" in the sense in which that word is used in the States. There *politics* means intriguing, underhand dealing and jobbery, and is always used in conversation to express that meaning. *Until I went to America the manufacturers of electrical machinery never had a consulting engineer to reckon with*, but dealt directly with the financiers who knew nothing about cost or efficiency of machinery. When they knew that I was to advise the Niagara Company, they tried by every means in their power to revert to the old plan. Every game of bluff, bounce and threats was used but without the least effect. One of our engineers in another department to mine, who knew nothing of electricity, was completely taken in by one of these firms. This and other intrigues hindered me a good deal in carrying out my plans. Then, again, I had at times great difficulty in keeping the president and vice-presidents in hand. One of the latter, after he had learnt a little about ohms and volts, believed himself capable of instructing me as to which tenders I ought to recommend for acceptance, and did his best to try to influence my judgment. Most of them began to think they knew something about the subject, and that they were quite capable of settling what tests the machines should be put to. All this was generally amusing enough, but became almost tragic at times when I found them endangering the whole work. On such occasions I would write to my millionaires and tell them that if they did not do what I told them they would be personally answerable to the directors and shareholders for any disaster that might occur. This always had the desired effect and my point was carried. I fear that at times they wished me at Jericho, but after any one of these tiffs was over I think they were glad that I had taken that line.

I have said that there were many new electrical problems to attack. One of these was a new departure on my part, which involved a very heavy piece of calculating and designing before I could be perfectly certain that my conclusions were correct. It occurred to me that with the large machinery we were using (the dynamos which I designed * were three or four times as powerful as any that had then been made) it would be best to make the alternating current reverse its direction as slowly as was consistent with making a good dynamo. This would not do so well for *lighting*, but for a *power* station like ours the advantages were powerful and numerous.

Then again, some of the manufacturers, threatened us with patent-litigation if we used certain types of machinery, so I had to get out designs of *another kind of motor* to drive the mills, so that in any eventuality we should be prepared and able to go on in spite of these threats. Then our first customers wanted continuous current, and I *had to select* a method of making the conversion. . . . In the afternoons I generally took a drive in a buggy on the Canadian side, where the roads were passable, and sometimes I rode. I had a *nigger* servant to look after the house, who differed from all his race. . . .

In this difference the nigger was similar to Prof. Forbes

An Englishman in America should always try to retain his Englishness—otherwise in a year or two he will be reduced to the level of an average American. Where all men think themselves equal, individuality is at a premium. An American once tried to find fault with me for pitching into my servant, because, forsooth, all men were equal. I never saw the man before, and would never see him again. So I told him that if he wished to be placed on a par with my valet I would willingly acquiesce, but he must not attempt to define my place on so short an acquaintance. . . .

It is unfortunate that Prof. Forbes never had any "Englishness" to retain. If Englishness means anything, it means refinement and good breeding. The process by which Forbes would reach the level of "the average American" is outlined in the Darwinian theory. It is not a process of reduction.

The dynamos were at last made and tested, after most annoying delays and disingenuousness on the part of the manufacturer. The makers of the transformers and machinery for getting a continuous current, on the other hand, were prompt and obliging, and the tests came out well. Then I got bids for the appliances for transmitting power to Buffalo. All the conclusions I had arrived at from my own designs were now confirmed. Their cost per horse power, even with my low frequency,* was a fifth part of those that had been used for lighting, and the efficiency guaranteed was as I had stated. I decided on all this transmission plant, and it is not now put in only because the Buffalo people want to get the power for next to nothing. There is too much "politics" in this business at Buffalo. Another triumph I have had is, that engineers all over the world have learned to appreciate *my low frequency of alternations*, while we ourselves have found new merits in it at every step. . . .

When this was all completed and the first plant in place, the period of construction and design gave way to a period of dividend-earning, and my continuing to take charge would have swallowed up too much of the annual income, so I concluded my engagement with the company.

Prof. Forbes's salary was $400 a month, including expenses, about one-half of what a good American bagman receives.

This letter from which I have made this extract attributes the splendid results which we attained mainly to engineering skill. I am inclined to believe that they were fully as much the result of an exercise of tact, judgment and forbearance, combined with firmness—qualities which I do not hesitate to say that both the officers of the company and myself recognized in each other, and without which we should have found it difficult to obtain satisfaction from the manufacturers. . . .

Of course he does not hesitate—not Forbes. Why should any man who has so plainly shown his tact, judgment and forbearance, combined with firmness, hesitate.

. . . Owing to the support I obtained from the acting directors, the whole work for which I was responsible has been put in place and set agoing without a single hitch. This is not usual in a novel work of so great magnitude. I

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and I have come to the conclusion that our company cannot afford at this time to make public the information it has acquired in its work on the Tesla motor. The Tesla patents and discoveries include many very important matters, and his patents particularly cover the multiphase forms of motors and generators now attracting so much attention.

You must have become aware that patent rights are no longer respected in this country; that whatever is brought out and fully explained is immediately availed of by unscrupulous competitors; and we now feel it is a matter of great importance to maintain for the present, and until we are well established, what are properly secrets of the trade. To no one would I sooner give the information asked for than to yourself, and I hope the day is not far distant when we will be able, with safety to ourselves, to meet your wishes in this respect.

Trusting that you will appreciate the reason given for not promptly complying with your request,

I am, very truly yours,

GEO. WESTINGHOUSE, JR.

(*Mr. George Westinghouse, Jr., to the London Times, Aug. 29, 1895.*)

. . . Business relations were established between Prof. Forbes and this company in 1888 by the purchase of his patent for a meter operated by hot air currents, and he was afterwards employed by us as an expert in a patent case and in making tests on transformers. He thus had every opportunity to become acquainted with our practice and ideas in connection with the use of alternating currents for light and power purposes, and also had an opportunity to see considerable of the early work on the Tesla motors. That such opportunities were valuable to him is shown by the fact that the first plan submitted by him for the transmission of power from Niagara Falls was almost identically on the lines that we had laid out for such work and freely discussed with him.

In consequence of Prof. Forbes having written the foregoing letter without stating that he was a competitor for the honor that would accrue to the successful designer of a complete plan, our company, for that and other good business reasons. refused to permit Prof. Forbes under any circumstances to visit its works or to have anything to do with the designing, constructing, or testing of the generators, and we are not aware that he has ever seen the apparatus which is now in operation at Niagara and for which he seeks to claim the entire credit.

. . . In our [World's Fair] exhibit generators, motors, and rotary transformers were operated at 3,600 alternations per minute, being practically identical with the frequency actually adopted at the Falls, and very different from Prof. Forbes's recommendation of about 1,000 alternations per minute.

Prof. Forbes made a suggestion for a device for commutating currents, in place of a rotary transformer, which device was built, and upon test the fact was disclosed that it was not anything like as good as the rotary transformer which we had designed and which form was afterwards adopted by a rival company, as Mr. Forbes says, on his recommendation.

WESTINGHOUSE ELECTRIC & MANUFACTURING CO.,
(GEO. WESTINGHOUSE, JR., President).

* (*Mr. George Westinghouse, Jr., to the London Times, Aug. 29, 1895.*)

After a lapse of two years, and prior to the design of the dynamo referred to by Prof. Forbes, this company submitted to the Cataract Construction Company plans and specifications for a dynamo, with a system of distribution for the operation of arc lights, incandescent lights, street cars, and for electrolytic purposes, including rotary transformers. Full information and particulars were communicated to the engineers and officers of the Cataract Construction Company. Owing to the purloining of our plans by a rival company and for other reasons all tenders for generators were rejected by the Cataract Construction Company, who afterwards, in September, 1893, submitted to us plans for a 5,000 H. P. generator, saying that such plans had been prepared by their engineers, and asking us to make a tender for its construction and erection. A careful consideration of the plans submitted disclosed the fact that if constructed according to such plans the generator would be a failure, and this company thereupon refused to tender on the drawings and specifications presented. We, however, offered to accept the general form of generator, and to re-design it so that it would be a perfect machine mechanically and electrically, and to submit new plans and specifications upon which the company would tender. This was agreed to by the Cataract Construction Company, and the generators now in use at Niagara Falls were built by us according to plans and specifications prepared by our own engineers. There is about the same difference between the machine designed by Prof. Forbes and that designed by us as there is between the picture of a man and the man himself—the appearance externally being very similar, but internally there is no resemblance whatever.

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* See letter of George Westinghouse, Jr., to "London Times."

feel confidence in asserting that so long as the instructions I insisted upon are acted on, there will be no trouble with the electrical machinery.

I penned a letter to the *Times*, which was published at the end of the year 1894, and from which I may make an extract:

"I am perched on the top of a small Eiffel tower, lately erected. . . ."

Nonsense, Forbes. You are farther from the earth than the top of the Eiffel tower. You are flying through limitless space, and if you get too near the sun, as did Icarus of old, and melt your wings, you will still fall to earth unbruised—if you can light on your cheek.

. . . The directors have no present desire to send the current to great distances. It will pay better to create a smokeless manufacturing town in the neighborhood. If required, the power could be sent much more than a hundred miles, and still be more economical than steam, even though coal is cheap there. In countries where power is much wanted, but very costly, the electrical transmission will be successful at distances of many hundreds of miles, Such cases occur in many places where there are valuable mines but no fuel.

In conclusion, I may say that the work done at Niagara is the forerunner of much more, and already I have in hand the preparation of plans of schemes nearly as important.

I also wish to bear tribute to the kindly friendship which I almost universally experienced at the hands of American engineers. Hardly a single case occurred where any jealousy was shown at an Englishman (or rather Scotchman) being selected to carry out the work.

GEORGE FORBES.

American engineers jealous of Forbes! Perish the thought!

ELECTRICITY has a warm love for Englishmen and for England, and this feeling is the rule rather than the exception in America. But we rejoice that Forbes belongs to England and not to us.

Polyphase Litigation.—We hear on good authority that the Helios Company, of Cologne, who are the owners in Germany of the Tesla patents, have brought actions at law for infringement against all the firms in Germany who are using the three-phase system of motors. In the United States, as we have already stated, the Westinghouse Company has brought suits against the General Electric Company in connection with the "monocyclic" system. And they have gone so far as to prosecute also the Stanley-Kelly Company for using the Stanley two-phase system, although in the motors of that Company the two circuits are kept separate, and not combined to make a rotatory field. Our British manufacturers will doubtless look on with feelings of gratification at the circumstance that, whoever gains or loses, the battle is being fought at the expense of their rivals.

The Tesla Patents in France.—It was recently stated in *L'Industrie Electrique* that Messrs. Schneider et Cie, of Creusot, who, in 1893, purchased exclusive rights to the Tesla rotary field patents for France, have entered suit against the French manufacturers of Brown and of Oerlikon motors in France, and against the Lyons representative of the Swiss firm of Alioath, which makes rotary field motors.

LEGAL NOTES.

THE TESLA POLYPHASE PATENTS.

The General Electric Co. has been granted more time, viz., until Nov. 16, to file evidence in the suit of the Westinghouse Co. against it for infringement of the Tesla patents; and the plaintiffs have twenty davs thereafter for cross-examination. The original limit was Oct. 7.

ETHERIC LIGHTING.

Stimulated and encouraged by the results produced by Mr. Tesla in obtaining phosphorescent vacuum tube lighting by means of currents of high frequency and high potential, inventors have taken up this work and results are already beginning to manifest themselves. In the path marked out for himself, Mr. D. McFarlan Moore has confined his efforts to the production of effects by the employment of comparatively low potentials intensified, however, by the abruptness of the impulses. The method of securing the desired abruptness of breaking of the current by placing the interruptor in a vacuum is an exceedingly simple expedient, which gives Mr. Moore's system one of its principal claims to recognition. The effects already obtained with the Moore apparatus, some of which we have witnessed, give promise of success in the creation of a practical illuminant for general purposes; but even in its present condition the system already possesses unquestioned commercial value.

Tesla Discharge.—The Lond. "Elec.," Oct. 4, notices a paper by Mr. Overbeck in the "Wied. Ann." No. 8, which shows that the Tesla discharge invariably consists of two oscillatory discharges of different frequencies, which latter are not the same as those of the primary and secondary circuits by themselves; in one case where the latter were both 10,000,000 per second those of the two discharge currents were 8,000,000 and 15,000,000 respectively.

INVENTIVE INDEPENDENCE.

History has, it is said, and a new instance proves it, an intolerable tendency to repeat itself. Some fifteen or twenty years ago, we were all—that is, those of us then in the field—we were all watching with intense interest, the endeavors of Edison, Sawyer, Weston, Maxim, Swan, Brush and others to create a practical commercial incandescent lamp. The struggle was intense. A golden goal lay ahead, and it was nip and tuck all the way. Jealous as each man was of the others, there can be no question that the successes of any one encouraged and stimulated all the rest in turn, and led on to further effort. At last the prize was reached, and the incandescent lighting art lifted itself suddenly out of the realm of visionary experiment and wild speculation, into that of tangible and concrete engineering and manufacture.

Vacuum tube lighting has now, in the same fashion, it seems to us, reached the point where the solid ground of practicality looms immediately in front. The earnest workers in the field are not few. Some have published their results, others keep silent; but between them all is the subtle interdependence which leads to simultaneous inventions, parallel discoveries, duplicate experiments, needless repetitions, and finally to differing types of apparatus and the choice of separate paths. We publish a letter this week, on page 478, which to those who have been through it all once before, will be a curious reminder of the earlier assertions of independent work and a not less curious augury of the nearness of the new goal. Although sharply challenged, we do not intend to recall what we said, any more than we intended when it was written to imply that the one inventor borrowed from the other. We simply repeat, that the knowledge of other work being done in the same field, must encourage and stimulate all along the line. It is not for us, or anybody else, yet to pronounce which method of giving light without heat is most preferable, most economical, or most original. All one can ask is that these various workers shall be speedy and industrious, for, heaven knows, the art they are seeking to establish is large enough to employ a hundred geniuses; and in the long run each will get his deserts. That Mr. Moore is pursuing his aim with courage, vigor, tenacity of purpose, and remarkable results is apparent to all who know him.

LETTERS TO THE EDITOR.

MOORE'S ETHERIC LIGHTING.

ON reading your editorial of the 23d inst., on "Etheric Lighting," we were greatly surprised to read,

"Stimulated and encouraged by the results produced by Mr. Tesla in obtaining phosphorescent vacuum tube lighting by means of high potentials and high frequencies, inventors have taken up this work and results are already beginning to manifest themselves."

We feel that this is hardly just to Mr. D. MacFarlan Moore. While we disclaim any intention of disparaging Mr. Tesla's work, we call your attention to the fact that you have unconsciously fallen into error in coupling Mr. Moore's name and Mr. Tesla's.

The public has gotten the impression that Mr. Moore's discoveries and inventions were due primarily to his being "*stimulated by Mr. Tesla.*"

Such is *not* the case. Mr. Moore's interest in phosphorescent lighting dates back a number of years and was never affected by Mr. Tesla's references to the subject.

Some of your readers are aware that there is nothing whatever in common between the widely differing methods employed by each inventor, except that the light is produced by electricity.

Moreover, Mr. Moore was the originator of the term "Etheric" in connection with his lighting system, and long before he had his present laboratory, had written and published a number of articles, intimating in a general way the theory he proposed to employ in producing light with a minimum of heat.

Facts have since demonstrated the correctness of his theory, though originally some of the best electrical authorities pronounced his ideas "impracticable."

The very issue containing your editorial records the fact that nine patents were granted to Mr. Moore on the day named and that many more would follow.

Some of these patents were granted after the Examiner had pronounced the claims non-operative by any known electrical law.

Mr. Moore proved his claims by laboratory demonstration and the patents issued. He was victor at all points.

You have seen Mr. Moore's confidential exhibitions in his laboratory, and in due time we expect you will reproduce the photographs taken at that time, and since, by their own, etheric light, and that you will impart information to your readers which meantime we prefer to keep in abeyance.

We would not trespass on your columns to correct the impression your editorial created, were it not that Mr. Moore's name has been repeatedly coupled with Mr. Tesla's. This was most noticeable at the time Mr. Moore's article on "The Light of the Future" appeared in Cassier's Magazine, July, 1894. The leading journals of the day, although they described only Mr. Moore's work, headed the articles in a way which gave readers the impression that the system referred to was worked out by Mr. Tesla, when in reality he had nothing whatever to do with it. "Honor to whom honor is due."

Moore Electrical Company,
E. J. WESSELS,
Vice-President.

NEWARK, N. J. Oct. 31, 1895.

Electricity Without Wires.

TO THE EDITOR OF THE HERALD:—

In reply to your question as to what discovery would do most to better our condition, in my opinion the demonstration that the earth's electrical charge can be distributed, and thereby electrical waves efficiently transmitted to any distance without the use of cables or wires, would be the most beneficial.

The conveying of motive power from sources such as Niagara in this manner to any place, however remote, would increase many times the productive capacity of mankind. It would bring millions of miserable creatures from the darkness of the coal pits to the light of day. It would cause a kinder feeling to spring up between the weak and the strong, which would lead to a generous adjustment of the evermore difficult questions of labor and capital.

Even if power could not be distributed, the mere transmission of intelligible signals would be of incalculable benefit. Such a realization would do away with the instability of the financial markets, which is the cause of much suffering and misery. It would greatly facilitate the evolution of noevl ideas, as well as the prevention of evils. It would increase the safety of travel and give a new impetus to the press and spread of knowledge. The first message transmitted would be the signal to general disarmament and a closer union of nations, and the words of the great German poet, "Seid umschlungen Millionen, diesen Kuss der ganzen Welt," would be deeply felt everywhere.

Our present knowledge is sufficient to fill us with the conviction that the solution of these important problems is not far off. May the new year witness these triumphs.

NIKOLA TESLA.

NEW YORK, Dec. 31, 1895.

POWER TRANSMISSION.

TESLA ON ELECTRICITY WITHOUT WIRES.

Mr. Tesla thus writes the New York *Herald* under date Dec. 31:—

In reply to your question as to what discovery would do most to better our condition, in my opinion the demonstration that the earth's electrical charge can be distributed, and thereby electrical waves efficiently transmitted to any distance without the use of cables or wires, would be the most beneficial.

The conveying of motive power from sources such as Niagara in this manner to any place, however remote, would increase many times the productive capacity of mankind. It would bring millions of miserable creatures from the darkness of the coal pits to the light of day. It would cause a kinder feeling to spring up between the weak and the strong, which would lead to a generous adjustment of the evermore difficult questions of labor and capital.

Even if power could not be distributed, the mere transmission of intelligible signals would be of incalculable benefit. Such a realization would do away with the instability of the financial markets, which is the cause of much suffering and misery. It would greatly facilitate the evolution of novel ideas, as well as the prevention of evils. It would increase the safety of travel and give a new impetus to the press and spread of knowledge. The first message transmitted would be the signal to general disarmament and a closer union of nations, and the words of the great German poet, "Seid umschlungen Millionen, diesen Kuss der ganzen Welt," would be deeply felt everywhere.

Our present knowledge is sufficient to fill us with the conviction that the solution of these important problems is not far off. May the new year witness these triumphs.

THE NEW TESLA RAILWAY MOTOR.

A gentleman, described by the St. Louis *Globe-Democrat* as "one of the shrewdest electrical engineers in the employ of the Westinghouse Electric and Manufacturing Company," was recently interviewed by a reporter of that paper, to whom the following statements were made in reference to the Westinghouse-Baldwin combination, and the new railway motor now being perfected by Nikola Tesla :

The Westinghouse and Baldwin companies have become convinced that the demand for electric locomotives will grow rapidly in the near future. The steam locomotive which the Baldwin company has been making for sixty years is not to be laid on the shelf right away, but that company has come to believe, I think, that it will gradually, but surely, be displaced by its electric successor, and has grasped the opportunity to take advantage of the coming change by joining forces with one of the two great electric manufacturing companies which control the supply of such motors in the United States.

The allied companies propose to perfect and to offer to the steam railroads electric locomotives which they will buy and use. The resources of both concerns; the electric inventions, devices and experts of the one ; the methods, the expert locomotive and running gear machinists of the other, are being taxed in the effort to produce a motor which the steam companies can use to advantage for any kind of service, but especially for the rapid and safe transportation of passenger trains running more frequently than the steam trains at the present time.

The demand first to be satisfied is for electric locomotives to draw passenger trains on the suburban roads of the trunk lines. The demand already exists —in fact, all the Eastern steam companies have placed large orders.

Tesla is working on an idea in the shape of a motor that I believe will about successfully equip a locomotive with the power desired. This motor is entirely original and truly marvelous. The secret lies in turning the inert and seemingly lifeless force of magnetism into an active force more powerful than steam or a current from a dynamo.

The principles of the motor, concisely put, are these : An electric current is passed through a circular magnet, in appearance resembling a life-preserver. It consists simply of a ring of iron with copper wire bound around it. The electric current generates a strong magnetic current which flashes around and around the circular magnet at terrific speed. Now, if one holds a nail close to an ordinary electric magnet it will be passive in the hand until it is brought close enough for the magnetic force to seize it, when it will fly out of the hand straight to the magnet. But if one holds a nail close to the circular magnet of Tesla it will begin to revolve in the hand ; that is, if the nail is held by the head and the point allowed to hang over the hollow center of the magnet, the point will move around in a circle, slowly at first, then faster and faster, until, if it is dropped upon the table in the center of the hollow it will spin around so rapidly that the eye can not follow its motions.

Several explanations are given of the phenomenon one that there are several magnetic currents in the iron ring and they are chasing one another around in a furious race, but the mystery is as profound as ever.

Another interesting experiment is the balancing of an iron wheel on a nail, or let the wheel revolve upon the finger, using the finger as the axle, and holding it close to the magnet. It will fly around at a rate that will take one's breath away. It is not necessary to touch the magnet at all. All one needs to do is to hold a piece of iron or steel in the hand and bring it within a foot of the magnet, and then he will feel a queer sensation, as of some invisible force trying to draw the piece of metal out of his hand, and, failing in this, trying to twist it around in a circle.

Such is the principle of the coming Tesla motor. In its application as a motive power on the railroad, the construction, of course, differs from that of the experimental magnet, but the idea is the same.

In equipping the new locomotives the circular magnet is attached to the bottom of the engine, and the axle upon which the wheels revolve passes through the center of the magnet without touching it. When the current is turned on, the magnetic force whirling around in the hollow of the magnet catches the axle and turns it. The power for generating this magnetic current can be transmitted by underground wires for almost any distance, and there is practically no waste of power or energy.

We think the time has arrived when we may, with perfect justice and propriety, clearly indicate the policy of this paper in relation to press notices of a character similar to that printed above.

We should like to know—

1st. Is the Westinghouse Company responsible for the statements in that article, or does it encourage its press agent to give public currency to such statements?

2d. If it does, what is the object of such statements?

3d. Who is the person referred to as "one of the shrewdest electrical engineers in the employ of the Westinghouse Company?"

We ask these questions because we should like to definitely fix the responsibility for the many obviously untruthful statements made in the article.

Can it be truthfully stated that either or both of the two great electrical manufacturing companies in this country control the supply of electric locomotives employing either direct or alternating currents? We think not. Indeed we know that this field of work is fully open to any one who wishes to enter it, or any who are already engaged in it.

We know that Mr. Tesla is not engaged on electric locomotive work, and the description of the motor given in the article and its principles of operation differ in no way from the well-known rotary field motor used for years past in this country and Europe.

Is it not about time that the large electrical manufacturing companies of this country stopped this kind of puffery and misstatement of facts? Such notices certainly do not materially strengthen the position of the company responsible for them in the eyes of the general public, nor increase the confidence of capitalists in electrical enterprises.

Any sensible business man knows if any company engaged in any line of business has a startlingly novel and useful invention, of such a revolutionary character as is supposed to be described in the above article, that it is most unwise to publicly announce the fact before the invention is ready for the market, such a course of action being invariably followed by its competitors exerting unusual diligence to find out what the new thing is, and stimulating them to make the utmost exertions not to be left behind in the race. An article of the kind referred to may indeed be looked upon as public notice to its competitors of the direction in which the company making the announcement is working—a thing which everyone possessing a modicum of common sense desires to avoid and carefully endeavors to conceal.

The public have already had enough of promises of what is going to be done and too little fulfilment of such promises.

REVIEWS

*Fisica Tecnologica: Elettricitá e Magnetismo Nozioni fondamentali della Elettrotecnica illustrate da una compendiosa Esposizione delle principali Applicazioni nell, attrale loro Svilluppo.** By RINALDO FERRINI, Professor at the Higher Institution of Milan. Second edition, entirely re-written and illustrated with 169 figures. Milan: Ulrico Hoepli, 1896. 8vo., pp. 534.

Among the numerous important treatises on electricity, for which we are indebted to Italian authors, the volume before us may justly claim an honourable place.

In his preface, Prof. Ferrini objects to some of the names for electrotechnical units which have found their way into Italian, as well as into other European languages. He objects to the abridgments "volt" and "farad," and would write these names in full. For "impedance" he would substitute "impediment"; for "voltage," "electric pressure," and for "shunt," "derivation." It may, however, be asked, whether it is not advantageous to have a set of identical terms used and understood by electricians in all countries, analogous to the names of weights and measures which have been introduced everywhere along with the metric system, and which are more cumbrous than the electrotechnical terms in question?

The first chapter of the work treats of electrostatics, and gives an exposition of the subject, which will not encounter any objections.

The second chapter takes up continuous currents and electrolysis. Among the practical applications of electrolysis there are some of unquestionable value, and others of doubtful utility. It has latterly been observed that aluminium obtained by the electrolytic process is liable to contain an impurity of sodium which, though small in amount, renders the metal very unstable, and open to destructive action (*Comptes Rendus*, cxxi., p. 794).

Goppelsroedor's electric production of coal-tar colours has not yet come into use on a commercial scale. Hermite's treatment of sewage, which is certainly practicable in maritime localities, is open to one grave objection, the organic nitrogen, or "allumenoid ammonia," and the other nitrogen compounds, are either decomposed, or allowed to remain in a soluble state, and consequently unutilised. Now, the great desideratum in the treatment of sewage, is to obtain all the nitrogenous compounds in such a form that they may be applicable to the land. Whether the effluent water from Hermite's process can be advantageously used in irrigation is yet undecided.

That copper can be refined electrically in a satisfactory manner is unquestionable. To the value of the Elmore process (which is here mentioned) we need not refer.

In the same chapter we have an account of the primary couples and batteries of Clamond, Gülcher, Smee, Grove, Bunsen and Daniell. In the table of electro-chemical equivalents (p. 91) we find no mention of platinum, but on p. 116 is a more complete table of the specific resistances of metals and alloys.

In tabulating the electric units with their definitions, the author proposes a set of symbols, such as C for the coulomb, A for the ampere, O for the ohm, V for the volt, F for the farad, J for the joule, and W for the watt.

* Technological Physics: Electricity and Magnetism. The fundamental notions of electrotechnics illustrated in a compendious exposition of their principal applications.

The third chapter discusses magnetic induction. We find here an account of aperiodic and ballistic galvanometers, of the galvanometer of Arsonval, the solenoid amperemeter or ammeter, the electro-dynamometer, the thermic ammeter, the Carpentier electrometer, the Siemens and Cardew voltmeters, and the wattmeter.

The fourth chapter treats of induction currents, and the fifth is devoted to dynamos, motors, and what may be in great part called the mechanical applications of electricity. There is an account of electric motors, continuous and alternating, of polyphase motors, of the monophase motors of Brown, of Benisohke's asynchronous motor, and of transformers.

Electric lighting is duly considered, as is natural in a work written in a country so rich in water-power as is Italy. The experiments of Tesla are not overlooked; but it is remarked that the conditions for such illumination are as yet much less advantageous than is the case with ordinary electric lamps.

The question of protection against lightning the author rightly regards as requiring further study. The disaster to the Town Hall of Brussels, though fitted with conductors according to the Franklin principle, all in perfect order, is unpleasantly significant.

The New York Herald January 17, 1896

TESLA'S NEW CURE BY SHAKING.

The Electrician Has a New Device for Giving Exercise Without Exertion.

Nicola Tesla, the electrician, has directed his inventive genius in a new direction. He has produced a machine which he calls an oscillator, and its object, briefly stated, is to produce a shaking up of the human system, thereby causing certain physical conditions which will result in the healing of some ailments.

He has also produced an artificial light which, under certain conditions, is powerful enough to penetrate the human body. The last named was taken up some months ago by a physician in Vienna, who, it is said, has discovered that by its use the bacilli of tuberculosis may be destroyed. By its means the most remarkable medical cures may become possible.

The oscillator is a platform, which produces a number of more or less violent mechanical vibrations. For persons whose systems are in need of exercise this is said to be particularly useful. Force of movement can be given to the oscillator equal to the exercise or shaking up of the system which could be obtained by walking or riding for half an hour or even an entire day. These results are obtained without the fatigue which would result were the exercise taken in customary ways. These conditions are brought about through the use of electricity, powerful but minute electric shocks being rapidly distributed through the system.

Former Mayor Abram S. Hewitt recently visited the laboratory of Mr. Tesla and submitted to an application of electricity in the region of his liver. While in Europe last year he submitted to electrical treatment for liver trouble and received much benefit.

Mr. Tesla intends making several oscillating machines and placing them in the hands of certain doctors or medical institutions for the purpose of having their usefulness positively determined.

[87665.]—**Tesla Coil.**—In No. 97, April, 1892, of the *Journal* of the Institution of Electrical Engineers, "Max" will find the report of Count Tesla's lecture at the Royal Institution on "Experiments with Alternate Currents of High Potential and High Frequency." The article is illustrated, and the coil used by Tesla is figured and dimensions given, with instructions for making. If "Max" finds any difficulty in getting the number, the Society's library is open to members of other scientific bodies, or, on application to the secretary, to the public generally. F. J. R.

FROM NICOLA TESLA.

He Writes About His Experiments in Electrical Healing.

Some weeks ago this journal published an interesting article concerning electrical oscillations as observed by the eminent scientist, Nicola Tesla. So much interest was shown in the subject that Mr. Tesla was appealed to directly and in response to that appeal he sends to The Detroit Free Press this open letter:

Nos. 46 and 48 E. Houston street,
New York, February, 10, 1896.

During the past few weeks I have received so many letters concerning the same subject that it was entirely beyond my power to answer all of them individually. In view of this I hope that I shall be excused for the delay, which I much regret, in acknowledging the receipt, and also for addressing this general communication in answer to all inquiries.

The many pressing demands which have been made upon me in consequence of exaggerated statements of the journals have painfully impressed me with the fact that there are a great many sufferers, and furthermore that nothing finds a more powerful echo than a promise held out to improve the condition of the unfortunate ones.

The members of the medical fraternity are naturally more deeply interested in the task of relieving the suffering from their pain, and, as might be expected, a great many communications have been addressed to me by physicians. To these chiefly this brief statement of the actual facts is addressed.

Some journals have confounded the physiological effects of electrical oscillations with those of mechanical vibrations, this being probably due to the circumstance that a few years ago I brought to the attention of scientific men some novel methods and apparatus for the production of electrical oscillations which, I learn, are now largely used in some modification or other in electro-therapeutic treatment and otherwise. To dispel this erroneous idea I wish to state that the effects of purely mechanical vibrations which I have more recently observed, have nothing to do with the former.

Mechanical vibrations have often been employed locally with pronounced results in the treatment of diseases, but it seems that the effects I refer to have either not been noted at all, or if so, only in a small degree, evidently because of the insufficiency of the means which have eventually been employed in the investigations.

While experimenting with a novel contrivance, constituting in its simplest form a vibrating mechanical system, in which from the nature of the construction the applied force is always in resonance with the natural period, I frequently exposed my body to coptinued mechanical vibrations. As the elastic force can be made as large as desired and the applied force need be very small, great weights, half a dozen persons, for instance, may be vibrated with great rapidity by a comparatively small apparatus.

I observed that such intense mechanical vibrations produce remarkable physiological effects. They affect powerfully the condition of the stomach, undoubtedly promoting the process of digestion and relieving the feeling of distress, often experienced in consequence of the imperfect function of the organs concerned in the process. They have a strong influence upon the liver, causing it to discharge freely, similarly to an application of a cathartic. They also seem to affect the glandular system, notably in the limbs; also the kidneys and bladder and more or less influence the whole body. When applied for a longer period they produce a feeling of immense fatigue, so that a profound sleep is induced.

The excessive tiring of the body is generally accompanied by nervous relaxation, but there seems to be, besides, a specific action on the nerves.

These observations, though incomplete, are, in my own limited judgment, nevertheless positive and unmistakable, and in view of this and of the importance of further investigation of the subject by competent men I prepared about a year ago a machine with suitable adjustments for varying the frequency and amplitude of the vibrations, intending to give it to some medical faculty for investigation. This machine, together with other apparatus, was unfortunately destroyed by fire a year ago, but will be reconstructed as soon as possible.

In making the above statements I wish to disconnect myself with the extraordinary opinions expressed in some journals, which I have never authorized and which, though they may have been made with good intent, cannot fail to be hurtful by giving rise to visionary expectations. Yours very truly,

N. TESLA.

The New York Herald February 23, 1896

TESLA AND THE ROENTGEN RAYS.

The Famous Electrician Has Succeeded in Making a Photograph of the Human Brain.

HIS FORMER INVENTION.

He Once Took Fairly Successful Cathode Pictures of Mark Twain, Joe Jefferson and Others.

HIS APPEARANCE DESCRIBED.



R. TESLA took a photograph of the human brain last week. I surprised the fact out of him in a conversation in which he was telling me for my own information something about the X ray, or "Roentgen ray" as it is known popularly. The photograph was not satisfactory, except as an evidence that it was possible to photograph through the skull. It remains to be seen whether the nature of the X ray limits its field to such demonstrations as have been made in the past, or whether, as Nikola Tesla says, you can take photographs through a brick wall twelve feet thick. The whole situation is summed up in his statement that if the Roentgen ray is etheric, as Roentgen believes it to be, its scope is limited to the penetration of comparatively thin substances. You can photograph through a book with it, but you cannot photograph through an inch of glass. But if the waves which produce the effects in what is called "cathode photography" are produced by waves propagated in straight lines like sound waves, their possibilities are almost boundless. Mr. Tesla has been at work in his shop on Houston street ever since the Roentgen experiments were made public, and he hopes to be able to determine in the near future the character of the agents which are at work in the Roentgen and other experiments.

TESLA'S DISCOVERY.

It is a remarkable fact that not to Roentgen nor to any of the recent experimenters is the credit of discovering the penetrative power of the X ray due. Its development, like that of most great discoveries, has been gradual and has proceeded by a regular process of evolution, in which many men of science have taken part. Mr. Tesla himself made public several years ago the fact that when there were sudden discharges of electricity through a wire, certain waves, which he designated "sound waves of electrified air," were propagated; or, as he himself explained it, "certain kinds of waves which I called 'sound waves of electrified air' are propagated from conductors when a strong rapidly vibrating current passes through them, such as sudden discharges from condensers. These propagate in straight lines like sound. They are longitudinal waves, penetrating bodies, and they cannot be stopped by interposing metal plates."

Whether his "sound waves of electrified air" are similar to the cathode ray or different from it Mr. Tesla does not yet know. But the real discovery of the Roentgen ray dates back even beyond Mr. Tesla's experiments and the use of the ray for photographing is not new. Lenard more than two years ago took photographs through metal plates and published results of experiments in the scientific papers. These experiments, like those of Mr. Tesla, were not of a popular character, and they attracted no attention outside scientific circles. It remained for Professor Roentgen to photograph money in a purse and to take pictures of the bones of the human hand. That appealed immediately to the popular imagination. When excitement has calmed down a little and the situation is reviewed credit will be given to all those who contributed to the development of the wonderful X ray and its application. Then another fact will be remembered and accorded to the credit of Mr. Tesla—that all the discoveries made through the popularization of the Roentgen experiments were made possible by a remarkable invention of Mr. Tesla—his converter. For, whether credit is given to Mr. Tesla in the reports of experiments or whether he is ignored or slighted by the mention of "a converter" used in the process, the Tesla converter is used universally to obtain the sudden discharges of electricity through which the X ray is produced.

Five or six years ago Mr. Tesla started out to find a way to produce an alternating current of high frequency of conversion from any kind of electricity. He found that he could discharge a condenser charged from a static machine (such as Roentgen is using in his experiments) or from any other source into a wire coil and get oscillations at a terrific rate. To get the secondary current which he wanted he put a second coil around the first. But the necessity of using miles of fine wire in the secondary coil made it expensive and limited its practical use. Then Mr. Tesla found a way to produce the same result with a few thick wires that was produced with a great many miles of thin wires. How he achieved this result is for scientists to know and understand. It is enough for the average intelligence to comprehend the fact that he produced a revolution in the electric world.

"If every one who uses my machine in electro-therapy alone would give me a quarter I would be a very wealthy man," he said with an ingenuous smile when I asked him what return beyond the fame of his achievement he had received. "It is used now by millions of persons, but I have never received a dollar from it, and there is no way in which I could."

I asked if there was any invention from which Mr. Tesla received an income—for ideas, however valuable, will not conduct costly experiments.

"I receive a small income from my invention of the rotating field," said Mr. Tesla, "and I have a small income from my home. And all of that I blow in here."

THE INVENTOR'S WORK.

It was said with an accent which robbed the words of the character of slang. The gesture which accompanied them took in comprehensively the dark spaces beyond the trim little office on the second floor of the Houston street building, which has been the headquarters of the inventor since he was burned out, a year ago. Here he has been conducting experiments with which he hopes to revolutionize the production of electric power. He believes he will be able to produce electricity before long at an infinitely smaller cost than at present is possible, and with an apparatus which will be comparatively simple and cheap. But the details of his experiments in this direction are known only to himself. He took me into his workshop one day recently, but his description of it was so brief and his whole manner so indicative of horror at the thought of publicity that we were not in the room more than a minute, and the amount of information I obtained about it could be summed up in one of the shortest paragraphs ever written.

Mr. Tesla is tall and slender, with very black, thick hair. He wears a very small mustache over a small mouth. All of his features are delicate. His cheeks are rather hollow but they have the flush of health. His cheek bones are conspicuous. His manner is cordial, and as attractive in its way as his appearance for he is not the careless, begrimed machinist as he issues from his shop, but a "well groomed" man, whose clothing is stylish and well fitting, and whose hands and face are as pink and clean as a baby's. Like most inventors, he is a late worker. The forces of both mind and body, he thinks, operate better at night than in the daytime. So he is often in his shop until two or three o'clock in the morning. He seldom comes down before noon. Occasionally he is attracted by "society" and he was one of the star features at a recent "function," at which Sarah Bernhardt also shone. But his work absorbs most of his time, and he has little taste for anything else.

HIS EARLY PICTURES.

A curious fact about Mr. Tesla, which is recalled by the recent experiments with the cathode rays, is the fact that he demonstrated first the possibility of taking photographs with those rays. He took photographs of Joe Jefferson, Mark Twain and others by their light, and these photographs were reproduced to illustrate a story about his workshop. But the experiments made then did not possess the quality of popularity as did the Roentgen experiments, or, in fact, the earlier experiments of Mr. Tesla himself. Probably the only parallel to the interest displayed by the public in the Roentgen experiments is to be found in the excitement which prevailed when it was announced that Mr. Tesla had produced an illuminating glow in the centre of a room without the use of wires or other electrical connections. The popular mind conjured up at once the picture of great halls illuminated by an artificial light diffused like the daylight, and the changes were rung for many days on the possibilities to be developed under the new discovery. All of the speculation about the practical application of the discovery ceased when the workshop of Mr. Tesla was destroyed by fire, and in its destruction was lost the apparatus which it may take the greater part of a lifetime to reproduce. But during the excitement which prevailed it was said the story of the demonstrations made by Mr. Tesla in London reached the eyes of the reading public through the medium of 30,000 American newspapers.

Electrical Progress.

NIKOLA TESLA thinks that "the discovery which would do most to better our condition would be the demonstration that the earth's electrical charge can be disturbed, and thereby electrical waves efficiently transmitted to any distance without the use of cables or wires." Edison says that "the discovery or invention which would do most to better the conditions of life" would be "the production of electricity direct from coal."

Engineering Magazine March 1896

PROFESSOR RÖNTGEN'S DISCOVERY OF A NEW RADIANCE.

By Michael I. Pupin.

RÖNTGEN'S discovery of what appears to be a new form of radiant energy has justly atracted universal attention. The interest attached to it is a twofold one: first, its purely scientific significance; second, its practical importance. The discovery may be stated broadly as follows: if an electric current be sent through a vacuum tube—the so-called Crookes tube,—then, in addition to the heat and fluorescent light generated in the glass of the tube, there is, according to Röntgen's discovery, another form of radiant energy generated, which we may call the Röntgen rays. The following characteristic elements describe this energy: it produces fluorescence in fluorescent substances, just as ultra-violet light; it affects the photographic plate, just as the actinic part of the solar spectrum; it penetrates all bodies, even the metals, in a greater or smaller degree, and it is neither reflected or refracted appreciably. No other known form of radiant energy resembles the Röntgen rays in this last respect.

Much has been written lately about this discovery, but little has been said which would serve as trusty and intelligible guidance to those who are not familiar with modern electric appliances. It seems desirable, therefore, to give here a brief and simple description of the apparatus, and of the method of operation.

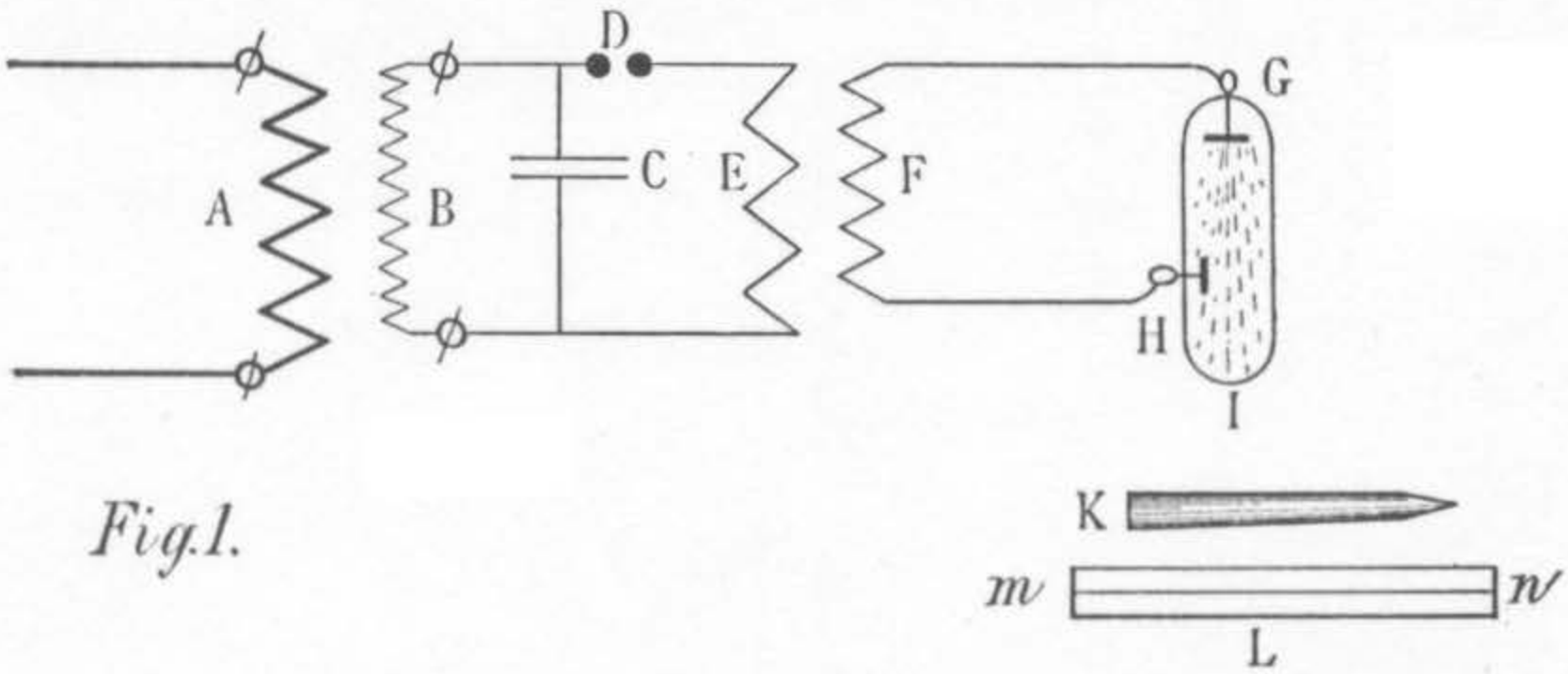


Fig. 1.

In Fig. 1 we have an ordinary induction coil, AB. Its primary coil, A, is connected to the mains of an alternating current circuit, and the supply of current is regulated by an auxiliary resistance-box. The secondary winding, B, is connected to a Leyden jar, C. A gal-

lon jar with a medium-sized coil gives a sufficiently strong effect. The jar is connected to an oscillatory transformer, EF, which needs a more detailed description. It can be constructed as follows. Take two large glass jars, A and B (Fig. 2); wind about eighteen turns of very coarse, well-insulated wire, aa, on the outside jar, B, and about two hundred turns of fine wire, bb, on the inside jar. Place the jar, A, into B, and fill the space between them with very hot paraffin. Pour very hot beeswax over the outside winding, aa, until a thick crust is formed. This is then an oscillatory transformer. The coarse wire winding, aa, is the primary, and the fine wire winding is the secondary, of this transformer. In Fig. 1 the primary, indicated by E, is connected to the Leyden jar, C, and the secondary to the vacuum tube, GH. The plateholder, L, containing the sensitive photographic plate, mm, is in line with the electrode, G, so that it is in the line of discharge from this electrode. The object, K, to be photographed, is placed between the tube and the plate.

Fig.2.

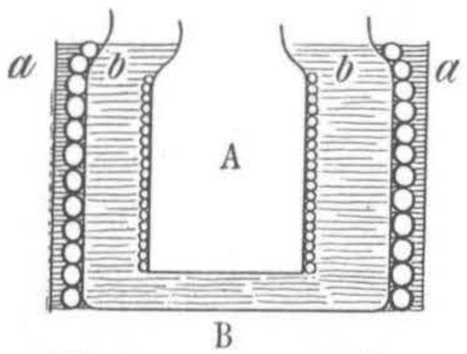
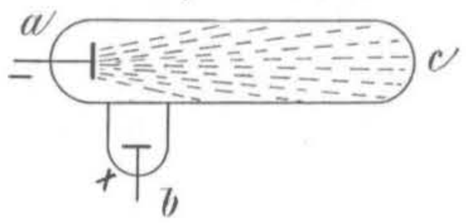


Fig.3.



We can pass now to the operation. Observe first that the circuit, CDE, contains an air-gap, D, between two small brass spheres. As soon as the current is admitted into A, there is induced a very high tension current in B, which charges the jar until the tension between the small spheres of the air-gap is high enough to break through. The jar discharges then, and the discharge current will oscillate back and forth in the circuit, CDE, at a rate of several hundred thousand vibrations per second. These vibrations die out rapidly, but the alternating current in B makes a break through the gap, D, at every alternation, and sets up, after each disruptive break, a series of oscillations. In fact, the circuit, CDE, may be compared to a church bell, and the disruptive action at the gap, D, performs the function of the swinging tongue of the bell. After each stroke, a series of waves spreads out into space,—melodious sound waves in one case, silent electric waves in the other. These rapidly-vibrating waves induce in the secondary circuit, F, a series of waves of the same rapidity, but of much



HAND TAKEN BY M. I. PUPIN.

Employing a Holtz Machine and a Crookes Tube. Time of Exposure, 50 Minutes.

higher tension. The oscillatory current in the tube, GH, produces a luminescence in the attenuated gas in the vacuum tube. If the vacuum is not very high, the luminescence is almost entirely within the gas itself; this is not the case in very high vacua. For the purpose of pointing out clearly how these Röntgen rays are produced, it is well

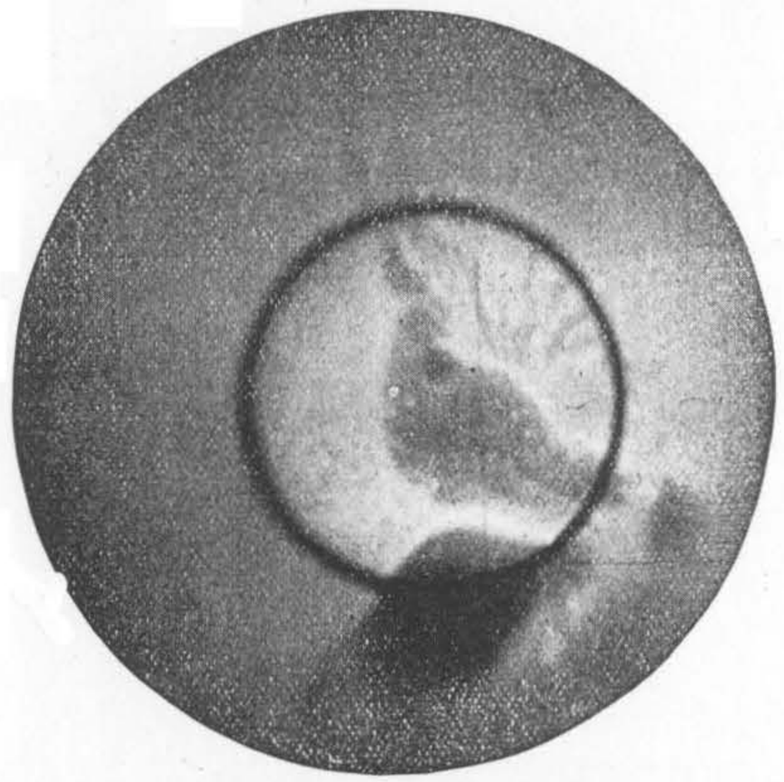
to consider briefly the electrical discharge in the tube when the vacuum is very high.

Fig. 3. represents a typical form of a vacuum tube, capable of giving a strong Röntgen effect. Two platinum wires, a and b, carrying aluminum discs, are sealed in a glass tube. They are the electrodes which are connected to the high tension coil. The electrode which at any moment is connected to the negative pole is called the cathode, and that connected to the positive pole is the anode. When the current is oscillatory, as in the arrangement described in Fig. 1, each electrode alternates periodically between being anode and cathode. Thus, in an alternating current reversing one hundred times per second, each electrode will be anode fifty times and cathode fifty times per second. Fix, now, any moment when a is the cathode and b is the anode. Suppose that the air pressure in the tube has been gradually reduced by the action of a mercury pump to something like one millionth of an atmosphere. The electrical discharge, which, as long as the vacuum is not high, appears as a bright luminescence of the gas, is hardly visible at this excessively low pressure.

In place of this luminescence of the gas, there appears in very high vacua a vivid fluorescence of the glass,—blue in American glass, green in German glass. This fluorescence is produced by faint streamers which proceed in straight lines from the cathode, as indicated by the dotted lines in Fig. 3. Where these streamers meet the tube, there the fluorescence and the heating of the glass take place. Professor Röntgen finds that this brightly-fluorescing surface in the walls of the tube is the seat of a radiant energy, which possesses the characteristic features described above. These rays, which Röntgen calls the X-rays, can be observed in a dark room by means of a paper screen saturated with an emulsion of a fluorescing substance. The discoverer employed barium platino-cyanid. Wherever the rays strike this screen, they cause it to fluoresce, and the intensity of the fluorescence measures the intensity of the Röntgen rays. By interposing a substance between the tube and the screen, the relative opacity of the substance for these rays can be determined. It is found that even metals are transparent to it, but in various degrees. Thus, if a given thickness of platinum will absorb a certain amount of these rays, it is found that the same amount of absorption will be produced by a lead plate of three times the thickness, by a zinc plate of six times the thickness, and by an aluminum plate of two hundred times the thickness. Wood, ebonite, rubber, water, and organic compounds, are more transparent than metals, but none of them are perfectly transparent, nor is any substance perfectly opaque. A fact deserving an especial mention is that glass, especially that containing lead, is nearly opaque. Bone is much more

opaque than flesh; the shadow of a human hand on a fluorescent screen will, therefore, show the skeleton darker than the flesh.

Another method of studying this new form of radiant energy is by means of photography. Röntgen found that a photographic film is affected by the X-rays, but, since these rays are neither reflected or refracted, it is useless to employ lenses. The plate remains shut up in the plate-holder, and the object to be photographed is placed upon it, so as to be between the tube and the plate, as indicated in Fig. 1. The time of exposure varies with the quality of the vacuum and the

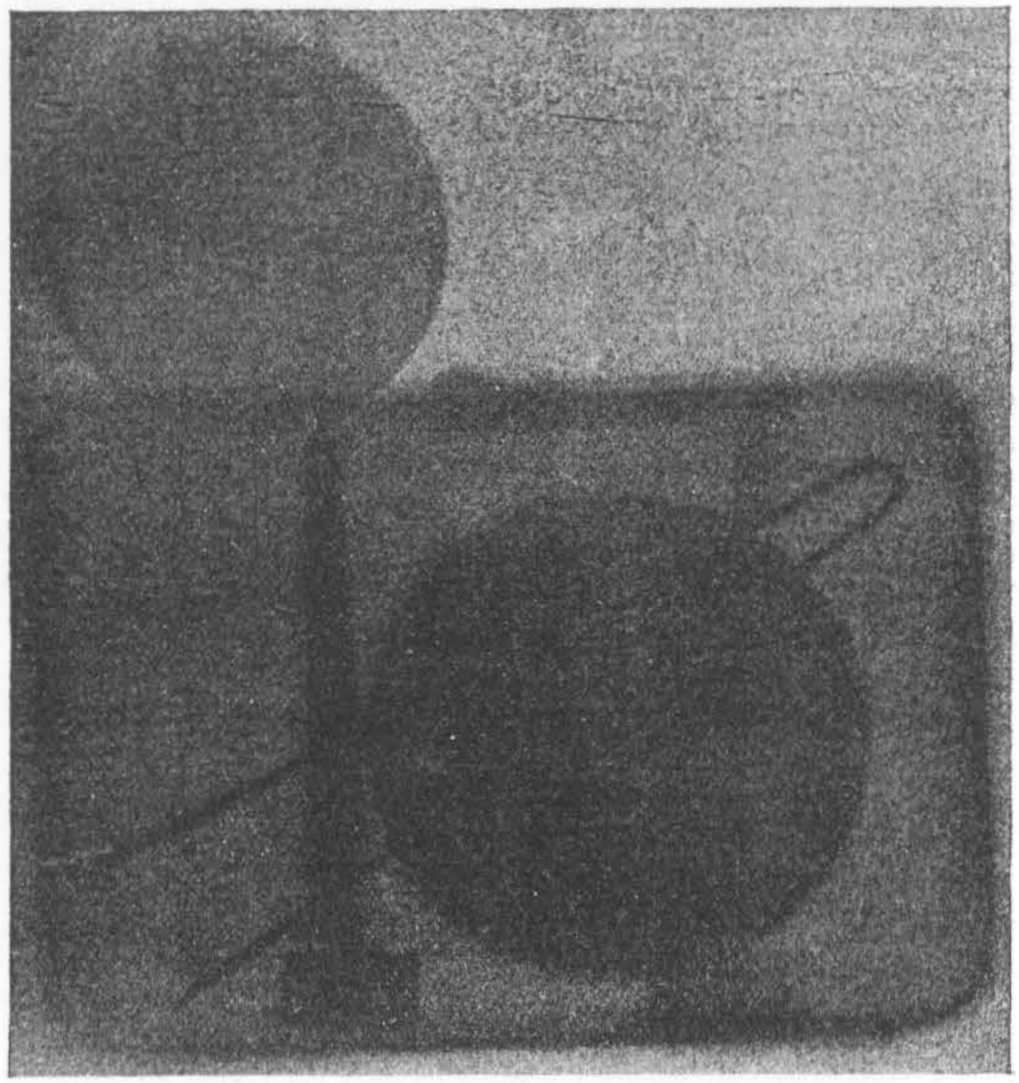


AN ALUMINUM DISC WITH FIGURES IN RELIEF.

The negative shows much detail and also want of homogeneity in the metal of the upper plate above the crest of of the bird, the plate being less transparent in this part than in the lower part. Taken by M. I. Pupin with a Holtz machine and an electrodeless tube. Time of exposure, 25 minutes.

electric tension employed. It may be as short as four minutes, or it may be as long as two hours. The nearer the tube is to the plate, the shorter is the time of exposure, but evidently the less defined will be the shadow picture. There is good prospect of perfecting both the means of producing the vacua and also the construction of the tubes, so as to produce the X-rays in a larger quantity. This would shorten the time of exposure, and also improve the definition of the photographs.

Röntgen's experiments have been repeated in this country in several laboratories,—at Harvard, Yale, Johns Hopkins, Princeton, and



ALUMINUM BOX CONTAINING AN ALUMINUM MEDAL AND HAIRPIN.
Under-exposed. Taken by M. I. Pupin.

in the writer's laboratory at Columbia. At the McGill University in Montreal a bullet was located in a man's leg by means of this photography. Similar reports have reached us from Europe. Several hospitals in this city intend to put in an outfit suitable for the production of the X-rays. The surgeons expect much help from this remarkable discovery, and the experimental results obtained in this country so far seem to hold out a very bright prospect.

But surgery is not the only profession which is going to reap the immediate benefits from the practical application of this discovery. Metallurgy and mineralogy expect to overcome some of their old difficulties with the aid of the X rays. Various minerals have a various degree of opacity for these rays, and it is not at all difficult to distinguish a real gem from an imitation. The occlusion of metals is

particularly easy to detect, since metals seem to be more opaque than other substances. But even the metals themselves have a various degree of opacity, as has been already pointed out. Hence, if two metals are mixed to make an alloy, and the mixture is not perfectly homogeneous, it would be an easy matter to detect the want of uniformity, provided, of course, that a sufficiently thin plate is cut from the sample to be examined; thick plates are too opaque to permit an appreciable part of the X-rays to pass through. It is, therefore, not quite clear to the writer how this new method of photography can be employed in its present stage of development to detect flaws in steel guns and armor-plates, unless these rays are made much more powerful than we have been able to make them so far, and unless also we discover photographic plates which are much more sensitive to these rays than the plates now in the market. The author confesses his belief, however, that we shall, in all probability, soon reach both these improvements. A sufficiently long exposure will, even now, as the writer knows from his own experiments, reproduce the various details in the structure of a body. So, for instance, the photograph of a pair of spectacles in a leather case and separated from the plate by a thin sheet of ebonite will, with sufficiently long exposure, show the curvature of the lenses. The photograph of an aluminum medal will sometimes come out so neat and well-defined as to show the lettering and the figures,—that is, in the negative. In the printing this fine detail is not always clearly shown. But it must be remembered that we are only at the beginning of a new art. We hope, and with reason, that this new photography will reveal the interior structure, not only of dead matter, but also of living organisms.

The photographs accompanying this article explain themselves.

Since writing the above I have been able to collect additional facts which seem of sufficient interest to merit mention.

The apparatus described above was discarded as too complicated and too severe on the tube. A six-plate Holtz machine made by the Galvano Faradic Company of New York was tried and gave complete satisfaction. The Röntgen effect with such a machine is sufficiently powerful, and the wear on the tubes is small. In fact, they seem to improve with use, instead of deteriorating. The tube should be connected in series with the outside coatings of the two jars, and the capacity of the jars should not be too large for the size of the tube. With a pear-shaped Crookes tube of 5 inches diameter half-pint jars give excellent results. A cylindrical vacuum tube without internal electrodes, but with external tinfoil coatings at the extremity of the tube, will do very well as a substitute for a Crookes tube. The

vacuum should be as high as anybody can possibly obtain. This is one of the good things of which we cannot have too much,—at least with the methods of exhausting now employed in this country. It should be observed that these methods are perfectly wretched.

Regarding the detail of the things photographed, it is important to observe that Röntgen photography acts differently from ordinary photography. We cannot speak here of over-exposure, unless we specify that it is over-exposure with regard to certain parts which are exposed. Take, for instance, the shadowgraph of a number of objects enclosed in an aluminum cigar box. With a short exposure the details of the structure of the box appear, but those of the enclosed objects do not. With a long exposure the box itself is almost invisible, but the details of the enclosed objects appear. A still longer exposure will make the things enclosed in the box disappear one by one. The most opaque will remain longest. Again, consider the photograph of the human hand. A short exposure gives nothing but the flesh. A little longer exposure brings out the nails. Still longer, and the skeleton begins to appear, whereas the flesh begins to disappear. Still longer, and nothing but the bones appear the various parts being accurately represented in their relative opacity. A still longer exposure will make the various parts of the skeleton disappear one by one, according to their relative opacity. A sufficiently-prolonged exposure would reveal opaque objects concealed in the bone itself. There is no doubt that by a sufficiently long exposure the homogeneity of not excessively thick metal plates can be examined with considerable accuracy.

M. I. P.

February 18, 1896.

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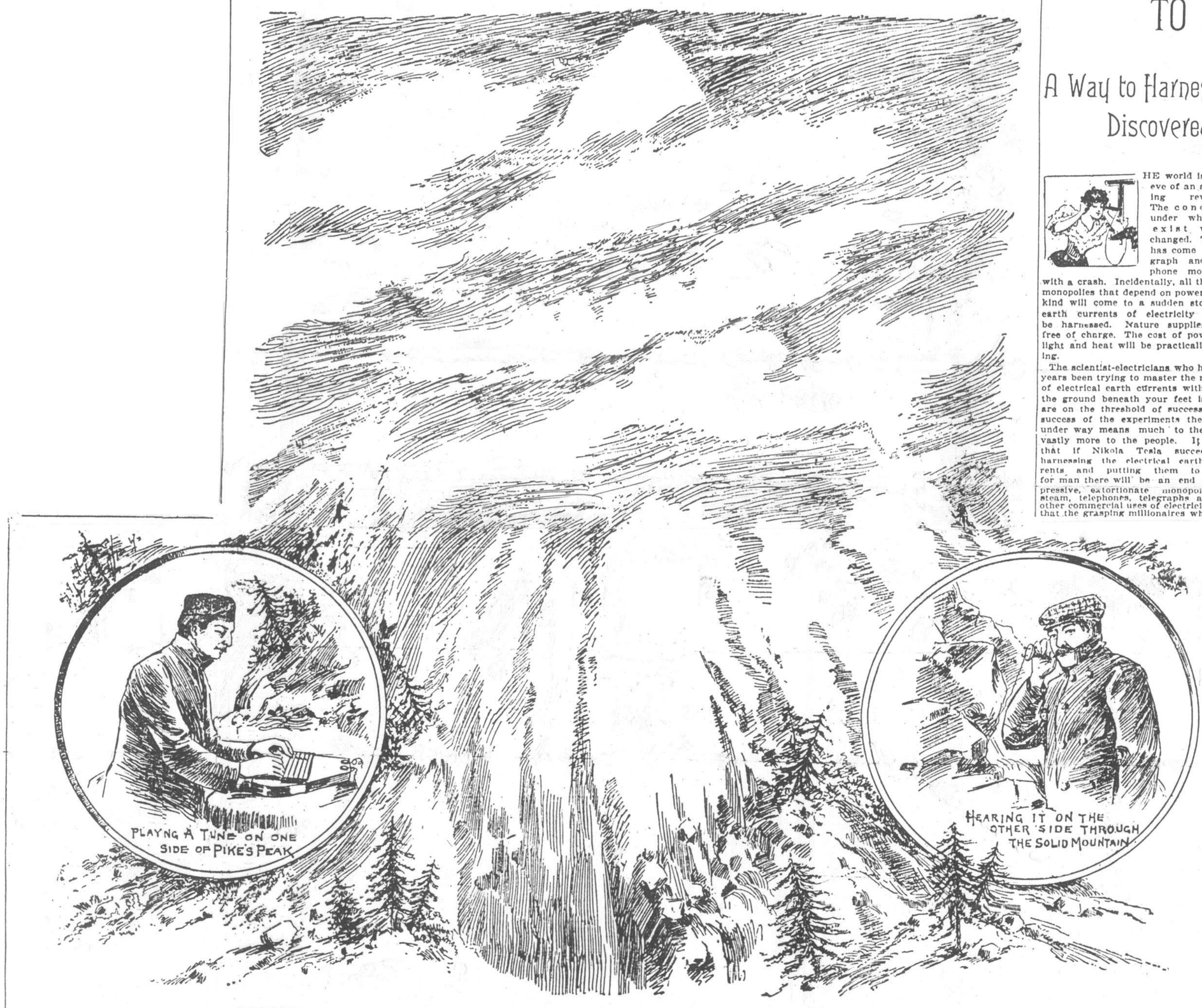
Tesla's Marvellous Achievement.



COMMUNICATING FOUR MILES THROUGH PIKE'S PEAK WITHOUT WIRES.

EARTH ELECTRICITY TO KILL MONOPOLY

A Way to Harness Free Electric Currents Discovered by Nikola Tesla.

THE world is on the eve of an astounding revelation. The conditions under which we exist will be changed. The end has come to telegraph and telephone monopolies with a crash. Incidentally, all the other monopolies that depend on power of any kind will come to a sudden stop. The earth currents of electricity are to be harnessed. Nature supplies them free of charge. The cost of power and light and heat will be practically nothing.

The scientist-electricians who have for years been trying to master the mystery of electrical earth currents with which the ground beneath your feet is filled, are on the threshold of success. The success of the experiments they have under way means much to them, but vastly more to the people. It means that if Nikola Tesla succeeds in harnessing the electrical earth currents and putting them to work for man there will be an end to oppressive, extortionate monopolies in steam, telephones, telegraphs and the other commercial uses of electricity, and that the grasping millionaires who have for two decades milked the people's purse with electrical fingers will have to relinquish their monopoly.

Nikola Tesla has discovered the secret of the electric earth currents of nature, and they will be adapted to the uses of man. He has succeeded in transmitting sound by the currents that make an electric rot of the earth. The transmission of power will follow. His experiments reduced to commercially practicable uses will mean that men will be able to tap the electric currents of the earth and make them serve the purposes of industry and of trade just as a well-digger over on Long Island taps water or a Pennsylvania miner opens a vein of coal. The mighty electrical energy that has been stored up in the earth for ages will be harnessed and made to move the machinery of men.

Electricity will be as free as the air. For the privilege of its use legislatures will not have to be bribed or men corrupted at the polls, and public boards will not have to be "seen" to bestow exclusive franchises upon corporations organized to use public property for purposes of private gain, and make the people pay the original cost of their investment and excessive charges for service in order to squeeze dividends out of copiously watered shares.

Monopolies for purveying steam power too will be forced to capitulate to free electricity, for with the latter manufacturers will only have to connect their dynamos with the earth current to set their machinery in motion. The successful adaptation of Tesla's discovery will administer a death-blow to the most galling slavery that has ever yoked the activities of men to the treadmill of monopoly. Tesla is the wizard who is going to emancipate modern industries from the shackles of corrupting, dividend-grabbing, monopolistic corporations.

Sound travels with amazing speed, but electrical vibrations travel so swiftly that it is difficult to conjure up a figure which will graphically illustrate their speed. Here is one that will, perhaps, convey a vivid and lucid impression. In fancy place yourself at a table with a revolver in one hand and a finger of the other hand on the key of a telegraph instrument connected with a wire that girdles the globe seven times and laps over on the eighth turn a distance. the pistol and simultaneously press the telegraph key. While the sound of the report of the revolver is travelling 1,120 feet the electrical impulse imparted by the pressure on the key will pass seven times [illegible] around the world through the wire with which the key is connected.

Sound travels 1,250 feet a second, an electrical impulse 186,000 miles a second. If the electrical currents with which the earth is filled can be harnessed and put to work a new era in electricity will have dawned. It is to the mastering of the mystery of these earth currents and their adaptation that scientists like Tesla have been striving.

In the course of Tesla's experiments it is reported he found that in the vicinity of large cities there were so many conflicting earth currents that satisfactory results could not be obtained. So he went out to Denver and near there found a better field for experimenting. There he met a friend interested in electrical research. They went to Pike's Peak. Conspicuous among their baggage were two autoharps.

Tesla and his friend scaled the rugged sides of the peak. At an elevation agreed upon they separated. Tesla skirted the peak and, on reaching a point precisely opposite the place at which he left his friend he stopped. The two experimenters, on a line drawn straight through the peak, were thus separated by four miles of stratified rock. The two autoharps had been very delicately attuned before the scientists parted, and a time fixed for Mr. Tesla's comrade to play an air (also agreed upon) on the autoharp.

Tesla waited patiently the arrival of the appointed time. Then he connected his harp with the ground in such a way as to secure harmonic resonance with the earth current. The manner and medium of this connection are secrets. The receiving autoharp was equipped with a microphone. As the time approached for his friend on the other side of the peak to strum the appointed tune Tesla listened with rapt attention.

At last, as a tuning-fork responds to its harmonic note sounded on the strings of a piano, the autoharp in Mr. Tesla's hands gave out the harmonic tones of "Ben Bolt," which his companion at his station four miles away straight through the peak was plucking from the tense wires of his instrument. The experiment was a success. After many tunes had been played Tesla and his companion descended the peak. A statement of the facts and results of the experiments was written and attested before a notary public as a matter of scientific record.

The electric currents are in the earth. Their strength is great enough to furnish all the power and light man needs. Mr. Tesla has overcome the initial difficulty, and has located and tapped the earth currents. The rest will follow, as followed the telephone, Prof. Bell's discovery of how to transmit speech over a wire.

TESLA'S STARTLING RESULTS IN RADIOGRAPHY AT GREAT DISTANCES THROUGH CONSIDERABLE THICKNESSES OF SUBSTANCE.

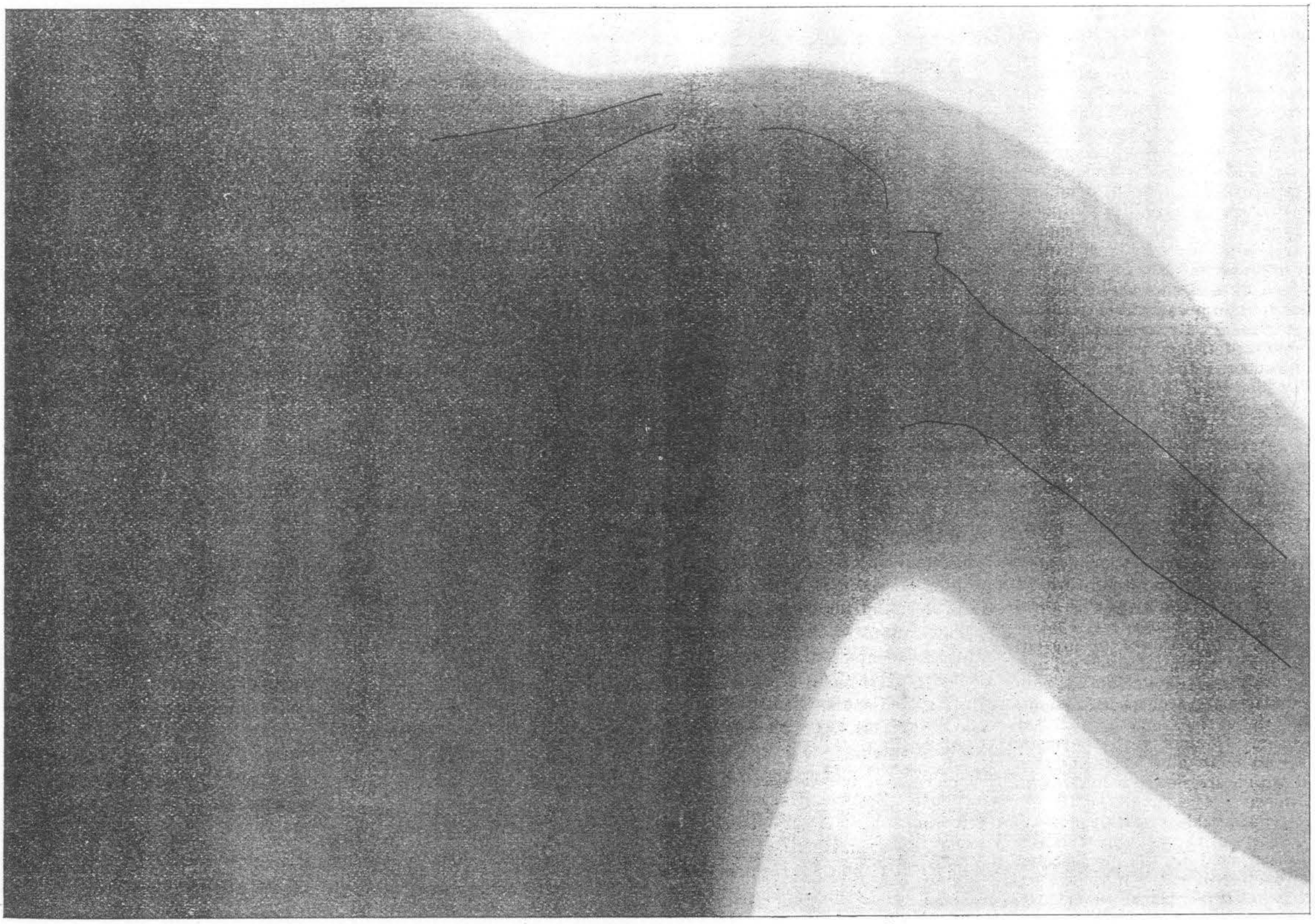


FIG. 1.—PHOTO-ENGRAVING OF TESLA RADIOGRAPH OF RIGHT SHOULDER OF A MAN, SHOWING RIBS AND SHOULDER AND UPPER ARM BONES—TAKEN THROUGH CLOTHING, BOARD, ETC., AT A DISTANCE OF FOUR FEET.

TESLA ON ROENTGEN RAYS.

A HIGHLY INTERESTING AND VALUABLE COMMUNICATION FROM THE TALENTED YOUNG INVENTOR.

TO THE EDITOR OF ELECTRICAL REVIEW:

One can not help looking at that little bulb of Crookes' with a feeling akin to awe, when he considers all that it has done for scientific progress—first, the magnificent results obtained by its originator; next, the brilliant work of Lenard, and finally the wonderful achievements of Roentgen. Possibly it may still contain a grateful Asmodeus, who will be let out of his narrow prison cell by a lucky student. At times it has seemed to me as though I myself heard a whispering voice, and I have searched eagerly among my dusty bulbs and bottles. I fear my imagination has deceived me, but there they are still, my dusty bulbs, and I am still listening hopefully.

After repeating Professor Roentgen's beautiful experiments, I have devoted my energies to the investigation of the nature of the radiations and to the perfecting of the means for their production. The following is a brief statement which, I hope, will be useful, of the methods employed and of the most notable results arrived at in these two directions.

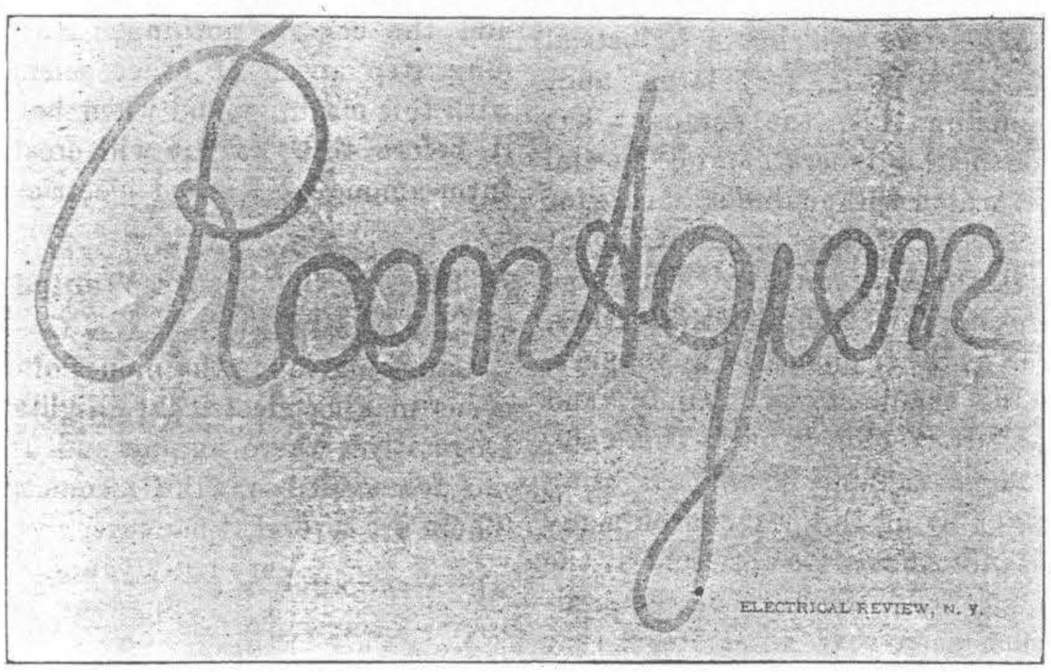


FIG. 2.—TESLA'S RESPECTS TO PROF. ROENTGEN—A RADIOGRAPH OF A WIRE SIGN TAKEN THROUGH A WOODEN COVER AT THE REMARKABLE DISTANCE OF ELEVEN FEET, WITH ONE-HALF HOUR'S EXPOSURE.

In order to produce the most intense effects we have first to consider that, whatever their nature, they depend necessarily on the intensity of the cathode streams. These again being dependent on the magnitude of the potential, it follows that the highest attainable electrical pressure is desirable.

To obtain high potentials we may avail ourselves of an ordinary induction coil, or of a static machine, or of a disruptive discharge coil. I have the impression that most of the results in Europe have been arrived at through the employment of a static machine or Ruhmkorff coil. But since these appliances can produce only a comparatively small potential, we are naturally thrown on the use of the disruptive discharge coil as the most effective apparatus. With this there is practically no limit to the spark length, and the only requirement is that the experimenter should possess a certain knowledge and skill in the adjustments of the circuits, particularly as to resonance, as I have pointed out in my earlier writings on this subject.

After constructing a disruptive coil suitable for any kind of current supply, direct or alternating, the experimenter comes to the consideration as to what kind of bulb to employ. Clearly, if we put two electrodes in a bulb, or use one inside and another outside electrode, we limit the potential, for the presence not only of the anode but of any conducting object has the effect of reducing the practicable potential on the cathode. Thus, to secure the result aimed at, one is driven to the acceptance of a single electrode bulb, the other terminal being as far remote as possible.

Obviously, an inside electrode should be employed to get the highest velocity of the cathode streams, for the bulbs without inside terminals

(Continued on page 134.)

TESLA ON ROENTGEN RAYS.

(*Concluded from page 131.*)

are much less efficient for this special object in consequence of the loss through the glass. A popular error seems to exist in regard to the concentration of the rays by concave electrodes. This, if anything, is a disadvantage. There are certain specific arrangements of the disruptive coil and circuits, condensers and static screens for the bulb, on which I have given full particulars on previous occasions.

Having selected the induction apparatus and type of bulb, the next important consideration is the vacuum. On this subject I am able to make known a fact with which I have long been acquainted, and of which I have taken advantage in the production of vacuum jackets and all sorts of incandescent bulbs, and which I subsequently found to be of the utmost importance, not to say essential, for the production of intense Roentgen shadows. I refer to a method of rarefaction by electrical means to any degree desirable, far beyond that obtainable by mechanical appliances.

Though this result can be reached by the use of a static machine as well as of an ordinary induction coil giving a sufficiently high potential, I have found that by far the most suitable apparatus, and one which secures the quickest action, is a disruptive coil. It is best to proceed in this way: The bulb is first exhausted by means of an ordinary vacuum pump to a rather high degree, though my experiences have shown that this is not absolutely necessary, as I have also found it possible to rarefy, beginning from low pressure. After being taken down from the pump, the bulb is attached to the terminal of the disruptive coil, preferably of high frequency of vibration, and usually the following phenomena are noted. First, there is a milky light spreading through the bulb, or possibly for a moment the glass becomes phosphorescent, if the bulb has been exhausted to a high degree. At any rate, the phosphorescence generally subsides quickly and the white light settles around the electrode, whereupon a dark space forms at some distance from the latter. Shortly afterward the light assumes a reddish color and the terminal grows very hot. This heating, however, is observed only with powerful apparatus. It is well to watch the bulb carefully and regulate the potential at this stage, as the electrode might be quickly consumed.

After some time the reddish light subsides, the streams becoming again white, whereupon they get weaker and weaker, wavering around the electrode until they finally disappear. Meanwhile, the phosphorescence of the glass grows more and more intense, and the spot where the stream strikes the wall becomes very hot, while the phosphorescence around the electrode ceases and the latter cools down to such an extent that the glass near it may be actually ice-cold to the touch. The gas in the bulb has then reached the required degree of rarefaction. The process may be hastened by repeated heating and cooling and by the employment of a small electrode. It should be added that bulbs with external electrodes may be treated in the same way. It may be also of interest to state that under certain conditions, which I am investigating more closely, the pressure of the gas in a vessel may be augmented by electrical means.

I believe that the disintegration of the electrode, which invariably takes place, is connected with a notable diminution of the temperature. From the point on, when the electrode gets cool, the bulb is in a very good condition for producing the Roentgen shadows. Whenever the electrode is equally, if not hotter than the glass, it is a sure indication that the vacuum is not high enough, or else that the electrode is too small. For very effective working, the inside surface of the wall, where the cathode stream strikes, should appear as if the glass were in a fluid state.

As a cooling medium I have found best to employ jets of cold air. By this means it is possible to operate successfully a bulb with a very thin wall, while the passage of the rays is not materially impeded.

I may state here that the experimenter need not be deterred from using a glass bulb, as I believe the opacity of glass as well as the transparency of aluminum are somewhat exaggerated, inasmuch as I have found that a very thin aluminum sheet throws a marked shadow, while, on the other hand, I have obtained impressions through a thick glass plate.

The above method is valuable not only as a means of obtaining the high vacua desired, but it is still more important, because the phenomena observed throw a light on the results obtained by Lenard and Roentgen.

Though the phenomenon of rarefaction under above conditions admits of different interpretations, the chief interest centers on one of them, to which I adhere—that is, on the actual expulsion of the particles through the walls of the bulb. I have lately observed that the latter commences to act properly upon the sensitive plate only from the point when the exhaustion begins to be noticeable, and the effects produced are the strongest when the process of exhaustion is most rapid, even though the phosphorescence might not appear particularly bright. Evidently, then, the two effects are closely connected, and I am getting more and more convinced that we have to deal with a stream of material particles, which strike the sensitive plate with great velocities. Taking as a basis the estimate of Lord Kelvin on the speed of projected particles in a Crookes' bulb, we arrive easily by the employment of very high potentials to speeds of as much as a hundred kilometres a second. Now, again, the old question arises: Are the particles from the electrode or from the charged surface generally, including the case of an external electrode, projected through the glass or aluminum walls, or do they merely hit the inner surface and cause particles from the outside of the wall to fly off, acting in a purely mechanical way, as when a row of ivory balls is struck? So far, most of the phenomena indicate that they are projected through the wall of the bulb, of whatever material it may be, and I am seeking for still more conclusive evidence in this direction.

It may not be known that even an ordinary streamer, breaking out suddenly and under great pressure from the terminal of a disruptive coil, passes through a thick glass plate as though the latter were not present. Unquestionably, with such coils pressures are practicable which will project the particles in straight lines even under atmospheric pressure. I have obtained distinct impressions in free air, not by streamers, as some experimenters have done, using static machines or induction coils, but by actual projection, the formation of streamers being absolutely prevented by careful static screening.

A peculiar thing about the Roentgen rays is that from low frequency to the highest obtainable there seems to be no difference in the quality of the effects produced, except that they are more intense when the frequency is higher, which is very likely due to the fact that in such case the maximum pressures on the cathode are likewise higher. This is only possible on the assumption that the effects on the sensitive plate are due to projected particles, or else to vibrations far beyond any frequency which we are able to obtain by means of condenser discharges. A powerfully excited bulb is enveloped in a cloud of violet light, extending for more than a foot around it, but outside of this visible phenomenon there is no positive evidence of the existence of waves similar to those of light. On the other hand, the fact that the opacity bears some proportion to the density of the substance speaks strongly for material streams, and the same may be said of the effect discovered by Prof. J. J. Thomson. It is to be hoped that all doubts will shortly be dispelled.

A valuable evidence of the nature of the radiations and progress in the direction of obtaining strong impressions on the plate might be arrived at by perfecting plates especially sensitive to mechanical shock or impact. There are chemicals suitable for this, and the development in this direction may lead to the abandonment of the present plate. Furthermore, if we have to deal with streams of material particles, it seems not impossible to project upon the plate a suitable substance to insure the best chemical action.

With apparatus as I have described, remarkable impressions on the plate are produced. An idea of the intensity of the effects may be gained when I mention that it is easy to obtain shadows with comparatively short exposures at distances of many feet, while at small distances and with thin objects, exposures of a few seconds are practicable. The annexed print is a shadow of a copper wire projected at a distance of 11 feet through a wooden cover over the sensitive plate. This was the first shadow taken with my improved apparatus in my laboratory. A similar impression was obtained through the body of the experimenter, a plate of glass, nearly three-sixteenths of an inch thick, a thickness of wood of fully two inches and through a distance of about four feet. I may remark, however, that when these impressions were taken, my apparatus was working under extremely unfavorable conditions, which admitted of so great improvements that I am hopeful to magnify the effects many times.

The bony structure of birds, rabbits and the like is shown within the least detail, and even the hollow of the bones is clearly visible. In a plate of a rabbit under exposure of an hour, not only every detail of the skeleton is visible, but likewise a clear outline of the abdominal cavity and the location of the lungs, the fur and many other features. Prints of even large birds show the feathers quite distinctly.

Clear shadows of the bones of human limbs are obtained by exposures ranging from a quarter of an hour to an hour, and some plates have shown such an amount of detail that it is almost impossible to believe that we have to deal with shadows only. For instance, a picture of a foot with a shoe on it was taken, and every fold of the leather, trousers, stocking, etc., is visible, while the flesh and bones stand out sharply. Through the body of the experimenter the shadows of small buttons and like objects are quickly obtained, while with an exposure of from one to one and a half hour the ribs, shoulder-bones and the bones of the upper arm appear clearly, as is shown in the annexed print. It is now demonstrated beyond any doubt that small metallic objects or bony or chalky deposits can be infallibly detected in any part of the body.

An outline of the skull is easily obtained with an exposure of 20 to 40 minutes. In one instance an exposure of 40 minutes gave clearly not only the outline, but the cavity of the eye, the chin and cheek and nasal bones, the lower jaw and connections to the upper one, the vertebral column and connections to the skull, the flesh and even the hair. By exposing the head to a powerful radiation strange effects have been noted. For instance, I find that there is a tendency to sleep and the time seems to pass away quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep and a quick lapse of time. Should these remarkable effects be verified by men with keener sense of observation, I shall still more firmly believe in the existence of material streams penetrating the skull. Thus it may be possible by these strange appliances to project a suitable chemical into any part of the body.

Roentgen advanced modestly his results, warning against too much hope. Fortunately his apprehensions were groundless, for, although we have to all appearance to deal with mere shadow projections, the possibilities of the application of his discovery are vast. I am happy to have contributed to the development of the great art he has created.

NIKOLA TESLA.

New York, March 7, 1896.

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NEW YORK, MARCH 11, 1896.

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TESLA'S RADIOGRAPHS.

We publish a welcome addition to the Roentgen ray literature. It is from the always interesting pen of Nikola Tesla, and is the first authorized description of the experiments of this thorough and conscientious inventor. Mr. Tesla gives full credit to the discovery by Roentgen, and is personally much elated over discoveries of his own as his careful experiments are developed. The Tesla radiographs we present show wonderful results under severe conditions. While Tesla has heretofore been silent since the announcement by Roentgen, he has not been idle, but has evidently been striving for valuable and tangible results. Further information from his laboratory will be awaited with interest.

MAY MEDICATE RAYS.

Nikola Tesla Hints That Streams of Chemicals May Be Projected Into the Body.

WILL PRODUCE SLEEPINESS.

Odd Effects Noticed While Making Radiographs of a Human Head.

BOMBARDMENT BY PARTICLES.

New Problems Presented by the Scientific Investigator of Roentgen's Discoveries.

Nikola Tesla, the electrician, since Professor Roentgen made known his discovery of X rays has been experimenting with them. He has been pursuing his researches on his own lines with tubes of his own make. His results and conclusions Mr. Tesla has made known in the current number of the Electrical Review. In connection with his communication the Electrical Review prints two remarkable radiographs.

One shows the right shoulder of a man taken under very severe conditions, as he wore his clothing and between him and the sensitized plate there was a plate of glass three-sixteenths of an inch thick and two inches of wood. This radiograph, which was made at a distance of four feet from the source of the X rays, shows the ribs, shoulder bones and bones of the upper arm.

The other radiograph shows a copper wire bent to form the word "Roentgen," and was made at a distance of eleven feet from the wooden slide covering the sensitized plate.

Mr. Tesla states that the rarefaction of Crooke's tubes, used in these experiments, may be increased by electrical means to any degree desirable—to a degree far beyond that obtainable by mechanical appliances.

VELOCITY OF THE RAYS.

In regard to the nature of X rays, he says:—"I am getting more and more convinced that we have to deal with a stream of material particles, which strike the sensitive plate with great velocities. Taking as a basis the estimates of Lord Kelvin on the speed of projected particles in a Crooke's bulb, we arrive easily, by the employment of very high potentials, to speeds of as much as a hundred kilometres a second. Now, again, the old question arises:—Are the particles from the electrode or from the charged surface generally, including the case of an external electrode, projected through the glass or aluminum walls, or do they merely hit the inner surface and cause particles from the outside of the wall to fly off, acting in a purely mechanical way, as when a row of ivory balls is struck? So far, most of the phenomena indicate that they are projected through the wall of the bulb, of whatever material it may be, and I am seeking for still more conclusive evidence in this direction."

"It is now demonstrated beyond any doubt that small metallic objects or bony or chalky deposits can be infallibly detected in any part of the body."

HOLLOWS IN BONES PICTURED.

Tesla has secured radiographs showing the bony structure of birds and rabbits, even to the hollow of the bones. He has secured a radiograph of a rabbit after an hour's exposure, in which not only every detail of the skeleton is visible, but also a clear outline of the abdominal cavity. The location of the lungs and the fur are also shown.

Radiographs of large birds show the feathers distinctly. In another instance an exposure of forty minutes gave a radiograph of the human skull, showing clearly not only the outline, but the cavities of the eyes, chin, cheek, nasal bones, the lower jaw and connections to the skull, the flesh and even the hair.

"By exposing the head to a powerful radiation," Mr. Tesla says, "strange effects have been noted. For instance, I find that there is a tendency to sleep and the time seems to pass away quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep and a quick lapse of time. Should these remarkable effects be verified by men with a keener sense of observation I shall still more firmly believe in the existence of material streams penetrating the skull. Thus it may be possible by these strange appliances to project a suitable chemical into any part of the body.

"Roentgen advanced modestly his results, warning against too much hope. Fortunately, his apprehensions were groundless, for, although we have to all apperances to deal with mere shadow projections, the possibilities of the application of his discovery are vast."

PROFESSOR MORTON'S SHADOWGRAPHS.

At his laboratory, in East Twenty-eighth street, yesterday Dr. William J. Morton made a picture of the bones of the hand, in which the hollows in the bones of the thumb were distinctly visible, and thus, then, was obtained a confirmation, though not so intended, of the results of Mr. Tesla's experiments mentioned. But, it was explained, the shadowgraphs delineating the hollows in bones show that the central portions of bones are less dense than the outer hard or ivorylike structure. The Roentgen process, it is therefore argued, by properly timed exposure will delineate the interior of the bone as well as the exterior and thus indicate the presence of any disease there. In this way the X rays will be of incalculable value to medicine and surgery.

The New York Sun March 11, 1896

TESLA AND THE X RAYS.

THEIR ALMOST MAGIC POWERS SHOWN BY HIS EXPERIMENTS.

The Young Electrician Obtains Results that Suggest New Fields of Usefulness for Prof. Roentgen's Marvellous Discovery—Possibilities, He Says, Are Vast.

An article by Nicola Tesla is published in the *Electrical Review* to-day describing his experiments in radiography. The scientific world has been eagerly awaiting an expression of opinion from Mr. Tesla, who is known to have begun his experiments within half an hour after the news of Prof. Roentgen's discovery was cabled to this country. Two remarkable radiographs are printed with the article. One of these shows the right shoulder of a man taken through his clothing and through a plate of glass three-sixteenths of an inch thick and two inches of wood. This radiograph, which was made at the distance of four feet from the source of the X rays, shows the ribs, shoulder bones, and bones of the upper arm. The other radiograph shows a copper wire bent to form the word "Roentgen," and was made at a distance of eleven feet from the wooden slide covering the sensitized plate.

Mr. Tesla also states that the rarefaction of Crookes tubes used in these experiments may be increased by electrical means to any degree desirable, far beyond that obtainable by mechanical appliances. In regard to the nature of X rays he says:

"I am getting more and more convinced that we have to deal with a stream of material particles, which strike the sensitive plate with great velocities. Taking, as a basis, the estimate of Lord Kelvin on the speed of projected particles in a Crookes bulb, we arrive easily, by the employment of very high potentials, to speeds of as much as a hundred kilometres a second. Now, again, the old question arises: Are the particles from the electrode or from the charged surface generally, including the case of an external electrode projected through the glass or aluminum walls, or do they merely hit the inner surface and cause particles from the outside of the wall to fly off, acting in a purely mechanical way, as when a row of ivory balls is struck? So far most of the phenomena indicate that they are projected through the wall of the bulb, or whatever material it may be, and I am seeking for still more conclusive evidence in this direction. It is now demonstrated beyond any doubt that small metallic objects or bony or chalky deposits can be infallibly detected in any part of the body."

Tesla has also secured radiographs showing the bony structure of birds and rabbits, even to the hollow of the bones. He has secured a radiograph of a rabbit after an hour's exposure in which not only every detail of the skeleton is visible, but also a clear outline of the abdominal cavity, the lungs, and the fur. Radiographs of large birds show the feathers distinctly. In another instance an exposure of forty minutes gave a radiograph of the human skull, showing clearly not only the outline, but the cavities of the eye, chin, cheek, nasal bones, the lower jaw and connections to the skull, the flesh, and even the hair. Mr. Tesla concludes his communication as follows:

"By exposing the head to a powerful radiation strange effects have been noted. For instance, I find that there is a tendency to sleep and the time seems to pass away quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep and the quick lapse of time. Should these remarkable effects be verified by men with keener senses of observation, I shall still more firmly believe in the existence of material streams penetrating the skull. Thus it may be possible by these strange appliances to project a suitable chemical into any part of the body.

"Roentgen advanced modestly his results, warning against too much hope. Fortunately his apprehensions were groundless, for, although we have to all appearance to deal with mere shadow projections, the possibilities of the application of this discovery are vast."

New York Times March 11, 1896

NIKOLA TESLA DISCUSSES X RAYS.

Important Results of Experiments with Roentgen's Discovery

The Electrical Review will publish to-day a communication from Nikola Tesla, describing, for the first time, his interesting experiments in radiography. The scientific world has been awaiting an expression of opinion from Mr. Tesla, who began his experiments within half an hour after the news of Prof. Röntgen's discovery was cabled to this country.

In connection with Mr. Tesla's communication, The Electrical Review will print two remarkable radiographs. One shows the slight shoulder of a man taken through his clothing, a plate of glass three-sixteenths of an inch thick, and two inches of wood. This radiograph, which was made at a distance of four feet from the source of the X rays, shows the ribs, shoulder bones, and bones of the upper arm.

The other radiograph shows a copper wire bent to form the word "Röntgen," and was made at a distance of eleven feet from the wooden slide covering the sensitized plate.

Mr. Tesla says the rarefaction of Crookes tubes used in these experiments may be increased by electrical means to any degree desirable—far beyond that obtainable by mechanical appliances. In regard to the nature of X rays, he says:

"I am getting more and more convinced that we have to deal with a stream of material particles, which strike the sensitive plate with great velocities. Taking as a basis the estimates of Lord Kelvin on the speed of projected particles in a Crookes bulb, we arrive easily by the employment of very high potentials, to speeds of as much as a hundred kilometers a second.

"Now, again, the old question arises: Are the particles from the electrode or from the charged surface generally, including the case of an external electrode, projected through the glass or aluminum walls, or do they merely hit the inner surface and cause particles from the outside of the wall to fly off, acting in a purely mechanical way, as when a row of ivory balls is struck? So far, most of the phenomena indicate that they are projected through the wall of the bulb, of whatever material it may be, and I am seeking for still more conclusive evidence in this direction.

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In another instance, an exposure of forty minutes gave a radiograph of the human skull, showing clearly not only the outline, but the cavities of the eye, chin, cheek, nasal bones, the lower jaw, and connections to the skull, the flesh, and even the hair. Mr. Tesla concludes his communication as follows:

"By exposing the head to a powerful radiation, strange effects have been noted. For instance, I find that there is a tendency to sleep and the time seems to pass away quickly. There is general soothing effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep and a quick lapse of time.

"Should these remarkable effects be verified by men with keener sense of observation, I shall still more firmly believe in the existence of material streams penetrating the skull. Thus it may be possible by these strange appliances to project a suitable chemical into any part of the body.

"Röntgen advanced modestly his results, warning against too much hope. Fortunately, his apprehensions were groundless, for although we have to all appearances to deal with mere shadow projections, the possibilities of the application of his discovery are vast. I am happy to have contributed to the development of the great art he has created."

The New York Tribune March 11, 1896

NIKOLA TESLA ON RADIOGRAPHY.

HIS INTERESTING EXPERIMENTS—AN ACCOUNT OF THEM BY HIMSELF.

"The Electrical Review" publishes to-day a communication from Nikola Tesla, describing for the first time his interesting experiments in radiography. The scientific world has been eagerly awaiting an expression of opinion from Mr. Tesla, who is known to have begun his experiments within half an hour after the news of Professor Röntgen's discovery was cabled to this country. In connection with Mr. Tesla's communication, "The Electrical Review" prints two remarkable radiographs. One of these shows the right shoulder of a man taken through his clothing, a plate of glass three-sixteenths of an inch thick and two inches of wood. This radiograph, which was made at the distance of four feet from the source of the X rays, shows the ribs, shoulder bones and bones of the upper arm. The other radiograph shows a copper wire bent to form the word "Röntgen," and was made at a distance of eleven feet from the wooden slide covering the sensitized plate.

A STREAM OF MATERIAL PARTICLES.

Mr. Tesla says that the rarefaction of the Crookes tubes used in these experiments may be increased by electrical means to any degree desirable, far beyond that obtainable by mechanical appliances. This method he describes. In regard to the nature of X rays, he says: "I am getting more and more convinced that we have to deal with a stream of material particles, which strike the sensitive plate with great velocity. Taking as a basis the estimates of Lord Kelvin on the speed of projected particles in a Crookes bulb, we arrive easily by the employment of very high potentials to speeds of as much as 100 kilometres a second. Now, again, the old question arises: 'Are the particles from the electrode or from the charged surface generally, including the case of an external electrode, projected through the glass or aluminum walls, or do they merely hit the inner surface and cause particles from the outside of the wall to fly off, acting in a purely mechanical way, as when a row of ivory balls is struck?' So far, most of the phenomena indicate that they are projected through the wall of the bulb, of whatever material it may be, and I am seeking for still more conclusive evidence in this direction. . . . . It is now demonstrated beyond any doubt that small metallic objects or bony or chalky deposits can be infallibly detected in any part of the body."

RADIOGRAPHS OF BIRDS AND RABBITS.

The writer has also secured radiographs showing the bony structure of birds and rabbits, even to the hollow of the bones. He has obtained a radiograph of a rabbit after an hour's exposure, in which not only every detail of the skeleton is visible, but a clear outline of the abdominal cavity, the location of the lungs and the fur are shown. Radiographs of large birds show the feathers distinctly. In another instance an exposure of forty minutes gave a radiograph of the human skull, showing clearly not only the outline, but the cavities of the eye, chin, cheek, nasal bones, the lower jaw and connections to the skull, the flesh and even the hair.

EFFECTS OF RADIATION ON THE HEAD.

Mr. Tesla closes his communication in the following words: "By exposing the head to a powerful radiation strange effects have been noted. For instance, I find that there is a tendency to sleep, and the time seems to pass away quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep, and a quick lapse of time. Should these remarkable effects be verified by men with keener sense of observation, I shall still more firmly believe in the existence of material streams penetrating the skull. Thus, it may be possible by these strange appliances to project a suitable chemical into any part of the body.

"Röntgen advanced modestly his results, warning against too much hope. Fortunately, his apprehensions were groundless, for, although we have to all appearance to deal with mere shadow projections, the possibilities of the application of his discovery are vast. I am happy to have contributed to the development of the great art he has created."

The New York Times March 12, 1896

VIEWS ON TESLA'S IDEAS

Doctors Are Much Interested in His Theory of X Rays.

POSSIBLE VALUE IN TREATING DISEASE

What Cyrus Edson and J. Mount Bleyer Say of the Deductions and Experiments of the Electrician.

The publication in THE NEW-YORK TIMES yesterday of the results of the experiments of Nikola Tesla in radiography has excited a great deal of interest in the medical profession. His conclusions were to the effect that the X rays were of the nature of a stream of material particles which strike the sensitive plate with great velocities.

It has been demonstrated by Mr. Tesla to his satisfaction that small metallic objects or bony or chalky deposits can be infallibly detected in any part of the human body. He also gives it as his opinion that it might be possible by the use of the X rays to project a suitable chemical into any part of the body, which would make it a valuable therapeutic agent.

Dr. Cyrus Edson, formerly Health Commissioner, when asked by a reporter for THE NEW-YORK TIMES about Tesla's deductions, said that he had been much interested in the subject and had given it considerable attention.

"It is an undoubted fact," said the doctor, "that you can decompose certain chemicals by means of light. The principle of photography rests upon this fact. These X rays decompose the chemicals with which the film is sensitized and effects this decomposition through what have hitherto been regarded as opaque bodies, such as the hand, for instance. Light is vibration, and it has been demonstrated that these X rays will pass through an opaque body. That these vibrations in passing through the skull should affect the delicate nerve tissues of the brain and stimulate them is a perfectly natural result.

"This accounts for the sensations experienced by Tesla when he exposed his head to a powerful radiation. But there is no more reason to believe that the X rays will carry a medicinal agent through the body and into the distant spot, the seat of disease, than that a ray of light will be able to project such a chemical on to the surface of the body. When we have succeeded in projecting medicine on to the exterior surface by means of light we may be able to penetrate into the interior by means of ultra-viole rays.

"The theory of the vibrations of light is not a new one. It originated with Sir Isaac Newton, who believed that luminous bodies shot out infinitely small particles in straight lines, which, by penetrating the transparent parts of the eye and falling on the nervous tissue, produced vision. Other philosophers drew a parallel between the properties of light and those of sound, and considered that as sound was certainly the effect of vibrations, or little waves projected through elastic bodies, so light might be nothing more than the consequence of similar vibrations transmitted with inconceivable velocity through a highly elastic medium. The wave hypothesis of light is at present generally adopted simply because it is in harmony with all the known phenomena discovered since the time of Newton.

"The deductions of Tesla as the result of his experiments are absolutely in harmony with the Newtonian theory. We can certainly expect some marvelous results from the X rays, things not even dreamed of yet. I believe that they will prove a valuable adjunct to medical science, and I think that the ultra violet rays will be sooner or later obtained by passing ordinary sunlight through certain media, without the agency of electricity."

Dr. J. Mount Bleyer, who has taken great interest in determining the effects of all light rays on animal and vegetable life, said yesterday:

"I am not at all surprised at the results of Tesla's experiments. I have been experimenting for some time with the associated light rays—the sunlight and the different colors, such as blue, red, and orange—in connection with the treatment of infectious diseases and vegetations. The results obtained by Tesla are simply marvelous, but are just what I expected. I have contended from the beginning, and it has now been proved beyond a doubt by Tesla, that this bombardment of particles does pass through glass and other materials at an enormous velocity. As far as the therapeutic effects of the rays are concerned, they may be likened in some way to a massage effect, if they do not form a high class of bacteracidal agent. As these experiments have been proved by Tesla, acting in a purely mechanical way, this would be a new and perhaps more beneficial way of using massage.

"As far as the photographing of certain deposits in the human system, such as the lung substance in phthisis and other pulmonary diseases, I have not yet reached the exact depth of radiography that Tesla has, but a short time ago, by means of the Röntgen rays, I made a fine photograph of the interior of the larynx of a patient where a tumor was situated, showing its exact location and condition, and which could not have been obtained with such exactitude in any other way that I know of.

"As to the sensations described by Tesla as having been experienced by him in his experiments, I have experienced exactly similar sensations in exposing my head to powerful radiation. It does not seem to me at all improbable that the suggestion made by Tesla of projecting a suitable chemical or medicament into any part of the body by means of the X rays may be found practical, for it is impossible to determine the results to be achieved by further experimentation. The present difficulty is that the Crookes tubes now in use for the making of radiographs are not powerful enough to be used for therapeutic purposes, which require very high potentials to secure good results, and nothing below that is of value.

"Solariums for the treatment of infectious diseases, with associated light rays, will no doubt be the next advance in hospital architecture. I have made a number of experiments with the associated light rays in hospital and among my private patients in cases of phthisis and tuberculosis. I have resorted to the treatment wherever it was possible, and never failed to obtain the best results. Ordinary light is one of the main factors in the growth of animal life. We know that sunlight is essential for the growth and development of both animal and vegetable tissue. We have in light a therapeutic agent that has been underestimated and neglected, and which should be taken up and thoroughly studied."

The New York Times March 13, 1896

CHARACTER OF THE X RAYS

Prof. Rood Inclined to Believe They Are Like Light Waves.

SHORTNESS, THOUGH, UNPRECEDENTED

His View Excludes All Idea of a Molecular Bombardment Outside of the Crookes Tube.

Ogden N. Rood, Professor of Physics in Columbia College, was asked yesterday by a reporter for THE NEW-YORK TIMES whether recent experiments with the Röntgen rays had altered his views as to the nature of the phenomena.

It will be remembered that before full details of Röntgen's discovery reached here Prof. Rood tentatively expressed his view that the rays were of the same nature as light waves, only much shorter than any previously known.

Since that time numerous theories have been suggested by experimenters on both sides of the Atlantic. One of these, adapted from Crookes, is that the rays represent a bombardment of the molecules in a highly rarefied atmosphere, and that this bombardment is communicated to other particles of matter outside the inclosing envelope. Prof. Rood thinks this theory in its entirety is not necessary to account for the Röntgen phenomena, and is extremely improbable in any case.

After glancing through the article by Nikola Tesla in The Electrical Review, also printed in part in THE NEW-YORK TIMES Wednesday last, Prof. Rood dictated the following statement of his views:

"It is never proper to frame a new hypothesis in order to account for discoveries when an old and well-established theory is capable of giving them an explanation. Our knowledge of the waves of light, of radiant heat, and of the ultra violet rays is confined within narrow limits.

"Thus far, according to our previous experience, the shorter the length of the wave the more it will be bent, or refracted, by substances in general. It, however, does not at all follow that this will hold good if the length of the wave is shortened to a degree beyond our experience.

"On the other hand, it is highly probable that if this shortening process goes on till the length of the wave has become of the same order of magnitude with the molecules of matter that the effect in the matter of refraction will diminish. This would account for the fact that no one has succeeded thus far in refracting or reflecting the Röntgen rays. In my own experiments I have so far found them to act in the same general way with waves of ordinary light, and I am inclined to believe that they are simply waves of light of unprecedented shortness.

"This view necessarily excludes all idea of a molecular bombardment outside of the Crookes tube. I believe that it will be eventually demonstrated that the Röntgen rays are capable of reflection and refraction, although it will require more delicate work than has thus far been extended in this direction."

General Electric—Westinghouse Electric & Manufacturing—*Agreement as to Patents.*—Late Thursday afternoon the directors of these companies reached an agreement for pooling their patents. This agreement will stop the costly litigation so long in progress and ensure the joint use of the patents during their life. Certain patents are excluded, but Charles A. Coffin, President of the General Electric, is quoted as stating that in a general way it can be said that all the patents held by the two companies for lighting and power will be included except those pertaining to cables and underground trolley material.

A statement given out by the two companies describes the agreement as follows: "The General Electric Co. has contributed 62½ per cent and the Westinghouse Electric & Manufacturing Co. 37½ per cent in value of the combined patents, and each company is licensed to use the patents of the other company, except as to the matters excluded, each paying a royalty for any use of the combined patents in excess of the value of its contribution to the patents. The patents are to be managed by a board of control consisting of five members, two appointed by each company and a fifth elected by the four so appointed."

The statement adds that it is expected the economies to be effected by this arrangement will be very considerable. The especial incentives leading to it were the recent decisions in favor of patents of the General Electric Company controlling the overhead system of electric railways, the approaching trials on a number of other important General Electric patents and the equally strong position of the Westinghouse Company in respect to power transmission covered by the patents of Nikola Tesla, etc.

An interesting account of the patents of the Westinghouse Company, including that on the underground trolley, was in the CHRONICLE of July 6, p. 25.—V. 61, p. 871; V. 62, p. 320.

ELECTRICITY IN RELATION TO DENTISTRY.[1]

BY GEORGE HELI GUY.

I SHALL confine myself to a brief reference to some of the departments of electrical work in which the members of the dental profession are likely to work out their own salvation. In considering this question, it is a most hopeful sign that, although until recently, electricity has been but little employed in dental surgery, except for the driving of mechanisms, cauterization, the translumination of soft tissue, or the illumination of cavities, yet the profession are taking kindly to it. A large section of your medical brethren are still regarding its progress and increasing popularity with distrust and blind unbelief. Not long since, I asked a leading fashionable physician in New York his opinion as to the likelihood of electricity being eventually taken up in earnest by the profession. He replied: "It never will be. I have tried it myself, and have come to the conclusion that there is nothing in it." The whole electrical apparatus of this physician turned out to be a small faradic battery, and he had been treating all ailments with the same kind of current. There are thousands of practitioners who still think as he did. But there are many signs which go to show that the progressive and intelligent section of the dental profession are going with the times, and I was struck, and very much gratified, when attending the Dental Convention last year, at Asbury Park, to see the intense interest and appreciation with which the papers discussing electrical problems were received. I read not long ago of some electrical experiments upon floating organisms. If a galvanic current be passed through a bath containing paramecia in sufficient abundance, a curious sight is observed. When contact is made, the whole crowd of paramecia fall into order with their noses toward the cathode, and begin to swim toward it in converging curves; while, if the current be reversed, the crowd breaks up, all its units turn around and begin to swim away, as if of one mind, from the new anode to the new cathode. The creatures are evidently more "comfortable" when swimming with the electric current than the reverse way. In another experiment, a number of tadpoles were put into a lantern bath. They began to move about very leisurely, and to jostle

1. Abstract of response to toast of "The Coming Dentist Electrically Considered," at the annual dinner of the Central Dental Association, of Northern New Jersey, at Newark, N. J., Feb. 17, 1896.

each other in all directions. On sending a current of electricity through the bath there was prodigious excitement. As Dr. Waller, who conducted the experiment, described it, "The tadpole community seems to have gone mad; a writhing mass is all that can be distinguished; but the disturbance does not take long to subside, and now all the tadpoles are fixed as if at attention, heads to anode, viz., traversed by a current from head to tail, stroked down the right way." It appears to me that the dentists, like the tadpoles, have begun to find that it is wise to yield themseves to the current of electrical progress that has set in; it points their heads the right way, and means, in the long run, less trouble, better work, and last, but not least, relatively better pay.

One of the great drawbacks to the adoption of electricity in general dental practice is the cheap outfit and the poor installation work. Any man who can put up an electric bell now calls himself an electrician. If it were not for the inspection department of the Board of Underwriters, there would be, from bad wiring, such a crop of fires in large cities as would render the lighting of the streets entirely unnecessary. But there are no such adequate official restrictions and precautionary measures for the protection of the dentist. Beware of cheap outfits. Don't try to save a dollar or two in your battery plant; get the best that is in the market. Go, for your motors, and your dental equipment, to the best houses, that spend money on experimentation instead of letting you pay for it directly, and that insure careful inspection, and sound installation, and don't subject you to the curses of defective wires, poor plugs, and inferior tackle of every description. I know of an instance in New York, where the dentist had the hard luck to be taken in hand by a cheap, so-called electrician. Before he got through, he spent $500 in his electrical outfit, and then he threw it out and vowed he wouldn't have anything more to do with electricity, as it was a rank fraud. Therefore, I say dental electric outfits are like bicycles; if you want one to wear well, run smoothly, and save lurid language, get the best you can lay your hands on; you will get gratifying results, and you won't have any hard things to say about electricity.

Now, as to the electrical possibilities of the future in dentistry. Although we can't gauge them, we have been lately getting some glimmering as to the trend they are likely to take. I wish I could help saying something about cataphoresis; but I can't. The coming work in cataphoresis will not only be vast in extent, but marvelous in its general bearing on dental practice. Many occasions constantly arise where anaesthetic drugs may be introduced into tissue and into dentine, and also other drugs, such as iodine, etc., may be used in the same way, and their familiar topical effects be vastly enhanced by the aid of electricity. Few can comprehend the limitations of this great aid to the local application of drugs within the cavity of the mouth. Broadly, it may be said that any drug that has been previously used without electricity within the mouth to produce specific effect, may now be electrically used with tenfold its former power for good. The subject of cataphoresis is already very wide, and I am not going to enter further upon it. I would, however, say, as it leads up to another point, that the question of the resistance of the liquid used has a most important bearing in the therapeutical applications of cataphoresis. If the resistance is too high, as with chloroform, sulphuric ether, alcohol, glycerine, etc., little or no current is conveyed, and no cataphoresis takes place, while on the other hand, if the electric resistance is too low, as with strong saline and acid solutions, much current passes, but little or no cataphoric action takes place. Now, you are all familiar with the points of the late discussion on guaia-cocaine. It may be, and undoubtedly is, an excellent anaesthetic, but it is ill-smelling and escharotic, and none of you like it. It has been proposed to add almond oil to it, but if the resistance is thus increased, more current will have to be used. Dr. Morton, however, has found a way out of the difficulty. He says that guaiacol alone, and other similar substances and derivatives, in themselves non-conductors of electricity, by the addition of a very minute quantity of some innocent substance of an electrolytic nature, like, say, salts of caffeine or quinine, or any salts of the alkaloids, may be caused to penetrate tissue by the aid of electricity, and thus exhibit anaesthetic effects unobtainable without the aid of the added electrolyte. But this is one of the points that you gentlemen will have to straighten out before the best results from cataphoresis can be reached.

Further developments in the uses of the different kinds of currents is another subject which is too comprehensive to be discussed here. I may, however, promise that the sinusoidal current will sooner or later find its way into dental laboratories. As you know, a dynamo current is uneven, but the sinusoidal, with its very high vibrations, has soft, wave-like impulses; the current is agreeable and soothing to the patient, and more horse-power of electricity can be administered than if the frequency were lower and the wave less symmetrical. For example, the present sinusoidal machines run up to 2,000 alternations per second, whereas the alternations per second of an induction coil would be, probably, at their highest limit, 500 per second. Added to that, the graphic curve from the induction coil would be comparatively unsymmetrical, i. e., irregular. It is these two elements, the frequency and the graphic curve, or, as D'Arsonval calls it, "the characteristic of excitation," which determines whether the current is painful or not, and it is pain only, which limits the extent to which the induced currents from ordinary medical apparatus may be administered. On this head, I may mention, that guesswork in electrical dosage will soon be a thing of the past. The time is approaching when electricity will be prescribed and administered not only in measured units of intensity, density, and time, but with definite ideas of the electromotive force curve, and of the therapeutic indications that a given curve may be expected to fulfill.

There are many other branches of electrodental work in which we are on the verge of epoch-making improvements, and among them are the important ones of translumination, implantation, and sterilization. For the purpose of translumination, it is probable that more attention will be paid to the intensifying of the light. For instance, instead of confining the lamps for that purpose to small candle-powers, they might be run up to, say, 20-candle-power. Until lately, the difficulty has been that candle-power produced heat. This has been practically overcome by enclosing the first bulb in a second bulb through which water is made to flow. But here comes the fascinating question of the part which the phosphorescent, or "etheric" light, the "Tesla glow," or, as it is also called, "the light of the future," will play in translumination. I had the pleasure about two years ago, of seeing, in Mr. Tesla's laboratory, a demonstration of the then newly developed phosphorescent light. The room was darkened, and electrostatic currents played into it at the rate of possibly a million vibrations a second. Vacuum tubes, in fancy shapes, lay all around, and as these were taken up and lifted into the "field" they burst forth into beautiful luminescence, and the room was illuminated. Tesla then prophesied that it would not be long before our houses were lighted without wires, and even without lamps, and that the night would be made as day by means of phosphorescent light caused by the play of current through air-exhausted tubes. Last year a photograph of Mr. Tesla was taken by this light. As a photograph it was not much to boast of, but as a piece of history, it was most interesting. It was the first time that a photograph had been taken by that light. That line of work was taken up by a man in your own city, Mr. D. McFarlan Moore, who in the short time that has since elapsed, has so developed it that he published a week or two ago, a bold and striking picture, possessing the clearness and strength of a daylight photograph, which was secured by a three-minute exposure under the new light in his laboratory. If such strides can be made in twelve months, and we are coming at such a rapid rate nearer to the electrician's—and, for the matter of that, the dentist's—ideal, of light without heat, I think it may pay the dentists to let their spirit of investigation drift in the direction of translumination by phosphorescent light.

Electricity as an agent in implantation, etc., of teeth is a very attractive subject, and we are on the eve of great developments in this field, but I must not detain you longer.

There is, however, an incident which I should like to tell you of, which bears on another important branch of work, sterilization. Some time ago, a German physician wrote to Mr. Tesla and said that he had been experimenting with the play of etheric light on the bacilli of tuberculosis, and not only had he killed the microbes while experimenting, but he had by the same means cured tubercular developments in the human subject. This letter, sad to say, was burnt up in the fire at the laboratory, and Mr. Tesla has never been able to find where it came from. Now, gentlemen, you will see how beautifully this bears on the question of sterilization: pyorrhoea alveolaris should have no further terrors when it can be swept out of the human jaw with a brush of glowing phosphorescence, and a new charm will be given to dental work when light will not only illume, but purify and sterilize, and even kill the deadliest germs that work havoc within the soft tissue of the mouth.

And now, gentlemen, the Röntgen rays—no speech to-day is complete without something about them. I don't think any of us yet realize what they may mean to dentistry. If it can be established that the cathodic rays will, like light, kill microbes, you see at once where it carries you. There is one thing, however, that cathodic rays have done, that you gentlemen, I am sure, will take careful note of. They have passed through ivory, and photographed pieces of metal on the other side. Where fangs and other parts of the teeth are being treated, it is often necessary to know which teeth already con-

tain filling. There is now no further difficulty about this. As metallic substances intercept light to a greater degree than bone does, a cathodograph will show the location of all the filling in the teeth which have already been operated upon. Dr. W. J. Morton has proposed to put the Röntgen rays within the cavity of the mouth, and a sensitive plate within the plate holder outside on the cheek, and thus reproduce the teeth, in situ, fangs, filling, etc. In this connection, it would also be possible to determine the existence of ostitis, deformations, diseases of the bone, pus deposits, etc., in fact, the whole concealed pathology of the teeth in their relation to the jaw and gums would be thus revealed.

ILLUSTRATED

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GENERAL ELECTRIC-WESTINGHOUSE COMBINATION.

A Mutual Working Agreement Made.

THE NEW ARRANGEMENT WILL SAVE HUNDREDS OF THOUSANDS OF DOLLARS IN LITIGATION AND EXPERT EVIDENCE TO BOTH COMPANIES — APPARENTLY AN EQUITABLE DIVISION OF PATENTS —A BOARD OF CONTROL WILL MANAGE THE PATENTS.

As predicted in the ELECTRICAL REVIEW some time ago, a working arrangement based on the patents owned by both companies has been entered into by the General Electric Company, of Schenectady, N. Y., and the Westinghouse Electric and Manufacturing Company, of Pittsburgh, Pa. This arrangement is in no sense a consolidation of the companies. Its object is to do away with the expensive patent litigation which has been indulged in for years by both these great concerns. The legal expenses and fees for expert testimony have been something enormous and out of all proportion to the commercial value of the patents involved. These expenses will be saved under the new mutual arrangement.

The news that such a deal had been made became public on the evening of March 12, when the following official statement, representing the views of both companies, was given out by Mr. Charles A. Terry, one of the counsel of the Westinghouse company:

Negotiations between the General Electric Company and the Westinghouse Electric and Manufacturing Company have resulted in an arrangement with respect to a joint use of the patents of the two companies, subject to existing licenses on terms

which are considered mutually advantageous.

It has been agreed that after certain exclusions the General Electric Company has contributed 62½ per cent and the Westinghouse Electric and Manufacturing Company 37½ per cent in value of the combined patents, and each company is licensed to use the patents of the other company, except as to the matters excluded, each paying a royalty for any use of the combined patents in excess of the value of its contribution to the patents.

The patents are to be managed by a board of control, consisting of five members, two appointed by each company and a fifth selected by the four so appointed. Both companies have acquired during their existence a large number of valuable patents, and numerous suits have been instituted in consequence of the infringement of these patents by one party or the other or by their customers. In the prosecution of these suits large sums of money have been expended and the general expenses of the companies have in this manner been greatly increased. It is expected that the economies to be effected will be very considerable and that the two companies and their customers will be mutually protected.

The especial incentives which led to the arrangement at this time were the recent decisions in favor of patents of the General Electric Company controlling the overhead system of electric railways, the approaching trials on a number of other important General Electric patents on controllers and details of electric railway apparatus and systems and other electrical devices, and the equally strong position of the Westinghouse company in respect to power transmission, covered by the patents of Nikola Tesla, and in view of its other patents in active litigation, some of which are of controlling importance.

President Charles A. Coffin, of the General Electric Company, stated on Saturday to the ELECTRICAL REVIEW that "the arrangement between the two companies had been formally approved by the directors of both companies. The agreement is as yet in skeleton form. It may take a few weeks to complete it. I should say it might perhaps be perfected and put into effect by June 1. It is the intention that it shall continue during the life of the patents of the companies. The patents which are excluded are foreign patents, which can not be embraced, patents on cable and underground railway materials, which are covered by licenses, and a few patents excluded for special reasons."

Continuing, Mr. Coffin said: The companies will stop fighting each other in the courts, and will join in prosecuting infringements of their patents. How much will be saved by the termination of litigation I can not say, as all legal expenses are included in one account. It would be necessary to separate the items to furnish actual figures. The saving, however, will be large.

No monopoly of the electrical business will be created by the agreement. There are other important concerns in the business. The General Electric and Westinghouse companies do not consolidate. They retain their entire independence and will, in fact, as heretofore, be competitors in business. Prices will doubtless be agreed upon which will benefit customers of the companies and the companies themselves, but and supplies. It has not yet been figured out how much the revenues of the companies will be increased by the arrangement, nor can it be until the arrangement has been put in more perfect form.

The first proposition for an agreement between the companies was made several years ago, but the negotiations which resulted in the agreement were opened recently.

Mr. Geo. Westinghouse, Jr., could not be seen, as he had left the city. Vice-President Geo. W. Hebard stated to the ELECTRICAL REVIEW that the announcement given out by Mr. Terry embodied what his company wished to say to the public.

The New York *Recorder* of March 13 referred to the deal as follows:

The annual meeting of the General Electric Company will be held in May, and efforts will be made to oust President Coffin. Yesterday Duer, Strong & Jarvis, lawyers, of 50 Wall street, advertised for the names and addresses of stockholders opposed to the management of Mr. Coffin. A. Pennington Whitehead of the firm said he represented clients whom he could not name. However, Mr. Coffin's master stroke in forming a combination with the Westinghouse company may temper the opposition materially. He is not at all worried, apparently, as to the security of his place as executive.

The authorized capital stock of the General Electric Company is $50,000,000, of which $10,000,000 may be preferred. The amount of common stock outstanding is $30,460,000 and of the preferred stock $4,252,000. Prior to August, 1893, dividends at the rate of eight per cent a year were paid on the common stock, but no dividends have been paid since that date. The preferred is entitled to dividends at the rate of seven per cent a year, and these are cumulative, so that when unpaid they become a lien on earnings. The dividends on the preferred stopped with the one due January, 1894. The company has issued $8,750,000 of five per cent debenture bonds, which are convertible into stock on the basis of $100 in stock for $120 in bonds.

The surplus reported by the company for the year ended January 31, 1895, after charging off $932,521 for old losses, depreciation, etc., was $414,643. The annual meeting takes place May 12. The company's principal works are at Schenectady, N.Y. It has other works at Harrison, N.J., and at Lynn, Mass. The company was organized on April 15, 1892, and acquired all of the capital stocks of the Edison Electric Light, Edison General Electric, Thomson-Houston Electric and Thomson-Houston International Electric companies. It controlled all the Edison patents for electric lighting.

The Westinghouse company has outstanding $179,150 old common stock, $5,333,940 assenting stock and $4,000,000 preferred seven per cent cumulative stock, $500,000 United States Electric Light Company six per cent bonds, $250,000 collateral trust five per cent notes and $194,560 old scrip for dividends. The company holds in its treasury $6,735 preferred stock and $663,349 assenting stock. The total net income of the company for the year ended March 31, 1895, was $802,409. The new works of the company are at East Pittsburgh, Pa.

A Boston man, acquainted with both companies, says that the agreement means that 12 per cent will be easily earned on both of the Westinghouse stocks and at least seven per cent will be earned on General Electric common. He claims that there has not been in five years so important a deal as this one.

Matthew Marshall, the well known financial writer for the New York *Sun*, referred to the deal on Monday last as "The Electric Treaty." He says: "As usual, the speculators for a rise in General Electric stock, who had early information of the negotiations which have resulted in the peace just announced, overestimated its beneficial effect upon the market. The stock, which, since last January, had been gradually going up from 22 to 35, jumped, upon the news of the making of the treaty, nearly to 40, but immediately receded and closed finally on Saturday at 37. This shows that the uninformed public is not convinced that the cessation of the war between the two companies guarantees anything more than a cessation of the losses resulting from the previous hostilities. Whether, eventually, positive profits will be reaped, is not yet certain."

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CHANGES for advertisements must be in this office by Friday noon for the following week's issue.

NEW ADVERTISEMENTS should be in the office not later than Saturday noon to insure publication the following week.

NEW YORK, MARCH 18, 1896.

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TESLA'S WORK IN RADIOGRAPHY.

Radiography leads all discoveries of modern times in the intelligent and spontaneous attention it has received from scientists and experimenters all over the civilized world. The announcement of Nikola Tesla's achievements in the new art, first published in the ELECTRICAL REVIEW of March 11, in the author's own modest language, has added fresh impetus to the work in this direction. His disruptive discharge coil has been universally used where the best results in radiography have been obtained, and his two marked improvements, namely, the single electrode tube and his method of rarefaction, promise great results. Other important points about Tesla's work are the fine details he has obtained in his radiographs, the great distance at which the radiographs have been made, and brief time of exposure.

We feel sure that the second communication from Mr. Tesla, which we publish in this issue, will be appreciated by our readers. He now produces shadows at 40 feet distance and promises still more. He, furthermore, brings out the important fact of reflection of the rays, demonstrating this property beyond any doubt, besides other interesting details bearing on the nature of the radiation. To most men the facts presented will appear as a revelation.

The pleasant criticism of our halftone reproduction of the radiograph of the shoulder of a man is, we admit, justified, but any one who knows the difficulties of the procedure involved will be convinced that as much was done as could be done under the circumstances.

Mr. Tesla is pursuing quietly his work and giving all credit to Roentgen; and it is significant, we think, that the first radiograph he produced in his laboratory was the name of the discoverer. We wish that such courtesies among scientists would always be practiced.

TESLA'S LATEST RESULTS.

HE NOW PRODUCES RADIOGRAPHS AT A DISTANCE OF MORE THAN FORTY FEET.

To the Editor of Electrical Review:

Permit me to say that I was slightly disappointed to note in your issue of March 11 the prominence you have deemed to accord to my youth and talent, while the ribs and other particulars of Fig. 1, which, with reference to the print accompanying my communication, I described as clearly visible, were kept modestly in the background. I also regretted to observe an error in one of the captions; the more so, as I must ascribe it to my own text. I namely stated on page 135, third column, seventh line: "A similar impression was obtained through the body of the experimenter, etc., through a distance of four feet." The impression here referred to was a similar one to that shown in Fig. 2, whereas the shadow in Fig. 1 was taken through a distance of 18 inches. I state this merely for the sake of correctness of my communication, but, as far as the general truth of the fact of taking such a shadow at the distance given is concerned, your caption might as well stand, for I am producing strong shadows at distances of 40 *feet*. I repeat, 40 feet and even more. Nor is this all. So strong are the actions on the film that provision must be made to guard the plates in my photographic department, located on the floor above, a distance of fully 60 feet, from being spoiled by long exposure to the stray rays. Though during my investigations I have performed many experiments which seemed extraordinary, I am deeply astonished observing these unexpected manifestations, and still more so, as even now I see before me the possibility, not to say certitude, of augmenting the effects with my apparatus at least tenfold! What may we then expect? We have to deal here, evidently, with a radiation of astonishing power, and the inquiry into its nature becomes more and more interesting and important. Here is an unlooked-for result of an action which, though wonderful in itself, seemed feeble and entirely incapable of such expansion, and affords a good example of the fruitfulness of original discovery. These effects upon the sensitive plate at so great a distance I attribute to the employment of a bulb with a single terminal, which permits the use of practically any desired potential and the attainment of extraordinary speeds of the projected particles. With such a bulb it is also evident that the action upon a fluorescent screen is proportionately greater than when the usual kind of tube is employed, and I have already observed enough to feel sure that great developments are to be looked for in this direction. I consider Roentgen's discovery, of enabling us to see, by the use of a fluorescent screen, through an opaque substance, even a more beautiful one than the recording upon the plate.

Since my previous communication to you I have made considerable progress, and can presently announce one more result of importance. I have lately obtained shadows by *reflected rays only*, thus demonstrating beyond doubt that the Roentgen rays possess this property. One of the experiments may be cited here. A thick copper tube, about a foot long, was taken and one of its ends tightly closed by the plate-holder containing a sensitive plate, protected by a fiber cover as usual. Near the open end of the copper tube was placed a thick plate of glass at an angle of 45 degrees to the axis of the tube. A single-terminal bulb was then suspended above the glass plate at a distance of about eight inches, so that the bundle of rays fell upon the latter at an angle of 45 degrees, and the supposedly reflected rays passed along the axis of the copper tube. An exposure of 45 minutes gave a clear and sharp shadow of a metallic object. This shadow was produced by the reflected rays, as the direct action was absolutely excluded, it having been demonstrated that even under the severest tests with much stronger actions no impression whatever could be produced upon the film through a thickness of copper equal to that of the tube. Concluding from the intensity of the action by comparison with an equivalent effect due to the direct rays, I find that approximately two per cent of the latter were reflected from the glass plate in this experiment. I hope to be able to report shortly and more fully on this and other subjects.

In my attempts to contribute my humble share to the knowledge of the Roentgen phenomena, I am finding more and more evidence in support of the theory of moving material particles. It is not my intention, however, to advance at present any view as to the bearing of such a fact upon the present theory of light, but I merely seek to establish the fact of the existence of such material streams in so far as these isolated effects are concerned. I have already a great many indications of a bombardment occurring outside of the bulb, and I am arranging some crucial tests which, I hope, will be successful. The calculated velocities fully account for actions at distances of as much as 100 feet from the bulb, and that the projection through the glass takes place seems evident from the process of exhaustion, which I have described in my previous communication. An experiment which is illustrative in this respect, and which I intended to mention, is the following: If we attach a fairly exhausted bulb containing an electrode to the terminal of a disruptive coil, we observe small streamers breaking through the sides of the glass. Usually such a streamer will break through the seal and crack the bulb, whereupon the vacuum is impaired; but, if the seal is placed above the terminal, or if some other provision is made to prevent the streamer from passing through the glass at that point, it often occurs that the stream breaks out through the side of the bulb, producing a fine hole. Now, the extraordinary thing is that, in spite of the connection to the outer atmosphere, the air can not rush into the bulb as long as the hole is very small. The glass at the place where the rupture has occurred may grow very hot—to such a degree as to soften; but it will not collapse, but rather bulge out, showing that a pressure from the inside greater than that of the atmosphere exists. On frequent occasions I have observed that the glass bulges out and the hole, through which the streamer rushes out, becomes so large as to be perfectly discernible to the eye. As the matter is expelled from the bulb the rarefaction increases and the streamer becomes less and less intense, whereupon the glass closes again, hermetically sealing the opening. The process of rarefaction, nevertheless, continues, streamers being still visible on the heated place until the highest degree of exhaustion is reached, whereupon they may disappear. Here, then, we have a positive evidence that matter is being expelled through the walls of the glass.

When working with highly strained bulbs I frequently experience a sudden, and sometimes even painful, shock in the eye. Such shocks may occur so often that the eye gets inflamed, and one can not be considered over-cautious if he abstains from watching the bulb too closely. I see in these shocks a further evidence of larger particles being thrown off from the bulb. Nikola Tesla.

New York, March 14 1896



THE RÖNTGEN X-RAYS

Nikola Tesla's Results and Theories

In the *Electrical Review* for March 11 appears the first authorized communication from Nikola Tesla regarding his work with the X-rays. The following is condensed from his full statement:

In order to produce the most intense effects we have first to consider that, whatever their nature, they depend necessarily on the intensity of the cathode streams. These again being dependent on the magnitude of the potential, it follows that the highest attainable electrical pressure is desirable. We are naturally thrown on the use of the disruptive discharge coil as the most effective apparatus. With this there is practically no limit to the spark length. If we put two electrodes in a bulb, or use one inside and another outside electrode, we limit the potential, for the presence not only of the anode but of any conducting object has the effect of reducing the practicable potential on the cathode. Thus, to secure the result aimed at, one is driven to the acceptance of a single electrode bulb, the other terminal being as far remote as possible.

Mr. Tesla then describes at length a process of his own for obtaining, by an electrical discharge of high potential from a disruptive coil through the bulb, a degree of rarefaction far beyond that obtainable by mechanical appliances, and goes on to say:

Though the phenomenon of rarefaction under above conditions admits of different interpretations, the chief interest centers on one of them, to which I adhere—that is, on the actual expulsion of the particles through the walls of the bulb. I am getting more and more convinced that we have to deal with a stream of material particles, which strike the sensitive plate with great velocities. A peculiar thing about the Röntgen rays is that from low frequency to the highest obtainable there seems to be no difference in the quality of the effects produced, except that they are more intense when the frequency is higher, which is very likely due to the fact that in such case the maximum pressures on the cathode are likewise higher. This is only possible on the assumption that the effects on the sensitive plate are due to projected particles, or else to vibrations far beyond any frequency which we are able to obtain by means of condenser discharges.

With apparatus as I have described, remarkable impressions on the plate are produced. The bony structure of birds, rabbits, and the like is shown within the least detail, and even the hollow of the bones is clearly visible. In a plate of a rabbit under exposure of an hour, not only every detail of the skeleton is visible, but likewise a clear outline of the abdominal cavity and the location of the lungs, the fur and many other features. Prints of even large birds show the feathers quite distinctly. Clear shadows of the bones of human limbs are obtained by exposures ranging from a quarter of an hour to an hour. A picture of a foot with a shoe on it was taken, and every fold of the leather, trousers, stocking, etc., is visible, while the flesh and bones stand out sharply. Through the body of the experimenter the shadows of small buttons and like objects are quickly obtained, while with an exposure of from one to one and a half hour the ribs, shoulder-bones, and the bones of the upper arm appear clearly.

An outline of the skull is easily obtained with an exposure of 20 to 40 minutes. In one instance an exposure of 40 minutes gave clearly not only the outline, but the cavity of the eye, the chin and cheek and nasal bones, the lower jaw and connections to the upper one, the vertebral column and connections to the skull, the flesh, and even the hair. By exposing the head to a powerful radiation strange effects have been noted. For instance, I find that there is a tendency to sleep and the time seems to pass away quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep and a quick lapse of time. Should these remarkable effects be verified by men with keener sense of observation, I shall still more firmly believe in the existence of material streams penetrating the skull. Thus it may be possible by these strange appliances to project a suitable chemical into any part of the body.

Criticism of Tesla's Statements

Dr. Cyrus Edson, formerly health commissioner, when asked by a reporter for the New York *Times* about Tesla's deductions, said that he had been much interested in the subject and had given it considerable attention. Said he:

It is an undoubted fact that you can decompose certain chemicals by means of light. The principle of photography rests upon this fact. These X-rays decompose the chemicals with which the film is sensitized and effects this decomposition through what have hitherto been regarded as opaque bodies, such as the hand, for instance. Light in vibration, and it has been demonstrated that these X-rays will pass through an opaque body. That these vibrations in passing through the skull should affect the delicate nerve tissues of the brain and stimulate them is a perfectly natural result. This accounts for the sensations experienced by Tesla when he exposed his head to a powerful radiation. But there is no more reason to believe that the X-rays will carry a medicinal agent through the body and into the distant spot, the seat of disease, than that a ray of light will be able to project such a chemical onto the surface of the body.

The theory of the vibrations of light is not a new one. It originated with Sir Isaac Newton, who believed that luminous bodies shot out infinitely small particles in straight lines, which, by penetrating the transparent parts of the eye and falling on the nervous tissue, produced vision. Other philosophers drew a parallel between the properties of light and those of sound, and considered that as sound was certainly the effect of vibrations, or little waves projected through elastic bodies, so light might be nothing more than the consequence of similar vibrations transmitted with inconceivable velocity through a highly elastic medium. The wave hypothesis of light is at present generally adopted simply because it is in harmony with all the known phenomena discovered since the time of Newton. The deductions of Tesla as the result of his experiments are absolutely in harmony with the Newtonian theory. We can certainly expect some marvelous results from the X-rays, things not even dreamed of yet. I believe that they will prove a valuable adjunct to medical science, and I think that the ultra violet rays will be sooner or later obtained by passing ordinary sunlight through certain media, without the agency of electricity.

Dr. J. Mount Bleyer, who has taken great interest in determining the effects of all light rays on animal and vegetable life, said:

I am not at all surprised at the results of Tesla's experiments. I have been experimenting for some time with the associated light rays—the sunlight and the different colors, such as blue, red, and orange—in connection with the treatment of infectious diseases and vegetations. The results obtained by Tesla are simply marvelous, but are just what I expected. I have contended from the beginning, and it has now been proven beyond a doubt by Tesla, that this bombardment of particles does pass through glass and other materials at an enormous velocity. As far as the therapeutic effects of the rays are concerned, they may be likened in some way to a massage effect, if they do not form a high class of bactericidal agent. Solariums for the treatment of infectious diseases, with associated light rays, will no doubt be the next advance in hospital architecture. I have made a number of experiments with the associated light rays in hospitals and among my private patients in cases of phthisis and tuberculosis. I have resorted to the treatment wherever it was possible, and never failed to obtain the best results. Ordinary light is one of the main factors in the growth of animal life. We know that sunlight is essential for the growth and development of both animal and vegetable tissue. We have in light a therapeutic agent that has been underestimated and neglected, and which should be taken up and thoroughly studied.

Ogden N. Rood, professor of physics in Columbia College, after glancing through the article by Nikola Tesla, dictated to a New York *Times* reporter the following statement of his views:

It is never proper to frame a new hypothesis in order to account for discoveries when an old and well-established theory is capable of giving them an explanation. Our knowledge of the waves of light, of radiant heat, and of the ultra violet rays is confined within narrow limits. Thus far, according to our previous experience, the shorter the length of the wave the more it will be bent, or refracted, by substances in general. It, however, does not at all follow that this will hold good if the length of the wave is shortened to a degree beyond our experience. On the other hand, it is highly probable that if this shortening process goes on till the length of the wave has become of the same order of magnitude with the molecules of matter that the effect in the matter of refraction will diminish. This would account for the fact that no one has succeeded thus far in refracting or reflecting the Röntgen rays. In my own experiments I have so far found them to act in the same general way with waves of ordinary light, and I am inclined to believe that they are simply waves of light of unprecedented shortness. This view necessarily excludes all idea of a molecular bombardment outside of the Crookes tube. I believe that it will be eventually demonstrated that the Röntgen rays are capable of reflection and refraction, although it will require more delicate work than has thus far been extended in this direction.

The New York Tribune March 20, 1896

TESLA'S X-RAY RESEARCHES.

IMPORTANT ADVANCES MADE—PICTURES AT FORTY FEET—RAYS REFLECTED—EVIDENCE OF PROJECTED PARTICLES.

Nikola Tesla in The Electrical Review.

I am producing strong shadows at distances of forty feet. I repeat, forty feet and even more. Nor is this all. So strong are the actions on the film that provision must be made to guard the plates in my photographic department, located on the floor above, a distance of fully sixty feet, from being spoiled by long exposure to the stray rays. . . . Even now I see before me the possibility, not to say certitude, of augmenting the effects with my apparatus at least tenfold! What may we then expect? We have to deal here, evidently, with a radiation of astonishing power, and the inquiry into its nature becomes more and more interesting and important. Here is an unlooked-for result of an action which, though wonderful in itself, seemed feeble and entirely incapable of such expansion, and affords a good example of the fruitfulness of original discovery.

The effects upon the sensitive plate at so great a distance I attribute to the employment of a bulb with a single terminal, which permits the use of practically any desired potential and the attainment of extraordinary speeds of the projected particles. With such a bulb it is also evident that the action upon a fluorescent screen is proportionately greater than when the usual kind of tube is employed, and I have already observed enough to feel sure that great developments are to be looked for in this direction. I consider Röntgen's discovery of enabling us to see, by the use of a fluorescent screen, through an opaque substance even a more beautiful one than the recording upon the plate.

Since my previous communication to you I have made considerable progress, and can presently announce one more result of importance. I have lately obtained shadows by reflected rays only, thus demonstrating beyond doubt that the Röntgen rays possess this property. One of the experiments may be cited here. A thick copper tube, about a foot long, was taken and one of its ends tightly closed by the plate-holder containing a sensitive plate, protected by a fibre cover as usual. Near the open end of the copper tube was placed a thick plate of glass at an angle of 45 degrees to the axis of the tube. A single-terminal bulb was then suspended above the glass plate at a distance of about eight inches, so that the bundle of rays fell upon the latter at an angle of 45 degrees, and the supposedly reflected rays passed along the axis of the copper tube. An exposure of 45 minutes gave a clear and sharp shadow of a metallic object. This shadow was produced by the reflected rays, as the direct action was absolutely excluded, it having been demonstrated that even under the severest tests with much stronger actions no impression whatever could be produced upon the film through a thickness of copper equal to that of the tube. Concluding from the intensity of the action by comparison with an equivalent effect due to the direct rays, I find that approximately 2 per cent of the latter were reflected from the glass plate in this experiment. I hope to be able to report shortly and more fully on this and other subjects. . . .

I am finding more and more evidence in support of the theory of moving material particles. . . . I have already a great many indications of a bombardment occurring outside of the bulb, and I am arranging some crucial tests which, I hope, will be successful. The calculated velocities fully account for actions at distances of as much as 100 feet from the bulb, and that the projection through the glass takes place seems evident from the process of exhaustion, which I have described in my previous communication. An experiment which is illustrative in this respect, and which I intended to mention, is the following: If we attach a fairly exhausted bulb containing an electrode to the terminal of a disruptive coil, we observe small streamers breaking through the sides of the glass. Usually such a streamer will break through the seal and crack the bulb, whereupon the vacuum is impaired; but, if the seal is placed above the terminal, or if some other provision is made to prevent the streamer from passing through the glass at that point, it often occurs that the stream breaks out through the side of the bulb, producing a fine hole. Now, the extraordinary thing is that, in spite of the connection to the outer atmosphere, the air cannot rush into the bulb as long as the hole is very small. The glass at the place where the rupture has occurred may grow very hot—to such a degree as to soften; but it will not collapse, but rather bulge out, showing that a pressure from the inside greater than that of the atmosphere exists. On frequent occasions I have observed that the glass bulges out and the hole through which the streamer rushes out becomes so large as to be perfectly discernible to the eye. As the matter is expelled from the bulb the rarefaction increases and the streamer becomes less and less intense, whereupon the glass closes again, hermetically sealing the opening. The process of rarefaction, nevertheless, continues, streamers being still visible on the heated place until the highest degree of exhaustion is reached, whereupon they may disappear. Here, then, we have a positive evidence that matter is being expelled through the walls of the glass.

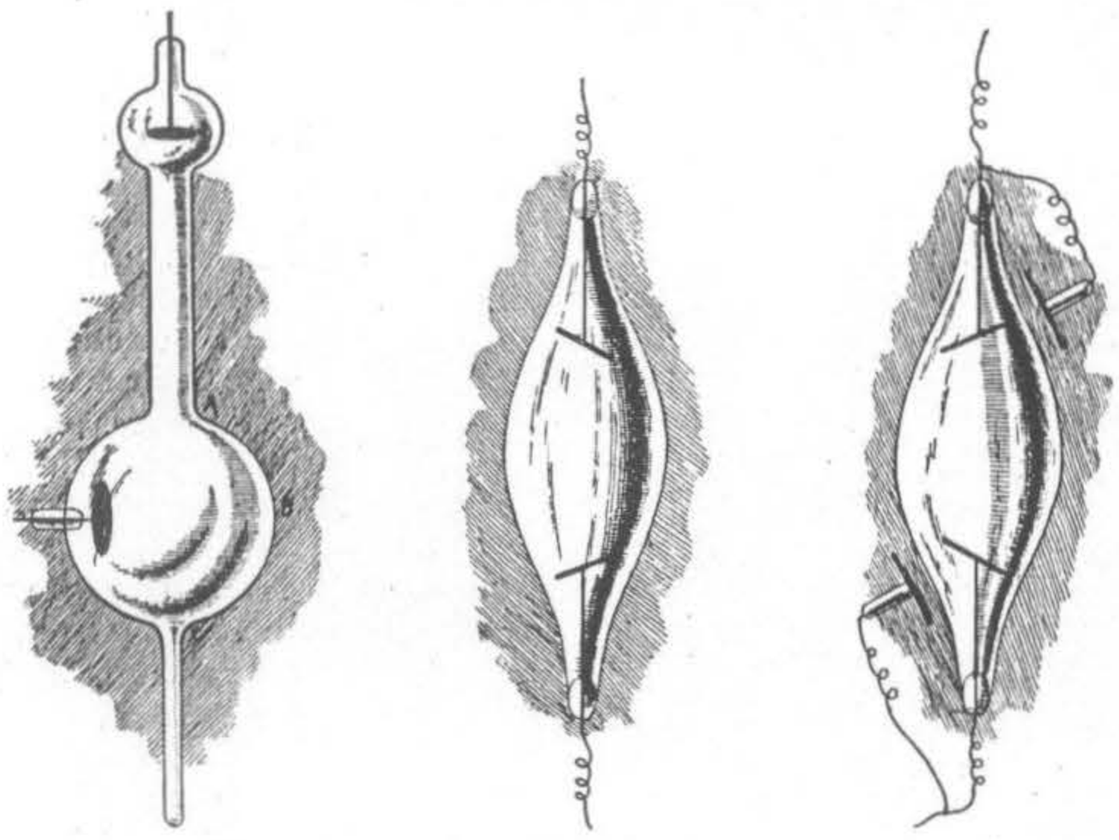
Edison's Röntgen Rays Experiments.

BY EDWIN J. HOUSTON AND A. E. KENNELLY.

Mr. Thomas A. Edison, after numerous experiments on the Röntgen rays with about 150 different glass vacuum tubes, has communicated the following information to us for publication :

First. There is no apparent advantage in obtaining a very high vacuum in the Crookes tubes employed for obtaining shadowgraphs of metal gratings. The effect of a very high vacuum is to require a greater voltage to produce fluorescence. The best degree of vacuum seems to be that at which the internal luminescence or striæ in the tube just disappear and fluorescence of the walls remains. The Röntgen rays are still produced even when internal striæ are observed, but are then much enfeebled.

Second. Thin walls are preferable to thick walls in the glass vacuum tubes. A thick wall will fluoresce more noticeably and become very hot. A thin wall will emit rays upon the photographic plate, but may scarcely fluoresce visibly and will remain very cool. This is proved by a number of experiments, of which the following is one : The tube of a shape roughly indicated in Fig 1 has its



FIGS. 1, 2 AND 3.—FORMS OF RAY LAMPS.

walls blown thick in the zone of *A C*, but thin at *B*. When this tube is exhausted and excited, the thin part, *B*, which is in the most active area, remains cool and the radiographic power is active, while the glass becomes hot in the ring *A C*. If B be made thick and *A C* thin, the glass at *B* may become melted by the heat, but its effect on a photographic plate is reduced, although its visible fluorescence is greater. Walls one eighth of an inch thick become unmanageable by excessive heating and rapid melting.

Third. For any given tube in a given condition of exhaustion, the radiographic power of the tube, *i. e.*, the swiftness with which is produced a developable image, is roughly proportional to the square of the fluorescent candle-power or total visible fluorescent light given out by the tube.

Fourth. The duration of exposure has been found to be as follows: With the most sensitive plates in an ordinary plate-holder having a vulcanized fibre light-tight cover of about $\frac{1}{32}$ of an inch in thickness, the time necessary for obtaining a good radiograph of a metal grating or grid is less than one second, when the tube is within ¼ of an inch of the grating and about ⅜″ from the sensitive plate. At two feet distance, the time for an equally good radiograph is approximately 150 seconds, and at three feet, 450 seconds. For rough purposes the duration of exposure may be reckoned as proportional to the square of the distance.

Fifth: Of the photographic plates as ordinarily employed for photographic purposes, the medium rapid plates appear to be the most suitable for Röntgen rays; *i. e.*, to require less duration of exposure. Rapid plates and slow plates appear to be equally unfavorable in regard to sensitiveness for Röntgen rays as compared with medium plates. To test this, a composite sensitive plate was made from five strips cut from plates of different photographic sensitiveness, and a radiograph of a series of metal bars was taken, with the bars at right angles to the strips of the composite plate. For the same exposure and same development, the definition of the radiograph produced did not bear any apparent relation to the photographic sensibilities of the strips according to their sensitometer numbers. The medium rapid plate gave, however, much the densest image in every such experiment.

Sixth: The power of a tube having a given degree of exhaustion and disposition of electrodes increases with the surface area of its fluorescent walls; thus, a large vacuum tube exposing a large total fluorescent surface has a more rapid action on the sensitive plate; *i. e.*, requires less exposure, but will require more voltage and more electric power to excite. On the other hand, for a given distance of the tube from the plate, the image is sharper and less distorted as the tube diminishes in size. Consequently, for a given tube used without a diaphragm, long distance and long exposure produce the sharpest radiograph. A small tube will produce a sharp image at a lesser distance, and for rapid exposures a very small tube at a very short distance is the best. The smallest tubes experimented with have been about one inch in diameter, with about two inches between electrodes, and with thin glass walls. A small tube requires a small E. M. F., so that tubes can be made to suit almost any induction coil.

Seventh. For a given thickness of glass wall, German glass appears to give better results than lead glass. The German glass employed gives a yellowish fluorescence, while lead glass gives a greenish fluorescence. These glasses phosphoresce visibly for at least ten minutes after the cessation of the discharge through the tube. A particular quality of Scotch boiler water-gauge glass used gives apparently equally good radiographic results, but does not appreciably phosphoresce after the cessation of the current. The residual phosphorescence has not yet been found to produce a visible photographic image. All phosphorescence yet observed is pale white, whatever the color of the preceding fluorescence under excitation.

Eighth. The form of the tube arrived at by a gradual process of selection is shown in Fig. 2. The length is about three times the diameter. This tube is made in various sizes. When the glass walls are thin for producing the best radiographic effect, a spark is apt to pierce the wall and destroy the vacuum. Partly on this account, tinfoil caps are placed over the extremities of the tube, as indicated by the shaded areas in the sketch. These tinfoil caps are in connection with the electrodes, and are cemented to the external surface of the tube by shellac.

Ninth. It was found in numerous trials with many tubes that the fluorescent and radiographic power of all the tubes without caps was greatly increased, roughly doubled, in fact, by bringing two metallic discs, connected with the respective electrodes, to the opposite points, represented in Fig. 3. The supposition is that the tube thus becomes at once an ordinary and electrodeless tube combined. The metal caps above mentioned were the outcome of these experiments, and not only have all these capped tubes remained unperforated, but their fluorescent and radiographic powers have been enhanced by the caps. The caps serve three purposes : (a) To stop piercing by permitting excessive sparking to escape over the external surface. (b) To increase the radiographic and fluorescent power. (c) To prevent undue heating of the internal electrodes, and a consequent charge of vacuum.

Tenth. The exciting apparatus consists of a large Ruhmkorff coil capable of giving a 12-inch spark, although such a length of spark is rarely required. The coil is excited either from a storage battery through an interrupter, or preferably from a 120-volt continuous-current circuit, through a bank of from 8 to 20 16-cp incandescent lamps arranged in parallel, with a rapidly rotating wheel-interrupter driven by a small motor. About 400 interruptions are made per second, and the duration of closure in the circuit is twice that of opening. An air-blast is directed upon the spark over the periphery of the interrupting wheel through a fine nozzle. This tends to produce a sudden breaking of the circuit. It has been found that greatly improved results have followed the removal of the usual condenser and the substitution of the air-blast. The resulting secondary E. M. F. is almost symmetrical, like an alternating E. M. F., and the two electrodes are apparently equally active. The secondary terminals of the induction coil are led directly to the vacuum tube. If the air-blast is removed and the condenser substituted, the fluorescent and radiographic power of the tube is greatly diminished.

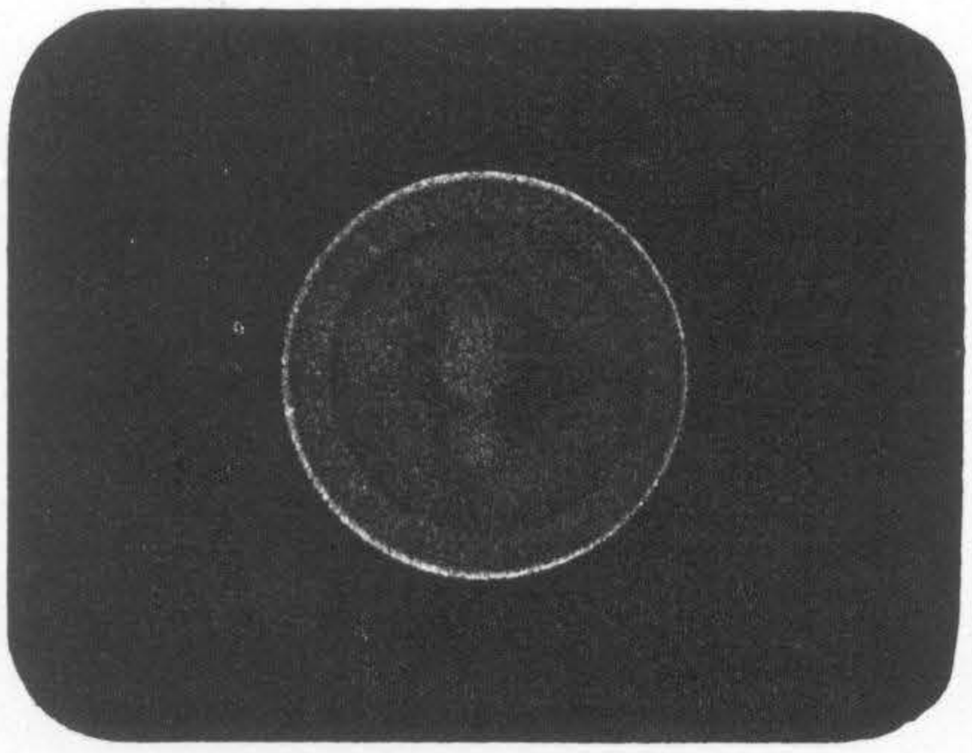
We believe that these observations of Mr. Edison cannot fail to be valuable to many practical workers with Röntgen rays. We hope to communicate further experimental results at some future time,

Röntgen Rays Experiments.

BY DAYTON C. MILLER.

Experiments with Röntgen rays have been carried on very persistently at the Case School of Applied Science for several weeks, and some very interesting results have been obtained. The main object has been to secure good photographs of the human skeleton in a living subject, and to increase the practical efficiency of the apparatus. The accompanying photograph of an aluminum medal will indicate the degree of success obtained.

A hand and forearm was photographed with an exposure of 20 minutes, while the medal required but five minutes. The Crookes tube used is of the well-known spherical form, having four elec-



RADIOGRAPH OF ALUMINUM MEDAL.

trodes, designed to show that the discharge in a high vacuum is independent of the anode, and is one of a set which was exhibited at the World's Fair. It was excited by an induction coil giving about a six-inch spark in air, when using a current of three amperes and 20 volts obtained from 11 cells of storage battery. The arm was held by bandages to the plate-holder, which was supported in an inclined position upon a special stand. The usual plate-holder slide of hard pasteboard was between the hand and plate. The tube was placed at a distance of 12 inches above the wrist. Rapid plates were used and developed in the usual way with eikonogen and hydrochinon developer. A photograph showing the bones of the fingers has been made with 10 seconds' exposure, the tube being at a distance of two inches. Of course, the outlines are not as well defined as when the tube is farther away.

Bullets have been clearly located in the hands of two men with exposures of eight minutes. The first one found had been carried for over fourteen years, and was thought to lie between the bones of the forearm. A single negative disproved this, while two photographs of the hand plainly located the ball at the base of the little finger. In the second case the bullet was received in the back of the hand last August, and five negatives, taken with the hand in various positions, all plainly located the ball at the base of the thumb.

The bones of the elbow joint and upper part of the arm, and of the foot, have been photographed with exposures varying from five to thirty minutes. Longer exposures do not give better results. Some of the negatives made clearly show the ligaments connecting the bones at the joints, while none have so far shown any blood vessels or nerves.

Besides the above, a number of other surgical cases have been satisfactorily examined. Among these were the determination of injuries done to the fingers by a planing machine, the extent of diseases of the bones of the hand, and the examination of a number of fractures of the bones of the forearm to ascertain the nature of the fracture, and whether the bones were properly set.

A most interesting study has been the position of the various small bones of the wrist in different positions of the hand.

Many interesting points are noted in the work, which are suggestive in a theoretical way, details of which are not ready for publication. As already announced by Prof. Rowland, it appears that the anode is as important in the matter as the cathode. We have a number of tubes which give results, but none better than the one mentioned, while a tube just received, of American manufacture, promises to equal the imported ones.

The success so far obtained with the arm and foot encourage us to think that still thicker portions of the human body may be studied advantageously, and experiments will be immediately undertaken in this direction.

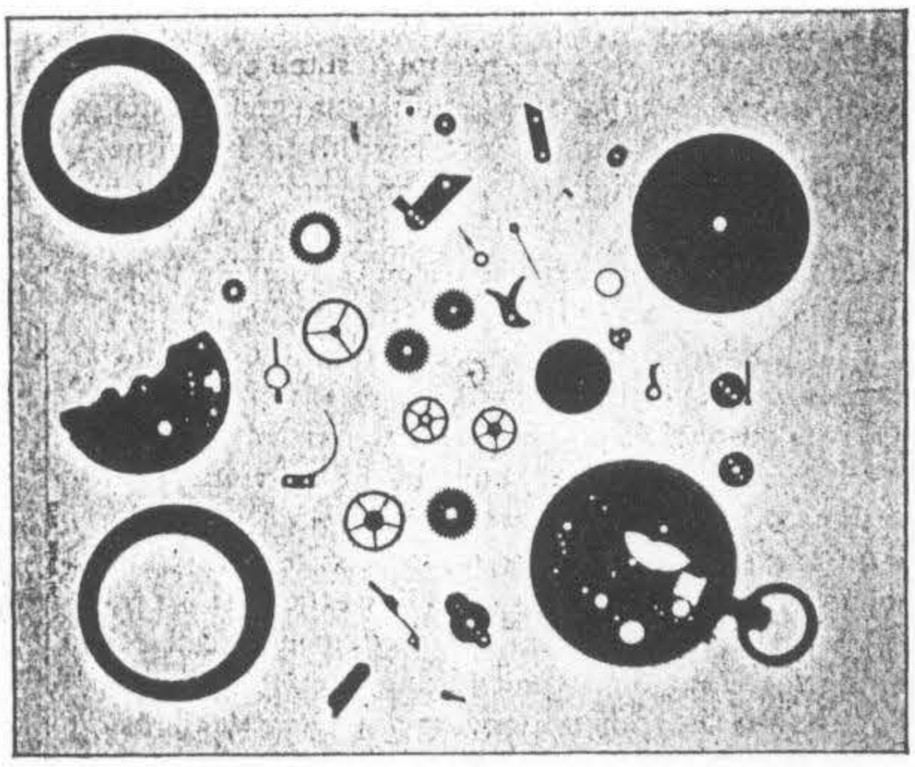
[The radiograph of the hand and forearm above referred to, which is very distinct in its outlines, has not been engraved owing to the unsatisfactory reproduction by the half-tone process of the delicate shadings of radiographs.—ED.]

Röntgen Rays.

The possibility of direct-vision radiography has for the past week been exploited in a sensational manner by the newspaper press. The invention of the apparatus for this purpose, the so-called "cryptoscope," is claimed by Prof. Salvione, of Rome, but, as pointed out by the London *Electrical Review*, this method was really used by Röntgen in his earliest experiments. Mr. Swinton, of England has been making some successful experiments in this direction, which are reported in the English electrical journals of March 6. He soaks a piece of blotting paper in a solution of barium platino-cyanide and places it inside a tube at the back of a sheet of opaque paper covering the end. The eye placed at the aperture at the other end of the tube can see a shadow of the object on the fluorescent paper.

Prof. Pupin has had no difficulty in seeing through solid bodies with the aid of such a screen. In an interview with the New York *Journal*, he states that it is easy to look through the bones of the hands, and when the light is just right even some of the muscles may be seen on the screen and traced throughout their length.

Mr. Edison used a disposition somewhat different from the above. He encloses very small crystals of platino-cyanide of barium between two plates of mica and secures this fluorescent screen at the bottom of a pasteboard box about 6 inches square and 7 inches deep. In extremely sensational accounts of his experiments in this line which have appeared in the daily press, it appears that a shadow may be seen on the screen when an object is passed between it and the source of Röntgen rays, though opaque substances are interposed between the object and the screen, but the outlines of the shadow are not well defined.



RADIOGRAPH OF PARTS OF WATCH.

Mr. Albert Sauver has taken some extremely sharp radiographs in the laboratory of the Illinois Steel Company. One of these we reproduce, showing the different parts of a watch. The sensitive plate was covered with a sheet of black paper placed in a cardboard box and the latter enclosed in another similar box. Quick plates were used, the exposure being about one and one half hours. The current was derived from a three-cell storage battery and an induction coil giving a three-inch spark was employed. The distance of the tube from the plate was five inches.

Among some recent radiographs taken in the Shallenberger laboratory is one of a human embryo, which illustrates in a striking manner the extent of the service which Röntgen rays will render to science. In this instance the stage of bone development is clearly indicated; some parts of the skeleton structure are shown to have neared their final shape, while others are as yet only partly developed. The growth of bone would appear to commence near the middle of the final length, the ends being formed last. Another radiograph taken by Mr. Herbert W. Shallenberger is of the head and neck of a fowl, in which the gullet is sharply outlined, showing that its substance is more opaque to rays than the surrounding flesh.

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VIEWS, NEWS AND INTERVIEWS.

In 1883 three men who have since become world famous, were at the University of Strasburg, although they were then unknown to one another or to fame. They were Paderewski, Roentgen and Tesla. Paderewski was at that time an instructor in music in the University; Roentgen was a professor of physics, and Tesla was installing the electric light plant in the University. Of the three men Roentgen was the last to achieve fame. When his X-ray discovery was announced, the recognition of his work was prompt and now he is Baron Roentgen. Tesla has declined several offers of titles and decorations made to him by rulers of foreign countries, but takes a proper pride in the honors conferred upon him by scientific bodies in different parts of the world.

The New York Sun March 25, 1896

WE MAY SIGNAL TO MARS

OR, GIRD THE EARTH WITH NEWS WITHOUT A WIRE.

Nicola Tesla Convinced that to the Latter Extent at Least His Plan Is Practicable, and Why Not Between Planets, as Between the Sun and the Earth?

Nicola Tesla, the electrician and scientist, has had in course of development for some time a project for instantaneous and simultaneous communication to all parts of the earth, and perhaps to some of the nearer planets. Mr. Tesla's plan does not deal with fireworks, or the illumination of a large part of the earth's surface in hope of attracting the attention of the dwellers on Mars, but deals wholly with the electric waves. In regard to it, Mr. Tesla said yesterday to a SUN reporter:

"I have had this scheme under consideration for five or six years, and I am becoming more convinced every day that it is based upon scientific principles and is thoroughly practicable. We know that electric disturbances on the sun are productive of similar disturbances on the earth in the form of thunder showers. Now, why is it not equally conceivable that a disturbance on the earth's surface should produce some tangible effect on other planets. The transmission of disturbances on the sun shows beyond doubt that waves of electricity are propagated through all space.

"The objection may be put forward that sufficient electrical disturbance cannot be made on the earth's surface, and that we should be wholly dependent upon thunder storms and other phenomena of nature for the success of our experiment. But, on the contrary, we can make all the artificial thunder and lightning we want. There is no difficulty in making electric apparatus with a spark gap of a mile, and if that did not prove effective it could be increased.

"Do not get the impression," continued Mr. Tesla, "that the success of the experiment is in any way dependent upon the light, noise, or vibration accompanying such an electric discharge. It is wholly through the electricity waves, which are propagated through the atmosphere and the ether beyond, that we may hope to obtain any results. But if there are intelligent inhabitants of Mars or any other planet, it seems to me that we can do something to attract their attention.

"This, of course, is the extreme application of this principle of the propagation of electric waves. The same principle may be employed with good effect for the transmission of news to all parts of the earth. It was formerly thought that in order to get any power out of electricity a conducting circuit must exist, but it has been shown that the same results may be accomplished with a single wire. It is perfectly possible to operate a motor or an electric light with just a single line of wire leading to the apparatus. It naturally occurred to me that, as the earth is a conductor, an electrical disturbance at one point, causing a change in the equilibrium of the earth's electricity, should be felt at all points on the earth's surface, and might be recorded by properly constructed instruments.

"The possibilities of such a transmission of intelligence cannot be exaggerated. Every city on the globe could be on an immense ticker circuit, and a message sent from New York would be in England, Africa, and Australia in an instant. What a grand thing it would be in times of war, epidemic, or panic in the money market!"

Mr. Tesla is at present engaged in finishing his calculations and perfecting the apparatus necessary for experiment in his new field of investigation, and he hopes soon to be able to show the practicability of his plan.

THE DEVELOPMENT OF THE NEW RADIOGRAPHY.

WE might expect from Nikola Tesla the most intelligent discussion of the new Röntgen rays, but we were not prepared for his announcement in the last week's *Electrical Review*. He says he is now producing strong shadow pictures at a distance of forty feet, and he finds it necessary to guard the plates in his photographic department on the floor above, and sixty feet away, from being spoiled by long exposure to strong rays. He confesses himself amazed by the astonishing power of this radiation, especially as he sees the certitude of augmenting the effects at least tenfold. These effects on a sensitive plate at so great distance he obtains by the use of a bulb with a single terminal, which permits the use of practically any desired potential, and the attainment of extraordinary speeds of the projected particles; for he adopts the theory, not yet generally accepted, that the action is not that of waves of a certain sort of light, but that of actual atoms or *ions* projected at enormous speed right through glass, wood or metals.

We owe to Mr. Tesla also the proof that the Röntgen rays can be partially reflected, and he has succeeded in obtaining radiographs with reflected rays. He was able to reflect about two per cent. of the rays from a thick glass, these reflected rays being made to pass through a copper tube, and then give a clear and sharp shadow.

But most surprising of all his statements is that which he offers in proof that the Röntgen phenomena are caused by moving material particles, like those supposed in Newton's corpuscular theory of light. He gives the following experiment:

"If we attach a fairly exhausted bulb containing an electrode to the terminal of a disruptive coil, we observe small streamers breaking through the sides of the glass. Usually such a streamer will break through the seal and crack the bulb, whereupon the vacuum is impaired. But, if the seal is placed above the terminal, or if some other provision is made to prevent the streamer from passing through the glass at that point, it ofter occurs that the stream breaks out through the side of the bulb, producing a fine hole. Now, the extraordinary thing is that, in spite of the connection to the outer atmosphere, the air cannot rush into the bulb as long as the hole is very small. The glass at the place where the rupture is may grow very hot, to such a degree as to soften; but it will not collapse, but rather *bulge out*, showing that a pressure from the inside greater than that of the atmosphere exists. On frequent occasions I have observed that the glass bulges out, and the hole, through which the streamer rushes out, becomes so large as to be perfectly distinguishable to the eye. As the matter is expelled from the bulb, the rarefaction increases, and the streamer becomes less and less intense, whereupon the glass closes again, hermetically sealing the opening. . . . Here we have positive evidence that matter is being expelled through the walls of the glass."

In the rapid development, by the concurrent labors of hundreds of students, of the discovery of Professor Röntgen, we see the advantage which comes, in science, from that fine and generous ambition which leads scholars to hasten to give to the world the results of their discoveries, that others may make applications and improvements. Professor Ramsay, who was associated with Lord Rayleigh in the discovery of argon last year, has suggested that a certain deference be paid to those who first announce a new discovery, by consulting them and getting their permission before others publish on the subject. This would be as foolish as it is impracticable. The analogy of patents, which he adduces, does not tell in favor of his claim. Every improvement on a patent is itself patentable. The honor which the discoveries of argon and the x rays have earned will not be diminished but rather enhanced by every new development of knowledge to which it gives occasion.

MAY SIGNAL STARS.

Electrical Envelope of the Earth, Nicola Tesla Says, Will So Be Used.

DETACHED ELECTRIC LIGHTS.

These as Well as the Problem of Heating Will Be Solved by His Electric Oscillator.

IT IS NEARING COMPLETION.

Great Inventor Speaks Modestly but Hopefully of Nea Possibilities of Electrical Science.

Nicola Tesla stood in the outer room of his laboratory, at No. 48 East Houston street, yesterday afternoon, and smiled as he said:—"My electric oscillator is nearing completion. I have spent years in experiments, and have been alternately encouraged and discouraged by the results. But now there is everything to promise success. It seems to be close ahead."

Mr. Tesla's remarks were occasioned by inquiries concerning the truth of a rumor that he was perfecting an instrument for communicating with the planets by means of electrical waves. The inventor nodded his handsome head and remarked:—

"Perhaps, in time. But not yet. We have to begin with little things before we can accomplish great ones. I am confident that the principles upon which I have been working are correct. How soon they will be demonstrated of course I cannot say. The perfection may come in ten minutes and perhaps not for years. But that it will be possible to signal all parts of the earth instantaneously, and that from the logical development of this it will be possible to signal the stars by electrical disturbances here I have no doubt whatever.'

HIS RECENT EXPERIMENTS.

"Years ago, in St. Louis, I delivered an address before the National Academy of Sciences. I then declared it would be possible to use economically the electricity in the atmosphere for lighting and heating, and, of course, for communication between different parts of the earth's surface. The problem was the conservation of electrical energy at the least possible cost to the other elements. That problem, I was confident then, I could solve by my oscillator. At present I am sure it can be done. From my most recent experiments I am convinced that within a very short time we shall be independent of the clumsy methods of generating electricity now in vogue. The electrical fluid in the atmosphere will give energy enough. The same electric envelope of the earth will enable us to send messages from one part of the globe to all other parts in an instant of time. The same element, which, I believe, finite and is not confined to this atmosphere, may be used to communicate with the other planets."

"Can you give any description of this apparatus?" I asked.

"I regret very much to say that I cannot at present. It is rather a tool than an apparatus. My experiments are made scientifically, on a small scale, for I have neither the money nor the space at my disposal to do more. But it is readily admitted that if I prove my principle in this minor way, and I am able to do what I am sure can be done with electricity in a limited fashion, it will only need an extension of method to accomplish the greatest results. Simultaneous announcements may then be made in all parts of the world. In case of disaster, of pestilence, of atmospheric disturbances, in all events which are international in their character, the word may be sent from any place to all other places. The principle is the same as that which was so generally discussed some time ago in regard to the possibility of signalling at sea, telephonically or otherwise, between ships or with the shore and without wire."

APPLIED TO LIGHT.

"Will the work accomplished by the oscillator be suited to the sending of messages of this kind?" I inquired.

"No, not at all," Mr. Tesla replied. "It will realize the possibility of generating light so that the means we now use will at once appear old fashioned. Electric light will be exceedingly cheap, and so will electric heat. The principle will be applied to all lines of necessity in which the use of the force is now important. In photography I have already achieved results from the experiments with the oscillator on the Roentgen principle at a distance of forty feet, and have secured photographs that are much more elaborate in detail than any others I have seen or that I have heard described."

The principle of lighting to which Mr. Tesla referred ,and which is a part of the discoveries which he declares he has made, will enable one to use electric lights unattached to any dynamo by wire or other medium. They may rest upon your drawing room table unilluminated, and by merely grasping them you may generate conditions which will make them glow and shed light.

The New York Tribune March 27, 1896

NIKOLA TESLA'S EXPERIMENTS.

BRIEF EXPOSURE TO X RAYS—MESSAGES BY ELECTRICAL WAVES.

The great length of time required for the exposure of objects to the X rays before satisfactory impressions could be obtained on the sensitized plates has hitherto proved a source of considerable trouble to scientists who have experimented with the new radiance. When operations were first begun in this country with the rays, an exposure of from two to three hours was often found necessary. To a large extent this fact was due to a paucity in the supply of good tubes. Gradually the experimenters improved their apparatus, by the importation, principally, of Crookes tubes, but even with the best vacuum tube that could be got in this way, exposures of from twenty to forty minutes were essential. Consequently, it is obvious, the discovery of a method for the perfection of the apparatus, whereby results could be obtained with more rapidity, would be of especial value and importance, particularly in the treatment of surgical cases.

It is interesting, therefore, to know that Nikola Tesla, the New-York scientist and electrician, has succeeded in taking photographs of various objects, including the bones of the hand, in the actual time of one second. To a Tribune reporter, who saw him yesterday at his laboratory, No. 46 East Houston-st., Mr. Tesla said that this result was due primarily to exceedingly high vacuum tubes, considerably higher in fact than the best Crookes tubes. Mr Tesla said he had exhausted the bulbs himself by electricity. He was also able, he said, with these tubes, to photograph articles at a distance of forty feet. Mr. Tesla was not inclined to make public the details of his method for making the tubes, although, he said, he had communicated his principles to several scientists, who had written testifying to the value of the bulbs in experiments with the X rays.

Speaking of the report that he was engaged in the development of an instrument for communicating with the nearer planets, and for conveying messages from one centre to another without wires, by means of electrical waves, Mr. Tesla said: "To say that I am developing an instrument to communicate with the planets is, to say the least, somewhat premature. But by electrical disturbances which will act upon my instrument I am confident that I shall be able to signal all parts of the earth instantaneously. In an address which I gave some few years ago to a scientific audience, I demonstrated that it would be possible to use the electricity in the atmosphere and the earth for lighting and heating and for communication with distant parts of the earth. The problem of conserving this electrical energy I am now at work upon, and by the aid of the apparatus I have made I am confident that we shall be able to get all the electrical energy we want from the atmosphere. The present methods of generating electricity would in that event become a thing of the past. This electric envelope of the earth will enable us to send messages to all parts of the world instantly, and, in the belief that this electrical fluid is not confined to this atmosphere, I think it is possible that we may be able to use it to communicate with other planets."

ELECTRO-PHYSICS AND MAGNETISM.

Röntgen Rays. Shettle. Lond. *Elec. Rev.* and *Elec. Eng.* March 6. —He claims that the cause of the phenomena discovered by Röntgen (referring to the photographic effect of the rays) is the direct result of electric stress and not, as was supposed, of invisible light. He describes an experiment in which a cotton-covered wire "was bent five times upon itself in parallel lines" and then fastened to a cardboard and placed directly on the sensitive surface of a photographic plate; a very thin magnetic strip was fastened to the back of the plate by strips of paper, the whole being wrapped in ruby and in black paper; an alternating current of eight amperes at a frequency of 40 was passed through the wire for about 45 minutes; a complete and distinct image of the magnetic strip and the paper fastening it was formed on the plate.—He claims that the "effects were the product of stress in the wire exercised through the glass plate upon the magnet and the paper." He endeavors to explain the process by which he thinks all photographs are taken; all forms of matter are polar, that is, assume a definite direction, and they are free to move in a magnetic field; owing to the terrestrial magnetism all matter exists in a magnetic atmosphere; when light, which is one of the distributing elements, falls on the sensitive surface, the molecules are thrown into motion and the general effects on the surface are the same; when it is reflected from an image the counterpart of that image would be produced on the plate; he claims that the same principle holds good in images obtained by the stress of magnetism, as the sensitive matter on the plate registers the various directions in which impressions have been conveyed to it directly or indirectly, through intermediate bodies; any body which intercepts the lines of stress modifies their effects on the plate; bodies of greater density interfere more with the lines of stress. Editorially it is thought that the image obtained by Dr. Shettle is due to electromagnetic induction and has nothing to do with the magnetic field produced by the magnet, a bar of soft iron it is thought would act equally well (from the photograph there appears to be no difference whatsoever between the poles and the middle of the magnet; also that where the paper overlaps the magnet the image is darker; the image of the magnet and the paper are about equally dark); the alternating current through the gridiron conductor would induce currents in the gelatine filament and this would cause decomposition of the salts in proportion to their intensity; the presence of the metallic bar on the back of the plate would modify the intensity of the currents in the film immediately above it (but the paper, which is a non-conductor, appears to act like the magnet, as far as causing the image is concerned).

Another article in the Lond. *Elec. Rev.* gives a brief summary of recent developments. The doubt which was expressed as to Blythswood's experiment being a genuine photographic effect has been removed by further experiment; at the suggestion of Lord Kelvin the sensitive plate was placed in a tight zinc box with an aluminum window in the lid, the box being carefully earthed and placed between the two poles of the large influence machine, which latter were two feet apart and produced a silent brush discharge; the object was placed either inside the box or outside on the aluminum window; photographs were obtained in half an hour. It is thought that the long-known electric shadows produced by influence machines may be due to the same cause; Holtz produced these shadows by using a point and a disc on his machine, the disc being hollow and covered with silk; conducting bodies between the point and the disc threw distant shadows on the silk of the disc, while insulating bodies were apparently transparent; he therefore concluded that the nature of the surface was important in determining the transparency; Lehmann found by using a disc on each electrode that a shadow of the interposed body was projected on the faces of both discs. Gossart and Chevallier made a curious discovery (see *Comptes Rendus*, 122, p. 316) which appears to add to the mystery concerning the nature of the radiations in the Crookes tube; they found that the Röntgen rays exercise a mechanical directive action on the vanes of the wheel in the Crookes radiometer; they created a field of force inside the radiometer, which is opposed to that due to the heat; the direction and intensity of the field of force around the Crookes tube was explored by means of the radiometer; it was found by experimenting with 20 substances that this force was transmitted and arrested by the same media as the Röntgen rays are; only when the radiometer was placed in the Crookes field was the field "modified by currents, especially by those of the exciting coil of the Crookes tube, modified by the presence of statically charged electrified bodies; and finally energetically distributed by a magnet"; by moving a magnet circularly about a radiometer the vanes in some way are set free and become again obedient to a source of heat; when placed in the path of cathode radiations the motion of the vanes is dampened, sometimes one pair and sometimes another taking up the axial position of equilibrium; when the current in the Crookes tube ceases the directive

action of the vanes persists for about five minutes afterward in spite of the constant action during that time of the Locatelli lamp; the vanes may be started again by directing on them the radiation from the anode, when they will at first undergo an impulsion opposite to the normal direction, which they afterward resume; the inertia effect, which lasts for five minutes, was obtained with a Ruhmkorff coil, but a Wimshurst machine failed to produce it; paraffin was found to be more transparent than air.

Henry thinks that his experiments verify the hypothesis of Poincaré that all fluorescing bodies emit Röntgen rays; a faint white image of a wire placed between a fluorescing body which had been exposed to light and a sensitive plate was produced on a dark rectangular background. Meslans made experiments to determine the influence of chemical constitution in the transparency of bodies to the Röntgen rays (see *Comptes Rendus*, 122, p. 309); he found that carbon and its compounds with hydrogen, oxygen and nitrogen is extremely transparent, but when combined with chlorine, sulphur, phosphorus or iodine, its opacity is considerably increased; he believes that the difference in the chemical constitution of the materials forming the nerves and the blood will without doubt enable photographs of these constituents of the body to be obtained by virtue of their unequal transparency. Prof. J. J. Thomson, in *Nature*, gives an account of some very interesting investigations; he tried to determine the leakage in air at different pressures; in following up his discovery that all bodies become conductors when traversed by these rays, he found that the rate of leakage is greater at a high pressure than at a low one, and for a wide range is approximately proportional to the square root of the pressure; he believes the leakage of electricity through non-conductors is considered to be due to a kind of electrolysis, "the molecule of the non-conductor being split up by Röntgen rays, which act the part played by the solvent in ordinary electrolytic solutions"; he obtained indications that the rate of leakage through air is proportional to the number of ions; he concludes that the Röntgen rays are not all of the same kind, and that their penetrative power varies greatly with the efficiency of the tube which produces them; he found that most tubes improve for a time after they are sealed off, and after attaining a maximum efficiency they then deteriorate.

According to the *Jour. des Inventeurs*, March 1, Mr. DE HEEN wrote to the French Academy of Sciences that according to his experiments the Röntgen rays of Lenard and Röntgen did not emanate from the cathode, but from the anode; to demonstrate this, one has only to place between the Crookes tube and the sensitive plate a screen of lead perforated with several holes allowing the rays to pass through; the direction of these on the photographic plate indicate that they emanate from the positive and not from the negative pole and that they are therefore anode rays.

According to the *Elek. Zeit.*, March 5, SATORI in Vienna stated that he obtained very intense Röntgen rays with a comparatively small influence machine by connecting the Crookes tube in series with a spark gap and in parallel with two condensers "whose outer coatings were short circuited," the machine gave a spark of about 12 cm; the result was not successful when the spark gap, which is in series with the tube, was omitted, probably because the voltage was then too low; that this method is much cheaper and simpler than the one usually used is self-evident, besides requiring no source of current, as the machine is turned by hand.

The paper by Mr. Perrin, noticed in the *Digest*, March 14, is published in full in the *Bul. Soc. Int. des Elec.* for February.

Present Ideas Concerning Cathode Rays. GUILLAUME. *La Nature*, Feb. 29.—He considers that the phenomena discovered by Röntgen is already becoming less mysterious and there appears a possibility of explaining it without having recourse to any new ideas; he believes that Raveau has come nearest to a satisfactory theory based on a remark of Prof. Schuster. In a previous article in that journal (July 28, 1894) Guillaume reproduced two photographs obtained by Lenard showing two spots produced by the cathode rays which are deflected and which are not deflected by a magnet; they show that the original rays consist of two distinct kinds, one of which is nearly independent of the effect of the magnet, while the other was deflected by a magnetic field into a band like a spectrum. He thinks it an established fact that the Röntgen rays are derived from the cathode rays, but are not cathode rays themselves; there is a great probability that the Lenard photographs were produced by two kinds of rays, one the true cathode rays and the others which are not deflected. There are at present two hypotheses, that of bombardment and that of radiation; that they are contradictory is not surprising if it is true that heretofore two absolutely different phenomena have been observed together. There is no doubt that Röntgen rays are essentially different from the cathode, and that they are produced at the point of impact of the original ones on a body; they diminish as the square of the distance measured from the point of impact. If the rays proceed in straight lines from the point where they are produced, it is none the less true that they do not come in a straight line from the cathode to objects exterior to the tube. He considers that the tests of the theory of longitudinal vibrations of the ether have not met with success, and he thinks this theory ought to be rejected, adding that it might be kept in reserve for the future "to be given in a still more embarrassing case." Lenard thought his phenomena might be explained by the hypothesis of very short wave-lengths; the difficulties in the way appear great, but he thinks Raveau has overcome most of them; it is known that ultra-violet radiation, which in general is very refrangible, is capable of traversing a body without being deflected or strongly absorbed; the abnormal refraction discovered by Lerous was considered an exceptional phenomenon; it consists in a reversing in the order of refrangibilities. Kundt found that many metals have an index less than unity in the visible spectrum and it is therefore natural that they possess a strong absorption and that when the band has once been passed they become more transparent; the coefficient becomes less than unity at the extremity of the band and increases again asymptotically toward unity; if it has been thought that most bodies are completely absorbent for low wave-lengths, it was perhaps due to the fact that it was not possible to produce sufficiently short waves; Chardonnet long ago showed the transparency of silver to ultra-violet rays.

Longitudinal Light. JAUMANN. Lond. *Elec.*, March 6; the first part of a translation of a paper from the *Wied. Ann.*, 51, p. 147.—The style is somewhat brief and not very clear. He gives results of experiments concerning the nature of light in a vacuum and of cathode rays, accompanied by a theory of electric phenomena in rarefied air, which he considers makes cathode rays and kindred phenomena perfectly intelligible. The first part refers to the determination of the direction of vibration of electric rays, which direction he states may be determined by discharge experiments; he gives what he calls a discharge law and shows how it can be used for determining the direction of vibration of cathode rays and of light in rarefied air; he claims to have given an experimental proof of the longitudinal character of cathode rays founded on the discharge effect of these rays; as they have a strong discharge effect he claims they are electric waves of great amplitude; they also have a strong discharge effect when their direction is perpendicular to the electrode surface and hence the direction of their electric oscillation coincides with their direction of propagation; "they are rays with a great longitudinal component, and, therefore, from symmetry, essentially pure longitudinal electric rays."

Movable Light Phenomena in Rarefied Gases Caused by Electric Oscillations. ELSTER and GEITEL; *Elek. Zeit.*, March 5; abstracted from the *Wied. Ann.*, 56, p. 733.—They describe experiments from which they conclude that cathode rays are not due to a bombardment of particles detached from the electrode, but are movements of the ether analogous to light, that is, to what Jaumann calls longitudinal light.

Resistance to Alternating Currents. BRYLINSKI. *Bul. Soc. Int. des Elec.*, February.—A communication referring to the recent paper of Mascart (*Digest*, Feb. 8 and Jan. 18). He gives a formula for finding the increase in the (apparent) resistance (due to the frequency) of copper wires of any given diameter for a frequency of 80; after reducing the formula of Mascart to the same form, he compares numerical results obtained from both of them for various diameters, with the results in the table of Lord Kelvin, showing that his (Brylinski's) formula gives closer results, although the other is sufficient for practical purposes. He then discusses the subject of iron wires, coming to conclusions which are quite opposite to those arrived at by Mascart; he finds that the increase of resistance produced by high-frequency currents in iron wire appears to be the only reason why it is impossible to use iron for long-distance telephone lines, while Mascart concluded that iron wire was better, all other conditions being the same; he takes a numerical example assuming the permeability to be about 100, according to Massin, and finds that the increase of resistance is much greater than for copper; in a table he gives the effective resistances of various iron wires for the frequencies corresponding to certain sounds of the human voices.

Experiment with an Incandescent Lamp and Magnet. SALOMONS. Lond. *Elec.* and *Elec. Eng.*, March 6; a brief abstract of a Physical Society paper.—When an incandescent lamp through which an alternating current passed, was brought near a continuous-current magnet the filament was found to be set into vibration; if brought sufficiently near, the vibrations were sufficiently intense to break the filament; the number and position of the nodes formed were found to be independent of the natural period of the filament, but depend on the frequency of the alternating current. Prof. Ayrton suggested that the magnetic leakage was very large in that experiment and wanted to know whether this method was more sensitive for mapping out the field than those ordinarily employed; he thought that the natural period of the filament would to a certain extent influence the results; he called attention to some measuring instruments in which a similar principle was made use of. Salomons replied that the arrangement was not intended for making measurements; the character of the vibrations remained unaltered for many hours; he found the vibrating filament useful for microscopic work, where a surface rather than a line of light was required.

Röntgen Rays.—The *Elec. Rev.*, March 11, contains an interesting article by Mr. TESLA, giving his views and results obtained by him, including a large reproduction of a photograph of the shoulder of a man, showing the ribs and upper arm bones taken at a distance of 4 feet, and another showing a clear image of wire taken at a distance of 11 feet. His experiments were directed toward investigating the nature of the radiations and to perfecting means for their production; their intensity depends on the intensity of the cathode streams, and he concludes that the

highest obtainable electric pressure is therefore desirable; the best results would therefore be obtained by using the disruptive discharge with which there is practically no limit to the spark-length, the only requirement being a certain knowledge and skill in the adjustment of the circuits, particularly as to resonance. By having two electrodes in the same bulb the potential is limited and one is therefore lead to the use of a single electrode bulb, the other terminal being as far away as possible; an inside terminal should be used as tubes without such terminals are much less efficient on account of loss through the glass; it is an error to suppose that concave electrodes will concentrate the rays; they are if anything a disadvantage. Regarding the vacuum, he calls special attention to an electrical method of rarefaction which may be used to any degree desirable, and gives a vacuum far beyond that obtainable by any mechanical appliances; although this can be done by means of a static machine, a disruptive coil is far better; after exhaustion with an ordinary vacuum pump, the bulb is attached to the disruptive coil, and there will then be at first a milky light throughout the bulb, and the phosphorescence of the glass, which subsides quickly, and a white light then settles around the electrode, a dark space forming at some distance from it; the light then becomes reddish and the terminal grows very hot, requiring careful regulation to prevent it from being consumed; after this the light again becomes white and gets weaker and weaker until the streams finally disappear, the phosphorescence growing more intense and the spot where the stream strikes the wall becomes very hot, the phosphorescence around the electrode ceases and it becomes quite cool; the gas in the tube has then reached the required degree of rarefaction; the process may be hastened by repeated heating and cooling and by the use of a small electrode; bulbs with external electrode may be treated in the same way; whenever the electrode is as hot if not hotter than the glass, it is a sure indication that the vacuum is not high enough or that the electrode is too small; as a cooling medium he found it best to use jets of cold air, thus enabling one to use very thin tubes. He thinks the opacity of the glass and transparency of aluminum have both been somewhat exaggerated. He believes that there is an actual expulsion of the particles through the walls of the bulb; he is becoming more and more convinced that the phenomena is due to a stream of material particles which strike the sensitive plate with a great velocity; based on an estimate of Lord Kelvin, he believes that with very high potentials the speeds are as great as 100 kilometers a second. Even an ordinary stream under a great pressure passes through a thick glass plate as though it were not there; from a low to the highest frequency obtainable there seems to be no difference in the quality of the effects produced except that they are more intense when the frequency is higher, which he thinks is due to the fact that the maximum pressures of the cathode are then also higher; this is on the assumption that the effects on the sensitive plate are due to projected particles or else vibrations far beyond any frequency which can be obtained by means of the condenser discharges; the fact that the opacity of a body bears some relation to the density speaks strongly for the material streams; strong impressions on the plate might be arrived at by perfecting plates especially sensitive to mechanical shock or impact; this may lead to the abandonment of the present plate. He has obtained remarkable impressions with the apparatus described; shadows may be obtained at distances of many feet while at small distances and with thin objects an exposure of a few seconds is sufficient; he hopes to be able to magnify the effects many times; with a rabbit exposed for one hour, not only the skeleton was visible, but there was also a clear outline of the abdominal cavity, the location of the lungs, the fur and other features being also shown; images of human limbs are obtained in a quarter of an hour to an hour; metallic objects and bony or chalky deposits can now be invariably detected in any part of the body; an outline of the skull is obtained in 20 to 40 minutes, the latter showing the cavities of the eye, and the chin, cheek and nasal bones, etc., as also the flesh and even the hair; the action of the rays on the head appears to cause a feeling of drowsiness, a sensation of warmth and a general soothing effect. It may be possible, he thinks, by these strange appliances to project a suitable chemical into any part of the body. The issue of March 18 contains a further contribution from the same author. After making a few corrections in his former article, he states that he is now producing strong shadows at a distance of 40 feet and even more, with "the possibility not to say certitude of augmenting the effects with my apparatus at least ten-fold"; he attributes the effects of this great distance to the use of a bulb with a single terminal which permits the use of practically any desired potential and the attainment of extraordinary speeds of the projected particles. He also obtained shadows by reflected rays only, thus demonstrating that the rays possessed this property; a thick copper tube was used at the one end of which the plate holder was placed, while at the other, open end, there was a thick plate of glass at an angle of 45 degrees above which was the bulb; a clear, sharp shadow was produced with an exposure of 45 minutes; he satisfied himself that no action would be produced through the copper tube; he also found that approximately 2 per cent. of the rays were reflected. He is finding more evidence in support of the theory of moving material particles and is arranging some crucial tests; a fairly exhausted bulb containing the electrode connected to the disruptive coil produced small streamers breaking through the sides of the glass, producing a fine hole through which, however, the air does not rush into the tube; the glass in the neighborhood of the rupture may grow hot enough to soften but it will not collapse but rather bulge out, showing that the pressure from the inside is greater than that of the atmosphere; as the matter is expelled from the bulb the rarefaction increases and the streamers become less intense, whereupon the glass closes again, hermetically sealing the opening; he thinks this a positive evidence that matter is being expelled through the walls of the glass.

The same journal contains brief extracts from articles published in daily papers, among which is one stating that Edison found that he could see with the naked eye all the bones of the hand, also moving objects through eight inches of wood; he states that it makes a great difference who does the glass blowing for the bulbs, as the nature of the breath of the glass blower is said to make a difference.

The *West. Elec.*, March 21, contains an article by Mr. Jones in which he expresses the belief that there is an analogy between ordinary light and this new radiation; the latter seems to be made up of many different rays which differ widely in penetrating power, just as white light is the sum of rays of various wave-lengths; the time of exposure decreases with the rise in voltage, but lower voltages will also produce radiations; a sheet of aluminum is fairly opaque to low potential radiation but quite transparent to those produced by higher voltages; he thinks his experiments justify the theory that Röntgen rays vary greatly in penetrating power and that the voltage at the tubes plays a similar part to temperature in producing light rays, new waves being excited as the temperature rises; he is carrying out further experiments. His results also indicate that each ray requires a definite time to produce its maximum effect; an experiment is described showing that particular rays produced their maximum effect in 5 to 15 minutes and that a longer exposure was useless.

E. P. Thompson, in the *Elec. Eng.* and *West. Elec.*, March 7, describes an application of the X-rays for seeing objects in motion; with the apparatus referred to in the *Digest*, Feb. 29, he saw the motion of the bones of the fingers when bent backward and forward; he believes that with this apparatus the skeleton of a fish could be seen in the act of swimming; he thinks a fracture in a limb could thus be made visible by bending or stretching the limb; another experiment showed the effect of a solid passing through a solid, which suggests a possibility in surgery where it is desirable to follow the point of the instrument through the flesh. He finds that certain precautions are necessary in preparing the fluorescent screens; when the barium platino-cyanide is crystallized on a sheet of paper, or if the crystals are pressed on the surface, the screens are of little use; excellent results were obtained when the cyanide was powdered as finely as possible and applied with the clearest colorless varnish on a piece of tracing cloth, to the depth of about one eighth of an inch, care being taken not to make it too thin; either side of the screen may be directed toward the tube; it is important to perform the experiments in a dark room.

The *Elec. Eng.*, March 11, contains an article by Prof. Stine in which he covers partly the same ground as in the article abstracted above. He considers that his experiments strongly confirm the theory of longitudinal vibrations; he has not been able to detect that the light speed of dry plates has an influence on the time of exposure to the X-rays, and he now prefers slow plates, as they give clearer shadows; an experiment seems to indicate that ultra-violet rays have nothing to do directly with the phenomena; he appears to think that fluorescence is not the cause of the photographing action; the anode and cathode streams seem to be identical; he tested many incandescent lamps as bulbs for producing these rays, and found only one that would answer, from which he concludes that the vacuum is too low; he obtained some negatives of tourmaline, which he thinks proves that the rays are not transverse in character, and that the ultra-violet wave theory can no longer be entertained. He calls attention to the difference between such photographs and the so-called "electrographs," which latter he thinks are the result of an electrolytic action on the silver salts; he considers that the cathode is the prime source, but that the fluorescent bulb is a secondary source; the yellowish-green fluorescence is thought to be due to the uranium in the glass; he made other experiments with uranium to find whether it was the cause of the rays, and did not obtain the slightest effect; the Crookes tubes should have an extremely high vacuum, so high that there is only a faint trace of purple light around the anode; a successful tube shows a green fluorescence, while in those that failed it is yellow; a tube improves with use; he thinks the photograph is not the result alone of molecular bombardment, but rather of the nature of electrolysis; the seat of the effect may be in the molecules containing a charge of static electricity and vibrating with a frequency of green fluorescence or ultra-violet light.

TESLA ON ROENTGEN'S RAYS.

THE leading article of the month on the Roentgen rays is Nikola Tesla's contribution on the subject appearing in the *Electrical Review*. At once on hearing of Roentgen's discovery, Mr. Tesla repeated the learned professor's experiment, and since then has been devoting his energies to the investigation of the nature of the radiations and to the perfecting of the means for their production. He describes in detail the methods he has employed and the arrangement of his apparatus. Suffice it here to say that he has been able to obtain shadows with comparatively short exposures at distances of many feet, while at small distances and with thin subjects, exposures of a few seconds are practicable. The first shadow taken with his improved apparatus was that of a copper wire bent so as to form the word "Roentgen," projected at a distance of eleven feet through a wooden cover over the sensitive plate. A similar impression was obtained through the body of the experimenter, a plate of glass, nearly three-sixteenths of an inch thick, a thickness of wood of fully two inches, and through a distance of about four feet. By improvements in his apparatus Mr. Tesla is confident that he can magnify the effects many times.

Continuing the account of his results, Mr. Tesla says: "The bony structure of birds, rabbits and the like is shown within the least detail, and even the hollow of the bones is clearly visible. In a plate of a rabbit under exposure of an hour, not only every detail of the skeleton is visible, but likewise a clear outline of the abdominal cavity and the location of the lungs, the fur and many other features. Prints of even large birds show the feathers quite distinctly.

"Clear shadows of the bones of human limbs are obtained by exposures ranging from a quarter of an hour to an hour, and some plates have shown such an amount of detail that it is almost impossible to believe that we have to deal with shadows only. For instance, a picture of a foot with a shoe on it was taken, and every fold of the leather, trousers, stocking, etc., is visible, while the flesh and bones stand out sharply. Through the body of the experimenter the shadows of small buttons and like objects are quickly obtained, while with an exposure of from one to one and a half hours the ribs, shoulder bones and the bones of the upper arm appear clearly on the sensitized plate. It is now demonstrated beyond any doubt that small metallic objects or bony or chalky deposits can be infallibly detected in any part of the body.

"An outline of the skull is easily obtained with an exposure of twenty to forty minutes. In one instance an exposure of forty minutes gave clearly not only the outline, but the cavity of the eye, the chin and cheek and nasal bones, the lower jaw and connections to the upper one, the vertebral column and connections to the skull, the flesh and even the hair. By exposing the head to a powerful radiation

strange effects have been noted. For instance, I find that there is a tendency to sleep and the time seems to pass away quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep and a quick lapse of time. Should these remarkable effects be verified by men with keener sense of observation, I shall still more firmly believe in the existence of material streams penetrating the skull. Thus it may be possible by these strange appliances to project a suitable chemical into any part of the body.

"Roentgen advanced modestly his results, warning against too much hope. Fortunately his apprehensions were groundless, for, although we have to all appearance to deal with mere shadow projections, the possibilities of the application of his discovery are vast. I am happy to have contributed to the development of the great art he has created."

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TESLA'S LATEST CONTRIBUTION TO SCIENCE.

We publish in this issue a communication from Mr. Tesla, which is even more interesting and important than his previous contributions presented in our columns. After announcing the extraordinary results obtained by means of his apparatus, which speak for the correctness of his conclusions regarding the character of the radiations, and after proving in crucial tests the long-sought-for property of reflection, he makes known a result which will probably lead to one of the most important realizations in science. His investigations of the reflective power of conductors disclose a singular relationship which seems capable of leading us to a deeper insight into the primary condition of matter than we have ever been able to obtain heretofore. Why is zinc, for instance, which is one of the first in Volta's electric contact series, one of the best reflectors? asks Tesla. Evidently such can only be the case if these mysterious rays emanating from the bulb convey matter in its primary state or condition. Let us hope that soon the full light of day will illuminate these obscure but immensely promising fields.

TESLA ON REFLECTED ROENTGEN RAYS.

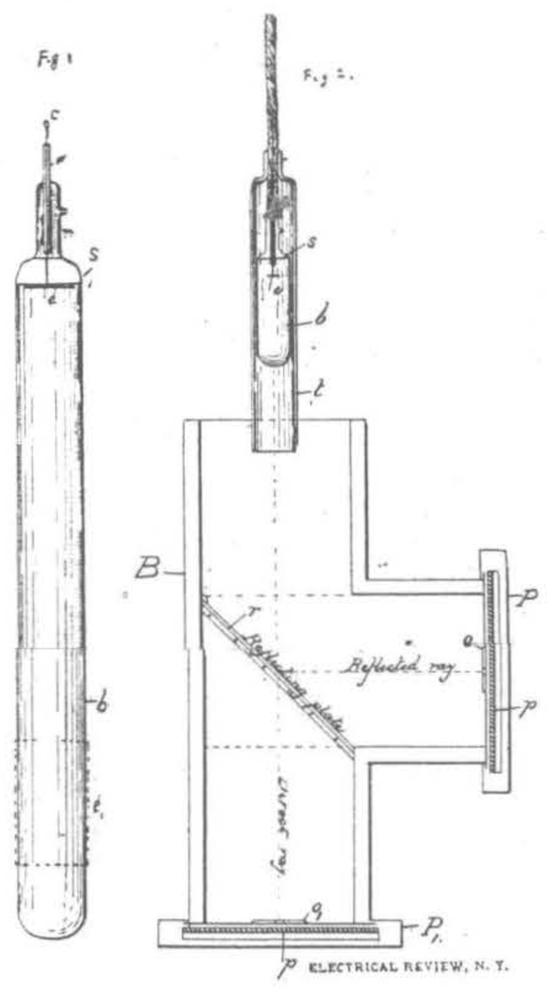
To the Editor of Electrical Review:

In previous communications to your esteemed journal in regard to the effects discovered by Roentgen, I have confined myself to giving barely a brief outline of the most noteworthy results arrived at in the course of my investigations. To state truthfully, I have ventured to express myself, the first time, after some hesitation and consequent delay, and only when I had gained the conviction that the information I had to convey was a needful one; for, in common with others, I was not quite able to free myself of a certain feeling which one must experience when he is trespassing on ground not belonging to him. The discoverer would naturally himself arrive at most of the facts in due time, and a courteous restraint in the announcement of the results on the part of his co-workers would not be amiss. How many have sinned against me by proclaiming their achievements just as I was good and ready to do it myself! But these discoveries of Roentgen, exactly of the order of the telescope and microscope, his seeing through a great thickness of an opaque substance, his recording on a sensitive plate of objects otherwise invisible, were so beautiful and fascinating, so full of promise, that all restraint was put aside, and every one abandoned himself to the pleasures of speculation and experiment. Would but every new and worthy idea find such an echo! One single year would then equal a century of progress. A delight it would be to live in such age, but a discoverer I would not wish to be.

Amongst the facts, which I have had the honor to bring to notice, is one claiming a large share of scientific interest, as well as of practical importance. I refer to the demonstration of the property of reflection, on which I have dwelt briefly.

Having had opportunities to make many observations during my experience with vacuum bulbs and tubes, which could not be accounted for in any plausible way on any theory of vibration as far as I could judge, I began these investigations—disinclined, but expectant to find that the effects produced are due to a stream of material particles. I had many evidences of the existence of such streams. One of these I mentioned, describing the method of electrically exhausting a tube. Such exhaustion, I have found, takes place much quicker when the glass is very thin than when the walls are thick, I presume because of the easier passage of the ions. While a few minutes are sufficient when the glass is very thin, it often takes half an hour or more if the glass be thick or the electrode very large. In accordance with this idea I have, with a view of obtaining the most efficient action, selected the apparatus, and have found at each step my supposition confirmed and my conviction strengthened.

A stream of material particles, possessing a great velocity, must needs be reflected, and I was therefore quite prepared—assuming my original idea to be true—to demonstrate sooner or later this property. Considering that the reflection should be the more complete the smaller the angle of incidence, I adopted from the outset of my investigations a tube or bulb *b* of the form shown in Fig. 1. It was made of very thick glass, with a bottom blown as thin as possible, with the two obvious objects of restricting the radiation to the sides and facilitating the passage through the bottom. A single electrode *e*, in the form of a round disk of a diameter slightly less than that of the tube, was placed about an inch below the narrow neck *n* on the top. The leading-in conductor *c* was provided with a long wrapping *w*, so as to prevent cracking, by the formation of sparks at the point where the wire enters the bulb. It was found advantageous for a number of reasons to extend the wrapping a good distance beyond the neck, on the inside and outside as well, and to place the seal-off in the narrow neck. On other occasions I have dwelt on the employment of an electrostatic screen in connection with such single-terminal bulbs. In the present instance the screen was preferably formed by a bronze painting *s*, slightly above the aluminum electrode and extending to just a little below the wrapping of the wire, so as to allow seeing constantly the end of the wrapping. Or else a small aluminum plate *s*, Fig. 2, was supported in the inside of the bulb above the electrode. This static screen practically doubles the effect, as it prevented all action above it. Considering, further, that



Figs. 1 and 2.—Illustrating Tesla's Experiments on Reflected Roentgen Rays.

the radiation sideways was restricted by the use of a very thick glass and most of it was thrown to the bottom by reflection, as I then surmised, it became evident that such a tube should prove much more efficient than one of ordinary form. Indeed, I quickly found that its power upon the sensitive plate was very nearly four times as great as that of a spherical bulb with an equivalent area of impact. This kind of tube is also very well adapted for use with two terminals by placing an external electrode e_1 as indicated by the dotted lines in Fig. 1. When the glass is taken thick the stream is sensibly parallel and concentrated. Furthermore, by making the tube as long as one desired, it was possible to employ very high potentials, otherwise impracticable with short bulbs.

The use of high potentials is of great importance, as it allows shortening considerably the time of exposure, and affecting the plate at much greater distances. I am endeavoring to determine more exactly the relation of the potential to the effect produced upon the sensitive plate. I deem it necessary to remark that the electrode should be of aluminum, as a platinum electrode, which is still persistently employed, gives inferior results and the bulb is disabled in comparatively short time. Some experimenters might find trouble in maintaining a fairly constant vacuum, owing to a peculiar process of absorption in the bulb, which has been pointed out early by Crookes, in consequence of which, by continued use, the vacuum may increase. A convenient way to prevent this I have found to be the following: The screen or aluminum plate *s*, Fig. 2, is placed directly upon the wrapping of the leading-in conductor *c*, but some distance back from the end. The right distance can be only determined by experience. If it is properly chosen, then, during the action of the bulb, the wrapping gets warmer, and a small bright spark jumps from time to time from the wire *c* to the aluminum plate *s* through the wrapping *w*. The passage of this spark causes gases to be formed, which slightly impair the vacuum, and in this manner, by a little skillful manipulation, the proper vacuum may be constantly maintained. Another way of getting the same result in a tube shown in Fig. 1 is to extend the wrapping so far inside that, when the bulb is normally working, the wrapping is heated sufficiently to free gases to the required amount. It is for this purpose convenient to let the screen of bronze painting *s* extend just a little below the wrapping, so that the spark may be observed. There are, however, many other ways of overcoming this difficulty, which may cause some annoyance to those working with inadequate apparatus.

In order to insure the best action the experimenter should note the various stages which I have pointed out before, and through which the bulb has to pass during the process of exhaustion. He will first observe that when the Crookes phenomena show themselves most prominently there is a reddish streamer issuing from the electrode, which in the beginning covers the latter almost entirely. Up to this point the bulb practically does not affect the sensitive plate, although the glass is very hot at the point of impact. Gradually the reddish streamer disappears, and just before it ceases to be visible the bulb begins to show better action, but still the effect upon the plate is very weak. Presently a white or even bluish stream is observed, and after some time the glass on the bottom of the bulb gets a glossy appearance. The heat is still more intense and the phosphorescence through the entire bulb is extremely brilliant. One should think that such a bulb must be effective, but appearances are often deceitful, and the beautiful bulb still does not work. Even when the white or bluish stream ceases, and the glass on the bottom is so hot as to be nearly melting, the effect on the plate is very weak. But at this stage there appears suddenly at the bottom of the tube a star-shaped changing design, as if the electrode would throw off drops of liquid. From this moment on the power of the bulb is tenfold, and at this stage it must always be kept to give the best results.

I may remark, however, that while it may be generally stated the Crookes vacuum is not high enough for the production of the Roentgen phenomena, this is not literally true. Nor are the Crookes phenomena produced at a particular degree of exhaustion, but manifest themselves even with poor vacua, provided the potential is high enough. This is likewise true of the Roentgen effects. Naturally, to verify this, provision must be made not to overheat the bulb when the potential is raised.

(Concluded on page 174.)

TESLA ON REFLECTED ROENTGEN RAYS.

(*Concluded from page 171.*)

This is easily done by reducing the number of impulses or their duration, when raising the potential. For such experiments, it will be found of advantage to use in connection with the ordinary induction coil a rotating commutator, instead of a vibrating brake. By changing the speed of the commutator, and also regulating the duration of contact, one is enabled to adjust the conditions to suit the degree of vacuum and potential employed.

In my experiments on reflection, presently considered, I have used the apparatus shown in Fig. 2. It consists of a T-shaped box throughout, of a square cross-section. The walls are made of lead over one-eighth of an inch thick, which, under the conditions of the experiments, was found to be entirely impervious, even by long exposures to the rays. On the top end was supported firmly the bulb *b*, inclosed in a glass tube *t* of thick Bohemian glass, which reached some distance into the lead box. The lower end of the box was tightly closed by a plate-holder P_1, containing the sensitive film p_1, protected as usual. Finally the side end was closed by a similar plate-holder P, with the sensitive protected film *p*. To obtain sharp images the objects *o* and o_1, exactly alike, were placed in the center of the fiber cover, protecting the sensitive plates. In the central portion of the box, provision was made for inserting a plate *r* of material, the reflective power of which was to be tested, and the dimensions of the box were such that the reflected ray and the direct one had to go through the same distance, the reflecting plate being at an angle of 45 degrees to the incident as well as reflected ray. Care was taken to exclude all possibility of action upon the plate *p*, except by reflected rays, and the reflecting plate *r* was made to fit tight all around in the lead box, so that no rays could reach the film p_1, except by passing through the plate to be tested. In my earliest experiments on reflection I observed only the effects of reflected rays, but in this instance, on the suggestion of Prof. Wm. A. Anthony, I provided the above means for simultaneously examining the action of the direct rays, which eventually passed through the reflecting plate. In this manner it was possible to compare the amount of the transmitted and reflected radiation. The glass tube *t* surrounding the bulb *b* served to render the stream parallel and more intense. By taking impressions at various distances I found that through a considerable distance there was but little spreading of the bundle of rays or stream of particles.

To reduce the error which is caused unavoidably by too long exposures and very small distances, I reduced the exposure to an hour, and the total distance through which the rays had to pass before reaching the sensitive plates was 20 inches, the distance from the bottom of the bulb to the reflecting plate being 13 inches.

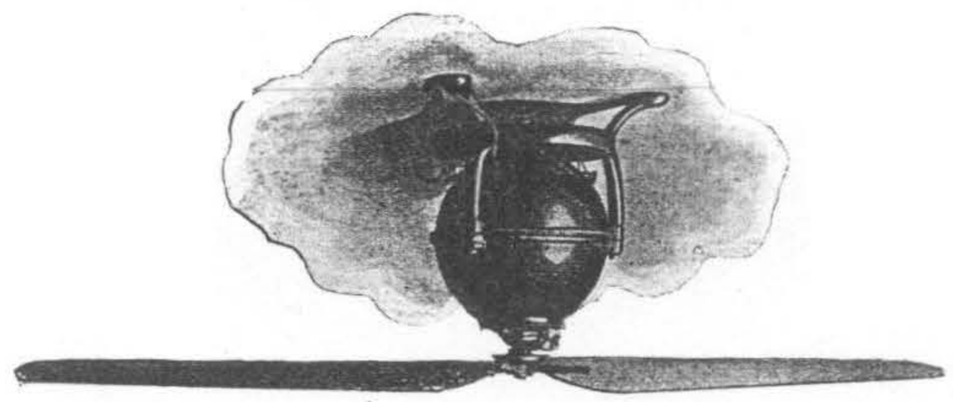
It is needless to remark that all the precautions in regard to the sensitive plates—constancy of potential, uniform working of the bulbs, and maintenance of the same conditions in general during these tests have been taken, as far as it was practicable. The plates to be tested were made of uniform size, so as to fit the space provided in the lead box. Of the conductors the following were tested: Brass, toolsteel, zinc, aluminum, copper, lead, silver, tin, and nickel, and of the insulators, lead-glass, ebonite, and mica. The summary of the observations is given in the following table:

Reflecting body.	Impression by transmitted rays.	Impression by reflected rays.
Brass.	Strong.	Fairly strong.
Toolsteel.	Barely perceptible.	Very feeble.
Zinc.	None.	Very strong.
Aluminum.	Very strong.	None.
Copper.	None.	Fairly strong, but much less than zinc.
Lead.	None.	Very strong, but a little weaker than zinc.
Silver.	Strong, a thin plate being used.	Weaker than copper.
Tin.	None.	Very strong; about like lead.
Nickel.	None.	About like copper.
Lead-glass.	Very strong.	Feeble.
Mica.	Very strong.	Very strong; about like lead.
Ebonite.	Strong.	About like copper.

By comparing, as in previous experiments, the intensity of the impression by reflected rays with an equivalent impression due to a direct exposure of the same bulb and at the same distance—that is, by calculating from the times of exposure under assumption that the action upon the plate was proportionate to the time—the following approximate results were obtained:

Reflecting body.	Impression by direct action.	Impression by reflected rays.
Brass	100	2
Toolsteel	100	0.5
Zinc	100	3
Aluminum	100	0
Copper	100	2
Lead	100	2.5
Silver	100	1.75
Tin	100	2.5
Nickel	100	2
Lead-glass	100	1
Mica	100	2.5
Ebonite	100	2

While these figures can be but rough approximations, there is, nevertheless, a fair probability that they are correct, in so far as the relative values of the impressions by reflected rays for the various bodies are concerned. Arranging the metals according to these values, and leaving for the moment the alloys or impure bodies out of question, we arrive at the following order: Zinc, lead, tin, copper, silver. The tin appears to reflect fully as well as lead, but, allowing for an error in the observation, we may assume that it reflects less, and in this case we find that this order is precisely the contact series of metals in air. If this proves true we shall be confronted with the most extraordinary fact. Why is zinc, for instance, the best reflector among the metals tested and why, at the same time, is it one of the foremost in the contact series? I have not as yet tried magnesium. The truth is that I was somewhat excited over these results. Magnesium should be even a better reflector than zinc, and sodium still better than magnesium. How can this singular relationship be explained? The only possible explanation seems to me at present that the bulb throws out streams of matter in some primary condition, and that the reflection of these streams is dependent upon some fundamental and electrical property of the metals. This would seem to lead to the inference that these streams must be of uniform electrification; that is, that they must be anodic or cathodic in character, but not both. Since the announcement, I believe in France for the first time, that the streams are anodic, I have investigated the subject and find that I can not agree with this contention. On the contrary, I find that anodic and cathodic streams both affect the plate, and, furthermore, I have been led to the conviction that the phosphorescence of the glass has nothing whatever to do with the photographic impressions. An obvious proof is that such impressions are produced with aluminum vessels when there is no phosphorescence, and, as regards the anodic or cathodic character, the simple fact that we can produce impressions by a luminous discharge excited by induction of a closed vessel, when there is neither anode nor cathode, would seem to dispose effectually of the assumption that the streams are issuing solely from one of the electrodes. It may, perhaps, be useful to point out here a simple fact in relation to the induction coils, which may lead an experimenter into an error. When a vacuum tube is attached to the terminals of an induction coil, both of the terminals are acted upon alike as long as the tube is not very highly exhausted. At a high degree of exhaustion both the electrodes act practically independently, and since they behave as bodies possessing considerable capacity, the consequence is that the coil is unbalanced. If the cathode, for instance, is very large, the pressure on the anode may rise considerably, and if the latter is made smaller, as is frequently the case, the electric density may be many times that on the cathode. It results from this that the anode gets very hot, while the cathode may be cool. Quite the opposite occurs if both of them are made exactly alike. But assuming the above conditions to exist, the hotter anode emits a more intense stream than the cool cathode, since the velocity of the particles is dependent on the electrical density, and likewise on the temperature.



THE LUNDELL "WHITE WINGS" ELECTRIC FAN.

From the previous tests an interesting observation can also be made in regard to the opacity. For instance, a brass plate one-sixteenth inch thick proved fairly transparent, while plates of zinc and copper of the same thickness showed themselves to be entirely opaque.

Since I have investigated reflection and arrived to results in this direction, I have been able to produce stronger effects by employing proper reflectors. By surrounding a bulb with a very thick glass tube the effect may be augmented very considerably. The employment of a zinc reflector in one instance showed an increase of about 40 per cent in the impression produced. I attach great practical value to the employment of proper reflectors, because by means of them we can employ any quantity of bulbs, and so produce any intensity of radiation required.

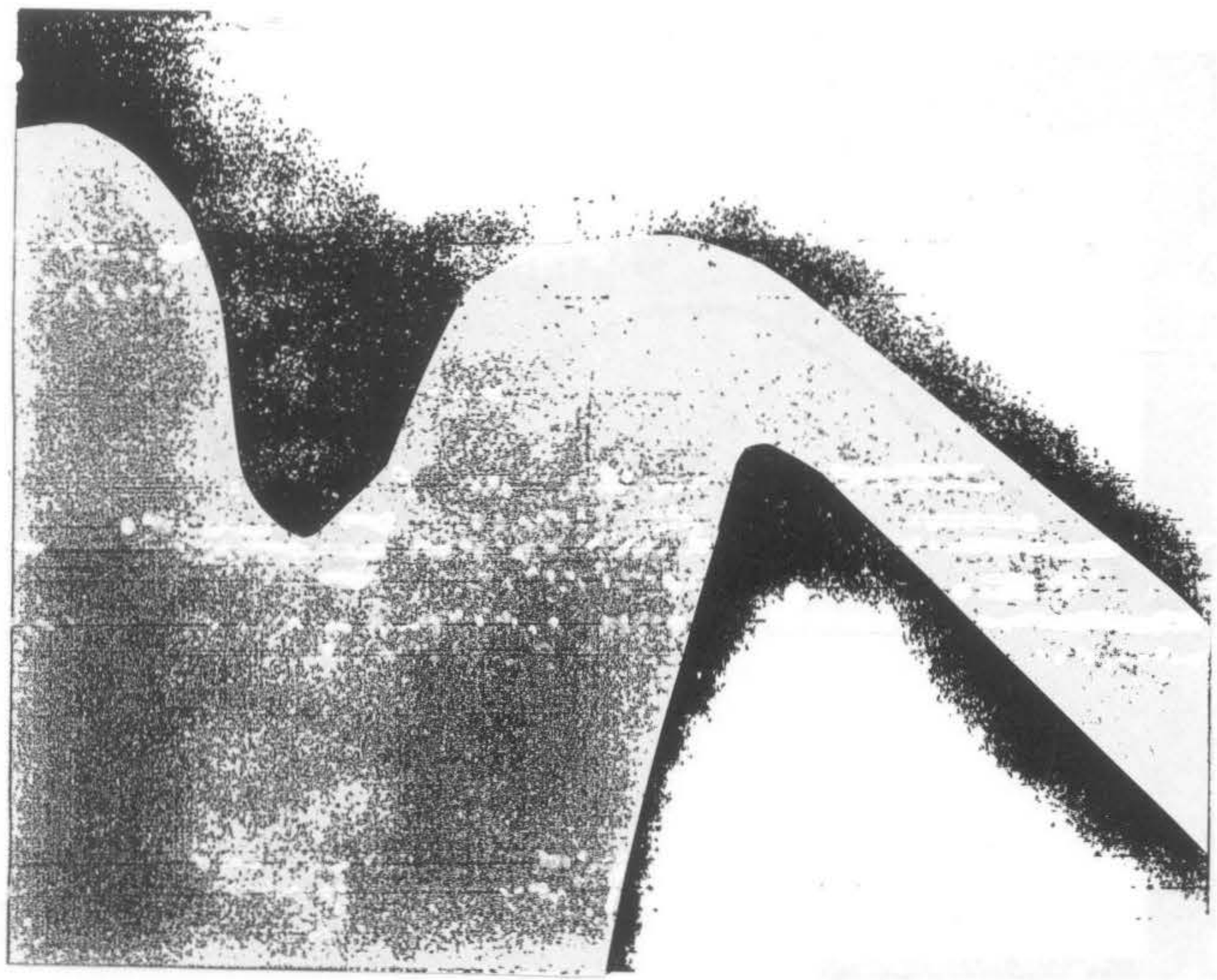
One disappointment in the course of these investigations has been the entire failure of my efforts to demonstrate refraction. I have employed lenses of all kinds and tried a great many experiments, but could not obtain any positive result.

NIKOLA TESLA.

New York, March 30.

Tesla on the X Rays.

None of the scientists who have made practical investigations as to the scope and value of the Röntgen ray discovery have reached more important or wonderful results than Nikola Tesla, the well-known inventor. A communication from him recently published in the *Electrical Review*, which is the organ of the best scientific thought and literature of the time, mentions some of the results of his experiments in radiography. He gives it as his opinion that the rarefaction of the Crookes tubes used in these experiments may be increased by electrical means to any degree desirable; far beyond that obtained by mechanical appliances. In the course of his experiments he secured radiographs showing the bony structure of birds and rabbits, even to the hollow of the bones. He has obtained a radiograph of a rabbit after an hour's exposure, in which not only every detail of the skeleton is visible but a clear outline of the abdominal cavity, the location of the lungs the fur, and many other features are shown. Radiographs of large birds show the feathers distinctly. In another instance an exposure of forty minutes gave a radiograph of the human skull, showing clearly not only the outline, but the cavities of the eye, chin, cheek, nasal bones, the lower jaw and connections to the skull, the flesh, and even the hair. In this connection he says: "By exposing the head to a powerful radiation strange effects have been noted. For instance, I find that there is a tendency to sleep, and the time seems to pass away quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep and a quick lapse of time. Should these remarkable effects be verified by men with keener sense of observation, I shall still more firmly believe in the existence of material streams penetrating the skull. Thus it may be possible, by these strange appliances to project a suitable chemical into any part of the body." He declares it to be already "demonstrated beyond any doubt that small metallic objects or bony or chalky deposits can be infallibly detected in any part of the living human body."



A TESLA RADIOGRAPH OF THE RIGHT SHOULDER OF A MAN, SHOWING THE RIBS AND THE BONES OF THE SHOULDER AND UPPER-ARM.

The illustration given herewith depicts one of the most remarkable of the Tesla radiographs. It shows the right shoulder of a man, taken through his clothing, a plate of glass three-sixteenths of an inch thick, and a thickness of wood of fully two inches, at a distance of four feet from the source of the X rays. The bones of the shoulder and of the upper-arm are plainly visible, but Tesla states that with improvements of his apparatus he will be able to produce much clearer and more distinct effects.

THE WESTINGHOUSE ELECTRICAL WORKS.

(FROM OUR NEW YORK CORRESPONDENT.)

THE new works of the Westinghouse Electric and Manufacturing Company are situated at Brinton, not far from Pittsburg, and on the line of the Pennsylvania Railroad, so that admirable transport facilities are secured. They have been built to replace the old works of the same company, which were located in Pittsburg, and where nearly 3000 hands were employed. These new works, which are not yet complete—such works never are finished—were visited by the members of the American Institute of Mining Engineers during their recent meeting at Pittsburg, and the excursion was one of the most interesting of the series provided for the entertainment of members by their hospitable hosts. As these works are of exceptional size, at all events in the United States, and as they represent the most advanced practice in electrical engineering, your correspondent purposes to describe them in some detail, assisted by illustrations kindly placed at his disposal by the engineer of the company.

Fig. 1, page 430, is a general view of these works. The company has 40 acres in this tract in a rectangular form, the frontage on the railway being 2300 ft. At present eight buildings have been erected, as follows: A machine shop 754 ft. long by 231 ft. wide, the ground floor of which covers 4 acres, while the galleries cover 3; a warehouse 754 ft. long by 76 ft. wide. At one end are the offices of the administration, engineering and drafting departments, and at the opposite end meters, arc lamps, switchboards, and similar apparatus are constructed. The other buildings are the pattern shop, the blacksmiths' shop (241 ft. by 80 ft.), the power house (206 ft. by 76 ft.), the drying and dipping shop (187 ft. by 25 ft.), and the brass foundry, which measures 241 ft. by 40 ft. (see plan, Fig. 2).

In respect to the interior of the machine shop, shown in Fig. 3, it may be said it is carefully arranged to reduce the labour in handling the material to a minimum. The building is divided into three aisles of equal width, and railway tracks extend through each the entire length of the building. Two 30-ton cranes are used for moving material. The side aisles contain a second storey, and each is divided by a row of columns supporting it, which also serve to carry the runways for two 10-ton travelling cranes. Ten stairways and 10 elevators furnish communication between the two floors, the elevators being driven by a belt from a 10 horse-power motor. The side walls of the buildings are of brick, and inclose steel columns supporting the floors and roof. The girders and roof are of steel, wood being used only for the window sashes and floors. The shops are unusually well lighted, and in the machine shop are 12 toilet rooms with ample washing facilities. It is well known that cleanliness on the part of the employés is productive of care in their work, and this question has been amply considered. By means of the fan system of hot air, a temperature of 60 deg. is maintained, and the 9,171,000 cubic feet of air is changed and rewarmed in 20 minutes. The amount of heating surface in the six heaters is 20,000 square feet, and the fans are driven by a 30 horse-power (Fig. 4) motor, the heated air being distributed by overhead blast-pipes.

Nearly all the machinery used in these great shops, comprising upwards of 1250 machine tools, is operated by Tesla polyphase motors, supplied with two-phase alternating current at a frequency of 25 cycles per second. This is the identical system worked out by the Westinghouse Electric and Manufacturing Company for the use of the Cataract Construction Company in their great work at Niagara Falls. The alternating current generators are located in the power house, from which current is conveyed by insulated conductors to motors conveniently placed throughout the various shops. The potential used is 200 volts, and this is supplied directly to the motors without the interposition of transformers. The line shafting throughout the buildings is divided into comparatively short sections, and motors ranging from 10 to 50 horse-power are employed to drive the sections; in certain cases large tools will be separately driven by independent motors.

In the power house three 500 horse-power two-phase generators, direct driven by Westinghouse compound engines, are installed. They are driven at a speed of 215 revolutions, and deliver current to two separate circuits, these currents differing in their time relation or phase by 90 deg. They are separately excited, current being derived from a small direct current machine.

In Fig. 4 is shown a 40 horse-power Tesla motor used for driving some of the large tools in the machine shop. In respect to this motor it may be said that the object which Nikola Tesla sought to attain when he began the work which led up to the invention of these motors, which are now so celebrated, was the elimination of the commutator—the weak point and the most troublesome element in all direct current motors, which at the time Tesla began his work were the only motors available for practical purposes. Since that time much has been done to improve the construction of commutators, but they still remain the weakest element in direct current machinery, and when well made are very expensive. They are necessarily built up of a large number of segments of copper, and each segment must be insulated from adjacent segments by insulation of ample strength for the potentials employed, and without the slightest crack or pinhole. Any failure to realise these conditions will cause a breakdown and interruption of service. Moreover, the constant rubbing of the brushes against the commutator, causes rapid wear of the metal and a breaking-down of the insulation, involving trouble in maintenance and cost in repair; and this deterioration of brush and commutator is, in spite of the best construction, inevitably more rapid than in the case of the alternating current motor, where the brushes bear against the rings of a collector. The engraving Fig. 6 shows an extremely well-made modern commutator, and Fig. 5 illustrates a collector. The latter consists essentially of rings of metal, usually copper or brass, centred on the same shaft, and separated from each other by heavy rings of insulating material. The parts, as compared with the commutator, are relatively few, and the insulation can be as heavy as desired. In the larger Tesla motors collectors are used, but in the smaller ones even these are discarded.

The efficiency of a 10 horse-power motor, delivering half load (5 horse-power) is 79 per cent.; under full load (10 horse-power) it is 84 per cent.; and under an overload of 50 per cent. (*i.e.*, when delivering 15 horse-power) its efficiency is 75 per cent. A 20 horse-power motor delivering 5 horse-power works at an efficiency of 78 per cent.; delivering 10 horse-power its efficiency is 84 per cent.; and at full load (20 horse-power) its efficiency is 82 per cent. A 50 horse-power motor delivers 5 horse-power at an efficiency of 72 per cent.; 10 horse-power at 81 per cent.; 20 horse-power at 89 per cent.; 30 horse-power at 91 per cent; 40 horse-power at 91 per cent.; 50 horse-power at 89 per cent.; 60 horse-power at 88 per cent. A 1 horse-power motor delivers $\frac{1}{4}$ horse-power at 61 per cent.; $\frac{1}{2}$ horse power at 72 per cent.; $\frac{3}{4}$ horse-power at 75 per cent.; 1 horse-power at 73 per cent., and $1\frac{1}{4}$ horse-power at 69 per cent.

These motors are intentionally so designed that their maximum efficiency occurs at a load somewhat less than their rated output. This is thought desirable for the reason that motors in shop work are apt to run at somewhat less than their rated outputs, and the net efficiency of the plant is therefore improved by so constructing the motors that they work at their best efficiency at from 10 per cent. to 25 per cent. less than the full loads which they are capable of carrying.

In using the polyphase system it should be noted that if the frequency selected be suitable, the shops can be lighted from the same circuits that are used to supply motors. The frequency adopted in the Westinghouse shops is 25 cycles per second, or 3000 alternations per minute. This permits incandescent lighting that is entirely satisfactory for shop work, but it is too low for arc lighting. A similar system of motors manufactured by the Westinghouse Electric and Manufacturing Company is designed for frequency of 60 cycles per second, or 7200 alternations per minute, and this is adapted to incandescent and arc lighting.

In Fig. 7 may be seen a Westinghouse engine direct connected to 500 horse-power two-phase generators.

Conspicuous in these vast works, the following branches are of great interest: The converter department, on the second floor, the winding department, the lightning arrester department, and the insulating department. In two of these the "coming woman" is in decided evidence. The electrical field is evidently a congenial one, and, judging from the samples we saw the occupation is a most healthy one. We were also shown the new Baldwin-Westinghouse electric locomotive. It is mounted on two four-wheeled trucks with 42-in. wheels, and each of the four axles is driven by a 200 horse-power single-geared motor under the car. Its weight is 160,000 lb., which rests on the eight driving wheels, and the horse-power is 1000.

A gas engine designed to utilise 50 per cent. of the heat energy of coal was also shown. It consisted of a three-cylinder engine on the Otto cycle, compounded, having one high-pressure and two low-pressure cylinders. The initial pressure is as high as 375 lb. per square inch, and the compounding gives a high rate of expansion. There still remains a good deal to be said about the construction and arrangement of these important works.

(*To be continued*)

THE WESTINGHOUSE ELECTRICAL WORKS.

(FROM OUR NEW YORK CORRESPONDENT.)

(*Concluded from page* 429.)

IT will be seen by reference to the plan, Fig. 2 of our last article on the new works of the Westinghouse Electrical Company at Brinton (see page 430 *ante*), that the general arrangement is of a very simple character. A small stream secures a complete water frontage, and branches from more than one railroad provide ample railway communications. The various buildings are all rectangular in plan, and placed in two parallel rows; a railway runs in front of the whole range, and branches are taken from it into, through, or close beside all of the buildings. Apart from the carpenters' shop, which is 200 ft. long, and somewhat isolated, the plan is quite symmetrical. The main building is the machine shop, 231 ft. wide by 754 ft. long, and having three lines of rails traversing it from end to end. Behind it is the blacksmiths' shop, with one through track, and 83 ft. by 243 ft. Parallel to these are four buildings—the warehouse, 70 ft. by 754 ft.; the power house, 76 ft. by 206 ft.; the punch shop, 76 ft. by 258 ft.; and the foundry, 150 ft. wide by 706 ft. long. Between the machine shop and the warehouse, which are separated by a passage 64 ft. wide, is a small building, the drying and dipping shop. These are all the shops that constitute the works at present, though doubtless before long they will be considerably enlarged. Figs. 8 to 11 are details that give some idea of the machine shop. From Fig. 8 it will be seen that this building consists of a central and two side spans, the former being 69 ft. wide, and the latter each 81 ft. 3 in. The general character of construction—the type of roof trusses, the columns, transverse and longitudinal bracing, are indicated in the sections, and are also shown in the perspective view of the power house, Fig. 22, a very similar character of construction being followed throughout; the walls in all the buildings are of brickwork, inclosing the steel columns that carry the roofs, flooring, &c. The central gallery of the machine shop is open to the roof, which is higher than that of the two side galleries; this arrangement allows the introduction of a row of clerestory

THE WESTINGHOUSE ELECTRICAL WORKS, BRINTON, NEAR PITTSBURG.

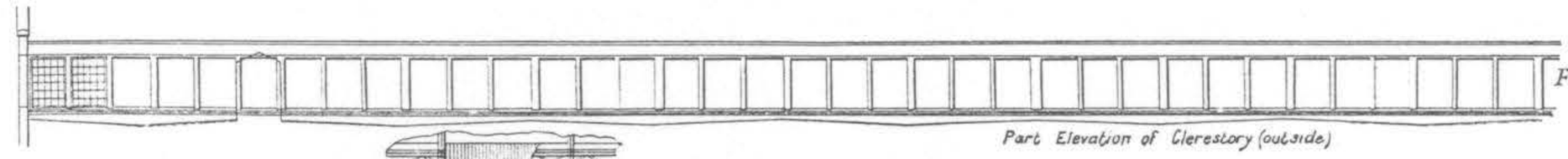


Fig. 10.

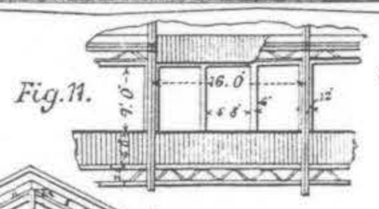


Fig. 11.

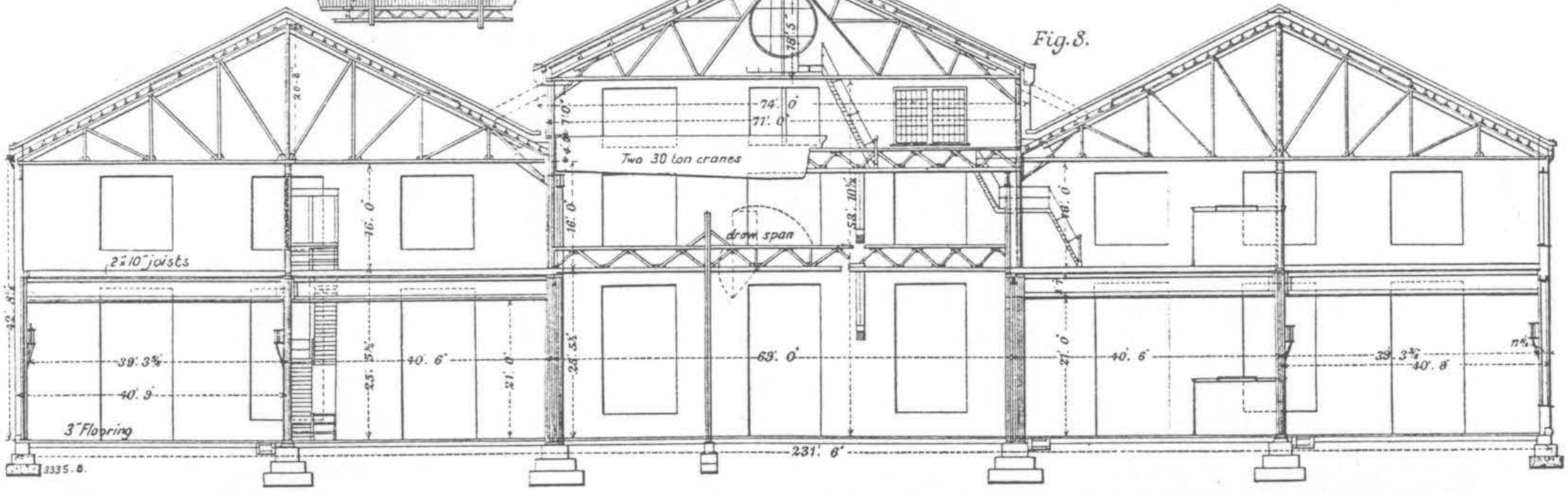


Fig. 8.

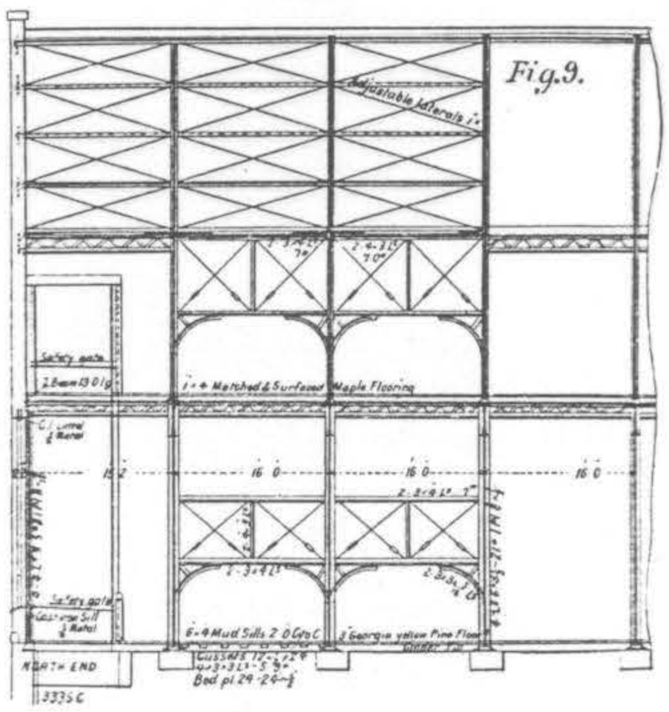


Fig. 9.

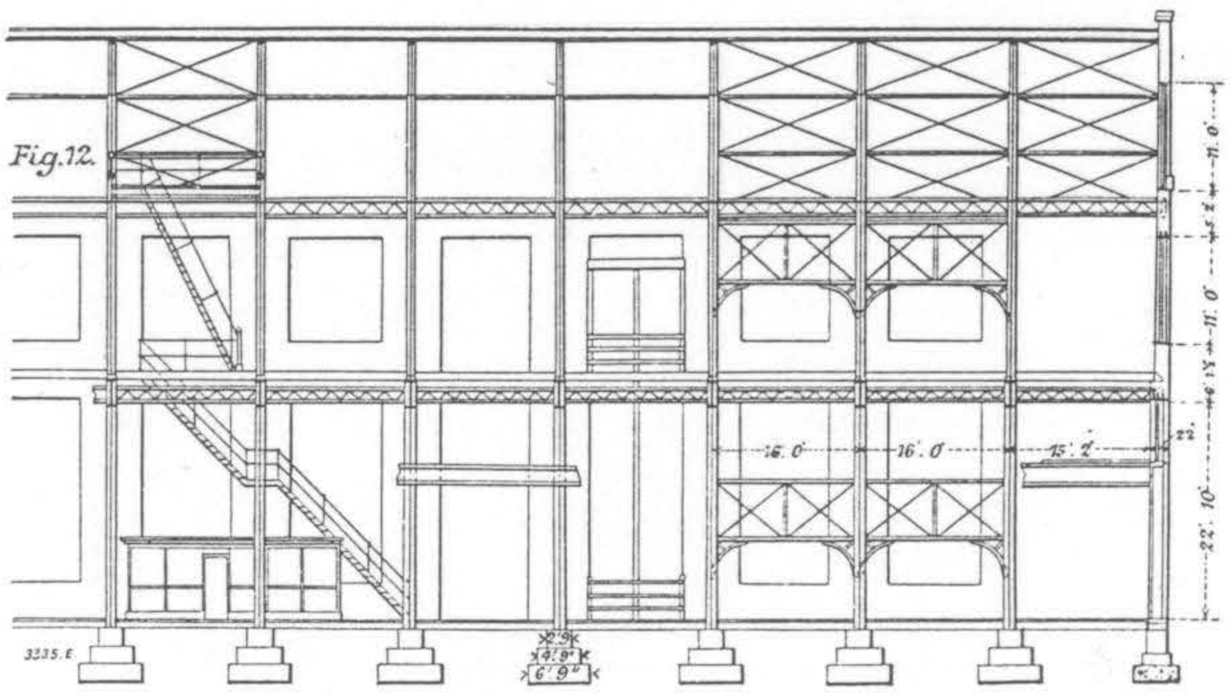


Fig. 12.

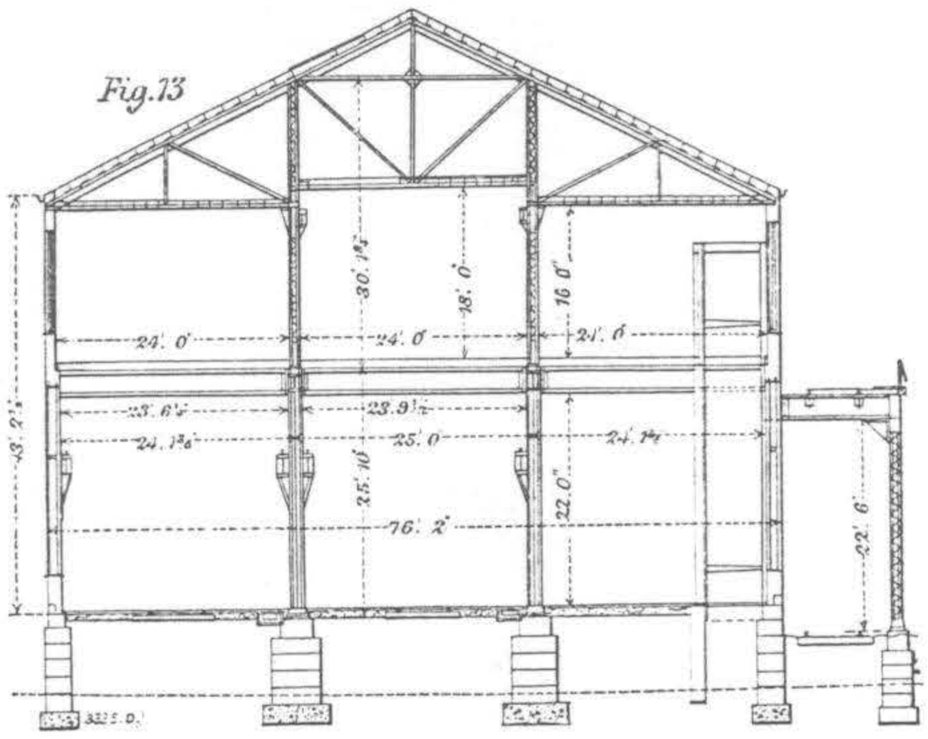


Fig. 13.

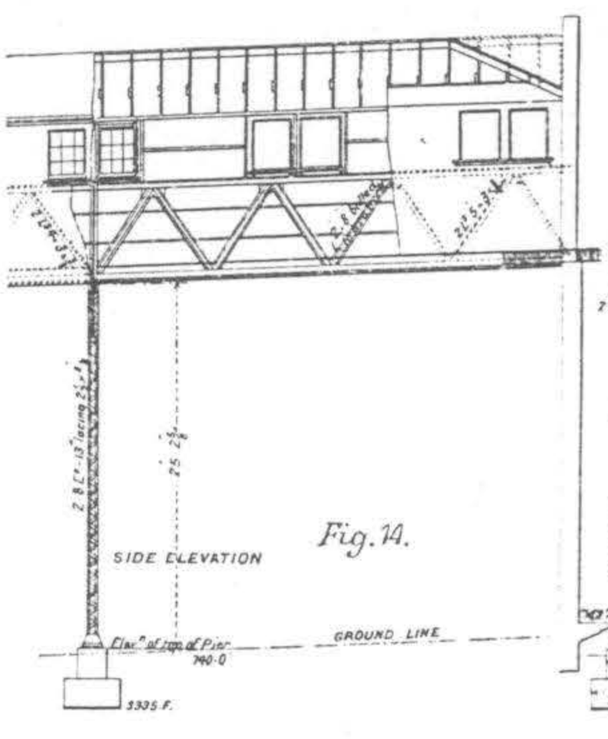


Fig. 14.

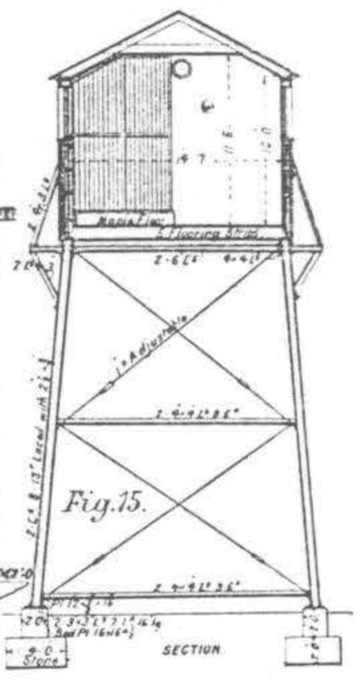


Fig. 15.

windows on each side beneath the roof springing (Figs. 10 and 11). A 30-ton travelling crane spans this central gallery, and runs on rails supported by the columns, from end to end of the building. The arrangement of the side galleries is symmetrical. Each is divided for its length, and nearly along the central axis, by a row of columns that carry the framing for an upper floor, which is also divided as shown in Fig. 8. Ten-ton travelling cranes are provided for the lower floors of this part of the shop. Communication between the different levels is provided by 10 stairways and 10 elevators. Heating this vast building, which contains nearly 10 million cubic feet, was a very serious undertaking, considering the extreme cold that usually prevails during the winter. Waste, as well as live, steam is used, and the air in the building is changed three times an hour. This is effected by means of a number of fans placed at some distance above the floor level, and each driven by a 30 horse-power Tesla motor. The warehouse is separated from the machine shop by a passage-way about 75 ft. in width. This building is of the same length as the machine shop, and is 76 ft. wide. Figs. 12 and 13 are respectively longitudinal and transverse sections; from the latter it will be seen that the building is divided into three galleries by the two rows of columns, running from end to end, and that there is an upper storey, the height of the ground floor being 25 ft. 10 in. Both floors are provided with 10-ton travelling cranes, the rail levels of which are shown in the section. Facility in handling and shipping goods is well arranged for in this building; it is connected with the machine shop by six bridges, of the type shown in Figs. 14 and 15; they are about 15 ft. wide and are provided with tracks, and, as shown on the plan, Fig. 2, there is a line of rails on the ground level on each side of the warehouse, so that goods may be loaded up along the whole length, there being ample door accommodation provided for this purpose. For loading into railway cars from the upper floor an elevated track is carried on a staging (Fig. 13). The dipping and drying shop between these two large buildings is about 30 ft. wide and

THE WESTINGHOUSE ELECTRICAL WORKS, BRINTON, NEAR PITTSBURG.

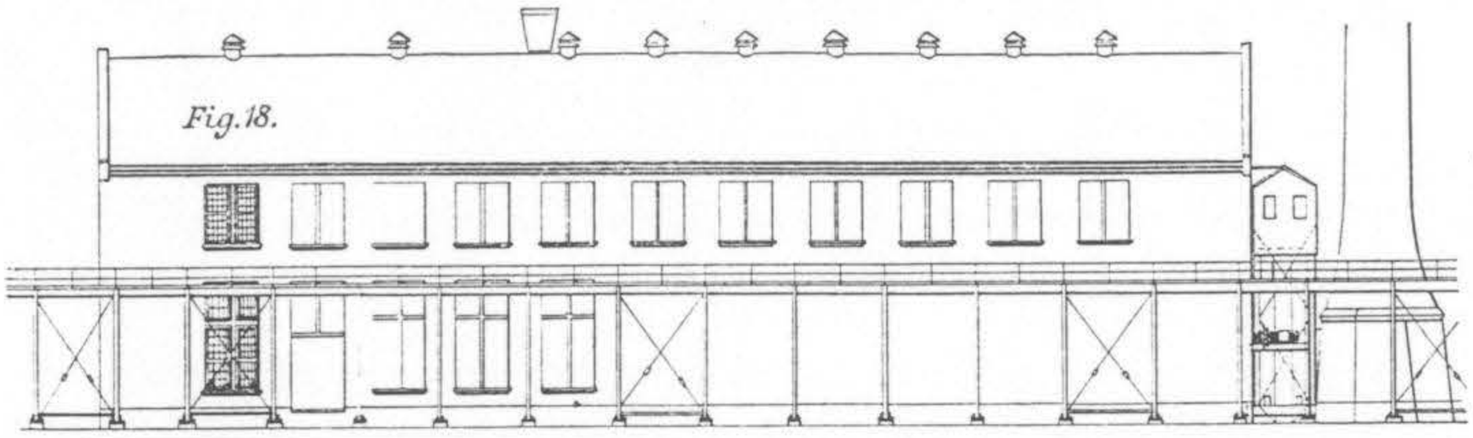


Fig. 18.

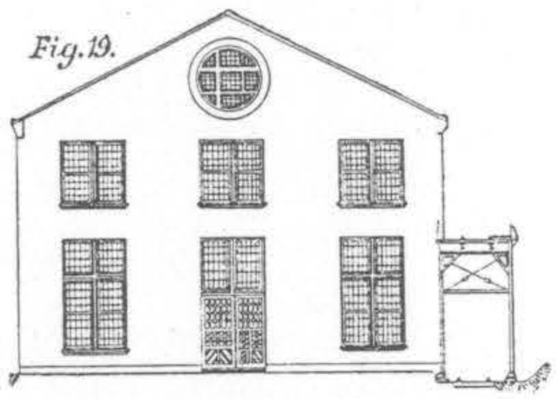


Fig. 19.

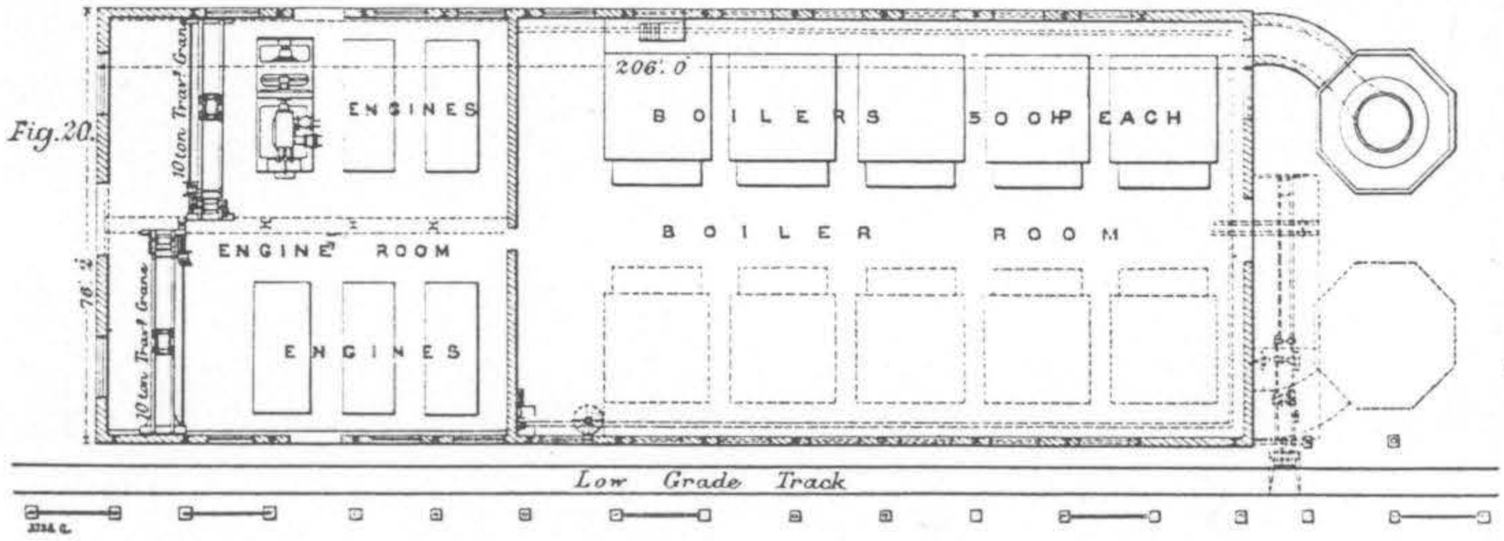


Fig. 20.

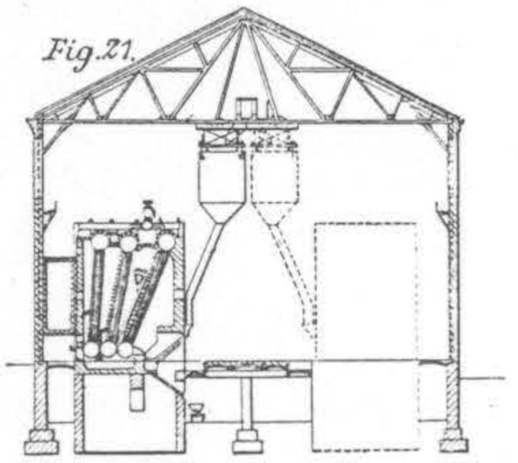


Fig. 21.

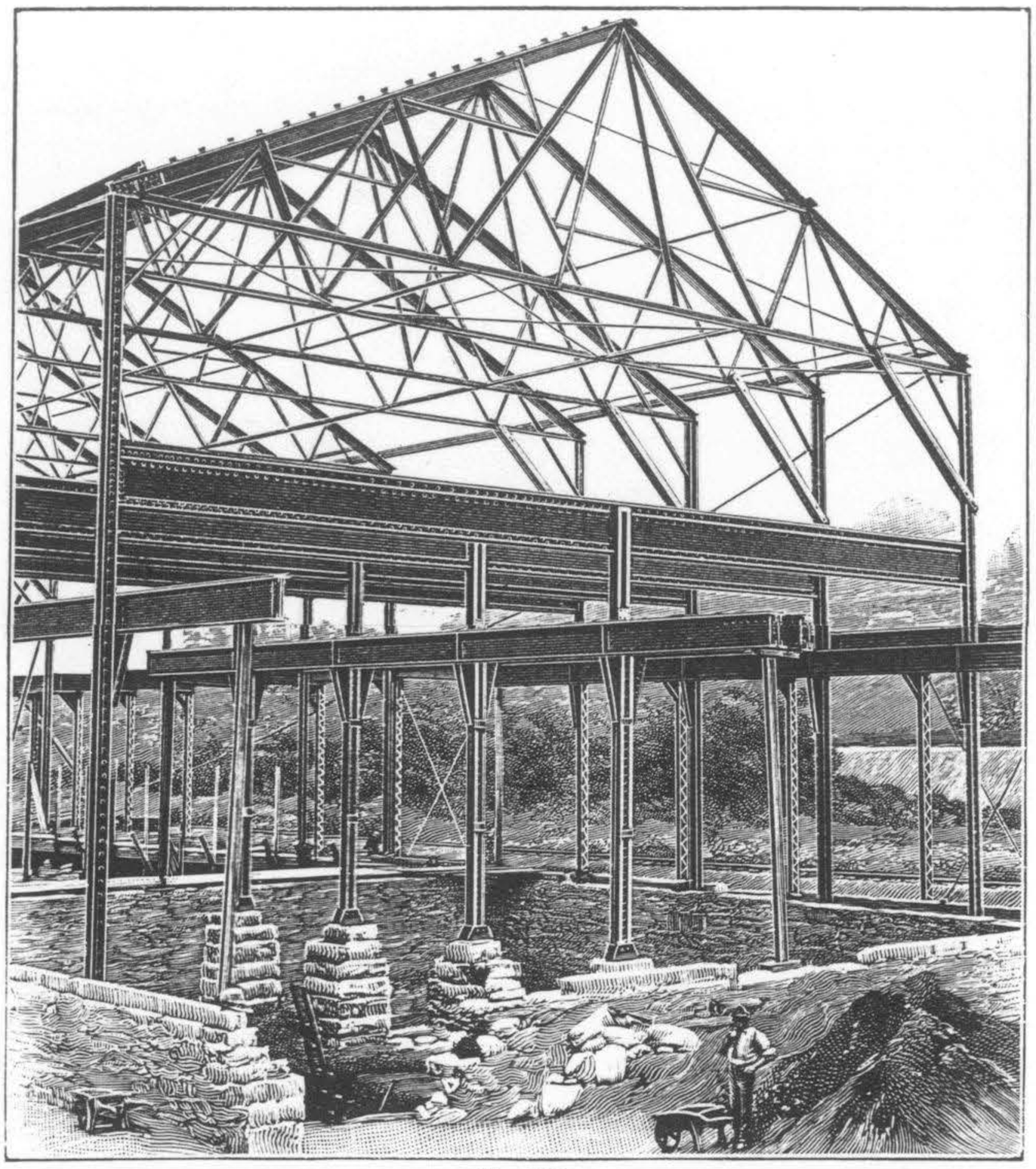


Fig. 22.

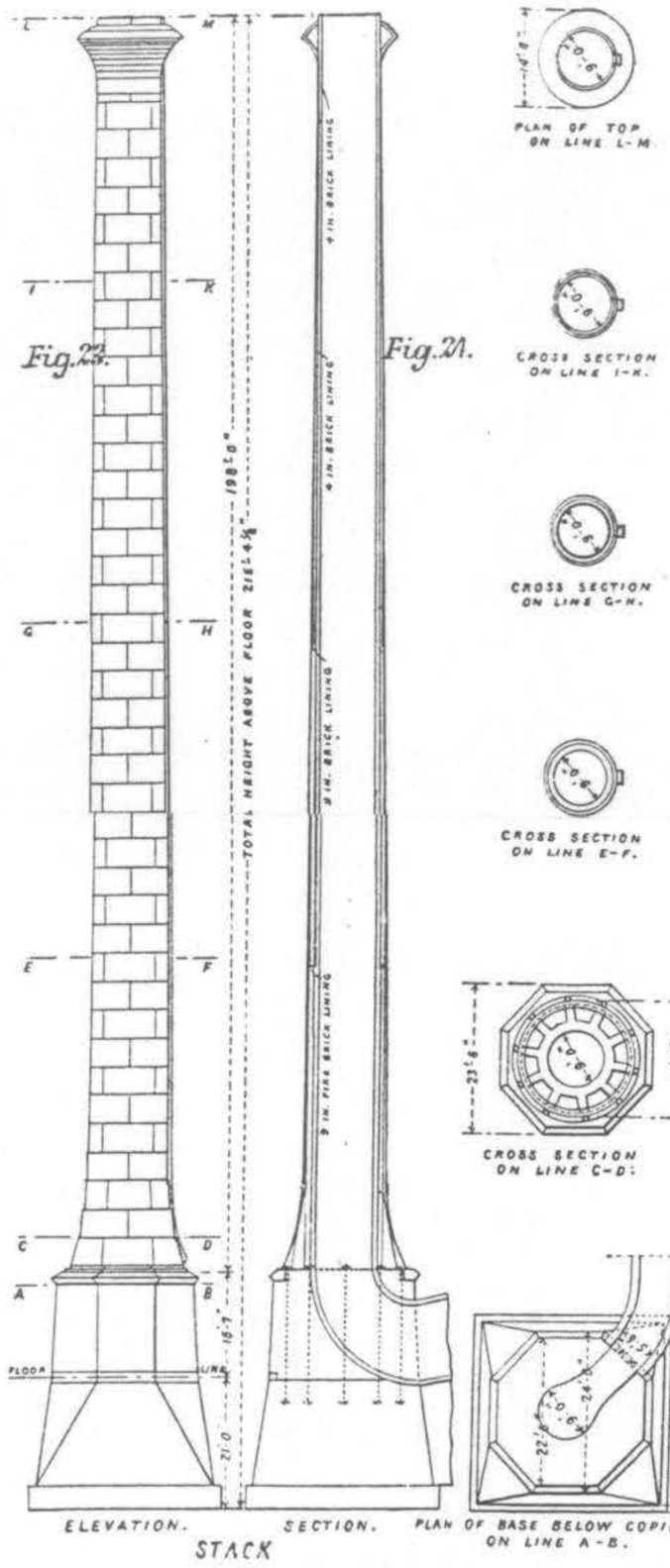


Fig. 23. Fig. 24. STACK

180 ft. long. In it all the nickel plating, japanning, varnishing, and general surfacing of finished parts is carried on.

The blacksmiths' shop is covered by single span trusses of 82 ft. 6 in. span; a cross-section of it is given in Fig. 16, page 502. Its construction is very similar to that of the other buildings, and calls for no special notice, except perhaps that the ventilating arrangements are excellent, and that all the power required is supplied by electrical motors mounted on the roof trusses to be out of the way. It contains 40 forges, and a large number of presses, hammers, &c.; one of the presses is driven by a 30 horse-power motor. Beyond comes the punch house (Fig. 17), a very important department, where so many pieces have to be stamped and cut into shape; it is 76 ft. 2 in. wide and 258 ft. long. As will be seen, it contains two storeys, besides a third floor near a part of the roof. The construction is somewhat heavier than that of the other buildings, and the first floor is formed with brick arches turned between the steel joists, while the small top storey, which is used as a store, is supposed to be fireproof. The heavier machinery is arranged on the ground floor, and is driven off shafting by a 40 horse-power motor. The appliances here comprise annealing ovens, hydraulic presses, and the heavier punching and shearing machines. Above, and also driven by shafting coupled to three motors of 20 horse-power each, are a large number

THE WESTINGHOUSE ELECTRICAL WORKS, BRINTON, NEAR PITTSBURG.

Fig. 16.

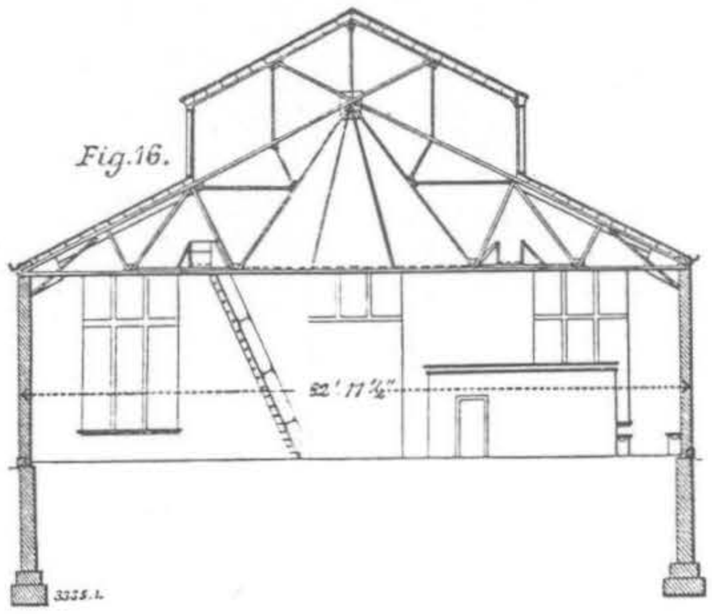
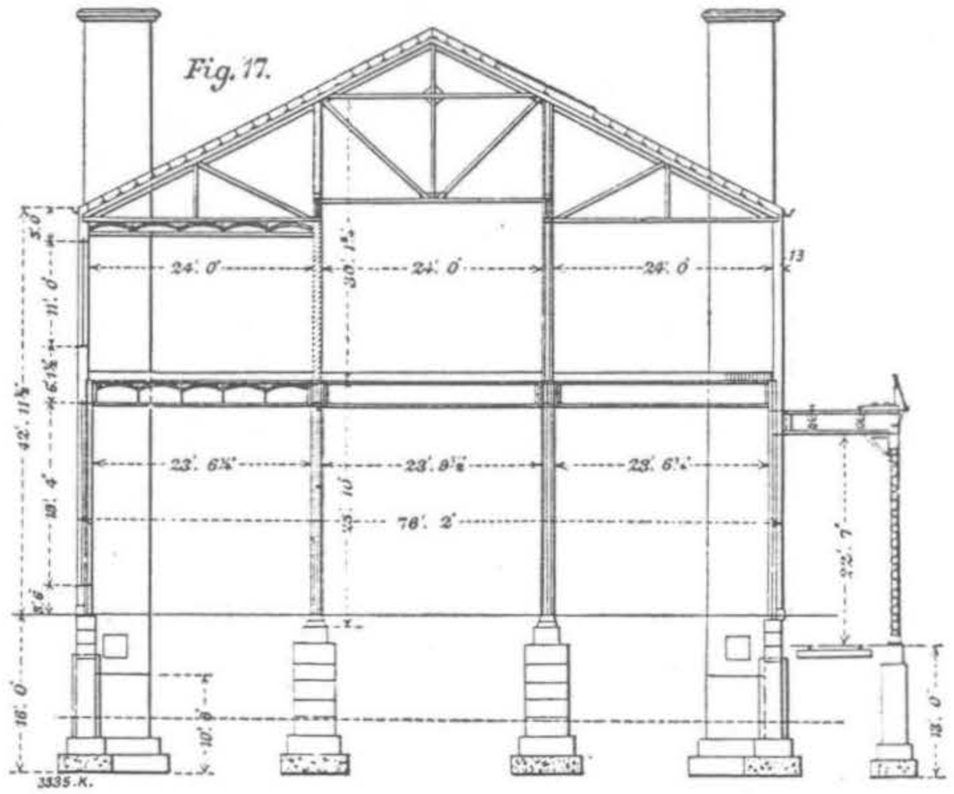
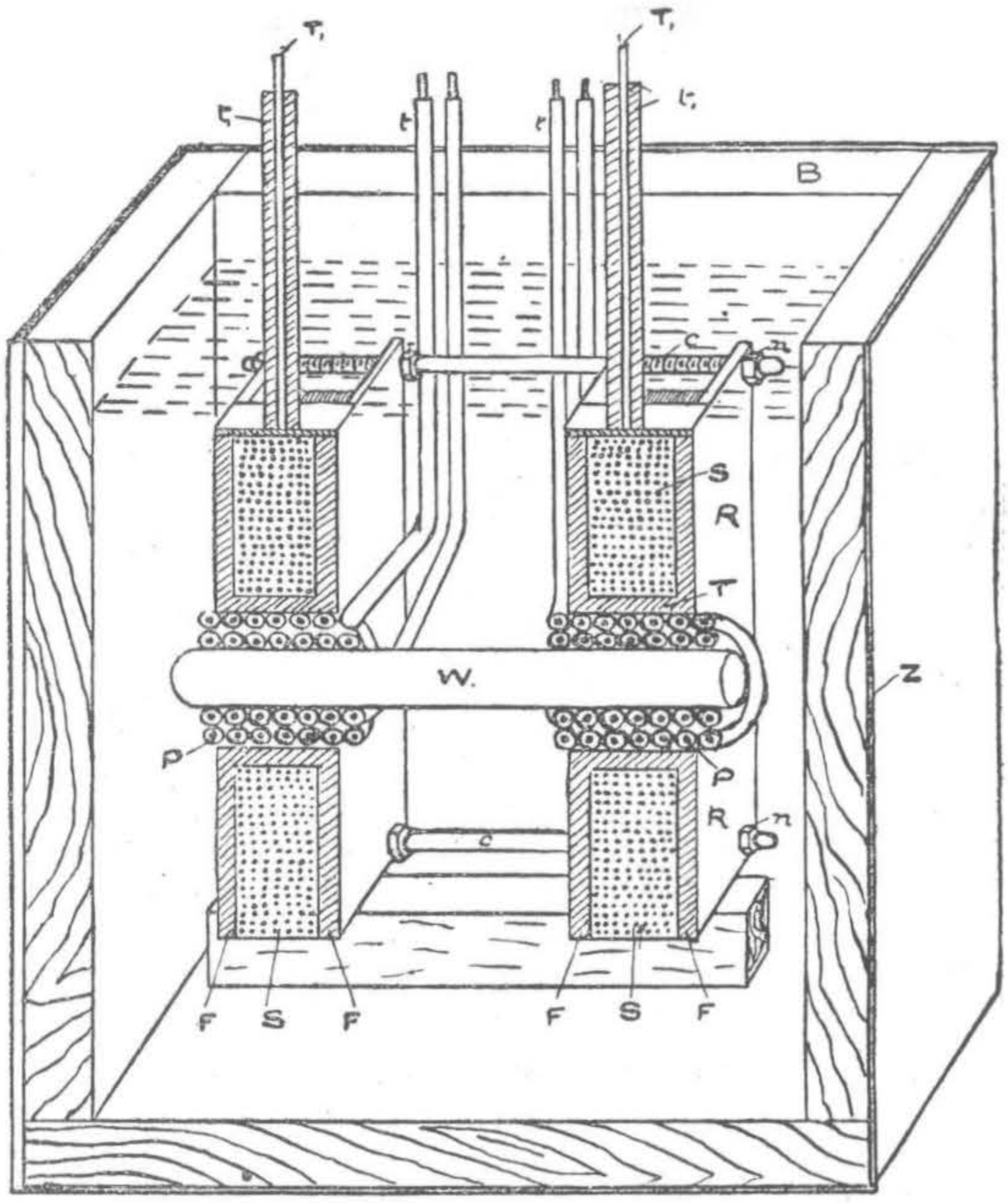


Fig. 17.



of lighter stamping, cutting, and milling tools. Between this shop and the warehouse is situated the power house, illustrated by Figs. 18 to 21. This is a very interesting part of the works, though it is as yet only half equipped, the arrangement being such that the plant can be duplicated, when the extension of the works renders this necessary. The building is divided into two parts, one for the engines, the other for the boiler-room. Along one side of the latter are ranged five boilers having a total capacity of 2500 horse-power, sufficient, including reserve, for the present requirements of the works. These boilers are of the Pierpoint water-tube type, and consist of three upper and three lower horizontal drums connected by inclined tubes 3½ in. in diameter; each boiler contains 5755 ft. of heating surface, and delivers its steam from the front and centre drums into a 20-in. steam main common to all the boilers. The fuel used is bituminous slack, delivered at the works at about 3s. a ton. Special appliances have been worked out and are in successful operation for storing and handling this coal, so that all labour is practically saved. The plant for this purpose is contained in a small building at one end of the power house. The coal is delivered by cars on a raised track into hoppers, after passing through a breaker. From the hoppers it is lifted by endless chains and buckets to a conveyor that delivers it into bins placed above the boilers; it then falls through delivery pipes from the bins to the receiver of a mechanical stoker; the ashes are collected and delivered into trucks almost automatically; the machinery for this part of the work is driven by a 30 horse-power motor. It was considered preferable not to adopt very large power units, and condensing engines were employed, the exhaust steam being used to heat the different buildings. There are five Westinghouse compound condensing engines, each of 500 horse-power, in the engine-room; they have cylinders 24 in. and 40 in. in diameter, with 18 in. stroke; their normal speed is 215 revolutions, and the steam pressure 125 lb. Each engine drives a separate generator, two of them being direct current, and the other three two-phase Tesla generators. These latter are driven at 215 revolutions, with 3000 alternations; the voltage is 230, and the loss is estimated at about 5 per cent. in the distribution of about 1000 ft. This power is distributed to a large number of motors throughout the entire works, as well as for lighting purposes and testing. For more detailed particulars of these magnificent works, the writer would refer your readers to the pages of the *Engineering Record*. In conclusion, he may mention that the Carnegie Steel Company, and the Shiffler Bridge Company, both of Pittsburg, supplied all the steel work for the buildings.



his lecture before the Royal Institution of Civil Engineers (Feb., 1892), Mr. Tesla thus described his coil:—"The coil consists of two spools of hard rubber, R R, held apart at a distance of 10cm. by bolts, *c*, and nuts, *n*, likewise of hard rubber. Each spool comprises a tube, T, of approximately 8cm. inside diameter, and 3mm. thick, upon which are screwed two flanges, F F, 24cm. square, the space between the flanges being about 3cm. The secondary, S S, of the best guttapercha-covered wire, has 26 layers, 10 turns in each, giving for each half a total of 260 turns. The two halves are wound oppositely, and connected in series, the connection between both being made over the primary. This disposition, besides being convenient, has the advantage that when the coil is well balanced—that is, when both of its terminals, $T_1 T_1$, are connected to bodies or devices of equal capacity—there is not much danger of breaking through to the primary, and the insulation between the primary and the secondary need not be thick. The primary P P is wound in two parts, and oppositely, upon a wooden spool, W, and the four ends are led out of the oil through the hard rubber tubes *t t*. The ends of the secondary $T_1 T_1$ are also led out of the oil through rubber tubes, $t_1 t_1$, of great thickness. The primary and secondary layers are insulated by cotton cloth, the thickness of the insulation, of course, bearing some proportion to the difference of potential between the turns of the different layers. Each half of the primary has four layers, 24 turns in each, giving a total of 96 turns. The coil is held in position in the oil on wooden supports, there being about 5cm. thickness of oil all round. The whole coil is immersed in boiled-out oil, contained in a box, B, of thick boards of hard wood, covered on the outside with a zinc sheet, Z, which is carefully soldered all round. The coil should be placed symmetrically to the metal cover, and the space between should not be too small; especially the two sides of the box, which are at right angles to the axis of the coil, should be sufficiently remote from the latter. Once the coil has been immersed, it should never be taken out of the oil for more than a few hours, else the guttapercha will crack up. The primary is No. 12, Brown and Sharpe gauge, ordinary line wire, with a thick cotton coating; the secondary is No. 24 Brown and Sharpe gauge wire, but the sections may be varied considerably. The kind of guttapercha wire in which the insulation sticks to the metal should be used, unless a special method is followed to expel all air. The coil is wound within an oil-tank, so that all interstices are filled up with oil. Paraffin or linseed oil may be used." W. C. Peake.

[87988.]—**Tesla Coil.**—"P. B. P." will find all he wants in "The Inventions, Researches, and Writings of Nikola Tesla," by T. C. Martin, published by the *Electrical Engineer*, New York; but in case he has not access to one of the large public libraries, I give some extracts from the book. In

TESLA WILL TRY TO CURE ROUSS

The Recorder Brings Electrician and Millionaire Together.

LAST HOPE OF THE BLIND MERCHANT

Has the Subtle Fluid Power to Restore His Fading Sight?

EXPERIMENT TO BE TRIED

With No Thought of Gain, but Simply to Help His Fellow Man, the Scientist Will, Under a Specialist's Supervision, Apply 100,000 Volts to the Sufferer's Optic Nerve.

Through the endeavors of a Recorder reporter two of the best-known characters in this country—Nikola Tesla, the greatest electrician the world has, perhaps, yet produced, and Charles Broadway Rouss, the multi-millionaire merchant—were brought together yesterday. The meeting had an important object. It resulted from a free-will offer on Mr. Tesla's part to place the results of his inventive genius at the disposal of the merchant for the sake of holding out to him the only possible chance for a recovery of his fast-waning eyesight.

Some time ago The Recorder reporter brought the fact of Mr. Rouss' sad plight to Mr. Tesla's notice and suggested the possible efficacy of the high-voltage currents. Mr. Tesla was at once interested, and quickly offered to place his apparatus at Mr. Rouss disposal.

"It cannot do him any harm, and it may possibly stimulate the optic nerves and awaken new life in them," he said, "and I am more than willing to render any service within my power."

The reporter found Mr. Rouss at first loth to consider the idea.

"That man's time is worth too much to be bothered about an old man's eyesight," he exclaimed with characteristic energy. "I wouldn't want to bother him. He is doing the whole world so much good that it would be wrong to make him stop to consider individuals. Why, I consider him the greatest man in the world."

When made to understand that Mr. Tesla had made the offer, and had even asked The Recorder reporter to bring Mr. Rouss to his laboratory, the merchant wellnigh broke down and said:

"Yes, I'll go with you any time; but I can't pay for it. I haven't money enough."

The reporter explained that Mr. Tesla would accept no remuneration for his services, but that his offer was prompted by sympathy and concern.

"But what are these currents like?" asked Mr. Rouss. "Maybe it will kill me!"

The reporter dispelled Mr. Rouss' fears by saying that he had had hundreds of thousands of volts passed through his own body at Mr. Tesla's laboratory without any ill effects.

"Take me to him!" cried Mr. Rouss. "I believe if there is one man in the world who can give me back my eyesight it's Tesla. And if he hasn't got any machine that will do it now, he'll invent one in a year or two!"

The meeting was arranged for yesterday afternoon at 3 o'clock, and when the reporter called at Mr. Rouss' great Broadway store the blind millionaire was anxiously awaiting his arrival.

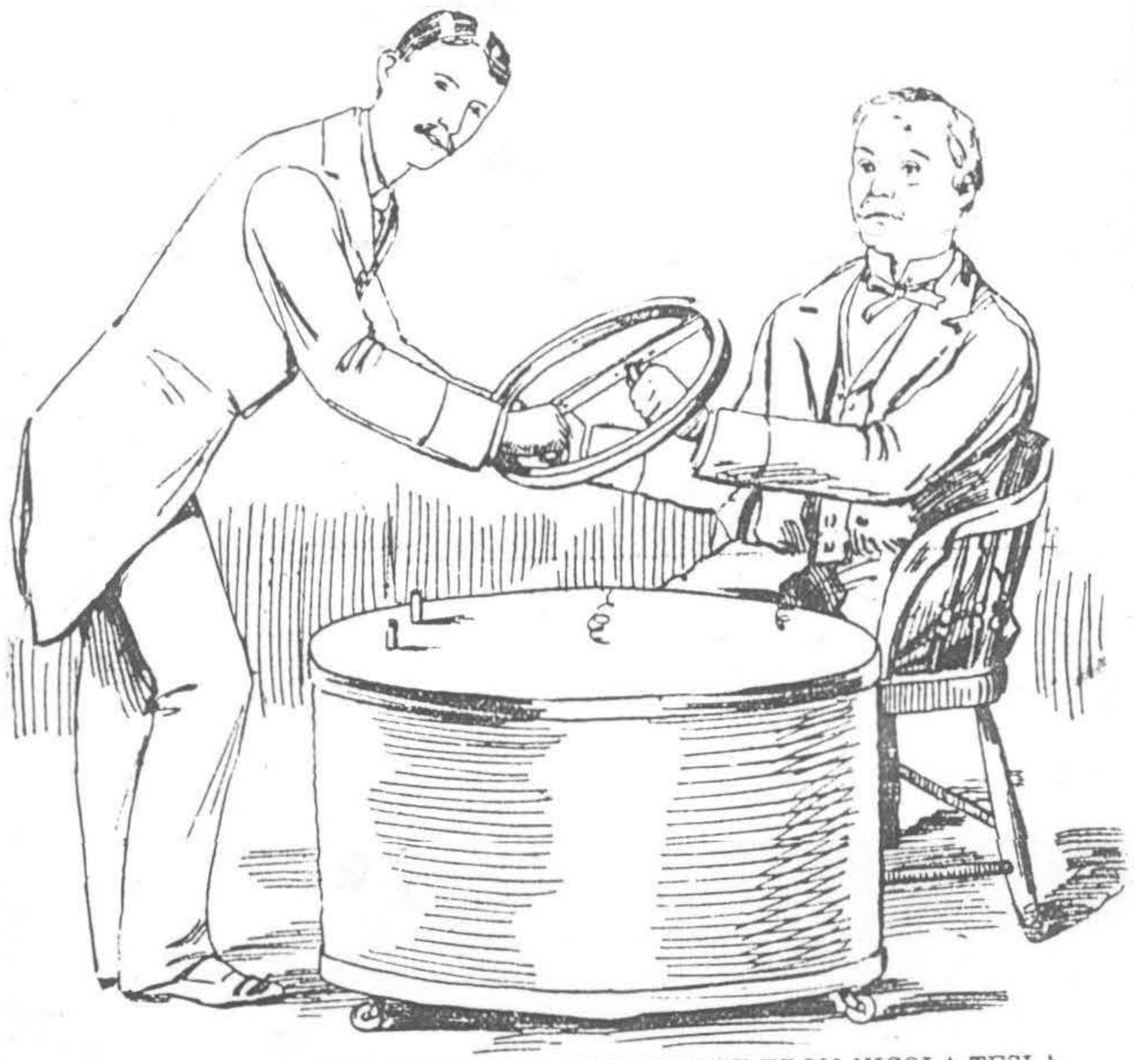
Mr. Rouss took the reporter's arm, and they started up Broadway together, but had not got past the store even before a crowd of newsboys and street urchins almost blocked the sidewalk.

"Good afternoon, Mr. Rouss!"

"How-de-do, Mr. Rouss?"

"Buy a paper, Mr. Rouss?"

There did not appear to be a man, woman or child on Broadway who did not seem to know him and have a kind word of greeting for him. To rid himself of the crowd of newsboys and gamins that thronged around, Mr. Rouss would now and again thrust his hand into his pocket and bring forth a handful of pennies, which he would toss into the air. A wild scramble would follow as the boys darted between one's very legs almost after the



BROADWAY ROUSS RECEIVING TREATMENT FROM NICOLA TESLA.

TESLA WILL TRY TO CURE ROUSS

(Continued from First Page.)

rolling pennies.

Suddenly Mr. Rouss stopped short, and turned to the reporter.

"Have a drink?"

In spite of his almost total blindness, some occult sense seemed to tell Mr. Rouss of the proximity of a cafe, and in another minute they were both leaning over the bar, the best of friends imaginable.

"Give me the cheapest thing you've got in the house, and"—as the bartender turned toward the reporter—"he'll take the same."

The strangely ordered drink might have been far worse, for the bartender was evidently well posted in Mr. Rouss' wants, and proceeded to concoct a mock champagne a la Rouss.

"It tastes like champagne; it's as good as champagne, and it's so much cheaper," said Mr. Rouss by way of explanation.

For the benefit of the uninitiated, the formula for this rarest of drinks is herewith given: Half a teaspoonful of powdered sugar, one and a half tablespoonfuls of whisky; ginger ale ad libitum.

After this dissipation Mr. Rouss was taken directly to Mr. Tesla's laboratory and there introduced to the great inventor.

"I was so sorry to hear about your affliction," said Mr. Tesla, looking into Mr. Rouss' vacantly staring eyes with a look of genuine concern. "My poor fellow, how dreadful it must be for you! Oh, I do hope I have some means of helping you. Sit down. Before we do anything else I am going to show you some experiments, just to give you an idea of what my work is like."

Then, with the tenderness of a woman, Mr. Tesla led the great merchant to a chair, and in a trice his visitors were transported to Wonderland.

It would be impossible to describe the many wonderful things that the inventor showed Mr. Rouss and the reporter. Electricity no longer seemed a new force, but a living thing, capable of putting life and motion into even inanimate objects.

"If I could only see better, perhaps I would understand more," said Mr. Rouss, "and I would give anything if I could only see you, but it's a privilege to even shake hands with you. I want you to give me a pair of new eyes, and if you can't do it now, you will some day. I want them to be blue eyes, please."

"My poor fellow," answered Mr. Tesla, "I only wish I could. Why don't you go into the country? The green is so restful to the eyes. I am sure that just to be among the waving trees and fair green fields would do your eyes good."

"I wouldn't leave the store; no, not for the world!" said Mr. Rouss. "It would kill me. I get down at 6 o'clock every morning, I leave at 7, and go to bed at 8. No, I couldn't leave the store, even for my eyes. Why, what would you do if you gave up your work and loafed around in the saloons here for even ten days? Why, it would kill you!"

"Yes," sighed Mr. Tesla, "the wretched liquors they sell would, if nothing else."

Then the great table-like spool which gathers the electric currents which Mr. Tesla's dynamoes charge the air with was wheeled in front of Mr. Rouss' chair, and the wire ends began to crackle ominously with the intensity of the current. Mr. Tesla took a hoop of metal in his hands, holding it by one of two handles that were attached to the centre piece. Then, taking Mr. Rouss' one hand in his, he placed the millionaire's other hand on the second handle of the hoop and held it over the huge spool or coil. A lurid flame played about the connection of the handles and hoop, and almost without his feeling it 100,000 volts were shot through Mr. Rouss' body.

"Perhaps," he whispered to the reporter, "you've all got me here to kill me and take my money."

When informed of the intensity of the current he was enduring Mr. Rouss' wonderment knew no bounds.

"That is all," said Mr. Tesla, putting away the hoop. "I merely wanted you to see that there was no pain or danger in the current. I take it constantly myself; and, indeed, don't think I could live without it. Of course, not being a physician, I would not venture to undertake any personal treatment, but what facilities I have are at your disposal. Under the guidance of your specialist, these currents might do good."

Then Mr. Rouss and the reporter left, and when again in the shady cool of the saloon, discussing more fake champagne (the reporter managed to get his hand on the bottle before it left the bar), Mr. Rouss decided to place his case in Mr. Tesla's hands, under the guidance of Dr. William F. Mittendorf, the well-known ophthalmotologist of 140 Madison avenue.

Later, at Mr. Rouss' request, the reporter called on Dr. Mittendorf, and the latter expressed himself as most eager to test the efficacy of these wonderful currents.

"I doubt," said the doctor, "whether they will do much or any good in Mr. Rouss' case, but surely if there is any possible chance it lies in this one direction, and I will do my part with the utmost pleasure."

So the treatment is to be instituted, and the one slender straw that offers eyesight to the erratic millionaire has been held out through the efforts of The Recorder.

Is Tesla to Signal to the Stars?

During the past week a number of the New York dailies contained interviews with Nikola Tesla, which were printed under "scare heads," such as, "May Signal Stars," "We May Signal to Mars." We reprint the following interview from the New York *Sun:*

"I have had this scheme under consideration for five or six years, and I am becoming more convinced every day that it is based upon scientific principles, and is thoroughly practicable. We know that electric disturbances on the sun are productive of similar disturbances on the earth in the form of thunder showers. Now, why is it not equally conceivable that a disturbance on the earth's surface should produce some tangible effect on other planets? The transmission of disturbances on the sun shows beyond doubt that waves of electricity are propagated through all space.

"The objection may be put forward that sufficient electrical disturbance cannot be made on the earth's surface, and that we should be wholly dependent upon thunder storms and other phenomena of nature for the success of our experiment. But, on the contrary, we can make all the artificial thunder and lightning we want. There is no difficulty in making electric apparatus with a spark gap of a mile, and if that did not prove effective it could be increased.

"Do not get the impression," continued Mr. Tesla, "that the success of the experiment is in any way dependent upon the light, noise, or vibration accompanying such an electric discharge. It is wholly through the electricity waves, which are propagated through the atmosphere and the ether beyond, that we may hope to obtain any results. But if there are intelligent inhabitants of Mars or any other planet, it seems to me that we can do something to attract their attention.

"This, of course, is the extreme application of this principle of the propagation of electric waves. The same principle may be employed with good effect for the transmission of news to all parts of the earth. It was formerly thought that in order to get any power out of electricity a conducting circuit must exist, but it has been shown that the same results may be accomplished with a single wire. It is perfectly possible to operate a motor or an electric light with just a single line of wire leading to the apparatus. It naturally occurred to me that, as the earth is a conductor, an electrical disturbance at one point, causing a change in the equilibrium of the earth's electricity, should be felt at all points on the earth's surface, and might be recorded by properly constructed instruments.

"The possibilities of such a transmission of intelligence cannot be exaggerated. Every city on the globe could be on an immense ticker circuit, and a message sent from New York would be in England, Africa and Australia in an instant. What a grand thing it would be in times of war, epidemic, or panic in the money market!"

Mr. Tesla, says the *Sun*, is at present engaged in finishing his calculations and perfecting the apparatus necessary for experiment in his new field of investigation, and he hopes soon to be able to show the practicability of his plan.

The following we abstract from an interview in the New York *Herald:*

"Years ago, in St. Louis, I delivered an address before the National Academy of Sciences. I then declared it would be possible to use economically the electricity in the atmosphere for lighting and heating, and, of course, for communication between different parts of the earth's surface. The problem was the conservation of electrical energy at the least possible cost to the other elements. That problem, I was confident then, I could solve by my oscillator. At present I am sure it can be done. From my most recent experiments I am convinced that within a very short time we shall be independent of the clumsy methods of generating electricity now in vogue. The electrical fluid in the atmosphere will give energy enough. The same electric envelope of the earth will enable us to send messages from one part of the globe to all other parts in an instant of time. The same element, which I believe to be finite and not confined to this atmosphere, may be used to communicate with the other planets."

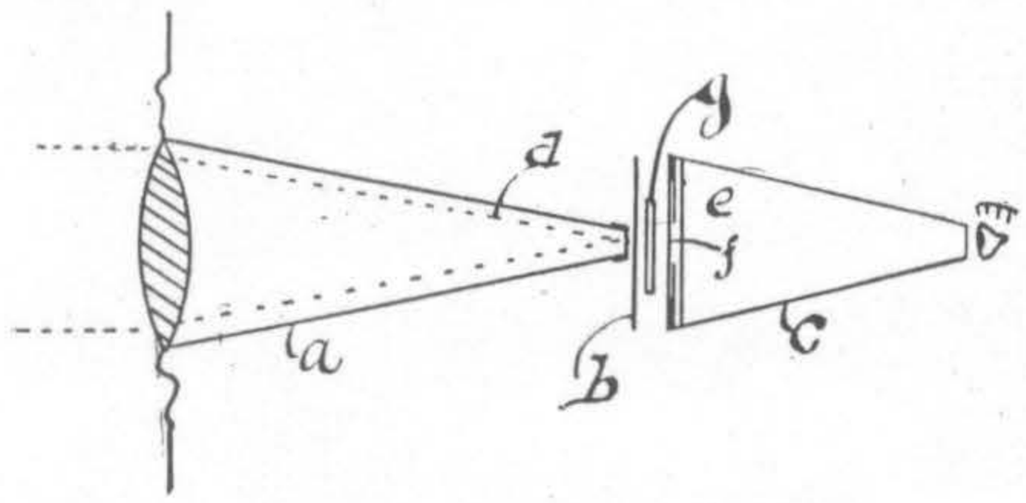
The oscillator referred to, it may be explained, is a combined steam engine and alternating-current generator, the piston of the engine being direct-connected to the armature or field of the alternator and oscillating to and fro at a rapid rate. It is consequently difficult to see how the reporters should have imagined it to be capable of such sartling performances.

PHOSPHORESCENCE AS THE SOURCE OF X-RAYS.

BY EDWARD P. THOMPSON, M. E.

ONE of the most important facts necessary in order to determine the nature of the X-rays is that which will prove their source. In the first place Prof. Röntgen alleges that they radiate solely from the phosphorescent spot upon the Crookes tube. Dr. Morton's experiment indicates the same feature. M. Charles Henry thinks he obtained X-rays from a phosphorescent substance, which he exposed to the light. Niewenglowski finds that phosphorescent bodies increase the penetrating power of sunlight like the sulphide of zinc increases that of X-rays. Poincaré at an early date advanced the hypothesis that the rays are due to phosphorescence, whether produced by electrical or other means. Professors Thomson and Rowland maintain that they radiate from the anode. Tesla has obtained effects by a closed bulb without any electrodes. In one of Tesla's experiments, he employed only one and either electrode, while the other was away off in space somewhere, and yet he obtained penetrating power at great distances. He is convinced that phosphorescence is not the source, because he believes that aluminum X-ray tubes do not phosphoresce. He gave no other explanation. Silvanus P. Thompson thinks that certain of his experiments prove that the rays do not come from either the cathode or from the phosphorescent spot individually, but jointly from both.

I have obtained fluorescence from X-rays after they have passed through a fluorescent substance. Experiments have also proved, apparently, that there are no X-rays radiating from the arc light, sun, flames or other sources of light. Other experiments show that although a Crookes tube may phosphoresce, yet no X-rays can be detected. Sometimes the phosphorescent light is local, occuring in spots here and there. It may be near the cathode or anode, or between them, or as in a tube



DETERMINING THE SOURCE OF THE X-RAY.

with which I experimented, the light was practically uniform on the whole surface, and a fluorescent screen was illuminated by all parts of the Crookes tube equally. Experiment also shows that with a given Crookes tube, the penetrating power of the rays seems to depend upon the electromotive force of the electrical energy, all other things remaining the same. Tesla, with his apparatus, has projected them through the thickest part of the human body, so as to affect the photographic plate.

Upon first reading the statement of Prof. Röntgen as to the phosphorescent spot being the source, it occurred to me that phosphorescence by other means might also radiate X-rays, and I was anxious to learn in the most emphatic manner the truth of the matter, whether it ended in negative or positive results. I have, therefore, been carrying out a series of experiments to determine whether ordinary phosphorscence will produce X-rays. Although I obtained negative results, yet the conclusion should not be drawn to the effect that X-rays may not be obtained by phosphorescence produced otherwise than by electricity, because by no possible means imaginable could I cause light to produce upon a Crookes tube the phosphorescence obtainable by the current, which, as well known, is visible even by daylight. Parenthetically, the intensity of light spoken of in text books is a misnomer. The light considered as to its penetrating power at the focus of the lens is no more intense than elsewhere. It will not penetrate anything to any greater distance by being condensed. It merely appears brighter to the eye, because there is more of it upon a given area, or because more of it has penetrated a given substance. The volume alone is greater.

To determine the degree of phosphorescence obtainable upon a Crookes tube by direct sunlight, it was placed inside of a box having an opening covered by violet glass. When the box was looked into, so as to exclude all other light the tube did not even appear green. However, under the same circumstances, uranium glass, barium platino cyanide, also a screen of ammonium uranate, potassium platino cyanide and others, each appeared of a vivid green or yellowish green. The experiment was repeated with focused sunlight on a very large scale, the lens being about five inches in diameter and having a focus of sixteen inches, and provided also with a funnel, white inside, which brought to a focus much diffused sunlight. The small end of the funnel was located in a dark room. The light was condensed upon violet glass.

The light passed through the glass, and, upon striking the phosphorescent and fluorescent materials, its refrangibility was changed; while the substances were as vividly green as when produced by the radiations in the Crookes tube, and, light cannot cause the same phosphorescence upon a Crookes tube did not become green. Uranium glass seemed as bright as when forming a Crookes tube highly charged. The Crookes tube had been before tested, and showed a green phosphorescence with a high electromotive force. The experiment with violet glass, although perfectly simple, and although the results, perhaps, could have been conjectured, proves that sunlight cannot cause the same pohsphorescence upon a Crookes tube as that produced by the current.

Another experiment indicated somewhat otherwise. In the direct focus, without blue glass, a livid green (as when electrified) was discernible as a fringe around the focus.

Inasmuch as the other substances fluoresced better with the violet light than with the electrified Crookes tube, as far as the eye could remember, an experiment was performed with the apparatus shown in the accompanying diagram, in order to determine whether condensed sunlight would produce sufficient phosphorescence for the generation of X-rays. The funnel above described was closed at the small end successively by different phosphorescent and fluorescent substances, b. The instrument which has now become known as the fluoroscope was directed towards the substance, b, which was made phosphorescent or fluorescent by the condensed sunlight, d, in order to detect fluorescence upon the screen, e, within the fluoroscope, which was covered at the large end partly with one thickness, b, partly with two thicknesses, and on another portion by three thicknesses of black paper.

The fluorescent screen, f, appeared green only at the part covered with one thickness. It was brighter without screen, b, which seems to contradict Niewenglowski's result. If there had been X-rays of any appreciable extent, they would have caused fluorescence through the three thicknesses and through a block of wood, g, interposed between the two fluorescent screens outside of the fluoroscope, as illustrated in the diagram. It should be noticed that the fluoroscope was exceedingly sensitive, and yet the results were negative.

The same instrument was tried with a Crookes tube generating X-rays by a current, and it became uniformly luminous at a distance of six feet from the electrified Crookes tube; therefore, it may be concluded, I think, that X-rays cannot be obtained from phosphorescence produced by sunlight. It may be noted that the objects were not placed exactly in focus because they would burn. The funnel, a, was cut off so that the cross sectional area of the path of the condensed rays was about one-fourth of an inch in diameter, and in this case heat absorbing substances were not needed further than that of the lens itself.

Aluminum was substituted for the block of wood, g, but no fluorescence occurred with the fluoroscope. The experiment was modified in a great many different directions; for example, by using the focused light when reflected from the screen, b, although (as the latter was made of a mixture of pulverized fluorescent material and varnish) the fluorescence was caused by reflection from each particle when the light was transmitted by the screen, as well as when reflected therefrom. A gas flame was also employed as a source of light; also sunlight without a lens.

Remembering how a little daylight entering the eye while viewing fluorescence by X-rays nearly neutralized the effect, I thought, perhaps, persistence of vision prevented my seeing any fluorescence which might have been produced through the three thicknesses of black paper, and therefore I applied the most severe test. A photographic plate with a metal ring attached to it was wrapped closely in several folds of black paper and inclosed in an aluminum box, which, in turn, was wrapped in cloth. On the outside of all was fastened a plate of uranium glass, which was exposed to direct sunlight for over seven hours. No effect whatever was produced upon the photographic plate. With X-rays, an effect would have occurred through the same thickness in a few minutes.

A large glass plate covered with calcic sulphide, which remains luminous in a dark room after having been exposed to sunlight, was tested. I exposed the plate to the condensed sunlight, forming a bright, luminous spot, and at another time I exposed the whole plate to sunlight for an hour or more. When the fluoroscope was directed toward it in the dark and certain experiments performed, sufficient light was produced

to illuminate the screen in the fluoroscope, but not through even a single thickness of black paper, but only enough to cast a shadow. Here again the bluish brightness of the luminous paint is not visible in daylight, while a Crookes tube energized by electricity radiates green light abundantly and is easily visible in daylight.

While these experiments do not prove that the X-rays do not have their source alone in the phosphorescence of a charged Crookes tube, yet they form substantial evidence that X-rays are not obtained from phosphorescence by sunlight.

ON THE SOURCE OF THE ROENTGEN RAY.

BY

H. M. Stine

A series of experiments extending over the past six weeks has at length yielded conclusive evidence and enabled the source and distribution of the ray to be mapped out around the entire tube with great clearness. Penumbral shadows were repeatedly plotted back to the tube and invariably pointed to

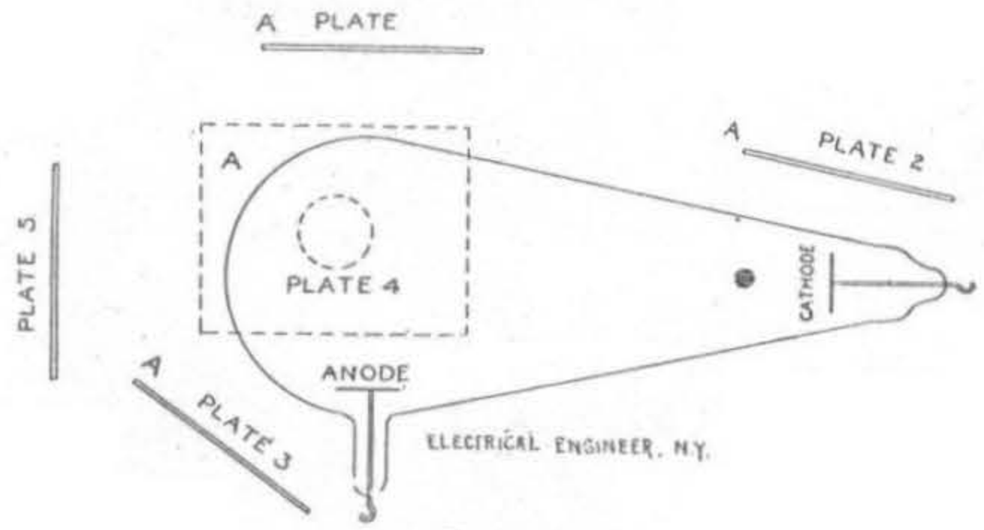


FIG. 1.

the area of the bulb opposite the cathode as the source of the distribution. These observations have already been published.[1]

It occurred to the writer that the best means to trace the ray distribution would be shadows cast by short metallic tubes. Half-inch lengths were cut from No. 18 gauge brass tubing, varying in diameter from ½ inch to 3 inches. In the first experiment, these were placed concentrically on a dry plate and placed parallel with the bulb in position marked 5 in Fig. 1,

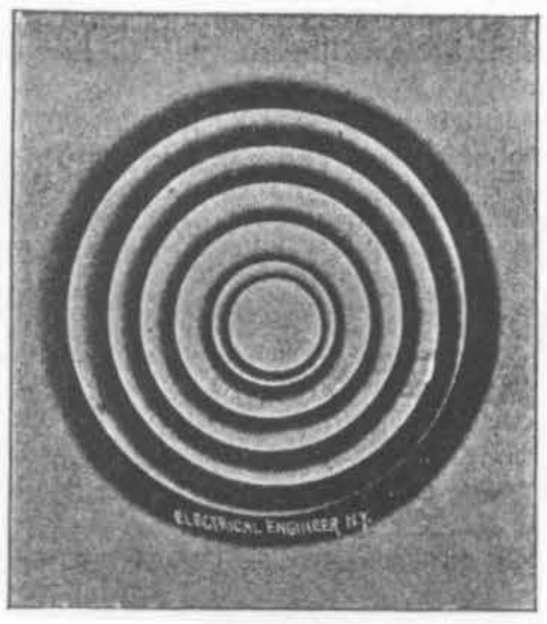


FIG. 2.

the distance of the plate from the bulb being 4 inches. The sciagraph is reproduced in Fig. 2.

Two separate effects are to be noted in all the sciagraphs of the tubes used. Both the length and direction of the shadow are clearly indicated and the vertical shadow of the metal itself. It will be noted that the latter seems to indicate the presence of rays which are more or less vertical. Plotting the shadows in Fig. 2 and noting that the vertical shadow does not appear beyond the third ring, we find that the source of the rays was on the surface of the bulb, and the area of the source was nearly or quite circular, and not much in excess of the diameter of the third ring, which was 1½ inches.

With such a clear and unmistakable result in possession, the next experiment was an attempt to decide whether this area was the only source of the ray. We were guided in this by some recently published emphatic statements that the ray was of anodic origin and did not, as popularly supposed, proceed

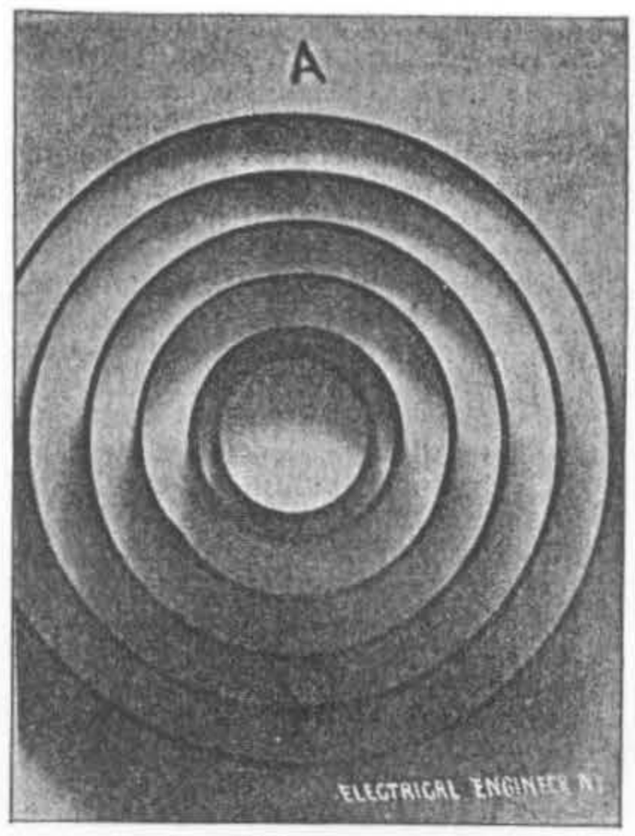


FIG. 3.

from the cathode. It was seen that while a screen could be misleading, the shadows cast by rings would be conclusive. Four plates were prepared for simultaneous exposure. The concentric rings were placed on one plate, and single rings, of 1 inch diameter and same height, were placed over the other plates. All these objects were placed as nearly as possible on the center of the plate. In Fig. 1 is shown the shape of the tube, the position of the electrodes and the plates, which were 3¼ by 4¼-inch in size, and placed 2½ inches from the bulb. The plates were marked with the letter "A" on the ends which were disposed as shown in the drawing. The resulting sciagraph from plate 1, is shown in Fig. 3, that from plate 2 in Fig. 4, from plate 3 in Fig. 5, and from plate 4 in Fig. 6.

To interpret the results, note first the sciagraphic effect of the rings, and second, the elliptical shadows of the intercepted inclined rays. If the latter be plotted, they all point to one area, the circular cathode imprint on the end of the bulb. We may now call this the prime source of the Röntgen ray. The vertical ring shadows, however, indicate numerous secondary and more or less weak sources. A general statement can then be made to the effect that about the entire surface of the tube is sciagraphically active. The four plates were developed to-



FIG. 4.

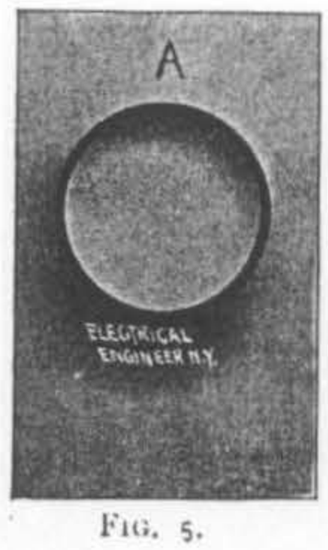


FIG. 5.

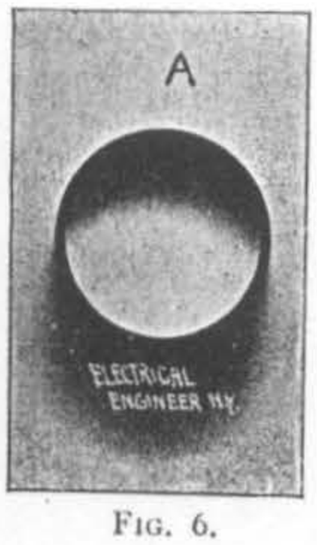


FIG. 6.

gether for an equal length of time. Plates 1 and 3 developed soonest, 4 a little slower, and the image on 2 was the last to appear. The resulting negatives are, however, all excellent and of about equal density. It is thus shown that a number of sciagraphs may be taken simultaneously if the entire tube be surrounded by plates. It might be added that the rings in Fig. 3 were held in concentric position with wedges of pine wood one-half inch thick, and since these do not show, they were entirely transparent for this length of exposure.

1. "Western Electrician", Mar. 7, p. 110 "Electrical Engineer", Mar. 11, p. 225.

COMMENT ON TESLA'S WORK.

VIEWS OF EMINENT PHYSICIANS AND SCIENTISTS ON TESLA'S ARTICLES ON ROENTGEN RAYS.

The articles from the pen of Nikola Tesla that have appeared in the ELECTRICAL REVIEW attracted a great deal of attention, particularly in the scientific world. They were widely quoted in the press of this country and abroad, and were probably seen by every person in the world interested. The New York *Times* interviewed a number of gentlemen in relation to Tesla's discoveries, and we quote below from its columns.

Dr. Cyrus Edson, formerly health commissioner of New York, when asked by the reporter about Tesla's deductions, said that he had been much interested in the subject and had given it considerable attention. Said he:

It is an undoubted fact that you can decompose certain chemicals by means of light. The principle of photography rests upon this fact. These X rays decompose the chemicals with which the film is sensitized and effects this decomposition through what have hitherto been regarded as opaque bodies, such as the hand, for instance. Light in vibration, and it has been demonstrated that these X rays, will pass through an opaque body. That these vibrations in passing through the skull should affect the delicate nerve tissues of the brain and stimulate them is a perfectly natural result. This accounts for the sensations experienced by Tesla when he exposed his head to a powerful radiation. But there is no more reason to believe that the X rays will carry a medicinal agent through the body and into the distant spot, the seat of disease, than that a ray of light will be able to project such a chemical on to the surface of the body.

The theory of the vibrations of light is not a new one. It originated with Sir Isaac Newton, who believed that luminous bodies shot out infinitely small particles in straight lines, which, by penetrating the transparent parts of the eye and falling on the nervous tissue, produced vision. Other philosophers drew a parallel between the properties of light and those of sound, and considered that, as sound was certainly the effect of vibrations, or little waves projected through elastic bodies, so light might be nothing more than the consequence of similar vibrations transmitted with inconceivable velocity through a highly elastic medium. The wave hypothesis of light is at present generally adopted simply because it is in harmony with all the known phenomena discovered since the time of Newton. The deductions of Tesla as the result of his experiments are absolutely in harmony with the Newtonian theory. We can certainly expect some marvelous results from the X rays—things not even dreamed of yet. I believe that they will prove a valuable adjunct to medical science, and I think that the ultra-violet rays will be sooner or later obtained by passing ordinary sunlight through certain media, without the agency of electricity.

Dr. J. Mount Bleyer, who has taken great interest in determining the effects of all light rays on animal and vegetable life, said:

I am not at all surprised at the results of Tesla's experiments. I have been experimenting for some time with the associated-light rays—the sunlight and the different colors, such as blue, red and orange—in connection with the treatment of infectious diseases and vegetations. The results obtained by Tesla are simply marvelous, but are just what I expected. I have contended from the beginning, and it has now been proved beyond a doubt by Tesla, that this bombardment of particles does pass through glass and other materials at an enormous velocity. As far as the therapeutic effects of the rays are concerned, they may be likened in some way to a massage effect, if they do not form a high class of bactericidal agent. Solariums for the treatment of infectious diseases, with associated-light rays, will no doubt be the next advance in hospital architecture. I have made a number of experiments with the associated-light rays in hospitals and among my private patients in cases of phthisis and tuberculosis. I have resorted to the treatment wherever it was possible, and never failed to obtain the best results. Ordinary light is one of the main factors in the growth of animal life. We know that sunlight is essential for the growth and development of both animal and vegetable tissue. We have in light a therapeutic agent that has been underestimated and neglected, and which should be taken up and thoroughly studied.

Ogden N. Rood, professor of physics in Columbia College, after glancing through the article by Nikola Tesla, dictated to a New York *Times* reporter the following statement of his views:

It is never proper to frame a new hypothesis in order to account for discoveries when an old and well-established theory is capable of giving them an explanation. Our knowledge of the waves of light, of radiant heat, and of the ultra-violet rays is confined within narrow limits. Thus far, according to our previous experience, the shorter the length of the wave the more it will be bent or refracted by substances in general. It, however, does not at all follow that this will hold good if the length of the wave is shortened to a degree beyond our experience. On the other hand, it is highly probable that, if this shortening process goes on till the length of the wave has become of the same order of magnitude with the molecules of matter, the effect in the matter of refraction will diminish. This would account for the fact that no one has succeeded thus far in refracting or reflecting the Roentgen rays. In my own experiments I have so far found them to act in the same general way with waves of ordinary light, and I am inclined to believe that they are simply waves of light of unprecedented shortness. This view necessarily excludes all idea of a molecular bombardment outside of the Crookes tube. I believe that it will be eventually demonstrated that the Roentgen rays are capable of reflection and refraction, although it will require more delicate work than has thus far been extended in this direction.

[*From the Western Electrician, March 21, 1896.*]

To many investigators who have been experimenting with X rays, the most important feature of Tesla's communication in the ELECTRICAL REVIEW last week was his reference to the influence of these rays upon a living subject. He said:

By exposing the head to a powerful radiation strange effects have been noted. For instance, I find that there is a tendency to sleep and the time seems to pass away quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep and a quick lapse of time.

This is a point that has been noted by other experimenters, and it has led to much speculation as to the possible effect of these rays upon the physical organism, although the subject has not received the consideration which it seems to be entitled to. But now that Tesla has called attention to it there is a probability that it will be given more attention, especially as he suggests that "it may be possible by these strange appliances to project a suitable chemical into any part of the body." He is not confident by any means of the correctness of his views, though, as he says, "Should these remarkable effects be verified by men with keener sense of observation, I shall still more firmly believe in the existence of material streams penetrating the skull."

The announcement of these conclusions by Tesla has already excited comment. Professor Stine does not agree with his eastern contemporary, and in an interview takes the ground that thus far not a single experiment has been made to show that the X ray has any physiological effect. He says that it has been tried on microbes without apparent result, and claims that the peculiar vibratory motion and the heat Tesla speaks about are much more noticeable when the tube does not give off the X ray than when it is in perfect working order. His conclusion is that "the pulsations one feels when making a sciagraph of the hand, for instance, are no doubt the effect of heat and the external change of electricity on the air." Concerning the suggestion that the X ray may be utilized to project chemicals into the human system, Professor Stine says that he can find no authority for such an opinion in the accepted theories of to-day.

[*From Leslie's Weekly, New York, April 2, 1896.*]

None of the scientists who have made practical investigations as to the scope and value of the Roentgen ray discovery have reached more important or wonderful results than Nikola Tesla, the well known inventor. Communication from him, recently published in the ELECTRICAL REVIEW, which is the organ of the best scientific thought and literature of the time, mentions some of the results of his experiments in radiography.

[*From The Independent, New York, March 26, 1896.*]

We might expect from Nikola Tesla the most intelligent discussion of the new Roentgen rays, but we were not prepared for his announcement in the last week's ELECTRICAL REVIEW. He says he is now producing strong shadow pictures at a distance of 40 feet, and he finds it necessary to guard the plates in his photographic department on the floor above, and 60 feet away, from being spoiled by long exposure to strong rays. * * * In the rapid development, by the concurrent labors of hundreds of students, of the discovery of Professor Roentgen, we see the advantage which comes, in science, from that fine and generous ambition which leads scholars to hasten to give to the world the results of their discoveries, that others may make applications and improvements.

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RADIOGRAPHY.

The ELECTRICAL REVIEW presents to its readers this week an unusually brilliant symposium of literature on the latest developments in radiography. Mr. Tesla supplements his previous communications to this journal with further remarks on his very interesting and valuable scientific work. The results achieved by Professor Enrico Salvioni, of Perugia, Italy, are chronicled by a well-known newspaper man who interviewed him for the ELECTRICAL REVIEW. Messrs. Scribner and McBerty, of Chicago, send us an important communication on the source of the X rays, on which Prof. Elihu Thomson makes some very interesting comments, and at the same time refers to his own work in a similar direction. Altogether, the past week has been a very interesting one as far as the X rays are concerned, and as usual the ELECTRICAL REVIEW presents the latest thought and achievement of the brightest minds that are at work on this very interesting topic. Our readers will appreciate the fact that while the real source and nature of the X ray are still a matter of speculation and doubt, important practical results have already been achieved in the development of Salvioni's cryptoscope and Edison's fluoroscope. These are probably but the primary steps in the evolution of a device which will be of untold value in the future practice of surgery and medicine. In the meantime the ablest minds in the electrical field are steadily at work endeavoring to determine the nature of a phenomenon which, according to at least one experimenter, enables solids to pass through solids.

Hardly had Tesla announced the important results of his investigations on reflection when he followed it up with a practical demonstration of the value of these results, as will be seen from the illustration on another page. The time is materially reduced, and a distance of four feet is, for such a radiograph, really remarkable, and shows the extraordinary performances of the Tesla coil. While the results which he describes in his present communication are very wonderful, there is still to be considered his statement, before made, that he is availing himself at the present time of only a small part of the capacity of his apparatus. The impressions obtained with short exposures by the help of a phosphorescent powder are not the less interesting and remarkable.

TESLA ON ROENTGEN RADIATIONS.

To the Editor of Electrical Review:

Having observed the unexpected behavior of the various metals in regard to the reflection of these radiations, as communicated in your issue of April 1, I have endeavored to settle several still doubtful points. As, for the present, it appeared chiefly desirable to establish the exact order of the metals, or conductors, in regard to their powers of reflection, leaving for further investigation the determination of the magnitude of the effects, I modified slightly the apparatus and procedure described in my communication just referred to. The reflecting plates were not made each of one metal, as before, but of two metals, the reflective power of which was to be compared. This was done by fastening upon a plate of lead the two metal plates to be investigated, so that the reflecting surface was divided in two halves by the joining line. Furthermore, to prevent any spreading and mingling of the rays reflected from both halves, I divided the lead box into two compartments by a thick lead plate through the middle. Care was taken that the density of the rays falling upon the reflecting surfaces was as uniform as possible, and with this object in view the glass tube surrounding the bulb was lifted up so as to just expose the half-spherical bottom of the latter. The bulb was placed as exactly as it was practicable in the center, so that both halves of the reflecting plate were equally exposed to the radiations.

Having failed to obtain, in former experiments, a record for iron owing to an oversight, I tried to ascertain its position in the series by comparing it with copper, using a plate made up of iron and copper. The experiments showed that iron reflected about as much as copper, but which metal reflected better was impossible to determine with safety by this method. Next I endeavored to find whether tin or lead was a better reflector, by the same method. Three experiments were performed, and in each case the metals behaved nearly alike, but tin appeared just a trifle better. Finally I investigated the properties of magnesium as compared with zinc. In fact, the experiments showed that magnesium reflected a little better.

I am not yet satisfied, in view of the importance of this relation of the metals with the means employed, and will try to devise an apparatus which will do away with all the defects of the present. The time of the exposure I have found practicable to reduce to a few minutes by the help of a fluorescent paper.

In my previous communications I have barely hinted at the practical importance of the use of suitable reflectors. One would be apt to conclude that, since, under the conditions of the previously described experiments, zinc, for instance, reflected only three per cent of the incident rays, the gain secured by the employment of such zinc reflector would be small. This, of course, would be an erroneous conclusion. First of all it should be remembered that in the instances mentioned before the angle of incidence was 45 degrees, and that for larger angles a much greater portion of the rays would be reflected. The exact law of reflection is still to be determined. Now, let us suppose the shadow of an object is taken at a distance, D. In order to get a sharp shadow we must take this distance not less than two feet, and I am finding it more and more necessary to adopt a still greater distance. If, for the sake of simplicity, we assume a spherical bulb and electrode, the radiation will be uniform on all sides, and any element of a surface of a sphere of radius D, drawn around the electrode, will receive an equal quantity of rays. The total surface of this sphere will be $4\pi D^2$. The object, the shadow of which is to be taken, may have a small area a, which gets only an insignificant part of the total rays emitted, this part being given by the proportion $\frac{a}{4\pi D^2}$. In reality we can not assume less than $\frac{a}{D^2\pi}$ as effective ratio, but even then, if D is very large and the object, that is, the area a, small, this ratio may be still so small that evidently, by the use of a proper reflector, we can easily concentrate upon the area a an amount of rays several times exceeding that which would fall upon it without the use of a reflector, in spite of the fact that we are able to reflect only a few per cent of the *total* incident rays.

As an evidence of the effectiveness of such a reflector, the annexed print of the shoulder and ribs of a man is shown. A funnel-shaped zinc reflector, two feet high, with an opening of five inches on the bottom and 23 inches at the top, was used in the experiment. A tube, similar in every respect to those previously described, was suspended in the funnel, so that just the static screen of the tube was above the former. The exact distance from the electrode to the sensitive plate was four and one-half feet. The distance from the end of the tube to the plate was three and one-half feet. The exposure lasted 40 minutes. The plate showed very strongly and clearly every bone, and shoulder and ribs, but I can not tell how clearly they will appear in the print. I selected the same object as in my first report in your columns on this investigation, so as to give a better idea of the progress made. The advance will be best appreciated by stating that the distance in this case was much more than double, while the time of exposure was less than one-half. The chief importance of a reflector consists, however, in this, that it allows the use of many bulbs without sacrifice of precision and clearness, and also the concentration of a great quantity of radiation upon a very small area.

Since the use of phosphorescent or fluorescent bodies in connection with the sensitive film has been suggested by Professors Henry and Salvioni, I have found it an easy matter to shorten the time of exposure to a few minutes, or even seconds. So far, it seems that the tungstate of calcium, recently introduced by Edison, and manufactured by Messrs. Aylsworth & Jackson, is the most sensitive body. I obtained a sample of it and used it in a series of tests. It fluoresces decidedly better than barium-platinocyanide, but, owing to the size of the crystals and necessarily uneven distribution on the paper, it does not leave a clean impression. For use in connection with the sensitive films, it should be ground very fine, and some way should be adopted of distributing it uniformly. The paper also must adhere firmly to the film all over the plate, so as to get fairly sharp outlines. The fluorescence of this body seems to depend on a peculiar radiation, because I tested several bulbs, which otherwise worked excellently, without producing a very good result, and I almost gained a false impression. One or two of the bulbs, how-

(Concluded on page 186.)

TESLA ON ROENTGEN RADIATIONS.

(*Concluded from page 183.*)

ever, effected it very powerfully. An impression of the hand was taken at a distance of about six feet from the bulb with an exposure of less than one minute, and even then it was found that the plate was overexposed. I then took an impression of the chest of a man at a distance of 12 feet from the end of the tube, exposing five minutes. The developed plate showed the ribs clearly, but the outlines were not sharp. Next, I employed a tube with a zinc reflector, as before described, taking an impression of the chest of an assistant at a distance of four feet from the bulb. The latter was strained a little too much in this experiment and exploded, in consequence of the great internal pressure against the bombarded spot. This accident will frequently occur when the bulb is strained too high, the preceding outward sign being an increased activity and vapor-like appearance of the gas in the bulb and rapid heating of the latter. The process causing the abnormal increase in the internal pressure against the glass wall seems to be due to some action opposite to that noted by Crookes and Spottiswoode, and is very rapid, and for this reason the experimenter should watch carefully for these ominous signs and instantly reduce the potential. Owing to the untimely end of the bulb in this last described experiment, the exposure lasted only one minute. Nevertheless, a very strong impression of the skeleton of the chest, showing the right and left ribs and other details, was obtained. The outlines, however, were again much less sharp than when the ordinary process without the phosphorescent intensifier was followed, although care was taken to press the fluorescent paper firmly against the film. From the foregoing it is evident that, when using the above means for shortening the time of exposure, the thickness of the object is not of very much consequence.

I obtained a still better idea of the quality of tungstate of calcium by observing the effect upon a fluorescent screen made of this chemical. Such a screen, together with a paper box, has been termed with the fanciful name "fluoroscope." It is really Salvioni's Cryptoscope with the lens omitted, which is a great disadvantage. To appreciate the performances of such a screen, it is necessary to work at night, when the eye has for a long time been used to the darkness, and made capable of noting the faint effects on the screen. In one instance the performance of this screen was particularly noteworthy. It was illuminated at a distance of 20 feet, and even at a distance of 40 feet I could still observe a faint shadow passing across the field of vision, when moving the hand in front of the instrument. Looking at a distance of about three feet from the bulb through the body of an assistant, I could distinguish easily the spinal column in the upper part of the body, which was more transparent. In the lower part of the body the column and the rest were practically not perceptible. The ribs were only very faintly seen. The bones of the neck were plainly noticeable, and I could see through the body of the assistant very easily a square plate of copper, as it was moved up and down in front of the bulb. When looking through the head I could observe only the outline of the skull and the chin-bone, yet the field of vision was still bright. Everything else appeared indistinct. This shows that improving of fluorescence will not aid us very much in the examination of the internal parts of the body. The solution rather will come through the production of very powerful radiations, capable of producing very strong shadows. I believe I have indicated the right way to secure this result. Although it must be admitted that the performance of such a screen is remarkable with the appliances I have used, I have, nevertheless, convinced myself of its still limited value for the purpose of examination. We can distinguish the bones in the limbs, but not nearly as clearly as a photographic impression shows it. Eventually, however, with the help of strong radiations and good reflectors, such fluorescent screens may become valuable instruments for investigation. A few weeks ago, when I observed a small screen of barium-platino-cyanide flare up at a great distance from the bulb, I told some friends that it might be possible to observe by the aid of such a screen objects passing through a street. This possibility seems to me much nearer at present than it appeared then. Forty feet is a fair width for a street, and a screen lights up faintly at that distance from a single bulb. I mention this odd idea only as an illustration of how these scientific developments may even affect our morals and customs. Perhaps we shall shortly get so used to this state of things that nobody will feel the slightest embarrassment while he is conscious that his skeleton and other particulars are being scrutinized by indelicate observers.

Fluorescent screens afford some help in getting an idea of the condition of the bulb when working. I hoped to find some evidence of refraction by means of such a screen, placing a lens between it and the bulb, and varying the focal distance. To my disappointment, although the shadow of the lens was observable at a distance of 20 feet, I could see no trace of refraction. The use of the screen for the purpose of noting the effects of reflection and diffraction proved likewise futile.

NIKOLA TESLA.

New York, April 6.

TESLA'S RADIOGRAPH OF A MAN'S SHOULDER AND RIBS THROUGH CLOTHING BY MEANS OF A REFLECTOR.—EXPOSURE FORTY MINUTES, DISTANCE FOUR FEET.—IMPRESSION PRODUCED WITHOUT A PHOSPHORESCENT INTENSIFIER. (SHIRT BUTTON ON TOP OF SHOULDER PLAINLY SHOWN.)

The New York Tribune April 9, 1896

MADE WITH REFLECTED X RAYS

MR. TESLA GETS SOME REMARKABLE PICTURES—IMPROVED METHODS.

Undeterred by Professor Röntgen's statement that he had been unable to change the course of the X rays when the latter had once been generated, many other scientists have undertaken to do so. Several weeks ago Nikola Tesla reported that he had succeeded in such an attempt. Only about 2 per cent of the invisible radiance was reflected from the copper plate employed by Mr. Tesla; the rest of it proceeded uninterruptedly. Since that time he has experimented with several other metals, and he tells "The Electrical Review" (New-York) this week that a surface of magnesium or zinc held at an angle of 45 degrees with the path of the rays will reflect about 3 per cent. "For larger angles," he adds, "a much greater portion of the rays would be reflected."

An important practical application of this discovery has been made by Mr. Tesla. Instead of using a flat plate he shapes his zinc into a funnel. Such a reflector, of course, works very much like a concave mirror. The vacuum tube by means of which the X rays developed was placed very near the centre of the mouth of the funnel. In this way he concentrated the radiance upon the object to be photographed, and produced not only a sharper image, but more rapid results than if no reflector had been employed. He estimates that there is a smaller waste of energy under these circumstances.

One of the pictures taken by Mr. Tesla with reflected X rays shows the ribs, collar-bone, shoulder-blade and upper arm of a man with great distinctness. The plate was exposed for forty minutes, which is only half the time required for an earlier photograph of the same subject at a shorter distance, but without a reflector. In the more recent skiagraph, moreover, the bones are clearly outlined, instead of being hazy streaks. Obviously, for purposes of surgical diagnosis, this is a notable gain.

The New York Herald April 10, 1896

CAN SEE THROUGH A MAN.

Nikola Tesla's Remarkable Achievements with the X Rays and a Luminous Screen.

Nikola Tesla, who was among the first to experiment with the Roentgen rays and who achieved some remarkable results, has an interesting article in the current number of the Electrical Review, in which he describes in detail his recent experiments. As a result of them he says he can see clear through the human body.

Tesla's ambition has been to develop electrical power enough to enable the rays to fully illumine the human body, and thus enhance their value to surgery. He shadowgraphed a man's ribs and the bones of his shoulder and arms some time ago, but he was not satisfied with the picture, because it failed to show the bones distinctly. This result, he says in his article, he has just obtained, and he has a shadowgraph in which the bones appear clearly outlined. This picture was taken four feet from the vacuum tube and after a comparatively short exposure.

An equally satisfactory shadowgraph, Mr. Tesla says, was obtained at a distance of twelve feet from the vacuum tube and after an exposure of only five minutes.

But the interesting portion of Mr. Tesla's article is that in which he tells how he was enabled to see through a man's body. He did this with the aid of a luminous screen, somewhat on the principle of Edison's fluoroscope, recently described in the HERALD. In the fluoroscope Edison used tungstate of calcium crystals only; in his luminous screen Tesla used these crystals, with barium platinum cyanide. The man through whom Tesla looked was placed between the luminous screens and the vacuum tube. Tesla says that when he looked at the screen it made the man's body luminous, so that he distinctly saw his backbone and all the details of his skeleton. A metal plate placed on the man's back and a coin were also, he says, revealed. This screen, he says, fluoresces at a distance of twelve feet from the rays.

Mr. Tesla says these remarkable effects were produced by reflecting the rays and contracting them in a funnel. Mr. Tesla is still pursuing his researches and expects to obtain even more sensational results soon.

Electrical Progress.

NICOLA TESLA is credited with a statement last week that he was satisfied he had a machine, which, when perfected, would enable him to make practical experiments in distributing electric waves about the earth so that messages might be conducted to all parts of the globe simultaneously. He believed that electric waves might be propagated through the atmosphere and even the ether beyond, a disturbance of the waves at any point being instantly felt at every point along them. He declared that he believed that the transmission of news about the earth by electric waves in the place of wires was no longer a dream.

Louisville Courier Journal April 12, 1896

Three Great Inventors.

What Is Going On In the Laboratories of Edison, Tesla and Moore Great Improvements In Electric Lighting Are Promised—Cheap and Effective Illumination.

(Correspondence of the Courier-Journal.)

New York, April 10.—We are soon to have electric lights so cheap that any one can afford to have them. At least, this is the promise of three noted electricians who have been working on the problem for some time past. The fact that Thomas A. Edison and Nikola Tesla are two of the three referred to, gives strong assurance that we may look for a revolution in our system of illumination in the near future. It begins to look as if the gas companies would be distanced this time, despite the discovery of the new method of producing acetylene, and will not be able hereafter to manufacture light for the million, as they have done in days gone by.

I had occasion to pay a number of visits to the laboratory of Mr. Edison near Llewellyn Park, N. J., within the past month, in order to find out how he was progressing in his experiments with the wonderful Roentgen rays, which seem to respect neither substance or shadow but go through everything. It was on one of these trips that I learned from Mr. Edison' own lips how he had practically succeeded in improving his incandescent lamp so that he could run twenty of them for each horse-power used. This is a distinct gain of 33 1-3 per cent., as at present only fifteen lamps can be run per horse-power.

"I started out with ten incandescent lamps per horse-power," said the Wizard, "and after a while succeeded in bringing these up to such a state of perfection as to string fifteen of them on a line for each horse-power employed. Now I have practically succeeded in improving my incandescent lamp so that I can put twenty lamps where I could use only fifteen before."

"Then you are not experimenting with etheric or phosphorescent lighting." I said.

"No," replied Mr. Edison. "I believe that the incandescent lamp can be improved so that it will give as good light at as small a cost as anything in the market. Besides, I don't take any stock in these graveyard lights that some electricians are experimenting with. The incandescent lamp sends out as soft and mellow a light as could be expected; it is quite adequate for all practical purposes."

"Would you care to say just how you have improved your new lamp?"

"Not just yet. I have still some finishing touches to make on it. You see, when Prof. Roentgen made his wonderful discovery of the X rays, I dropped everything in order to repeat the experiments here. These rays open up wonderful possibilities in the electrical world, and may make it necessary for us to completely reconstruct the undulatory theory of light. Just think where we are now! Photographing through wood and metal, talking by telephone a thousand miles away, telegraphing under the ocean despite of storm and tempest—why, one of these days we shall perhaps see by electricity."

Of course, it is idle to look for the improved incandescent lamp until Mr. Edison gets tired of his investigation of the Roentgen rays. The truth is, when the great electrician begins to experiment in any one line, he sticks to his work as close as a hen does to her nest, when she is hatching out a lot of eggs. He has eyes and ears only for the subject in hand, and nothing can take him away from his work. He even dreams over his theories—that is, when he takes time to sleep, for sometimes he will continue right along in his laboratory for three days at a stretch without shutting an eye.

"You will keep your carbon filament in the improved incandescent lamp, and not dispense with it as Tesla proposes to do?" I asked.

"Oh, yes," he replied. "No need of changing that now. I had quite a time finding it; I searched all over creation. They are using cellulose now, but it isn't much cheaper than the Japanese bamboo splints that I first used."

"Then you think your latest improvements will cheapen electric lighting?" I asked again.

"I don't see how it can help it," replied Mr. Edison. "If I can run twenty lamps where I now use only fifteen, don't you see that there will be considerable saving."

"Have you taken out your patents yet?"

"No—nor shall I. I don't believe in getting things patented any more. It doesn't protect you. The only safe way is to keep the secret yourself as far as possible."

And the great electrician hereupon began to experiment with a telephone, in the hope of transmitting the Roentgen rays by wire to any distance, just as in the case of sound waves. As he did so, he added:

"Faraday could only turn the most delicate needle at first with his electrical current; yet to-day an electrical engine is hauling a train of forty cars. You must not despise the day of small beginnings."

Nikola Tesla is almost as prominent a figure in the electrical world as the "Wizard of Menlo Park." He is the man who allowed 250,000 volts to pass through his body, who discovered the art of transmitting electricity without a wire, and who has promised to make sunshine as soon as he can safely care for the 8,000,000 volts necessary for that purpose. His laboratory on South Fifth avenue was burned down a year ago, and he lost a great many valuable instruments for experimental purposes, some of which can never be replaced. This is why the world has not heard so much of Mr. Tesla during the past year. Those of his friends who have been permitted to witness his late experiments at the new laboratory on East Houston street, say that he has made some remarkable discoveries which will soon be announced.

I had a pleasant chat with Mr. Tesla the other day, and learned from him that he has about perfected his new phosphorescent light, which will come as near artificial daylight as anything yet attempted. There will be no filament in the glass bulb; nevertheless, it will glow with all the brilliancy of an arc light. The current employed will be of low voltage, but it will be changed into one of high potential by induction coils. In this way three improvements will be affected over the present incandescent lamps—brighter illumination, no deadly wires and cheaper cost.

Mr. Tesla is not yet ready to give to the public the details of his wonderful invention, but those who have seen the new light say that it will work a revolution in methods of illumination. Some remarkable photographs have already been obtained from it. It is stated that the cost will be scarcely one-half of the rates that at present prevail.

Mr. Tesla had a somewhat amusing experience not long ago in this connection. In the course of his experiments he accidentally discovered that rapid vibration has physiological effects on the human body. That a sick man, for example, may be so shaken up as to be cured of his ailments. Mr. Tesla thereupon made an "oscillator" a sort of platform which produces very rapid mechanical vibrations, and tried it upon some of his friends, Hon. Abram S. Hewitt among others. The "oscillator" worked like a charm, and some one put a squib in the papers about it which went the rounds of the country. Very soon Mr. Tesla was deluged with letters by people who wanted to be "shaken up." It seemed as if half the human family had torpid livers.

Mr. Tesla's experience in this respect was duplicated by Mr. Edison. As soon as it became generally known that the Wizard had been able to photograph through boards and the human body, letters poured into Llewellyn Park from all over the country, stating that the writers had needles, bullets or foreign substance in them. "I had no idea," said Mr. Edison, "that the country had so many patriots with bullets in their bodies. It seems from my mail as if every other person must have got hit with a stray shot."

The third electrician who is grappling with the problem of cheap illumination is Mr. D. McFarlan Moore, who claims to have solved the secret of the fire-fly. Following close upon the heels of Roentgen's rays, the discovery promises to work a revolution in electric illumination, and foreshadows an era of one unbroken day.

Mr. Moore is comparatively unknown to fame. For several years past he has been quietly at work in his Newark laboratory—which, curiously enough, is within a stone's throw of Edison's old place—and success seems at last to have crowned his efforts. He calls the new kind of illumination "etheric lighting" for want of a better name, and employs only the most simple apparatus to manufacture it. Indeed, like Roentgen's rays, the wonder is that some electrician has not before this time hit upon Mr. Moore's discovery. It is certainly as simple as it is remarkable in the effects produced. Not only is it the nearest approach to the production of light without heat that the world has yet seen, but the whole illumination is obtained from an ordinary current of low voltage.

There are no hairpin filaments in Mr. Moore's system, as with the incandespoint his walking stick in the air in any direction, as Franklin did with his lightning rod, and the electric fire will come down and illuminate the place. It doesn't matter which way the stick is pointed, he will be sure to get light sufficient to find his way upstairs.

Neither of the inventions I have just described has been placed on the market as yet, but they are liable to make their appearance almost any day. Meanwhile the oil trusts, the acetylene trusts and some of the big electric light companies would do well to be on the lookout for cheap illumination, for it is bound to come. Three electric experts have said it, and it is greatly to their credit. Perhaps we shall soon be even better off than the people at the North Pole. They have daylight half the year, whereas we are now promised artificial daylight for every hour in the twenty-four.

FRANCIS LEON CHRISTMAN.

ROENTGEN RAY LAMPS AND OTHER EXPERIMENTS.

BY

Thomas A. Edison.

A VACUUM tube, the inner portion of which has fused to it crystals of tungstate of calcium when exhausted to the X-ray stage, gives out scarcely any of the rays; on the other hand, the tubes shine with a splendid white fluorescence. We have here a true fluorescent lamp, possibly commercial, as a very small bulk gave in the photometer 2½ candle power with an extremely small amount of energy. The white light is of a character not unpleasant, but quite the contrary. The spectroscope reveals the reason; the spectrum has strong red rays.

Tubes with aluminum electrodes become coated with transparent aluminum, which, as time goes on, gets so thick as to become visible. The X-ray is greatly diminished, not, I think, so much on account of absorption of the wave after generation, but through lack of elasticity, the concussive action or energy being absorbed by deforming the aluminum.

Silicon carbide is a conductor for high-tension current, a fact previously noted by Tesla. It is a very good conductor. I have substituted pieces of the carbide for aluminum; no air comes therefrom; it does not absorb air; it cannot be melted, nor does it blacken the glass. The voltage can be increased to a point where the glass melts. It may possibly prove the most practical substance for electrodes in high vacua. The only difficulty is the contact between the carbide and platinum wire.

With all glass used for making bulbs the sodium line shows in the spectroscope; there is evidently a decomposition due to the current, electrolytic or otherwise. Combustion tube glass has the least; lime soda glass, that is, the glass used for dry plate photography, has the most. This latter glass is the most transparent to the X-ray, but the continuous decomposition of the glass makes it almost impossible to maintain a vacuum except when connected to the pump, and even then the effect of the current is greater in producing gas than the capacity of the pump to exhaust, but the ray is very powerful.

Experiments were made with over twelve hundred substances in the form of crystals and precipitates. Not one fluoresces through thick cardboard when the sources of energy are the arc light, a six-inch spark in air, a vacuum tube with vacuum so high that a ten-inch spark leaves it dark, and the direct rays of the sun from 11 till 2 p. m.

Another fact supporting the theory that the X-ray is a wave due to concussion is that crystals of calcium tungstate are very sensitive to agitation or slight friction, giving off light. It is also of interest to note that by a properly arranged sensitive flame and phonographic listening tubes, my assistants have made it responsive to the X-ray.

ARE ROENTGEN RAY PHENOMENA DUE TO SOUND WAVES?

BY PROF. WM. A. ANTHONY.

THE observations of Mr. Edison, recorded in his article in The Electrical Engineer of April 8, do not appear to me to warrant the conclusion at which he arrives. It is well known that sound shadows are not as sharply defined as light shadows and the reason is that the wave lengths of sound are very great compared to those of light. The shorter the wave lengths the sharper should be the shadows; that is, the less should the geometrical shadow be encroached upon by the radiant energy. Now the geometrical shadows for apparatus arranged as in Edison's Fig. 1 would be included between the lines a a'. Rays deflected into the shadow, as shown in that figure, could not have been due to a true difraction, but must have been due to some other cause.

The experiments of Le Conte, to which Mr. Edison refers, so far from warranting the conclusion that Edison draws from his own experiment seem to me to show that Edison's result could not be due to diffraction, and therefore has no bearing upon the question as to the nature of the Röntgen radiations. Le Conte's experiments show comparatively sharp sound shadows. Even at a distance of twelve feet from the pile, only one foot in diameter, casting the shadow, there was no apparent penetration within the geometrical boundary. If any such effect as Edison shows had occurred, the shadows should have been completely obliterated at one foot behind the pile.

The beautiful experiments of Professor Stine and of Scribner and M'Berty indicate a straight line propagation of the Röntgen radiations, and go far to prove that the result obtained by Edison must have been due to some other cause than that to which he ascribes it. These experiments were admirably adapted to demonstrate th source of the Röntgen rays, and led us back to the conclusion originally announced by Röntgen himself, which has always seemed to me to be the true one, notwithstanding all the different conclusions that have been drawn from later experiments. These results go to show how carefully Röntgen had studied the phenomena before making his original announcement.

These experiments seem to demonstrate conclusively that the source of the Röntgen radiations is the bombarded surface of the glass. It is probable, as suggested by Professor Elihu Thomson, that this bombardment produces two effects, one the Röntgen radiations and the other phosphorescence of glass, and that the greater the phosphorescence, the less the Röntgen rays.

I have always wondered why some of the various experimenters upon these phenomena have not made experiments to demonstrate, first, whether the Röntgen radiations are propagated as waves, or are flying particles shot off from the source, and, second, if waves, what is the wave length? If they are wave motions, whether the vibrations are longitudinal or transverse, the fact should be capable of demonstration by diffraction phenomena. Professor Snow, of the Wisconsin University, has suggested a method by which the test could be made.

A parallel beam of rays might be obtained by allowing the vibrations to pass successively through two narrow slits in lead screens placed a little distance apart. This beam being received upon a grating consisting of finer copper wires laid parallel to each other, should, if the radiations are wave motions, give diffraction phenomena that would demonstrate the fact, and also furnish data for computing the wave length, if the radiations consist of a few definite wave lengths only. The question whether those radiations are wave motions or an actual translation of particles, seems to me the most important one to be settled at this stage of the investigation, and I hope some one will take the matter up.

CANDLE POWER OF THE X-RAYS.

BY EDWARD P. THOMPSON.

I USED the following method in order to obtain a rough idea as to the strength of the Röntgen rays as compared with those of a candle. The process, of course, will not give the true candle-power, for the simple reason that the X-rays are not visible, but nevertheless, what may be termed the equivalent of the candle-power may be measured, so that the result impresses one with the extreme weakness of the rays in one sense, although they have so great a penetrating power.

In order to obtain the best results roughly, I receded from the Crookes' tube while looking into the skiascope, until the luminosity disappeared, and then measured the distance between the screen and the Crookes tube. It was about six feet. This represents about the usual power of X-rays, except in Tesla's results where he obtains fluorescence of calcic tungstate at 40 feet. Of course, the luminous rays of the Crookes tube were extinguished by the double thickness of black paper between it and the fluorescent screen.

I then held the skiascope (the name suggested by Prof. Magie, and which I think is by far the best) so as to face the candle, and I walked away from the same until the luminosity of the screen disappeared. The distance was likewise measured. In this case there should be no opaque substance between the candle and the screen. When it is between the Crookes tube and the screen, it has practically no effect upon the X-rays, whereas it would cut off all the rays from the candle. The distance in the latter case was about 120 feet. If the power of X-rays varies inversely as the square of the distance, a candle is 400 times more powerful in producing fluorescence than the X-rays, particularly from a Crookes tube that I employed and charged with the particular apparatus. In the same manner the candle-power of the X-rays from any Crookes tube could be measured.

It is assumed that the fluorescent screen represented the total energy for producing fluorescence as far as the X-rays were concerned. However, the candle rays are not all converted into fluorescent light; for those below the green, including yellow, orange, red and infra-red rays, produce no luminosity upon the fluorescent screen; therefore this method does not compare all the energy of the X-rays with the energy of the candle rays, but it serves to give a rough comparison. It is assumed that the fluorescent screen converted all the ultra-violet rays, violet, indigo, blue and green rays into luminous rays. This assumption may cause unknown errors in the result.

Neither would a corresponding photographic method be exact, because the silver compound would not be chemically acted upon by the infra-red rays. It should be noticed also that both methods are based upon the assumption that all the rays in both cases are converted into green rays of light by means of the fluorescent screen and into chemical energy by the photographic plate.

It remains a fact, however, that as far as we are able to transform the energies, the X-rays are weak as compared with those from the candle. Both will produce fluorescence and chemical action, but the candle very much more powerfully than the X-rays. When the two sets of rays are compared on other grounds, the Röntgen rays are more powerful, as, for for example, in reducing the sparking distance either for a positively or negatively charged insulated plate. Again, from another point of view, the candle rays can be turned out of their course by reflection or refraction. It still remains true, however, in the rough, that inasmuch as fluorescence and chemical action are both produced by the two forms of energy, therefore, these phenomena serve as a standard upon which to operate in order to obtain what may properly be called candle-power, with the restriction that it is not the true candle-power, because things of exactly the same nature are not compared. In the case of the candle-power of the sun, arc light, oxy-hydrogen flame, the incandescent lamp, gas flame, etc., their natures are the same as that of the candle, namely, all have all the luminous rays of the spectrum, but some more than others, so that in these cases we are comparing the rays of similar natures.

DIFFUSIVE REFLECTION OF ROENTGEN RAYS.*

BY DR. M. I. PUPIN.

The following communication contains a brief description of a series of experiments with Roentgen radiance which were conducted during the last six weeks. The results of these experiments seem to possess a sufficient scientific and practical importance to merit notice. The most important refer to diffuse reflection or scattering of Roentgen radiance. It seems desirable to state first, briefly, the disposition of the apparatus and the method of experimentation.

Induction Coil and Interrupter.—A powerful coil was found indispensable for strong effects and satisfactory work. The vibrating interrupter is too slow and otherwise unsatisfactory, and it was replaced by a rotary interrupter consisting of a brass pulley 6 inches in diameter and 1¼ inches in thickness. A slab of slate ¾ inch thick was inserted and the circumference was kept carefully polished. This pulley was mounted on the shaft of a Crocker-Wheeler ⅛ H. P. motor giving 30 revolutions and therefore 60 breaks per second. Two adjustable Marshall condensers of 3 microfarads each were connected in shunt with the break and the capacity adjusted carefully until the break spark was a minimum and gave a sharp cracking sound. Too much capacity will not necessarily increase the sparking, but it will diminish the inductive effect which is noticed immediately in the diminished intensity of the discharge. A powerful coil with a smoothly working rotary interrupter will be found a most satisfactory apparatus in experiments with Roentgen radiance.

Edison's Fluoroscope.—A fluorescent screen, made by Aylsworth & Jackson of East Orange, N. J., according to Mr. Edison's directions, will be found an indispensable aid in these experiments. The salt employed is tungstate of calcium, and it is so powerful that with a satisfactorily working tube it will show a noticeable fluorescence at a distance of *over 30 feet*. Those who have struggled with barium-platino-cyanide screens will appreciate fully Mr. Edison's improvement. This fluorescent screen was employed successfully for three distinct purposes. First, to study the operation of the vacuum tube un-

*Presented before the New York Academy of Sciences, April 6, 1896.

der various conditions; secondly, to shorten the time of exposure in photography; and thirdly, to study the phenomena of diffuse reflection or scattering of Roentgen radiance.

The Most Efficient Working of the Tube—The Critical Temperature.—The tubes employed were an old pear-shaped Crookes tube with a cross and several pear-shaped German tubes imported some time ago by Eimer & Amend, of New York. They all had disks at each electrode. Very satisfactory tubes are also being made now at the lamp works of the General Electric Company at Harrison, N. J. These were also employed in my experiments with completely satisfactory results. No fresh tube works quite satisfactorily with a powerful coil and a rapid rate of interruptions; it heats too much, and the vacuum becomes thus rapidly impaired and the intensity of the Roentgen radiance is very much diminished. This is true even of larger tubes. Each new tube must undergo first an electric treatment. I described this matter at some length at the meeting of the Academy on March 2. Since that time I have investigated it more fully and brought it to a satisfactory termination. Mr. Tesla has also in the meantime discussed this matter, but in what appears to me to be a somewhat fanciful way. He imagines that the vacuum of a Crookes tube becomes more and more attenuated by the passage of current through it on account of the expulsion of the gas through the walls of the bulb. He maintains that he even succeeded in piercing electrically a small hole in the tube through which the gas from the vacuum was expelled with so enormous a velocity as to prevent the outside air from rushing in. This marvelous experiment does certainly support Mr. Tesla's favorite molecular bombardment theory, but it seems to leave us with the gloomy prospect of having to refill our tubes from time to time with a fresh vacuum. The following experiments, however, lead to the conclusion that this necessity will probably never arise and that Mr. Tesla's interpretation of the cause of variation of the vacuum during the discharge is probably wrong. The electrical treatment of the tube is simply this: Pass a sufficiently strong current until the tube becomes so hot as to lose much of its Roentgen radiance. Stop then and let it cool. Repeat the operation, and observe that after each operation the vacuum has gone up and that the Roentgen effect becomes stronger. It is not advisable to drive the vacuum much beyond the sparking distance between the electrodes on the outside. But even if this point has been reached, then a judicious application of the Bunsen flame to the tube will enable the coil to force and maintain a strong enough current through the tube so as to heat it gradually, which increases the facility with which the discharge passes through the tube. The fluoroscope tells us that there is then a perfectly definite temperature at which the tube will work most efficiently, and it is desirable to operate the tube at this temperature. This can be easily done by directing currents of air against those parts of the tube where it heats most, that is, against the parts opposite to the electrodes. By a suitable regulation of the air currents, and a careful watching with the fluoroscope, the tube can be kept steadily at the temperature of its highest efficiency for hours. A deviation above or below this point will produce a very large diminution in the Roentgen effect. This temperature of highest efficiency is so sharply defined that it looks very much like a critical point in the discharge. Below this temperature the discharge is in straight lines from the cathode, and the portion of the glass opposite to the cathode fluoresces much more intensely than the rest. Above this temperature the discharge begins to spread in all directions from the cathode and the whole tube fluoresces strongly. There is then considerable flickering until the temperature is sufficiently above the critical temperature. The tube heats then rapidly and a yellowish mist begins to rise from the anode. As soon as the air blast begins to cool the tube, this mist begins to clear away and the whole tube regains a clear transparence. If the tube is made too cool the discharge becomes too faint; there is very little heating, because the coil fails to force a strong enough current. The Bunsen burner will aid the coil then to force a sufficiently strong discharge again. The blackening of the tube by the disintegration of the electrodes seems to be the only thing that will determine the length of its life.

The Combination of a Fluorescent Screen with a Photographic Plate—Photography at a Long Distance from the Tube and Through the Heavier Parts of the Human Body.—With an arrangement of apparatus as described above it was found possible to produce very much stronger photographic effects, but not sufficiently strong for penetration through the thigh and the trunk of the human body at reasonably short exposures and at long enough distances from the tube to obtain the desirable clearness in the pictures of these massive parts. A completely successful application of Roentgen's beautiful discovery to surgery depends for the present on a successful solution of the problem just mentioned. I have obtained one satisfactory solution with the method which I first described before the Academy on March 2. It consists in placing in contact with the photographic plate a fluorescent screen and thus transforming most of the Roentgen radiance into visible light before it reaches the sensitive film. Photographs of the hand were thus obtained at a distance of 25 feet from the tube with an exposure of half an hour. At the distance of four inches the hand can be photographed by an exposure of a few seconds. It was in this manner only that I succeeded in photographing on a single plate the whole chest, shoulders and neck of my assistant with an exposure of seventy minutes and at a distance of three feet between the plate and the tube. The collar button and the buttons and clasps of the trousers and the vest show very strongly through the ribs and the spinal column. This result seems to prove beyond all reasonable doubt the applicability of radiography to a much larger field in surgery than was expected a few weeks ago.

Diffuse Reflection of the Roentgen Radiance.—The question of reflection and refraction of the X-rays is a very important one. I was discussed by Prof. Roentgen in sections 7 and 8 of his original essay. Neither by photography nor by the fluorescent screen could he detect an appreciable refraction with certainty. A reflection from metallic surfaces in the immediate vicinity of a photographic film was detected, "but," quoting Roentgen's own words, "if we connect these facts with the observation that powders are quite as transparent as solid bodies and that, moreover, bodies with rough surfaces are in regard to the transmission of X-rays, as well as in the experiment just described, the same as polished bodies, one comes to the conclusion that regular reflection, as already stated, does not exist, but that the bodies behave to the X-rays as muddy media do to light."

In face of these observations made by Prof. Roentgen, Prof. Rood's and Mr. Tesla's experiments must be interpreted as a confirmation of Prof. Roentgen's results, and not as a demonstration of the existence of a regular reflection. If I understood Prof. Rood's words correctly, no claim is made by him of a discovery of regular reflection, for he says: "These facts and the character of the deformations point very strongly to the conclusion that in the act of reflection from metallic surfaces the Roentgen rays behave like ordinary light." Mr. Tesla, however, infers with much confidence regular reflection from his theory of bombardment. His method is the same as that of Prof. Rood, that is, he places a reflecting plate at an angle of 45 degrees to the direct ray and then places the photographic plate at right angles to the direction in which the reflected ray should pass if regular reflection existed. On account of the greater power of his apparatus his time of exposure was one hour, whereas that of Prof. Rood was ten hours. It is evident, however, that an effect upon the photographic plate does not prove the existence of regular reflection, as Mr. Tesla maintains with much assurance and with much rejoicing over the realization of the prophecy which he made, inspired by his molecular bombardment theory.

In my experiments on reflection I aimed at getting rid of the photographic plate and substituting the fluorescent screen in its place. Two conditions had to be fulfilled to make this substitution possible. First, a very powerful and perfectly steady discharge had to be maintained; secondly, a very sensitive fluoroscope had to be employed. The first was accomplished by the apparatus and the operations described above. The second was found in Mr. Edison's tungstate of calcium fluoroscope. The tube was placed between two thick planks of pine coated with sheet lead one-sixteenth of an inch thick. This screening was found to be somewhat insufficient when the tube operated at maximum efficiency, and another screen, consisting of a thick copper plate, had to be employed. The planks were placed so as to form a wedge around the tube. The cathode streamer was horizontal and passed through a vertical slit formed by the edges of the two screening lead-covered planks. In front of this slit was a fixed pivot on which a mirror could be rotated. The mirror consisted of a polished sheet of platinum pasted upon a rectangular piece of pine board of nearly the same area as the platinum sheet and about one inch thick. The slit was made one-sixteenth inch wide and its image was examined by means of the fluoroscope. The tube was six inches from the slit.

a. Quite near the slit the image was sharp and intense. But as the fluoroscope was gradually moved away from the slit its image broadened out somewhat, and there was at each side of it a diffuse border. At about two inches from the slit the image of the slit looked like a wide spectral line upon the less luminous background of a wide band which shaded off gradually into the dark space of the screen. With increase of distance the relative intensities of the two grew more and more equal, and at about six inches from the slit the whole fluorescent screen (about 6 ins. by 4 ins.) was uniformly illuminated. There was evidently a diffuse scattering of the X-rays in their passage through the air. This inference was confirmed by other experiments which will be discussed presently. Various well-known devices were employed to concentrate the cathode rays along the axis of the tube, as, for instance, wrapping tinfoil around the tube. This, however, did not diminish the gradual diffusion of the image of the slit on the fluorescent screen when the distance between the slit and the fluoroscope was gradually increased. Up to about three inches from the slit the real image of the slit could still be distinguished easily from the diffuse background as a band of maximum intensity.

b. The platinum mirror was now placed quite near the slit and at a convenient angle to the direction of the ray and the fluoroscope was placed quite near the mirror. There was a faint illumination of the fluorescent screen, but it was perfectly uniform. Not the slightest indication of an image of the slit could be detected, although the distance between the slit and the mirror plus the distance between the mirror and the fluorescent screen was less than the distance at which the image of the slit on the fluorescent screen appeared as a band of maximum intensity when observed directly. A change in the angle of the mirror produced but a small change in the fluorescence of the screen, and then the change seemed to be such as to approach a maximum when the mirror and the fluorescent screen were parallel to each other. The same experiment was repeated with other metals and with the same result. This experiment, therefore, does not speak in favor of regular reflection.

c. Turning the mirror completely around, so that the face of the wooden block on which the metal plate was fastened served as a mirror, it was found that the fluorescent effect upon the screen was

stronger than with the platinum. A pad of paper of about the same size as the wooden block acted more strongly than the platinum or any other metal. Various substances were tried, like glass, vulcanite, the hand, various metals, and they all produced a diffuse reflection of varying intensity, and at all angles of inclination. In all cases the maximum effect seemed to take place when the broadest side of the reflecting object was about parallel to the fluorescent screen. But the fluorescence was very weak as long as the slit was narrow.

d. The slit was now made wider, and the same series of experiments was repeated with various widths of the slit. The fluorescence of the exploring screen increased, of course, with the width of the fluorescent screen. The observations made with the narrow slit were confirmed. In every case the maximum intensity on the exploring screen was obtained when the broadest side of the reflecting object was about parallel to the screen. Wood and other transparent insulators produced in general a stronger effect than metals. No accurate quantitative comparisons have yet been made. Among the insulators experimented with, wood produced the strongest effect, and among the metals aluminum was the weakest. The thickness of the reflecting plate increases the effect; this increase will go on until the reflecting plate is several inches thick if this plate is an insulator. In the case of metals, however, like sheets of iron or copper, the increase in the fluorescent effect ceases as soon as the reflecting plate becomes thick enough to be practically opaque to the direct ray.*

e. The human body when in the path of the X-rays will act as a reflector. It is quite an easy matter to detect a person walking across the room in the vicinity of the slit, for as soon as a person crosses the path of the X-rays the fluoroscope will light up. While making this particular observation, I noticed that when the tube was operating especially well a faint fluorescence was still present even if no reflecting body was in front of the slit. Precautions were observed to exclude any radiance that might reach the fluoroscope directly by a sort of diffraction around the edges of the slit, but still the fluorescence in the fluoroscope persisted. There was evidently a diffuse scattering of the Roentgen radiance in the air itself. This, however, was so small that it was distinctly noticeable only when the tube operated so powerfully that a strong image of the hand on the fluorescent screen could be obtained by the radiance reflected from a pine board two inches thick and sixteen inches squared, placed at a distance of six inches from the slit. With a good-sized tube of proper vacuum and working at the temperature of highest efficiency, this intensity is not at all difficult to obtain, provided, of course, that one has sufficient electric power to excite the tube.

These experiments prove beyond all reasonable doubt that the Roentgen radiance is diffusely scattered through bodies, gases not excepted. We may call it diffuse reflection if we choose, provided that we do not imply thereby that we must necessarily assume an internal intermolecular regular reflection in order to explain the phenomenon. For if a puff of smoke be forced through a pile of wood some of it will come out pretty well scattered, although we cannot speak here of a reflection in the ordinary sense, but rather of deflection, reserving the term "reflection" for those particular cases in which the angle of incidence is equal to the angle of deflection. It might turn out, for instance, that the X-rays are due to a circulating motion of ether, and that the stream lines are partially deflected and diffusely scattered within the molecular interstices of ponderable substances. Appearances seem to speak more in favor of this view than in favor of a wave motion of ether.

The diffuse scattering of the Roentgen radiance by bodies placed in its path may be also described by saying that *every substance when subjected to the action of the X-rays becomes a radiator of these rays*. This statement will be more complete than the statement that a diffuse reflection takes place, if my observation should prove correct that the maximum effect in the fluoroscope is obtained when the largest surface of the body acted upon by the Roentgen radiance is placed parallel to the fluorescent screen. For in that case the secondary radiation due to the diffuse scattering will proceed normally to the surface of the intercepting body.

The fact that opaque bodies like metals are less effective in producing this secondary radiation leads to the conclusion that there is in these bodies an internal dissipation of the Roentgen radiance much greater than in the case of transparent dielectric substances. A properly constructed bolometer should give us much information on this point, and it is my intention to take up this subject as soon as time and facilities will permit.

These diffusion effects, which are present even in air, bring the Roentgen radiance into still closer resemblance to the principal features of the cathode rays which were studied by Prof. Lenard. The difference in their behavior towards magnetic force is still to be explained. Is it not possible that this magnetic effect in air is marked by the diffuse scattering of the X-rays?

In conclusion, I wish to observe that among the several theories proposed to account for the properties of the X-rays we may insert one which can be easily inferred from the somewhat neglected essay which the late Prof. von Helmholtz wrote toward the closing days of his life. It is the essay, "Inferences from Maxwell's Theory Concerning the Motion of Pure Ether" (Wissenschaftliche Abh., B. III, p. 526; Wied. Ann., Vol. LIII, pp. 135–143).

Postscript.—My attention has just been called to an investigation published by MM. A. Imbert and H. Bertin-Sans in the *Comptes Rendus* of March 2, pp. 524–525, in which experiments almost identical with those of Prof. Rood and Mr. Tesla were described, and the inference drawn that the X-rays are diffusively reflected and that the amount of this reflection depends much more on the nature of the reflecting substance than on the degree of its polish.

In an article in the *Electrical Review* of April 8, Mr. Tesla states that he also employed recently a fluorescent screen for the purpose of shortening the time of exposure in photographing with the X-rays. He attributes the suggestion of this method to Salvioni, of Italy, and Charles Henry, of France. This calls for a comment on my part. I have been unable to locate Mr. Tesla's source of Italian information. The French source is in *Comptes Rendus* of February 10, p. 312. There is no explicit statement there, nor a suggestion that a fluorescent screen would be practicable in connection with X-ray photography, but I admit that this can be easily inferred. There is no doubt that the idea of employing the fluorescent screen must have occurred to a great many people as soon as they received full information concerning Roentgen's discovery, as it occurred to me. I made the first successful experiment on February 7, and have the plates still in my possession, signed by a gentleman who was experimenting with me on that day. On February 8, I wrote an article which appeared in *Science* of February 14. In this article the following sentence will be found: "A fluorescent screen placed in front of the sensitive plate for the purpose of shortening the time of exposure gave encouraging results." The same sentence occurs in an article published in ELECTRICITY of February 12. Ever since that time I worked faithfully on this matter, and how successful I was may be inferred from the following letter which Prof. Arthur G. Webster, of Clark University, wrote to the Worcester *Gazette* of March 2:

To the Editor of the *Gazette*.

Sir: In case the interest in the Roentgen rays still holds out it may not be an intrusion to your columns if I describe an experiment which I saw made yesterday morning. My own supply of glass tubing having run out, and my efforts to procure some from New York having been of no avail, I ran down to New York to procure some supplies and to talk over matters with my friend, Professor Pupin of Columbia College, who has obtained some of the best results in this country.

Sunday morning I went with Professor Pupin to his laboratory to try the effect of a fluorescent screen in front of the plate. I placed my hand under the bulb and in five minutes the current was stopped. I was skeptical as to anything appearing on the plate, but as I have been skeptical with regard to many things connected with this matter which have turned out to be true, I was not greatly surprised when the plate developed up plainly. The res of was the best plate that I have yet seen. All the bones of the hand showed with extreme sharpness, even the small bones of the wrist being perfectly plain, in marked contrast to most of the pictures that have been published. Whereas the time of five minutes may not seem wonderful to those who have read the report of the five seconds' exposure at Harvard, it is necessary to have compared the results in order to make a fair comparison. One who has tried the experiments and seen how long it takes to obtain a good result can judge of an improvement. Whereas the idea of a fluorescent screen is one that must have occurred to many, as it did to the writer, I think that Dr. Pupin should enjoy the credit of having actually carried it ou and shortened the time of exposure ten and twenty time thereby.

Very truly yours,

ARTHUR G. WEBSTER.

On the same day I described this method at considerable length before the New York Academy of Sciences. Within the last few weeks, since Messrs. Aylsworth & Jackson succeeded in making just the screens which I wished to have, my success of Roentgen ray photography has been all that I could wish for it.

My only object in working on the improvement of the Roentgen ray photography was for the purpose of widening its scope of application to surgical diagnosis. I think that I have succeeded completely in it and I wish full credit for the work done.

M. I. PUPIN.

Columbia University, April 14, 1896.

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*The effect of varying the thickness of interposed metals appears to give sometimes anomalous results. Thus two sheets of polished tin appeared to give less of the scattering effect than one. This point needs additional inquiry.

THE ROENTGEN RAYS.*

By Edwin J. Houston, Ph.D., and A. E. Kennelly, Sc.D.

THE announcement of a scientific discovery has seldom produced so intense an excitement throughout the civilised world as has that made in December last, by Prof. W. C. Röntgen, of Würzburg, Bavaria, concerning his ability to obtain a photograph of the bones of an animal through its living integument. His announcement, indeed, has created so intense an excitement and enthusiasm that, although the discovery is practically only a few weeks only, yet his experiments have been repeated in all parts of the world.

The authors have been requested, by the Franklin Institute, to present to its members a *rèsumé* of the facts that are known concerning Röntgen's discovery, as well as of some of the theoretical explanations which have been offered in connection therewith.

The paper in which Prof. Röntgen announced his discovery was addressed to the Würzburg Physico-Medical Society in December last. Prof. Röntgen describes in this paper the method he adopted for obtaining the peculiar form of radiant energy now generally known as the Röntgen rays, and for which he proposed the provisional name of X rays. On passing the discharge from a large Ruhmkorff coil through a suitably exhausted tube of the Hittorf, Lenard, or Crookes type, a peculiar effect, invisible to the eye, is produced in the region outside the tube. This effect, however, can be rendered visible by the fluorescence excited in a paper screen, painted with a solution of barium-platino-cyanide. In vacuum tubes of the type referred to, the passage of the proper discharge is attended by the production of rays, called cathode rays—that is, rays projected in straight lines from the cathode, or negative electrode, of the vacuum tube.

It was observed by Crookes that these cathode rays were not produced to an appreciable degree until a certain high vacuum was reached. Crookes showed by his experiments that, in so high a vacuum, matters could be regarded as existing in a fourth state or condition, to which he gave the name of the

Radiant or Ultra-Gaseous State.

The highly rarefied matter contained in these vacua is capable of producing characteristic effects when subjected to heat or electrification. For example, when an electric discharge is passed through the residual atmosphere in the tubes, the molecules are shot off in rectilinear paths from the cathode, and wherever they strike the walls of the glass tube, or suitable bodies placed in the tube, they produce a faint fluorescent light. Crookes showed that these cathode rays were capable of being deflected from their original rectilinear paths by the action of a magnet. They thus behave in conformity with the view that they consist of streams of negatively charged molecules, the deflecting action being merely a particular kind of electro-magnetic action, well seen in the deflection of a voltaic arc by a magnet, or in the electro-magnetic motion of the armature of the electric motor.

Hertz discovered that the cathode rays readily pass through thin films or screens of mica, or even of metal. He showed that, in fact, metallic films were even more transparent to the cathode rays than films of mica. For example, when such metallic screens were interposed in the vacuum tube between the cathode and the glass walls on the tube opposite the cathode, fluorescence was still developed in portions of the tube which would have corresponded to the shadow of the screen, had it been opaque.

Lenard, at one time an assistant of Hertz, took the matter up, and showed that fluorescence could be produced by the cathode rays outside the glass vacuum tube. For this purpose, he placed a small window of aluminium in the walls of his vacuum tube, so that the stream of cathode rays would impinge upon this window. A change of some sort appeared to occur at the window. While in the tube the rays proceeded along straight lines, unless deflected by a magnet; outside the window they preserved rectilinear paths, but radiated in all directions from the window as a source. These rays, produced outside the vacuum tube by the cathode rays within the vacuum tube, may be called

The Lenard Rays.

In common with the cathode rays, the Lenard rays possess the power of producing fluorescence in fluorescent substances upon which they impinge. They differ from the cathode rays in the fact that, in the air, they are visible to the eye as a faintly glowing stream or pencil, which rapidly diminishes in intensity, at comparatively short distances from the window. All the effects of the Lenard rays became lost at a distance of a few centimetres from the window, so rapid is their absorption in the air or other media. Hydrogen was found to be the least absorptive—that is, the most transparent medium; but hydrogen, under great pressure, becomes more opaque. Lenard showed that many of the metals are partially transparent to his rays, and that sensitive photographic plates, or films, are quickly blackened by their influence. In fact, Lenard took shadow photographs of opaque or semi-opaque bodies, by interposing them in the path of the rays before they impinged upon the sensitive photographic plate held in a light-tight box, provided with an aluminium cover or slide. Lenard found that the opacity of different substances to his rays varied, approximately, with their density.

In the paper before referred to, Röntgen announced that, when a suitably exhausted vacuum tube is placed under a cover of blackened pasteboard, fluorescent effects can be obtained, not merely at a distance of a few centimètres, but even at a distance of two metres, in air. He employed for this purpose a paper screen painted with a solution of barium-platino-cyanide. The Röntgen rays, unlike the Lenard rays, are invisible to the eye, even close to the vacuum tube. No window is necessary in the vacuum tube to produce the Röntgen effect, although Röntgen has produced the effect through an aluminium window. As in the case of the Lenard rays, the Röntgen rays are radiated in rectilinear paths in all directions from the portions of the walls of the tube subjected to the bombardment of the cathode rays.

It will thus be seen that a similarity exists between the Lenard and the Röntgen rays, so far as their method of production is concerned. In each, the source of the rays is to be traced to the impact of the cathode rays upon the wall of the vacuum tube in which they are produced. In each, the rays possess the power of exciting fluorescence in suitable bodies on which they impinge; in each, they possess the power of passing through substances opaque to ordinary light, the opacity in each case increasing apparently with the density, although not in direct proportion.

The Röntgen rays appear to differ from the Lenard rays in the fact that they are not so readily absorbed by air or other media. If no absorption existed, the intensity of the rays would, of course, diminish as the square of the distance from their source. Röntgen claims that he has observed that this rate of diminution in the intensity of his rays does exist within the limits of observational error. This peculiarity of the Röntgen rays has greatly enhanced their practical value.

Similarity of the Lenard and Roentgen Rays.

It will be seen, therefore, that the difference between the Lenard and the Röntgen rays is not marked. The difference appears to be one of degree rather than one of kind. There is, however, at least one difference in the rays under discussion. Lenard found that his rays are not appreciably deflected by a magnet when passing through air, but that deflection does occur when his rays were allowed to traverse a highly-exhausted chamber. Röntgen mentions that, up to the present time, he has not been able to produce any deflection of his rays by a magnetic field. This has been confirmed by Dr. Oliver Lodge. Röntgen is also experimenting with the action of an electrostatic field, but we believe he has not as yet announced any result.

The curious fact pointed out by Röntgen in the paper before referred to of the ability of his rays to produce upon a sensitive photographic plate photographs of the shadows of, say, the bones of the hand in the living subject, has naturally caused great popular excitement and interest. There can be no doubt that this fact will prove of great value to the surgeon, especially if, as would seem probable, means are perfected for the production of these rays with increased power.

Röntgen states, as a result of observation, that his rays are apparently incapable of reflection, refraction, or interference. If refraction does exist, it must be of very limited amount. These facts have led Röntgen to suggest that his rays are not light in the ordinary physical sense of the term; that is, that they do not consist of a transverse vibration propagated in the ether, according to electro-magnetic laws, but that possibly they may be a longitudinal motion propagated in the ether, a condition which Prof. S. P. Thompson has happily named "ultra-violet sound," and which others have called "ethereal sound" and "longitudinal light."

The details of the method for producing Röntgen rays do not appear yet to have been published by Prof. Röntgen. Physicists, however, have very generally reproduced them, although thus far the shddowgraphs obtained in this country do not present the sharpness and depth which apparently characterise Prof. Röntgen's shadowgraphs.

Modus Operandi.

The authors have successfully obtained Röntgen rays by the use of a large induction coil excited directly by storage cells through an interrupter, the secondary terminals of the induction coil being led directly to the terminals of the Crookes tube. In this case the cathode is the source of cathode rays in the tube, and the surface of the glass opposite to the cathode, where fluorescence is produced, is the source of the Röntgen rays. We have found, however, as others have done, that by far the best results are obtained by using a high-frequency discharge through the Crookes tube. This is conveniently done by exciting the primary of the induction coil from a 50-volt alternating-current circuit, such as is employed for supplying incandescent lamps on commercial alternating-current circuits at, say, 15,000 alternations per minute. The secondary terminals of the induction coil are led to a battery of Leyden jars through the primary coil of a Tesla induction coil immersed in oil. The secondary terminals of the Tesla coil are then connected directly to the Crookes tube. Under these conditions torrents of high-frequency discharges pass between the discharging knobs of the induction coil, which are separated to a distance of perhaps five millimètres, the frequency being determined by the capacity and inductance of the Leyden-jar circuit, including the Tesla primary. These high-frequency discharges induce in their turn high-frequency and high-tension discharges in the Crookes tube. In such cases both electrodes of the Crookes tube are alternately cathodes, and the glass wall opposite to each electrode becomes fluorescent, and, therefore, the source of Röntgen rays.

The practical difficulties in connection with the production of the Röntgen rays arise from the fact that the Crookes tubes, as ordinarily constructed, are not designed to stand the molecular bombardment of the cathode rays, when of fairly great power, for any considerable length of time. Since the ordinary Röntgen shadowgraphs require exposures lasting usually half an hour, and sometimes several hours, a great liability exists to excessive heating of the tubes and the destruction of their vacua. Indeed, at times, the heat produced by the molecular bombardment of the cathode rays is sufficient to melt the glass walls of the tubes, as the authors, most probably in common with others, have ascertained to their loss.

Since the high-frequency discharges obtained by the use of a Tesla coil are not characterised by such marked heating effects, either at the walls of the tubes or in the electrodes, they are greatly to be preferred for producing shadowgraphs. Independently of this, however, they appear to produce a more powerful image. Possibly the velocity with which the molecules are projected from the cathode, or their number, or both, are increased.

Tesla Coil.

A simple form of Tesla coil may be made by winding a primary of about eighty turns of No. 19 A.W.G. cotton-covered copper wire over a glass tube about ¾in. in diameter, and inserting this inside a slightly larger glass tube, over the surface of which has been wound a secondary of about 400 turns of about No. 31 A.W.G. fine silk-covered copper wire. The coil is then immersed in some high insulating oil, such as rosin oil.

In the shadowgraph of such portions of the human body as, for example, the hand, the bones cast the most marked shadows, and the surrounding tissues produce shadows intermediate in intensity. The density of the shadow which is cast upon the plate depends apparently upon the total quantity of matter which the rays have to traverse. Thus, a short passage through a dense substance produces the same depth of shadow as a long passage through a rare medium. In order to obtain sharp definition, the use of a diaphragm is recommended. An iron or lead plate provided with a suitable aperture, and placed between the tube and the photographic plate, is suitable for the purpose.

It is stated by Prof. Silvanus P. Thompson that distinct shadow photographic effects have been produced by the ordinary arc light, so that it would appear that some Röntgen effect is produced by the voltaic arc.

It has recently been discovered by Prof. Pupin and others that, in order to obtain the cathode rays in a vacuum tube, it is not necessary to employ electrodes within the tube itself; but if pieces of tinfoil are placed outside the vacuum tube, and the terminals of the high tension coil are connected therewith, discharges are produced in the vacuum tube by electrostatic induction. These discharges produce fluorescence in the tube, and the fluorescent glass is again the region of Röntgen rays.

Molecular Bombardment.

This would appear to show that the Röntgen rays are produced by molecular bombardment by the molecules of the residual atmosphere of the high vacuum, and that the metallic cathode is only to be regarded as an auxiliary means for producing this bombardment.

Prof. J. J. Thomson has recently made the extremely important discovery that the Röntgen rays tend to discharge an electrified body on which they impinge, and this whether the charge of the body be positive or negative. Prof. Thomson finds that a charged body constitutes a more sensitive test for the presence of the Röntgen rays than is afforded by either a sensitive photographic plate or a fluorescent screen. This effect takes place whether the charged body be covered by a layer of paraffin, sulphur, or vulcanite. In other words, as Prof. Thomson points out, the remarkable fact exists that

* From the *Journal* of the Franklin Institute.

an insulating layer becomes electrically leaky while being traversed by the Röntgen rays.

Hitherto no means have been known, beyond mere thermal influence, for altering the electrical insulating power of solid materials by radiant energy of any character. The discovery of this property of effecting electric discharge makes the ray far more wonderful and important to physicists than its property of penetrating opaque solids as displayed in shadowgraphs.

The degree of exhaustion in the vacuum tube, which is the source of the Röntgen rays, appears to be that required for rectilinear molecular bombardment. Edison has shown, experimentally, that below a certain exhaustion the Röntgen effect is negligibly small, while above a certain exhaustion the intensity of the effect again decreases. In general, it may be said that a vacuum which produces a bluish violet light on the passage of the discharge is too low to produce the Röntgen effect. The best results are obtained when little or no discharge is visible within the tube; but the walls are rendered fluorescent with a peculiar greenish tinge. This is usually obtained at about one-millionth of an atmosphere.

Since the Röntgen effect is evidently due to molecular bombardment, and varies with the degree of the vacuum, it would appear that good experimental work can be conducted, both by ascertaining the best degree of vacuum in tubes containing rarefied air, and by ascertaining whether gases other than air will produce, in such tubes, better results. It would appear that the Röntgen rays must be either a material propagation or an ethereal propagation. A material propagation would require either that ordinary matter be projected rectilinearly as a whole along the rays, or that some disturbance in matter is projected along them.

The burden of probability seems to be against the assumption that the Röntgen rays consist of a material propagation, since they not only traverse opaque, dense substances, but also appear to be unaffected by a magnet. Assuming, therefore, that the Röntgen rays are an ethereal propagation, they must either consist of a translatory movement of the ether, or of some disturbance propagated along it. Such a disturbance would, probably, have to be periodic or vibratory. The vibrations might be transverse, or they might be longitudinal to the path of the ray. Physical science is acquainted with transverse ethereal vibrations, such being, in fact, electro-magnetic vibrations, or ordinary light. These vibrations differ in their frequency, and hence in their wave-lengths, but are not known to differ in their speed through free ether. In the ether within material substances their velocity of propagation is reduced, as is evidenced by their refrangibility. This is true of all known transverse vibrations from the lowest frequency, far below the red, produced by the discharge of a Leyden jar, and detected only by electrical methods; through the higher-frequency waves, still in the infra-red and constituting direct heat; throughout the limits of the visible spectrum, and beyond the violet in that frequency which is detectable only by chemical or by electric eyes. The marked characteristics of these transverse vibrations are their refrangibility, their reflectibility, and their possibility of interference—characteristics which are all apparently wanting in the Röntgen rays.

It would, therefore, appear that the Röntgen rays are not transverse vibrations of the ether. If they are, they do not appear to lie within the range of frequency hitherto explored, a range extending from about 100,000 to about 1,000,000,000,000,000 (a quadrillion) waves per second. There is reason to believe that, if they have a wave-length, this wave-length is long, compared with that of visible light, since they pass through appreciable distances of gross matter, distances measured in centimètres or hundredths of a mètre, rather than in microns or millionths of a mètre. Such waves would correspond to dark heat-waves, in the infra-red.

It is known that ultra-violet light possesses the power of discharging a negatively charged body upon which it falls directly, while, as Prof. J. J. Thomson has discovered, the Röntgen rays can discharge bodies either positively or negatively charged, even while imbedded in a layer of highly insulating material.

Longitudinal Ethereal Vibrations.

Dr. Lodge has shown that, when polarised ultra-violet light strikes such a negatively charged polished plate, it is most effective in producing discharge when striking at an angle, instead of perpendicularly, and, consequently, the discharge may, perhaps, be effected by a longitudinal component of the impact. This seems to favour the supposition that the Röntgen rays are longitudinal ethereal vibrations.

The material substances with which we are familiar, and which are capable of transmitting vibrations transversely to the direction of propagation, are also capable of transmitting longitudinal vibrations. The fact that longitudinal vibrations in the ether have hitherto remained undiscovered has caused no little inconvenience in the framing of hypotheses concerning the action and properties of the ether. If ether resembles material substances, its velocity of propagation for longitudinal vibrations would be much greater than that of its velocity of propagation for transverse vibrations; consequently, for any given frequency of vibration, the wave-length would be greater than that of light waves.

Summing up, then, while it is far too early to form a reliable conclusion concerning the nature of the Röntgen rays, such evidence as does exist would appear to favour the theory of longitudinal vibrations in the ether.

Whatever may be the future of the Röntgen rays, so far as their practicable applicability or scientific value is concerned, great praise must be accorded to Prof. Röntgen for the exceedingly interesting and important contribution he has made to this branch of molecular physics.

Röntgen Rays.—The *Elec. Rev.*, April 1, contains another communication from Mr. Tesla, the greater part of which is descriptive of his researches with the reflection of Röntgen rays, including an illustration of the apparatus used. His researches have strengthened his conviction that the rays are streams of material particles possessing a great velocity, and they should therefore be capable of being reflected; he describes and shows a form of tube which consists of a cylinder of very thick glass, the bottom of which is made very thin, and the top of which contains the single electrode which should be of aluminum, as platinum gives inferior results, and the bulb is disabled in a comparatively short time; he describes briefly how a fairly constant vacuum may be maintained and produced electrically. It is not literally true that the Crookes vacuum is not high enough for producing the Röntgen phenomena, which manifest themselves even with poor vacua, provided the potential is high enough; to prevent overheating when the potential is raised, the number of impulses or their duration should be reduced, and it is therefore well to use a rotating commutator in connection with the ordinary coil instead of a vibrating make-and-break; with this rotating commutator the conditions may be adjusted to suit the degree of the vacuum and the potential. In his experiments with reflection he used a T-shaped box of lead, which was found to be entirely impervious; the bulb was placed at one end of the straight piece, and the sensitive plates were placed over both of the other ends, the reflecting plate being secured at the proper angle in the middle; one plate would therefore be affected by transmitted rays and the other by those which are reflected; images which were exactly alike were placed over the two plates. The results of the observations are given in a table for 12 different materials most of which were metals, and approximate calculations were made to show the relative impression by reflected rays, which appears to have varied from 0 per cent. for aluminum to 3 per cent. for zinc, the percentage being based on the impression by direct action; he considers these figures fairly correct as relative values; arranging the metals according to these values, he arrives at the following order: zinc, lead, tin, copper, silver; this order is precisely that in the contact-series of metals in air, which if true he considers an extraordinary fact; the one possible explanation he thinks is that the bulb throws out streams of matter in some primary condition and that their reflection depends on some fundamental and electrical properties of the metals; this seems to infer that these streams must be of uniform electrification, that is, anodic or cathodic, but not both. He does not agree with the statement that the streams are anodic, as he finds that both affect the plate; also that the phosphorescence of the glasses has nothing to do with the photographic impressions, for when aluminum vessels are used there is no phosphorescence. In connection with induction coils, both terminals of a tube are acted upon alike, as long as the tube is not very highly exhausted; at a high degree of exhaustion both electrodes act practically independently and the coil is then unbalanced; a hot anode emits a more intense stream than a cool cathode. He found that a brass plate of $\frac{1}{16}$ inch thickness proved fairly transparent while copper and zinc plates of the same thickness were entirely opaque. With the use of proper reflectors he produced stronger effects; by surrounding a bulb with a thick glass tube the effect may be considerably increased; the use of a zinc reflector showed an increase of about 40 per cent.; by the proper use of reflectors any number of bulbs may be used, thus producing any desired intensity of radiation. He has failed so far in his efforts to demonstrate refraction, although he tried a great many experiments. The issue of April 8 contains another communication from him. In making further experiments with reflection he used two metallic plates simultaneously, placed next to each other, so as to compare their reflecting power; a thick lead plate divided the box into two halves to prevent the rays from intermingling; the result showed that iron reflected about as much as copper, and that tin was a trifle better than lead, also that magnesium was a little better than zinc. He found it possible to reduce the time of exposure of plates to a few minutes with the aid of fluorescent paper placed near the sensitive film. Although zinc reflected only 3 per cent. of the rays when the angle was 45 degrees, the amount would be much greater for larger angles, and as such a large proportion of the rays radiate out into space, a reflection of even a small proportion of them may increase the effect several times; as an evidence of the effectiveness of such a reflector, he shows a print of the shoulders and ribs of a man which was obtained with the aid of a funnel-shaped reflector in connection with the tube; the exposure was 40 minutes, and the plate showed very strongly every bone and rib; the chief use of the reflector is that it allows the use of many bulbs without sacrifice of precision, as also a concentration on a small area. By the use of fluorescent bodies in connection with a sensitive film, he has shortened the time of exposure to even a few seconds; owing to the large size of the crystals of tungstate of calcium, the impression is not very clear; for use in connection with sensitive films it should therefore be ground very fine and distributed uniformly and the paper should adhere firmly to the film all over the plate. The fluorescence of this body seems to depend on a peculiar radiation, as it was different with different bulbs, which otherwise worked very successfully; an impression of a hand was taken at six feet in less than a minute, and even then it was over-exposed; the bulbs are very apt to explode, owing to the great internal pressure against the bombarded spot; when using phosphorescent paper in connection with the film the time of exposure is reduced so much that the thickness of the object is not of very much consequence. The fluoroscope of Edison, he states, is really Salvioni's cryptoscope with the lens omitted, which he thinks is a great disadvantage; with it he could easily distinguish the spinal column in the upper part of the body, which is more transparent than the lower, at a distance of about three feet from the bulb; through the body he could easily see the shadow of a square plate of copper; he thinks that improving the fluorescence will not add much in the examination of the internal parts of the body, and that the solution will probably come through the production of very powerful radiations; the fluoroscope does not give nearly as clear impressions as the photograph; the use of the screen for noting the effects of reflection, refraction and diffraction proved futile. The same journal publishes some comments on Tesla's work, by others, which, however, contain nothing of importance, technically.

The same journal contains an interview with Prof. Salvioni. He mentions briefly that he endeavored to find the velocity of the rays, so as to decide whether they are light or matter, and the conclusions so far obtained lead him to believe that they are matter, but he is not sure of the result; he also attempted to find whether objects present color phenomena analogous to those of light, and the results so far have been negative, giving support to the supposition that the rays are projected matter, but he has not yet reached definite conclusions. In the impression of a frog, if over-exposed, the ribs disappeared, showing the lungs, heart and another organ corresponding to the spleen. He also studied the transparency of the eye, arriving at the conclusion that it is hardly transparent. He describes his cryptoscope (see *Digest*, March 14). In an experiment he noticed that when he touched the tube with the hand, the luminous aspect varied, the tube first losing its fluorescence, which is then re-excited, reaching a great maximum, and is then relegated to the anode; it is sufficient to bring a metallic point connected with the earth or with the cathode, in contact with the tube, to obtain a very intense fluorescence confined to about one square centimetre, opposite to the place at which the tube is touched; "with this system the exhaustion of the tube can also be avoided, as with the metallic point the fluorescent zone can be successively displaced."

McClure's Magazine contains an interview with Prof. Röntgen by a reporter of that journal, which is reprinted in the *Elec. Rev.*, April 1; parts of it are interesting, although it does not contain anything of importance scientifically.

The *Elec. Eng.*, April 8, contains a short article by Mr. Edison suggesting that the X-ray was a sound wave of very small wave length, and that the shadows were sound shadows; he refers to an article by LeConte in the *Phil. Mag.*, Feb., 1882, a reprint of which with illustrations accompanies the article, on experiments with sound shadows. Edison describes an experiment in which the source of X-rays was placed on one side of a steel plate and on the other side it was noticed by means of the fluoroscope, that the rays seem to be refracted or bent around the edges of the plate. In another experiment which he believes tends to confirm the theory, he found that liquids do not fluoresce, while crystals alone do, crystal being "resonant to the wave." In another experiment he found that a tube with too low a vacuum, which ordinarily produces no X-rays, can be made to generate them by a powerful blast of air on the spark of the break wheel, and a spark gap in the secondary. Another observation was that the sharpness of the shadow depends on the abruptness of the break. With Sprengel pumps used for incandescent lamps, the vacuum is too high for the best results; if a definite amount of air is allowed to enter the bulb, the rays will flash out with great brilliancy, diminishing again as the exhaustion is continued.

The same journal contains an article by Dr. Morton, in which he gives an illustrated description of a bulb with a piece of fluorescent material mounted in it, and from this he believes the X-rays proceed. He also describes another form of tube, consisting of a glass cylinder with rounded ends, having an external electrode in the form of a disc of aluminum at one end, and a cap of aluminum covering the other end and the greater part of the walls of the tube, the edges nearest the other electrode being serrated, to provide for possible sparking between the electrodes and thus prevent perforation of the tube; the rays pass through the large cap-shaped anode, the cathode being the smaller one; this bulb is said to work well with a static machine.

The same journal contains an article by E. P. Thompson, describing experiments to determine whether ordinary phosphorescence will produce these rays; while his experiments do not prove that the rays do not have their source alone in the phosphorescence of a charged tube, yet he believes that they form substantial evidence that the rays are not obtained from phosphorescence by sunlight. There is also published in the same issue a reprint of a Röntgen photograph of 29 different objects, made by Prof. Terry, of the U. S. Naval Academy.

According to the *Amer. Jour. of Science* for April, DOELTER showed that different gems may be distinguished from each other and from their imitations by means of the X-rays; the true diamond may be distinguished from the false one; rock crystal, topaz, strass and spinel are opaque to the rays, while the varieties of the corundum, such as the ruby and sapphire, transmit them to some extent; among the minerals there are

exceptions to the accepted relation between the opacity and the density; sulphur, realgar, quartz and fluorite are quite opaque; corundum transmits somewhat, while diamond and graphite transmit much better; silicates are opaque, which is also true of mica in layers of one mm; in sections of about one third mm it is possible to distinguish between the transmissive powers of amphibole, garnet, quartz, mica and feldspar.

The *Sc. Amer.*, April 4, contains a brief description of some of Edison's experiments.

Electricity as an Exact Science. CROCKER. *Elec. Eng.*, April 1.—A brief report of a recent lecture before the Franklin Institute. He showed that electricity was one of the exact of the known sciences, being second only to astronomy; the most important test of the science is the power of prediction; a dynamo or motor can to-day be calculated from drawings before the machine is built, more nearly than by a test made of the machine itself; this assertion cannot be made of a steam engine or other like machines; other illustrations of the exactness of the science are given.

The New York Herald April 18, 1896

SAW THROUGH THREE MEN.

Nicola Tesla Has a Tube by Which He Looks Through Three Bodies.

Nicola Tesla was very busy with his experiments when I called yesterday afternoon at his laboratory in Houston street. He had a very elaborate apparatus at one end of the laboratory for the generation of the X rays. The vacuum tube was more than four feet long, and so great was the electrical power applied to it that it was filled with a brilliant fluorescence for its entire length.

With this big, brilliant tube and his fluorescent screen, which is simply cloth coated with tungstate of calcium crystals, Mr. Tesla is able to see clear through a human body, and the other day, when he put three of his workmen in a row, he saw through them all.

The New York Tribune April 18, 1896

NIKOLA TESLA'S EXPERIMENTS.

THE X RAYS DO NOT REVEAL OBJECTS PLAINLY TO HIM AS YET.

In his laboratory, which occupies two floors of the building at No. 46 East Houston-st., Nikola Tesla is delving day after day in the mysteries of the X rays, whose discovery has set the world talking. His article published recently in "The Electrical Review," with reference to the progress he had made by using a conical reflector was read with great interest by all the experts.

Since then he has made still further progress. To a Tribune reporter who found him at his laboratory yesterday afternoon Mr. Tesla said: "The reports that have been printed regarding my work have sometimes been inaccurate and exaggerated. The statement that I have succeeded in seeing plainly through the bodies of three of my assistants at one time is rather too strong. I have no time to spare my assistants for any foolish experiments. Still, I have no doubt that the light of the X rays, as I reflect them, would be seen through three bodies at one time. But as yet I have not been able to define with sufficient clearness the organs of the body. They still remain too vague and shadowy.

"Since the publication of my article in 'The Electrical Review' I have made some progress. I am working steadily, and I have great hopes for the future. It can safely be said that the subject has great possibilities.

"As for the talk of my rivalry with Mr. Edison, that is all rubbish. We have always been on the most friendly terms. We are working with the same end in view, namely, the development of the subject to its fullest."

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CHANGES for advertisements must be in this office by Friday noon for the following week's issue.

NEW ADVERTISEMENTS should be in the office not later than Saturday noon to insure publication the following week.

NEW YORK, APRIL 22, 1896.

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Tesla's latest investigations of the many interesting scientific questions arising from the Roentgen ray discovery are published in this issue. No step in the various stages that he has so far presented to the readers of the ELECTRICAL REVIEW is more interesting or suggestive. The relation which he demonstrates to exist between the series obtained by arranging the metals according to their reflective power and Volta's contact series in air, proves that the rays emitted from the bulb are not an isolated phenomenon, but are emitted everywhere. Particularly suggestive is the observation that all conductors emit streams similar to those discovered by Roentgen, and that the sun and other sources of radiant energies must pour forth rays of the nature of the cathode. To those devoted chiefly to the practical applications of Roentgen's discovery, Tesla's latest observations with a fluorescent screen, showing that even the heart can be seen, will appear most promising, while his investigation of the important effect discovered by Prof. J. J. Thomson (who has contributed so much to the advancement along these lines) can not fail to be of the greatest interest to scientific men.

TESLA'S LATEST ROENTGEN RAY INVESTIGATIONS.

To the Editor of Electrical Review:

Further investigations concerning the behavior of the various metals in regard to reflection of these radiations have given additional support to the opinion which I have before expressed; namely, that Volta's electric contact series in air is identical with that which is obtained when arranging the metals according to their powers of reflection, the most electro-positive metal being the best reflector. Confining myself to the metals easily experimented upon, this series is magnesium, lead, tin, iron, copper, silver, gold and platinum. The last-named metal should be found to be the poorest, and sodium one of the best, reflectors. This relation is rendered still more interesting and suggestive when we consider that this series is approximately the same which is obtained when arranging the metals according to their energies of combination with oxygen, as calculated from their chemical equivalents.

Should the above relation be confirmed by other physicists, we shall be justified to draw the following conclusions: *First*, the highly exhausted bulb emits material streams which, impinging on a metallic surface, are reflected; *second*, these streams are formed of matter in some primary or elementary condition; *third*, these material streams are probably the same agent which is the cause of the electro-motive tension between metals in close proximity or actual contact, and they may possibly, to some extent, determine the energy of combination of the metals with oxygen; *fourth*, every metal or conductor is more or less a source of such streams; *fifth*, these streams or radiations must be produced by some radiations which exist in the medium; and *sixth*, streams resembling the cathodic must be emitted by the sun and probably also by other sources of radiant energy, such as an arc light or Bunsen burner.

The first of these conclusions, assuming the above-cited fact to be correct, is evident and uncontrovertible. No theory of vibration of any kind would account for this singular relation between the powers of reflection and electric properties of the metals. Streams of projected matter coming in actual contact with the reflecting metal surface afford the only plausible explanation.

The second conclusion is likewise obvious, since no difference whatever is observed by employing various qualities of glass for the bulb, electrodes of different metals and any kind of residual gases. Evidently, whatever the matter constituting the streams may be, it must undergo a change in the process of expulsion, or, generally speaking, projection—since the views in this regard still differ—in such a way as to lose entirely the characteristics which it possessed when forming the electrode, or wall of the bulb, or the gaseous contents of the latter.

The existence of the above relation between the reflecting and contact series forces us likewise to the third conclusion, because a mere coincidence of that kind is, to say the least, extremely improbable. Besides, the fact may be cited that there is always a difference of potential set up between two metal plates at some distance and in the path of the rays issuing from an exhausted bulb.

Now, since there exists an electric pressure or difference of potential between two metals in close proximity or contact, we must, when considering all the foregoing, come to the fourth conclusion, namely, that the metals emit similar streams, and I therefore anticipate that, if a sensitive film be placed between two plates, say, of magnesium and copper, a true Roentgen shadow picture would be obtained after a very long exposure in the dark. Or, in general, such picture could be secured whenever the plate is placed near a metallic or conducting body, leaving for the present the insulators out of consideration. Sodium, one of the first of the electric contact series, but not yet experimented upon, should give out more of such streams than even magnesium.

Obviously, such streams could not be forever emitted, unless there is a continuous supply of radiation from the medium in some other form; or possibly the streams which the bodies themselves emit are merely reflected streams coming from other sources. But since all investigation has strengthened the opinion advanced by Roentgen that for the production of these radiations some impact is required, the former of the two possibilities is the more probable one, and we must assume that the radiations existing in the medium and giving rise to those here considered partake something of the nature of cathodic streams.

But if such streams exist all around us in the ambient medium, the question arises, whence do they come? The only answer is: From the sun. I infer, therefore, that the sun and other sources of radiant energy must, in a less degree, emit radiations or streams of matter similar to those thrown off by an electrode in a highly exhausted inclosure. This seems to be, at this moment, still a point of controversy. According to my present convictions a Roentgen shadow picture should, with very long exposures, be obtained from all sources of radiant energy, provided the radiations are permitted first to impinge upon a metal or other body.

The preceding considerations tend to show that the lumps of matter composing a cathodic stream in the bulb are broken up into incomparably smaller particles by impact against the wall of the latter, and, owing to this, are enabled to pass into the air. All evidence which I have so far obtained points rather to this than to the throwing off of particles of the wall itself under the violent impact of the cathodic stream. According to my convictions, then, the difference between Lenard and Roentgen rays, if there be any, lies solely in this, that the particles composing the latter are incomparably smaller and possess a higher velocity. To these two qualifications I chiefly attribute the non-deflectibility by a magnet which I believe will be disproved in the end. Both kinds of rays, however, affect the sensitive plate and fluorescent screen, only the rays discovered by Roentgen are much more effective. We know now that these rays are produced under certain exceptional conditions in a bulb, the vacuum being extremely high, and that the range of greatest activity is rather small.

I have endeavored to find whether the reflected rays possess certain distinctive features, and I have taken pictures of various objects with this purpose in view, but no marked difference was noted in any case. I therefore conclude that the matter composing the Roentgen rays does not suffer further degradation by impact against bodies. One of the most important tasks for the experimenter remains still to determine what becomes of the energy of these rays. In a number of experiments with rays reflected from and transmitted through a conducting or insulating plate, I found that only a small part of the rays could be accounted for. For instance, through a zinc plate, one-sixteenth of an inch thick, under an incident angle of 45 degrees, about two and one-half per cent were reflected and about three per cent transmitted through the plate, hence over 94 per cent of the total radiation remain to be accounted for. All the tests which I have been able to make have confirmed Roentgen's statement that these rays are incapable of raising the temperature of a body. To trace this lost energy and account for it in a plausible way will be equivalent to making a new discovery.

Since it is now demonstrated that all bodies reflect more or less, the diffusion through the air is easily accounted for. Observing the tendency to scatter through the air, I have been led to increase the efficiency of reflectors by providing not one, but separated successive layers for reflection, by making the reflector of thin sheets of metal, mica or other substances. The efficiency of mica as a reflector I attribute chiefly to the fact that it is composed of many superimposed layers which reflect individually. These many successive reflections are, in my opinion, also the cause of the scattering through the air.

In my communication to you of April 1, I have for the first time stated that these rays are composed of matter in a "primary" or elementary condition or state. I have chosen this mode of expression in order to avoid the use of the word "ether," which is usually understood in the sense of the Maxwellian interpretation, which would not be in accord with my present convictions in regard to the nature of the radiations.

An observation which might be of some interest is the following: A few years ago I described on one occasion a phenomenon observed in highly exhausted bulbs. It is a brush or stream issuing from a single electrode under certain conditions, which rotates very rapidly in consequence of the action of the earth's magnetism. Now I have recently observed this same phenomenon in several bulbs which were capable of impressing the sensitive film and fluorescent screen very strongly. As the brush is rapidly twirling around I have conjectured that perhaps also the Lenard and Roentgen streams are rotating under the action of the earth's magnetism, and I am endeavoring to obtain an evidence of such motion by studying the action of a bulb in various positions with respect to the magnetic axis of the earth.

In so far as the vibrational character of the rays is concerned, I still hold that the vibration is merely that which is conditioned by the apparatus employed. With the ordinary induction coil we have almost exclusively to deal with a very low vibration impressed by the commutating device or brake. With the disruptive coil we usually have a very strong superimposed vibration in addition to the fundamental one, and it is easy to trace sometimes as much as the fourth octave of the fundamental vibration. But I can not reconcile myself with the idea of vibrations approximating or even exceeding those of light, and think that all these effects could be as well produced with a steady electrical pressure as from a battery, with the exclusion of all vibration which may occur, even in such instance, as has been pointed out by De La Rive. In my experiments I have tried to ascertain whether a greater difference between the shadows of the bones and flesh could be obtained by employing currents of extremely high frequency, but I have been unable to discover any such effect which would be dependent on the frequency of the currents, although the latter were varied between as wide limits as was possible. But it is a rule that the more intense the action the sharper the shadows obtained, provided that the distance is not too small. It is furthermore of the greatest importance for the clearness of the shadows that the rays should be passed through some tubular reflector, which renders them sensibly parallel.

In order then to bring out as much detail as possible on a sensitive plate, we have to proceed in precisely the same way as if we had to deal with flying bullets hitting against a wall composed of parts of different density with the problem before us of producing as large as possible a difference in the trajectories of the bullets which pass through the various parts of the wall. Manifestly, this difference will be the greater the greater the velocity of the bullets; hence, in order to bring out detail, very strong radiations are required. Proceeding on this theory I have employed exceptionally thick films and developed very slowly, and in this way clearer pictures have been obtained. The importance of slow development has been first pointed out by Professor Wright, of Yale. Of course, if Professor Henry's suggestion of the use of a fluorescent body in contact with the sensitive film is made use of, the process is reduced to an ordinary quick photographic procedure, and the above consideration does not apply.

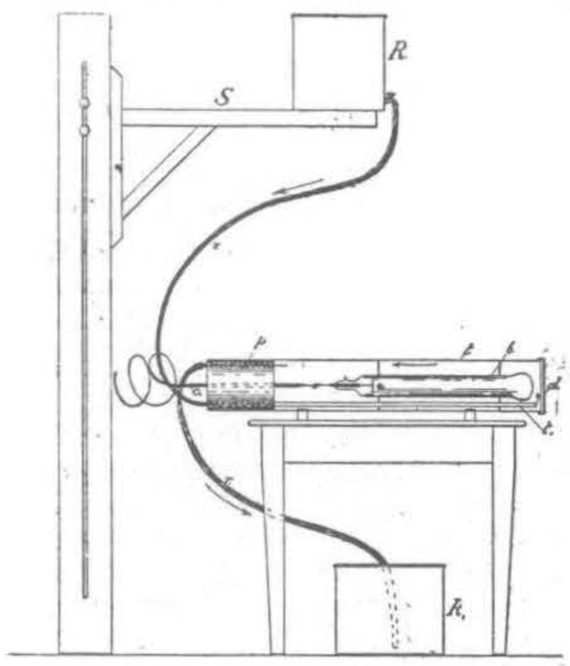
It being desirable to produce as powerful a radiation as possible, I have continued to devote my attention to this problem and have been quite successful. First of all, there existed limitations in the vacuum tube which did not permit the applying of as high a potential as I desired; namely, when a certain high degree of exhaustion was reached a spark would form behind the electrode, which would prevent straining the tube much higher. This inconvenience I have overcome entirely by making the wire leading to the electrode very long and passing it through a narrow channel, so that the heat from the electrode could not cause the formation of such sparks. Another limitation was imposed by streamers which would break out at the end of the tube when the potential was excessive. This latter inconvenience I have overcome either by the use of a cold blast of air along the tube, as I have mentioned before, or else by immersion of the tube in oil. The oil, as it is now well known, is a means of rendering impossible the formation of streamers by the exclusion of all air. The use of the oil in connection with the production of these radiations has been early advocated in this country by Professor Trowbridge. Originally I employed a wooden box made thoroughly tight with wax and filled with oil or other liquid, in which the tube was immersed. Observing certain specific actions, I modified and improved the apparatus, and in my later investigations I have employed an arrangement as shown in the annexed cut. A bulb *b*, of the kind described before, with a leading-in wire and neck much longer than here shown, was inserted into a large and

(Concluded on page 211.)

TESLA'S LATEST ROENTGEN RAY INVESTIGATIONS.

(*Concluded from page 207.*)

thick glass tube *t*. The tube was closed in front by a diaphragm *d* of pergament, and by a rubber plug P in the back. The plug was provided with two holes, into the lower one of which a glass tube t_1, reaching to very nearly the end of the bulb, was inserted. Oil of some kind was made to flow through rubber tubes *r r* from a large reservoir R, placed on an adjustable support S, to the lower reservoir R_1, the path of the oil being clearly observable from the drawing.



By adjusting the difference of the level between the two reservoirs it was easy to maintain a permanent condition of working. The outer glass tube *t* served in part as a reflector, while at the same time it permitted the observation of the bulb *b* during the action. The plug P, in which the conductor *c* was tightly sealed, was so arranged that it could be shifted in and out of the tube *t*, so as to vary the thickness of the oil traversed by the rays.

I have obtained some results with this apparatus which clearly show the advantage of such disposition. For instance, at a distance of 45 feet from the end of the bulb my assistants and myself could observe clearly the fingers of the hand through a screen of tungstate of calcium, the rays traversing about two and one-half inches of oil and the diaphragm *d*. It is practicable with such apparatus to make photographs of small objects at a distance of 40 feet, with only a few minutes exposure, by the help of Professor Henry's method. But, even without the use of a fluorescent powder, short exposures are practicable, so that I think the use of the above method is not essential for quick procedure. I rather believe that in the practical development of this principle, if it shall be necessary, Professor Salvioni's suggestion of a fluorescent emulsion, combined with a film, will have to be adopted. This is bound to give better results than an independent fluorescent screen, and will very much simplify the process. I may say, however, that, since my last communication, considerable improvement has been made in the screens. The manufacturers of Edison's tungstate of calcium are now furnishing screens which give fairly clean pictures. The powder is fine and it is more uniformly distributed. I consider, also, that the employment of a softer and thicker paper than before is of advantage. It is just to remark that the tungstate of calcium has also proved to be an excellent fluorescent in the bulb. I tested its qualities for such use immediately and find it so far unexcelled. Whether it will be so for a long time remains to be seen. News reaches us that several fluorescent bodies, better than the cyanides, have been discovered abroad.

Another improvement with a view of increasing the sharpness of the shadows has been proposed to me by Mr. E. R. Hewitt. He assumed that the absence of sharpness of the outlines in the shadows on the screen was due to the spread of the fluorescence from crystal to crystal. He proposed to avoid this by using a thin aluminum plate with many parallel grooves. Acting on this suggestion, I made some experiments with wire gauze, and, furthermore, with screens made of a mixture of a fluorescent with a non-fluorescent powder. I found that the general brightness of the screen was diminished, but that with a strong radiation the shadows appeared sharper. This idea might be found capable of useful application.

By the use of the above apparatus I have been enabled to examine much better than before the body by means of the fluorescent screen. Presently the vertebral column can be seen quite clearly, even in the lower part of the body. I have also clearly noted the outlines of the hip bones. Looking in the region of the heart I have been able to locate it unmistakably. The background appeared much brighter, and this difference in the intensity of the shadow and surrounding has surprised me. The ribs I could now see on a number of occasions quite distinctly, as well as the shoulder bones. Of course, there is no difficulty whatever in observing the bones of all limbs. I noted certain peculiar effects which I attribute to the oil. For instance, the rays passed through plates of metal over one-eighth of an inch thick, and in one instance I could see quite clearly the bones of my hand through sheets of copper, iron and brass of a thickness of nearly one-quarter of an inch. Through glass the rays seemed to pass with such freedom that, looking through the screen in a direction at right angles to the axis of the tube, the action was most intense, although the rays had to pass through a great thickness of glass and oil. A glass slab nearly one-half of an inch thick, held in front of the screen, hardly dimmed the fluorescence. When holding the screen in front of the tube at a distance of about three feet, the head of an assistant, thrust between the screen and the tube, cast but a feeble shadow. It appeared some times as if the bones and the flesh were equally transparent to the radiations passing through the oil. When very close to the bulb, the screen was illuminated through the body of an assistant so strongly that, when a hand was moved in front, I could clearly note the motion of the hand through the body. In one instance I could even distinguish the bones of the arm.

Having observed the extraordinary transparence of the bones in some instances, I at first surmised that the rays might be vibrations of high pitch, and that the oil had in some way absorbed a part of them. This view, however, became untenable when I found that at a certain distance from the bulb I obtained a sharp shadow of the bones. This latter observation led me to apply usefully the screen in taking impressions on the plate. Namely, in such case it is of advantage to first determine by means of the screen the proper distance at which the object is to be placed before taking the impression. It will be found that often the image is much clearer at a greater distance. In order to avoid any error when observing with the screen, I have surrounded the box with thick metal plates, so as to prevent the fluorescence, in consequence of the radiations, reaching the screen from the sides. I believe that such an arrangement is absolutely necessary if one wishes to make correct observations.

During my study of the behavior of oils and other liquid insulators, which I am still continuing, it has occurred to me to investigate the important effect discovered by Prof. J. J. Thomson. He announced some time ago that all bodies traversed by Roentgen radiations become conductors of electricity. I applied a sensitive resonance test to the investigation of this phenomenon in a manner pointed out in my earlier writings on high frequency currents. A secondary, preferably not in very close inductive relation to the primary circuit, was connected to the latter and to the ground, and the vibration through the primary was so adjusted that true resonance took place. As the secondary had a considerable number of turns, very small bodies attached to the free terminal produced considerable variations of potential on the latter. Placing a tube in a box of wood filled with oil and attaching it to the terminal, I adjusted the vibration through the primary so that resonance took place without the bulb radiating Roentgen rays to an appreciable extent. I then changed the conditions so that the bulb became very active in the production of the rays. The oil should have now, according to Prof. J. J. Thomson's statement, become a conductor and a very marked change in the vibration should have occurred. This was found not to be the case, so that we must see in the phenomenon discovered by J. J. Thomson only a further evidence that we have to deal here with streams of matter which, traversing the bodies, carry away electrical charges. But the bodies do not become conductors in the common acceptance of the term. The method I have followed is so delicate that a mistake is almost an impossibility.

NIKOLA TESLA.

New York, April 20.

The New York Herald April 22, 1896

SAW A MAN'S HEART.

Nicola Tesla Makes Two Important Announcements of His Ray Experiments.

Nicola Tesla is devoting much time to the scientific investigation of the Roentgen ray effects. In a communication to the Electrical Review he announced among others two interesting results he has achieved. One of these is that if a sensitive film be placed between two plates, say of magnesium and copper, a true Roentgen radiograph would be obtained after a very long exposure in the dark. Another wonderful result Tesla has obtained is that by the use of a new type of fluorescent screen, devised in his laboratory, he has been able to greatly increase the sharpness of the outlines in a shadow on the screen and to actually see the human heart., Regarding this, Tesla says:—

"By the use of this apparatus I have been enabled to examine much better than before the body by means of the fluorescent screen. Presently the vertebral column can be seen quite clearly, even in the lower part of the body. I have also clearly noted the outlines of the hip bones. Looking in the region of the heart, I have been able to locate it unmistakably. The background appeared much brighter, and this difference in the intensity of the shadow and surrounding has surprised me. The ribs I could now see on a number of occasions quite distinctly, as well as the shoulder bones. Of course there is no difficulty whatever in observing the bones of all the limbs."

This latter discovery, he thinks, is capable of extensive practical application.

TESLA AND ROENTGEN RAYS

BEHAVIOR OF METALS ON THE SCALE OF CHEMIC AFFINITY.

Every Metal or Conductor Is More or Less a Source of Such Streams—These Streams or Radiations Must Be Produced by Some Radiations Which Exist in the Medium.

Nikola Tesla, in the present number of the *Electrical Review*, gives the results of his latest Röntgen ray investigation. He says that the behavior of the various metals in regard to reflection of these radiations gives additional support to his previously expressed opinion that Volta's electric contact series in air is identical with that which is obtained when arranging the metals according to their powers of reflection—the most electro-positive metal being the best reflector. He confined himself to the following metals most easily experimented upon, viz.: Magnesium, lead, tin, iron, copper, silver, gold and platinum. Tesla decides that it is fair to draw the following conclusions:

First, the highly exhausted bulb emits material streams which, impinging on a metallic surface, are reflected; second, these streams are formed of matter in some primary or elementary condition; third, these material streams are probably the same agent which is the cause of the electro-motive tension between metals in close proximity or actual contact, and they may possibly, to some extent, determine the energy of combination of the metals with oxygen; fourth, every metal or conductor is more or less a source of such streams; fifth, these streams or radiations must be produced by some radiations which exist in the medium; and, sixth, streams resembling the cathodic must be emitted by the sun and probably also by other sources of radiant energy, such as an arc light or Bunsen burner."

Tesla then proceeds to give his reasons for arriving at these conclusions.

In explanation of the fact that there exists an electric pressure or difference of potential between two metals in close proximity or contact, he says:

"We must, when considering all the foregoing, come to the fourth conclusion, namely, that the metals emit similar streams, and I therefore anticipate that, if a sensitive film be placed between two plates, say, of magnesium and copper, a true Röntgen shadow picture would be obtained after a very long exposure in the dark. Or, in general, such picture could be secured whenever the plate is placed near a metallic or conducting body, leaving for the present the insulators out of consideration. Sodium, one of the first of the electric contact series, but not yet experimented upon, should give out more of such streams than even magnesium.

"Obviously, such streams could not be forever emitted, unless there is a continuous supply of radiation from the medium in some other form; or possibly the streams which the bodies themselves emit are merely reflected streams coming from other sources. But since all investigation has strengthened the opinion advanced by Röntgen that for the production of these radiations some impact is required, the former of the two possibilities is the more probable one, and we must assume that the radiations existing in the medium and giving rise to those here considered partake something of the nature of cathodic streams.

"But if such streams exist all around us in the ambient medium, the question arises, whence do they come? The only answer is: From the sun. I infer, therefore, that the sun and other sources of radiant energy must, in a less degree, emit radiations or streams of matter similar to those thrown off by an electrode in a highly exhausted inclosure. This seems to be, at this moment, still a point of controversy. According to my present convictions, a Röntgen shadow picture should, with very long exposures, be obtained from all sources of radiant energy, provided the radiations are permitted first to impinge upon a metal or other body.

"The preceding considerations tend to show that the lumps of matter composing a cathodic stream in the bulb are broken up into incomparably smaller particles by impact against the wall of the latter, and, owing to this, are enabled to pass into the air. All evidence which I have so far obtained points rather to this than to the throwing off of particles of the wall itself under the violent impact of the cathodic stream. According to my convictions then, the difference between Lenard and Röntgen rays, if there be any, lies solely in this, that the particles composing the latter are incomparably smaller and possess a higher velocity. To these two qualifications I chiefly attribute the non-deflectibility by a magnet, which I believe will be disproved in the end. Both kinds of rays, however, affect the sensitive plate and fluorescent screen, only the rays discovered by Röntgen are much more effective. We know now that these rays are produced under certain exceptional conditions in a bulb, the vacuum being extremely high, and that the range of greatest activity is rather small."

Tesla believes that the Röntgen rays are incapable of raising the temperature of the body. He adds that to trace the lost energy which amounts to 94 per cent. and account for it in a plausible way will be equivalent to making a new discovery.

By the use of certain apparatus which he describes, Tesla says:

"I have been enabled to examine much better than before the body by means of the fluorescent screen. Presently the vertebral column can be seen quite clearly, even in the lower part of the body. I have also clearly noted the outlines of the hip bones. Looking in the region of the heart I have been able to locate it unmistakably. The background appeared much brighter and this difference in the intensity of the shadow and surrounding has surprised me. The ribs I could see on a number of occasions quite distinctly, as well as the shoulder bones. Of course, there is no difficulty whatever in observing the bones of all limbs. I noted certain peculiar effects which I attributed to the oil. For instance, the rays passed through plates of metal over one-eighth of an inch thick, and in one instance I could see quite clearly the bones of my hand through sheets of copper, iron and brass of a thickness of nearly one-quarter of an inch. Through glass the rays seemed to pass with such freedom that, looking through the screen in a direction at right angles to the axis of the tube, the action was most intense, although the rays had to pass through a great thickness of glass and oil. A glass slab nearly one-half of an inch thick, held in front of the screen, hardly dimmed the fluorescence. When holding the screen in front of the tube at a distance of about three feet, the head of an assistant, thrust between the screen and the tube, cast but a feeble shadow. It appeared some times as if the bones and the flesh were equally transparent to the radiations passing through the oil. When very close to the bulb, the screen was illuminated through the body of an assistant so strongly that, when a hand was moved in front, I could clearly note the motion of the hand through the body. In one instance I could even distinguish the bones of the arm.

"Having observed the extraordinary transparence of the bones in some instances, I at first surmised that the rays might be vibrations of high pitch, and that the oil had in some way absorbed a part of them. This view, however, became untenable when I found that at a certain distance from the bulb I obtained a sharp shadow of the bones. This latter observation led me to apply usefully the screen in taking impressions on the plate. Namely, in such cases it is of advantage to first determine by means of the screen the proper distance at which the object is to be placed before taking the impression. It will be found that often the image is much clearer at a greater distance. In order to avoid any error when observing with the screen, I have surrounded the box with thick metal plates, so as to prevent the fluorescence, in consequence of the radiations, reaching the screen from the sides. I believe that such an arrangment is absolutely necessary if one wishes to make correct observations."

Tesla decides finally that the announcement of Prof. J. J. Thomson that all bodies traversed by Röntgen radiations became conductors of electricity in the common acceptation of the term conductor is not true. Tesla concludes his article by saying that the method that he (Tesla) has followed is so delicate that a mistake is almost an impossibility.

HUMAN HEART STANDS REVEALED

With the Aid of a Fluorescent Screen Nikola Tesla Can See It in a Living Subject.

NATURE FULL OF X RAYS.

The Sun and Other Sources of Radiant Energies Have All Anticipated Roentgen.

SOME STARTLING DEDUCTIONS.

NIKOLA TESLA'S latest experiments with the cathode rays have enabled him to reach and reveal to human eyesight the human heart in a living subject.

This is an extraordinary fact. To our ancestors it would have seemed a miracle that could be ascribed only to some supernatural agency—preferably to that of the devil, for, in the gloomy mood which they carefully cultivated, the devil appeared to be a more potent agent in mundane affairs than Divinity itself. Even to us of the present, who have carefully eliminated the supernatural, either in the form of God or devil, and who have been calloused to the marvels of the natural world by the thick coming sensations which, day by day and even hour by hour, crowd upon our senses, this is an event altogether out of the common. But we still preserve some of the failings of our devil haunted progenitors. After the first stunning effect of an announcement of this sort we rebound into an unreasonable state of expectancy. We are not content with the marvel of the moment. We would anticipate the future. We would outstrip nature and plunge into the supernatural. We exaggerate, we augur the utmost. We are disappointed if our fondest anticipations are not immediately realized.

There are people who imagine at once that the human heart would be revealed as utterly and clearly as though it were laid bare by the surgeon's scalpel. Perhaps some go so far as to hope to see that living heart inscribed legibly with its secrets. Queen Mary said that when she was dead the word Calais would be found indelibly engraved on her heart. Some folk would not be satisfied unless Nikola Tesla revealed to them the very letters of such an inscription.

TESLA IS SILENT.

Mr. Tesla himself is sensible of this overweening expectation. So for the moment he has determined to make no further revelations. He will wait patiently until the future has arrived and the revelations expected in the present have been approximately realized. He knows how unreasonable are the demands of the public after the first burst of startled incredulity is over. Belief will succeed that incredulity if the facts warrant belief, but that belief becomes utterly importunate and unreasonable.

"If I tell people," complained Mr. Tesla when I saw him in his laboratory yesterday, "that science has gone so far and no further they are disappointed. Because they expect everything they do not realize that even a very little is an immense advance. By the aid of the Roentgen rays I have, it is true, been able to examine much better than before the interior of the body. I have been able to locate by ocular inspections the region of the heart. But when I explain that it is simply a dim adumbration and not a clear vision people turn away disappointed. Therefore at present I deem it best not to add anything to the article just published in the Electrical Review. I shall wait until I have something to report that will approximately meet the o'erleaping expectations of the public."

THE SUN EMITS X RAYS.

"The revelations of that article are astounding enough, in all conscience. Tesla demonstrates that what are known as the Roentgen rays are not an isolated phenomenon, but are emitted everywhere. All conductors emit streams similar to those discovered by Roentgen. The sun itself and other sources of radiant energies pour forth rays similar to those emitted by an electrode in a highly exhausted enclosure. His present conviction is that a Roentgen shadow picture should, with very long exposure, be obtained from all sources of radiant energy, provided the radiations are permitted first to impinge upon a metal or other body. Hence he has been led to increase the efficiency of reflectors by providing, not one, but separated successive layers for reflection, by making the reflectors of thin sheets of metal, mica or other substances.

To scientists interested in the practical application of Roentgen's discovery Tesla's latest observations with a fluorescent screen will seem most promising. The ordinary reader will be better satisfied with results than with technical explanations of his method. Here, briefly, are the results as he has chronicled them:—

WHAT TESLA HAS DONE.

He has succeeded in gaining a clear view of the vertebral column, even in the lower part of the body. He has also clearly noted the outlines of the hip bones. Looking in the region of the heart he has been able to locate it unmistakably.

"The background appeared much brighter, and this difference in the intensity of the shadow and surrounding has surprised me." The ribs he could now see on a number of occasions quite distinctly, as well as the shoulder bones. Of course, there is no difficulty whatever in observing the bones of all limbs. In one instance he could see quite clearly the bones of his hand through sheets of copper, iron and brass of a thickness of nearly one-quarter of an inch. Through glass the rays seemed to pass with such freedom that, looking through the screen in a direction at right angles to the axis of the tube, the action was most intense, although the rays had to pass through a great thickness of glass and oil. A glass slab nearly one-half of an inch thick, held in front of the screen, hardly dimmed the fluorescence.

When holding the screen in front of the tube, at a distance of about three feet, the head of an assistant thrust between the screen and the tube cast but a feeble shadow. It appeared sometimes as if the bones and the flesh were equally transparent to the radiations passing through the oil. When very close to the bulb the screen was illuminated through the body of an assistant so strongly that when a hand was moved in front Mr. Tesla could clearly note the motion of the hand through the body. In one instance he could even distinguish the bones of the arm.

You cannot arrest time in its flight or roll it backward. Therefore you cannot say what a past generation would have thought of these manifestations. But you can do the next best thing. If you have a grandmother who has not kept up with the trend of events seek her out and explain to her in simple language just what Tesla has effected. As the supposition is that she has never heard of Tesla's name, and as she may not know Latin, you cannot expect her to say, "Aut Diabolus aut Tesla." But in her simple retrograde manner she may allude to Diabolus alone in the vernacular terminology.

The New York Herald April 27, 1896

NIKOLA TESLA BURNED.

Touched a Heavily Charged Wire While Engaged in Experiments.

Nikola Tesla, whose interesting experiments with a fluorescent screen, as showing the action of a man's heart, were described in the Sunday HERALD, has one hand swathed in bandages these days.

This is the result of an accident while conducting his experiments in his laboratory. He was deeply interested in his work, and perhaps became somewhat careless. At any rate, his hand touched a wire charged with a large amount of electric fluid. It was only for an instant. but that was long enough for the flesh of the fingers to be badly seared, while the ends, around the nails, were seriously burned.

While painful, the wounds were not dangerous and he will be all right in a few days.

Professor Roentgen's New Discoveries.

[*Cable to the Sun, New York, April 26.*]

Professor Roentgen has published several important new discoveries connected with the X rays. He has ascertained that all solid bodies can generate them under the influence of cathode rays, the only difference being as regards intensity. The most intense are produced by platina. He further says that the insertion of the Tesla apparatus between the ray-producing apparatus and the Ruhmkorff apparatus is highly advantageous. He has made several experiments which confirm his observation that X rays can discharge electric bodies, and that air illuminated by the rays can do the same. He further declares that electric bodies surrounded not by air, but by hydrogen or by highly rarefied air, are also discharged by the rays, though much more slowly.

RECENT WORK WITH RÖNTGEN RAYS.

IN our last week's number, Prof. J. J. Thomson brought together and discussed observations of prime importance selected from the mass of material recently published on Röntgen rays. As a supplement to this, and in continuation of the general summaries which have already appeared in NATURE, we present the following notes on papers and communications received during the past few days.

Prof. Oliver Lodge has sent us the following announcement, dated April 20.

"It has been asserted that the action of X-rays on a film is a photographic one, depending on the fluorescence of the glass backing. The truth is that a film on a ferrotype plate is just about as rapid as a similar film on glass. Thick films are much better than thin. It may be further interesting to state that if the platinum disk on which the kathode rays inside the bulb are converged is connected to the kathode, it fails to act as a source; if it be insulated, it acts fairly; while if it is connected to the anode, it constitutes a vigorous source."

It will be remembered that Prof. Röntgen found that "films can receive the impression as well as ordinary dry plates" (NATURE, January 23, p. 274), but he was doubtful whether the photographic effect was secondary or not.

From a number of papers dealing with various properties of Röntgen's rays, we learn that Herren V. Novák and O. Sulc (Prague) have observed the relative opacity for X-rays of different substances, both simple and compound (*Zeitschrift für Physikalische Chemie*, xix. 3). They conclude that the absorbing powers of the chemical element depend on their atomic weight alone, and that the absorbing power of a compound depends only on the atomic weights of the elements of which it consists, and not on the complexity of its molecules. It seems probable that the *average* atomic weight of a compound affords an index of its absorbing power. In the *Jenaische Zeitschrift für Naturwissenschaft*, Dr. A. Winkelmann and Dr. R. Straubel (Jena) have investigated the refraction of Röntgen rays, and by using prisms of various metals, obtain in each case a value of about 1 : 0·0038 referred to air. They also have measured the reflection produced by a sheet of tinfoil, and the relative transparency of different kinds of glass to Röntgen radiations. All glasses made with lead are found to be comparatively opaque. The same writers have experimented on the action of fluor-spar in intensifying the actinic effects of X-rays, and have found that the best results are obtainable with a coarse powder of the fluor-spar; finer powders producing a less marked effect. This effect is due to fluorescence, the spar emitting radiations whose index of refraction is about 1·48; indicating a wave-length of 219×10^{-6}. The March number of the *Atti della Reale Accademia dei Lincei* contains two papers, one by Signor Augusto Righi, and the other a joint paper by Drs. A. Fontana and A. Umani (Rome), both of which deal with the effect of Röntgen rays in stopping the action of Crookes' radiometer. The effect is found to be purely electrostatical, and to be due to the electrification of the glass bulb containing the radiometer; when the bulb is wetted, or electrification prevented by the interposition of a conducting screen, the radiation from a Crookes' tube does not affect the radiometer in any way whatever.

Mr. A. W. Isenthal has sent us the following letter, *à propos* of Winkelmann and Straubel's paper. He says:—"It may be of interest to your readers to learn that, within the last few weeks, Prof. Dr. Winkelmann and Dr. Straubel, of Jena University, have been successful in reducing the exposure required for the production of radiograms to a few seconds only. Acting on the few directions given, I have made a few preliminary trials, the result of which is very promising. By simply backing the sensitive plate with a most inexpensive material, I have obtained fair negatives of the finger-bones in about ten seconds, using only a 3-inch spark. As the rays in this method have first to pass through the glass of the sensitive plate, there is a probability of still further reducing the necessary exposure by substituting sensitive films (on celluloid) for the ordinary photographic plate."

With reference to the use of fluorescent screens in reducing the time of exposure, we have received the following letter from Dr. H. Van Heurck, of the Botanical Gardens, Antwerp, through Dr. Wynne E. Baxter:—

"I notice in your issue of April 16, that Messrs. L. Bleekrode and J. William Giffcrd announce that they have been able to reduce the time of exposure in radiography by the use of a fluorescent screen. Mr. Basilewski communicated the same fact to the Paris Académie des Sciences on March 23 last. Allow me, however, to lay claim to priority in this application of fluorescent screens, as the same was announced by me in various Antwerp journals on March 8, and again on the 12th of that month, in the *Annales* (*Belges*) *de Pharmacie*, an extract from which, in pamphlet form, I send herewith. You will also find described therein a chemical substance, viz. a newly-discovered double fluoride of uranyl and ammonium, with which screens can be made, at a nominal cost, of a luminosity and of a clearness superior to that of any screen now known to exist."

The combination of a fluorescent screen with a photographic plate was one to which every worker with Röntgen rays would naturally be led. Prof. M. L. Pupin gave a description of the combination before the New York Academy of Sciences on March 2. At a meeting of the Academy on April 6, reported in *Science* of April 10, he described an arrangement of apparatus by means of which it was found possible to produce very strong photographic effects, "but not sufficiently strong for penetration through the thigh and the trunk of the human body at reasonably short exposures and at long enough distances from the tube to obtain the desirable clearness in the pictures of these massive parts. A completely successful application of Röntgen's beautiful discovery to surgery depends for the present on a successful solution of the problem just mentioned. I have obtained one satisfactory solution with the method which I first described before the Academy on March 2. It consists in placing in contact with the photographic plate a fluorescent screen, and thus transforming most of the Röntgen radiance into visible light before it reaches the sensitive film. Photographs of the hand were thus obtained at a distance of twenty-five feet from the tube with an exposure of half an hour. At the distance of four inches the hand can be photographed by an exposure of a few seconds. It was in this manner only that I succeeded in photographing on a single plate the whole chest, shoulders, and neck of my assistant, with an exposure of seventy minutes and at a distance of three feet between the plate and the tube. The collar-button and the buttons and clasps of the trousers and the vest show very strongly through the ribs and the spinal column. This result seems to prove beyond all reasonable doubt the applicability of radiography to a much larger field in surgery than was expected a few weeks ago."

A communication on the same branch of the subject has been received from Mr. A. A. C. Swinton, under date April 22. We print his letter in full.

"The chemical action of the Röntgen rays upon a photographic film may be either a direct action or may be a secondary effect, due to the fluorescence produced in the support, or in the gelatine and silver bromide of the film itself. Be this as it may, the fact that an ordinary photographic film supported on celluloid is almost completely transparent to the rays, as may easily be proved with a cryptoscope, and also the fact that it is possible to simultaneously impress many super-imposed films, show that only a very small fraction of the energy in the rays is utilised under ordinary circumstances.

"As long ago as January 30, in some remarks that I made at the close of Mr. Porter's demonstration at University College, I suggested as a means of more completely utilising the energy in the rays, and thereby shortening the necessary exposure, the use of suitable fluorescent material applied either in the form of a screen behind the photographic film, or introduced into the substance of the film itself.

"Since I first made this suggestion, I have tried numerous experiments in the direction indicated. These were at first unsuccessful owing to the screens used not having been properly prepared. Some weeks ago, however, on renewing the experiments with a screen thickly coated with potassium platino-cyanide and gum, placed behind a celluloid photographic film, I obtained conclusive evidence that by this means the necessary exposure could be greatly shortened, and that in a less degree the same result could be accomplished by the employment of a screen thickly covered with powdered fluor-spar.

"The chief objection to this method lies in the fact that it is very difficult to avoid granular results. Unless the fluorescent material be in a very fairly divided condition, its grain shows distinctly and mars the detail of the finished picture. The platino-cyanide does not work so efficiently when finely powdered as when in moderately coarse crystals, but good results can be obtained by thickly coating a thin celluloid film with an emulsion of this salt ground to fine powder in collodion, and using the screen so prepared with its celluloid surface in contact with the

sensitive surface of the photographic film. I have obtained considerably better results with a finely ground sample of tungstate of calcium, prepared for me by Messrs. Hopkin and Williams. This may be used either in loose powder or made up with gum into a paste and dried.

"With this substance it is easy to obtain sharp and fully-exposed negatives of the hand in from five to ten seconds with a moderately excited tube, with which, with ordinary arrangements, one to two minutes' exposure would be necessary.

"I have also tried some special plates prepared for me by Messrs. Marion, into the sensitive emulsion of which fluorescent substances such as powdered fluor-spar and calcium tungstate were introduced before application to the glass. Though the results so far obtained by this method are not very satisfactory owing to granularity, the presence of the fluorescent substance in the photographic film appears undoubtedly to increase its sensitiveness to the rays.

"There is a wide field for further research on the lines above indicated, both with regard to suitable fluorescent substances and the best method for their application."

A paper by Dr. Ferdinando Giazzi, of the Regio Istituto Tecnico, Perugia, is of importance in this connection, and the following translation of it, by Mr. G. H. Baillie, will be useful to chemists who are preparing fluorescent salts for use with Röntgen rays:

"Some days ago Prof. Ruata called my attention to the telegram sent by Edison to Lord Kelvin, and published in NATURE, according to which calcium tungstate, when suitably crystallised, showed fluorescent phenomena under the action of X-rays in a far more marked degree than barium platino-cyanide.

"I immediately consulted Prof. Bellucci, who informed me that calcium tungstate could be easily obtained from either sodium tungstate or tungstic acid, two commercial products selling at a low price. Having obtained these from the firm of Bonavia of Bologna, I set to work and produced some calcium tungstate, but in an amorphous form, which was, as far as I could test with the coil at my disposal, insensible to X-rays. I shall not describe all the attempts I made by wet and dry processes to obtain the salt in the desired form. I merely say that I never have dealt with a body so intractable. The following is the process I finally adopted in preparing it for surgical purposes. I treated a dilute aqueous solution of sodium tungstate with a solution of calcium chloride, given to me by my colleague Prof. Corneliani; I thoroughly washed the resulting pure white precipitate, and dried it at a gentle heat in a porcelain capsule. Next I made a small hole in a piece of fresh retort-carbon, and filled it with the precipitate, which I fused and boiled by means of a small flame from an oxyhydrogen blowpipe. After boiling for some seconds (at a bright white heat), I gradually removed the substance from the hottest parts of the flame, so that solidification took place only after a few minutes. In this way I obtained five globules of calcium tungstate of the required structure. I powdered them in an iron mortar and sifted the powder on to a gummed card, which I exposed in the camera to Röntgen rays. The result was most striking; I saw at once the shadow of the skeleton of my hand more clearly than I ever have with other preparations. A surgeon with this product, good Crookes' tubes, a large coil, and an apparatus such as I have arranged, could certainly dispense with the tedious process of photography.

"I publish this note for the assistance of those who perchance have not yet succeeded in preparing the invaluable tungstate in the desired form."

So far as the utility of the method of reducing exposure by means of fluorescent screens is concerned, the advantage gained must be understood only in a comparative sense. Some investigators obtain excellent results without the use of the screen in less time than others with a screen. Dr. John Macintyre, who has sent us several communications previously upon his work with Röntgen rays, has something to say about the reduction of exposure by screens, in a letter just received. He remarks:

"The object of this note is not to minimise the importance of any aid which the physicist may place in the hand of the surgeon. I have been aware of this new method, but my experience in practice has not encouraged me meantime to pursue it largely, because of want of time in developing what I consider of greater importance, viz. a better Crookes' tube. In surgery what we require may be divided into two parts: (1) rapid views of objects, and (2) permanent records. In practice we must have for the former not photographs but direct vision, and for the second, of course, rapid exposures. Now it may occasionally happen that a permanent record is desirable o. what must be done almost instantaneously. That point I think ought to be reached ere long.

"Some weeks ago I recorded a photo of the elbow-joint in 1¾ minutes, and that at a time when we did not understand the tubes as well as now. Since then I have obtained records of metallic objects in half a second, and the bones of the hand in six seconds, without the aid of fluorescent screens. What we desire most, however, in practice is a better Crookes' tube for fluorescent screens in direct vision. At present I go while the tube is being exhausted, and test the result before it is taken off the pump. When I am examining an object with the screen, or about to photograph, I heat the tube and keep the current passing through until the maximum effect is obtained. I have now seen by this means the different bones of the extremities and joints; moreover, I have no difficulty in seeing through the body itself. The spine ribs, sternum, clavicle and scapula can be seen; and I have shown to several medical men the shadow of a coin in the gullet (impacted for six months), opposite the fourth dorsal vertebra. Foreign bodies in the extremities are, as a rule, easily seen.

"For the examination of the cavities inside the head, *e.g.* the antrum, or mouth, or pharynx, also the teeth, I now place fluorescent screens in the mouth, and the Crookes' tube outside, either above or below the level of the buccal cavity as required, and sharp images are thus obtained on the screen of not only foreign bodies, but also of the bones of the face, and roots of the teeth as well.

"Other tissues than the bones are now yielding. I have photographed the side of the neck, and shown the tongue, hyoid bone, the pharygeal cavity, cartilages of larynx and trachea of the living adult subject.

"At present we cannot afford to ignore any aid, and hence we are glad to have such hints as the fluorescent screens in photography; but it is not unlikely that all such will be more or less dispensed with as a better source of the X-rays is obtained, viz. a still better Crookes' tube."

Since the above was written, and in consideration of the question at issue, Dr. Macintyre informs us that he has made a further series of experiments on the question of rapid exposures. The tube used was one of the now well-known ordinary focus tubes, made in Glasgow. He has obtained a well-defined image of metallic objects, and distinct, though faint, image of the bones of the fingers with one flash of the Crookes' tube, produced by a single vibration of the mercury interrupter, a large coil giving an eleven-inch spark, and, of course, without using any fluorescent screen. What the extent of the time of exposure was cannot be said, but he describes it as an unknown, unmeasured, small fraction of a second. In another experiment he was able to obtain a distinct image of the bones of the forearm with sixty similar flashes of the tube.

Prof. O. N. Rood found indications of reflection of Röntgen rays from a platinum surface on March 9, and on March 13, after an exposure of ten hours, he obtained a good negative, capable of furnishing prints, of a piece of iron wire netting reflected from a sheet of ordinary platinum foil and through a plate of aluminum (*Science*, March 27). The conclusion he arrived at from inspection of the image was that "in the act of reflection from a metallic surface the Röntgen rays behave like ordinary light." Experiments made to ascertain the percentage of the rays reflected, indicated that platinum foil reflected the 1/260th part of the X-rays incident on it at an angle of 45°.

Upon the question of reflection and refraction of Röntgen radiance, Prof. Pupin pointed out in his paper read before the New York Academy of Science, on April 6, that it was discussed by Prof. Röntgen in Sections 7 and 8 of his origina essay. Neither by photography nor by the fluorescent screen could Prof. Röntgen detect an appreciable refraction with certainty. A reflection from metallic surfaces in the immediate vicinity of a photographic film was detected, "but," translating Röntgen's own words, "if we connect these facts with the observation that powders are quite as transparent as solid bodies, and that, moreover, bodies with rough surfaces are, in regard to the transmission of X-rays, as well as in the experiment just described, the same as polished bodies, one comes to the conclusion that regular reflection, as already stated, does not exist, but that the bodies behave to the X-rays as muddy media do to light." "In face of these observations," continues Prof. Pupin, "Prof. Rood's and Mr. Tesla's experiments must be interpreted as a confirmation of Prof. Röntgen's results, and not as a

demonstration of the existence of a regular reflection. Mr. Tesla infers regular reflection from his theory of bombardment. His experimental method is the same as that of Prof. Rood; that is, he places a reflecting plate at an angle of forty-five degrees to the direct ray, and then places the photographic plate at right angles to the direction in which the reflected ray should pass if regular reflection existed. On account of the greater power of his apparatus, his time of exposure was one hour, whereas that of Prof. Rood was ten hours. It is evident, however, that an effect upon the photographic plate does not prove the existence of regular reflection."

In his own experiments on reflection, Prof. Pupin aimed at getting rid of the photographic plate and substituting the fluorescent screen in its place.

He concludes as follows :—"These experiments prove beyond all reasonable doubt that the Röntgen radiance is diffusely scattered through bodies, gases not excepted. We may call it diffuse reflection, if we choose, provided that we do not imply, thereby, that we must necessarily assume an internal inter-molecular regular reflection, in order to explain the phenomenon. For if a puff of smoke be forced through a pile of wood, some of it will come out pretty well scattered, although we cannot speak here of a reflection in the ordinary sense, but rather of deflection, reserving the term 'reflection' for those particular cases in which the angle of incidence is equal to the angle of deflection. It might turn out, for instance, that the X-rays are due to a circulating motion of ether, and that the stream lines are deflected and diffusely scattered within the molecular interstices of ponderable substances. Appearances seem to speak more in favour of this view than in favour of a wave motion of ether. The diffuse scattering of the Röntgen radiance by bodies placed in its path may be also described by saying that *every substance when subjected to the action of the X-rays becomes a radiator of these rays*. . . . The fact that opaque bodies, like metals, are less effective in producing this secondary radiation, leads to the conclusion that there is in these bodies an internal dissipation of the Röntgen radiance much greater than in the case of transparent dielectric substances. A properly constructed bolometer should give us much information on this point, and it is my intention to take up this subject as soon as time and facilities will permit. These diffusion effects, which are present even in air, bring the Röntgen radiance into still closer resemblance to the principal features of the kathode rays which were studied by Prof. Lenard. The difference in their behaviour towards magnetic force is still to be explained. Is it not possible that this magnetic effect in air is masked by the diffuse scattering of the X-rays?"

Our American correspondent says :—"Tesla has found that the X-rays are reflected from certain metals tested in the same order as in Volta's electric contact series in air. Zinc reflects 3 per cent. at an angle of 45°. Below it stand lead and tin, but his observations do not yet show which reflects more highly. Below these in order come copper and iron about the same, then silver. His first observations led him to infer that magnesium would reflect still more than zinc, and sodium most of all. Subsequent experiment has verified the conjecture as to magnesium; but sodium has not yet been tested. By availing himself of the reflection from a zinc cone, he has taken a picture of the ribs of an assistant at a distance of four feet from the vacuum tube, and with an exposure of forty minutes. His apparatus is so constructed that the bulb or bulbs are at the large end of the cone, and the subject at the small end, where the rays are concentrated. The cone or funnel is constructed at an angle less than 30°, so that the incident rays are reflected more than 3 per cent; and especially more the small end of the funnel the rays approach within a very few degrees of parallelism with the reflecting zinc. Prof. Tesla thinks the theory that the X-rays consist of streams of radiant matter, is confirmed by these results. He has not yet been able to detect any refraction of the X-rays."

In the summary of work done in connection with Röntgen rays (page 522), we give an account of experiments made by Prof. Joly, which demonstrate the existence of reflection.

"In confirmation of these experiments," writes Mr. Alfred W. Porter, "may I point out that a similar phenomenon to that described by Prof. Joly has been present on all my skeletal radiographs. Immediately surrounding the sharp geometric shadow of the flesh of the fingers a black line exists on the *negative*. This is especially noticeable where two fingers overlap one another; the partial shadow cast by one finger preventing the deposit on the plate from becoming so dense as to obscure the presence of the black line. I enclose a *positive* which shows the presence of the corresponding white line very clearly. M attention was first called to the presence of this line on my pictures on January 28, by Mr. John T. Morris, of this College. I believe that the prominence of the finger-nails is due to the same cause. I have also taken graphs of over-lapping wood, metal, and ivory objects which exhibit the same phenomena."

We have received the prints referred to by Mr. Porter, and they entirely bear out his description of the appearance presented.

For some time past Prof. FitzGerald and Mr. Fred. T. Trouton, at Trinity College, Dublin, have sought evidence of crystalline action, both on transmission and reflection at grazing incidence of Röntgen rays. Though so far this has been without success, we learn that they have noticed a marked scattering of the rays in transmission through some substances. The following arrangement is convenient for showing this. "On a plate of lead, which has a slit cut in it, is placed a sheet of, say, solid paraffin 2 or 3 m.m. thick, so as to cover one end of the slit; over this is laid a strip of lead—but slightly wider than the slit—so as to just entirely cover the slit. No direct radiation then can pass from a Crookes' tube, placed vertically over the slit, to a sensitive plate placed behind the lead; but with a lengthened exposure (20 to 30 minutes) with a focus tube, a darkening is found on developing at the end where the paraffin is placed. If the paraffin be then moved to the centre or other end, so as to eliminate accidental effects, on again exposing the darkening action is found to follow the paraffin. Some darkening always occurs even where there is no solid body. How much of this is due to successive reflections from the lead sheet and strip, or how much is due to scattering of the rays by air, is not easy to say."

Mr. Dayton C. Miller has obtained some good results at Case School of Applied Science in Cleveland, Ohio, U.S.A., but the exposures he finds necessary are longer than those given by the foremost workers in Great Britain. The tube used by him is spherical in shape, and about five inches in diameter. The coil gives a six-inch spark in air, and is excited by a current of about sixty watts, obtained from fifteen cells of storage battery. The voltage used varies from twelve to twenty. With this apparatus and power, Mr. Miller says :—

"The bones of the fingers are distinctly shown with exposures of ten seconds, while exposures varying from two to ten minutes are regularly used in locating bullets and shot in the hand, and in examining injured or deformed hands. An excellent picture of a hand and fore-arm, placed diagonally across an 11 × 14 plate, has been made with twenty minutes' exposure. The entire detail of the lettering and design of an aluminium medal has been taken in five minutes. Numerous interesting surgical cases of fractured and diseased arm-bones have been examined with satisfactory results. Photographs of the chest and head have been made with exposures of one hour in each case. A surprising amount of detail is visible. The chest picture shows the shoulder-joint, the collar-bone, the spinal column with its articulations, and a dark streak along its length corresponding to the spinal cord, and eight ribs on each side of the spine. In the region of the heart the detail is less conspicuous, indicating that the heart is more opaque than the lung tissue."

Mr. W. L. Goodwin, of the School of Mining, Kingston, Canada, has sent us the results of experiments made to determine the relative opacities of various substances to Röntgen rays. The only details as to the method employed is that the results were obtained "by photography with a small Crookes' tube similar in shape to a radiometer, but constructed to show the revolution of a platinum vane covered on one side with mica." The relative opacities thus determined are as follows :—

I. SOLIDS :—

Transparent: Paraffin wax, wood charcoal, coke (in part), asphalte, albertite, starch, diamonds.

Fairly transparent: Citric acid, jet, anthracite, amber, natrolite, caustic potash, caustic soda, borax, soda crystals.

Somewhat transparent: Silicified wood, Epsom salts, serpentine, staurolite, stilbite, lazulite, $H_2(NH_4)PO_4$, cryolite, Mohr's salt, analcite, Na_2CO_3, borax glass, nitre, Rochelle salt.

Somewhat opaque: Mica, tourmaline, wulfenite, axinite, spinel, calcite, aragonite, kaolin, $NiSO_4(NH_4)_2SO_4.6H_2O$, $NiSO_4.K_2SO_4.6H_2O$, &c.

Opaque: Roll sulphur, crystal of rhombic sulphur, fluor-spar, topaz, beryl, ruby, quartz, NaCl, chalco-pyrite, $H_2(NH_4)AsO_4$, H_2KAsO_4, K_3FeCy_6, $K_2Cr_2O_7$, orpiment, anhydrite, celestine, barite.

Sulphuric acid is as opaque as the same thickness of sulphur. Water is more opaque than paraffin wax.

A number of crystals of about the same thickness were photographed on the same plate, and an attempt made to judge of their relative transparency with a scale from 1 to 10, with the following results:—

H_2KAsO_4	1
$H_2(NH_4)AsO_4$...	2
$NiSO_4.(NH_4)_2SO_4.6H_2O$	3
$MgSO_4.K_2SO_4.6H_2O$...	3
$NiSO_4.K_2SO_4.6H_2O$	3·5
$MgSO_4.(NH_4)_2SO_4.6H_2O$	4
$ZnSO_4.(NH_4)_2SO_4.6H_2O$	4
$CoSO_4.K_2SO_4.6H_2O$	4
$CoSO_4.(NH_4)_2SO_46H_2O$	4
$H_2(NH_4)PO_4$	5
Paraffin wax	10

The different values of arsenic and phosphorus in the isomorphous acid arseniates and phosphates are to be remarked.

Thin sections of a granite composed principally of quartz and feldspar and of a hornblende-gabbro were photographed. In both cases the feldspar was found to be distinctly more transparent than the other constituents.

Prof. E. Doelter, of Graz, has communicated to the *Naturwissenschaftliche Verein für Steiermark* some observations relating to the opacity of different rocks and minerals for the Röntgen rays, and their use as providing a test of the genuineness of precious stones. Dr. Doelter finds that (1) the opacity does not always increase with the density, although minerals having a specific gravity greater than 5 are relatively opaque; (2) the complexity of the chemical constitution of a mineral affects its opacity, but no general law of relationship can be enunciated; (3) dimorphous minerals exhibit but slight differences in their behaviour with regard to the rays in their different forms; (4) in most crystals, the amount of absorption does not depend sensibly on the direction of the incident rays; (5) all minerals naturally fall into about eight well-defined groups, according to their opacity, the order being as follows: diamond, corundum, talc, quartz, rock-salt, Iceland spar, &c. The diamond is ten times as transparent as corundum, and 200 times as transparent as tinfoil.

Mr. W. Ackroyd and Mr. H. B. Knowles have systematically examined the opacity of a number of substances for Röntgen rays, with a view to determining whether it bears any relation to molecular weight (*Journal* of the Society of Dyers and Cleaners, April).

With this view they have compared the isomorphous sulphates, $RSO_4, 7H_2O$ of the eighth group of metals, iron, nickel, and cobalt; the oxides, RO, of some members of the second natural group, viz. magnesium, zinc, and mercury; the isomorphous oxides, R_2O_3, of the metals aluminium, chromium, and iron. In each of these series there are presumably similarly shaped molecules for comparison, and the disturbing factor is the difference of molecular weight. The result of an hour and a half's exposure showed that the alumina was practically transparent, the chromium sesquioxide semi-transparent, while the ferric oxide was opaque. In other words, the opacity of the substance was in some direct relation to the molecular weight. There are here marked differences with big jumps in molecular weights. The same observation applies to the oxides of magnesium, zinc, and mercury. The isomorphous sulphates of iron, nickel, and cobalt are extremely interesting, because of the nearness of the specific gravity numbers, and also of the molecular weights. The iron compound, with lower specific gravity and molecular weight, appears to be the least opaque of the three, while the nickel and cobalt compounds of nearly the same specific gravity and molecular weight have approximately the same degree of opacity. The following table correlates these facts with other properties:—

Compound.	Sp. gr.	Molecular weight.	Colour.	Behaviour to Röntgen rays.
$FeSO_4, 7H_2O$	1·85	278	Light green	Slightlyless opaque than others in this group.
$NiSO_4, 7H_2O$	1·95	280	Deep green	About the same relative opacity.
$CoSO_4, 7H_2O$	1·92	281	Pink	
Al_2O_3	4·00	103	White ...	Transparent.
Cr_2O_3	4·99	153	Green ...	Semi-opaque.
Fe_2O_3	5·13	160	Brown ...	Opaque.
MgO	3·42	40	White ...	Transparent.
ZnO	5·47	81	White ...	Semi-opaque.
HgO	11·13	216	Red	Opaque.

The foregoing figures, conclude the authors, demonstrate the weakness of an unqualified law of density, as the denser oxide of zinc is more transparent than the less dense ferric oxide. But they point out that, adopting the legitimate method, which they have initiated, of comparing only compounds with kinship, each of the above bodies conforms to the law of density as well as of molecular weight in relation to opacity.

Dr. A. Sella and Dr. Q. Majorana (*Rend. R. Accad. dei Lincei*) describe certain experiments on the influence of Röntgen rays on the sparks produced by the discharge of an induction coil in air. The sparking distance is found to be shortened by the Röntgen rays, this effect taking place whenever these rays fall on the positive pole. In this respect the phenomenon is the reverse of that obtained by Hertz with ultra-violet light, the effect of which is to lengthen the sparking distance whenever it falls on the negative pole. The authors found that the simultaneous actions of Röntgen rays and of ultra-violet light could be made to neutralise each other by arranging the coil to give a spark of suitable length (in their experiments about 30 mm.). When the sparking distance was less, the Hertz effect predominated; when the sparking distance exceeded 30 mm., the Röntgen rays had the greater influence.

Dr. Filippo Campanile and Dr. Emilio Stromei communicate to the *Rendiconto dell' Accademia delle Scienze fisiche e matematiche* (Naples) a note on the phosphorescence and the Röntgen rays in Crookes' and Geissler's tubes. The conclusions arrived at are as follows: (1) When in the circuit of an induction coil, containing a Crookes' tube, a spark is thrown off from the positive pole, the phosphorescence of the tube and the efficacy of the Röntgen radiations are augmented. (2) As the length of the spark increases the phosphorescence at first increases to a maximum, and then decreases. (3) If, on the other hand, the spark is thrown off from the negative pole, the phosphorescence and the Röntgen rays are thereby diminished. The same experimenters have also succeeded in obtaining Röntgen rays with an ordinary Geissler's tube. These radiations possessed all the characteristics of those which emanate from a Crookes' tube.

Signor E. Villari, writing in the same journal, considers that the phenomena of discharges in tubes seem to indicate the existence not only of kathodic but also of anodic rays. While the kathodic rays travel in straight lines and produce a negative charge wherever they strike the tube, the suggested anodic rays diffuse themselves all round the anode, and communicate a positive charge to the whole surface of the tube over which they are diffused.

The fundamental character of the new rays has led speculators to make various surmises as to a possible connection between these radiations and the phenomenon of gravitation, and two lengthy memoirs have been written on the subject by Rudolf Mewes.[1] In the second of these the author claims to have proved experimentally that gravitation is propagated through the ether with the velocity of light.

Finally, attention may profitably be called in this summary to the April number of the *Proceedings* of the Physical Society. In the admirable collection of abstracts of physical papers there published, will be found concise descriptions of the scope and results of no less than forty papers concerned with Röntgen rays.

[1] "Licht Electricitäts und X-Strahlen" (pp. 54); "Die Fortpflanzungs-Geschwindigkeit der Schwerkraftstrahlen" (pp. 93). (Berlin: M. Krayn, 1896.)

Röntgen Ray Investigations. TESLA. *Elec. Rev.*, April 22.—His investigations with reflection have confirmed his opinion that Volta's electric contact series in air are identical with the order of the metals arranged according to their power of reflection, the most electro-positive metal being the best reflector; platinum is the poorest and sodium one of the best; this order is approximately the same as that with reference to their energies of combination with oxygen; should this be confirmed by other physicists, the following conclusions would be justified; first, that highly exhausted bulbs emit material streams which are reflected from metallic surfaces; second, these streams are formed of matter in some primary or elementary condition; third, the streams are probably the same agent which is the cause of the electromotive tension between metals in close proximity; fourth, every metal or conductor is more or less a source of such streams; fifth, these streams must be produced by some radiations which exist in the medium; sixth, streams resembling the cathodic must be emitted by the sun, and probably also by other sources of radiant energy; these conclusions are discussed in detail. He predicts that if a sensitive film is placed between a magnesium and a copper plate, a true Röntgen shadow picture would be obtained after a long exposure in the dark; he thinks it probable that there is a continuous supply of such radiations from the medium in some form, and that they come from the sun, from which he concludes that with very long exposures Röntgen shadow pictures could be obtained from all sources of radiant energy, provided the radiations are permitted first to impinge upon a metal or other body; he suggests that the lumps of matter composing a cathodic stream in the bulb are broken up into small particles by impact against the walls of the tube and are thereby enabled to pass into the air; the difference between Röntgen and Lenard rays is that the particles composing the former are incomparably smaller and have a higher velocity, which he believes is the reason why they are not deflected by a magnet; he tried to find whether the deflected rays possessed distinctive features but could notice no difference; it is important to find out what becomes of the energy of these rays; his tests have confirmed Röntgen's statement that the rays are incapable of raising the temperature of a body. He has increased the efficiency of the reflectors by providing separate successive layers for reflection, by making the reflector of thin sheets of metal or mica. He recalls a former experiment in which a brush or stream issuing from a single electrode rotated very rapidly due to the earth's magnetism, and he thinks that perhaps the Lenard and Röntgen streams also rotate under the action of the earth's magnetism. He does not favor the idea of vibrations approximating those of light and thinks that all these effects could be produced with steady electrical pressure like that from a battery, with the exclusion of all vibrations; he found no effect due to changes of the frequency although it was varied between wide limits; to obtain clear shadows it is very important to pass the rays through some tubular reflector which makes them approximately parallel; clearer pictures were obtained by using very thick films developed very slowly. He has succeeded in making the radiation more powerful and describes and illustrates his new form of apparatus in which the rays were made to pass through various thicknesses of circulating oil; with this apparatus he claims to have obtained better results. By mixing a non-fluorescent powder with the fluorescent material for a screen he found that the general brightness was diminished, but that the shadows were sharper; the vertebral column could be seen quite clearly even in the lower part of the body, as also the outlines of the hip bones; he located the heart unmistakably, the background for which appeared to be brighter; the bones of the hand could be seen very clearly through sheets of copper, iron and brass nearly one fourth of an inch thick, and through glass the rays seemed to pass with great freedom, one half an inch of glass hardly dimming the fluorescence; it appeared sometimes as if the bones and flesh were equally transparent to radiations passing through the oil; the motion of a hand could be clearly seen through the body; it is of advantage to determine by means of the screen the proper distance at which an object should be placed before taking the photographic impression. The effect noticed by Prof. J. J. Thomson, that bodies traversed by these rays became conductors, was further investigated, but the conclusion could not be confirmed, and he (TESLA) claims that it is a further evidence of the existence of streams of matter, but not that the bodies become conductors in the common acceptation of the term.

NIKOLA TESLA'S WORK.

WONDERS HE HAS ACCOMPLISHED AND OTHERS HE PROMISES.

His Achievements in Electrical Research—Endless Possibilities of Problems He Is Now at Work Upon—His Experiments with the Roentgen Rays—His Personality

Nikola Tesla is a man about whom the general public knows very little. There have been magazine articles about him and books about him, and, since Prof. Roentgen made known his discoveries in X-ray photography, Tesla's experiments with the discoveries with experiments followed up the discoveries with experiments of his own, the papers from time to time have told how Tesla had "seen the human heart" and had "photographed the human brain" and done other wonderful things. His name has been on the tongues of many people, but not one man in a hundred could tell what Tesla had done for science, or very little if anything about him personally.

Tesla himself is responsible for the lack of popular knowledge of himself. He isn't one of the kind to hide his light under a bushel, but he likes the light shine and hides himself. He doesn't like to see his name in print. He doesn't like to be praised for what he has done or is doing. He wants, more than anything else, to be let alone. He discourages notoriety of any sort. When newspaper men call on him to ask him questions he is the quintessence of courtesy and politeness. He is willing to tell them anything they want to know about electricity or any of the other subjects on which he is well informed, but on one subject —Tesla—he is silent. When THE SUN reporter called on him early last week and told him that he had been instructed to write a story about Tesla and his inventions, the inventor said:

"Don't; there has been too much already," and he said it in a way that showed he meant it. It was only after a second visit and much earnest urging that he would consent to the publication of anything, and he surrounded his consent with conditions.

He was asked to tell which of his many inventions he considered the most useful and satisfactory to him, and he replied that first in the list was the transmission of power with the help of wires. This power was the alternating electric current now in use. Next he mentioned the motor that made possible the transmission of power with only a single wire. It used to be supposed that two wires were necessary to complete a circuit, one for the electricity to come back on. This motor does away with the extra wire, and lessens the expense and the waste. Third, he mentioned the thing which he hoped to accomplish: Doing away with that wire altogether, and using the earth. In a lecture delivered before the American Institute of Electrical Engineers in 1891, Tesla said:

"We are whirling through endless space, with an inconceivable speed, all around us everything is spinning. Everything is revolving. Everywhere is energy. There must be some way of availing ourselves of this energy more directly. With the power derived from it, with every form of energy obtained without effort, from the store forever inexhaustible, humanity will advance with giant strides. The mere contemplation of these magnificent possibilities expands our minds, strengthens our hopes and fills our hearts with extreme delight."

He had this third thing in mind when he delivered the lecture. He has been working now ten years to accomplish it, and he has had encouraging success with his experiments.

Of his inventions, in this talk with THE SUN reporter, he mentioned fourth the perfecting of an apparatus for the production of electric vibrations; fifth, the production of light without any carbon such as is required in the ordinary incandescent lamp. Light is produced by the means of electrical vibration. By the method proposed 200 times the light can be had with the same power. Sixth, he mentioned the evolution of the oscillator, a work on which he has been engaged five or six years and which is about ready to be put into general use. Then he says:

"Of the energy that goes to the making of a cubic light 95 per cent. is wasted. The oscillator, combined with the Niagara engine and the dynamo combined and in use it means the saving of the energy that is now wasted."

Of the problems he has worked on Tesla said:

"They affect humanity as a whole." The energy that is wasted must be saved, he said. He spoke of the utilization of the power of Niagara Falls and of its possibilities and the possibilities in nature elsewhere. He said the existing faults of society are to be overcome only by producing more energy; that energy was in nature and the problem of getting control of it and of utilizing it was the problem on which he worked. He covered a field of ordinary invention. He thought only of the great problems. He observed that they would be mastered and the whole world would benefit.

Tesla is a man of striking personality. He is unusually tall and his body is well proportioned and is crowned with jet-black hair. His manner is quick and impulsive. In speech he is earnest. He wastes few words. He has a bearing impressive, one with the fact that he is a man of action. He is only 39 years old. He was born in Smiljan, Lika, on the Military Confine of Austria-Hungary, of the Serbian race. His father was a clergyman in the Greek Church. His mother was a woman of great inventive invention. Tesla got his early education at Gospich in a public school, and later spent three years in the Higher Real Gymnasium at Carlstadt, Croatia. He saw his first steam engine while at the latter school. He inherited his mother's love of invention, and when he left school in 1873 he went to experimenting with electricity against the wish of his father, who wanted him to enter the ministry. He was not in the question, and then his father wanted him to become a college professor of mathematics and physics and with that purpose sent him to the Polytechnic School at Gratz.

In this school there was a grammne dynamo, and Tesla, with the notion that the brushes of a dynamo could be operated without commutator or brushes, such as this one was equipped with, began work that resulted in one of the ideas that later developed one of his great inventions, a rotating field motor.

The idea of becoming a professor vanished, and he took up the engineering curriculum. For the next few years he kept up his studies, and succeeded in inventing several things in connection with the telephone. Then he went to Paris, where he saw a wider field. After a few years there in the course of which he met many Americans, who told him of opportunities in his field of investigation here, he came to America. He hunted out Thomas A. Edison, and went to work in his laboratory. In Thomas Commerford Martin's book, "The Inventions, Researches, and Writings of Tesla," Tesla's connection with Edison is mentioned, and the author says:

"It was impossible, however, that with his own ideas to carry out, and with his own inventions to develop, Mr. Tesla could long remain in even the most delightful employ; and his work now attracting attention he left his Edison ranks to join a company intended to make and sell an arc lighting system based on some of his inventions in that branch of the art. With unceasing diligence he brought this system to perfection, and saw it placed on the market. But the thing which most occupied his time and thought, however, all through these years was his old discovery of the rotating field principle for creating current work, and the application of it in motors that have now become known the world over."

Up to this time the alternating current wasn't in favor with electrical engineers. They knew little about it and did not realize its value. It wasn't until 1886 that Tesla himself succeeded in perfecting a practical operation the idea he had conceived when he was a student at the Polytechnic Institute. It is the completion and perfection of several of this invention that will enable the Niagara Falls Power Company to transmit its power far from the falls where it is generated with the aid of the forces of nature.

But before telling what Tesla has done, more may be said about Tesla the man, his work and how he works. He is a man of very regular habits, wherein he differs from Edison, who works by spurting at the top speed for a stretch, sometimes longer, when he has on hand something that interests him. Tesla is up at noon, spurning at 6 o'clock. He has a lot of gymnastic exercises that he goes through with regularly. He has a light breakfast and then he loses little time getting to his work. He takes an hour for his lunch and for a bundle of the day and the afternoon is devoted to hard work. He usually works until 8 o'clock in the evening, but often it is midnight or thereabouts. His laboratory is at 46 East Houston street.

He has a clerk who attends to visitors. Keeps away cranks, keeps a record of callers, sees that everybody who has real business with the inventor is provided with the latest copy of some scientific paper which Mr. Tesla is engaged. He also has a dozen or more mechanics who are as loyal to him as Edison's men are to him; but the nature of his work and the magnitude of the problems he sets himself to solve do not permit of their rendering him the same sort of assistance that the Wizard's men furnish to their employer. A friend of Tesla's was asked what was the most interesting trait of his character. He replied:

"His love of humanity and his friendship for young men who are ambitious to succeed and love their work. Tesla would become misanthropic. He is jealous of no man. I believe if he worked on a problem twenty years, and was about realizing success just as another succeeded, he would be as happy as if he had succeeded himself. His interest in his work is entirely a desire to advance the science for the benefit of all mankind. I think this is shown by the fact that he is not a rich man. He could have been a millionaire if he had had any desire to be so."

If he had devoted his time and energies and his inventive genius to money making there is no question but that he would be rich to-day. Tesla can invent anything. Tell him what you want and he will work at it until he accomplishes it. But if he devoted his time to inventions of that sort, the broader propositions and problems would go by the board. He would have no time for them. It is to solve them that he delights to work.

Now, to take up some of the things Tesla has done. It may be said, to begin with, that to talk about Tesla's inventions leads one into a maze of electrical terms that defy the understanding of the mind not educated to the technicalities of his work, his discoveries, and his inventions here would be about as intelligible as a column of Hebrew jargon. Hence, all that will be attempted is to tell what he has accomplished. First, take the transmission of power.

When Tesla came into the field in America, as stated before, little was known of the alternating current. The single alternating current was used, but for the purpose of lighting only. The continuous current was used almost exclusively.

The continuous current system is very good for short lines, but with it energy cannot be delivered successfully at any great distance at high pressure. To deliver the continuous current at high pressure at a distance would require the use of wires so heavy that they would be cumbersome and entirely impracticable for use. Tesla made an alternating current motor that permitted the transmission of energy long distances at high pressure over thin wires, the electricity being used at the same pressure or at a lower or a higher pressure, whichever was desired, by means of a transformer. Thus the bridling of the power in Niagara was made possible, and natural forces everywhere can be similarly harnessed and made to do the work that has been heretofore done at great cost by other forms of force and energy. A great many smaller inventions are included in this great one. Its possibilities are just now beginning to be realized. Tesla's discoveries in connection with this motor, it is said, were the prime cause of the recent consolidation of the Edison and the Westinghouse Electric Companies.

In this motor two wires were used for the transmission of the current. Tesla believed that the extra wire was a useless expense; that all the work could be done with one, and no return circuit was necessary. So he set himself about the work of finding a way to accomplish this. He did accomplish it, and now it is possible through the earth to transmit the energy with the aid of only one wire. This invention, however, has not been of the same practical use as the other. It is now in a state in the direction of accomplishing the third thing that Tesla is aiming at. That is the transmission of power and intelligence without any wires, by means of the earth itself. If such a thing can be accomplished the human mind can hardly conceive of the possibilities. Tesla believes that it can be accomplished. The fact that he believes it is proved by the ten years of work he has devoted to experimenting on that line.

Next in order, as Tesla mentioned them, is the perfection of an apparatus for the production of electrical vibrations. Electrostatics is the science of electricity at rest. Tesla demonstrated that for the production of light waves, primarily, electrostatic effects must be brought into play, and he formed the opinion that all electrical and magnetic effects may be referred to electrostatic molecular forces. In a glass bulb filled with electrostatically charged molecules he found that by agitating them, causing them to vibrate, to strike against each other, brilliant light was produced. No carbon was required, such as is used in the ordinary incandescent light. There was nothing but the glass bulb. Tesla's accomplishment was the making of apparatus to stir up the molecules within that bulb, and apparatus and are ever present, while the carbon heretofore needed is expensive. This apparatus is nearing perfection now, and lamps which furnish light without carbon are in sight. The saving in the cost of electric lighting will be tremendous, and, as measured by Tesla, 100 times the light will be produced with the same energy that is now used in the production of the ordinary incandescent lights. This will mean more light with less power and less expense, because there will be no expensive carbons required.

Last on Tesla's list is the oscillator, now perfected and ready to be put on the market. It is estimated that nine-tenths of all the dynamos in the world are now operating by steam power. Every step in the production of electricity by steam power is attended with waste and loss of power and energy. The problem Tesla set out to solve was the saving of the 95 per cent. of energy that was wasted. Actual tests showed that only 5 per cent. of the energy used in making incandescent lights manifested itself as light. The 95 per cent. was lost. There was loss in every step from the putting of the coal into the furnace to the delivery of the electricity. Tesla has combined an engine and a dynamo. Steam is forced into the engine at high pressure, which produces an extremely rapid vibration of a steel rod, and this rod or piston is so adapted to a set of magnets that the mechanical energy of the vibrations is converted into electricity. Fly wheels and governing balls and eccentrics and valves and all the rest of the complicated mechanism required for the purpose of control or regulation are done away with.

The steam cylinder with its piston is the only thing that does the work about a steam engine. All the rest takes up room and produces nothing, so if they can be done away with the energy that it takes to run them is saved. Tesla's oscillator does away with them. The oscillator converts the energy of steam into electricity directly. It would appear that this invention, if it does all that Tesla claims, will revolutionize all business that requires energy in the form of steam or electric forces to operate it. The machine doesn't take up one-tenth of the room needed by an ordinary engine and dynamo.

Probably the oscillator and the new system of lighting would not have been long in coming if Tesla had it not been for the destruction of Tesla's laboratory last year. He had these and other inventions very well perfected, and in his shop the result of years of work. He had many models of machinery that he could not replace. All that was left to him was the ideas of how these things had to be done over again. He said himself at the time that a million dollars could not repay the loss.

Tesla's work with the Roentgen ray photography and the results he has accomplished have been more extensive than those and results done and accomplished by any other experimenter. His first published statement of what he had done with the rays was made after the discovery of the photography. He had experimented in the meantime incessantly. His pictures and his statements appeared first in the *Electrical Review*. He succeeded in taking the picture of the shoulder of a man showing the ribs and shoulder joint. The upper arm bone was taken through clothing and a board partition at a distance of four feet. His experiments extended over a period of months. In his paper he said:

"The bony structure of birds, rabbits, and the like is shown within the least detail, and even the hollow of the bones is clearly defined. In a plate of a rabbit, under exposure of an hour, not only every detail of the skeleton is visible, but likewise a shadow picture of the abdominal cavity and the location of the lungs, the liver, and many other features. Prints of even large birds show the feathers quite distinctly.

"Clear shadows of the bones of human limbs are obtained by exposures ranging from a quarter of an hour to an hour, and whole plates have shown such an amount of detail that it is almost impossible to believe that we have to deal with shadows only. For instance, a picture of a foot with a shoe on was taken, and every fold of the leather, trousers, stocking, &c., is visible, while the flesh and bones stand out sharply. Through the body of the experimenter the shadows of small buttons and like objects are quickly obtained, while with an exposure of from one to one and a half hours the ribs, shoulder bones, and the bones of the upper arm appear clearly, as is shown in the annexed print. It is now demonstrated beyond any doubt that small metallic objects or bony or chalky deposits can be infallibly detected in any part of the body.

"An outline of the skull is easily obtained with an exposure of twenty to forty minutes. In one instance an exposure of forty minutes gave quite clearly not only the outline, but the cavity of the eye, the chin, and cheek and nasal bones, the lower jaw with its connections to the upper one, the vertebral column and connections to the skull, the flesh, and even the hair. By exposing the head to a longer action still more details have been noted. For instance, I find that there is a tendency to sleep, and the time seems to pass away quickly. There is a sensation of feeling effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep and a quick lapse of time. Should these results be effects be verified, by men with keener sense of observation, it will be still more likely that in the existence of material streams penetrating the skull. Thus it may be possible by these strange agencies to convey to a suitable chemical into any part of the body.

"Roentgen advanced modestly his results, warning against too much hope. Fortunately his apprehensions were groundless, for although we have to all appearance to deal with mere shadow projections, the possibilities of the application of his discovery are such that I am happy to have contributed to the development of the great art he has created."

Tesla has prepared five plates since, his one, in each of which he has told something about some branch of the new photography that had heretofore been unknown. Some of his pictures he has obtained are wonderful. The last and the one that created the most talk is a picture of a man which shows, among other things, the outline of the heart. Tesla showed this picture to THE SUN reporter, together with a picture of a leg and foot, to show the simplicity of the experiments of the work of the Roentgen photography.

Tesla was once asked if he was well off. His reply was:

"If every man who uses my machine in electro-therapy alone were to give me a quarter I would be a very wealthy man. I never received a dollar for it, and there is no way in which I could. I receive a small income from my invention in the rotating field, and I have a small income from home. All this I spend here."

Regarding the future he has said:

"I expect to live to be able to set a machine in the middle of this room and move it by the energy of the solar agency than the medium in motion around us."

Electrical Progress.

On Apparatus for Cathography.

By NIKOLA TESLA.

In order to produce the most intense effects, we have first to consider that, whatever their nature, they depend necessarily on the intensity of the cathode streams. Then, again, being dependent on the magnitude of the potential, it follows that the highest attainable electrical pressure is desirable.

To obtain high potentials we may avail ourselves of an ordinary induction coil, or of a static machine, or preferably of a disruptive discharge coil. If we put two electrodes in a bulb, or use one inside and another outside electrode, we limit the potential, for the presence not only of the anode, but of any conducting object, has the effect of reducing the practicable potential on the cathode. Thus, to secure the result aimed at, one is driven to the acceptance of a single electrode bulb, the other terminal being as far remote as possible.

Having selected the induction apparatus and type of bulb, the next important consideration is the vacuum. On this subject I am able to make known a fact with which I have long been acquainted, and of which I have taken advantage in the production of vacuum jackets and incandescent bulbs, and which I subsequently found to be of the utmost importance, not to say essential, for the production of intense Roentgen shadows. I refer to a method of rarefaction by electrical means to any degree desirable, far beyond that obtainable by mechanical appliances.

Though this result can be reached by the use of a static machine, as well as of an ordinary induction coil giving a sufficiently high potential, I have found that by far the most suitable apparatus, and one which secures the quickest action, is a disruptive coil. It is best to proceed in this way: The bulb is first exhausted by means of an ordinary vacuum pump to a rather high degree, though my experiences have shown that this is not absolutely necessary, as I have also found it possible to rarefy, beginning from low pressure. After being taken down from the pump, the bulb is attached to the terminal of the disruptive coil, preferably of high frequency of vibration, and usually the following phenomena are noted: First, there is a milky light spreading through the bulb, or possibly for a moment the glass becomes phosphorescent, if the bulb has been exhausted to a high degree. At any rate, the phosphorescence generally subsides quickly and the white light settles around the electrode, whereupon a dark space forms at some distance from the latter. Shortly afterwards the light assumes a reddish color and the terminal grows very hot. This heating, however, is observed only with powerful apparatus. It is well to watch the bulb carefully and regulate the potential at this stage, as the electrode might be quickly consumed.

After some time the reddish light subsides, the streams becoming again white, whereupon they get weaker and weaker, wavering around the electrode until they finally disappear. Meanwhile, the phosphorescence of the glass grows more and more intense, and the spot where the stream strikes the wall becomes very hot, while the phosphorescence around the electrode ceases and the latter cools down to such an extent that the glass near it may be actually ice-cold to the touch. The gas in the bulb has then reached the required degree of rarefaction. The process may be hastened by repeated heating and cooling and by the employment of a small electrode.

I may state here that the experimenter need not be deterred from using a glass bulb, as I believe the opacity of glass, as well as the transparency of aluminum, are somewhat exaggerated, inasmuch as I have found that a very thin aluminum sheet throws a marked shadow, while, on the other hand, I have obtained impressions through a thick glass plate.

The above method is not only valuable as a means of obtaining the high vacua desired, but it is still more important, because the phenomena observed throw a light on the results obtained by Lenard and Roentgen.

Though the phenomenon of rarefaction under above conditions admits of different interpretations, the chief interest centers on one of them, to which I adhere—that is, on the actual expulsion of the particles through the walls of the bulb. I have lately observed that the latter commences to act properly upon the sensitive plate only from the point when the exhaustion begins to be noticeable, and the effects produced are the strongest when the process of exhaustion is most rapid, even though the phosphorescence might not appear particularly bright. Evidently, then, the two effects are closely connected, and I am getting more and more convinced that we have to deal with a stream of material particles, which strike the sensitive plate with great velocities. Taking as a basis the estimate of Lord Kelvin on the speed of projected particles in a Crookes' bulb, we arrive easily by the employment of very high potentials to speeds of as much as a hundred kilometers a second.

It may not be known that even an ordinary streamer, breaking out suddenly and under great pressure from the terminal of a disruptive coil, passes through a thick glass plate as though the latter were not present. Unquestionably, with such coils pressures are practicable which will project the particles in straight lines even under atmospheric pressure. I have obtained distinct impressions in free air, not by streamers, as some experimenters have done, using static machines or induction coils, but by actual projection, the formation of streamers being absolutely prevented by careful static screening.

A valuable evidence of the nature of the radiations and progress in the direction of obtaining strong impressions on the plate might be arrived at by perfecting plates especially sensitive to mechanical shock or impact. There are chemicals suitable for this, and the development in this direction may lead to the abandonment of the present plate. Furthermore, if we have to deal with streams of material particles, it seems not impossible to project upon the plate a suitable substance to insure the best chemical action.

By exposing the head to a powerful radiation strange effects have been noted. For instance, I find that there is a tendency to sleep and the time seems to pass away quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep and a quick lapse of time. Should these remarkable effects be verified by men with keener sense of observation, I shall still more firmly believe in the existence of material streams penetrating the skull. Thus it may be possible to project a suitable chemical into any part of the body.

Since my above-mentioned discoveries I have made considerable progress, and can presently announce one more result of importance. I have lately obtained shadows by reflected rays only, thus demonstrating beyond doubt that the Roentgen rays possess this property. One of the experiments may be cited here. A thick copper tube, about a foot long, was taken and one of its ends tightly closed by the plate-holder containing a sensitive plate, protected by a fiber cover as usual. Near the open end of the copper tube was placed a thick plate glass at an angle of 45° to the axis of the tube. A single terminal bulb was then suspended above the glass plate at a distance of about eight inches, so that the bundle of rays fell upon the latter at an angle of 45°, and supposedly reflected rays passed along the axis of the copper tube. An exposure of forty-five minutes gave a clear and sharp shadow of a metallic object. This shadow was produced by the reflected rays, as the direct action was absolutely excluded, it having been demonstrated that, even under the severest tests with much stronger actions, no impression whatever could be produced upon the film through a thickness of copper equal to that of the tube. Concluding from the intensity of the action by comparison with an equivalent effect due to the direct rays, I find that approximately two per cent of the latter were reflected from the glass plate in this experiment.

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CHANGES for advertisements must be in this office by Friday noon for the following week's issue.

NEW ADVERTISEMENTS should be in the office not later than Saturday noon to insure publication the following week.

NEW YORK, MAY 20, 1896.

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TESLA'S ACHIEVEMENTS IN VACUUM TUBE LIGHTING.

The ELECTRICAL REVIEW has from the outset closely followed the promising work of Nikola Tesla. We had the privilege of announcing in 1886, for the first time, Tesla's investigations in a system of electric lighting. Early in 1888 we were the first to announce his epochal discovery of the multiphase system of power transmission, and since that time it has been our pleasant duty to keep our readers well informed on the various subjects of his important researches, of which we only mention his latest contributions to the great discoveries of Roentgen, which were exclusively published in our columns. It is, therefore, no small satisfaction for us to now first record another significant advance of this indefatigable worker. Ever since Tesla showed in his memorable lecture before the American Institute of Electrical Engineers, five years ago, the fascinating experiments with vacuum tubes, he has untiringly labored on, simplifying and improv- his methods, not for a moment diverted by other tasks—nor even discouraged by so great a calamity as the recent destruction of his laboratory—from the problem of producing an efficient and practical system of electrical illumination.

No more impressive result of Tesla's earnest efforts could be shown than that which is outlined in our present issue. The portrait of the great inventor, which, especially in view of the extraordinary way in which it was obtained will not fail to interest the scientific world, is a striking illustration of what he has done. Surely, since he has produced a vacuum tube which is capable of supplying any volume of light desired, even more than a powerful arc light, we can not hesitate to express our positive conviction that the introduction of a more perfect illuminant is near at hand.

TESLA'S IMPORTANT ADVANCES.

HIS REMARKABLE ACHIEVEMENTS IN VACUUM TUBE LIGHTING.

A representative of the ELECTRICAL REVIEW visited the laboratory of Mr. Tesla last week and found him engaged in putting the final touches to certain improvements in vacuum tube illumination. He was enthusiastic as to the results arrived at to such a degree that he expressed his positive confidence as to having made very important advances.

While reluctant to speak at present extensively on the subject of his most recent investigations, he authorized the statement to the effect that he has been most successful in several lines of work he has been following up for a long time, only temporarily interrupted by the lamented destruction of his laboratory by fire about a year ago.

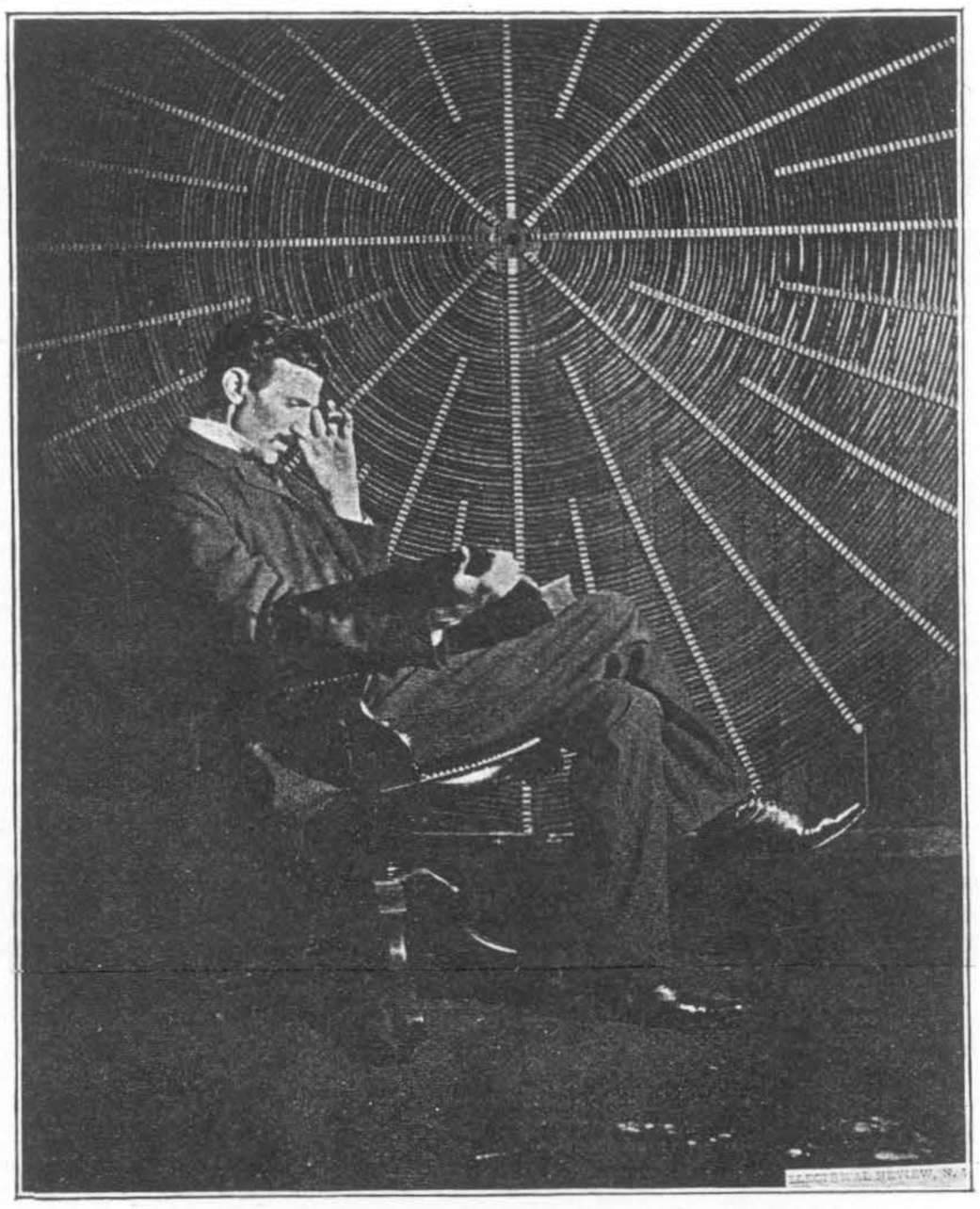
When asked about his often-mentioned oscillator he said that a commercial machine is now being completed with which he expects to show the superiority of this mode of generating electricity.

He further stated with evident elation that in the study of the Roentgen phenomenon he has made great progress, so much so that he is now able to perceive through an Edison improved Roentgen-screen, recently purchased from Aylsworth & Jackson, of this city, the heart of an assistant so clearly as to note its expansions and contractions. In some instances he could locate evident defects in the lungs of a number of persons.

As to his continuous efforts to improve his system of lighting by vacuum tubes, with which he has been identified during a number of years, Tesla said that he has been more successful than he had ever dared to hope. His methods of conversion from ordinary to high-frequency currents are rendered simple in the extreme, the devices are thoroughly reliable and require no attention. Last, but most important of all, he has succeeded in increasing the candle-power of the tubes to practically any intensity desired.

A remarkable and most telling result of the advances he has made in the last direction is a portrait, which he has reluctantly allowed us to use, and which was obtained by *two seconds'* exposure to the light of a *single vacuum tube* of small dimensions. Tesla stated further that photographs obtained by the light of such powerful tubes show an amount of detail which no picture taken by the sun or flash light is capable of disclosing. This feature is only faintly shown in the reproduction on this page. The photograph was made by Tonnelé & Company, artists' photographers, who aided Mr. Tesla in his attempts to photograph by the light of phosphorescent tubes about two years ago.

When asked, Mr. Tesla said, in explanation of the picture, speaking with deep feeling, that the volume he was reading was one of the "Scientific Papers," of Maxwell, given to him as a token of friendship by Professor Dewar; the chair a gift of his warmest friend, Mr. E. D. Adams; and as to the queer coil to



TESLA IN HIS LABORATORY—PORTRAIT OBTAINED BY AN EXPOSURE OF TWO SECONDS TO THE LIGHT OF A SINGLE VACUUM TUBE WITHOUT ELECTRODES, HAVING A VOLUME OF ABOUT 90 CUBIC INCHES, GIVING APPROXIMATELY A LIGHT OF 250 CANDLE-POWER—PHOTOGRAPHED BY TONNELÉ & CO. COPYRIGHTED BY THE "ELECTRICAL REVIEW."

his left, Mr. Tesla hesitatingly remarked that it was the object "dearest of all in his laboratory," having been a most valuable instrument in his many-sided investigations.

Mr. Tesla added, good humoredly, that, had it not been for the extraordinary manner in which the photograph was taken, he would not have given this explanation even to such an important personage as the representative of the ELECTRICAL REVIEW.

The Apotheosis of Electricity.

THE latter half of the present century is to science what the Augustan age of Rome or the Elizabethan age of England was to literature. In our time the Muses have been superseded by the goddess of Electricity. Beside the name of a Shakespeare or a Virgil, that of an Edison or a Tesla is blazoned on the scroll of time; and as the words of the former are in all men's hearts and mouths, so the works of the latter are to-day in all men's minds and hands. Human genius, which in earlier days was esteemed bold to have lain a hand upon old ocean's mane, now has seized the cosmic currents of earth and sky, *givers of light and life*, yet swift and sure emissaries of death, and become the triumphant task-master of electricity—"that subtle and sublime agent of the Almighty, the most potent factor in the everlasting mystery of creation."



F. W. HAWLEY.

The National Electrical Exposition, held in conjunction with the nineteenth annual convention of the National Electric Light Association, puts this stupendous achievement, in all its bearings, before the eyes of the American public in the dazzling show which now occupies the Grand Central Palace in New York City. Governor Morton opened this unprecedented exposition by pressing a golden electrical key—the same which President Cleveland used in opening the world's fair at Chicago. The whole building blazed with light and vibrated with motion at this signal, which also, through telegraphic communication, fired simultaneously four guns, at the four sides of the country—namely, at Augusta, Maine, New Orleans, San Francisco, and St. Paul, Minnesota. And the electrical current thus turned on was generated at Niagara Falls by the power of the cataract, transmitted 462 miles over telegraph wires. This is by far the longest transmission of electricity for power or lighting purposes ever accomplished in the world, thus far.

The visitor saw around him at that moment, as he may see at the exposition any day until the end of the month, working machines and devices illustrating every conceivable application of electricity and electrical energy. Every kind of electric light invented up to date contributes to the general illumination there. Some idea of the magnitude of this branch alone may be obtained from the official statement that the delegates present at the convention represent nearly ten thousand electric-lighting plants in the United States, with an aggregate of capital amounting to seven hundred and fifty million dollars.

The vast space of the main floor in the "Palace" is taken up mostly with the countless exhibits of electrical mechanisms used in telegraphy and telephony, railway transportation, lighting, motors, and power. These fill about two hundred sections, occupied by leading companies and firms. In the middle of the hall is the popular *clou* of the show—the large working model of the Falls of Niagara, with the river above and below, the islands and Canadian shore, and a section of the city of Niagara, showing the power plant just completed there at an expense of six million dollars. Connected with this model are a number of telephone transmitters, in communication with receivers placed at Niagara above the great cataract itself. By this means it is possible to hear, at a distance of four hundred and sixty-two miles, the actual roar of the falls—which, however, is not a "roar" at all, but a deep, awesome diapason, pronounced by a musician to be "a perfectly constructed musical tone, or complete series of tones all in grand unison as in an organ." Near by is a forty-foot section of the Erie Canal, with real water, and model canal-boats run by the new electric bank haulage system, which is actually being put into operation on that ancient water-way. Another potent attraction, on the second floor, is the practical demonstration of the use of the Röntgen X rays, by means of Edison's fluoroscope.

Of course the exhibit of the Edison Electric Illuminating Company is a conspicuous feature. It includes a dynamo controlling section complete, with storage battery attached; and an almost infinite variety of electrical apparatus and inventions.

Although it is Nikola Tesla's alternating current motor which makes possible the long-distance transmission of energy over ordinary wires, as from Niagara in the present instance, yet there is comparatively little in this or in Tesla's other inventions and discoveries that could be made effective in a popular exhibit. Thus it happens that Tesla is practically unrepresented at the exposition, at this present writing. It is likely, however, that his "oscillator" and other mechanisms will be in place there by the time these notes are printed.

In connection with our illustrations of the exposition we give a portrait of Mr. Frank W. Hawley, chairman of the reception committee, and one of the most efficient workers for the success of the great show. Mr. Hawley has been prominently identified with the enterprise of applying electricity to the Erie Canal, and the elaborate model already mentioned was constructed at his special direction for the National Electrical Exposition.

HENRY TYRRELL.

The New York Herald May 21, 1896

TESLA'S LIGHT IS PERFECTED.

After Years of Endeavor He Declares Its Success to His Friends.

STEADY AS THE SUNLIGHT.

While the Incandescent Lamp Gives but Three Per Cent of Illumination His Produces Ten.

TO INCREASE IT TO FORTY.

No New Dynamos Necessary, the Current Used Being from the Street Circuit.

Nikola Tesla has solved the problem which he set before himself many years ago, and which may revolutionize the system of electric lighting. It is, electrical experts say, the nearest perfect adaptation of the great force of nature to the use of man.

In Mr. Tesla's laboratory, in Houston street, is a bulb not more than three inches in length, which when the current turns into it becomes a ball of light. The heat is almost imperceptible. With it a very large room is so lighted that it is possible to read in any corner. Yet this is done without films and without the attachments necessary in existing lights.

The rays are so strong that the sharpest photographs may be taken by them. No new dynamo is required to produce the current. The bulb is attached to a wire connected with the street current. There is no danger of harmful shock in its use.

Stories have come from time to time from Mr. Tesla's laboratory that he was experimenting on a light of this sort. Rumors of success and failure have followed each other and Mr. Tesla's friends were inclined to doubt that he would succeed. A half dozen times the discovery was at his finger tips, only to elude him. But now he has told his friends of his success.

TO SAVE MORE YET.

Mr. Tesla has been working for many years on his theory of the necessity and the practicability of the conservation of electrical energy. The present incandescent light gives only three per cent of illuminating power. The other ninety-seven per cent is wasted in heat.

In accordance with his theories, which have been already applied successfully to the economical transmission of the electric fluid, he applied himself to the saving of some of this wasted energy in electric lighting.

The bulb which he has perfected gives ten per cent of light and loses ninety per cent of energy. Mr. Tesla declares that he will, with the aid of a few more experiments, be able to produce forty per cent of light, so that the waste will be reduced to only sixty per cent, or thirty-seven per cent less than at present.

The principle of light is vibration. The illumination is secured by means of what Mr. Tesla terms a vibrator within a bulb, which holds the vibrating needle within a vacuum. The needle vibrates so rapidly that the figures per second sound imaginary, but it is this intensity of energy which gives the light its brilliancy and its apparent steadiness. The lights do not have to be renewed.

HIS PHOTOGRAPH TAKEN.

Friends who recently visited Mr. Tesla saw him photographed by means of his light. The exposure was but two seconds in the light of a single vacuum tube or bulb, without electrodes, having a volume of about ninety cubic inches. The light given was approximately 250 candle power. The photograph was as sharp in outlines as though it were taken in full sunlight.

Mr. Tesla has recently obtained many photographs in his study of the Roentgen ray. He has photographed the heart of one of his assistants so accurately as to note its expansions and its contractions, and he has also been able to locate defects in the lungs of several persons, the presence of tubercles being very evident.

The announcement of Mr. Tesla's discoveries created a genuine sensation at the Electrical Show last night and was the topic of conversation among the experts in the application of power. The light was commented upon also at the meeting of the American Institute of Electrical Engineers which was held in the exhibition building.

The New York Morning Journal May 22, 1896

EDISON AND TESLA RIVALS.

EACH HAS INVENTED A VACUUM ELECTRIC LIGHT OF WONDERFUL SOFTNESS AND ILLUMINATING POWER.

Nikola Tesla has devised a light as steady as the sun and more brilliant than any artificial light now in use. He is guarding the secret of its production jealously, but it is known that the light is created within a vacuum tube by an electric current passing through a wire that touches the tube, but does not enter it. As friends of Tesla, who have learned something of the system, a current of electricity passing close to the vacuum tube disturbs the remaining particles of air—for no tube can be made a complete vacuum—and the vibrations of these atoms creates the light. The effect can be had by touching the electric wire at any point with a vacuum tube, and as the tubes are easily made, it is claimed by Tesla's friends that the system will be a commercial success. The secret, which Tesla guards, is how to make the tubes, and the strength of the current that must be used.

One of the advantages in the system, it is claimed, is that whereas now only three per cent of illuminating power is obtained from the amount of energy expended, by Tesla's invention there will be ten per cent of illuminating power. In ordinary incandescent lights much of the energy is lost in heat. Tesla's tubes when in brilliancy are nearly cold. The light is white and is as pleasant to the eye as the moon's reflections.

Dr. Park Benjamin, a well known electrical expert, at the electrical show last night said:

"I don't know what Tesla has discovered, but I have faith in his ability, and I know he has been working hard to produce a successful vacuum tube light. The tubes are like the Crooke's tube, except that the air is not exhausted to the same degree. The molecules remaining are, of course, far apart and the electricity causes them to vibrate violently. All light is caused by vibration, so there is the secret of the whole thing. If the tube was not a vacuum, the air particles would be close together and there would not be the same effect. If the air was exhausted as in the Crooke's tube, there would not be enough of the molecules vibrating to cause the white light."

B. E. Green, a personal friend of Tesla's, said:

"In gas lighting less than 1 per cent of energy consumed produces light. In incandescent electric lighting about 3 per cent is available. We are able now to run about fifteen 16-candle power lights with one horse-power, and electricians have considered the possibilities to be about twenty 16-candle power lights to one horse-power. So it can be readily seen that any present form of illumination would be placed at serious disadvantage in competition with a system which could double or triple the efficiency."

In a few days the experts attending the electrical show will be given a view of a new vacuum tube light, the invention of Thomas A. Edison. Adjoining the black X ray booth is a smaller room for the use of the men who operate the apparatus producing the X ray.

Yesterday arrangements were made to drape this room in white. In this room will be given the first view to the persons outside of his laboratory of Mr. Edison's new light. The inventor has as yet made no announcement of his new light to the public, although a couple of months ago he stated that he had made a discovery in vacuum tube lighting in a paper written for an electrical journal.

When seen last night in regard to the great light claimed to have been made by Tesla, Mr. Edison said:

"The claim that Tesla has invented a lamp that gives ten per cent power may be correct. I have never seen it and consequently can not say that he has or has not. Fore sometime I have been experimenting with vacuum tubes and have a lamp that gives from twelve to fifteen per cent light. It is a white light and just what it is I will not state. I will, however, show it, and after it has been seen will tell what it is.

"One lamp will light a room in every corner, and you can take a photograph by it. But that means nothing, as a two-candle incandescent lamp raised to about six-candle power will take photographs. The vitascope pictures are printed by incandescent lamps. One of the new lamps will give as much light as all the Moore tubes scattered about the Electrical Exhibition.

"If Tesla has a light why don't he show it. He is in New York on Houston street, not so far away. Moore is showing his light and I will show mine. Let Tesla come along and show. What counts in the world is the man who produces not the man who talks. I found out a long time ago that if you talked about a thing it wasn't remembered, but if you produced it was remembered."

"Is the new light one that can be put on the market at a reasonable figure?" Mr. Edison was asked.

"Yes," he replied. "I think it is at the point right now. I believe it can be manufactured cheaply and quickly. Three are being made and I will show them; not to the public, but to the people interested in electric lighting. The booth will be draped in white and you can take all the photographs you want. The only thing I care to say about the lamp at present is that it gives a brilliant white light, that is 12 to 15 per cent light."

The New York Herald May 22, 1896

TESLA'S NEW ELECTRIC LIGHT.

Is Adapted to Private Houses and Cheaper Than Other Illuminants.

Nikola Tesla, whose new electric light was described in yesterday's HERALD, said yesterday he had little more to add to it. He said it was adapted for use in private houses and would be cheaper than any other method of illumination. There was no needle or wire within the bulb. The bulb was as near a vacuum as could be obtained, and the vibrations of electricity within caused the high white intensity of the light.

The fact was, he added, that the great power would have to be modified rather than increased—at present it was more than sufficient for ordinary purpses. Electricity, he said, could be taken from a trolley wire or any other conductor of electricity. He would not go into further details yesterday.

Mechanical Progress.

Tesla's New Electric Light.

A New York despatch says Nikola Tesla has solved the problem which he set before himself years ago, and which may revolutionize the system of electric lighting. It is thought to be the nearest perfect adaptation of the electric current for light uses. In his laboratory is a bulb three inches in length which, when the current is turned on, becomes a bulb of light. With it a large room is lighted so it is possible to read in any corner. This is done without the attachments necessary in existing lights. The rays are so strong that photographs may be taken by them. No new dynamo is required to produce the current. As compared with the incandescent light the Tesla bulb gives a greater per cent of light. The principle of the light is vibration. Illumination is secured by the means of what Tesla terms a vibrator within the bulb, which holds the vibrating needle within a vacuum. The needle vibrates so rapidly that the figures per second sound imaginary, but it is this intensity of energy which gives the light its brilliancy and its apparent steadiness.

TESLA'S BRIGHT LIGHT

Apparently Most Simple in Construction, Yet Its Penetrative Power Is Enormous.

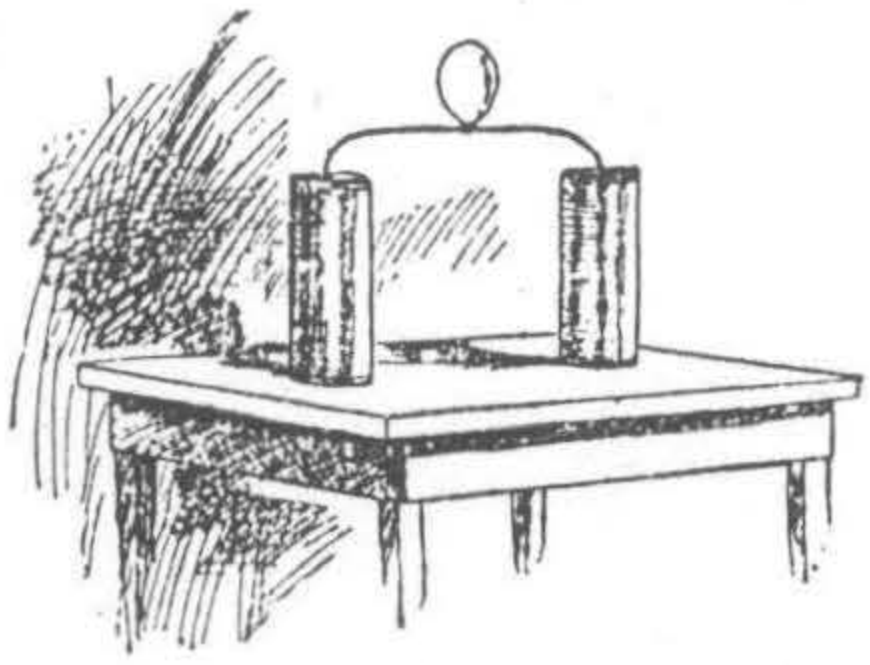
HIS TRIBUTE TO MR. EDISON.

Will Not Make Public the Principles of His Light Until He Is Able to Save More Energy.

NOW HE LOSES NINETY PER CENT.

When He Has Reduced This to Sixty Per Cent He Will Give Away Chunks of the Sun.

How soon Nikola Tesla will consent to make public his new light and give its principles to the world he will not say. He declared yesterday that when it has reached the perfection which he believes it is capable of he will present his discovery before an electrical or other scientific society and demonstrate that not only is it the realization of a principle which he enunciated in St. Louis eight or ten years ago, and so set electricians experimenting along those lines, but that the light may be manufactured cheaper than any other form of electric lighting known. It will be to electric illumination what his oscillator is to the generation of the fluid. With the latter the expensive and elaborate conversion of power is saved and the energy developed almost directly from steam. So with the vacuum light. Without



TESLA'S LAMP.

filaments and without their attendant perishable quality, with nothing save a vacuum and an enormous vibratory power of electricity, light will be made as nature makes it, by the vibration of the molecules.

THE RETORT COURTEOUS.

Mr. Edison said yesterday that if Mr. Tesla had invented a light so wonderful, why not show it and demonstrate to the world by action rather than by words that the lamp was a reality and not a theory. Mr. Tesla was shown Mr. Edison's statement, and he smiled as he said:—

"I entirely agree with Mr. Edison that it is much better to act than to talk. I do, however, desire to say this:—Over the head of my bed in the Gilsey House hangs an incandescent lamp. I use it every night before I go to sleep, for I have the bad habit of reading after I have retired. I have never yet turned the current from this lamp without mentally expressing my gratitude to the man who made that method of lighting possible."

With this bucket of hot coals for Mr. Edison Mr. Tesla shut himself up in his workshop.

In that workshop is a little table, by the side of which is Mr. Tesla's place where he does most of his work, with plans for the development of his theories of electricity. On this table stands the wonderful lamp which, with the same number of cubic inches as a 16-candle power incandescent lamp and with the same voltage from the street current as the ordinary lamp has, is able to give forth a light of 250 candle power.

TESLA'S LAMP.

It is a very simple looking contrivance. Two brass cylinders, looking for all the world like the empty shells of shot for a rapid fire cannon, stand about six inches apart. A light wire extends between the two, which probably contain coils, but about them Mr. Tesla will not say a word. Directly in the centre of this thin wire is an ordinary electric light bulb used for incandescent lighting. The little point usually at the bottom of the bulb points upward. There is no filament in the vacuum. It appears merely as an ordinary bulb would appear if the carbon filament had been destroyed, but the interior has been exhausted of air many times more than the incandescent light bulb. When the current is turned into the electrodes and so into the bulb there is no foreign substance to burn. The electric molecules have the vacuum all to themselves. They move at the rate of from 3,000,000 to 4,000,000 vibrations a second. No one point gets bright and then seems to ignite the rest, as in the bulb usually seen. There comes a glow, just as there is a glow in the eastern sky at dawn, and then it becomes rapidly intenser, until the whole interior of the bulb sends out light, just as though a piece had been cut out of the edge of the sun and packed into the little glass receptacle.

WITH MORE ENERGY SAVED.

This is what the Tesla light does when it is used now when it loses ninety per cent of energy and only uses ten per cent in light. The difficulty which the inventor is experiencing in reducing the loss of energy to sixty per cent is the securing of a complete vacuum. This is the greatest problem perhaps which is set before him, but when it is understood that the vacuum which is secured in the Crookes tubes is many times greater than that used so far by Mr. Tesla it may be appreciated that he is not confronted with an insuperable difficulty. Of course the production of tubes or bulbs which are thin enough to permit of the full benefit of the light and are still strong enough to withstand the atmospheric pressure from without is at present very expensive. Mr. Edison, however, has produced a tube for his fluoroscope which is much cheaper and more effective than the Crookes tube. This, it is believed, demonstrates that the commercial difficulty may be readily overcome and Mr. Tesla's light, even with its vastly increased power, will be possible for any one to use. The increase in power, should he reduce the loss of energy to sixty per cent, will enable him to secure a light of nearly one thousand candle power in a bulb of the size of the ones which now give forth sixteen candle power.

SOMETHING LIKE IT ON SHOW.

Some idea may be formed of the Tesla light by an inspection of the tubes which are shown at the Electrical Exhibition by Mr. Farren Moore. They, too, give forth light as a result of the vibrations of electrical energy, but in them the rapidity of the vibrations only amounts to a few hundred a second, whereas in the Tesla bulb they number among the millions. Mr. Moore's lights burn with a bluish flame, which is not divisable with a prism. The Tesla light is as white as sunlight, and the prism shows upon a screen all the colors of a rainbow. It may be believed, therefore, that the Tesla light is the nearest approach yet to natural light, the definite markings of the divisions of the colors of the spectrum proving its clearness and intensity.

Mr. Moore has worked along the same lines as Mr. Tesla and is entitled, electricians say, to great credit in being able to demonstrate the practicability of Mr. Tesla's ideas of electric light production by means of vibrations, but the results of his experiments have not yet produced an illuminating power which is practicable in competition with the incandescent light, while Mr. Tesla's friends declare that his light far exceeds it.

PHOTOGRAPHING THE HEART.

The experiments which Mr. Tesla has been making with the Roentgen phenomena and which have been successful in permitting him to photograph tissues of varying density instead of bone, have been made possible by his adaptation of this principle of light generation, by means of vibration. The same principle applied to similar processes make the X rays so penetrating that the most delicate gradations are discernible. It is not outside of the bounds of probability that Mr. Tesla will be able to produce a photograph as the culmination of his efforts which will show the organs of the body and the entire structure of the frame as well. His present ability to see the contraction and expansion of the heart, and the imperfections of the lungs in a living body makes his hopes doubly assured.

WHAT EXPERTS SAY.

MacFarlane Moore Is Pessimistic When Discussing the Claims Put Forth by Mr. Tesla.

LIGHT FROM VACUUM TUBES.

The New Method May Become of Commercial Value, but Is Too Costly Now.

T. C. MARTIN HAS MUCH FAITH.

Max Osterberg Believes in the Possibilities of Success by Some Experimenter.

Nikola Tesla's claim that he has perfected a system of lighting by means of excited vacuum tubes has aroused great interest in the electrical world, and provoked no end of discussion. The matter is the one leading topic of conversation at the Electrical Exposition, in the Grand Central Palace, where experts in electricity and men versed in the mysteries of vacuum tubes are to be found day and night.

One of these is Mr. D. MacFarlane Moore, who has invented a system of lighting by means of vacuum tubes, and who calls the light thus produced "etheric light." When I spoke to him about Tesla's light he said:—

"Tesla five years ago made a few experiments and prophesied a great deal, but, judging from reports that were published comparatively recently, he found the 'nut a hard one to crack,' and has made but little headway beyond what has been known for almost two hundred years. I think I made a gigantic stride in lighting a whole lecture hall, a photograph of which, by the vacuum tube light, is better than one by daylight.

"I then lighted the stage in a lecture before an audience of more than one thousand persons. After this a portion of my apparatus was moved to the Electrical Exposition and it immdiately became one of the leading attractions at the great show, not excluding Edison and the Roentgen rays. My light led everything else when Governor Morton opened the exposition, and again when Chauncey Depew's famous telegram had started and arrived. Tesla and Edison are stirred up, and now announce that they have not given up the race, but have also made advances and can now produce a bright light. But the proof of the pudding is in the eating. They do not show their light.

STILL DOUBTFUL.

"The high rate of vibration Tesla now claims is nothing new, because he claimed the same thing several years ago. It is now claimed that he can make a light 250 candle power. This is a vague statement, and needs confirmation. He claims it has ten per cent efficiency, therefore the rest of the energy must be heat, and his small bulb must get impracticably hot. These are vital shortcomings, because the new light must properly resemble daylight—that is an intense light in a small bulb is most decidedly not wanted, and cold light is not only wanted, but must be attained, or the system will be very costly to operate.

"Again, the proper current is of as much value as the proper light. Tesla's current is of such a high voltage that it can never be handled in a practical manner, and besides is dangerous; and this high rate of vibration prevents it being sent over a wire, which again makes it impracticable. The voltage of my current is low, and it can be sent over any reasonable length of wire.

COMPLICATED AND COSTLY APPARATUS.

"Again, Tesla's aparatus is large, complicated and costs many thousands of dollars; mine is very small and inexpensive. My methods were discussed on Wednesday morning before that intensely critical scientific body, the American Institute of Electrical Engineers. During the discussion I stated that the efficiency of my apparatus was 11,000,000 per cent better than that used by Tesla in one of his lectures. This statement was met by violent opposition from several of the leading college professors present. In fact they flatly denied that such could be the case. I replied by inviting them to make the test themselves. They accepted the invitation and made their test the same evening, and reported that I had not actually done myself justice—that the apparatus was even better than I had claimed.

"For several years Edison has fought the idea of a new light, but lately he got much interested. He visited my booth at the show last Saturday; to-day he claims to be able to produce a brighter light than either Tesla or myself, and says he will not do as Tesla does, but will show his light at the exposition. It is obvious to everybody that the ultimate in artificial light production will not be reached until we have imitated day.

"Edison, like Tesla, is trying to make units of light. The light Edison will show will consist of a small bulb containing the same material he has used on his kind of fluoroscope. The Edison bulb will be excited by the old Ruhpkorff induction coil, in a manner that has been known of for many years, but as a wofully insufficient piece of apparatus. The only difference will be that Edison will use a new chemical with the bulb to be fluoresced, but nevertheless it will last but for a short time, while my tubes, being empty, have unlimited life."

VACUUM LIGHTING NEXT.

I also approached Mr. T. C. Martin, the editor of the Electrical Engineer, on the subject, and he said:—

"It is thought by many that the next advance in electrical illumination must come in the direction of vacuum lighting. If it does not it is difficult to know just what is to be aimed at. And when such far sighted men as Tesla say it is worth going for—and he has been insisting on it for years past—you may depend upon it there is something in it."

"But what is the difference between the old methods and this new one?"

"Well, in the arc lamp you have the light produced by the jumping of the current from one stick of carbon to the other. The feeding of the carbons toward each other has to be regulated carefully, as they are rapidly consumed in the heat of the arc, which is next to the sun in its fierceness. In the incandescent lamp you have a small filament of carbon shut up in a small glass globe. The friction or resistance of that filament to the current flowing in the circuit causes the carbon to glow and give light, but as the air has no access to the filament it is not consumed, in the ordinary sense, although after a time it is used up. In the new method there are no carbon points to burn up, no filaments to break down or sealed globes to dim. There is simply a glass bulb, more or less exhausted of air. When in that condition if electricity be applied to what is left—rarified air, ether or what not—the bulb gives forth a luminiscence or phosphorescence that is bluish white in color and powerfully actinic. Some of these bulbs have had short wires leading into them, some have had phosphorescent materials placed in them, but the vacuum tube, as generally understood, means just the plain bulb of glass. Such tubes have been lit up simply by waving them in highly electrified air, but the current is usually led to them by caps or cups of tinfoil slipped on the outside ends. Methods differ in this respect, as do those for getting the bulb into such an electrically agitated condition as to give the best results."

"When do you expect the new method to become commercial?"

"Any time. It can be used now for spectacular and decorative effects. It will have a large place in the arts when ripe, with the best lamps invented and the best methods approved by experience. But the other methods will in all probability long remain in vogue. They have an enormous sphere of usefulness, and will doubtless grow for many years yet, while the new will also win a big realm for itself."

BELIEVES IT IS POSSIBLE.

Max Osterberg, E. E., who is in charge of Professor Pupin's exhibit at the Electrical Show, said:—

"The very fact that a number of our most prominent men have of late devoted their time and energy to vacuum tube lighting is sufficient reason to believe in the possibility. The idea itself, of course, is quite old, but the methods are new and there are about as many methods an investigators. Among the prominent experimenters, one may possibly develop into a practical inventor and produce a commercial result. One line of investigators believes in high frequency, high pressure, alternating current; another uses a direct current with a vibrator in a vacuum; a third produces luminosity of the tubes by resonance effects, and still others are at work on the perfection of the lamp, which seems to be the vital part of the entire problem. The demonstrations thus far made in vacuum tube lighting suffice to show its adaptability to special uses, although its field may be unfitted for general illumination."

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How To Make and Use a Tesla High-Frequency Coil.

TO THE EDITOR OF ELECTRICAL REVIEW:

In hopes to aid your correspondent "F. P. L." * in the matter of a Tesla high-frequency coil, I beg to offer my experience, gained after long search.

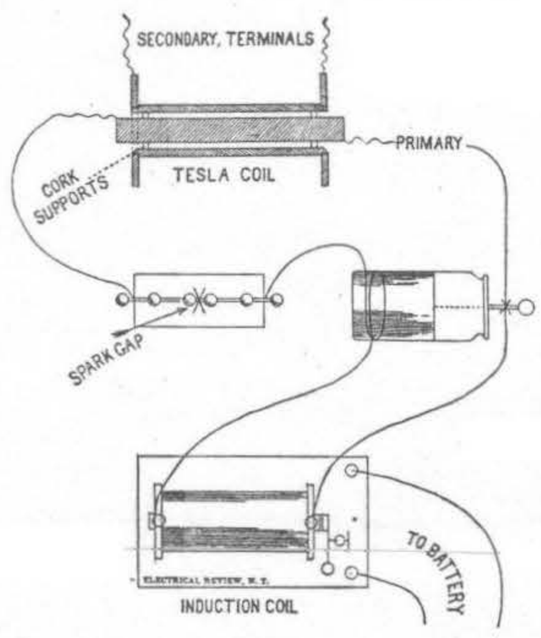

FIG. 1.—SECTIONAL VIEW OF TESLA COIL.

Go to some reliable wood turner and have a spool turned of three and one-half inches, outside diameter, with the interior turned out two and one-half inches diameter. Have a solid piece turned on which to wind your primary, two inches diameter and 14 inches long. The length of the first hollow spool should be 12 inches. It would be well to have the first spool one-half inch longer at each end, or 13 over all, but turned down one-quarter inch deep and of a width of one-quarter inch, so that a check block can be turned to slip on the end of the outer spool for appearance sake, and to which the terminals of the secondary wire can be led. The rough sketch herewith, Fig. 1, will give you the proper idea.

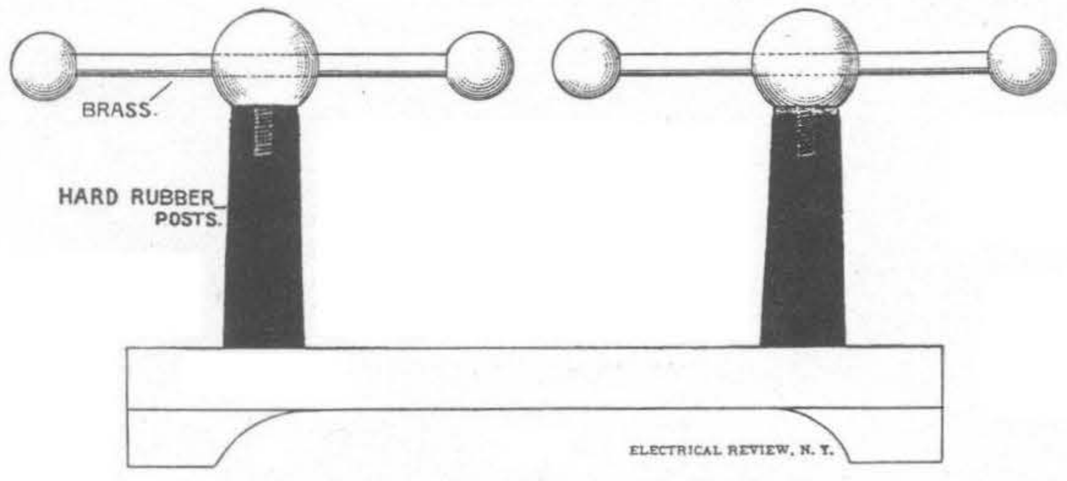

FIG. 2.—DISCHARGER USED WITH TESLA COIL.

For the primary, wound on the solid core, use No. 18 double cotton-covered wire wound in a single layer, with the ends being fastened to the core and left with plenty of projecting wire. For the secondary, use No. 36 double silk-covered wire carefully and compactly wound across the outer spool in a single layer. After winding, both the inner coil and the outer should be carefully shellaced; and it would be well, as I have done, to boil all wood pieces in paraffine before winding.

Such a coil can be operated for high-frequency effects by an ordinary spark coil giving at least two-and-one-half-inch spark. To do this you will require a Leyden jar ordinarily known as a half-gallon jar. The discharge of the jar must be made through the primary circuit of the Tesla coil and care must be taken to arrange the wires so that you will not short-circuit the induction coil. I have endeavored to sketch you the ordinary form of discharger (Fig. 2), with well polished balls which must be drawn apart to the limit of the sparking distance of your Leyden jar. Another way would be to keep the discharging balls tolerably near together and use an air blast across the gap when the coil is in operation. The effects by this latter method are much greater.

To give the Tesla effects, the Tesla coil should be placed in an oil-tight wooden box and covered with oil; otherwise the streams formed will pass through the coil sectionally and occasion a great loss of energy.

A Crookes bulb, which I can not operate with my three-inch spark coil *alone*, fluoresces readily when the Tesla coil is operated by the same induction coil. Yours truly,

ELLIOTT WOODS.

Washington, D. C., May 14.

* See "A Disruptive Coil Wanted," ELECTRICAL REVIEW, May 13, 1896.

NOTES.

Nikola Tesla.—Mr. Tesla, a few days ago, announced the discovery of a method of inducing millions of etheric vibrations per second within a vacuum tube without using any direct electrical connection. An ordinary 16-candle bulb gives by this method, it is said, a light equal to 250 candles, which is sufficient to light very pleasantly a large room. It enables rapid and perfect photographs to be taken. Its commercial efficiency is claimed to be three times as great as that of the prevailing system, and it provides an ample margin for further improvement. *Voilà tout.*

Niagara Power Transmission, the Electrical Exposition and Mr. Johnston's Libel Suit.

It is to be regretted that the holding of the National Electrical Exposition at New York and the remarkable demonstration of the transmission and application of electricity from Niagara Falls to the exhibition were attended by an unpleasant incident which cannot fail to detract from the general good feeling that has prevailed up to the present time. An eastern publication, the *Electric Railway Gazette*, published an editorial under the title "Transmission of Power Extraordinary," in which it pronounced the exhibition of the model of the Niagara Falls power plant operated by current from the Falls a "fake" and seriously reflected upon the gentlemen who were identified with the project. The article had the effect of creating a sensation and brought the hitherto obscure publication into prominence. The management of the exposition was naturally indignant at the outrageous charges, and the gentlemen who had planned and executed the project issued statements in which they flatly denied the accusation. Their personal and professional reputation alone should have protected them from even an insinuation of trickery or fraud. T. C. Martin, with whom the scheme originated, made the following statement:

For nearly a year past I had believed it possible to deliver Niagara energy over wire at the exposition, and some months ago set out to do it by securing a small model of the Niagara power plant to begin with, then permission from the Niagara Falls Power company to connect with the power house, Tesla apparatus from the Westinghouse Electric & Manufacturing company for the transmission to the model, two wires from the Western Union Telegraph company, and wires from the American Telegraph & Telephone company (long-distance telephone) to transmit the roar also to the model. The plan has been, to my positive knowledge, carried out, as I have personally watched the accomplishment of my plan. The electrical engineers coöperating have been A. S. Brown of the Western Union company, Nikola Tesla, L. B. Stillwell of the Westinghouse company, assisted by Messrs. Maclaren and Zimmerman and F. A. Pickernell of the Long Distance Telephone company. I would add that as the Western Union wires are available only in the evening, I carried out the suggestion of A. S. Brown of sending storage batteries to Niagara to be charged, so that the model could also be run in that way for the benefit of daytime visitors, who might otherwise be disappointed. This difference of method in daytime and at night has been carefully explained in labels and printed statements, so that there could be no doubt or misapprehension as to the facts. The Niagara transmission over Western Union wires has been a great success, doing far more than was expected. In fact, failure was freely predicted by many.

In addition to the foregoing statement a card was prepared by L. B. Stillwell of the Westinghouse company, in which that gentleman said:

The power used to operate the small Tesla motor at the electrical exposition comes from Niagara. During the evening it is transmitted over a circuit consisting of three conductors. Two of these are wires ordinarily used for telegraphic purposes by the Western Union Telegraph company. The third is the earth. In technical language, it is a case of tri-phase alternating current transmission. For a time direct or continuous current was used. When the alternating current is in use the potential as measured across any two conductors at the Niagara end of the line is approximately 500 volts. The currents are delivered to the exposition building at a potential approximating 250 volts. The gentlemen in charge of this undertaking have accomplished precisely what they undertook to accomplish, and the transmission is an unqualified success.

The following announcement was officially made by the exposition management:

The National Electrical Exposition company, through its counsel, J. G. Wells, on Saturday, May 23d, brought suit in the Supreme Court against the W. J. Johnston company, publisher of the *Electric Railway Gazette* and the *Electrical World*, for $50,000 damages for libel, the suit being based upon an article in the last issue of the first named paper, charging that the exhibition of Niagara power transmission at the electric show is in the nature of a "fake" and "gigantic fraud" upon the public. The officers of the National Electrical Exposition company are: H. J. Smith, general superintendent of the Edison Illuminating company of New York; W. F. Weiss, vice-president of the New York Steam Heating company; George F. Porter, secretary of the National Electric Light association; C. O. Baker, Jr., of the Baker Platinum Refining company; R. B. Corey, General Incandescent Arc Light company; H. L. Lufkin, Crocker-Wheeler Electric company, and E. F. Peck of the Peck Electric company.

A letter was also issued, signed by "W. J. Johnston, editor *Electric Railway Gazette*," of which the following is a copy:

In the *Electric Railway Gazette* of May 10th appeared an item, written immediately after the opening of the electrical exposition, saying that the success of the experiment in the transmission of electric power from Niagara to New York savors strongly of "fake." The author of the paragraph believed at the time that he had grounds for making the assertion. He has since made a thorough examination of the circumstances, however, and satisfied himself that he was entirely mistaken in what he said, and a correction will be made in the next issue of the *Gazette*, dated May 25th. I need not add that both the author of the item and I regret the appearance in an electrical journal of anything that might be construed as a reflection upon the good faith of the well-known companies and gentlemen to whose efforts are due the success of the Niagara transmission.

Pittsburgh Dispatch May 31, 1896

TESLA AT THE TOP

After a Bitter Struggle He Is Now the King of Inventors.

FOUGHT HARD FOR RECOGNITION.

An Interesting Interview Secured in His New York Laboratory.

HE TAKES PICTURES WITH A NEW LIGHT

[WRITTEN FOR THE DISPATCH.]

It is now generally agreed among electrical men that Nicola Tesla is the greatest electrical inventor of the age. In all his works he has conclusively shown himself to be far ahead of anyone else in originality of thought, in his conception of the wonderful possibilities of electricity and in their development.

More than ten years ago, even before he was working in Pittsburg, his mind was quite positive that, in his invention of the now well known Tesla motor, and the equally important Polyphase system of long distance power transmission, he had opened to the electrical industry a new and most important field of exploitation. Then, however, he could find few people who believed in him, and many looked upon his schemes and plans as grand and wonderful imaginations of a theorist, but whose ideas would never stand the test of practicability.

Nevertheless, Mr. Tesla was not discouraged by the criticisms passed upon his work. He was convinced that he was right, and he continued his researches, his experiments and his labors undaunted, knowing that his time to smile would come at last. And it did.

When the gigantic power of the falls of Niagara began to operate the large generators, ready to distribute electrical energy of 5,000 horse power, it was a great triumph for Tesla. Since then, of course, everybody has come to the conclusion that Mr. Tesla's ideas were correct on that matter, and those who were once known as the most pronounced skeptics are now his staunchest admirers and believers.

Startled London Scientists.

It was long before the triumph at Niagara, however, that Tesla astounded the whole civilized world in another direction, and that was in 1892, when he, a comparative youth, appeared before the Institution of Electrical Engineers of London, England, and showed to some of the most renowned men in electrical science, experiments and phenomenon which they had never dreamed of. He exhibited a motor running on one wire, and also without any connection whatever with the generator, demonstrating the possibility of running motors without wires altogether. He created a sensation when he handled electrical currents of the enormous pressure of 250,000 volts, and his audience was amazed as they viewed his demonstrations of phosphorescent lighting.

Mr. Tesla repeated that lecture before all the learned societies of Europe, and wherever he went he was received with the greatest distinction. Honors were showered upon him by the crowned heads of the old world. Since then the name of this great electrical inventor has become familiar throughout the world, and he is considered the greatest electrical genius of the age.

These wonderful triumphs of the young electrician are always gloried in by people in Pittsburg, because it was here he practically commenced to develop the wonders which have startled the world of late years.

The Dispatch Brought Him Out.

The Dispatch especially takes a great interest in the career of Tesla, because it was through this paper he first uttered to the world the marvelous ideas

The original was obtained by two seconds' exposure to the light of a single vacuum tube of very small dimensions.

Speaking about this photograph Mr. Tesla remarked that pictures taken by the light of such tubes show an amount of detail which no picture taken by the sun on flashlight is capable of disclosing.

MATOR.

THE INVENTIONS OF NIKOLA TESLA.

While everybody knows that Nikola Tesla is one of the greatest—perhaps the greatest—living discoverer in the field of electricity, not every one knows just what Mr. Tesla has done. It may be said, to start with, that to talk about Tesla's inventions leads one into a maze of electrical terms that defy the understanding of the mind not educated in electricity and anything like a description of the technicalities of his work, his discoveries, and his inventions here would be about as valuable as a column of Hebrew jargon. Hence, all that will be attempted is to tell what he has accomplished. First, take the transmission of power.

When Tesla came into the field in America little was known of the alternating current. The single alternating current was used, but for the purpose of lighting only. The continuous current was used almost exclusively.

The continuous current system is very good for short line work, but with it energy cannot be delivered successfully at any great distance at high pressure. To deliver the continuous current at high pressure at a distance would require the use of wires so heavy that they would be cumbersome and entirely impracticable for use. Tesla made an alternating current motor that permitted the transmission of energy long distances at high pressure over thin wires, the delivery being made at the same pressure or at a lower or a higher pressure, whichever was desired, by means of a transformer. Thus the bridling of the power in Niagara was made possible, and natural forces everywhere can be similarly harnessed and made to do the work that has heretofore been done at great cost by other forms of force and energy. A great many smaller inventions are included in this great one. Its possibilities are just now beginning to be realized. Tesla's discoveries in connection with this motor, it is said, were the prime cause of the recent consolidation of the Edison and the Westinghouse Electric Companies.

In this motor two wires were used for the transmission of the current. Tesla believed that the extra wire was a useless expense; that all the work could be done with one, and no return circuit was necessary. So he set himself about the work of finding a way to accomplish this. He did accomplish it,

and now it is possible through his invention to transmit the energy with the aid of only one wire. This invention, however, has not been of the same practical use as the other. It is merely a step in the direction of accomplishing the third thing that Tesla is aiming at. That is the transmission of power and intelligence without any wires, by means of the earth itself. If such a thing can be accomplished the human mind can hardly conceive of the possibilities. Tesla believes that it can be accomplished. The fact that he believes it is proved by the ten years of work he has devoted to experimenting on that line.

Next in order is the perfection of an apparatus for the production of electrical vibrations. Electrostatics is the science of electricity at rest. Tesla demonstrated that for the production of light waves, primarily, electrostatic effects must be brought into play, and he formed the opinion that all electrical and magnetic effects may be referred to electrostatic molecular forces. In a glass bulb filled with electrostatically charged molecules he found that by agitating them, causing them to vibrate, to strike against each other, brilliant light was produced. No carbon was required, such as is used in the ordinary incandescent light. There was nothing but the glass bulb. Tesla's accomplishment was the making of apparatus to stir up the molecules which don't cost anything and are ever present, while the carbon heretofore needed is expensive. This apparatus is nearing perfection now, and lamps which furnish light without carbon are in sight. The saving in the cost of electric lighting will be tremendous, and, as measured by Tesla, 200 times the light can be produced with the same energy that is now used in the production of the ordinary incandescent lights. This will mean more light with less power and less expense, because there will be no expensive carbons required.

Last on Tesla's list is the oscillator, now perfected and ready to be put on the market. It is estimated that nine-tenths of all the dynamos in the world are operated by steam power. Every step in the production of electricity by steam power is attended with waste and loss of force and energy. The problem Tesla set out to solve was the saving of the 95 per cent. of energy that was wasted. Actual tests showed that only 5 per cent. of the energy used in making incandescent lights manifested itself as light. The 95 per cent. was lost. There was loss in every step from the putting of the coal into the furnace to the delivery of the electricity. Tesla has combined an engine and a dynamo. Steam is forced into the engine at high pressure, which produces an extremely rapid vibration of a steel rod, and this rod or piston is so adapted to a set of magnets that the mechanical energy of the vibration is converted into electricity. Fly wheels and governing balls and eccentrics and valves and all the rest of the complicated mechanism required for the purpose of control or regulation are done away with.

The steam cylinder with its piston is the only thing that does the work about a steam engine. All the rest take energy, but produce nothing; so if they can be done away with, the energy that it takes to run them is saved. Tesla's oscillator does away with them. The oscillator converts the energy of steam into electricity directly. It would appear that this invention, if it does all that it promises, will revolutionize all business that requires energy in the form of steam or electric force to operate it. The machine doesn't take up one-tenth of the room needed by an ordinary engine and dynamo.

Probably the oscillator and the new system of lighting would both have been in use long ago had it not been for the destruction of Tesla's laboratory last year. He had these and other inventions very near completion. He had in his workshop the result of years of work. He had many models of machinery that he could not replace. All the work that had been done in making these things had to be done over again. He said himself at the time that a million dollars could not repay the loss.

Regarding the future he has said:

"I expect to live to be able to set a machine in the middle of this room and move it by the energy of no other agency than the medium in motion around us."—*N. Y. Sun.*

Tesla and Edison Apparatus.

To the Editor of Electrical Review:

You deserve the hearty thanks of all who are interested in the progress of the Roentgen-ray researches for the many excellent articles which have appeared in your journal upon the subject, but especially for those emanating from Mr. Tesla. Nothing has been done which promises more for the aid of medicine and surgery than these experiments of Mr. Tesla, for his appliances appear to have developed more penetrating power and greater definition of the tissues of the body than those of any other experimenter.

You would confer a great favor upon those who are attempting to follow in the wake of these able investigators, if you would take pains to present in your columns a detailed description of the apparatus that is employed by them. It would be very interesting to a large number of your readers, I am sure, if you would have a competent member of your staff describe in detail the apparatus employed both by Mr. Edison and Mr. Tesla. The structure of the coils they make use of, the manner of getting the interruptions in the circuit, the frequency of interruptions and the electro-motive force employed; also the source of, amount and electro-motive force of the current used to excite the primary coil. These are bits of information which all persons need who are attempting to secure equally good results with those that have been reported from the laboratories of these two able investigators. Would it be presumption on my part to ask you to furnish this information through the columns of your journal?

Very truly yours,

W. J. Herdman.

University of Michigan, Ann Arbor, May 26.

General Electric.—Westinghouse Electric & Manufacturing.—The board of control is reported to have completed the work of settling all the patent suits in which the two companies had engaged, numbering more than three hundred. W. D. Updegraff, private secretary to George Westinghouse, Jr., says that under the new arrangement the board of control, consisting of C. A. Coffin, President of the General Electric; F. D. Fish, its General Counsel; George Westinghouse, Jr.; P. D. Cravath, of New York, counsel for the Westinghouse Co., and F. B. Thomas, of New York, will enter suits and prosecute for both companies. The agreement as to common use of patents it is understood went into effect June 1.—V. 62, p. 689, 780.

Western Electrician.

EVERY SATURDAY.

PUBLICATION OFFICES:
Suite 510 Marquette Building, CHICAGO.
TELEPHONE, MAIN 1746.

EASTERN OFFICE: 108 TIMES BUILDING, NEW YORK.

Trade Supplied by Western News Co.

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SUBSCRIPTION, in advance, postage prepaid, $3.00 for a full year of 52 numbers; in clubs of four or more, $2.50, with free extra copy for eight subscriptions; foreign countries, $5.00 a year; single copies, 10 cents. When change of address is requested, the old address as well as the new should be given.

CORRESPONDENCE relating to electricity or any of its practical applications is cordially invited, and the co-operation of all electrical thinkers and workers earnestly desired. Clear, concise, well written articles are especially welcome; and communications, views, news items, local newspaper clippings, or any information likely to interest electricians, will be thankfully received and cheerfully acknowledged.

ADVERTISING.—THE WESTERN ELECTRICIAN—**the only general electrical paper published in the West**—thoroughly covers a territory *exclusively its own.* THIS IS A CLAIM WHICH CAN BE MADE BY NO OTHER ELECTRICAL JOURNAL IN THE UNITED STATES. Electrical merchants and manufacturers *desiring western trade* will appreciate the UNEQUALED VALUE of this journal as an advertising medium in its special field. Advertising rates are moderate, and will be furnished on application.

HIGH WATER MARK
CIRCULATION, 16,630.

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THE WESTERN ELECTRICIAN'S first special electric light convention number (dated May 9th) contained 7,576 square inches of advertising. For the same week the *Electrical World* contained 7,326, the *Electrical Engineer* 3,687 and the *Electrical Review* 3,375 square inches of advertising.

The WESTERN ELECTRICIAN'S advertising, therefore, exceeded that of the *Electrical World* by **250** inches, that of the *Engineer* by **3,889** inches and that of the *Review* by **4,201** inches. It exceeded the combined advertising of the *Review* and *Engineer* by **514** inches.

The steady advancement of special convention advertising in the WESTERN ELECTRICIAN can be shown by a little table well worthy of attention:

Issue.	Number of Advertising Pages.	Total Number of Pages.	Square Inches of Paid Advertising Matter.
March 3, 1894....	40	56	4,145
February 23, 1895.	52	68	5,593
May 9, 1896.....	72	88	7,576

These figures are carefully and accurately compiled. They illustrate more forcibly than words a steady and vigorous growth during the hard times. It is to be remembered, also, that, in computing the square inches of advertising, all announcements of the WESTERN ELECTRICIAN or the Electrician Publishing company are rigorously excluded, so that the result shows net, *bona fide*, paid advertising. The figures show a growth of 2,000 square inches in a year. They are eloquent and may be left to speak for themselves.

THERE has been a good deal of talk of late about what Edison and Tesla are about to do in the way of astonishing the world with their discoveries in electric lighting, but thus far there have been no practical results made public. However, we are encouraged in the belief that each of the gentlemen named has something up his sleeve which, after the manner of Herrmann, he proposes to flash upon the public at a propitious moment. With owl-like wisdom an eastern contemporary sagely remarks: "We cannot hesitate to express our positive conviction that the introduction of a more perfect illuminant is near at hand." Well, well! How very definite, to be sure!

In the meantime, while Edison and Tesla are talking about their plans, or rather their friends are talking for them, D. MacFarlan Moore is going ahead and trying to accomplish something in the way of commercial utilization of the vacuum tube light with which Tesla has been experimenting so long. There are many prominent engineers who agree with the views expressed by Mr. Wessels in his communication on this subject, which appears elsewhere in this issue. One cannot read this contribution without feeling that there is cause for criticism of the policy pursued in attaching so much importance to the vague promises that are said to emanate from the "wizard" and the "magician" of the profession, but which many are disposed to consider the product of the lively imagination possessed by a newspaper writer who furnishes popular electrical stories to metropolitan dailies.

COMMUNICATION.

Claims of Moore, Tesla and Edison.

To the Editor of the WESTERN ELECTRICIAN:

In some of the New York papers I recently noticed articles headed "Tesla's Achievements," which would be amusing were they not misleading.

Stripped of ambiguity, they stated Mr. Tesla will, "with the aid of a few more experiments, be able to produce 40 per cent. of light and his perfected (?) bulb gives 10 per cent. of light." We need not concern ourselves with what Mr. Tesla is "going to do," as the outcome of the "few more experiments" is purely speculative.

Five years ago Mr. Tesla announced he would revolutionize the lighting field. The public saw some faint electrical pyrotechnics, then nothing was seen or heard. No wonder the *Mail and Express* of May 22, 1896, concluded: "There is nothing new in Mr. Tesla's work. His light is the same as he showed to the Society of Electrical Engineers five years ago."

In the *Electrical Engineer*, November 13, 1895, I pointed out the constant tendency of the press to credit Mr. Tesla with the achievements of other inventors! No one will begrudge him credit, if any, due for original work actually demonstrated before reliable witnesses; but the articles I am criticizing are misleading in that they credit to Mr. Tesla, Mr. Moore's achievements. If Moore is substituted for Tesla, the articles will be fairly accurate, if all reference to what is "going to be" is omitted.

The absence of filaments in the tubes is mentioned. The fact cannot be disproved that the first tube-lighted room in this world's history was lighted by Mr. Moore's vibrator and vacuum tubes. Neither Mr. Edison nor Mr. Tesla has shown a room lighted by vacuum tubes up to this time. It was Mr. Moore who first demonstrated commercial etheric lighting. He lighted a room with his tubes over a year ago, as the signed laboratory register and photographs witness. Long before that he lighted the laboratory with lamps and by them obtained clear photographs, along side of which the Tesla pictures published in the April, 1895, *Century* are very obscure. Before the *Century* article appeared, I showed Mr. Moore's photographs to prominent electrical engineers.

Mr. Moore alone is entitled to the credit of having discovered new fundamental principles and made them operative. In this credit neither Mr. Edison nor Mr. Tesla is justly entitled to share. Yet the dailies are devoting much space to what is "going to be" and ignoring what is. They head articles "Edison and Tesla Rivals" and shut their eyes to the fact that Mr. Moore is the only one who has shown a tube-lighted room. They print accounts of what "will be," but Mr. Moore demonstrates nightly what is.

The unfounded advertising Mr. Tesla is getting is based upon the *Electrical Review* article of May 20, 1896. That article says that the *Review's* representative saw Tesla's tube. Did others see it? It is proper to inquire—

First—Was the representative (name not given) a qualified electrical engineer, capable of judging, or merely a non-technical journalist?

Second—Who made the test of power said to be consumed?

Third—How was the illuminating capacity of the tube measured?

Fourth—Was the light diffused for any length of time, or evanescent?

Fifth—Did the light work on alternating and direct circuits, or only on one of them?

Sixth—How much power was used?

Seventh—Is the system practical? It is well known that in Mr. Tesla's experiments five years ago such enormous voltages were used as made them absolutely useless for any but laboratory use. Moreover (discarding the factor of danger), the cost of insulation would be ruinous, even if, as was not the case, commercial results had been obtained.

Assuming, however, that all the articles stated was true, why has Mr. Tesla not publicly shown his tube? Why is he not present at the electrical show? If prevented from coming, why does he not send a representative with the tube? He never had a better chance than the show affords. As Mr. Edison said, "Moore is showing his light and I will show mine. Let Tesla come along and show his. What counts in the world is the man who produces, not the man who talks."

Against Mr. Tesla's statement of what he is "going to

do," the discriminating electrical public will place what Mr. Moore actually did and is doing. Mr. Tesla lectured in 1891 and has shown absolutely nothing since. Mr. Moore's record follows:

1891.	Mr. Moore claimed he could produce better results than Mr. Tesla showed in his lecture.
1893, Sept. 20.	Mr. Moore read his paper before the American Institute of Electrical Engineers on "A New Method for the Control of Electric Energy." Discussion followed, and the paper was printed in the Institute's *Transactions*,
1894, April 1.	Mr. Moore showed fine photographs from unretouched negatives taken by his lamps.
1894, July.	Mr. Moore's article on "The Light of the Future" appeared in *Cassier's Magazine*, nine months ahead of the Tesla (*Century*) article.
1895, May.	Mr. Moore lighted a room in his laboratory with vacuum tubes for the first time in history.
1895, December.	Mr. Moore was photographed by his tubes and a full-page reproduction appeared in the *Electrical Engineer*, New York, the *Electrical Review*, London, and elsewhere.
1896, April 22.	Mr. Moore lectured before the American Institute of Electrical Engineers on "Recent Developments in Vacuum Tube Lighting," and showed many forms of lamps and tubes, closing by lighting the hall with 27 vacuum tubes. The photograph of the hall, taken by those tubes after a five-minute exposure, from an unretouched negative, appeared in the *Electrical Engineer* on May 5, 1896.
1896, May 4.	Mr. Moore lighted up Governor Morton by a frame of seven feet six inch tubes as he opened the electrical exposition, and showed the signs "N. E. L. A." and "Let There Be Light" above Governor's Morton's head.
1896, May 6.	Mr. Moore lectured under the auspices of the National Electric Light association (President Wilmerding presiding) and lighted the stage with his vacuum tubes.
1896, May 16.	Mr. Moore lighted his tubes in the form of flying arrows, and kept them lighted while Dr. Depew made his speech.
1896, May 20.	Mr. Moore participated in the American Institute of Electrical Engineers' discussion of his paper, and, by exhibiting his apparatus and tubes, more than proved his claims. He scored a great victory, and the parties who, before making the tests, had denied his claims, admitted Mr. Moore was right and they were wrong.
1896, May 4 and every week-day to date.	Mr. Moore's chamber of light has been visited by thousands, who have seen and wondered at his artificial daylight. They make an unimpeachable crowd of witnesses to the great simplicity and inexpensiveness of his apparatus and its low voltage.

Is it not singular (to say the least) that only after Mr. Moore made this unimpeachable record did newspaper articles appear, stating what Messrs. Edison and Tesla were "going to do."

Yet many of the dailies are silent about Mr. Moore, and even the lecture he delivered at the request of the National Electric Light association was only referred to by one of the electrical journals, although the hall was filled with a thousand delegates and others. President Wilmerding held one of the tubes and showed the induction effects when Mr. Moore lighted the stage.

Mr. Moore's demonstrations have greater historic value than press effusions, and these demonstrations cannot be ignored.

Mr. Moore is most willing to continue his public demonstrations after the electrical show closes. Will Mr. Tesla show his tubes at the same time? Let instruments be used by competent electrical experts. Then let the results of the competitive test be published authoritatively. The public will always prefer actual achievements to speculative theories.

The Goebel litigation showed conclusively the unwisdom of allowing incorrect statements to go unrefuted when made. This is one of my reasons for writing this letter. If further argument be needed to demonstrate that Mr. Moore was absolutely first in the vacuum tube lighting field (ahead of Messrs. Edison and Tesla) it will be found in the fact that he secured in the last three years some 20 patents for his inventions in vacuum tube lighting, and further, that a number of his applications are awaiting action in the Patent Office. At no time were there any "references" to Edison or Tesla, and the patents were only issued after Mr. Moore had gone to Washington, set up a miniature laboratory in the United States Patent Office, and proved to the examiners that they were wrong when they originally wrote "each of the claims therefore must be denied on the ground of inoperativeness." Although the examiners said his system would not work by any known law, Mr. Moore proved that it did work, came off a victor at all points and received his patents.

The editor of the *Electrical Review* saw Mr. Moore's laboratory lighted by vacuum tubes in 1894 and was photographed at that time by the light of the tubes. On the day the *Review* published the Tesla article, Mr. Moore appeared before the American Institute of Electrical Engineers and submitted his apparatus for tests. The result of the tests made by such men as Prof. W. A. Anthony, Prof. Nichols of Cornell, Nelson W. Perry and others proved that Mr. Moore had understated rather than overstated, his claims. Let Mr. Tesla produce his tube, face the same searchlight, and if he passes muster, he will get all the credit really due him.

No matter what Mr. Edison, Mr. Tesla or anyone else may produce, the fact remains that to D. MacFarlan Moore alone belongs the credit of first having produced commercial light by means of vacuum tubes.

It is largely to put this fact indisputably on record that I have written this letter.

EDWARD J. WESSELS,
President Moore Electrical company.

Newark, N. J., May 25, 1896.

Tesla and Marriage.—Our sprightly contemporary, the *Electrical Journal*, takes issue with Mr. Nikola Tesla as to the undesirability of marriage for inventors, and after disproving his statement that few great inventions have been made by married men, proceeds as follows: "We are great admirers of Mr. Tesla and his work. We give him credit for mighty good hard sense. We do not think he is like the Frenchman who excused his bachelorhood on the ground that he was "one butterfly, zat fly from ze flower to ze flower and sip ze honey." We know, too, that Mr. Tesla's nature is a very intense one, but we have just faith enough in women—especially American women—to make Mr. Tesla a straight-out offer to find a girl for him who will not only match his intensity in all respects, but who will tax his inventive genius to the utmost—and hence encourage it—trying to explain where he was at 2 A. M. some night when she had gone to his laboratory to bring him home and found it dark, although he had told her he was going to have to "stay down town to work to-night." Then again, if Mr. Tesla were to have ordinary Benedict luck and half a score of little Teslas, his inventive genius would be kept up to a white heat, hustling for the wherewithal to supply their wants. Mr. Tesla knows that "necessity is the mother of invention." Fie, Mr. Tesla, fie, we say. Get married. You'll get strong, be happy, sleep o'nights; and if you leave an invention or two less to posterity, you will leave a more material and fully as necessary a legacy in another shape. Besides, they try to steal inventions from a man; they don't steal his children, seldom his wife, and never the pleasures that a married man falls heir to."

JOURNAL OF ELECTRICITY.

Illustrated Review of the Industrial Applications of Electricity, Gas and Power.

EDITED BY

F. A. C. PERRINE, D. Sc., and GEORGE P. LOW.

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EDITORIAL.

All of these experimenters have obtained in their laboratories wonderfully interesting results and they have been enabled to produce startling effects of great brilliancy which have drawn to their preliminary experiments the attention of reporters from the daily press, the result being that where a more thorough knowledge of the problem is lacking, one is almost inclined to believe that we are on the verge of a great revolution in both the manner and efficiency of illumination. Indeed, it may be that we are soon to see the solution of the problem of economical illumination, but if this is true it will be through the agency of some discovery not less startling than the recently announced Roentgen phenomenon.

The problem is not, as the daily papers would have us believe, bounded by the production of an economical lamp along lines which have been experimentally developed in the laboratory, but is one that has not yet been attempted, that of the economical generation and distribution of high frequency currents. Until this problem shall have been attacked and a practical solution proposed, the lighting effects already obtained must be confined to the sphere of laboratory experiments, and however great may be their beauty and whatever theoretical efficiency we may calculate for the system of illumination, we can only expect to see their application many years in the future.

HIGH FREQUENCY EXPERIMENTS

One evening after Tesla had been exhibiting some of the wonderful phenomena produced by his high frequency currents and displaying vacuum tubes without electrodes illuminated by induction from the current flowing in a neighboring wire, he was asked if it would be possible to so insulate the leads in this system of lighting as to prevent unauthorized use of the current, and he replied that a covering of hard rubber one foot thick would do the insulating very nicely, provided that the dielectric would not succumb to the heat generated in it. Though this remark was made more than four years ago, and though Tesla, Edison and McFarlane Moore have all made advances in the field of illumination with high frequency currents, there has been no means of distributing such remains to-day, as it has since the beginning of this line remains today, as it has since the beginning of this line of experimentation, without practical solution. Judging from the papers that have been published, Moore expects to employ current from an ordinary lighting system and to generate his high frequency currents at the points where they are used by the means of a specially devised interrupter. Tesla's plans have frequently been stated to embody the use of the oscillator generator requiring a distribution of high pressure steam and sometimes to embody the Tesla transformer with a spark gap interrupter. So far as is known at the present time, Edison has not attacked the problem of distribution, but has only concerned himself with the production of high frequency lamps.

ELECTRIC "L" CARS.

Tesla's Discovery of the Rotating Magnetic Field Has Solved the Problem of Motive Power.

TEST FOR THE MANHATTAN.

Officials Will Watch an Early Application of the System at the Westinghouse Works.

GREAT PROMISES ARE MADE.

Speed, Safety and Economy Result, It Is Claimed, from Tesla's Latest Find.

THAT electricity will be the motive power on the New York elevated railways is quite well assured, and promises to be certain within a few days. The trial trip of a new motor is to be made at Pittsburg by the Westinghouse Electric Company so soon as arrangements are made with the elevated railway people to witness it.

"The trial trip will likely be made within ten days, though it may be longer," said Mr. George Westinghouse, two days ago, when I saw him in his office. "We are now almost ready, and will notify the elevated people according to the understanding between us. The experiments and severest tests have produced the most satisfactory results. In fact, the new motor is away beyond our expectations. It is Tesla's greatest discovery, and solves the problem of rapid transit motive power. It cannot help being the power to be used."

ROTATING MAGNETIC FIELD.

Nikola Tesla was found in his laboratory, in East Houston street, surrounded by the mysterious appliances of his science, and quite ready to give information of interest to the public.

"This polyphase alternating current as used in the new motor to be soon put on its trial trip in Pittsburg is sure to furnish the motive power for our elevated roads," he said. "It cannot be avoided, simply because it will do the work surely, safely and economically. Then it is so easily managed, and without the constant danger of requiring an expert electrician to care for it.

"Now, the whole secret lies in my discovery of what is known as the rotating magnetic field. What it is I cannot explain, neither is it explainable. I can only give the facts which have been discovered through experiment. The discovery of these scientific facts has done entirely away with the commutator, which has heretofore been used on all electric motors. This commutator, with its close adjustment, delicate and intricate parts, has been the cause of all of the trouble. It is that complicated piece of machinery which shows the scores of pieces of brass arranged fan like, only making an entire circle. A slight injury to this commutator, which may arise from the presence of even a drop of water, may destroy the whole machine. The danger is now all done away with by discarding the commutator entirely.

"This result is accomplished by utilizing the rotating magnetic field, which simply means that if a circular metal disk is placed on an axle and brought near the electric coil it will revolve. The disk touches nothing but its own bearings, yet it revolves and thus produces power. This power is what is used in the new motor."

PREPARING FOR THE TRIAL.

In the yards of the Westinghouse Electric Company, at East Pittsburg, a new combination electric locomotive engine and passenger car is now being equipped with these new motors, and in a few days will be ready for the trial trip. When all is in readiness the motor car will be coupled to five passenger coaches, and the special test for the benefit of the Manhattan Elevated Railway officials will be given. An actual demonstration of results now known will follow, and the gas and smoke producing engine will disappear from the streets of New York.

The new locomotive, which was in place last week, is forty-six feet long on the outside and thirty-eight feet inside. There are seats on both sides running lengthwise and exactly like "L" coaches. The motorman will stand at one end of the car. There will be a controller or lever at either end, and it will not be necessary to turn the locomotive. A pilot will be at either end to brush obstructions from the track.

There will be no fireman on the new locomotive, which will be equipped with air as well as hand brakes. It has a cast iron bottom to give it adhesion and weight. On the heavy axles are four motors of 100 horse power each, and the hauling capacity will be equal to that of 400 horses. The motors have been tested and were found equal to the task of hauling six or seven "L" passenger coaches in addition to the locomotive at a maximum speed of twenty-eight miles per hour. The average that would be maintained on the Manhattan system, it is claimed, would be from sixteen to eighteen miles per hour.

The new locomotive is entirely different from the first electric locomotive equipped at the Westinghouse works, and by which it was intended to make the "L" test. This machine is now used exclusively in shifting freight cars in and about the Westinghouse yards. Then a second one, which was an improvement on the first, was equipped. It in turn gave way to the Suburban electric locomotive, which contains all the improvements known to date. This is what has delayed the test.

This will be the first time the Tesla system will be used for railway work, and it is expected to revolutionize the present trolley and steam railroads. The cars are standard gauge and the test will take place on the tracks of the Turtle Creek branch of the Pennsylvania Railway. The line has been wired, the double trolley system being used, and the tracks reballasted, so that the highest speed can be attained. The test track, which is about three miles long, has been divided with posts set in the ground every quarter of a mile. These posts are numbered from one up, and represent the "L" stations. At these posts the train will be stopped and started as if running on the elevated tracks in New York. With stop watches the time of stopping and starting will be taken. In a preliminary test with the direct current a speed of ten miles per hour within a distance of sixty feet was acquired.

The train will be exactly the same weight as an "L" train, and everything will be arranged so that the test will be as if it occurred in New York.

SOME OF THE ADVANTAGES.

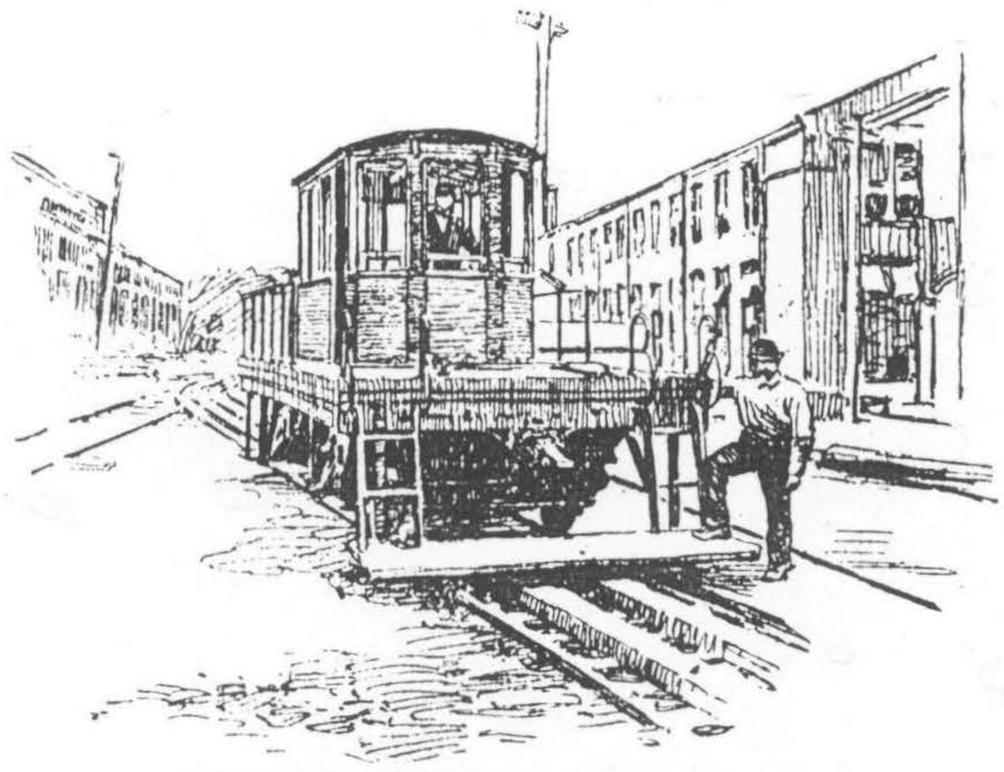
One advantage claimed for the new system, and one that will be appreciated in New York, is that the current used to run and light the trains could also be utilized to light the stations and operate a passenger elevator service.

The great advantage of the alternating system is that it saves lives in case a person takes hold of a live wire. Using the direct current 500 volts are necessary for ordinary street car work. This must be transmitted over expensive copper wire. By the invention of Tesla the current can be transmitted long distances over ordinary iron telegraph or telephone wires. The voltage can be so reduced that a person might take hold of a live wire with safety. He would be shocked, but would not be killed. With the general introduction of the new system it is claimed that electrocutions from the trolley will be rare.

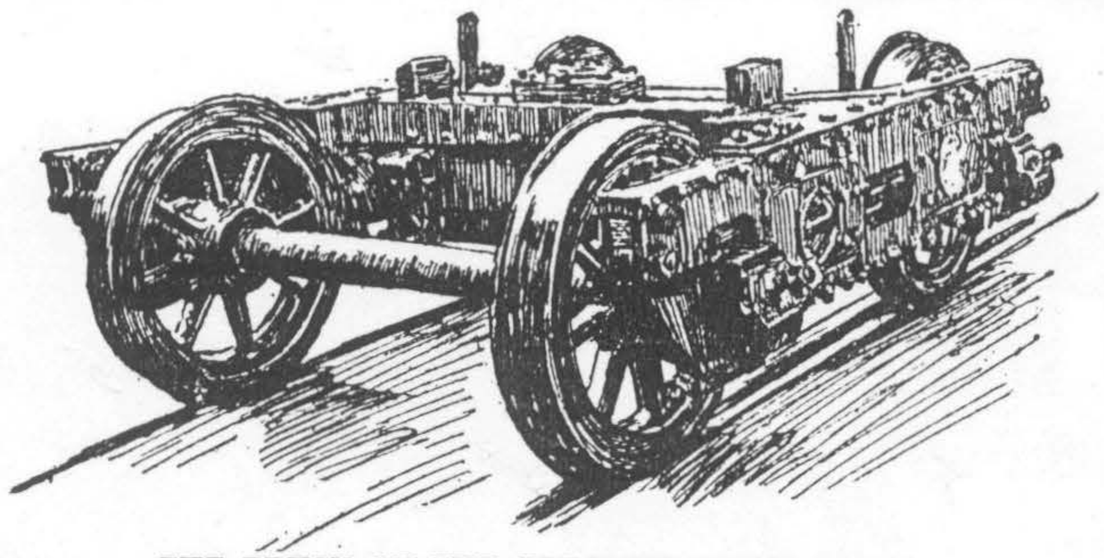
In the direct current motor the commutator, which gathers the electricity from the armature and carries it to the brush, and the brush itself, are expensive and necessary features. They are continually breaking, wearing out and needing repairs, and add largely to the maintenance and operative cost of the system.

With the Tesla polyphase motor, these difficulties are obviated. The heavy copper feed wires, which are always dangerous by reason of having to carry at least 500 volts, will be replaced by lighter wires having a voltage of about 210. No commutators or brushes are needed, the armature playing in a field. The power plant can be located many miles away from the road if found necessary. If the new system is adopted in New York one power plant in Westchester could furnish sufficient power to operate all the "L" lines and surface roads in the city. This would do away with the expense of having to erect power houses where land is valuable, and where the smoke would prove a nuisance.

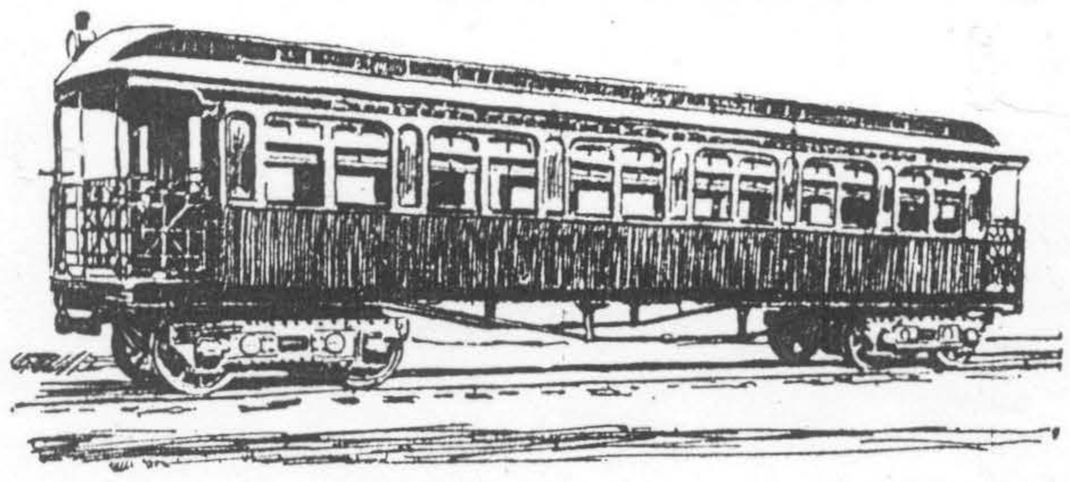
When the great revolution in street railway motive power will be completed it is difficult to say, for both sides have moved slowly and been conservative. The street railway people have been slow to decide on changes that would involve expense and perhaps prove experimental, and the men who are furnishing the capital for the great plants that are making the tests have been equally conservative. But within a few weeks there has been a great change, and both sides appear to think that they stand on safe ground, that the problem has been solved and that the great change is about to be entered upon. The questions of speed, safety, durability, convenience and economy appear to have been settled, and now only a formal acceptance of the inevitable is necessary. It means much for a great railway company to revolutionize its motive power, but the Manhattan Elevated people have admitted for some time that a change would come, and they have only delayed to be certain that the new system embodied all of the requisites. Now, all sides appear satisfied that the trial being arranged for at Pittsburg will be satisfactory, pronounce the fate of steam in cities and establish electricity as the great motive power.



THE FIRST ELECTRIC LOCOMOTIVE



THE TRUCK OF THE ELECTRIC LOCOMOTIVE.



THE LATEST ELECTRIC LOCOMOTIVE.

ILLUSTRATED
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A Journal of Scientific and Electrical Progress.

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TESLA DESCRIBES AN INTERESTING FEATURE OF THE X-RAY RADIATIONS.

TO THE EDITOR OF ELECTRICAL REVIEW:

The following observations, made with bulbs emitting Roentgen radiations, may be of value in throwing additional light upon the nature of these radiations, as well as illustrating better properties already known. In the main these observations agree with the views which have forced themselves upon my mind from the outset, namely, that the rays consist of streams of minute material particles projected with great velocity. In numerous experiments I have found that the matter which, by impact within the bulb, causes the formation of the rays, may come from either of the electrodes. Inasmuch as the latter are by continued use disintegrated to a marked degree, it seems more plausible to assume that the projected matter consists of parts of the electrodes themselves rather than of the residual gas. However, other observations, upon which I can not dwell at present, lead to this conclusion. The lumps of projected matter are by impact further disintegrated into particles so minute as to be able to pass through the walls of the bulb, or else they tear off such particles from the walls, or generally bodies, against which they are projected. At any rate, an impact and consequent shattering seems absolutely necessary for the production of Roentgen rays. The vibration, if there be any, is only that which is impressed by the apparatus, and the vibrations can only be longitudinal.

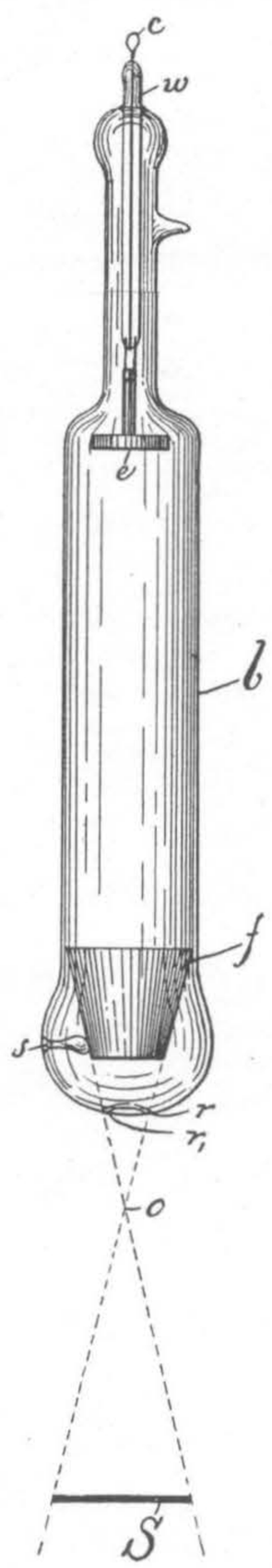


DIAGRAM ILLUSTRATING TESLA'S EXPERIMENT.

The principal source of the rays is invariably the place of first impact within the bulb, whether it be the anode, as in some forms of tube, or an inclosed insulated body, or the glass wall. When the matter thrown off from an electrode, after striking against an obstacle, is thrown against another body, as the wall of the bulb, for instance, the place of second impact is a very feeble source of the rays.

These and other facts will be better appreciated by referring to the annexed figure, in which a form of tube is shown used in a number of my experiments. The general form is that described on previous occasions. A single electrode *e*, consisting of a massive aluminium plate, is mounted on a conductor *c*, provided with a glass wrapping *w* as usual, and sealed in one of the ends of a straight tube *b*, about five centimetres in diameter and 30 centimetres long. The other end of the tube is blown out into a thin bulb of a slightly larger diameter, and near this end is supported on a

glass stem *s* a funnel *f* of thin platinum sheet. In such bulbs I have used a number of different metals for impact with a view of increasing the intensity of the rays and also for the purpose of reflecting and concentrating them. Since, however, in a later contribution, Professor Roentgen has pointed out that platinum gives the most intense rays, I have used chiefly this metal, finding a marked increase in the effect upon the screen or sensitive plate. The particular object of the presently described construction was to ascertain whether the rays generated at the inner surface of the platinum funnel *f* would be brought to a focus outside of the bulb, and further, whether they would proceed in straight lines from that point. For this purpose the apex of the platinum cone was arranged to be about two centimetres outside of the bulb at *o*.

When the bulb was properly exhausted and set in action, the glass wall below the funnel *f* became strongly phosphorescent, but not uniformly, as there was a narrow ring *r r* on the periphery brighter than the rest, this ring being evidently due to the rays reflected from the platinum sheet.

Placing a fluorescent screen in contact or quite close to the glass wall below the funnel, the portion of the screen in the immediate neighborhood of the phosphorescent patch was brightly illuminated, the outlines being entirely indistinct. Receding now with the screen from the bulb, the strongly illuminated spot became smaller and the outlines sharper, until, when the point *o* was reached, the luminous part had dwindled down to a small point. Moving the screen a few millimetres beyond *o* caused a small dark spot to appear, which widened into a circle and became larger and larger in the same measure as the distance from the bulb was increased (see S), until, at a sufficiently large distance, the dark circle covered the entire screen. This experiment illustrated in a beautiful way the propagation in straight lines, which Roentgen originally proved by pinhole photographs. But, besides this, an important point was noted; namely, that the fluorescent glass wall emitted practically no rays, whereas, had the platinum not been present, it would have been, under similar conditions, an efficient source of the rays, for the glass, even by weak excitation of the bulb, was strongly heated. I can only explain the absence of the radiation from the glass by assuming that the matter proceeding from the surface of the platinum sheet was already in a finely divided state when it reached the glass wall. A remarkable fact is, also, that, at least by a weak excitation of the bulb, the edges of the dark circle were very sharp, which speaks strongly against diffusion. By exciting the bulb very strongly, the background became brighter and the shadow S fainter, though it continued to be plainly visible even then.

From the preceding it is evident that, by a suitable construction of the bulb, the rays emanating from the latter may be concentrated upon any small area at some distance, and a practical advantage may be taken of this fact when producing impressions upon a plate or examining bodies by means of a fluorescent screen.

N. TESLA.

New York, July 1, 1896.

Tesla Transformers for Röntgen Photography.—Fig. 1 shows a complete Tesla apparatus, being patented by Mr. L. Miller, for obtaining high tension oscillating discharges from the street electric light mains, where the current is alternating. The illustration is taken from a set of apparatus supplied to St. Bartholomew's Hospital for obtaining photographs of injured limbs, &c., by means of Röntgen rays. Messrs. Miller & Woods supply a standard

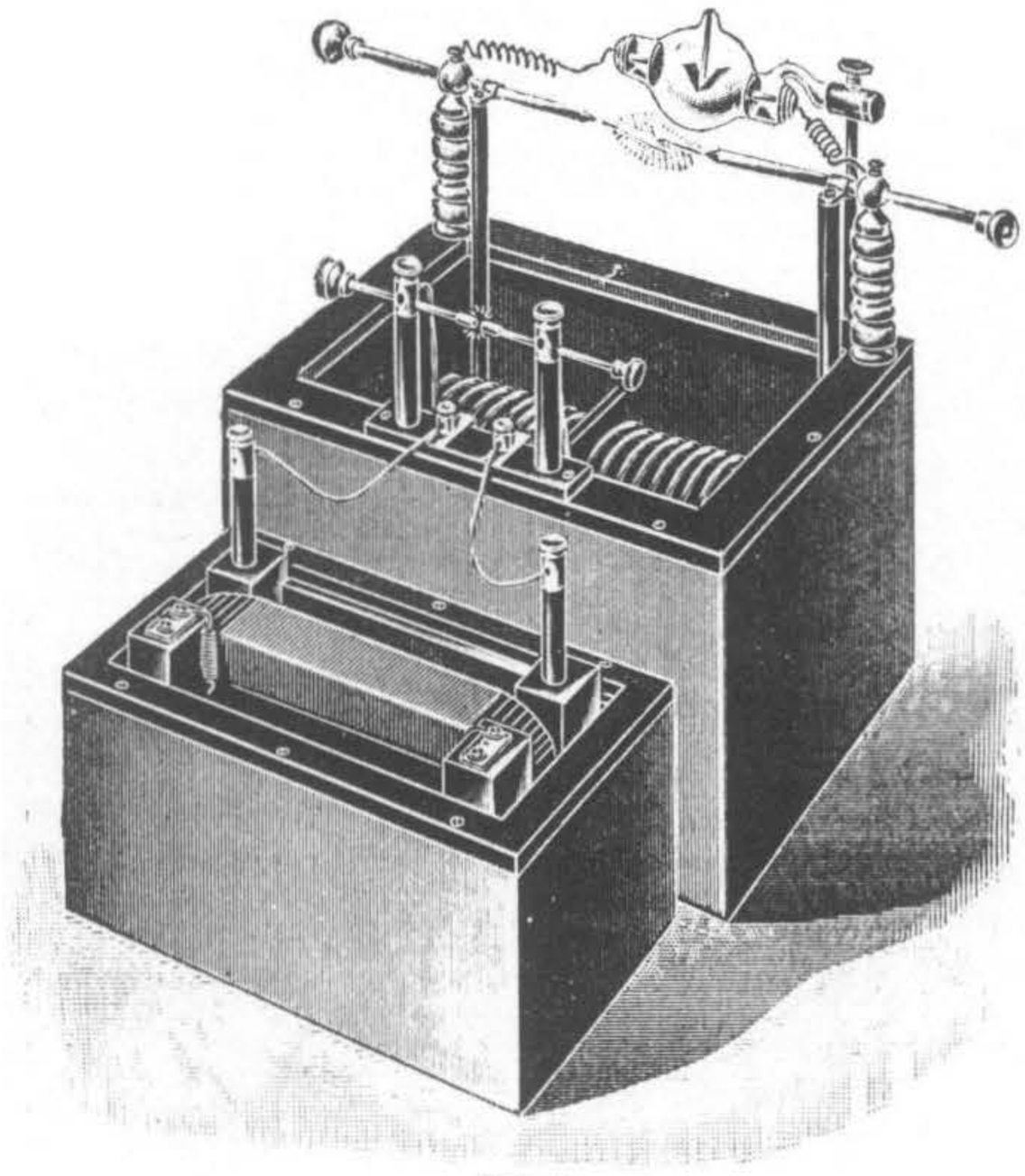


FIG. 1.

set which gives a stream of sparks over more than a 6-inch air gap. The set consists of a step up transformer (fig. 1) from 100 volts to about 6,000 volts, and taking the same current as two lamps of 16 candle-power each; a condenser; and a Tesla transformer to about 70,000 volts. The condenser discharges by rapid oscillations of current across the spark gap (shown in figure) through the primary thick wire winding of the Tesla coil. Induced currents are then set up in the inner thin wire secondary winding of the Tesla coil.

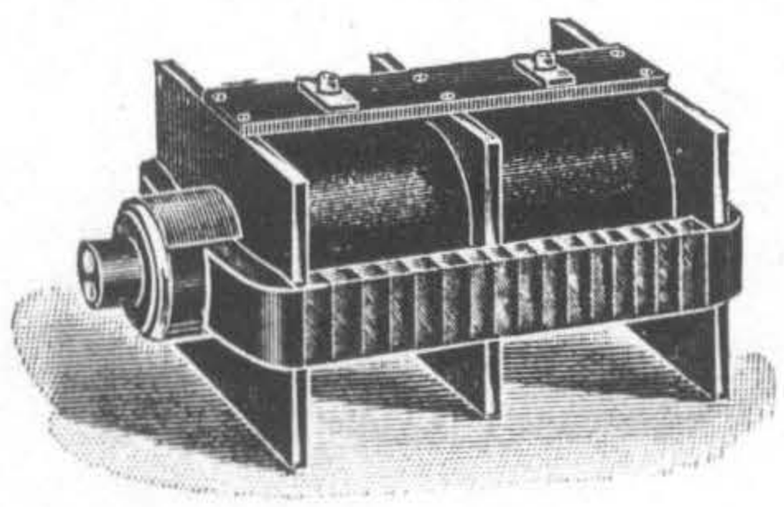


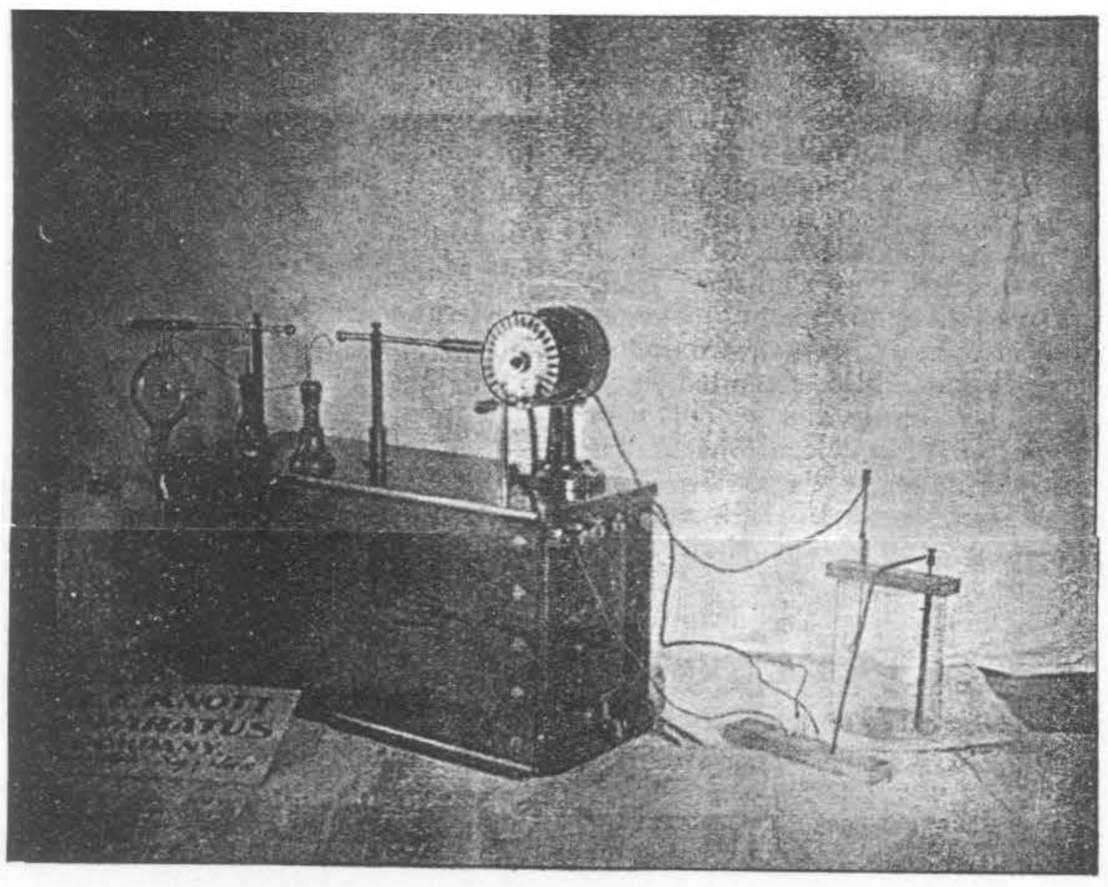
FIG. 2.

These are led to the discharge rods and can be used to excite Röntgen rays in a single or double focus tube as shown, or demonstrate the Tesla experiments. The boxes in which the above are contained are filled with mineral oil. Fig. 2 shows a high tension transformer which can be used up to about 4,000 volts without oil. It is said to be a neat compact form of transformer for exciting vacuum tubes, ozone generators, &c., and can readily be connected to the electric mains by means of a lampholder attached to a piece of flexible cord.

New Tesla Coil for X-Ray Work.

During the last few months the subject of exciting Crookes tubes has received much attention from electricians and scientists in general. It is not surprising, therefore, that enterprising experimenters have placed upon the market various devices which they believe to be an improvement over the old methods of exciting these tubes. The difficulties in the way were not easy to surmount. First of all it was found there must be an exceedingly rapid discharge of the current through the tube. Second, this discharge must be of sufficiently high potential to make it vigorous. Third, the amperage must be so low as to produce little or no heat in the tube itself. This last point was a subject of great moment, as in one form of the tube where the cathode rays focus upon the glass itself it was found that if a large amount of current was used the glass became heated and the tube collapsed.

Many experiments have been performed showing the adaptability of



A New Tesla Coil for X-Ray Work.

the Holtz machine to this work. At present, however, no satisfactory device has been hit upon by which a Holtz machine can be made to give sufficiently rapid discharges combined with durability and readiness to work under all climatic conditions. Any one of these points seems to have been attained, but to our knowledge no similar machine has yet been able to meet them all.

The induction coil seems to have been productive of better results in that it can be relied upon under all atmospheric conditions, and with proper care is not so liable to get out of order. The difficulty, however, of making a complete break of sufficient rapidity in the primary current, has rendered this apparatus of little practical value for hospital work. Furthermore, the problem of adjusting the ratio between the primary and secondary coil has not yet been settled, so that many of the induction coils placed upon the market have been found to be exceedingly destructive to the Crookes tubes. This deterioration of the tubes, when used on these coils, has been from overheating either the aluminum or platinum electrode. In either event the degree of vacuum would be changed, and hence the efficiency of the tube greatly interfered with.

The wonderful and startling results produced by Nikola Tesla during the early stages of this work lead many to believe that much was to be hoped for in the development of the form of apparatus used by him. A coil known as the modified Tesla coil has been placed upon the market by the L. E. Knott Apparatus Company, of 14 Ashburton Place, Boston, Mass. This coil contains many new features entirely different from anything before seen in the practical electrical field. They have employed a new form of transformer, which lifts the current from 52 to about 35,000 volts. The principle of this transformer does not differ materially from that of the induction coil, except the ratio of the core to the primary and secondary is so adjusted that the principle of the regular alternating current transformer applies. Also, by a new method of insulation, the secondary coil is so wound that each layer is surrounded by an oil of high insulating properties. A new feature also has been introduced in the condenser since not only the transformer and oscillator, but also the condenser itself, is immersed in oil. Great improvement has been made here in the condensing surface since the old method of using tinfoil has been discarded and a much more permanent copper plate substituted. By an arrangement of the primary of the transformer, also, either a 52 or 104-volt current can be used equally well. If the former, the machine will take six amperes. If the latter, about three. When working on the number of watts here indicated, a steady discharge of something over eight inches is obtained. The frequency is so high that striking Tesla effects are also produced. Many of the experiments that are so ably discussed in Tesla's little book can be shown with great satisfaction with the coil here described.

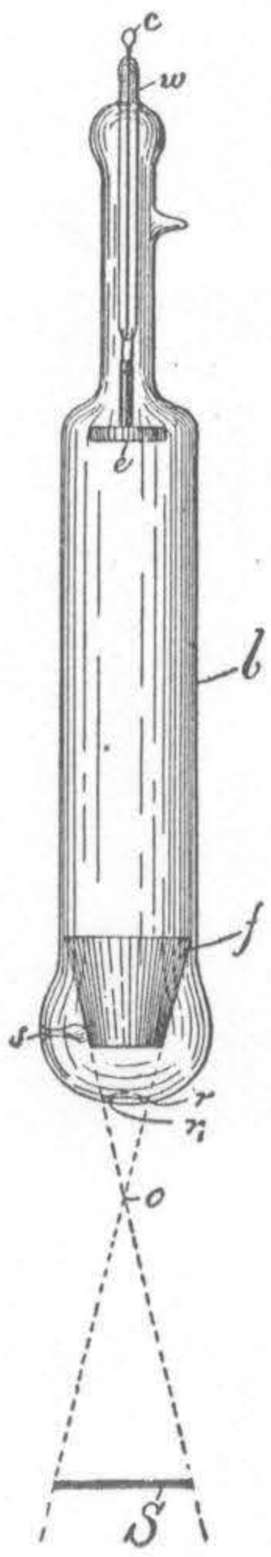
It is not thought that the problem of running a high-frequency coil on a direct current has ever before been successfully solved. Wonderfully successful work, it is said, has been done by this coil so excited.

The great improvement, however, on this coil is the mechanical spark gap which renders the discharge of the condenser absolutely uniform and the rapidity of the discharge under the control of the operator. As the manufacturers of these coils are in the physical and chemical apparatus business, and dealing with hospitals, it is but natural that they should endeavor to place a coil on the market which is especially adapted to this kind of work. We are pleased to know of their success and to know that the instruments have so far been developed that surgeons find them of great practical value. The manufacturers of these coils have recently issued an eight-page pamphlet on the use of the X rays, and are soon to issue a new edition containing their recent improvements. The amount of energy they have shown is surely commendable.

SCIENCE.

TESLA'S NEW X-RAY EXPERIMENTS.

AMONG all scientific men of recognized authority Nikola Tesla has stood practically alone in his views of the constitution of the Röntgen rays, in that he has been inclined to regard them not as vibrations but as actual streams of fine particles passing directly through the pores of material bodies. The objections to such a hypothesis are evident, and it is therefore interesting to see that Tesla adheres to it and now brings forward some special experiments that seem to strengthen it considerably. We quote part of a description of these experiments contributed by the experimenter himself to *The Electrical Review* (July 8). Says Mr. Tesla:



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"In the main these observations agree with the views which have forced themselves upon my mind from the outset, namely, that the rays consist of streams of minute material particles projected with great velocity. In numerous experiments I have found that the matter which, by impact within the bulb, causes the formation of the rays, may come from either of the electrodes. Inasmuch as the latter are by continued use disintegrated to a marked degree, it seems more plausible to assume that the projected matter consists of parts of the electrodes themselves rather than of the residual gas. However, other observations, upon which I can not dwell at present, lead to this conclusion. The lumps of projected matter are by impact further disintegrated into particles so minute as to be able to pass through the walls of the bulb, or else they tear off such particles from the walls, or generally bodies against which they are projected. At any rate, an impact and consequent shattering seems absolutely necessary for the production of Röntgen rays. The vibration, if there be any, is only that which is impressed by the apparatus, and the vibrations can only be longitudinal.

"The principal source of the rays is invariably the place of first impact within the bulb, whether it be the anode, as in some forms of tube, or an enclosed insulated body, or the glass wall. When the matter thrown off from an electrode, after striking against an obstacle, is thrown against another body, as the wall of the bulb, for instance, the place of second impact is a very feeble source of the rays.

"These and other facts will be better appreciated by referring to the annexed figure, in which a form of tube is shown used in a number of my experiments. The general form is that described on previous occasions. A single electrode *e*, consisting of a massive aluminum plate, is mounted on a conductor *c*, provided with a glass-wrapping *w* as usual, and sealed in one of the ends of a straight tube *b*, about 5 cm. in diameter and 30 cm. long. The other end of the tube is blown out into a thin bulb of a slightly larger diameter, and near this end is supported on a glass stem *s* a funnel *f* of thin platinum sheet. . . . The particular object of the presently described construction was to ascertain whether the rays generated at the inner surface of the platinum funnel *f* would be brought to a focus outside of the bulb, and further, whether they would proceed in straight lines from that point. For this purpose the apex of the platinum cone was arranged to be about 2 cm. outside of the bulb at *o*.

"When the bulb was properly exhausted and set in action, the glass wall below the funnel *f* became strongly phosphorescent, but not uniformly, as there was a narrow ring *r r* on the periphery brighter than the rest, this ring being evidently due to the rays reflected from the platinum sheet."

By holding a phosphorescent screen outside the bulb and shifting it to and fro, Mr. Tesla showed that the rays focus at *o*. He goes on to say:

"This experiment illustrated in a beautiful way the propagation in straight lines, which Röntgen originally proved by pinhole photographs. But, besides this, an important point was noted, namely, that the fluorescent glass wall emitted practically no rays, whereas, had the platinum not been present, it would have been, under similar conditions, an efficient source of the rays, for the glass, even by weak excitation of the bulb, was strongly heated. I can only explain the absence of the radiation from the glass by assuming that the matter proceeding from the surface of the platinum sheet was already in a finely divided state when it reached the glass wall. . . .

"From the preceding it is evident that, by a suitable construction of the bulb, the rays emanating from the latter may be concentrated upon any small area at some distance, and a practical advantage may be taken of this fact when producing impressions upon a plate or examining bodies by means of a fluorescent screen."

The New York Herald July 25, 1896

TESLA ON X RAYS.

Believes Them To Be Moving Material Particles That Affect Tissue and Organs.

WILL APPLY CRUCIAL TESTS.

Radiations from the Bulb That Have an Effect, Sometimes Harmful, on Human Brain.

MAY INJURE HAIR AND EYES.

On Other Hand, Roentgen's Discovery May Possibly Be Used to Destroy Bacilli.

That Roentgen rays are moving material particles, having an appreciable effect on human tissues and organs, and that they may likely be used as a means to destroy disease bicilli, are conclusions that Nicola Tesla has arrived at as the result of his experiments during the past six months; but he awaits crucial tests before positively announcing his clusions as scientific facts.

Mr. Tesla was found in his laboratory. He was very busy, but he found time to answer the several vital questions put to him as to the effect of X rays on physical health and bacilli life.

MOVING MATERIAL PARTICLES.

"In my attempts to contribute my humble share to further knowledge of the properties of the Roentgen rays," Mr. Tesla said, "I am finding more and more evidence in support of the theory of moving material particles. It is not my intention, however, to advance just now any view as to the bearing of such a fact upon the present theory of light, but I merely seek to establish the fact of the existence of such material streams in so far as the isolated effects are concerned. I have already a great many indications of a 'bombardment' occurring outside of the bulb from which the rays emanate, and I am arranging some crucial tests, which I hope will be successful, and which will prove whether or not I am right in my conclusions.

"Now, if these material streams are impinging themselves against substances toward which they are directed it is natural that some effect should follow the contact. It is not unreasonable to say that organs and tissues may be affected. We often read in reports made by experimentalists that human hair has fallen out from the effect of frequent use of the rays, and I have myself noted that effect in my experiments.

"I have also noticed that, when working with highly strained bulbs, I frequently experience a sudden, and sometimes even painful, shock in the eye. Such shocks may occur so often that the eye gets inflamed, and one canno' be considered overcautious if he abstains from watching the bulb too closely. These shocks are to me further evidence of larger particles being thrown off from the bulb.

"If these conclusions, which seem to be forced on me by the experience coming from experiment, are correct, then it may be that the rays have an effect on bacilli. Indeed, Professor Roentgen himself has announced it as his firm belief that bacilli can be destroyed by the rays, and his experiments warrant his conclusion. Yet we must wait patiently to hear from those who are investigating in this direction before formulating scientific conclusions.

EFFECTS ON THE BRAIN.

"The theory of material particles," continued Mr. Tesla, "and the theory that the rays affect the human system are borne out by my own further experience in the laboratory here. By exposing the head to a powerful radiation strange effects have been noted. For instance, I find that there is a tendency to sleep, and the time seems to pass away quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of my head. An assistant experienced identically the same sensations as myself.

"Should these remarkable effects be verified by men with keener sense of observation, I shall still more firmly believe in the existence of material streams penetrating the skull. Thus it may be possible by these strange appliances to project a suitable chemical into any part of the body."

Discharge of an Electrified Body by Means of the Tesla Spark.

IT has been shown that a body charged with electricity may be discharged by means of the rays from a Röntgen bulb. I find, also, that an electrified body is rapidly discharged by the influence of a high-frequency spark, such as that produced by the Tesla apparatus. The discharging action was shown in this way. A high-frequency spark was produced between two rather blunt points, one inch apart in air, no bulb being used. A gold-leaf electroscope, placed far away from the influence of the spark, was used to test the electrical condition of the charged bodies—viz. a stick of sealing-wax and a rod of glass. The sealing-wax was rubbed, and the electroscope indicated that it was well charged. It was again rubbed, and then brought to within a foot of the points, and by means of a key in the battery circuit the Tesla coil was thrown into action for an instant. On testing the sealing-wax rod with the electroscope, it was found to be entirely discharged. A similar experiment was next made with a glass rod; the glass rod was entirely discharged by the Tesla spark. From a previous experiment, it was seen that the electrification of the rods was dissimilar. The influence, then, of the high-frequency spark is to discharge electricity of either sign.

FREDERICK J. SMITH.

Oxford, July 17.

CONSTRUCTION OF A TESLA-THOMSON HIGH FREQUENCY COIL.

BY PROF. A. F. MCKISSICK.

The following is a description of the construction of a Tesla-Thomson high frequency coil, large enough to give a five-inch spark and excite Röntgen ray tubes.

To excite the Tesla-Thomson coil, a high

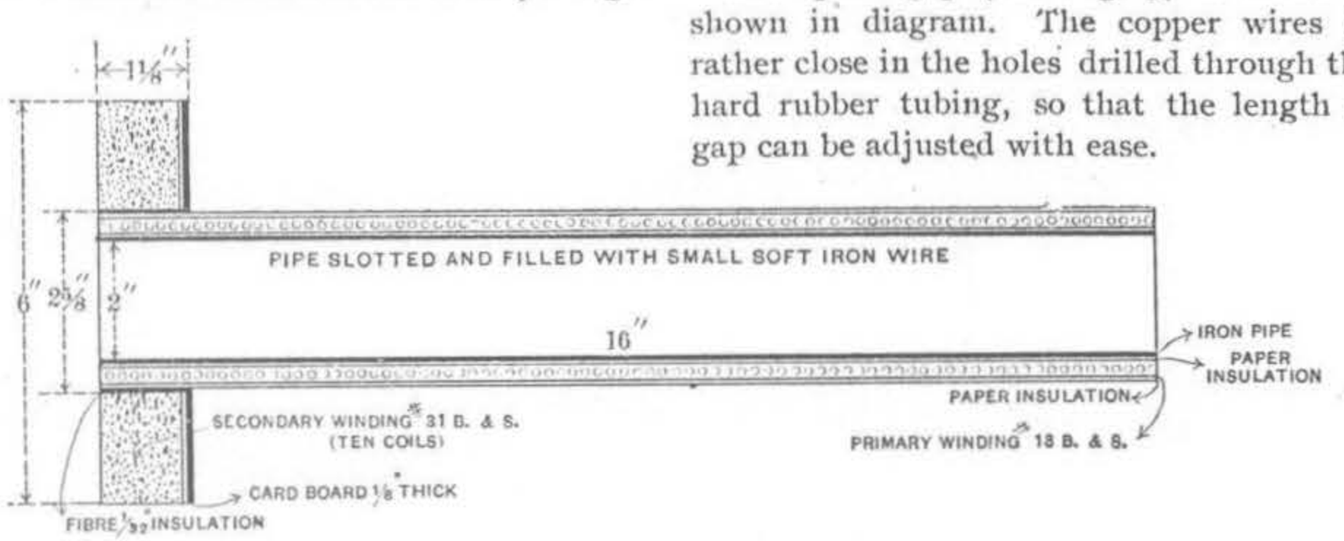

FIG. 1.—HIGH TENSION TRANSFORMER.

potential transformer of from 10,000 to 15,000 is necessary. The construction of this transformer will be first given. Fig. 1 gives a partial cross-section of the trans-

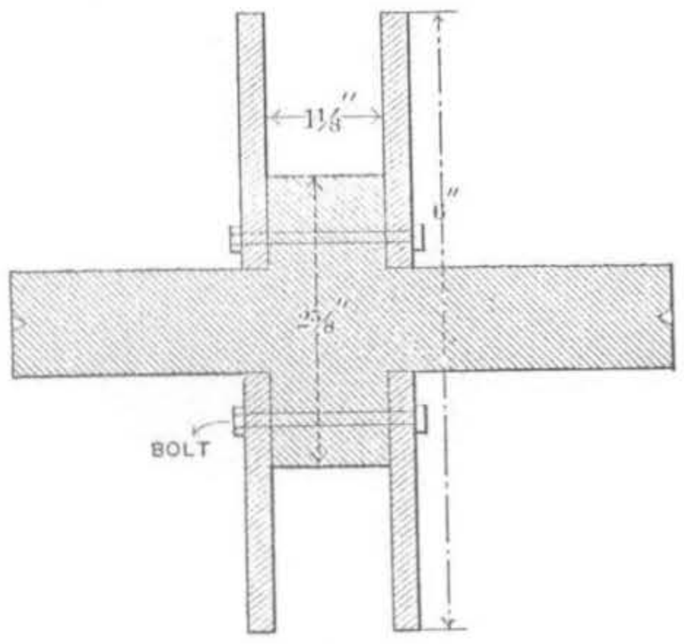

FIG. 2.—FORM FOR WINDING COILS.

former, which is made as follows: A two-inch iron pipe, sixteen inches long is slotted the whole length, either in a milling machine, planer or shaper. This slot need not be more than 1/16 in. in width. The pipe is then insulated with ordinary wrapping paper to an outside diameter of 2⅛ ins., shellac being freely used, and is then wound with No. 13 B. & S. double cotton-covered wire for its whole length (one layer). It is then covered with paper and shellaced until the outside diameter is 2⅝ ins.

The next step is to fill the pipe with soft iron wires, No. 16 B. & S., each wire being cut eighteen inches long. This completes the primary winding of the high tension transformer.

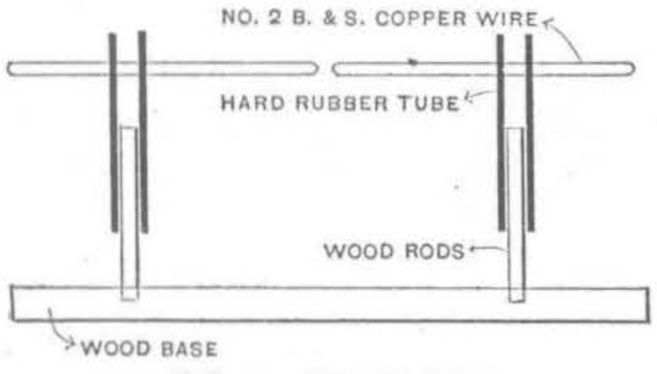

FIG. 3.—SPARK GAP.

The secondary winding of this transformer consists of ten coils wound in a form and thoroughly taped and insulated. This form is shown in Fig. 2, and can be easily made of wood. The wire is wound in this form, shellaced, removed, taped and baked. These coils are then slipped over the primary winding, between each coil being placed a disk of cardboard ⅛ in. thick, care being taken to connect the coils so that none will be in opposition.

The spark gap (see Fig. 3) is made as shown in diagram. The copper wires fit rather close in the holes drilled through the hard rubber tubing, so that the length of gap can be adjusted with ease.

The condenser is made of ordinary 10 in. × 12 in. window glass. A sheet of tin foil 8 ins. × 10 ins. is pasted on one side of the glass with shellac, leaving a margin of one inch.

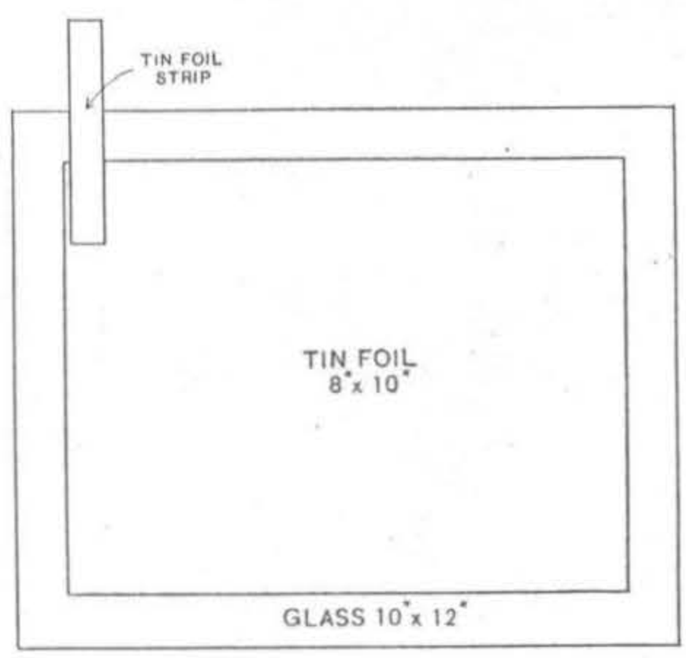

FIG. 4.—CONDENSER PLATE.

(See Fig. 4.) A strip of tin foil two inches wide is placed across one corner, this strip being placed alternately on each side. For each side of this condenser there should be fifteen plates.

To build this condenser proceed as follows: Place on a smooth surface a condenser plate with the connecting strip projecting on the right. On top of this plate place another piece of glass, 10 ins × 12 ins., that has no tin foil on it at all. Then place a condenser plate with the strip projecting on the left. Then a piece of glass without tin foil, and on top of this a condenser plate with the strip projecting on the right, and so on. This construction gives two thicknesses of glass between each sheet of tin foil, which is absolutely necessary.

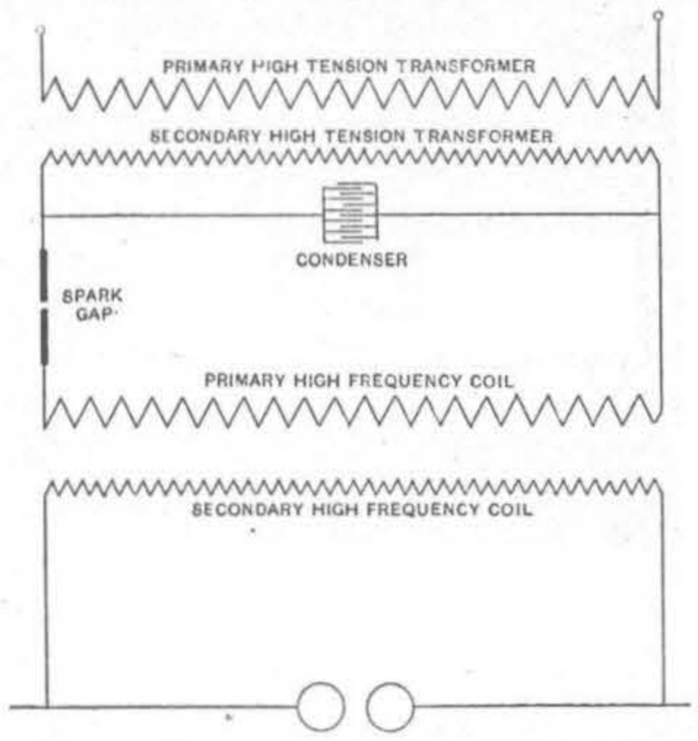

FIG. 6.—DIAGRAM OF CONNECTIONS.

The high frequency coil is made as follows: Wind an eight-inch paper cylinder eighteen inches long with No. 31 B. & S. double cotton-covered wire (or larger), leaving a margin at each end of about one inch. This is the secondary winding. The primary winding is placed on a twelve-inch paper cylinder eighteen inches long and consists of fourteen turns of four No. 8 B. & S. double cotton-covered wires in parallel. Each of these No. 8 wires is wound on separately, then the four ends at the beginning and ending are soldered together. Between wires of different polarity, as an extra precaution, two turns of cord are wound. The primary and secondary coils are then shellaced and baked. After being baked, the secondary coil is placed concentrically (see Fig. 5) inside the primary and the connections as shown in Fig. 6 then made.

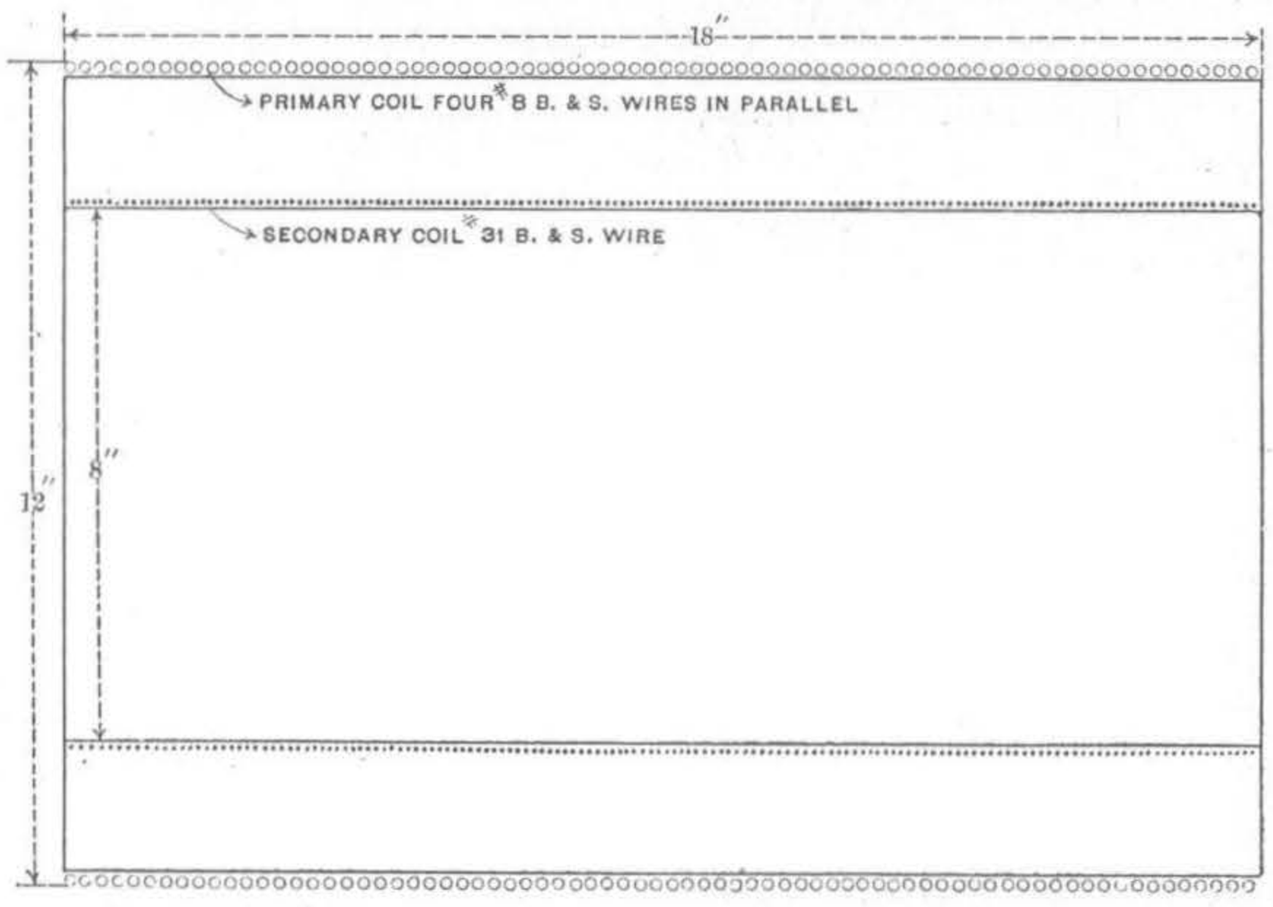

FIG. 5.—PRIMARY AND SECONDARY COILS OF HIGH FREQUENCY TRANSFORMER.

The primary of the high tension transformer must be excited with an alternating current. With a frequency of 60 cycles per second 50 volts will suffice, and for 125 cycles per second 100 volts. The length of the spark from the secondary of the high frequency coil will depend on the width of the "spark gap," consequently, in exciting a tube it is best to start with the "spark gap" very short, then gradually increase until the tube is properly excited. When the terminals of the secondary high frequency coil are separated farther than five inches, a spark will pass from the secondary to the primary of the high frequency coil. By the use of a good insulating oil a much longer spark can be obtained from the high frequency coil, but for exciting Röntgen ray tubes a five-inch spark will be sufficient.

AN interesting account of the first visit of Tesla to the plant of the Niagara Falls Power company is furnished by a special correspondent of the WESTERN ELECTRICIAN on another page in this issue. It is worthy careful perusal, and must of necessity attract much attention among the friends and admirers of the great investigator, as it presents his impressions of the greatest electric power equipment of the world. It was the first opportunity the visitor had of seeing in practical operation the special apparatus which he designed for the great generating station which put into practice the theories he had developed after years of careful study and experiment. It would be impossible to describe the sensation which such an impressionable mind as Tesla's must have experienced on first beholding in operation the system of development and transformation of the power of the great waterfall into electrical energy with which he had so much to do. That must be left to the reader's imagination. Our correspondent declares that Tesla was delighted with the manner in which his discoveries had been adapted to practical use by the engineers, and that he was particularly pleased with the successful operation of the transformers upon which he had spent so much time and thought and labor. He looks for still greater accomplishments in the electrical field. At present, he said, he was devoting all of his attention to the transmission problem, and he added that he would continue his study and experimental work in this direction until he had obtained results that would be satisfactory to him. Speaking of the project for transmitting power to Buffalo from the Niagara plant, Tesla said of the undertaking: "Its success is certain." Of the commercial feature of the question, he said that the power company could sell current in Buffalo at a much lower price than the present cost of power in that city. Altogether the visit was eminently satisfactory to the great inventor. He inspected the power plant "from top to bottom," as he expressed it, and pronounced it "the greatest and the best, the most thoroughly equipped in the world." He said that it came up to his expectations; in fact, surpassed them. "It is one of the wonders of this century!" he exclaimed. This view will find general acceptance. The world is greatly indebted to Nikola Tesla for his share in bringing about this accomplishment.

Nikola Tesla at Niagara Falls.

By Orrin E. Dunlap.

Nikola Tesla paid his first visit to the great electrical power plant of the Niagara Falls Power company on Sunday, July 19th. In the party with Tesla were George Westinghouse, Jr., president of the Westinghouse Electric & Manufacturing company of Pittsburg, and his son, H. H. Westinghouse; Thomas N. Ely of Philadelphia, superintendent of motive power of the Pennsylvania railroad, Commodore George W. Melville of Washington, chief engineer of the United States Navy; Edward D. Adams, president of the Cataract Construction company, and William B. Rankins, secretary of the company; Paul D. Cravath, counsel for the Westinghouse company, and George Urban, Jr., of Buffalo, president of the Cataract Power & Construction company of Buffalo, which company was organized recently to distribute the electric power in Buffalo.

Quite naturally, the event of Tesla's visit was one of importance, for never before had his eyes rested on this greatest of power plants. For four years he had refused to leave his work and visit the Falls, preferring to work out his theories and await the proper time to see them put into practical use and operation. Tesla was delighted with the manner in which his discoveries had been adapted to practical use by the engineers, and he unhesitatingly declared that there was no doubt of the success of the gigantic undertaking and that power would be transmitted to Buffalo without the least semblance of failure in any important detail. He was greatly interested in the working of the transformers invented by him, and the great electrician declared that they solved one of the most difficult and important problems in electrical science.

It is a well known fact that Tesla does not like to speak of himself. He will talk freely about electrical discoveries or inventions, but when his own are broached he modestly says that he prefers to say little about them.

"I do not like to speak of what I am doing or what I hope to do," said he. "It is enough to let others do that when what I have done is before the world. I am content to be in my workshop and to work day and night to discover something which we are looking for and which will assist the development of electricity as a great and universal power. The time will come when steam will not be used for commercial purposes. I am working to bring that about." This, then, is the present great ambition. He desires to see electricity fully occupy the power field.

"I came to Niagara Falls," said he, "to inspect the great power plant and because I thought the change would bring me needed rest. I have been for some time in poor health, almost worn out, and I am now trying to get away from my work for a brief spell and at the same time see the great results of electrical development within the last half dozen years. Those results have been wonderful, have far surpassed the expectations of the people generally, but they are what those who have made electricity their study for years and their life work have expected and have labored so hard to bring about. Yet scientists are not content and great wonders in the future development of electric power for many purposes are anticipated and are confidently expected by the great men in all countries who are trying to discover nature's secrets and to develop the things which God has placed within the reach of those who will seek that they may find."

"What do you think of the Niagara power plant, Mr. Tesla? Is it fully up to your ideas and expectations?"

It was this question that aroused the great electrician's enthusiasm. "Yes," said he; "it is all and more than I anticipated it would be. It is fully all that was promised. It is one of the wonders of this century. The power-producing plant of the Cataract Construction company is a marvel in its completeness and in its superiority of construction. When it shall be in full operation the results in many ways will be wonderful; will be surprising to those who have doubted that such things could be accomplished. In its entirety, in connection with the possibilities of the future, the plant and the prospect of future development in electrical science, and the more ordinary uses of electricity, are my ideals. They are what I have long anticipated and have labored, in an insignificant way, to contribute toward bringing about."

"What, in your judgment, will be the effect on Niagara Falls?"

"The first effects naturally will be to the advantage of Niagara Falls, and the falls will be the greatest reaper of benefits. The result of this great development of electric power will be that the falls and Buffalo will reach out their arms and will join each other and become one great city. United they will form the greatest city in the world."

"This is your first visit to the plant?"

"Yes, I came purposely to see it. I am somewhat interested in the working of some of the machinery. But, and it is a curious thing about me, I cannot stay about big machinery a great while. It affects me very much. The jar of the machinery curiously affects my spine and I cannot stand the strain."

"It is Mr. Tesla's two-phase system which is used," put in Secretary Rankine, who was standing by. "It is the new and great system of the two-phase alternating currents."

"What do you think of the transmission of electric power to Buffalo? Is it an assured undertaking?" Tesla was asked.

"Its success is certain. The transmission of electricity is one of the simplest of propositions. It is but the application of pronounced and accepted rules which are as firmly established as the air itself."

"Do you think the cost of electric power in Buffalo will be half, or lower, than the present cost of steam?"

"I do not know what is the cost of steam power in Buffalo."

"About $60 to $70," said Mr. Rankine.

"Well," continued Mr. Tesla, "the cost certainly will be much less than the cost of steam. The beauty of using electricity for industrial purposes is that you can use it without any loss. When you get done with your work you just shut it off until you want it again; therefore there is no appreciable percentage of loss except that in transmission. On the other hand you cannot use steam without loss. Steam must be kept up. That involves a loss of 20 per cent. at the start, which is continuous and must be counted as a fixed loss. No matter if steam were cheaper than electricity there would be a great saving in favor of electricity because of its adaptability, its freedom from smoke and dust and the fact that it may be shut off when it is not needed."

At this point Secretary Rankine advanced a piece of news. "Buffalo," said he, "will have its first installment of electric power by November. You may say that without fear of making any mistake. The first delivery will be about 1,000 horse power, all that we can give this fall. It will be the initial installment of the 10,000 horse power which we must furnish under our franchise within the ensuing year. The contract for the construction of the pole line will soon be let. The work will be pushed rapidly and Buffalo will find that the company will be faithful to all of its agreements."

In regard to the transmission of power Tesla continued: "It is cheaper to transmit electricity in large quantities than in small. The larger the force the less the loss in transmission. The loss in transmission of power to Buffalo, for instance, will be comparatively small because of the large quantity which Buffalo will receive."

Tesla was averse to speaking of his recent investigations of the vacuum electric lamp and telegraphy without the use of wires.

"I am not prepared to say anything now about those little schemes of mine," said Mr. Tesla. "They must stand aside for awhile. Just now I am devoting my time to the study and development of the transmission and insulation of electricity. Until I get these matters well worked out and obtain satisfactory results I shall do little else. I shall return to my laboratory in New York and continue my work, I am delighted with my trip to the Falls. I have been from top to bottom of the power plant. You may say it is the greatest and the best, the most thoroughly equipped in the world."

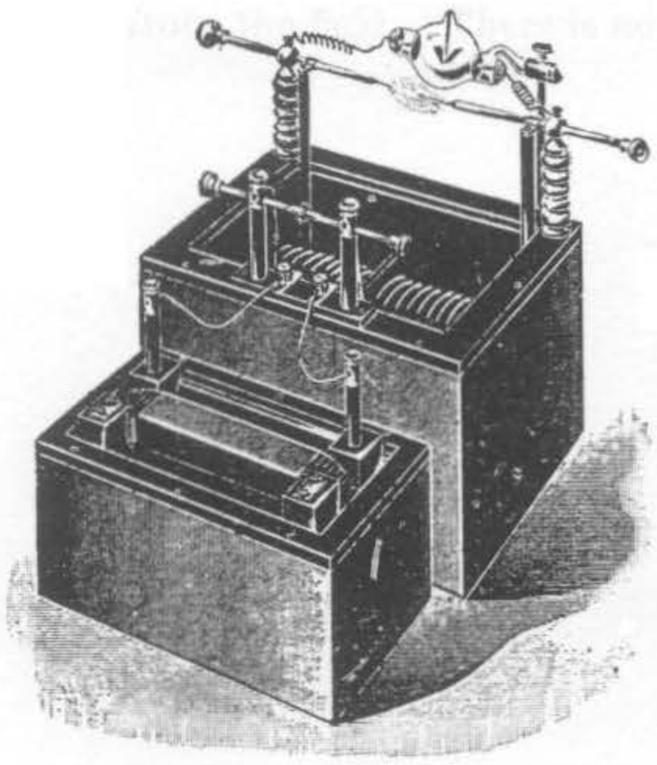

FIG. 1.—AN ENGLISH FORM OF TESLA APPARATUS.

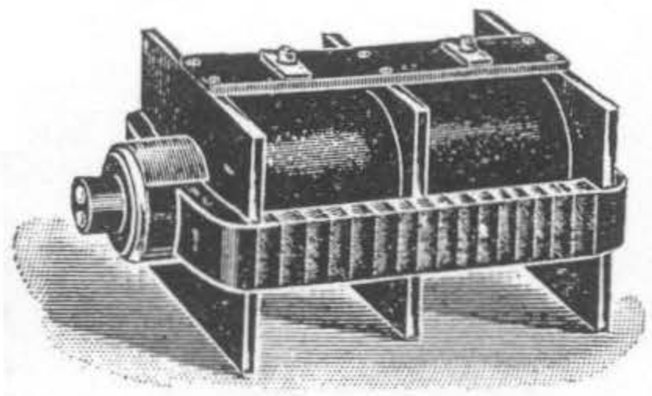

FIG. 2.—HIGH-TENSION TRANSFORMER.

An English Form of Tesla Apparatus for Radiography.

The accompanying illustrations show a form of Tesla apparatus which is being made by an English firm. The London *Electrical Review* describes this apparatus as follows:

Fig. 1 shows a complete Tesla apparatus, being patented by Mr. L. Miller, for obtaining high-tension oscillating discharges from the street electric light mains, where the current is alternating. The illustration is taken from a set of apparatus supplied to St. Bartholomew's Hospital for obtaining photographs of injured limbs, etc., by means of Roentgen rays. Messrs. Miller & Woods supply a standard set which gives a stream of sparks over more than a six-inch air gap. The set consists of a step-up transformer, Fig. 1, from 100 volts to about 6,000 volts, and taking the same current as two lamps of 16-candle-power each; a condenser, and a Tesla transformer to about 70,000 volts. The condenser discharges by rapid oscillations of current across the spark gap (shown in figure) through the primary thick wire winding of the Tesla coil. Induced currents are then set up in the inner thin wire secondary winding of the Tesla coil. These are led to the discharge rods and can be used to excite Roentgen rays in a single or double-focus tube as shown, or demonstrate the Tesla experiments. The boxes in which the above are contained are filled with mineral oil. Fig. 2 shows a high-tension transformer which can be used up to about 4,000 volts without oil. It is said to be a neat, compact form of transformer for exciting vacuum tubes, ozone generators, etc., and can readily be connected to the electric mains by means of a lamp-holder attached to a piece of flexible cord.

NICOLA TESLA, electrical expert and engineer, was recently shown a published statement which was telegraphed from Buffalo to the effect that he had discovered a method for successfully transmitting electricity long distances, and when asked as to the truth of it, replied: "Yes; I did state that electricity can be transmitted long distances upon a commercial basis over a distance of at least 500 miles. I will stake my reputation and my life upon it. I only qualify it by adding that the amount of power transmitted must be quite considerable."

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NEW YORK, AUG. 12, 1896.

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TESLA ON THE NATURE OF THE ROENTGEN RAYS.

In our present issue we publish another important communication from Mr. Tesla in regard to the Roentgen rays. Mr. Tesla has worked ceaselessly, and in his articles, exclusively published in our columns, he has made most valuable contributions to the knowledge of this fascinating subject. His opinions carry the greater weight as they are supported by a mass of experimental evidence, and as his insight into many phenomena has proved to be true. What services has he not rendered to science and industry merely by his demonstrations of the action of air or gases in condensers and high-tension transformers! His present contribution is, in part, a summing up of the observations already made by him, and is particularly important in this, that it substantiates the ideas originally expressed by Professor Roentgen.

Mr. Tesla brings forward many convincing arguments to show that these rays consist of streams of matter in some primary condition, which is, to a certain extent, equivalent to saying that they are streams of ether into which the matter is dissolved by the violent impact.

There is thus opened up a wonderful possibility of transformation of matter into its primary constituents, never before contemplated or thought possible, and it is safe to say that a more absorbing subject for study and investigation could not be found in physical science.

DELETERIOUS EFFECTS OF X RAYS ON THE HUMAN BODY.

It seems that the wonderful effects of X rays have not all been learned. One of the newest of these takes the form of a physical effect upon the person who uses powerful X-ray apparatus for comparatively long periods at a time. Mr. H. D. Hawks, a graduate in the class of 1896, of Columbia College, has for the past few weeks been giving exhibitions in the vicinity of New York with an unusually powerful X-ray outfit. Mr. Hawks, during the afternoon and evening of each day for four days, was working around his apparatus for from two to three hours at a time. At the end of four days he was compelled to cease active work, owing to the physical effects of the X rays upon his body. The first thing Mr. Hawks noticed was a drying of the skin, to which he paid no attention, but after awhile it became so painful it was necessary to stop all operations. The hands began to swell and assumed the appearance of having a very deep sunburn. At the end of two weeks the skin all came off the hands. The knuckles were especially affected, they being the sorest part of the hand. Among other effects were the following: The growth of the finger nails was stopped and the hair on the skin that was exposed to the rays all dropped out, especially on the face and sides of the head. The hair at the temples has entirely disappeared, owing to the fact of Mr. Hawks having placed his head in close proximity to the tube to enable spectators to see the bones of the jaw. The eyes were quite bloodshot and the vision was considerably impaired. The eyelashes began to fall out and the lids to swell. The chest was also burned through the clothing, the burn resembling sunburn. Mr. Hawks's disabilities were such that he was compelled to suspend work for two weeks. He consulted physicians, who treated the case as one of parboiling.

To overcome these effects of the X rays, Mr. Hawks first tried covering his hand with vaseline and then putting a glove on, but the hand was at once burned again, the glove affording no protection whatever. The hand was finally protected by covering it with tin foil. Mr. Hawks coincides with Tesla's belief that X rays are practically minute material particles thrown off from the walls of the tube. The apparatus used was a 10-inch induction coil, manufactured by Ritchie & Son, of Brookline, Mass. The primary circuit was opened and closed by means of a rotary brake mounted on the shaft of a motor, there being 120 breaks a second. The tube used was a focusing tube, made by Emil Greiner, of New York.

Mr. Hawks has made a careful study of his case and has reached the conclusion that no other cause than his exposure to the X rays is responsible for his condition. His personal appearance certainly bears out his statement. The ELECTRICAL REVIEW will be glad to hear from any of its readers who have experienced similar effects, even in a lesser degree.

Roentgen Rays or Streams.

To the Editor of the Electrical Review:

In the original report of his epochal discoveries, Roentgen expressed his conviction that the phenomena he observed were due to certain novel disturbances in the ether. This opinion deserves to be considered the more as it was probably formed in the first enthusiasm over the revelations, when the mind of the discoverer was capable of a much deeper insight into the nature of things.

It was known since long ago that certain dark radiations, capable of penetrating opaque bodies, existed, and when the rectilinear propagation, the action on a fluorescent screen and on a sensitive film was noted, an obvious and unavoidable inference was that the new radiations were transverse vibrations, similar to those known as light. On the other hand, it was difficult to resist certain arguments in favor of the less popular theory of material particles, especially as, since the researches of Lennard, it has become very probable that material streams, resembling the cathodic, existed in free air. Furthermore, I myself have brought to notice the fact that similar material streams —which were subsequently, upon Roentgen's announcement, found capable of producing impressions on a sensitive film—were obtainable in free air, even without the employment of a vacuum bulb, simply by the use of very high potentials, suitable for imparting to the molecules of the air or other particles a sufficiently high velocity. In reality, such puffs or jets of particles are formed in the vicinity of every highly charged conductor, the potential of which is rapidly varying, and I have shown that, unless they are prevented, they are fatal to every condenser or high-potential transformer, no matter how thick the insulation. They also render practically valueless any estimate of the period of vibration of an electro-magnetic system by the usual mode of calculation or measurement in a static condition in all cases in which the potential is very high and the frequency excessive.

It is significant that, with these and other facts before him, Roentgen inclined to the conviction that the rays he discovered were longitudinal waves of ether.

After a long and careful investigation, with apparatus excellently suited for the purpose, capable of producing impressions at great distances, and after examining the results pointed out by other experimenters, I have come to the conclusion which I have already intimated in my former contributions to your esteemed journal, and which I now find courage to pronounce without hesitation, that the original hypothesis of Roentgen will be confirmed in two particulars: first, in regard to the longitudinal character of the disturbances; second, in regard to the medium concerned in their propagation. The present expression of my views is made solely for the purpose of preserving a faithful record of what, to my mind, appears to be the true interpretation of these new and important manifestations of energy.

Recent observations of some dark radiations from novel sources by Becquerel and others, and certain deductions of Helmholtz, seemingly applicable to the explanation of the peculiarities of the Roentgen rays, have given additional weight to the arguments on behalf of the theory of transverse vibrations, and accordingly this interpretation of the phenomena is held in favor. But this view is still of a purely speculative character, being, as it is at present, unsupported by any conclusive experiment. Contrarily, there is considerable experimental evidence that some matter is projected with great velocity from the bulbs, this matter being in all probability the only cause of the actions discovered by Roentgen.

There is but little doubt at present that a cathodic stream within a bulb is composed of small particles of matter, thrown off with great velocity from the electrode. The velocity probably attained is estimable, and fully accountable for the mechanical and heating effects produced by the impact against the wall or obstacle within the bulb. It is, furthermore, an accepted view that the projected lumps of matter act as inelastic bodies, similarly to ever so many small lead bullets. It can be easily shown that the velocity of the stream may be as much as 100 kilometers a second, or even more, at least in bulbs with a single electrode, in which the practicable vacua and potentials are much higher than in the ordinary bulbs with two electrodes. But, now, matter moving with such great velocity must surely penetrate great thicknesses of the obstruction in its path, if the laws of mechanical impact are at all applicable to a cathodic stream. I have presently so much familiarized myself with this view that, if I had no experimental evidence, I would not question the fact that some matter is projected through the thin wall of a vacuum tube. The exit from the latter is, however, the more likely to occur, as the lumps of matter must be shattered into still much smaller particles by the impact. From my experiments on reflection of the Roentgen rays, before reported, which, with powerful radiations, may be shown to exist under all angles of incidence, it appears that the lumps or molecules are indeed shattered into fragments or constituents so small as to make them lose entirely some physical properties possessed before the impact. Thus, the material composing the electrode, the wall of the bulb or obstruction of any kind placed within the latter, are of absolutely no consequence, except in so far as the intensity of the radiations is concerned. It also appears, as I have pointed out, that no further disintegration of the lumps is attendant upon a second impact. The matter composing the cathodic stream is, to all evidence, reduced to matter of some primary form, heretofore not known, as such velocities and such violent impacts have probably never been studied or even attained before these extraordinary manifestations were observed. Is it not possible that the very ether vortexes which, according to Lord Kelvin's ideal theory, compose the lumps, are dissolved, and that in the Roentgen phenomena we may witness a transformation of ordinary matter into ether? It is in this sense that, I think, Roentgen's first hypothesis will be confirmed. In such case there can be, of course, no question of waves other than the longitudinal assumed by him, only, in my opinion, the frequency must be very small—that of the electro-magnetic vibrating system—generally not more than a few millions a second. If such process of transformation does take place, it will be difficult, if not impossible, to determine the amount of energy represented in the radiations, and the statement that this amount is very small should be received with some caution.

As to the rays exhaustively studied by Lennard, which have proved to be the nucleus of these great realizations, I hold them to be true cathodic streams, projected through the wall of the tube. Their deflectibility by a magnet shows to my mind simply that they differ but little from those within the bulb. The lumps of matter are probably large and the velocity small as compared with that of the Roentgen rays. They should, however be capable in a minor degree of all the actions of the latter. These actions I consider to be purely mechanical and obtainable by other means. So, for instance, I think that if a gun loaded with mercury were fired through a thin board, the projected mercury vapor would cast a shadow of an object upon a film made especially sensitive to mechanical impact, or upon a screen of material capable of being rendered fluorescent by such impact.

The following observations made by myself and others speak more or less for the existence of the streams of matter.

I—PHENOMENA OF EXHAUSTION.

On this subject I have expressed myself on another occasion. It is only necessary to once more point out that the effect observed by me should not be confounded with that noted by Spottiswoode and Crookes. I explain the latter phenomenon as follows: The first fluorescence appearing when the current is turned on, is due to some organic matter almost always introduced in the bulb in the process of manufacture. A minute layer of such matter on the wall produces invariably this first fluorescence, and the latter never takes place when the bulb has been exhausted under application of a high degree of heat or when the organic matter is otherwise destroyed. Upon the disappearance of the first fluorescence the rarefaction increases slowly, this being a necessary result of particles being projected from the electrode and fastening themselves upon the wall. These particles absorb a large portion of the residual gas. The latter can be again freed by the application of heat to the bulb or otherwise. So much of the effects observed by these investigators. In the instance observed by myself, there must be actual expulsion of matter, and for this speak following facts: (a) the exhaustion is quicker when the glass is thin; (b) when the potential is higher; (c) when the discharges are more sudden; (d) when there is no obstruction within the bulb; (e) the exhaustion takes place quickest with an aluminum or platinum electrode, the former metal giving particles moving with greatest velocity, the latter particles of greatest weight; (f) the glass wall, when softened by the heat, does not collapse, but bulges outwardly; (g) the exhaustion takes place, in some cases, even if a small perceptible hole is pierced through the glass; (h) all causes tending to impart a greater velocity to the particles hasten the process of exhaustion.

II—RELATION BETWEEN OPACITY AND DENSITY.

The important fact pointed out early by Roentgen and confirmed by subsequent research, namely, that a body is the more opaque to the rays the denser it is, can not be explained as satisfactorily under any other assumption as that of the rays being streams of matter, in which case such simple relation between opacity and density would necessarily exist. This relation is the more important in its bearing upon the nature of the rays, as it does not at all exist in light-giving vibrations, and should consequently not be found to so marked a degree and under *all conditions with vibrations*, presumably similar to and approximating in frequency the light vibrations.

III—DEFINITION OF SHADOWS ON SCREEN OR PLATE.

When taking impressions or observing shadows while varying the intensity of the radiations, but maintaining all other conditions as nearly as possible alike, it is found that the employment of more intense radiations secures little, if any, advantage, as regards the definition of the details. At first it was thought that all there was needed was to produce very powerful rays. But the experience was disappointing, for, while I succeeded in producing rays capable of impressing a plate at distances of certainly not less than 30 metres, I obtained but slightly better results. There was one advantage in using such intense rays, and this was that the plate could be further removed from the source, and consequently a better shadow was obtained. But otherwise nothing to speak of was gained. The screen in the dark box would be at times rendered so bright as to allow reading at some distance plainly, but the shadow was not more distinct for all that. In fact, often a very strong radiation gave a poorer impression than a weak one. Now, a fact which I have repeatedly observed and to which I attach great importance in this connection, is the following: When taking impressions at a small distance with a tube giving very intense rays, no shadow, unless a scarcely perceptible one, is obtained. Thus, for instance, the flesh and bones of the hand appear equally transparent. Increasing presently gradually the distance, it is found that the bones cast a shadow, while the flesh leaves no impression. The distance still increased, the shadow of the flesh appears, while that of the bones grows deeper, and in this neighborhood a place can be found at which the definition of the shadow is clearest. If the distance is still further continually increased, the detail is lost, and finally only a vague shadow is perceptible, showing apparently the outlines of the hand.

This often-noted fact disagrees entirely with any theory of transverse vibrations, but can be easily explained on the assumption of material streams. When the hand is near and the velocity of the stream of particles very great, both bone and flesh are easily penetrated, and the effect due to the difference in the retardation of the particles passing through the heterogeneous parts can not be observed. The screen can fluoresce only up to a certain limited intensity, and the film can be affected only to a certain small degree. When the distance is increased, or, what is equivalent, when the intensity of the radiation is reduced, the more resisting bones begin to throw the shadow first. Upon a further increase of the distance the flesh begins likewise to stop enough of the particles to leave a trace on the screen. But in all cases, at a certain distance, manifestly that which under the conditions of the experiment gives the greatest difference in the trajectories of the particles within *the range perceptible on the screen or film,* the clearest shadow is secured.

IV—THE RAYS ARE ALL OF ONE KIND.

The preceding explains the apparent existence of rays of different kind; that is, of different rates of vibration, as it is asserted. In my opinion, the velocity and possibly the size of the particles both are different, and this fully accounts for the discordant results obtained in regard to the transparency of various bodies to these rays. I found, for example, in many cases that aluminum was less transparent than glass, and in some instances brass appeared to be very transparent as compared with other metallic bodies. Such observations showed that it was necessary, in making the comparison, to take rigorously equal thicknesses of the bodies and

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ROENTGEN RAYS OR STREAMS.

(*Concluded from page 79.*)

place them as closely together as possible. They also showed the fallacy of comparing results obtained with different bulbs.

V—ACTION ON THE FILMS.

Many experiments with films of different thicknesses show that decidedly more detail is obtainable with a thick film than with a thin one. This appears to me to be a further evidence in support of the above views, as the result can be easily explained when considering the preceding remarks.

VI — THE BEHAVIOR OF VARIOUS BODIES IN REFLECTING THE RAYS,

on which I have previously dwelt, will, if verified by other experimenters, leave no room for a doubt that the radiations are streams of some matter, or possibly of ether, as before observed.

VII—THE ENTIRE ABSENCE OF REFRACTION

and other features possessed by the light waves has, since Roentgen's announcement, not yet been satisfactorily explained. A trace at least of such an effect would be found if the rays were transverse vibrations.

VIII—THE DISCHARGE OF CONDUCTORS

by the rays shows, in so far as I have been able to follow the researches of others, that the electrical charge is taken off by the bodily carriers. It is also found that the opacity plays an important part, and the observations are mostly in accord with the above views.

IX—THE SOURCE OF THE RAYS

is, I find, always the place of the first impact of the cathodic stream, a second impact producing little or no rays. This fact would be difficult to account for unless streams of matter are assumed to exist.

X—SHADOWS IN SPACE OUTSIDE OF THE BULB.

An almost crucial test of the existence of material streams is afforded by the formation of shadows in space at a distance from the bulb, to which I have called attention quite recently. I will presently refer to my preceding communication on this subject, and will only point out that such shadows could not be formed under the conditions described, except by streams of matter.

XI—ALL BODIES ARE TRANSPARENT TO VERY STRONG RAYS.

Experiments establish this fact beyond any doubt. With very intense radiations, I obtain, easily, impressions through what may be considered a great thickness of any metal. It is impossible to explain this on any theory of transverse vibrations. We can show how one or other body might allow the rays to pass through, but such explanations are not applicable to *all* bodies without exception. On the contrary, assuming material streams, such a result is unavoidable.

A great many other observations and facts might be added to the above, as further evidence in support of the above views. I have noted certain peculiarities of bodies obstructing a cathodic stream within the bulb. I have observed that the same rays are produced at all degrees of exhaustion and using bodies of vastly different physical properties, and have found a number of features in regard to the pressure, the vacuum, the residual gas, the material of the electrode, etc., all of which observations are more or less in accord with what I have stated before. I hope, however, that there is enough in the present lines to enlist the attention of others.

NIKOLA TESLA.

New York, August 11, 1896.

ROENTGEN RAYS ARE MATERIAL.

So Says Nikola Tesla After an Investigation That Confirms His Long Standing Belief.

THE MATTER CAN BE FELT.

Particles Bombard the Tube and Act as Inelastic Bodies Similar to Small Lead Bullets.

MOVE AT GREAT VELOCITY.

The Roentgen rays—the wonderful X rays, as commonly called—which have astonished the world by bringing light out of dark places, even illuminating the human body, are now declared to be material particles by no less an authority than Nikola Tesla.

Mr. Tesla has been led to take this view for some time from the results of experiments which he has been conducting in his laboratory, as told by the HERALD after an interview with him. But now he comes forward without hesitation and says that the electrical conditions within the tube from which the rays issue produce absolute particles. They are material as cannon balls; infinitesimal and attenuated, it is true, but actual material which bombard the glass and any object which may come in line with their motion. And this motion is no insignificant thing, and would make the most rapid moving cannon ball appear to stand still, for Mr. Tesla says his experiments show them to move at a velocity of not less than sixty-two miles a second. In the measurements he uses he calls it "100 kilometres a second."

Mr. Tesla further says he can feel the effects of these particles striking against his eye, and has noted the sensation produced when they come in contact with his brain.

MR. TESLA'S DECLARATION.

Mr. Tesla makes public his conclusions in relation to the Roentgen rays in a letter to the Electrical Review of this week, in which—after referring to Professor Roentgen's theory that the rays were longitudinal waves of ether—he says:—

"After a long and careful investigation with apparatus excellently suited for the purpose, capable of producing impressions at great distances, and after examining the results pointed out by other experimenters, I have come to the conclusion, which I now find courage to pronounce without hesitation, that the original hypothesis of Roentgen will be confirmed in two particulars—first, in regard to the longitudinal character of the disturbances; second, in regard to the medium concerned in their propagation.

"There is but little doubt at present that a cathodic stream within a bulb is composed of small particles of matter, thrown off with great velocity from the electrode. The velocity probably attained is estimable, and fully accountable for the mechanical and heating effects produced by the impact against the wall or obstacle within the bulb. It is, furthermore, an accepted view that the projected lumps of matter act as inelastic bodies, similarly to ever so many small lead bullets. It can be easily shown that the velocity of the stream may be as much as one hundred kilometres a second, or even more.

SHATTERED INTO FRAGMENTS.

"But, now, matter moving with such great velocity must surely penetrate great thicknesses of the obstruction in its path, if the laws of mechanical impact are at all applicable to a cathodic stream. I have presently so much familiarized myself with this view that, if I had no experimental evidence, I would not question the fact that some matter is projected through the thin wall of a vacuum tube. The exit from the latter is, however, the more likely to occur, as the lumps of matter must be shattered into still much smaller particles by the impact.

"From my experiments it appears that the lumps or molecules are indeed shattered into fragments or constituents so small as to make them lose entirely some physical properties possessed before the impact.

MATTER TURNED TO ETHER.

"The matter composing the cathode stream is," continues Mr. Tesla in his letter, "to all evidence, reduced to matter of some primary form, heretofore not known, as such velocities and such violent impacts have probably never been studied or even attained before these extraordinary manifestations were observed. Is it not possible that the very ether vortexes which, according to Lord Kelvin's ideal theory, compose the lumps, are dissolved, and that in the Roentgen phenomena we may witness a transformation of ordinary matter into ether? It is in this sense that, I think, Roentgen's first hypothesis will be confirmed.

"The important fact pointed out early by Roentgen and confirmed by subsequent research—namely, that a body is the more apoque to the rays the denser it is—cannot be explained as satisfactorily under any other assumption as that of the rays being streams of matter, in which case such simple relation between opacity and density would necessarily exist. This relation is the more important in its bearing upon the nature of the rays, as it does not at all exist in lightgiving vibrations, and should consequently not be found to so marked a degree and under all conditions with vibrations, presumably similar to and approximating in frequency the light vibrations.

"An almost crucial test of the existence of material streams is afforded by the formation of shadows in space at a distance from the bulb. Such shadows could not be formed under the conditions described, except by streams of matter."

Nikola Tesla and Matrimony.

Those who are acquainted with the History of Socrates must have read how, upon his making a discourse concerning Love, he pressed his point with so much success that all the bachelors in his audience took the opportunity of getting married on the first occasion, and all the married men immediately took horse and galloped home to their wives. We think that it is rather a pity that Mr. Tesla did not hear Socrates on this subject for his own good, though for the good of science in general we much prefer that he should be reminded of it a score of centuries or so later. According to a New York daily paper, Nikola Tesla is a disciple of the Baconian theory, that the man who marries gives hostages to fortune. "I do not believe," he says, "that an inventor should marry, because he has so intense a nature and so much in it of wild passionate qualities that in giving himself to a woman he might love, he would give everything, and so take everything from his chosen field." It can readily be imagined with what reluctance Mr. Tesla would allow his views on this important question to be heralded broadcast to the world, but in doing so he is doubtless actuated by a sense of duty to his fellow inventors, and "simple duty hath no place for fear." Those of us who had the pleasure, a short time ago, of meeting this gentle, unassuming and clever man, can hardly reconcile our views of him as a woman-hater; rather we would interpret this information concerning him as representing him to be not a woman-hater so much as a devotee of science. If he were the former we should feel disposed to remind him that it is very usual for those who have been severe upon marriage in some part or other of their lives, to enter into the Fraternity of Benedicts which they have ridiculed, and to see their raillery return upon their own heads. Marriage, which is a blessing to another man falls upon such an one as a judgment. Congreve's "Old Bachelor" is a literary example of this kind, and Hymen takes his revenge in kind on those who turn his mysteries into ridicule. Mr. Tesla is yet a young man, and doubtless he will be the first to admit that he has much to learn. Possibly his immersion in the deep seas of pure science have so far flooded out from his experience, that emotional life, which, after all, is the only part of life which is worth living. We are not going to take up the cudgels on behalf of matrimony, neither are we going to enlist the resources of our memory in discovering great inventors who caught inspiration and obtained zest for their work, and encouragement to persevere unto the end by associating their lives with women whom they really loved. The history of scientific development is full of such instances, and, if Mr. Tesla is unaware of them, it is only another illustration of the tremendous concentration which he brings to the matters he may have on hand to the entire exclusion of everything else which is interesting in the world. To turn from pathos to bathos, one would have thought that the material advantages, which to many orders of mind is associated with the idea of wife, would have appealed to him when he received, in the course of one of his experiments, a shock of three and a half million volts. It is said that this shock, entering his body above the shoulder, signalised its departure by leaving a hole in his sock. Being a bachelor, it may be presumed that he did not have anyone to mend it, but if he had been of a practically reflective turn of mind, it ought to have occurred to him that matrimony did present some material advantages. Of course Mr. Tesla may be quite invulnerable to Cupid's shafts, but somehow or other we doubt it. We are great admirers of him and his work, and we give him credit for good hard sense, and we do not think he is like the Frenchman who excused his bachelorhood on the grounds that he was "one butterfly zat fly from flower to flower and sip ze honey;" the very fact of his being such a devotee to his science proves that his nature is a very intense one. We have faith enough in women to believe that his fate will come, and that some one will be found who is not only a match for his intensity in all respects, but who will tax his inventive genius to the utmost; for example, in trying to explain where he was at 2 o'clock some night when she had gone to his laboratory to bring him home, and found it dark, although he had told her he was going to "stay down town to work to-night." We are afraid that Mr. Tesla has been studying *Punch*, whose well-known advice about getting married is a household word. Or possibly he may remember Æsop's Fables: the frogs there were extremely wise; they had a mind for some water, but they knew they would have to go down a deep well for it, from which it would be impossible to get out, and so they elected to hop round the edge of the well and contemplate it without committing themselves. Or again, Mr. Tesla may remember that old saying that "he who marries a wife may possibly take an eel by the tail." Whatever may be the cause of the abnormal emotional condition in which this distinguished scientist finds himself, we hope that it will soon be removed, for we are convinced that science in general, and Mr. Tesla in particular, will be all the richer when he gets married.

DISCHARGE OF AN ELECTRIFIED BODY BY MEANS OF THE TESLA SPARK.

In a communication to "Nature" Mr. Frederic J. Smith states that it has been shown that a body charged with electricity may be discharged by means of the rays from a Röntgen bulb. "I find, also, that an electrified body is rapidly discharged by the influence of a high-frequency spark, such as that produced by the Tesla apparatus. The discharging action was shown in this way. A high-frequency spark was produced between two rather blunt points, one inch apart in air, no bulb being used. A gold-leaf electroscope, placed far away from the influence of the spark, was used to test the electrical condition of the charged bodies—viz., a stick of sealing-wax and a rod of glass. The sealing-wax was rubbed, and the electroscope indicated that it was well charged. It was again rubbed, and then brought to within a foot of the points, and by means of a key in the battery circuit the Tesla coil was thrown into action for an instant. On testing the sealing-wax rod with the electroscope, it was found to be entirely discharged. A similar experiment was next made with a glass rod; the glass rod was entirely discharged by the Tesla spark. From a previous experiment, it was seen that the electrification of the rods was dissimilar. The influence, then, of the high-frequency spark is to discharge electricity of either sign."

NIKOLA TESLA AT NIAGARA FALLS.

Mr. Orrin E. Dunlap, in the *Western Electrician*, says that Nikola Tesla paid his first visit to the great electrical power plant of the Niagara Falls Power Company on Sunday, July 19th. In the party with Tesla were George Westinghouse, jun., president of the Westinghouse Electric and Manufacturing Company, of Pittsburg, and his son, H. H. Westinghouse; Thomas N. Ely, of Philadelphia, superintendent of motive power of the Pennsylvania Railroad; Commodore George W. Melville, of Washington, chief engineer of the United States Navy; Edward D. Adams, president of the Cataract Construction Company, and William B. Rankine, secretary of the company; Paul D. Cravath, counsel for the Westinghouse Company; and George Urban, jun., of Buffalo, president of the Cataract Power and Construction Company, of Buffalo, which company was organised recently to distribute the electric power in Buffalo.

Quite naturally, the event of Tesla's visit was one of importance, for never before had his eyes rested on this greatest of power plants. For four years he had refused to leave his work and visit the Falls, preferring to work out his theories and await the proper time to see them put into practical use and operation. Tesla was delighted with the manner in which his discoveries had been adapted to practical use by the engineers, and he unhesitatingly declared that there was no doubt of the success of the gigantic undertaking, and that power would be transmitted to Buffalo without the least semblance of failure in any important detail. He was greatly interested in the working of the transformers invented by

him, and the great electrician declared that they solved one of the most difficult and important problems in electrical science.

It is a well known fact that Tesla does not like to speak of himself. He will talk freely about electrical discoveries or inventions, but when his own are broached he modestly says that he prefers to say little about them.

"I do not like to speak of what I am doing or what I hope to do," said he. "It is enough to let others do that when what I have done is before the world. I am content to be in my workshop and to work day and night to discover something which we are looking for, and which will assist the development of electricity as a great and universal power. The time will come when steam will not be used for commercial purposes. I am working to bring that about." This, then, is the present great ambition. He desires to see electricity fully occupy the power field.

"I came to Niagara Falls," said he, "to inspect the great power plant, and because I thought the change would bring me needed rest. I have been for some time in poor health, almost worn out, and I am now trying to get away from my work for a brief spell, and at the same time see the great results of electrical development within the last half dozen years. Those results have been wonderful, have far surpassed the expectations of the people generally, but they are what those who have made electricity their study for years and their life work have expected, and have laboured so hard to bring about. Yet scientists are not content, and great wonders in the future development of electric power for many purposes are anticipated, and are confidently expected, by the great men in all countries who are trying to discover Nature's secrets, and to develop the things which God has placed within the reach of those who will seek that they may find."

"What do you think of the Niagara power plant, Mr. Tesla? Is it fully up to your ideas and expectations?"

It was this question that aroused the great electrician's enthusiasm. "Yes," said he; "it is all and more than I anticipated it would be. It is fully all that was promised. It is one of the wonders of this century. The power-producing plant of the Cataract Construction Company is a marvel in its completeness and in its superiority of construction. When it shall be in full operation the results, in many ways, will be wonderful; will be surprising to those who have doubted that such things could be accomplished. In its entirety, in connection with the possibilities of the future, the plant, and the prospect of future development in electrical science, and the more ordinary uses of electricity, are my ideals. They are what I have long anticipated, and have laboured, in an insignificant way, to contribute toward bringing about."

"What, in your judgment, will be the effect on Niagara Falls?"

"The first effects naturally will be to the advantage of Niagara Falls, and the falls will be the greatest reaper of benefits. The result of this great development of electric power will be that the Falls and Buffalo will reach out their arms, and will join each other, and become one great city. United, they will form the greatest city in the world."

"This is your first visit to the plant?"

"Yes; I came purposely to see it. I am somewhat interested in the working of some of the machinery. But, and it is a curious thing about me, I cannot stay about big machinery a great while. It affects me very much. The jar of the machinery curiously affects my spine, and I cannot stand the strain."

"It is Mr. Tesla's two-phase system which is used," put in Secretary Rankine, who was standing by. "It is the new and great system of the two-phase alternating currents."

"What do you think of the transmission of electric power to Buffalo? Is it an assured undertaking?" Tesla was asked.

"Its success is certain. The transmission of electricity is one of the simplest of propositions. It is but the application of pronounced and accepted rules which are as firmly established as the air itself."

"Do you think the cost of electric power in Buffalo will be half, or lower than the present cost of steam?"

"I do not know what is the cost of steam power in Buffalo."

"About $60 to $70," said Mr. Rankine.

"Well," continued Mr. Tesla, "the cost certainly will be much less than the cost of steam. The beauty of using electricity for industrial purposes is that you can use it without any loss. When you get done with your work, you just shut it off until you want it again; therefore there is no appreciable percentage of loss, except that in transmission. On the other hand, you cannot use steam without loss. Steam must be kept up. That involves a loss of 20 per cent. at the start, which is continuous, and must be counted as a fixed loss. No matter if steam were cheaper than electricity, there would be a great saving in favour of electricity, because of its adaptability, its freedom from smoke and dust, and the fact that it may be shut off when it is not needed."

At this point Secretary Rankine advanced a piece of news. "Buffalo," said he, "will have its first instalment of electric power by November. You may say that without fear of making any mistake. The first delivery will be about 1,000 horse power, all that we can give this fall. It will be the initial instalment of the 10,000 horse power which we must furnish under our franchise within the ensuing year. The contract for the construction of the pole line will soon be let. The work will be pushed rapidly, and Buffalo will find that the company will be faithful to all of its agreements."

In regard to the transmission of power, Tesla continued: "It is cheaper to transmit electricity in large quantities than in small. The larger the force the less the loss in transmission. The loss in transmission of power to Buffalo, for instance, will be comparatively small becau e of the large quantity which Buffalo will receive."

Tesla was averse to speaking of his recent investigations of the vacuum electric lamp and telegraphy without the use of wires.

"I am not prepared to say anything now about those little schemes of mine," said Mr. Tesla. "They must stand aside for awhile. Just now I am devoting my time to the study and development of the transmission and insulation of electricity. Until I get these matters well worked out, and obtain satisfactory results, I shall do little else. I shall return to my laboratory in New York and continue my work. I am delighted with my trip to the Falls. I have been from top to bottom of the power plant. You may say it is the greatest and the best, the most thoroughly equipped in the world."

NICOLA TESLA ON FAR SEEING.

The Inventor Talks Interestingly on the Transmission of Sight by Wire.

HAS A PRACTICABLE SCHEME.

Will Not Tell Exactly What It Is, Lest Ill Be Caused by False Impressions.

DIFFICULT AND FASCINATING.

He Draws a Captivating Picture of the Pleasures of the Imagination.



THERE is a subject which has exercised the imagination, excited the ambition and damped over and over again the ardor of the genius of invention for hundreds of years.

It is that of "seeing beyond the limits of sight."

Long distance speaking and long distance hearing have been accomplished long ago, and are to-day the common property of all. But to be able to see the person in Chicago, San Francisco, London or Hong Kong, with whom one speaks—that has not yet been made possible. Many scientists have declared the feat possible. Many scientists have tried to solve the problem. Not one has yet succeeded. All agree that when the solution is arrived at it will mean a revolution in the world's conditions.

I found Mr. Nicola Tesla in his laboratory yesterday, and propounded to him that difficult question about photography by electricity. He was, for once, in a communicative condition of mind; for, be it well understood, these inventors are generally so absorbed in their projects that, forsooth, they have not even time to speak to a newspaper man! But yesterday I was fortunate, and here is what Tesla said:—

Mr. Tesla's Views.

"This problem of transmitting sight by wires or otherwise to any distance is as difficult as it is fascinating. It must not be compared as to its technical difficulties with the transmission of pictures or even colors by such means. These are comparatively easy tasks.

"The solution of this problem has been attempted very many times, and more recently a further stimulus to research in this direction has been given by the magnificent inventions of Alexander Graham Bell, of the telephone and photophone. As soon as it became possible to transmit the strains of an entire opera over a wire the mind jumped immediately to the conclusion that seeing by similar methods will also soon become an accomplished fact. This appeared the more reasonable, as Bell succeeded in transmitting speech through the medium of no more than a ray of light. The activity in this direction has not abated, but, on the contrary, has increased, especially since we have learned more about the nature of light through the discoveries of Heinrich Hertz.

"Notwithstanding this, I have not found a single idea or experiment recorded which, in my estimation, would have even the faintest chance of success. The old fact, known to the ancients, that one can see through a hollow wire, has been more firmly established—that's all. This may appear to be a strong statement, but so far as actual accomplishment is concerned it is true. Many schemes have been proposed, but it was mostly a case of a hollow wire or a hollow project. Still, the task is not to be considered hopeless. On the contrary, in all probability individual investigators have found more or less rational solutions of the problem, only the difficulties to be overcome are enormous and the realization is still far, far off.

"I could hardly name two, or perhaps three, other problems or lines of investigation which have taxed my own powers of thinking as much as this. And yet, while in these other lines I have considerably realized, as regards this problem of transmitting sight I am still very far from positive demonstration by experiment. You should not infer from this that all my efforts to find a solution have been futile. Only experience has made me more exacting, and even pessimistic, as to the final carrying out of my ideas, while, I am happy to say, I have remained as optimistic as I ever was in their first conception. Very often during the day I conceive ideas which give me pleasure and hope, but in the calm retirement of the night, when things appear to me more as they are, my practical sense deals mercilessly with the projects I have formed.

"As a rule, all is rejected, and I realize with sorrow that the day has been spent in vain. But the next day the imagination starts off again, nothing the worse for the punishment. After going on for many years this constant effort of building and again destroying no doubt cripples the powers of execution, but it develops very much the analytical and critical faculties. You may tire yourself out repeatedly by overcoming an imaginary danger, but you become more expert in finding means of escape and prepared to meet any calamity. So, in investigation, one becomes distrustful of the beauties of the ideas as they first present themselves, and particularly apprehensive of error.

Importance of Certitude.

"It is one of the most important considerations for every worker to render himself continuously an account of the degree of certitude, when, either going from known facts, he systematically seeks to attain some novel result, or when, conversely, beginning from an abstract idea, he endeavors to reach its realization. Perhaps it is useful to give an illustration to this effect. There is:—

"First—The absolute certitude or truth which we always strive for, but never can reach.

"Second—There is the certitude of physical facts which we arrive at through our senses and which depends on the precision of the latter.

"Third—There is the experimental demonstration, less certain than the existence of the physical facts themselves, as it contains elements of uncertainty in the features of the experiment.

"Fourth—There is the logical inference or conclusion from physical facts, less certain than the experiment, as it lacks the tangible evidence of the latter.

"Fifth—There is mathematical demonstration, less certain, again, than mere logical conclusion, as it carries with itself possible errors or mistakes in methods and symbols.

"Sixth—There is the accurate estimate from some positive facts by experiment, logical conclusion, or calculation.

"Seventh—There is the approximate estimate from few precise, but insufficient facts by the same methods.

"Eighth—There is the probable estimate, when no precise facts are available.

"Ninth—There is the consideration of mere practicability.

"Tenth—There is the consideration of mere possibility, with no practicability, and eleventh, there is the entirely impossible, that which is against all the positive facts observed, or logical deductions, or mathematical demonstrations based on them. There is where, as Mr. Dana might say, the 129-cent dollars are located.

'I am now able to indicate, in a general way, how far I have gone toward the solution of the problem. After many fruitless efforts I have conceived an idea. I have for a long time scrutinized it and found it agreed with all the established facts I knew, hence, as far as I was capable to decide, it is possible. Next I have examined the difficulties which I had to overcome in carrying the idea into practice and have found that they were not insuperable; hence my scheme is practicable. Then I have searched for means of carrying it out, and close analysis of these has led me to the conviction that my idea will probably be carried out.

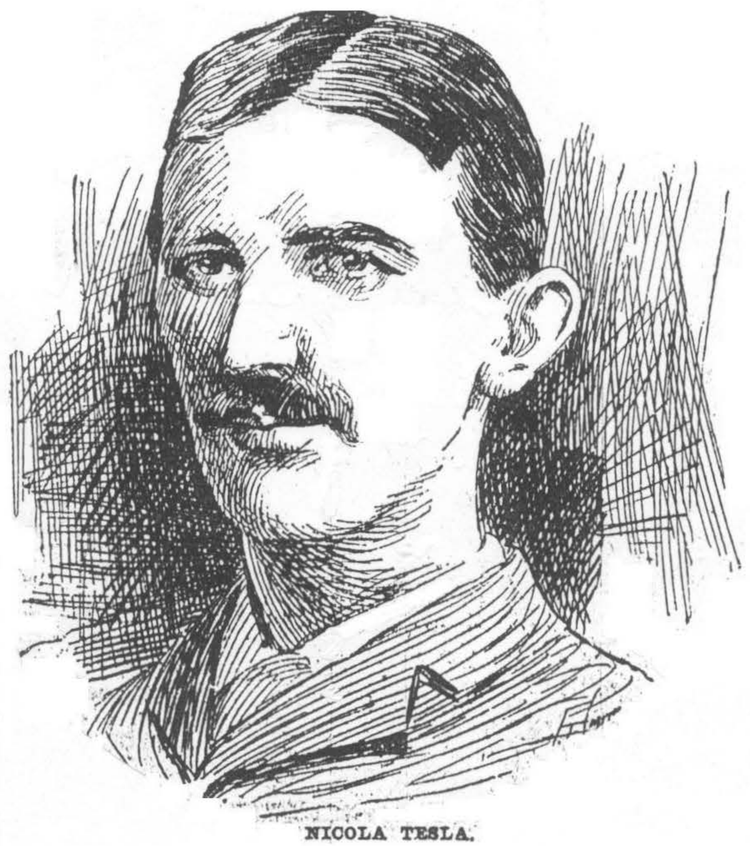
"Finally, after a long study, mostly experimental, of all the means and conditions, I have arrived at a few precise facts, enough to make an approximate estimate of all the elements involved in a practical demonstration, and—here I am sticking, sticking since three years.

Mr. Tesla's Idea.

"I say that I conceived an idea. In reality I have conceived many, but for the benfit of my fellow men and myself they will never be known. They were either fallacious or impracticable, products of a heated inventor's imagination. But this particular idea is of a different kind.

"It withstood my critical examination for weeks, months, and years. Now, when through so long a time no flaw in an idea can be found, when through all stages of excitation and subsequent relaxation it maintains its firm hold upon reason; when, as the knowledge of the subject increases and the desire to accomplish grows more intense by approach to realization, it returns after each period of exhaustion with increased force, then this idea is a truth. That is, it is a truth so far as the individual observer is concerned, for there is still the superior scrutiny of many which may disclose errors which he was incapable of perceiving.

"Naturally, you expect me to tell you all about my scheme. This I cannot do. You may think it is a question of a patent. Nothing could be further from my mind than this. Many scientific men think that an idea should be given to the world as soon as conceived, thinking that nothing would be lost in this way, and arguing also that even an erroneous idea may reveal some truth to others. This may be so, but we must consider that error breeds error, and that inestimable ill can be caused by wrongly impressing the younger generation. Now, while I have convinced myself that my scheme is fundamentally correct, there are still details in its execution in which I may be mistaken. I can, therefore, only give a general outline of what I have recognized as absolutely necessary for a practical realization.



NICOLA TESLA.

"But before I do this let me ask you, have you ever considered what vision means to you, have you ever thought how much enjoyment you are deriving from the magnificent panorama which is daily unfolding before your eyes? Have you ever abandoned yourself to the raptures of contemplation of a world you yourself create? You want a palace, and there it stands, built by architects finer than Michael Angelo—aye, even finer than my friends McKim, Mead & White. You fill it with marvellous paintings, and statuary and all kinds of objects of art. You summon fairies if you are fond of them. Now, perhaps, you want to sit on a throne, and there is your throne, greater than that of Great Britain! And all your subjects are around you—countless subjects. No fellows to run after you with a pistol, as fellows do after illustrious personages, like William and Nicholas or Li Hung Chang. And if they would, what do you care? You stop their bullets in midair.

"Now you walk out in the streets of a wonderful city. Perchance it is one of my cities. Then you may see that all the streets and halls are lighted by my beautiful phosphorescent tubes, that all the elevated railroads are propelled by my motors, that all the traction companies' trolleys are under ground and supplied by my system, and that all the currents are supplied by my oscillators, or else that my friends of the Cataract Construction Company are transmitting all the power by my system from a far-off Niagara. And now, perhaps, you meet a tramp in the street, and you reach in your pocket and give him something. Five cents, you think. No, sir; you give him not less than $5,000,000.

"Strangely, though, instead of collapsing at your generosity, he looks at you in an insolent way and turns the money in his hand and says, contemptuously:—'Take it back; you mean skinflint.' And then you throw down your royal insignia and you begin to grapple with him. You are endowed with giant strength, and he is no fellow to fool with, either. At any rate, the issue is uncertain. He may be stronger, and then, well—then you wake up, saved, but badly used up. If you defeat him, then you recompense him royally by giving him your insignia and your throne, and you continue your adventurous voyage peacefully and contented.

"Suddenly you throw yourself in the roar of a battle, you cut and slash, and a whole army of noble knights flees before you. And now something rattles in the bushes, and you, who know no fear, you run away. Then you may witness a terribly impressive scene of years gone by. You witness the death of your father or your mother, and you go through all the agonies again. You realize the immense gulf that separates you from them. Then overwhelming desire takes hold of you to be with them again. You know it is impossible to get them back; but never mind, you will invent something, you will discover some force which will reunite those separated molecules and make them form those lovely shapes so dear to you.

"And now suddenly there comes a revulsion, and you are throwing a stick at a cat in a backyard. You miss it, too, aggravating circumstance. But years afterward you can tell the exact spot on the wall, you can tell every mark of the stick, and you see exactly how the cat's fur was brushed one or the other way. So your imagination leads you on, from sorrow to joy, from work to play, and all this world is ever present, ever ready for your pleasure and enlightenment, and at your wish and command. All this world, real or imaginary, it matters little, you want to be able to see through some such thing as a wire, for if you succeed in transmitting sight you will see it all.

Difficulty of the Task.

"You may appreciate in a general way the difficulty of the task, but if you have not studied it as closely as I did you will not know the real difficulty. You will, of course, ask how is it that I can transmit the enchanting notes of a Paderewski concert all over one line. There are innumerable intonations, there are color and volume. But you must remember that this whole is brought about only by variation of pitch and intensity of the notes. This you can all reproduce at a distance by means of a wire. You may go even further than that. You may transmit all colors over three channels or even one channel. Technically this problem is incomparably more difficult, because you have still to find a medium for transmission, as the vibrations are inconceivably rapid. But when you come to the transmission of shapes there the difficulty begins!

"The most wonderful thing about the eye is its capability of conveying to the mind the idea of tridimensional extension. Although a result of touch, change of place or generally previous experience, it nevertheless is possible only through the medium of the eye. And such conception can be conveyed to the mind only by countless points of action. To illustrate:—I have in this room, say, fifty coils, each of which has its own rate of vibration. I send a composite vibration through the room and I am able to make any one of these coils respond.

"Now, imagine that I had a contrivance in the middle of this room and I had provided it with as many coils, each of which would be controlling the motion of the mechanism in a different direction. I can then cause the motion of this contrivance in as many different directions as the combination will permit. But the number of these motions is limited, and to accomplish a motion in any direction imaginable I must have an infinite number of such coils.

"Now, this is precisely what the optic nerve does. Your body is a mechanism which converts the energy of the food into other forms of energy. You are surrounded by influences which primarily affect your eye and so direct your motions. This may seem a bold statement, but I have so far convinced myself of its truth that I can think of no subject, I can conceive no idea of anything without being able to locate the first visual impression which started the train of thought.

"To give an example, rather unusual, I dream of a ship struck by a tidal wave. A few days later reports reach me that an Atlantic steamer has been struck by such a wave. I now search for the primary image which caused my dream. I search a long time and in vain, but finally, after weeks of fruitless effort, I find a picture in a show window, which I recognize as having given me the original impression. You may think of a friend you have not seen since many years, and you may turn around the corner and he stands before you.

"If you are not an experienced observer you actually think you have not seen him; but you are wrong, for you have seen him, only unconsciously. When you have familiarized yourself with such facts, you begin to look at the eye as a mechanical contrivance, and you are led to think how to imitate it, and then you are on the right track. In order to transmit shape, you recognize the necessity of hundreds, thousands or more channels of transmission, each independent, each capable of transmitting impressions of any intensity.

"Now, however difficult the task of transmitting sight to a distance in this sense may be, some results, possibly valuable, can be easily accomplished by primitive means. So, for instance, I have for many years believed that we may provide a building with a system of tubes, and by mirrors placed in them enable persons to see each other in distant parts of the building. It may even be possible to witness in this manner a performance on a stage, and for many practical purposes such a result would have a permanent value. If the mirrors be simply placed in a tube the transmission could not be effected to a considerable distance, because of the loss in the successive reflections, but I have overcome this by supplying additional light from another source, and at small distances I believe the project to be entirely feasible.

As to the Roentgen Ray.

"There still exists much confusion in regard to the possibilities offered by the Roentgen rays. By means of them we can discern the contours of an object—even its interior, to a certain extent—at distances of twenty or thirty feet or more. Perhaps we may be able to project rays through a mountain and locate lumps of mineral therein; but that is a remote possibility.

"However, through their agency, nothing be done toward the solution of the great problem in question. Nor can we hope to arrive at a practical result by a conversion of light waves into longer waves and their reconversion into the original form, as has been suggested.

"The chief difficulty, as before stated, only lies in providing countless independent channels between properly constructed receiving and transmitting instruments. It is in this direction that I have thought and worked. With what success I hope eventually to show."

my friends McKim, Mead & White. You fill it with marvelous paintings and statuary and all kinds of objects of art. You summon fairies if you are fond of them. Now, perhaps, you want to sit on a throne, and there is your throne, greater than that of Great Britain! And all your subjects are around you—countless subjects. No fellows to run after you with a pistol, as fellows do after illustrious personages, like William and Nicholas or Li Hung Chang. And if they would, what do you care? You stop their bullets in midair. Now you walk out in the streets of a wonderful city. Perchance it is one of my cities. Then you may see that all the streets and halls are lighted by my beautiful phosphorescent tubes, that all the elevated railroads are propelled by my motors, that all the traction companies' trolleys are under ground and supplied by my system, and that all the currents are supplied by my oscillators, or else that my friends of the Cataract Construction Company are transmitting all the power by my system from a far-off Niagara. And now, perhaps, you meet a tramp in the street, and you reach in your pocket and give him something. Five cents, you think. No, sir; you give him not less than $5,000,000.

"Strangely, though, instead of collapsing at your generosity, he looks at you in an insolent way and turns the money in his hand and says, contemptuously:—'Take it back you mean skinflint.' And then you throw down your royal insignia and you begin to grapple with him. You are endowed with giant strength, and he is no fellow to fool with, either. At any rate, the issue is uncertain. He may be stronger, and then, well—then you wake up, saved, but badly used up. If you defeat him, then you recompense him royally by giving him your insignia and your throne, and you continue your adventurous voyage peacefully and contented.

"Suddenly you throw yourself in the roar of a battle, you cut and slash, and a whole army of noble knights flees before you. And now something rattles in the bushes, and you, who know no fear, you run away. Then you may witness a terribly impressive scene of years gone by. You witness the death of your father or your mother, and you go through all the agonies again. You realize the immense gulf that separates you from them. Then overwhelming desire takes hold of you to be with them again. You know it is impossible to get them back; but never mind, you will invent something, you will discover some force which will reunite those separated molecules and make them form those lovely shapes so dear to you.

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Tesla as a Seer.—The following curious extract is from an interview by a New York *Herald* reporter with Mr. Nikola Tesla, the subject of the interview being "the transmission of sight by wires or otherwise." After stating that he had arrived at a few precise facts bearing on that problem, but yet enough to make an approximate estimate of all the elements involved in a practical demonstration, Mr. Tesla says "Have you ever abandoned yourself to the raptures of the contemplation of a world you yourself create? You want a palace, and there it stands, built by architects finer than Michael Angelo—aye, even finer than if by

The New York Tribune September 13, 1896

TESLA'S ELECTRIC OSCILLATOR.

IMPROVED APPARATUS FOR EXCITING WAVES OF HIGH FREQUENCY.

It is now four or five years since Nikola Tesla startled the electricians of the world by allowing a current of 200,000 volts to pass through his body. And it was nearly or quite as long ago that he produced a beautiful effulgence in a sealed glass tube by electrical means, yet without connecting the tube with a wire. These and other wonderful achievements of that eminent investigator have been the outgrowth of his study of "high frequency" and "high potential" currents. In fact, his most brilliant and original experiments for several years have been conducted in this, his favorite, department of research, and he has contributed greatly to the general stock of knowledge on this subject.

Every schoolboy, nowadays, knows the difference between a direct and an alternating current; and the practical electrician, if not the schoolboy, is aware that an alternating current may have oscillations of almost any frequency. The waves may number only twenty-five to the second, as in the great Niagara dynamos, or they may occur several thousand times as frequently. It is only the low-frequency current that is used commercially at present; but Mr. Tesla has repeatedly expressed his belief that practical results of great importance ought to be developed out of the use of high-frequency currents.

Few readers of The Tribune need to be reminded of the difference between the volume and the pressure or potential of an electric current. The one is expressed in "amperes," and the other in "volts." When, for any reason, you transform a current so as to raise the voltage, you correspondingly reduce the amperage. You cannot by any such operation increase the total energy, which is calculated by multiplying the number of volts by the number of amperes.

Reference is here made to these elementary principles of electrical science in order to render more intelligible the announcement that Mr. Tesla has nearly perfected a new piece of apparatus, which is designed to transform both the frequency and the potential of an alternating current, and do so very economically. It frequently happens that pioneers in scientific investigation find it necessary to make a special tool before they can manufacture the article they have in view. Perhaps that tool is a new mathematical formula or a novel chemical process, or a bit of electrical apparatus. In any case, it is a means to an end. This latest invention, or improvement on old devices, with which Mr. Tesla is to be credited, is to be regarded in the same light. His goal is the production of cheap, cold light in vacuum tubes; and the new instrument is designed to help him and others in attaining that object. Mr. Tesla has imitators, and there are people audacious enough to think of themselves as his rivals. But, after all, the great number and broad scope of his experiments and their character place him distinctly at the front in this magnificent field of inquiry. The public grows impatient at times because Mr. Tesla does not occasionally "report progress," like a Congressional committee; but, as The Tribune has often remarked, it is the privilege of genius to take its own time and work in its own way.

Already Mr. Tesla has given to science many useful hints and suggestions as to the arrangement of well-known pieces of apparatus in electrical work. His famous "disruptive discharge coil," designed to excite subordinate waves of enormous frequency (millions to the second) in an electric circuit, may be cited by way of illustration. The instance also serves to show that the new apparatus is not the first of its kind which he has originated for the same purpose. As yet Mr. Tesla does not want to furnish details regarding his latest advance in this direction. But it seems probable that it will replace the costly "induction coils" now extensively used in much laboratory work. Such coils costs hundreds, even thousands, of dollars. In Röntgen-ray photography, as well as the production of "the light of the future," the new apparatus is likely to prove exceedingly useful. The author of it calls it an "electrical oscillator," but is careful to explain that it is a very different sort of a contrivance from his well-known "mechanical oscillator," which exercises the functions of a steam engine and a dynamo combined.

CONSTRUCTION OF A TESLA-THOMSON HIGH FREQUENCY COIL.

By Prof. A. F. McKISSICK.

THE following is a description, from the *American Electrician*, of the construction of a Tesla-Thomson high frequency coil, large enough to give a 5-inch spark and excite Röntgen ray tubes.

To excite the Tesla-Thomson coil, a high potential transformer of from 10,000 to 15,000 volts is necessary. The construction of this transformer will be first given. Fig. 1

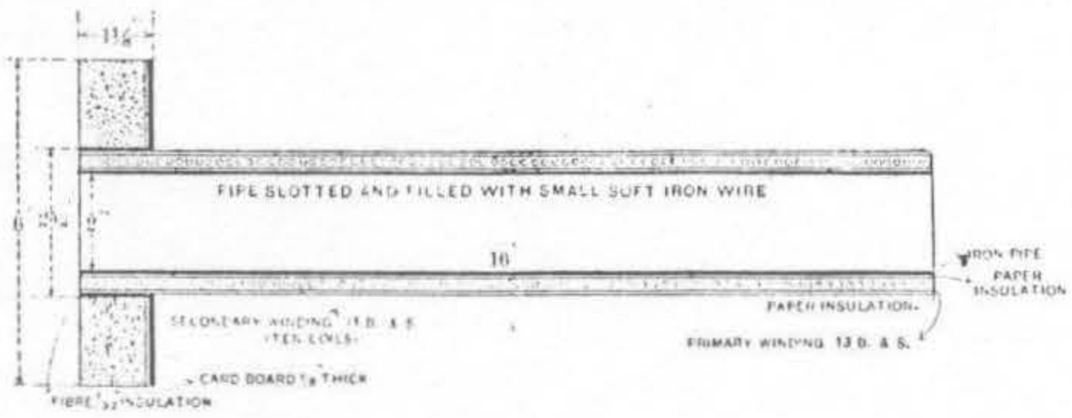

FIG. 1.

gives a partial cross-section of the transformer, which is made as follows:—A 2-inch iron pipe, 16 inches long, is slotted the whole length, either in a milling machine, planer or shaper. This slot need not be more than $\frac{1}{16}$th inch in width. The pipe is then insulated with ordinary wrapping paper to an outside diameter of $2\frac{1}{8}$ inches, shellac being freely used, and is then wound with No. 13 B. & S. double cotton-covered wire for its whole length (one layer). It is then covered with paper and shellaced until the outside diameter is $2\frac{5}{8}$ inches.

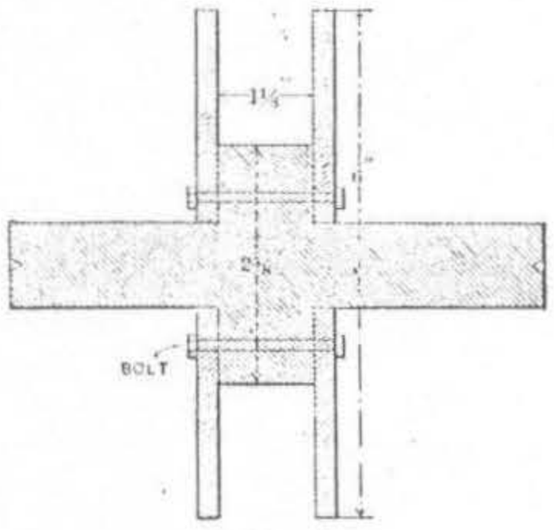

FIG. 2.

The next step is to fill the pipe with soft iron wires, No. 16 B. & S., each wire being cut 18 inches long. This completes the primary winding of the high tension transformer.

The secondary winding of this transformer consists of 10 coils wound in a form and thoroughly taped and insulated. This form is shown in fig. 2, and can be easily made of wood. The wire is wound in this form, shellaced, removed, taped and baked. These coils are then slipped over the primary winding, between each coil being placed a disc of cardboard $\frac{1}{8}$th inch thick, care being taken to connect the coils so that none will be in opposition.

The spark gap (see fig. 3) is made as shown in diagram.

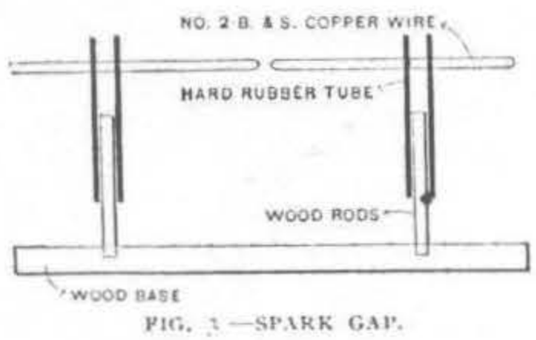

FIG. 3.—SPARK GAP.

FIG. 3.

The copper wires fit rather close in the holes drilled through the hard rubber tubing, so that the length of gap can be adjusted with ease.

The condenser is made of ordinary 10-inch × 12-inch window glass. A sheet of tin foil 8 inches × 10 inches is pasted on one side of the glass with shellac, leaving a margin

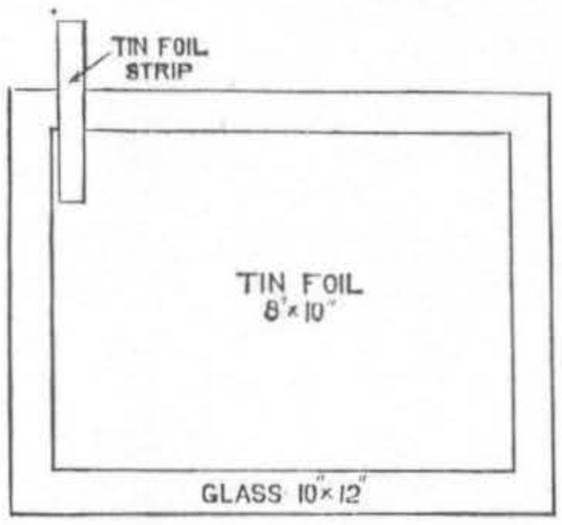

FIG. 4.

of 1 inch. (See fig. 4.) A strip of tin foil 2 inches wide is placed across one corner, this strip being placed alternately on each side. For each side of this condenser there should be 15 plates.

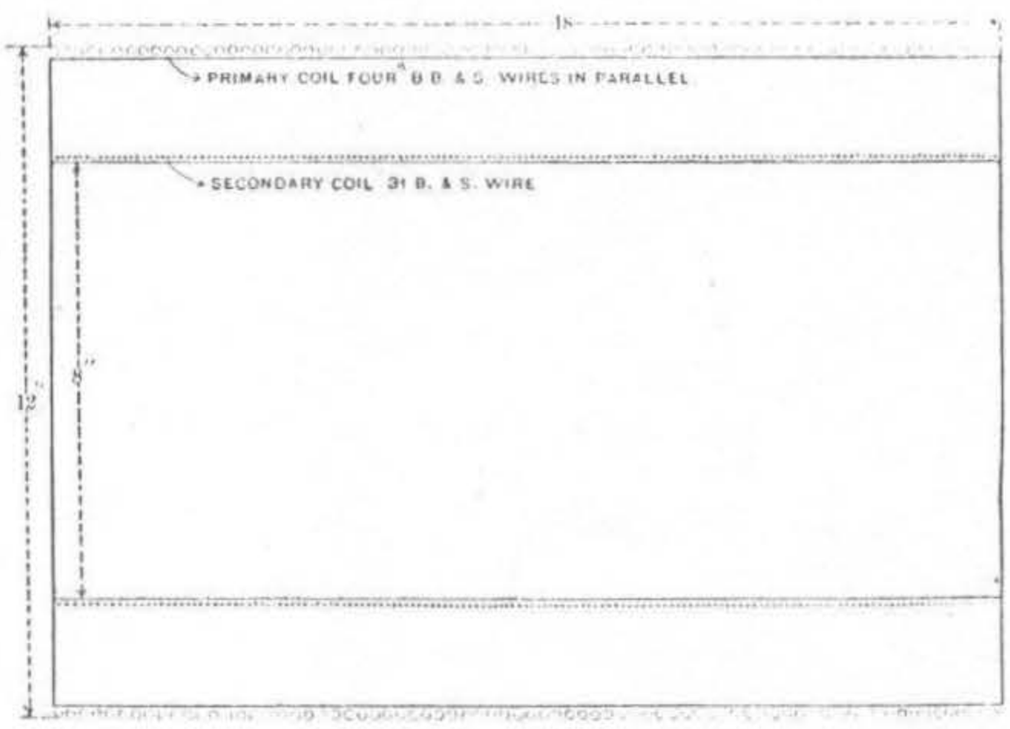

FIG. 5.

To build this condenser proceed as follows:—Place on a smooth surface a condenser plate with the connecting strip projecting on the right. On top of this plate place another piece of glass, 10 inches × 12 inches, that has no tin foil on it at all. Then place a condenser plate with the strip projecting on the left. Then a piece of glass without tin foil, and on top of this a condenser plate with the strip projecting on the right, and so on. This construction gives two thicknesses of glass between each sheet of tin foil, which is absolutely necessary.

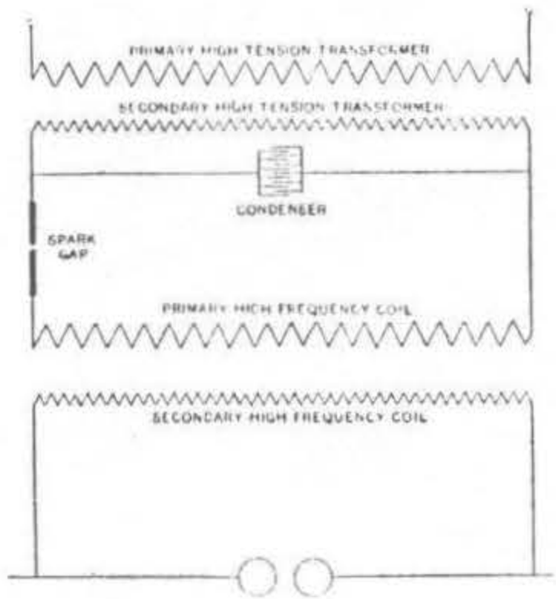

FIG. 6.

The high frequency coil is made as follows :—Wind an 8-inch paper cylinder 18 inches long with No. 31 B. & S. double cotton-covered wire (or larger), leaving a margin at each end of about 1 inch. This is the secondary winding. The primary winding is placed on a 12-inch paper cylinder 18 inches long, and consists of 14 turns of four No. 8 B. & S. double cotton-covered wires in parallel. Each of these No. 8 wires is wound on separately, then the four ends at the beginning and ending are soldered together. Between wires of different polarity, as an extra precaution, two turns of cord are wound. The primary and secondary coils are then shellaced and baked. After being baked, the secondary coil is placed concentrically (see fig. 5) inside the primary and the connections as shown in fig. 6 then made.

M. TESLA ON THE ROENTGEN RAYS.

ACCORDING to statements recently published, the Röntgen rays are now declared, by M. Nikola Tesla, to be material particles. M. Tesla states that the electrical conditions within the tube from which the rays issue produce absolute particles. He further says he can feel the effects of these particles striking against his eye, and has noted the sensation produced when they come in contact with his brain. He says: There is little doubt now that a cathodic stream within a bulb is composed of small particles of matter thrown off at great velocity from the electrode. The velocity probably obtained can be estimated, and fully accounts for the mechanical and heating effects produced by the impact against the wall or obstacle opposed to the bulb. It is furthermore an accepted view that the projected lumps of matter act as inelastic bodies, like innumerable infinitesimal bullets. It can be shown that the velocity of the stream may be as much as 100 kilos. a second, or even more. But matter moving with such great velocity must surely penetrate great thicknesses of the obstruction in its path, if the laws of mechanical impact are at all applicable to a cathodic stream. I have so much familiarised myself with this view that, if I had no experimental evidence, I would not doubt that some matter is projected through the thin wall of a vacuum tube. The exit from the latter is, however, the more likely to occur, as the lumps of matter

must be shattered into still much smaller particles by the impact. From my experiments it appears that the lumps or molecules are indeed shattered into fragments or constituents so small as to make them lose entirely some physical properties possessed before the impact. The matter composing the cathode stream is, continues M. Tesla in his letter, reduced to matter of some primary form heretofore not known, as such velocities and such violent impacts have probably never been studied or even attained before these extraordinary manifestations were observed. The important fact pointed out early by Röntgen and confirmed by subsequent researches, namely, that a body is the more opaque to the rays the denser it is, cannot be explained as satisfactorily by any other assumption than that of the rays being streams of matter, in which case such simple relation between opacity and density would necessarily exist. This relation is the more important in its bearing upon the nature of the rays, as it does not at all exist in light-giving vibrations, and should consequently not be found to so marked a degree and under all conditions with vibrations presumably similar to and approximating in frequency the light vibrations. An almost crucial test of the existence of material streams is afforded by the formation of shadows in space at a distance from the bulb. Such shadows could not be formed under the conditions described except by streams of matter.

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NEW YORK, SEPT. 23, 1896.

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THE TESLA ELECTRICAL CONDENSER.

In this week's issue of the ELECTRICAL REVIEW we take pleasure in recording again an important advance made by Mr. Tesla. In a patent issued last week he describes a novel form of electrical condenser, especially adapted for high frequency currents.

It will be remembered by all those who have followed his work that a few years ago Mr. Tesla demonstrated the hurtful action of the air in ordinary condensers, and showed the necessity of completely excluding gaseous matter from the condenser in order to secure efficiency. His demonstrations applied not only to condensers proper, but to all sorts of induction apparatus. In his lectures Mr. Tesla described, as a convenient means for exclusion of the gas, the employment of a vacuum for forcing the dielectric between the conducting armatures.

The improvement, now described, implies the exclusion of the gas and the employment of condenser armatures, consisting of a fluid conductor, such as an electrolyte. Mr. Tesla informs us that condensers of this type have been in use in his laboratory for the past few years, and that they show absolutely no increase of temperature by constant use. Many of the remarkable experiments with which he has delighted a few privileged visitors to his laboratory would have been impossible without these well-nigh perfect instruments.

We feel sure that all those who have occasion to use such appliances, as, for instance, in the Roentgen experiments, will be amazed at the performance of this form of condenser. As Mr. Tesla points out repeatedly in his writings, it is of the utmost importance to exclude the air from the active surfaces, as by a layer of oil on the top, otherwise the mere employment of an electrolyte would not overcome the inherent defects in the condenser of the usual form.

Tesla's Electrical Condenser.

The following is the inventor's own description of his electrical condenser, for which patent was issued September 15, 1896:

Be it known that I, Nikola Tesla, a citizen of the United States, residing at New York, in the County and State of New York, have invented certain new and useful improvements in electrical condensers, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

It has heretofore been announced and demonstrated by me that, under ordinary conditions, the efficiency of an electrical condenser is greatly increased by the exclusion of air or gaseous matter in general from the dielectric. In a patent granted to me December 8, 1891, No. 464,667, I have shown and described a convenient and practicable means of accomplishing this result by immersing the conducting plates or armatures of the condenser in an insulating fluid, such as oil.

My present invention, while based upon this important feature of the practically complete exclusion of air or gas from the dielectric, is an improvement on the forms of condenser heretofore described and used by me.

Fig. 1

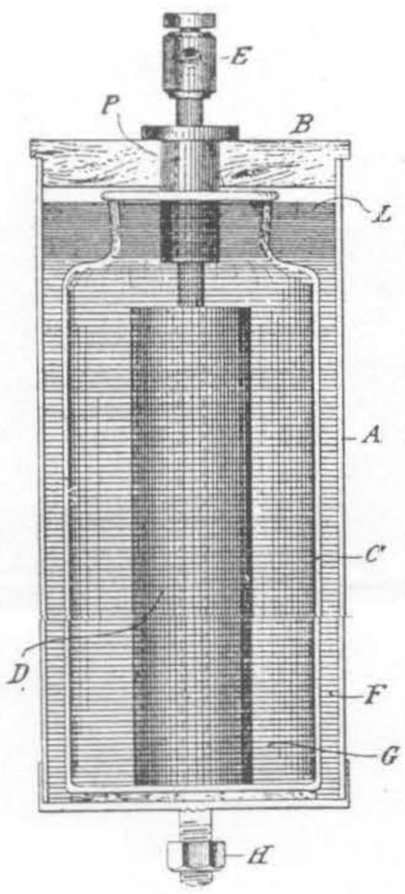
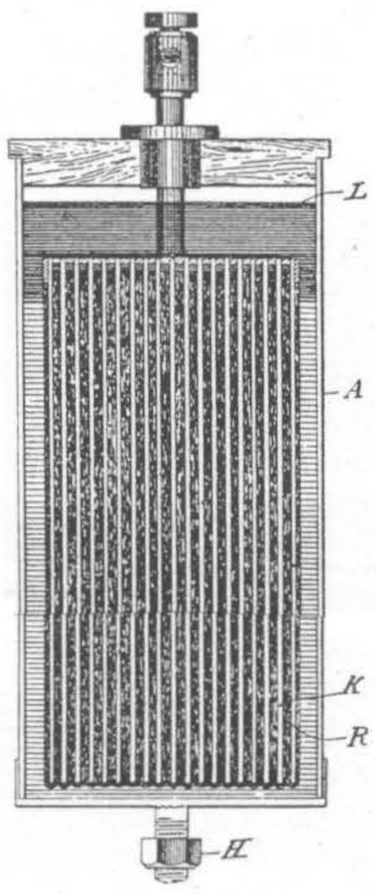


Fig. 2



SECTIONAL VIEW OF THE TESLA CONDENSER.

According to my present invention, I employ an electrolyte, or, in general, a conducting liquid in lieu of a solid, as the material for the armatures of the condenser, under conditions more fully hereinafter described, whereby air or gas will be practically prevented from exercising upon the condenser or the more active portions of the same, the detrimental effects present in such devices as heretofore made. Such condensers are especially advantageous when used with circuits of great rates of electrical vibration, because of the high conducting capacity of such fluids for currents of this character. There is, however, a general advantage derived from the fact that the conducting fluids have a high specific heat, so that the temperature remains constant, a condition in many cases highly advantageous, and not met with in condensers of ordinary construction.

In the accompanying drawings, annexed in illustration of the manner in which my improvement is or may be carried into practice, Fig. 1 is a view partly in vertical section of a condenser constructed in accordance with the invention.

Fig. 2 is a part vertical section of a modified form of such condenser.

A designates a jar or receptacle partly or wholly of conducting material, and provided with a closely fitting cap or cover B, preferably of insulating material.

Within this receptacle is a smaller jar or vessel C, of insulating material, containing a conducting electrode D, supported by the cover B, through which passes a suitable terminal E, which may be incased in an insulating plug P.

The spaces within the jars or receptacles are nearly filled with a conducting liquid F, G, such as a saline solution, the two bodies of such liquid, in the inner and outer receptacles, constituting the condenser armatures.

Above the conducting solution in each of the receptacles is poured a layer of oil or other insulating liquid, which serves to prevent access of air to the highly charged armatures.

The terminals for the two armatures may be provided in various ways, but in such forms of condenser as that illustrated, I prefer to utilize the conducting portion of the outer receptacle as one terminal, securing a binding post to the same as at H, and to employ an electrode D of suitably extended surface immersed in the liquid of the inner receptacle and in electrical connection with the binding post E.

It is desirable in some cases to modify the construction of the condenser, as when a larger capacity is required. In such instances, in order to secure the substantial benefits of the improvement above described, I construct the instrument as shown in Fig. 2.

In this case I employ a jar or receptacle A, which is preferably used also as one terminal, and filled with a conducting liquid, as before. Into the latter extends a series of connected conductors K, inclosed and fully insulated from the liquid by a coating of such material as gutta-percha R. These conductors are electrically joined to a terminal E, which extends up through the cover B, and constitute one of the armatures of the condensers.

On the surface of the electrolyte or conducting liquid is poured a quantity of oil L, for the purpose above stated.

While I have illustrated the invention in its preferred form for general practical purposes, it will be understood that, without departure from the invention, its construction may be greatly varied and modified.

What I claim is:

1. In an electric condenser constructed or provided with means for the exclusion of air and gas, an armature composed of a conducting liquid, as herein set forth.

2. A condenser comprising as armatures two bodies of conducting liquid electrically insulated, and contained in a receptacle from which air and gas are excluded.

3. A condenser comprising two bodies of conducting liquid electrically insulated and contained in a receptacle, and a seal of insulating liquid on the surfaces of the liquid, as set forth.

In testimony whereof, I have hereunto set my hand this 15th day of June, 1896.

[88960.]—**Tesla Apparatus for X-Ray Work.**—See my reply (88810) in "ENGLISH MECH." for Sept. 11, 1896. The only difference you need make will be to wind the secondary with about ten layers of No. 36 instead of No. 32, using thin red vulcanised fibre ($\frac{1}{64}$in. thick) between each layer of wire. Of course, you must use a resistance in circuit with the primary, so as to limit the current to about six ampères; otherwise you may heat the wire injuriously.

S. BOTTONE.

TESLA'S ELECTRICAL OSCILLATORS.

The important researches and experiments which Nikola Tesla has been carrying on for years, and which have created such a widespread interest in the scientific world, have culminated in the production of thoroughly practical and efficient electrical oscillators or transformers for the conversion of ordinary direct or alternating currents into electrical vibrations of any desired frequency. In five patents, granted to him September 22, 1896, he shows typical forms of his apparatus as adapted to any of the usual sources of supply. The remarkably clear and simple description of the features involved makes it perfectly easy for any one to understand the operation of these most valuable appliances.

The numerous uses to which these high-frequency transformers can be put will, we believe, cause their rapid and extensive introduction, and it is difficult to estimate the benefit which will result to science and industry from their applications. For lighting with phosphorescent bulbs or tubes, for the production of Roentgen phenomena, for the manufacture of ozone, argon and such bodies, for electro-therapeutic employment, and many uses for which induction coils are suitable, they afford ideal instruments. New applications will no doubt be found, but it is very probable that their chief employment will be for purposes of lighting by high-frequency currents, in which Tesla is the recognized pioneer.

We quote the exact language of the inventor in describing a few forms of his appliances for high-frequency phenomena:

The object of my present improvements is to provide a simple, compact and effective apparatus for producing these effects, but adapted more particularly for direct application to and use with existing circuits carrying direct currents, such as the ordinary municipal incandescent lighting circuits. The way in which I accomplish this, so as to meet the requirements of practical and economical operation under the conditions present, will be understood from a general description of the apparatus which I have devised. In any given circuit, which for present purposes may be considered as conveying direct currents or those of substantially the character of direct or continuous currents, and which, for general purposes of illustration, may be assumed to be a branch or derived circuit across the mains from any ordinary source, I interpose a device, or devices, in the nature of a choking coil, in order to give to the circuit a high self-induction. I also provide a circuit controller of any proper character that may be operated to make and break said circuit. Around the break, or point of interruption, I place a condenser, or condensers, to store the energy of the discharge current, and in a local circuit, and in series with such condenser, I place the primary of a transformer, the secondary of which then becomes the source of the currents of high frequency. It will be apparent from a consideration of the conditions involved that, were the condenser to be directly charged by the current from the source, and then discharged into the working circuit, a very large capacity would ordinarily be required, but by the above arrangement the current of high electro-motive force, which is induced at each break of the main circuit, furnishes the proper current for charging the condenser, which may, therefore, be small and inexpensive. Moreover, it will be observed that, since the self-induction of the circuit through which the condenser discharges, as well as the capacity of the condenser itself, may be given practically any desired value, the frequency of the discharge current may be adjusted at will.

Fig. 1 is a diagrammatic illustration of the apparatus, and Fig. 2 a modification of the same.

Referring to Fig. 1, A designates any source of direct current. In any branch of the circuit from said source, such, for example, as would be formed by the conductors A″ A″ from the mains A′ and the conductors K K, are placed self-induction or choking coils B B and a circuit controller C. This latter may be an ordinary metallic disk or cylinder with teeth or separated segments D D, E E, of which one or more pairs, as E E, diametrically opposite, are integral or in electrical contact with the body of the cylinder, so that when the controller is in the position in which the two brushes F F bear upon two of said segments E E, the circuit through the choking coils B will be closed. The segments D D are insulated, and while shown in the drawings as of substantially the same length of arc as the segments E E, this latter relation may be varied at will to regulate the periods of charging and discharging.

The controller C is designed to be rotated by any proper device, such, for example, as an electro-magnetic motor, as shown in Fig. 2, receiving current either from the main source or elsewhere. Around the controller C, or, in general, in parallel therewith, is a condenser H, and in series with the latter the primary K of a transformer, the secondary L of which constitutes the source of the currents of high frequency which may be applied to many useful purposes, as for electric illumination, the operation of Crookes tubes, or the production of high vacua.

L′ indicates the circuit from the secondary, which may be regarded as the working circuit.

A more convenient and simplified arrangement of the apparatus is shown in Fig. 2. In this case the small motor G, which drives the controller, has its field coils in derivation to the main circuit, and the controller C and condenser H are in parallel in the field circuit between the two coils. In such case the field coils M take the place of the choking coils B. In this arrangement, and, in fact, generally, it is preferable to use two condensers, or a condenser in two parts, and to arrange the primary coil of the transformer between them. The interruptions of the field circuit of the motor should be so rapid as to permit only a partial demagnetization of the cores. These latter, however, should in this specific arrangement be laminated.

In a modified arrangement the coils operating the interrupter are placed in series with a coil of large self-induction, or the latter is dispensed with by giving to the coils a suitable self-induction. Quoting the inventor, "this apparatus may be constructed and combined in very compact form and small compass. Its operation involves but a small expenditure of energy, while it requires practically no care or attention for the continued

production of ozone in unlimited amount."

Dwelling specifically upon the conversion of alternating or undulating currents, Mr. Tesla says:

When the potential of the source periodically rises and falls, whether with reversals or not is immaterial, it is essential to economical operation that the intervals of interruption of the charging current should bear a definite time relation to the period of the current, in order that the effective potential of the impulses charging the condenser may be as high as possible. I therefore provide, in case an alternating or equivalent electro-motive force be employed as the source of supply, a circuit controller which will interrupt the charging circuit at instants predetermined with reference to the variations of potential therein. The most practicable means for accomplishing this, of which I am aware, is to employ a synchronous motor connected with the source of supply and operating a circuit controller which interrupts the charging current at or about the instant of highest potential of each wave, and permits the condenser to discharge the energy stored in it through its appropriate circuit. This apparatus, which may be considered as typical of the means employed for carrying out the invention, I have illustrated in the accompanying drawings.

Referring to Fig. 3, A designates any source of alternating or equivalent current, from which lead off mains A′ A″. At any point where it is desired to produce the high-frequency currents, a branch circuit B is taken off from the mains, and, in order to raise the potential of the current, a transformer is employed, represented by the primary C and secondary D. The circuit of the secondary includes the energizing coils of a synchronous motor E and a circuit controller, which, in the present instance, in Fig. 3, is shown as composed of a metal disk F with insulated segments F′ in its periphery and fixed to the shaft of the motor. An insulating arm G, stationary with respect to the motor shaft and adjustable with reference to the poles of the fixed magnets, carries two brushes H H, which bear upon the periphery of the disk. With the parts thus arranged, the secondary circuit is completed through the coils of the motor whenever the two brushes rest upon the uninsulated segments of the disk and interrupted through the motor at other times. Such a motor, if properly constructed, in well understood ways, maintains very exact synchronism with the alterations of the source, and the arm G may, therefore, be adjusted to interrupt the current at any determined point in its waves. It will be understood that by the proper relations of insulated and conducting segments and the motor poles, the current may be interrupted twice in each complete wave at or about the points of highest potential. The self-induction of the circuit containing the motor and controller should be high, and the motor itself will usually be constructed in such manner that no other self-induction device will be needed. The energy stored in this circuit is utilized at each break therein to charge a condenser K. With this object the terminals of the condenser are connected to the two brushes H H or to points of the circuit adjacent thereto, so that when the circuit through the motor is interrupted, the terminals of the motor circuit will be connected with the condenser, whereby the latter will receive the high-potential inductive discharge from the motor or secondary circuit.

The condenser discharges into a circuit of low self-induction, one terminal of which is connected directly to a condenser terminal and the other to the brush H opposite to that connected with the other condenser terminal, so that the discharge circuit of the condenser will be completed simultaneously with the motor circuit and interrupted while the motor circuit is broken and the condenser being charged.

The discharge circuit contains a primary M of a few turns, and this induces in a secondary N impulses of high potential, which, by reason of their great frequency, are available for the operation of vacuum tubes P, single terminal lamps R, and other novel and useful purposes.

It is obvious that the supply current need not be alternating, provided it be converted or transformed into

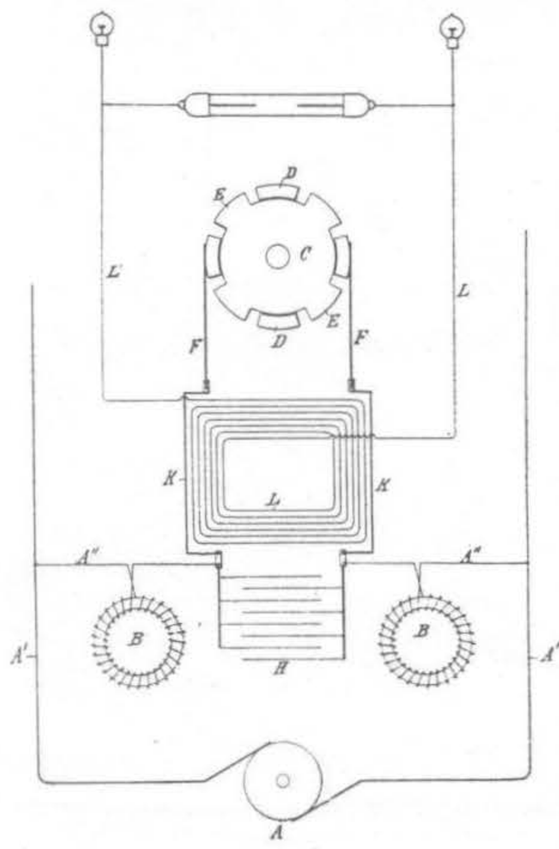


FIG. 1.—TESLA'S ELECTRICAL OSCILLATOR—DIAGRAM ILLUSTRATING CONNECTIONS OF OSCILLATOR AS ADAPTED TO AN ORDINARY MUNICIPAL LIGHTING CIRCUIT.

an alternating current before reaching the controller. For example, the present improvements are applicable to various forms of rotary transformers, as is illustrated in Fig. 4.

E′ designates a continuous-current

With such arrangement it is evident that any two adjacent segments *c c* become the terminals of an alternating current source, so that if two brushes H H be applied to the periphery of the cylinder, they will take off current during such portion of the wave as the width of segment and position of the brushes may determine. By adjusting the position of the brushes relatively to the cylinder, therefore, the alternating current delivered to the segments *c c* may be interrupted at any point in its waves.

While the brushes H H are on the conducting segments, the current which they collect stores energy in a circuit of high self-induction formed

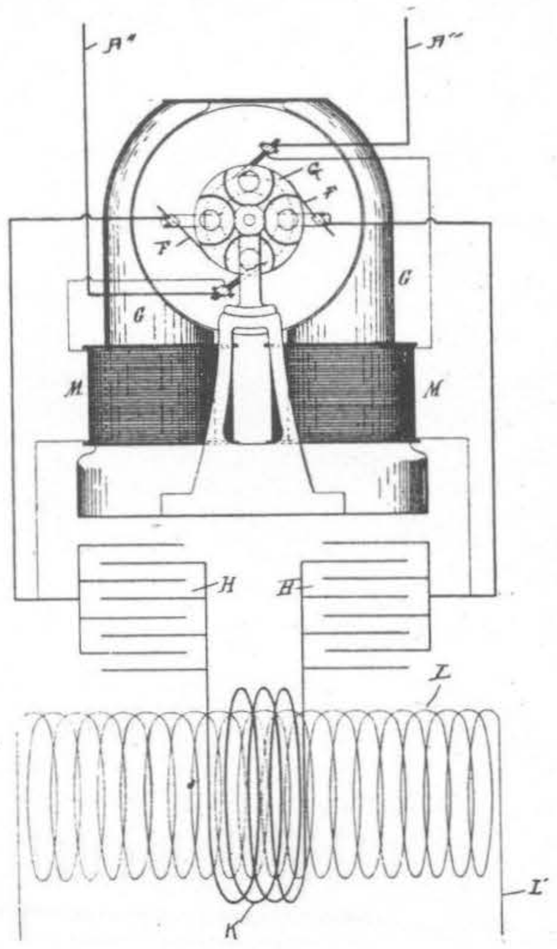


FIG. 2.—TESLA'S ELECTRICAL OSCILLATOR—DRAWING ILLUSTRATING A SIMPLIFIED FORM OF OSCILLATOR AND CONNECTIONS.

by the wires *f f*, self-induction coils S S, the conductors B B, the brushes and commutator. When this circuit is interrupted by the brushes H H passing on to the insulating segments of the controller, the high-potential discharge of this circuit charges the condensers K K, which then discharge through the circuit of low self-induction containing the primary M. The secondary circuit N contains any devices, as P R, for utilizing the current.

In other arrangements, circuit controllers of special construction are shown mounted on the shaft of a generator, and a transformer is employed in connection to raise the tension of the supply current.

In regard to the regulation of his system Tesla says:

It is well known that every electric circuit, provided its ohmic resistance does not exceed certain definite limits, has a period of vibration of its own analogous to the period of vibration of a weighted spring. In order to alternately charge a given circuit of this character by periodic impulses impressed upon it and to discharge it most effectively, the frequency of the impressed impulses should bear a definite relation to the frequency of vibration possessed by the circuit itself. Moreover, for like reasons the period or vibration of the discharge circuit should bear a similar relation to the impressed impulses or the period of the charging circuit. When the conditions are such that the general law of harmonic vibrations is followed, the circuits are said to be in resonance or in electro-magnetic synchronism, and this condition I have found in my system to be highly advantageous. Hence in practice I adjust the electrical constants of the circuits so that in normal operation this condition of resonance is approximately attained. To accomplish this, the number of impulses of current directed into the charging circuit per unit time is made equal to the period of the charging circuit itself, or, generally, to a harmonic thereof, and the same relations are maintained between the charging and discharge circuit. Any departure from this condition will result in a decreased output, and this fact I take advantage of in regulating such output by varying the frequencies of the impulses or vibrations in the several circuits.

Inasmuch as the period of any given circuit depends upon the relations of its resistance, self-induction, and capacity, a variation of any one or more of these may result in a variation in its period. There are, therefore, various ways in which the frequencies of vibration of the several circuits in the system referred to may be varied, but the most practicable and efficient ways of accomplishing the desired result are the following: (*a*) Varying the rate of the impressed impulses of current, or those which are directed from the source of supply into

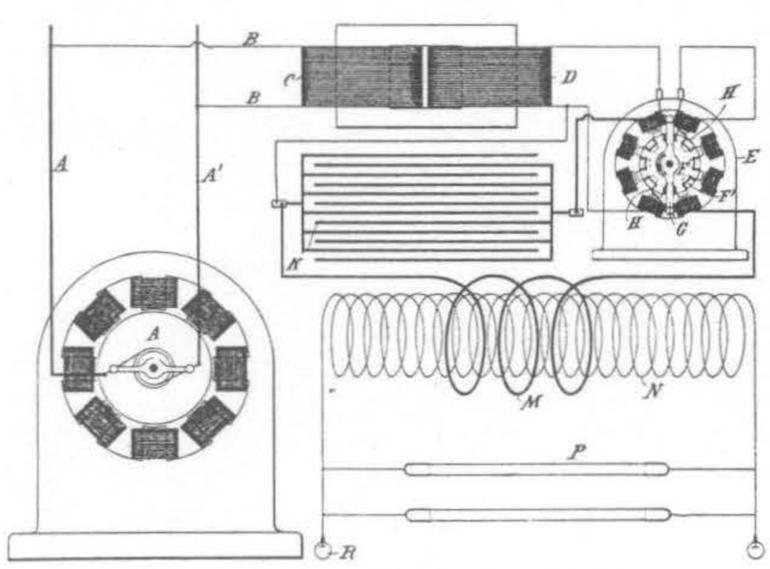


FIG. 3.—TESLA'S ELECTRICAL OSCILLATOR—DIAGRAM ILLUSTRATING APPARATUS AND CONNECTIONS AS ADAPTED TO A MUNICIPAL ALTERNATING CURRENT OF SUPPLY.

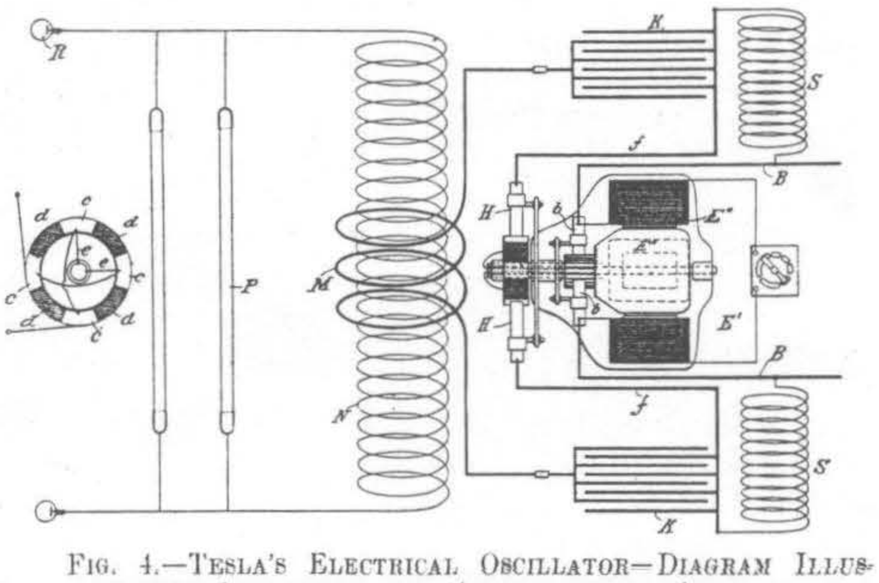


FIG. 4.—TESLA'S ELECTRICAL OSCILLATOR—DIAGRAM ILLUSTRATING APPARATUS AND CONNECTIONS AS ADAPTED TO A FORM OF ROTATING TRANSFORMER OPERATED FROM A MUNICIPAL LIGHTING CIRCUIT.

motor, here represented as having four field poles wound with coils E″ in shunt to the armature. The line wires B B connect with the brushes *b b* bearing on the usual commutator.

On an extension of the motor shaft is a circuit controller composed of a cylinder, the surface of which is divided into four conducting segments *c* and four insulating segments *d*, the former being diametrically connected in pairs, as shown in detail in Fig. 4.

Through the shaft run two insulated conductors *e e* from any two commutator segments 90 degrees apart, and these connect with the two pairs of segments *c*, respectively.

the charging circuit, as by varying the speed of the commutator or other circuit controller; (*b*) varying the self-induction of the charging circuit; (*c*) varying the self-induction or capacity of the discharge circuit.

To regulate the output of a single circuit which has no vibration of its own by merely varying its period would evidently require, for any extended range of regulation, a very wide range of variation of period; but in the system described, a very wide range of regulation of the output may be obtained by a very slight change of the frequency of one of the circuits when the above mentioned rules are observed.

Electrical Review

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Special Notice to Advertisers.

CHANGES for advertisements must be in this office by Friday noon for the following week's issue.

NEW ADVERTISEMENTS should be in the office not later than Saturday noon to insure publication the following week.

NEW YORK, SEPT. 30, 1896.

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TESLA'S ELECTRICAL OSCILLATORS.

Those who have followed the development of electrical industry in recent years, and more particularly the application of alternating currents for industrial purposes, will be able to justly appreciate the great services which Mr. Nikola Tesla has rendered to the world in this field of endeavor by his discovery of the rotating magnetic field, recorded in this journal early in 1888. They will remember that a few years after this publication, Tesla startled the scientific world through his brilliant lectures here and abroad, in which he disclosed entirely novel phenomena, produced by high-frequency currents. In these lectures he showed for the first time the possibility of lighting by means of phosphorescent bulbs and tubes. The currents he obtained either by specially constructed machines or by means of a new form of induction coil, now commonly known as the Tesla coil, or transformer.

Since his original announcement in this later field, Tesla has incessantly labored to simplify and improve his methods and apparatus, and as an evidence of his progress we only need recall to our readers his valuable contributions to the Roentgen phenomena, which he was able to so exhaustively investigate by the help of his perfected coils, or "oscillators." We also recorded, a few months ago, the remarkable results he obtained in the production of light of high candle-power by vacuum tubes.

Mr. Tesla now comes forward with perfected and extremely simple transformers, or oscillators, adapted to every-day use with ordinary sources of current supply. We believe that the importance of the advent of these new implements for the development of science and industry can not be overestimated. That high-frequency currents are destined to play an important part in the practical applications of electricity there can be no doubt, and with the introduction of efficient high-frequency transformers adapted to ordinary circuits their numerous uses are sure to come at once. The old and familiar form of induction coil, with its multitude of uses, can not possibly survive when a new inductive apparatus is at hand fully as simple, but far more economical, and requiring only a minute fraction of the wire needed in the old form.

Tesla has been working arduously for a number of years to bring about these results, as evidenced by the publication of his always original researches, and it is most unfortunate that his progress was delayed by the destruction of his laboratory a year and a half ago.

We heartily congratulate him on his practical success, as placed on record in the patents granted to him last week, on which we dwell on another page in this issue.

The New York Herald September 30, 1896

TESLA'S LATEST DISCOVERY.

Makes Practicable the Lighting of Vacuum Glass Bulbs Without the Usual Filaments.

The last issue of the Electrical Review describes the latest electrical invention of Nikola Tesla. He has succeeded, it says, in perfecting his so called electrical oscillators, or machines for the economical production of rapid electrical vibrations. By means of the oscillators he is confident that his lighting by glass bulbs, without the usual filament of the incandescent lamp, will become practicable.

They are, besides, capable of developing far more powerful Roentgen rays than was heretofore possible with the old apparatus, and they lend themselves to numerous other uses, such as photography, the production of ozone and other chemical combinations, and to electro-therapeutic treatment. Tesla's work has always attracted great attention among electrical workers, but it is probable that these latest contributions of his will prove more fruitful and far reaching than his previous achievements.

In an editorial the Electrical Review says:—

"We recorded a few months ago the remarkable results he obtained in the production of light of high candle power by vacuum tubes. Mr. Tesla now comes forward with perfected and extremely simple transformers, or oscillators, adapted to every day use, with ordinary sources of current supply. We believe that the importance of the advent of these new implements for the development of science and industry can not be overestimated.

"That high-frequency currents are destined to play an important part in the practical application of electricity there can be no doubt, and with the introduction of efficient high-frequency transformers adapted to ordinary circuits their numerous uses are sure to come at once.

"The old and familiar form of induction coil, with its multitude of uses, cannot possibly survive when a new inductive apparatus is at hand, fully as simple but far more economical and requiring only a minute fraction of the wire needed in the old form."

The New York Tribune September 30, 1896

TESLA'S LATEST DISCOVERY.

HE SUCCEEDS IN PERFECTING MACHINES FOR THE ECONOMICAL PRODUCTION OF RAPID ELECTRICAL VIBRATIONS.

Nikola Tesla has succeeded in perfecting his electrical oscillators or machines for the economical production of rapid electrical vibrations. By means of these he is confident that his lighting by glass bulbs, without the usual filament of the incandescent lamp, will become practicable. They are, besides, capable of developing far more powerful Röntgen rays than was heretofore possible with the old apparatus, and they lend themselves to numerous other uses, such as photography, the production of ozone and other chemical combinations, and to electro-therapeutic treatment.

"The Electrical Review," which to-day announces the inventor's success, says of his latest work: "Tesla, since he startled the scientific world by showing for the first time the possibility of lighting by means of phosphorescent bulbs and tubes, has incessantly labored to simplify and improve his methods and apparatus, and now comes forward with perfected and extremely simple transformers, or oscillators, adapted to every-day use with ordinary sources of current supply.

"That high-frequency currents are destined to play an important part in the practical applications of electricity there can be no doubt. The old and familiar form of induction coil, with its multitude of uses, cannot possibly survive when a new inductive apparatus is at hand fully as simple, but far more economical, and requiring only a minute fraction of the wire needed in the old form."

[88998.]—**Roentgen-Ray Work.**—No: I believe I am right in saying that with a coil the Tesla gives absolutely no increase in length of spark; rather the other way. The radiographic effects from coil direct are at least quite as good as when used in conjunction with the Tesla. S. Bottone.

[89000.]—**Tesla Effects** are due to increased frequency and high potential. The increased frequency depends on the oscillatory nature of the Leyden jar discharge. The lighting up of the incandescent lamp is probably a discharge through the vacuum and through the outer glass of tube, and will probably end in the fracture of the lamp. Roughly, the voltage of a 3in. spark is 150,000 volts.
S. Bottone.

Tesla's Oscillator.

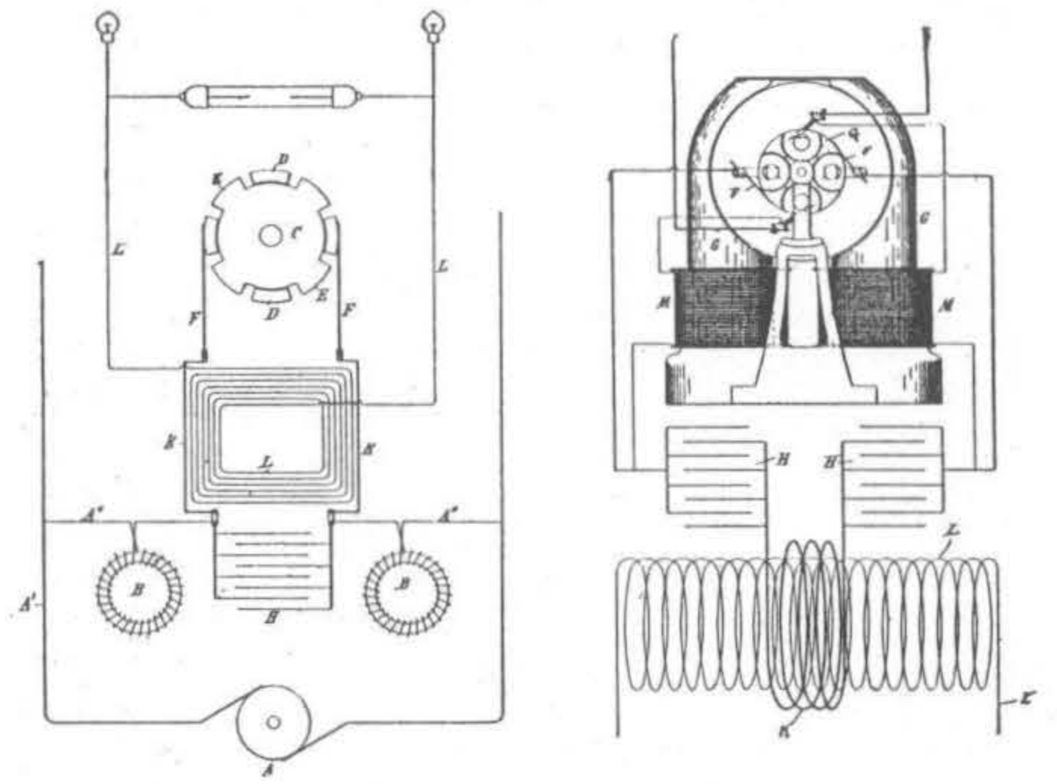
Nikola Tesla was used to distinguish himself by a closer attention to business than to publicity, and the more was hoped for from him for that reason. Of late he has occasionally allowed enthusiasm and hope to run away with speech, and he has told too freely what he was going to do. It is always wiser to do a thing before talking about it. It saves chagrin, accusation and misunderstanding. There is little doubt that Tesla is the foremost electrician in the country, if not in the world. Mr. Edison has perfected more than he has invented. Mr. Tesla has fallen upon or has reasoned out devices that promise to revolutionize the systems of power and lighting that so recently revolutionized the methods of steam, water and other forces. The oscillator, which he was to have shown last winter he has now succeeded in perfecting, according to the Electrical Review, and he offers it in so concise and economical a form that the prevalent machinery of lighting would seem to be doomed to speedy abolition. It gives some idea of the tremendous velocity and force of the subtle fluid of which we still know so little, when we learn that the new machine can produce 100,000,000 vibrations in a second. Granted that it does but a thousandth part of that and the wonder is little less. By interrupting the current every sixty-millionth part of a second a vivid light is induced in vacuum tubes which appear to be disconnected with the apparatus. The new process also yields the Roentgen ray, can be employed in the separation of the new element argon and likewise the production of ozone, and may prove to be of value in electrical therapeutics. The advantage of the light over that of incandescent and arc lamps is that while it is brighter it is also softer and more diffused. so that the observer is not dazzled or blinded. Probably it is also steadier. The usual and existing appliance for breaking the current is entirely mechanical in its operation and only a few hundred vibrations, at the most, can be induced in a second. The high vibrations of the Tesla machine make the light practically if not mathematically constant. We live in an age of progress and wonders, but they multiply so fast that our grandchildren may look upon us as fogies.

TESLA HIGH FREQUENCY APPARATUS OPERATED FROM LOW POTENTIAL DIRECT CURRENT CIRCUITS.

THE brilliant experiments in high frequency and high potential currents made by Mr. Tesla have been carried out by the aid of initial alternating currents raised from low to high potential. But in order to simplify the methods of work in this field, Mr. Tesla has devised a type of apparatus noted in our Patent Record last week, which enables currents of the desired high potential to be obtained from ordinary low potential continuous current circuits. In carrying out this scheme, Mr. Tesla employs a circuit breaker, around the contacts of which a condenser is connected, to store the energy of the discharge current; and in a local circuit and in series with the condenser he places the primary of a transformer, the secondary of which then becomes the source of the high frequency currents.

The accompanying diagram, Fig. 1, shows one form of the apparatus. The choking coils, B B, and circuit breaker, C, are placed in circuit with the continuous current mains, A. The circuit breaker is rotated by a continuous current motor. In parallel with the circuit breaker is the condenser, H, and in series with the latter the primary, K, of a transformer,, the secondary, L, of which is the source of the high frequency currents.

Another, more convenient form of the apparatus is the arrangement shown in Fig. 2. In this case the motor, G, which



FIGS. 1 AND 2.—TESLA'S SIMPLIFIED HIGH FREQUENCY APPARATUS.

drives the circuit breaker, has its field coils in derivation to the main circuit, and the controller, C, and condenser, H, are in parallel in the field circuit between the two coils; the field coils, M, taking the place of the choking coils, B.

In this arrangement, and in fact generally, according to Mr. Tesla, it is better to use two condensers or a condenser in two parts and to arrange the primary of the transformer between them. The breaks of the field circuit should be so rapid as to permit only of partial demagnetization of the cores which should be laminated.

It will be apparent from a consideration of the conditions involved that were the condenser to be directly charged by the current from the source and then discharged into the working circuit a very large capacity would ordinarily be required, but by the above arrangement the current of high electromotive force which is induced at each break of the main circuit furnishes the proper current for charging the condenser, which may therefore be small and inexpensive. Moreover, it will be observed that since the self-induction of the circuit through which the condenser discharges, as well as the capacity of the condenser itself, may be given practically any de-

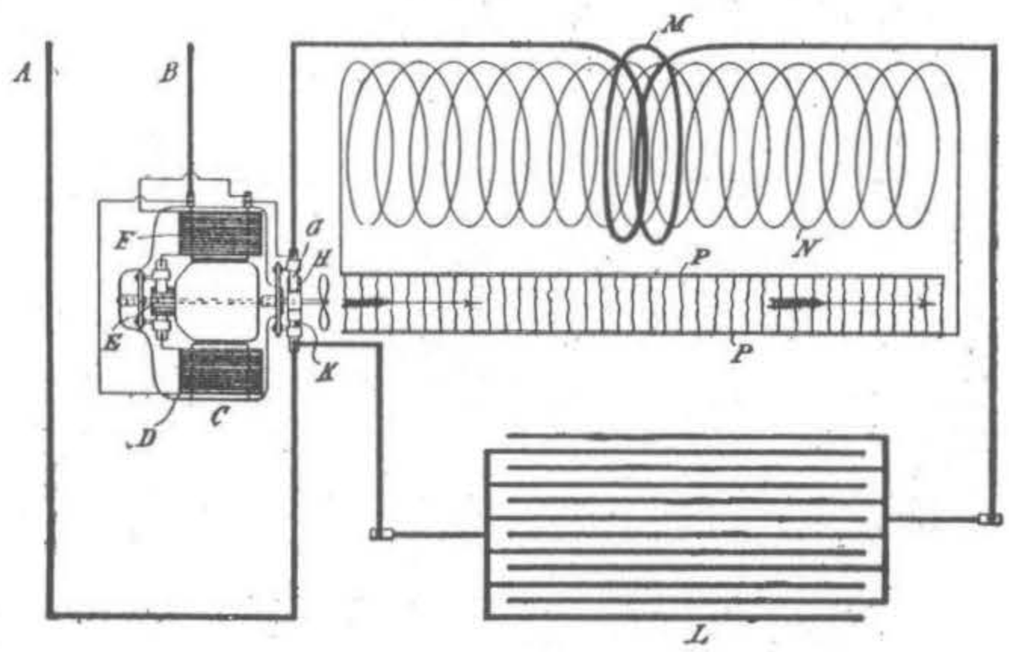


FIG. 3.—TESLA'S OZONE GENERATOR.

sired value, the frequency of the discharge-current may be adjusted at will.

Mr. Tesla has also devised a number of other methods for accomplishing the same object, which form the subject matter for a number of patents just issued to him.

Among the uses to which Mr. Tesla proposes to put the new arrangement is the generation of ozone in large quantities. The engraving, Fig. 3, shows the simple method employed for

this purpose. The high frequency brush discharge takes place between the metal plates, P P, and a current of air is forced between the latter by the fan blower attached to the motor that drives the circuit breaker.

LETTERS TO THE EDITOR.

[The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, or to correspond with the writers of, rejected manuscripts intended for this or any other part of NATURE. *No notice is taken of anonymous communications.]*

A Note on the Tesla Sparkand X-Ray Photography.

A CROOKES' radiometer was supported by its stem about four inches above the hand, which was placed upon a photographic plate enclosed in two light-tight cases. The terminals of a Tesla coil were placed about half an inch from the bulb on either side of it, inclined to one another at an angle of 120°, the vertex of the angle being in the axis of the radiometer. The Tesla discharge was allowed to bombard the bulb for four minutes. On development a clear picture of the bones in the hand appeared. The experiment shows that the X-ray photo can be produced when an exhausted bulb is used having no terminals.

I failed entirely to get any X-ray results when only the usual induction sparks bombarded the bulb, these sparks often destroying the vacuum. My Tesla apparatus gives a spark three inches long in air at normal pressure. The mica radiometer vanes after many experiments lost nearly all the black substance with which they were coated; it appeared in the form of a deposit on the inside of the bulb, and it was deposited in the form of concentric circles, the centres of which were situated exactly opposite to the ends of the pointed conductors attached to the Tesla coil.

Thinking that the mica vanes in the Crookes' radiometer might have played a considerable part in producing the X-ray photograph, I replaced the radiometer by a well-exhausted bulb 4 c.m. diameter, made of soda glass; the bulb was placed with respect to the conductors from the Tesla coil in the same position as the radiometer in the former experiment. I found that with the same exposure and distance, a good X-ray photograph of the bones in the hand was produced. During the experiment the bulb was lit up with a bright and yellowish green glow. Since the Tesla discharge rapidly produces ozonised air which is irritating to the nose, throat and lungs, it is best to place the terminals in a draught of air moving away from the operator.

Oxford, October 17. FREDERICK J. SMITH.

PART TWO.

THE SUNDAY TIMES-HE

The Sunday Chicago Times Herald CHICAGO, OCTOBER 25, 1896.—FORTY-FOUR PAGES.

FINDS NATURE'S SECRET

Has Mrs. Benedict Solved Tesla's Great Problem?

ATOMIC SHEATH BROKEN.

Research Reveals the Force Long Sought by Scientists.

VIBRATION'S POWER FREED.

Claim That Electricity May Be Supplanted.

EFFECT ON AERIAL NAVIGATION.

Discoverer Believes That Human Life Will Be Prolonged Through Its Agency.

DETROIT, Mich., Oct. 24. Nikola Tesla:—I have discovered the hiding place of universal force, of that most vital and terrible thing, the fountain of pure electrical fluid.

Universal force is in the inter-atomic atmosphere and cannot be brought into open demonstration except by disrupting the atomic sheath, which has never been accomplished, except under veiled conditions, and then unwittingly and without recognition.

The phenomenon of the dynamite explosion when it takes place in open air apparently disrupts or disentangles or destroys every vestige of material substance included within a certain radius, from the apex of its prime energy, but I understand the methods by which these disruptions may be produced both in the air and upon the earth.

If the great master, Nikola Tesla, may think what I have said worth his attention I would be pleased to give him my plans.

With such power released and under control. I can see no reason why aerial navigation is not within easy reach, or why, with this most intense of all motor concept, the free activity of fluid electricity in its primal strength and vitality may not be applied to human life in its greatest complex and most extreme and minute extremities, why human life may be not only freed from depleted fiber and tissue, but prolonged for great periods of time. I give these suggestions, fully realizing what I say, and also understanding methods by which far more can be accomplished. I know there are countless discreet movements in the human body merging their energies into the complex and continuous. Also that they lose energy or that the atomic piston rods fall or move with much less rapidity from lack of the supply of pure electric energy.

Nikola Tesla has seen the inconceivable rapidity of the atomic movements in the human body, the fierce flames and vibration giving and receiving the lectric atomic energies and vitalities in every most minute viscera of every structure, and I am also conscious that he understands far more than I am able to express of this motor power of the universe alike in atom or whole, and of the infinite possibilities yet to be revealed to the world.

I am a woman past the meridan of physical years, but I have given all the best energy of the years I have had searching for the unseen, and at last I have been rewarded. I have just returned to Detroit from a four years' sojourn on the deserts of Colorado, away from books and papers, and I have known but very little of what has been done in the world during that time. Since my return it has been suggested that I write to you, giving my theories.

I believe I outlined my discovery and have given some suggestion of the magnitude of its possibilities, if such a discovery is developed.

That I am a woman does not exclude me from understanding so great a wonder.

Hoping I may hear from you, I subscribe myself, respectfully,

MRS. RENEW BENEDICT, Detroit, Mich.

This is a copy of a letter which Mrs. Renew Benedict, a lineal descendent of Benjamin Franklin, has written to Nikola Tesla, the great electrician. Tesla has been seeking for years to discover the solution of the problem Mrs. Benedict claims that she has solved. Mrs. Benedict had determined to mail the letter to Tesla, but finally changed her intentions, believing that if the announcement was made through THE TIMES-HERALD Mr. Tesla would be certain to see it, and would consider her discoveries more carefully than if he first learned of them through an unknown source.

If anyone should have been predestined to make a discovery which would revolutionize electrical science no better person could be found than Mrs. Benedict. She is a lineal descendant of Benjamin Franklin, the philosopher who discovered the identity of lightning and electricity. When less than a day old she was carried by her mother to the roof in deference to an old-time custom, and there above the flooded valleys of the keystone state was told to look up and be "high-minded."

As if to verify the custom, the child began life as a seer of visions and a dreamer of dreams. Before she could speak strange and marvelous revelations came to her which so impressed themselves on her infant mind that her first spoken syllables were themes of a world unknown, and on subjects since revealed through the interpretation of science.

When grown to womanhood Renew Daniels became a teacher in the romantic community of New Bergon, that ideal wild of Pennsylvania over which Ole Bull presided, a dreamer at the feet of the master and a teacher in a log schoolhouse, whence the strains of the magic violin had power to lure every pupil, leaving the youthful instructor free to close the temple of learning and follow the vagaries of genius.

These scenes passed like a dream, and Renew Daniels became Renew Benedict and was lost sight of in the retirement of domestic life. After that season of blessedness came widowhood, and years of sorrow and research. The strange doctrine of theosophy attracted her, and she studied it until she became an adept, reaching the highest circles, a member of the "king's chamber."

It was then that an inspiration seized Renew Benedict to go into the desert and learn the law of vibration. She purchased a ranch at Colorado Junction, and for the past four years has labored with pick and shovel on a fruit farm planted by her own hands. Suddenly she believed that she was enlightened and found herself on the verge of a great discovery, which even the latest disciple of science, Nikola Tesla, has not as fully fully developed, although working on the same lines.

Scientific men not only Nikola Tesla but others in America as well as German and French physicists, have been struggling with the problem of force. Electricity as known to-day is unknown. Although it has been made the servant of man, no man knows its nature. But slight advance has been made in the real knowledge of it since Franklin, Mrs. Benedict's ancestor, discovered its positive and negative conditions. For some time it was regarded as imponderable, as a tangible thing, an indivisible mass, but with the light shed by the latter experiments of science, the conclusion has been reached that it is a composition of something else as yet unknown. This may be what Mrs. Benedict has discovered.

The theory that light and heat was imponderable was held for years, as it has been held that electricity was an imponderable. But the world of science now believes that "imponderable" is only a word employed to mask ignorance of causes. Science discovered that light was a vibratory motion in the ether, while heat was a vibratory motion of atoms and molecules. This has engendered various theories as to the nature of electricity, and by some it has been thought to be due to rotations of matter.

Vibratory motion has been guessed to be the cause of electricity. Scientists have held that theory, but none have been able to prove it conclusively. Vibratory motion is the cause of the great phenomena of natural science, light, heat and electricity. Mrs. Benedict believes she has found a new force, perhaps akin to electricity, for which the scientists have been blindly groping, and which, like light and heat and what we call electricity, is due to vibrations.

Empty space is a perfect nonconductor of electricity. Tesla and Bell have proved this. It has been discovered that an electric spark would not pass through a vacuum, but that it would jump three feet in the air rather than bridge the eighth of an inch where there was no conducting material. It is therefore apparent that electricity or the force imperfectly known by that name exists in the air.

As the electro-magnetic theory is now well established, it implies that ether waves, either long or short, have their origin in the movements of matter of one size or another. The forces in electricity are the result of two effects. As light is an effect of forces in ether, and heat is an effect of forces in matters, so electricity, as it is known, is the result of an effect in matter and an effect in ether, the second being caused by the first.

Scientists have made sure of one thing. This is that electricity never manifests itself, except when there is some mechanical disturbance, which is termed vibration, in ordinary matter, and every exhibition of electricity may always be traced back to a mass of matter. Some of the electricians have confined themselves to a study of that which takes place in matter, others to that which takes place in ether. The confusion of scientists has been due to this divided experimental condition.

On the other hand, it has been the belief of Tesla and his followers, as well as scientists in France and Germany, that there is some latent force as yet unknown at work behind this, and they have believed that if the energy stored in each individual atom of matter could be released it would result in the securing of tremendous force with little waste.

Tesla believes that this can be secured by rapid vibrations. His theory is that all manifestations of energy are but the different tangible or apparent evidences of one force, and he has set himself to discover that force. All energy, whatever its form or manifestation, is, according to him, simply molecular agitation of greater or less degree. If that be true, then heat and light are merely the results of molecular agitation, and could this agitation be set up by purely mechanical means, heat or light would result. Then all forces would be found to be one.

It is the bold idea of Tesla that by causing matter to pass to the stage of luminous vibration, without remaining, for any appreciable time, in the stage of heat vibration, he could produce light without heat, and he has come very near success, thus proving the kinship of the phenomena.

Tesla started with the idea of setting matter into vibration at a rate approximating that of light, which is at the rate of 2,500,000 vibrations a second. He expected that under such violent agitation it would emit light. But he has not succeeded in producing so great a vibration, although wonderful luminous effects produced at a lower rate foretell his success. His discoveries have astonished the scientific world, and have paved the way for Mrs. Benedict's discovery.

The vibratory theory of a universal force is not new. It was surmised by ancient philosophers, and Pythagoras taught his pupils that the same forces underlaid both the harmonies of music, which are the result to vibrations, and the motion of the heavenly bodies. Leucippus believed, as Tesla has believed, and as Mrs. Benedict has discovered, that atoms possess within themselves a principle of energy. This belief extended so far as to enter upon the range of natural theology, and the theory of Democritus was that the soul's construction approached the hypotheses of vibratory physics. The mystics believed that matter is latent force, and force free matter. To liberate the force contained in the matter was their aim, but this was abandoned as impossible by the scientists of a century ago, although the realization of the ideas of the ancients now seems at hand.

Sound, the result of vibration of the waves of the air, enters into Mrs. Benedict's ideas. The explosion of dynamite or electricity in a vacuum would not be audible to our imperfect sense of hearing, and no man can see an atom, yet it is believed that it is there and that the laws governing nature's world may be revealed, as the telescope and microscope have daily revealed the existence of things hitherto unknown.

No man can see an atom. It is the indivisible substance of which everything is composed, innumerable atoms being required to make the mass. Electricity is the result of atomic friction, light and heat are have been found to be due to the same causes. Natural forces of heat, light and electricity are due to a disturbance of harmony, caused by the effort of each atom to assert its power over its neighbor—to separate itself from the average harmony of the mass and become independent. The individual atoms are each sustained by life, or in other words, the vibrations. The atoms independently separate from the light rays, and restored to the average harmony of the mass after absorbing vibration of the mass is the new condition of energy called electricity.

"I do not believe," says Edison, "that matter is inert; to me it seems that every atom is possessed of a certain amount of intelligence."

Mrs. Benedict, the descendant of Franklin, seems to have succeeded in releasing the atom from its sheath, giving it the ability to accomplish almost everything that is now done by other forces, while its possibilities for the future surpass the dreams of the wildest romancers.

Mrs. Benedict is now in Detroit. She is not a woman of fashion, for she has lived out of the world and has not even heard of balloon sleeves. In answer to a leading question she said:

"Yes, I believe that I have discovered the hiding place of universal force, of that most terrible and subtle thing, the fountain of pure electric fluid, not a highly impregnated substance in which electricity may be engendered or collected, but the fountain of the eternal and endless force itself. I believe that I have not only discovered its hiding place, but a means by which it can be liberated."

"Are you willing to give it to the world?"

"I am willing to give suggestive propositions to the world through the press of what this force is and where it can be found, and how it may be seized upon and brought into submission, but my actual method must remain my secret in the cause of science until I am fully prepared to demonstrate it to scientists. My secret is the disruption of the atomic sheath. I know Tesla is working on the same lines, but he has not accomplished that result. I believe that I have solved the problem, and when this great power is released and conserved in the interests of mankind, I can see no reason why aerial navigation will not be a result. Human life can also be indefinitely prolonged by the renewal of the vital functions, by use of the energizing power now wasted. This elixir of life will be produced when the vibratory force is released from its atomic sheath."

"Will you explain the method?"

"Yes. When dynamite explosions take place in the open air, they apparently disrupt or destroy every vestige of material substance included within a certain radius from the apex of its prime energy. But the power of the explosion is not contained within the dynamite, but the force generated by the gunpowder explosion is held in concentric waves, by its compact in the etheric glycerin envelope, which compact so intensifies the blow struck upon the air as to cause the air to retrovert upon itself with such intense vibration as to disrupt the atomic sheath and liberate the terrible force secreted within."

"Why has this never been discovered before?"

"The world has not been ready for a discovery of such godlike proportions. The atomic world is waiting for a Columbus—a liberator. It has never been compelled to yield its

[89000.]—**Tesla Effects.**—The cause of the innocuousness of these seems not to have been determined with certainty. If the impulses alternate at the rate of a million per second, it can easily be imagined that one of these would not have time in $\frac{1}{1000100}$th of a second to produce a destructive effect on the tissues, and at the expiry of that minute interval an impulse operating in the opposite direction, and therefore tending to counteract the first, would follow, while its destructive tendency would, in turn, be neutralised by the third impulse, and so on. Analogous results occur in hearing, where, as the pitch of a note is gradually increased, it becomes more and more shrill till it reaches a certain rapidity of vibration which varies with individual hearers, and then the sensation of sound ceases entirely. On the other hand, it was lately maintained in a leading medical journal that the great potential, and not the high frequency, is the operating cause. As the potential is increased the quantity of electricity is diminished, and may at last become so small as to be too weak to injure the human frame. Mr. Harcourt will find much interesting information bearing on the lighting-up of an incandescent lamp on short circuit in Tesla's lecture on "Light and other High Frequency Phenomena," delivered before the Franklin Institute, Philadelphia, February, 1893, and before the National Electric Light Association, St. Louis, March, 1893.

A. T.

[89311.]—**Tesla Coil.**—Provided you do not use a higher battery-power on your coil itself than you have usually employed, the presence of the Tesla transformer will not affect your coil in the slightest degree.

S. BOTTONE.

[89311.]—**Tesla Coil.**—Since your coil has the secondary wound in two sections only, it will be as well to be careful with it. If you mean to make it a part of a Tesla apparatus, you are almost certain to spoil it.

F. C. ALLSOP.

[39398.]—**Tesla Coil.**—No, to both queries. If your coil works badly, the Tesla will do worse. With a good steady running coil, the Tesla, as it increases the voltage, and also the oscillation frequency, enables a given coil to light up tubes which, owing to their high resistance, would be unworkable by the coil alone. But I am very doubtful whether, beyond this, any real advantage is gained—in other words, whether better radiographs are not to be obtained from a given coil by using a tube suitable to it, rather than by attempting to raise the voltage of the coil by the use of a Tesla to suit a higher voltage tube. S. Bottone.

Electrical Review

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NEW YORK, DEC. 2, 1896.

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TESLA'S LATEST CONTRIBUTION TO THE ROENTGEN-RAY PHENOMENA.

In this issue of the ELECTRICAL REVIEW we have the pleasure to bring to the attention of our readers another contribution on the subject of the Roentgen rays from the pen of Mr. Tesla, which, like all previous articles, conveys much useful and interesting information.

Mr. Tesla dwells on the nature of the rays, and brings out in strong relief some ideas and results which he has already recorded in our columns, and at the same time advances new observations and conclusions that can not fail to attract the attention of all workers in this new and fruitful field of investigation. We believe the possibilities pointed out of producing nitrogen compounds will prove of the greatest value.

The medical profession must indeed be indebted to Mr. Tesla for the valuable hints he gives for the application of Roentgen's discoveries to surgery.

His announcement of the real causes of the deleterious effects on the skin noted by a number of experimenters will be a welcome and timely revelation.

Mr. Tesla touches on the recently brought out and sensational subject of "making the blind see" by means of the Roentgen rays, presenting arguments and regretfully showing the hopelessness of such a task.

This latest communication will particularly interest the readers of the ELECTRICAL REVIEW by the wealth of the suggestions and important information it conveys.

TESLA ON THE ROENTGEN STREAMS.

To the Editor of Electrical Review:

The following lines may contain some useful information for physicists and physicians. Those who, in the exercise of their professional duties, are applying the discoveries of Roentgen to the relief of the suffering by determining the position of foreign objects or ascertaining the condition of local troubles or malformations in the organism, are apt to be disappointed in many instances. While it is perfectly easy to find the position of a foreign object in the head, neck and all soft tissues of the body, and detect some far gone trouble in the lungs, often the location of even such a large and opaque object as a bullet, when imbedded in certain bony parts of the trunk of the patient, may be attended with difficulties. Success will be invariably attained if the suggestions which are given below, and which are the outcome of a number of observations of such cases, are strictly followed.

In order to make the present statements self-contained and more useful, I deem it of advantage to say a few words in regard to the Roentgen rays. According to all evidences so far obtained by me, I entertain the view, which I have expressed on other occasions, that these rays are formed by streams of some matter projected with great velocity, and generally intermittently, from the walls of the tube. The intermittent character is only due to this feature of the apparatus usually employed for the production of the rays; but the oscillatory or intermittent discharge is not absolutely necessary, as I have produced unidirectional currents of high tension which are likewise capable of generating strong rays, and as a static machine may be used with a like result. The mode of formation of these rays or streams is, for the present purposes, of little importance. The small particles within the bulb, which are the original cause, may be ions, formed by a process of electrolysis, or they may be comparatively larger particles of the electrode, or perhaps molecules of the residual gas. At any rate, it is probable that the particles are very minute, and that, therefore, the velocities of the cathodic streams within the vessel are such and the impacts so violent as to cause a further disintegration of the cathodic matter to a state probably never before studied by physicists. We may have to deal, as I have already suggested, with an actual breaking up of the ether-vortexes, which, according to Lord Kelvin's theory, compose the material particles, or we may be confronted with a dissolution of matter into some unknown primary form, the Akasa of the old Vedas. Experiments show that this matter is reflected, sometimes very well, sometimes poorly; but in all cases the various metals behave in a curious manner, which I have studied, and the results obtained, though probably not free of error, because of the great difficulties in getting an exact estimate in such an investigation, were, nevertheless, sufficiently positive as to lead me to the conviction that the same medium or element which is concerned in the setting up of the electro-motive tension between metals in contact is present in the streams of Roentgen. It might have been proper to say, in the spirit of more modern views on contact electricity, that these streams are formed by ether, but I have preferred to use the term "primary matter;" for, although the expression "ether" conveys a perfectly definite idea to the scientific mind, there exists, nevertheless, much vagueness as to the structure of this medium. The matter projected is not revealed by spectral analysis, and it does not seem to produce any appreciable mechanical nor even heating effects, nor is it deflected by a magnet, all of which facts tend to show that it can not be composed of *molecules* of any known substance. The streams exercise a powerful action upon a photographic plate or fluorescent screen, but I look upon these results as obvious consequences of the energetic impact.

Of the various more or less plausible views in regard to the formation of these streams outside of the vessel, the simplest, to my mind, is to assume an actual projection through the walls of the bulb of the disintegrated cathodic matter. Granted that there are particles sufficiently small within the bulb, then all velocities, up to many thousands of kilometers per second, are not only possible, but also probable; and, even if the particles would not be further disintegrated by the impact against the wall or other comparatively opaque body within the bulb, they surely would penetrate through great thicknesses of most substances. My experiments in this direction have shown that all the disintegration is practically accomplished in the first impact against the more or less impenetrable obstacle within the bulb, the second impact having seemingly little effect, as might be inferred from well established mechanical principles. I have also found that the place of first and most energetic impact, be it the anode, cathode or wall of the vessel, is invariably the principal source of the rays or streams. Again, quite in accordance with mechanical principles, the penetrative power of the streams is the greater the more complete the disintegration. Thus, for instance, rays which have traversed thick opaque objects, and are presumably further disintegrated, pass more freely through dense substances. An observation to this effect has likewise been made by Professor Wright, who was the first to publish definite results in the United States. I find that bulbs with thick walls give rays of greater penetrating power. It should be, of course, understood that I do not mean by this a greater outward effect. It is principally the above fact which makes it appear more probable that the matter projected is not a *homogeneous stream*, but consists of particles of varied magnitude moving with different velocities, for, were the former the case, the penetrative power would depend chiefly on the velocity. In the practical use of the Roentgen streams it would, therefore, seem very important to find a method of filtering and rendering them homogeneous, for only by such a method can we hope to obtain exact results in their investigation. Streams of perfectly uniform velocity and character, if produced, would no doubt be more suitable for the purposes of research.

Since the disintegration of the electrodes, especially if they are of aluminum, is so slow that no appreciable diminution of the weight results even after long use; it follows that the matter conveyed by the Roentgen streams is so minute as to escape detection. Some bulbs, which I have used for a number of months, showed that the bombarded spot of the glass was entirely permeated with particles of the aluminum electrode, but it would probably require years of constant use to accumulate any appreciable amount of matter outside. Referring to a tube with an electrode of aluminum, it is a noteworthy fact that, if properly managed, it does not impair in quality, but, on the contrary, seems to improve; whereas, when a platinum electrode is used, the life of the bulb is very short, owing to the conductor being deposited on the walls, which deposit, as I have explained on another occasion, renders difficult the passage of the discharge. Namely, as soon as some of the projected particles strike the conducting layer, they impart a similar electrification to the latter, and a repulsion is exerted upon the particles following. The result is an apparent increase in the resistance of the tube. The above defect of the platinum electrode, despite of its effectiveness, must, in my opinion, lead to its abandonment.

It has been suggested that the Roentgen rays may be due simply to a propagation of electro-static stress; but, on this assumption, it is difficult to conceive how rays could be produced in instances when the glass wall is at a high temperature and consequently conducting, or when the impact plate or inclosure is of metal and connected to the ground. Stokes has recently considered the possibility that the impact of the cathodic stream on one side of a partition might give rise to a molecular motion on the other side without necessarily there being a transit through the partition. According to this view, which I have likewise considered some time ago, it would appear that the material streams might start on the outer side of the wall of the tube, in which case only the air would be responsible for the effects, and the futility of a spectral analysis test would be in a certain measure accounted for. But is it not more probable to assume an actual passage and shattering of matter, as all evidences point in this direction? Assuming that, as Professor Stokes now thinks it probable, the disturbance is non-periodic and still capable of producing effects characteristic of transverse vibrations of extremely high frequency, it seems to me a serious question whether the old Newtonian views on light should not be reconsidered rather than the conclusion drawn that the novel manifestations observed by Roentgen are due to transverse vibrations, when there is no experimental evidence to this effect, nor even a satisfactory explanation found how the cathodic impact might give rise to waves of a higher frequency than those of light.

Being, as I am, firmly convinced of the existence of material streams, I look upon the unsuccess of the attempts of demonstrating an actual transit of matter as being due to either the minuteness of the amount or else to the state of the matter, but rather to the former cause, as all peculiarities of the streams point in this direction. In my opinion, no experimenter need be deterred from carrying on an investigation of the Roentgen rays for fear of poisonous or generally deleterious action, for it seems reasonable to conclude that it would take centuries to accumulate enough of such matter as to interfere seriously with the process of life of a person. But I look confidently to the demonstration of actions of a purely qualitative nature. For instance, despite of the danger of such an assertion by encouragement which might be given to quacks, I would say that I expect with the utmost confidence the demonstration of a germicidal action. In addition to the physiological effects, to which I have early drawn attention, I have more recently observed with powerful tubes that a sensation of pain is produced in the forehead above the eyes just as soon as the current is turned on. This sensation is very similar to that one frequently experiences when stepping from a dark room into the glare of bright sunlight, or when walking for some time over fields of fresh-fallen snow.

As to the hurtful actions on the skin, which have been variously reported, I note that they are misinterpreted. These effects have been known to me for some time, but I have been unable, on account of pressing matters, to dwell on the subject. They are not due to the Roentgen rays, but merely to the ozone generated in contact with the skin. Nitrous acid may also be responsible, to a small extent. The ozone, when abundantly produced, attacks the skin and many organic substances most energetically, the action being no doubt heightened by the heat and moisture of the skin. After exposing the hand, for instance, for some time, the skin loses its elasticity, which causes a tension and pain, and subsequently an inflammation and blistering. This occurs mostly only at short range, but may be produced by a single terminal bulb, or generally by a very highly exhausted bulb, in which the terminals act independently, at greater distance. Owing to this, I have always taken the precaution, when getting impressions with the rays, to guard the person by a screen made of aluminum wires which is connected to the ground, preferably through a condenser. The radical means, however, of preventing such actions is to make impossible the access of the air to the skin while exposing, as, for instance, by immersing in oil. As this would be inconvenient in most cases, a metallic screen should be resorted to. The action of the ozone on some substances, when placed near the bulb in such a way that the gas is generated on their surfaces, is so powerful that the substances are practically destroyed in a few minutes. When a wire heavily insulated with rubber is connected to the terminal of a high-frequency coil, sometimes an exposure of barely a minute is sufficient to completely wreck the rubber insulation. There are certain commercial insulating compounds which are even more quickly destroyed, but which I will not enumerate, because of a possible disadvantage to the manufacturers. Gutta-percha, beeswax and paraffine stand the attack very well, and such

(Continued on page X.)

TESLA ON ROENTGEN STREAMS.

(Continued from page 277.)

wires should be used with high-frequency coils. This powerful action of the ozone was observed by me first about two years ago, when performing an experiment which was shown to many persons in my laboratory. The experiment consisted of charging a person, standing on an insulated stand, with a potential approximating one and one-half million volts, which was alternated several hundred thousand times a second. Under such conditions luminous streams break out on all parts of the body, especially abundantly on the feet, hands, hair, nose and ears. I subjected myself a number of times to this experiment, which seemed to offer no other danger except the possible rupture of a blood vessel, if the skin was very dry and non-conducting. I then noted on myself and others after effects resembling much those attributed to the Roentgen rays. With currents produced by perfected electrical oscillators, such as were described in one of your recent issues, [See ELECTRICAL REVIEW, September 30, 1896.—ED.] the production of the ozone is so abundant that it is sufficient to merely turn on the current for a few seconds and ozonize strongly the atmosphere of a large hall. These currents are also capable of bringing about chemical combinations, of which the chief is that of the nitrogen with the oxygen of the atmosphere, and an immense possibility, which I have been following up for a long time, is opened up; namely, the combination of the nitrogen of the atmosphere on an industrial scale by practically no other means than mechanical power. If merely fertilizers of the soil would be manufactured in this manner, the benefits to humanity derived therefrom would be incalculable. From the above-named action of the ozone, it follows that the experimenter should use the indicated precaution, for, while ozone in small quantities is a most beneficial disinfectant, when generated in large quantities it is not free of danger.

It is an unpleasant duty to say on this occasion a few words on the subject of "making the blind see" by means of the Roentgen rays. This sensational topic has been given a wide circulation in the journals. Is it not cruel to raise such hopes when there is so little ground for it? For, first of all, the rays are not demonstrated to be transverse vibrations. If they were, we would have to find means for refracting them to make possible the projection of a sufficiently small image upon the retina. As it is, only a shadow of a very small object can be projected. What possible good can result from the application of these rays to such purposes? The shape of the small object might eventually be recognized by impressing the retina, but the sense of touch is more than sufficient to convey such impressions. Luminous sensations are well known to be excited in two ways; namely, by mechanical shock and electrical transmission. Both of these, I think, are present in the Roentgen streams, and hence such an effect on the optic nerve might be expected. I may say, however, that I can not confirm some of the experiments reported. For instance, when a hand is put before the closed eyes it is easy to distinguish the shadow, much the same as before the light of a candle; but when the tube is inclosed, and all light from the same excluded, I fail to get such an impression. The latter is, therefore, chiefly due to ordinary light, or else my tubes act differently from those experimented with by others. It may be proper to recall here that in ordinary bright sunlight, especially in the southern climates, it is easy to distinguish the shadow of objects, and even their rough outlines, with the eyes shut.

Proceeding on the assumption that we have in reality to deal with material streams, it is important to inquire which are the best conditions to be maintained when taking impressions with the sensitive screen or plate. First, the experimenter will easily observe that there are two causes which, with a given bulb and coil, tend to increase the intensity of the impressions. One of these may be said to lie in the bulb, the other in the coil. The latter, being most generally made of many turns of fine wire, is very sensitive to changes in the capacity of bodies attached to its terminals. The capacity of these bodies, therefore, in such a coil largely determines the difference of potential. At a certain degree of exhaustion this capacity assumes such a value that the pressure rises to a maximum, this tending to give the highest velocity to the cathodic stream, and, consequently, to give rise to the most intense rays. But at that degree of exhaustion it may happen, and usually does happen, that the cathodic streams are not most abundant. To produce the best result it is necessary that both of these causes should be made to cooperate by a careful proportioning of the dimensions of the bulb, which, in practice, is very difficult, inasmuch as the experimenter has to avail himself of commercial bulbs which may or may not be best suitable for his coil. This simple consideration shows the great advantage of the use of a coil which contains no fine wire and is capable of giving a heavy current through the secondary far in excess of what even the largest bulb requires.

Assuming the physician has learned how to manipulate his apparatus to best advantage, he will next notice that, to secure the clearest definition, he will have to maintain a certain pressure on the terminals of the tube, dependent chiefly on the distance and degree of opacity of the object investigated. It goes without saying that the definition is the better the smaller the spot from which the rays are emanating, but this is true only when impressions are taken at very small distances. When the distances are large, it is a disadvantage to use a too small radiating surface, as then the density is diminished to such a degree that the action is too weak. Discarding this consideration, it is clear that, if the rays are intense, the more opaque portions of the body are likewise penetrated and much detail is lost, whereas, when the rays are less intense, the impression might be altogether too weak to bring out sufficient detail.

To illustrate in a popular manner the best way to proceed, I shall avail myself of a simple illustration. Suppose that there would be imbedded between two panels of cloth a foreign object, such as a coin, and it is desired to locate it. We may accomplish this by placing behind the cloth a cardboard, for instance, and then firing from a certain distance a load of fine shot through the cloth in the region where the coin is supposed to be located. The shot will penetrate the cloth on all points except on the place where the coin is located, and on the cardboard behind, this place will be plainly indicated by the absence of the marks. Exactly in this way we proceed in applying the Roentgen rays to the location of such a body. Roentgen gave us a gun to fire—a wonderful gun, indeed, projecting missiles of a thousandfold greater penetrative power than that of a cannon ball, and carrying them probably to distances of many miles, with velocities not producible in any other way we know of. These missiles are so small that we may fire them through our tissues for days, weeks, months and years, apparently, without any hurtful consequence. Instead of the cardboard to indicate the path of the missiles, he gave us what is properly called a Roentgen screen, which becomes luminous on all places where it is hit by the missiles. Where the latter are prevented from hitting the screen by the intervention of the opaque body, the screen does not glow and we observe the shadow of the object. It is simple enough to project the shadow of an object in this way, but when it is required to show the finer detail of the structure of the object, the difficulty begins. It will at once appear that, to produce such a result to best advantage, two conditions will have to be more or less realized. Firstly, the screen should be composed of such material that it is capable of becoming luminous by the *faintest impact;* and, secondly, the missiles should all be of uniform size, and should move with uniform velocity. Neither of these two conditions has so far been realized in practice, for all the bodies we know require a violent impact to become luminous, and no way has been found as yet to produce a uniformity in velocity and magnitude of the supposed projectiles. But a little thought leads immediately to the conclusion that there will be a certain velocity of the missiles which will give, under all conditions, the best definition. This velocity is easily ascertained by trial. Evidently the definition will be best when the bullets which pass through the densest parts of the body strike the screen so feebly as to not make it light up, whereas, those passing through portions of slightly smaller density hit it sufficiently strong as to make it light up feebly. The more sensitive the screen to impact, that is, the weaker an impact is required to make the screen light up, the more detail will be revealed. It therefore follows that, in the application of the Roentgen rays, not the body which fluoresces strongest, but the one which is most sensitive, is best suited for finer work.

The above considerations have led me to adopt the following procedure, which, in practice, has proved very successful. The Roentgen screen is first applied to the body to be investigated, the pressure at the terminals of the tube being very much reduced. The pressure is then slowly and gradually raised. It will be presently observed that, at a certain pressure, the shadow of the object examined is clearest. But as the vacuum is increasing, the pressure generally rises, and the image gets blurred in spite of the screen getting much brighter. Just as soon as the clearness is slightly diminished, the experimenter should for a few moments reverse the current, lowering a little the vacuum in this manner. The current being again given the direction it had at first, namely, that which causes a slow and steady increase of the vacuum, the shadow gets again clear, and by such easy manipulation the best result may be secured. An additional advantage, however, is gained, because the frequent reversals produce a brighter phosphorescence of the screen. When taking a photograph, the bulb should be watched through the screen and the switches manipulated in the above manner.

To give a practical example of the effectiveness of this procedure, I need only mention one of the instances which have come to my notice. A few months ago I investigated the case of Mr. Cornelius Mack, of Watertown, Mass. Mr. Mack, while performing his duties many years ago, was struck by a bullet which lodged somewhere in the chest and could not be located. I applied the screen vainly a number of times; for although the streams penetrated the body with such ease as to make the screen behind appear bluish white, and reveal all the bones of the body, I could not observe the missile. I then resorted to the above indicated means, and immediately and easily the exact location of the projectile, between the shoulder blade and one of the ribs, was ascertained and the bullet successfully extracted. NIKOLA TESLA.

New York, November 30.

The New York Herald December 2, 1896

X RAYS ON THE BLIND.

Nikola Tesla Deprecates the Holding Out of Hope to the Sightless and Says Facts Do Not Warrant It.

The Electrical Review will publish to-day an exhaustive communication from Nikola Tesla on his latest experiment with the X ray. Tesla states that the sunburn effects noted by many experimenters are not due directly to the rays, but to the ozone generated by the rays in contact with the skin.

In referring to the recently widely heralded experiment for making the blind see by means of the Roentgen rays, he regretfully remarks:—

"Is it not cruel to raise such hopes when there is so little ground for it? For, first of all, the rays are not demonstrated to be transverse vibrations. If they were, we would have to find means for refracting them to make possible the projection of a sufficiently small image upon the retina. As it is, only a shadow of a very small object can be projected. What possible good can result from the application of these rays to such purposes?

"I cannot confirm some of the experiments reported. For instance, when a hand is put before the closed eyes it is easy to distinguish the shadow, much the same as before the light of a candle; but when the tube is enclosed and all the light from the same excluded, I fail to get such an impression. The latter is, therefore, chiefly due to ordinary light."

Tesla then points out a possible method of manufacturing fertilizers by electricity. "With currents produced by perfected electrical oscillators it is possible to combine the nitrogen of the atmosphere. If merely fertilizers of the soil would be manufactured in this manner the benefits to humanity derived therefrom would be incalculable."

He concludes with an interesting description of an improvement in the method of taking X ray impressions in surgical cases.

The New York Tribune December 2, 1896

TESLA'S EXPERIMENTS WITH X RAYS.

"The Electrical Review" will publish to-day a communication by Nikola Tesla concerning his recent experiments with X rays. He says that the sunburn effects observed in the use of the rays are not due directly to the rays, but to the ozone generated by the rays, and adds: "The ozone, when abundantly produced, attacks the skin and many organic substances most energetically." By the use of perfected oscillators, he asserts, "the production of ozone is so abundant that it is sufficient merely to turn on the current for a few seconds to strongly ozonize the atmosphere of a large hall." He hints at the possible manufacture of fertilizers by the use of the electrical current, and goes on: "If merely fertilizers of the soil could be manufactured in this manner, the benefits to humanity derived therefrom would be incalculable."

The inventor does not think it is possible to make the blind see by means of the X rays, because by means of the rays only the shadow of a small object can be projected. He declares that he cannot confirm some of the experiments reported, and remarks: "When a hand is put before the closed eyes it is easy to distinguish the shadow, much the same as before the light of a candle, but when the tube is inclosed, and all the light from the same excluded, I fail to get such an impression. The latter is, therefore, chiefly due to ordinary light."

NEWS AND NOTES.

MR. TESLA ON THERMO ELECTRICITY.

In a letter to the editor of the Buffalo Enquirer, Mr. Nikola Tesla replies as follows in regard to an inquiry on the subject of the future of electricity:

"The transmission of power has interested me not only as a technical problem, but far more in its bearing upon the welfare of mankind. In this sense I have expressed myself in a lecture, delivered some time ago.

"Since electrical transmission of energy is a process much more economical than any other we know of, it necessarily must play an important part in the future, no matter how the primary energy is derived from the sun. Of all the ways the utilization of a waterfall seems to be the simplest and least wasteful. Even if we could, by combining carbon in a battery, convert the work of the chemical combination into electrical energy with very high economy, such mode of obtaining power would, in my opinion, be no more than a mere makeshift, bound to be replaced sooner or later by a more perfect method, which implies no consumption of any material whatever.

THE WONDERFUL EXPANSION IN THE USE OF ELECTRIC POWER.

By Louis Bell.

THE transmission and distribution of energy is the latest of the great electrical arts. To be sure, in the almost prehistoric days before the invention of the dynamo, there were electric motors, as there were electric locomotives and electric lights, electric heaters and electric boats; but the ingenuity of Henry, Jacobi, Davidson, and Page led to no useful end. Their machines were relegated to the scrap-heap or the cabinet shelf by the same grim logic of economy that, in the fullness of time, has forced the modern motor into the front rank of industrial improvement.

When, just a quarter of a century ago, Gramme and Siemens gave the dynamo substantially its present form, every kind of electrical work received a sudden and powerful impetus. The subsequent half-dozen years were crowded with developments. In 1873 the first motor of modern type was put into operation at the Vienna Exposition by Fontaine and Breguet, the motor working a little pump through a mile or so of cable. In the next few years motors were occasionally exhibited or put to temporary use, but it was not until the autumn of 1878 that experiments and demonstrations culminated in commercial operation.

The time was propitious; the growth of electro-plating and electrotyping had given the dynamo-builders encouragement and occupation; the arc lamp had outgrown the laboratory and the lecture-room, and was becoming a practical illuminant. It was whispered, too, that, if the experiments then in progress on incandescent lamps were successful on a commercial scale, the problem of general electric lighting was to be at last accounted as solved.

More than this, some convenient and economical means of transmitting and distributing mechanical power had long been badly needed, and men were ready to turn hopefully to the potent force that had already achieved so much. Power transmission by wire ropes and by compressed air had already been weighed in the uncompromising balance of experience, and had been found wanting,— the former in flexibility, the latter in efficiency.

In the latter part of 1878 MM. Chrétien and Félix installed in the beet-sugar works at Sermaige the first commercial electric motor, operating a little hoist used in unloading the beets from the boats in

which they were brought down the river. During the succeeding winter four thousand tons of beets were thus unloaded, and the cost was found to be about forty per cent. less than unloading by hand The appearance of this historical motor is shown in Fig. 1. It developed only two or three horse power, and received its energy from a similar generator about twenty rods away. From this beginning has sprung the prodigious growth of to-day.

The next summer the first electric railway was put into operation at the Berlin Exhibition,—a single car, capable of carrying fifteen or twenty passengers, and running over fifty rods of track. The trans-

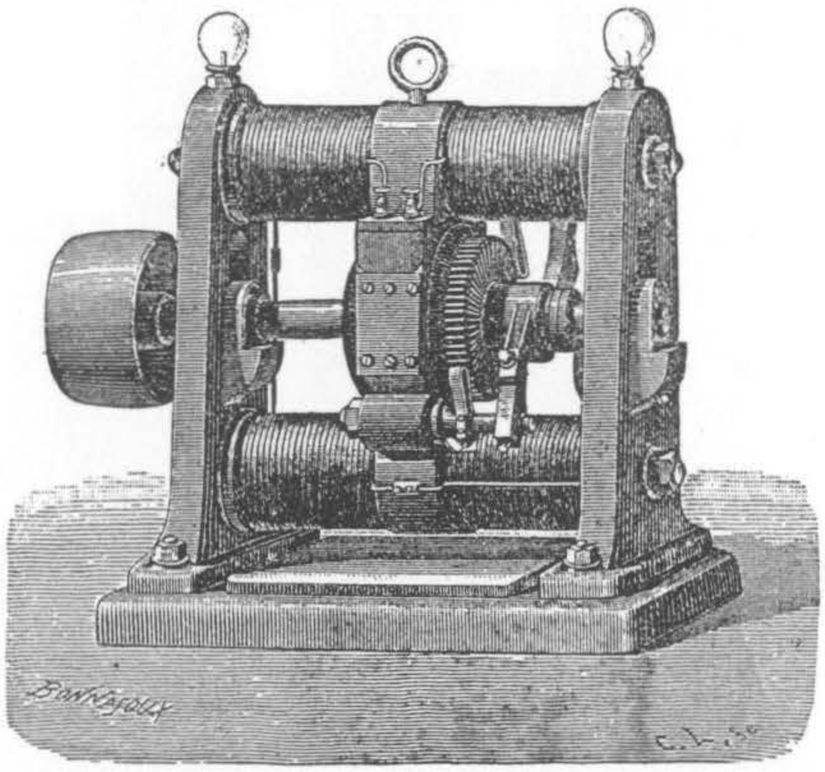


FIG. 1. ONE OF THE FIRST COMMERCIAL MOTORS.

mission of energy to both stationary and moving motors was quickly taken up in this country. S. D. Field and Edison were pioneers in the work; in fact, the former was actively experimenting when the foreign work was made known; and presently scores of inventors were busy, with true Yankee push, in working out the manifold applications of electrical motive power.

At first the only available sources of current were the recently-established arc-light circuits. Upon these small motors began to appear soon after 1880, and with increasing frequency in the next succeeding years. Soon Edison lighting-stations became available, and during 1882 and 1883 small motors began to go into service in con-

nection with them. By the fall of 1884, when the Philadelphia Electrical Exhibition was in progress, the electric motor was firmly established as a machine commercially available, and its valuable properties were well understood. In fact, the Electrical Expositions of 1881 in Paris and 1882 in Munich had shown the capabilities of motor service, and at the latter had been shown the first experiment in long-distance power transmission,—an experiment more daring and revolutionary even than the famous one at Lauffen-Frankfort nine years later.

This work was done by Marcel Deprez, and consisted in the transmission of power from Miesbach to Munich, — thirty-seven miles, a distance longer than is spanned by any commercial plant in operation to-day. The line was of common telegraph wire, and the energy delivered was less than half a horse power, which was employed in driving a centrifugal pump. The voltage of the dynamo was about 1350, and both generator and motor were specially-wound Gramme machines. The station at Miesbach, the first power-transmission plant in the world, is shown above in Fig. 2.

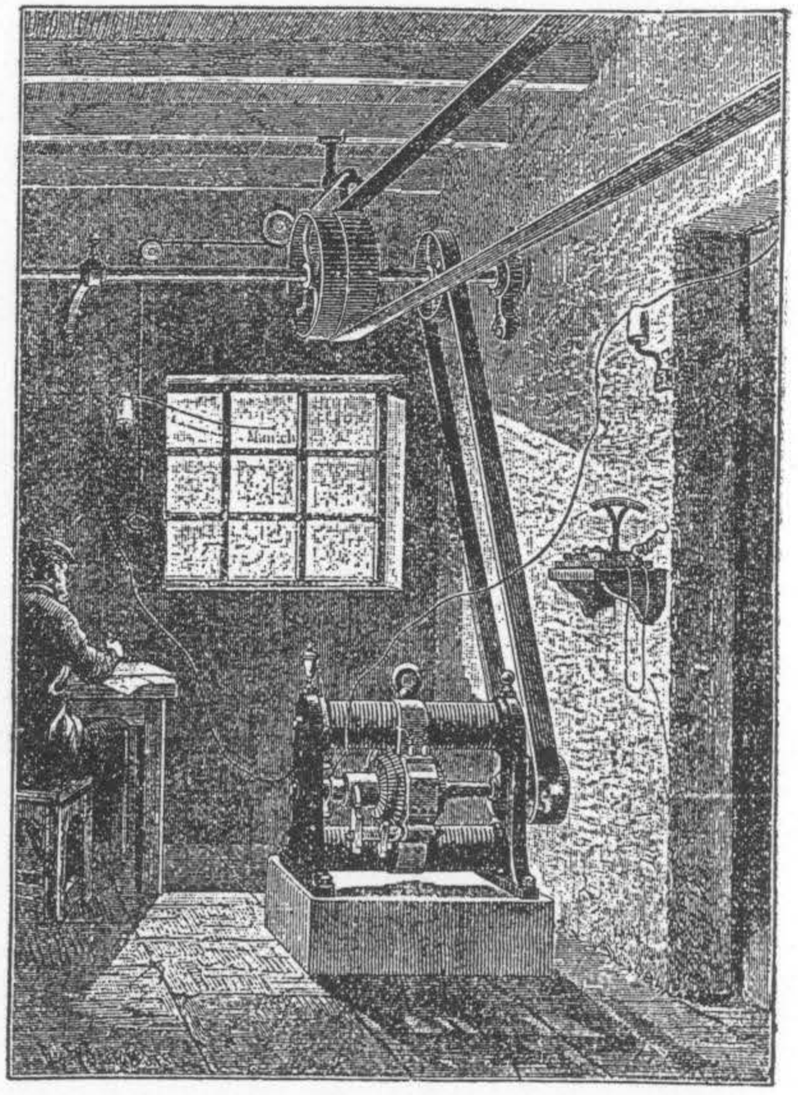


FIG. 2. THE MIESBACH POWER STATION.

From 1884 the development of the motor, following up the growth of electric lighting, was increasingly rapid, and by the autumn of 1886

it was estimated that there were no less than five thousand electric motors in use in the United States.

At the same period there were nine electric railways in operation, running fifty-eight motor cars and aggregating thirty-five and one-half miles of track. Many battery motors are included in this estimate, and the arc circuit was still an important source of power.

Thereafter the growth of the art was mainly in the direction of railway service, though the incandescent lighting stations soon began to take on motor service in considerable amounts.

In 1888 came the Tesla motor that has since played so important a part in the development of electric power, particularly in the past few years. As electric railways became more and more common, and engineers became more familiar with the construction and management of dynamos for fairly high voltages, motor work began to assume larger proportions and to reach out over greater distances. A few special motor circuits were installed at 220 and 500 volts, and a successful series motor distribution was started in San Francisco. But more experience was needed, and the time was not yet ripe, so that it was not until 1890 that power transmission as such began to gather headway. From 1890 dates the real period of industrial development.

By this time it was well ascertained that the electric motor was a thoroughly efficient and reliable machine, capable of being trusted with important work and fully able to compete with steam power under conditions that could often be realized. With power derived from ordinary central stations the motor was often far more economical in its operation than small steam engines with their attendant inconvenience and care; and it was obvious enough that no known means of transmitting power was so efficient or convenient for general purposes. Given a cheap source of power, the problem of its economical distribution was at last solved.

It was but natural that the mining regions of the far west, where coal was very expensive and water power plenty, should have been the scene of the first attempts at the electrical transmission of power. About the beginning of 1890 several transmission plants were put in operation, employing for the most part 500-volt railway generator and distributing power for mills, pumps, and hoists. This was only a useful makeshift, and it was necessary to break away from ordinary voltages before power transmission could assume the industrial importance that is its due. The step was not an easy one, for high voltage was a dreadful bug-a-boo in 1890; but taken it was, both with continuous and with alternating currents, and early in the next season two notable plants went into operation: one at the Dalmatia Mine, Califor-

nia, transmitting 100 h. p. at 1,800 volts 1½ miles; the other at Telluride, Col., delivering a similar amount of power 2½ miles away by means of a monophase alternating current at an effective pressure of 3,000 volts. A single synchronous motor was used, brought up to speed by a Tesla split-phase starting motor. At the Dalmatia Mine Brush continuous-current machines were used, one at each end of the line.

The polyphase systems were as yet undeveloped, as shown by the use of monophase current instead; but the Tesla motor had already been in use, for in the summer of 1890 several Hercules mining machines had been equipped with them and put into regular service near Pittsburg. One of these pioneer machines—the first commercial polyphase induction motor—is shown in Fig. 3. Then, in the summer of 1891, came the Frankfort Electrical Exhibition, which gave to electric power development the final impulse needed. Since then the transmission work in this country has been, with a few trivial exceptions, entirely polyphase. The next year saw much experimentation, much growth of ordinary motor service, but no power-transmission plants, save a small monophase synchronous one at Walla Walla, Washington, and another, closely similar to the Telluride plant, but of double the capacity, and working over a line 12½ miles long, at Bodie, Cal. A notable step was taken, however, in the establishment of a long-distance lighting plant, delivering energy from the generating plant in San Antonio Cañon to the towns of Pomona and San Bernar-

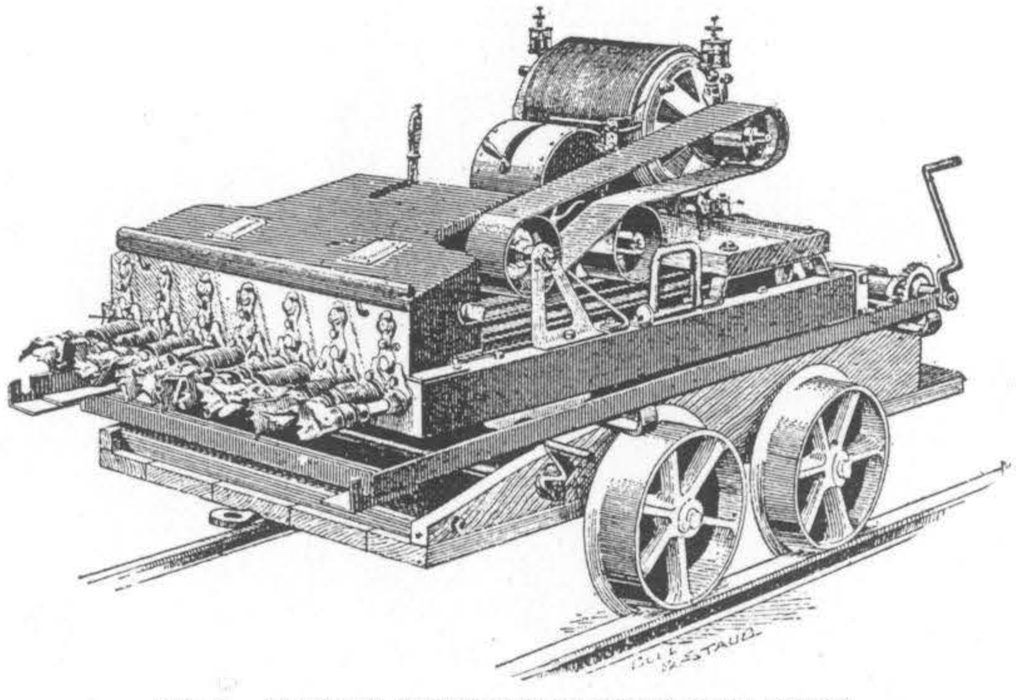


FIG. 3. HERCULES MINING-MACHINE WITH TESLA MOTOR.

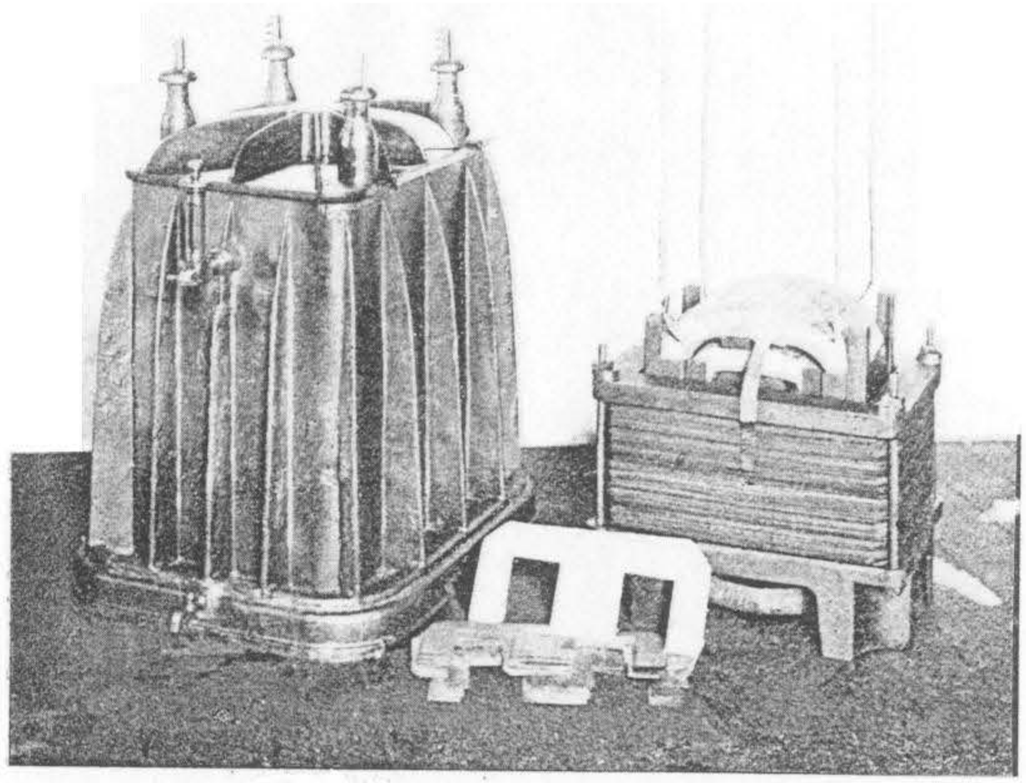


FIG. 4. POMONA TYPE TRANSFORMER.

dino, Cal., distant respectively 13¾ and 28¾ miles. An ordinary alternating generator was used, but the voltage was raised to 10,000 volts by a bank of twenty step-up transformers in series. It was the first commercial use of so high a pressure, and the extreme distance of transmission has been exceeded only within the past year. One of these historical raising transformers is shown in Fig. 4.

The hard times were now drawing near, but the good work went along, and 1893 saw marked and substantial progress in the use of electric motive power. Not only was there steady increase in the installation of motors for every purpose, but the Columbian Exposition was rich in transmission apparatus, and before the end of the year three polyphase plants had gone into service, and—what was worthy of special note—the final steps had been taken to furnish the great Niagara plant with generators of American design and manufacture.

During the times of dire financial stress in 1893 and 1894, when many industries were completely prostrated, the electrical distribution of power grew as it had never grown before. Business men saw an opportunity of reducing operating expenses by securing cheap power, and grasped it. Aside from all the motors sold for factories

and work-shops, contracts were made by the leading electrical companies for more than a score of polyphase transmission plants.

Notable among these were two great cotton mills at Columbia and Pelzer, S. C., equipped throughout with polyphase motors, for the most part applied directly to groups of machines, dispensing with the costly and complicated systems of belting and shafting heretofore used in such factories. Fig. 5 shows the generating plant at Pelzer, with its three 750-kilowatt three-phase generators, directly coupled to turbines, delivering current at 3,300 volts to the mills 3½ miles away.

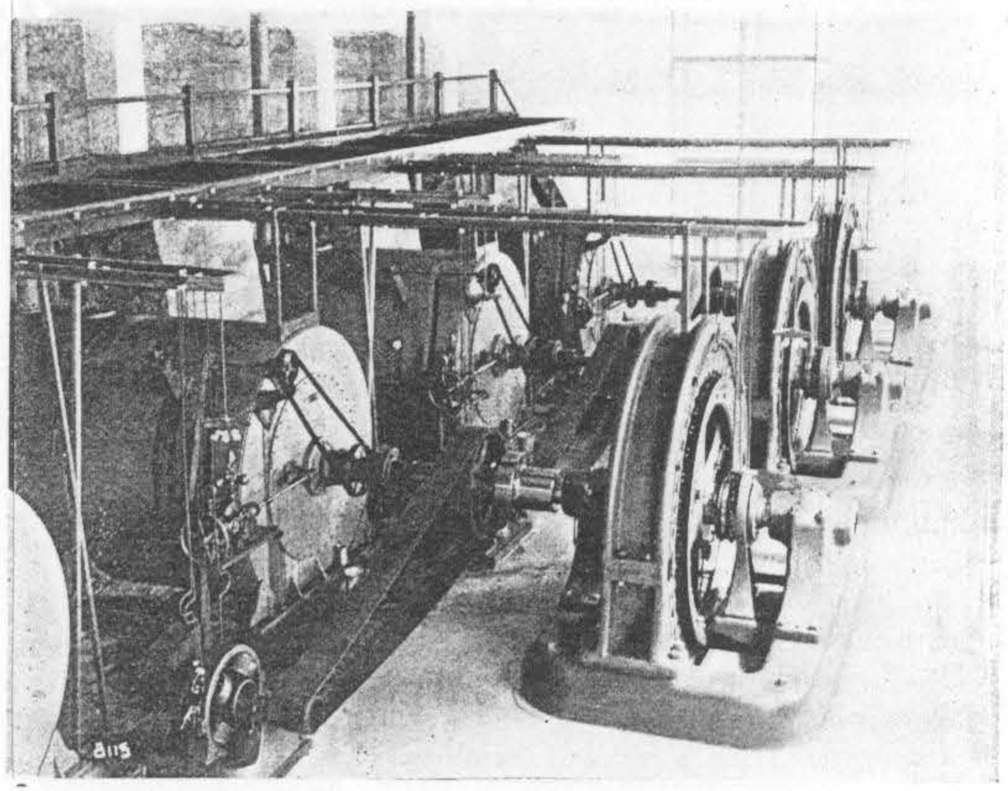


FIG. 5 THE PELZER DYNAMO ROOM.

The next year saw increased activity and epoch-making work. In the early summer the Folsom-Sacramento three-phase plant went into operation, of 3,000 kilowatts capacity, furnishing all the power and light used in Sacramento 23 miles away,—the longest commercial transmission that had yet been installed. A little later the huge Niagara plant went into operation with its 5,000-h. p. generators,—an installation that for size and startling engineering features will stand unique for many a year to come. Fig. 6 shows the present appearance of this immense station, of which so much has been heard of late that further description is needless.

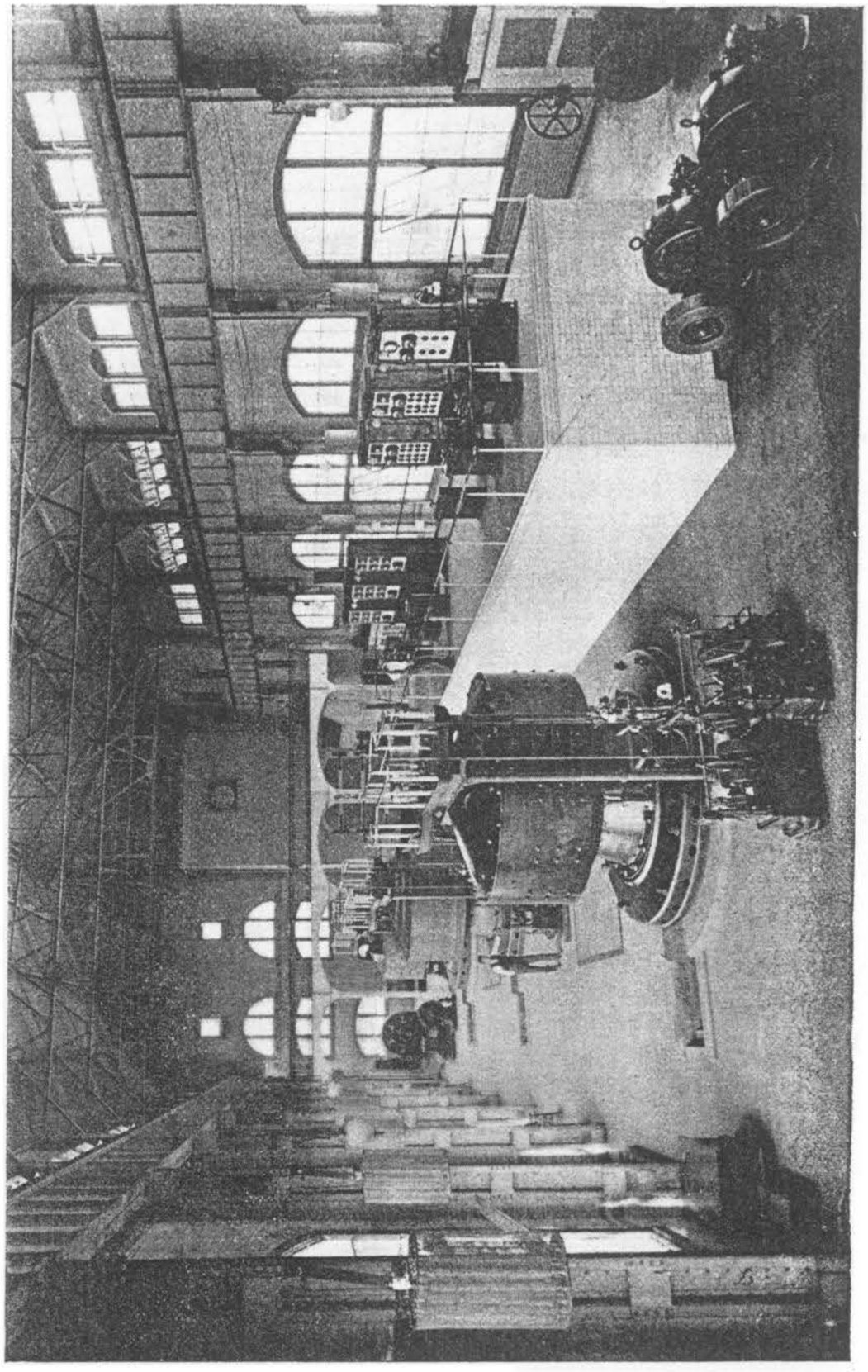


FIG. 6. INTERIOR OF THE GREAT NIAGARA POWER STATION.

In early autumn another sensational advance was scored in the starting of the enormous electric locomotives in the Baltimore & Ohio tunnel under the city of Baltimore. These colossal machines more than equalled in power the largest freight locomotives in existence, and their performance made the first great inroad into the realm of heavy railroad work,—an incursion that will be pushed into the very citadel of steam. Fig. 7 shows one of these locomotives, weighing 96 tons, and with a draw bar pull of more than 60,000 pounds.

Motor plants of every kind have multiplied, and the past year has seen greater progress than any which preceded it. Specially notable has been the transmission of power 35 miles into Fresno, Cal., at 11,000 volts,—the longest commercial transmission yet accomplished

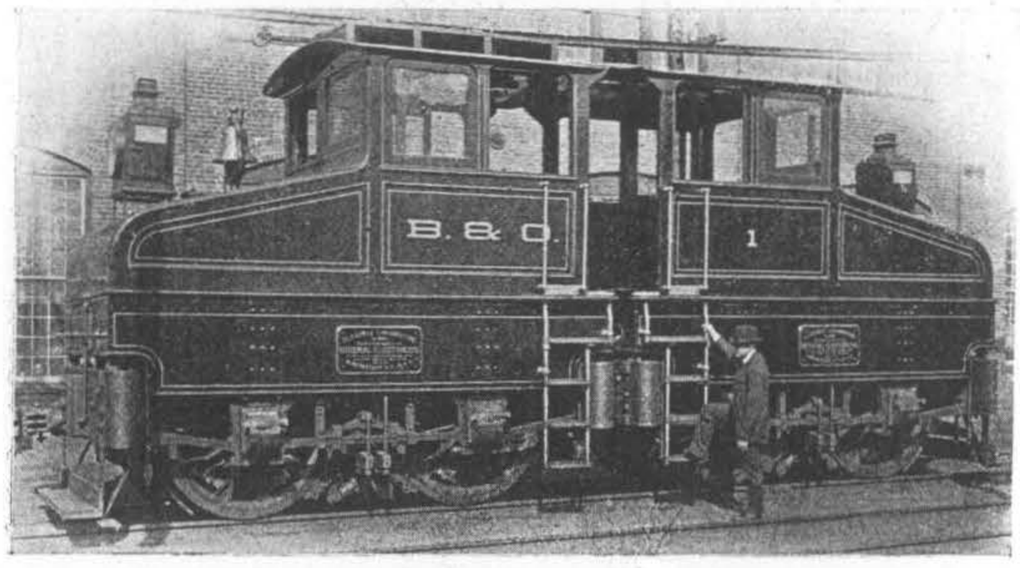


FIG. 7. BALTIMORE AND OHIO ELECTRIC LOCOMOTIVE.

anywhere; and very recently the long-delayed delivery of power from Niagara to Buffalo,—1,000 h. p. over a 27-mile line, with immense increase in immediate prospect.

And through all this growth one fact has been conspicuous; wherever electric power has come, it has found a profitable market; the steam engine has gone out, and the electric motor has come in. There has been no failure, no long struggle with unprofitable conditions; the motor has done its work, and pushed its competitors to the wall.

It is hard, indeed, to estimate the growth of electric motive power during the last decade. In place of the little group of struggling electric roads of ten years ago, we have to-day very nearly 13,000 miles of track equipped with not less than 30,000 motor cars. The railway motors in use aggregate fully a million horse power, and the generating plants close to five hundred thousand.

During the year just past, about 1,900 miles of electric-railway track have been built, and nearly 5,000 motor cars have been added to the equipment list. This increase means an aggregate investment of something like $35,000,000,—a prodigious sum to be added to a single industry in a year that has been far from prosperous.

Of stationary electric motors the number defies exact calculation, in so many directions and from so many sources has the growth extended. A single plant in New York city carries nearly 10,000 h. p. in motors upon its circuits, and the aggregate of those thus operated from central stations primarily intended for lighting certainly reaches 100,000 h. p. Those operated by scattered stations and power-transmission plants, and used in miscellaneous ways, bring the probable total amount of power to 250,000 h. p. Including railway work, it is safe to say that the gross power of the electric motors used in the United States is at present not less than 1,250,000 h. p. Of power-transmission plants proper, inaugurated mainly for motor purposes, there are now probably 150,—about 100 of them using the modern polyphase systems, which, by simplifying the question of distribution, have made power transmission practicable. A score of these plants transmit power 10 miles or more, and half a dozen over 20 miles. When we compare such a list with the little group of small power plants that were running five years ago, the strength of the cause that has scored such gains in times so troublous is self-evident.

The secret of this astonishing growth lies in the simple fact that capital will be invested to effect certain retrenchment even when it cannot be obtained for any other purpose. In prosperity men will work harder to make a dollar than to save one; in adversity this tendency is reversed.

The saving secured by the use of electric power is so considerable in many cases that ordinary prudence has demanded a sufficient investment to secure this advantage. One of the mining plants to which reference has been made has been paying for itself at the rate of five per cent. a month. Under many conditions electric power must now be regarded as an industrial necessity. Its position is secure, and the burden of proof rests to-day upon those who doubt.

For the future the outlook is bright. The pioneering period has gone by, and present successes render argument needless. The growth of the next few years will be along two lines. First, we shall see an enormous extension of electric-railway work. The steam railroads are beginning to submit to the inevitable, and one by one we shall see them employing electricity, certainly for branch and suburban service, perhaps even on long lines.

When the public wants an express service at 100 miles per hour,

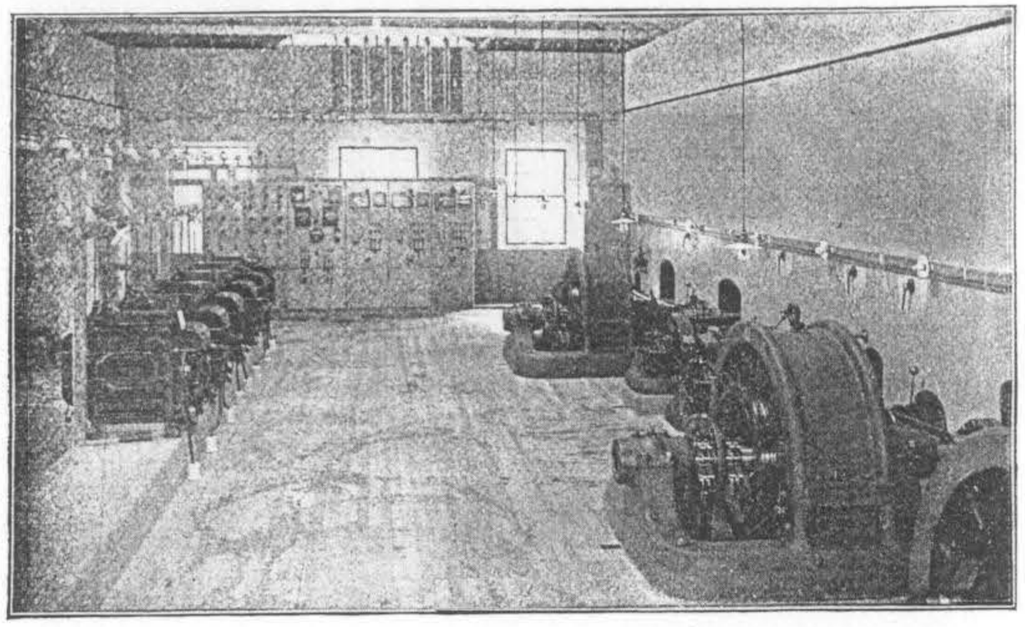
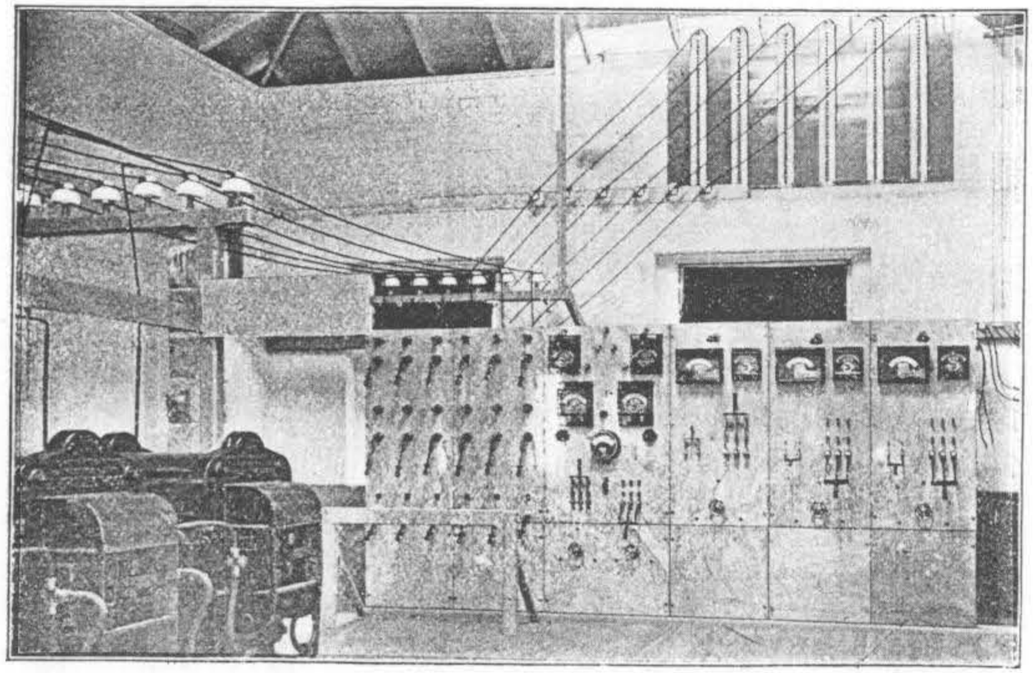


FIG. 8. THE GENERATOR ROOM OF THE FRESNO POWER-PLANT.

the means is at hand, and very little experimenting will have to be done. Not less important in its effect on the people is the growth of small electric roads in the country districts, tending to check the centralization of population and industry that is so grave a cause for anxiety in our national growth.



HIGH TENSION LINES LEADING FROM THE FRESNO STATION.

Second, there will be in the immediate future an immense development of the natural power resources of the country. One of the curious results of the power-transmission work already accomplished has been the rediscovery of numerous water powers which were quite forgotten until electrical power transmission called attention to them. Some of these have lurked in the most unsuspected places, where all the conspicuous powers had long ago been utilized. There are unemployed water powers enough within fifty miles of New York to displace every steam engine in the metropolis at a profit, if they were but rendered available.

It is now certain that the distance mentioned can be successfully overcome by apparatus already available. The recent transmission of power 35 miles into Fresno, Cal., already mentioned, has made clear the way, and no appreciable difficulties can be met in fifteen or twenty miles more. This Fresno plant, notable as the longest transmission in the world, is worthy of further description. The power house far up among the hills is shown in Fig. 8. The motive power is obtained from Pelton wheels working under an effective head of more than 1,400 feet. Each wheel is directly coupled to a three-phase generator, delivering current to the raising transformers at a pressure of 700 volts. It leaves the transformers at 11,000 volts for its long line through the foot hills and the San Joaquin valley into Fresno.

The present transmission is about 1,000 h. p., devoted to the distribution of light and power in Fresno and neighboring towns. Until this line went into operation, there was some distrust of very-long-distance work, some fears of unexpected and unpleasant developments that might be met on very long alternating-current circuits. These fears have now been finally dispelled by success, and, long before the power of Niagara was delivered in Buffalo, the success of that momentous enterprise was made certain, so far as electrical difficulties go, by the experience acquired in distant California.

With the power of overcoming long distances that has now been gained, a field is opened for the employment of electric power, the extent of which nothing short of prophesy can estimate. Not less than 5,000,000 hydraulic h. p. is ready to be utilized in this country of ours, when industry calls for it. Water power, to be sure, is not invariably a cheaper source of energy than coal, but the chances are generally in its favor.

And when water power is unavailable, there remains the splendid possibility of transmitting electrical energy instead of hauling coal,—taking the fuel at the pit's mouth and using it to spin electric motors in the thousand factories of a city fifty or one hundred miles away. The first steps have been taken in this direction already, and some

progress, at least, is certain. The time has come when cities will begin to defend themselves against the defilement of the free air. The smoke palls that hang gloomily over most large cities are blots on our boasted civilization, and they are to-day without the excuse of necessity or economy. More than this, they have passed beyond the bounds of toleration, and the general tendency of municipal legislation is now to enforce the remedy which hygiene, comfort, and domestic economy unite in demanding.

There is no good reason why every wheel that turns within the limits of a large city should not derive its motive power from a plant far beyond the city limits. Moreover, at prices now reached not infrequently by electrical-transmission plants, heating by electricity becomes economically practicable. With heat, light, and power derived from a single great plant, almost ideal conditions are realized, and such a possibility is now within our reach. When so splendid a goal is in sight, there is little chance that the advantage already gained will be lost through slothfulness and neglect, and for the great tasks pertaining to human industry electrical power will ere long have no serious competitor.

The illustrations of the Miesbach power station and the Hercules mining machine are republished by permission of *The Electrical World*.

TESLA'S NEW INTERRUPTER.

An Electrical Current Broken 80,000 000 Times a Second.

Nikola Tesla, the great electrician, has just taken outS patents for a device for producing almost incalculable electrical vibrations, and the Electrical Review gives a full description of the invention and its uses. It was by the use of this device that Mr: Tesla has been able to demonstrate the scientific possibility of producing brilliant illumination by means of vacuum tubes that were not in mechanical contact with the electric source. Under the influence of a current of electricity interrupted 60,000,000 or 80,000,000 times a second the tubes with which Mr. Tesla was experimenting burst into brilliant white light, which was demonstrated by photography to be much more powerful than the arc electric light, although the tubes were entirely disconnected and stood so far away from the exciting coils that Mr. Tesla sat in a large armchair between the tubes and the coil while he was photographed by the light of the tubes. No such effect has ever been produced by any other means, and this gives only a rough indication of the ways in which Mr. Tesla's latest patented device may be of use in the arts. For the production of Roetgen rays, the making of ozone and argon, and for electro-therapeutic treatment, the new device will find immediate use. The interruption of electrical currents for the purpose of breaking these currents into electrical waves or vibrations has heretofore been a mechanical operation. In its simplest this is done by the commutator or vibrating armature of the Rumfkoff induction coil. The vibrations of such an armature or even of the needle with which the armature has been replaced in some devices, must be confined within the narrow limit of a few hundred to the second. Rotating interrupters, connecting and breaking the electrical circuit, with a change in the position of their teeth as they revolved, added much to the number of interruptions which could be obtained, but even their best speed bore but a pitiful relationship to the 100,000,000 or more vibrations a second which Mr. Tesla calculates that he has obtained from his device.

The simplicity of the latter is one of its remarkable features.



THE TESLA PATENTS REVOKED IN GERMANY.

The Elektrotechnische Zeitschrift quoting the Köln. Ztg. states that the suit of the Allgemeine Elektricitäts-Gesellschaft of Berlin against the Aktien-Gesellschaft Helios of Cologne, for the revocation of the Tesla patents was tried before the German Patent Office and resulted in the revocation of the patents according to paragraph 11 of the German Patent Laws. The case will be appealed to the Imperial Court by the Helios Company. Just what "Tesla patents" were revoked is not stated. The term is usually applied in this country to those dealing with induction motors requiring phase currents for their operation.

The paragraph of the German Patent Law above referred to reads as follows.

§ 11. A patent can be revoked after the expiration of three years, reckoned from the date of publication of allowance.

1. If the patentee fails to carry out his invention in Germany to a suitable extent, or at least to do everything that is necessary to ensure its being carried out.

2. If the grant of license to others for using the invention appears to be demanded in the interest of public welfare, but the patentee nevertheless refuses to grant such license upon adequate compensation and against sufficient security.

Tesla Experiments. VICENTINI and PACKER. Lond. *Elec.*, Jan. 1; noticed briefly from *Nuovo Cimento*, October —They describe some experiments made with large glass plates covered with tinfoil; also an instrument called a siren, operated by Tesla discharges and producing notes from a low pitch up to one transcending the limits of hearing.

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WHAT WILL SHE DO WITH IT?

THE marriage union of Niagara with Buffalo was celebrated last week, three months after the consummation. But in reality, the festivities were precipitate rather than tardy, for had matters been left to the ordinary course of physical events, the arrival of Niagara at Buffalo would be a convivial opportunity for our descendants 60,000 years hence. A little computation will show that at its crab-like travel of two feet a year, Niagara would not have eaten its way backward through shale and limestone to the water front of Buffalo in any shorter period. Thus do the modern inventor and the genius of electricity anticipate the flight of time. It is curious that the same year which learned the discovery of the supersubtle X-ray should have witnessed, at the other end of electricity's scale, the harnessing and distribution of Niagara's illimitable energy. The year 1896 was memorable, and when we have fairly emerged from its wrecks and disasters we shall recognize its many lasting benefits. In America we established anew our national honor; we vindicated our right to lordship in this Western world; by a treaty of arbitration we federated willing England into the American Union of mutually pacific States; and chief among the triumphs of peace, we subdued nature at Niagara that we might give larger liberty to every American workman.

How wild and fantastic it all seemed a few short years ago, this Niagara project! The tightrope dancer balancing himself painfully above the roaring, awful abyss of the Falls had not more nerve and courage than the men whose money and brain have created a new power center for the world, to whose balance industries must now poise themselves as do peoples in international politics. A region of 22 miles radius, with Buffalo as its center of attraction and Niagara as its source of power, has within six years been made the potential heart of manufactures in the United States. The organizers of the great enterprise have gone to Niagara and after a brief but decisive struggle are able to turn around and say to all who need cheap power and are willing to come to the Buffalo region for it: "We have met the great Cataract—and she is yours." The Delilah who has tamed this Samson of water powers can invite us all to witness and enjoy the spectacle, without fear of harm or future danger for anyone, and in the knowledge that Samson is the better man for having his hair cut in a civilized fashion. Of a truth, the salad, festive days of Niagara are over, and a career of strenuous effort has begun. While the older methods of utilization disfigured her, this modern plan is unobstrusive in its continuation or protection of her charms. As a matter of fact, the power of Niagara has more beauty than her beauty has power, for hitherto the human intellect and imagination have avoided her as a background for their creations. Ideas vary as to desirable qualities. Dean Stanley admired Jenny Lind immensely, but said she would have been simply delightful if she had not sung. The deep note of Niagara is now mitigated into the cheerful hum of toil; the present picturesque aspect of the Falls is preserved and conserved; Buffalo has attained the long-felt wish of seeing Niagara at play and work in her back yard—and the Power company is already selling 25,000 horse-power for somewhere around half a million dollars a year. Is not this a happy result in common for aesthete, financier, inventor and engineer? And how rarely it happens!

To Buffalo we would simply address the friendly admonition of liberality. It has cost that city absolutely nothing to have the power of Niagara brought to her doors. Freely she has received, freely let her give. Now is the time for her to encourage the Niagara Power Company to spend more money in her behalf. The whole question now that Buffalo has got the power is: What will she do with it? If she reward largeness of enterprise with corresponding largeness of welcome, there is no doubt as to her future. No greater mistake can be made than for people or city to stand suspiciously aloof when great progressive enterprises touching their welfare are afoot. "We don't own it," growled a passenger angrily when disturbed in his sleep and told that his services were needed at the pumps because the steamer was going down. Such narrowness of mind is always suicidal, and nothing that represents thrift, property and courage is ever injuriously affected without the community feeling it far more than the few individuals. The dignified and manly plea of Mr. Stetson at the banquet, for honorable treatment of his company which right through the hard times has spent its money with Niagara profusion, must find a cordial response from every public-spirited Buffalonian.

In a sense, the Niagara-Buffalo banquet was a distinct tribute to the modern electrical inventor, and as all these sentiments crystallize around personalities, the honors were paid very appropriately to Mr. Tesla, who when everybody else felt dubious, said the thing must be, taught us how to do it—and it is. That such men as Brush, Thomson, Sprague and other electricians were there to share these honors, was eminently fitting and fortunate, for while each great worker does something, no one genius can do it all. What such men need from us is encouragement, sympathy, applause. The hanging of Frank Sprague in effigy at Louisville because his trolley freed the mule, simply shows that the way of the inventor, like that of other transgressors, is generally hard. The extent of his innovation marks the degree of his impropriety, and society has usually seen to it in days gone by that the punishment should fit the crime. Even now, when the inventor is becoming more and more a person to magnify, it is all struggle for him; frequent defeat, rare victory; headlong torrents and sheer cliffs to breast and lift above; and once in a while, like Capt. Webb, the brave swimmer is carried under, a victim to his own intrepidity. We cannot follow these men in all their efforts and intuitions, but we can feel for them as fellows, sorrow when achievement lingers, rejoice when victory greets some golden morning, and, as on occasions like this Niagara banquet, drink royal toasts of amity and admiration in their honor.

Banquet Celebrating the Niagara Falls Transmission.

At the Ellicott Club in Buffalo, on Tuesday of last week, was held the banquet to celebrate the successful transmission of the power of Niagara Falls to Buffalo. About 400 guests were present. Among them were Niko a Tesla of New York, Elihu Thomson of Lynn, Mass., E. J. Houston of Philadelphia, Charles F. Brush of Cleveland, Elisha Gray of Chicago, Charles A. Coffin of Boston, George Westinghouse of Pittsburg, John E. Hudson of Boston, W. J. Johntson, D. O. Mills, Edward A. Adams, Francis Lynde Stetson, Charles Lanier and W. J. Arkel of New York, Enos Barton of Chicago, W. H. Lawrence of Cleveland, Frederic A. Nichols of Toronto, Dr. Louis Duncan of Baltimore, C. A. Cutler of New York, S. Dana Green of Schenectady, Dr. Coleman Sellers of Philadelphia, Joseph Wetzler and T. C. Martin of New York.

Letters of regret were read from President Cleveland, President elect McKinley, Governor Black and others.

When the menu had been disposed of, Francis Lynde Stetson acted as toastmaster. The toast "The Company" was responded to by Mr. Stetson himself; "Welcome to Buffalo," by Mayor Jewett; "The Empire State," by Controller Roberts; "Electricity," by Nikola Tesla; "The City of Buffalo," by Charles W. Goodyear; "Water Power," by Charles A. Pillsbury of Minneapolis.

TESLA ON ELECTRICITY.

HIS ADDRESS IN FULL ON THE OCCASION OF THE COMMEMORATION OF THE INTRODUCTION OF NIAGARA FALLS POWER IN BUFFALO AT THE ELLICOTT CLUB, JANUARY 12, 1897.

I have scarcely had courage enough to address an audience on a few unavoidable occasions, and the experience of this evening, even as disconnected from the cause of our meeting, is quite novel to me. Although in those few instances, of which I have retained agreeable memory, my words have met with a generous reception, I never deceived myself, and knew quite well that my success was not due to any excellency in the rhetorical or demonstrative art. Nevertheless, my sense of duty to respond to the request with which I was honored a few days ago was strong enough to overcome my very grave apprehensions in regard to my ability of doing justice to the topic assigned to me. It is true, at times—even now, as I speak—my mind feels full of the subject, but I know that, as soon as I shall attempt expression, the fugitive conceptions will vanish, and I shall experience certain well known sensations of abandonment, chill and silence. I can see already your disappointed countenances and can read in them the painful regret of the mistake in your choice.

These remarks, gentlemen, are not made with the selfish desire of winning your kindness and indulgence on my shortcomings, but with the honest intention of offering you an apology for your disappointment. Nor are they made—as you might be disposed to think—in that playful spirit which, to the enjoyment of the listeners, is often displayed by belated speakers. On the contrary, I am deeply earnest in my wish that I were capable of having the fire of eloquence kindled in me, that I might dwell in adequate terms on this fascinating science of electricity, on the marvelous development which electrical annals have recorded and which, as one of the speakers justly remarked, stamp this age as the Electrical Age, and particularly on the great event we are commemorating this day. Unfortunately, this my desire must remain unfulfilled, but I am hopeful that in my formless and incomplete statements, among the few ideas and facts I shall mention there may be something of interest and usefulness, something befitting this unique occasion.

Gentlemen, there are a number of features clearly discernible in, and characteristic of, human intellectual progress in more recent times—features which afford great comfort to the minds of all those who have really at heart the advancement and welfare of mankind.

First of all, the inquiry, by the aid of the microscope and electrical instruments of precision, into the nature of our organs and senses, and particularly of those through which we commune directly with the outside world and through which knowledge is conveyed to our minds, has revealed their exact construction and mode of action, which is in conformity with simple and well established physical principles and laws. Hence the observations we make and the facts we ascertain by their help are *real* facts and observations, and our knowledge is *true* knowledge. To illustrate: Our knowledge of form, for instance, is dependent upon the positive fact that light propagates in straight lines, and, owing to this, the image formed by a lens is exactly similar to the object seen. Indeed, my thoughts in such fields and directions have led me to the conclusion that most all human knowledge is based on this simple truth, since practically every idea or conception—and therefore all knowledge—presupposes visual impressions. But if light would not propagate in accordance with the law mentioned, but in conformity with any other law which we might presently conceive, whereby not only the image might not bear any likeness to the object seen, but even the images of the same object at different times or distances might not resemble each other, then our knowledge of form would be very defective, for then we might see, for example, a three-cornered figure as a six or twelve-cornered one. With the clear understanding of the mechanism and mode of action of our organs, we remove all doubts as to the *reality* and *truth* of the impressions received from the outside, and thus we bar out—forever, we may hope—that unhealthy speculation and skepticism into which formerly even strong minds were apt to fall.

Let me tell you of another comforting feature. The progress in a measured time is nowadays more rapid and greater than it ever was before. This is quite in accordance with the fundamental law of motion, which commands acceleration and increase of momentum or accumulation of energy under the action of a continuously acting force and tendency, and is the more true as every advance weakens the elements tending to produce friction and retardation. For, after all, what *is* progress, or—more correctly—development, or evolution, if not a movement, infinitely complex and often unscrutinizable, it is true, but nevertheless exactly determined in quantity as well as in quality of motion by the physical conditions and laws governing? This feature of more recent development is best shown in the rapid merging together of the various arts and sciences by the obliteration of the hard and fast lines of separation, of borders, some of which only a few years ago seemed unsurpassable, and which, like veritable Chinese walls, surrounded every department of inquiry and barred progress. A sense of connectedness of the various apparently widely different forces and phenomena we observe is taking possession of our minds, a sense of deeper understanding of nature as a whole, which, though not yet quite clear and defined, is keen enough to inspire us with the confidence of vast realizations in the near future.

But these features chiefly interest the scientific man, the thinker and reasoner. There is another feature which affords us still more satisfaction and enjoyment, and which is of still more universal interest, chiefly because of its bearing upon the welfare of mankind. Gentlemen, there is an influence which is getting strong and stronger day by day, which shows itself more and more in all departments of human activity, an influence most fruitful and beneficial—the influence of the artist. It was a happy day for the mass of humanity when the artist felt the desire of becoming a physician, an electrician, an engineer or mechanician or—whatnot—a mathematician or a financier; for it was he who wrought all these wonders and grandeur we are witnessing. It was he who abolished that small, pedantic, narrow-grooved school teaching which made of an aspiring student a galley-slave, and he who allowed freedom in the choice of subject of study according to one's pleasure and inclination, and so facilitated development.

Some, who delight in the exercise of the powers of criticism, call this an assymetrical development, a degeneration or departure from the normal, or even a degradation of the race. But they are mistaken. This is a welcome state of things, a blessing, a wise subdivision of labors, the establishment of conditions most favorable to progress. Let one concentrate all his energies in one single great effort, let him perceive a single truth, even though he be consumed by the sacred fire, then millions of less gifted men can easily follow. Therefore it is not as much quantity as quality of work which determines the magnitude of the progress.

It was the artist, too, who awakened that broad philanthropic spirit which, even in old ages, shone in the teachings of noble reformers and philosophers, that spirit which makes men in all departments and positions work not as much for any material benefit or compensation—though reason may command this also—but chiefly for the sake of success, for the pleasure there is in achieving it and for the good they might be able to do thereby to their fellow-men. Through his influence types of men are now pressing forward, impelled by a deep love for their study, men who are doing wonders in their respective branches, whose chief aim and enjoyment is the acquisition and spread of knowledge, men who look far above earthly things, whose banner is Excelsior! Gentlemen, let us honor the artist, let us thank him, let us drink his health!

Now, in all these enjoyable and elevating features which characterize modern intellectual development, electricity, the expansion of the science of electricity, has been a most potent factor. Electrical science has revealed to us the true nature of light, has provided us with innumerable appliances and instruments of precision, and has thereby vastly added to the exactness of our knowledge. Electrical science has disclosed to us the more intimate relation existing between widely different forces and phenomena and has thus led us to a more complete comprehension of Nature and its many manifestations to our senses Electrical science, too, by its fascination, by its promises of immense realizations, of wonderful possibilities chiefly in humanitarian respects, has attracted the attention and enlisted the energies of the artist; for where is there a field in which his God-given powers would be of greater benefit to his fellow-men than this unexplored, almost virgin, region, where, like in a silent forest, a thousand voices respond to every call?

With these comforting features, with these cheering prospects, we need not look with any feeling of incertitude or apprehension into the future. There are pessimistic men, who, with anxious faces, continuously whisper in your ear that the nations are secretly arming—arming to the teeth: that they are going to pounce upon each other at a given signal and destroy themselves; that they are all trying to outdo that victorious, great, wonderful German army, against which there is no resistance, for every German has the discipline in his very blood—every German is a soldier. But these men are in error. Look only at our recent experience with the British in that Venezuela difficulty. Two other nations might have crashed together, but not the Anglo-Saxons; they are too far ahead. The men who tell you this are ignoring forces which are continually at work, silently but resistlessly—forces which say Peace!

There is the genuine artist, who inspires us with higher and nobler sentiments, and makes us abhor strife and carnage. There is the engineer, who bridges gulfs and chasms, and facilitates contact and equalization of the heterogeneous masses of humanity. There is the mechanic, who comes with his beautiful time and energy-saving appliances, who perfects his flying machine, not to drop a bag of dynamite on a city or vessel, but to facilitate transport and travel. There, again, is the chemist, who opens new resources and makes existence more pleasant and secure; and there is the electrician, who sends his messages of peace to all parts of the globe. The time will not be long in coming when those men who are turning their ingenuity to inventing quick-firing guns, torpedoes and other implements of destruction—all the while assuring you that it is for the love and good of humanity—will find no takers for their odious tools, and will realize that, had they used their inventive talent in other directions, they might have reaped a far better reward than the sestertia received. And then, and none too soon, the cry will be echoed everywhere. Brethren, stop these highhanded methods of the strong, these remnants of barbarism so inimical to progress! Give that valiant warrior opportunities for displaying a more commendable courage than that he shows when, intoxicated with victory, he rushes to the destruction of his fellow-men. Let him toil day and night with a small chance of achieving and yet be unflinching; let him challenge the dangers of exploring the heights of the air and the depths of the sea; let him brave the dread of the plague, the heat of the tropic desert and the ice of the polar region. Turn your energies to warding off the common enemies and dangers, the perils that are all around you, that threaten you in the air you breathe, in the water you drink, in the food you consume. Is it not strange, is it not shame, that we, beings in the highest state of development in this our world, beings with such immense powers of thought and action, we, the masters of the globe, should be absolutely at the mercy of our unseen foes, that we should not know whether a swallow of food or drink brings joy and life or pain and destruction to us! In this most modern and sensible warfare, in which the bacteriologist leads, the services electricity will render will prove invaluable. The economical production of high-frequency currents, which is now an accomplished fact, enables us to generate easily and in large quantities ozone for the disinfection of the water and the air, while certain novel radiations recently discovered give hope of finding effective remedies against ills of microbic origin, which have heretofore withstood all efforts of the physician. But let me turn to a more pleasant theme.

I have referred to the merging together of the various sciences or departments of research, and to a certain perception of intimate connection between the manifold and apparently different forces and phenomena. Already we know, chiefly through the efforts of a bold pioneer, that light, radiant heat, electrical and magnetic actions are closely related, not to say identical. The chemist professes that the effects of combination and separation of bodies he observes are due to electrical forces, and the physician and physiologist will tell you that even life's progress is electrical. Thus electrical science has gained a universal meaning, and with right this age can claim the name "Age of Electricity."

I wish much to tell you on this occasion—I may say I actually burn for desire of telling you—what electricity really *is*, but I have very strong reasons, which my co-workers will best appreciate, to follow a precedent established by a great and venerable philosopher, and I shall not dwell on this purely scientific aspect of electricity.

There is another reason for the claim which I have before stated which is even more potent than the former, and that is the immense development in all electrical branches in more recent years and its influence upon other departments of science and industry. To illustrate this influence I only need to refer to the steam or gas engine. For more than half a century the steam engine has served the innumerable wants of man. The work it was called to perform was of such variety and the conditions in each case were so different that, of necessity, a great many types of engines have resulted. In the vast majority of cases the problem put before the engineer was not, as it should have been, the broad one of converting the greatest possible amount of heat energy into mechanical power, but it was rather the specific problem of obtaining the mechanical power in such form as to be best suitable for general use. As the reciprocating motion of the piston was not convenient for practical purposes, except in very few instances, the piston was connected to a crank, and thus rotating motion was obtained, which was more suitable and preferable, though it involved numerous disadvantages incident to the crude and wasteful means employed. But until quite recently there were at the disposal of the engineer, for the transformation and transmission of the motion of the piston, no better means than rigid mechanical connections. The past few years have brought forcibly to the attention of the builder the electric motor, with its ideal features. Here was a mode of transmitting mechanical motion simpler by far, and also much more economical Had this mode been perfected earlier, there can be no doubt that, of the many different types of engine, the majority would not exist, for just as soon as an engine was coupled with an electric generator a type was produced capable of almost universal use. From this moment on there was no necessity to endeavor to perfect engines of special designs capable of doing special kinds of work. The engineer's task became now to concentrate all his efforts upon one type, to perfect one kind of engine—the best, the universal, the engine of the immediate future; namely, the one which is best suitable for the generation of electricity. The first efforts in this direction gave a strong impetus to the development of the reciprocating high-speed engine, and also to the turbine, which latter was a type of engine of very limited practical usefulness, but became, to a certain extent, valuable in connection with the electric generator and motor. Still, even the former engine, though improved in many particulars, is not radically changed, and even now has the same objectionable features and limitations. To do away with these as much as possible, a new type of engine is being perfected in which more favorable conditions for economy are maintained, which expands the working fluid with utmost rapidity and loses little heat on the walls, an engine stripped of all usual regulating mechanism—packings, oilers and other appendages—and forming part of an electric generator; and in this type, I may say, I have implicit faith.

The gas or explosive engine has been likewise profoundly affected by the commercial introduction of electric light and power, particularly in quite recent years. The engineer is turning his energies more and more in this direction, being attracted by the prospect of obtaining a higher thermodynamic efficiency. Much larger engines are now being built, the construction is constantly improved, and a novel type of engine, best suitable for the generation of electricity, is being rapidly evolved.

There are many other lines of manufacture and industry in which the influence of electrical development has been even more powerfully felt. So, for instance, the manufacture of a great variety of articles of metal, and especially of chemical products. The welding of metals by electricity, though involving a wasteful process, has, nevertheless, been accepted as a legitimate art, while the manufacture of metal sheet, seamless tubes and the like affords promise of much improvement. We are coming gradually, but surely, to the fusion of bodies and reduction of all kinds of ores—even of iron ores—by the use of electricity, and in each of these departments great realizations are probable. Again, the economical conversion of ordinary currents of supply into high-frequency currents opens up new possibilities, such as the combination of the atmospheric nitrogen and the production of its compounds; for instance, ammonia and nitric acid, and their salts, by novel processes.

The high-frequency currents also bring us to the realization of a more economical system of lighting; namely, by means of phosphorescent bulbs or tubes, and enable us to produce with these appliances light of practically any candle-power. Following other developments in purely electrical lines, we have all rejoiced in observing the rapid strides made, which, in quite recent years, have been beyond our most sanguine expectations. To enumerate the many advances recorded is a subject for the reviewer, but I can not pass without mentioning the beautiful discoveries of Lenard and Roentgen, particularly the latter, which have found such a powerful response throughout the scientific world that they have made us forget, for a time, the great achievement of Linde in Germany, who has effected the liquefaction of air on an industrial scale by a process of continuous cooling; the discovery of argon by Lord Rayleigh and Professor Ramsay, and the splendid pioneer work of Professor Dewar in the field of low temperature research. The fact that the United States have contributed a very liberal share to this prodigious progress must afford to all of us great satisfaction. While honoring

the workers in other countries and all those who, by profession or inclination, are devoting themselves to strictly scientific pursuits, we have particular reasons to mention with gratitude the names of those who have so much contributed to this marvelous development of electrical industry in this country. Bell, who, by his admirable invention enabling us to transmit speech to great distances, has profoundly affected our commercial and social relations, and even our very mode of life; Edison, who, had he not done anything else beyond his early work in incandescent lighting, would have proved himself one of the greatest benefactors of the age; Westinghouse, the founder of the commercial alternating system; Brush, the great pioneer of arc lighting; Thomson, who gave us the first practical welding machine, and who, with keen sense, contributed very materially to the development of a number of scientific and industrial branches; Weston, who once led the world in dynamo design, and now leads in the construction of electric instruments; Sprague, who, with rare energy, mastered the problem and insured the success of practical electrical railroading; Acheson, Hall, Willson and others, who are creating new and revolutionizing industries here under our very eyes at Niagara. Nor is the work of these gifted men nearly finished at this hour. Much more is still to come, for, fortunately, most of them are still full of enthusiasm and vigor. All of these men and many more are untiringly at work investigating new regions and opening up unsuspected and promising fields. Weekly, if not daily, we learn through the journals of a new advance into some unexplored region, where at every step success beckons friendly, and leads the toiler on to hard and harder tasks.

But among all these many departments of research, these many branches of industry, new and old, which are being rapidly expanded, there is one dominating all others in importance—one which is of the greatest significance for the comfort and welfare, not to say for the existence, of mankind, and that is the electrical transmission of power. And in this most important of all fields, gentlemen, long afterwards, when time will have placed the events in their proper perspective, and assigned men to their deserved places, the great event we are commemorating to-day will stand out as designating a new and glorious epoch in the history of humanity—an epoch grander than that marked by the advent of the steam engine. We have many a monument of past ages; we have the palaces and pyramids, the temples of the Greek and the cathedrals of Christendom. In them is exemplified the power of men, the greatness of nations, the love of art and religious devotion. But that monument at Niagara has something of its own, more in accord with our present thoughts and tendencies. It is a monument worthy of our scientific age, a true monument of enlightenment and of peace. It signifies the subjugation of natural forces to the service of man, the discontinuance of barbarous methods, the relieving of millions from want and suffering. No matter what we attempt to do, no matter to what fields we turn our efforts, we are dependent on power. Our economists may propose more economical systems of administration and utilization of resources, our legislators may make wiser laws and treaties, it matters little; that kind of help can be only temporary. If we want to reduce poverty and misery, if we want to give to every deserving individual what is needed for a safe existence of an intelligent being, we want, to provide more machinery, more power. Power is our mainstay, the primary source of our many-sided energies. With sufficient power at our disposal we can satisfy most of our wants and offer a guaranty for safe and comfortable existence to all, except perhaps to those who are the greatest criminals of all—the voluntarily idle.

The development and wealth of a city, the success of a nation, the progress of the whole human race, is regulated by the power available. Think of the victorious march of the British, the like of which history has never recorded. Apart from the qualities of the race, which have been of great moment, they own the conquest of the world to—coal. For with coal they produce their iron; coal furnishes them light and heat; coal drives the wheels of their immense manufacturing establishments, and coal propels their conquering fleets. But the stores are being more and more exhausted, the labor is getting dearer and dearer, and the demand is continuously increasing. It must be clear to every one that soon some new source of power supply must be opened up, or that at least the present methods must be materially improved. A great deal is expected from a more economical utilization of the stored energy of the carbon in a battery; but while the attainment of such a result would be hailed as a great achievement, it would not be as much of an advance towards the ultimate and permanent method of obtaining power as some engineers seem to believe. By reasons both of economy and convenience we are driven to the general adoption of a system of energy supply from central stations, and for such purposes the beauties of the mechanical generation of electricity can not be exaggerated. The advantages of this universally accepted method are certainly so great that the probability of replacing the engine dynamos by batteries is, in my opinion, a remote one, the more so as the high-pressure steam engine and gas engine give promise of a considerably more economical thermodynamic conversion. Even if we had this day such an economical coal battery, its introduction in central stations would by no means be assured, as its use would entail many inconveniences and drawbacks. Very likely the carbon could not be burned in its natural form as in a boiler, but would have to be specially prepared to secure uniformity in the current generation. There would be a great many cells needed to make up the electro-motive force usually required. The process of cleaning and renewal, the handling of nasty fluids and gases and the great space necessary for so many batteries would make it difficult, if not commercially unprofitable, to operate such a plant in a city or densely populated district. Again, if the station be erected in the outskirts, the conversion by rotating transformers or otherwise would be a serious and unavoidable drawback. Furthermore, the regulating appliances and other accessories which would have to be provided would probably make the plant fully as much, if not more, complicated than the present. We might, of course, place the batteries at or near the coal mine, and from there transmit the energy to distant points in the form of high-tension alternating currents obtained from rotating transformers, but even in this most favorable case the process would be a barbarous one, certainly more so than the present, as it would still involve the consumption of material, while at the same time it would restrict the engineer and mechanic in the exercise of their beautiful art. As to the energy supply in small isolated places as dwellings, I have placed my confidence in the development of a light storage battery, involving the use of chemicals manufactured by cheap water power, such as some carbide or oxygen-hydrogen cell.

But we shall not satisfy ourselves simply with improving steam and explosive engines or inventing new batteries; we have something much better to work for, a greater task to fulfill. We have to evolve means for obtaining energy from stores which are forever inexhaustible, to perfect methods which do not imply consumption and waste of any material whatever. Upon this great possibility, which I have long ago recognized, upon this great problem, the practical solution of which means so much for humanity, I have myself concentrated my efforts since a number of years, and a few happy ideas which came to me have inspired me to attempt the most difficult, and given me strength and courage in adversity. Nearly six years ago my confidence had become strong enough to prompt me to an expression of hope in the ultimate solution of this all-dominating problem. I have made progress since, and have passed the stage of mere conviction such as is derived from a diligent study of known facts, conclusions and calculations. I now feel sure that the realization of that idea is not far off. But precisely for this reason I feel impelled to point out here an important fact, which I hope will be remembered. Having examined for a long time the possibilities of the development I refer to, namely, that of the operation of engines on any point of the earth by the energy of the medium, I find that even under the theoretically best conditions such a method of obtaining power can not equal in economy, simplicity and many other features the present method, involving a conversion of the mechanical energy of running water into electrical energy and the transmission of the latter in the form of currents of very high tension to great distances. Provided, therefore, that we can avail ourselves of currents of sufficiently high tension, a waterfall affords us the most advantageous means of getting power from the sun sufficient for all our wants, and this recognition has impressed me strongly with the future importance of the water power, not so much because of its commercial value, though it may be very great, but chiefly because of its bearing upon our safety and welfare. I am glad to say that also in this latter direction my efforts have not been unsuccessful, for I have devised means which will allow us the use in power transmission of electro-motive forces much higher than those practicable with ordinary apparatus. In fact, progress in this field has given me fresh hope that I shall see the fulfillment of one of my fondest dreams; namely, the transmission of power from station to station without the employment of any connecting wire. Still, whatever method of transmission be ultimately adopted, nearness to the source of power will remain an important advantage.

Gentlemen, some of the ideas I have expressed may appear to many of you hardly realizable; nevertheless, they are the result of long-continued thought and work. You would judge them more justly if you would have devoted your life to them, as I have done. With ideas it is like with dizzy heights you climb: At first they cause you discomfort and you are anxious to get down, distrustful of your own powers; but soon the remoteness of the turmoil of life and the inspiring influence of the altitude calm your blood; your step gets firm and sure and you begin to look—for dizzier heights. I have attempted to speak to you on "Electricity," its development and influence, but I fear that I have done it much like a boy who tries to draw a likeness with a few straight lines. But I have endeavored to bring out one feature, to speak to you in one strain which I felt sure would find response in the hearts of all of you, the only one worthy of this occasion—the humanitarian. In the great enterprise at Niagara we see not only a bold engineering and commercial feat, but far more, a giant stride in the right direction as indicated both by exact science and philanthropy. Its success is a signal for the utilization of water powers all over the world, and its influence upon industrial development is incalculable. We must all rejoice in the great achievement and congratulate the intrepid pioneers who have joined their efforts and means to bring it about. It is a pleasure to learn of the friendly attitude of the citizens of Buffalo and of the encouragement given to the enterprise by the Canadian authorities. We shall hope that other cities, like Rochester on this side and Hamilton and Toronto in Canada, will soon follow Buffalo's lead. This fortunate city herself is to be congratulated. With resources now unequaled, with commercial facilities and advantages such as few cities in the world possess, and with the enthusiasm and progressive spirit of its citizens, it is sure to become one of the greatest industrial centers of the globe.

X RAYS, APPARATUS AND METHODS.

ABSTRACT OF PAPER READ BEFORE THE ELECTRICAL SECTION OF THE FRANKLIN INSTITUTE, PHILADELPHIA, DECEMBER 1, 1896, BY ELMER G. WILLYOUNG AND H. LYMAN SAYEN.

That Professor Roentgen's discovery of the X ray has initiated many lines of thought promising to greatly extend our knowledge of physical phenomena, as well as to revise many

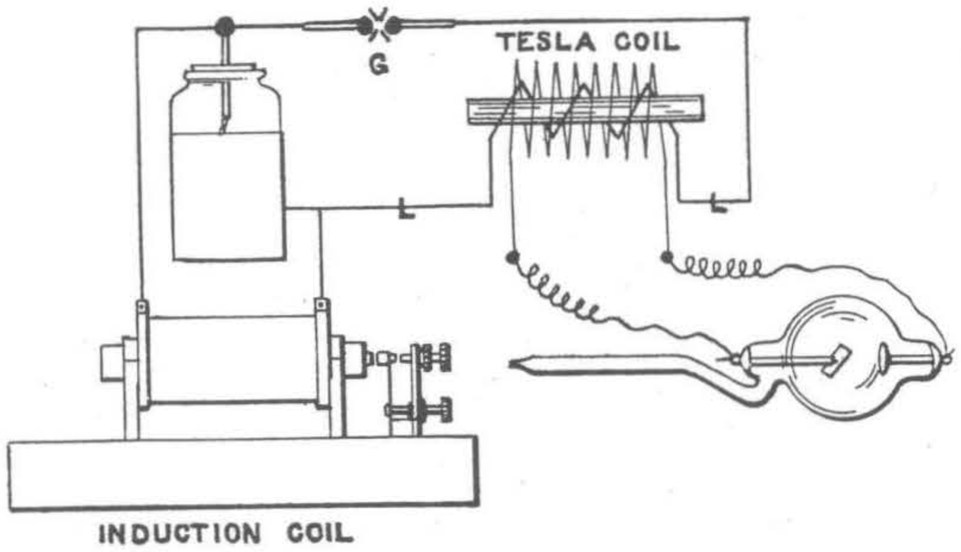


FIG. 1.—"X-RAYS, APPARATUS AND METHODS."—DIAGRAM OF TESLA HIGH-FREQUENCY COIL.

of our previously accepted views, is generally admitted. That the practical results accruing to humanity by virtue of the applications of this discovery in surgical and medical practice are of even greater promise and value is equally conceded. The writers have been engaged for a number of months past in developing apparatus and methods for practical work with especial reference to the needs of the physician and surgeon. For conciseness we split the matter under discussion into a series of subordinate heads, each of which we shall briefly treat.

THE COIL OR GENERATING SOURCE.

Thus far the only apparatus known which will produce X rays readily and profusely is the "transformer." Not the commercial transformer of every-day use, however, but its earlier and, for most purposes, less efficient form, the "induction coil." Such a transformer gives exceedingly great electro-motive forces, capable of producing discharge over long air gaps. When the discharge from such a coil is passed through properly exhausted and constructed tubes, we have a very vigorous generation of X rays.

Two arrangements of the induction coil are advocated. The one is known as the Tesla or "high-frequency" coil, and the other is the direct and old-fashioned use of the simple induction coil, in which the high secondary electro-motive force is delivered direct to the terminals of the tube.

THE HIGH-FREQUENCY COIL

consists of two induction coils, the induced secondary current of the first being used to charge a Leyden jar. The primary of the second coil is joined, in series with a spark gap, to the two coatings of the Leyden jar. When the Leyden jars are fully charged they discharge across the air gap, this discharge being, by well known laws of electrical circuit flow, an oscillating one of exceedingly high frequency—millions or more oscillations per second. We thus have the primary of the second coil excited by an alternating current of exceedingly great voltage and frequency, so that *its* secondary produces a discharge of still *greater* electro-motive force and of this same high frequency. So great is this final electro-motive force that it is generally necessary to immerse the entire second coil, primary and all, in a tank of oil, since no solid insulation has yet been found capable of standing these great electro-motive forces without breakdown.

To excite the Tesla coil we may use either an interrupted direct current or an ordinary alternating circuit joined directly to the primary of the first coil. But the final result is, in either case, an alternating, high-potential, high-frequency current. In the tube, therefore, we also have an alternating discharge.

THE INDUCTION COIL.

The primary must be excited by an interrupted direct current which may

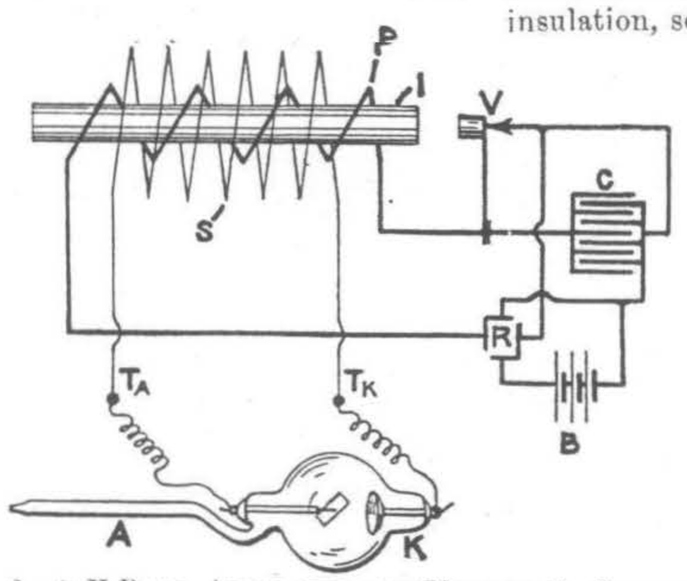


FIG. 2.—"X-RAYS, APPARATUS AND METHODS."—CONNECTIONS OF SIMPLE INDUCTION COIL.

be supplied by primary batteries, storage batteries, or a commercial circuit, as convenience and inclination may elect. The secondary is joined directly to the tube terminals. Around the primary is joined a condenser. At break this condenser charges (thus preventing the extra induced current due to the large self-induction of the primary). but, being "short circuited" by the primary, at once discharges about the iron core in a direction opposite to the regular "make" current, thus reducing (if correctly proportioned) the magnetic intensity of the iron core to zero. All this takes place so quickly that the practical effect of the action is merely to assist and intensify the dropping off of the core's magnetism —to shove it along—hasten it. Considering the secondary, now, we find that we shall have at *break* an induced discharge of greatly higher electro-motive force than the discharge at *make*, owing to the falling off of the core's magnetism *at* break being greatly sharper than its growth at make. The effect of this is to give secondary discharges in *one direction only* at all times when the parallel spark gap is not *greatly* shorter than the *maximum* obtainable spark gap for that particular condition of running the coil, the *make* induced current at such times being of too small electro-motive force to get across the gap at all. This is always the condition when X-ray tubes are used. A further function of the condenser is to suppress *burning* at the "break" terminals or points of interruption by taking up the energy of the magnetic discharge of the coil.

In the construction of the induction coil a number of points may be noted. Our secondaries are wound in sections one-eighth-inch thick (according to the plan originally proposed, we believe, by Ritchie). These sections are separated from one another by a large number of disks of paper of a brand especially selected as free from carbon particles and baked at a temperature a little below charring point for some time immediately before use—this to drive out moisture. These sections are then assembled and immediately immersed in a special insulation composition having a very high melting point and some slight viscosity at all temperatures. Paraffine we absolutely prohibit, as being apt to crack and absorb moisture. After cooking for some time in the insulation, so as to drive out the last traces of moisture, the stack of sections is subjected to a further treatment, by which it is finally cooled, with *all air removed*. This we consider a point of the highest importance, as air present anywhere in the secondary becomes electrified and bombards to and fro, gradually softening the insulation and eventually breaking down the coil. (See Tesla's writings on "High-Frequency Phenomena" for confirmation of this point.) With this plan of construction we have no static leaks of energy or small direct leaks within the coil itself, and deliver the full energy of discharge at the secondary terminals. We find ourselves able to secure in this way a full inch of spark, in all sizes of coils, with considerably less than one pound of wire, No. 34 Brown & Sharpe. We believe that, more than anything else, the large quantities of wire required to produce a given spark length with many of the coils now in use is due to the presence of air and consequent loss of energy by static bombardment in the secondary. As regards the insulating composition used by us, we may say that we find its power of resistance to spark discharge to be four or five times that of hard rubber. In the arrangement of our secondary we separate it from the primary by a heavy hard-rubber tube and, in addition, by a tube of this composition.

THE ADJUSTABLE CONDENSER.

A coil is working to best advantage when there is a certain definite relation between its primary current, secondary spark distance and condenser capacity. Frequency of break must also be considered. As coils have heretofore been built, however, the condenser value has been fixed once for all and admits of no change, albeit both spark gap and primary current, and primary current may be so changed. To remedy this we have devised a form of switch, by means of which the condenser capacity may be shifted at will and instantly by simply turning the switch. The effect upon the secondary discharge is very marked, both volume and musical note of the spark changing with the position of the switch. We have made some experiments in the use of a condenser in the parallel *with the primary*. The volume of the secondary discharge seems, in many cases, to be greatly increased. We find this idea exceedingly convenient in general experimental work with alternating currents; indeed, it being possible with it to alter condenser capacity as quickly and as readily as we may self-induction or resistance.

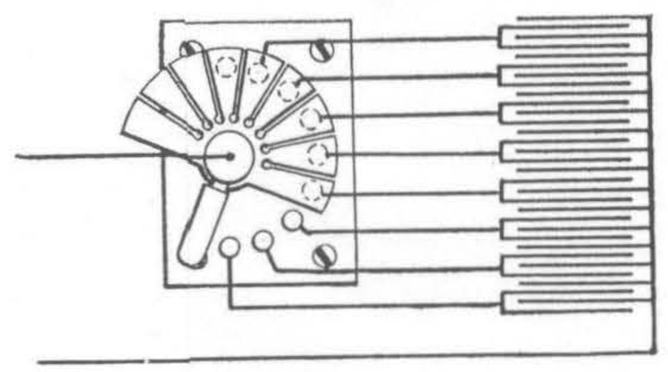


FIG. 3.—"X-RAYS, APPARATUS AND METHODS."—THE AUTHORS' FORM OF SWITCH.

In arranging coils to operate from few or many cells of battery, it is, of course, merely a matter of winding the primary of coarse or fine wire, the number of ampere turns being kept the same. It is interesting to note, as we have noted experimentally many times, that the larger the primary electro-motive force the smaller must be the condenser capacity employed, and *vice versa*. This is, of course, only to be expected, since capacity and self-induction are inverse functions of one another.

PRIMARY CURRENT.

This may be either from primary batteries, storage batteries, or from a

commercial direct-current circuit. Primary batteries have too high resistance to give sufficient current for coils of much size—say four-inch and over—unless joined in parallel, and then we need a number of such groups to secure the requisite electro-motive force. They are a nuisance to attend to, soon run down and are expensive to operate. Storage batteries are exceedingly satisfactory, are comparatively inexpensive to operate and require practically no attention. Charging them is more or less of a nuisance, however, especially where they must be sent out of the building, as they usually must, besides throwing the entire apparatus out of use while charging is going on, unless one have a reserve set of batteries.

The utilization of a direct commercial circuit, such as the Edison 110-volt E. G., where such is available, is in every way the most convenient and satisfactory. Until Professor Roentgen's discovery, no method of

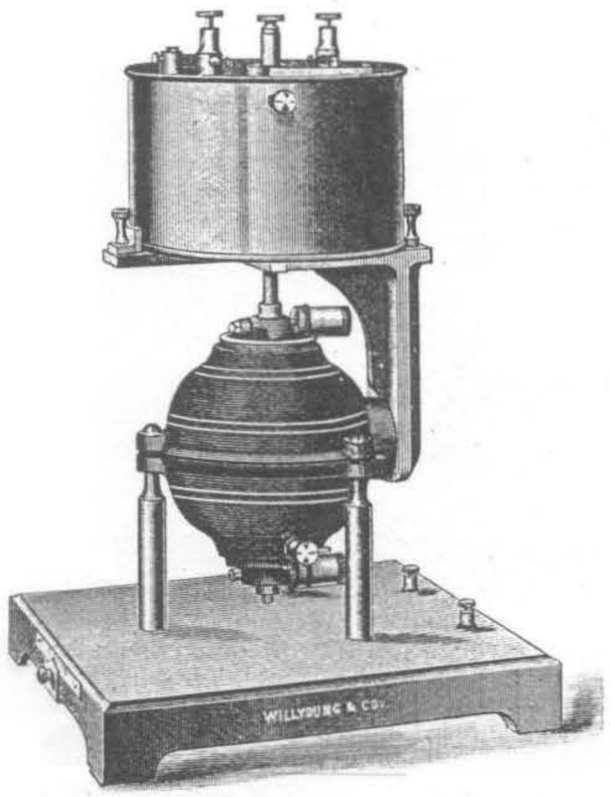


FIG. 4.— "X RAYS, APPARATUS AND METHODS."—THE AUTHORS' DEVICE FOR OPERATING COILS ON COMMERCIAL CIRCUITS.

operating large coils upon such a circuit had been developed. Recently, however, several methods have been brought out, notably that of the "air break" with air blast to blow out the spark, as used by Dr. Wm. J. Morton, Dr. M. I. Pupin and others. We have devised a form of apparatus to accomplish this purpose. A Lundell one-twelfth-horse-power motor is supported upon a base with its shaft vertical. A casting attached to the motor supports above the latter a copper can made up of two concentric cylinders joined by a ring below, so that the shaft passes up through the inner cylinder and thus avoids the necessity of a stuffing box. From the shaft is hung, well within the can, a heavy brass wheel having stretches of insulating slate let into its periphery. A hard-rubber lid fits over the top of the can. Mounted upon this lid are two brushes, one bearing against the wheel periphery and the one against the shaft; suitable springs and screws allow the brush tension to be varied. From the commercial circuit leads are brought to these two brushes, the current being first passed through the primary of the coil and a rheostat in series. Before the lid is put in place, the can is filled with distilled water; ordinary hydrant water will answer, although its usual impurity causes the water to soon dirty, besides allowing a certain amount of electrolysis during use. With distilled water the break may be run for a number of hours without change of the water, and very little heating takes place. The real function of the water is not so much to drown the spark as to prevent heating, although it does, of course, also assist in quenching the spark. But a condenser is the real spark extinguisher, and this we connect around the break just as we would around an ordinary vibrating break.

The advantages of this break over all forms of vibrating break thus far known and over other forms of rotary break are:

A. Convenience: Mere throwing of a switch being all that is required to start and stop the apparatus.

B. Noiselessness: Only the drowsy hum of the motor being heard.

C. Reliability: No chance of sticking, as with vibrating breaks.

D. Variable rate of break, secured by adjusting rheostat in base of motor.

E. Smooth, unvarying fluoroscopic images, owing to the much larger number of breaks per unit of time.

Two milled heads at top of can permit its lid (carrying brushes) to be withdrawn. A similar head at top of shaft loosens break-wheel, and two heads at bottom of can allow it to be lifted away for cleaning and renewal and replenishing of water.

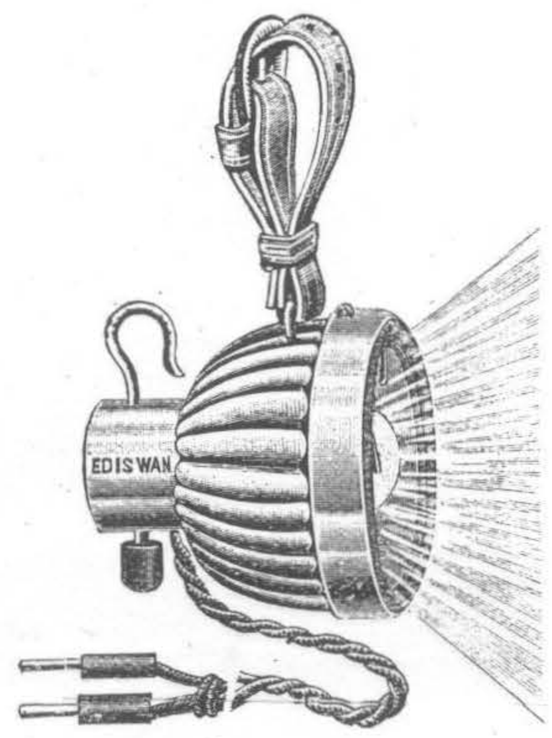
We use three makes and three breaks per revolution and find best results at from 1,200 to 1,400 revolutions per minute (equal to 3,600 to 4,800 interruptions). We may secure as many as 2,000 revolutions (6,000 interruptions) per minute by cutting out the motor regulator.

In operation, the brush bearing upon break-wheel should be *positive*, so as to prevent any electrolysis of the break-wheel. We have often broken between 15 and 20 amperes through this wheel for a considerable length of time without any overheating or overwear of the wheel. Should the wheel wear in time to an undesirable degree, it may be removed and turned down. Provision is also made for replacing the brushes when desired.

GENERAL CONSIDERATIONS REGARDING BREAK FREQUENCY.

The question as to whether there is a certain best frequency of break for a given coil or tube, or both, has puzzled not a few. Very little has been experimentally determined regarding this point. It is certain, however, that, with a given coil or tube, shortness of exposure is *not* exactly inversely as the number of breaks. Indeed, it is often far from being so. Some of the best X-ray pictures that have been taken have been by use of the old "hammer" break of Ritchie, and four or five clicks of the break have sufficed. Using the same tube and coil, but a rapidly vibrating or rotary break, required 40 or 50 breaks to accomplish the same results. It would appear, hence, that the energy of X-ray radiation *per break* is a function of the number of breaks per unit of time.

We are inclined to believe that this is a matter purely of the "time constant" of the coil. The iron of the core requires a certain time to magnetize or demagnetize. With the breaks few, ample time is given for this process; but when the breaks become rapid this is no longer possible, so that the secondary electro-motive force falls. This may easily be verified by observing the maximum spark length of any coil. With single breaks few and far between, we get much longer spark maxima than if the breaks are frequent. The thickness of the sparks is also greatly increased. If, however, we increase the primary electro-motive force for the more rapid break, we may bring up the secondary spark length to the value given by the single breaks. We should thus be able to shorten the exposure as much as we please by merely increasing the rate of break



THE "CAT-EYE" ELECTRIC BICYCLE LAMP.

and the primary electro-motive force at the same time. But here we are limited by the *tube*, which can not *dissipate* more than a certain definite amount of energy in a given time, and will break down if overdriven. We see, therefore, that, whether we use slow breaks or fast breaks, the actual time of exposure remains practically the same, the few breaks requiring to be distributed over the same *time* as the much larger number of rapid breaks. All this, of course, applies to the photographic plate. For fluoroscopy we require rapid breaks, in order to escape the otherwise distressing flickering.

In the above connection particular attention is directed to one point—the rate of break *must not be too great*. If it is, the iron no longer has time to magnetize and demagnetize. The result is an *alternating* secondary discharge instead of the *direct* discharge desired, and this means blackening of the tube, rapid fluctuations of the vacuum and general deterioration of the tube. *We doubt whether with any coil of size suitable for X-ray work a rate of break greater than 5,000 per minute should ever be employed.*

[*To be concluded.*]

X RAYS, APPARATUS AND METHODS.

ABSTRACT OF PAPER READ BEFORE THE ELECTRICAL SECTION OF THE FRANKLIN INSTITUTE, PHILADELPHIA, DECEMBER 1, 1896, BY ELMER G. WILLYOUNG AND H. LYMAN SAYEN.

(*Continued from page 45.*)

TESLA COIL OR INDUCTION COIL—WHICH?

Having carefully examined the results, apparatus and methods of others all over the country, devotees some of the "high-frequency" coil, some of the induction coil, and having made many and careful experiments with both forms of apparatus ourselves, we favor the induction coil. Our reasons for this preference are briefly stated:

A. Simplicity: One coil instead of two.

B. Ease of Manipulation: There being more than double the number of factors to attend to in the Tesla coil than in the induction coil.

C. Cleanliness: The "high-frequency" coil requires an oil bath, which must be renewed from time to time to avoid gumming. It is difficult, also, to find an oil which will not, eventually, act upon the insulation of the wire by virtue of the acid or other impurities which the former may contain.

D. Sharp Definition: The "high-frequency" coil produces an alternating discharge — thus with the double-focus tube giving us two sources of X radiation and consequent blurring of the image. If a single-focus tube be used, the discharge in one direction is either lost or tears off particles of the platinum reflector, thus blackening the tube and soon destroying its effectiveness.

E. Noiselessness: This, from the surgeons' and physicians' standpoint, is perhaps the most important consideration. With tube in action the induction coil is practically noiseless, save for the low hum of motor or vibrator. Improperly designed vibrators often rattle and rasp in a very irritating manner. In the "high-frequency" coil, however, the disruptive discharge over the air gap is the vital cause of its action. It is much more violent than a discharge of corresponding length from the induction coil, being of a rattling, cracking character. That such noise can not but have a most unpleasant effect upon the patient who comes into the operating-room in a condition of more or less nervous collapse anyway is obvious.

F. Strain on Tube: It has been argued by advocates of the "high-frequency" coil that it is much less hard upon the tubes. Our own observation has been just the reverse of this and has satisfied us that the wear and tear is very much less with the induction coil.

G. Results: Although we have diligently examined, we have yet to see results obtained by any form of apparatus superior to those made right here in Philadelphia by Dr. Goodspeed, of the University of Pennsylvania; Dr. Stern, of the Polyclinic Hospital; ourselves, and many others who might be mentioned, and this either as regards detail, penetration or quickness of exposure. Indeed, we may say that we have never seen results obtained with the Tesla coil that are equal in any of the above respects to the results just referred to.

THE TUBE.

Many forms of tubes have been suggested. With practically no exception, all tubes now in use employ as cathode a concave aluminum disk, whose center of curvature is at the center of a small platinum plate (three-eighths to three-quarters square inch in area), the plane of the plate being inclined to the normal from center of the concave cathode. This platinum plate is sometimes made the anode — sometimes the anode is a separate plate or wire elsewhere in the tube. This form of tube is known as the "focus" tube, the cathode rays being focused upon the platinum plate, which then becomes the active source of X rays. In the double-focus tube we have two concave cathodes at opposite ends of the tube, the platinum wire reflector being in the form of a wedge with a side presented to each of the concave cathodes.

In the use of the tube everything depends upon the vacuum, X rays seeming to be of a heterogenous character just as are light rays, the quality of the X ray varying with the degree of vacuum. The higher the vacuum, the more penetrating power the tube has. Hence it is well to select tubes and use different tubes for different purposes. A tube of extremely high exhaustion is best for working through the body, but with forearm, hands, feet, etc., the tube has too great penetration, the bones appearing almost equally transparent with the flesh.

The chief difficulty with most tubes is the change of vacuum which takes place in use. This is thought to be due to the occlusion of the residual gas upon the inner surface of the glass—resulting in an increased vacuum. It may be partially restored by heating the tube by use of a spirit lamp or Bunden flame. This must be very carefully done, however, to avoid cracking the tube. When the platinum reflector is used simply as an anti-cathode, and the anode is aluminum, a simple reversal of the discharge will prove fairly successful. Some makers have adopted the scheme, practiced now for many years, of blowing a small side pocket upon the tube, into which is placed phosphoric anhydride or some other chemical substance or composition absorbing moisture. When heated, this substance gives off vapor to make up for the loss. It is difficult, however, to drive off just the right amount of vapor in this way, and the vacuum is liable to be made too low, in which case flesh and bone are about equally opaque. So rapid is this change of vacuum, that in most cases involving over a few minutes' exposure or running of the tube, one of the above methods becomes necessary. In any case, eventual almost complete exhaustion seems to be the rule, and the tube must then be returned to the makers and re-exhausted.

"Blackening" is another cause of decreased efficiency in the tube. It is due to deposition of platinum upon the inner surface of the tube.

The "Bowdoin" tube, shown in Fig. 5, was devised after a considerable amount of experimental work by Professors Robinson and Hutchins, of Bowdoin College. In general design it does not differ essentially from many other forms of focus tube upon the market. The two respects in which the tube does differ from other tubes are: 1st. In the arrangement of electrodes the reflector plate is not connected to the coil at all, but merely acting as an obstacle to the bombarding rays, while the anode is a disk at the end of the tube away from the cathode. This arrangement is found to perfectly and entirely prevent blackening, no matter how long the tube may be used.

The most important feature of this tube is, however, the presence upon its interior surface of a fluorescent material which has been fused right into the surface of the glass. As the tube is used, this material, either by the bombardment, or heating, or both, gives off just enough air or vapor to make up for the occlusion due to the natural working of the tube. The vacuum, therefore, tends to remain always constant. Although it seems almost absurd that one could put in just enough of this material to make up for the gas otherwise lost, yet it is a fact that these tubes remain practically unchanged in vacuum at all times, the equivalent spark length retaining its value at all times within, at the outside, a variation of 10 per cent.

In use the tube requires no "nursing" whatever. It should always have to start with a parallel spark gap which should be quite small, say an inch or an inch and one-half, and either the primary current or the vibrator tension adjusted so as to produce only very small secondary discharge. The energy of this secondary discharge may then be immediately increased until the reflector plate shows a dull red spot of about half the size of the nail of the little finger. The tube is now in its most efficient condition, and, with a well constructed and smooth-working brake, may be run for an hour or two without the slightest attention. The "getting ready," as above described, takes considerably less time than the time it has taken us to describe it. Indeed, in our own work, we do not trouble to make this preliminary adjustment at all, as we make it once for all when we first begin to work with a tube, and do not afterward disturb it, merely closing down the switch when starting work.

[*To be concluded.*]

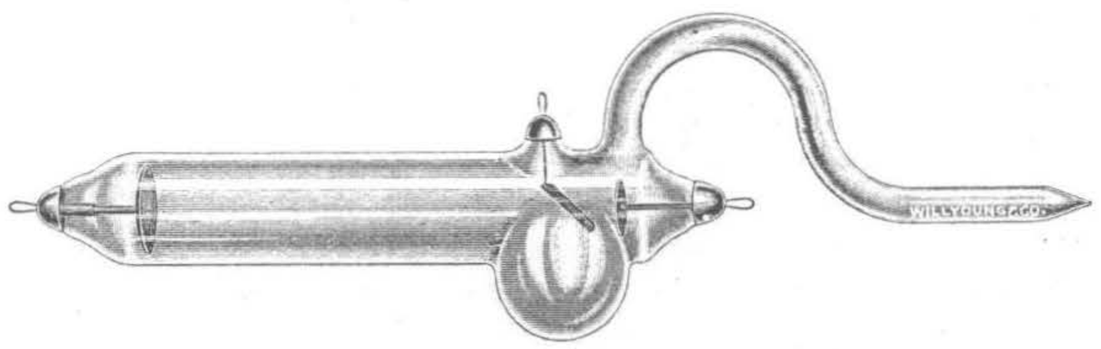


FIG. 5.—"X RAYS, APPARATUS AND METHODS."—THE BOWDOIN TUBE.

X RAYS, APPARATUS AND METHODS.

ABSTRACT OF PAPER READ BEFORE THE ELECTRICAL SECTION OF THE FRANKLIN INSTITUTE, PHILADELPHIA, DECEMBER 1, 1896, BY ELMER G. WILLYOUNG AND H. LYMAN SAYEN.

(*Concluded from page 51.*)

LIFE OF TUBES.

The life of tubes in general is limited.

A. By time required for the vacuum to become too great, hence requiring re-exhaustion.

B. By ability to stand the electrical strains.

A. Applies to all tubes so far as we know, save the Bowdoin tubes, probably six or eight hours continuous working, or the equivalent suffices to incapacitate the average tube. We think that, even with the Bowdoin tube, there is an evident tendency to eventual very high vacuum, but the time required would be very great relatively, say 10 to 15 times that operative in the case of other types of tubes.

B. All well made tubes (from the glass-blower's standpoint) are about equally liable to this limitation. It is probable that these strains are cumulative in their effects upon the tube, the latter gradually weakening until, eventually, breakdown takes place, with secondary discharges much less than would have been originally required for breakdown.

THE STAND

has been divided for applied X-ray work. With it the tube may be placed in any position within a cylinder six feet high and six feet in diameter, thus making it possible to get under or over a patient, no matter what the latter's position. Rods of vulcanized fiber clamp to the stand in any position and carry the lead wires of the tube, thus keeping them away from one another and from the metal of the stand. They carry little spring clips at their extremities, by which the wires are caught without tying or bending. The whole stand is of bicycle tubing and very rigid.

THE SUBJECT.

The patient should, of course, be placed in as easy a position as possible. For body pictures, hip and knee joints, etc., a recumbent position may be assumed. The plate should lie beneath and upon a stiff board backing to avoid risk of breakage. Work upon the shoulder, neck, head, etc., may be done with the patient straddling a straight-backed chair facing the back and leaning the body against the back for support. The plate may be bound fast to the body by bandages.

LAWS FOR EXPOSURE.

Since the X rays proceed in straight lines from (approximately) a point source, the intensity of their action varies inversely as the square of the distance from the source. Hence the time of exposure should vary directly as the thickness of the intervening substance. To apply these principles in practice, take a trial picture of the hand at five-inch distance, this being amply sufficient for good definition with such small bones. Say one minute is required for a good result. Then to take a hip joint, we estimate the thickness of the latter to be, say, 10 times that of the hand. We must, therefore, expose 10 minutes on account of thickness alone. But owing to the greater distance of bones from plate, the tube must be removed much further to get definition. At least 15 inches from the dry plate should be given—this is three times the distance used for the hand, from which the times require to be as the square of these figures, or as one is to nine. The total exposure must, therefore, be 90 minutes. This method gives something to go upon. After a little experience, perhaps the most convenient thing to do is to arrange a little table, based upon previous results, and showing times and distances required for well defined results for distinctive parts of the body.

SHORT EXPOSURES.

We have obtained, and do regularly obtain, without difficulty, well defined pictures showing complete detail of the osseous structure involved in times and with distances from dry plate to reflector, as below:

Hand and wrist, 5 to 10 seconds at 5 inches.

Forearm, 10 to 15 seconds at 5 inches.

Arm above elbow, ½ to 1 minute at 7 inches.

Shoulder, 10 to 15 minutes at 10 inches.

Thorax, 15 to 30 minutes at 10 inches.

Hip joint, 30 to 45 minutes at 12 to 15 inches.

Stones in kidneys, 30 to 45 minutes at 12 to 15 inches.

Glass, iron, lead, etc., in any part of trunk, 30 minutes on an average at 12 to 15 inches.

We have very carefully investigated every claim to quicker exposures than these, often by a personal visit, sometimes by correspondence with personal friends whose reliability was undoubted. We have been unable to learn of any results equally good having been obtained in shorter times by any one, at any place, with any form of apparatus, and we do not believe any such have been obtained.

MANIPULATION DEVELOPMENT OF THE PLATE.

Suitable and well constructed apparatus is not the only essential to good results. A great deal depends upon the operator, and comparatively trivial differences in procedure make all the difference between success and failure. We describe here the method which we follow and which allows us to count with certainty upon securing at least nine successful plates for every 10 exposures.

A. General Adjustment: First, see that the coil is working smoothly, so as to give a uniform discharge in the primary. The secondary spark points should be separated by the distance given by the makers as proper for the tube. The coil must then be adjusted, either by changing the electro-motive force at the primary or by variation of the vibrator adjusting springs so as just not to spark over this air gap. The tube should then be joined in parallel with this secondary spark gap. The coil may then be started up, using the fluoroscope to show whether direction of discharge is right. If not, the primary current should be reversed. If X rays are not now profuse, the secondary discharge points should be further separated and the vibrator springs tightened so as to produce correspondingly greater discharge. Continue this until either X rays are secured as desired or the tube becomes too hot, or possibly bluish, or pink in color. Blue denotes too low a vacuum to expect X rays, but often a gentle running of the tube for 10 or 15 minutes while in this condition will raise the vacuum to a suitable value. Pink denotes a very low vacuum and usually means, in a tube which has ever been right, a puncture or leak. Such a tube can only be made good by re-exhaustion and repair. With most tubes a vivid green fluorescence is the sign of the X-ray vacuum. With the Bowdoin tubes, as also with many others, the most efficient condition is with the platinum reflector plate at cherry-red heat over an area of half or two-thirds that of the little finger nail.

Sometimes the vacuum will be too high for the production of X rays with any length of secondary discharge. It may be reduced by gentle warming of the tube by a spirit-lamp flame. Some reverse the current in the tube, but this is apt to blacken.

Sticking of the vibrator must be guarded against; it is often fatal to the tube. This is because of the much larger current through the primary when such sticking occurs. Upon release, therefore, a secondary discharge much above normal is produced, and this the parallel spark gap is unable to carry off. The tube, therefore, receives much more energy than it should, and may break down, even though the parallel spark gap be as advised by the manufacturers.

B. The Plate and its Development: We have used at one time and another a number of different makes of plates with very fair success. For some time past we have confined ourselves to the Carbutt X-ray plates, and, though we are not prepared to say that they are the best plates to use, the results are so uniformly good as to make it seem inadvisable to us to try other plates not radically different in principle.

For developer we use the Carbutt "J. C. tabloids"—three J and three C to five ounces of water—add about two drams of restrainer (the usual 10 per cent solution). Dr. Stern, of the Philadelphia Polyclinic, advises heating this developer until quite warm to the touch just before using. This we have found so good that we have adopted it as part of our procedure.

From 15 to 20 minutes will be required for development. The image will come up very slowly and not very sharply. Not much detail will be visible by holding up to the light. Continue development until the general main outlines have appeared and faded away to a general blackness upon the glass side. Then rinse and hypo.

The fixing generally requires from a half-hour to two or three hours. This long time is probably partly due to the unusual thickness of the Carbutt X-ray films, but probably even more to some chemical condition set up by the unusually large quantities of restrainer used. Mr. Carbutt advises three J and three C tabloids to six ounces of water to 20–30 drops restrainer. Our experience is that a plate so developed always requires intensification — a tedious nuisance which can never give so good results as a normally exposed and developed plate.

TO TELEGRAPH

Around the Great World

WITHOUT WIRES.

A New System Evolved Fraught with Immense Possibilities and Which Scientists Are Studying.

LABORS OF TESLA AND EDISON.

TO girdle the earth with telegraphy without the use of telegraph wires has been the dream of many an electrical inventor. There is a fascination in the theory of harnessing those mysterious etheric streams of electricity which stratify the upper atmosphere, and harnessing them for the purpose of the world's enlightenment and civilization. But it has never been done.

Many an inventor has tried it and failed. Many an inventor has spent his life dreaming of potentialities without hitting upon the key to the secret. The whirling world generates electricity just like a dynamo. It is a sort of giant revolving battery, terrifically polarized, sparkling, streaming at one end with the aurora, which sends off its ribbons of magnetic currents in vast, flickering fingers, which girdle the earth with a power strong enough to run the world's engines, could it once be bridled and bitted and snaffled by man.

Scientists know the power is there, and they dream of it and reach for it with half blind eyes, and uncertain fingers, too weak to scratch the surface of the secret, and too dazed to do anything but grope for it.

As yet wireless telegraphy is in its infancy. It is an infancy that will grow, however, and one day in the coming century the infant may become a giant that will bowl the world down the ringing grooves of change, bound and swathed with a power that will roll the blessed old ball to the foot of God's throne—bloodless, stainless, warless and with a record as white as the wings of the sinless angels who will then inhabit it.

At least, the scientists think so, and why should I, a mere layman in scientific matters, contradict them? Telegraphing as it is at present is more or less of an annoyance compared with telephones—barring the central office; and if they can be improved so as to facilitate the transmission of general news, the sooner the problem is solved the better.

A Wonderful Invention.

The latest scientist to take a header into the sea of wireless telegraphy is a young man named Mr. Marconi, who has recently evolved a system of telegraphy without wires, which depends not on electro-magnetic but on electrostatic effects. That is to say, the new system is based on Hertzian waves, which have a vibration of not less than 250,000,000 a second.

Think of it! These Hertzian waves are to electricity what the X rays are to visual perception; but, unlike the X ray, they do not die out easily. They simply take hold of one end of an electric stream and shake it into waves so infinitesimally small and keen that it would take the ear of a fairy to hear the magnetic surf beating on the shores of cloudland.

These vibrations are projected through space in straight lines, but, like light, they are capable of reflection and refraction and of focusing, and right upon this fact the scientists have based their dreams of wireless telegraphy. With the fact that the Hertzian waves exhibit all the phenomena of light before them, the scientists have gone to work to construct instruments that will handle these waves, as heliographs handle the rays of the sun. They may succeed. It is to be hoped they will. In the meantime, Mr. Marconi, Mr. Edison and Mr. Tesla will strive for the grand result that will enable them to drum upon the electric streams as a farmer drums upon a tin pan to hive a refractory swarm of bees.

In speaking of Mr. Marconi's invention in London recently, Mr. Preece, the telegraphic expert of the London Post Office, admitted that telegraphing without wires was no new thing. Probably Mr. Preece meant that inadvertent telegraphing by means of induction was no new thing. Here in the United States, in 1878, there were but two wires running from Kansas City to Denver. Many a time I have sat in the Denver office with the first wire idle, yet the instruments were responding to the messages being sent on the second wire. And at no point in all that treeless waste of arid land between the two cities were the two wires nearer to each other than three or four feet.

It must have been this "induction" of dry and magnetic atmospheres that first gave scientific men the idea of telegraphing without wires. Mr. Preece, whom I have quoted above, says that in 1884 operators in the telephone exchange in London were able from sounds heard to read messages that were in transit from London to Bradford by the telegraph wires. The post office wires were under ground and the telephone wires above ground, and careful experiment showed that this fact accounted for the telegraphic messages to Bradford being read by the telephone company. Yet, all the same, it was a mere case of induction.

The invention of young Marconi seems to have dealt with the problem from an entirely different standpoint. It does not deal with the inducing of a current from a neighboring wire. In fact, induction has nothing to do with it. It is an electro-static wave question, and the only thing that now remains to be done is to ascertain the distance to which these telegraphic signals can be transmitted.

The great difference between the Marconi and the inductive methods of wireless telegraphy is that the former does away entirely with the wires at each end. Vibrations are set up by one apparatus and received by the other.

Tesla's Experiments.

On our side of the water wrestling with this very problem we have Nicola Tesla and Thomas Edison. Tesla is more or less of a dreamer. Give him an idea and he will expand it to the stars if he sees possibilities in it. He is an inventive electrical poet, who takes hold of an idea, and with philosophy as a fulcrum tries to unlock the universe. Nevertheless he has worked out some astonishing problems, and is even now completing an invention with which he hopes to circle the globe with telegraphic sound without the aid of wires.

Fully ten years ago Tesla declared that it would be possible to use economically the electricity in the earth's atmosphere for communication between widely divergent points. The problem in his mind was the conservation of electrical energy at the least possible cost.

Long and wearily did Tesla puzzle his brain over this problem. He discarded the induction scheme almost immediately. Induction is more or less a matter of propinquity. Then he hit upon the scheme of oscillation. He went to work upon an oscillator, which was nothing less than an instrument to throw out and produce the enormously swift Hertzian waves.

Through this instrument he thought it possible to solve the problem of aerial telegraphy. In speaking of this possibility Tesla said:—"In time the electric envelope of the earth will enable us to send messages from one part of the globe to all other parts in an instant."

This is a rather broad assertion, but there are those who believe as Tesla does, that the electrical elements of the earth and the atmosphere are infinite, and that it will be only a matter of time when these forces of nature are subjugated to the will of mankind.

Tesla also asserted that this electrical element of the earth's atmosphere might at some future time be utilized for communication with other planets of our system. Here is a dream indeed. Those who have suggested such communication in the past have expended their mental ingenuity on schemes for gigantic electric lettering on the world's deserts and plains.

This would be aerial telegraphing with a vengeance. But do not get nervous. Nothing of the kind will ever occur, unless some fool with a billion dollars to spare leases Sahara Desert for his interstellar electric plant. This is something of a digression, but let us follow it a bit further. Supposing such gigantic lettering were possible, and supposing that return signals were received, what would it prove?

Nothing more than an interchange of intelligence, surely. Nothing more would be possible. What would be the first word flashed across the abyss of space? "God," of course. And right here we would stall. No human ingenuity could go further than this, unless some strange comet should flare across the sky to hinge another word upon. Telegraphic communication along the currents of the earth's upper atmosphere may be possible, but interstellar talk is as far off as Byron's dream of darkness.

And yet Tesla believes great things of his oscillator, and, upon being asked once whether it would be possible to signal to the stars, replied:—

"Perhaps in time. Not yet. There are many things to be fixed first. I have no doubt that it would be possible to signal to the stars."

Well, it may be so. If in the future I shall stand on the pale and ghost haunted hills of the moon, looking across the soundless tracts of space to the red disk of the world, and shall hear a far cry tingling to the stars, a voice that wails through the waste lands like the cry of a lost soul, I shall know that it is Tesla, or Edison, or some terrestrial philosopher howling for the central office of the universe.

As for telegraphing around the earth without wires, ah! that is a different thing. We believe in Tesla and we believe in Edison. Give them an inch of success, and eventually they will make it a mile. Both have said that such a thing is possible, and both know what they are talking about.

As early as 1886 Edison made successful experiments in induction telegraphy from moving trains, sending and receiving telegrams on the Staten Island Rapid Transit road during almost an entire afternoon. The train from which Mr. Edison experimented consisted of five cars, with metal roofs, which were made continuous with pieces of insulated copper wire and connected in the rear car with an ordinary telegrapher's outfit. There was a leap of at least fifty feet from the train to the wires running beside the track, and the bankers and capitalists smiled when they saw the preparations. Very few of them believed that such a thing was possible.

Edison's Induction Scheme.

The train left Clifton at half-past one P. M., and before it had gone a quarter of a mile the instrument in the rear car was clicking merrily. An operator had been stationed at Clifton with a special set of instruments. To this operator the capitalists and others upon the train had delivered many sealed messages.

Before Tottenville was reached all these messages had been received on the train, leaping through the fifty feet of space to the metal roofs of the cars and so to the telegraph instrument. On the return trip despatches were sent from the train to all parts of the country. One message was in Latin, but it got through the atmosphere all right.

Mr. Henry Seligman, the banker, telegraphed to his banking house for Lake Shore quotations and got an answer before the train stopped running. On this occasion Edison stated that a leap of six hundred feet was possible.

Edison began work in 1892 on a marine telegraph based upon the principle of induction. This invention was patented, and by it Mr. Edison was enabled to telegraph a goodly distance across water without the use of wires.

But the great difficulty with all these experiments, whether with induction or Hertzian waves, is that the waves will not follow the curvature of the earth's surface. In this respect they are related to the X rays, which, in fact, seem to be a sort of illuminated electricity.

The point to overcome in telegraphing long distances without wires is to obtain a sufficient elevation to overleap the curvature of the earth's surface, and to reduce to a minimum the earth's absorption of the electric current. "At sea," said Edison, in speaking of marine telegraphy, "from an elevation of one hundred feet I can communicate a great distance without wires, and by repeating these signals from ship to ship communication can be established across seas and oceans.

"Collisions in fogs can be prevented and ships approaching a dangerous coast can be assured of safety."

It would be rather a hard matter to obtain one hundred feet elevations at sea, but there are many mountain chains that would afford splendid opportunities for experiment, if not for practical use. In fact, Tesla has already telegraphed a goodly distance from one mountain peak to another without the use of wires.

Aerial Mountain Telegraphy.

If the terrific impulse of these Hertzian waves is not overestimated, a sort of mountain telegraph might be established from Washington Territory to Nicaragua, and, with a few towers, even to the lower part of Chili and Patagonia. From lofty Mount Everest the signals could be flashed, peak by peak, to Mount Hood, Ranier, Shasta, and so down that long continental vertebra of granite to Gray's Peak, Long's, Lincoln's, Pike's, the Holy Cross, La Veta, through the Sierra Madre to Popocatapetl, Orizaba, into Nicaragua, across the Isthmus and into the cloud soaring Cordilleras.

Here the peaks would be higher and communication probably more clear and swift. Down the lofty line of snowy summits the news would click as swift as thought, from Chimborazo to Aconcagua, and along the snowy range into strange, dismal lands, and at last the Patagonian, crouching with a wondering face over his miserable fire with the despatch in his hands, would know that Casey had struck out.

This may be an exaggeration, but the fact remains that many scientists are so thoroughly convinced that the use of atmosphere and earth currents of electricity is practicable that they are working with might and main to bring about the desired end.

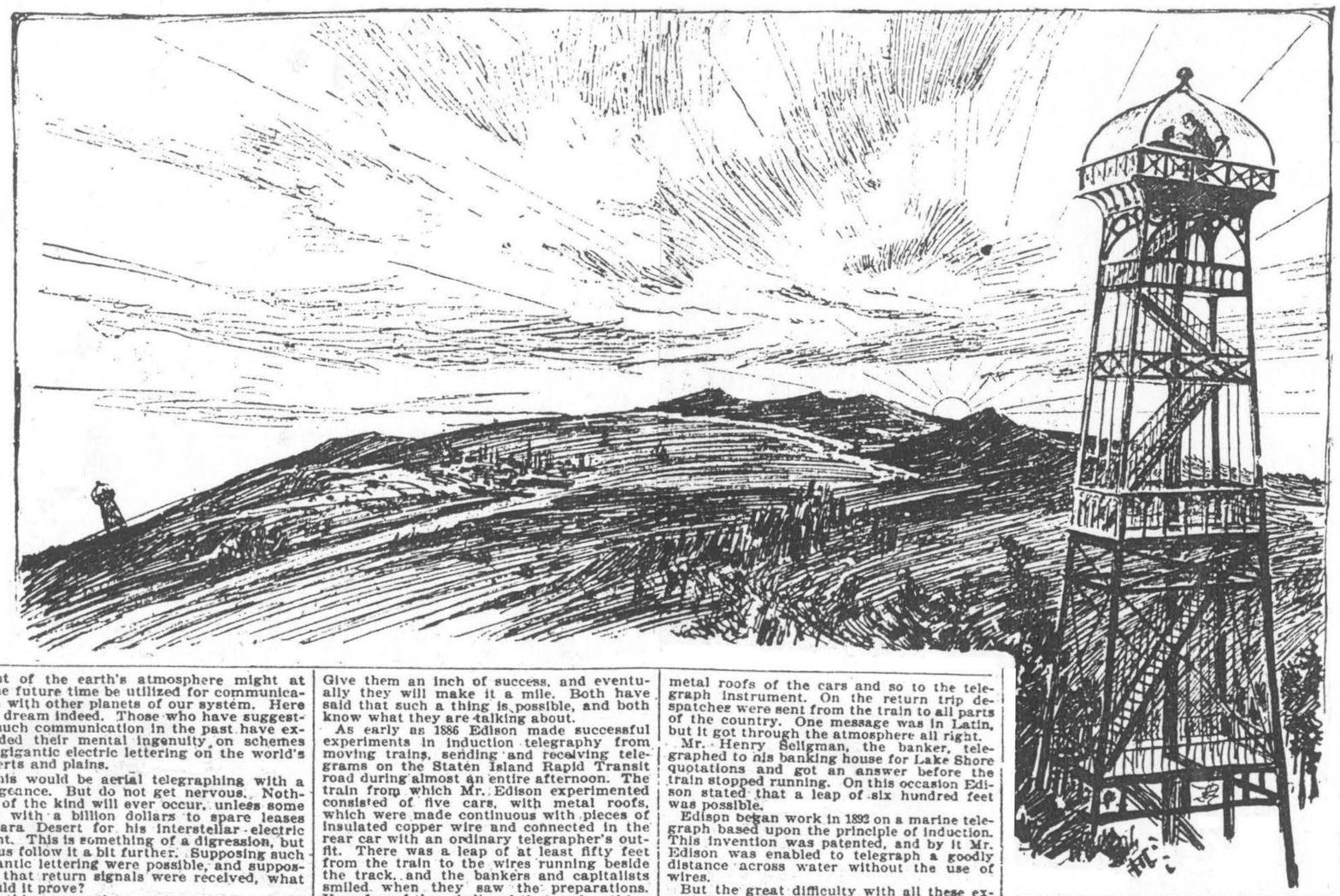
In a recent interview, Marconi, the man who has recently interested London on the subject of telegraphy without wires, said:—

"I have long believed that instantaneous and simultaneous communication to all parts of the earth is possible by means of electric waves. I am becoming more convinced every day that such communication can be based upon scientific principles which can be controlled at will.

"Those huge disturbances on the sun, which are nothing more nor less than waves of electricity, are productive of similar disturbances on the earth in the form of storms. Why should not disturbances of the electric currents of the earth's atmosphere be made intelligible? It is not necessary that a conducting circuit must exist.

"An electrical disturbance at one point causing a change in the equilibrium of the earth's electricity should be felt at all points of the earth's surface, and I think it possible to record them. The possibilities of such a transmission of intelligence cannot be exaggerated. A message sent from London would be in America, Africa and Australia in an instant."

AS STATIONS FOR AERIAL TELEGRAPHY WITHOUT WIRES WOULD APPEAR.



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MR. TESLA'S VIEWS ON THE FUTURE OF ELECTRICITY.

THE inauguration of the Buffalo-Niagara electric transmission, brought together, as our report showed, a representative gathering of influential men and elicited a number of memorable addresses. Of the speeches devoted to the technical side, that of Mr. Tesla's deserves more than passing notice, as containing the expression of his latest views and convictions on subjects which he has made his special study for some time past. Speaking of the types of prime movers in use to-day, Mr. Tesla gives no encouragement for the future of the reciprocating high speed engine in its present form, nor for the steam turbine. His ideal engine is one which expands the working fluid with utmost rapidity and loses little heat in the walls; an engine stripped of all usual regulating mechanism, packings, oilers and other appendages and forming part of an electric generator. Mr. Tesla, though not mentioning it by name, here evidently referred to his oscillator, brought out in 1893. As to the outlook for a carbon consuming battery. Mr. Tesla does not consider it over-promising, viewed from the standpoint of a source of power. The probability of replacing the engine-dynamos by batteries is, in Mr. Tesla's opinion, a remote one, the more so as the high pressure steam engine and the gas engine give promise of a considerably more economical conversion. Mr. Tesla also sees drawbacks lurking in the fact that carbon to be consumed in batteries has to be prepared for that purpose and cannot be used as found, as it is under the boiler. The manipulation, cleaning, renewal, regulation, etc., of the batteries, and their size, together with the character of the liquids employed in them, would make it difficult, if not unprofitable, to handle such a plant in a densely populated city district. While thus expressing little faith in the carbon battery, Mr. Tesla has hopes for the ultimate supply of isolated plants or dwellings in the development of what he calls a light "storage battery," involving the use of chemicals manufactured by cheap water power, such as some carbide or oxy-hydrogen cell. We incline to the opinion that what Mr. Tesla has in mind partakes more of the nature of a primary gas battery.

But it is Mr. Tesla's conclusions on the results of his own particular work which will perhaps command the greatest attention among electrical engineers and the public at large. It will be recalled that in his very first lecture at Columbia University in 1891 he threw out the suggestion that it might be possible to operate engines at any point on the earth "by the energy of the medium." Six years of continued study have brought him beyond the stage of mere conviction, and he now feels sure that the realization of his ideas is not far off. But at the same time Mr. Tesla confesses the disappointing conclusion reached by him that under the theoretically best conditions such a method of obtaining power cannot equal in economy, simplicity and many other features the present method of converting the energy of falling water into electric current, and transmitting it over long distances at high potential. With this conviction of the greater utility of water power, Mr. Tesla has bent his energies to the means of transmitting it, and now informs us that he has devised means which permit of power transmission at potentials much higher than are now considered practical. He hints further that the progress he has made gives him fresh hope that he will be able to transmit power from station to station without the em-

ployment of connecting wires, but he adds that, whatever method of transmission be ultimately adopted, nearness to the source of power will remain an important advantage. We cannot help expressing our gratification at this promised realization of one of Mr. Tesla's fondest dreams, but we hardly expect that the manufacturers of wire will receive the announcement in a like spirit of joy. Mr. Tesla has thrown out enough in his remarks to put the public again on the qui vive. The electrical community will await with impatience the practical demonstration of his new methods, accept the "report of progress" and "extend the time of the committee."

Electricity. Tesla. *Elec. Rev.*, Jan. 27.—A reprint in full of his recent address at Buffalo; it is very general in character. He discusses the features of human intellectual progress in recent times, which chiefly interest the scientific man, the thinker and the reasoner; he refers to the influence of the artist; electricity has been one of the most potent factors in the elevating features which characterize modern intellectual development; he refers to the merging together of the various sciences or departments of research and the connection between different forces and phenomena; only a brief reference is made to high-frequency currents; the electric transmission of power is considered to be the most important industrial application. In referring to the direct production of electricity from carbon in a battery, he states that he does not think it will be as much of an advance as some seem to believe; he favors the mechanical generation and considers the probability of replacing the present generators by batteries as a very remote one; he has confidence in the development of a light storage

battery involving the use of chemicals manufactured by cheap water power, such as some carbide or oxygen-hydrogen cell; he refers to means for obtaining energy from stores which are forever inexhaustible without combustion or waste of any material, stating that he has had the matter under consideration for a number of years, and believing the problem will ultimately be solved; he thinks the realization of the idea is not far off; he refers to the possibility of the operation of engines on any point of the earth "by the energy of the medium" (presumably a misprint); but he adds that under the theoretically best conditions such a method of obtaining power cannot equal in economy and simplicity the conversion of the energy or running water into electrical energy; he has devised means for using for transmission E. M. Fs. much higher than practical with ordinary apparatus; he believes he will succeed in transmitting power without the employment of any connecting wire.

MR. TESLA AS A BUG KILLER.

THERE can be no doubt as to the invasion of the domain of agriculture by electricity. Last week we noted the results obtained on a farm in Germany, and hardly a week goes by without its news of farmers using the telephone in their operations, experiments at agricultural stations with all kinds of current in stimulating seeds and plants, or the use of power from lighting or trolley circuits in running farm machinery. Indeed, it may be said to be doubtful whether the factory or the farm is to be the new scene of electricity's next triumphs.

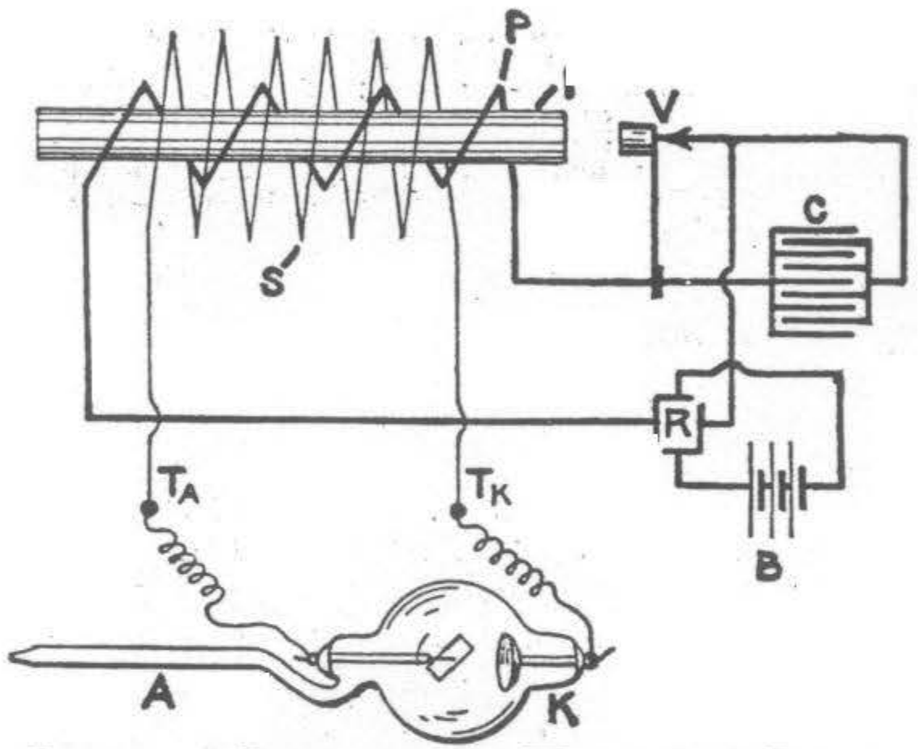
It will be remembered that not long ago, Mr. Tesla suggested that part of the energy of powers like that of Niagara might be applied to furnishing nitrogenous elements to the soil, so that better crops could be secured. This may explain why a Mr. S. S. Harvey in the South wrote to him asking if electricity could not be used in a general pervasive way to kill off the bugs that are such a pest in orchards and vineyards. Mr. Tesla, with wonted courtesy, admitted the importance of the subject and said in response to the inquiry: "It is sure that we can destroy these detrimental insects in certain ways by the help of electricity, but to what extent the trees would be affected by the application of these means I do not know, and it could only be settled by a series of experiments. I have some ideas on the subject, and think that an apparatus for experimentation could be produced in a short time. I am resolved to think over the matter in the hope to arrive at some tangible result."

We have no doubt that to some people the idea of a notable electrical inventor devoting his time to devising bug traps and "sure deaths" smacks rather of the grotesque and ridiculous; but in reality Mr. Tesla could not undertake anything of more real and practical value. When one stops to consider how famine, ruin and devastation afflict the human race because of such pests as the locust, phylloxera, army worm and potato bug, it is evident there is work to do of real vital importance to a great many people.

LEGAL NOTES

THE TESLA PATENTS REVOKED IN GERMANY.

As was announced in these columns several weeks ago, two of Mr. Tesla's patents have been revoked in Germany. We now learn that these patents are numbered 47,012 and 47,885, respectively, and entitled "Combination of a Transformer and a Source of Current," and "Connection of the Coils of Current Generators with Motors."



CORRECTED DIAGRAM.—MR. WILLYOUNG'S PAPER.

A Correction in Mr. Willyoung's Paper on X Rays.

TO THE EDITOR OF ELECTRICAL REVIEW:

An error occurred in Fig. 2 of my article, "X Rays, Apparatus and Methods," in your issue of January 27. The error is one of inadvertence on the part of the draftsman, apparently. I will be glad to have it corrected through your columns. As the figure was originally printed, the battery "B" was short-circuited through the reversing switch "R."

Very truly yours,

ELMER G. WILLYOUNG.

Philadelphia, February 2.

TESLA ON LONG LIFE AND SLEEP.

Being asked for his views on reasons and signs of longevity, Mr. Tesla said: "A man receives a certain term of life; so many hours to pass on this earth—I mean hours when he is alive, awake; I do not count the hours when he is sleeping; I do not believe they are, strictly speaking, included in his term of life. When a man really lives he is dying hour by hour, but when he sleeps he is accumulating vital forces which will make him go on living. In other words, in measuring out our dole of hours to each one of us, the great timekeeper stops his count while we are sleeping. Therefore, the longer a man sleeps the longer he will remain on earth. Nearly all long-lived people have been great sleepers. When De Lesseps was on the ocean he would sleep twenty hours on a stretch. Gladstone is a great sleeper, and averages twelve hours a day. I can believe that a man who would learn to sleep eighteen hours a day might live 200 years." Mr. Tesla is himself a very poor sleeper.

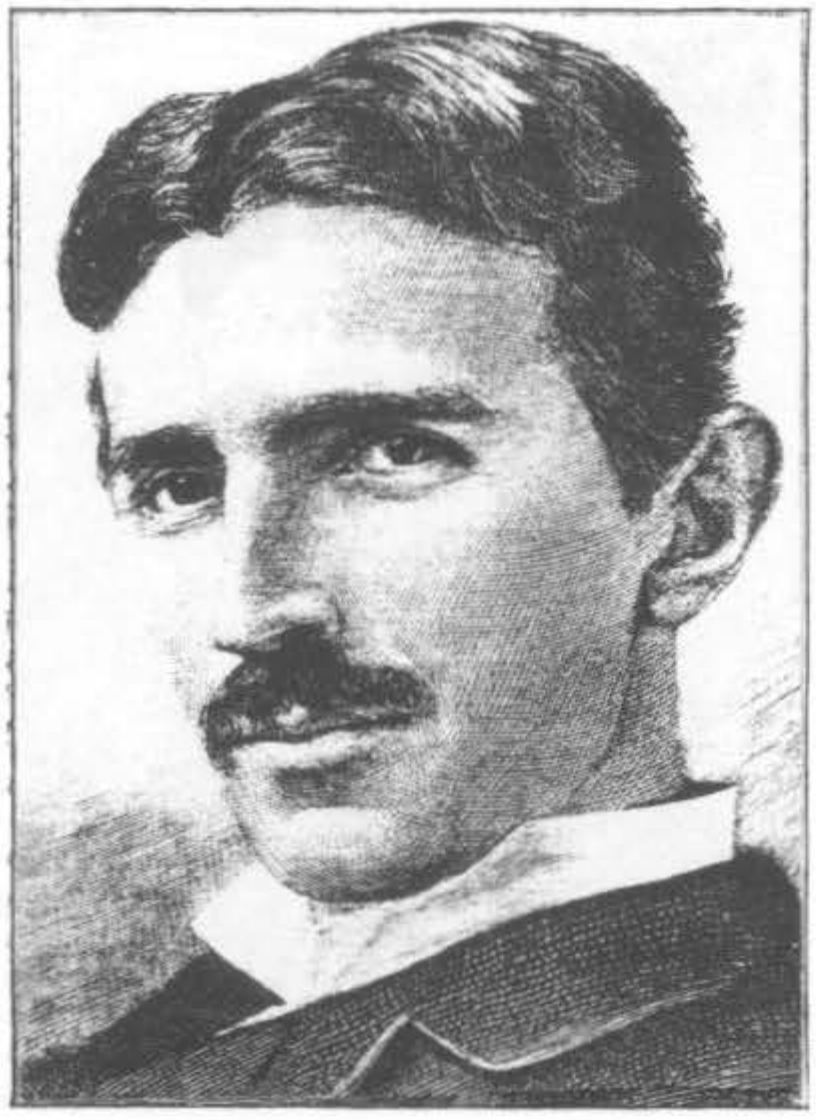
[90061.]—**Coil: Tesla and Skiagraphs.**—To MR. BOTTONE.—I don't think you will improve matters by using a Tesla in conjunction with your coil. The same winding as described would be suitable, in case you were inclined to try it. By "heavy" paraffin oils are meant those having a high boiling-point. But better still is good linseed oil, in which a little rosin has been dissolved. You will be able to shorten your exposures by one-half if you use Cadett's "Lightning" plates. It is quite right to use the cells coupled in parallel, because it is current in ampères, and not volts, you require. I should not advise you to use more than six cells; but I think if your cells had elements 5in. by 10in. you would get even better results. S. BOTTONE.

Cassier's Magazine March 1897

THE AGE OF ELECTRICITY.

By Nikola Tesla.

THE commemoration of the recent introduction into the city of Buffalo of electric power from Niagara Falls was made the occasion of a banquet, held at the Ellicott Club, at Buffalo, on January 12, 1897, the hosts being the Niagara Falls Power and Conduit Company, and the distinguished guests the men, principally, to whose business and engineering talents the world owes the remarkable Niagara undertaking so recently brought to successful completion. Probably none among these has been more honoured than Mr. Nikola Tesla, whose electrical researches and practical accomplish-



FROM A PHOTO BY SARONY.

Nikola Tesla

ments have been the talk of the world, and whose polyphase alternating current system was the one eventually adopted in the work at Niagara Falls. After the banquet, in responding to the toast, "Electricity," Mr. Tesla spoke at length of the various sciences, with special reference, naturally to electricity, and from his remarks the appended extracts have been made, picturing in a graphic and striking manner the dependence upon power of the development and wealth of cities, the success of nations, the progress of the whole human race, in fact, as he himself put it. —THE EDITOR.

For more than half a century the steam engine has served the innumerable wants of man. The work it was called to perform was of such variety, and the conditions in each case were so different that, of necessity, a great many types of engines resulted. In the vast majority of cases the problem put before the engineer was not, as it should have been, the broad one of converting the greatest possible amount of heat energy into mechanical power, but it was rather the specific problem of obtaining the mechanical power in such form as to be best suitable for general use. As the reciprocating motion of the piston was not convenient for practical purposes, except in very few instances, the piston was connected to a crank, and thus rotating motion was obtained, which was more suitable and preferable, though it involved numerous disadvantages incident to the crude and wasteful means employed. - But until quite recently there were at the disposal of the engineer, for the transformation and transmission of the motion of the piston, no better means than rigid mechanical connections.

The past few years have brought

forcibly to the attention of the builder the electric motor, with its ideal features. Here was a mode of transmitting mechanical motion, simpler by far, and also much more economical. Had this mode been perfected earlier, there can be no doubt that the majority of the many different types of engines would not exist, for just as soon as an engine was coupled with an electric generator a type was produced capable of almost universal use. From this moment on there was no necessity to endeavour to perfect engines of special designs capable of doing special kinds of work. The engineer's task became now to concentrate all his efforts upon one type, to perfect one kind of engine—the best, the universal, the engine of the immediate future; namely, the one which is best suitable for the generation of electricity.

The first efforts in this direction gave a strong impetus to the development of the reciprocating high-speed engine, and also to the turbine, which latter was a type of engine of very limited practical usefulness, but became, to a certain extent, valuable in connection with the electic generator and motor. Still, even the former engine, though improved in many particulars, is not radically changed, and even now has the same objectionable features and limitations. To do away with these as much as possible, a new type of engine is being perfected in which more favourable conditions for economy are maintained, which expands the working fluid with utmost rapidity and loses little heat on the walls, an engine stripped of all usual regulating mechanism—packings, oilers and other appendages—and forming part of an electric generator; and in this type, I may say, I have implicit faith.

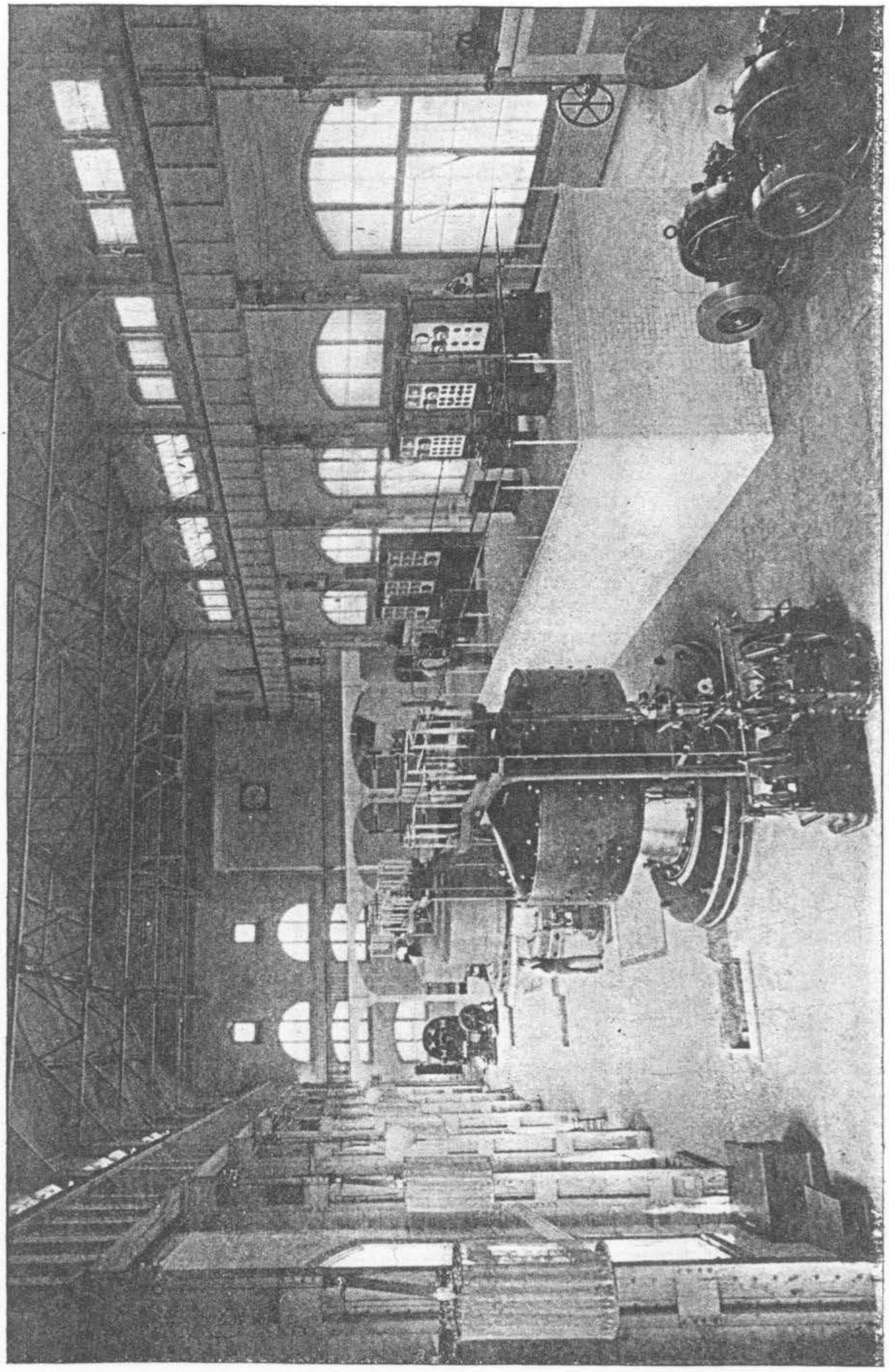
The gas or explosive engine has been likewise profoundly affected by the commercial introduction of electric light and power, particularly in quite recent years. The engineer is turning his energies more and more in this direction, being attracted by the prospect of obtaining a higher thermodynamic efficiency. Much larger engines are now being built, the construction is constantly improved, and a novel type of engine, best suitable for the generation of electricity, is being rapidly evolved.

There are many other lines of manufacture and industry in which the influence of electrical development has been even more powerfully felt,—for instance, the manufacture of a great variety of articles of metal, and especially of chemical products. The welding of metals by electricity, though involving a wasteful process, has, nevertheless, been accepted as a legitimate art, while the manufacture of metal sheet, seamless tubes and the like affords promise of much improvement.

We are coming gradually, but surely, to the fusion of bodies and reduction of all kinds of ores—even of iron ores—by the use of electricity, and in each of these departments great realisations are probable. Again, the economical conversion of ordinary currents of supply into high-frequency currents opens up new possibilities, such as the combination of the atmospheric nitrogen and the production of its compounds; for instance, ammonia and nitric acid, and their salts, by novel processes.

The high-frequency currents also bring us to the realisation of a more economical system of lighting; namely, by means of phosphorescent bulbs or tubes, and enable us to produce with these appliances light of practically any candle power. Following other developments in purely electrical lines, we have all rejoiced in observing the rapid strides made, which, in quite recent years, have been beyond our most sanguine expectations.

To enumerate the many advances recorded is a subject for the reviewer, but I cannot pass without mentioning the beautiful discoveries of Lenard and Roentgen, particularly the latter, which have found such a powerful response throughout the scientific world that they have made us forget, for a time, the great achievement of Linde in Germany, who has effected the liquefaction of air on an industrial scale by a process of continuous cooling; the discovery of argon by Lord Raleigh and Professor



A RECENT VIEW OF THE INTERIOR OF THE NIAGARA FALLS POWER HOUSE.

Ramsay, and the splendid pioneer work of Professor Dewar in the field of low temperature research. The fact that the United States have contributed a very liberal share to this prodigious progress must afford to all of us great satisfaction.

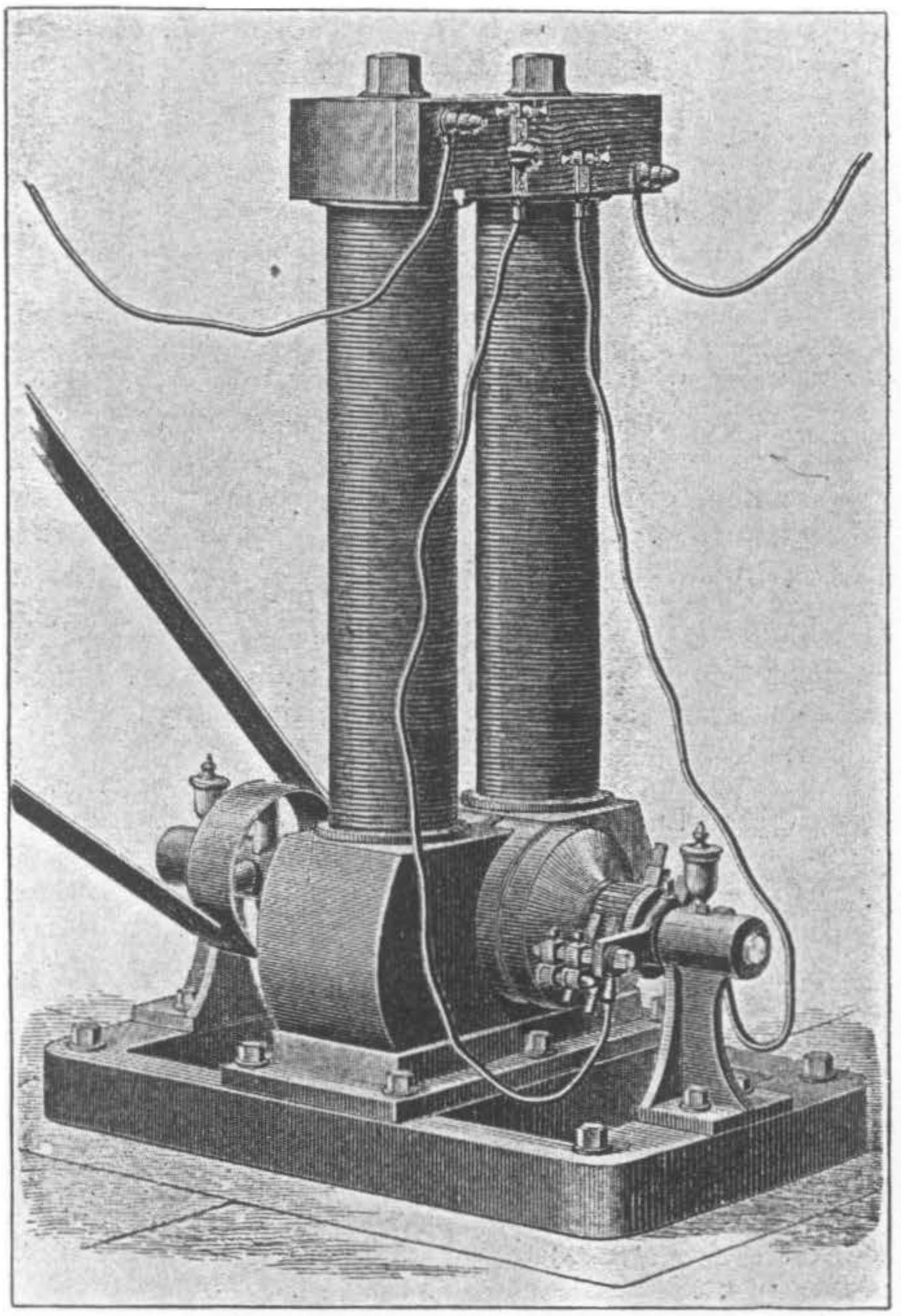
While honouring the workers in other countries and all those who, by profession or inclination, are devoting themselves to strictly scientific pursuits, Americans have particular reasons to mention with gratitude the names of those who have so much contributed to this marvelous development of electrical industry in the United States. Bell, who, by his admirable invention enabling us to transmit speech to great distances, has profoundly affected our commercial and social relations, and even our very mode of life; Edison, who, had he not done anything else beyond his early work in incandescent lighting, would have proved himself one of the greatest benefactors of the age; Westinghouse, the founder of the commercial alternating system; Brush, the great pioneer of arc lighting; Thomson, who gave us the first practical welding machine, and who, with keen sense, contributed very materially to the development of a number of scientific and industrial branches; Weston, who once led the world in dynamo design, and now leads in the construction of electric instruments; Sprague, who, with rare energy, mastered the problem and insured the success of practical electrical railroading; Acheson, Hall, Willson and others, who are creating new and revolutionising industries here under our very eyes at Niagara.

Nor is the work of these gifted men nearly finished at this hour. Much more is still to come, for, fortunately, most of them are still full of enthusiasm and vigour. All of these men and many more are untiringly at work investigating new regions and opening up unsuspected and promising fields. Weekly, if not daily, we learn through the journals of a new advance into some unexplored region, where at every step success beckons friendly, and leads the toiler on to hard and harder tasks.

But among all these many departments of research, these many branches of industry, new and old, which are being rapidly expanded, there is one dominating all others in importance—one which is of the greatest significance for the comfort and welfare, not to say for the existence, of mankind, and that is the electrical transmission of power. And in this most important of all fields long afterwards, when time will have placed the events in their proper perspective, and assigned men to their deserved places, the great event we are commemorating to-day will stand out as designating a new and glorious epoch in the history of humanity—an epoch grander than that marked by the advent of the steam enigne.

We have many a monument of past ages; we have the palaces and pyramids, the temples of the Greek and the cathedrals of Christendom. In them is exemplified the power of men, the greatness of nations, the love of art and religious devotion. But that monument at Niagara has something of its own, more in accord with our present thoughts and tendencies. It is a monument worthy of our scientific age, a true monument of enlightenment and of peace. It signifies the subjugation of natural forces to the service of man, the discontinuance of barbarous methods, the relieving of millions from want and suffering.

No matter what we attempt to do, no matter to what fields we turn our efforts, we are dependent on power. Our economists may propose more economical systems of administration and utilisation of resources, our legislators may make wiser laws and treaties, it matters little; that kind of help can be only temporary. If we want to reduce poverty and misery, if we want to give to every deserving individual what is needed for a safe existence of an intelligent being, we want to provide more machinery, more power. Power is our mainstay, the primary source of our many-sided energies. With sufficient power at our disposal we can satisfy most of our wants and offer a guaranty for safe and comfortable existence to



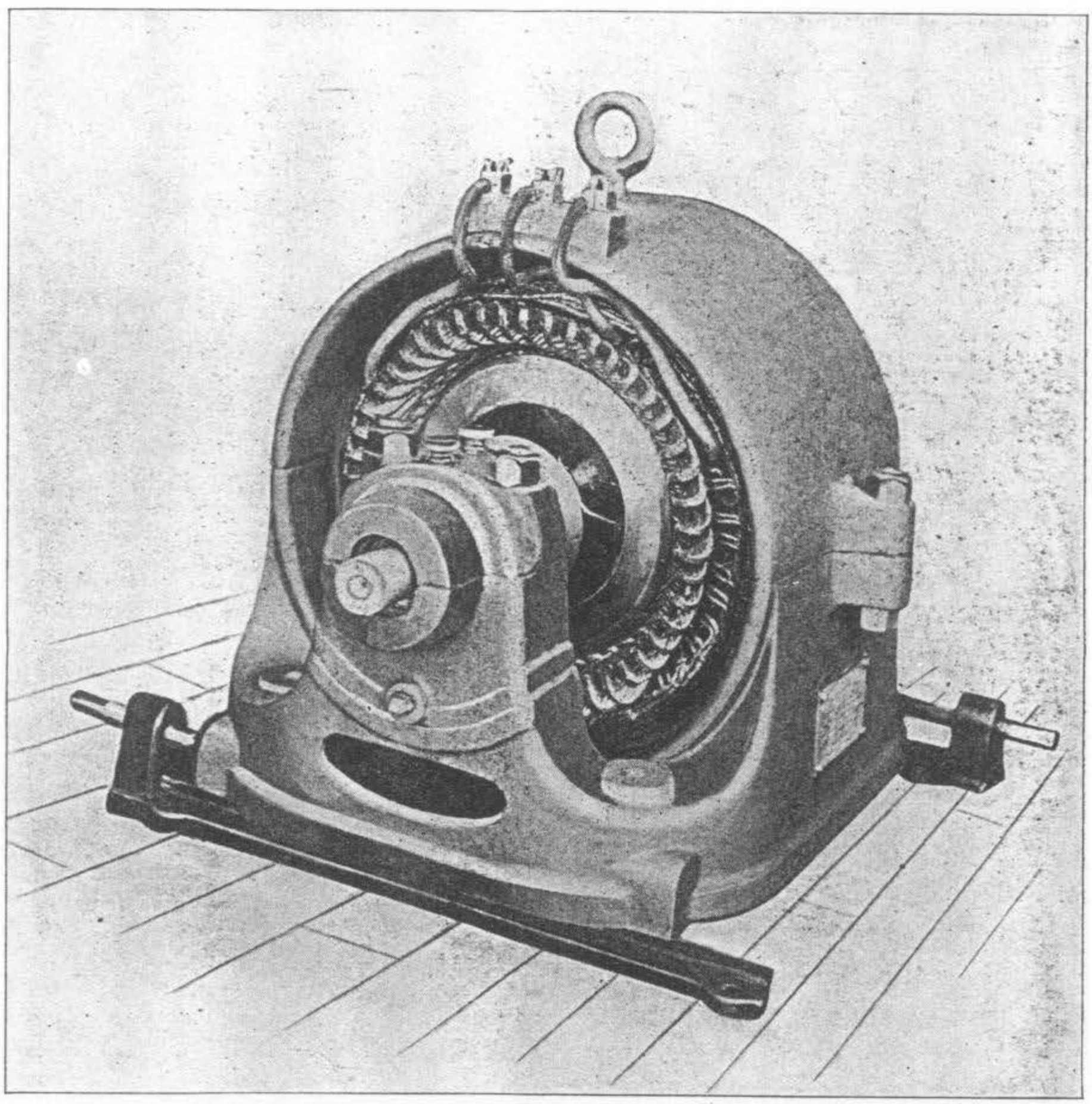
AN EARLY EDISON MOTOR, BUILT IN 1880.

all, except perhaps to those who are the greatest criminals of all—the voluntarily idle.

The development and wealth of a city, the success of a nation, the progress of the whole human race, is regulated by the power available. Think of the victorious march of the British! Apart from the qualities of the race, which have been of great moment, they owe the conquest of the world to—coal. For with coal they produce their iron; coal furnishes them light and heat; coal drives the wheels of their immense manufacturing establishments, and coal propels their conquering fleets. But the stores are being more and more exhausted, the labour is getting dearer and dearer, and the demand is continuously increasing.

It must be clear to every one that soon some new source of power supply must be opened up, or that at least the present methods must be materially improved. A great deal is expected from a more economical utilisation of the stored energy of the carbon in a battery; but while the attainment of such a result would be hailed as a great achievement, it would not be as much of an advance towards the ultimate and permanent method of obtaining power as

some engineers seem to believe. By reason both of economy and convenience we are driven to the general adoption of a system of energy supply from central stations, and for such purposes the beauties of the mechanical generation of electricity cannot be exaggerated. The advantages of this universally accepted method are certainly so great that the probability of replacing the engine dyna-

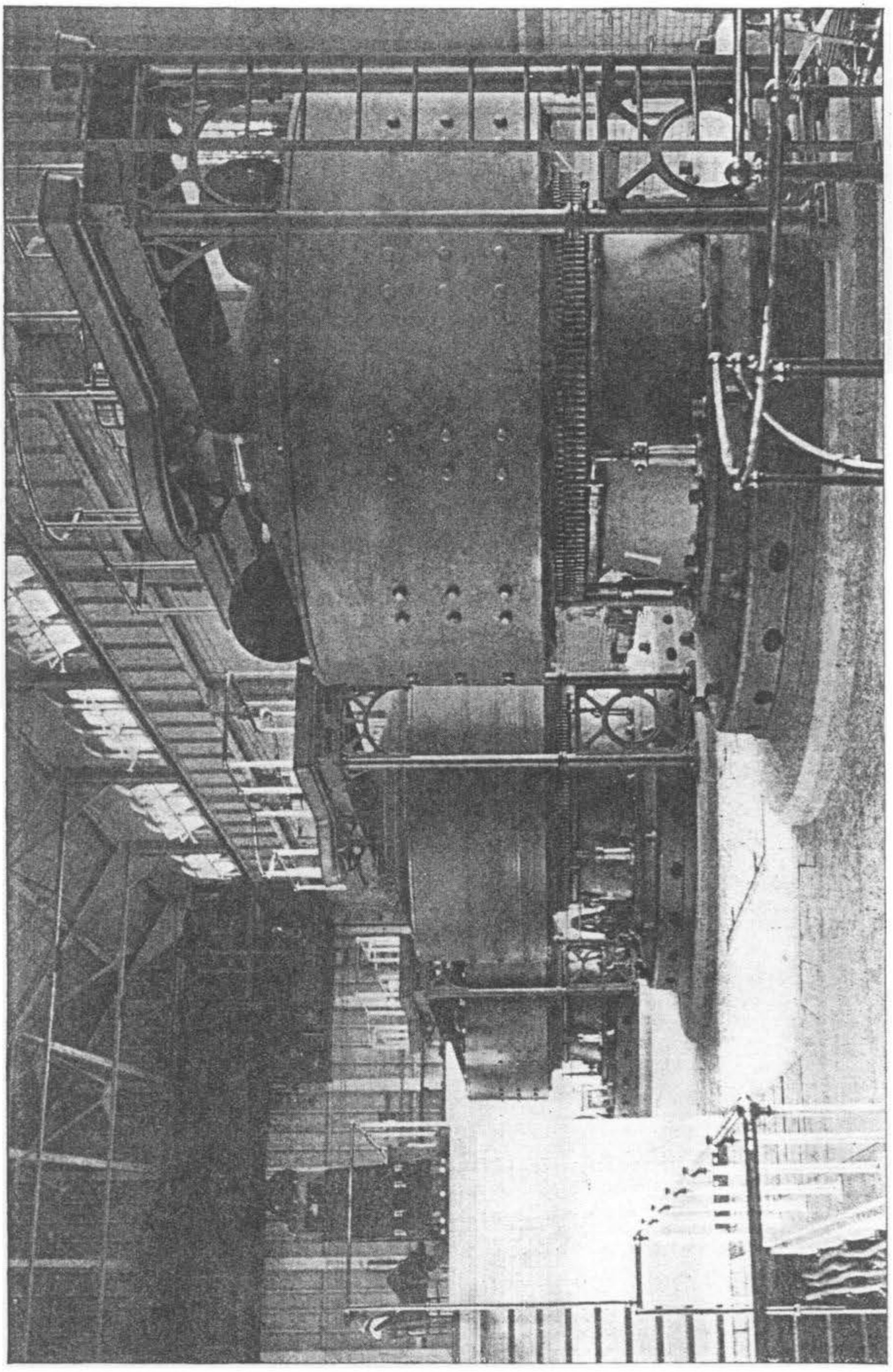


A MODERN TESLA MOTOR AS MADE BY THE WESTINGHOUSE ELECTRIC AND MFG. CO

mos by batteries is, in my opinion, a remote one, the more so as the high-pressure steam engine and gas engine give promise of a considerably more economical thermodynamic conversion.

Even if we had this day such an economical coal battery, its introduction in central stations would by no means be assured, as its use would entail many inconveniences and drawbacks. Very likely the carbon could not be burned in its natural form as in a boiler, but would have to be specially prepared to secure uniformity in the current generation. A great many cells would be needed to make up the electro-motive force usually required. The process of cleaning and renewal, the handling of nasty fluids and gases and the great space necessary for so many batteries would make it difficult, if not commercially unprofitable, to operate such a plant in a city or densely populated district.

Again, if the station be erected in the outskirts, the conversion by rotating



ANOTHER VIEW OF THE NIAGARA FALLS POWER HOUSE INTERIOR.

transformers or otherwise would be a serious and unavoidable drawback. Furthermore, the regulating appliances and other accessories which would have to be provided would probably make the plant fully as much, if not more, complicated than the present. We might, of course, place the batteries at or near the coal mine, and from there transmit the energy to distant points in the form of high-tension alternating currents obtained from rotating transformers, but even in this most favourable case the process would be a barbarous one, certainly more so than the present, as it would still involve the consumption of material, while, at the same time, it would restrict the engineer and mechanic in the exercise of their beautiful art. As to the energy supply in small isolated places, as dwellings, I have placed my confidence in the development of a light storage battery, involving the use of chemicals manufactured by cheap water power, such as some carbide of oxygen-hydrogen cell.

But we shall not satisfy ourselves simply with improving steam and explosive engines or inventing new batteries; we have something much better to work for, a greater task to fulfill. We have to evolve means for obtaining energy from stores which are forever inexhaustible, to perfect methods which do not imply consumption and waste of any material whatever. Upon this great possibility, upon this great problem, the practical solution of which means so much for humanity, I have myself concentrated my efforts for a number of years, and a few happy ideas which came to me have inspired me to attempt the most difficult, and given me strength and courage in adversity.

Nearly six years ago my confidence had become strong enough to prompt me to an expression of hope in the ultimate solution of this all-dominating problem. I have made progress since, and have passed the stage of mere conviction such as is derived from a diligent study of known facts, conclusions and calculations. I now feel sure that the realisation of that idea is not far off. But precisely for this reason I feel impelled to point out here an important fact, which I hope will be remembered.

Having examined for a long time the possibilities of the development I refer to, namely, that of the operation of engines on any point of the earth by the energy of the medium, I find that even under the theoretically best conditions such a method of obtaining power cannot equal in economy, simplicity and many other features the present method, involving a conversion of the mechanical energy of running water into electrical energy and the transmission of the latter in the form of currents of very high tension to great distances. Provided, therefore, that we can avail ourselves of currents of sufficiently high tension, a waterfall affords us the most advantageous means of getting power from the sun sufficient for all our wants, and this recognition has impressed me strongly with the future importance of the water power, not so much because of its commercial value, though it may be very great, but chiefly because of its bearing upon our safety and welfare.

I am glad to say that also in this latter direction my efforts have not been unsuccessful, for I have devised means which will allow us the use in power transmission of electro-motive forces much higher than those practicable with ordinary apparatus. In fact, progress in this field has given me fresh hope that I shall see the fulfillment of one of my fondest dreams; namely, the transmission of power from station to station without the employment of any connecting wire. Still, whatever method of transmission be ultimately adopted, nearness to the source of power will remain an important advantage.

Some of the ideas I have expressed may appear to many hardly realisable; nevertheless, they are the result of long continued thought and work. With ideas it is as with dizzy heights. At first they cause you discomfort and you are anxious to get down, distrustful of your own powers; but soon the remoteness of the turmoil of life and the inspiring influence of the altitude calm your blood; your step gets firm and sure and you begin to look—for dizzier heights.

In the great enterprise at Niagara we see not only a bold engineering and commercial feat, but far more, a giant stride in the right direction as indicated both by exact science and philanthropy. Its success is a signal for the utilisation of water powers all over the world, and its influence upon industrial development is incalculable. We must all rejoice in the great achievement and congratulate the intrepid pioneers who have joined their efforts and means to bring it about. It is a pleasure to learn of the friendly attitude of the citizens of Buffalo and of the encouragement given to the enterprise by the Canadian authorities. We shall hope that other cities, like Rochester on this side and Hamilton and Toronto in Canada, will soon follow Buffalo's lead. This fortunate city herself is to be congratulated. With resources now unequaled, with commercial facilities and advantages such as few cities in the world possess, and with the enthusiasm and progressive spirit of its citizens, it is sure to become one of the greatest industrial centres of theglobe.

ELECTRICAL SECTION.

Stated Meeting, December 22, 1897.

MR. CLAYTON W. PIKE, President, in the chair.

X-RAYS, APPARATUS AND METHODS.

BY ELMER G. WILLYOUNG AND H. LYMAN SAYEN.

That Professor Roentgen's discovery of the X-ray has initiated many lines of thought, promising to greatly extend our knowledge of physical phenomena as well as to revise many of our previously accepted views, is generally admitted. That the practical results accruing to humanity by virtue of the applications of this discovery in surgical and medical practice, are of even greater promise and value, is equally conceded. The writers have been engaged for a number of months past in developing apparatus and methods for practical work with especial reference to the needs of the physician and surgeon. For conciseness, we have arranged the matter under consideration in a series of subordinate heads, each of which we shall briefly discuss. Your programme committee has thought that some of the results secured might be interesting, in view of the fact that very little literature regarding the technique of X-ray work has thus far been published.

The Coil or Generating Source.—Thus far the only apparatus known which will produce X-rays readily and profusely is the "transformer." By this, however, we do not mean the commercial transformer of every-day use, but its earlier, and for most purposes less efficient form, the "induction coil." Such a transformer gives exceedingly great electromotive forces capable of producing discharge over long air gaps. When the discharge from such a coil is passed through properly exhausted and constructed tubes, we have a very vigorous generation of X-rays.

Two arrangements of the induction coil are advocated. The one is known as the Tesla or "high-frequency" coil, and the other is the direct and old-fashioned use of the simple induction coil, in which the high secondary E.M.F. is delivered direct to the terminals of the tube.

The High-Frequency Coil.—Fig. 1 shows the diagram of the Tesla combination or "high-frequency" coil. It consists, as will be seen, of two induction coils, the induced secondary current of the first being used to charge a Leyden jar. The primary of the second coil is joined, in series with a spark gap, to the two coatings of the Leyden jar. When the Leyden jars are fully charged, they discharge across

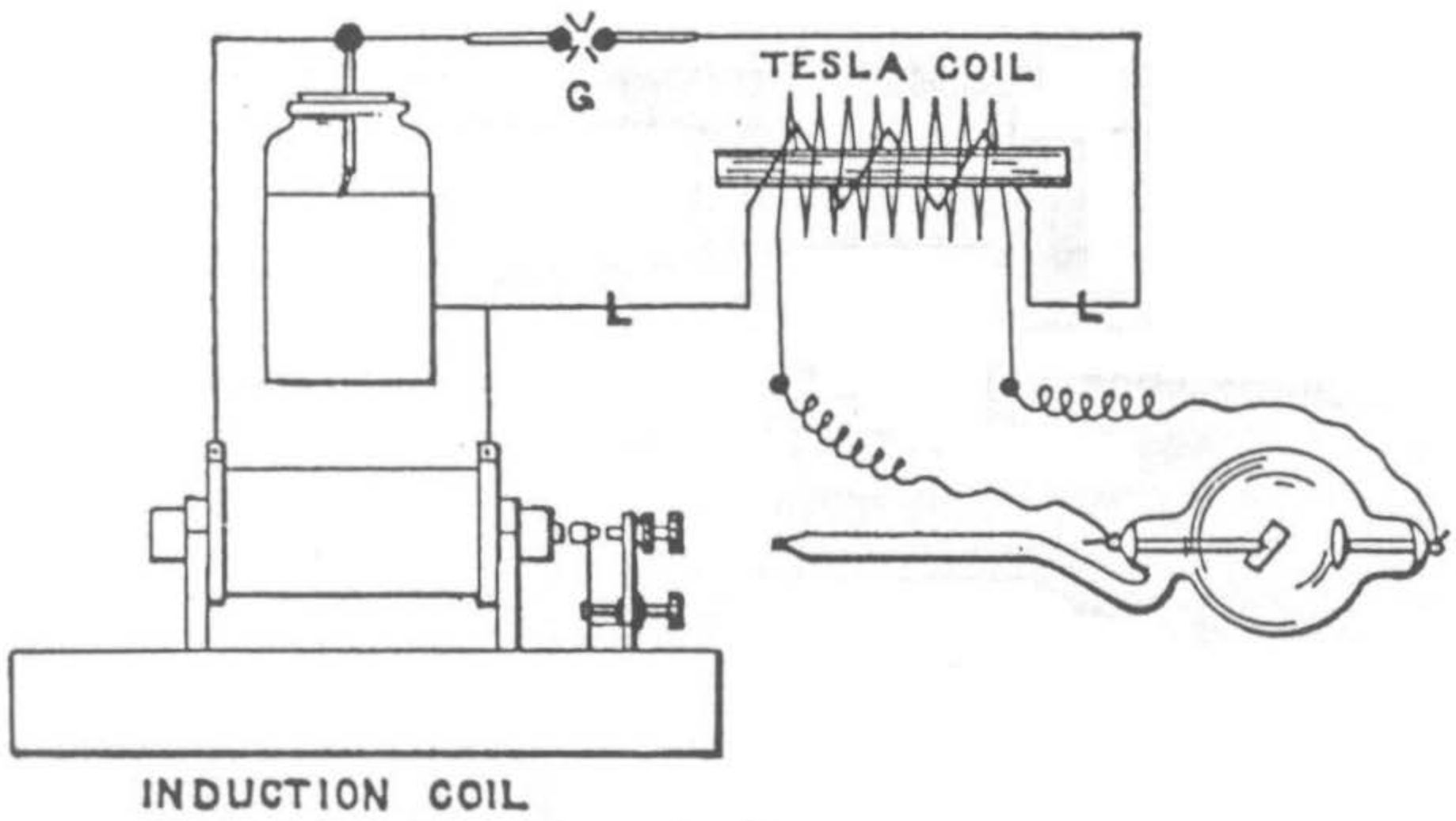


FIG. 1.

the air-gap, this discharge being, by well-known laws of electrical circuit flow, an oscillating one of exceedingly high frequency—millions or more oscillations per second. We thus have the primary of the second coil excited by an alternating current of exceedingly great voltage and frequency, so that *its* secondary produces a discharge of still *greater* E.M.F. and of this same high frequency. So great is this final E.M.F., that it is generally necessary to immerse the entire second coil, primary and all, in a tank of oil, since no solid insulation has yet been found capable of standing these great E.M.F.'s without breakdown.

To excite the Tesla coil, we may use either an interrupted direct current or an ordinary alternating circuit joined directly to the primary of the first coil. But the final result is, in either case, an alternating, high-potential, high-frequency current. In the tube, therefore, we also have an alternating discharge.

The Induction Coil.—We illustrate, in *Fig. 2*, the scheme of connections, etc., of the simple induction coil. The primary must be excited by an interrupted direct current, which may be secured from primary batteries, storage batteries, or a commercial circuit as may be determined by convenience or inclination. The secondary is joined directly to the tube

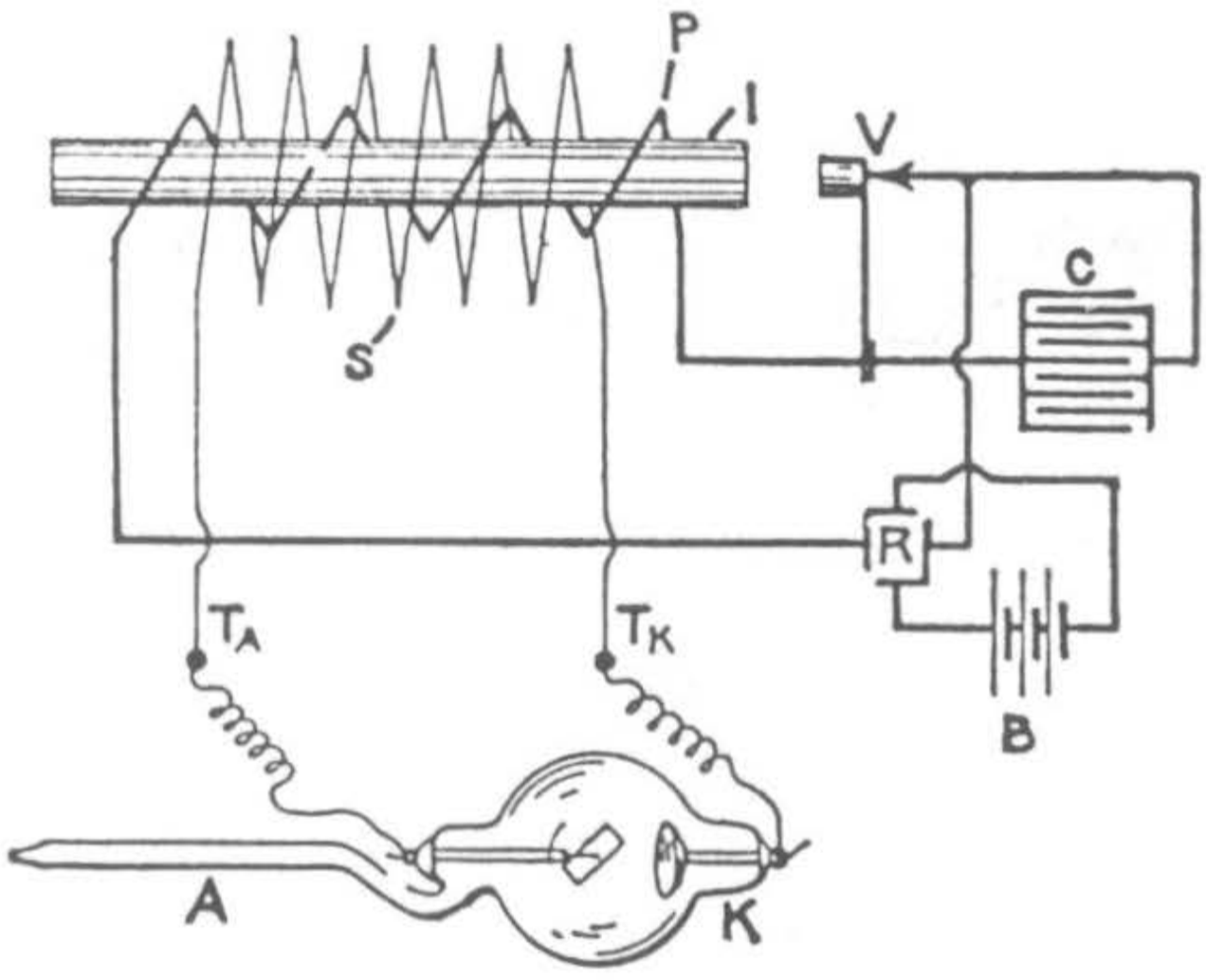


FIG. 2.

terminals. The usual means employed for securing the interruptions is some form of vibrating spring device, automatically operated by the core of the coil itself, the magnetic pull of the core attracting a mass of iron which, by its motion, separates two contact points, thus allowing a properly placed spring to draw it back, closing the circuit again, when the cycle is repeated. Such a device is employed in most forms of virbating electric bells and is indicated in the diagram. Around the break is placed a condenser. At break, this condenser charges (thus preventing the extra induced current due to the large self-induction of

the primary), but, being "short-circuited" by the primary, at once discharges about the iron core in a direction *opposite* to the regular "make" current, thus reducing (if correctly proportioned) the magnetic intensity of the iron core to zero. All this takes place so quickly that the practical effect of the action is merely to assist and intensify the dropping off of the core's magnetism—to shove it along—hasten it. Considering the secondary, now, we find that we shall have at *break* an induced discharge of greatly higher E.M.F. than that at *make*, owing to the falling off of the core's magnetism *at* break being greatly sharper than its growth at make. The effect of this is to give secondary discharges in *one direction only* at all times when the spark gap is not *greatly* shorter than the *maximum* obtainable spark gap for that particular condition of running the coil, the *make* induced current at such times being of too small E.M.F. to get across the gap at all. This is always the condition when X-ray tubes are used. A further function of the condenser is to suppress *burning* at the "break" terminals or points of interruption by taking up the energy of the magnetic discharge of the coil.

In the construction of the induction coil, a number of points may be noted. Our secondaries are wound in sections $\frac{1}{8}$-inch thick (according to the plan originally proposed, we believe, by Ritchie). These sections are separated from one another by a large number of discs of paper of a brand especially selected as free from carbon particles, and baked at a temperature a little below charring point for some time immediately before use—this to drive out moisture. These sections are then assembled and immediately immersed in a special insulation composition having a very high melting point, with high specific heat, and some slight viscosity at all temperatures.

Paraffine we absolutely prohibit as being apt to crack and absorb moisture. The melting point of paraffine, also, is so low (not over about 140° F. for the highest), that in warm weather there is serious risk of displacement of some of the sections by their own weight; for the same reason but little energy can be dissipated from the secondary.

Another grave danger in the use of paraffine is that due to the acid which it usually contains. This attacks the wire, forming copper sulphate, which dissolves gradually into and throughout the mass of the paraffine, thus effectually destroying its insulating properties.

After cooking for some time in the insulation, to drive out the last traces of moisture, the stack of sections is subjected to a further treatment, by which it is finally cooled *with all air removed.* This we consider a point of the highest importance, as air present anywhere in the secondary becomes electrified and bombards to and fro, gradually softening the insulation and eventually breaking down the coil. (For confirmation of this point, see Tesla, on "High-Frequency Phenomena.") With this plan of construction we have no static leaks of energy, or small direct leaks within the coil itself, and deliver the full energy of discharge at the secondary terminals. We find ourselves able to secure in this way a full inch of spark in all sizes of coils with considerably less than 1 pound of wire, No. 34 B. & S.* We believe that, more than anything else, the large quantities of wire required to produce a given spark length with many of the coils now in use is due to the presence of air, and consequent loss of energy by static bombardment, in the secondary. As regards the insulating composition used by us, we may say that we find its power of resistance to spark discharge to be four or five times that of hard rubber. In the arrangement of our secondary, we separate it from the primary by a heavy hard-rubber tube, and, in addition, by a tube of this composition.

The Adjustable Condenser.—A coil is working to best advantage when there is a certain definite relation between its primary current, secondary spark distance, and condenser capacity. Frequency of break must also be considered. As coils have heretofore been built, however, the condenser value has been fixed once for all and admits of no change, albeit both spark gap and primary current may be so

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* In our latest coils not over three-quarters of a pound to the inch of spark is used.

changed. To remedy this, we have devised a form of switch shown in the diagram, *Fig. 3*, by means of which the condenser capacity may be shifted, at will and instantly, by simply turning the switch. The effect upon the secondary discharge is very marked, both volume and musical note of the spark changing with the position of the switch. We find this idea exceedingly convenient in general experimental work with alternating currents, it being possible with it to alter condenser capacity as quickly and as readily as we may self-induction or resistance. (We have made some experiments in the use of a condenser in parallel *with the primary*. The volume of the secondary discharge seems, in many cases, to be greatly increased.)

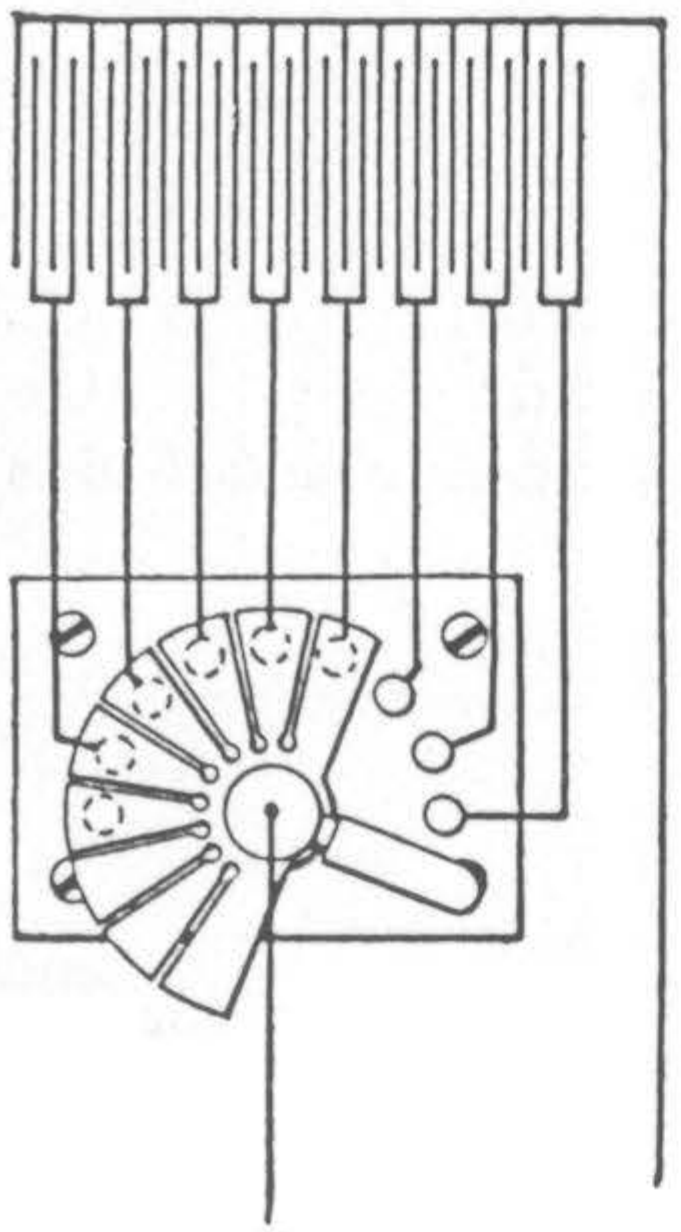

FIG. 3.

In arranging coils to operate from few or many cells of battery it is, of course, merely a matter of winding the primary with coarse or fine wire, the number of ampère turns being kept the same. It is interesting to note, as we have noted experimentally many times, that the larger the primary E.M.F. the smaller must be the condenser capacity employed, and *vice versa*. This is, of course, only to be expected, since capacity and self-induction are inverse functions of each other.

Primary Current.—This may be either from primary batteries, storage batteries, or from a commercial direct-current circuit. Primary batteries have too high resistance to give sufficient current for coils of much size—say 4 inches and over—unless joined in parallel, and then we need a number of such groups to secure the requisite E.M.F. They require constant attention, soon run down, and are expensive to operate. Storage batteries are exceedingly satisfactory, are comparatively inexpensive to operate, and require practically no attention. Charging them is more or less of an annoyance, however, especially where they must be sent

out of the building, as they usually must, besides throwing the entire apparatus out of use while the charging is going on, unless one have a reserve set of batteries.

The utilization of a direct commercial circuit, such as the Edison 110-volt (*c. g.*, where such is available), is, in every way, the most convenient and satisfactory. Until Professor Roentgen's discovery, no method of operating large coils upon such a circuit had been developed. Recently, however, several methods have been brought out, notably that of the

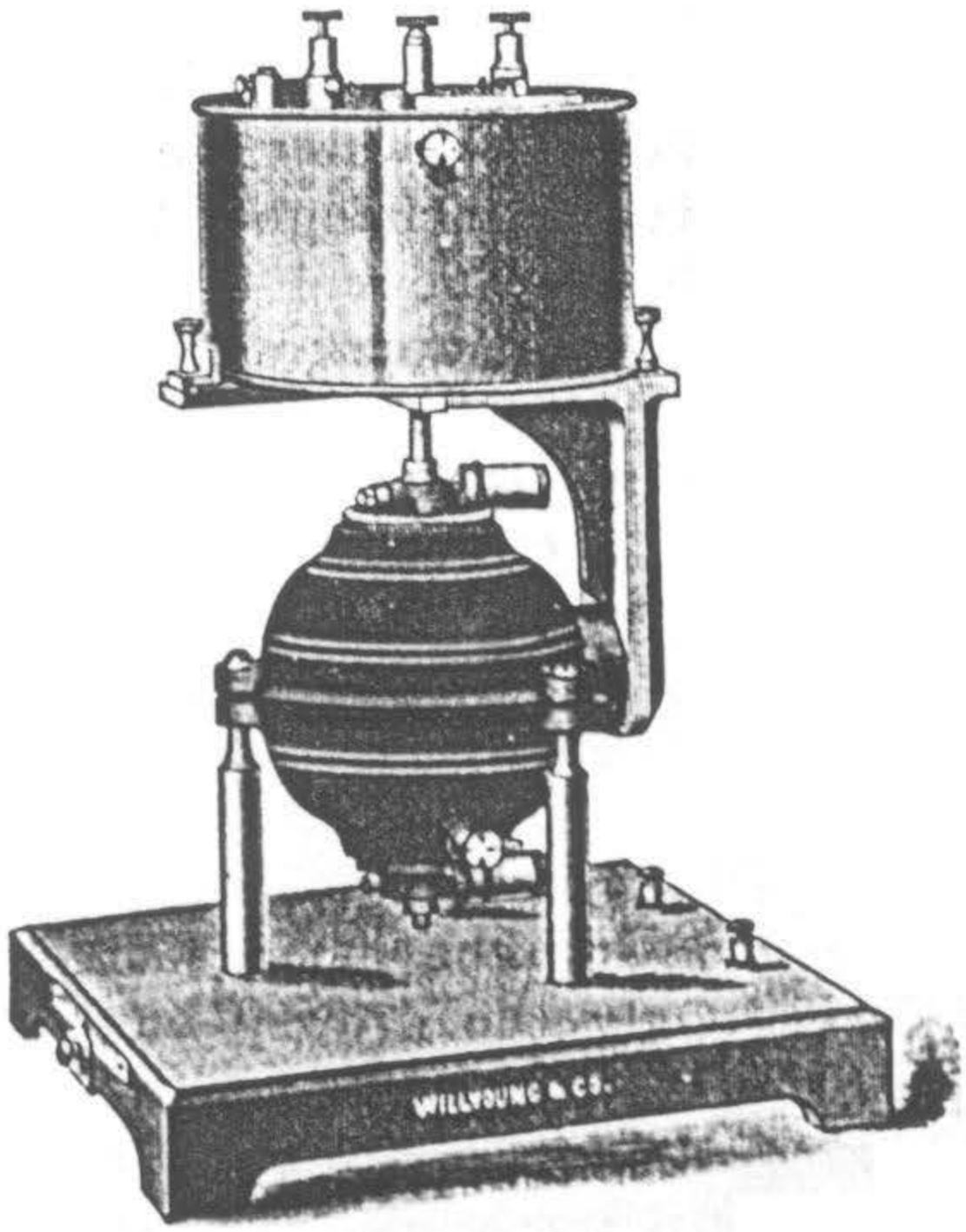

FIG. 4.

"air break," with air blast to blow out the spark, as used by Dr. Wm. J. Morton, Dr. M. I. Pupin, and others. In *Fig. 4* we show a form of apparatus devised by us to accomplish this purpose. A Lundell $\frac{1}{12}$ horse-power motor is supported upon a base with its shaft vertical. A casting, attached to the motor, supports above the latter a copper can made up of two concentric cylinders joined by a ring below, so that the shaft passes up through the inner cylinder and thus avoids the necessity of a stuffing-box. From the shaft is

hung, well within the can, a heavy brass wheel, having stretches of insulating slate let into its periphery. A hard-rubber lid fits over the top of the can. Mounted upon this lid are two brushes, one bearing against the wheel periphery and one against the shaft; suitable springs and screws allow the brush tension to be varied. From the commercial circuit leads are brought to these two brushes, the current being first passed through the primary of the coil and a rheostat in series. Before the lid is put in place the can is filled with distilled water; ordinary hydrant water will answer, although its usual impurity soon causes the water to become dirty, besides allowing a certain amount of electrolysis during use. With distilled water the break may be run for a number of hours without change of the water and very little heating takes place. The real function of the water is not so much to drown the spark as to prevent heating, although it does, of course, also assist in quenching the spark. But a condenser is the real spark extinguisher, and this we connect around the break just as we would around an ordinary vibrating break.

The advantages of this break over all forms of vibrating break thus far known, and over other forms of rotary break, are:

(*a*) *Convenience.*—Mere throwing of a switch being all that is required to start and stop the apparatus.

(*b*) *Noiselessness.*—Only the drowsy hum of the motor being heard.

(*c*) *Reliability.*—No chance of sticking, as with vibrating breaks.

(*d*) *Variable Rate of Break.*—Secured by adjusting rheostat in base of motor.*

(*e*) *Smooth, Unvarying Fluoroscopic Images* by reason of the large number of breaks per unit of time.

Another great advantage of the rotary break is the almost perfect control which it gives over the spark length.

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* We have found that the vacuum of a tube often gets into such a condition as to make the tube absolutely unworkable at a given frequency of break, whereas, a slight *change* of frequency immediately restores the X-radiation.

This is on account of the independence of the coil and the break, thus permitting the breaking of any desired value of current without the slightest change in either frequency or character of break. With the usual vibrating break, operated by the core of the coil, the character and frequency of break is necessarily a function of the value of current, being broken and changed with it. It is impossible, with a large coil, *e. g.*, to get uniform and continuous secondary discharges of a length very small compared with the maximum capacity of the coil, since to such short sparks would correspond a magnetization of the core insufficient to operate the vibrator at all. But with the rotary break we may make the current as small as we please, without in the slightest degree interfering with the frequency and precision of the break.

Two milled heads at top of can permit its lid (carrying brushes) to be withdrawn. A similar head at top of shaft loosens break-wheel, and two heads at bottom of can allow it to be lifted away for cleaning and renewal and replenishing of water.

We use three makes and three breaks per revolution and find best results at from 1,200 to 1,400 revolutions per minute (equal to 3,600 to 4,800 interruptions). We may secure as many as 2,000 revolutions (6,000 interruptions) per minute, by cutting out the motor regulator.

In operation, the brush bearing upon break-wheel should be *positive*, so as to prevent any electrolysis of the break-wheel. We have often broken between 15 and 20 ampères through this wheel for a considerable length of time without any overheating or excessive wear of the wheel. Should the wheel wear in time to an undesirable degree it may be removed and turned down. Provision is also made for replacing the brushes when desired.

General Considerations Regarding Break Frequency.—The question as to whether there is a certain best frequency of break for a given coil or tube or both, has puzzled not a few. Very little has been experimentally determined regarding this point. It is certain, however, that, with a given coil or tube, shortness of exposure is *not* exactly inversely as the

number of breaks. Indeed, it is often far from being so. Some of the best X-ray pictures that have been taken have been by the use of the old "hammer" break of Ritchie, and 4 or 5 clicks of the break have sufficed. Using the same tube and coil, but a rapidly vibrating or rotary break, required 40 or 50 breaks to accomplish the same results. It would appear, hence, that the energy of X-ray radiation *per break* is a function of the number of breaks per unit of time.

We are inclined to believe that this is a matter purely of the "time constant" of the coil. The iron of the core requires a certain time to magnetize and demagnetize. With the breaks few, ample time is given for this process, but when the breaks become rapid this is no longer possible, so that the secondary E.M.F. falls—this may easily be verified by observing the maximum spark length of any coil--with single breaks, few and far between, we get much longer spark maxima than if the breaks are frequent. The thickness of the sparks is also greatly increased. If, however, we increase the *primary* E.M.F. for the more rapid break we may bring up the secondary spark length to the value given by the single breaks. We should thus be able to shorten the exposure as much as we please, by merely increasing the rate of break and the primary E.M.F. at the same time; but here we are limited by the *tube* which cannot *dissipate* more than a certain definite amount of energy in a given time and will break down if overdriven. We see, therefore, that whether we use slow breaks or fast breaks, the actual time of exposure remains practically the same, the few breaks requiring to be distributed over the same *time* as the much larger number of rapid breaks. All this, of course, applies to the photographic plate. For fluoroscopy we require rapid breaks in order to escape the otherwise distressing flickering.

In the above connection, particular attention is directed to one point—the rate of break *must not be too great*. If it is, the iron no longer has time to magnetize and demagnetize. The result is an *alternating* secondary discharge instead of the *direct* discharge desired, and this means blackening of

the tube, *rapid fluctuations of the vacuum, and general deterioration of the tube. We doubt whether, with any coil of size suitable for X-ray work, a rate of break greater than 5,000 per minute should ever be employed.*

Tesla Coil or Induction Coil—Which?—Having carefully examined the results, apparatus and methods of others all over the country, devotees some of the "high-frequency" coil, some of the induction coil, and having made many and careful experiments with both forms of apparatus ourselves, we favor the induction coil. Our reasons for this preference are briefly stated:

(*a*) *Simplicity.*—One coil instead of two.

(*b*) *Ease of Manipulation.*—There being more than double the number of factors to attend to in the Tesla coil than in the induction coil.

(*c*) *Cleanliness.*—The "high-frequency" coil requires an oil bath, which must be renewed from time to time to avoid gumming. It is difficult, also, to find an oil which will not, eventually, act upon the insulation of the wire by virtue of the acid or other impurities which the former may contain.

(*d*) *Sharp Definition.*—The "high-frequency" coil produces an alternating discharge - thus with the double focus tube giving us *two* sources of X-radiation and consequent blurring of the image. If a single focus tube be used, the discharge in one direction is either lost or tears off particles of the platinum reflector, thus blackening the tube and soon destroying its effectiveness.

(*e*) *Noiselessness.*—This, from the surgeon's and physician's standpoint, is, perhaps, the most important consideration. With tube in action, the induction coil is practically noiseless, save for the low hum of motor or vibrator. Improperly designed vibrators often rattle and rasp in a very irritating manner. In the "high-frequency" coil, however, the disruptive discharge over the air gap is the vital cause of its action. It is much more violent than a discharge of corresponding length from the induction coil, being of a rattling, cracking character. That such noise cannot but have a most unpleasant effect upon the patient who comes

into the operating room in a condition of more or less nervous collapse to begin with is obvious.

(*f*) *Strain on Tube.*—It has been argued by advocates of the "high-frequency" coil that it is much less hard upon the tubes. Our own observation has been just the reverse of this, and has satisfied us that the wear and tear is very much less with the induction coil.

(*g*) *Results.*—Although we have diligently examined, we have yet to see results obtained by any form of apparatus superior to those made in Philadelphia by Dr. Goodspeed, of the University of Pennsylvania; Dr. Stern, of the Polyclinic Hospital; ourselves, and many others who might be mentioned, and this either as regards detail, penetration or quickness of exposure. Indeed, we may say that we have never seen results obtained with the Tesla coil that are equal in any of the above respects to the results just referred to.

The Tube.—Many forms of tubes have been suggested. With practically no exception, all tubes now in use employ as cathode a concave aluminum disc, whose center of curvature is at the center of a small platinum plate ($\frac{3}{8}$ to $\frac{3}{4}$ square inch in area) the plane of the plate being inclined to the normal from center of the concave cathode. This platinum plate is sometimes made the anode—sometimes the anode is a separate plate or wire elsewhere in the tube. This form of tube is known as the "focus" tube, the cathode rays being focussed upon the platinum plate, which then becomes the active source of X-rays. In the double-focus tube we have two concave cathodes at opposite ends of the tube, the platinum wire reflector being in the form of a wedge with a side presented to each of the concave cathodes.

In the use of the tube everything depends upon the vacuum, X-rays seeming to be of a heterogeneous character, just as are light rays, their quality varying with the degree of vacuum. The higher the vacuum the more penetrating power the tube has, hence it is well to select tubes and use different tubes for different purposes. A tube of extremely high exhaustion is best for working through the body, but with forearm, hands, feet, etc., such a tube has

too great penetration, the bones appearing almost equally transparent with the flesh.

The chief difficulty with most tubes is the change of vacuum which takes place in use. This is thought to be due to the occlusion of the residual gas upon the inner surface of the glass—resulting in an *increased* vacuum; advocates of the bombardment theory believe it to mean an actual driving of the gas out through the body of the tube. It may be partially restored by heating the tube by use of a spirit lamp or Bunsen flame. This must be very carefully done, however, to avoid cracking the tube. When the platinum reflector is

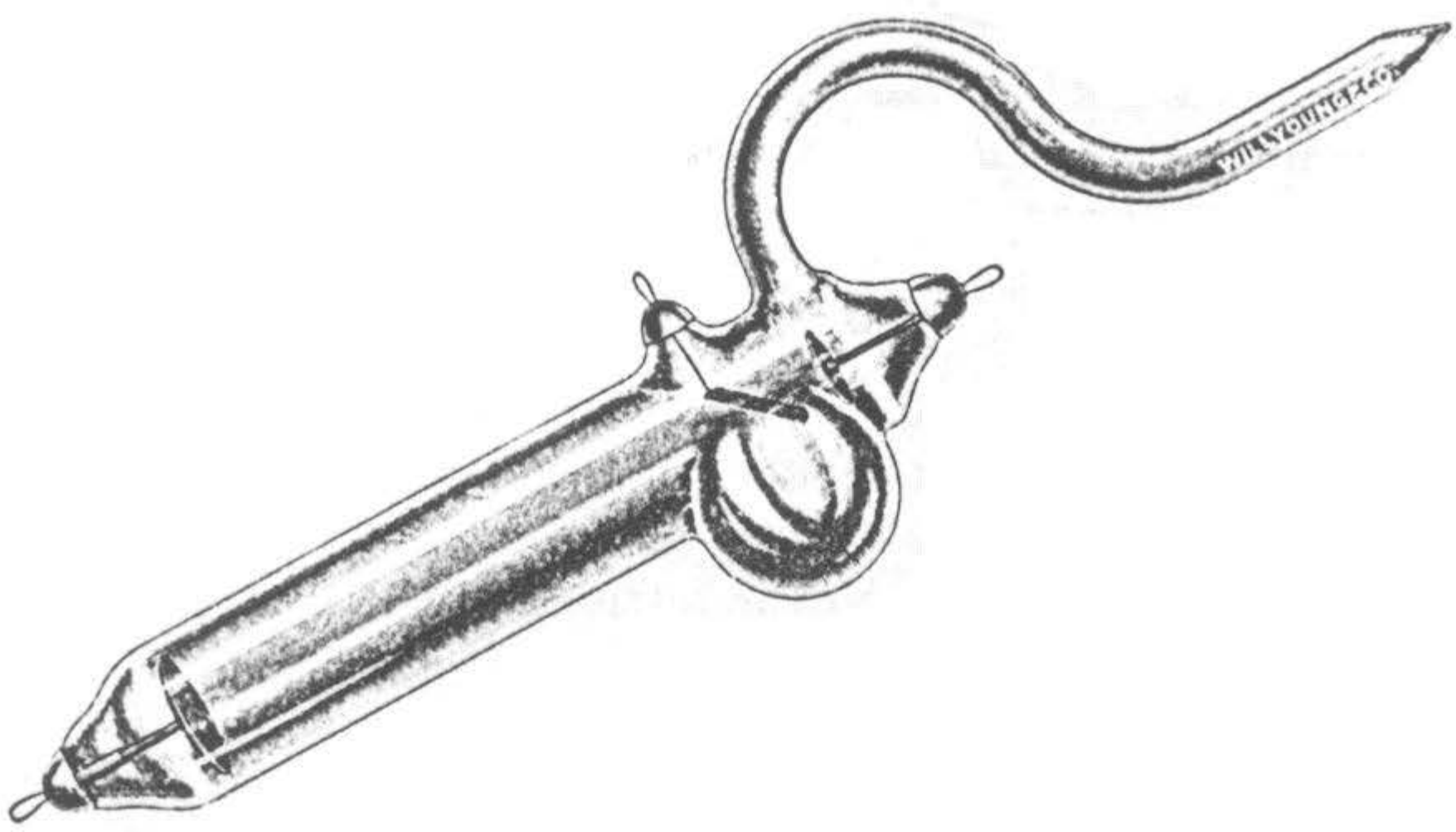

FIG. 5.

used simply as an anti-cathode, and the anode is aluminum, a simple reversal of the discharge will prove fairly successful. Some makers have adopted the scheme, practised now for many years, of blowing a small side pocket upon the tube, into which is placed phosphoric anhydride or some other chemical substance or composition absorbing moisture. When heated, this substance gives off vapor to make up for the loss; it is difficult, however, to drive off just the right amount of vapor in this way, and the vacuum is liable to be made too low, in which case flesh and bone are about equally opaque. So rapid is this change of vacuum with the majority of tubes, that in most cases involv-

ing over a few minutes' exposure or running of the tube one of the above methods becomes necessary. In any case, eventual, almost complete, exhaustion seems to be the rule, and the tube must then be returned to the makers and re-exhausted.

"Blackening" is another cause of decreased efficiency in the tube. It is due to deposition of platinum upon the inner surface of the tube.

The "Bowdoin" tube, shown in *Fig. 5*, was devised after a considerable amount of experimental work, by Profs. Robinson and Hutchins, of Bowdoin College. In general design it does not differ essentially from many other forms of focus tube upon the market. The two respects in which the tube does differ from other tubes are, first, in the arrangement of electrodes, the reflector plate not being connected to the coil at all, but merely acting as an obstacle to the bombarding rays, while the anode is a disc at the end of the tube away from the cathode. This arrangement is found to perfectly and entirely prevent blackening, no matter how long the tube may be used.

The most important feature of this tube is, however, the presence upon its interior surface of a fluorescent material which has been fused into the surface of the glass.* As the tube is used, this material, either by the bombardment or heating, or both, gives off just enough air or vapor to make up for the occlusion due to the natural working of the tube. The vacuum, therefore, tends to remain always constant. Although it seems almost absurd that one could put in just enough of this material to make up for the gas otherwise lost, yet it is a fact that these tubes remain practically unchanged in vacuum for a very long period.

In use the tube requires no "nursing" whatever. It should always have, to start with, a parallel spark gap, which should be quite small, say 1 inch or 1½ inch, and either the primary current or the vibrator tension adjusted so as to

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*The fluorescent quality is not supposed to have any effect upon the result; it merely *happens* that the particular substance found most effective is fluorescent.

produce only a very small secondary discharge. The energy of this secondary discharge may then be immediately increased until the reflector plate shows a dull red spot of about half the size of the nail of the little finger. The tube is now in its most efficient condition, and, with a well constructed and smooth working break, may be run for an hour or two without the slightest attention. The "getting ready," as above described, takes considerably less time than the time it has taken us to describe it. Indeed, in our own work, we do not trouble to make this preliminary adjustment at all, as we make it once for all when we first begin to work with a tube and do not afterward disturb it, merely closing down the switch when starting work.

Life of Tubes.—The life of tubes in general is limited—

(*a*) By time required for the vacuum to become too great, hence requiring re-exhaustion.

(*b*) By ability to stand the electrical strains.

(*a*) Applies to all tubes, so far as we know, save the Bowdoin tubes—probably six or eight hours' continuous working, or the equivalent suffices to incapacitate the average tube. We think that even with the Bowdoin tube there is an evident tendency to eventual very high vacuum, but the time required is quite large, relatively, say ten to fifteen times that operative in the case of other types of tubes.

(*b*) All well-made tubes (from the glass-blower's standpoint) are about equally liable to this limitation. It is probable that these strains are cumulative in their effects upon the tube, the latter gradually weakening until eventually breakdown takes place with secondary discharges much less than would have been originally required for breakdown.

The Stand.—The stand, shown in *Fig. 6*, has been devised by us for applied X-ray work. With it the tube may be placed in any position within a cylinder 6 feet high and 6 feet in diameter, thus making it possible to get under or over a patient, no matter what the latter's position. Four rods (two are not shown in the figure) of vulcanized fibre clamp to the stand in any position and carry the lead wires of the tube, thus keeping them away from one another and

from the metal of the stand. They carry little spring clips at their extremities, by which the wires are caught without tying or bending.* The whole stand is of bicycle tubing and very rigid.

The Subject.—The patient should, of course, be placed in as easy a position as possible. For body pictures, hip and knee joints, etc., a recumbent position may be assumed. The plate should lie beneath and upon a stiff board backing to avoid risk of breakage. Work upon the shoulder, neck, head, etc., may be done with the patient straddling a straight-backed chair, facing the back, and leaning the body against the back for support.† The plate may be bound fast to the body by bandages.



FIG. 6.

Laws for Exposure.—Since the X-rays proceed in straight lines from (approximately) a point source, the intensity of their action varies inversely as the square of the distance from the source. Hence, the *time of exposure* should vary directly as the *thickness* of the intervening substance and the square of the distance from the plate. To

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* This is also a great convenience in changing the position of the stand after everything is connected up—as must often be done. The wires simply slip out of the clips, thus relieving the tube of all strain.

† For this suggestion we are indebted to the practice of Dr. Max Stern, of the Philadelphia Polyclinic.

apply these principles in practice, take a trial picture of the hand at 5 inches distance, this being amply sufficient for good definition with such small bones. Say one minute is required for a good result. Then to take a hip joint, we estimate the thickness of the latter to be, say, ten times that of the hand. We must, therefore, expose ten minutes on account of thickness alone. But, owing to the greater distance of bones from plate, the tube must be removed much further to get definition. At least 15 inches from the dry plate should be given—this is three times the distance used for the hand from which the *times* require to be as the squares of these figures, or as one is to nine. The *total* exposure must, therefore, be ninety minutes. This method gives something to go upon. After a little experience, perhaps the most convenient thing to do is to arrange a little table, based upon previous results, and showing times and distances required for well-defined results for distinctive parts of the body.

Short Exposures.—We have obtained and do regularly obtain without difficulty well-defined pictures, showing complete detail of the osseous structure involved in times and with distances from dry-plate to reflector, as below:

Hand and wrist	5 to 10 seconds,	at 5	inches.
Forearm	10 " 15 "	" 5	"
Arm above elbow	½ " 1 minute,	" 7	"
Shoulder	10 " 15 minutes,	" 10	"
Thorax	15 " 30 "	" 10	"
Hip joint	30 " 45 "	" 12 to 15	inches.
Stones in kidneys	30 " 45 "	" 12 " 15	"
Glass, iron, lead, etc., in any part of trunk	30 minutes on an average,	at 12 to 15	inches.

We have very carefully investigated every claim to quicker exposures than these, often by a personal visit, sometimes by correspondence with personal friends whose reliability was undoubted. We have been unable to learn of any results equally good having been obtained in shorter times by any one at any place with any form of apparatus, and we do not believe any such have been obtained.

Manipulation—Development of the Plate.—Suitable and well-constructed apparatus is not the only essential to good results. A great deal depends upon the operator, and com-

paratively trivial differences in procedure make all the difference between success and failure. We describe here the method which we follow and which allows us to count with certainty upon securing at least nine successful plates for every ten exposures.

General Adjustment.—First see that the coil is working smoothly and so as to give a uniform discharge in the primary. The secondary spark points should be separated by the distance given by the makers as proper for the tube. The coil must then be adjusted either by changing the E.M.F. at the primary or by variation of the vibrator adjusting springs, so as just *not* to spark over this air gap. The tube should then be joined in parallel with this secondary spark gap. The coil may then be started up, using the fluoroscope to show whether direction of discharge is right. If not, the primary current should be reversed. If X-rays are not now profuse, the secondary discharge points should be further separated and the vibrator springs tightened so as to produce correspondingly greater discharge. Continue this until either X-rays are secured as desired, or the tube becomes too hot, or possibly bluish or pink in color. Blue denotes too low a vacuum to expect X-rays, but often a gentle running of the tube for ten or fifteen minutes, while in this condition, will raise the vacuum to a suitable value. Pink denotes a *very* low vacuum and usually means, in a tube which has ever *been* right, a puncture or leak; *such a tube* can only be made good by re-exhaustion and repair. With many tubes a vivid green fluorescence is the sign of the X-ray vacuum. With the Bowdoin tubes, as also with many others, the most efficient condition is with the platinum reflector plate at cherry-red heat over an area of one-half or two-thirds that of the little finger nail.

Sometimes the vacuum will be too high for the production of X-rays with *any* length of secondary discharge. It may be reduced by gentle warming of the tube by a spirit-lamp flame. Sometimes reversal of the current in the tube will answer, but this is apt to blacken.

Sticking of the Vibrator must be guarded against—*it is often fatal to the tube.* This is because of the much larger

current through the primary when such sticking occurs. Upon release, therefore, a secondary discharge much above normal is produced, and this the parallel spark gap is unable to carry off. The tube, therefore, receives much more energy than it should, and may break down even though the parallel spark gap be as advised by the manufacturers.

(*b*) *The Plate and Its Development.*—We have used at one time and another a number of different makes of plates with very fair success. For some time past we have confined ourselves to the Carbutt X-ray plates, and though we are not prepared to say that they are the best plates to use, the results are so uniformly good as to make it seem advisable to us to try other plates not radically different in principle.

For developer, we use the Carbutt "J. C. tabloids"—3 J and 3 C, to 5 ounces of water—*add about 2 drachms of restrainer* (the usual 10 per cent. solution). Heating this developer to about 65° or 70° F. just before using, we also find to have beneficial results.

From 15 to 20 minutes will be required for development. The image will come up very slowly and not very sharply. Not much detail will be visible by holding up to the light. Continue development until the general main outlines have appeared and faded away to a general blackness upon the glass side. Then rinse and hypo.

The fixing generally requires from a half hour to two or three hours. This long time is probably *partly* due to the unusual thickness of the Carbutt X-ray films, but probably even more to some chemical condition set up by the unusually large quantities of restrainer used. Mr. Carbutt advises *3* J and *3* C tabloids to *6* ounces of water to *20-30 drops restrainer*. Our experience is that a plate so developed *always requires intensification*; a tedious nuisance, which can never give as good results as a normally exposed and developed plate.

Fluoroscopy.—As a really efficient aid to investigation or to surgical practice, the fluoroscope has thus far proved rather disappointing. In case of very definite fractures of arm or of leg below the knee, as also in certain cases of gunshot wound in these same parts, the fluoroscope will afford definite knowl-

edge. But in all troubles affecting the trunk, upper leg, etc., the indications are too blurred and vague to be relied upon. A good part of this indefiniteness is doubtless due to the *phosphorescent* quality of the screen, which causes images to be retained for an appreciable time after they are formed, so that unsteady holding produces superposed images, while we also have a molecular disturbance extending in every direction in the plane of the screen, producing visibility where no direct X-ray disturbance has been produced. Part of the difficulty is also probably due to the natural inefficiency of the screen, which, as employed in this country, is merely of tungstate of calcium. The platinum salts, especially the platinum barium cyanide, is much superior to the tungstate of calcium, but considerably more expensive; it is generally used abroad. The results obtained with it are much more brilliant than those gotten with the tungstate. It is probable that there are other salts or combinations of salts still more powerful than the platinum.

In using the fluoroscope the room should be made as dark as possible, as the eye thus becomes many times as sensitive. Good tubes are often condemned on account of lack of appreciation of this fact and because they do not reveal much detail when used in a lighted room. We have often seen tubes which would not reveal even the bones of the hand in a lighted room, which, after keeping the eyes in the dark for five or ten minutes, would give very clear fluoroscopic images of the ribs, spinal vertebræ, heart, etc.

It does not follow at all that tubes giving poor fluoroscopic results will also give poor photographic results, or *vice versa*, although usually there is a certain correspondence between the two ideas.

General Considerations.—Speaking mainly from the surgeon's point of view, only experience can insure good results with X-ray apparatus. No matter how simple the apparatus may be, how many safeguards be embodied in it, how explicit and full the directions, there are still a vast number of little points which no book can teach, no tongue tell, and which must be learned. To do the best work, one must be something of a physicist, a photographer, surgeon and doc-

tor, all in one. If he *is* not he must *learn* to be by occasionally injuring his apparatus, and certainly by breaking many tubes.

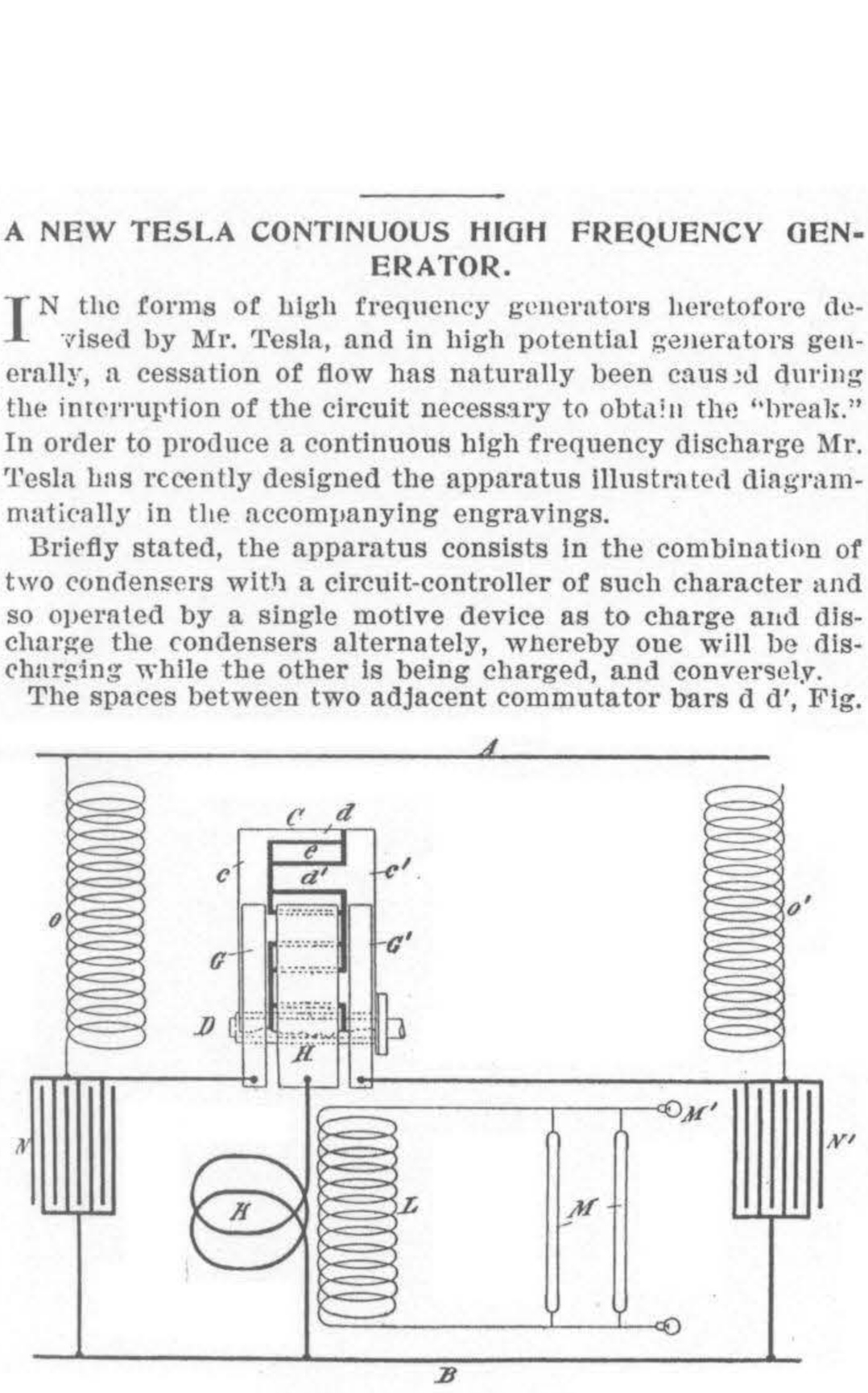
Particularly must the practitioner be cautioned against expecting too much. Many come to their fluoroscope or X-ray photograph for the first time, expecting to see the whole structure of the body exposed before them as if upon a painted wall chart. This is never the case. Except in the case of the hand, foot or forearm, but little could ever be made out in the fluoroscope were one unaware of what *should* be seen. The photographic plate results are usually better and more definite, but even here interpretation is often difficult.

A NEW TESLA CONTINUOUS HIGH FREQUENCY GENERATOR.

IN the forms of high frequency generators heretofore devised by Mr. Tesla, and in high potential generators generally, a cessation of flow has naturally been caused during the interruption of the circuit necessary to obtain the "break." In order to produce a continuous high frequency discharge Mr. Tesla has recently designed the apparatus illustrated diagrammatically in the accompanying engravings.

Briefly stated, the apparatus consists in the combination of two condensers with a circuit-controller of such character and so operated by a single motive device as to charge and discharge the condensers alternately, whereby one will be discharging while the other is being charged, and conversely.

The spaces between two adjacent commutator bars d d', Fig.



FIGS. 1 AND 2.

2, are equal in arc to the width of one of the bars and are filled in with blocks of metal insulated from the other conducting portions of the device. The two heads c c' are insulated from each other. Upon the periphery of this commutator bear three brushes G G' H, the two former resting upon the continuous metallic portions of the two heads, respectively, the latter being in position to bear upon the projections d d' and blocks e alternately.

The brush H is connected to the main B through a primary coil K of low self-induction in inductive relation to a secondary L, which constitutes the ultimate source of the current of high frequency which the apparatus is designed to develop. The brushes G G' are connected with the main B through condensers N N', respectively, and to the main A through self-induction or choking coils O O', these latter being used in order that the inductive discharge of the accumulated energy therein may be taken advantage of in charging the condensers.

The operation of the apparatus is as follows: By the rotation of the commutator C the brush H is caused to pass over the projections d, closing the circuits through the primary K and the two cylinders alternately. These two circuits are so adjusted as to have the same capacity, self-induction, and resistance. When this brush is in electrical connection with any projection d' from the part c', the circuit is closed between mains A and B through coil O', brush G', brush H, and coil K. Energy is therefore accumulated in the coil O'. At the same time the condenser N' is short-circuited through the brush G', brush H, and coil K, and discharges through this circuit the energy stored in it, the discharge being in the form of a series of impulses which induce in the secondary L corresponding impulses of high potential. When brush H breaks the circuit through coil O', the high-potential discharge or "kick" from the latter rushes into and recharges the condenser N', but as soon as the brush H has passed over the intervening block e and reached the next segment d it closes the circuit through coil O and short-circuits the condenser N, so that high-frequency currents from either one or the other of the two condensers are flowing through the primary K practically without interruption. Thus without increasing the size or power of the motive device or complicating in any material degree the commutator these devices are made to perform double duty and the output of the apparatus as a whole greatly increased.

It is also evident that all phase differences in the charging and discharging of the condensers may in like manner be se- and reached the next segment d it closes the circuit through the same motor and circuit-controller might be made to charge more than two condensers in succession and to discharge them in the same order.

ILLUSTRATED

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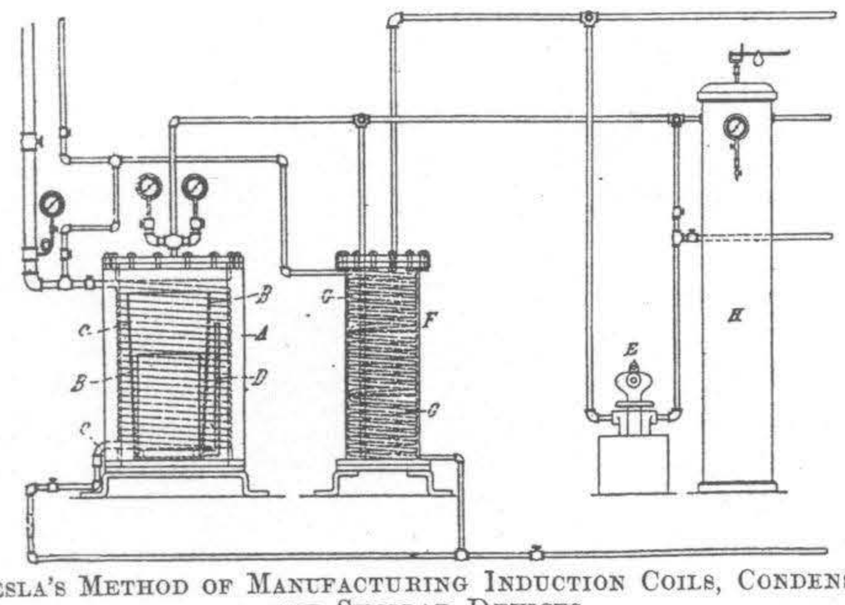
Tesla's Improved Condensers and Induction Coils.

Ever since Mr. Tesla discovered the hurtful action of the air and gaseous matter in induction coils and condensers, he has applied himself to perfecting his apparatus and methods with the view of overcoming the fatal defects produced by these causes. As an evidence of his progress in this direction, the ELECTRICAL REVIEW publishes herewith an abstract of a patent granted to Mr. Tesla on February 23, 1897, which was filed in the United States Patent Office on November 5, 1896. In his specification Mr. Tesla says:

My invention is an improvement in



TESLA'S METHOD OF MANUFACTURING INDUCTION COILS, CONDENSERS AND SIMILAR DEVICES.

the manufacture of electrical condensers, coils and other devices of a similar character, in which conductors designed to form paths for currents of high potential are brought into close proximity with each other. Among such devices are included many forms of condensers, transformers, self-induction coils, rheostats and the like.

It has heretofore been shown by me that the efficiency and practicability of such devices are very greatly enhanced by the exclusion of air or gas from the dielectric separating the conductors or remote portions of the same conductor, and the object of my present improvement is to secure such exclusion of air in as perfect a manner as possible in a convenient and practicable way. To this end I place the condenser, or other device to be treated, in a receptacle, from which the air may be more or less perfectly exhausted, and while in vacuum I introduce an insulating substance, which liquefies when subjected to heat, such as paraffine, which surrounds the said device and finds its way into its interstices.

When the device has become thoroughly saturated with the insulating material, it is allowed to cool off usually until the material begins to solidify. Air is then admitted under pressure to the receptacle containing the device, and the pressure maintained until the whole mass of insulating material has solidified. By this treatment, the presence of air or vacuous spaces in the dielectric, which are otherwise liable to form by the contraction of the insulating material when cooling, is prevented.

Any plan may be followed or apparatus used for securing the two conditions necessary to the attainment of the desired result; that is to say, applying the fluid insulating material in vacuum and subsequently subjecting it to or solidifying it under pressure. The degree of exhaustion or of pressure may vary, very good results being secured by a vacuum of about 29 inches and a pressure of about 100 pounds. It may be stated, however, that when hydraulic pressure is applied, very much higher pressures are readily secured and are of advantage.

In order to facilitate the carrying out of the process, I have devised a simple and useful apparatus, which is illustrated partly in section in the accompanying drawing. As the parts of said apparatus are all of well known construction, the apparatus as a whole will be fully understood without a full description of its details.

A is a tank or receptacle that may be closed air-tight. Within this tank is a steam coil C, surrounding a vessel B, preferably with slightly sloping sides and provided with a tube or pipe D, opening into it near its base.

The condenser or other device to be treated is placed in the vessel B, and around the receptacle is packed a suitable insulating material in quantity sufficient, when liquefied by heat, to flow through the pipe D into the vessel B, and fill the space in the latter up to the top of the condenser or other device placed therein.

It is desirable to run into the pipe D enough melted material to fill it before using the apparatus, and to make the pipe of a poor heat-conducting material, so that a little time will elapse after the heat is applied to melt the material in the tank A before the flow through the pipe begins.

When the apparatus has been thus prepared, the air from the interior of the tank A is withdrawn as completely as practicable by an air-pump E, and steam is passed through the coil C. In order to prevent access of any of

the volatile constituents of the insulating material to the pump, a condenser F, with a cooling coil G, is interposed in the piping between the tank and pump. After a partial vacuum has been secured in the tank A, and the liquefied insulating material has been run into the vessel B, the pump may be stopped and the tank connected with a receiver H, from which the air has been exhausted, and the apparatus allowed to stand until all the interstices of the condenser have been permeated with the insulating material. The steam is then shut off and cold water passed through the coil C. The connections with the pump are then reversed and air is forced into the tank and receiver H, and the further cooling and solidification of the insulating material carried on under a pressure considerably greater than that of the atmosphere. After the insulating material has cooled and solidified, the condenser or other device, with the adhering mass of insulating material, is removed from the receptacle, and the superfluous insulating material taken off.

I have found that condensers, transformers and similar apparatus treated by this process are of very superior quality, and especially suited for circuits which convey currents of high frequency and potential. * * * *

The claim of the patent reads as follows :

The improvement in the manufacture of electrical devices, such as condensers, which consists in inclosing the device in an air-tight receptacle, exhausting the air from the receptacle, introducing into a vessel containing the device an insulating material rendered fluid by heat, and then, when said material has permeated the interstices of the said device, subjecting the whole to pressure, and maintaining such pressure until the material has cooled and solidified.

LENARD RAYS, DISCHARGING POWER, GREAT VARIETY AND MAGNETIC DEFLECTION IN HYDROGEN.

BY EDWARD P. THOMPSON.

The contents of a communication from Dr. Philip Lenard, of Heidelberg, may be of interest as shedding some light on the relations between X-rays and external cathode rays. The occasion of the open letter is my treatment of the external radiations from a discharge tube (Crookes tube), and especially my discussion of his own researches, which were originally published in several foreign proceedings of societies, and in foreign languages, some of them being published by *Berlin Akad.*, January 15, 1893; *Wied. Ann.*, January, 1894, LVI, p. 225; *Wied. Ann.*, vol. LI, p. 259, and papers and articles of 1895 and 1896.

Translations of these and other papers, discussions of Lenard's results by other investigators and Lenard's latest theories were considered in my own language, under about 20 headings, in the book, "Roentgen Rays and Phenomena of the Anode and Cathode," setting forth in a classified manner the various facts, principles and theories relating to external cathode (or Lenard) rays.

Dr. Lenard, in stating that "we agree in all you have said on my experiments in the text of your book", discloses succinctly his present valued opinions on three points in this English letter. One of his remarks seems to indicate that he does not agree in all points with Professor Roentgen.

In Section 77, I stated:

"A remarkable occurrence was the accomplishment of the discharge at a much greater distance than that at which phosphorescence was exhibited. See also experiments of Roentgen, who suggested that Lenard had to do with X-rays in his experiment, but thought they were cathode rays. The maximum distance for the discharge was 30 centimetres, measured normally to the aluminum window. He (Lenard) admitted that the experiment was not carried far enough to know whether the effect was due to the action of the cathode rays upon the surrounding air or upon the plate."

The above related experiments were performed, it should be remembered, before Roentgen's discoveries.

Dr. Lenard now says, as stated in the letter referred to:

"I do not think the electric (discharging) actions at a great distance from the window of my apparatus due to Roentgen rays, because I have convinced myself in the meantime that these latter rays are only present in minute traces, and that there is another explanation of the effect observed. The air is made conducting by the deflectible cathode rays near the window, and afterwards extends to parts further apart, whilst retaining its conducting property."

As to the next point, I went so far in the matter of the variety of rays as to head one paragraph "*Cathode Rays of Various Kinds are Variably Diffused.*" As intimated in his early papers, Lenard still reasons in the present open letter that there are "rays of an unbroken series of an infinitely great number of different rays, varying gradually in properties".

Lenard has generally been misunderstood regarding the magnetic deflection of cathode rays outside of the discharge tube. Dr. Lenard makes this point very clear. The book states, on page 66:

"The author could not find in Lenard's papers any positive or negative proofs that he had actually deflected the external cathode rays by a magnet while passing through air or gas *at ordinary pressures.* * * * *" Dr. Lodge, who briefly reviewed Lenard's experiments, expressed the same opinion. (See *The Electrician*, London, January 31, 1896, p. 439.) Dr. Lenard modifies this by saying, "I have effected the deflection in hydrogen. The deflection is not visible in air of ordinary pressure, only because such air is too turbid to show any distinct rays at all which could be distinctly observed at sufficient length to show deflectibility."

Regarding the book in general, he very graciously condescends to compliment and encourage an American author by saying, "I find it very useful for getting information as to the very extended recent literature on the subject;" and he exhibits the usual great man's modesty by referring to his world-wide known and wonderful discoveries, thus: "You have given much space to my own little share in the work."

Time of X-Ray Exposures.

To the Editor of Electrical Review:

In your issue of February 17 I note two letters, entitled "Time of Exposure in X-Ray Work" and "X-Ray Apparatus," which refer to statements made in the recent Franklin Institute paper by Mr. Sayen* and myself, just abstracted in your columns, and which require reply.

Regarding time of exposure, your correspondent, Dr. Monell, states that "five minutes, a good tube and a good operator will suffice for the trunk"; also, that he obtained "a negative of metallic objects through the trunk, etc., * * * * in five minutes". In our paper I stated that as a regular thing 15 to 30 minutes is required for a trunk picture "*showing complete detail of osseous structure involved*". To obtain metallic objects *through* the body is generally considerably easier than to get the same object *in* the body, largely because, in the former case, the object is *on* the plate, so that the shadow is compact and sharp. I should consider five minutes rather a *long* exposure for a bullet *through* the body (bullet being on plate side) with a good tube, apparatus and operator. But *detail* of bony structure, etc., is a very different matter, and to the best of my knowledge can not be regularly secured in times less than I stated. That there may be *occasional* cases of exposures greatly less than I have given, producing fine results, I do not doubt. One case has recently been recalled to my attention, though it had slipped my mind at the time my paper was written. It is that of a trunk picture taken by Dr. A. W. Goodspeed, of the University of Pennsylvania, only a few weeks after the original Roentgen announcement was made. The tube was the orthodox pear-shaped "aluminum cross" tube of the Crookes series—distance from plate something like 20 inches, and time of exposure *one minute*. The result was almost perfect, the bony structure being very completely and shapely detailed. But Dr. Goodspeed has never been able to do anything like this again, either with the same or other tubes, and has no explanation to offer for the wonderfully good result on this occasion. Probably "there are others."

Regarding Mr. Renny's letter, I think probably we both have the same views as to low and high-exhaustion tubes. The use of such terms in such a connection is purely relative. If we get the exhaustion *too* high, we *do* wipe out almost everything; if *too low*, everything casts equal shadows. Speaking generally, we must use low tubes for hand, arm and leg, from knee down; high tubes for body, hip joint, etc.

I should be glad to know how Mr. Renny's Tesla coil, "having none of the disadvantages which he says such coils must necessarily have", is made. The disadvantages of the Tesla coil, as compared with the induction coil, and as given by me, were:

1. Tesla coil has at least twice the number of parts—more complex.

2. Tesla coil uses oil—not so cleanly.

3. Tesla coil requires an operating spark gap—noisy.

4. Tesla coil produces alternating currents—we get either *two* foci and consequent blurring, *or* reversal of the tubes and consequent blackening.

1 and 3 *must* be true, since they embody the very definition of the Tesla coil; 2 is not necessarily true, but happens to be actually true, according to the practice of the majority of manufacturers of Tesla apparatus; 4 is true in all the tubes I know of, or, at least, recall at present. I would not say that a tube might not be constructed, of which this objection would not be true, but I know of no such tube now made.

Whether or not the Tesla coil or induction coil puts the larger strain upon the tube is a matter of opinion, and I so implied in my paper.

Elmer G. Willyoung.

Philadelphia, February 20.

* X-Ray Apparatus and Methods, Electrical Review, January 27, February 3 and February 10, 1897.

Leslie's Weekly March 18, 1897

Tesla's New World.

THIS revolving globe generates every moment enough electricity, if it could be stored in batteries, to run all the machinery of the world for the balance of time. At the North Pole this electricity streams off in beautiful red ribbons called the auroras, and we see this phenomenon on account of the highly attenuated condition of the atmosphere. But everywhere, as high as the air reaches, around this earth is this immense wealth of nature, yet man, in his blindness and puniness, continues to manufacture with his little dynamos what nature has placed before him in such abundance. He does not need to manufacture another spark; he needs only to use an infinitesimal fraction of what is already made and the world of intelligence will become a whispering-gallery, and the world of his machinery will move in its appointed motion out of the forces of the invisible air.

For more than ten years scientists have known that man was wasting his time and energy burning coal and wood, denuding his forests, impoverishing his soil, and blackening the air of his cities, and then, with all his boasted speed, to move comparatively as a cripple. A few of them knew this, and one of them, Nikola Tesla, was bold enough to say that he could change all this. Well, it hasn't yet been changed, but while I was in his laboratory the other day he looked up from one of his machines with the confidence of Archimedes lighting his face. "I have found the way of my dream and will soon show it to the world." Mr. Tesla, as is well known, has harnessed Niagara and now he is read to harness the globe.

A few hundred feet in the air, just above what is known as the magnetic disturbance of the earth's surface, the electric waves run in long, straight lines. They are called the Hertzian waves, after young Hertz, their discoverer. These waves are, in fact, found everywhere in the air, but up there they can be used without the danger of local disturbance, and Mr. Tesla has, by a long series of experiments, learned to take hold of them and flash a light precisely as a sunbeam is flashed from a mirror. He has also learned to throw the electric energy of these waves into a battery and turn a distant machine connected with this battery by a wire. Mr. Tesla has a machine in his laboratory, that he calls an oscillator, that generates these waves and projects them into the atmosphere just as nature does. With this oscillator he has succeeded in making every calculation necessary to flash a message without a wire to any part of the earth, or to take the electric waves generated by the great power of Niagara and grind wheat in Argentina, or run the trolley-cars in Sydney. This is no longer speculation, but science, and with time and capital such a gigantic scale will be realized.

What is necessary is to build here and there, on the high points of the earth, tall towers and put into the tops of these towers machines to gather and focus these waves, just as the mirror gathers and focuses the sunbeams. Mr. Tesla said to me that, with a tower tall enough and with machines big enough, he could send a message from New York to London without a wire, but for transmitting electric energy for running machinery at this distance it would require a series of towers. But there never will be any necessity for running machinery at that long distance from the source of energy. It is over long distances that we want to telegraph. With such a station at New York not only could we talk to Europe without wires, but every ship on the Atlantic could communicate with us, and assistance could be rendered to any one of them in distress. The seas would be robbed of over half their terrors. But this means of communication would render it impossible for a few persons to conceal important information long enough to take advantage of the public. Every financial panic has had its origin in the way the telegraph or cable news has been concealed, but a tall tower flashing its messages on the city would protect the public and would immensely help nations to readily understand each other in an international crisis threatening war.

It is now known that light is sound carried to a point of vibration beyond hearing. There are scientists, and among them Mr. Tesla, who believe that the two terms may be convertible—that is to say, that we might take a sunbeam and so graduate it down as to hear something of the terrific storms that are constantly sweeping over that luminary. So it may not be impossible to attach the telephone and phonograph to these waves that may be made to blink around the globe as the winking diamonds in the girdle of a woman's waist. If we ever talk and sing across the wide seas this is possibly the only way, for it should be understood that wires can be distributed from these high stations into every house.

Mr. Tesla has gone so far as to say that it is possible to communicate with other planets of our system by throwing gigantic letters with these tall-tower lights on the face of the earth. This is downright dreaming, and here we part company with this great artist of science.

D. F. ST. CLAIR.

Mr. Remy's Tesla Coil.

TO THE EDITOR OF ELECTRICAL REVIEW:

Your issue of March 3 contains an article regarding some of my work, which I wish to answer. I agree with Mr. Willyoung that taking metallic objects placed next to plate, after the rays have passed through the body, and taking objects embedded in the body are two different things. When experimenting, to learn the time of exposure, I place objects *on* the body opposite the plate and next the tube. I will now attempt to describe, as Mr. Willyoung suggests, my Tesla coil, which does not have the disadvantage he enumerates. The disadvantages named in the article are:

1. "Tesla coil has at least twice the number of parts—more complex."

This is, of course, true; but in the instrument I use, the high-potential transformer, condenser and Tesla coil are permanently fixed in a permanently closed wooden box, which has not been open since the instrument was made. The terminals and spark-gap are, of course, on the outside of this box.

A machine may be constructed in this way, which is more convenient to operate, as only one adjustment—the length of operating spark-gap—is necessary, and this may be accomplished by simply turning one screw. A machine of this kind, properly designed, is much less liable to damage by use, or jars, or improper handling.

2. "Tesla coil uses oil—not so cleanly."

My coil does not use oil; there are streamers in the box, I suppose, but the machine takes less current than two 16-candle-power lamps, anyway, and the streamers are not hurting the insulation, as the only insulation depended on is space, or air.

3. "Tesla coil requires an operating spark-gap—noisy."

I use about 5,000 or 6,000 volts for Tesla coil primary, and it makes no more noise than a vibrator for induction coil.

4. "Tesla coil produces alternating currents—we get either two foci, and consequent blurring, or reversal of the tubes, and consequent blackening."

Good detail may be obtained with double focus tubes where the foci are close together; but for the very finest work single focus tubes may be made for Tesla coil current; in fact, such tubes can now be bought on the market, but, of course, they take twice the time, other things being equal.

B. P. REMY.

Anderson, Ind., March 23.

ELECTRIC POWER TRANSMISSION.

"CASSIER'S" for March prints a portion of the remarks made by Nikola Tesla, the inventor, in responding to the toast, "Electricity," at a banquet held in Buffalo in January last to commemorate the introduction into that city of electric power from Niagara Falls.

Naturally Mr. Tesla dwelt on the immense significance of the electrical transmission of power and its attendant problems. "We have to evolve means," he said, "for obtaining energy from stores which are forever inexhaustible, to perfect methods which do not imply consumption and waste of any material whatever."

"Nearly six years ago my confidence had become strong enough to prompt me to an expression of hope in the ultimate solution of this all dominating problem. I have made progress since, and have passed the stage of mere conviction such as is derived from a diligent study of known facts, conclusions and calculations. I now feel sure that the realization of that idea is not far off. But precisely for this reason I feel impelled to point out here an important fact, which I hope will be remembered.

ADVANTAGES OF WATERFALLS.

"Having examined for a long time the possibilities of the development I refer to—namely, that of the operation of engines on any point of the earth by the energy of the medium—I find that even under the theoretically best conditions such a method of obtaining power cannot equal in economy, simplicity and many other features the present method, involving a conversion of the mechanical energy of running water into electrical energy and the transmission of the latter in the form of currents of very high tension to great distances. Provided, therefore, that we can avail ourselves of currents of sufficiently high tension, a waterfall affords us the most advantageous means of getting power from the sun sufficient for all our wants, and this recognition has impressed me strongly with the future importance of the water power, not so much because of its commercial value, though it may be very great, but chiefly because of its bearing upon our safety and welfare.

"I am glad to say that also in this latter direction my efforts have not been unsuccessful, for I have devised means which will allow us the use in power transmission of electro-motive forces much higher than those practicable with ordinary apparatus. In fact, progress in this field has given me fresh hope that I shall see the fulfillment of one of my fondest dreams—namely, the transmission of power from station to station without the employment of any connecting wire. Still, whatever method of transmission be ultimately adopted, nearness to the source of power will remain an important advantage."

NOTES.

A New Tesla Apparatus.—In the forms of high-frequency apparatus heretofore devised by Mr. Tesla, and in high-potential generators generally, a cessation of flow has, says the New York *Electrical Engineer*, naturally been caused during the interruption of the circuit necessary to obtain the "break." In order to produce a continuous high-frequency discharge Mr. Tesla has recently designed an apparatus, which, briefly stated, "consists of the combination of two condensers with a circuit controller so operated by a motive device as to charge and discharge the condensers alternately, whereby one will be discharging while the other is being charged, and conversely." The effect of such an arrangement would appear to be simply to double the number of discharges per second, and to complicate a necessarily somewhat delicate arrangement of apparatus.

The New York Herald April 7, 1897

TESLA TELLS OF HIS DISCOVERY.

The Distinguished Investigator Finds a New Source of the Roentgen Rays.

IT IS BY AN ELECTRIC ARC.

Members of New York Academy of Sciences Listen to an Address on His Recent Experiment.

SATISFIED OF ITS VALUE.

The fourth annual reception and exhibition of the New York Academy of Sciences, in the American Museum of Natural History, were brought to an interesting close last evening. In addition to addresses by Professor J. J. Stevenson, president of the Academy, and by Morris K. Jesup, president of the Museum, Nicola Tesla also spoke about some of his recent experiments.

The most important part of Dr. Tesla's address, which was "On the Streams of Lenard and Roentgen, with Novel Apparatus for Their Production," was an announcement that he had discovered a new source of the Roentgen ray.

"This new source of the Roentgen ray," said he, "I discovered recently. An electric arc is the source. That is the simple way of putting it. In my experiments I found that the arc gave a wonderful light, which surprised and delighted me. My experiment is to be developed, but I have found enough to satisfy me of the value of the new source."

EXPECTS GOOD RESULTS.

Dr. Tesla then described that when the arc went to the cathode there was a strong light, but it was when it went to the anode that the wonderful results were obtained. The speaker said that he worked with a platinum cathode and an aluminum cathode.

"I cannot say anything more about this experiment at the present time," continued he, "but I think that in the future the results will be satisfactory in every way."

The speaker had before him on the table some of his novel electrical apparatus, by which he showed several of his experiments, particularly in producing electrical vibrations.

Dr. Tesla finally announced that he would not trespass further upon the time of the audience, in spite of the gesticulations of the Academy members to go on.

HE WAS HUNGRY.

"To be frank with you," said he, "I have had no dinner."

THEIR WISHES GRATIFIED.

The audience applauded, and there were earnest appeals for him to continue. Then they left their seats and made a rush for the platform to induce Dr. Tesla to explain more about his experiments. He gratified their wishes by giving them a half hour's additional description of his work with the apparatus.

In his address President Stevenson, of the New York Academy of Sciences, referred to the encouraging results of the investigators of the organization, and thanked the authorities of the American Museum of Natural History for the use of the building. President Jesup, of the Museum, in response said that the Academy members were always welcome to the Museum. He referred to the happy and cordial relations that exist in the Scientific Alliance.

The New York Times April 7, 1897

A CROWD TO HEAR TESLA.

The Academy of Science Exhibition This Year Draws Well.

It is estimated that at least 4,000 persons went to the American Museum of Natural History yesterday afternoon and last evening, to see the exhibit made by the Academy of Science.

In an address in the lecture room, R. E. Dodge, Secretary of the academy, said that not only was it the most successful exhibition of the society in point of scientific display and attendance, but people who went were not actuated by mere curiosity. They asked questions about all that they saw, and asked them with an intelligent understanding.

An address much to the same effect was made by Prof. J. J. Stevenson, President of the academy.

Nicola Tesla, the electrician, delivered a short address to all the people that the large lecture room would hold. He had with him on the platform an array of his high-pressure, rapid-vibration instruments, which he used to demonstrate his remarks.

The New York Post April 8, 1897

LENNARD-RAY PHOTOGRAPHS.

Nikola Tesla's Successful Experiments.

"I have been greatly disappointed," said Nikola Tesla, speaking to-day of his address before the Academy of Science on Tuesday evening, "that I entirely forgot to mention one of the most interesting and important facts in connection with the photographs I exhibited. How I could have forgotten anything so salient I do not know, but I did, and it has ever since much vexed me. I had been describing my discovery of the identity of the Lennard-ray and the Roentgen-ray, and when I showed the photographs I failed to say that most of them had been taken by means of the Lennard bulb. As you can see, the photographs are wonderfully clear, showing even the muscles of the subject, and of course are vital confirmation of my discovery of the identity of the Lennard with the Roentgen-ray. What I did was first to take Lennard's bulb and use it in connection with the ordinary transformer, the result being the same as in the experience of Lennard, namely, a failure to produce a light. But when I used it with my new transformer it proved perfectly effective, and enabled me to take these fine photographs."

Mr. Tesla exhibited to the members of the Academy the wonderful new apparatus which he called electrical oscillators, a novel kind of transformers based upon a discovery made by him six years ago which enabled him to produce from ordinary currents, direct or alternating, electrical vibrations of 1,500,000 per second. These vibrations were desirable for the attainment of many practical results, the most important being the improvement of electric lighting. This system is inefficient and expensive, and to produce the same or better results upon lines of economy requires enormous electrical vibrations, which Mr. Tesla has been able to secure by his new apparatus. These vibrations can be used in many other ways for the economical production of things necessary to mankind. Mr. Tesla said that they could, for instance, be used profitably in the manufacture of ozone and other chemical products and fertilizers. He said it furnished an ideal instrument for the production of the Roentgen rays. Its advent means the abolition of many devices of older design, particularly, Mr. Tesla said, of the use of the induction coil. A remarkable feature of the machine Mr. Tesla exhibited was that, although it can furnish any pressure desired, it contains no fine wire.

Coming to the subject of the Roentgen rays, Mr. Tesla announced that he had made two important discoveries. The first is a powerful source in an electric arc under certain conditions. The second is the demonstration in a peculiar way, which he described, of the deflection of the rays by a magnet. The discovery is particularly important in that this fact was needed to establish the identity of the Roentgen-ray and the ray discovered by Lennard in 1891. Through this discovery Lennard appears as the original discoverer of these rays, although in his address on Tuesday night Mr. Tesla said that he did not want to take from Prof. Roentgen the least bit of credit for his remarkable achievement in this line.

Mr. Tesla showed diagrams and designs tending to prove his theory that Roentgen-rays were formed by streams of minute electrified particles of matter projected from the bulb at an extreme velocity. This view is not in accordance with that adopted by the great majority of scientists, which is that the rays are formed by transverse vibration. Prof. Roentgen's theory is that they are formed by longitudinal vibration. Mr. Tesla promised that the tremendous vibration established by him would ultimately result in telegraphing without wires.

TESLA'S NEW DISCOVERIES.

GREAT ACHIEVEMENTS ANNOUNCED TO THE ACADEMY OF SCIENCE.

One Will Revolutionize the Methods of Electric Lighting, and One, He Promised, Will Result Ultimately in Telegraphing Without Wires—Roentgen Rays Are Lennard Rays.

After many months of silence, Nikola Tesla spoke night before last at the Academy of Science, and, as always happens on such occasions, the scientific knowledge of the world was the richer thereby. Mr. Tesla, without going deeply into the details of his methods, announced three discoveries that he has made, and gave practical illustrations of them. One will revolutionize the present methods of electric lighting, will exert a tremendous influence upon a hundred different things, and will open to the investigator an infinite number of highways of research, and will end, Mr. Tesla says, in bringing about that sought-for end of all electricians, the transmission of information through space without the agency of wires now needed. The second discovery announced was that of a new and more powerful source of the Roentgen rays. The third, and Mr. Tesla says this will be the most important and interesting to scientists, is the identification of the Roentgen with the Lennard rays.

Mr. Tesla exhibited on Tuesday night a new and perfected apparatus which he called electrical oscillators, a novel kind of transformers based upon a discovery made by him six years ago which enabled him to produce from ordinary currents, direct or alternating, electrical vibrations of many millions per second. These vibrations were desirable for the attainment of many practical results, the most important being the present system of lighting. This system is inefficient and expensive, and to produce the same or better results upon lines of economy requires enormous electrical vibrations, which Mr. Tesla has been able to secure by his new apparatus. By the use of these vibrations a vacuum tube may be made to emit a powerful light and furnish a lamp that is practically indestructible.

This bare statement of fact is all that Mr. Tesla is willing to give to the public at the present time, for he has not yet explained his methods to the scientific world, but his demonstration of his discovery at the Academy of Science was most complete. Its importance, as can be easily seen, hardly can be exaggerated.

These vibrations can be used in many other ways for the economical production of things necessary to mankind. Besides the lighting problem there are others that require extraordinarily frequent vibrations for their economical solution. Mr. Tesla announces that the manufacture of ozone and other chemical products now attained by costly processes may be done economically and cheaply by these vibrations. Mr. Tesla announced not long ago that by the use of these currents it was possible to manufacture fertilizers by using no other agent than merely mechanical power such as a waterfall or steam.

The use of these currents in the transmission of power is also very probable. Mr. Tesla has worked on this principle a large part of the time since he made his announcement before the Scientific Societies in 1891, and, as he said on Tuesday night, the machine he exhibited before the Academy of Sciences was the consummation of his labors in this direction. He said it furnished an ideal instrument for the production of the Roentgen rays, and what renders it particularly valuable is that it can be attached to any circuit and will furnish high economies. Its advent means the abolition of many devices of older design, particularly, Mr. Tesla said, of the use of the induction coil. A remarkable feature of the machine Mr. Tesla exhibited was that, although it can furnish any pressure desired, it contains no fine wire, and he illustrated by a simple experiment the advantage of the new principle over the old. The coils of the older principle require several miles of fine wire to develop a pressure equivalent to that developed by Mr. Tesla's machine that has none.

Coming to the subject of the Roentgen rays, Mr. Tesla announced that he had made two important discoveries. The first is a powerful source in an electric arc under certain conditions. This opens up a new field for research, and is most promising, as the rays obtained are very powerful and produce clearer images than those produced by present methods. The second and the one Mr. Tesla places in importance above the other is the demonstration in a peculiar way, which he described, of the deflection of the rays by a magnet. The discovery is particularly important in that this fact was needed to establish the identity of the Roentgen ray and the ray discovered by Lennard in 1891. Through this discovery Lennard appears as the original discoverer of these rays, although in his address on Tuesday night Mr. Tesla said that he did not want to take from Prof. Roentgen the least bit of credit for his remarkable achievement in this line. Mr. Tesla said that in 1894 he himself was investigating the actinic action of phosphorescent bodies and observed the Roentgen rays, but did not recognize them. He said that ever since Roentgen's announcement of his discovery scientists have been endeavoring to establish the identity between the Roentgen and Lennard rays by deflecting them by a magnet. The deflection, however, was so slight that the finest instruments could not record it. Mr Tesla tried for a long time and failed. At last he invented an instrument that accumulated the rays until he got such a power that a boy could perform the experiment.

Besides the things already referred to, Mr. Tesla showed diagrams and designs tending to prove his theory that Roentgen rays were formed by streams of minute electrified particles of matter projected from the bulb at an extreme velocity. This view is not in accordance with that adopted by the great majority of scientists, which is that the rays are formed by transverse vibration. Prof. Roentgen's theory is that they are formed by longitudinal vibration.

Mr. Tesla promised that the tremendous vibration established by him would ultimately result in telegraphing without wires.

The New York Times April 9, 1897

TESLA KEEPS HIS SECRETS.

Refrains from Gratifying the Curiosity of Electricians About His Experiments.

It is only once in two or three years that Nicola Tesla, the electrician, can be persuaded to give a lecture. He contributes occasionally to electrical publications, but he carefully refrains in these communications from letting his fellow-electricians know what he is driving at in his experiments.

When it was announced that he was to deliver a demonstrative lecture recently before the Academy of Science, in this city, the large lecture hall in the American Museum of Natural History was crowded until there was not standing room. Tesla is not an agreeable lecturer. Despite his long residence in this country, he speaks decidedly broken English, and as he persists in using technical words, many of them coined by himself, it is very difficult to follow him.

Two hundred or more electricians who went to hear him speak before the academy in hope that he would reveal something of the nature of his investigations were disappointed. They failed to discover what he is "driving at." Tesla made apparently free use of his wonderful high power instruments for producing rapid vibration, but beyond suggesting their value in scientific experiments, and remarking that their practical value would be made apparent to everybody before long, he kept his own counsel. His closing sentence was an epigram: "What Nature does not choose to reveal to us, it is no use trying to force from her by bolts and screws."

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Notice of Removal.

THE ELECTRICAL ENGINEER

on and after April 14 will occupy its handsome and commodious new suite of offices, entire south wing, eleventh floor, of the Beard Building, 120 Liberty street, New York City. It will not only thus be most advantageously situated at the heart of the machinery and electrical district, but will enjoy an increase of several hundred feet floor space. The offices are convenient to all railroads and ferries, and an invitation to visit them is cordially extended to all friends and patrons of the journal.

MR. TESLA ON ROENTGEN RAYS.

LAST week Mr. Tesla gave some of the results of his experiments in the domain of Röntgen rays, before the New York Academy of Sciences, and showed some of his latest types of high frequency generators. Mr. Tesla still adheres to his original view that the Röntgen effects are due to the action of molecules projected from the tube at high velocities, but we must confess our inability to reconcile this view with the results of his experiments in deflecting the Röntgen rays by means of a magnet, unless we assume the molecules charged and at the same time endowed with a vortical motion, a point which Mr. Tesla did not elaborate on. It is so rarely that Mr. Tesla appears on the lecture platform that it is to be regretted that the conditions surrounding his last appearance were not more favorable. It was hardly fair to Mr. Tesla, or to the large audience which had assembled solely to greet him, to delay his appearance until two other estimable speakers had taken up the time of the audience for nearly three-quarters of an hour. The result was that it was close on to 10 o'clock before Mr. Tesla began, and he was forced to conclude his address in its initial stages. It is to be hoped, for the benefit of the science at large that Mr. Tesla will find time to write out his address in full for the Transactions of the Academy. Brief as his utterances were, they were extremely interesting and they evidenced a mellowing and a mastery indicative of higher perfection than ever of his powers as an investigator and elucidator of obscure natural phenomena.

ROENTGEN RAYS

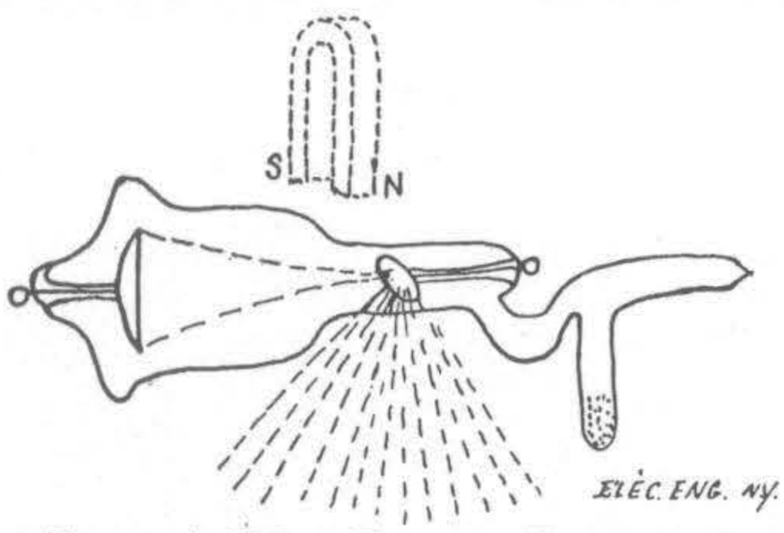
ROENTGEN RAY BURNS.

BY PROF. ELIHU THOMSON.

THE cause of the injury to the skin which follows an exposure to a source of Röntgen rays is still a subject for discussion. It is known that a comparatively short exposure at sufficiently small distances from the source will produce the effect. It has been claimed by some that Röntgen rays do not produce the mischief, but that the effect is essentially electro-static. Others have expressed the opinion that ozone and other substances present in the neighborhood of the excited tube are the real causes of the injury.

It has seemed desirable to set at rest, by experiment, these doubtful theories. The very peculiar nature of the injury itself, its course of development, the accidental circumstances under which it has occurred, have all tended to negative any theory except that which regards rays from the tube as the true cause. These rays might be either Röntgen rays, or rays so closely analogous as to be with difficulty distinguished therefrom.

The first effect after exposure is a slight reddening of the skin which is made more easily discernible by a little friction over the spot affected. This lasts two, three or more days and tends to fade. In the writer's experience, at the end of a week there has been an almost complete absence of any noticeable effect on the skin. On the ninth day, however, the affected part was found to redden, and this increased for a few days until blistering and sloughing took place with slow and tedious healing. These effects were noted in the case of the exposure of the little finger of the left hand and are at present writing in progress upon a portion of the third finger of the same hand, in consequence of an exposure for only twelve minutes to the rays from a special tube. This tube was made for the purpose of obtaining strong effects by lessening the working distance from the bombarded spot on the platinum, which is the source of the rays.



PROF. THOMSON'S X-RAY TUBE FOR POWERFUL EFFECTS.

The accompanying sketch shows the general form of the tube. It is narrowed around the platinum anode and the glass is also made thin around the same. It is thus possible to get the finger, the fluorescent screen, or the photographic film, very close to the bombarded spot on the platinum anode. The distance need be not over one-half an inch as a minimum. By the use of a magnet the spot on the platinum could be shifted so as to be very close to the glass and upon the edge of the platinum sheet. The intensity of the radiation per unit of surface was increased thereby, according to the law of inverse squares, which seems to hold in this case. This use of the magnet is indicated in dotted lines and is very convenient for directing the cathode rays upon any part of the platinum anode; which anode might in fact be faced with a variety of different substances, or have its surface differently formed, or curved at places while the cathode beam could be directed first to one part and then to another and the effects noted. If a platinum anode has been perforated by the beam at one point the tube is still useful, for a slight effect of the magnet puts the beam upon a new surface. Many a good tube may thus be made to do service even after several holes have been melted through the platinum sheet.

With such a source of rays as the tube shown it was easy to try an experiment the result of which seems to the writer to leave no doubt of the fact that Röntgen rays, or rays of the same general characteristics, do actually cause the burns and injury which may follow prolonged exposures to the Röntgen radiation. The left hand was covered with a lead sheet of over 1-16 inch in thickness and an oblong hole of about three-fourths of an inch long and about five-sixteenths inch wide, cut through it at the part just over the third finger between the first and second joint. This limited the passage of rays to the part of the finger under the opening.

But around the finger and under the middle of the opening was placed a strip of heavy tinfoil about 3-16 inch wide. This divided the exposed area into two parts. One of these parts in turn was covered with two layers of thin aluminum leaf gummed to the finger. Thus there were, in fact, three spots on the finger within the opening, one covered with aluminum foil or leaf, another with heavy tinfoil, and the third left entirely bare. The opening in the lead sheet was brought close to the platinum anode, so that the finger was about ⅝ inch distant from the bombarded spot.

The exposure was for a period of twelve minutes, which it was thought would be sufficient. The result at first was two faintly reddened spots, one having the outline of the part under the opening in the lead shield covered by the aluminum foil, and corresponding thereto, and the other corresponding to the bare spot. Under the tinfoil strip there was no action. These reddened spots, though scarcely visible, could be developed by slight friction, but gradually faded until, at the end of a week, from the time of exposure, they were with great difficulty distinguishable from the rest of the skin, even after the spot was rubbed. On the ninth day, however, they returned and the spots became painful and a little swollen. This has continued to increase and will probably end in blistering, sloughing and final healing. The part covered by the tinfoil is sharply marked from the others in being entirely unaffected. The effect produced through the aluminum leaf is about the same as on the bare spot, showing that thin aluminum does not stop the rays which produce harm.

It is needless to say that the effect is proved by the experiment to be neither electro-static, nor ozonic, but merely a result of certain rays reaching the skin surface, and such rays are probably those of the Röntgen rays not readily absorbed. According to the law of inverse squares an exposure of 12 minutes at ⅝ inch distance would require, at 10 inches distance, for equal effects, about 50 hours, or over two days. There is, then, no occasion for any alarm at the effects of Röntgen rays, as exposures of sufficient duration to produce harm are rarely if ever necessary.

In regard to the claim which has been made that injury only follows exposures made by induction coils, while static machines do not produce the effect, it may be said that in the writer's former experiment, of which the little finger was made the subject, a large capacity static machine was used, and the result was severe enough. The present experiment was made with an induction coil as the source of electric discharges, and as yet there is no difference in the results. The effect is now, of course, limited to two small spots a little distance apart.

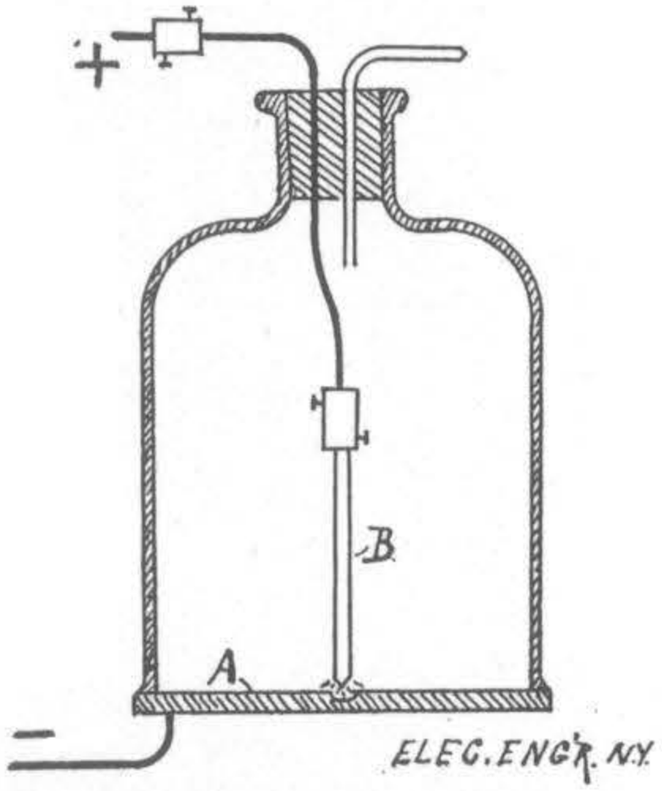
MR. TESLA BEFORE THE NEW YORK ACADEMY OF SCIENCES.

ON April 6, Mr. Nikola Tesla delivered before the New York Academy of Sciences an address "On the Streams of Lenard and Röntgen, with Novel Apparatus for Their Production." The lecturer began by stating that in 1894, in experimenting to determine the actinic action of phosphorescent light emanating from vacuum tubes, he had found that the actinic power of Crookes tubes varied greatly, and in the most anomalous manner. Thus some tubes emitting a strong light had very little action on photographic plates, while some showing a feeble light acted very strongly on such plates. A large number of these plates, made by Tonnele for the Century Magazine, were stored in Mr. Tesla's laboratory when it was destroyed by fire, and thus he was unable now to examine them for the Röntgen effects. He believed that he had just missed the discovery which made Röntgen famous and though he was thoroughly familiar with Lenard's work, he did not see far enough.

Mr. Tesla then reviewed his work in the direction of obtain-

ing a reliable apparatus for generating high frequency currents, which he recognized as the keynote to the production of vacuum tube lighting. He told how he had met with difficulties at every point; how a small bubble of air would destroy the value of the coil, or how one-quarter of an inch of wire too much or too little would throw a coil out of balance; how one day a coil would run cold and on another day hot, etc. By finally calling to his aid the condenser, Mr. Tesla stated, he had succeeded in obtaining the desired action and now nothing stood in the way of securing millions of vibrations from ordinary circuits. The lecturer then briefly explained the principle of the condenser discharge as applied to high frequency currents, and pointed to various types of apparatus on the lecture table designed to utilize the principle.

In order to demonstrate the action of the high frequency currents Mr. Tesla attached a circular loop of heavy copper wire to the terminals of a high frequency generator and



TESLA'S ARC X-RAY GENERATOR.

brought to brilliant incandescence a small lamp connected diametrically across the heavy loop; the illumination of the lamp could be varied by connecting it to various points on the diameter of the loop. Mr. Tesla also lit the lamp by the current induced in a second loop brought in proximity to the first. He explained that the coil accomplishing this work had a resistance of 600 ohms and an inductance of 6 henrys; the coil was connected to the circuit one-half the time and took from the primary circuit only 5 watts.

Mr. Tesla next showed a vacuum tube lit from the terminals of another high frequency machine. He also showed a coil consisting of a single turn of heavy wire which formed the core, as it were, of a small coil of a few turns wound on a paper cylinder surrounding the heavy wire. When connected to a high frequency generator, this apparatus gave a 4-inch spark with an expenditure of energy equal to that taken by one lamp. Mr. Tesla stated that his high frequency generators were so constructed that they could be connected to any existing circuits, direct or alternating.

Returning to the Röntgen rays, the lecturer stated that he had succeeded in discovering a new source of these rays, far more powerful than any heretofore available, though the difficulty of maintaining it was very great. This new source is the electric arc; not the ordinary arc, however. The arc required for the purpose is that maintained between a platinum terminal and an aluminum plate, as illustrated in the accompanying diagram, where A represents the aluminum plate and B the platinum, enclosed in a glass jar.

Mr. Tesla stated that he had also succeeded in deflecting the Röntgen rays by a magnet. He had proved this by deflecting the rays into a condenser placed a long distance from the source of the rays, and which in 5 seconds was charged sufficiently to throw a galvanometer needle off the scale.

THE NEW YORK ACADEMY OF SCIENCE.

AN INTERESTING ELECTRICAL EXHIBITION — ADDRESS BY NIKOLA TESLA, ANNOUNCING RECENT ACHIEVEMENTS.

The New York Academy of Sciences gave its fourth annual reception and exhibit of recent progress in science in the American Museum of Natural History, New York, April 5 and 6.

In the division devoted to chemistry, in charge of Charles A. Doremus, were exhibited a number of electric furnaces, and in the electrical division, in charge of G. F. Sever, were to be seen a number of historical collections of incandescent and arc lamps, instruments of precision, Crookes tubes, induction coils, etc. Mr. W. H. Meadowcroft exhibited a Thomson 14 inch spark inductorium, and tubes and fluoroscopes, and Dr. M. I. Pupin had on view an induction coil and circuit breaker for the generation of Roentgen rays. Dr. Max Osterberg exhibited some specimens of German tubes, and Dr. Doremus showed one of the original Henry induction coils.

Tuesday evening a large audience assembled to listen to an address by Nikola Tesla on "The Streams of Lenard and Roentgen and Novel Apparatus for their Production". The lecturer had on exhibition a number of his perfected electrical oscillators, designed particularly to be used in place of the induction coils of old type. He exhibited numerous diagrams illustrating results obtained by him in his experiments, to ascertain the nature of the Roentgen rays. There were over 100 different working drawings of bulbs, showing the extent of the ground covered by the lecturer in this field. There were, besides, a number of remarkable photographs exhibited, which were taken by means of one of the small oscillators exhibited. These instruments and photographs were examined with the keenest interest after the lecture by a large number who remained and insisted on a supplementary lecture, which Mr. Tesla kindly consented to give, notwithstanding that, as he playfully remarked, he had not yet had his dinner.

Mr. Tesla introduced the subject of his lecture by stating that at the close of 1894 he investigated the actinic power of phosphorescent bodies, and during these experiments, which were carried on by the assistance of Tonnelé & Company, photographers of this city, working for the *Century Magazine*, a great number of plates showed curious marks and defects, which were noted both by the speaker and the photographers, but not recognized as being due to the Roentgen rays. Just as he was beginning to look into the nature of the phenomena his laboratory was burned, and before his work was thoroughly resumed in his new laboratory Roentgen's discovery was announced.

Mr. Tesla first described the instruments exhibited, dwelling on the principles underlying them, and he illustrated, in a few striking experiments, the practical and economical features of the machines. The greatest interest seemed to be evinced by the audience when he lighted brilliantly a vacuum tube with one of his machines, giving, as he said, 800,000 vibrations a second. What rendered them particularly valuable, he stated, was that they worked equally well on alternating or direct-current circuits, and transform these currents with high economy into high-frequency electrical vibrations.

Mr. Tesla announced two important discoveries relating to the Roentgen rays. First, he said he had discovered a new and powerful source of the rays in an electric arc, formed under peculiar conditions. The second discovery was the deflection of the Roentgen rays by means of a magnet. This discovery is particularly important in establishing the identity of the Roentgen rays, and those discovered by Lenard in 1891, and is, therefore, one of the most valuable contributions to our knowledge of these rays.

Tesla dwelt also on some phenomena of rotation of bodies in bulbs, and, among other things, described his method of determining exactly the speed of a dynamo when taking readings.

To a few interested scientific men Mr. Tesla showed a great number of diagrams illustrating experiments he had performed which tended to prove the correctness of the views he holds in regard to the Roentgen phenomena being caused by material particles projected with great velocity.

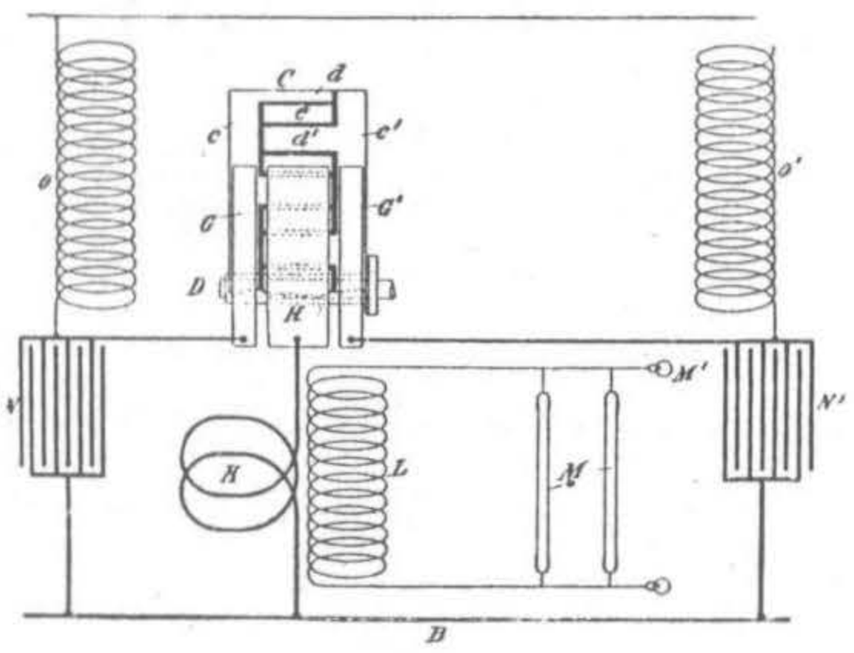
The ELECTRICAL REVIEW hopes to be able to present in full, in an early issue, Mr. Tesla's lecture.

A NEW TESLA CONTINUOUS HIGH FREQUENCY GENERATOR.*

In the forms of high frequency generators heretofore devised by Mr. Tesla, and in high potential generators generally, a cessation of flow has naturally been caused during the interruption of the circuit necessary to obtain the "break." In order to produce a continuous high frequency discharge Mr. Tesla has recently designed the apparatus illustrated diagrammatically in the accompanying engravings.

Briefly stated, the apparatus consists in the combination of two condensers with a circuit controller of such character and so operated by a single motive device as to charge and discharge the condensers alternately, whereby one will be discharging while the other is being charged, and conversely.

The spaces between two adjacent commutator bars, *d d'*, fig. 2, are equal in arc to the width of one of the bars, and are filled in with blocks of metal insulated from the other conducting portions of the device. The two heads, *c c'*, are





Figs. 1 and 2.

insulated from each other. Upon the periphery of this commutator bear three brushes, G G' H, the two former resting upon the continuous metallic portions of the two heads, respectively, the latter being in position to bear upon the projections, *d d'*, and blocks, *e*, alternately.

The brush, H, is connected to the main, B, through a primary coil, K, of low self-induction in inductive relation to a secondary, L, which constitutes the ultimate source of the current of high frequency which the apparatus is designed to develop. The brushes, G G', are connected with the main, B, through condensers, N N', respectively, and to the main, A, through self-induction or choking coils, O O', these latter being used in order that the inductive discharge of the accumulated energy therein may be taken advantage of in charging the condensers.

The operation of the apparatus is as follows:—By the rotation of the commutator, C, the brush, H, is caused to pass over the projections, *d*, closing the circuits through the primary, K, and the two cylinders alternately. These two circuits are so adjusted as to have the same capacity, self-induction, and resistance. When this brush is in electrical connection with any projection, *d'*, from the part, *c'*, the circuit is closed between mains, A and B, through coil O', brush, G', brush, H, and coil, K. Energy is therefore accumulated in the coil, O'. At the same time the condenser, N', is short-circuited through the brush, G', brush, H, and coil, K, and discharges through this circuit the energy stored in it, the discharge being in the form of a series of impulses which induce in the secondary, L, corresponding impulses of high potential. When brush, H, breaks the circuit through coil, O', the high-potential discharge or "kick" from the latter rushes into and recharges the condenser, N', but as soon as the brush, H, has passed over the intervening block, *e*, and reached the next segment, *d*, it closes the circuit through coil, O, and short-circuits the condenser, N, so that high-frequency currents from either one or the other of the two condensers are flowing through the primary, K, practically without interruption. Thus without increasing the size or power of the motive device or complicating in any material degree the commutator, these devices are made to perform double duty and the output of the apparatus as a whole greatly increased.

It is also evident that all phase differences in the charging and discharging of the condensers may in like manner be obtained, and the same motor and circuit-controller might be made to charge more than two condensers in succession and to discharge them in the same order.

* New York *Electrical Engineer*.

The New York Herald April 16, 1897

X RAYS ARE ATOMS.

Atomic Disturbance Causes the Most Recently Observed X Ray Phenomena, Say Scientists.

NICOLA TESLA'S DECISION.

Disagrees with Roentgen That They Are Merely a Disturbance of Ether.

HIS RECENT EXPERIMENTS.

The Rays Are Due to a Longitudinal Disturbance of a Material Nature, Says Dr. Tesla.

Profound interest has been aroused among electricians and physiologists in this city concerning the information that at a recent meeting of the Academy of Sciences in Paris the phenomena of the influence of the X or Roentgen rays upon the human physique had been discussed at length. Professor Sorel, of Havre, said he had found the use of the rays dangerous, inasmuch as they had caused in some of the persons on whom he had experimented violent inflammation of the lungs.

Professor Crookes, the inventor of the tubes, added that he believed the effect of the rays was immensely varied, and that he had discovered some instances in which patients rather enjoyed the burning sensations caused by the rays.

TESLA AHEAD OF THE FRENCH.

These declarations call attention again to the statements made many months ago by Nicola Tesla, who in the discovery of these phenomena was the pioneer. He told of the effect of the rays upon human flesh, as well as upon the nerves and muscles, and the declarations before the Academy of Sciences in Paris have been really supplemental to his statements.

Within a very few days Dr. Tesla held his hand before a very powerful bulb, whence were thrown the Roentgen rays and after a comparatively short interval found that it had been affected by them to a degree that surprised him. The appearance of the hand and the sensation were as though the member had been held before an open fire until the cuticle had dried.

When the pain had passed away Dr. Tesla made another experiment with the hand and discovered that it was extremely sensitive to the influence of the rays, the hand's sensation of burning being increased as it was placed as a whole or in part within the rays. This convinced him anew that the rays were composed of atomic matter, and that the effect upon the flesh was caused by the dynamic force of the discharge of these millions of atoms of matter.

MANIFOLD ACTIONS ON TISSUES.

During the course of a conversation yesterday with Dr. Tesla it was learned that more and more evidences are being obtained that the Crookes bulbs emitting Roentgen or Lenard rays exercise manifold actions on the human tissues. Outside of the superficial effects produced on the skin, they seem to be capable of affecting even internal tissues.

Dr. Tesla said it had been reported in a number of instances that, when a conducting object was placed behind the person, either accidentally or with a view of increasing the effect upon the photographic plate, a burn similar to that produced on the portion of the body directly exposed to the bulb was also found on the back of the body, and such a result could only be due to secondary actions of the bulb and not directly to any kind of radiation.

PLATINUM'S HURTFUL EFFECTS.

Dr. Tesla's own observations have shown so far that the hurtful actions are chiefly produced by bulbs in which platinum is used, either as electrode or as impact plate. As Dr. Tesla suggested some time ago, a screen of aluminum wire interposed between the person and the bulb and connected to the ground by a wire is a very effective remedy against injury.

In presence of many observations of like nature it is difficult to look upon the rays as being due to transverse vibrations of the ether, a view held by the majority of scientific men. There are abundant facts now that they are rather a longitudinal disturbance of a material nature and not merely such a disturbance of the ether as Roentgen originally announced.

THE TESLA PATENTS IN ENGLAND.

TO THE EDITOR OF THE ELECTRICIAN.

SIR: Our attention has just been called to a paragraph in your issue of the 9th inst., on the subject of "The Polyphase Patents in Germany," in which the following passage occurs:—"In view of the manner in which the Westinghouse Company keeps the English Tesla patents 'hung up,' it would be interesting to know just what they and the English manufacturers think of the present situation."

The statement that the English Tesla patents, of which we are the owners, are being "hung up" by us, is entirely without foundation, and therefore misleading. The facts are, we became possessed of these patents about ten months since, when we immediately took the very earliest opportunity of acquainting the trade generally that such was the case, and we have responded to all applications which we have received for licences, and have already granted a number. As no doubt you did not intentionally wish to state that which is not entirely in accordance with the facts, we should be much obliged if you would be good enough to insert this letter in your next issue.—Yours, &c.,

WESTINGHOUSE ELECTRIC COMPANY (LIMITED).
Arthur E. Scanes, Secretary,
4, Victoria-mansions, London, S.W., April 15, 1897.

TESLA ON THE HURTFUL ACTIONS OF LENARD AND ROENTGEN TUBES.

To the Editor of Electrical Review:

The rapidly extending use of the Lenard and Roentgen tubes or Crookes bulbs as implements of the physician, or as instruments of research in laboratories, makes it desirable, particularly in view of the possibility of certain hurtful actions on the human tissues, to investigate the nature of these influences, to ascertain the conditions under which they are liable to occur and—what is most important for the practitioner—to render all injury impossible by the observance of certain rules and the employment of unfailing remedies.

As I have stated in a previous communication to your esteemed journal (see Electrical Review of December 2, 1896), no experimenter need be deterred from using freely the Roentgen rays for fear of a poisonous or deleterious action, and it is entirely wrong to give room to expressions of a kind such as may tend to impede the progress and create a prejudice against an already highly beneficial and still more promising discovery; but it can not be denied that it is equally uncommendable to ignore dangers now when we know that, under certain circumstances, they actually exist. I consider it the more necessary to be aware of these dangers, as I foresee the coming into general use of novel apparatus, capable of developing rays of incomparably greater power. In scientific laboratories the instruments are usually in the hands of persons skilled in their manipulation and capable of approximately estimating the magnitude of the effects, and the omission of necessary precautions is, in the present state of our knowledge, not so much to be apprehended; but the physicians, who are keenly appreciating the immense benefits derived from the proper application of the new principle, and the numerous amateurs who are fascinated by the beauty of the novel manifestations, who are all passionately bent upon experimentation in the newly opened up fields, but many of whom are naturally not armed with the special knowledge of the electrician—all of these are much in need of reliable information from experts, and for these chiefly the following lines are written. However, in view of the still incomplete knowledge of these rays, I wish the statements which follow to be considered as devoid of authoritativeness, other than that which is based on the conscientiousness of my study and the faith in the precision of my senses and observations.

Ever since Professor Roentgen's discovery was made known I have carried on investigations in the direction indicated by him, and with perfected apparatus, producing rays of much greater intensity than it was possible to obtain with the usual appliances. Commonly, my bulbs were capable of showing the shadow of a hand on a phosphorescent screen at distances of 40 or 50 feet, or even more, and to the action of these bulbs myself and several of my assistants were exposed for hours at a time, and although the exposures took place every day, not the faintest hurtful action was noted—as long as certain precautions were taken. On the contrary, be it a coincidence, or an effect of the rays, or the result of some secondary cause present in the operation of the bulbs—as, for example, the generation of ozone—my own health, and that of two persons who were daily under the influence of the rays, more or less, has materially improved, and, whatever be the reason, it is a fact that a troublesome cough with which I was constantly afflicted has entirely disappeared, a similar improvement being observed on another person.

In getting the photographic impressions or studying the rays with a phosphorescent screen, I employed a plate of thin aluminum sheet or a gauze of aluminum wires, which was interposed between the bulb and the person, and connected to the ground directly or through a condenser. I adopted this precaution because it was known to me, a long time before, that a certain irritation of the skin is caused by very strong streamers, which, mostly at small distance, are formed on the body of a person through the electrostatic influence of a terminal of alternating high potential. I found that the occurrence of these streamers and their hurtful consequence was completely prevented by the employment of a conducting object, as a sheet of wire gauze placed and connected as described. It was observed, however, that the injurious effects mentioned did not seem to diminish gradually with the distance from the terminal, but ceased abruptly, and I could give no other explanation for the irritation of the skin which would be as plausible as that which I have expressed; namely, that the effect was due to ozone, which was abundantly produced. The latter peculiarity mentioned was also in agreement with this view, since the generation of ozone ceases abruptly at a definite distance from the terminal, making it evident that a certain intensity of action is absolutely required, as in a process of electrolytic decomposition.

In carrying further my investigations, I gradually modified the apparatus in several ways, and immediately I had opportunities to observe hurtful influences following the exposures. Inquiring now what changes I had introduced, I found that I had made three departures from the plan originally followed: First, the aluminum screen was not used; second, a bulb was employed which, instead of aluminum, contained platinum, either as electrode or impact plate; and third, the distances at which the exposures took place were smaller than usual.

It did not require a long time to ascertain that the interposed aluminum sheet was a very effective remedy against injury, for a hand could be exposed for a long time behind it without the skin being reddened, which otherwise invariably and very quickly occurred. This fact impressed me with the conviction that, whatever the nature of the hurtful influences, it was in a large measure dependent either on an electrostatic action, or electrification, or secondary effects resulting therefrom, such as are attendant to the formation of streamers. This view afforded an explanation why an observer could watch a bulb for any length of time, as long as he was holding the hand in front of the body, as in examining with a fluorescent screen, with perfect immunity to all parts of his body, with the exception of the hand. It likewise explained why burns were produced in some instances on the opposite side of the body, adjacent to the photographic plate, whereas portions on the directly exposed part of the body, which were much nearer to the bulb, and consequently subjected to by far stronger rays, remained unaffected. It also made it easy to understand why the patient experienced a prickling sensation on the exposed part of the body whenever an injurious action took place. Finally, this view agreed with the numerous observations that the hurtful actions occurred when air was present, clothing, however thick, affording no protection, while they practically ceased when a layer of a fluid, quite easily penetrated by the rays, but excluding all contact of the air with the skin, was used as a preventive.

Following, now, the second line of investigation, I compared bulbs containing aluminum only with those in which platinum was used besides, ordinarily as impact body, and soon there were enough evidences on hand to dispel all doubt as to the latter metal being by far the more injurious. In support of this statement, one of the experiences may be cited which, at the same time, may illustrate the necessity of taking proper precautions when operating bulbs of very high power. In order to carry out comparative tests, two tubes were constructed of an improved Lenard pattern, in size and most other respects alike. Both contained a concave cathode or reflector of nearly two inches in diameter, and both were provided with an aluminum cap or window. In one of the tubes the cathodic focus was made to coincide with the center of the cap, in the other the cathodic stream was concentrated upon a platinum wire supported on a glass stem axially with the tube a little in front of the window, and in each case the metal of the latter was thinned down in the central portion to such an extent as to be barely able to withstand the inward air pressure. In studying the action of the tubes, I exposed one hand to that containing aluminum only, and the other to the tube with the platinum wire. On turning on the former tube, I was surprised to observe that the aluminum window emitted a clear note, corresponding to the rythmical impact of the cathodic stream. Placing the hand quite near the window, I felt distinctly that something warm was striking it. The sensation was unmistakable, and, quite apart from the warmth felt, differed very much from that prickling feeling produced by streamers or minute sparks. Next I examined the tube with the platinum wire. No sound was emitted by the aluminum window, all the energy of the impact being seemingly spent on the platinum wire, which became incandescent, or else the matter composing the cathodic stream was so far disintegrated that the thin metal sheet offered no material obstruction to its passage. If big lumps are hurled against a wire netting with large meshes, there is considerable pressure exerted against the netting; if, on the contrary—for illustration—the lumps are very small as compared with the meshes, the pressure might not be manifest. But, although the window did not vibrate, I felt, nevertheless, again, and distinctly, that something was impinging against the hand, and the sensation of warmth was stronger than in the previous case. In the action on the screen there was apparently no difference between the two tubes, both rendering it very bright, and the definition of the shadows was the same, as far as it was possible to judge. I had looked through the screen at the second tube a few times only when something detracted my attention, and it was not until about 20 minutes later, when I observed that the hand exposed to it was much reddened and swollen. Thinking that it was due to some accidental injury, I turned again to the examination of the platinum tube, thrusting the same hand close to the window, and now I felt instantly a sensation of pain, which became more pronounced when the hand was placed repeatedly near the aluminum window. A peculiar feature was that the pain appeared to be seated, not at the surface, but deep in the tissues of the hand, or rather in the bones. Although the aggregate exposure was certainly not more than half a minute, I had to suffer severe pain for a few days afterward, and some time later I observed that all the hair was destroyed and that the nails on the injured hand had grown anew.

The bulb containing no platinum was now experimented with, more care being taken, but soon its comparative harmlessness was manifest, for, while it reddened the skin, the injury was not nearly as severe as with the other tube. The valuable experiences thus gained were: The evidence of something hot striking the exposed member; the pain *instantly* felt; the injury produced *immediately* after the exposure, and the increased violence due, in all probability, to the presence of the platinum.

Some time afterward I observed other remarkable actions at very small distances from powerful Lenard tubes. For instance, the hand being held near the window only for a few seconds, the skin seems to become tight, or else the muscles are stiffened, for some resistance is experienced in closing the fist, but upon opening and closing it repeatedly the sensation disappears, apparently no ill effect

(Continued on page 211.)

TESLA ON THE HURTFUL ACTIONS OF LENARD AND ROENTGEN TUBES.

(*Continued from page 207.*)

remaining. I have, furthermore, observed a decided influence on the nasal discharge organs similar to the effects of a cold just contracted. But the most interesting observation in this respect is the following: When such a powerful bulb is watched for some time, the head of the observer being brought very close, he soon after that experiences a sensation so peculiar that no one will fail to notice it when once his attention is called to it, it being almost as positive as touch. If one imagines himself looking at something like a cartridge, for instance, in close and dangerous proximity, and just about to explode, he will get a good idea of the sensation produced, only, in the case of the cartridge, one can not render himself an account where the feeling exactly resides, for it seems to extend all over the body, this indicating that it comes from a general awareness of danger resulting from previous and manifold experiences, and not from the anticipation of an unpleasant impression directly upon one of the organs, as the eye or the ear; but, in the case of the Lenard bulb, one can at once, and with precision, locate the sensation: it is in the head. Now, this observation might not be of any value except, perhaps, in view of the peculiarity and acuteness of the feeling, were it not that exactly the same sensation is produced when working for some time with a noisy spark gap, or, in general, when exposing the ear to sharp noises or explosions. Since it seems impossible to imagine how the latter could cause such a sensation in any other way except by directly impressing the organs of hearing, I conclude that a Roentgen or Lenard tube, working in perfect silence as it may, nevertheless produces violent explosions or reports and concussions, which, though they are inaudible, take some material effect upon the bony structure of the head. Their inaudibility may be sufficiently explained by the well founded assumption that not the air, but some finer medium, is concerned in their propagation.

But it was in following up the third line of inquiry into the nature of these hurtful actions, namely, in studying the influence of distance, that the most important fact was unearthed. To illustrate it popularly, I will say that the Roentgen tube acts exactly like a source of intense heat. If one places the hand near to a red-hot stove, he may be instantly injured. If he keeps the hand at a certain small distance, he may be able to withstand the rays for a few minutes or more, and may still be injured by prolonged exposure; but if he recedes only a little farther, where the heat is slightly less, he may withstand the heat in comfort and any length of time without receiving any injury, the radiations at that distance being too weak to seriously interfere with the life process of the skin. This is absolutely the way such a bulb acts. Beyond a certain distance no hurtful effect whatever is produced on the skin, no matter *how long* the exposure. The character of the burns is also such as might be expected from a source of high heat. I have maintained, in all deference to the opinions of others, that those who have likened the effects on the skin and tissues to sunburns have misinterpreted them. There is no similarity in this respect, except in so far as the reddening and peeling of the skin is concerned, which may result from innumerable causes. The burns, when slight, rather resemble those people often receive when working close to a strong fire. But when the injury is severe, it is in all appearances like that received from contact with fire or from a red-hot iron. There may be no period of incubation at all, as is evident from the foregoing remarks, the rays taking effect immediately, not to say instantly. In a severe case the skin gets deeply colored and blackened in places, and ugly, ill-foreboding blisters form; thick layers come off, exposing the raw flesh, which, for a time, discharges freely. Burning pain, feverishness and such symptoms are of course but natural accompaniments. One single injury of this kind, in the abdominal region, to a dear and zealous assistant—the only accident that ever happened to any one but myself in all my laboratory experience—I had the misfortune to witness. It occurred before all these and other experiences were gained, following directly an exposure of five minutes at the fairly safe distance of 11 inches to a very highly-charged platinum tube, the protecting aluminum screen having been unfortunately omitted, and it was such as to fill me with the gravest apprehensions. Fortunately, frequent warm baths, free application of vaseline, cleaning and general bodily care soon repaired the ravages of the destructive agent, and I breathed again freely. Had I known more than I did of these injurious actions, such unfortunate exposure would not have been made; had I known less than I did, it might have been made at a smaller distance, and a serious, perhaps irremediable, injury might have resulted.

I am using the first opportunity to comply with the bitter duty of recording the accident. I hope that others will do likewise, so that the most complete knowledge of these dangerous actions may soon be acquired. My apprehensions led me to consider, with keener interest than I would have felt otherwise, what the probabilities were in such a case of the internal tissues being seriously injured. I came to the very comforting conclusion that, no matter what the rays are ultimately recognized to be, practically all their destructive energy must spend itself on the surface of the body, the internal tissues being, in all probability, safe, unless the bulb would be placed in very close proximity to the skin, or else, that rays of far greater intensity than now producible were generated. There are many reasons why this should be so, some of which will appear clear from my foregoing statements referring to the nature of the hurtful agencies, but I may be able to cite new facts in support of this view. A significant feature of the case reported may be mentioned. It was observed that on three places, which were covered by thick bone buttons, the skin was entirely unaffected, while it was entirely destroyed under each of the small holes in the buttons. Now, it was impossible for the rays, as investigation showed, to reach these points of the skin in straight lines drawn from the bulb, and this would seem to indicate that not all the injury was due to the rays or radiations under consideration, which unmistakably propagate in straight lines, but that, at least in part, concomitant causes were responsible A further experimental demonstration of this fact may be obtained in the following manner: The experimenter may excite a bulb to a suitable and rather small degree, so as to illuminate the fluorescent screen to a certain intensity at a distance of, say, seven inches. He may expose his hand at that distance, and the skin will be reddened after a certain duration of exposure. He may now force the bulb up to a much higher power, until, at a distance of 14 inches, the screen is illuminated even stronger than it was before at half that distance. The rays are now evidently stronger at the greater distance, and yet he may expose the hand a very long time, and it is safe to assert that he will not be injured. Of course, it is possible to bring forth arguments which might deprive the above demonstration of force. So, it might be stated, that the actions on the screen or photographic plate do not give us an idea as to the density and other quantitative features of the rays, these actions being entirely of a qualitative character. Suppose the rays are formed by streams of material particles, as I believe, it is thinkable that it might be of no particular consequence, in so far as the visible impression on the screen or film is concerned, whether a trillion of particles per square millimetre strike the sensitive layer or only a million, for example; but with the actions on the skin it is different; these must surely and very materially depend on the quantity of the streams.

As soon as the before-mentioned fact was recognized, namely, that beyond a certain distance even the most powerful tubes are incapable of producing injurious action, no matter how long the exposure may last, it became important to ascertain the safe distance. Going over all my previous experiences, I found that, very frequently, I have had tubes which at a distance of 12 feet, for illustration, gave a strong impression of the chest of a person with an exposure of a few minutes, and many times persons have been subjected to the rays from these tubes at a distance of from 18 to 24 inches, the time of exposure varying from 10 to 45 minutes, and never the faintest trace of an injurious action was observed. With such tubes I have even made long exposures at distances of 14 inches, always, of course, through a thin sheet or wire gauze of aluminum connected to the ground, and, in each case, observing the precaution that the metal would not give any spark when the person was touching it with the hand, as it might sometimes be when the electrical vibration is of extremely high frequency, in which case a ground connection, through a condenser of proper capacity, should be resorted to. In all these instances bulbs containing only aluminum were used, and I therefore still lack sufficient data to form an exact idea of what distance would have been safe with a platinum tube. From the case previously cited, we see that a grave injury resulted at a distance of 11 inches, but I believe that, had the protecting screen been used, the injury, if any, would have been very slight. Taking all my experiences together, I am convinced that no serious injury can result if the distance is greater than 16 inches and the impression is taken in the manner I have described.

Having been successful in a number of lines of inquiry pertaining to this new department of science, I am able at present to form a broader view of the actions of the bulbs, which, I hope, will soon assume a quite definite shape. For the present, the following brief statement may be sufficient. According to the evidences I am obtaining, the bulb, when in action, is emitting a stream of small material particles. There are some experiments which seem to indicate that these particles start from the outer wall of the bulb; there are others which seem to prove that there is an actual penetration of the wall, and, in the case of a thin aluminum window, I have now not the least doubt that some of the finely disintegrated cathodic matter is actually forced through. These streams may simply be projected to a great distance, the velocity gradually diminishing without the formation of any waves, or they may give rise to concussions and longitudinal waves. This, for the present consideration, is entirely immaterial, but, assuming the existence of such streams of particles, and disregarding such actions as might be due to the properties, chemical or physical, of the projected matter, we have to consider the following specific actions:

First. There is the thermal effect. The temperature of the electrode or impact body does not in any way give us an idea of the degree of heat of the particles, but, if we consider the probable velocities only, they correspond to temperatures which may be as high as 100,000 degrees centigrade. It may be sufficient that the particles are simply at a high temperature to produce an injurious action, and, in fact, many evidences point in this direction. But against this is the experimental fact that we can not demonstrate such a transference of heat, and no satisfactory explanation is found yet, although, in carrying my investigations in this direction, I have arrived at some results.

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In our present issue we publish a communication from Nikola Tesla, giving, in an exhaustive and instructive manner, the results of his experiments with the Roentgen rays, relating chiefly to their deleterious actions on human tissues. The many novel facts which Mr. Tesla brings out, and his careful deduction from them, will afford valuable and most welcome information to the vast army of experimenters who are engaged in exploring this attractive field. Mr. Tesla, while recognizing the existence of certain grave perils, suggests safeguards and repeats his warning against statements prejudicial to the development of this new and wonderful art.

ROENTGEN RAYS MADE HARMLESS.

Nicola Tesla Tells in a Carefully Prepared Paper How They May Become Safe for All Uses.

DISCOVERY OF THEIR CAUSE.

It Is the Discharge of Small Material Particles, and He Advises the Use of Aluminum.

TREATMENT FOR THE BURNS.

It has been known for some time that Nicola Tesla has been making exhaustive investigations concerning the Roentgen rays, not alone for their use in scientific demonstration, but also for their effects upon the human system. He has made a number of valuable announcements before scientific bodies, notably before a recent meeting of the Academy of Sciences, and has made important communications through the HERALD.

Mr. Tesla has now given voice to his deductions, so far as he has determined them, in a long statement of his experience with the rays in to-day's Electrical Review, and in the course of it makes some announcements certain to create wide discussion and comment in the scientific world. Summing up his experimental experiences, Mr. Tesla says:—

FOUR CHANGES SUGGESTED.

It would seem advisable, first, to abandon the use of bulbs containing platinum; second, to substitute for them a properly constructed Lenard tube, containing pure aluminum only, a tube of this kind having, besides, the advantage that it can be constructed with great mechanical precision, and therefore is capable of producing much sharper impressions; third, to use a protective screen of aluminum sheet, or instead of this a wet cloth or a layer of fluid; fourth, to make the exposures at a distance of at least fourteen inches, and preferably to expose longer at a greater distance.

Mr. Tesla cites several instances of the injurious effects of the rays which have come under his personal observation in his laboratory, which go far to bear out the announcements, already made in the HERALD, of the manner in which the rays affect the system, but beyond this Mr. Tesla has discovered why the rays have this injurious influence, and the theory is as novel as it is valuable. He says:—

According to the evidences I am obtaining, the bulb, when in action, is emitting a stream of small material particles. There are some experiments which seem to indicate that these particles start from the outer wall of the bulb; there are others which seem to prove that there is an actual penetration of the wall, and in the case of a thin aluminum window I have now not the least doubt that some of the finely disintegrated cathodic matter is actually forced through.

These streams may be simply projected to a great distance, the velocity gradually diminishing without the formation of any waves, or they may give rise to concussions and longitudinal waves. This for the present consideration is entirely immaterial.

ENERGY SPENT ON THE SURFACE.

After his own painful experience with the rays, as well as their effect upon other persons whom he had observed, Mr. Tesla comes to this conclusion as to their effect beyond the surface.

"I come," he says, "to the very comforting conclusion that no matter what the rays are ultimately recognized to be, practically all their destructive energy must spend itself on the surface of the body, the internal tissues being in all probability safe, unless the bulb should be placed in very close proximity to the skin, or else that rays of far greater intensity than now produceable are generated."

Mr. Tesla cites a case where the rays had a serious effect on one of his assistants, and incidentally gives the treatment for the burns produced. Concerning this he says:—

In a severe case the skin gets deeply colored and blackened in places, and ugly, ill foreboding blisters form; thick layers come off, exposing the raw flesh, which for a time, discharges freely. Burning pain, feverishness and such symptoms are, of course, but natural accompaniments.

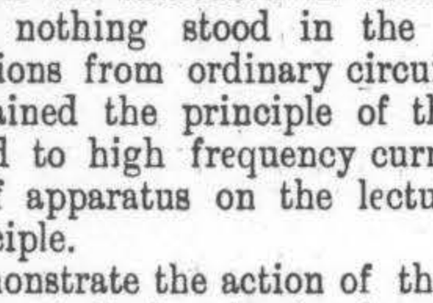
An injury of this kind happened to one of Tesla's assistants following directly an exposure of five minutes at the fairly safe distance of eleven inches. Warm baths, free application of vaseline and general bodily care soon repaired the ravages.

MR. TESLA ON X RAYS.

On April 6th, Mr. Nikola Tesla delivered before the New York Academy of Sciences an address "On the Streams of Lenard and Röntgen, with Novel Apparatus for Their Production." The lecturer began by stating that in 1894, in experimenting to determine the actinic action of phosphorescent light emanating from vacuum tubes, he had found that the actinic power of Crookes tubes varied greatly, and in the most anomalous manner. Thus some tubes emitting a strong light had very little action on photographic plates, while some showing a feeble light acted very strongly on such plates. A large number of these plates, made by Tonnele for the *Century Magazine*, were stored in Mr. Tesla's laboratory when it was destroyed by fire, and thus he was unable now to examine them for the Röntgen effects. He believed, says the New York *Electrical Engineer*, that he had just missed the discovery which made Röntgen famous, and though he was thoroughly familiar with Lenard's work, he did not see far enough.

Mr. Tesla then reviewed his work in the direction of obtaining a reliable apparatus for generating high frequency currents, which he recognised as the keynote to the production of vacuum tube lighting. He told how he had met with difficulties at every point; how a small bubble of air would destroy the value of the coil, or how one-quarter of an inch of wire too much or too little would throw a coil out of balance; how one day a coil would run cold and on another day hot, &c. By finally calling to his aid the condenser, Mr. Tesla stated, he had succeeded in obtaining the desired action, and now nothing stood in the way of securing millions of vibrations from ordinary circuits. The lecturer then briefly explained the principle of the condenser discharge, as applied to high frequency currents, and pointed to various types of apparatus on the lecture table designed to utilise the principle.

In order to demonstrate the action of the high frequency currents Mr. Tesla attached a circular loop of heavy copper wire to the terminals of a high frequency generator and brought to brilliant incandescence a small lamp connected diametrically across the heavy loop; the illumination of the lamp could be varied by connecting it to various points on the diameter of the loop. Mr. Tesla also lit the lamp by the current induced in a second loop brought in proximity to the first. He explained that the coil accomplishing this work had a resistance of 600 ohms and an inductance of 6 henrys; the coil was connected to the circuit one-half the time, and took from the primary circuit only 5 watts.



Mr. Tesla next showed a vacuum tube lit from the terminals of another high frequency machine. He also showed a coil consisting of a single turn of heavy wire which formed the core, as it were, of a small coil of a few turns wound on a paper cylinder surrounding the heavy wire. When connected to a high frequency generator, this apparatus gave a 4-inch spark with an expenditure of energy equal to that taken by one lamp. Mr. Tesla stated that his high frequency generators were so constructed that they could be connected to any existing circuits, direct or alternating.

Returning to the Röntgen rays, the lecturer stated that he had succeeded in discovering a new source of these rays, far more powerful than any heretofore available, though the difficulty of maintaining it was very great. This new source is the electric arc; not the ordinary arc, however. The arc required for the purpose is that maintained between a platinum terminal and an aluminium plate, as illustrated in the accompanying diagram, where A represents the aluminium plate and B the platinum, enclosed in a glass jar.

Mr. Tesla stated that he had also succeeded in deflecting the Röntgen rays by a magnet. He had proved this by deflecting the rays into a condenser placed a long distance from the source of the rays, and which in 5 seconds was charged sufficiently to throw a galvanometer needle off the scale.

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MR. TESLA ON X-RAY BURNS.

IT may be considered a rule of nature that every beneficent manifestation of force may be accompanied by deleterious effects unless guarded against by suitable precautions, and the Röntgen ray is no exception to the rule. The very earliest experimenters in this field noted a harmful action of the rays on the skin, but of late instances have been reported of serious injury due to so-called X-ray burns. It is probable that the cases mentioned are due more to neglect or improper treatment of the injury than to the original effect of the "burn;" nevertheless, it is eminently desirable that all possible means be adopted for the prevention of the injury to begin with, on the old principle that an ounce of prevention is better than a pound of cure. Mr. Nikola Tesla has doubtless done as much X-ray work as any one, and with apparatus whose sheer power has probably not been exceeded by that of any worker in this field and invariably without harmful results, when certain precautions were taken. The means employed with such good results, and their raison d'être, are described in an interesting communication appearing in our contemporary, The Electrical Review.

For the prevention of X-ray burns Mr. Tesla finds that a chief precaution is to interpose between the bulb and the person a thin sheet of aluminum or aluminum wire gauze, connected to the ground directly or through a condenser. This screen, according to Mr. Tesla, prevents the formation of electro-static streamers, which would otherwise issue from the body, and which have an irritating effect. In the course of his experiments, Mr. Tesla observed, however, that the injurious effects did not seem to diminish gradually with the distance from the terminal, but ceased abruptly. He accounts for this as due to the effect of the ozone generated, and supports this view by the fact that the generation of ozone ceases at a definite distance from the terminal.

But perhaps the most striking fact developed by Mr. Tesla in these investigations is, that bulbs containing platinum electrodes are more injurious that those provided with alu-

minum electrodes, in support of which assertion he cites a number of experiments.

To sum up, Mr. Tesla advises: 1. The abandonments of bulbs containing platinum. 2. The substitution for them of a properly constructed Lenard tube, containing pure aluminum only. 3. The use of a protecting aluminum screen, as indicated above, or, instead of this, a wet cloth or a layer of fluid. 4. Exposure at no less distance than 14 inches, and preferably to expose longer at a greater distance. As regards other physiological influences of the X-ray, Mr. Tesla records the fact that since he has begun to work with the X-rays his health has been improved and he has been entirely relieved of a troublesome cough; this same effect was observed on another person. He has also observed that when the head is brought close to a powerful tube the effect is similar to that produced when working for some time with a noisy air gap. As the X-ray tube gives forth no sound, Mr. Tesla concludes that the tube produces violent explosions and concussions, which, though they are inaudible, have some effect on the bony structure of the head. Their inaudibility, he explains on the assumption that not air, but some finer medium, is concerned in their propagation. In conclusion, it may be stated that Mr. Tesla still adheres to his oft-expressed opinion, that the X-ray tube when in action emits a stream of small material particles. Some of his experiments would seem to indicate that these particles start from the outer wall of the tube; others again seem to prove that there is an actual penetration of the wall, and, in the case of a thin aluminum window, Mr. Tesla has not the least doubt that some of the finely disintegrated cathodic matter is actually forced through. Mr. Tesla stands practically alone in his advocacy of the corpuscular theory of the Röntgen rays, but his faith in its correctness seems to be growing stronger as time passes and his experiments multiply.

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THE HARMFUL EFFECTS OF THE X-RAY.

BY DR. F. S. KOLLE.

THE editorial in the last issue of The Electrical Engineer on Mr. Tesla's investigations of the harmful effects of the X-ray is a very timely contribution to the literature of the subject.

It seems to be a peculiar fact that these harmful results or effects are kept from the eyes of experimenters, whereas in my estimation they should be recorded for the benefit of all. Even Tesla reluctantly cites a case of dermatitis, as having occurred in his laboratory. If we cannot receive the valuable inferences of such experimenters as Edison, Tesla, Thomson, etc., then we cannot expect to advance in perfecting this scientific discovery. It should therefore be the duty of every one to record such effects from time to time, as he deems valuable, without further consideration or question whether or not such report might harm or decrease the revenue, derived from the new art. It is self-evident that we must all profit thereby in the end.

Tesla divides the effects of the rays into four divisions, namely, thermal, electrical, electro-chemical and mechanical.

The thermal effect he believes to be shown by the injurious results produced, resembling exposure to heat; although no idea of the degree of heat of the particles is given, yet he says: "If we consider the probable velocities only, they correspond to temperatures which may be as high as 100,000 degrees Centigrade." That this thermal property exists, is certainly shown by the heat effects, such as reddening, pain and even blistering, when a part of the body is injudiciously brought too near an active tube. If this is true, then we are at a loss to demonstrate the transference of the temperature by any present known method.

2. That the rays exhibit certain electrical properties is readily shown by their power of discharging electrified bodies, in an exceedingly short space of time. I consider this in favor of the theory of Tesla that the rays owe their property to minute material particles. This electrical property might have some influence on the skin or part of body exposed. If these local currents are so strong or destructive they certainly resemble the high frequency current effect of Tesla, as no actual shock is experienced by such currents, yet these direct currents of extremely high potential show no hurtful action on the body.

3. If we are to believe that the rays exterior to the tube are made up of material particles of whatever nature, then it is possible that these particles may carry with them or are composed of an electro-chemical substance, and here Tesla holds that with the rays coming from a tube, whose reflectors or impact plate were made of aluminum, no hurtful effects were noted, claiming just the contrary for tubes containing platinum electrodes. This is certainly a most interesting study, and need not necessarily surprise us. I have rarely used focus tubes whose impact electrode consisted of aluminum. The tubes as used in my laboratory contain the usual concave mirror of aluminum and the platinum plate. The fact that the one is dangerous or more so than the other, can only be ascertained, in my belief, by such men as Tesla, Edison, Thomson, etc. For such study, and to develop sufficient evidence, large and complicated apparatuses are required which few are fortunate enough to possess. The usual outfit, that is, one that will answer all purposes medico-surgically, need be put of from 12 to 14 inches spark capacity, and with such apparatus it would be quite impossible to obtain such results as Tesla gives us.

4. The theory of material particles holds good in the mechanical effects produced. It is quite likely that particles of whatever nature violently thrown against each other or the tissues of the body, must necessarily produce heat which may be sufficient to create tissue change. From the above conclusions of Tesla, we must always consider his theory of the nature of the rays, one or the other of his classifications would hardly hold, if other theories be advanced. Yet all these are plausible, and further results are eagerly awaited, as light in darkness, by thousands of experimenters. That the harmful action of the rays have been exaggerated, may be said to be true, when we consider the number of amateurs working in this enchanting art; most, with the exception of very few cases, would hardly have come to the ears of the eager public, who, believing all and considering none, only too readily condemn the entire work. And no wonder! It is but a short time ago I received a communication from Germany, where iodoform had been mistaken for pieces of glass in a man's arm and two operations were undertaken to remove same, where none actually existed. The radiogram showed a foreign body, but this happened to be the dressing applied to the wound in the arm. Such mistakes would not occur if responsible men undertook the work.

As the first experimenter in Brooklyn, and since February 4, 1896, I have had but one case of irritation of the skin and one of alopecia or baldness, resulting from exposure to the rays, during which time I have used tubes daily for hours at a time. The case of dermatitis, otherwise known as inflammation of the skin, was of mild type and under proper treatment abated in 12 days. The case of resulting baldness which is believed to be the first recorded in the world, was fully described in a previous number of The Electrical Engineer, and even here a complete recovery followed.

Yet, I have been called upon to treat numerous cases for other experimenters and in each case I was satisfied that the result was, to a great extent, due to too short a distance between the tube and part exposed. In fact, I have recently seen a case where a large gangrenous piece of the integument had to be removed. Such discharging and blistered wounds make up a great number of these painful affections. That they do not respond to treatment as quickly as diseases of similar nature, produced by other causes, is not true. No one would expect skin to grow under a layer of fine and gangrenous material. Instead, the acrid discharge retards and aggravates the conditions. Proper treatment is required to obtain a happy result.

But all this is not preventive. What shall be done as a prophylactic measure to protect the patient from such effects? Simply study your apparatus, know what it is capable of doing, know from experience the distance your tube should be placed from the body, know its value in emanations, and you will experience little trouble. A further preventive to protect the parts, as I have said in former papers, is the use of an unguentum, in the form of lanoline or vaseline, applied to the skin of the part to be exposed. This protects it from the powerful action of the ozone produced, which is known to be a powerful destructive agent of organic material. I have never felt any ill effects from the ozone generated by an induction apparatus; in truth, I feel better now than ever, and a slight post pharyngeal catarrh has disappeared during the last few moments of experimenting.

Moist dressings protect the parts as well as an ointment; this accounts for few bad effects in tissue by hospital radiographers, where injured members are usually dressed with moist dressings. Tesla uses a thin sheet or netting of aluminum connected to a condenser or the earth, as a collector of the electrical effects of the rays, being placed between the tube and the part exposed. That the interposition of such a metal products, can be readily felt by the amau-radiscope which I have used in the experiments with the blind (N. Y. Med. Journ., Jan. 16, '97). By using such screen the peculiar strain felt in the region of the frontal lobes of the brain is not felt as much as with the usual fluoroscope. I believe the marked anæsthetic effects noted by early experimenters, were due to the continued and monotonous vibrations of the rheotome and need not necessarily be accredited to the rays, although the highly vibrated etheric waves may have some appreciable effect on the auditory nerve.

Distance and time of exposure need careful study, and I would advise all beginners rather to increase the time than to shorten the distance and less harmful results will be attained. Until we receive further convincing proof of preventives the above precautions can be relied upon with comparative safety.

216 Seventeenth street, Brooklyn, N. Y.

[90743.]—**Tesla Apparatus.**—As I have used this apparatus many times for X-ray work, I can give "H. B." (query 90743) the information he asks for. Working off the main with a transformer and Tesla coil, I have obtained perfect radiographs, and without damaging the Crookes tube. The great point to be observed is to have the current on only for short intervals, say on for five seconds, then off for the same period, and so on; by this means the tube is kept cool, and may be used many times. Do not use the double cathode tubes, as the "focus" is indifferent: the resulting picture obtained with such tubes frequently shows the bones double. With an ordinary focus tube, a carefully-adjusted condenser, a small spark gap, and an intermittent current, the Tesla is quite satisfactory for X-ray work. Moreover, old tubes that refuse to work on an induction coil may be readily excited by the higher tension currents of the Tesla; but if you have a continuous current, use it with an induction coil. I have premised that you intend working off the alternating main, for which the outlay (a transformer and small Tesla) is only £6. F. J. R.

[90743.]—**Tesla Apparatus.**—With ordinary "focus" tubes of, say, 3in. to 4in. spark capacity, little or no advantage is gained by using a Tesla, as these tubes can be served equally well by an ordinary 3in. or 4in. induction coil. But with some of the larger bianodic tubes, such as I am now putting on the market, taking 6in. and 8in. sparks to work them, Tesla transformers, worked direct from alternating-current mains, present great advantages. They give at once the high E.M.F., the fairly large ampèrage, and the high frequency of discharge which is essential to rapid photogra phic and clearly visible "screen" effects. S. BOTTONE.

[90743.]—**Tesla Apparatus.**—I should like to exchange experiences with regard to above. My spark coil gives a full 3in. spark using an accumulator, a good steady current, and I get a fully exposed "radiograph" of the hand in from four to six minutes. I made a Tesla according to a specification which, to be brief, "was to make the above 3in. coil do the work of a 6in. or 8in." It did nothing of the sort. I, therefore, made another with modifications, an immense improvement on the first; but I do not get an *increased length of spark*, and with X-ray tubes I do not notice any advantage in the use of the Tesla adaptation—rather the reverse, because the tube appears to tire very rapidly. On the other hand, the luminous effects obtained are remarkable. I get, with ease, the effects (to the extent, of course, of my somewhat limited electrical resources) described by Tesla himself, such being, I need hardly say, most interesting. From a strictly X-ray point of view, so far as my experience goes, I find no advantage whatever from the Tesla over the ordinary coil. I do not find that you get "any more out of it than you put in"—e.g., if you are using a weak and spasmodic source of electrical current, you cannot expect powerful results. I say this because from certain writings (not in the "E.M.") one would infer that, with a 1in. or 2in. spark coil and two or three chromic-acid cells, you can do the work of a £30 outfit. I am not so rash as to deny this altogether; but in the absence of further detail and information, I rather doubt it. P.S.—If likely to interest any of our readers, I will send sketch of my own home-made Tesla.

J. P. N.

The New York Sun June 6, 1897

TESLA GRIPS THE WORLD.

HIS WIRELESS TELEGRAPH PERFECTED AT LAST.

Already He Has Sent and Received Signals at a Distance of 20 Miles—Instantaneous Communication with the Uttermost Parts of the Earth Without Wires the Possible Outcome.

At last Nikola Tesla has reached a point in his investigation of the possibility of telegraphing without wires to make a positive announcement of his achievements. It has been one of his dreams for years. He has worked at the problem long and anxiously. But his talk has always been guarded and indefinite. He spoke of the possibility that the thing might be done, and once, a few months ago, he went so far as to call it a probability. He was more positive and sanguine then than ever before, but still he was not ready to talk of achievements. But at last the work has reached a stage where the modest attitude of uncertainty and hope gives way to positiveness and assurance, and the definite announcement of success is made. Mr. Tesla declares that he has produced electrical devices with which he can actually send and receive messages by a system which can be so applied as to make it possible for an operator in New York to communicate with ease and certainty with the people of any part of the earth, and perhaps, even with those of the stars, if any of these are inhabited.

"The machines which I have completed," Mr. Tesla said yesterday, "will carry messages through the earth for a distance of twenty miles or so. I have sent and received signals with them, and I feel confident that I am not mistaken in saying that the problem upon which I have spent many days and nights is solved. Of course it is possible that I am mistaken. I have made mistakes before, but not many. I shall at once make machines which I expect will enable me to telegraph to any part of the earth as readily as I can within a limited distance by means of the ones I have.

"If I have a machine which will throw a stone from here to there," continued Mr. Tesla, pointing from the floor at his feet to the door of his laboratory, "then I do not need to doubt that I can make one which will throw the stone fifty miles if I can control the necessary power."

Mr. Tesla was not ready to explain in detail the devices which he uses for telegraphing without wires, but he talked freely about the principles which were involved and made it clear that the results were obtained by the use of some form of his electrical oscillator, recently patented. As long ago, he said, as when he was putting up telephone wires in Budapest he observed that electrical impulses were carried long distances without the intervention of wires. There was a telegraph cable one and a half or two miles away over which messages were being sent by the Morse code, and at times he could read these messages through the telephone. This set him to investigating the electrical condition of the air. He became satisfied that the messages were conveyed to the telephone wires by induction.

In 1890 he announced his belief that by means of electrical impulses of an extremely high rate, never yet attained at that time, bright light might be obtained from Crookes tubes, and in 1891 he made this announcement in London.

"I believed at that time that telegraphing might be conducted through the earth without wires," he said yesterday, "but I was afraid to say so for fear I should be laughed at and discredited by the older and abler men who were the leaders in electrical science."

It was not until 1893, when he appeared before the National Electrical Lighting Association at St. Louis, that he first declared his belief in the possibility of telegraphing over the whole earth without wires. Then he explained the general method which he believed would make this possible, if he could get a machine which should be able to disturb the static electricity of the earth. In that year he had an electrical exhibit at the World's Fair in Chicago and among his visitors was Prof. Helmholz.

"I spoke of my project to Prof. Helmholz," Mr. Tesla said yesterday, "and told him how I thought it might be accomplished. 'Yes, it is possible,' he said, 'but it would take much power.' I was very much pleased with this admission by this great master, and gratified that he did not condemn the idea, as many of my coworkers had done. I did not tell him then that I had already solved that part of the problem."

The solution to which Mr. Tesla referred was brought about through the work which he had done in developing his electrical oscillator, which he was working upon particularly in connection with the production of light from the Crookes tubes. The energy of the electric current, like that of flowing water, is displayed only when the current is interrupted. A familiar example of this may be seen in the common medical battery where the current flowing from one pole to the other may be passed through the most sensitive parts of the body, and yet not be felt. Pass the same current through a Ruhmkorff coil, interrupting the secondary current by the vibrations of the commutator, and it will twist up the muscles of the strongest man and make him powerless.

Before Tesla's time interruptions of this sort had been produced only by mechanical means and could number only a few hundred a second. His electrical oscillator acts upon the principle of a bell, where a single stroke of the hammer sets the metal vibrating with a rapidity commensurate with its bulk, and these vibrations can be continued indefinitely by repeated strokes of the hammer at slow intervals. Mr. Tesla now makes oscillators which will interrupt the current millions of times in a second. In explaining the theory upon which his new devices for telegraphing over the whole earth works, Mr. Tesla used a simple simile.

"Suppose the whole earth," he said, "to be like a hollow rubber ball filled with water, and at one place I have a tube attached to this, with a plunger in the tube. If I press upon the plunger the water in the tube will be driven into the rubber ball, and as the water is practically incompressible, every part of the surface of the ball will be expanded. If I withdraw the plunger, the water follows it and every part of the ball will contract. Now, if I pierce the surface of the ball several times and set tubes and plungers at each place the plungers in these will vibrate up and down in answer to every movement which I may produce in the plunger of the first tube. If I were to produce an explosion in the centre of the body of water in the ball, this would set up a series of vibrations in the whole body. If I could then set the plunger in one of the tubes to vibrating in consonance with the vibrations of the water, in a little while and with the use of a very little energy I could burst the whole thing asunder."

This, Mr. Tesla said, would explain in a rude way how he proposed to set the whole of the static electricity of the earth in motion, for telegraphic purposes, by taking advantage of the incompressibility and elasticity of the electric fluid. Then he told of some of the interesting results which he had accomplished in studying the theory and effect of vibrations. In one case he set a steel ring, four inches thick, vibrating, and by repeated but gentle continuations of the vibrations burst the ring. In another case he took a steel bar an inch in diameter, set it vibrating, and kept it going until its internal disturbance was so great that first a section of the rod broke loose from one end and flew off and then another section flew off from the other end.

In applying these principles to the telegraphic purpose Mr. Tesla had first to work out the theory and then to make instruments which would set up the proper vibrations and others again which would catch and record them.

"I have perfected my machines and got excellent results," Mr. Tesla said yesterday. "I have thought of this system of telegraphing not as a mere commercial matter, but as a means of bringing the nations of the earth closer together. I conceive that the use of this system will not do away with the use of telegraph wires, but will on the other hand make more work for them. It is true that millions of my machines might be used without those of one lot interfering with those of another lot, but the manner in which I conceive that the system should be used is this: Have a machine at each commercial or political centre and send out from each place, under an international agreement, all the political, financial, or other news, to be read at every other part of the world at the same moment. The news could be distributed then over the wire lines or otherwise. Financial panics and even wars might be done away with if this were done."

Mr. Tesla says the transmission of signals is not the only result which may be achieved by his new scheme.

"This was what I at first thought," he said, "but from the results of my experiments I am now hopeful that I shall be able to substantiate another thing—the transmission of power from place to place."

If it were proved possible to transmit power without wires, and to considerable distances, it would solve the greatest problem which now constricts the use of electricity for many purposes.

"If ever we are able to communicate with the stars it would be by this method," Mr. Tesla declared.

When asked what the effect of electrical storms would be on his system, Mr. Tesla said they would undoubtedly interfere more or less with the working of the instruments locally.

Before the interview with him ended he made a statement regarding his Crookes tubes lighting system which will interest many persons.

"The system is now a commercial possibility," he declared. "I don't like the word 'commercial,'" he added, "but what I mean is that I have succeeded in bringing down the cost of the light so that it will compare favorably with other means of lighting."

Mr. Tesla took up one of the many lighting tubes which were lying about and, starting the current through one of his oscillators, held the tube near the poles. The tube was shaped like a gridiron and was about eight inches square. As it drew near the electric arc of the oscillator it began to glow, and when it was close by it was all ablaze with a pure light.

"If it were night," Mr. Tesla said, "this light would diffuse itself over this whole room, so that you could read anywhere, although the candle power of the light is low."

His lights would be supplied by wires running across each room, but they could be produced without any connection with the wires if desired. Another form of tube, he said, gave a light many times more brilliant than the arc electric light, and this was suitable for such things as searchlights.

The New York Herald June 7, 1897

TESLA'S LATEST INVENTION.

Hopes To Be Able to Communicate by Electricity Throughout the Earth Without Wires.

Nikola Tesla feels certain that he has at last perfected a system of telegraphy without wires which will enable him to communicate with any point on the surface of the earth, and perhaps even with the stars, if any beings exist there intelligent enough to receive and return a message.

So far Mr. Tesla has experimented only within limited distances, but the success which he has met with induces him to believe that he has realized his hopes. He has long believed that messages might be sent through the earth without wires, and he has for several years been working upon his plans.

The necessary energy for performing the work of transmission is secured through the electrical oscillators which he invented, and which are capable of interrupting a current millions of times in a single second. His idea is based upon the elasticity of the static electricity of the earth, and his theory is that if this is disturbed by vibrations at a given point the same vibrations may be felt and recorded at any other given point. He is at work upon machines which are to transmit and receive these vibrations. He says that he has secured excellent results and that he has been able to send messages through twenty miles of earth.

Mr. Tesla thinks that his invention may be of the utmost importance in transmitting news affecting international interests throughout the entire world at the same moment, thus preventing wars and panics. He hopes also that he may be able by the same method ultimately to transmit power. If communication with the stars is ever established, he is confident that it will be through his method.

In addition to this discovery, Mr. Tesla has been experimenting with light derived from Crookes tubes, and he thinks that he has devised a system which will make them.

The New York Herald June 7, 1897

CAUSE AND EFFECT.

To illustrate certain powerful electrical experiments he is making, Professor Tesla compares the earth to a hollow ball filled with water. He says:—"At one place I have a tube attached to this, with a plunger in the tube. If I press upon the plunger the water in the tube will be driven into the ball." The Professor is liable to be accused of producing the recent earthquakes and the eruption of Aetna.

The New York World June 7, 1897

TESLA'S TRIUMPH.

When Morse found out the possibility of sending messages from one place to another by the electric telegraph his invention was only the clumsy beginning of a system. He used two wires to complete the circuit.

Presently somebody discovered that only one wire was necessary, because by "grounding" it at each end the earth could be made to do the rest of the work.

From that hour to this—from the time when it was discovered that the earth could be made to do half the work—it has been the problem of electricians to make the earth do all of it. It has been certain that sooner or later we should do our telegraphing without wires.

Mr. Tesla now announces that he has accomplished this. He can send signals for twenty miles without the use of wires. Any system that sends signals can be made to send messages. And when signalling for twenty miles is possible, signalling for any conceivable distance is a thing not far off.

This earth of ours is a great magnet, a gigantic dynamo. We have only to learn how to apply its practically illimitable magnetic powers to our uses in order to "make the whole world kin" in a degree never dreamed of by the poet who invented that phrase.

ALL THE WORLD IN INSTANT TOUCH.

Tesla's Greatest Idea Is Ready for a Practical Test.

MESSAGES BUT NO WIRES.

Twenty Miles the Limit Now, but His New Machine May Reach the Antipodes.

THE STARS NOT OUT OF REACH.

Electrical Energy Will Be Much Cheaper with No Costly Wiring Needed.

A LIGHT THAT RIVALS THE SUN.

Garrett P. Serviss Discusses the Famous Electrician's Marvelous Inventions.

Mr. Nicola Tesla has anticipated the twentieth century by telegraphing without wires. He has transmitted electric signals through the earth a distance of twenty miles, and received similar signals in return.

He believes that the system he has just perfected will render it possible to communicate intelligence from any point on the globe to any other point without the intervention of wires or connecting lines of any kind.

At present only a beginning has been made, but the principle is established, and when the details have all been worked out it may be that greater distances than those which separate the different quarters of the earth will prove to be traversable by electric vibrations under the control of human intelligence.

If a message can be sent around the earth without wires or cables, it may possibly be sent from the earth to the moon or to Venus or to Mars.

All this, however, is for the future. At present it is enough to know that such messages have actually been transmitted a distance as great as from New York to Menlo Park.

The details of his method have not yet been made public by Mr. Tesla, but his experiments with high frequency electric currents and the wonderful results he has attained in the production of light without wires have prepared the public as well as the world of science for some such announcement as that which now comes concerning the new system of telegraphy.

How eagerly and expectantly men of science have been peering in the direction of this great discovery is well shown by some remarks made by an English authority, Prof. W. E. Ayrton, in a recent lecture in London.

He was speaking particularly of marine telegraphy and of the difficulties at present encountered in connecting the continents by wire.

"But there is no doubt," he said, "that the day will come, may be when you and I are forgotten, when copper wires, gutta-percha coverings and iron sheathings will be relegated to the museum of antiquities.

"Then when a person wants to telegraph to a friend, he knows not where, he will call in an electro-magnetic voice which will be heard loud by him who has the electro-magnetic ear, but will be silent to every one else.

"He will call 'Where are you?' and the reply will come loud to the man with the electro-magnetic ear, 'I am at the bottom of the coal mine, or crossing the Andes, or in the middle of the Pacific.'

"Or perhaps no voice will come at all, and he may then expect the friend is dead. Think what that will mean. Think of the calling which goes on from room to room, then think of that calling when it extends from pole to pole—a calling quite audible to him who wants to hear, absolutely silent to him who does not."

The ink that printed the report of Prof. Ayrton's lecture was not yet dry when Mr. Tesla had begun the accomplishment of the scientific miracle which the lecturer described.

Indeed, probably before the lecture was composed on one side of the Atlantic the feat had been done on the other side.

For Prof. Ayrton's "electro-magnetic voice" put one of Mr. Tesla's electric oscillators, and for his "electro-magnetic ear" one of Mr. Tesla's electric receivers, and practically you have what was in London a mere dream of the scientific imagination transmitted in New York into a dazzling scientific fact.

Astounding as this discovery seems, many things have heretofore shown clearly that it was coming, but few probably expected that it would come so soon.

How rapidly it will be developed will depend upon the possibility of increasing the energy of the impulses sent out through the ether and of improving and perfecting the devices for their reception.

But if a message of this kind can be transmitted twenty miles to-day there is reason to hope that it may be transmitted across the sea or the continent before the end of the century.

GARRETT P. SERVISS.

TESLA TELLS THE STORY.

Will Make the Earth Vibrate to a Signal Code and Furnish Light Without Filaments.

Nikola Tesla announces that he has so nearly perfected three of his wonderful discoveries that he will soon be ready to put them to a practical test.

One, of which he had given some hint before, is a machine which will set the whole earth in vibration.

These vibrations, set to the measures of an international code, may be read at any part of the earth, this making possible communication, without wires, between any place and its antipode.

Then he has so improved his electrical oscillator that he is able to produce from a glass tube, without the usual filament of the incandescent lamp, a white light, in which only 10 per cent. of the electrical energy will be expended in heat, instead of 97 per cent., as in the incandescent light.

And last, though by no means least, he fully believes he will be able to transmit electrical power from place to place without the use of wires.

"I have so improved my machine," he says, "that I am able to transmit signals through the earth for a distance of twenty miles. I am now at work on another which will not be hampered or affected by any distance, even though it be half around the globe.

"But, more, the transmission of signals in this manner is not the only result I have arrived at, although it was the only end I had in view.

"I have been able to substantiate the principle that it is a possibility to send electrical energy from one point to another without wires."

Think, for a moment, of the immense advantage of knowing instantly what is going on in all the commercial centres of the world; of being informed at once of any international embroglio which may affect the business interests of the whole globe.

Every city in the world would be a station on an immense ticker circuit, and important news would go from one part of the world to the other with the rapidity of a lightning flash.

Imagine, if you will, an immense rubber bag filled with water. At one point a tube is inserted and in this tube is a piston. Press on the piston rod and the incompressible water expands the rubber bag.

Withdraw the piston and the bag shrinks just as much as there is water drawn into the tube. Now place in the rubber another tube with a piston. At every pressure on the first piston rod the effect will be felt and measured in the second tube.

Let a certain action of one piston indicate a word or a sentence; watch the other piston and you may read it.

This illustrates the principle upon which Tesla bases his idea of telegraphing through the earth. The qualities of electricity are inertia, incompressibility and elasticity.

He decided, after investigation, that if the electro-static condition of the earth could be disturbed in one place, the disturbance would be felt all over the earth.

Then, if this disturbance was created by a machine, any similar machine, at any other point, should be susceptible to the disturbance.

What then, he argues, is necessary other than to have each degree of disturbance accord with a code signal, regulate the disturbance so as to send any message you wish, and, at all other places where there are similar machines the message will be recorded.

The idea first occurred to Tesla when he was putting up a telephone system in Budapest. Two miles away was a Morse telegraph cable, and on the telephone wire every message that went over the cable could be heard.

Although the telephone wire and the cable were grounded the communication was by induction.

Tesla devoted himself to the idea, occasionally speaking about it. He received little encouragement until he was at the Chicago Exposition, and Prof. Helmholz, the greatest electrician of the century, called on him. To him Tesla outlined his plan. The professor thought for a minute and then said:

"Yes, I think you can do it. The great obstruction, however, is that you will require such enormous power."

Even then Tesla had in mind a machine which, he felt assured, would remove that obstruction. It is this machine he has perfected.

Just what it is like he declines to say, but inasmuch as at the time of his talk with Prof. Helmholz he was developing his electric oscillators that he might substantiate his claim that light might be produced from tubes it is believed the oscillator is the machine.

It is a producer of wonderful vibrations, Tesla claiming he can get 50,000,000 vibrations a second. He exhibited the very way which, he said, developed 800,000 vibrations a second.

More than probable it is that by means of the application of one of these oscillators to the static electricity in the earth he hopes to produce the disturbances without employing a remarkable amount of power.

With one of these oscillators Tesla has caused a bar of steel one inch thick to vibrate with such rapidity that literally it has broken itself to pieces, a fragment falling from one end, a second from the other and so on. In the same way he has shattered a ring of steel four inches wide.

"What experiments have you made in the transmission of signals by this apparatus?" he was asked.

"I have one that I know will operate over a distance of twenty miles. What more do I need? I know my best machine will do all I require of it.

"If I have a machine that will throw a stone five feet it is not necessary for me to construct another before I can know the stone may be thrown ten feet. All that is necessary is that I thoroughly understand the motive power, and from that I can tell."

"In what way will your discovery be applied?"

"There might be one in every large city in the world operated by an international agreement, so that all public news might be known instantly in every country.

"It would put every important point in the world in instant touch with every other. Millions of these stations might be established.

"No. I do not think it will do away with the telegraph lines or the cables, for it would be almost impossible to use these machines to filter all the news to the public.

"To my mind it will increase the business of the telegraph and cable companies.

"I feel it will be a great boon to humanity. To my mind it will avoid wars, will prevent panics and will enlist the sympathies of all the rest of the world for any section that may be in distress.

"This may be only a dream, but I feel that if we are ever to communicate with the stars it will be by this method and this only."

"There are wonderful commercial opportunities in this discovery made by Tesla as to the transmission of electrical power from point to point without wires.

It makes possible the erection of one central station, from which power can be sent wherever needed at a cost greatly below what is charged at present, for the copper feeding wires which are now used to transmit power from the central station are the heaviest item of expense.

When the question of motive power for the underground road was under consideration by the Rapid Transit Commission and electricity was advocated it was stated that the cost of the feeding wires alone for the underground line would be $7,000,000.

Could the electrical power produced at Niagara Falls be distributed without wires the cost would be so lessened that many more persons could avail themselves of the power, and the same condition might have its effect in the report of the commission which has just examined the Falls of the Nile, with a view to their adaptability to the production of electrical energy.

Factories and large workshops where electricity is employed, distributed among the various rooms by wire, would be operated at a greatly reduced expense; railroads would do away with their costly trolleys, and in every branch of trade where the electric fluid plays its part the outlay would be decreased.

No idea as to how he will accomplish this wireless transmission could be gained from Inventor Tesla, but it may be guessed that his oscillators will be brought into play in the development of his plan.

They are the important factor in the production of the new white light he has invented.

"I can safely say now," he declared, "that from tubes a white light can be produced at a cost which is at least comparable to that of other light, and easily within the reach of all."

He picked up a Crookes tube and placed it near the points of an oscillator, which developed 800,000 vibrations a second.

Instead of the phosphorescent glow usually produced from the tubes, a white light, wonderfully diffusive, was given out, even though the sunlight was streaming in through the windows.

The muscles of Tesla's arm contracted as the contact was first made.

"That was a voltage of 50,000," he said, as he put away the tube, "and it entered my body, as you saw."

The difficulty of producing such light heretofore was that its cost, because of the electrical energy required, was nearly ten times as great as that of the incandescent lamps.

With the oscillators it is different, however. They give the required energy and at a reduced cost.

"This light," said Tesla, "is not so brilliant as to be of a high candle power, yet it is very diffusive and will fill a room with a beautiful illumination. By the way, we have always accustomed our eyes to a light that is too brilliant.

"While in the incandescent lamp more than 96 per cent. of the power is expended in heat, I have got as much as 60 per cent. of light out of one of these tubes. But of course such an amount is not practical.

"I have also another tube, which, taking its energy from the oscillator, is brighter than any arc light by ten times, and makes a wonderful searchlight not to be compared to any that are in use. It is really like the sun."

Regarding the application of these tubes to houses Tesla said it would be done ordinarily with wires through each room, though where this was impossible the light could be produced without wires.



EDISON POOH-POOHS IT.

Nikola Tesla's Announcement Is Incomprehensible to the Wizard of Menlo Park.

Thomas A. Edison smiled when a World reporter asked for his views of Tesla's claims. "I don't find anything in them for discussion," said he. "It is all incomprehensible to me. He does not tell of anything accomplished. There is nothing that I can grasp, no facts that form even a basis of discussion.

"I have done something in the general field of work suggested by Mr. Tesla's claims, but I left it when I found that it was not profitable or practicable.

"For instance, a few years ago we succeeded in telegraphing from a moving train of cars to a terminal station or to another train. We could throw a current over the train, and by a simple apparatus. The entire plant would cost only $150. The process was fully described in the newspapers at the time.

"It was never of any practical value, aside from locating work trains along the road. We also showed that a current could be transmitted from one kite to another in the air.

"It might be possible," Mr. Edison said, with a smile, "to send a wave to England by the use of 5,000,000 or 6,000,000 horse-power, a wave that would transmit a letter, and it might be possible to transmit twenty waves or a word a day. The power required would be enormous. No, I can see nothing in this scheme described in such a vague, uncertain way."



TRANSMITTING SOUND THROUGH PIKE'S PEAK.

TESLA'S WIRELESS TELEGRAMS.

Nearly every telegraphic inventor has for years dreamed in his waking hours of the possibility of communicating without wires. From time to time there has appeared in the technical journals a reference to experiments showing the almost universal belief among electricians that, some day, wires would be done away with. Experiments have been made attempting to prove the possibilities, but it has remained for Mr. Nikola Tesla to advance a theory, and experimentally prove it, that wireless communication is a possibility, and a by no means distant possibility. Indeed, after six years of careful and conscientious work, Mr. Tesla has arrived at a stage where some insight into the future is possible.

A representative of the ELECTRICAL REVIEW receives the assurance personally from Mr. Tesla who, by the way, is nothing if not conservative, that electrical communication without wires is an accomplished fact, and that the method employed and principles involved have nothing in them to prevent signals and messages being transmitted and intelligibly received between distant points. Already he has constructed both a transmitting apparatus and an electrical receiver, which at distant points is sensitive to the signals of the transmitter, regardless of earth currents or points of the compass. And this has been done with a surprisingly small expenditure of energy.

Naturally, Mr. Tesla is averse to explaining all details of his invention, but allows it to be understood that he avails himself of what, for the present, may be termed the electrostatic equilibrium; that if this be disturbed at any point on the earth, the disturbance can with proper apparatus be distinguished at a distant point, and thus the means of signaling and reading signals becomes practicable once the required concrete instruments are available. Some years ago Mr. Tesla announced his belief in the possibilities, but he did so only after having satisfied himself by actual tests of apparatus designed by him. Much work had yet to be done, and he has since then given close attention and study to the problem.

Details are not yet available, for obvious reasons, and we now merely chronicle Mr. Tesla's statement that he has really accomplished wireless communication over reasonably long distances with small expenditure of energy, and has only to perfect apparatus to go to any extent. Morse's 40-mile experiment in the old days was on a far less certain basis than the wireless possibilities of to-day.

Tesla's work with high frequency and high-potential currents has been notable. As long ago as 1891 he foretold the present results, both as to vacuum tube lighting and intercommunication without wires. The former had in his hands assumed a condition capable of a public demonstration of the phenomena of the electrostatic molecular forces. Numberless experiments were carried out, and from what then was a startling frequency of 10,000 per second, Mr. Tesla has advanced to what now is moderate work at 2,000,000 *oscillations per second*. Such almost inconceivable results are plainly out of all possible reach by any mechanical rotation of a commutator. And so long as efficiency of lighting is, as Mr. Tesla observes, dependent upon extremely high frequency, it would seem his efforts are in the one and only direction likely, in vacuum tube lighting, to lead to success. Success, according to Mr. Tesla, is already assured, but he will not come before the public until every detail of a practicable and commercial system is complete, and the day for such a consummation, he now states, is near at hand.

[90848.]—**Tesla Coil.**—The subjoined figures will, I hope, do away with the necessity for a very verbose description:—Procure a glass tube, 2in. diameter and 6in. in length. This can be bought for 5d. or 6d.—the short glass chimneys used for Argand burners exactly answer the purpose. Fit a bung to each end, insert about the half of a 3in.

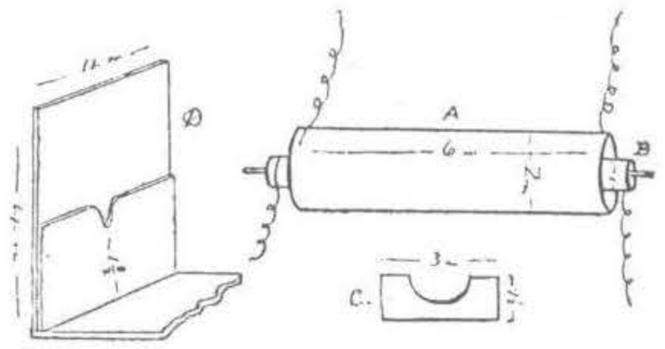

FIG. 1.—A, glass tube, 2in. diameter, wound with about 450 turns of No. 36 s.c. wire; the tube is kept off the bottom of box by two narrow strips of guttapercha, ⅛in. thick, shaped as at C. B, wood cylinder for primary, wound with about 50 turns of g.p.c. wire, No. 22; cylinder is 1in. longer than glass tube through which it passes, held or fixed in position by the thin wood projections in ends, which fit in grooves cut in, or specially glued on, ends of box. D, one end of box shown.

wire nail, and mount between a couple of small brackets. It will then be comparatively easy to wind upon it the length of No. 36 wire required. The wire I use is double silk-covered. The reel of wire is tested for continuity, then soaked in melted paraffin wax, and mounted on a temporary spindle ready for winding from. Coil about 12in. of the wire into a spiral, and fasten it securely with a bit of waxed thread ¼in. from one end of tube and start winding, fairly tight, close and even turns, until within ¼in. of other end of tube; tie here same side as started from and leave 12in. free wire. Now wind primary much in the same way. The rod is a length of hardwood ruler, 1in. diameter and 1in. longer than the glass tube. The extra lengths shown (as at B) are merely to support the primary exactly in centre of tube to keep it fixed there. With these extensions, therefore, the primary rod will be the exact length of box. Put on primary 50 turns of No. 22 wire, evenly separated; tie the ends tightly, then go over the whole surface of wire turns three or four times with shellac varnish. It is hardly necessary to say that the G.P. supports for tube (as C, Fig. 1) are made to adhere to the glass simply by warming the edges. The containing-box is of ¼in. walnut (fretwork wood), and measures

made 4 by 4 by 8, put together with glue and screws, thoroughly well varnished inside and out, and the joins inside covered with pitch. Boiled oil is provided sufficient to reach within ½in. of top. All the free ends of wires must be passed through rubber tubes: the two from secondary taken out on one side of box, and the primary on the other. Below (Fig. 2) is ground plan of connections. I mount these on one end of a board, 10 by 12, or so; thus leaving room for Tesla tank to stand at the other end. The terminals *a* and *c* are mounted on raised blocks of wood; the stand itself has been practically soaked in shellac varnish, and is mounted on four glass supports. The condenser is a quart Leyden jar. The utmost care must be taken with the "secondary" ends to secure the best insulation. In default of "hard rubber tubing of great thickness," I take these rubber-covered ends as soon as they come out of the oil and are "on the straight," so to speak,

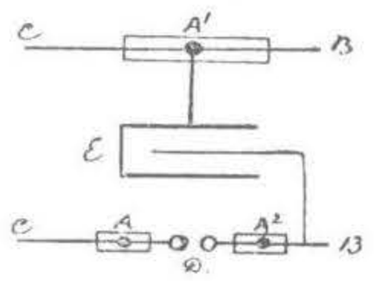

FIG. 2.—A^1 A^2 A, ordinary binding-screws; B B, wires to Ruhmkorff secondary terminals; C C, wires from Tesla primary; D, spark gap; E, condenser (outside connected to A^1, inside to A^2).

through glass tubes of various thicknesses fitting one within the other, building them up in two upright cases, one at each end of the tank, using plenty of pitch and rubber wherever possible, then terminal binding screws at top of each. A lid should be fitted to tank, and after pouring in the oil some hours should elapse before attempting to use the coil. I think above will be clear enough; if not, I shall be glad to assist anyone, in spite of a feeling that I am quite a tiro myself. I repeat, I get with above coil no longer spark than with the ordinary coil used by itself, but increased vibrations as I understand it, different effects altogether—e.g., attach to the terminals two L-shaped pieces of brass wire, so as to get two parallel lengths of wire 3in. to 4in. apart. From this little instrument, which from its cost, so cheap is it, that it might almost be reckoned a toy, to quote Dr. Tesla's article, "the discharge appears in the form of powerful brushes and luminous streams issuing from all points of the two straight wires," &c. J. P. N.



Telegraphing Without Wires

NICOLA TESLA, in an Interview in the New York *Sun*

The machines which I have completed will carry messages through the earth for a distance of twenty miles or so. I have sent and received signals with them, and I feel confident that I am not mistaken in saying that the problem upon which I have spent many days and nights is solved. Of course it is possible that I am mistaken. I have made mistakes before, but not many. I shall at once make machines which I expect will enable me to telegraph to any part of the earth as readily as I can within a limited distance by means of the ones I have. I spoke of my project to Prof. Helmholz in 1893 and told him how I thought it might be accomplished. "Yes, it is possible," he said, "but it would take much power." I was very much pleased with this admission by this great master, and gratified that he did not condemn the idea, as many of my co-workers had done. I did not tell him then that I had already solved that part of the problem. I have perfected my machines and got excellent results. I have thought of this system of telegraphing, not as a mere commercial matter, but as a means of bringing the nations of the earth closer together. I conceive that the use of this system will not do away with the use of telegraph wires, but will on the other hand make more work for them. It is true that millions of my machines might be used without those of one lot interfering with those of another lot, but the manner in which I conceive that the system should be used is this: Have a machine at each commercial or political center and send out from each place, under an international agreement, all the political, financial, or other news, to be read at every other part of the world at the same moment. The news could be distributed then over the wire lines or otherwise. Financial panics and even wars might be done away with if this were done. From the results of my experiments I am now hopeful that I shall be able to substantiate another thing—the transmission of power from place to place.

In explaining the theory upon which his new devices for telegraphing over the earth work, Mr. Tesla said:

Suppose the whole earth to be like a hollow rubber ball filled with water, and at one place I have a tube attached to this, with a plunger in the tube. If I press upon the plunger the water in the tube will be driven into the rubber ball, and as the water is practically incompressible, every part of the surface of the ball will be expanded. If I withdraw the plunger, the water follows it and every part of the ball will contract. Now, if I pierce the surface of the ball several times and set tubes and plungers at each place the plungers in these will vibrate up and down in answer to every movement which I may produce in the plunger of the first tube. If I were to produce an explosion in the center of the body of water in the ball, this would set up a series of vibrations in the whole body. If I could then set the plunger in one of the tubes to vibrating in consonance with the vibrations of the water, in a little while and with the use of a very little energy I could burst the whole thing asunder.

New York *Sun*

Mr. Tesla was not ready to explain in detail the devices which he uses for telegraphing without wires, but he talked freely about the principles which were involved and made it clear that the results were obtained by the use of some form of his electrical oscillator, recently patented. As long ago, he said, as when he was putting up telephone wires in Budapest he observed that electrical impulses were carried long distances without the intervention of wires. There was a telegraph cable one and a half or two miles away over which messages were being sent by the Morse code, and at times he could read these messages through the telephone. This set him to investigating the electrical condition of the air. He became satisfied that the messages were conveyed to the telephone wires by induction. Then he told of some of the interesting results which he had accomplished in studying the theory and effect of vibrations. In one case he set a steel ring, four inches thick, vibrating, and by repeated but gentle continuations of the vibrations burst the ring. In another case he took a steel bar an inch in diameter, set it vibrating, and kept it going until its internal disturbance was so great that first a section of the rod broke loose from one end and flew off and then another section flew off from the other end.

Electrical Review, New York

A representative of the *Electrical Review* receives the assurance personally from Mr. Tesla who, by the way, is nothing if not conservative, that electrical communication without wires is an accomplished fact, and that the method employed and principles involved have nothing in them to prevent signals and messages being transmitted and intelligibly received between distant points. Already he has constructed both a transmitting apparatus and an electrical receiver, which at distant points is sensitive to the signals of the transmitter, regardless of earth currents or points of the compass. And this has been done with a surprisingly small expenditure of energy. Naturally, Mr. Tesla is averse to explaining all details of his invention, but allows it to be understood that he avails himself of what, for the present, may be termed the electrostatic equilibrium; that if this be disturbed at any point on the earth, the disturbance can with proper apparatus be distinguished at a distant point, and thus the means of signaling and reading signals becomes practicable once the required concrete instruments are available. Morse's 40-mile experiment in the old days was on a far less certain basis than the wireless possibilities of to-day.

WIRELESS TELEGRAPHY.

The discoveries and inventions of Nikola Tesla have excited much interest in the scientific world, and, notwithstanding the fact that he has been very reticent regarding his achievements and prospective improvements, hints of his purposes have been dropped occasionally; so that so much of the public as is interested in him or his discoveries has been able to form a fair idea of the nature of his work. His inventions in the line of alternating current generators and motors are now well known, but his experiments in currents of high frequency and high potential are not so familiar.

Very recently Mr. Tesla has announced that he has completed his wireless telegraph to such an extent as to permit of telegraphy through the earth for a distance of 20 miles or more, and his experiments satisfy him of the feasibility of wireless telegraphy on a much more extended scale. In fact, he aims at nothing less than the establishment of a system of telegraphy that shall include the whole earth, and by which items of news may be distributed from one political or commercial center to every other such center throughout the world. This, Mr. Tesla claims, is possible without the interference of one set of signals with another.

He has constructed and tested both transmitting and receiving apparatus, and has found that a surprisingly small expenditure of energy is required. It is impossible at this writing to secure details of the apparatus, but it is known that he utilizes the static equilibrium of the earth. This he disturbs at one point, making signals which can be distinguished at one or more distant points.

In his earlier experiments in high frequency currents Mr. Tesla attained a frequency of 10,000 per second; now 2,000,000 oscillations per second is not deemed extraordinary. It is said that the success of the system is assured, but he will not come before the public until every detail is completed. It is understood that the transmission of power from place to place by means of a similar system is contemplated.

While Mr. Tesla has been wrestling with this great problem in this country, Mr. Marconi, a young Anglo-Italian, has been working on the same line in England under the direction of Mr. Preece. It is reported that Mr. Preece has succeeded in telegraphing with certainty and sufficient rapidity from Penarth to Weston-super-Mare, a distance across the water of seven or eight miles, without wires, and it is believed that this distance can be greatly extended.

It is said by The Engineer that the apparatus devised by Marconi is extremely ingenious, and has for its object the getting out of the Hertzian vibrations sufficient work for telegraphic purposes. The apparatus comprises a transmitter and receiver. The former consists mainly of a small Ruhmkorff induction coil excited by a couple of battery cells. The secondary or high tension wires terminate each in a metallic ball. Between the two balls is placed a cubical box containing oil. In the opposite sides of the box are fixed two brass balls, oiltight, so that one-half of each ball is in the oil in the box and the other half outside of the box. The balls do not touch. The whole arrangement has been designed by an Italian professor, Righi. On sending a current through the induction coil, Hertzian vibrations are set up in the balls and communicated to the ether. The oil has a peculiar effect, acting as a species of brake, the rapidity of the wave vibrations being only about one-half of that stated by Dr. Lodge. These vibrations are then given off into space all around in every direction. So far as known, nothing save metals appears to be opaque to them, and here, therefore, we have an analogy with the Roentgen ray.

Marconi's receiver consists of a tube about ¼ of an inch in diameter and 3 inches long, in which are two silver plugs terminating in wires, the ends of which are soldered to the silver plugs. The wires are fused into the glass. The tube is exhausted to a near approach to absolute vacuum. The faces of the two silver plugs are very close to each other, and the space between is filled up with an impalpable metallic dust. On the nature of this dust much depends. It must suffice to say that there are in it three constituents, one of which is nickel. Under ordinary conditions this powder will not conduct electricity, save feebly. Its resistance is very high. If a Hertzian ray falls on the little tube, the dust is polarized like the filings in a Hughes test tube, and the powder becomes a conductor. It will be seen at once that we have here a make and break which can be acted on from a distance, and an ordinary Morse sounder does the rest. But matters, after all, are not quite so simple. It is easy to dispatch into space Hertzian waves at intervals corresponding to dots and dashes, but the powder in the receiver, once polarized, remains polarized. To get over this obstacle, a tiny hammer is so arranged that, the moment a current passes through the tube, the hammer taps the side of the tube and depolarizes the powder ready for the next signal.

There is nothing in common between ethereal or wireless telegraphy and telegraphy by induction; the phenomena are wholly distinct. The Hertzian radiance is akin to light, and the polarization of the powder in the receiver finds its analogue in the molecular change which is wrought by light in a sensitized plate.

HERTZ WAVE TELEGRAPHY BY THE MARCONI SYSTEM.

(From our London Correspondent.)

AT last the truth about the "Marconi mysteries" has been revealed. In a lecture at the Royal Institution on June 4, Mr. W. H. Preece told us what the Marconi invention really is—and a great many other things as well which we knew before. The sensational articles in the lay magazines and in the daily papers ascribed to Marconi the discovery (or invention, as it was perhaps more appropriately termed) of a new kind of electrical radiations which had quite different properties to Hertz rays, which would penetrate anything from a brick wall or a few hundred yards of solid hill to iron plates a foot or so in thickness and blow up the powder magazine of an enemy's ironclad, and do several other truly remarkable and characteristic feats. Marconi has actually devised a very sensitive and seemingly reliable form of coherer, which can detect Hertz waves generated by a Righi radiator several miles distant.

Marconi no doubt deserves great commendation for having worked out an ingenious and efficient apparatus, and having brought us a step nearer to the practical utilization of Hertz waves; but the fact of his abstaining from stating in the interviews and articles that have been published that his work has been nothing more than modifications in the details of apparatus devised by his more illustrious predecessors, has entirely prevented him from receiving that genuine tribute of praise, which almost amounts to veneration, usually accorded so freely to successful workers in the realms of science.

The Marconi coherer consists of a small glass tube four centimetres long, into which two silver pole-pieces are inserted, separated from each other by about half a millimetre. This thin space is filled with a mixture of nickel and silver filings—96 per cent. of nickel, 4 per cent. of silver and a trace of mercury. The tube is exhausted to a vacuum of 4 mm. and sealed. It forms part of a circuit containing a battery cell and a sensitive telegraph relay. Normally the resistance across the powder gap of the receiver is several thousands of ohms, but when the Hertz wave falls on it, it is reduced to about 5 ohms.

Mr. Preece did not say whether the increased sensitiveness of the relay was chiefly due to the composition or the finely divided state of the metal filings, or to the use of a vacuum. In other respects the coherer does not differ very much from that devised by Lodge some four years ago; the principle was first shown by M. E. Branly in 1890. The main defect in the Lodge coherer was that after receiving a wave it did not "decohere" without being shaken or tapped. Marconi gets over this difficulty by putting in the "local" circuit of the relay a small electrically worked hammer, so that on the reception of each signal the glass tube is lightly tapped. The sound made by this little hammer upon the glass is sufficient to read Morse signals from, but, of course, a Morse ink writer or any other instrument can be put in the local circuit.

The transmitter is, as already stated, Prof. Righi's form of Hertz radiator. Two spheres of solid brass, 4 inches in diameter, are fixed in an oil-tight case of insulating material, filled with vaseline oil, so that a hemisphere of each is exposed, and the other hemisphere is immersed in the oil bath. The oil seems to maintain the surfaces of the spheres clean, thus obviating the frequent polishing required in the original apparatus of Hertz. Mr. Preece also stated that it impresses on the waves excited by the sparks between the spheres a uniform and constant form. Two smaller spheres are fixed close to the opposite sides of the two larger spheres, and these smaller ones are connected to the secondary of the induction coil. Morse signals are made by a key in the primary circuit of the coil. The waves produced by this apparatus are very short, generally about 120 cm. long. With a 6-inch spark coil, signals were transmitted to a distance of four miles; for greater distances sparks up to 20 inches were used. Mr. Preece has succeeded in transmitting signals over a distance of eight miles across the Bristol Channel with the Marconi apparatus.

For shorter distances the poles of the coherer are connected to two "wings" of copper, each in series with a small retardation coil. When signalling over longer distances the wings are removed, one pole of the coherer is connected to earth, and the other extended to the top of a mast or by a kite connected with aluminum wire to the coherer. It seems that during the experiments signals were actually received through hills. Mr. Preece explained this by a diagram in which the electric ray was depicted curving round the top of the hill in a very accommodating way. It would seem more probable, however, that, as the beam is naturally somewhat diffused, some rays may be reflected round the sides of the hill by other conducting obstacles, or perhaps the hill was actually not a good enough conductor to absorb the rays, and was to a certain extent transparent to them. Another "apparent anomaly" was that Marconi's relay acts even when enclosed in a metal box. During the lecture Mr. Preece put the instrument in a galvanized iron dust bin, and yet it received the signals transmitted from another room. He also assured his audience that he had performed the same experiment in a hermetically sealed box. This would only prove, however, that the coherer is extremely sensitive and that the intensity of the waves transmitted is so great, that they are not entirely absorbed by the fraction of an inch of metal.

Besides intending to employ this system of telegraphy to signal to lightships and lighthouses from the shore, Mr. Preece intends to use it for a regular public telegraph service to the island of Sark, in the English Channel, as this island is at present not connected to any submarine cable.

When Marconi's patents have been published an interesting question will be whether they have any commercial value. We believe that the use of a vacuum in a coherer has been proposed and even used before. The combination of a coherer with a relay is no new idea, and Lodge proposed in 1894 the employment of an electric vibrator to act as what Mr. Preece calls a decoherer. Moreover, without wishing to lessen the credit due to Marconi, we cannot but think that had the British Telegraph Administration given one of the great English physicists like experimental facilities, the same, or even better, results would have been obtained.

TESLA'S TELEGRAPH TO MARS.

Discussing methods of telegraphing to Mars, Mr. Nikola Tesla says: "The inhabitants of the planets, Mars, for example, must have intelligence. Their life must be made up of events. They must have a conception of time. And therefore they must have means of measuring time, of recording events. Without that they could have no history.

"Thus upon a mathematical basis I believe a system could be founded which in the course of time could be developed into an intelligible code, capable even of conveying the most intricate communications. There is no limit to the possibilities of its development.

"It is upon the result of that calculation that I base the declaration of my belief that a serious attempt at transfer of intelligence to Mars will be made within a short time. Of course, I mean 'short' in the scientific sense. But I would not undertake to say how short or how long that time will probably be."

Tesla's Transmission without Wires.—Mr. Tesla announces in an American journal that by his well known system of transmitting intelligence by means of electrical "resonance" between points widely apart, without any connecting wires, he has lately been able to signal 20 miles. Mr. Tesla confesses, says the N.Y. *Electrical Engineer*, that the system is still liable to break down in bad weather, but such results will doubtless encourage him to persevere until the distance is many times greater, and the method is quite independent of disturbing atmospheric or terrestrial effects.

A DREAM TO BANISH NIGHT.

Nicola Tesla has had a dream. He has thought to banish night by pouring out the sunlight upon the earth even after the orb of day has passed below the horizon. Patiently for years he has experimented in his laboratory, and now he dares to proclaim a dimly glowing reality to his dream.

The wand of his magic is the vacuum tube. It realizes the desideratum of light without heat eagerly sought by Edison, Moore and other magicians of the dawning century. Brought near a current of electricity, but with no direct connection, the tube brightens into a soft, clear white light. The intensity of the light varies with the pressure of the current and the quantity of air left in the tube.

The wizard has done more than this. By passing a current through a broken circuit he has produced luminous clouds without a vacuum. This triumph opens the way for the fulfilment of his dream.

He would use the rarefied air of the earth itself as a medium. Erecting one lofty pole at New York and another a hundred miles away at Philadelphia, he would send a powerful current from one to the other through the upper regions of the rarefied air. Under the pressure of a few thousand horse-power he believes that the sky along its pathway would give forth a light bright as that of the clear full moon. Increase the current to higher potency, and even the light of day might descend upon the earth.

A height of ten miles above the earth would be necessary to reach in order to obtain air of a rarety best adapted to the path of the light. Yet with a more powerful current at the lower altitude, light might be produced which would serve every practical purpose.

Could standards be raised ten miles into the air? Let Tesla demonstrate that light cheap and powerful can be so produced, and more than one bold engineer will be ready to attempt the feat.

WESTINGHOUSE COMPANY'S ANNUAL REPORT.

FULL TEXT OF PRESIDENT WESTINGHOUSE'S REPORT TO THE STOCKHOLDERS—ANNOUNCEMENT OF A LARGE CONTRACT—A DIVIDEND DECLARED — BOARD OF DIRECTORS RE-ELECTED.

Your board of directors present herewith the balance sheet showing the financial condition of your company as of March 31, 1897.

Owing to the removal operations from the old into the new shops, your board of directors was unable to present a balance sheet for March 31, 1896, based upon actual values of inventories.

The class of electrical business conducted by your company has been in a depressed condition during the past two years, owing to the almost complete interruption in the building of new railways and new power stations. Notwithstanding these unfavorable conditions and the heavy charges to current expense account, due to the removal to the new works and the making of new tools, patterns, etc., the company's earnings have exceeded the amount required for the dividends on the preferred stock, which have been promptly paid.

By comparing the present balance sheet with that for March 31, 1895, it will be seen that there has been made a reduction in the surplus account of $1,577,735.93, due to amounts written off in connection with the disbandment of the old factories, the sale of obsolete tools, machinery and stock, depreciation of inventory, bad debts, the adjustment and settlement of old accounts, and the book loss from the sale of stocks and bonds owned by the company, and also the book loss resulting from the sale, at the price mentioned below, of $3,000,000, par value, of "assenting stock."

On June 4, 1896, your company authorized the increase of its capital stock from $10,000,000 to $15,000,000, and your board of directors effected a sale of $3,000,000, par value, of the new assenting stock thus authorized to the Security Investment Company, of Pittsburgh, which realized to the company $2,489,000, of which amount $1,260,000 was received in cash, $329,000 was represented by patents and property, and the remaining $900,000 in interest-bearing notes secured by collateral; $300,000 of such notes were payable July 5, 1897, and have been paid; $300,000 are payable July 5, 1898, and the remaining $300,000, July 5, 1899.

Pursuant to the terms of the contract with the General Electric Company, for the exchange of licenses under the patents of the two companies, of which you were notified by a circular letter dated April 2, 1896, your company has purchased outright for $216,600 the Tesla patents for multiphase-current motor, in order that both companies might manufacture apparatus covered by those patents without the payment of royalties, other than those provided for in the agreement between the two companies. For like reasons your company purchased, for $72,231.17, the entire capital stock of the R. D. Nuttal company, which has a complete workshop for its purposes, and manufactures trolleys for the General Electric Company and your company, and gears and other railway supplies for the general market. The stock purchased is considered fully worth its par value of $118,000. Your company also purchased for $58,500 and the transfer of certain patents acquired through its agreement with the Security Investment Company, 12,433 shares of the Electro-Magnetic Traction Company, out of a total issue of 20,000 shares.

The agreement between the General Electric company and your company has been in force a little over a year, and the wisdom and value of the union of patents has been fully established. The patents of the two companies, thus brought together, have a commercial value which can not be adequately appreciated by those not familiar with the electrical business. These patents are numbered by the thousand, and, within the field covered by the company's business, relate to every conceivable electric system and kind of apparatus to the minutest detail. Their present book value is less than the sum expended in acquiring and developing them. The terms of the contract between the General Electric Company and your company fix the respective values of the patents at 62½ per cent for the General Electric Company and 37½ per cent for your company. The patents owned by your company are carried at $4,689,080.89, or less than 37½ per cent of the aggregate book value of the patents of both companies. Many of these patents have already been sustained by the courts, while in numerous instances infringers, after being made acquainted with the situation, have agreed to cease infringing.

During the past year many valuable patents have been acquired in the interest of the two companies at moderate cost, while the expense of carrying on suits has been greatly less than the sum formerly expended by the two companies.

A liberal course is being pursued in the enforcement of these valuable rights, and there is reason to expect that the time is near at hand when the patent property now being managed as a common interest will be generally recognized as exceeding in value and importance that of any other manufacturing interest.

These items appear on the books at cost. It was the expectation of your board of directors that a large part of the bonds and stocks of lighting companies on hand could be disposed of from time to time, but there has been no market for the sale of such securities during the past two years. These stocks and bonds have, as a rule, increased in intrinsic value, and it is proposed to pursue the policy of selling them whenever advantageous terms can be secured.

It has not yet been possible to dispose of the old factories of your company and of the United States and Consolidated companies. It is expected that with the improvement of business a market will be found for these properties.

It is the hope of your board of directors that the proceeds of the sale of stocks and bonds and old factories will, in the near future, be sufficient to care for the indebtedness of the company, leaving the quick assets for the regular current business.

The utilization of water power, and its transmission by electricity, have given great prominence to the Tesla patents, which, together with numerous other patents controlled by your company and the General Electric Company, should insure to the two companies the sale of all the power-transmission apparatus used in this country.

About two years ago your company installed at Niagara Falls, for the Cataract Construction Company, three 5,000-horse-power generators, and in January of this year were awarded by that company the contract for five additional generators of the same capacity, which are now under construction.

Your company has also just been awarded a contract for 15 5,000-horse-power generators by the St. Lawrence Power Company, which is the largest single order yet given for power-transmission apparatus.

Your company should derive great benefit from the execution of this contract, since no other company has yet attempted work of this size and importance. The securing of these contracts was, without doubt, due to the success of your apparatus at Niagara Falls, and to the most complete facilities which your company now has at its new works, at East Pittsburgh, for the manufacture of large electrical units.

Your company has made marked progress in the development of apparatus for the operation of suburban and interurban trains on main railways, and it has installed at East Pittsburgh, on the tracks of the Pennsylvania Railroad, experimental apparatus, where important experiments are constantly being carried on. We believe your company is now more fully equipped and has better facilities for work of this kind than any other concern.

Your workshops at East Pittsburgh are in complete order, and have the advantages for manufacturing which it was contemplated they should possess. Its facilities, arrangements, machinery and tools enable it to undertake work of the largest character which may be proposed. All that has been said heretofore with reference to the property of your company at this place, and the opportunity it affords for economical operations, has been more than borne out by the facts. These works stand on your books at $2,769,886.26, of which $1,290,732.85 is for real estate and buildings, and $1,479,153.41 for machinery and tools, making an exceptionally low cost for works of such great capacity.

The engineers of your company have acquired a world-wide reputation in mechanical and electrical engineering, a fact well illustrated by the close copying by other manufacturers of plans, systems and designs which had their origin in your offices or works. The character of the apparatus turned out at your new works has given your company substantial trade advantages.

By order of the board,

GEORGE WESTINGHOUSE,
President.

Pittsburgh, Pa., June 23.

BALANCE SHEET, MARCH 31, 1897.

ASSETS:		
Cash in banks		$330,193 89
Bills receivable		43,207 09
Accounts receivable		1,604,547 19
Material in stock and in course of manufacture (at cost of labor and material)		1,636,612 33
Amounts advanced leased companies		569,766 56
Bonds (par value, $1,395,094.79)		1,352,655 31
Stocks (par value, $10,470,611.02)		4,612,223 87
Real estate and buildings, Pittsburgh.		455,115 71
New factory—land and buildings.	$1,290,732 85	
Less—First Mtg. on land and bldgs. (final payment due April 1, 1900) $325,000 00		
First Mtg. second purchase of land (due July 1, 1899) 59,300 00	384,300 00	
Total		906,432 85
Machinery and tools		1,479,153 41
Miscellaneous		286,306 40
Charters, franchises and patents		4,689,080 89
		$17,965,295 05
LIABILITIES:		
Accounts payable		$484,534 21
Bills payable, issued for merchandise.		207,151 12
Discount with collateral		1,399,506 89
Contract and contingent liabilities:		
Script dividend		194,560 00
Collateral trust bonds		590,000 00
U. S. E. L. Co.'s six per cent 15-year bonds. $50,000, payable annually.. (Bills receivable under discount, $907,155 33.)		350,000 00
Capital Stock:		
Preferred, 79,921.06 shrs.	$3,996,053 00	
Assenting, 163,902.52 "	8,195,126 00	
Common, 2,934 "	146,700 00	
	12,337,879 00	
(In treasury, 56,097.48 shares Assenting, and 78.94 shares preferred.)		
Surplus		2,401,664 28
		$17,965,295 50

The old board of directors was re-elected as follows: Charles Francis Adams, Lemuel Bannister, August Belmont, N. W. Bumstead, A. M. Byers, Marcellus Hartley, George W. Hebard, Henry B. Hyde, Brayton Ives and George Westinghouse.

On June 22 Treasurer Kobbé sent out this announcement:

At a meeting of the board of directors of the Westinghouse Electric and Manufacturing Company held this day, a regular quarterly dividend of one and three quarters per cent (1¾%) upon the preferred stock of the company was declared, payable July 1, 1897, to stockholders of record, the transfer books to close on June 25, 1897, at 3 P. M., and to open on July 3, 1897, at 10 A. M.

NIKOLA TESLA, THE ELECTRICIAN.

BY CHARLES BARNARD.

THE republic has the property of a magnet; it attracts iron characters. New York is the intellectual and commercial center of the country and the magnetic "field of force" is most intense in our greatest city. It has been said by many that, while the city attracts strong characters, it is not the best place for the higher intellectual life. The student and thinker should seek the calm of sleepy, academic towns "far from the madding crowd." These forget that modern life makes it possible to have the deepest seclusion and space for high thinking in the very focus of the city. Eternal calm is not the only desirable thing. Friction, attrition, even heavy grinding are as essential to the intellectual life as to cut glass.

It is, therefore, not surprising to find to-day one of the few great students of our times, a man of remarkable intellectual gifts, drawn from the far East of Europe to our chief city. In the turmoil of the dry-goods district he has set up his workshop, and by his presence added new fame to Broadway. Just as Ericsson lived and worked in New York, far from his native fiords, so to-day Nikola Tesla works in his Houston Street laboratory, far from the mountain home of his ancient Serbian race.

In Smiljan Lika, Austria-Hungary, there has long lived an old and respected family. One branch of this family had born to them in 1857 a son. The father was a clergyman in the Greek Church, the mother apparently a Connecticut Yankee astray in another race. She was not only a good housemother, but she had the precious gift of handiness, and was a designer and maker of those ancient tools the loom and churn. It is small wonder that the son of such parents should have at once the mechanic and the prophetic mind.



NIKOLA TESLA.

The boy Nikola attended the public school at Gospich. At the end of three years he graduated to the *Real Schule.* At the end of three more years he advanced to the higher *Real Schule* at Carstatt, Croatia, graduating in 1873. It is curious to note that it was here the youthful Nikola first saw a locomotive. Naturally the father hoped the son's education would lead him to the church, but the boy's bent of mind was too pronounced to long admit of such expectations. He seemed plainly destined for a professor of physics, and joined the Polytechnic School at Gratz. This too proved a blind guess at the young man's future. In the lecture-room there was soon mental rebellion. In vain the professor demonstrated the impossible. The student denied the impossible. Curiously, the subject under discussion was a Gramme dynamo, requiring, as was clearly demonstrated, commutators or brushes. The student imagined a dynamo without brushes. Imagination is the mother of invention. The youth clearly had an inventive mind. He could see the impossibilities of other minds quite possible in his own. Teaching was not for such a student. After one year at the Polytechnic he began the study of engineering. On graduation he, with a broad grasp of the great world-sciences, saw that he must be a linguist, and mastered several languages that he might be unhampered by locality. His feet turned westward. Prague and Budapest were but way-stations in his progress. He served as assistant engineer in the government telegraph engineering department and began at once to suggest improvements on the practical side of the science. The field was too small. He must go farther, was soon in Paris, where he secured employment in an electric light company.

Here he seemed to catch the wider air of another land. He met Americans who

told him of the greater chances of a newer civilization. He was already a dreamer of dreams scientific. Where could dreams be so quickly realized as in America? Without hesitation he sailed at once for New York and went on the day he landed to the laboratory of Edison. Mind sought mind. Smiljan, Prague, Paris, Orange, New Jersey, marked the progress to the West. Here was room and space enough to work—to realize dreams, to prove the impossible to be real and practical. Naturally, with an original mind there must be special methods, peculiar environment, and in time the young Tesla sought, in the heart of roaring Broadway, the seclusion and calm of his own laboratory, where he might work out in his own way his own ideas. The experience in the Edison laboratory was invaluable, but it was an experience and not an end.

Almost immediately in his new workshop Tesla brought with infinite diligence some of his ideas to practical commercial results. He had come to the right place. Business and capital are the handmaids of invention. It is wise to dream in their neighborhood. Now began the real life of an original mind exploring the higher ranges of the most difficult and least known science in the world. Under his eye the dim horizon of the unknowable began to retreat, in his workshop a light that was never seen on sea or land flared up in purple fires—the flames of the cosmos, the very pulse-beats of the planet made visible in almost unearthly fire.

It is one of the perplexities of science that the schoolmasters have fenced the field into town lots of knowledge, while there is clearly to-day one great science of the universe. For the common mind it is enough to master a corner lot of knowledge. For greater minds mathematics, chemistry, mechanics, physics are only branches of knowledge, and the student must possess all. To be a great electrician you must be mechanic, engineer, chemist, steamfitter, gas-man, lineman—everything, and be good in every trade. To be an inventor and discoverer means to add to all knowledge patience, diligence, and imagination—and the greatest of these is imagination. This universal knowledge, this imagination, appear to be the chief characteristics of the student workman Nikola Tesla. It is their rare combination and the remarkable results that have come from his labors that have attracted the attention of the scientific world and made the Houston Street workshop famous.

There was printed three years ago a book* of five hundred pages cataloguing Mr. Tesla's inventions and discoveries up to 1874. A single invention would have been regarded as sufficient for the fame of a lifetime, and yet since the publication of that immense list of work accomplished Mr. Tesla has gone on perfecting and completing work already done and invading new fields of science. To the average reader this catalogue of Mr. Tesla's work is simply unintelligible, because the science of electricity has been compelled to coin new terms to express new knowledge. "Polyphase currents," "rotating magnetic fields," "currents of high frequency and high potential" are terms employed to express in part some of Mr. Tesla's work, and yet it is almost impossible to make them clear without a new language.

Broadly stated, Mr. Tesla's inventions are improvements in the making of dynamos, the reduction of the cost of producing and conveying electricity. His most remarkable researches have been in that new field of electrical study made possible by his own inventions. He creates electrical conditions unknown before, and under these new conditions exhibits nature in wholly new and unexpected aspects. Producing by new appliances new forms of electrical manifestations, he proves that under new conditions new phenomena appear. Some of these phenomena are so strange that they appear unreal, unearthly. Light that is cold, white, harmless, flames that do not burn, innocent lightnings suggest the magical art, yet they are simply workshop experiments that may some day be household conveniences.

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* Inventions, Researches and Writings of Nikola Tesla. Martin. New York: The Electrical Engineer.

The most striking application of his ideas to practical work upon a large scale is shown at Niagara. Here was designed to be the greatest utilization of natural power ever attempted. It was proposed to harness the power of the falls and to convey the power to a distance by means of electricity. Familiar plans and appliances were suggested. Mr. Tesla proposed new plans, new methods, and declared that new results could be obtained. His advice was taken and the actual utilization of the power of Niagara in the streets of Buffalo is to-day a monument to his prophetic insight. The most interesting single invention brought out by Mr. Tesla is, perhaps, his mechanical and electrical oscillator. This prime mover or motor is in line with modern science, because it seeks to reduce the steam-engine to the last simplicity, to reduce the number of its parts, to reduce its cost of construction and maintenance, and to increase its value as a prime mover used to produce electricity. It is a steam-engine joined to a dynamo, but free from all belts, gearing, or other mechanical transformer of power. It is direct acting, its own piston-rod bearing the armature of the dynamo. Its invention and application show its inventor to have combined the mind of a Watt and a Franklin with the highest skill of the steam-engine builder.

This most important invention is still the subject of study. Its perfected form may or may not be reached. It is potential of great things, because it has already opened a new field in electrical research, already suggested whole districts of work and study in which other able men are already busy.

Civilization is to-day based on power. The continued progress of the race demands cheap and abundant power. The very front and aspect of all our cities are being changed because cheap power has come into our streets. If people can be conveyed quickly and cheaply their houses will be farther apart, gardens and parks will grow, tenements will be deserted for cottages, flats for homes. Manufactures, commerce, governments, armies, and navies are everywhere seeking power. Human strength and labor and the labor of animals are daily freed from heavy toil because power can be conveyed by a wire. Power cheapens living and makes life easier. It is better than charity because it reduces the struggle for existence. The true helper of the race is the man of science who shows us how to produce and convey power cheaply. True science seeks to utilize power as found in nature for the benefit of humanity. All science is for the uplifting of men and women.

These simple statements are doubly interesting because they express Nikola Tesla's own thoughts upon science. He said much of this in other words in a notable speech at a banquet in Buffalo given to celebrate the conveyance of power from Niagara to Buffalo. Tesla is not alone a plodding workman. He is a dreamer of wise dreams, a poet, and a humanitarian, working with new tools for the benefit of all. He is a man who wonders at the folly of men who invent guns when they might invent tools. His spirit is naturally hopeful. He looks forward to new things, to improved science that shall work to uplift the common lot of man. He looks not so much at the world as at the universe. He finds power in the waterfall, and at the same time looks forward to a time when we may, perhaps, tap the unseen forces of the planets and use the cosmic energy that swings the stars in their courses. He looks to a time when power shall be so cheap, so universal, that all labor shall be done by tireless machines and every man's life be thus so much more worth living.

Born in Eastern Europe, it is interesting to observe that Tesla's speeches and writings are examples of clear and vigorous English. He can explain in the purest technical language his inventions to the understanding of men of science, and yet speak to plain folks in English that is simple, direct, and touched with a Shakespearian flavor, as if he had gone to the right source for his models. His first important paper was read before the American Institute of Electrical Engineers in New York in May, 1888. Since then he has spoken before learned bodies in England and in France

and several times in this country. Everywhere he has been received with the highest honors, everywhere listened to with profound attention. To show the spirit of the man we may quote two paragraphs from a lecture delivered before the Institution of Electrical Engineers, London, England, in February, 1892. They also happily illustrate the man's use of a language not his mother tongue. Speaking of Crookes and his experiments and writings, he says:

> When I was at college, a good while ago, I read in a translation (for then I was not familiar with your magnificent language), the description of his experiments on radiant matter. I read it only once in my life—that time—yet every detail about that charming work I can remember to this day. Few are the books, let me say, which can make such an impression upon the mind of a student.

In the same lecture he says:

> We observe how the energy of an alternating current traversing the wire manifests itself—not so much on the wire as in the surrounding space—in the most surprising manner, taking the forms of heat, light, mechanical energy, and, most surprising of all, even chemical affinity. All these observations fascinate us, and fill us with an intense desire to know more of these phenomena. Each day we go to our work in the hope of discovering—in the hope that some one, no matter who, may find a solution of one of the great pending problems; and each succeeding day we return to our task with renewed ardor. And even if we are unsuccessful our work has not been in vain: in these efforts we have found hours of untold pleasure, and we have directed our energies to the benefit of mankind.

It is one of the essentials of modern scientific research and invention that there be uninterrupted seclusion. Mr. Tesla is at work. His workshop is therefore sacred to work, and few people have visited or can visit it. He is at work. It is enough for us to wait until the master workman comes forth in his own time and in his own way tells us what he is doing. It is enough that he is at work not alone for himself and for those who may buy and sell his inventions, but for "the benefit of mankind." He has been thought to be a dreamer, because no stream of practical, every-day, selling "notions" flows from his shop. Yet what he has done has modified much that is done in this special field of work. His position is that of a leader, an inspirer, the guide blazing a new path through the forest, leading toward undiscovered countries of knowledge. It is fortunate for us he is here in our own time and country, if for nothing more than the inspiration of his presence, the example for all our young people. He is at home now. He is an American in the best sense, working here because this is the grandest place in the world to do grand work. The roar of Broadway that jars the windows of his shop cannot disturb its calm, and yet this very nearness to the active life of a great city is of itself a help and inspiration to work. He is still a young man, of tireless energy and exhaustless patience. Wonders have already come from his hand and mind, greater things may yet be near. At present we can simply wait, knowing that such minds never labor long in vain.

Electrical Progress.

Tesla's Wireless Telegrams.

Experiments have been made attempting to prove the possibilities, but it has remained for Nikola Tesla to advance a theory, and experimentally prove it, that wireless communication is a possibility, and a by no means distant possibility. Indeed, after six years of careful and conscientious work, Mr. Tesla has arrived at a stage where some insight into the future is possible. He is averse to explaining all details of his invention, but allows it to be understood that he avails himself of what, for the present, may be termed the electrostatic equilibrium; that if this be disturbed at any point on the earth, the disturbance can with proper apparatus be distinguished at a distant point, and thus the means of signaling and reading signals becomes practicable once the required concrete instruments are available. Some years ago Mr. Tesla announced his belief in the possibilities, but he did so only after having satisfied himself by actual tests of apparatus designed by him. Much work had yet to be done, and he has since then given close attention and study to the problem.

Details are not yet available, and we now can merely chronicle Mr. Tesla's statement that he has really accomplished wireless communication over reasonably long distances with small expenditure of energy, and has only to perfect apparatus to go to any extent. Morse's forty-mile experiment in the old days was on a far less certain basis than the wireless possibilities of today.

Tesla's work with high frequency and high-potential currents has been notable. As long ago as 1891 he foretold the present results, both as to vacuum tube lighting and intercommunication without wires. The former had in his hands assumed a condition capable of a public demonstration of the phenomena of the electrostatic molecular forces. Numberless experiments were carried out, and from what then was a startling frequency of 10,000 per second, Mr. Tesla has advanced to what now is moderate work at 2,000,000 *oscillations per second.* Such almost inconceivable results are plainly out of all possible reach by any mechanical rotation of a commutator. And so long as efficiency of lighting is, as Mr. Tesla observes, dependent upon extremely high frequency, it would seem his efforts are in the one and only direction likely, in vacuum tube lighting, to lead to success. Success, according to Mr. Tesla, is already assured, but he will not come before the public until every detail of a practicable and commercial system is complete, and the day for such a consummation, he now states, is near at hand.—Electrical Review.

)RK JOURNAL
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DNESDAY, AUGUST 4, 1897.—11 PAGES. PRICE ONE CENT

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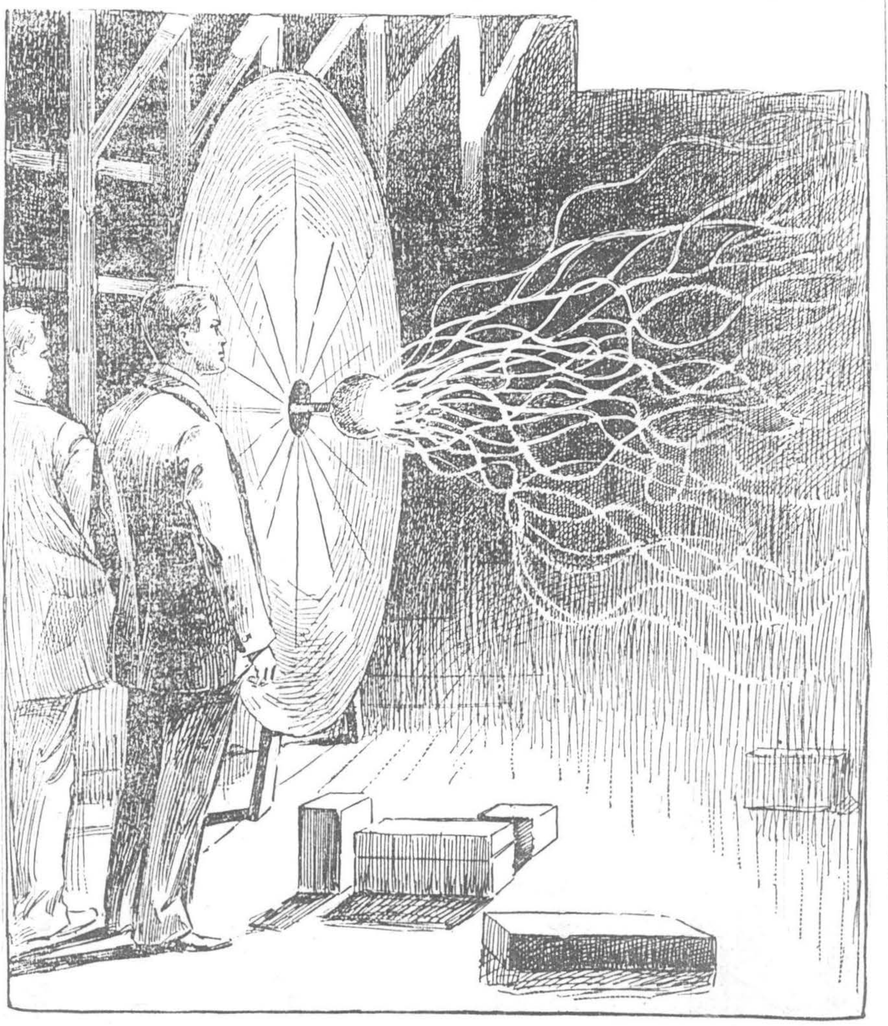


A Demonstration Made at Tesla's Laboratory Yesterday.

In his laboratory, in Houston street, Nicola Tesla gave a demonstration yesterday of his great discovery. A huge disc was hung on a frame. From the centre of the disc an electrode protruded. The demonstration was certainly weird. A crackling sound filled the room. Serpent-like flames shot from the electrode—not from pole to pole, but darting out until they vanished. Tesla said the electrical disturbance created was felt throughout the globe.

TESLA ELECTRIFIES THE WHOLE EARTH.

The Inventor Announces the Success of His Life-Long Dream.

MADE A DEMONSTRATION

Produces an Electrical Disturbance Which, He Says, Is Felt Everywhere.

A TREMENDOUS VOLTAGE.

Fiery Flames, Like Serpents, with Power to Kill, Spring from an Electrode.

WILL PUBLISH THE DISCOVERY.

Says His Facts Will Be Given to Science as Soon as His Data, Now Being Arranged, Is Completed.

Nicola Tesla announced yesterday the completion of his latest discovery—the simultaneous transmission of messages by means of the earth's electrical currents to as many scattered points on the surface of the globe as may be desired. This he regards as by far his greatest achievement. He will follow his usual custom and lay his information before the world of science in his own words and accompanied by his own computations and conclusions. To a few intimates he gave a thrilling demonstration of the operation of his device for arresting and subjecting to control under natural laws the electrical substances in and about the earth. His latest invention, device or discovery is to produce such a disturbance of the electricity of the earth which can be felt and noted simultaneously at all parts of the globe.

The Private Demonstration.

Tesla had his rooms in the laboratory on Houston street darkened. From a room adjoining the one in which he and his visitors stood a current was turned on invisibly. A huge black disk hung on a frame about eight feet in diameter, from the centre of which protruded a brass electrode seven inches in diameter. As the group gazed at this the apartment was filled with a crackling sound, which increased till it sounded like the rattle of musketry. Bright flames shot from the electrode, not from pole to pole, as in ordinary demonstrations. Like fiery serpents the wavy coils of flame darted in graceful lines around the disk. The longest sparks were fully eight feet from the point when they burst into dazzling brilliancy to the vanishing point. These electrical sparks were undoubtedly the longest flashes of light ever produced by similar means.

A Meteorological Display.

It seemed like a terrific lightning display, with the snapping, crackling sound, displacing the reverberation of heaven's artillery, and all remarked the weird and awing effect of the exhibition.

"What are you doing?" was asked Tesla.

"I am producing," said he, "an electrical disturbance of intense magnitude, which is continuing throughout the entire earth. In other words, I am producing a disturbance of the earth's charge of electricity which can be felt to the uttermost parts of the earth."

"And the result will be?"

"Ah," said Tesla, his face lighting up and his spare figure vibrant with pride and enthusiasm, "that is almost incomprehensible. This electrical disturbance by means of certain simple instruments can be felt and appreciated at any point of the globe. In this way messages can be sent the entire earth around and be taken up at any part of the earth without the aid or intervention of wires in any way at all."

Voltage Beyond Computation.

"What is the voltage?" Tesla was asked.

He motioned expressively with his long finger and said quickly, "As far as voltage is concerned, that is almost beyond computation. Yet, let me tell you, I stood in front of that flame and had that charge shot through me and experienced no unpleasant sensation. Dangerous? Yes, it is dangerous and I shall not repeat the experiment, for it exposes the blood to a terrific tension. If those tongues of living flame touched an artery and it burst, in an instant one would be bloodless and lifeless."

"Practically then if, say, Queen Victoria were to die, and these instruments for picking up and appreciating the vibrating ether were in place, a message could be sent simultaneously to every quarter of the British Empire, and all her subjects apprised of her demise?" inquired a spectator.

"Precisely. The shock transmitted from the sending point would be appreciable anywhere on earth. This is my greatest and latest discovery, which I intend to give to the scientific world as soon as my data, which is now virtually complete, is arranged."

The Brooklyn Eagle August 4, 1897

TESLA'S NEW DISCOVERY.

Claims to Be Able to Utilize Free Electrical Currents.

The New York Journal this morning prints the following:

Nicola Tesla announced yesterday the completion of his latest discovery—the simultaneous transmission of messages by means of the earth's electrical currents to as many scattered points on the surface of the globe as may be desired. This he regards as by far his greatest achievement. He will follow his usual custom and lay his information before the world of science in his own words and accompanied by his own computations and conclusions. To a few intimates he gave a thrilling demonstration of the operation of his device for arresting and subjecting to control under natural laws the electrical substances in and about the earth. His latest invention, device or discovery is to produce such a disturbance of the electricity of the earth which can be felt and noted simultaneously at all parts of the globe.

Tesla had his rooms in the laboratory on Houston street darkened. From a room adjoining the one in which he and his visitors stood a current was turned on invisibly. A huge black disk hung on a frame about eight feet in diameter, from the center of which protruded a brass electrode seven inches in diameter. As the group gazed at this the apartment was filled with a crackling sound, which increased till it sounded like the rattle of musketry. Bright flames shot from the electrode, not from pole to pole, as in ordinary demonstrations. Like fiery serpents the wavy coils of flame darted in graceful lines around the disk. The longest sparks were fully eight feet from the point when they burst into dazzling brilliancy to the vanishing point. These electrical sparks were undoubtedly the longest flashes of light ever produced by similar means.

It seemed like a terrific lightning display, with the snapping, crackling sound displacing the reverberation of heaven's artillery, and all remarked the weird and awing effect of the exhibition.

"What are you doing?" was asked Tesla.

"I am producing," said he, "an electrical disturbance of intense magnitude, which is continuing throughout the entire earth. In other words, I am producing a disturbance of the earth's charge of electricity which can be felt to the uttermost parts of the earth."

"And the result will be?"

"Ah," said Tesla, his face lighting up and his spare figure vibrant with pride and enthusiasm, "that is almost incomprehensible. This electrical disturbance by means of certain simple instruments can be felt and appreciated at any point of the globe. In this way messages can be sent the entire earth around and be taken up at any part of the earth without the aid or intervention of wires in any way at all."

"What is the voltage?" Tesla was asked.

He motioned expressively with his long finger and said quickly, "As far as voltage is concerned, that is almost beyond computation. Yet, let me tell you, I stood in front of that flame and had that charge shot through me and experienced no unpleasant sensation. Dangerous? Yes, it is dangerous and I shall not repeat the experiment, for it exposes the blood to a terrific tension. If those tongues of living flame touched an artery and it burst in an instant one would be bloodless and lifeless."

Practically, then, say, if Queen Victoria were to die, and these instruments for picking up and appreciating the vibration ether were in place, a message could be sent simultaneously to every quarter of the British Empire and all her subjects apprised of her demise?" inquired a spectator.

"Precisely. The shock transmitted from the sending point would be appreciable anywhere on earth. This is my greatest and latest discovery, which I intend to give to the scientific world as soon as possible."

TESLA DID NOT INDORSE IT.

Electrical Expert Says He Subscribed for No Stock in Mansione's Flying Machine.

Gaetano Mansione, "formerly of Naples, Italy," is calling the attention of his New York friends to "his recent invention of a flying machine, patent applied for." Mr. Mansione, it is announced, is ready to let a company put the new invention on the market, provided persons desiring to join the company will buy shares at $50 each, the par value of the shares being $500.

"Experts who have examined the plans," Mr. Mansione's circular explains, "pronounce the machine practicable and express their belief that Mr. Mansione has solved the problem of aerial navigation." To this bit of information is added the further statement that "the money subscribed for stock is to be used in building the machine for experimental purposes," and that "no payment is due until the corporation is effected."

It is set forth in the circular that Nicola Tesla, the electrical expert, "has subscribed for the first share of stock and indorses the machine." Mr. Tesla was much surprised when I showed him the circular containing this statement, and said:—

"Gaetano Mansione called on me some time ago and stated that he had invented a flying machine which, he thought, was to revolutionize everything before done in this direction. I believed him deserving enough to offer him small help, which he accepted, but I advised him to perfect his machine and to show it in working order to some people of means. That is all I know about it.

"If I ever would indorse any flying machine it would be one constructed by men like Langley or Maxim. It is unnecesary to say that most of the people who are working in this field have not the remotest idea of the difficulties to be overcome. I myself have spent many spare hours in the solution of the problem, and so far my chief result can be summed up in the statement that I have learned to appreciate the difficulties of it. I wish you would emphatically disconnect my name with any such scheme as the one you have just shown to me."

I was unable to find Mr. Mansione, to ask about the success of his efforts to form a flying machine company. His machine, I learned, consists of a balloon to keep the outfit above the earth and an apparatus to guide its flight through the air.

NIKOLA TESLA'S EXPERIMENTS.

Denies That He Announced Completion of His Wireless Telegraphy Tests.

Nikola Tesla this morning denied the report that he had announced the completion of his discovery of a method of telegraphy without wires. Occasional reports of the progress of the work had been published from time to time, he said. His experiments had been repeatedly shown in strict confidence to some of his personal friends, but the publication of them in any detail must have been a violation of confidence. As a matter of fact, no experiments were made at the laboratory yesterday. The inventor, however, was willing to give some account of his work up to the present time.

"In a lecture delivered about four years ago," he said, "before the National Electric Light Association in St. Louis—that was in March, 1893—I explained a certain scheme for producing electrical disturbances with the object of transmitting intelligible messages, and even power, from place to place without the use of any wires.

"The principle is this: An electrical oscillator is connected by one of its terminals to earth and another is led to an insulated object of considerable bulk. This object should preferably be at a great height where the air is less dense and transmits more easily the disturbance.

"Such an apparatus is then exactly what in mechanics would be a suction pump. Periodically it draws electricity out and forces it again into the earth, thereby altering rhythmically the electrostatic potential in the earth as well as in the air.

"This scheme I had, as a matter of fact, conceived many years before. But I had previously lacked the courage to present it to the scientific world. At the time of the St. Louis lecture I had already seen such results that I gathered courage enough to announce the project seriously.

"Shortly afterward, on my return to this city, I actually demonstrated by means of an improved apparatus that I was indeed able to create a disturbance in the manner described in the lecture.

"In my pleasure and excitement at this success I could not refrain from showing the first experiments to a few intimate friends. When later my laboratory burned down and the first instrument with which I had succeeded in my demonstration, and which I valued above any other, was destroyed, it was no small consolation to me that a few men whom I hold in high esteem had seen the first evidence of my success. They were my friends. Of course, all the experiments that I have made to this day have been shown only in confidence and with the express understanding that no popular publication should be made of them until I had acquainted the scientific world with my results.

"It appeared several years ago that the result I aimed at would be very difficult, if not impossible, to attain. The method, nevertheless, as I have outlined it, is simple, involving merely the use of a properly constructed oscillator connected with the ground and with an elevated object; also a sensitive and properly adjusted receiver at a distance, similarly connected with the ground and with an object at a considerable height. For the purposes of this receiver I consider a balloon most suitable.

"These disturbances with which I am experimenting are produced by methods and devices which I have been perfecting more recently, and from present results I do not consider it at all impracticable to obtain, if such were desired, electric sparks a mile in length. They could be readily secured by apparatus designed on these novel lines. I now obtain sparks as long as eight feet, and can produce local disturbances. What I affirm is that the disturbances in this city may be made perceptible in London or throughout the world.

"The voltage is very high, beyond computation. For a wild guess I should place the voltage at 50,000,000. I have stood in the course of the sparks, but I consider them dangerous.

"Scientific results are what I have been chiefly interested in. But there are many possibilities of turning the methods to practical use. For instance, if I wished to make a fortune I should have only to take out patents on methods for exploding torpedoes or powder magazines at a distance by means of electrical disturbances produced in this manner. But to dispel popular and erroneous opinions on this point it is appropriate to say that whereas it is perfectly possible to ignite an explosive by a suitably arranged apparatus at a distance, yet this fact will not revolutionize warfare. The enemy could avail himself of similar methods with like results."



TESLA ELECTRIFIES THE EARTH.

According to the New York "Journal," of August 4, Mr. Tesla announces the completion of his work for the transmission of messages from one point to another on the earth, without the aid of wires. To give an idea of the high potential currents used in this work, he showed a large disc, from the center of which protruded a spherical electrode shooting forth long streams of ethereal flame. Mr. Tesla stated that the electrical disturbance thus created was felt throughout the globe. The article is graphically illustrated with a large picture of the contrivance for emitting the discharge.

The New York Herald August 5, 1897

TESLA BUILDS A MARVEL OF FORCE

His Oscillator, He Declares, Will Transmit Without Wires Power Thousands of Miles.

MANY MILLIONS OF VOLTS.

He Says the Electrical Disturbance Caused by the Machine Will Be Felt All Over the Globe.

A ROARING, SILVER FLAME,

Nikola Tesla announced four years ago that he had discovered a plan for transmitting intelligible signals and power to great distances without wires, but his assertion was received with scepticism, notwithstanding he described the principles of his discovery in lectures before the Franklin Institute, in Philadelphia, and before the National Electric Light Association, in St. Louis.

Mr. Tesla, not discouraged, pursued his investigations, and now declares his discovery is capable of producing an electrical disturbance strong enough to be felt all over the earth. He says his discovery will not only make it possible to send messages, but also to transmit power without wires by means of an immense electrical tension, measuring many million volts.

GIVES FORTH A ROARING, WHITE FLAME.

Mr. Tesla recently has given several demonstrations of his discovery. I saw the apparatus in his laboratory yesterday. It resembles a spider web of wires fastened to a black disk ten feet in diameter. The wires coine together in the centre, where there is a brass ball six inches in diameter. The machine, which its inventor calls an oscillator, is fastened to a wooden screen. Mr. Tesla allowed me to see the oscillator from a distance, but refused to give any technical description of it.

The wires are all arranged with perfect exactness, not varying a hair's breadth from the right position. When the machine is in action a roaring flame, resembling a stream of molten silver, breaks from the brass ball and shoots into the air for eight or ten feet. The noise made by the crackling flame is deafening. Power to operate the apparatus is obtained from an ordinary electric current.

According to Mr. Tesla's theory, the earth and air being charged with electricity, his apparatus operates on the earth as would pumping air into a rubber bag. The disturbance from the machine is felt instantly all over the globe.

NO LIMIT TO ITS POWER.

This electrical disturbance travels on the alternating currents with which the earth and air are charged at the rate of several million miles a second. The inventor's idea is to take up the vibrations from his apparatus with a delicate instrument that makes them perceptible and intelligible in several ways.

Mr. Tesla told me that these vibrations could not be directed to any given place, but must radiate to every quarter of the globe. To send messages of a private nature, a code must be used. He said a machine built on a large scale would transmit great power through the upper strata of the air.

Mr. Tesla said this power could be transmitted, theoretically, to any distance. His invention, described in his own language, might be compared to a pump which forces electricity in and out of the earth, producing a violent disturbance.

TESLA HAS FIRED THE SPARK FLASHED ROUND THE WORLD

The Wizard of Science Says He Has Enslaved Earth's Mightiest Force for the Use of Man.

Most Marvellous Method of Transmitting Power Universally by Means of Electric Vibration.

By Julius Chambers.

THIS is the Electric age.

Nicola Tesla has completed the device or machine by which he expects to project electrical vibratory impulses to the most distant part of the world. He will do this by battery, and harnessing a force that no human ingenuity could create. He will cause the earth to vibrate in certain keys for definite utilities.

Tesla declares that he is misunderstood by those who think that he is seeking merely to transmit intelligence from one part of the globe to another without wires. Telegraphy is a small factor in his marvellous problem. He aims at the transmission of power—power that will produce mechanical effects, such as the propulsion of ships and the operating of mills. This is a utilitarian era, and nobody recognizes that fact more clearly than this remarkable young wizard of science.

"The Journal's description of my completed invention was quite accurate," said Mr. Tesla, as we stood together in his wondershop on Houston street. "I have gone far enough to assure myself and to convince others that my theory regarding the transmission of electric vibration, for whatever purpose it may be utilized, is practicable."

"How do you expect to recognize the vibrations at a point distant from the place of original projection?" I asked.

"That is a mere detail," exclaimed the inventor, his whole body vibrant with enthusiasm. "Instruments pitched in the proper key will promptly indicate the presence of the electric wave. Vibrationsof of different intensities will be taken up by these delicate appliances at different places. If the instruments at Paris, for example, are caused to operate, it will be because the vibratory current is pitched in the key to which they are set. If the wave passes over London and Paris and be recognized at Berlin or Moscow, it will be because the vibratory wave was originally projected with a view to recognition only by the mechanism located at one or other of those places. You see how simple that is?"

"And you feel confident of complete ultimate success?" was asked.

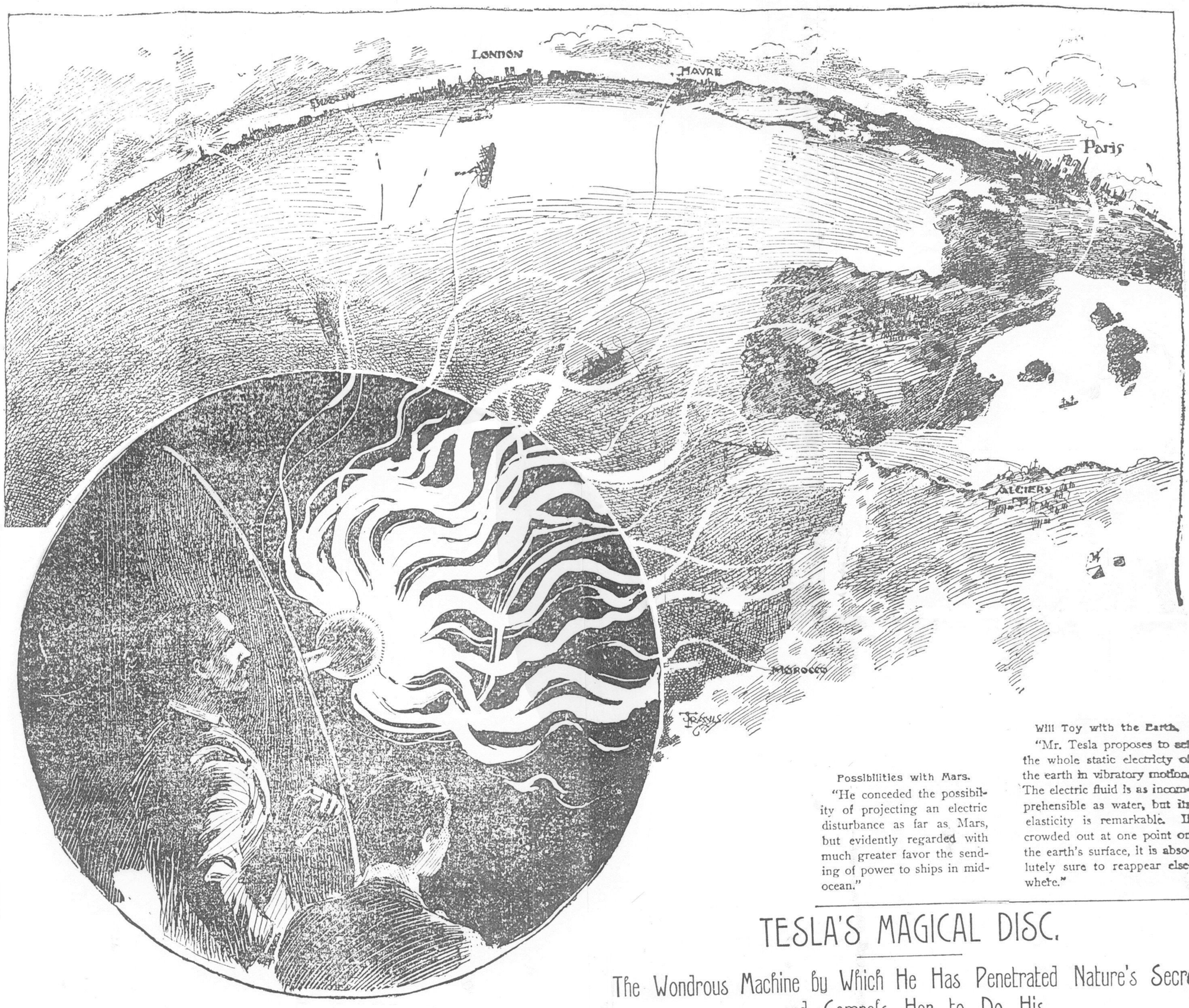
"I believe that with the machine now completed I can disturb the electrical conditions of the earth," was the prompt rejoinder. "That I shall be able to transmit thought or information I am convinced; and I hope with equal assurance to supply power to distant localities on this earth, without the medium of wires."

"Give me an example."

"At Niagara it may be possible to generate electrical energy that can be used to drive mills in New England, railroad trains across the prairies and steamships across the sea."

The tall, spare figure of the young scientist seemed to grow in stature. His wonderful eyes gave much character to his pale face as he talked of forging nature's own thunderbolts into human thought and harnessing earth's own forces to do new and incredible service for mankind.

It is impossible not to be filled with admiration for genius. This idea of overpowering



TESLA'S EXTRAORDINARY PREDICTION.

"I believe that with the machine now completed I can disturb the electrical conditions of the earth," was the prompt rejoinder. "That I shall be able to transmit thought or information I am convinced; and I hope with equal assurance to supply power to distant localities on this earth, without the medium of wires.

"At Niagara it may be possible to generate electrical energy that can be used to drive mills in New England, railroad trains across the prairies and steamships across the sea!"

ble!" Bulwer in "The Coming Race" had Tesla in mental contemplation. Although the engineer was not born, Tesla is the hero of that remarkable novel. The people that Bulwer described drew light, power and human emotions from electricity.

After a half hour with Mr. Tesla any man who is suddenly asked to define electricity must answer:

Vibration.

And what is that? will naturally follow.

Vibration is life itself.

The inventor was in a sanguine mood, but did not go to the length of predicting immediate results of great scientific value. He conceded the possibility of projecting an electric disturbance as far as Mars, but evidently regarded with much greater favor the sending of power to ships in mid-ocean. John W Keely taught the world, in his clumsy way, twenty years ago, that vibrations develop mechanical energy; but Tesla, from accurately human data, has reasoned out the problem of starting on this earth's surface electric waves that will break upon the shores of other worlds. He says it can be done!

By disturbing the static conditions on this earth he also hopes to render possible the sending of messages of hope and encouragement to future Nansens and Andrees. By a series of stupendous etheric vibrations the French in communicated with from New York or Washington.

Light, we know, is transmitted on vibratory waves. The planets only shine by reflected light from the sun; in other words, the light must first travel to Mars or Jupiter, and thence back to us. In Tesla's opinion it is beyond all human possibility to construct a lamp strong enough to be seen on Mars; but the earth is a storehouse of energy that can be drawn on to any extent—making it easy to send electrical currents to any point without wires. He explained the theory upon which his device for telegraphing over the whole earth in the following simple simile:

"Suppose the earth to resemble a hollow rubber ball, filled with water," began Mr. Tesla. "At one place I have a tube, with a plunger, attached to the surface of this ball. If I press upon the plunger the water in the tube will be driven into the ball and every part will be expanded. If I withdraw the plunger the water follows it and every part of the ball will contract. Now, if I pierce the surface of that ball in several places and set up tubes and plungers at each place, these plungers will vibrate up and down in response to every movement that I may produce in the plunger of the first tube. An agitation in the centre of the ball, a series of vibrations in the whole body would occur. If I could then set the plunger in one of the tubes to vibrating in consonance with the vibrations I could burst the whole thing asunder."

In a non-technical way this indicates how Mr. Tesla proposes to set the whole static electricity of the earth in vibratory motion. The electric fluid is as incompressible as water, but its elasticity is remarkable. If crowded out at one point on the earth's surface it is absolutely sure to reappear elsewhere.

"What I have set out to do, I believe I have accomplished," said Mr. Tesla. "I spoke of my hopes when I addressed the Franklin Institute, of Philadelphia, in 1893, but I did not expect to see the end so near at so early a day. Just how far I can send these electric waves I know not. Accurate and very sensitive instruments will be required to demonstrate that point of the work. But when the proper vibratory impulse is met the response will be instantaneous."

Thus calmly does Mr. Tesla discourse regarding his plan to convert the Atlantic Ocean ferry into a trolley line! He declined to exhibit the machine to me, but he gave the following description:

In a large darkened room is hung a black disk about eight feet across, and from the centre of this disk protrudes a brass electrode seven inches in diameter. When the current of high voltage is turned on the apartment is filled with crackling sounds, soon increasing into a succession of crashes. Bright and forked streaks of flame shoot eight feet toward the centre of the room, bursting into dazzling sparks at the vanishing point.

The spectacle, as described in the Journal, is appalling—weird, unnatural, dreadful. But Tesla says it is the

Possibilities with Mars.

"He conceded the possibility of projecting an electric disturbance as far as Mars, but evidently regarded with much greater favor the sending of power to ships in mid-ocean."

Will Toy with the Earth.

"Mr. Tesla proposes to set the whole static electricty of the earth in vibratory motion. The electric fluid is as incomprehensible as water, but its elasticity is remarkable. If crowded out at one point on the earth's surface, it is absolutely sure to reappear elsewhere."

TESLA'S MAGICAL DISC.

The Wondrous Machine by Which He Has Penetrated Nature's Secrets and Compels Her to Do His Bidding.

"He declined to exhibit the machine to me, but gave the following description:

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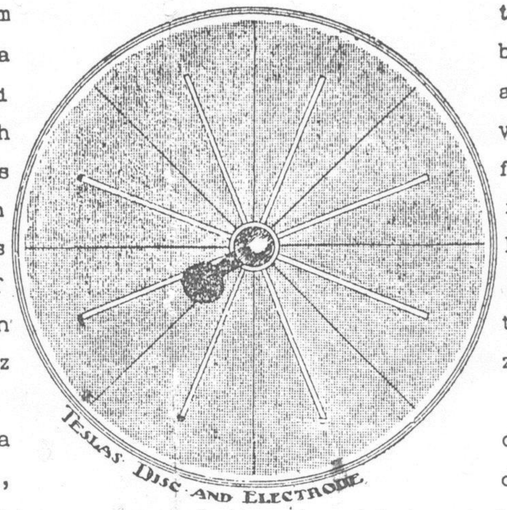

"The Specta cle is appalling- wierd, unnatural, dreadful. But Tesl says it is the motive power and the thought transmitter of the nea future."

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Tesla is quietly pursuing his fruitful labors, and, devoted as he is to the cause of science, remains undisturbed by journalistic sensationalism and consequent criticism of the uninformed. In this issue he again makes a particularly valuable and practical contribution to the important field which Lenard and Roentgen have opened up.

TESLA ON THE SOURCE OF ROENTGEN RAYS AND THE PRACTICAL CONSTRUCTION AND SAFE OPERATION OF LENARD TUBES.

To the Editor of Electrical Review:

I have for some time felt that a few indications in regard to the practical construction of Lenard tubes of improved designs, a great number of which I have recently exhibited before the New York Academy of Sciences (April 6, 1897), would be useful and timely, particularly as by their proper construction and use much of the danger attending the experimentation with the rays may be avoided. The simple precautions which I have suggested in my previous communications to your esteemed journal are seemingly disregarded, and cases of injury to patients are being almost daily reported, and in view of this only, were it for no other reason, the following lines, referring to this subject, would have been written before had not again pressing and unavoidable duties prevented me from doing so. A short and, I may say, most unwelcome interruption of the work which has been claiming my attention makes this now possible. However, as these opportunities are scarce, I will utilize the present to dwell in a few words on some other matters in connection with this subject, and particularly on a result of importance which I have reached some time ago by the aid of such a Lenard tube, and which, if I am correctly informed, I can only in part consider as my own, since it seems that practically it has been expressed in other words by Professor Roentgen in a recent communication to the Academy of Sciences of Berlin. The result alluded to has reference to the much disputed question of the source of the Roentgen rays. As will be remembered, in the first announcement of his discovery, Roentgen was of the opinion that the rays which affected the sensitive layer emanated from the fluorescent spot on the glass wall of the bulb; other scientific men next made the cathode responsible; still others the anode, while some thought that the rays were emitted solely from fluorescent powders or surfaces, and speculations, mostly unfounded, increased to such an extent that, despairingly, one would exclaim with the poet:

"O gluecklich wer noch hoffen kann,
Aus diesem Meer des Irrtums aufzutauchen!"

My own experiments led me to recognize that, regardless of the location, the chief source of these rays was the place of the *first* impact of the projected stream of particles within the bulb. This was merely a broad statement, of which that of Professor Roentgen was a special case, as in his first experiments the fluorescent spot on the glass wall was, incidentally, the place of the first impact of the cathodic stream. Investigations carried on up to the present day have only confirmed the correctness of the above opinion, and the place of the first collision of the stream of particles —be it an anode or independent impact body, the glass wall or an aluminum window—is still found to be the principal source of the rays. But, as will be seen presently, it is not the only source.

Since recording the above fact my efforts were directed to finding answers to the following questions: First, is it necessary that the impact body should be within the tube? Second, is it required that the obstacle in the path of the cathodic stream should be a solid or liquid? And, third, to what extent is the velocity of the stream necessary for the generation of and influence upon the character of the rays emitted?

In order to ascertain whether a body located outside of the tube and in the

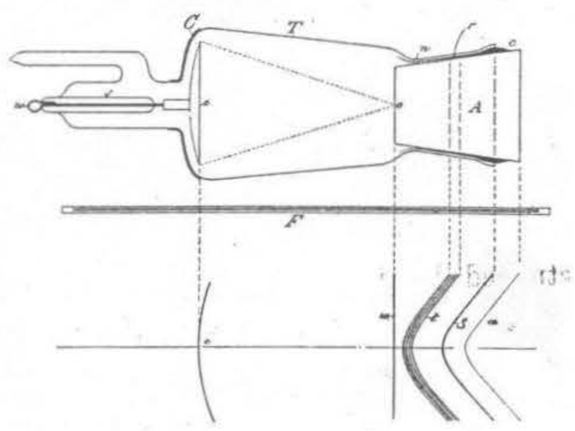


Fig. 1.—Illustrating an Experiment Revealing the Real Source of the Roentgen Rays.

path or in the direction of the stream of particles was capable of producing the same peculiar phenomena as an object located inside, it appeared necessary to first show that there is an actual penetration of the particles through the wall, or otherwise that the actions of the supposed streams, of whatever nature they might be, were sufficiently pronounced in the outer region close to the wall of the bulb as to produce some of the effects which are peculiar to a cathodic stream. It was not difficult to obtain with a properly prepared Lenard tube, having an exceedingly thin window, many and at first surprising evidences of this character. Some of these have already been pointed out, and it is thought sufficient to cite here one more which I have since observed. In the hollow aluminum cap A of a tube as shown in diagram Fig. 1, which will be described in detail, I placed a half-dollar silver piece, supporting it at a small distance from and parallel to the window or bottom of the cap by strips of mica in such a manner that it was not

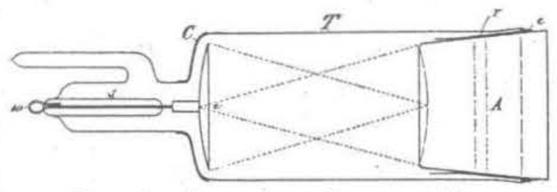


Fig. 2.—Improved Lenard Tube.

touching the metal of the tube, an air space being left all around it. Upon exciting the bulb for about 30 to 45 seconds by the secondary discharge of a powerful coil of a novel type now well known, it was found that the silver piece was rendered so hot as to actually scorch the hand; yet the aluminum window, which offered a very insignificant obstacle to the cathodic stream, was only moderately warmed. Thus it was shown that the silver alloy, owing to its density and thickness, took up most of the energy of the impact, being acted upon by the particles almost identically as if it had been inside of the bulb, and, what is more, indications were obtained, by observing the shadows, that it behaved like a second source of the rays, inasmuch as the outlines of the shadows, instead of being sharp and clear as when the half-dollar piece was removed, were dimmed. It was immaterial for the chief object of the inquiry to decide by more exact methods whether the cathodic particles actually penetrated the window, or whether a new and separate stream was projected from the outer side of the window. In my mind there exists not the least doubt that the former was the case, as in this respect I have been able to obtain numerous additional proofs, upon which I may dwell in the near future.

I next endeavored to ascertain whether it was necessary that the obstacle outside was, as in this case, a solid body, or a liquid, or broadly, a body of measurable dimensions, and it was in investigating in this direction that I came upon the important result to which I referred in the introductory statements of this communication. I namely observed rather accidentally, although I was following up a systematic inquiry, what is illustrated in diagram Fig. 1. The diagram shows a Lenard tube of

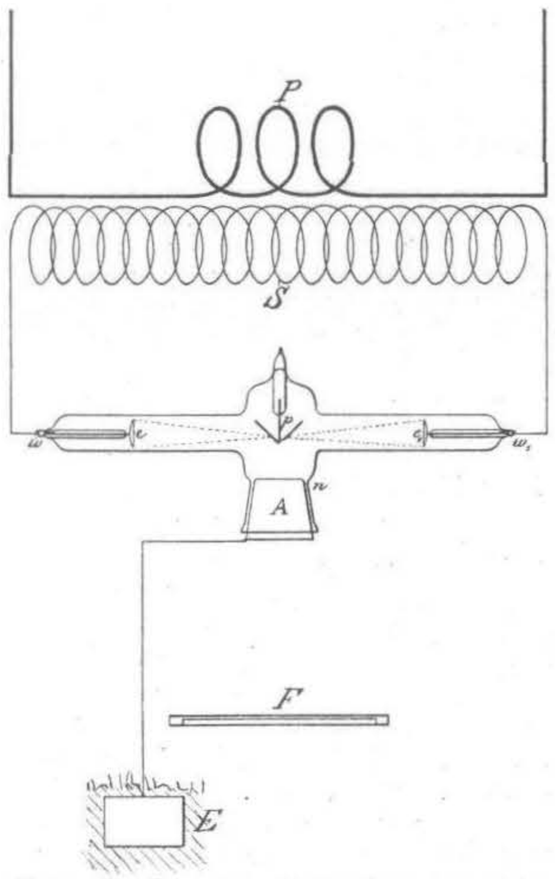


Fig. 3.—Illustrating Arrangement with Improved Double-Focus Tube for Reducing the Injurious Actions.

improved design, consisting of a tube T of thick glass tapering towards the open end, or neck *n*, into which is fitted an aluminum cap A, and a spherical cathode *e*, supported on a glass stem *s*, and platinum wire *w* sealed in the opposite end of the tube as usual. The aluminum cap A, as will be observed, is not in actual contact with the ground-glass wall, being held at a small distance from the latter by a narrow and continuous ring of tinfoil *r*. The outer space between the glass and the cap A is filled with cement *c*, in a manner which I shall later describe. F is a Roentgen screen such as is ordinarily used in making the observations.

Now, in looking upon the screen in the direction from F to T, the dark lines indicated on the lower part of the diagram were seen on the illuminated background. The curved line *e* and the straight line W were, of course, at once recognized as the outlines of the cathode *e* and the bottom of the cap A respectively, although, in consequence of a confusing optical illusion, they appeared much closer together than they actually were. For instance, if the distance between *e* and *o* was five inches, these lines would appear on the screen about two inches apart, as nearly as I could judge by the eye. This illusion may be easily explained and is quite unimportant, except that it might be of some moment to physicians to keep this fact in mind when making examinations with the screen as, owing to the above effect, which is sometimes exaggerated to a degree hard to believe, a completely erroneous idea of the distance of the various parts of the object under examination might be gained, to the detriment of the surgical operation. But while the lines *e* and W were easily accounted for, the curved lines *t*, *g*, *a* were at first puzzling. Soon, however, it was ascertained that the faint line *a* was the shadow of the edge of the aluminum cap, the much darker line *g* that of the rim of the glass tube T, and *t* the shadow of the tinfoil ring *r*. These shadows on the screen F clearly showed that the agency which affected the fluorescent material was proceeding from the space outside of the bulb towards the aluminum cap, and chiefly from the region through which the primary disturbances or streams emitted from the tube through the window were passing, which observation could not be explained in a more plausible manner than by assuming that the air and dust particles outside, in the path of the projected streams, afforded an obstacle to their passage and gave rise to impacts and collisions spreading through the air in all directions, thus producing continuously new sources of the rays. It is this fact which, in his recent communication before mentioned, Roentgen has brought out. So, at least, I have interpreted his reported statement that the rays emanate from the irradiated air. It now remains to be shown whether the air, from which carefully all foreign particles are removed, is capable of behaving as an impact body and source of the rays, in order to decide whether the generation of the latter is dependent on the presence in

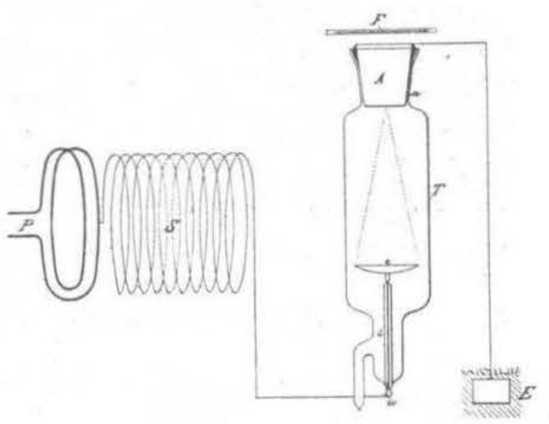


Fig. 4.—Illustrating Arrangement with a Lenard Tube for Safe Working at Close Range.

the air of impact particles of measurable dimensions. I have reasons to think so.

With the knowledge of this fact we are now able to form a more general

(Concluded on page 71.)

TESLA ON ROENTGEN RAYS.

(Concluded from page 67.)

idea of the process of generation of the radiations which have been discovered by Lenard and Roentgen. It may be comprised in the statement that the streams of minute material particles projected from an electrode with great velocity in encountering obstacles wherever they may be, within the bulb, in the air or other medium or in the sensitive layers themselves, give rise to rays or radiations possessing many of the properties of those known as light. If this physical process of generation of these rays is undoubtedly demonstrated as true, it will have most important consequences, as it will induce physicists to again critically examine many phenomena which are presently attributed to transverse ether waves, which may lead to a radical modification of existing views and theories in regard to these phenomena, if not as to their essence so, at least, as to the mode of their production.

My effort to arrive at an answer to the third of the above questions led me to the establishment, by actual photographs, of the close relationship which exists between the Lenard and Roentgen rays. The photographs bearing on this point were exhibited at a meeting of the New York Academy of Sciences—before referred to—April 6, 1897, but, unfortunately, owing to the shortness of my address, and concentration of thought on other matters, I omitted what was most important; namely, to describe the manner in which these photographs were obtained, an oversight which I was able to only partially repair the day following. I did, however, on that occasion illustrate and describe experiments, in which was shown the deflectibility of the Roentgen rays by a magnet, which establishes a still closer relationship, if not identity, of the rays named after these two discoverers. But the description of these experiments in detail, as well as of other investigations and results in harmony with and restricted to the subject I brought before that scientific body, will appear in a longer communication which I am slowly preparing.

To bring out clearly the significance of the photographs in question, I would recall that, in some of my previous contributions to scientific societies, I have endeavored to dispel a popular opinion before existing that the phenomena known as those of Crookes were dependent on and indicative of high vacua. With this object in view, I showed that phosphorescence and most of the phenomena in Crookes bulbs were producible at greater pressures of the gases in the bulbs by the use of much higher or more sudden electro-motive impulses. Having this well demonstrated fact before me, I prepared a tube in the manner described by Lenard in his first classical communication on this subject. The tube was exhausted to a moderate degree, either by chance or of necessity, and it was found that, when operated by an ordinary high-tension coil of a low rate of change in the current, no rays of any of the two kinds could be detected, even when the tube was so highly strained as to become very hot in a few moments. Now, I expected that, if the suddenness of the impulses through the bulb were sufficiently increased, rays would be emitted. To test this I employed a coil of a type which I have repeatedly described, in which the primary is operated by the discharges of a condenser. With such an instrument any desired suddenness of the impulses may be secured, there being practically no limit in this respect, as the energy accumulated in the condenser is the most violently explosive agent we know, and any potential or electrical pressure is obtainable. Indeed, I found that in increasing the suddenness of the electro-motive impulses through the tube—without, however, increasing, but rather diminishing the total energy conveyed to it—phosphorescence was observed and rays began to appear, first the feebler Lenard rays and later, by pushing the suddenness far enough, Roentgen rays of great intensity, which enabled me to obtain photographs showing the finest texture of the bones. Still, the same tube, when again operated with the ordinary coil of a low rate of change in the primary current, emitted practically no rays, even when, as before stated, much more energy, as judged from the heating, was passed through it. This experience, together with the fact that I have succeeded in producing by the use of immense electrical pressures, obtainable with certain apparatus designed for this express purpose, some impressions in free air, have led me to the conclusion that in lightning discharges Lenard and Roentgen rays must be generated at ordinary atmospheric pressure.

At this juncture I realize, by a perusal of the preceding lines, that my scientific interest has dominated the practical, and that the following remarks must be devoted to the primary object of this communication—that is, to giving some data for the construction to those engaged in the manufacture of the tubes and, perhaps, a few useful hints to practicing physicians who are dependent on such information. The foregoing was, nevertheless, not lost for this object, inasmuch as it has shown how much the result obtained depends on the proper construction of the instruments, for, with ordinary implements, most of the above observations could not have been made.

I have already described the form of tube illustrated in Fig. 1, and in Fig. 2 another still further improved design is shown. In this case the aluminum cap A, instead of having a straight bottom as before, is shaped spherically, the center of the sphere coinciding with that of the electrode *e*, which itself, as in Fig. 1, has its focus in the center of the window of cap A, as indicated by the dotted lines. The aluminum cap A has a tinfoil ring *r*, as that in Fig. 1, or else the metal of the cap is spun out on that place so as to afford a bearing of small surface between the metal and the glass. This is an important practical detail as, by making the bearing surface small, the pressure per unit of area is increased and a more perfect joint made. The ring *r* should be first spun out and then ground to fit the neck of the bulb. If a tinfoil ring is used instead, it may be cut out of one of the ordinary tinfoil caps obtainable in the market, care being taken that the ring is very smooth.

In Fig. 3 I have shown a modified design of tube which, as the two types before described, was comprised in the collection I exhibited. This, as will be observed, is a double-focus tube, with impact plates of iridium alloy and an aluminum cap A opposite the same. The tube is not shown because of any originality in design, but simply to illustrate a practical feature. It will be noted that the aluminum caps in the tubes described are fitted inside of the necks and not outside, as is frequently done. Long experience has demonstrated that it is practically impossible to maintain a high vacuum in a tube with an outside cap. The only way I have been able to do this in a fair measure is by cooling the cap by a jet of air, for instance, and observing the following precautions: The air jet is first turned on slightly and upon this the tube is excited. The current through the latter, and also the air pressure, are then gradually increased and brought to the normal working condition. Upon completing the experiment the air pressure and current through the tube are both gradually reduced and both so manipulated that no great differences in temperature result between the glass and aluminum cap. If these precautions are not observed the vacuum will be immediately impaired in consequence of the uneven expansion of the glass and metal.

With tubes, as these presently described, it is quite unnecessary to observe this precaution if proper care is taken in their preparation. In inserting the cap the latter is cooled down as low as it is deemed advisable without endangering the glass, and it is then gently pushed in the neck of the tube, taking care that it sets straight.

The two most important operations in the manufacture of such a tube are, however, the thinning down of the aluminum window and the sealing in of the cap. The metal of the latter may be one thirty-second or even one-sixteenth of an inch thick, and in such case the central portion may be thinned down by a countersink tool about one-fourth of an inch in diameter as far as it is possible without tearing the sheet. The further thinning down may then be done by hand with a scraping tool; and, finally, the metal should be gently beaten down so as to surely close the pores which might permit a slow leak. Instead of proceeding in this way I have employed a cap with a hole in the center, which I have closed with a sheet of pure aluminum a few thousandths of an inch thick, riveted to the cap by means of a washer of thick metal, but the results were not quite as satisfactory.

In sealing the cap I have adopted the following procedure: The tube is fastened on the pump in the proper position and exhausted until a permanent condition is reached. The degree of exhaustion is a measure of perfection of the joint. The leak is usually considerable, but this is not so serious a defect as might be thought. Heat is now gradually applied to the tube by means of a gas stove until a temperature up to about the boiling point of sealing wax is reached. The space between the cap and the glass is then filled with sealing wax of good quality; and, when the latter begins to boil, the temperature is reduced to allow its settling in the cavity. The heat is then again increased, and this process of heating and cooling is repeated several times until the entire cavity, upon reduction of the temperature, is found to be filled uniformly with the wax, all bubbles having disappeared. A little more wax is then put on the top and the exhaustion carried on for an hour or so, according to the capacity of the pump, by application of moderate heat much below the melting point of the wax.

A tube prepared in this manner will maintain the vacuum very well, and will last indefinitely. If not used for a few months, it may gradually lose the high vacuum, but it can be quickly worked up. However, if after long use it becomes necessary to clean the tube, this is easily done by gently warming it and taking off the cap. The cleaning may be done first with acid, then with highly diluted alkali, next with distilled water, and finally with pure rectified alcohol.

These tubes, when properly prepared, give impressions much sharper and reveal much more detail than those of ordinary make. It is important for the clearness of the impressions that the electrode should be properly shaped, and that the focus should be exactly in the center of the cap or slightly inside. In fitting in the cap, the distance from the electrode should be measured as exactly as possible. It should also be remarked that the thinner the window, the sharper are the impressions, but it is not advisable to make it too thin, as it is apt to melt in a point on turning on the current.

The above advantages are not the only ones which these tubes offer. They are also better adapted for purposes of examination by surgeons, particularly if used in the peculiar manner illustrated in diagrams Fig. 3 and Fig. 4, which are self-explanatory. It will be seen that in each of these the cap is connected to the ground. This decidedly diminishes the injurious action and enables also to take impressions with very short exposures of a few seconds only at close range, inasmuch as, during the operation of the bulb, one can easily touch the cap without any inconvenience, owing to the ground connection. The arrangement shown in Fig. 4 is particularly advantageous with a form of single terminal, which coil I have described on other occasions and which is diagramatically illustrated, P being the primary and S the secondary. In this instance the high-potential terminal is connected to the electrode, while the cap is grounded. The tube may be placed in the position indicated in the drawing, under the operating table and quite close, or even in contact with the body of the patient, if the impression requires only a few seconds as, for instance, in examining parts of the members. I have taken many impressions with such tubes and have observed no injurious action, but I would advise not to expose for longer than two or three minutes at very short distances. In this respect the experimenter should bear in mind what I have stated in previous communications. At all events it is certain that, in proceeding in the manner described, additional safety is obtained and the process of taking impressions much quickened. To cool the cap, a jet of air may be used, as before stated, or else a small quantity of water may be poured in the cap each time when an impression is taken. The water only slightly impairs the action of the tube, while it maintains the window at a safe temperature. I may add that the tubes are improved by providing back of the electrode a metallic coating C, shown in Fig. 3 and Fig. 4.

NIKOLA TESLA.

New York, August 9.

A NEW FORM OF INDUCTION COIL.

READ AT THE FOURTEENTH GENERAL MEETING OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, ELIOT, ME., JULY 26–28, 1897, BY PROF. ELIHU THOMSON.

The induction coil presently to be described, it is believed, constitutes a new type employing the principle of a "substitute primary" or "secondary primary," which principle has been applied by me in a variety of ways.

The prime object of this coil is to permit the direct connection to circuits of considerable potential for obtaining energy for the production of high-potential discharges, like those of a Ruhmkorff coil for working Roentgen-ray vacuum tubes, and for such like purposes. The object, also, was to avoid the employment of banks of lamps or storage batteries, and to limit the energy consumed to only that amount required to work the coil itself. Furthermore, no larger condensers than those ordinarily used with an induction coil of equal capacity are needed, and no air-blast, while the coil as a whole is still available as an ordinary Ruhmkorff without change in its structure or connections.

To illustrate the principle, reference is made to Fig. 1, where *p n* represent connections to mains at, say, 110 volts difference of potential; I I is an iron wire core around which are wound two coils, one over the other, either of which may, of course, be the primary. The inner coil P in the figure is made the primary, and is wound with many turns of comparatively fine wire. For 110 volts it may have some thousands of turns and be wound with a wire safe for .5 to .75 ampere. The outside wire S may be coarse or fine. In the figure it is quite coarse and of relatively few turns, since it is assumed to give low potential and large current. The coil S is so proportioned as to be practically almost short-circuited at intervals by its load at B, which is three-cells of storage battery in series, for example. The object is assumed to be that the batteries are charged by transference of energy from coil P to S at low potential in S. The coil S should have ample copper so as to lower its internal resistance as much as possible; the resistance of the cells B should be low; and the average voltage of discharge of S much superior to the counter electro-motive force of B. Two synchronously revolving break-pieces, E, F, which may, in fact, be combined into one, are used; E is for governing the intervals of passage of current in coil P and connection of condenser C across the break or interruption periodically made between one terminal of P by a brush G and a metallic segment on E occupying a considerable arc on its periphery. Brush H connects to main *n*. Back of the main segment on E is a small condenser segment in continuous connection with one side or foil of the condenser, and the other side is connected to the other terminal of P, or that leading direct from line *p*. The contact maker and breaker F has a segment which is in continuous connection with one terminal of battery B to be charged, and which touches a stationary brush J, at or about the time of the break between brush G on the main segment of E. The battery B may have terminals by which it may furnish current while being charged.

Now let the break-wheels E and F be given rapid revolution, say, 10, 20 or 30 per second. The contact of brushes G and H with the main segment of E passes current for a certain considerable fraction of the revolution, at full line potential of 110 volts, through primary P. The current rises gradually during this period, and may at the end attain a value of one ampere, more or less. With slow revolution it would be limited by the resistance of P chiefly, but at rapid rates, the time constant of P acting as a self-induction, determines the ultimate value of current before breaking. Upon the break of brush G with the main segment it touches the condenser segment, which is thereby put across the break; but the circuit of S is also closed by contact of segment on F with brush J. The condenser receives only a small charge on account of the circuit of S having been closed. In fact, the break at G with main segment of E would be nearly sparkless without the condenser C, but what slight self-induction is not wiped out by the mutual induction of the currents in S and P is very easily taken care of.

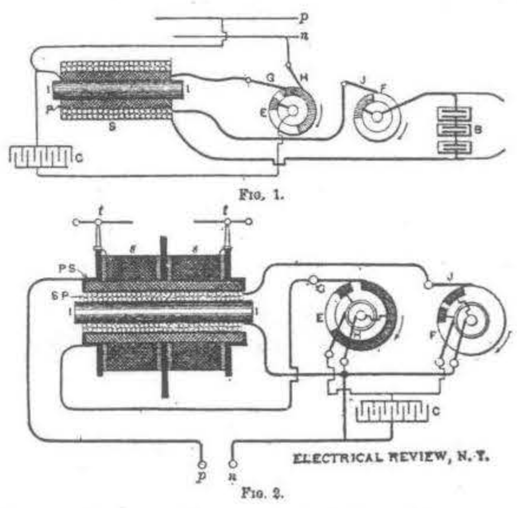


Fig. 1. Fig. 2.

PROF. ELIHU THOMSON'S NEW FORM OF INDUCTION COIL.

The magnetizing of the core I I or absorption of energy is by P, while delivery of energy is by S, acting as if nearly on a closed circuit. This condition, however, does not involve much waste of energy if the ohmic resistance of the circuit of S be low enough. Here, then, is a transfer of energy from one circuit to another while the currents are direct currents in each circuit. To insure this being the case in S, the time of contact of segment on F with brush J must be selected so as not to permit any reversal; i. e., the break of said segment with K must be timed to be made on the cessation of the first impulse or discharge from S. To do this an ammeter, responding to direct currents only, placed in the battery circuit or in the leads from S, will indicate a maximum direct current when the segment F is of proper extent, and less under other conditions.

With the principles of the above apparatus in mind it is easy to understand the action of my new form of induction coil, which may be described, briefly, as follows: The iron core I, Fig. 2, of the induction coil is wound with the ordinary coarse primary coil and terminals provided therefor. Then a coil of intermediate gauge, between the inner primary and the outer secondary, is wound. It is to be capable of being connected across a circuit of 110 volts as with coil P, Fig. 1. This coil is the true primary or energy supplying coil, but for convenience and saving of wire I prefer to connect it in as the under portion of the real secondary circuit. It thus becomes useful as a part of the secondary itself, and having several thousand turns adds a considerable fraction to the total potential of the secondary. The secondary is, as usual, of quite fine wire of many thousands of turns, well insulated throughout.

In Fig. 2 the coarse coil is marked S P, and the intermediate coil P S, while that outside is marked S. The functions of the coils S P and P S are to act as secondaries and primaries alternately. This is, in fact, an essential function of S P, but is only incidental to coil P S, having been connected into the secondary circuit S, whose terminals are at *t t*. The break-wheels E F are like those of Fig. 1, except that in F there is a much shorter main segment and a condenser segment following, as in E. There is no battery in the circuit of S P, but it is put on dead short-circuit at intervals, just at the time P S is broken. Coil P S receives current from line at *p n*, at 100 to 200 volts, or more. On the break of this circuit at brush G the ampere turns, so to speak, are shifted suddenly into circuit of S P, closed on itself by J F. The consequence is that even at slow breaks no spark occurs at the rupture of G E. As soon as the current has been fully established in S P on short circuit, and after brush Q has got entirely away from all metallic connections on E, the main segment of F breaks the circuit of S P, which is conveying a very heavy current at low potential. The condenser C is put instantly across the break, and the spark flies between terminals *t t*. In this way a coil of the size of a six-inch Ruhmkorff gives a torrent of six-inch sparks, with an average current from a 110-volt line of about one-half an ampere. A simple motor or clock-work may be used to drive the break-wheels E , which are made of fair diameter to insure accuracy in operation. The best results are only to be obtained when the proportioning of the parts is carefully done, and with a knowledge of the result to be obtained.

The discharges are indistinguishable from those of a similar Ruhmkorff. In fact, the coil described might be used with the same condenser C as an ordinary Ruhmkorff coil energized by batteries. In this case the terminals of the coil section P S are disconnected, brush J lifted and battery inserted between brush G and terminal of S P, which goes to J in Fig. 2. The break-wheel E or F, when run with low potentials, may be immersed in water in the usual way to facilitate sharp breaks, but the apparatus has been very successfully run, at full output, dry, or a little heavy oil on the break suffices. Also, the flux of current in S P may be made by a magnet to break its own circuit under water when the current has risen to a predetermined amount. In other words, it may be provided with the usual automatic break, damped or adjusted not to get into tremulous vibration. It will be seen from the above description that a new way of energizing an induction coil or other transforming apparatus has been embodied, and that it consists in the rapid substitution of secondary and primary functions in the coil S P.

Tesla's System of Energy Transmission to a Distance Without Wires.

In view of the many reports which are appearing in the sensational dailies about Tesla's work, it appears only justice to this earnest and modest worker that we should publish the following sensible statement reported in such a competent and carefully edited journal as the *Sun*, of this city. The statement is reported as follows in its evening issue of August 4:

Nikola Tesla this morning denied the report that he had announced the completion of his discovery of a method of telegraphy without wires. Occasional reports of the progress of the work had been published from time to time, he said. His experiments had been repeatedly shown in strict confidence to some of his personal friends, but the publication of them in any detail must have been a violation of confidence. As a matter of fact, no experiments were made at the laboratory yesterday. The inventor, however, was willing to give some account of his work up to the present time.

"In a lecture delivered about four years ago," he said, "before the National Electric Light Association, in St. Louis—that was in March, 1893—I explained a certain scheme for producing electrical disturbances with the object of transmitting intelligible messages, and even power, from place to place without the use of any wires.

"The principle is this: An electrical oscillator is connected by one of its terminals to earth, and another is led to an insulated object of considerable bulk. This object should preferably be at a great height, where the air is less dense and transmits more easily the disturbance.

"Such an apparatus is then exactly what in mechanics would be a suction pump. Periodically it draws electricity out and forces it again into the earth, thereby altering rhythmically the electrostatic potential in the earth as well as in the air.

"This scheme I had, as a matter of fact, conceived many years before. But I had previously lacked the courage to present it to the scientific world. At the time of the St. Louis lecture I had already seen such results that I gathered courage enough to announce the project seriously.

"Shortly afterward, on my return to this city, I actually demonstrated by means of an improved apparatus that I was indeed able to create a disturbance in the manner described in the lecture.

"In my pleasure and excitement at this success, I could not refrain from showing the first experiments to a few intimate friends. When, later, my laboratory burned down, and the first instrument with which I had succeeded in my demonstration, and which I valued above any other, was destroyed, it was no small consolation to me that a few men whom I hold in high esteem had seen the first evidence of my success. They were my friends. Of course, all the experiments that I have made to this day have been shown only in confidence and with the express understanding that no popular publication should be made of them until I had acquainted the scientific world with my results.

"It appeared several years ago that the result I aimed at would be very difficult, if not impossible, to attain. The method, nevertheless, as I have outlined it, is simple, involving merely the use of a properly constructed oscillator connected with the ground, and with an elevated object; also a sensitive and properly adjusted receiver at a distance, similarly connected with the ground, and with an object at a considerable height. For the purposes of this receiver, I consider a balloon most suitable.

"These disturbances with which I am experimenting are produced by methods and devices which I have been perfecting more recently, and from present results I do not consider it at all impracticable to obtain, if such were desired, electric sparks a mile in length. They could be readily secured by apparatus designed on these novel lines. I now obtain sparks as long as eight feet, and can produce local disturbances. What I affirm is that the disturbances in this city may be made perceptible in London or throughout the world.

"The voltage is very high—beyond computation. For a wild guess I should place the voltage at 50,000,000. I have stood in the course of the sparks, but I consider them dangerous.

"Scientific results are what I have been chiefly interested in. But there are many possibilities of turning the methods to practical use. For instance, if I wished to make a fortune I should only have to take out patents on methods for exploding torpedoes or powder magazines at a distance by means of electrical disturbances produced in this manner. But to dispel popular and erroneous opinions on this point, it is appropriate to say that, whereas, it is perfectly possible to ignite an explosive by a suitably arranged apparatus at a distance, yet this fact will not revolutionize warfare. The enemy could avail himself of similar methods with like results."

Interesting Information on Tesla Coil Experiments.

To the Editor of Electrical Review:

Since the publication in a previous number of the Electrical Review, of some suggestions I made to a subscriber of your journal relative to the construction of a Tesla coil, or high-frequency transformer, of small dimensions, a large number of inquiries have been addressed to me, which I have been unable to answer owing to lack of opportunity. As these inquiries have been made evidently by persons in possession of ordinary induction coils, of moderate power, I propose to help them in a measure by giving, through the medium of the Electrical Review, the benefit of my experience.

In the first place I desire to state that my results have been attained largely through the extreme kindness of Messrs. Tesla and Thomson, both of whom have been generous enough to respond to early correspondence on the subject of high-frequency coils.

Of course the best effects have been produced by specially constructed transformers. At the same time the ordinary induction coil, if it possess the efficiency claimed for it, in modern construction can be made to do good work in connection with a suitable condenser and high-frequency transformer. When properly built these small transformers make excellent exciters for the double-focus type X-ray tubes. The present suggestions are for a high-frequency transformer operated by ordinary induction coils from three-inch spark upward.

Fig. 1 shows the method of construction with an arrangement of winding different from that shown in my first communication. In the present type the primary winding is placed on the outside. A hollow wooden spool is provided, 12 inches in length, three inches in diameter, with the interior bored out to a diameter of two inches. If desired each end can be turned down one-half inch in width, and one-fourth inch in depth, to provide a position for two cheek blocks, sometimes to be employed with advantage, especially as resting feet for the coil. Two wooden washers are then turned with the outer diameter to fit the interior of the large spool, and these washers have a central opening one and one-half inch in diameter. Through these washers is inserted a central wooden spool turned to fit 13 inches in length, and on this inner spool the secondary winding is placed. A brass binding post screwed into each end of the inner spool serves to give outlet to the secondary winding, and is of some advantage as a permanent connection for the secondary winding when it is desired to experiment much with different primaries, and it becomes necessary to handle the coil much.

From 20 to 25 turns of No. 8 heavily insulated wire is wound on the outer surface, and approximately 250 turns of double silk covered No. 26 to No. 28 wire is wound in one layer, on the inner spool. This gives a ratio of 10 to 1, in transformation, but as Tesla has said, this ratio may be even much greater when the condenser is discharged through the primary. I have found that any estimate is liable to be far from the truth, for the secondary discharge, varying as it does with different conditions at the spark gap, is hard to estimate. My experience has been that different induction coils require different condenser capacities, due probably to the fact that the resistance of the different secondaries, and consequently the quantity output of the coils used, varied. Generally speaking, a condenser made of a plate of good glass, and having a tinfoil surface of about 50 to 90 square inches on each side, is sufficient. With such a condenser and winding as given, energized by a coil giving three to five-inch spark, the terminals of the high-frequency coil give a fairly heavy stream of sparks about three inches in length. I have found, however, that the spark length of a high-frequency transformer does not always measure its efficiency. For instance, one induction coil of larger spark rating — 10 inches — with slightly different condenser capacity, gave high-frequency streams, four inches between terminals of high-frequency coil, while the snapping spark similar to that given by the ordinary coil, scarcely exceeded one inch in length. Yet this particular high-frequency coil has been the best energizer of tubes that I have tried. It was evident that the frequency was great, due, as I afterwards discovered, to a primary winding of very heavy wire and few turns. With insufficient education in these matters, progress can be made only by incessant experiment, and the coil I submit for the benefit of my amateur friends is one which can be readily taken out of the oil bath necessary for its efficient operation, and experimental windings can easily be substituted for those here given. The spark gap and condenser connections are shown in the sketch. Fig. 3 shows a completed coil for high-frequency work, constructed by me.

With this form of coil, intelligently operated, many of Tesla's beautiful experiments are readily made, besides those which may occur—as they surely will—to the experimenter. Two years of high-frequency experimenting has been one of my chief pleasures and a never failing source of entertainment to friends. The full measure of satisfaction was attained, however, when the double focus tube came into the market and I found my high-frequency coil ample for X-ray work.

Elliott Woods.

Washington, August 12.

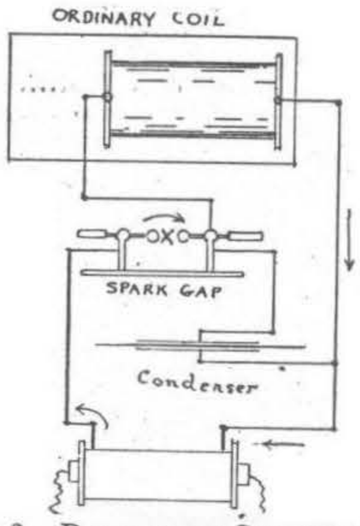


Fig. 2.—Diagram of Connections.

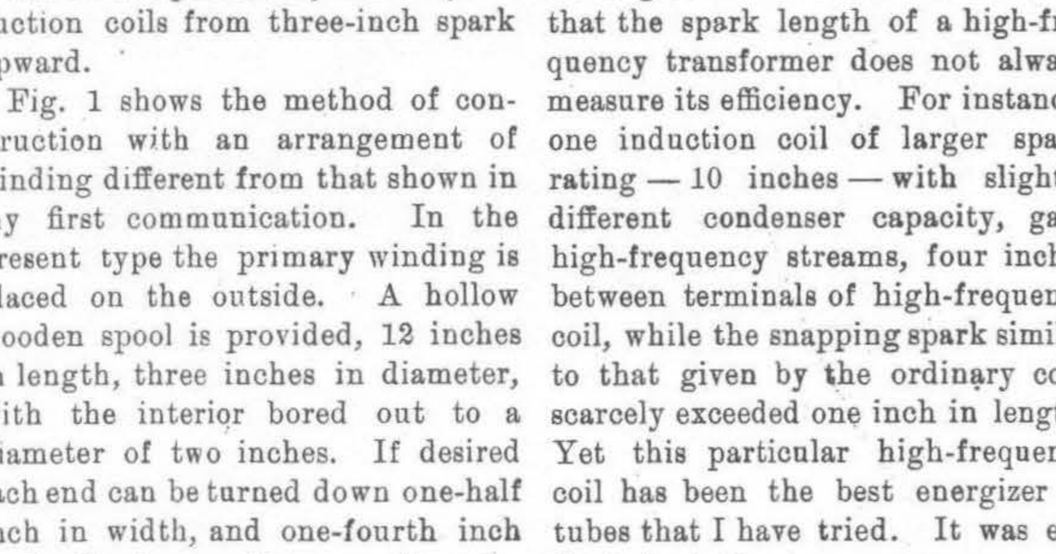


Fig. 1.—Sectional View of High-Frequency Tesla Coil.

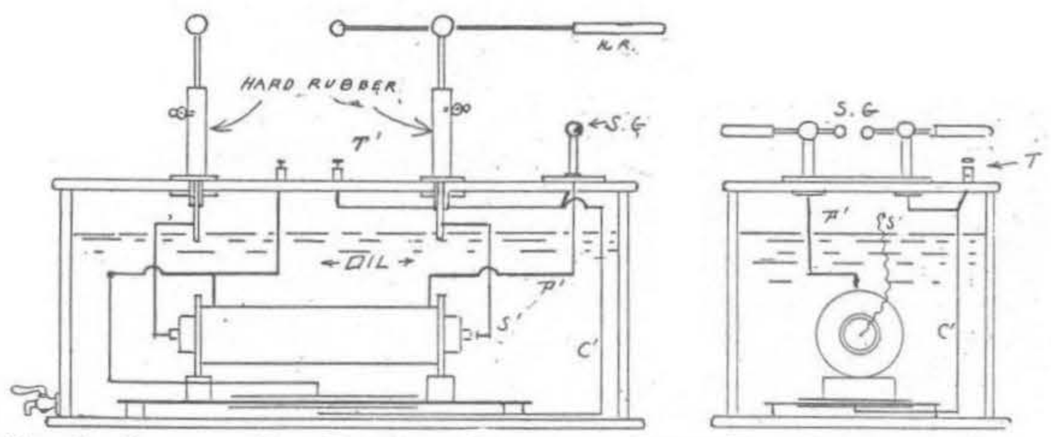


Fig. 3.—Side and End Views of Completed Tesla High Frequency Coils.

Lord Kelvin.

Lord and Lady Kelvin arrived in New York city on the "Campania" last Friday en route to the meeting of the British Association for the Advancement of Science, which begins at Toronto, Ont., on August 18. Aside from being one of the most remarkable scientific men of the century, Lord Kelvin gives evidence of his great vitality in making, at the age of 73, a transatlantic voyage to attend the sessions of a scientific body. He was born at Belfast, Ireland, in June, 1824. His father, Dr. James Thomson, was at that time lecturer on mathematics at the Royal Academical Institute at Belfast, but he removed with his family to Glasgow on receiving an appointment to the professorship of mathematics in the university there. Lord Kelvin's writings are voluminous, and he is a member of many societies, both at home and abroad. He has borne the title of Lord Kelvin since 1892. He has been president of the mathematical and physical section of the British Association five times, and in 1890 he succeeded Sir George Gabriel Stokes, Bart., as president of the Royal Society.

On his arrival in New York Lord Kelvin was met by a number of newspaper men, to whom he said:

"This is my second visit to America. I have not missed a meeting of the Royal Society in more than 40 years, and I have come now to attend the meeting in Toronto. I was here before when the meeting was at Montreal in 1884. We shall leave New York in the morning and go to Niagara Falls. There I shall inspect the great electric power plant. From there we go to Toronto. After the meeting closes we may go to Vancouver, simply to see the country. In that event our stay will cover considerable time. In any event the date of my return is uncertain."

Lord Kelvin said that he had come across the ocean largely to observe, but that he should read a paper at the meeting of the association. He expressed much interest in some of the latest developments in electrical science in this country, such as Mr. Tesla's scheme for telegraphing without wires, and the use of the third rail for transmitting electric power for traction purposes directly and without feeder wires, as is done between Berlin and Hartford, Ct.

"I have not received information regarding Mr. Tesla's methods," said Lord Kelvin, "which is definite enough to enable me speak about them, but I have no doubt we shall hear more of this at the meeting."

In regard to the recently opened garbage destructor works at Shoreditch, England, Lord Kelvin said:

"It is only six weeks since the works were opened, but they have proved themselves to be a great success. Ten tons of 'dust' are equal, we calculate, to one ton of coal for steam making. Enough energy is now obtained to operate the municipal electric lighting plant, and so long as 'dust' is obtainable not an ounce of coal need be used. Whatever dust or refuse is collected has combustible qualities, and is therefore available."

In speaking of Lord Kelvin last week, Mr. Tesla expressed himself as follows:

"His mathematical essays on electricity, magnetism and heat stand almost alone, veritable monuments. The practical public can better appreciate a part of what he has done when I say that for the past 50 years we have been depending on instruments invented by him for the measurement of a great many quantities, and it is impossible to estimate the benefits to science which have come from his instruments, which even now are used in every scientific laboratory in the world. He has given us the perfected mariner's compass, and just imagine what this has done for navigation and commerce; and in ocean telegraphy he has given us the delicate instruments which are now used for recording messages under all seas. If Lord Kelvin were a young man, we might express admiration for his achievements, but his age has almost given sanctity to the eminence of his position."

ROENTGEN RAYS

ON THE SOURCE OF ROENTGEN RAYS AND THE PRACTICAL CONSTRUCTION AND SAFE OPERATION OF LENARD TUBES.[1]

BY NIKOLA TESLA.

AS will be remembered, in the first announcement of his discovery, Röntgen was of the opinion that the rays which affected the sensitive layer emanated from the fluorescent spot on the glass wall of the bulb; other scientific men next made the cathode responsible; still others the anode, while some thought that the rays were emitted solely from fluorescent powders or surfaces. My own experiments led me to recognize that, regardless of the location, the chief source of these rays was the place of the first impact of the projected stream of particles within the bulb. This was merely a broad statement, of which that of Prof. Röntgen was a special case, as in his first experiments the fluorescent spot on the glass wall was, incidentally, the place of the first impact of the cathodic stream. Investigations carried on up to the present day have only confirmed the correctness of the above opinion, and the place of the first collision of the stream of particles—be it an anode or independent impact body, the glass wall or an aluminum window—is still found to be the principal source of the rays. But, as will be seen presently, it is not the only source.

Since recording the above fact my efforts were directed to finding answers to the following questions: First, is it necessary that the impact body should be within the tube? Second, is it required that the obstacle in the path of the cathodic stream should be a solid or liquid? And, third, to what extent is the velocity of the stream necessary for the generation of and influence upon the character of the rays emitted?

In order to ascertain whether a body located outside of the

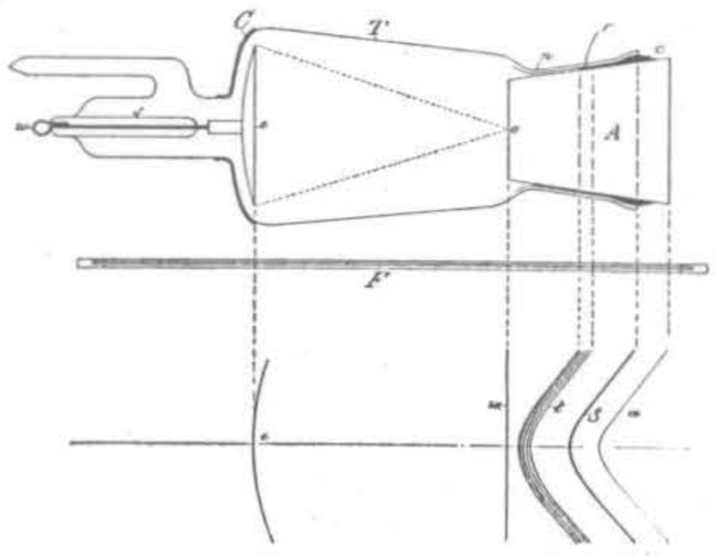


FIG. 1.

tube and in the path or in the direction of the stream of particles was capable of producing the same peculiar phenomena as an object located inside, it appeared necessary to first show that there is an actual penetration of the particles through the wall, or otherwise that the actions of the supposed streams, of whatever nature they might be, were sufficiently pronounced in the outer region close to the wall of the bulb as to produce some of the effects which are peculiar to a cathodic stream. It was not difficult to obtain with a properly prepared Lenard tube, having an exceedingly thin window, many and at first surprising evidences of this character. Some of these have already been pointed out, and it is thought sufficient to cite here one more which I have since observed. In the hollow aluminum cap, A, of a tube, as shown in diagram Fig. 1, which will be described in detail, I placed a half-dollar silver piece, supporting it at a small distance from and parallel to the window or bottom of the cap by strips of mica in such a manner that it was not touching the metal of the tube, an air space being left all around it. Upon exciting the bulb for about 30 to 45 seconds by the secondary discharge of a powerful coil of a novel type now well known, it was found that the silver piece was rendered so hot as to actually scorch the hand; yet the aluminum window, which offered a very insignificant obstacle to the cathodic stream, was only moderately warmed. Thus it was shown that the silver alloy, owing to its density and thickness, took up most of the energy of the impact, being acted upon by the particles almost identically as if it had been inside of the bulb, and, what is more, indications were obtained, by observing the shadows, that it behaved like a second source of the rays, inasmuch as the outlines of the shadows, instead of being sharp and clear as when the half-dollar piece was removed, were dimmed. It was immaterial for the chief object of the inquiry to decide by more exact methods whether the cathodic particles actually penetrated the window or whether a new and separate stream was projected from the outer side of the window. In my mind there exists not the least doubt that the former was the case, as in this respect I have been able to obtain numerous additional proofs.

I next endeavored to ascertain whether it was necessary that the obstacle outside was, as in this case, a solid body, or a liquid, or broadly, a body of measurable dimensions. I observed accidentally what is illustrated in Fig. 1. The diagram shows a Lenard tube of improved design, consisting of a tube, T, of thick glass tapering toward the open end, or neck, n, into which is fitted an aluminum cap, A, and a spherical cathode, e, supported on a glass stem, s, and platinum wire, w, sealed in the opposite end of the tube as usual. The aluminum cap, A, as will be observed, is not in actual contact with the ground glass wall, being held at a small distance from the latter by a narrow and continuous ring of tinfoil, r. The outer space between the glass and the cap, A, is filled with cement, c, in a manner described below. F is a Röntgen screen such as is ordinarily used in making the observations.

Now, in looking upon the screen in the direction from F to T, the dark lines indicated on the lower part of the diagram were seen on the illuminated background. The curved line, e, and the straight line, w, were, of course, at once recognized as the outlines of the cathode, e, and the bottom of the cap, A, respectively, although, in consequence of a confusing optical illusion, they appeared much closer together than they actually were. For instance, if the distance between e and o was 5 inches, these lines would appear on the screen about 2 inches apart, as nearly as I could judge by the eye. This illusion may be easily explained and is quite unimportant, except that it might be of some moment to physicians to keep this fact in mind when making examinations with the screen as, owing to the above effect, which is sometimes exaggerated to a degree hard to believe, a completely erroneous idea of the distance of the various parts of the object under examination might be gained, to the detriment of the surgical operation. But while the lines, e and w, were easily accounted for, the curved lines, t, g, a, were at first puzzling. Soon, however, it was ascertained that the faint line, a, was the shadow of the edge of the aluminum cap, the much darker line, g, that of the rim of the glass tube, T, and t the shadow of the tinfoil ring, r. These shadows on the screen, F, clearly showed that the agency which affected the fluorescent material was proceeding from the space outside of the bulb towards the aluminum cap, and chiefly from the region through which the primary disturbances or streams emitted from the tube through the window were passing, which observation could not be explained in a more plausible manner than by assuming that the air and dust particles outside, in the path of the projected streams, afforded an obstacle to their passage and gave rise to impacts and collisions spreading through the air in all directions, thus producing continuously new sources of the rays. It is this fact which, in his recent communication before mentioned, Röntgen has brought out. So, at least, I have interpreted his reported statement that the rays emanate from the irradiated air. It now remains to be shown whether the air, from which all foreign particles are carefully removed, is capable of behaving as an impact body and source of the rays, in order to decide whether the generation of the latter is dependent on the presence in the air of impact particles of measurable dimensions. I have reasons to think so.

With the knowledge of this fact we are now able to form a more general idea of the process of generation of the radiations which have been discovered by Lenard and Röntgen. It may be comprised in the statement that the streams of minute material particles projected from an electrode with great velocity in encountering obstacles wherever they may be, within the bulb, in the air or other medium or in the sensitive layers themselves, give rise to rays or radiations possessing many of the properties of those known as light. If this physical process of generation of these rays is undoubtedly demonstrated as true, it will have most important consequences, as it will induce physicists to again critically examine many phenomena which are at present attributed to transverse ether waves, which may lead to a radical modification of existing views and theories in regard to these phenomena, if not as to their essence, so, at least, as to the mode of their production.

[1] From The Electrical Review.

My effort to arrive at an answer to the third of the above questions led me to the establishment, by actual photographs, of the close relationship which exists between the Lenard and Röntgen rays. I prepared a tube in the manner described by Lenard in his first classical communication on this subject. The tube was exhausted to a moderate degree, either by chance or of necessity, and it was found that, when operated by an ordinary high-tension coil of a low rate of change in the current, no rays of any of the two kinds could be detected, even when the tube was so highly strained as to become very hot in a few moments. Now I expected that, if the suddenness of the impulses through the bulb were sufficiently increased, rays would be emitted. To test this I employed a coil of a type which I have repeatedly described, in which the primary is operated by the discharges of a condenser. With such an instrument any desired suddenness of the impulses may be secured, there being practically no limit in this respect, as the energy accumulated in the condenser is the most violently explosive agent we know, and any potential or electrical pressure is obtainable. Indeed, I found that in increasing the suddenness of the electromotive impulses through the tube—without, however, increasing, but rather diminishing the total energy conveyed to it—phosphorescence was observed and rays began to appear, first the feebler Lenard rays and later, by pushing the suddenness far enough, Röntgen rays of great intensity, which enabled me to obtain photographs showing the finest texture of the bones. Still, the same tube, when again operated with the ordinary coil of a low rate of change in the primary current, emitted practically no rays, even when, as before stated, much more energy, as judged from the heating, was passed through it. This experience, together with the fact that I have succeeded in producing by the use of immense electrical pressures, obtainable with certain apparatus designed for this express purpose, some impressions in free air, have led me to the conclusion that in lightning discharges Lenard and Röntgen rays must be generated at ordinary atmospheric pressure.

I have already described the form of tube illustrated in Fig. 1, and in Fig. 2 another still further improved design is shown. In this case the aluminum cap, A, instead of having a straight bottom as before, is shaped spherically, the center of the sphere coinciding with that of the electrode, e, which itself, as in Fig. 1, has its focus in the center of the window of cap, A, as indicated by the dotted lines. The aluminum cap, A, has a tinfoil ring, r, as that in Fig. 1, or else the metal of the cap is spun out on that place so as to afford a bearing of small surface between the metal and the glass. This is an important practical detail as, by making the bearing surface small, the pressure per unit of area is increased and a more perfect joint made. The ring, r, should be first spun out and then ground to fit the neck of the bulb. If a tinfoil ring is used instead, it may be cut out of one of the ordinary tinfoil caps obtainable in the market, care being taken that the ring is very smooth.

In Fig. 3 I have shown a modified design of tube. This, as will be observed, is a double focus tube, with impact plates or iridium alloy and an aluminum cap, A, opposite the same. It will be noted that the aluminum caps in the tubes described are fitted inside of the necks and not outside, as is frequently done. Long experience has demonstrated that it is practically impossible to maintain a high vacuum in a tube with an outside cap. The only way I have been able to do this in a fair measure is by cooling the cap by a jet of air, for instance, and observing the following precautions: The air jet is first turned on slightly and upon this the tube is excited. The current through the latter, and also the air pressure, are then gradually increased and brought to the normal working condition. Upon completing the experiment the air pressure and current through the tube are both gradually reduced and both so manipulated that no great differences in temperature result between the glass and aluminum cap. If these precautions are not observed the vacuum will be immediately impaired in consequence of the uneven expansion of the glass and metal.

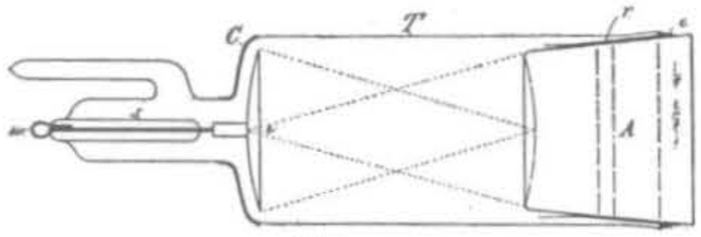


FIG. 2.

With tubes, as those described, it is quite unnecessary to observe this precaution if proper care is taken in their preparation. In inserting the cap the latter is cooled down as low as it is deemed advisable without endangering the glass, and it is then gently pushed in the neck of the tube, taking care that it sets straight.

The two most important operations in the manufacture of such a tube are, however, the thinning down of the aluminum window and the sealing in of the cap. The metal of the latter

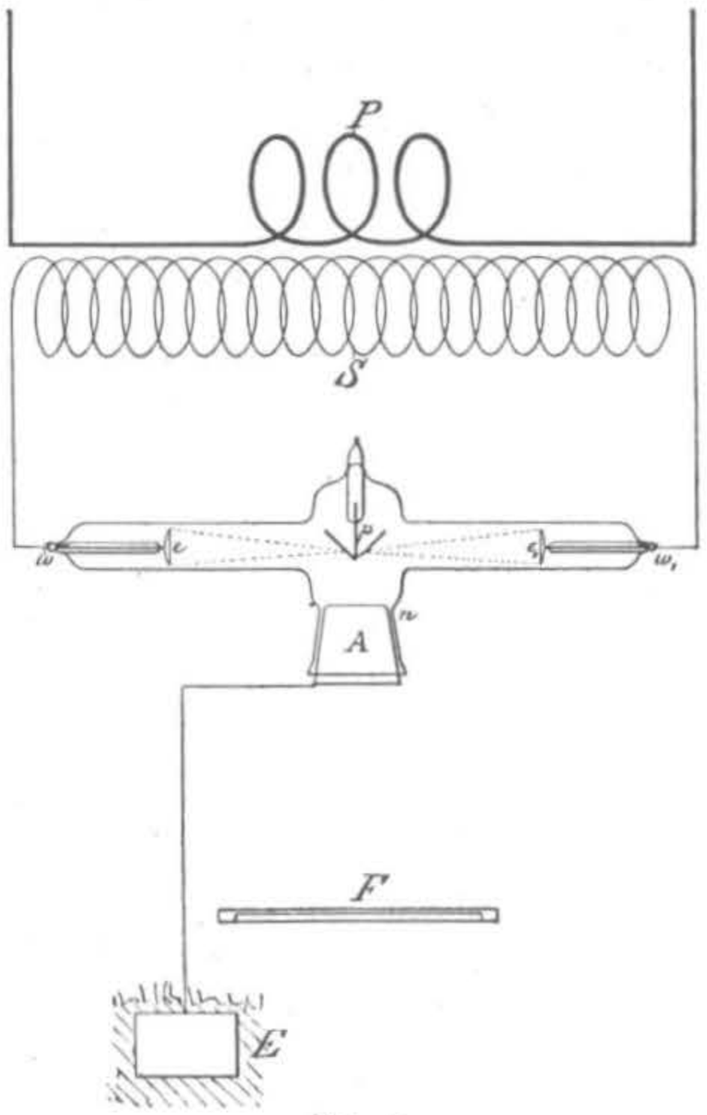


FIG. 3.

may be 1-32d or even 1-16th of an inch thick, and in such case the central portion may be thinned down by a countersink tool about ¼th of an inch in diameter as far as it is possible without tearing the sheet. The further thinning down may then be done by hand with a scraping tool; and, finally, the metal should be gently beaten down so as to surely close the pores which might permit a slow leak. Instead of proceeding in this way I have employed a cap with a hole in the center, which I have closed with a sheet of pure aluminum a few thousandths of an inch thick, riveted to the cap by means of a washer of thick metal, but the results were not quite as satisfactory.

In sealing the cap I have adopted the following procedure: The tube is fastened on the pump in the proper position and exhausted until a permanent condition is reached. The degree of exhaustion is a measure of perfection of the joint. The leak is usually considerable, but this is not so serious a defect as might be thought. Heat is now gradually applied to the tube by means of a gas stove until a temperature up to about the boiling point of sealing wax is reached. The space between the cap and the glass is then filled with sealing wax of good quality; and, when the latter begins to boil, the temperature is reduced to allow its settling in the cavity. The heat is then again increased, and this process of heating and cooling is repeated several times until the entire cavity, upon reduction of the temperature, is found to be filled uniformly with the wax, all bubbles having disappeared. A little more wax is then put on the top and the exhaustion carried on for an hour or so, according to the capacity of the pump, by application of moderate heat much below the melting point of the wax.

A tube prepared in this manner will maintain the vacuum very well, and will last indefinitely. If not used for a few months, it may gradually lose the high vacuum, but it can be quickly worked up. However, if after long use it becomes necessary to clean the tube, this is easily done by gently warming it and taking off the cap. The cleaning may be done first with acid, then with highly diluted alkali, next with distilled water, and finally with pure rectified alcohol.

These tubes, when properly prepared, give impressions much sharper and reveal much more detail than those of ordinary make. It is important for the clearness of the impressions that the electrode should be properly shaped, and that the focus should be exactly in the center of the cap or slightly inside. In fitting in the cap, the distance from the electrode should be measured as exactly as possible. It should also be remarked that the thinner the window, the sharper are the impressions, but it is not advisable to make it too thin, as it

is apt to melt in a point on turning on the current.

The above advantages are not the only ones which these tubes offer. They are also better adapted for purposes of examination by surgeons, particularly if used in the peculiar manner illustrated in diagrams, Fig. 3 and Fig. 4, which are self-explanatory. It will be seen that in each of these the cap is connected to the ground. This decidedly diminishes the injurious action and enables also to take impressions with very short exposures of a few seconds only at close range, inasmuch as, during the operation of the bulb, one can easily touch the cap without any inconvenience, owing to the ground connection. The arrangement shown in Fig. 4 is particularly advantageous with a form of single terminal, which coil is diagramatically illustrated, P being the primary and S the secondary. In this instance the high-potential terminal is con-

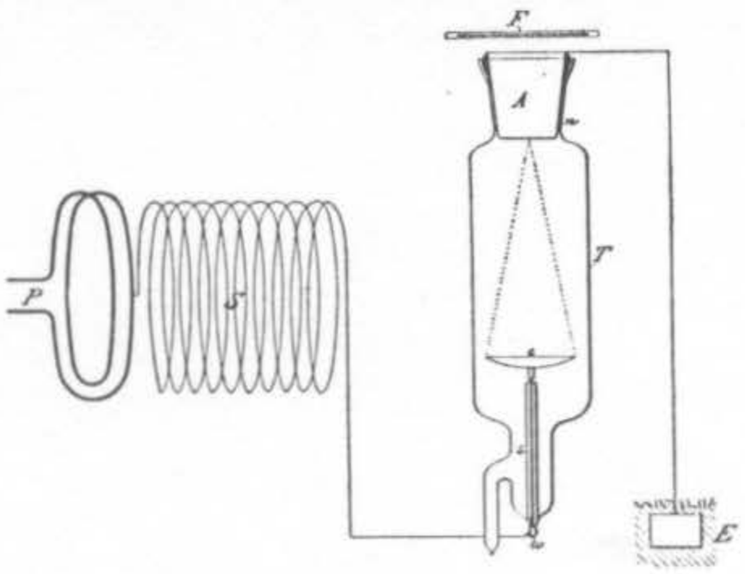


FIG. 4.

nected to the electrode, while the cap is grounded. The tube may be placed in the position indicated in the drawing, under the operating table and quite close, or even in contact with the body of the patient, if the impression requires only a few seconds as, for instance, in examining parts of the members. I have taken many impressions with such tubes and have observed no injurious action, but I would advise not to expose for longer than two or three minutes at very short distances. In this respect the experimenter should bear in mind what I have stated in previous communications. At all events it is certain that, in proceeding in the manner described, additional safety is obtained and the process of taking impressions much quickened. To cool the cap, a jet of air may be used, as before stated, or else a small quantity of water may be poured in the cap each time when an impression is taken. The water only slightly impairs the action of the tube, while it maintains the window at a safe temperature. I may add that the tubes are improved by providing back of the electrode a metallic coating, C, shown in Fig. 3 and Fig. 4.

NOTES.

Tesla Electrifies the Earth.—It is queer that the American inventors cannot dispense with sensational interviews. We sometimes are inclined to doubt whether an untechnical interviewer is always at fault. Thus the New York *Journal* announces the completion of Mr. Tesla's work for the transmission of messages from one point to another on the earth without the aid of wires. To give an idea of the high potential currents used in this work, he showed the interviewer a large disc, from the centre of which protruded a spherical electrode shooting forth long streams of ethereal flame. Mr. Tesla stated that the electrical disturbance thus created was felt throughout the globe.

TESLA, MARVEL OF THE WORLD.

Life, Habits and Philosophy of the Scientist.

SPENDS $15 FOR A MEAL.

He Has Never Married Because He Believes that a Woman Would Interfere with His Work.

NEW YORK, Aug. 20.—The name of Nicola Tesla has again flashed around the earth. He is the foremost man in the world. No human being has ever reached the pinnacle upon which he stands to-day.

Almost coincident with the announcement that he has solved the great problem upon which he has been at work for nearly seven years, comes the news that an Italian youth, Guglielmo Marconi, has discovered the means of telegraphing without wires.

The scientific world acknowledges the value of Marconi's invention. It admits its practical use. The same men who honor Marconi worship Tesla. Marconi has explained, and his methods are easily grasped. Tesla has simply said that he has accomplished his great work, and they believe.

Years ago those recognized as masters admitted that Tesla had no peer in abstract electrical research. To-day the most scientific, the farthest advanced, look upon him with rapt admiring eyes. That which he says he has accomplished seems like the dream of an intoxicated god. The most brilliant and wonderful flights of imagination become feeble and pitiful beside Tesla's facts.

When the young man announced publicly, about five years ago, that he believed the time would come when he would be able to transmit electrical vibration without wires, it was looked upon as a dream in nowise to be taken seriously.

The dream has become a reality. If any man knows the secret of the invenion by which the results have been accomplished he has guarded it closely. Tesla has given his word that it is so. The suspicious scientific world that demands convincing proof has taken his assertion, accepted it as a demonstrated fact.

The discovery of Marconi is admittedly one possessing enormous practical value. But it does not compare with the achievements of Tesla. Telegraphy is an unimportant factor in the great scheme. It is the transmission of power that is the vital principle.

With his machine he can disturb the electrical conditions of the earth, and make the electrostatic force do his will.

As he told one writer, he hopes to make Niagara Falls drive mills in New England, send ships across the sea, and transmit thought or information to the uttermost parts of the earth.

As to the working out of the mechanical part of the problem Tesla gives no information. It is a mere detail in his mind, something that any able electrical engineer can do. It is a trifle with which he has not time to bother.

The achievement carries with it another that has been more talked about, the making of light without wires. Tesla has produced a light that has all the brilliancy and qualities of sunlight. And it can be made cheaper than the ordinary electric light.

These latest wonders he has worked arouse an intense interest in the personality of the man. It is in keeping with his work.

TESLA'S EARLY LIFE.

The early facts of his life are well enough known. He was born in Smiljan, a village of perhaps forty houses, in Lika, on the borderland region of Austro-Hungary, of the Serbian race, which has maintained an unceasing struggle with Turkey for freedom. In his native language there are a hundred words for knife, and only one for mercy.

His father was an eloquent clergyman in the Greek Church, in which a younger brother is now a recognized force. His mother possessed extraordinary mechanical skill.

Nicola was intended for the priesthood. He passed four years in the public school at Gospich and three years in the Real Skule. Then he was sent to Carstatt, Croatia, where he spent three years in the Higher Real School, graduating in 1873.

He devoted himself to electricity and magnetism. His father consented to his taking a scientific course, and he entered the Polytechnic School at Gratz.

He was not yet 20 when he told his professor that it was possible to operate a dynamo without commutator or brushes, and he was laughed at as a foolish boy. But the time came when he made the rotating field principle an accomplished fact.

From Gratz he went to Prague and Budapesth to study languages, and to broadly qualify himself for his profession. He entered the Government telegraph department. Afterward he went to Paris, searching for more knowledge. He connected himself with an electric lighting concern.

It was while he was in Paris, in 1882, that he perfected the rotating field principle, which has had a profound influence upon dynamo electrical machinery. He purposed giving his discovery to the world. But wise business men, who learned of its value, urged him to first secure a patent. Tesla had no thought of a patent.

Americans whom he met in Paris urged him to come to this country. He acted swiftly. The day he arrived in the United States Tesla went to work in Edison's laboratory.

Afterward he became associated with different companies, which placed his inventions upon the market, for Tesla has made many which only electricians know about.

It was a little more than seven years ago that he established a laboratory in South Fifth avenue, in New York, and devoted himself to that research and experiment that is his joy and ambition.

HIS PERSONAL APPEARANCE.

These bald facts give little hint of the man himself. So far as personal appearance goes no one can look upon him without feeling his force. He is more than six feet tall and very slender. Yet he possesses great physical power. His hands are large, his thumbs abnormally long, and this is a sign of great intelligence. His hair is black and straight, a deep, shining black. He brushes it sharply from over his ears, so that it makes a little ridge with serrated edges.

His cheekbones are high and prominent, the mark of the Sclav; his skin is like marble that age has given the first searing of yellow. His eyes are blue, deeply set, and they burn like balls of fire. Those weird flashes of light he makes with his instrument seem also to shoot from them. His head is wedge-shaped. His chin is almost a point.

So much for the appearance of the man. Never was a human being filled with loftier ideals. Never did a man labor so unceasingly, so earnestly, so unselfishly for the benefit of his race. Tesla is not rich. He does not trouble himself about money. Had he chosen to follow in the footsteps of Edison he could be, perhaps, the richest man in the world, and Tesla is just 40 years old.

Tesla equipped himself with the best technical education that Europe and America could furnish. He mastered all that the men who had gone before him had accomplished. And all the while he reasoned for himself.

Nothing of importance that Tesla has discovered has been an accident. For a quarter of a century he has lived with his whole consciousness near the bosom of nature. He has wrested her secrets from her. He has learned the source of her power. Now he has harnessed it that man may be happier and better.

To the layman Tesla's life seems to be bound up in vibrations. Three or four years ago electricians declared that 300 a second was the limit. Tesla announced that he was sure he could obtain 30,000,000 vibrations a second. Already he has secured 50,000,000, and the end is far off. These figures show the relative position of Tesla and other electrical scientists.

The daily life of this man has been the same, practically, ever since he has been in New York. He lives in the Gerlach, a very quiet family hotel, in 27th street, between Broadway and Sixth avenue. He starts for his laboratory before 9 o'clock in the morning. All day long he lives in his weird uncanny world, reaching forth to capture new power to gain fresh knowledge.



NICOLA TESLA, THE WONDER WORKER.

No stranger ever sees him at his work. No one knows of his assistants. At rare intervals he presents some experiments in his laboratory, and there is no sacrifice that thousands of people would not make to gain admission to these.

Usually he works until 6 o'clock, but he may stay later. The absence of natural light does not trouble him. Tesla makes sunlight in his workshop.

At exactly 8 o'clock he enters the Waldorf. He is attired in irreproachable evening clothes. In the winter time he never wears an evening jacket, but always the coat with tails.

PAYS $15 FOR HIS DINNER.

He walks directly to a table in the farthest corner of the palm garden, which is reserved for him. He carries two or three newspapers in his hands, and one of these he perches before him.

No gourmet who dines at the Waldorf can order a better dinner than Tesla. It is an elaborate dinner of many courses. He drinks a fine Burgundy and a fine champagne, a quart of one and a pint of the other. His dinner costs Tesla never less than $15, and seldom more. It is practically the only meal he eats during the day. He never tips the waiter or the man who takes care of his hat and coat less than a dollar.

He finishes his dinner at exactly 10 o'clock, and leaves his hotel, either to go to his rooms to study or to return to his laboratory to work through the night.

Two or three times a week he will go to a barber shop. He demands that the towels and covering on the chair be changed, and does not object to the barber using the common mug and brush. He insists upon having his head rubbed for nearly half an hour.

These are the only occasions when Tesla appears in public. Perhaps two or three times a year some one may dine with him. He is a bold man who will dine with Tesla. If he has any sense at all he will realize that he can give the scientist not the slightest title of information about anything that interests him. And he cannot understand about what Tesla is talking for more than two minutes at a time. For this marvelous mind lives in a realm so weird and so awful that the ordinary intelligence draws back affrighted.

Tesla is, above all things, a serious man, undoubtedly the most serious man in New York. Yet he has a keen sense of humor and the most beautiful manners. He is the most genuinely modest of men. He knows no jealousy. He has never decried the accomplishments of another, never refused credit.

When he talks you listen. You do not know what he is saying, but it enthralls you. You feel the importance without understanding the meaning. He speaks the perfect English of a highly educated foreigner, without accent and with precision. He speaks six or eight languages equally well.

He speaks constantly about electrostatic force, that mighty power which he has chained at last. And this he has explained.

"Electrostatic force is that which governs the motion of the atoms," he said when he was asked about it. "It is the force which causes them to collide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an infinite variety of ways, according to Nature's fanciful designs, and form all these wondrous structures we see around us. It is, in fact, if our present views be true, the most important force for us to consider in Nature."

WHY HE HAS NOT MARRIED.

Tesla has never married, and it is not likely that he ever shall. His father and mother are both dead. His brothers are in his native land. Tesla is an American citizen. It is not likely that any child shall bear his name in this country. He has elected to devote his whole life to his work, and for this reason he is denied the love and companionship of a good woman. And this, too, he has explained.

"I believe that a writer or a musician should marry. They gain inspiration that leads to finer achievement.

"But an inventor has so intense a nature, with so much in it of wild, passionate quality that, in giving himself to a woman, he would give up everything, and so take everything from his chosen field. It is a pity, too; sometimes we feel so lonely."

But the inventor who succeeds has his recompense, and this also has Tesla spoken about.

"In my student days I have known what it was to pass forty-eight hours at a stretch at a gaming table, undergoing intense emotion, that which most people believe is the strongest that can be known, but it is tame and insipid compared with that sublime moment when you see the labor of weeks fructify in a successful experiment that proves your theories."

Many times has Nicola Tesla known that supreme happiness. And he is likely to know it often again. It is impossible that his life work can be finished at 40. It would seem that his powers are only reaching their maturity.

No man has ever occupied the place that he has, for he is not only an uncrowned king of science, he is not only the deepest, more original investigator; he is a real discoverer of wonderful forces, and inventor of the harness to control them, and, in addition to all these things, he is a seer as well. And only the ignorant have courage to scoff at him.

FRANKLIN CHESTER.

ELECTRICITY DURING THE LAST FIVE YEARS.

BY FRANZ BENDT.

TRANSLATED FOR "THE CHAUTAUQUAN" FROM THE GERMAN "UEBER LAND UND MEER."

IT is mostly through its practical results that a science appeals to the general public for anything more than a casual attention. This fact is nowhere more noticeable than in electricity, which has loaded humanity with gifts and in a comparatively short time has revolutionized customs and business so that the present era not unjustly has been called "the age of electricity." The term is doubly appropriate because, as all signs indicate, we are not at the end but only just at the beginning of the electrical epoch. Moreover, it should be noted, the wonderful and mysterious manner in which the electrical forces are manifested have thoroughly aroused astonishment, even in adepts, and a thirst for knowledge in the laity.

In glancing over the many practical acquisitions of the young science one gets the impression that for its years it has developed strongly and powerfully, if also disproportionately. Yet many branches of the electrical science have broadened out into mighty industries. Its practical side, electrotechnics, already has been divided into two parts, the weak current and the strong current technics, and the exponents of these two parts belong to different classes of vocations hotly rivaling each other.

A brief forecast of the history of the science will help us to appreciate its development during the last five years.

The oldest branch of the new technic does service in propagating news. It is now about seventy years that its electric spark has carried messages across oceans and over wide continents. The amount of lines and conducting wires connected with them is at the present time something imposing, and not less so is the growth that both have shown from year to year. Altogether the wires would reach about five times from the earth to the moon.

Yet more marvelous than the development of telegraphy is the development of long-distance speaking, or telephoning, already a dangerous rival to telegraphy. We are about to enjoy an extension in both lines of culture here on German soil. At the present time there are in the German Empire 93,768.46 miles of lines and 440,682.44 miles of conducting wires to convey written and spoken messages. The number of telegraph stations here is 28,281. Especially significant is the growth in the number of city telephone stations; during the last year their number has increased from 109,960 to 125,810.

The technical improvement in this region

is evidenced by the development of new telephone lines to connect cities. The longest line in Germany is found between Berlin and Memel, extending over the remarkable distance of 621.37 miles. The great distance cannot influence the audibility, for the hearing qualities are excellent. During the preliminary experiments for the laying of these connections, the experts at the German imperial post arrived at the important judgment that this line might be lengthened about threefold without injury. If they succeed in establishing communication over such a long distance, the feat will place German telephone engineers at the head of their profession, for telephonic transmission over 1864 miles never before has been accomplished except by way of experiment.

The sea cable also is a modern development, and to its possibilities, too, there is no limit. At present experts are engaged in the task of laying its conducting wires through the great ocean. Then, with the perfection of this gigantic plan, one can send a despatch around the whole world in a moment. The circuit will be complete.

While the weak current technics has consumed almost two thirds of a century in her upbuilding, her younger sister, the strong current technics, in a comparatively short time has grown into a giant. What about five years ago was mere project now is actual fact. We need mention only the extension within this time of the electrical railway.

The special problem of strong current technics was, how practically to work out methods for transmitting power. They arrived at a definite solution of this problem in the year 1891, at the electrical exposition in Frankfort on the Main, when they succeeded in leading from Lauffen on the Neckar to the exposition city their current, by means of the electric motive conductor. Since then, the hopes which were built on this solution have for the most part been realized.

One of the greatest of these outcomes, that already is much talked of, we admire in the plant for transmitting power from Niagara Falls. Of the 5,000,000 horse-power which these greatest falls of the world exert every minute, 15,000 are diverted and put to use through a region fifteen and one half miles in radius. Buffalo, for instance, which lies within the circumference of this circle, owes its light and its business power to its electrical career at Niagara Falls.

On German soil, too, and especially in the Rhine regions, similar plants at this moment are in progress of building. By means of powerful turbines they aim to draw from the Rhine about 10,500 horse-power and to send them, by means of an electric motor, to cities and factories in all directions within a radius of twelve and one half miles.

It is obvious that power transmitted in such quantities can be sold cheap. Already its price has caused a depreciation of about thirty per cent in steam machinery. Carefully planned improvements and centralization in such an industrial district are the best methods to increase the wealth of a country and to add to the prosperity of its inhabitants. The industries of the upper Rhine, for example, previously enjoyed only a mere existence, because their life element, coal, had become exhausted. The electrical current which the new plant will send out will be able, without doubt, to convert the Rhine region establishments into places of business activity.

Already modern methods of power-transmission are beginning to make their way even into that conservative branch of industry, agriculture. Lately at Dietrichshagen, in the vicinity of Rostock, in experiments before the representatives of the Prussian ministry of agriculture, it was demonstrated clearly, time and again, that in this business one could work more cheaply by the use of mechanical than of animal power. The significance of this is plain to be seen when it is considered that in the cultivation of the soil in Germany there are employed about 2,500,000 horses and 500,000 draught oxen. According to the reckoning of most competent business people, German farmers could aggregate a yearly saving of 210,000,000 marks, or $49,980,000, by the general use of mechan-

ical power. The experiments at Dietrichshagen led to the conclusion that by the use of electrical power-transmission and its application in electrical plows one could cut down expenses fifty per cent. The conclusion would take on a still more favorable appearance if this power, always ready for work, should find application to other purposes, such as running sugar factories, and the farmer should utilize for the production of electric currents the energy that nature places at his disposal in the form of falling or flowing streams.

In the large cities, too, they already use the electric current very effectively in the trades. The electric stations which were set up there for the generation of light also furnish currents for power, and a considerable number of working establishments have furnished their machines with it at a comparatively small cost.

Since this has been done the mighty electric current has stood at the service of the investigator as well as the tradesman everywhere, and great strides have been made in the application of the remarkable power. Thus within a few years new scientific results have developed which, such as electrochemics, for instance, have influenced the authorities to establish special chairs of learning in the high schools. Electrochemics has arisen from the union of electricity with chemistry. Until shortly ago the combination and separation of substances was effected by a comparatively weak current at a low temperature. A world of new phenomena opened to the investigators when they attacked the physical world with powerful currents and the previously unheard-of high temperatures. These multitudinous scientific conquests are made applicable through the methods of power-transmission to industrial uses, and prove valuable acquisitions to all manufactories.

One of the most fortunate discoverers in the realm of electrochemics, whose results are peculiarly adapted to rouse interest in wide circles, is Henry Moissan of Paris. With the force of the current he conquered fluorin, which most stubbornly of all the elements has resisted isolation, and presented it, free of all combinations, to the eye of the investigator—the first time it ever was seen in a free state. In his electric oven he crystalized coal to diamonds, and gold, copper, and resisting graphite were neglected and melted down into the form of little scales. These and similar experiments give an important idea of the almost creative power that the strong current lends humanity over material.

Besides such new knowledge, electrochemics has ripened the prominent practical results and has placed others nearer attainment. The extraction of the far-famed aluminum from clay takes place almost immediately under the influence of the powerful current. In like manner soda is formed from kitchen salt almost without expense if you take into account the value of the important second product. Electricity has been used successfully also to purify streams and rivers and to free them effectively from the death germs most inimical to humanity, such as cholera, typhus, malaria, etc.

Such wonderful properties explain why among the laity so often the question arises, What is electricity? Yet a few years ago a physicist would have had to stand abashed, for he knew no more of the mysterious sphinx than the questioner. Now the question can be answered, if not wholly, at least in part.

During the departing century natural philosophers have arrived at the knowledge that light and radiating heat are caused by swinging motions of a fine substance called ether. That electrical phenomena demanded a similar explanation was undoubted by every intelligent physicist; but the remarkable form of energy stubbornly refused to divulge its secret. The German physicist Heinrich Hertz first lifted the veil and showed that electricity spread out into space in waves 39.37 inches (a meter) long. This finally led to the proof that all force was expressed in the form of the billowy movements of ether. The only difference between light, radiating heat, and electricity in appearance is in the length of their respective waves.

On the theoretical judgment that electrical waves roll out into space, Nikola

Tesla built up his experiments, which afford interesting glimpses into the future development of electrotechnics. Only consider what an advantage would be gained, if, without intervening wires, verbal or written messages could be sent over the wide world, if, without cables, currents could be conducted, lamps fed, and especially if electrical energy could be made to go in whatever place one desired. To make that possible is no longer the wish of a fruitless fancy, but already has been partly realized. Thus Tesla has made tubes a meter long light up brightly without connecting them anywhere, and Preece in London has telegraphed several miles through sea water without any cable.

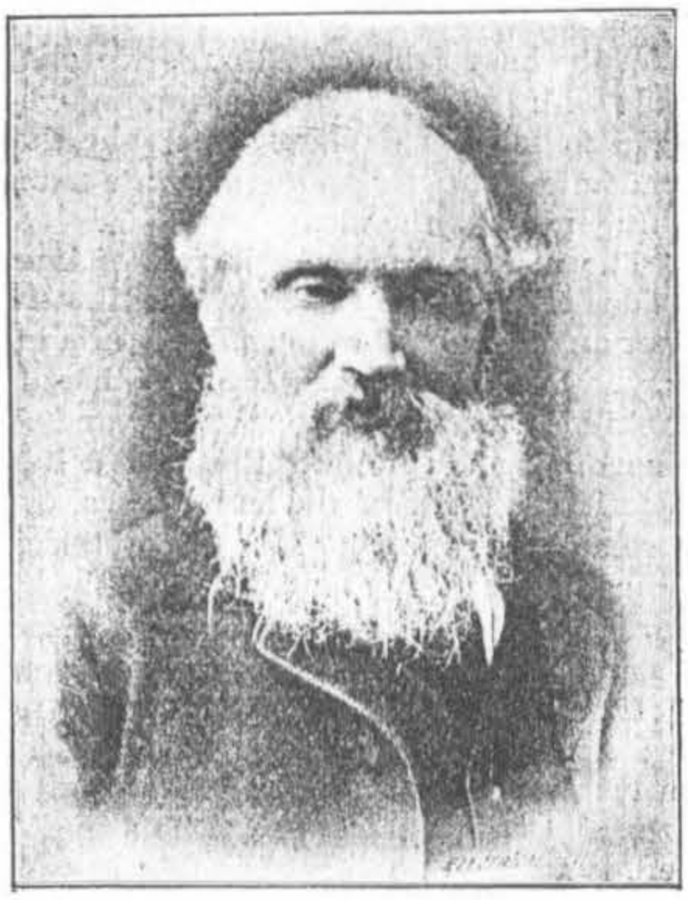
In order to excite the remarkable light tube Tesla makes use of a peculiar machine, which conducts the so-called alternating current at a high speed of alternations. With this he made observations on wonderful phenomena. It is pretty generally known that alternating currents are dangerous; in fact they already have cost many human lives. Through the use of an ordinary machine for alternating currents, all organic life may be annihilated. But the immeasurably stronger and faster alternating Tesla current does no harm whatever to animals and people by passing through them. For instance it was found that dogs subjected to a current that made 4,500 alternations in a second were not disturbed, while an equally strong current of 120 alternations killed them. By further experiments on animals Professor Houston arrived at the general knowledge that with the increase of alternations—from a certain limit up—the danger from the currents diminishes and the effect even becomes beneficial. When the number of alternations is increased until they equal those of the waves of ether, which brings down the sunlight, they are able to exert on the surface of the body the same beneficial effects as ether. In fact Tesla has set out to use his current for remedial purposes.

Only shortly ago Roentgen's marvelous discovery gave us a new outlook on the phenomena and results of nature's forces. So great an impression has it made upon us all that it is almost unnecessary to dwell on the peculiar X-rays, invisible in themselves, that expose to view the interior of opaque bodies, and on the practical results to which already they have given place and which are yet to grow out of them. These things have been set forth at length in the journals during the last year, and for months have occupied whole columns of the newspapers. Yet we here may mention the greatest theoretical importance of the Roentgen discovery. It has shown that the X-rays are manifested through the wave motions of ether and that these waves are the smallest that ever yet have been observed.

SCIENCE

AN EMINENT VISITING SCIENTIST.

LORD KELVIN, better known as Sir William Thomson, for he was sixty-eight years old and had many years of scientific eminence behind him when he was raised to the English peerage in 1892, arrived in New York recently, on his way to the meeting of the British Association in Toronto. He was met, of course, by a number of reporters, and said the usual polite things in the resulting interviews. More interesting than these is the opinion of the great English scientist expressed by Nikola Tesla, as reported by James Creelman for the New York *Journal*. Said Mr. Tesla:



LORD KELVIN.

By courtesy of *The Electrical Review*.

"One of the reasons why I do not like to speak of Lord Kelvin is that I can not find words to express my admiration for the genius of this remarkable man, and my gratitude for what he has done for humanity at large, and for those who, like myself, are following some of the paths he has opened. He occupies a unique position in the scientific world, not only by reason of his achievements, but also by the fact that he has been active and productive during a period seldom allotted to workers in scientific fields. Usually the efforts of the mind prematurely consume the man. But in a few cases, occurring now and then in a century, an exceptionally gifted and vigorous personality appears and leaves an impression which lasts for ages. Lord Kelvin is such a man. But not only is this true of him, but he has also, what few great scientific men have had, a lovable nature, which years have only broadened and intensified.

"His mathematical essays on electricity, magnetism, and heat almost stand alone, veritable monuments. The practical public can better appreciate a part of what he has done when I say that for the past fifty years we have been depending on instruments invented by him for the measurement of a great many quantities, and it is impossible to estimate the benefits to science which have come from his instruments, which even now are used in every scientific laboratory in the world. He has given us the perfected mariner's compass, and just imagine what this has done for navigation and commerce; and in ocean telegraphy he has given us the delicate instruments which are now used for recording messages under all the seas.

"If he were a young man, we might express admiration for his achievement, but his age has almost given sanctity to the eminence of his position."

This is Lord Kelvin's second visit to America, as he was here in 1884, at the Montreal meeting of the British Association. He read a paper at the recent Toronto meeting.

"WE recorded last spring," says *Science*, "the sale of a great auk's egg for £294. Tho the subject has, perhaps, no greater scientific interest than that of the sale of a rare postage-stamp, it may be noticed that another of the eggs, slightly cracked, has been sold in London for £168. The purchaser, Mr. Middlebrook, has now three specimens in his collection."

THE SUNDAY World's MAGAZINE

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A WOMAN Who Owns Her Own Zoo
IN THIS ISSUE OF THE
The Sunday Magazine.

MAN MAY BE MADE TO LIVE 1,000 YEARS.

Prof. Virchow's Splendid Vision of a New Race of Methuselahs.

How the Physically Perfect Man Might Be Bred.

Nearly 4,000 Centenarians Now Living in the United States.

CAN man be made to live forever?

If, by careful living, men can reach the age of one hundred years, why cannot life be prolonged still further?

Science is holding out the hope that the prophecy of Scripture may be fulfilled—that man's last enemy, Death, may be vanquished and human life be prolonged indefinitely.

The remarkable statements made by Prof. Virchow and Nicola Tesla, which are printed on this page, point directly to the possible restoration of the marvellous human age limits recorded in the Old Testament, when the patriarchs, like Methuselah and Noah, lived nearly one thousand years. What man has done in former ages he may do again. He may even transcend it, for man's knowledge of the mechanism of his own body, of its chemical constitution and processes, and of all the diseases that assail it, is incalculably greater now than in the days before the deluge.

Prof. Virchow's recent declaration is startling indeed. He told the International Congress at Moscow a few days ago, in substance that he believed the last secret of life, how to keep life alive and defend it against the assaults of disease effectively and for an indefinite length of time, extending over centuries, would be discovered within the life-time of many members of that Congress.

This is a sublimely grand vision—man storming the mysterious citadel of his own existence, robbing the King of Terrors of his crown, and renewing his youth at will from century to century by the application of his own knowledge of life's inmost secrets.

Not only does Virchow declare his belief in the solution of the problem of keeping human life alive by arresting the processes that now destroy it within a little more than thirty-three years, on an average, and within a century at the most, but Tesla indicates how it will be done. The microbe is the enemy to be destroyed. The destruction of the microbe in all its forms is already being planned and plotted for in all the scientific laboratories of the world.

When the detection of all the disease-breeding bacilli is made easy and certain—and that will be done within a few years—Tesla tells us that the rest will be simply the work of each individual man and woman. The intermarriage of the physically perfect will, in Tesla's judgment, provided the perfect types of humanity thus married observe strictly the laws of health, result in producing a race of men who "will live and retain their faculties for centuries."

That human life may be prolonged very far beyond the limit of years now accepted as usual and inevitable is not indeed a matter of speculation. The average length of human life has already been notably increased within the past thirty years. The death rates of all civilized countries has been going steadily down. Fewer people died per thousand this year in New York City, for example, than died here in 1887. The same is true of London, of Paris, of Berlin and Vienna. Sanitary precautions, health laws, hygienic discoveries of various kinds have done this.

And while the mass of people are living longer on the average, it is remarkable how frequently more than centenarians are reported as having just died in different parts of the world. To live to be one hundred years old is no longer to be distinguished. Especially is the United States a centenarian country. Human century plants are fast becoming commonplace individuals in the land.

4,000 AMERICAN CENTENARIANS.

The census of 1890 disclosed the fact that nearly 4,000 persons were living in the United States, every one of whom was more than one hundred years old. In Massachusetts alone there were, in the ten years ending with 1890, 203 deaths reported of persons who had all lived more than a century. That showed the one-hundred-year limit of life to be already attained in that State by one in every 1,300 of its population. Iowa reported 500 persons living in the same year at ages above ninety years, and twenty-one persons who had passed their one hundredth birthday.

The British Registrar-General's returns show that in 1891 twenty-one persons were living in London aged upward of one hundred years each. Haller, a famous statistician, collected the figures on this subject for all England a few years ago, and within its boundaries he found authentic records of 1,000 persons who had lived from 100 to 110 years, 60 persons who had scored between 110 and 120 years, 29 who had lived from 120 to 130 years, 15 who had reached ages from 130 to 140 years, 6 who had attained ages from 140 to 150 years, and 1 person who had actually celebrated the 169th anniversary of his birth.

Already, then, we are living in a time when one hundred years is proved to be an easily attainable age, provided the candidate for centenarian honors is of sound hereditary constitution and observes the rules that prolong life.

What Virchow and Tesla hold out to us as a possible scientific realization of the near future is that, with perfected means for the detection of the slightest assault by their microbic enemies upon the blood and tissues of the human body, and men and women willing to live on strictly hygienic principles and bring children into the world, life may be indefinitely prolonged.

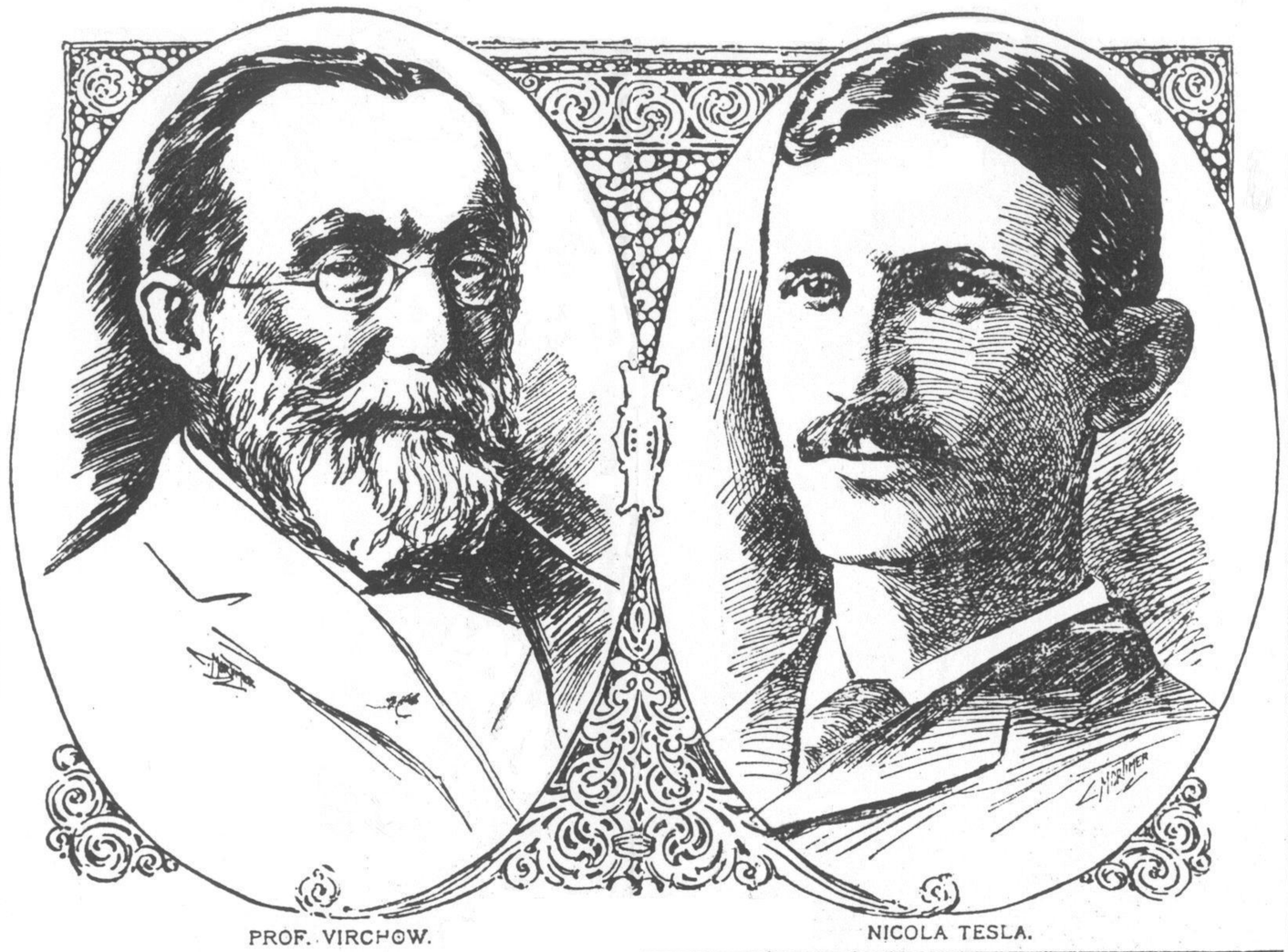
Virchow has declared that all life comes from the cell. No living man has studied more deeply the phenomena of life—its beginning, its growth, its culmination and its final decay and death. John Hunter, his celebrated forerunner in this field of inquiry, closed his researches by saying, "Every living thing comes from an egg." Virchow says: "All life comes from a cell."

Everything that lives, whether it be a plant, a tree or an animal, begins its life in a cell, and is built up of cells, each separate cell having a distinct life of its own. "I have been able," says Virchow in a lecture before the Royal Society of England, "to demonstrate the existence of cells in those parts where their presence appeared most doubtful—in bone and connective tissues, and have been able to give utterance to the dictum, omnis cellula a cellula, (every little living cell came from a pre-existing, living cell). The cell is the seat and vehicle of disease, the seat and carrier also of individual life. It possesses the property of irritability, and the changes in its substance, providing these do not of themselves destroy life, produce local disease."

From this demonstration it follows that if Virchow's latest prophecy comes true, and the principle of cell life is finally discovered, man will know how to "keep life alive" by reinforcing it with new life, just as a declining fire is reinforced with new fuel. The life-time of an approximately perfect human body, bred from previous approximately perfect human organizations, may then be extended, at first from periods of from twenty to fifty years, beyond the 100 years already frequently attained.

Then, as the careful reproduction of approximately perfect men and women proceeds, each successive generation will approach more nearly to perfection—with sounder vital organs, purer blood, stronger bones, and a physical equipment in every respect more durable.

(Continued on Page 26.)



PROF. VIRCHOW. NICOLA TESLA.

Nicola Tesla Says Perfected Men Might Live for Centuries.

All Life Is From a Cell and All Death From Microbes.

The Classic Types of the Sculptors Can Be Surpassed.

TESLA SAYS MEN MAY YET LIVE FOR CENTURIES.

"THERE is absolutely no doubt in my mind that the latent power fully exists in man to greatly prolong the average length of his life by the exercise of extraordinary care and the proper utilization of the various instruments which science, day by day, is placing at his disposal. A large proportion of the people who die nowadays before reaching what is commonly called old age can trace the cause of their death to the fact that microbes of every kind are allowed by them to enter their bodies through the swallowing of microbe-laden water and food and through the inspiration of microbe-laden air. How many people are really careful to-day about the water they drink, the food they swallow and the air they breathe? And how many millions of people would be careful if they knew the difference between microbe-laden food and air and those which are really pure?

"Now, instead of whole armies of us plunging into the disgraceful and contemptible task of killing each other in battle, instead of thousands of our master minds spending all their lives in the invention and construction of some terrible machines to kill other human beings, why should not all of us join hands together and shoulder to shoulder turn all our physical and mental energies to killing and warding off all our common enemies and dangers as men? I refer to the perils that are all about us, that threaten us in the air we breathe, the water we drink and the food we consume.

"Is it not strange and shameful that human beings, creatures in the highest state of development in this world, beings with such immense powers of thought and action, the masters of the globe, should be absolutely at the mercy of our unseen foes, that we should not know whether a swallow of food or drink brings us joy and life or pain and death?

"The economical production of high-frequency currents of electricity, which is now an accomplished fact, enables us to generate easily and in large quantities ozone for the disinfection of the water and the air, while certain novel radiations recently discovered give hope of finding effective remedies against ills of microbic origin which have hitherto withstood all efforts of the physician.

"Let the whole world turn against our real foe—disease. Then, with the certain discovery of hundreds of such secrets as the Roentgen rays in their various forms, and countless other means of detecting the presence of bacilli and microbes in the blood, the disordered conditions of the tissues and vital parts, with the legal intermarriage of only such as are physically perfect down to the smallest detail of tissue, blood and bone, and with the proper observance of the laws of health, it is by no means too much to expect that man can ultimately prolong the average length of his life to one hundred years. I believe we are learning to live more intelligently every year. It is very gratifying, for one thing, to find that children are being brought up more carefully than ever before. I believe that with the most careful scientific marriage a race of men and women may in time be developed in which individuals will live and retain their faculties for centuries."

VIRCHOW BELIEVES THE KEY TO LIFE WILL BE FOUND.

"LIFE has no other origin than life itself, and this is one of the great truths which the labors of pathologists and biologists of the present century have established beyond the possibility of a doubt. If the life that is taken from life is taken from a highly-developed life so will be the life that is taken. My earnest hope and belief is that the final mystery of life, the key to life, the principle which keeps life alive, will be solved by the biologists and pathologists before all the members of the present Congress are dead."—Prof. Virchow to the International Congress at Moscow, Aug. 19, 1897.





A PERFECT WOMAN'S PROPORTIONS.	
Height	5 ft. 6 inches.
Width of neck	4 inches.
Width of shoulders	14 inches.
Width of chest between the arms	8 inches.
Fullest width of waist	10½ inches.
Width of hips at front	13 inches.
Front width of leg just above the knee	11 inches.
Front width of calf	11 inches.
Front width of ankle	2½ inches.
Weight	140 pounds.

A PERFECT MAN'S PROPORTIONS.	
Height	6 ft. 2½ inches.
Girth of chest	46 inches.
Girth of waist	38 inches.
Length of upper leg	17 inches.
Length of lower leg	14½ inches.
Largest girth of thigh	2[illegible] inches.
Girth of calf	16 inches.
Length of arm	26 inches.
Weight	190 pounds.

EMINENT SCIENTISTS DECLARE THAT THERE IS NO LIMIT TO THE LIFE OF HUMAN BEINGS.

(Continued from Page 25.)

In this way the perfected men and women of the coming age, foreseen by Virchow and Tesla, will be born with a much longer lease of life to begin with—built to live 150 years.

Assume that these perfected types of human life avoid all disease-inducing habits and practices, live temperately in all things, make no drafts of folly on their stock of vital energy, and call to the protection [illegible]ore of life all the resources of the latest scientific [illegible]veries. Koch and his school have shown how all malignant disease proceeds from bacilli. Diphtheria, typhus, cholera, the plague, consumption and all the other dragons that destroy human life are simply so many species of bacilli.

THE NEW SEARCHLIGHT.

The X ray permits the inmost secrets of the body to be undovered. With its aid the first appearance of the assailing microbe will be easily signalled. Under its searching light the earliest symptom of functional disturbance will be apparent. And every physician knows that men die by thousands daily simply because their internal maladies were not discovered in time to make resistance successful.

"All life is from a cell," cries Virchow. "All death is from a bacillus," cries Koch. To discover how the life principle of the cell may be fed and renewed is one-half of the problem of making men live three, four, five or ten times as many years as they do now. Virchow believes that half of it will be solved within the lives of many men now living.

The other half of the problem is how to detect and destroy the attacking bacillus and thus baffle death. And half of that half-problem is already solved. Those who are familiar with the results reached by expert horticulturists in the perfecting of plants by careful selection of seeds, so that marvellously beautiful flowers have been at length evolved from continually improving growths, will easily believe that whenever men and women in any considerable number choose to enter the marriage relation with the studied purpose of producing more perfect types of humanity, startling results will be gained. If they and their children and their children's children shall continue to blend the science of health with the sentiment of love, the result, in the course of time, would surely be the appearance of a distinctly higher and nobler order of men and women of such splendid stature and perfectly proportioned bodies as would surpass the loftiest conceptions of human strength, symmetry of limb and beauty of face, which the sculptor's inspired chisel has embodied in the marbled gods.

POSSIBILITIES OF SCIENTIFIC PARENTAGE.

The lesson of the scientific methods of stock raising by which cows and sheep, stronger, larger-limbed and longer-lived that our fathers ever saw, and horses capable of speed performances such as they would have said were beyond the bounds of possibility, are all hints in the same direction.

To state the problem in arithmetical shape: If Thomas Parr lived 152 years, his lifetime stretching across three centuries, from the fifteenth to the seventeenth, in an age that was unsanitary and unscientific, when the hundred and one aids to long life and defenses against disease and death which are at our service to-day were unknown and undreamed of, how long might a human life of strength originally equal to Parr's, derived from several generations of constantly perfecting human types, be made to last, when Virchow's promise has been realized and the principle of reinforcing life has been discovered on the one hand, and Koch's promise or immunity from microbes has been fulfilled on the other?

Clearly, if Parr, in the darkness and ignorance of the fifteenth and sixteenth centuries, the days of the Great Plague, when pestilence stalked the earth unchallenged, was able to achieve 152 years, the perfected man of the twentieth century of light and science may be expected to easily reach 200 years, and advance by natural stages of improvement, until the man who lives 500 years will be no more celebrated than Thomas Parr is now.

SULLIVAN'S DEFECT AS A PHYSICAL MODEL.

The process of improving the human type by reproducing it from the most perfect types, the improved types in their turn peopling the world with yet more nearly perfect types, will have as its natural starting point the most ideal type of the physical man of which we now have knowledge.

This is a matter of proportionate measurements, which the authorities on the human form have definitely laid down. The figure of the most ideal man yet developed—a foreshadowing of the perfected man who is coming—is shown on this page. It is adapted from the famous statue of "The Boxer," by the sculptor Donoghue. It was modelled, as to the body, from John L. Sullivan in his best form. But the legs are not those of Sullivan.

Dr. Oliver Wendell Holmes, who inspected Sullivan about that time, and whose anatomical learning was second to that of no man of his time, pronounced him to be a model of form—except as to his legs. They were too small. The legs were modelled, strange to say, from those of a bantam-weight boxer, who weighed sixty pounds less than Sullivan—Johnny Murphy—long known as Harvard's favorite boxing instructor.

IDEAL MEASUREMENTS.

The measurements of Corbett at twenty-seven years of age may be cited as those of one of the approximately best human physiques living to-day. Standing 6 feet 1 inch in his bare feet, he weighed 185 pounds. His neck measured 17 inches, his chest 38 inches, expanding to 42¼ inches; his waist 33 inches, his thighs 21 inches, his calves 14½ inches, his arms outstretched gave 6 feet 2 inches from finger-tips to finger-tips, his biceps measured 14½ inches, his forearm 11½ inches, his wrist 6¼ inches; his glove size was 8, his hat size 7½ and his shoe size 8. Yet he was not precisely proportioned.

It is doubtful if any man living exactly meets all the measurements that make a perfectly proportioned man. Somewhere in his make-up there is a defect, a surplus inch or an inch lacking. We shall have to wait for the perfectly proportioned man until the visions of Virchow and Koch and Tesla are all fulfilled, and the production of higher types from high types, and higher yet from the higher thus created, and so on, has culminated in the man and woman filled with health, proof against disease, of exactly proportionate measurements, and possessing the secret of keeping life alive, fitted to live for four or five centuries.

THE LATEST ANTI-GERM DISCOVERIES.

Within the past fortnight two new scientific appliances have been announced which will make it easier for the coming man to grow proof against microbes and measure his years by hundreds. Dr. Robert Xavier Glering, of Baltimore, has found a way of using X rays so as to obtain photographic pictures, not merely of the bones of the body, but of every tissue in the body, in detail—all its muscles, interior organs, blood vessels and nerves. No symptom of disease can evade this photographic test. Dr. Robert L. Watkins, of this city, at the same time announces the invention of what he calls the micromotoscope. With this instrument, a combination of the microscope and the vitascope, the presence of any bacilli in the blood can, he asserts, be unerringly detected. Such inventions herald the age when disease will not be cured, but prevented.

Dr. Howard Lilienthal, of No. 111 Madison Avenue, consulting physician to Mount Sinai Hospital, discussing Virchow's prophecy says: "Any new apparatus or method which will enable physicians to discover the presence of curable diseases earlier than the present methods do, will undoubtedly result in the prolongation of human life. Still, it is rather too early to decide the amount of good done to medicine by the newly announced apparatus of Dr. Glering, of Baltimore, and Dr. Watkins, of this city. We should wait a little to see if they are really practical. I do believe, however, that it is only a question of a few years when science will place in the hands of man appliances like the X ray which will enable him to prolong his own life for no inconsiderable period.

"Only last week I was reading a book of Gould's and was simply astounded to find in its pages a long list of men and women who had been known by the author to have lived to the ages of 150 and 175 years. Certainly if the people mentioned by Gould could live to the age of 175 without the aid of such scientific appliances as the X ray it is only reasonable to expect that others can live just as long, if not longer, if they have placed in their hands the apparatus without number which are sure to be discovered in the years to come.

"It will no doubt surprise the world at large to learn that Virchow, the greatest living authority on all medical matters, and who is President of the International Association of Surgeons, which has just concluded its big congress at Moscow, is reported by the Medical Record to have said in his address to that body that he firmly believes the time will come when man will learn the key to prolonging life, and that he (Virchow) is inclined to believe that as soon as the twentieth century that one great secret of life will be laid bare by the men of science."

WHAT DR. CYRUS EDSON THINKS.

Dr. Cyrus Edson says: "While I believe that microbes are not such an unmixed evil, in that they serve to kill out the physically and mentally weak, I believe, nevertheless, that the discovery of such appliances as those attributed to Glering and Watkins, if they can ever become practical, will be the means of lengthening human life enormously.

"I think that Tesla goes to rather an extreme and looks too far into the future when he says that men can ultimately live so long, but I do believe, also, that in a few generations a large number of appliances will be discovered, each of which, doing its little share, will serve to place it within man's reach to lengthen his life by fifty years, or even more. But when I say this I want it understood that the appliances can serve to lengthen the lives of those only, and none others, who will devote themselves from the beginning to strictly sober, temperate lives, entirely free from the vices which are now so common.

"Even at the present day any physician can enormously lengthen the life of any physically perfect man who will agree to abstain entirely from intemperate and vicious habits. The difficulty is to find the man who is willing to sacrifice his inclination for vice to his mere wish to live a long life. But, given a man and woman who are willing to devote themselves to such purely hygienic lives, and whom these appliances show to be minutely physically and mentally perfect, their offspring will be healthier than the average man, and consequently longer lived."

A WOMAN PHYSICIAN'S THOUGHT.

Dr. Donohue, the clever woman physician-director of the New York Hospital for Women, at No. 213 West Fifty-fourth street, and who is a daughter of the late celebrated athlete, Capt. Donohue, of Newburg, says:

"The mere discovery of these various appliances like the X-rays, and those of Drs. Glering and Watkins, if they are practical, will unquestionably give the medical man better opportunity of locating and diagnosing diseases of all kinds. But these discoveries for the locating of diseases will not in themselves so materially serve to lengthen human life. If we will set to work and, after perfecting apparatus to detect disease in such obscure and little known places, invent means of curing the diseases we have so cleverly located, then unquestionably the man who leads a temperate, non-vicious life can prolong that life indefinitely.

"If we could make it possible to allow only the intermarriage of such persons as are shown by these means to be really physically perfect, down to the smallest detail of tissue and blood, then it is more than likely that by ages and ages of breeding men who led hygienic lives, descended from physically perfect men who had also led hygienic lives, we might produce a race that might live double, treble and possibly a hundredfold more years than the average man of this present time."

E. B. Foote, M. D., of No. 130 Lexington avenue, who is the author of several well-known works of medical interest, says: "I certainly agree with Mr. Tesla when he says that human life can ultimately be prolonged indefinitely. For the past fifty years all of our large cities have been devoting enormous sums of money to the construction of proper drainage and other public sanitation, and, as everybody now knows, the death-rate in our large cities at the present day is strikingly smaller than it ever has been in all medical history.

"This shows conclusively that man has the power within him to prolong his own life. If it were possible to have fifteen or twenty generations of men live strictly temperate lives, with the total abandonment of vicious habits, and abstinence from coffee, tea, tobacco and alcohol, together with the marriage of only such women as the newest appliances of X-rays and other scientific discoveries would show to be physically perfect, even to the absence of microbes of any disease in the blood and tissues, then I believe that the last man of the line would compare favorably in age with Methuselah and the other famous old men of Biblical tradition. The trouble will be to find the men to live such purely scientifically perfect lives."

DR. KUHN BELIEVES IT.

Dr. F. W. Kuhn, head surgeon of the Eastern District Hospital, Brooklyn, says: "Man's life is rendered extinct when the germs and microbes in his body succeed in getting the upper hand. If man can utilize science in locating these germs and killing them off, unquestionably even the men of our own generation can prolong their own lives by a number of years.

"If the old men of Biblical note could live for such long years I do not see any good reason why men of the present and the centuries to come could not live a great deal longer than sixty, eighty or ninety years. While, of course, microbes existed in the time of Methuselah and the other patriarchs, I believe that their number was so infinitesimally small that men were entirely free from contamination by them, and thus were able to live to such great ages. But with the continual increase in the number of microbes and the consequent increase of the number swallowed by man in his food, water and the air he breathes, the more desperate has been the battle of his vital parts with these hostile germs, and consequently the earlier has been his consignment to the grave. Invent appliances to destroy these myriads of microbes and you invent means to prolong man's life, and the more thorough the character of the appliances invented the more nearly will the men of the future approach in age the years of the patriarchs the Bible tells about."

These opinions of representative physicians show that Virchow's and Tesla's prophecies of a coming race that will possess the secret of renewing life, defying disease and living through many centuries are well within the bounds of possibility.



A SUMMARY OF ROENTGEN RAY THEORIES.—I.

BY A. VOSMAER AND F. L. ORTT.

(Electrical Research Laboratory, The Hague, Holland.)

THE most important question whether Röntgen rays are to be considered as falling into the domain of light, or whether they are something else, has occupied so many minds, that the literature on this subject has grown enormously; but is it settled yet whether they are transversal waves of very small wave-length, or longitudinal waves, or vortex motion of the ether, or longitudinal impulses, or due to electromagnetic dispersion, or radiant matter? Having read so many theories, with so many supporters and opposers, one gets puzzled what to believe. Not a small part of the confusion is caused by the number of contradictory experiments; and no wonder at this, the question being, in fact, of the utmost complication—that is to say, not only as to the nature of the rays themselves, but also the way in which to get them. Being engaged in the study of silent electric discharges, it was rather in our line to consider the question of cathodic, as well as of our anodic, discharges. Thus we arrived at a conclusion about the nature of Röntgen rays, which explains a great deal, though we must confess that certain assumptions have to be made. This is not an attempt to explain this most difficult problem, but to suggest an hypothesis that is most nearly in accordance with experiments, so far as they go.

We consider Röntgen rays to be nothing but discharged cathode rays, and will now test this hypothesis by seeing how it will explain some of the most striking experiments and facts. As a matter of fact, cathode rays are deflected by a magnet; they obey the law of attraction of a current by a magnet; i. e., they behave as a current or stream of negatively charged particles. These negative particles impinge upon the glass wall of the tube, which, as is well known, possesses a strong positive (external) charge. Is there anything strange in the idea that those particles may lose their charge when in contact with the positive charged wall, and proceed on their way as discharged particles? These discharged particles cannot be, and are not, attracted by a magnet; why should they be? Hence the essential difference between cathode and Röntgen rays is explained. Röntgen rays would thus discharge a negatively or positively charged body, as a matter of course, since any electrified body, struck by neutral particles, always loses its charge.

Now let us consider some important details; in the first place, with regard to the focus tube. Some people do not accept the property of being reflected as possessed by the Röntgen rays. It seems to us that the experiments of Tesla with his T-tube, allowing him to take simultaneously a sciagraph from reflected and from rays that have passed through different plates of metal, are conclusive in this respect; but they prove that the total amount of reflection varies not very much for the least and for the best reflectors; the maximum result obtained with zinc (platinum does not seem to have been tested) was only 3 per cent. Probably platinum will give a higher percentage of reflected rays; but even then it does not sufficiently account for the large difference of efficiency of the ordinary and the focus tube. According to our theory the real cause of the high efficiency of the focus tube lies in the fact that the cathode rays strike on an actual anode, instead of upon an anode by induction.

This, so far, is not new. To quote Lodge, in an article written some time ago: "Hence, undoubtedly the X-rays do not start from cathode, or from anything attached to it, but do start from a surface upon which the cathode rays strike, whether it be an actual anode or only an anti-cathodic surface; best, however, if it be an actual anode."

Röntgen and Rowland had discovered the same thing. According to our theory, it is evident that the negatively charged particles can lose their charge sooner and more completely when they strike an actual anode, than when they strike an anode by induction (of greater surface, and thus of smaller density). Everybody will agree with Prof. Peckham, where he says that the discharge-tube is a resonator for its coil, and when the coil and tube are properly attuned the maximum effect is obtained. We should say, when the discharging capacity of the surface struck by the cathode rays can keep time with the vibrations of the intermittent current or stream of charged particles, the most intense Röntgen rays will be obtained. If discharging—or, better to say, neutralizing—of the waves of negative particles from the cathode be not synchronous with their impinging upon the focus or wall, they cannot lose all their charge, and will proceed either as particles with a minute negative charge, or with a minute positive charge, or perhaps mixed with neutral parts. The result will be feebler Röntgen rays, and, according to the preponderance of the one or the other particles, these rays will discharge an electrified body and give it charge according to its own charge. Borgmann found that a negatively charged plate, when exposed to Röntgen rays, lost its charge to become positively charged; when the plate was positively charged, it lost part of its charge. Righi found just the contrary; a positively charged plate lost its charge to end with a negative charge. Porter, and nearly all other experimenters, found in all cases a complete loss.

We could explain these differences by admitting that neither Borgmann nor Righi had pure Röntgen rays, but had them mixed with positive and negative rays, respectively. We consider Porter's $X_1X_2X_3$ rays and Lenard's gamut of rays of more and less magnetic deflectibility, as Röntgen rays of less and more purity, i. e., neutrality. The more perfectly the negative charge has been taken away by the anode—without, however, imparting a positive charge instead—the more intense the Röntgen rays will be, and the stronger penetrating power they will possess. It is hardly necessary to say that it must be very difficult to obtain perfectly neutral rays; this end will obviously only be attained when the whole system of generating—current, frequency, self-induction, capacity, vacuum, size and form of tube, and all the rest—be in true harmony with one another; and to realize this, means no small thing to do in practice.

We do not venture to say that our theory explains everything, but we do think it explains much; we do not ignore the fact that it is difficult to understand how the Crookes' radiant matter could pass through the glass wall as discharged matter, but the theory of ether motion also presents difficulties. Experiments on the Lenard rays passing as charged particles through aluminum, are described in "Nature," of May 27 (p. 93). Why should the etheric disturbance in the air answer so closely to the vacuum in the tube? Why should the rays, if they be ether vibrations, which in any case must be of so short a wave-length that the well known properties of light do not show, make any difference whether they are obliged to pass through one or the other metal or material? If the intermolecular space be of any influence on them, one should expect refraction in those materials that show greater resistance to the rays passing.

The strongest proof for our theory is Lafay's experiment, where he found that Röntgen rays, passed through a negatively charged leaf of silver, can again be deflected by a magnet, and in the same direction as the cathode rays in the tube; and when the leaf was positively charged, in the opposite direction. That means that neutral, non-deflectible rays, after recharging, become again sensitive to the magnet; the deflection being absolutely in accordance with electromagnetic laws of attraction and repulsion. Unfortunately this experiment, repeated by Lodge, has not been confirmed by him; but it is easy to understand that recharging, just like discharging, is no simple thing to accomplish.

(Our next issue will contain a review of the theory of Messrs. Vosmaer and Ortt.—Eds. E. E.)

[1]From London Nature

AN INTERESTING REVIEW OF X-RAY PRACTICE.

Gold Foil Screen Described by Mr. Elliott Woods.

MANY IMPORTANT EXPERIMENTS INSTRUCTIVE TO THE SURGEON AND THE MANUFACTURER OF X-RAY APPARATUS—THE AUTHOR BELIEVES THAT THE DANGER FROM THE RAYS IS EXAGGERATED, AND STATES THAT THEY ARE HARMLESS UNDER THE PRECAUTIONS ANNOUNCED — BATH OF HIGH-FREQUENCY CURRENTS BENEFICIAL FOR X-RAY BURNS—TESLA'S VALUABLE WORK IN THIS NEW FIELD.

To the Editor of Electrical Review:

Some publicity has been given by the daily press to an alleged discovery made by me of a method of making the X ray harmless. In a local paper of this date considerable importance has been attached to an accidental chat with a reporter, and this so-called discovery magnified to a considerable degree. Now, to be exact and at the same time to aid, if possible, in the study of the X-ray phenomena, particularly in the application of the rays to surgical studies, I desire to correct these press reports to a considerable extent and state what really has been done.

First, nothing has been accomplished that is not the result, directly, of Mr. Tesla's already published results; and my experiments are merely modifications of his methods. Mr. Tesla utilizes aluminum sheet or gauze. I use gold leaf, such as gilders use, and this only because aluminum sheet was not to be had in the city.

My experiments having brought me in contact with a number of surgeons in the city, who desired to note the condition of injured bones which had been treated by them, I felt a natural anxiety that the patients they presented for examination should not suffer from the much-heralded results of a continued exposure to rays generated by a powerful apparatus. Previous to the publication of Mr. Tesla's article, wherein he details his experiments with tubes of platinum and aluminum anodes, and aluminum sheet or gauze earth connected, I had contented myself with brief exposures, both for photographic and visual purposes. I deemed this precaution necessary, for accounts were numerous of the effect of the rays and the patients were timid. On the other hand, from the date of Roentgen's announcement, I have exposed my person freely, both in experimenting and for exhibition purposes, and as yet have failed to receive the slightest injury. The tubes used are the most powerful obtainable, excited by various coils and high-frequency apparatus. I will return to this later.

In the course of an examination made on the foot of a patient, to locate a broken needle, I placed the tube about 12 inches from the foot, and was surprised to note, after putting the tube into action, that a tolerably heavy spark could be drawn from the bottom of the foot. In frequent shifting of the foot, necessary to properly examine and sketch the position of the small piece of needle, the patient complained of the unpleasant feeling caused by the spark, but I learned that a "hot feeling," which he mentioned early in the examination, subsided when I held his foot in my hand. It was evident that the foot in this case was the outlet for a considerable charge of electricity which the patient had been able to accumulate from the tube and wires, because of his well insulated position on the reclining-table used, and that he was relieved by the additional condenser added when I connected my body to his. Taking note of the two facts obtained in this examination, and remembering Mr. Tesla's work with the aluminum screen, I carried on some experiments with the only metal sheet I had which was sufficiently transparent, and that was gold foil. I prepared a screen about 10 by 10 inches, and of cardboard, putting on it a temporary coating of gold foil. When not connected to earth, a considerable spark could be obtained from it, which spark entirely ceased, of course, when the foil was earth connected. Placing the hand of a volunteer assistant behind this foil screen, properly connected, no spark was secured. I gave my hand generous exposure under the screen and no ill effects have been noted. Placing the screen close to the tube so that my face could be brought within six inches, I failed to note the heating sensation which I nearly always feel when exhibiting my skull without the screen. Here I wish to remark that my cheek and that portion of the body between the shoulder blades are the only portions of the body which take note of this effect. Now, it would seem that whatever danger symptoms lurk in the rays, all are effectually stopped by an earth-connected screen of this kind and one made of gold leaf on cardboard is nearly transparent on account of the thinness of the metal leaf. In fact, I have failed to find any absorption produced by it on the platinum-barium screen. There might be more shown when using less powerful tubes, but with those used by me the absorption is inappreciable. There are no special claims for this "discovery" as published. To Tesla belongs everything that attaches to it, being as it is a modification of his method. I hope, however, that experimenters will not fail to try *thoroughly* the gold leaf or other thin leaf metal, which is inexpensive, readily procurable when aluminum may not be. This type of screen, while it has proved its security, as a makeshift, in the cases where it has been used by me, may not prove safe in other cases.

I hope every one who utilizes the X-rays for more than exhibition purposes merely will study these screening effects of leaf metal, and give surgeons who desire to install suitable apparatus relief from their fears, for these fears seem to be widespread, and patients are at the present day more fearful of the ray than of the knife. In any event, I would warn the handlers of powerful apparatus to take heed of the first sensation of heat when spoken of by the patient. It is likely to be the first sign of dissolution of tissue. While patients are apt, as a result of report, to be timid, it would be well to state frankly to them the possible sensations which might be felt and ask them to control their imagination sufficiently well to give their actual sensations.

Different persons appear to differ in their sensations when under the influence of a copious generation of the rays. Some are affected at the eyelids. Some feel the sensations of an electric discharge; while others state that their hands or faces are bombarded by invisible dust. These various sensations are worth consideration. They lead me to an opinion that the majority of persons, by reason of bodily state of health, are immune, at least to ordinary exposures. Some, according to my experience, are extremely sensitive, and it would be well for operating surgeons to take carefully into account the nervous condition of the patient.

A nervous person—and by that I mean one naturally so—is a fit subject for the metal screen. Some tissues of the body appear to be more susceptible than others. Particularly does this appear to be the case with the tissues of the head. I can always experience that "hot sensation" in the head, and in that portion of the body between the shoulders, when I exhibit my heart on the screen. Other parts of my body are not susceptible. The sensations, when experienced, are unmistakable, and a sensible patient can readily give his operating surgeon the note of warning. The surgeon should know his apparatus thoroughly, and content himself with brief exposures; and here I would suggest, out of experience, that before a powerful apparatus is used, every means should be resorted to in becoming acquainted, not only with the coil used to excite the tube, but the tube also.

A coil excited by a battery, while ample for ordinary exhibitions, is apt to fluctuate in its output by reason of the fall in the exciting current. It is advisable, when the coil is to be used for surgical operations, that it be excited by a motor-generator giving a constant current and voltage, and operated by an electric lighting circuit. It is essential that the tube for such operations be of the very best adjustable vacuum type, for then the surgeon can be assured of a constancy in the generation and penetrating power of the rays. With these tubes the vacuum can be adjusted so that the rays may not, in cases of examination of the limbs, be of themselves dangerous. When adjusted for examination of the trunk, and the vacuum being maintained high to obtain great penetration, and a high voltage used in the exciting apparatus, the metal screen should be interposed. It is the indiscriminate, careless handling of the exciting apparatus that is responsible largely for accidents. The surgeon would never handle the lance except by the best and well studied method. The X-ray tube is worthy of the same study and careful manipulation.

By far the best exciting apparatus, either direct or high frequency (which can sometimes be charged by a direct-current coil), is that operated from a lighting circuit. The inconstancy of current is largely avoided and the vacuum of the tube having been adjusted can be readily maintained. This is of safe and great importance in surgical operations; and while I do not wish to cast slander on coils operated by batteries, I have found that it is hard to obtain these important items from a battery-driven coil. Confidence in your tube and coil and knowledge that the current and voltage will remain practically constant is a factor of safety to the patient.

I now beg to call the attention of surgeons to so-called burns produced by X rays. Their features are well known. The persistence against ordinary remedies, I believe, is now admitted. Some time ago I read in an article copied from the foreign press that high-frequency currents were found beneficial treatment. When, by exhibiting my skull, I experience the heating sensation mentioned before, I generally give my affected cheek a bath of high-frequency currents, from *one* terminal of the high-frequency coil. If a surgeon have a case of injury from the rays, let him try this remedy if he can find such a coil in the neighborhood. I do not say it will cure, but rather ask a trial of it; and if I may be permitted to wander from the subject a trifle, I would add to try these high-frequency currents for fresh colds, weakness of voice, and general affections of the throat, remembering that the application should be made with the hand, laying it on the throat *first*, then connecting the operating surgeon's body to *one* terminal of a weakly excited, high-frequency coil. These coils are prolific generators of ozone. Excite the coil and let the patient inhale the ozone from either a funnel and tube held over the discharge, or by getting his mouth conveniently near. If an inhaling funnel is used, it should be of rubber to prevent shock, and the patient should be allowed to use it to suit the sensitive state of the affected membranes.

From a careful study of the effects of X rays on the tissue I am led to theorize that it is an electrical decomposition of the tissue, which can be prevented by the use of the metal screen. In treating a case of burn already produced, with high frequency currents, it would be well to use a spray discharge, avoiding carefully the spark which is apt to pass if the electrode is brought too near. I would suggest the spray of the static machine. But the main thing

is to make the X ray harmless, and whether we believe with Tesla that the rays are projections of material particles, or whether they are mere electric waves, the virus—if I may so term it—seems to be extracted when we force them to pass through a metal screen. These carriers of decomposition, in whatever form we may choose to look upon them as possessing, become apparently harmless after such a passage. The surgeon knows the utility of the X ray, but many are fearful of the effect. Manufacturers of X-ray apparatus should, by all means, further their own interests by giving competent instruction to purchasers, based on the experience of users, and particularly on the splendid investigations of Tesla, which have been published. It would be good policy for colleges to train surgeons in the manipulation of apparatus, and the subject would hardly fail of interest where so much benefit is involved and some dangers due to carelessness to be avoided.

I am inclined to believe from my personal experience that the dangers are greatly exaggerated. I am more inclined to lay bad experiences, already in evidence, to bodily conditions. I hope to experiment on this feature for the benefit of surgeons. I earnestly hope that experiences may be noted by surgeons in the handling of the rays on persons of various temperaments and that they be published in the proper journals.

In any event, it appears that X rays are harmless under the precautions named. ELLIOTT WOODS.

Washington, D. C., Sept 6.

HAVE CONTROL OF TESLA'S INVENTIONS

The Kings County Electric Company Will Revolutionize Things

IN THE ELECTRICAL WORLD.

Three Brooklynites Who Are Deeply Interested in the New Enterprise—A Plan Which, It Is Hoped, Will Result in the Manufacture of Electricity at Such a Low Rate That Present Conditions Will Be All Upset—D. O. Mills, ex-Governor Flower and Vice President Hobart Interested In the Venture. Power for Metropolitan Surface and L Roads One of the Prizes the New Company Has In View—A Great Project.

Brooklyn will shortly be the scene of one of the greatest scientific and industrial battles of the age. The breastworks and fortifications are already being built. The genius of Tesla is to try conclusions with the wisdom and experience of Edison. This great struggle for supremacy in science and finance will have its seat of war right in Brooklyn, though its outposts will spread throughout this state and into Jersey. Just how far it will eventually extend its lines no one can at present say, for that lies principally in the outcome of the battle that is now beginning in this city. In other words the Edison Electric Company has a rival in the field whose strength will probably soon be felt. The Edison people have an inkling of what is about to take place, but they pretend to look upon it as not very important. In Montague street the Kings County Electric Light and Power Company have established an office in the second floor of the recently rebuilt and improved building next to the Real Estate Exchange. By the general public little is known of this concern. The employes there refuse to even give the names of the officers of the company and direct all inquirers to see A. M. Young. A. M. Young has no particular hour of arriving at the office nor of departing—and even if caught by questioners he is a little less communicative, if possible, than the clerks. It is said on good authority, however, that Bridge President William Berri, Seth L. Keeney and Felix Campbell, president of the People's Trust Company, are much interested in the new company. Mr. Berri, when questioned about the enterprise by an Eagle reporter, said:

"It is a very big scheme and one in which Mr. Keeney and I are very much interested, but we cannot say just at present just what is in the project. It is a great enterprise, with lots of money in it, but for many reasons its intentions cannot be told now."

Felix Campbell shook his head when interviewed and said: "Yes, there is such a company organized and I have been told of it, but I have been away and do not know who is behind it."

Mr. Julian Fairchild, president of the Kings County Trust Company, who is a director of the Edison Company, said:

"We know the intentions of the Kings County Electric Light and Power Company, and if they think they work in secret they are mistaken. Perhaps we would fear their power if we did not know that the men whom we believed at first were in it are not. We have investigated and find that J. Pierpont Morgan and D. O. Mills are not behind it with their capital, and Governor Flower is the biggest man they have."

The company as it now stands, it is understood, will put into actual practice and work the inventions of Nikola Tresla, upon which he has been working for years and which have been brought to a practical industrial basis within the last year. Vice President Hobart, it is understood, with two other prominent financiers of New Jersey, will take hold of the enterprise in that state.

Ex-Governor Roswell P. Flower and Messrs. Morgan and Mills will represent New York City and the state, while Messrs, Berri, Campbell and Keeney will see to the work in Brooklyn that has already been commenced. Behind these men will stand the genius of Tesla and their wealth will bring out the result of inventions that he has already demonstrated in a more or less forcible degree.

Ostensibly the presidetn of the new company is Charles Cooper. It was he who secured the franchise for the electric plant in this city and it is said that he was at first more than willing to sell it for somewhere in the neighborhood of $50,000. But he did not then realize the possibilities that lay behind this franchise and they have grown to such an extent that Mr. Cooper, it is now stated, would not dispose of this franchise or his holdings in the company for $600,000 cash. Mr. Cooper is the man who pushed the gas combination through to a successful climax. Mr. A. M. Young is the business manager of the concern and is pushing forward the work in Brooklyn.

The first demonstration on the part of the company that they meant business and big business was the purchase of a piece of property on the East River that involved an expenditure of half a million dollars. It was the block running from East River to John street, between Bridge and Gold. In the first transaction the Kings County Electric Light Company bought from Squibb & Sons, the chemists, for $185,000, the chemical plant situated on Gold and Johns streets, running down to the river front, with a frontage of 185 feet on East River and John street and a depth of 475 feet. It has several brick buildings upon it at present. This is the first piece of property owned by the company and with the exception of the big piece of land bought by the Squibbs adjoining it it is the only considerable waterfront that is not controlled by the warehouse combination. It is here that the first plant will be built and it is an excellent site, for the coal may be easily and cheaply brought to the works and there are many other advantages coming from the water front obtained. Fifty miles of subway have already been laid by the company, and it is now said that just as soon as the power plant is ready fully a hundred miles of wire will be ready to receive the electric current and the big fight will be on in earnest.

President Berri said that no bonds would be offered and no shares sold at large and that the company was already fully organized and backed by well equipped men in the financial world. The company admits, through the president, that the Tesla inventions and his new systems are controlled by them. How much this means cannot be fully stated until the company chooses to make all its plans public, but it may be said that Tesla has long been at work upon the problem of transmitting power of high voltage to any distance without the expensive loss that is a part of the systems now in use. Mr. Tesla came to America with the idea of entering a field where inventive genius would be appreciated and had in his mind then the problem which he is said to have to a great measure solved. He worked for a time under Edison, for whom he has the greatest admiration. But soon the pupil became too great for the master and he left him to joint a company to make and sell an arc lighting system based on some of his inventions in that branch of art and which had in them the then unworked theory of the alternating current which Tesla had experimented upon successfully in Paris. So full was he of the wonderful possibilities in his surprising discoveries that he was for publishing then abroad, but he was induced by friends to put his inventions and discoveries to the test through interested capital, which was soon obtained. A suggestion of what is about to be disclosed through the company now formed may be had from an address made by Tesla in May, 1891, before the American Institute of Electrical Engineers in New York, in which he spoke of the possibilities of alternating currents and the transmission of high potential currents. He stated then a step had been made in the advance of electrical lighting and power giving.

"But there is a possibility of obtaining energy not only in the form of light, but motive power," said Mr. Tesla, "and energy of any other form in some more direct way from the medium. The time will be when this will be accomplished and the time has come when one may utter such words before an enlightened audience without being considered a visionary. The mere contemplation of these possibilities expands our minds, strengthens our hopes and fills our hearts with supreme delight."

And this man who spoke so enthusiastically then of the discovery he was on the eve of making some time later spoke of the progress he had made in the distribution of light and power in these words:

"I am led to believe now that in our future distribution of electrical energy by currents of very high tension, liquid insulation will be used. The cost is a great drawback, but if we employ an oil as an insulator the distribution of electrical energy with something like 100,000 volts, and even more, becomes, at least, with higher frequencies, so easy that it could hardly be called an engineering feat. With oil insulation and alternate current motors, transmission of power can be effected with safety and upon an industrial basis at distances of as much as a thousand miles."

That was several years ago, and it is now stated that this modern genius has worked out his theory to a practical basis and Edison will meet a foe worthy of him in his own field. It is said that the railroads of this city, the Brooklyn Heights, the elevated roads and all the transportation lines will be enabled to sell their plants or dispose of them to the new company and obtain all their power from the plant that will work wih the inventions of Tesla. D. O. Mills, it is said, has satisfied himself of the practicability of the scheme and, with his interests in metropolitan railroad companies, is anxious to have it put to the test.

MAY SUPPLY RAILROADS.

New Tesla Electric Company Has Made Them Propositions.

COST TO BE MUCH REDUCED.

After the Eagle Was Published Last Night the Promoters of the New Enterprise Were Deluged With Applications for Stock From Would-Be Investors — Machinery Involving New Ideas to Be Built.

Further information in regard to the Kings County Electric Light and Power Company shows that this new factor in Brooklyn's industrial world is more important that was at first believed. The account in the Eagle created considerable interest in financial and business circles and only a short time after the paper was on the street the demand for stock in the new company began and the offices of the concern were burdened with applications for information. It should be said right here for the benefit of would be investors, that every cent of stock has been contributed and shares cannot be cought at any price, according to the statement of those in authority. As stated before, Mr. Cooper is nominally the president at present, but in about ten days the directors of the company will elect the officers and in six months the concern will, it is said, be at work supplying power and light, for which they already have more orders than they can possibly take care of for some time.

All the local railroads are greatly interested in the outcome of the new electric company's experiments here and it is more than possible that every one of them will be supplied with power by the new company. Negotiations to this effect have been conducted with Presidents Rossiter, Johnson, Heins and Sullivan of the trolley roads and also with Presidents Uhlmann and Jourdan of the Brooklyn and Kings County Elevated Companies, which are to change their motive power to electricity this fall. One of the largest holders in the new electrical company said to-day that all of the railroad presidents had considered the scheme with favor and if the Tesla inventions prove to be all that is claimed for them and the prices are as low as promised, it is assured that the entire local railroad system will be operated by power from the Kings County Company.

If this is accomplished it is the present intention of the trolley roads to sell their present power houses to the new electrical company. This will give the new company a plant of sufficient capacity to supply all Brooklyn with electricity.

The electricians say that the machinery of the new company is the finest ever manufactured and that the plant has cost less than half what would have been paid for it ten years ago, as all iron work and machinery of every kind is at its lowest just at this time. The electricty will be produced by the newly invented machinery at half the expenditure with the old method. It will only cost half as much to lay the mains as it did a few years ago and added to this is the enormous advantage that Tesla's inventions give the concern, as it is now known that the electrical genius has devised a means of transmitting a current without loss to any distance, and the company can as well supply power to the outer fringes of Greater New York as easily as to a business house half a block away. This means that the greatest problem in electric power has been solved.

The power house, which will take up all the grounds on the river front to John street and from Gold to Bridge, a piece of property, 185x475 feet, will be equipped, it is said, with the finest machinery ever manufactured and a condenser will be included so that water may be obtained directly from the river. Coal can easily be brought in barge loads and deposited on the docks of the company. As soon as the project was started the demand for power was immediate and, as has been stated, even with the new inventions of multiplying, producing and carrying capacity, it will not be possible to meet these demands until new power houses have been erected. New plants will be established in South Brooklyn and along the water front as rapidly as possible.

Just who will be the officers of the new company is not at present known. While Messrs. Kecney, Campbell and Berri are the heaviest holders in Brooklyn there are many other men of the city interested in the new company and all, of course, will have a say in the naming of the men who will take active control of its affairs. Vice President Hobart, ex-Governor Flower and other men who were mentioned in the article of yesterday will, of course, have an active interest in the Brooklyn as well as other ends of the work. Men of financial and business importance from other states are heavily interested and the company is already established on a firm financial basis and has behind it men who will not hesitate to advance its advantages by the expenditure of almost any amount of money called for by the active managers.

The advantage of having a power house established in a central position has already been recognized by the dispensers of electrical force and that is why the Edison and other big establishments have their plants as nearly as possible to the center of business localities where the demand lies. In transmitting power to railroads the idea has been advanced and is being put into practice of having central dispensing stations along the line. But even then a considerable loss has been suffered in sending the power to the stations and all along the line. Tesla's new system will do away with this loss. With this fact known the active interest of ex-Governor Flower and D. O. Mills, as well as other big railroad men of the vicinity is doubly important, as it will probably be a question of time, and no considerable time, when all the railroads of the metropolitan district will be getting their power directly from the plants of the new company.

This morning it was learned by an Eagle reporter that the first business of the company would not be competitive but would be in an entirely new field in Brooklyn and New York. It is certain, however, that electric lighting and power dispensing will not be monopolized in this vicinity within a few months from now. The first idea of the new company was to supply the new demand created every day by new industries and it was with that intention that Charles Cooper obtained his franchise. The control of the Tesla patents, however, and the advantages obtained through the genius of the inventor soon developed new possibilities that wholly outgrew the original intentions of Mr. Cooper and the capitalists behind him. The Cooper company has been continued for convenience until the directors of the concern deem it advisable to elect its regular officers and begin business upon the large scale that is now possible.

"There is no mystery about it," one of the interested men said this morning. "It is a pure business venture with certain details that the directors do not deem it necessary to immediately disclose. While the publication of the plans of the company could not possibly injure it in any way, it would be of no benefit to us. We do not care to boom the company. That fact is apparent when it is said that not a bit of stock could be obtained by any one and we would not reveal the advantages we possess for that purpose. The Eagle's article created something like a sensation and that was just what we did not want to happen. All the money we want is now invested, and we would rather go right ahead in a regular business way with our work. In ten days, perhaps, the details of the organization may be published in the report of the company and then any information desired in regard to the general work of the company may be obtained, but we have no desire to publish any facts at present for purely business reasons. The Eagle's article, however, was correct except that it really did not give more than an idea of the magnitude of the concern."

The New York Herald September 23, 1897

LIGHT COMPANY'S EXTENSIVE PLANS.

It Contemplates Rivalry of the Edison Concerns, Using Nicola Tesla's Inventions.

SITE BOUGHT FOR A PLANT.

William Berri Interested and Perhaps J. P. Morgan and Former Governor Flower.

MR. HOBART ALSO MENTIONED.

The Kings County Electric Light and Power Company has established an office in Montague street, Brooklyn, and proposes to be a business rival to the Edison Electric Company. Among the Brooklyn men interested in the new concern are President Berri, of the Bridge Trustees; Seth L. Keeney and Felix Campbell, president of the People's Trust Company. Mr. Berri admitted yesterday that he and the other men named were interested in the venture, but he refused to give any details.

Julien D. Fairchild, president of the Kings County Trust Company, who is a director in the Edison Company, said that he was well aware of the plans of the rival company, but did not fear its power. He said that J. Pierpont Morgan and D. O. Mills were not behind it, and that former Governor Roswell P. Flower was the largest financial backer.

It is understood that the new company will adopt the devices and discoveries of Nicola Tesla. In this State the business of the company will be handled by Messrs. J. P. Morgan and D. O. Mills, while Vice President Hobart will be one of the financial backers in the State of New Jersey.

Charles Cooper is said to be the president of the new company. He obtained the franchise for the electric plant and he is said to have been more than ready to sell it at one time for $50,000. Now, report says, he holds it to be worth $600,000.

The company has purchased the block fronting on the East River and John street, from Bridge to Gold streets, Brooklyn, at a cost of $500,000. This is about the only large piece of water front property not controlled by the Warehouse Trust, and it is here the first plant of the company is to be erected.

Fifty miles of subway have been laid, and by the time the plant is ready it is expected to have one hundred miles of wire ready for operation.

Mr. Berri said that neither the bonds nor stock of the company would be sold at large. There is no secret made of the intention to adopt Tesla's discoveries. He has been long at work on the problem of transmitting high voltage power without the losses that now exist. He is said to have solved this difficulty by means of a liquid insulator.

Scribner's Magazine October 1897

ABOUT THE WORLD

vibrations on the Herz radiator principle, with a rapidity of 225,000,000 vibrations per second, these waves seem to be carried through the ether, if unobstructed by material obstacles, equally in all directions, and his delicate receiver has no difficulty in receiving and recording them across the Bristol Channel. The feat is possible only in places where an unobstructed expanse of ether interposes between the transmitting and receiving instruments.

The idea of wireless telegraphy is no new one. Men have been thinking of it almost ever since the Morse inventions came to the world. The astonishing Mr. Edison had his try, and abandoned the attempt for more immediately promising work. Aside from the young Italian, Marconi, Nikola Tesla has the most ambitious projects in this direction and, indeed, Mr. Tesla contemplates the possibility of an even vaster feat, for he believes he can transmit electrical power without wires. Should he accomplish such a thing, the bounds of electrical utility will be extended more radically than by any other discovery the world has seen. Mr. Tesla is not yet ready to publish the details of his experiments, but he has explained to interviewers that it is the static electricity of the earth which he will exploit in furnishing the power necessary for his wireless transmission. He has already sent signals via the earth current to and fro through a distance of twenty miles, and announces unhesitatingly that he shall in time be able to telegraph without wires to any part of the earth's surface.

Tesla used a striking and simple simile in explaining how he intended to disturb and capture the earth's electricity. He said to his interviewer: "Suppose the whole earth to be like a hollow rubber ball filled with water, and at one place I have a tube attached to this, with a plunger in the tube. If I press upon the plunger the water in the tube will be driven into the rubber ball, and as the water is practically incompressible, every part of the surface of the ball will be expanded. If I withdraw the plunger, the water follows it and every part of the ball will contract. Now, if I pierce the surface of the ball several times and set tubes and plungers at each place, the plungers in these will vibrate up and down in answer to every movement which I may produce in the plunger of the first tube. If I were to produce an explosion in the centre of the body of water in the ball, this would set up a

IN these days the layman is apt to protect himself in a cloak of *blasé* acquiescence from the ever-fresh demands upon his mental powers made by mechanical wonders. But the most fatigued and agnostic intelligence will scarcely fail to respond to the proposal of the electrical "wizards" to telegraph from one part of the earth's surface to another without the use of wires. In Europe, a young electrician named Marconi has actually succeeded in transmitting and receiving messages through a distance of nine miles, with no connection between the sending and receiving instruments save that furnished by the circumambient ether. Marconi has found that when a transmitting instrument—which is so simple in its elements that one is tempted to describe it in detail—is made to utter electrical



series of vibrations in the whole body. If I could then set the plunger in one of the tubes to vibrating in consonance with the vibrations of the water, in a little while and with the use of a very little energy, I could burst the whole thing asunder."

In the same way, Mr. Tesla proposes, with a comparatively small power uttered in vibrations of marvellous rapidity, to urge into action the terrestrial current. The inventor thinks it possible that his machine when perfected may be set up, one in each great centre of civilization, to flash the news of the day's or hour's history immediately to all the other cities of the world; and stepping for a sentence out of the realms of the workaday world, he offers a prophecy that any communication we may have with other stars will certainly be by such a method—a prophecy which has all the picturesque and imaginative charm to be desired, together with an unusual quality of prudence and safety.

MARCONI TELEGRAPHY.

In July, experiments with this system were made at Spezzia by a Commission of the Royal Italian Fleet, assisted by the inventor. The results, of which the following is an abstract, are reported in the *Rev. Marittima* :—

A transmitter, and a receiver for controlling purposes, were set up on land ; a second receiver being placed on board ship. In one experiment the ship lay at anchor, in another the ship steamed away from, or approached, the telegraphing station on shore. The results obtained were :—1. Under favourable atmospheric conditions, *i.e.*, in the absence of electric strain in the air, messages were successfully transmitted from land to the ship in motion, over a distance of 8·9 nautical miles (10·5 miles). 2. The presence of electric strain in the atmopshere made the reading of messages by the Marconi apparatus impossible. 3. It was found, also, that the intervention of mountains, islands, or headlands between the transmitter and the receiver made the reading of the messages impossible. 4. The intervention of masts or chimneys, or the like, was also found to considerably reduce the distance at which messages could be distinctly read ; for example, if the receiver was fixed abaft the ship, and the ship was steaming directly toward the sending station on shore, the distinctness of the messages was considerably reduced.

The account given by Mr. Marconi, in an interview published by the *Dailg Chronicle*, is somewhat more sanguine. He says :—

I sent messages from the Arsenal of San Bartolomeo and the *San Martino*, an armour-clad fighting ship, completely armed and cruising in the open sea 12 miles distant from the fortress. My receiver was hidden in the cabin, under the guns, under the engines, in fact, anywhere on board, so long as the vertical wire conductor remained exposed. No matter where the receiver was, it "ticked" out the message in due course. I used conductors 90 feet high to procure this result, and am now preparing a receiver to take a message from a distance of 40 miles. The fact of the message being sent to a vessel which was practically one mass of metal made no difference. In Rome, to communicate to houses I had a conductor 3 feet high. For the transmission of signals across the Bristol Channel it was 100 feet high, but it is difficult to say off hand how far the question of distance is determined by the height of the conductor. You see I got signals to a greater distance at Spezia with a conductor 10 feet less in height. The induction coil used in Italy was much less powerful, as the signals were obtained by a 6-inch spark worked by a small portable battery of eight volts. This disproves the statement of certain scientists who have declared that my results have only been secured by the employment of a large amount of battery power.

In the *Chronicle* interview Mr. Marconi defends his invention against the charges of want of novelty which have very freely been brought against it. He claims that he has greatly improved the Branly coherer, and invented for it the electro-magnetic tapper, a claim which has been questioned by Lodge. But we think there can be no doubt that Marconi is the true and first inventor of the elevated electrodes on the receiver and transmitter, and this detail appears to have contributed more to extend the possible distance of telegraphy by electric waves than anything that has been discovered since the time of Hertz and Branly. In the interview above referred to, Mr. Marconi insists on this point, saying :—

I think, too, that my invention deserves all the protection it has secured, for what I have really discovered is this, that by bringing one pole of the transmitter and one pole of the receiver in contact with the earth, and joining the other poles of the instruments to vertical conductors of sultable height, I can send a message 12 miles with an amount of battery power that would not obtain any effect at all, even at 100 yards, if used by the Branly, Lodge, or Righi apparatus.

No doubt the Law Courts will some day be asked to settle the differences between the rival claimants for the invention of wireless telegraphy. In the meantime the heated discussions on the subject which are appearing in some of our contemporaries appear to be futile.

M. Del Proposto gives the following mathematical theory of the working of the Marconi apparatus. Since the transmitter and receiver in the Marconi system are connected by induction, the efficiency and range of the apparatus can be determined by a consideration of the coefficient of mutual induction.

Cœteris paribus the current induced in the receiver is proportional to this coefficient, which is given by the expression

$$\mathrm{M} = \int\int \frac{ds\ ds^1 \cos\varepsilon}{r} \qquad (1)$$

in which ds and ds^1 are elements of the two circuits, ε the angle between them, and r their distance apart. In the Marconi apparatus with vertical wires (taken as parallel) $\varepsilon = 0$, r = constant, the expression becomes

$$\mathrm{M} = \frac{h^2}{r} \qquad (2)$$

h being the height of the wires. Equation (1) is reduced to equation (2) if, at any instant, the current has the same sign at every part of each apparatus, an admission which cannot, however, be made *a priori*. According to (2) the range of an apparatus of given sensibility will be proportional to the square of the height of the vertical wires. But it must not be forgotten that in increasing the length of the vertical wires, we increase their self-induction and their capacity. This, in accordance with the formula

$$\mathrm{T} = \frac{\pi\sqrt{c\,\mathrm{L}}}{v}$$

(v = the velocity of light, T = duration of an oscillation) will reduce the frequency of the oscillations. The decrease of the range due to diminished frequency may be compensated by increasing the original current, *i.e.*, the energy of the discharge.

The electromagnetic force is horizontal if the wires of the apparatus are vertical ; consequently the transmission by the Marconi apparatus will not be disturbed by horizontal con-

ductors, such as telegraph and telephone wires. But vertical conductors may cause serious disturbances in the transmission; Hertz indeed has shown that a frame of parallel wires suitably arranged in relation to the waves may stop them. If two receivers are placed at considerably different distances, the nearest receiver may absorb so much of the energy of the electric waves that it will be impossible to produce any effect on the more distant instrument. The electromagnetic waves are propagated in every direction, and if these waves encounter conductors capable of acting as receivers (and all conductors can do so to a certain extent), the transmission between the two instruments will be seriously interfered with.

Reflectors are not likely to be successfully used with the Marconi apparatus. Hertz found that reflectors were useless with waves 7 m. in length, and the Marconi waves are much longer than this. Before reflectors can be successfully used, it will be necessary to reduce very considerably the length of the waves, but these reflectors will have to be very large, comparable in dimensions, in fact, with the vertical wire.

The propagation in every direction is the principal objection to the Marconi system. Multiple reception of messages may, to a certain extent, be obviated by tuning, but it would always be easy to bring any receiver into tune by trial.

MR. TESLA ON HIGH SPEED ELECTRIC RAILROADING.

In an interview with a New York Journal reporter Mr. Tesla gives his views on high speed railroading. He says:

"The projectors of the road to be operated by means of the alternating current evidently realize what a vast undertaking they are entering into, as is indicated by their capitalization. First of all, it is not only practicable, but easy of perfection. The question of great speed will be greatly controlled by the quality of the track and the running gear on the cars. Properly constructed tracks, on level country, will permit a rate of speed as high as 150 miles an hour, and perhaps 200, as its stated by the president of the company, but it is certain that 100 miles an hour can be made with safety.

"So far as any personal discomfort is concerned, it is my impression that without curves and heavy grades such as are found on surface roads, the flight of a train traveling 100 miles an hour would not be any more unpleasant than one traveling 60. An air line road built eight feet above the ground, with no obstructions, and perfected running gear and heavy tracks, would cover the distance between here and Chicago easily in nine hours, and mail and light freight could even travel at the 150 mile rate.

"The venture is a big one—large enough, I should say, for the government to handle. It will revolutionize railroad travel and work great changes in commerce between cities wide apart.

"The popular impression that the speed is too great amounts to nothing. Balloonists have gone 150 miles an hour, and so far as a question of velocity is concerned, it depends upon the machinery and the excellence of the track. The human frame can stand the trip just as easily as at half that speed.

"If the General Electric Company has offered to sign a contract to equip the road I am satisfied that all the petty obstructions have been carefully investigated, and that the promoters mean business. Either the General Electric Company or the Westinghouse can supply the power if others will supply the capital. So far as the alternating current is concerned, it will supply the speed."

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CHANGES for advertisements must be in this office by Friday noon for the following week's issue.

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LORD KELVIN SAILS FOR HOME.

Lord and Lady Kelvin sailed on the "Campania" for England last Saturday morning after a visit of nearly three months in the United States and Canada. He left delighted with his American visit, stating that he had made notes enough of new ideas to keep him thinking all the rest of his life, and expressed quite an interest in the wonderful development of electric traction. Before sailing, Lord Kelvin made two visits to Tesla's laboratory in New York city, where some new scientific results were shown to him. Lord Kelvin is respected and loved by every electrical and scientific worker in the United States, and all wish him a pleasant return voyage and many years of continued usefulness at Glasgow University.

CORRESPONDENCE.

"Wireless Telegraphy."

In your interesting article on this subject in your issue for the 8th inst., you say: "We think there can be no doubt that Marconi is the true and first inventor of the elevated electrodes on the receiver and transmitter."

In a book entitled "The Inventions, Researches and Writings of Nikola Tesla," published early in 1894, pages 346—9, will be found much interesting matter with regard to what is therein termed "the transmission of intelligible signals, or perhaps even power, to any distance without the use of wires." In particular, an arrangement of transmitter and receiver, each connected with one terminal to earth, and with the other terminal to an insulated body of large surface, shown in a diagram as elevated above the earth, is suggested for the purpose of what is indexed as "telegraphy without wires."

Without in any way desiring to detract from the credit that is due to Mr. Marconi for the results that he has obtained, I think that it is only fair to Mr. Tesla that attention should be called to the above.

A. A. C. Swinton.

Cambridge Philosophical Society - Proceedings

(1) *Electrical Oscillations in Wires.* By Mr H. C. POCKLINGTON, St John's College.

1. In this paper are discussed some problems relating to the propagation of electrical oscillations along wires. The wire is always supposed to be a perfect conductor, and to have a circular cross-section, the diameter of which is small compared with the other dimensions of the system. We have therefore to solve the equations $\nabla^2(P, Q, R) = V^2 \frac{d^2}{dt^2}(P, Q, R)$, conv. $(P, Q, R) = 0$, with the further condition that at the surface of the wire the vector (P, Q, R) is perpendicular to the surface. The method of solution used is to start with the simplest solution of the general equations and by adding an infinite number of such solutions together to obtain one of sufficient generality. The arbitrary function which represents the infinite number of arbitrary constants introduced into this last solution is then found from an equation deduced from the surface condition. This last part of the work is conducted by means of approximations.

2. The simplest solution of the general equations, that corresponding to the solution $\phi = 1/r$ of the equation $\nabla^2\phi = 0$, is given by the formulae*

$$P = \frac{d^2\Pi}{dx\,dz},\quad Q = \frac{d^2\Pi}{dy\,dz},\quad R = \frac{d^2\Pi}{dz^2} + \alpha^2\Pi,\ \text{where}\ \Pi = e^{\iota\alpha r}e^{\iota pt}/r,$$

in which $2\pi/p$ is the period of the disturbance, and $2\pi/\alpha\,(= 2\pi V/p)$ the wave-length corresponding in free ether to this period. This result can be expressed in words as follows. The electric force due to an elementary Hertzian oscillation with the element of length ds as axis, is compounded of two forces; the first of these is derived from a potential function $-\frac{d\Pi}{ds}$, and the second is a force $\alpha^2\Pi$ parallel to ds. This system of forces satisfies the equations of propagation of electric force everywhere excepting at the element ds. If we place an infinite number of such elements consecutively so as to form a curve, of which ds will then be an elementary arc, and attribute varying strengths λ to them, we shall obtain a system of forces which satisfies the equations of propagation everywhere except on the curve. The resulting system of forces is

$$(P, Q, R) = -\left(\frac{d}{dx}, \frac{d}{dy}, \frac{d}{dz}\right)\int ds\lambda\frac{d\Pi}{ds} + \alpha^2\int ds\,(l, m, n)\,\lambda\Pi.$$

* Hertz, *Wied. Ann.* 1889, vol. 36, p. 4; *Electrical Waves* (tr. Jones), p. 140.

If the curve is either closed or has its extremities at infinity, this is equivalent to

$$(P, Q, R) = \left(\frac{d}{dx}, \frac{d}{dy}, \frac{d}{dz}\right)\int ds\frac{d\lambda}{ds}\Pi + \alpha^2\int ds\,(l, m, n)\,\lambda\Pi \ldots(1).$$

This is a general solution containing an arbitrary function λ.

3. It now remains to consider the equation derived from the surface conditions. At a point at a small distance ϵ from the curve we have, neglecting all terms that are not large,

$$\int ds\,\Pi\frac{d\lambda}{ds} = -2\frac{d\lambda}{ds}\log\epsilon\,.\,e^{\iota pt},$$

and similarly for $\int ds\,l\lambda\Pi$, etc., so that, to this order of approximation,

$$P = -\left\{2\frac{d}{dx}\frac{d\lambda}{ds}\log\epsilon - 2\alpha^2 l\lambda\log\epsilon\right\}e^{\iota pt},$$

and similarly for Q and R.

The component of force along the wire therefore is, to this order,

$$-2\left(\frac{d^2\lambda}{ds^2} + \alpha^2\lambda\right)\log\epsilon\,.\,e^{\iota pt}.$$

The force tangential to the cross-section of the wire $= 0$ to this order. Hence the system of forces given by (1) is a solution of the problem (to this order) provided that

$$\frac{d^2\lambda}{ds^2} + \alpha^2\lambda = 0\ \text{ or }\ \lambda = e^{\iota\alpha s},$$

and the disturbance is propagated along the wire with velocity V and without diminution of amplitude. This is only what might have been expected from a knowledge of what happens in the case of a straight wire; for if in our case we take the electrical forces to be finite near the wire, at a finite distance they are zero.

4. It is clear that in order to obtain results of much interest we must approximate more closely. We will now consider the equations obtained by neglecting only small quantities of the first and higher orders.

As given by (1) the force at any point on the wire tangential to the axis is the same for all points on the same cross-section, and contains two terms, one containing $\log\epsilon$, the other finite. The force tangential to the cross-section is finite and varies for a given value of s as the cosine of some azimuth angle.

Suppose now that we shift the curve formed by the Hertzian elements through a small distance of the second order. The effect is to change the value of the component tangential to the cross-section by a finite amount which varies as the cosine of some azimuth angle, and that parallel to the axis of the wire by an amount of the first order of small quantities.

By making such a shift of appropriate magnitude and direction at every point, we can therefore eliminate the component tangential to the cross-section. At the same time, the component parallel to the wire is unaltered (to our order). Hence we may still derive the surface condition from (1) by taking the integration along the axis of the wire.

The condition thus obtained is

$$0 = \frac{d}{ds}\int ds\,\frac{d\lambda}{ds}\,\Pi + \alpha^2\{l\int ds\, l\lambda\Pi + m\int ds\, m\lambda\Pi + n\int ds\, n\lambda\Pi\}\ldots(2).$$

5. *Circular Ring.* The simplest case that we can consider is that of a circular ring. Let the radius of the ring be a, the radius of the wire ϵ as before, and let the axis of symmetry be chosen as the axis of z. We shall assume $\lambda = A\cos r\phi$, where ϕ defines a point on the axis of the wire. This assumption will be justified later.

At the point (ϖ, θ, z)

$$\int ds\,\frac{d\lambda}{ds}\,\Pi = -rA\int_0^{2\pi} d\phi\,\Pi\sin r\phi$$

$$= -rA\int_0^{2\pi} d\phi\,\Pi_0(\sin r\theta\cos r\phi + \cos r\theta\sin r\phi)\,e^{\iota pt},$$

where Π_0 is the value that Π takes when ϕ is put for $(\theta-\phi)$ and 0 for t, and is thus a function of ϕ, ϖ, z only,

$$= -2rAe^{\iota pt}\sin r\theta\int_0^{\pi} d\phi\,\Pi_0\cos r\phi;$$

$$\int ds\, l\lambda\Pi = -A\int_0^{2\pi} a\,d\phi\,\Pi\cos\phi\cos r\phi$$

$$= Aae^{\iota pt}\left[\cos(r+1)\theta\int_0^{\pi} d\phi\,\Pi_0\cos(r+1)\phi\right.$$

$$\left. + \cos(r-1)\theta\int_0^{\pi} d\phi\,\Pi_0\cos(r-1)\phi\right],$$

as above; and $\int ds\, n\lambda\Pi = 0.$

Hence (2) becomes

$$0 = \left[-2rA\,\frac{r\cos r\theta}{a}\int_0^{\pi} d\phi\,\Pi_0\cos r\phi\right.$$

$$\left. + \alpha^2 Aa\cos r\theta\int_0^{\pi} d\phi\,\Pi_0\{\cos(r+1)\phi + \cos(r-1)\phi\}\right]e^{\iota pt},$$

or
$$\int_0^{\pi} d\phi\,\Pi_0\cos r\phi\,(r^2 - \alpha^2 a^2\cos\phi) = 0 \ldots\ldots\ldots\ldots(3),$$

the disappearance of θ justifying the assumption made as to the form of λ. In this equation for finding α we may give to ϖ and z in Π_0 any values which correspond to a point on the surface of the wire. The simplest values are $\varpi = a+\epsilon$, $z=0$, and these should therefore be chosen.

6. The special case $r=1$, which corresponds to the fundamental node of the wire, is that of the most interest and will be investigated in detail.

In this case, (3) becomes on substituting for Π_0 its value (when $z=0$),

$$\int_0^{\pi} d\phi\,\frac{e^{\iota\alpha\sqrt{a^2-2a\varpi\cos\phi+\varpi^2}}}{\sqrt{a^2-2a\varpi\cos\phi+\varpi^2}}\{\cos\phi - \tfrac{1}{2}\alpha^2a^2(1+\cos 2\phi)\} = 0,$$

or, putting $\varpi = a+\epsilon$,

$$\int_0^{\pi} d\phi\,\frac{\frac{1}{2}\alpha^2a^2 - \cos\phi + \frac{1}{2}\alpha^2a^2\cos 2\phi}{\sqrt{2a(a+\epsilon)(1-\cos\phi)+\epsilon^2}}$$

$$+\int_0^{\pi} d\phi\,\frac{e^{2\iota\alpha a\sin\frac{1}{2}\phi}-1}{2a\sin\frac{1}{2}\phi}(\tfrac{1}{2}\alpha^2a^2 - \cos\phi + \tfrac{1}{2}\alpha^2a^2\cos 2\phi) = 0\ldots(4),$$

where in the second integral ϵ has been put $=0$, since we are neglecting small quantities.

The first integral in (4) is, calling $2\alpha a = x$, $\log\frac{8a}{\epsilon} = L$, and neglecting small quantities,

$$\frac{1}{a}\left\{2 - \frac{x^2}{3} + \left(\frac{x^2}{4} - 1\right)L\right\}$$

The second integral is, putting $\phi/2 = \psi$,

$$\int_0^{\frac{\pi}{2}} d\psi\,\frac{e^{\iota x\sin\psi}-1}{\sin\psi}\left\{\frac{x^2}{8a}(1+\cos 4\psi) - \frac{1}{a}\cos 2\psi\right\}$$

$$= \iota\int_0^{\frac{\pi}{2}} d\psi\,\frac{\sin(x\sin\psi)}{\sin\psi}\left\{\frac{x^2}{8a}(1+\cos 4\psi) - \frac{1}{a}\cos 2\psi\right\}$$

$$+\int_0^{\frac{\pi}{2}} d\psi\,\frac{\cos(x\sin\psi)-1}{\sin\psi}\left\{\frac{x^2}{8a}(1+\cos 4\psi) - \frac{1}{a}\cos 2\psi\right\}\ldots(5).$$

Now, n being an integer,

$$\frac{2}{\pi}\int_0^{\frac{\pi}{2}} d\psi \cos 2n\psi \cos(x\sin\psi) = J_{2n}(x),$$

$$\frac{2}{\pi}\int_0^{\frac{\pi}{2}} d\psi \cos 2n\psi \frac{\sin(x\sin\psi)}{\sin\psi} = \int_0^x dx\, J_{2n}(x)$$

$$= -2\left[J_{2n-1}(x) + J_{2n-3}(x) + \ldots + J_1(x)\right] + \int_0^x dx\, J_0(x).$$

Therefore the first integral in (5) is

$$\frac{\iota\pi}{2a}\left\{-\frac{x^2}{4}J_3(x) + \left(2-\frac{x^2}{4}\right)J_1(x) + \left(\frac{x^2}{4}-1\right)\int_0^x dx J_0(x)\right\},$$

and (4) becomes, on re-arrangement and multiplication by a,

$$\left(\frac{x^2}{4}-1\right)L = \frac{x^2}{3} - 2 - \frac{\iota\pi}{2}\left\{-\frac{x^2}{4}J_3(x) + \left(2-\frac{x^2}{4}\right)J_1(x) + \left(\frac{x^2}{4}-1\right)\int_0^x dx\, J_0(x)\right\}$$

$$-\left\{\frac{x^2}{8}\int_0^{\frac{\pi}{2}} d\psi \frac{\cos(x\sin\psi)-1}{\sin\psi}(1-2\cos 2\psi+\cos 4\psi)\right.$$

$$\left.+\left(\frac{x^2}{4}-1\right)\int_0^{\frac{\pi}{2}} d\psi \frac{\cos(x\sin\psi)-1}{\sin\psi}\cos 2\psi\right\} \ldots(6).$$

This equation gives x and thence α with an error of the order of ϵ/a. It can only be solved by trial. If however ϵ is so small that errors of the order of $1/L^2$ can be neglected, we may use an approximate solution of the above. A first approximation is $x^2=4$ or $x=2$. A second is obtained by putting $x=2$ on the right-hand side of (6). This gives

$$\left(\frac{x^2}{4}-1\right)L = \cdot 485 - \cdot 703\iota,$$

so that

$$\alpha = \frac{1}{a}\{1 + (\cdot 243 - \cdot 351\iota)/L\}.$$

Hence the period of the oscillation is equal to the time required for a free wave to traverse a distance equal to the circumference of the circle multiplied by $1-\cdot 243/L$, and the ratio of the amplitudes of consecutive vibrations is $1 : e^{-2\cdot 21/L}$ or $1 : 1-2\cdot 21/L$. It is easy to verify from first principles that the decrease in amplitude of the vibrations is of this order.

7. *Induced Vibrations in a Ring.* We will now consider the case of a ring upon which plane waves are incident in a direction parallel to the axis of the ring.

Let the coordinate axes be chosen as before, and let the incident vibration be given by

$$P = R = 0, \quad Q = Ae^{\iota\alpha z}e^{\iota pt}.$$

The tangential force at the point θ due to this wave together with a disturbance induced in the wire of the fundamental mode and magnitude B, is to be equated to zero, giving

$$0 = Ae^{\iota pt}\cos\theta - 2Be^{\iota pt}\frac{\cos\theta}{a}\int_0^{\pi} d\phi\, \Pi_0 \cos\phi\,(1-\alpha^2a^2\cos\phi).$$

If we neglect ϵ/a in comparison with unity, this becomes, as in § 6,

$$0 = A + \frac{2B}{a^2}\left[\left\{2-\frac{x^2}{3}+\left(\frac{x^2}{4}-1\right)L\right\}\right.$$

$$+\frac{\iota\pi}{2}\left\{-\frac{x^2}{4}J_3(x)+\left(2-\frac{x^2}{4}\right)J_1(x)+\left(\frac{x^2}{4}-1\right)\int_0^x dx J_0(x)\right\}$$

$$+\frac{x^2}{8}\int_0^{\frac{\pi}{2}} d\psi \frac{\cos(x\sin\psi)-1}{\sin\psi}(1-2\cos 2\psi+\cos 4\psi)$$

$$\left.+\left(\frac{x^2}{4}-1\right)\int_0^{\frac{\pi}{2}} d\psi \frac{\cos(x\sin\psi)-1}{\sin\psi}\cos 2\psi\right].$$

Unless $x=2$, this gives

$$B = \frac{2Aa^2}{(4-x^2)L},$$

so that in general the induced vibration is small, and the thinner the wire the smaller the induced vibration. The phase is the same as or opposite to that of the electric displacement in the plane of the ring due to the incident wave: If, however, $x = 2 = 2+\xi$, where ξ is small, we may put $x=2$ in all the terms not involving L, and get

$$B = \frac{Aa^2}{-2L\xi + \cdot 970 - 1\cdot 055\iota}.$$

The maximum amplitude of the induced vibration is obtained when $2L\xi = \cdot 970$, or $\alpha = x/2a = \{1+\cdot 243/L\}/a$, i.e. when the period of the incident wave is the same as the free period of the ring; the amplitude then is $\cdot 948Aa^2$, and the phase is in quadrature

with that of the wave. It is noteworthy that the amplitude of the induced vibration is independent of the thickness of the wire. If the incident wave is not proceeding in a direction perpendicular to the ring, the problem can still be solved by a method similar to the above. The vibrations induced in the ring will however not be confined to the fundamental, but will include vibrations of all modes.

8. *Helix.* We will now consider the case of vibrations propagated along an infinite wire wound into a uniform helix. Let the equations of the axis of the wire be $x = a\cos\phi$, $y = a\sin\phi$, $z = a\phi\tan\omega$. We shall assume $\lambda = Ae^{\iota\beta\phi}$. This assumption is justified later. The value of the force tangential to the wire at the point (ϖ, θ, z) is $e^{\iota\beta\theta}$ times that at the point $(\varpi, \theta, z - a\theta\tan\omega)$. Hence (2) gives

$$0 = Ae^{\iota pt}\left[\left(\frac{d}{ds}\right)_{\theta=0} e^{\iota\beta\theta}\int_{-\infty}^{\infty} d\phi\,\iota\beta e^{\iota\beta\phi}\Pi_0 + \alpha^2\left\{\cos\omega\int_{-\infty}^{\infty} d\phi\, a\cos\phi e^{\iota\beta\phi}\Pi_0 + \sin\omega\int_{-\infty}^{\infty} d\phi\, a\tan\omega e^{\iota\beta\phi}\Pi_0\right\}\right],$$

where Π_0 is the value that Π takes when $t = 0$ and ϕ is put for $\phi - \theta$.

Hence $$0 = \int_{-\infty}^{\infty} d\phi\, e^{\iota\beta\phi}\,(\alpha^2a^2\tan^2\omega - \beta^2 + \alpha^2a^2\cos\phi)\,\Pi_0 \ldots(7).$$

In obtaining this equation small quantities only have been neglected. If however ϵ/a is very small, we may in this equation neglect all finite quantities in comparison with those of the order of $\log\epsilon/a$. In this case we may with advantage find an approximate value of the right-hand side of (7).

Assuming κ any finite quantity, and neglecting terms that are finite, the right-hand side of (7) is

$$\int_{-\infty}^{-\kappa} d\phi\, e^{\iota\beta\phi}\,\frac{e^{-\iota a a}\phi\tan\omega}{-a\phi\tan\omega}\{\alpha^2a^2\tan^2\omega - \beta^2 + \alpha^2a^2\cos\phi\}$$

$$+\int_{-\kappa}^{\kappa} d\phi\,\frac{\alpha^2a^2\sec^2\omega - \beta^2}{\sqrt{2a\,(a+\epsilon)(1-\cos\phi) + a^2\phi^2\tan^2\omega + \epsilon^2}}$$

$$+\int_{\kappa}^{\infty} d\phi\, e^{\iota\beta\phi}\,\frac{e^{\iota a a\phi\tan\omega}}{a\phi\tan\omega}\{\alpha^2a^2\tan^2\omega - \beta^2 + \alpha^2a^2\cos\phi\}.$$

The second integral is, neglecting finite quantities,

$$-2\,(\alpha^2a^2\sec^2\omega - \beta^2)\,\frac{\cos\omega}{a}\log\epsilon.$$

The first and last can be reduced to sums of integrals of the form $\int_{\kappa}^{\infty} d\phi\,\frac{e^{-\gamma\phi}}{\phi}$. This integral* is $-\log\gamma$ to our order, and thus the first and last integrals give

$$\frac{1}{a\tan\omega}\,[(\alpha^2a^2\tan^2\omega - \beta^2)\log(\alpha^2a^2\tan^2\omega - \beta^2)$$

$$+\tfrac{1}{2}\alpha^2a^2\log\{(1+\beta+\alpha a\tan\omega)(1-\beta+\alpha a\tan\omega)(1+\beta-\alpha a\tan\omega)(1-\beta-\alpha a\tan\omega)\}],$$

and therefore the approximate form of (7) is

$$2\,(\alpha^2a^2\sec^2\omega - \beta^2)\sin\omega\log\epsilon = (\alpha^2a^2\tan^2\omega - \beta^2)\log(\alpha^2a^2\tan^2\omega - \beta^2)$$

$$+\tfrac{1}{2}\alpha^2a^2\log\{(1+\beta+\alpha a\tan\omega)(1-\beta+\alpha a\tan\omega)(1+\beta-\alpha a\tan\omega)(1-\beta-\alpha a\tan\omega)\}\ldots(8).$$

Several cases may occur. (i) In general, if α is not small, the only term of importance is that on the left, so that

$$\alpha^2a^2\sec^2\omega - \beta^2 = 0, \text{ or } \beta = \alpha a\sec\omega,$$

and the velocity of propagation measured along the wire is

$$\frac{p}{\beta}a\sec\omega = \frac{p}{\alpha} = V,$$

the same result as that obtained in the case of a circle.

(ii) If however α and β are small, the first term on the right is also of importance. If α and β are so small that $\log\epsilon$ can be neglected in comparison with $\log(\alpha^2a^2\tan^2\omega - \beta^2)$, i.e. if the product of the wave-length of the disturbance into the radius of the wire is very large compared with the square of the radius of the helix, we have $\alpha^2a^2\tan^2\omega - \beta^2 = 0$, or $\beta = \alpha a\tan\omega$, and the velocity of propagation measured along the wire is

$$\frac{p}{\beta}a\sec\omega = \frac{p}{\alpha}\operatorname{cosec}\omega = V\operatorname{cosec}\omega,$$

so that the disturbance is propagated with a velocity V measured along the axis of the helix.

If α and β are small, but not so small that $\log\epsilon$ can be neglected, i.e. if the product of the wave-length into the radius of the wire is comparable with the radius of the helix, the velocity of propagation has an intermediate value†. It is easy to see that a like result does not follow if we try to make $(\alpha^2a^2\tan^2\omega - \beta^2)$ small without making α and β small.

* J. W. L. Glaisher, *Phil. Trans.*, 1870, p. 369.

† Hertz, *Wied. Ann.* 1889, vol. 36, p. 21; *Electrical Waves* (tr. Jones), p. 158, has proved experimentally that this is the case.

(iii) If one of the factors, e.g. the last, of the term under the second log sign be small we have, since α and β cannot then both be small,

$$2(\alpha^2 a^2 \sec^2\omega - \beta^2)\sin\omega \log\epsilon = \tfrac{1}{2}\alpha^2 a^2 \log(1-\beta-\alpha a\tan\omega).$$

In this case we must have $\beta < \alpha a \sec\omega$, so that the velocity of propagation measured along the wire must be greater than V. There is however no superior limit to the value that it may have. There is an inferior limit to α. Hence for periods which are not greater than a certain value, there are two velocities of propagation along the wire, one $= V$ given by (i), the other, $> V$, given by (iii).

No other cases arise by making α and β great, since we must then recur to (7), as (8) does not then hold; and here if α and β are great, we simply have $\alpha^2 a^2 \sec^2\omega - \beta^2 = 0$, the case considered in (i).

(2) *On Circles, Spheres and Linear Complexes.* By Mr J. H. GRACE.

This paper is printed in the *Transactions,* Vol. XVI. Part III.

(3) *Reduction of a certain Multiple Integral.* By ARTHUR BLACK. Communicated by Professor M. J. M. HILL, M.A., Sc.D., F.R.S.

This paper is printed in the *Transactions,* Vol. XVI. Part III.

(4) *On the Gamma Function.* By Mr H. F. BAKER.

The Gamma Function could be defined for real values of x by the conditions (i) that $\Gamma(1)=1$, (ii) that $\Gamma(x+1)=x\Gamma(x)$, (iii) that, for a fixed finite h, as x tends to $+\infty$, the difference

$$\frac{\Gamma'(x+h)}{\Gamma(x+h)} - \frac{\Gamma'(x)}{\Gamma(x)}$$

tends always to zero. The condition (iii) was well known, being deducible from the result

$$\frac{\Gamma'(x)}{\Gamma(x)} - \log x = \int_0^\infty [e^{-xt} - (1+t)^{-x}]\frac{dt}{t},$$

and was of suitable character for a definition; it was desirable however to deduce it immediately from the equation

$$\Gamma(x) = \int_0^\infty e^{-t}t^{x-1}dt;$$

this note dealt with such a deduction.

The New York Herald October 31, 1897

ELECTRICAL CURE FOR SKIN DISEASE.

Nikola Tesla Envelops the Human Body in Luminous Flame with Wondrous Results.

Announcement of a Curious Discovery

NIKOLA TESLA is now in the midst of intricate electrical experiments which promise most valuable hygienic results, so soon as he declares himself ready to put his recently acquired knowledge into practical operation, for the ridding of the human skin of all extraneous matter, including parasites of every nature, whether they are virulent disease germs or not.

These experiments have been conducted by Mr. Tesla for some time within the secret precincts of his laboratory, and all of the matters involved, from the first inception to the last experiment, have received most careful consideration, and a number of times in his published writings he has hinted at what he believed and what he expected to accomplish, but only incidentally, and in a manner that has made his readers anxious to know just what it is he expects to do and how he intends to accomplish it.

Mr. Tesla was found in his laboratory yesterday, with head and hands full of matters electrical, as usual, and when spoken to of the interest his hints and suggestions of what he was doing had aroused he hesitated for a moment before answering.

Then, as a foundation, the electrician explained that it is a fundamental electrical law, well known, that two bodies charged with the same kind of electricity, either positive or negative, repel each other; that if a body be charged with electricity from a static machine the electricity accumulates on its surface.

"Now," continued Mr. Tesla, "if there are small bodies of the minutest weight on that electrically charged surface; and if they are conductors capable of taking electricity, they will also become charged with the same kind of electricity that the surface has received. What is the result under the law of repulsion? There is a force at work between them and the surface, which strongly tends to part the two, and the particles are thrown off, frequently with great force. In fact, this force can be increased to pressure of any desired magnitude. Just the form of apparatus I am using, and which accomplishes this thing, I must keep secret for a time yet.

"This repulsion under the pressure I have referred to is increased the more under the law that governs it, for if a given electrical pressure is doubled the repulsion is increased fourfold, and even more than this, on account of another law, because electricity preferably accumulates on points, and an extremely small body is practically a point. So the normal accumulation on the surface referred to—say it is of brass—is exceeded by the accumulation on the small bodies that may be on that surface.

"I have found ways of producing all degrees of pressure; even to a degree that approaches more or less to that of lightning; and the repulsion exerted on the small particles—when a body is charged with such a tremendous pressure—is so great as to actually tear asunder not only the firmly adhering small objects, but the very particles of the metal on which they rest. Now, for an illustration, if a brass ball is painted with bronze paint—which is conducting—the whole of the paint is almost thrown away when the pressure is turned

"But further. You know how firmly bronze paint adheres when it has dried. It requires great force to tear it away, but under the pressure I refer to not only is the bronze torn from the brass surface, but the hard brass itself is subjected to such a pressure that its particles are torn asunder, scattered with great force and thrown away, not only to distances measured by feet, but measured by miles. Keep up the action, and finally the entire solid brass ball would be carried away, but ages would be required to accomplish this result with the present apparatus, because of the smallness of the particles. Still, if the pressure was sufficiently great—as in the case of a lightning stroke—the brass ball could be destroyed in an infinitesimal period of tin e.

"Now we will see what all of this leads up to. I know that the scientific fact of the result described is accomplished, and we will consider its application to the human body in cases of skin disorders or any disorders that may arise from the skin being attacked by disease germs or parasites of any sort. Since small particles on a body can be thrown from it by the means I have told you of, it is thinkable or even very probable that a human body may in this way rid itself of any extraneous particles that may be on it, and as the disease germs, if any, would be among these particles, the possibility and practicability of such treatment naturally suggests itself.

"I have tried experiments in line with this suggestion and have reached most remarkable and startling results, that impress me as being of great value. They will be continued and their actual value positively ascertained before the method is unqualifiedly recommended.

"By means of my apparatus I have applied an electrical current from a static machine so as to agitate the air surrounding a human subject in a most extreme and remarkable manner. The startling effect was to make the person when operated on in a darkened room appear to be clouded in a haze of luminous mist.

"The electrical pressure not only violently agitated the air around the body, but the repelling force threw off all particles with such violence that their extremely rapid motion through the atmosphere caused a friction that consumed them, and for the fraction of a second making them luminous, so much so as to cause them to appear like myriads of infinitisimal meteors shooting in all directions away from the repelling body.

"I have gone far enough with these experiments to suggest the possibility of completely enveloping the human body in an actual sheet of flame, without injury to either the skin or the nerves.

POWER TRANSMISSION

TESLA'S HIGH POTENTIAL TRANSFORMER.

IN his experiments involving high potentials Mr. Nikola Tesla has for some time past made use of a special form of induction coil, and in a recent patent issued to him he describes several forms specially adapted to be used in connection with a system of high potential power transmission. To accomplish the desired object Mr. Tesla employs an induction coil or transformer in which the primary and secondary coils are wound in such manner that the convolutions of the conductor of the latter will be farther removed from the primary as the liability of injury from the effects of potential increases, the terminal or point of highest potential being the most remote, and so that between adjacent convolutions there shall be the least possible difference of potential.

The type of coil in which the last named features are present is the flat spiral, and this form Mr. Tesla generally employs, winding the primary on the outside of the secondary and taking off the current from the latter at the center or inner end of the spiral.

In constructing his improved transformers Mr. Tesla employs a length of secondary which is approximately one-quarter of the wave length of the electrical disturbance in the circuit including the secondary coil, based on the velocity of propagation of electrical disturbances through such circuit, or, in general, of such length that the potential at the terminal of the secondary which is the more remote from the primary shall be at its maximum. In using these coils the inventor connects one end of the secondary, or that in proximity to the primary, to earth, and in order to more effectually provide against injury to persons or to the apparatus he also connects it with the primary.

The accompanying diagram, Fig. 1, illustrates the plan of winding and connection employed in constructing the improved coils and the manner of using them for the transmission of energy over long distances.

A designates a core, which may be magnetic, around which the coil B is wound in spiral form. C is the primary, which is wound around in proximity to the secondary. One terminal of the latter will be at the center of the spiral coil, and from this the current is taken to line. The other terminal of the secondary is connected to earth and also to the primary.

When two coils are used in a transmission system in which the currents are raised to a high potential and then reconverted to a lower potential, the receiving transformer will be

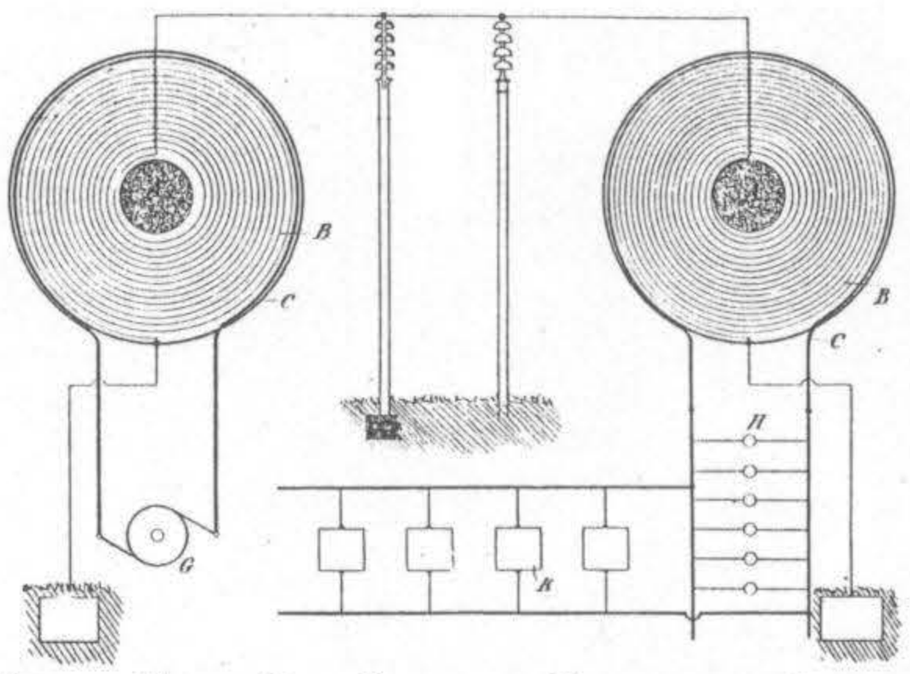


FIG. 1.—TESLA HIGH POTENTIAL TRANSMISSION SYSTEM.

constructed and connected in the same manner as the first—that is to say, the inner or center end of what corresponds to the secondary of the first will be connected to line and the other end to earth and to the local circuit or that which corresponds to the primary of the first. In such case also the line wire should be supported in such manner as to avoid loss by the current jumping from line to objects in its vicinity and in contact with earth—as, for example, by means of long insulators, mounted, preferably, on metal poles, so that in case of leakage from the line it will pass harmlessly to earth. In Fig. 1, where such a system is illustrated, a dynamo G is rep-

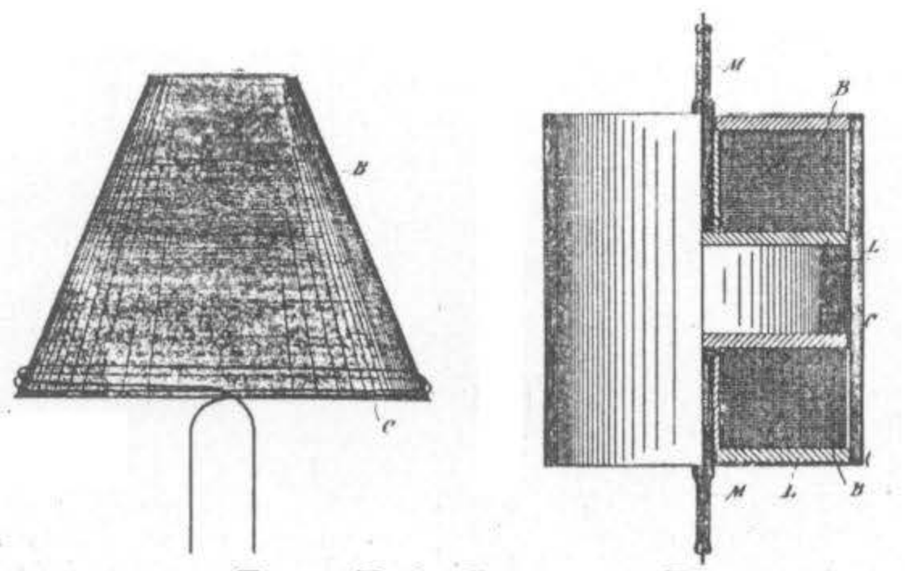
resented as supplying the primary of the sending or "step-up" transformer and lamps H and motors K are shown as connected with the corresponding circuit of the receiving or "step-down" transformer.

Instead of winding the coils in the form of a flat spiral the secondary may be wound on a support in the shape of a frustum of a cone and the primary wound around its base, as shown in Fig. 2.

In practice for apparatus designed for ordinary usage the coil is usually constructed on the plan illustrated in Fig. 3. In this figure L L are spools of insulating material upon which the secondary is wound—in the present case, however, in two sections, so as to constitute really two secondaries. The primary C is a spirally-wound flat strip surrounding both secondaries B. The inner terminals of the secondaries are led out through tubes of insulating material M, while the other or outside terminals are connected with the primary.

The length of the secondary coil B or of each secondary coil when two are used, as in Fig. 3, is, as before stated, approximately one-quarter of the wave length of the electrical disturbance in the secondary circuit, based on the velocity of propagation of the electrical disturbance through the coil itself and the circuit with which it is designed to be used—that is to say, if the rate at which a current traverses the circuit, including the coil, be 185,000 miles per second, then a frequency of 925 per second would maintain 925 stationary waves in a circuit 185,000 miles long, and each wave length would be 200 miles in length. For such a frequency Mr. Tesla would use a secondary 50 miles in length, so that at one terminal the potential would be zero and at the other maximum.

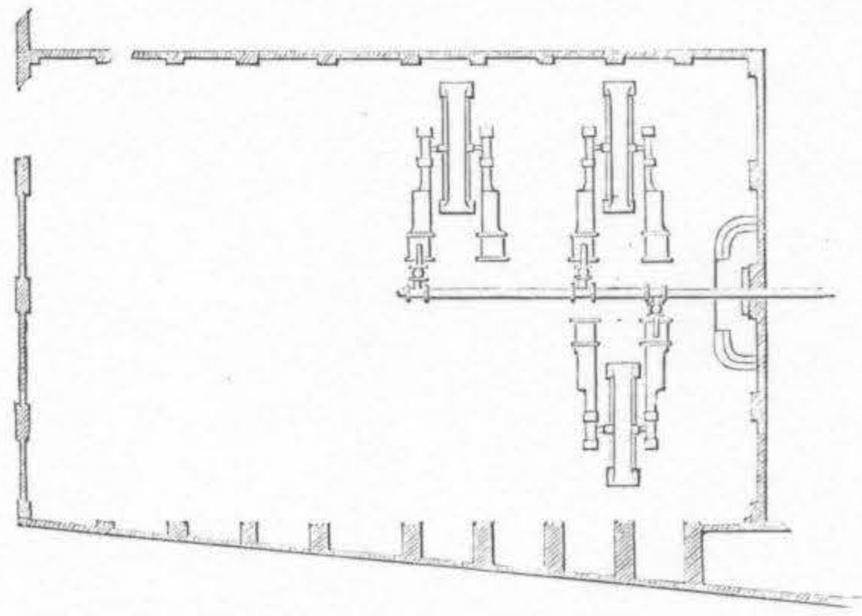
Coils of this character, according to Mr. Tesla, have several



FIGS. 2 AND 3.—TESLA HIGH POTENTIAL TRANSFORMERS.

important advantages. As the potential increases with the number of turns the difference of potential between adjacent turns is comparatively small, and hence a very high potential, impracticable with ordinary coils, may be successfully maintained. As the secondary is electrically connected with the primary the latter will be at substantially the same potential as the adjacent portions of the secondary, so that there will be no tendency for sparks to jump from one to the other and destroy the insulation. Moreover, as both primary and secondary are grounded and the line-terminal of the coil carried and protected to a point remote from the apparatus the danger of a discharge through the body of a person handling or approaching the apparatus is reduced to a minimum.

from multiphase machinery. As a concession to this opinion, it may be pointed out that in some of the Continental stations where multiphase plant is employed, the three-phase current is merely transmitted to distant points, and there utilised to drive continuous current machinery. This does not, however, obtain in every case, for at Baden, Milan, and a large number of other places on the Continent, multiphase current is being supplied direct to both motors and lamps without causing, as far as we can learn,

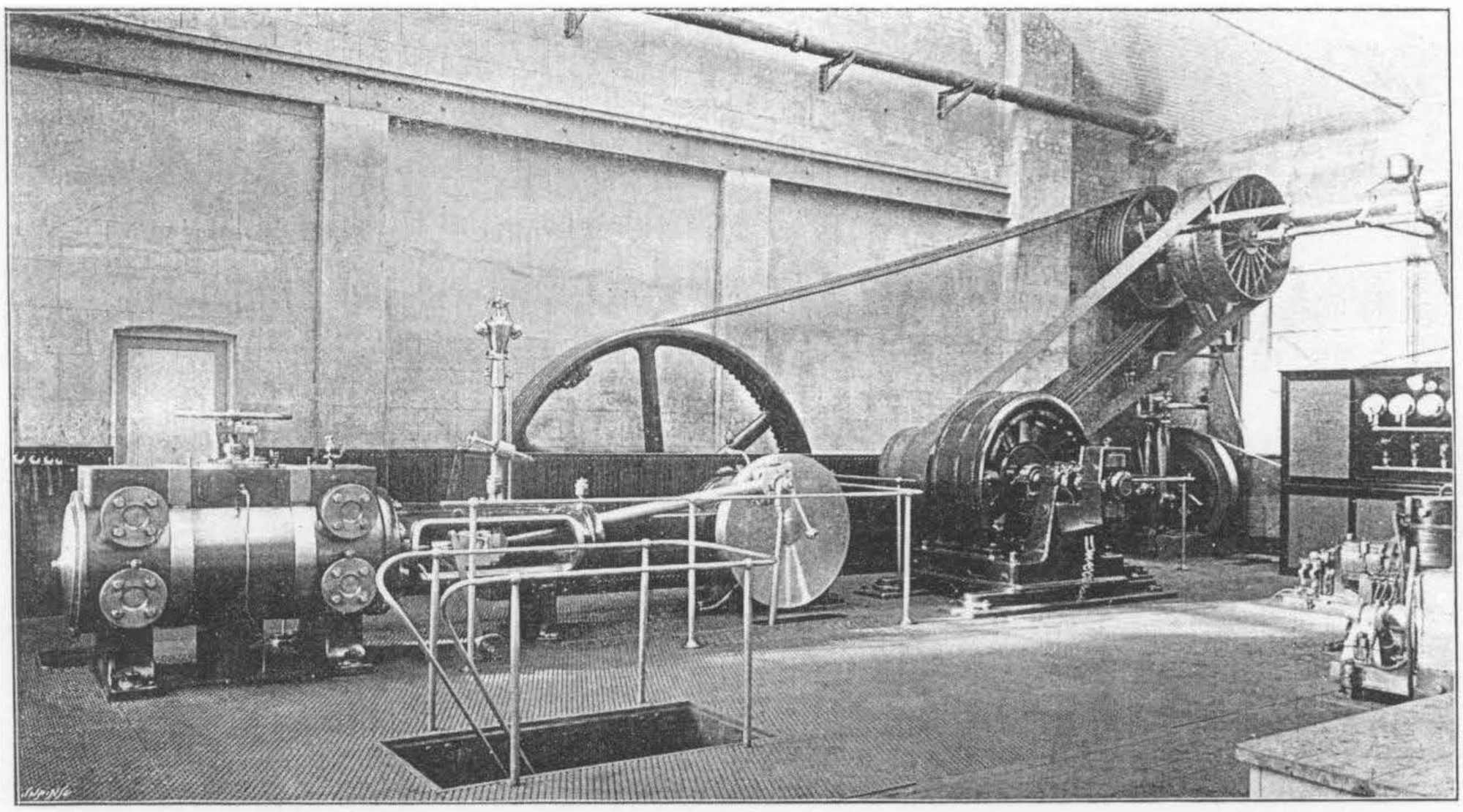


Direct Coupled Plant, Capacity of 660 Units (see p. 661).

THE INTRODUCTION OF MULTIPHASE WORK IN THE UNITED KINGDOM.

The question as to why multiphase work has not been more generally adopted in this country is one that must have occurred to many. It is generally conceded that a large measure of success has attended the systems that have been laid down in different parts of the European Continent and America, and these systems have been examined and duly praised from time to time by English engineers. At the same time there was—and, no doubt, there still remains—a feeling that there were certain limitations in a multiphase system. A commonly-expressed opinion was that though a multiphase system might show distinct advantages when used solely for power purposes, certain complications would arise if an attempt were made to do both lighting and driving any complications. At Baden, Messrs. Brown, Boveri's shops are being driven from the town supply, which is on the two-phase system, and a considerable amount of lighting is being done, indeed the power required for lighting is about equal to that required for motive power purposes.

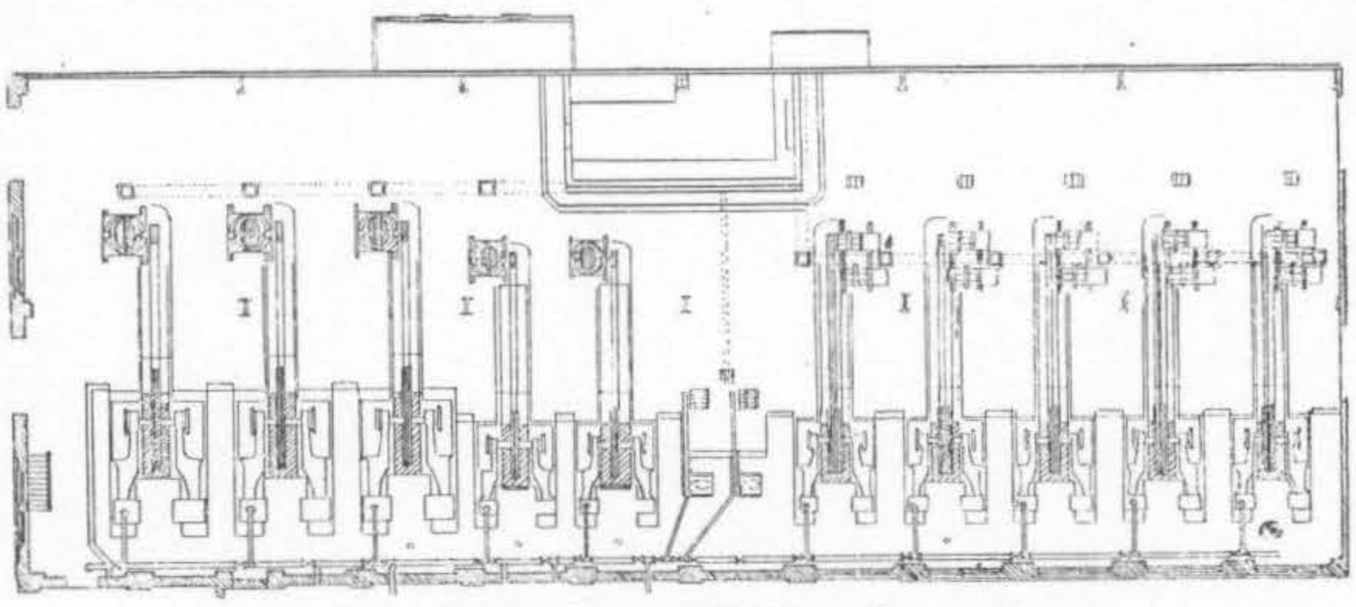
In spite of the reluctance of English engineers to take up multiphase work, it has been held that for some purposes the induction motor is most desirable. As was said some time ago in these columns:* "Now that the commutatorless motor is perfected in the form of single-phase, two-phase, and three-phase induction motors, these somewhat lame devices (enclosing motors and brushes) are not likely to be perpetuated. The only motor for fiery mains is the induction motor. They can be started with sufficient torque for all practical purposes, and are absolutely sparkless, and, in reality, much safer to handle than continuous current motors. This last claim for induction motors is generally overlooked, but



Single Engine Driving 80 kw. Generator at Messrs. Richardson & Sons.

* Rankin Kennedy, Electrical Review, Vol. 39, September 11th, 1896.

from the facilities offered in transforming the alternating currents used in induction motors, we can work them at much lower electric pressures than the continuous motor; for in order to run the continuous motor with wires at any reasonably low cost, we must use 300 to 700 volts right up to the motor. We cannot transform down to 100 or 50 volts as we can with the induction motor. Using the induction motor, we can transmit a large power at very small loss through thin wires to a long distance, and then still be able to apply a low pressure to the motor."

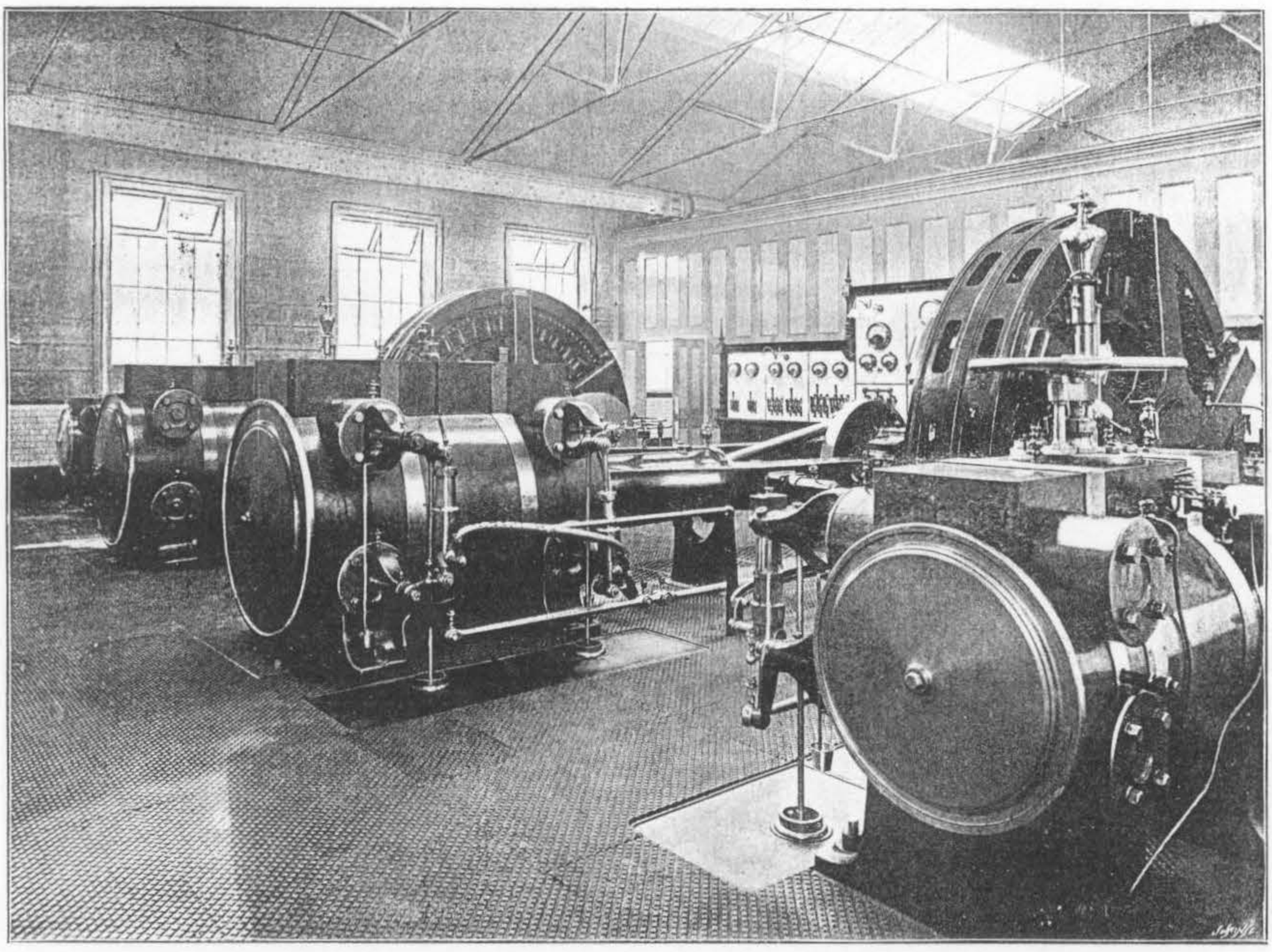


Rope Driven Plant, 650 Units Capacity.
(See page 661.)

The foregoing advantages were in all probability appreciated by most electrical engineers, but before there could be much extension of the induction motor, it was necessary to satisfy English engineers on one point, and that was, How do we stand in regard to patent rights? It must be confessed that the position has been an unsatisfactory one, and we can hardly accuse the reputed owners of the patents of unduly advertising their rights. There seemed to be insuperable difficulties in the way of obtaining authoritative information as to what were the patents, or to what extent they governed the three-phase motor. On all hands the question was raised, but as no satisfactory reply could be given, manufacturers, for the most part, gave up all idea of entering into the manufacturing of multiphase motors, and it is this difficulty, more than all others, that has retarded their introduction into this country. One of the most definite opinions given on the subject was that of Mr. Rankin Kennedy, which appeared in these columns,* to the effect that:—"There are some good and valid patents concerning the various 'improvements' on polyphase motors, but it is extremely doubtful whether any one, or more of them, can be held as a master patent controlling the whole of the polyphase motor business."

Considering, therefore, the delicacy of the whole question, the announcement that Messrs. Thomas Richardson & Sons, of Hartlepool, in conjunction with Messrs. Brown Boveri, had made arrangements to manufacture multiphase machinery in this country was naturally of considerable interest.

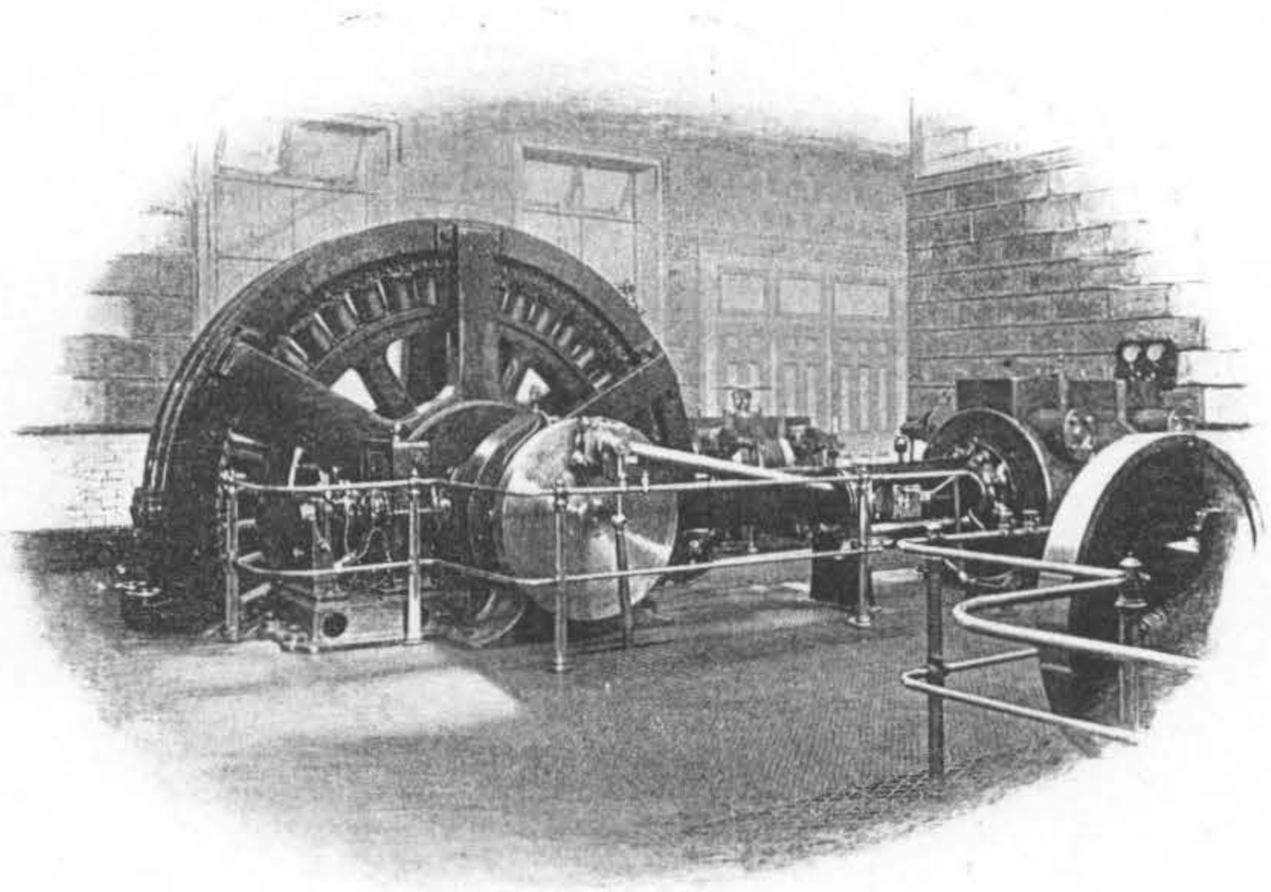
We have recently learned how Messrs. Richardson & Sons came to add so interesting a department to their extensive engineering business, and it will be entertaining to recount how the multiphase motor question was approached by them. Sir Thomas Richardson has long been impressed with the value of electrical driving, and he has for some years been a staunch adherent of the system. In order to obtain a comprehensive knowledge of the various methods of electrical transmission over short distances, Sir Thomas Richardson and Mr. D. B. Morison visited the Continent, and the result of their investigations was to establish in their minds the marked superiority of multiphase methods. When they sought, however, to introduce



General View of Multiphase Generators at Messrs. Richardson & Sons.

* Electrical Review, Vol. 39, p. 496.

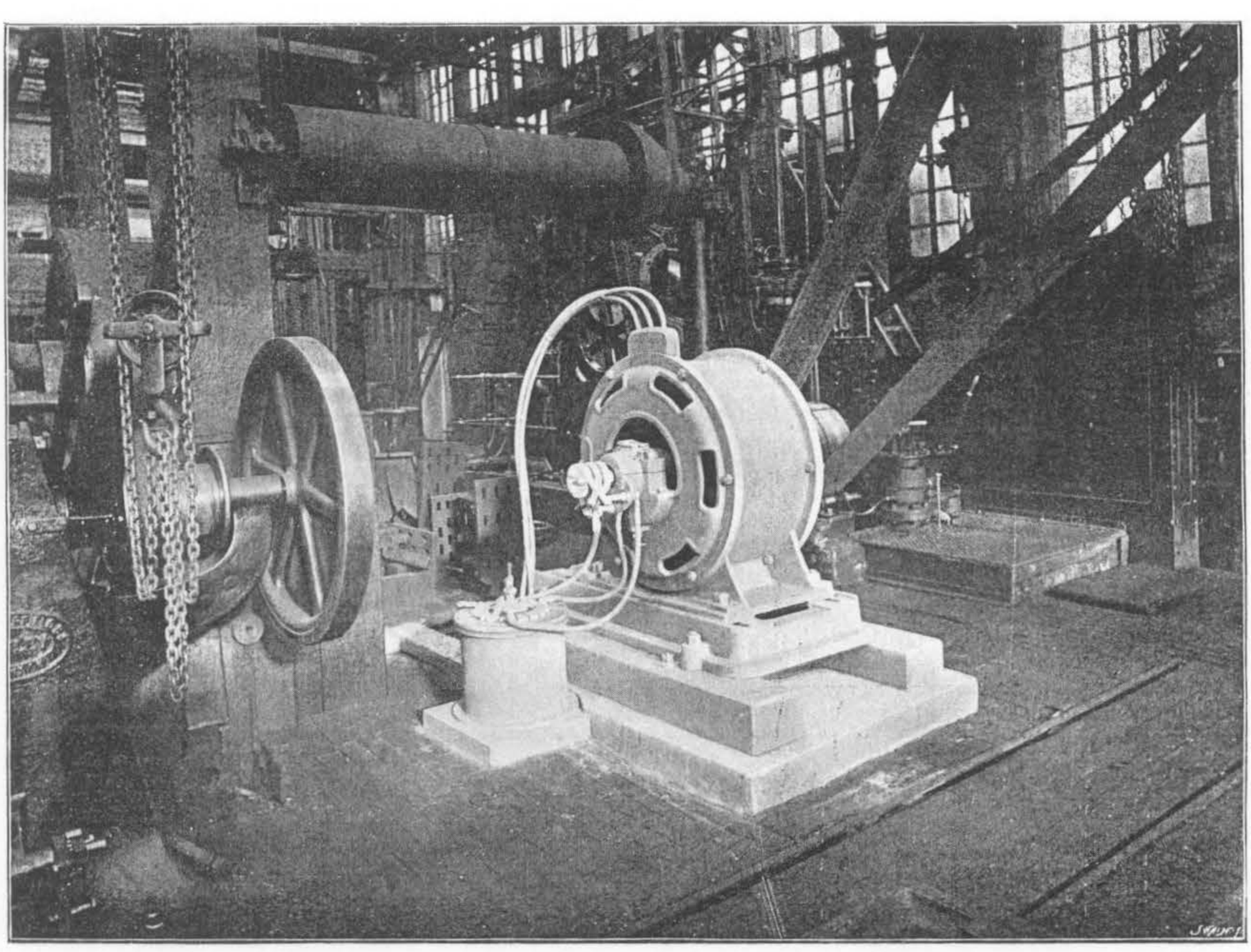
three-phase working into their own works, they were immediately confronted with the patent question; but not to be turned aside by an obstacle of this nature, they sought legal assistance, and went into the whole question of the patent rights for induction motors in this country. The result of their somewhat elaborate investigations was to satisfy themselves that the Tesla patent really covered the ground, and so convinced were they of this fact, that negotiations were immediately commenced with the Tesla Company for a license to use and manufacture multiphase motors. The preliminary negotiations were most unpromising, however, and when pressure was brought to bear on the Tesla Company, the patent rights were transferred to the Westinghouse Company. Difficulties again arose, but ultimately satisfactory arrangements were completed.



Multiphase Generator at Messrs. Richardson & Sons.

Whatever difference of opinion there may be on the legal aspects of the question, Messrs. Richardson & Sons are to be heartily congratulated on arriving at one solution of an apparently intricate problem. They have not only cleared the air of the mystery that surrounded the ownership of the induction motor; they have laid down a plant for multiphase working on a sufficiently large scale to demonstrate the simplicity and economy of the system. It will be admitted, from the illustrations of the generating plant, that Messrs. Richardson & Sons have provided a model station, and for arrangement and soundness of design we do not think that this country has anything superior to show.

Without taking into consideration this latest addition to multiphase systems, we suppose, at the outside, there are not more than four or five in the United Kingdom, and these are



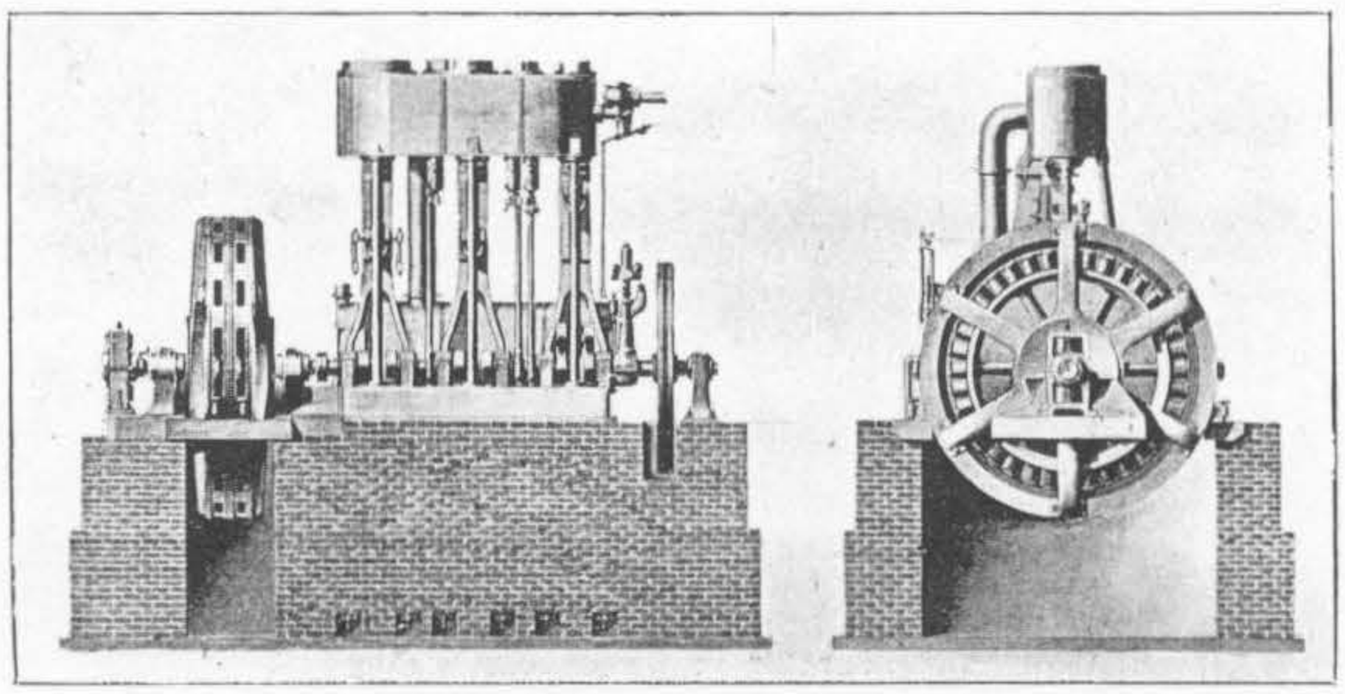
Multiphase Motor Driving Shafting at Messrs. Richardson & Sons.

The position then at the present moment with regard to three-phase patents in this country, and, of course, it must be remembered that the present position has been arrived at without the intervention of the Courts, is that it is necessary to obtain a license from the Westinghouse Company.

only of moderate size. There is a small one at Glasgow of 100 horse-power, and another of about 130 H.P. in Edinburgh, in both of which cases "Brown's" machinery is employed; in addition, there is the one at the Liverpool Grain Warehouses, which was recently described in these

columns, and probably there are one or two others on a small scale.

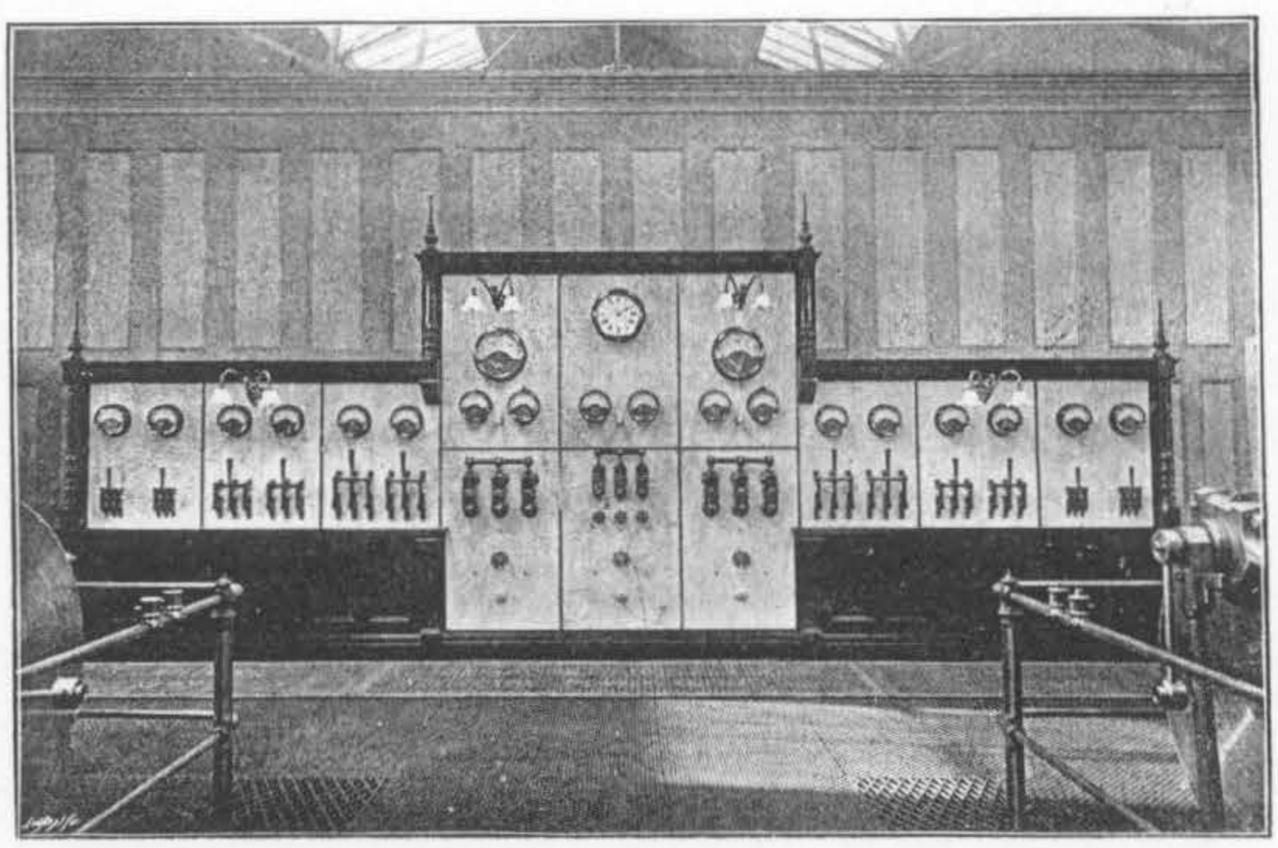
The plant, which has been laid down by Messrs. Richardson and Sons, aggregates about 1,250 H.P. There are at the present moment, as will be seen from the illustration, two large fly-wheel generators driven by horizontal compound engines, and a smaller machine of 80 kw. driven by a single engine, which is intended for night shifts. Each of the fly-wheel generators is capable of absorbing 420 brake H.P., which is the full output of the engines. The generators supply three-phase current to motors placed at different parts of the works. The plant is located in a well-designed building, the interior of which is lined with terra cotta coloured plaster, which helps to give a pleasing appearance to the station. The steam raising plant consists of two marine type boilers, generating steam at 160 lbs.



Messrs. Richardson & Sons' Direct Coupled Vertical Engine and Multiphase Generator.

The fly-wheel generators run at a speed of 125 revolutions, and generate three-phase currents at a tension of 200 volts between each terminal, and at a frequency of about 41 per second.

The rotating part of these machines consist of the fly-wheel of the engines, on the circumference of which are fixed the poles of the field magnet system. The winding of these poles consists of a spiral of copper strip, wound up on edge, the several convolutions of strip being insulated from the neighbouring turns by layers of varnished paper. This rotating field magnet revolves within the fixed armature. The laminated iron core of the armature is securely held in a cast-iron frame, the whole being divided into two parts for convenience and handling. This ring-shaped armature is supported in position on two star shaped cast-iron frames, which in turn are carried centrally on trunnion rings, bolted to the frame of the engines.



Multiphase Switchboard at Messrs. Richardson & Sons.

The armature, when in position, is thus like a wheel, capable of being rotated round the trunnion ring mentioned above.

The turning moment exercised on the armature by the rotating field magnet when the machine is doing work, is taken up on small bed-plates on the ground level at the outer circumference of the armature.

These bed-plates are so arranged that, on loosening the tightening screws (seen on the photograph at the circumference of the armature), part of the bed-plate can be slipped out of its place, which allows the armature to be rotated, there being then sufficient clearance for the screws and their bosses to pass through the embrace of these bed-plates.

The advantages claimed for this mode of construction are firstly, the possibility of carrying the armature absolutely centrally with regard to the rotating part, and secondly, that it allows easy access to any part of the armature for cleaning or possible repair, without making the pit in which the armature is situated so large as would otherwise be required.

The simplicity of the switchboard, as evidenced by the illustration, is one of the most noteworthy features of this plant. It is made up of three larger and six smaller marble panels, the larger ones being for the generators and the smaller ones for the feeders. One great point about the board is that the back is quite open, and access can be obtained to it from the adjoining room. Connections are brought from the dynamos by means of flat strips carried in tunnels, and the strip is continued along the back of the board, the size decreasing as the end of the feeder connections is reached. The fuses are fixed at the back of the board. Each panel carries a three-point switch and a voltmeter and ammeter, large dial ammeters easily read from all parts of the room indicating the total output of the plant. The mains throughout the works are carried in underground tunnels and supported on porcelain insulators.

The synchronising arrangements are simplicity itself, a pair of 200-volt incandescent lamps being used for each machine. No artificial load being used, no difficulty whatever is found in using any combination of the three machines in parallel.

Thirteen motors are installed in the shops; the sum of the powers of these machines is just over 500 H.P., five of them are 65 H.P. machines, the others vary in size down to 10 H.P.

A motor of 20 B.H.P. drives the pattern shop, and it is interesting to observe that this motor has repeatedly been tested to double its working load. This motor drives from a floor above the wood-working shop, the motors in all other cases being fixed on the floor and driving upwards. The illustration which we give shows one of the motors driving the whole of one of the engineering shops, thus supplanting an old beam engine, which is situated just behind the motor.

The "Brown" multiphase motor is too well known to need further description. The windings of the fixed part of the motor which are traversed by the main current are carried through tunnels in the laminated iron. These tunnels are insulated with layers of varnished paper, which has been found a very satisfactory insulator for all tensions.

The rotating part of the large motors is also wound with a multiphase winding, the three ends of which are brought out to sliding contact rings on the shaft At starting, a three-branch resistance is inserted between these rings, to regulate the current at starting in the same manner as in a continuous current machine.

As a point in favour of the economies already effected at Messrs. Richardson & Sons by the introduction of the multiphase plant, it is worth noting that it is expected that the

fly-wheel generators will supply power for the whole of the works, which hitherto has necessitated the use of *ten boilers*.

It is very evident that considerable interest is being taken in multiphase transmission, and at the present moment Messrs. Richardson & Sons have orders in hand for multiphase plant equivalent to 1,500 H.P. The type of combined plant which is being recommended is shown in the annexed sketch, and consists of a triple expansion engine of the vertical type, coupled direct to a three-phase generator. We trust that every success will attend the courageous efforts of Messrs. Richardson's to introduce multiphase machinery into this country.

Mr. Charles F. Higgins, formerly chief assistant to Brown, Boveri & Co., is superintending the electrical department at Messrs. Richardsons. It may be mentioned that Mr. Higgins has been intimately concerned in the introduction of multiphase machinery into this country, and has supervised the erection of all the "Brown" multiphase plant including the small plants at Glasgow and Edinburgh. Messrs. Geipel & Lange, of 68, Victoria Street, are the London agents for Messrs. Richardson & Sons.

TELEGRAPHY WITHOUT WIRES.

The following intelligent summary of the present status of the problem of telegraphy is condensed from a recent editorial utterance of the *Scientific American*, and will be found of interest :

Nikola Tesla has lately announced that he has completed his wireless telegraph to such an extent as to permit of telegraphy through the earth for a distance of twenty miles or more, and his experiments satisfy him of the feasibility of wireless telegraphy on a much more extended scale. In fact, he aims at nothing less than the establishment of a system of telegraphy that shall include the whole earth, and by which items of news may be distributed from one political or commercial center to every other such center throughout the world. This, Mr. Tesla claims, is possible without the interference of one set of signals with another.

He has constructed and tested both transmitting and receiving apparatus, and has found that a surprisingly small expenditure of energy is required. It is impossible, at this writing, to secure details of the apparatus, but it is known that he utilizes the static equilibrium of the earth. This he disturbs at one point, making signals which can be distinguished at one or more distant points.

In his earlier experiments in high frequency currents Mr. Tesla attained a frequency of 10,000 per second ; now 2,000,000 oscillations per second is not deemed extraordinary. It is said that the success of the system is assured, but he will not come before the public until every detail is completed. It is understood that the transmission of power from place to place by means of a similar system is contemplated.

While Mr. Tesla has been wrestling with this great problem in this country, Mr. Marconi, a young Anglo-Italian, has been working on the same line in England under the direction of Mr. Preece. It is reported that Mr. Preece has succeeded in telegraphing with certainty and sufficient rapidity from Penarth to Weston-super-Mare, a distance across the water of seven or eight miles, without wires, and it is believed that this distance can be greatly extended.

It is said by *The Engineer* that the apparatus devised by Marconi is extremely ingenious, and has for its object the getting out of the Hertzian vibrations sufficient work for telegraphic purposes. The apparatus comprises a transmitter and receiver. The former consists mainly of a small Ruhmkorff induction coil excited by a couple of battery cells. The secondary or high tension wires terminate each in a metallic ball. Between the two balls is placed a cubical box containing oil. In the opposite sides of the box are fixed two brass balls, oil-tight, so that one-half of each ball is in the oil in the box and the other half outside of the box. The balls do not touch. The whole arrangement has been designed by an Italian professor, Righi. On sending a a current through the induction coil, Hertzian vibrations are set up in the balls and communicated to the ether. The oil has a peculiar effect, acting as a species of brake, the rapidity of the wave vibrations being only about one-half of that stated by Dr. Lodge. These vibrations are then given off into space all around in every direction. So far as known, nothing save metals appears to be opaque to them, and here, therefore, we have an analogy with the Röentgen ray.

Marconi's receiver consists of a tube about ¼ inch in diameter and 3 inches long, in which are two silver plugs terminating in wires, the ends of which are soldered to the silver plugs. The wires are fused into the glass. The tube is exhausted to a near approach to absolute vacuum. The faces of the two silver plugs are very close to each other, and the space between is filled up with an impalpable metallic dust. On the nature of this dust much depends. It must suffice to say that there are in it three constituents, one of which is nickel. Under ordinary conditions this powder will not conduct electricity, save feebly. Its resistance is very high. If a Hertzian ray falls on the little tube, the dust is polarized like the filings in a Hughes test tube, and the powder becomes a conductor. It will be seen at once that we have here a make and break which can be acted on from a distance, and an ordinary Morse sounder does the rest. But matters, after all, are not quite so simple. It is easy to dispatch into space Hertzian waves at intervals corresponding to dots and dashes, but the powder in the receiver, once polarized, remains polarized. To get over this obstacle, a tiny hammer is so arranged that, the moment a current passes through the tube, the hammer taps the side of the tube and depolarizes the powder ready for the next signal.

There is nothing in common between ethereal or wireless telegraphy and telegraphy by induction; the phenomena are wholly distinct. The Hertzian radiance is akin to light, and the polarization of the powder in the receiver finds its analogue in the molecular change which is wrought by light in a sensitized plate.

Wireless Telegraphy.

There are two errors in connection with wireless telegraphy that are being constantly repeated, viz., that Marconi has done nothing new, and that the British Post Office neglected the work of Dr. Oliver Lodge and took up that of Marconi. When such a statement is reiterated by so eminent an authority as Prof. Silvanus Thompson, one feels constrained to enter some protest. At a lecture on "Signalling without Wires," recently delivered at the London Institution, Prof. Thompson, after very properly extolling the magnificent work of Hertz and Lodge, asked what had Marconi done? Nothing new! But surely before Marconi came to this country there had been no serious attempts at signalling over considerable distances. We presume if either Dr. Lodge, or even Mr. Tesla, had thought they were so near such striking results, they would have been unceasing in their efforts to carry the experiments a little further than they did. Moreover, we feel sure that if Dr. Lodge had brought something definite before the British Postal authorities they would have taken up his discovery as readily as they did Marconi's. At the same time, whatever may be the commercial future of systems of signalling across space, its development may be said to be due to the minds of many.

The New York Herald December 19, 1897

CHRISTMAS UPON ADRIATIC'S SHORES.

—As Recalled by—

NIKOLA TESLA.

NIKOLA TESLA does not often speak at length about himself or his wonderful electrical inventions, but he sat and talked for an hour or two the other day with a friend about Christmas in the province of Lika, which is a part of the Austro-Hungarian empire and lies close to the Adriatic Sea, near Herzigovina, Dalmatia and Bosina. Tesla passed much of his boyhood in Smiljan, a town of Lika, where his father was pastor of a Greek church, but went from there while yet a boy.

"Christmas festivities in my country," said Mr. Tesla, "differ much from Christmas festivities here, yet there are many similarities, too. We begin the celebration on the day before Christmas by fasting. We do not altogether abstain, being privileged to eat freely of fish and all vegetable foods, but we may partake of no flesh meats, nor milk, nor eggs. This day is devoted largely to reflection, and its observance lasts until late on Christmas Eve.

"We rise very early in my country on Christmas morning—as early as three o'clock at the latest—to go to church and hear mass. All the morning until eleven o'clock is given over to religious services of one sort or another, and but little if any food is taken until that hour. By that time, however, every one is hungry, and a liberal luncheon is eaten, no discrimination being made against the heartiest food.

"Every one in my country is fond of coffee, which is generally drunk in large cups, with cream or milk. We may drink coffee on the day before Christmas, but without milk only, and as we are allowed to resume the use of milk in coffee on the day itself, you may be sure we then indulge freely in the delicious drink. After this breakfast, the gentlemen are served with liquors and little cakes.

The Christmas Dinner.

"The Christmas dinner comes later in the day, and I assure you it is always a meal to remember. No, we do not serve turkey there as the chief dish, and I am not sure that I can name any dish that may properly be said to take the turkey's place, unless it be roasted pig.

"I do not remember a Christmas dinner without a roasted pig in my country. The pig selected is always very young and small, and is roasted entire after dressing, the cooking being attended to with great care and prolonged until the skin is crisp and crackling. Besides the Christmas pig there are many other dishes served on the great Christmas festival—all the good things, in fact, that can be devised, the same as in America; and every one eats as heartily as possible, another point in which the people of my country and Americans are alike.

"There is always a Christmas tree wherever there are children in my country, and the good house mothers and fathers prepare and decorate them with much loving care, to the great delight of the little ones. There are always present a-plenty on the trees, of course, but, even so, gift giving is not so much a feature of the holiday time here as there.

"The stockings are not hung up on Christmas eve, as here, in my country, but on St. Nicholas Day, which falls some days earlier than Christmas. In America the festival of St. Nicholas, or Santa Claus, and Christmas seem to be combined, but there they are kept separate, and the children have two days of holiday rejoicing and frolic in place of one.

"As a matter of fact, they have more than that, since the observance of Christmas itself lasts two or three days after the day itself, during all which time the greatest jollity prevails, and family reunions are held. There is much visiting back and forth, and seasonable greetings fill the air.

"But sometimes," continued the electrician musingly, as if thinking of other days, "the reunions are not held, and the visiting exists in the wishes of the people only. That is when the deep snows come.

A Land of Mighty Snows.

"For you must know," he went on, "that my country is not only cold in the winter, but subject at times to great snowfalls, the like of which I have never seen in the New World—snowfalls so deep that a man's head would be far below the level of the light and feathery substance in many places; snowfalls that are often accompanied by wild, fierce winds, piling the flakes up into enormous drifts in some places and sweeping the rock bound soil clean in others; snowfalls that it is not well to encounter unless shelter is near, and that have buried many a human victim beneath a milk white death mantle.

"Not all these terrible storms come in the winter season, either, as I have excellent cause to remember. My country is high above the sea level, my home was two thousand feet and more straight up from the tide, and many there be who live one, two, almost three thousand feet higher."

TESLA'S LATEST ADVANCES IN VACUUM-TUBE LIGHTING.

APPLICATION OF TUBES OF HIGH ILLUMINATING POWER TO PHOTOGRAPHY AND OTHER PURPOSES.

To the Editor of Electrical Review:

A few years ago I began a series of experiments with a view of ascertaining the applicability of the light emitted by phosphorescent vacuum tubes to ordinary photography. The results soon showed that, even with a tube giving no more light than the equivalent of one half of a candle, objects could be easily photographed with exposures of a few minutes, and the time could be reduced at will by pushing the tube to a high candle-power. Photographs of persons were likewise obtained at that time and, if I am not mistaken, these were the first likenesses produced with this kind of illumination. However, a number of facts, not pertaining to the subject presently considered, were observed in the course of these experiments which, had they been immediately published, might have materially hastened important scientific developments which have taken place since. To dwell on these and other experimental results obtained at that time, more extensively at the first opportunity, is one of my good resolutions for the coming year. A calamity, unfortunately, interrupted my labors for a short period, but as soon as I was able I took up again the thread of the investigation, which was not only interesting in connection with the principal object in view, but was also useful in many other respects. So, for instance, in making observations as to the efficiency or any peculiarity of the vacuum tubes, the photographic plate was found to be an excellent means of comparison, note being taken of the distance and time of exposure, character of the phosphorescent body, degree of rarefaction and other such particulars of moment.

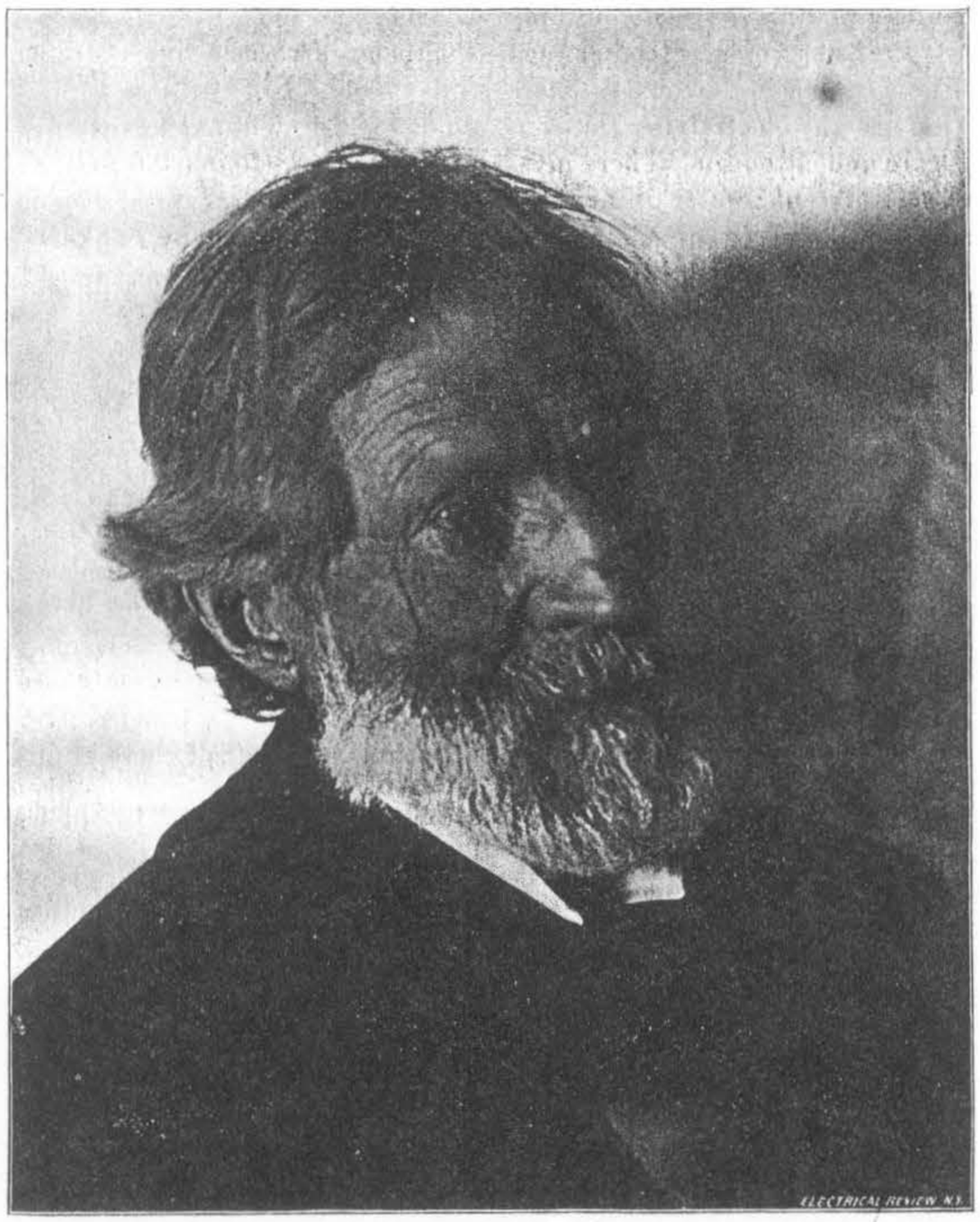


Fig. 1.—"Tesla's Latest Advances in Vacuum-Tube Lighting." Photograph Made by the Light of a Single Vacuum Tube, at a Distance of Five Feet; Exposure, Five Seconds.

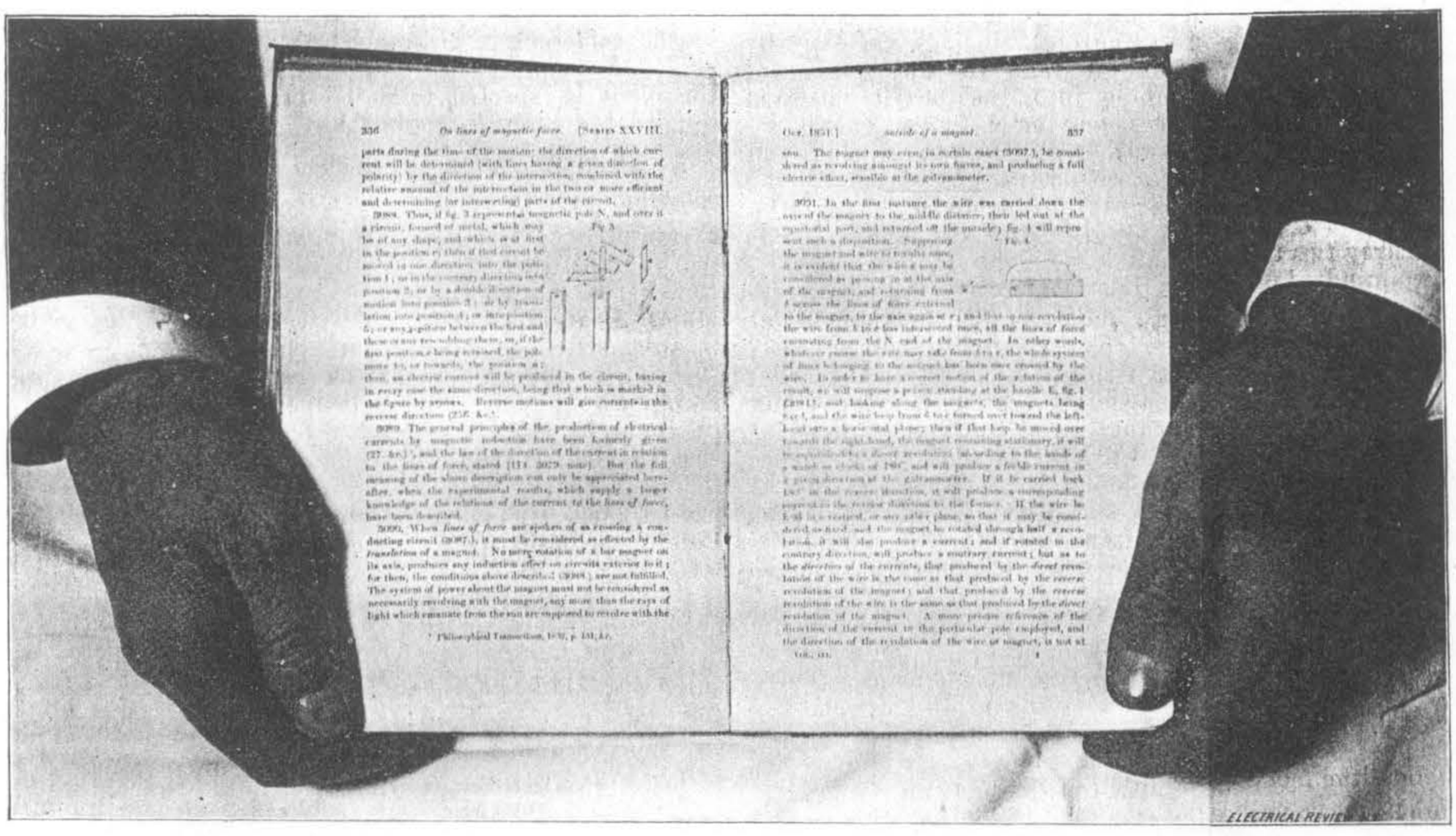


Fig. 2.—"Tesla's Latest Advances in Vacuum-Tube Lighting."—Two Historical Pages Photographed by the Light of a Single Vacuum Tube at a Distance of Four Feet; Exposure Two Seconds.

A rather curious feature in the photographs obtained with tubes of moderate illuminating power, as a few candles, was that the lights and shadows came out remarkably strong, as when very short exposures are made by flashlight, but the outlines were not sharp and practically no detail was visible. By producing tubes of much greater candle-power, a notable improvement in this respect was effected, and this advance prompted me to further efforts in this direction, which finally resulted in the production of a tube of an illuminating power equal to that of hundreds, and even thousands, of ordinary vacuum tubes. What is more, I believe that I am far from having attained the limit in the amount of light producible, and believe that this method of illumination will be eventually employed for light-house purposes. This probably will be considered the oddest and most unlooked-for development of the vacuum tube.

Simultaneously with this progress a corresponding improvement was made in the efficiency of the light produced. A few words on this point might not be amiss, considering that a popular and erroneous opinion still exists in regard to the power consumed by vacuum tubes lighted by ordinary means. So deeply rooted is this opinion which, I will frankly confess, I myself have shared for a long time, that, shortly after my own first efforts, Sir David Solomons and Messrs. Pike & Harris undertook to introduce in England such tubes on a large scale in competition with the incandescent system of lighting. The enterprise, which was commented on in the technical periodicals, was commendable enough, but it was not difficult to foretell its fate; for although the high-frequency currents obtained from the alternator yielded better economical results than interrupted currents, and although they were obtained in a convenient and fairly economical manner, still the efficiency of the whole system was necessarily too small for competition with incandescent lamps. The reasons for the great power consumption, which may often be as much as 10 times that taking place in incandescent

lamps for an equivalent amount of light, are not far to seek. A vacuum tube, particularly if it be very large, offers an immense radiating surface, and is capable of giving off a great amount of energy without rising perceptibly in temperature. What still increases the dissipation of energy is the high temperature of the rarefied gas. Generally it is supposed that the particles are not brought to a high temperature, but a calculation from the amount of the energy consumed during a given period of time, and the amount of matter contained in the tube, leads to results which would seem to indicate that, of all the means at disposal for bringing a small amount of matter to a high temperature, the vacuum tube is the most effective. This observation may lead to valuable uses of such tubes in astronomical researches, and a line of experiment to this end was suggested to me recently by Dr. Geo. E. Hale, of the Yerkes Observatory. As compared with these disadvantages the incandescent lamp, crude and inefficient as it undoubtedly is, possesses vastly superior features. These difficulties have been recognized by me early, and my efforts during the past few years have been directed towards overcoming these defects and have finally resulted in material advances, so that I find it possible to obtain from a tube of a volume not much greater than that of a bulb of an incandescent lamp, about the same amount of light produced by the latter, without the tube becoming overheated, which is sure to take place under ordinary conditions. Both of these improvements, the increase of candle-power as well as degree of efficiency, have been achieved by gradual perfection of the means of producing economically harmonical electrical vibrations of extreme rapidity. The fundamental principle involved is now well known, and it only remains to describe the features of the system in detail, a duty with which I expect to be able to comply soon, this being another one of my good resolutions.



FIG. 3.—"TESLA'S LATEST ADVANCES IN VACUUM TUBES."—PHOTOGRAPH OF THE EXPERIMENTER'S HAND MADE BY THE LIGHT OF A SINGLE IMPROVED VACUUM TUBE OF 1,000 CANDLES. EXPOSURE TWO SECONDS; DISTANCE FROM THE TUBE FOUR FEET.

The purpose of the present communication is chiefly to give an idea in how far the object here aimed at was obtained. The photographs shown were taken by a tube having a radiating surface of about two hundred square inches. The frequency of the oscillations, which were obtained from an Edison direct-current supply circuit, I estimated to be about two million a second. The illuminating power of the tube approximated about one thousand candles, and the exposures ranged from two to five seconds, the distance of the object being four to five feet from the tube. It might be asked why, with so high an illuminating power, the exposures should not be instantaneous. I would not undertake to satisfactorily answer this question, which was put to me recently by a scientific man, whose visit to my laboratory I still vividly recollect. Likenesses can, of course, be obtained with instantaneous exposures, but it has been found preferable to expose longer and at a greater distance from the tube. The results so far obtained would make it appear that this kind of light will be of great value in photography, not only because of the fineness of the lines, but also because the artist will be able to exactly adjust the conditions in every experiment so as to secure the best result, which is impossible with ordinary light. He will thus be made entirely independent of daylight, and will be able to carry on his work at any hour, night or day. It might also be of value to the painter, though its use for such purposes I still consider problematical.

I anticipate that much detail will naturally be lost in the reproductions through the half-tone process and press work, however good, but I hope that enough will be shown to demonstrate the advantageous features of this light in photography and its practical usefulness in this art.

In conclusion, I wish to thank Mr. R. L. Newman for kindly consenting to the use of his photograph.

NIKOLA TESLA.
New York, Jan. 3.

ROENTGEN-RAY NOTES.

BY WILLIAM ROLLINS.

X—SCATTERED ROENTGEN RAYS.

In a previous note I said the wave length depended on the potential and degree of exhaustion in the tube; a low potential and vacuum giving waves of such length as to make strong contrasts between bones and soft tissues in the human body; a high vacuum and potential giving less contrast, because the shorter waves generated went through the bones also. When we wished to see through greater thickness and yet have marked contrast, I recommended increasing the amperage, thus keeping the wave length unchanged, but increasing the amount of light, and stated that this did not much change the relative transparencies within the limits of an ordinary apparatus. It is the object of the present note to show why there is any change in the relative transparencies. In attempting to use ordinary light with one of my X-ray cameras, made to find stones in the bladder, I so enclosed a 20,000-candle-power arc that no light could escape into the room except through a small hole directed toward the abdomen. Though this light came through the tissues, it was too scattered to show structure, and this is naturally what happens with Roentgen rays, though in a less degree, because of their shorter wave length.

If we generate these waves of such a length as to lose all detail in the soft tissues we may still have the bones very dark by contrast. If we try to make the bones lighter by increasing the amperage, keeping the potential the same to prevent altering the wave length, we can make them very bright, if we have a big condenser and discharge it rapidly, but the brightness is due to scattered light and we do not see any more of their structure. If we want more details in the bones we must develop waves of shorter wave length, and when we have done this by increasing the potential and the vacuum we can make the bones as bright as before and yet see their structure, because the light is less scattered. Now, if we increase the amperage as before we make them still lighter and lose the structure, because we are using enough light to come through the denser parts, but being scattered light it shows no detail.

XI—MAKING THE COOLED ANODE OF OTHER METALS THAN PLATINUM.

In describing the A-W-L Roentgen-ray tube, I mentioned the cost of the platinum as a possible objection, and promised to describe a method of reducing the expense. In some experiments to determine what metal was best for that part of the anode receiving the cathode discharge, I used a brass anode, the only platinum being a short tube where it was sealed into the glass. As Kirmayer & Oelling, who make my tubes, find no difficulty in this construction, I see no present reason why it may not be employed. By soldering different metals to the end of these anodes, I have tried to determine which was best to use as a target in a reflecting focus tube. Tubes work so differently that it is difficult to compare them; and, to overcome this, I have arranged the metals to be tested around the periphery of an iron disk, which, being revolved by a magnet, enables me to bring any one quickly in position to receive the cathode discharge. Even then it is difficult to determine the relative values; but at present platinum seems well adapted to the purpose.

XII—BURNING FROM A VACUUM TUBE NOT GENERATING ROENTGEN RAYS. (TESLA'S SCREEN.)

Mr. Tesla long ago told us how to prevent burning, and, as his statements are always facts of nature, no proof is required to support them. I simply approach his fact from another point of view. I exhausted a tube to such a degree that no Roentgen light could be produced with the potential I employed, the discharge going around the tube. By exposing my hand it was severely burned. Yet, I have frequently exposed the same hand for 50 hours in a single month to a tube in which powerful Roentgen light was being generated, using the Tesla grounded aluminun screen, without producing any greater effect than slight redness and roughness of the skin. Cases of burning are not infrequent, and patients are nervous under examination, because they have known some one who has been burned. If a few physicians were sued for malpractice this would be immediately stopped, for there is no surer incentive to knowledge than to make ignorance and incredulity costly.

The Brooklyn Eagle January 6, 1898

TESLA'S NEW TUBES.

The Light an Excellent Substitute for Daylight.

Nicola Tesla, the noted electrician, has invented a new light after a long time spent in experiments. Tesla says that by using large vacuum tubes the light will be so powerful that photographs can be taken as easily at night as in the day. This light will also be used for lighthouse purposes and he predicts that colors may be distinguishable. At present Tesla declines to discuss his discovery, but he says he hopes to provide a light strong enough to pierce the densest fog. Accompanying some photographs which Mr. Tesla sent to the Electrical Review showing the result of his discovery was a letter which describes the experiments as follows:

The photographs shown were taken by a tube having a radiating surface of about 200 square inches. The frequency of the oscillations, which were obtained from an Edison direct current supply circuit, I estimated to be about 2,000,000 a second. The illuminating power of the tube approximated about 1,000 candles, and the exposures ranged from two to five seconds, the distance of the object being four to five feet from the tube. It might be asked why, with so high an illuminating power, the exposures should not be instantaneous. I would not undertake to satisfactorily answer this question, which was put to me recently by a scientific man, whose visit to my laboratory I still vividly recollect.

Likenesses can, of course, be obtained with instantaneous exposures, but it has been found preferable to expose longer and at a greater distance from the tube. The results so far obtained would make it appear that this kind of light will be of great value in photography, not only because of the fineness of the lines, but also because the artist will be able to exactly adjust the conditions in every experiment, so as to secure the best result, which is impossible with ordinary light. He will thus be made entirely independent of daylight and will be able to carry on his work at any hour, night or day. It might, also, be of value to the painter, though its use for such purposes I still consider problematical.



NIKOLA TESLA'S NEW PHOTOGRAPHY.

This Picture Was Reproduced from a Photograph Made by the Light of a Single Vacuum Tube, at a Distance of Five Feet, Exposure Five Seconds.

EQUAL TO SUNLIGHT.

Tesla with His Perfected Vacuum Takes Photographs as Well by Night as by Day.

NO MORE "FLASH" PICTURES

Powerful Rays Reveal Every Line in the Subject Photographed with Startling Distinctness.

TO ILLUMINE LIGHTHOUSES.

Nikola Tesla, the well known electrician, announces an important discovery to-day in the Electrical Review. He says that he has perfected vacuum tubes of such high illuminating power that they may be used in lighthouses, and that they will enable the photographer to work by night as well as by day. He even suggests that by means of this light the painter may be able to distinguish colors as well at night as he can by the clear, soft light of day.

The result which Mr. Tesla has attained represents several years of patient experimenting. His work was somewhat retarded by the burning of his laboratory in 1895. He is not ready yet to describe his invention in detail. He promises to do soon. He always speaks in a conservative way of his discoveries. I called yesterday at his laboratory. His bearing was one of great elation.

"It is of more importance," he said, "to discover new principles, to find out scientific facts, than to invent mere appliances."

LIGHT AS OF NOONDAY.

The results which Mr. Tesla has attained have been achieved by the use of his vacuum tubes and his oscillator. The light which he is able to produce by this means is as bright as that of the noonday sun. By its use every line of the object photographed may be made to stand out clearly and distinctly.

Mr. Tesla has taken several photographs by this light, which are reproduced in the Electrical Review. I saw the original photographs yesterday at the office of the publication. Half tone engraving cannot begin to do justice to the extreme clearness and delicacy of these photographs. It is possible to give only a suggestion of the clearness of the original in a picture such as is used for the purpose of newspaper illustration. The accompanying portrait is from one of the half tones. The original photograph was made under the light of a single vacuum tube at a distance of five feet, with an exposure of five seconds.

A STARTLING EFFECT.

Every wrinkle in the face of the man is clearly shown. The hairs of the beard and the eyelashes are distinct. The effect is almost startling. The face seems to stand out from the paper. This photograph was taken, too, without the discomfort to the subject which attends the use of the flashlight.

The most remarkable photograph is that of the hand of Tesla. It was made by the light of a single improved vacuum tube of one thousand candle power, at a distance of four feet, after an exposure of two seconds. The lines of the hand stand forth so clearly that the palmist may read them with the greatest care. Every detail is reproduced with microscopic accuracy. The veins of the wrists and the fine lines upon the cuticle are faithfully shown. The texture of the inventor's coat is shown in several inches of the sleeve and the linen threads of the cuff are almost distinct. The shadows about the wrists and fingers give the impression that you are looking at a hand of flesh and blood.

Another photograph is that of an open book upon electricity, supported by two hands. This was done by a vacuum tube, at a distance of four feet, with an exposure of two seconds.

PICTURES PRAISED.

Nicola Tesla Commends the Effort of the Herald in Telegraphing Sketches of Shaw Trial.

OTHER PAPERS SURPRISED.

George Palmer, Head of the Journal Art Department, Says a Distinct Advance Has Been Made.

PUBLIC MUCH INTERESTED.

The enterprise of the HERALD in presenting to its readers telegraphed pictures illustrating the trial of Eli Shaw at Camden, N. J., was much praised yesterday by experts and by the public. For years there have been experiments looking toward the transmission of pictures by wire. The HERALD has been the first to make a practical application of a much discussed process to the purposes of newspaper illustration. The directors of the art departments of the various newspapers were deeply interested, and some of them spoke highly of the distinct advance which the HERALD has made in newspaper illustration.

Nicola Tesla, the distinguished scientist, who has made exhaustive researches in the realm of electricity, was deeply interested in the HERALD'S pictures. He was seen yesterday afternoon at his laboratory, at No. 46 East Houston street.

MR. TESLA'S COMMENDATION.

"I would say in a general way," he said, "that, of course, the HERALD'S efforts are very commendable. As long as we have journals which are willing to expend sums of money for such experiments, inventions will progress.

"The fundamental principles of these transmissions of characters and pictures to a distance over a wire [redacted] back, and may be really traced to Caselli, an Italian who many years ago availed himself of the electro-chemical principle for this purpose. Numerous attempts have been made since, with more or less success, and the fundamental idea has been carried out in many ways by various inventors. Edison, I believe, was one of the most arduous workers in this field, and produced an interesting device in the form of a pen for transmitting characters.

"Professor Gray, however, made a notable step in advance by perfecting his telautograph, which is now in practical use. With this instrument characters and sketches can be readily transmitted over a wire to great distances. There is no doubt that Bell's telephone, Edison's phonograph and the telautograph of Gray have all helped to bring about these last improvements.

"But if I am correctly informed I think that the honor of having successfully transmitted such pictures with devices such as the HERALD describes belongs to Mr. N. S. Amstutz, a young engineer of Cleveland, who has to my knowledge worked indefatigably on this task for a number of years. I have in my possession some samples which he gave me two years ago, which are altogether remarkable. However, Mr. Amstutz's invention was described in periodicals almost three years ago, and of these I may cite the Scientific American, April 6, 1895, which I happen to find. I would not attempt to criticise the invention described in the HERALD, as I have not followed the development of the art in its minute details.

IT IS A DISTINCT ADVANCE.

"The HERALD has made a distinct advance," said George Palmer, the head of the art department of the New York Journal. "The pictures of the Shaw trial are the most practicable thing in the line of sending pictures by wire which I have ever seen. Any fair minded man, upon being shown these pictures and having been assured that they were absolutely authentic, could not for a moment that they mean an important step in newspaper illustration. I am glad to see the HERALD make a success of the process.

"I would make the criticism that at present it seems difficult to get the delicate shades of expression. Of course, the process may be greatly improved. In the pictures of Norcross and Cox, the jurors in the Shaw case, I notice that the men have strong features. I should like to see the process tried with the faces of women and children. It seems to me that in transmitting pictures of scenes and diagrams that this process will prove of great utility.

"I am greatly interested in the matter, because for years I have been following the experiments."

M. C. Ernsberger, the director of the art department of the New York Tribune, said yesterday afternoon that the HERALD had shown great enterprise and had added a valuable factor to the art of newspaper illustration.

MR. TESLA'S ANNOUNCEMENT.

Mr. Tesla makes his announcement in a letter to the editor of the Electrical Review. In speaking of his experiments in photography he says:—

The photographs shown were taken by a tube having a radiating surface of about two hundred square inches. The frequency of the oscillations, which were obtained from an Edison direct-current supply circuit, I estimated to be about two million a second. The illuminating power of the tube approximated about one thousand candles, and the exposures ranged from two to five seconds, the distance of the object being four to five feet from the tube. It might be asked why, with so high an illuminating power, the exposures should not be instantaneous. I would not undertake to satisfactorily answer this question, which was put to me recently by a scientific man, whose visit to my laboratory I still vividly recollect.

Likenesses can, of course, be obtained with instantaneous exposures, but it has been found preferable to expose longer and at a greater distance from the tube. The results so far obtained would make it appear that this kind of light will be of great value in photography, not only because of the fineness of the lines, but also because the artist will be able to exactly adjust the conditions in every experiment so as to secure the best result, which is impossible with ordinary light. He will thus be made entirely independent of daylight and will be able to carry on his work at any hour, night or day. It might also be of value to the painter, though its use for such purposes I still consider problematical.

TO PIERCE FOGS.

Another development of Mr. Tesla's vacuum tube, which will prove of incalculable value concerns lighthouses. It is well known that it is difficult to secure a light which will penetrate fog. It is believed that light from the vacuum tube will eventually be used for this purpose. It is likely that practical experiments will soon be made in some lighthouse on this coast for the purpose of demonstrating the practicability of Mr. Tesla's invention.

"By producing tubes of much greater candle power," says Mr. Tesla in his letter, speaking of progress in electric lighting, "a notable improvement in this respect was effected, and this advance prompted me to further efforts in this direction, which finally resulted in the production of a tube of an illuminating power equal to that of hundreds, and even thousands, of ordinary vacuum tubes. What is more, I believe that I am far from having attained the limit in the amount of light producible, and believe that this method of illumination will be eventually empoyed for lighthouse purposes. This probably will be considered the oddest and most unlooked for development of the vacuum tube."

Mr. Tesla also says in his letter that he finds that from an ordinary vacuum tube, not much greater in volume than an ordinary incandescent lamp, about the same amount of light is produced as from the incandescent lamp without any overheating.

The New York Times January 6, 1898

NEW LIGHT IN PHOTOGRAPHY.

Nikola Tesla Develops Vacuum Tubes to Make Pictures Regardless of the Sun.

The art of photography will hereafter be independent of sunlight and will be relieved of the inconvenience and discomfort of the flashlight if Nikola Tesla's claims for his latest development of the vacuum tubes are well founded. Illuminating power for lighthouses will also be enormously increased if his discovery is successful.

The Electrical Review of to-day prints an article on the new application of the tube and reproduces photographs taken by the new light, as evidence that sunlight may not only be dispensed with, but is excelled by the intensity of the vacuum rays. It is likely that experiments in the application of the light to lighthouses will soon be made.

The Review says editorially that this particular application is the oddest and most unlooked for development of the vacuum tube, and is evidently deeply impressed with its value.

Mr. Tesla last night declined to discuss his discovery, saying that more time than he could then spare would be required to explain it.

The New York Tribune January 7, 1898

TESLA'S VACUUM TUBE LIGHT.

HE HAS MADE NOTABLE PROGRESS IN IMPROVING IT.

A brief, but interesting announcement was made by Nikola Tesla this week in regard to the advances effected by him in a line of experiment in which he has been engaged for several years. The two forms of electric lamp now in common use employ, respectively, the incandescence of an inclosed filament and the arc produced at a gap in a circuit. The mode of illumination which Mr. Tesla has sought to develop is the agitation of the particles of a highly rarefied gas in a so-called "vacuum tube."

That particular form of apparatus, in the hands of Geissler, Crookes and other physicists, emitted only a faint luminosity. Röntgen discovered that it also gave birth to a powerful, but utterly invisible, radiance. But Tesla has now multiplied the brilliancy of the visible light several hundred times, perhaps several thousand times. "The Electrical Review," his chosen mouthpiéce among the technical papers, printed a letter from the great investigator yesterday, in which he said that he believes that he is even yet "far from having attained the limit in the amount of light producible, and believes that this method of illumination will be eventually employed for lighthouses."

The more immediate application which Mr. Tesla proposes for his light, however, is to photography, to which it is admirably suited by its intensity, penetrating power and the facility with which it may be regulated. His letter is accompanied by three photographs to illustrate this point. A vacuum tube of about one thousand candle-power afforded the light for these pictures, and it was placed at a distance of about four or five feet from the objects represented. An exposure of from two to five seconds was deemed preferable to instantaneous work.

The agitation of the gaseous particles remaining in the vacuum tube is caused by creating oscillations of extreme frequency and abruptness in the electrical current which does the work. Mr. Tesla has long been famous on both sides of the Atlantic for his researches into the possibility of exciting such waves, and for his varied methods of doing so. His "discharger" and his "oscillator," already well known to electricians, are only two of the forms of apparatus which he has tried. Mr. Tesla admitted to a Tribune reporter yesterday that it was by means of his oscillator that he had achieved his recent successes in vacuum-tube lighting. He estimates the frequency of the electrical vibrations in these experiments at about two million per second. But the collisions and bombardment resulting from this shaking up of the confined gaseous particles gave rise, he thought, to ether waves, both of the same frequency as those of sunlight and of still higher frequencies.

The great inventor maintains a gracious but tantalizing reserve at present when asked as to the amount of energy (measured by watts) which he consumes per candle-power, but manifests much secret satisfaction with this phase of the subject.

Electrical Progress.

Nicola Tesla's New Engine.

Tesla says that coal will not play so important a part in producing the power of the earth as wood does now, and shows an invention of his in the experimental stage, about which he declares that there is no possibility of its failure. He declares that the apparatus is so simple that the least learned in mechanics can comprehend it, and if it were fully described others might seize his idea, patent it, and control a blessing which he intends shall be a free gift to the world. This is so extraordinary, so totally at variance with established customs, that it is almost as unbelievable as the discovery itself.

In the center of a large room with a glass roof Tesla will place a huge cylinder of thick glass on a bed of asbestos, supported by a firm stone pedestal placed in the center of the room. The circle will be laid lengthwise, and will be surrounded by a circle of mirrors covered with asbestos coats to refract the rays of the sun into the glass cylinder. The cylinder will always be kept full of water, which will have been treated by a secret chemical process, which Tesla claims to have devised, and which, he says, is the only complicated part of the discovery. All day long, while the sun shines, its rays will be refracted into the glass cylinder. The chemical treatment makes the water easily susceptible to heat, and in a little while the vaporizing begins. The steam thus in the cylinder is carried to a steam engine of the ordinary description. The engine in turn will generate electricity, which will be stored and transmitted by cables to the factory and the home. The power house will store sufficient electricity to meet all demands during the time that the sun does shine, although it may be clouded over for weeks at a time. "Most people will contend that the plan to harness the rays of the sun and make them operate the machinery of man, and to give light and heat, is the idle fancy of a dreamer," said Tesla. "I would indeed be surprised if they were to contend otherwise. There has never yet been proposed a single great scientific enterprise that has not at first been met with ridicule and laughed at as something beyond the bounds of possibility. Every one will remember the days of horse cars, when electric street railways were first talked about as possibilities. The suggestions of cars running along the streets without horses in front of them was laughed at. But now people have trolley cars running in villages where, a few years ago, horse cars were considered too expensive, and they pay no more attention to the marvel they witness every day than they do to an express wagon rumbling along the same street. It will be the same with the motive power generated by harnessing the rays of the sun. The first two months that the generating stations are in operation they will be places of intense interest, but after that people will think no more about them, except as places of business. They will regard them as little as they do gas tanks, electric light plants or water reservoirs. They will simply suggest monthly or quarterly bills, such as they now pay for water or gas, except that the bills will be much smaller. I do not care at this time to go into details. I have not yet begun the practical part of the work. I wish to have the experimental part so completed that no one can stick a pin into it. But I will say that the results so far achieved are all that I could desire, and they place all possibility of a failure beyond the shadow of a doubt. I am certain that the new apparatus will come into speedy and general use. Its cost is so insignificant that it cannot be ignored. After the apparatus has been placed in any station there is absolutely no expense in running it for years, except the salaries of engineers and the small cost of the wear and tear of the apparatus, which will be eventually anything but expensive. The whole business will be so simply arranged that there will be no probability of its breaking down; but even if it should happen that one station would be useless for a short time, the immense amount of electricity always at hand—for it will cost practically no more to generate 5000 volts than to generate so many million volts—will bridge over the difficulty. There would be nothing to prevent the generation of a whole year's supply in case of an accident in the generating machinery. There is nothing unnatural in the proposition to have the sun drive the machinery of the earth and, indirectly, to heat and light the planet at night as well as by day. It is a great deal less artificial than for men to delve down into the bowels of the earth at so much trouble and loss of life in order to get a few handfuls of coal to run an engine a short time and then to make spasmodic return trips for more. As to the proposition to have each city look after the heating and lighting of the homes of its inhabitants, there is nothing more extraordinary about it than the present system of cities supplying water pipes and sewers and private companies supplying steam heat, gas light, electric light and motive power." All of which has been said before.

THOS. A. EDISON JR. is credited with announcing that he can photograph thought. Nicola Tesla tells a New York paper that he has "harnessed the rays of the sun" and will compel them to operate machinery and give light and heat. This invention is still in the experimental stage, but he declares that there is not a possibility of its failure. He has discovered a method of producing steam from the rays of the sun. The steam runs a steam engine which generates electricity. It is probable the dailies have distorted the utterances of these electricians, who usually let results attest the worth of their efforts.

HIGH ELECTROMOTIVE FORCE.

PROF. JOHN TROWBRIDGE.

I have lately perfected a large plant for the study of the discharges of electricity through gases which I believe is more extended, and on a larger scale, than any at present in existence ; and I have obtained some results with it, especially in the subject of high electromotive force, which throw light upon many mooted points. The source of electricity which produces the electrical discharges is obtained from ten thousand storage cells. From these cells I obtain very approximately twenty thousand volts, and by means of a peculiar apparatus called Planté's rheostatic machine, I am enabled to obtain over one million volts—which enables me to experiment with powerful discharges in air, more than four feet in length.

By the employment of storage cells in the subject of the discharges of electricity through gases, one can form a fair estimate of the amount of energy that is employed to produce the desired effects—for instance, the X rays ; while with the use of electrical machines or induction coils and transformers it is extremely difficult, if not impossible, to form an accurate estimate. Fig. 1 is an illustration of the type of cells of which the battery consists. Each cell is composed of a test tube 5½ inches long and ¾ of an inch internal diameter containing two strips of lead which are separated from each other by rubber bands and are immersed in dilute sulphuric acid. The surfaces of the lead strips are roughened by a mechanical device, and the cells are charged in multiple circuit by means of a dynamo machine. When the cells are properly formed, each one gives two volts and has an internal resistance of one-quarter of an ohm. The problem of insulating these cells was a serious one ; but it was practically solved by mounting the cells in sets of threes, in holes bored in a block of wood which had been carefully boiled in paraffine. The mechanician of the laboratory, Mr. George Thompson, devised a simple switch board which enables me to throw the cells into multiple or into series—to use the entire ten thousand, or suitable portions of this number. The battery gives eight amperes of current with twenty thousand volts, and this amount of energy is amply sufficient to kill a man. By accident an operator received the shock from only one thousand of the cells and was badly shocked and burned. It is prudent therefore in experimenting with this battery to use rubber gloves, even in throwing the switches, and it is recommended to employ only one hand covered with a rubber glove and to keep the other hand in a pocket.

I had at first intended to use this large battery in the study of electrical discharges through Crookes tubes, but I speedily found that X rays could not be excited by a difference of potential represented by twenty thousand volts. I found that at least one hundred thousand volts were necessary to produce them strongly, and I, therefore, resolved to construct a Planté rheostatic machine. This machine is simply an apparatus by means of which Leyden jars are first charged in parallel and are then discharged in series or by cascade. That is, all the inside coatings of the jars are connected to the negative terminal of the ten thousand cells, and all the outside coatings are connected to the positive terminal of the cells. When the cells are charged, the inside of one Leyden jar is connected to the outside of the next, and so on. In this way a very high electromotive force can be obtained. I use sixty Leyden jars in the form of plates of glass 15 × 18 inches coated on both sides with tinfoil. Starting with twenty thousand volts, I can exalt this to one million two hundred thousand volts. The accompanying illustration (Fig. 2) shows the Planté machine. The mechanician of the laboratory has introduced a notable improvement in the apparatus of Planté. Instead of a revolving commutator such as was used by the latter, Mr. Thompson employed lever arms, by means of which the jars were first charged in parallel and then discharged in series. It was found that the apparatus designed by Planté could not be used for higher voltages than one or two thousand without serious error and loss. By means of this apparatus I can study electrical discharges at least four feet in length—of great body—which are produced by an electromotive force of one million two hundred thousand volts. This apparatus possesses the great advantage that it enables one to obtain a fairly exact measure of such high voltage. When we reflect that the trolley car employs only

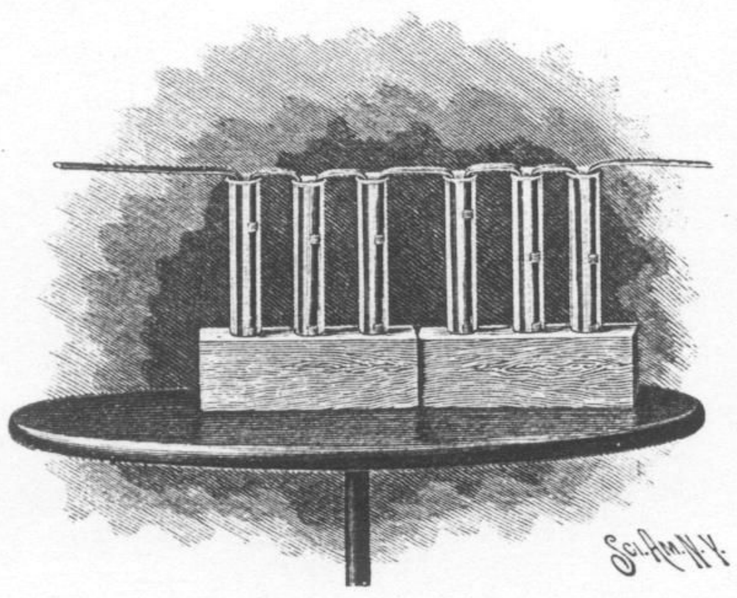


Fig. 1.—THE CELLS.

five hundred volts, and in the system of transmission of power from Niagara Falls it is proposed to use only ten thousand volts, it is evident that the effects produced by voltages of over a million must be of great scientific interest.

The study of such high electromotive forces immediately showed that previous estimates of the electromotive force necessary to produce a spark of a certain length were highly erroneous. For instance, Heydeweiler, a German investigator, believes that Prof. Elihu Thomson's statement, that a spark of five feet in length which he produced required a voltage of five hundred thousand, is very wide of the mark, and Heydeweiler maintains that one hundred thousand would be nearer the truth. I find that even Prof. Thomson's estimate must be more than doubled. Experiments with my apparatus show conclusively that the length of the electric spark between points separated by more than one inch varies directly with the electromotive force. A spark forty-eight to fifty inches in length requires an electromotive force of one million two hundred thousand volts, and a discharge of lightning one mile long would therefore require the enormous number of over one hundred million volts. In reflecting upon the development of such enormous energy in the air we can understand why telephone bells ring during a thunder storm ; why subsidiary sparks occur in networks of wires ; and why telegraphic messages are interrupted. The world beneath the thunderstorm throbs and pulsates with the oscillatory discharges of lightning.

One of the most interesting results of my study of powerful disruptive discharges is the discovery that such discharges will pass through glass tubes which are exhausted to such a high degree that they are said to contain a vacuum ; for the eight-inch spark of a Ruhmkorff coil prefers to jump around the tube to passing through the extremely rarefied space in the interior of the tube. Such tubes, however, are brilliantly lighted by a difference of potential of a million volts and readily show the X rays, and exhibit the skeleton of the hand in a fluoroscope. The so-called brush discharge from the positive terminal of the Planté machine extends visibly to a distance of over a foot. If the hand is exposed to this brush, it produces the well known X ray burn, such as various investigators have received in taking photographs of the skeletons of their hands, or in testing the condition of Crookes tubes by exposing their hands before a fluoroscope. The skin of the hand becomes irritable and turns a bright red color, especially after exposure to cold winds.

This result interested me greatly; for it proved that the so-called X ray burn could be produced by the brush discharge of very high electromotive force. The extent of the influence of this powerful brush discharge is very great. For instance, photographic plates in a plate holder carefully insulated from the ground and covered with a plate of glass half an inch in thickness show the inductive action of the brush discharge from the positive terminal, which is distant at least a foot. These inductive effects are manifested by star-shaped figures on a photographic plate. They are surrounded by dark clouds. When the burn on the back of one's hand produced by such brush discharges is examined by a microscope, similar centers of disturbance (in this case points of inflammation) are seen. Although the Leyden jars of my machine are carefully insulated on supports of vulcanite which are mounted on dry wood, which in turn is supported on rubber, I can obtain a discharge of more than two feet in length when I bring a point connected to the steam pipes to the neighborhood of one terminal of the machine. The other terminal of the machine is carefully insulated. This experiment shows conclusively that it is of no use to insulate lightning rods. My experiments thus far show that no vacuum which I can produce can resist the discharges which are caused by one million volts. It now becomes an interesting question whether there exists mechanical or chemical means by which a so-called vacuum can be produced which will resist such discharges.

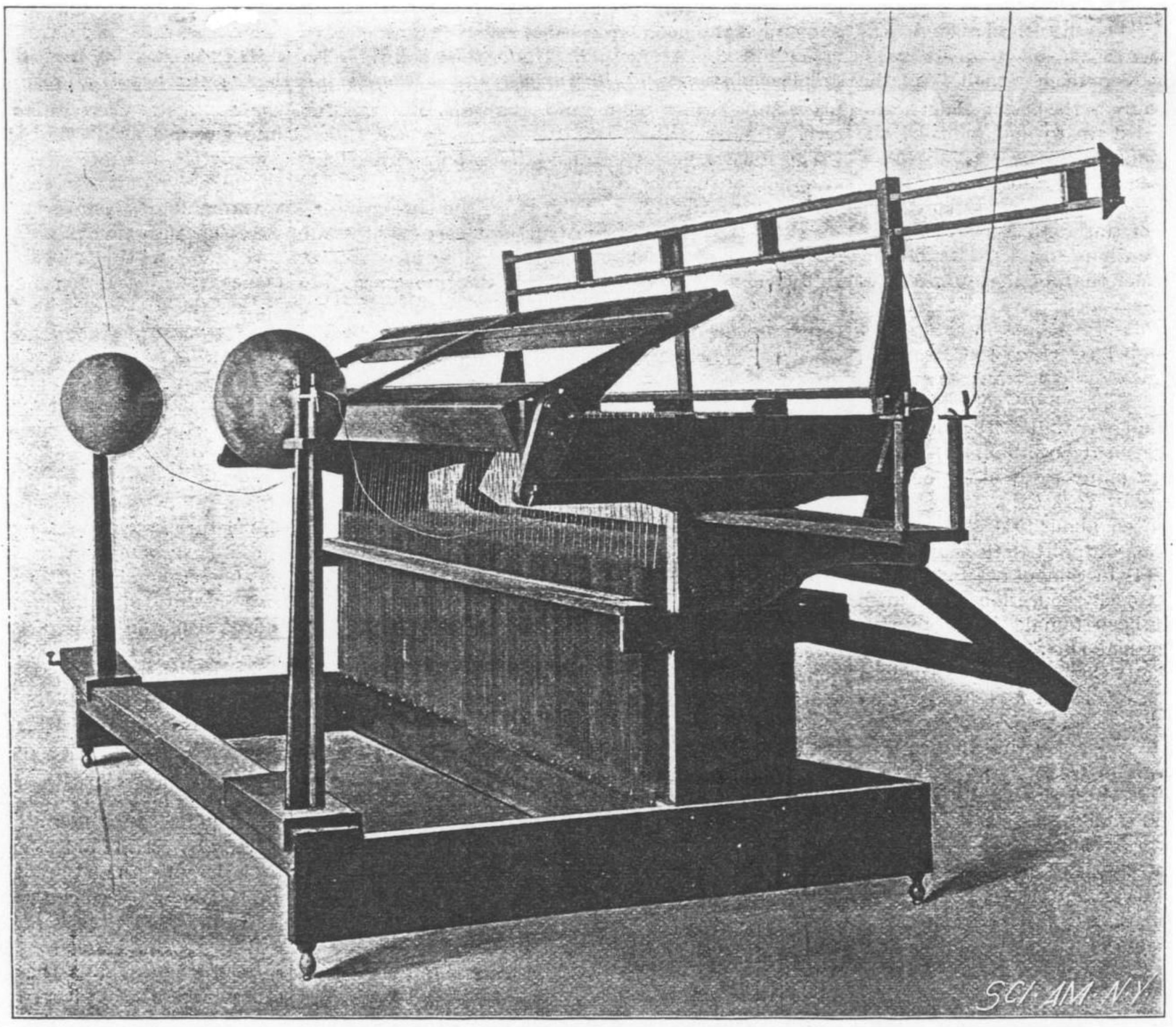


Fig. 2.—PLANTÉ RHEOSTATIC MACHINE.

The New York Herald January 16, 1898

NIKOLA TESLA'S HAND SEEN BY A PALMIST.

FROM A PHOTOGRAPH BY VACUUM TUBE LIGHT.

A photograph of the left hand of Nikola Tesla has been submitted to a professional palmist, and he, without knowing to whom the hand belonged, tells what his art teaches him of the original. Mr. Tesla photographed his own hand last week by means of light from his wonderful perfected vacuum tubes, and he kindly consented that the picture should be submitted for a "reading."

The picture, without marks or other indications as to whose hand it was, was submitted to Sir Henry Onequi, who was not given any intimation as to the identity of his subject. Here is what he says, and the reader may draw his own conclusions:—

By Sir Henry Onequi, Palmist.



THIS palm indicates a person who has a remarkable amount of will power and a great deal of energy. The head line would indicate a very shrewd and active mind; a person who could be capable of becoming a great leader, while the heart line would indicate a remarkable degree of love. Great feeling and great duration is shown by the life line, although this line, being the one line running toward the Mount of Mercury, would indicate that the person should be quite a philosopher.

The line of Venus being so strongly developed would indicate a great lover of the opposite sex, although the head line seems to hold this in check. We find that the person would be liable to suffer the latter part of life through heart trouble, which may be quite severe.

The fate line would indicate great success, but as I only have one hand to read from these statements are subject to a change, because I have not the other hand to verify them. Travels are shown very distinctly. That the person should be one who would be very just and honorable in all dealings is shown. He is one who could not be driven one step, but could be led by kindness to the extremes through life.

The hand also indicates a great many changes to be brought about, and it looks as if these changes were brought about through the influence of others. The palm indicates that the person would make great success in financial affairs, although there is shown one very heavy loss.

There should be two marriages in life. Domestic relations should be very happy. One heavy loss by fire is indicated by the cross. One great gain, brought about through personal perseverance and will power, is shown, which is to be of great satisfaction. The person should have one great gain through a change made in the latter part of life.

This person would not be one to be trifled with, should be a great lover of justice and make success as an orator.

I would be pleased to see the other hand to verify these statements.



PHOTOGRAPH OF THE PALM OF NIKOLA TESLA

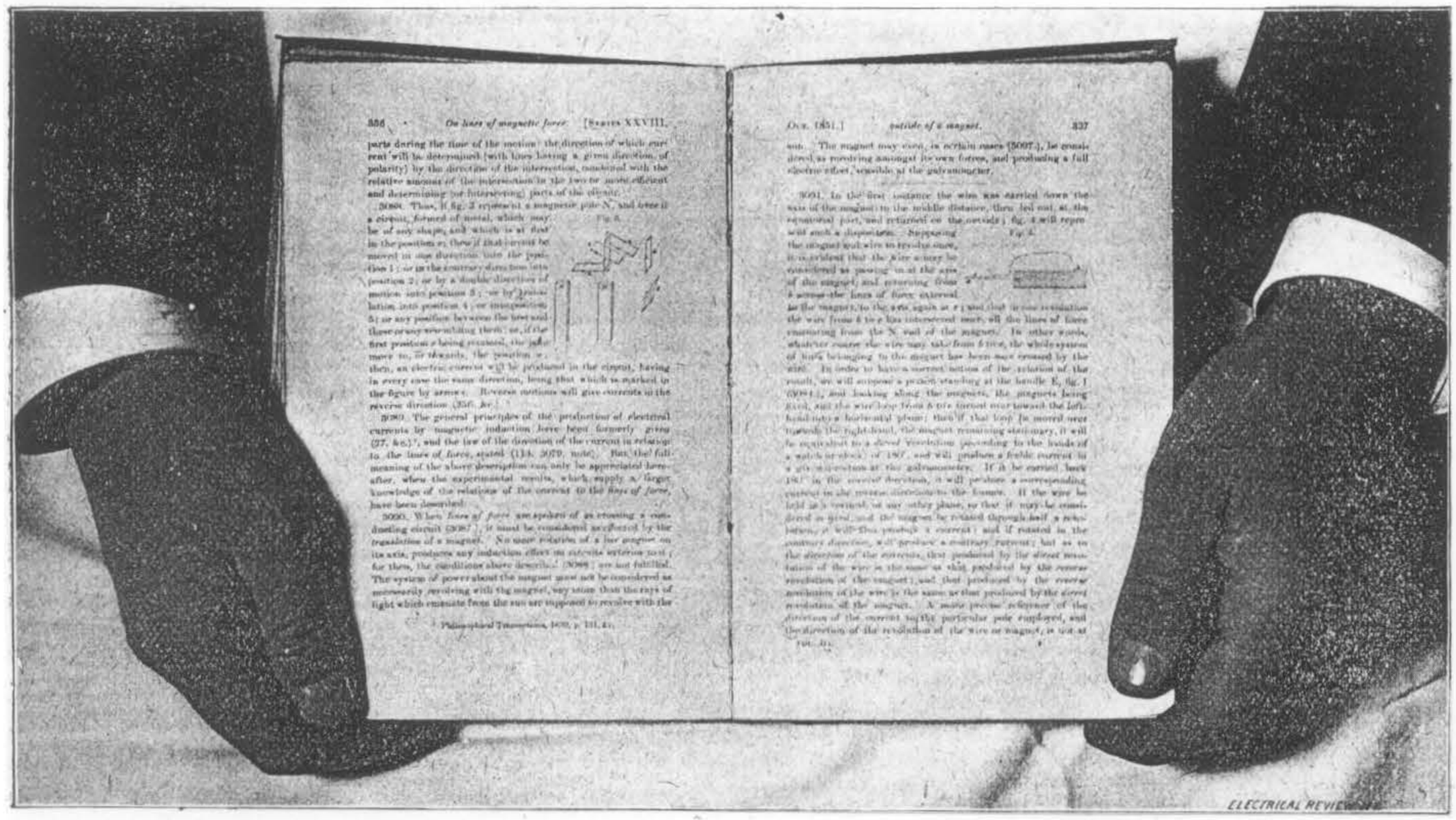
SCIENTIFIC

The Use of Vacuum-tube Lighting in Photography

NIKOLA TESLA, in the *Electrical Review*, New York. Condensed for PUBLIC OPINION

A few years ago I began a series of experiments with a view of ascertaining the applicability of the light emitted by phosphorescent vacuum tubes to ordinary photography. The results soon showed that, even with a tube giving no more light than the equivalent of one-half of a candle, objects could be easily photographed with exposures of a few minutes, and the time could be reduced at will by pushing the tube to a high candle-power. Photographs of persons were likewise obtained at that time and, if I am not mistaken, these were the first likenesses produced with this kind of illumination. A rather curious feature in the photographs obtained with tubes of moderate illuminating power was that the lights and shadows came out remarkably strong, as when very short exposures are made by flashlight, but the outlines were not sharp and practically no detail was visible. By producing tubes of much greater candle-power, a notable improvement in this respect was effected, and this advance prompted me to further efforts in this direction, which finally resulted in the production of a tube of an illuminating power equal to that of hundreds, and even thousands, of ordinary vacuum tubes. What is more, I believe that I am far from having attained the limit in the amount of light producible, and believe that this method of illumination will be eventually employed for lighthouse purposes. This probably will be considered the oddest and most unlooked-for development of the vacuum tube.

The purpose of the present communication is chiefly to give an idea in how far the object here aimed at was obtained. The photographs were taken by a tube having a radiating surface of about two hundred square inches. The frequency of the oscillations, which were obtained from an Edison direct-current supply circuit, I estimated to be about two million a second. The illuminating power of the tube approximated about one thousand candles, and the exposures ranged from two to five seconds, the distance of the object being four to five feet from the tube. It might be asked why, with so high an illuminating power, the exposures should not be instantaneous. I would not undertake to satisfactorily answer this question, which was put to me recently by a scientific man. Likenesses can, of course, be obtained with instantaneous exposures, but it has been found preferable to expose longer and at a greater distance from the tube. The results so far obtained would make it appear that this kind of light will be of great value in photography, not only because of the fineness of the lines, but also because the artist will be able to exactly adjust the conditions in every experiment so as to secure the best result, which is impossible with ordinary light. He will thus be made entirely independent of daylight, and will be able to carry on his work at any hour, night or day. It might also be of value to the painter, though its use for such purposes I still consider problematical.



PHOTOGRAPHED BY THE LIGHT OF A SINGLE VACUUM TUBR AT A DISTANCE OF FOUR FEET; EXPOSURE TWO SECONDS.—*Electrical Review.*

Teslaic.—In the issue of the New York *Electrical Review* for Jan. 5 is a communication by Mr. Nikola Tesla. He has added his latest advances in vacuum-tube lighting. We are only restrained from giving his communication in full because of the photographs which illustrate it. To reproduce these would detract from their clearness. The author refers to his experiments of a few years ago, which were for a time laid aside, but examples of figures are given with tubes of moderate illuminating power, whereas he is enabled to produce tubes of much greater candle-power—in fact, illuminating power equal to that of hundreds and even thousands of ordinary vacuum tubes; and he says "What is more, I believe that I am far from having attained the limit in the amount of light producible, and believe that this method of illumination will be eventually employed for lighthouse purposes. This probably will be considered the oddest and most unlooked-for development of the vacuum tube." He points out that at the time of his previous experiments an endeavour was made to introduce vacuum-tube lighting into this country. He thought it was bound to fail, as indeed it did. The power consumption was very large for the amount of light produced. The reason of this, he says, is not far to seek. "A vacuum tube, particularly if it be very large, offers an immense radiating surface, and is capable of giving off a great amount of energy without rising perceptibly in temperature. What still increases the dissipation of energy is the high temperature of the rarefied gas. Generally it is supposed that the particles are not brought to a high temperature, but a calculation from the amount of the energy consumed during a given period of time, and the amount of matter contained in the tube, leads to results which would seem to indicate that, of all the means at disposal for bringing a small amount of matter to a high temperature, the vacuum tube is the most effective. . . . As compared with these disadvantages, the incandescent lamp, crude and inefficient as it undoubtedly is, possesses vastly superior features. These difficulties have been recognised by me early, and my efforts during the past few years have been directed towards overcoming these defects, and have finally resulted in material advances, so that I find it possible to obtain from a tube of a volume not much greater than that of a bulb of an incandescent lamp about the same amount of light produced by the latter, without the tube becoming overheated, which is sure to take place under ordinary conditions. Both of these improvements, the increase of candle-power as well as degree of efficiency, have been achieved by gradual perfection of the means of producing economically harmonical electrical vibrations of extreme rapidity." Mr. Tesla tells us that his experiments have been made from an Edison direct-current supply circuit, and the frequency he estimates it about 2,000,000 a second. The illuminating power of the tube approximated to about 1,000 c.p.

SCIENCE AND INVENTION.

VACUUM-TUBE LIGHTING AGAIN.

SOME time ago, as readers of THE LITERARY DIGEST will remember, we heard a great deal about methods of lighting with vacuum-tubes caused to glow by means of the electric discharge. It was abundantly proved at the time that such light is



Courtesy of *The Electrical Review.*

TESLA'S HAND.

easily produced and that it is very soft, white, and pleasant, but its production has not yet been put on a commercial basis. In *The Electrical Review* (January 5) Nikola Tesla, who has long

experimented in this direction, gives some of the reasons why glow-tube lighting has not yet been financially successful, and predicts that it will soon be used widely for photography, if for no other purpose. Says Mr. Tesla:

"The reasons for the great power consumption, which may often be as much as ten times that taking place in incandescent lamps for an equivalent amount of light, are not far to seek. A vacuum-tube, particularly if it be very large, offers an immense radiating surface, and is capable of giving off a great amount of energy without rising perceptibly in temperature. What still increases the dissipation of energy is the high temperature of the rarefied gas. Generally it is supposed that the particles are not brought to a high temperature, but a calculation from the amount of the energy consumed during a given period of time, and the amount of matter contained in the tube, lead to results which would seem to indicate that, of all the means at disposal for bringing a small amount of matter to a high temperature, the vacuum-tube is the most effective. . . . As compared with these disadvantages the incandescent lamp, crude and inefficient as it undoubtedly is, possesses vastly superior features. These difficulties have been recognized by me early, and my efforts during the past few years have been directed toward overcoming these defects, and have finally resulted in material advances, so that I find it possible to obtain from a tube of a volume not much greater than that of a bulb of an incandescent lamp about the same amount of light produced by the latter, without the tube becoming overheated, which is sure to take place under ordinary conditions. Both of these improvements, the increase of candle-power as well as degree of efficiency, have been achieved by gradual perfection of the means of producing economically harmonical electrical vibrations of extreme rapidity."

The photographs taken by Mr. Tesla with his light were, he tells us, from a tube with a radiating surface of about 200 square inches, energized by a current having about two million oscillations in a second. The candle-power of the light was about 1,000, and exposures varied from 2 to 5 seconds, at a distance of 4 to 5 feet, this being found more satisfactory than instantaneous exposures close to the tube. Mr. Tesla concludes:

"The results so far obtained would make it appear that this kind of light will be of great value in photography, not only because of the fineness of the lines, but also because the artist will be able exactly to adjust the conditions in every experiment so as to secure the best result, which is impossible with ordinary light. He will thus be made entirely independent of daylight, and will be able to carry on his work at any hour, night or day. It might also be of value to the painter, tho its use for such purposes I still consider problematical."

An Imperial Electrical Inventor.

THE career of American electric street railway apparatus in Germany may be destined to be a short and merry one, for the news has come very circumstantially of late that the Emperor himself proposes to invent a new electrical car for Berlin, and, if for Berlin, then for all Germany. A few years back, Prince Henry, the Emperor's brother, repeated all the sensational Tesla experiments with currents of high voltage and high frequency, and not many months ago we noted the fact in these columns that the Emperor, the Prince and some high army officers were taking a special electrical course. This all goes to confirm the rumor. We are sure his majesty can help the electric railway art materially, for it has been said that he has a rolling eye of genius just like Edison's; although we have never seen Mr. Edison roll his eye, unless a wink is included in the expression. But what worries us is that we don't see where the Emperor is to get the time; he is so busy. There is Turkey to be patronized; Greece to be snubbed; Russia to be flattered; France to be flouted; England to be insulted, and China to be cut up, all of which he is giving personal attention to, conscientiously. But his majesty is also otherwise engaged, in oratory, music, art, the drama, yachting and a few other diversions. Now the success of such railway inventors as Sprague and Short has come from pretty close attention to one thing. It is true that Tesla dines at Delmonico's; that Edward Weston delights in his big naphtha launch, his camera or his telescope; that Elihu Thomson and Steinmetz persist in scorching on their beloved bicycles; but, after all, their one serious thought and aim in life is electrical investigation and invention. We are sorry that so far as the Emperor's character has interpreted itself to us, his great genius lacks concentration. This is electricity's loss, but we may all just as well make up our minds to stand it. If there is one constant element in the case, it is the Emperor's inconstancy; and he will soon be forgetting that electric car for a balloon, a gun, a picture or a navy.

NICOLA TESLA SEES NO DANGER TO LABOR IN THE INCREASE OF MACHINERY AND ELECTRICAL PROGRESS.

The Poor Have Been Benefitted More Than the Rich by Inventions and Discoveries of Labor-Saving Means, Asserts This Great Practical Scientist in Answer to a Labor Leader's Questions.



NICOLA TESLA.

THE old question of the effect of inventions and improved machinery upon the labor market is again receiving a good deal of attention, in view of the strike in the cotton mills and the wonderful developments of electrical science. The latter, in particular has already demonstrated that it can greatly diminish the labor-cost of modern production.

Any change in the condition of one industry affects in some degree the conditions of other industries the world over. If the harnessing of electricity has lessened the demand for certain kinds of labor in the same way that it has unquestionably lowered the price of horses in cities where they formerly drew street cars, it may not be unreasonable to inquire whether it has had and will have an effect upon labor in other lines.

Mr. Edison's inventions have affected several classes of artisans and large numbers of laborers as well. So have Mr. Tesla's. These and other men of genius are ardently toiling with brain and hand to add to the mechanical means of industrial production. The shackling of Niagara may be followed by the exacting of a tribute of labor from the ocean, the utilization of its constant undulation for the generating of electricity and the driving of machinery.

Henry Weissman, who was long the head of the national organization of American bankers, is one of the best known. He has become rather more conservative since he was known as a star orator of the San Francisco "sand lots" in the 80's. Mr. Weissman commands the confidence of workingmen. He was largely instrumental in bringing about the passage of laws in the East compelling sanitary improvements in the conduct of the baking business. His knowledge of the conditions and needs of labor has been acquired through years of practical study.

Mr. Weissman has drawn up for the Sunday Post-Dispatch a series of questions and submitted them to Nicola Tesla. They cover the whole topic of wages as affected by invention, and Mr. Tesla's answers will be read with interest by every student of labor problems:

1. Is it your opinion that labor-saving machinery benefits workingmen or workingwomen in general?

1. Certainly it is. The whole tendency of mechanical progress is to make life easier and more enjoyable for the whole of mankind. It does not benefit any class or classes to the exclusion of other classes. It indeed brings things within the reach of the many that formerly could be had only by the few. It lights our public streets, for instance, as well as the parlors of the aristocrat once were lighted. It has made a 100-mile excursion of as little cost as a stage-coach ride of 20 miles in the old days. It has lessened the price of flour—in fact, of nearly every manufactured thing. And it brings the products of foreign countries to the doors of the poor at so moderate an expense that from many of them they are no more debarred to the extent of their needs than is the man of millions.

2. If that has lessened the cost of articles is the workman benefited?

2. I suppose you mean that other conditions may overbalance that kind of benefit. What conditions?

3. Is it not true that while invention and discovery have increased the catalogue of the things that are within the reach of the laboring man and his family, the disproportion between the need of the laboring class and the luxury of the unproductive rich has also increased? In other words, of the added profit from production which is obtained from the use of labor-saving devices, does not the capitalist and the rich consumer get a share greatly out of proportion to the increased agency of capital in production?

3. That query goes so far into the domain of political economy, pure and simple, that I should feel much hesitation in attempting to answer it scientifically, as alone it should be answered. That would necessarily bring into review everything that affects the relations and co-operation of labor and capital. I am disposed to think that laws of natural adjustment in the social economy have not been altered by the fact that many very remarkable, very useful and consequently very lucrative inventions have been made. The principle of supply and demand is still at the bottom of the economic system. The power of self-indulgence, of wants or of self-satisfaction of needs, as the case may be, is dependent upon the purchasing power of the individual, which again is nothing more or less, as regards the laborer, than the earning power. This again must be referred to the demand for one's services, which is more or less qualified by the degree or the absence or presence of competition.

If in some directions the effect of improved devices has been in a measure to lessen the demand for workmen (numerically, I mean), it has also constantly tended to cheapen the average livelihood. You must consider, too, a fact that is commonly lost sight of—that after all the main distinction between the lives of the very rich and those of the moderately thrifty poor, aside from the possession of leisure and the ability to dispose of their time, is the elegance in which the former may indulge. Now, very little has come to pass in many years to cheapen what, strictly speaking, may be called elegance. Pictures, statuary, fine carvings, rich hangings, rare rugs, all these and many other things of aristocratic or curious value are proportionately dearer to-day, as compared with the general cost of living, than ever they were. It is so with the service in the rich man's household. He pays thousands for the salary of a cook and even of a private secretary, where his prototype paid some paltry hundreds. Analyze the matter thoroughly and I think you will find that the material possessions which most distinguish the rich from the poor have shared very little, if at all, in the general depreciation of prices. On the other hand, it is acknowledged that the general trend of wages for the past 12 years or more has been upward.

4. Has not labor-saving machinery lessened the market for labor?

4. In one sense I will answer that query in the negative. The march of invention has increased the demand for intelligent labor by creating new and ever-widening fields for it. It has enlarged very greatly the aggregate rewards of labor. It has established for the laboring man an incentive for the improvement of his mental faculties, such as was never given him before. He knows that trained intelligence, coupled with mechanical skill, offers him the best chance of advancement. It must be remembered, too, that shortened hours of labor were not thought of until manufacturing by swift machinery became the controlling fact in industrial life.

The new employments that have been provided by inventive talent are agreeable and interesting, besides prompting more surely to self-improvement than the old. Electricity is the one great force for the future service of man. It is the ultimate force, and the end of its development may not be foreseen. The transition states of labor that may be in part caused by the industrial revolutions that are due to it are not to be put permanently to its charge. Rather to the charge of the slow intellect of the man which did not sooner realize that nature might offer him such help. If there are incidental ups and downs of labor we must not allow them to obscure to our vision the steadily increasing average of progress in labor's condition. If in the new employments there are fewer places for the mere laborer than in the old, it must be remembered that the new employments draw to them men from the ranks of the mere laborers who before had no such prospect of betterment. Electricity may in this sense be likened to the magnet which selects the grains or flakes of valuable metal from the heap of neglected screenings from the mine.

As the hitherto unregarded intelligences advance the men who are left in the ranks of common labor will find themselves less crowded. Thus there will be a compensation for common or the less skilled labor.

No. I do not think that any alarmist theory based upon the increase of labor-saving machinery will stand the test of logic for a moment.

SOCIETIES AND ACADEMIES.

LONDON.

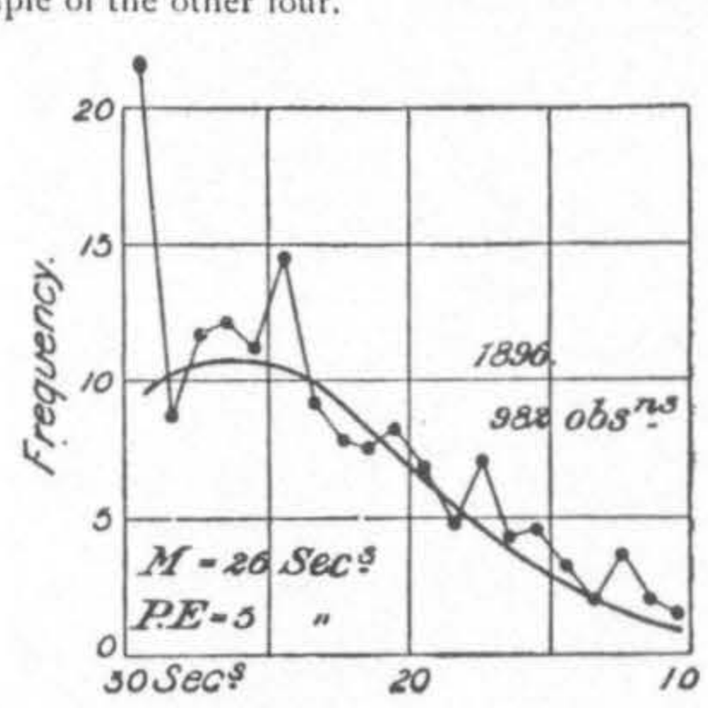
Royal Society, December 13, 1897.—"An Examination into the Registered Speeds of American Trotting Horses, with Remarks on their Value as Hereditary Data." By Francis Galton, D.C.L., F.R.S.

It is strange that the huge sums spent on the breeding of pedigree stock, whether of horses, cattle, or other animals, should not give rise to systematic publications of authentic records in a form suitable for scientific inquiry into the laws of heredity. An almost solitary exception to the disregard shown by breeders and owners, of exact measurements for publication in stud books, exists in the United States with respect to the measured speed of "trotters" and "pacers" under defined conditions. The performance of one mile by a trotter, harnessed to a two-wheeled vehicle, carrying a weight of not less than 150 lbs. inclusive of the driver, in 2 minutes 30 seconds qualifies him for entry in the "Trotting Register," giving him, as it were, a pass-degree into a class of horses whose several utmost speeds or "records" are there published.

The system of timing was first put into practice more than fifty years ago, and has since been developed and improved. In 1892 a considerable change was made in the conditions by the introduction of bicycle wheels with pneumatic tyres, which produced a gain of speed, the amount of which is much discussed, but which a prevalent opinion rates at 5 seconds in the mile. Thenceforward the records are comparable on nearly equal terms. All trotting performances up to the 2′ 30″ standard are registered in the large and closely printed volumes of "Wallace's Year Book," published under the authority of the American Trotting Association. Vols. viii.–xii. refer to the years 1892-6, and it is from the entries in these that the following remarks are based.

The object of my inquiry was to test the suitability of these trotting (and pacing) records for investigations into the laws of heredity. I had to determine whether the observations fell into a tolerably smooth curve; and, if so, whether that curve was a tolerable approach to the normal curve of frequency. In the latter event the observations would fall into line with numerous anthropometric and other measures which have been often discussed, and which, when treated by methods in which the arithmetic mean is employed, yield results that accord with observed facts.

I had 5705 extracts made from the entries published in the Year Books for the five years 1892–6. It was tedious work, and I thought it unnecessary to repeat it to check the results, being satisfied after some examination that they were quite accurate enough for general conclusions. They were arranged in columns; the first to the left contained entries of all observations recorded as 2′ 29·0″, 29¼″, 29½″, or 29¾″; that is of all under 2′ 30″ down to 2′ 29″ inclusive. The second column referred to 2′ 28″·0, 28″¼, 28″½, and 28″¾, and so on with the rest. These were then reduced to percentages and diagrams were drawn from them, of which the following, for the year 1896, is one; it will serve as a fair sample of the other four.



If divided by the eye into imaginary columns corresponding to those in the tables, the point representing the sum of the observations of 2′ 29″·0′, 29″¼, 29″½ and 29″¾ will be found in the middle of the first imaginary column, that is to say it stands vertically above the point that lies half way between 29 and 30 on the scale along the base. The dots are connected by thin lines to show the trace or curve of the observations. The smooth curves are those of normal frequency, calculated from the values of the mean (M) and of the probable error (P.E.), which are given in the diagrams.

Leaving aside for the moment the strange pinnacle that rises on the extreme left of every diagram, we see that the traces of the rest of the observations run very roughly, but not intolerably so. In each diagram they seem to be disposed about a fundamentally smooth curve. Considering the smallness of the interval, namely, only one second, that separates the observations assigned to each pair of successive columns, together with the experience derived from other kinds of statistical curves, it seems to me that the run of the observations is good enough to certify their general trustworthiness. As regards the pinnacle it is different matter, and is one which when beginning work, as

did, on the 1892 entries only, was very perplexing. However, by persevering with the other years, it became increasingly plain that the pinnacle was a false maximum; in 1896 it was certain that the true maximum lay well within the portion of the curve included in the diagram. The explanation of the pinnacle then became obvious[1]; it was that the tolerance granted to those horses who failed by only a little to qualify themselves, was extended considerably beyond the quarter second for which I was prepared. The cases of 2′ 30·0″ were few; they do not appear in the diagram, but their addition would be quite insufficient to remove the difficulty. If the pinnacle were distributed among *two* adjacent columns outside and to the left of the diagram it would smooth away the incongruity, so I suspect that cases of "under 2′ 32″ and down to 2′ 30″" are habitually rated at a trifle less than 2′ 30″. Consequently I had no hesitation in wholly disregarding the entries that helped to make the pinnacle, namely, the whole of those contained in the first column to the left in every one of the diagrams. The course thereupon became clear and straightforward. I estimated the position of the mean value for each year, from inspection of the curve of that year, allowing myself to be somewhat biassed in estimating its point of culmination by the curves of the adjacent years; similarly as to the probable error. Now that the curves are drawn, I see that somewhat better fits might have been made, but they are close enough to show the existence of a fair amount of correspondence between the observed values and those calculated according to the law of normal frequency. It is near enough to remove hesitation in working with the arithmetic mean.

I now come to the fundamental purpose of this memoir, which is to point out the existence in the registers of the American Trotting Association, of a store of material most valuable to inquirers into the laws of heredity, which accumulates and increases in value year by year. But it seems to me hardly worth while to discuss hereditary influence on speed in horses, unless the records of at least their sires and of their dams, and those of each of their four grandparents, as well as their own record, are all known. Even in this case (according, at least, to my own theory) one quarter of the hereditary influences are unknown and have to be inferred. It is practically impossible to make an adequate collection of the names of horses who fulfil the above conditions out of the entries in the "Trotting Register," each search requiring many cross references and occupying a long time, while the number of futile searches before attaining a success is great. On the other hand, the breeders and possessors of these notably bred horses must be familiar with the required facts, and would assuredly be delighted to have them known. There need, therefore, be little difficulty in obtaining materials for the much desired table. In the meantime I am sending circulars to the chief breeders in America, in hopes of making a start.

The great need for genealogical data of an exact numerical kind, by those who prosecute inquiries into the laws of heredity, is the justification that I offer for submitting these remarks to the Royal Society.

Physical Society, January 21.—Mr. Shelford Bidwell, President, in the chair.—Prof. Fitzgerald exhibited some photographs by Mr. Preston in illustration of the Zeeman effect, for various cases, including those of iron, cadmium, zinc, and sodium. These photographs and the method of obtaining them have already been described. The cause of doubling is now attributed by Prof. Fitzgerald to absorption by the surrounding vapour. In a particular case he examined a double line that exists in one of the photographs. Under the polariser the two lines are at first distinctly seen; but when the polariser is turned, a thin line appears in the middle, and this central line is, therefore, circularly polarised in a direction opposite to that of the outer pair of lines. The reason for the appearance of doubling in the first position of the polariser is that the central line is there completely absorbed out by the surrounding vapour.—Prof. Oliver Lodge then gave a communication concerning his work on "Electric Signalling without Connecting-wires." From the nature of the oscillatory disturbances emanating from any of the customary forms of Hertz vibrator, syntony has hitherto been only very partially available as a means for discriminating between receivers. There is in fact so rapid a decrease in the amplitude of the vibrations that almost any receiver can respond to some extent. Discrimination by syntony is possible with magnetic systems of space telegraphy where the magnetic energy much exceeds the electric, *i.e.* as between two separated inductive coils; and by the use of such coils, appropriately applied, the author has been able to attain fair syntony even with true Hertz waves, *i.e.* he has constructed spark-gap oscillators, with sufficient persistence of vibration, and syntonised resonators. The "coherer" principle can be applied to either a purely magnetic or to the Hertzian system. It was first used by Prof. Lodge in devising lightning-guards, and afterwards in his magnetic system of telegraphy by inductive circuits, each in series with a Leyden-jar; a pair of knobs in near contact, or other over-flow gap, being provided in the receiving apparatus. This was the first meaning of a "coherer" in the electrical sense as used by Prof. Lodge. It referred to a *single* contact between two metal knobs. The term has since been extended by others to the filings-tube of M. Branly, and some confusion has arisen, for M. Branly does not consider that simple coherence and break explains fully the behaviour of his instrument. Prof. Lodge is disposed to agree, for he finds that the resistance of almost any form of coherer varies in rough proportion to the received impulses, and that there are other peculiarities (to be mentioned later). He is, therefore, inclined to think that the action cannot after all be entirely explained as due to mere "welding," but that there is something more to be learnt about it. The sensitiveness of a coherer depends upon the number of loose contacts; it is a maximum for a single contact, *i.e.* for a needle-point lightly touching a steel spring. With this sensitive coherer, hardly any "tapping-back" is required for decoherence, but it wants delicate treatment when properly adjusted, and the greatest current through it should not approach a milliampere. On the other hand, a Branly tube rather improves under rough treatment; in such a tube the author prefers to use iron filings in the best possible vacuum; brass, too, is very good, but rather less easy to manage. Aluminium is thoroughly bad, and gold, for an opposite reason, will not work—its surface is too clean. Points, or small surfaces for making contact with the filings, are better than large surfaces. The usual method of connecting the coherer across the gap of an ordinary Hertz receiver, in parallel with the telegraph instrument and battery, has the unavoidable objection that they shunt away part of the received oscillations. With the syntonic receiver of Prof. Lodge, which contains no gap, but a closed wire coil instead, this difficulty no longer exists; for the coherer can now be in series with the detecting instrument, and in so far as these obstruct the oscillations they may be shunted out in various ways, as the author describes. The main feature of his new syntonised vibrators is this self-inductance coil, whose function it is to prolong the duration of the oscillations, and thereby to render syntony possible. Although such a coil acts disadvantageously in so far as it possesses resistance, the resistance does not increase so fast as the self-induction. The coil should consist of thick copper of highest conductivity, and it should have maximum inductance for given resistance. For similar reasons, the capacity-areas should also be of highest conductivity, their dimensions should increase outwards from the spark-gap, as triangles. The receiver must have no gap, it should be accurately bridged over when a transmitter is used as receiver. The limit of speed of response depends upon the telegraphic instrument. Dr. Muirhead adapted a siphon-recorder to the purpose, because it is one of the quickest responders; he arranged it so that it could be used with intermittent currents direct. Under these intermittent impulses the siphon trembles; and instead of the ordinary siphon-signals, the slip is marked with dots and dashes. Constant mechanical tremor is usually employed for decoherence, but the author finds that decoherence can be brought about by electrical means, without any mechanical tremor, by connecting the coherer momentarily to a circuit less effective as a collector than that of the proper capacity-areas of the syntonised receiver. The battery and galvanometer detector-circuit may be used for this purpose, the coherer being momentarily connected to it, and while so connected letting it experience an impulse from a distance. Prof. Lodge has designed a revolving commutator by means of which the coherer can be rapidly changed over from the resonating circuit to the instru-

[1] I should like to take the opportunity afforded by the appearance of an abstract of my memoir in NATURE to correct a questionable suspicion, namely, that the pinnacles in the diagrams are due to tolerance shown towards horses who failed by a very little to qualify for the much-coveted rank of standard trotters. I am assured on excellent authority that the strict conditions of timing make this impossible (among other reasons there are three timers). On the other hand, there is a vast competition *just* to pass the 2′ 30″ limit; and when a horse has done so, his owner often does not care to train him for racing, but rather to utilise him at once for breeding or other purposes. The question is too complicated to discuss here at length. Suffice it that the 2′ 29″ to 2′ 30″ records are not homogeneous with the rest, and should be discarded as I proposed.—F. G.

ment-circuit, and finally to the "tapping-back" apparatus. A coherer is more sensitive when thus isolated and exposed to the full influence of the received oscillations; the subsequent detection of the effect by altered connections is very convenient for laboratory measurements. A diagram of a series of plotted measurements showed that the resistance of an undisturbed filings-tube is approximately a direct function of the intensity of the received stimulus, whether successive stimuli increased or decreased in strength. This electrical process of "tapping-back" is to be depended upon, but the process long continued fatigues the tube until a mechanical shake is employed to restore it. Large size apparatus made by Dr. Muirhead for actual distant syntonic work was exhibited, and means were shown for protecting and isolating the coherer when its receiving areas were being used as emitters; also a switch used for changing at one moment all the connections from "sending" to "receiving." Prof. Threlfall said he had come to the same conclusion as Prof. Lodge as to the advisability of diminishing the number of contact-points in the coherer. He had endeavoured to produce longer and more persistent waves, and thus to set afield greater effective energy. It was desirable to keep the waves as parallel as possible. He thought there was some probability that the wave-fronts could be altered and rendered more conformable by a process of diffraction. Mr. Rutherford also had found it best to work with long waves. He fully appreciated the advantage of increasing the capacity of the oscillator by extending the surface of the metallic plates. Mr. Campbell-Swinton asked whether experiments had been made to verify Hertz results as to the influence of reflectors behind oscillators and receivers. He had found them disadvantageous. A single wire behind either apparatus seemed partially to annul the effect. He also asked whether Prof. Lodge had observed the extraordinary sensitiveness of coherers to small changes of current in neighbouring circuits. Prof. Lodge, in reply, said he had observed the sensitiveness to slight sudden variations of current referred to by Mr. Campbell Swinton; for instance, when electric lamps were switched on or off. The effect of mirrors had been studied by Prof. Fitzgerald. They required to be of large dimensions as compared to the oscillator and receiver, otherwise the true reflections were not obtained. Dr. Silvanus Thompson afterwards exhibited a Tesla oscillator. This apparatus is intended to replace the two induction coils and spark-gap arrangements used by Mr. Tesla for high frequency experiments. It consists of an induction coil with a separate self-inductance coil in the primary circuit. This self-inductance coil is also used as an electromagnet for the separate interrupter of the primary circuit. A condenser is connected between one end of the primary coil and one terminal of the interrupter, so as to include both of them between its terminals. The primary is a single turn of copper strip, six inches wide. The secondary is one layer of thick wire; each turn separated from the next by an air space. The supply current, about half an ampere, may be taken from the electric-light mains at almost any voltage from 50 to 200, direct or alternating. Prof. Lodge said it would work quite well at 10 volts. He pointed out also that if the straight discharge-rods at the spark-gap were free to slide, the discharge drove them back into their sockets. Prof. Fitzgerald said it was stated at Toronto that the spark was broken at the interrupter when the condenser was charged, and that by the time the condenser was ready to discharge, the contact at the interrupter had been made again. It seemed to him that the condenser discharges and surgings must take place at a rate far higher than the period of the mechanical movement of the interrupter. The condenser charges and discharges were very rapid. It was not what is ordinarily called the "time constant" that was involved, for that only referred to constant voltage. Here the voltage was changing very rapidly indeed. Prof. Herschel asked if such an apparatus was suitable for work with Röntgen rays. Dr. Thompson, in reply, congratulated Mr. Tesla upon the perfect working and compactness of his invention. The present form was not suited for Röntgen ray experiments, but Mr. Tesla had designed a special coil that was excellent for that purpose. —The President proposed votes of thanks, and the meeting was adjourned until February 11.

PARIS.

Academy of Sciences, January 24.—M. Wolf in the chair. —On the reduction of some double integrals, and on a new invariant in the theory of algebraic surfaces, by M. Émile Picard.—Addition to a preceding note on the Zeeman effect, by M. A Cornu. Some results of measurements showing that the magnitude of the separation produced increases with the refrangibility of the ray.—On the conditions of formation of alkaline carbides, and the carbides of magnesium and of the alkaline earths, by M. Henri Moissan. Metallic potassium, if left for a long time in acetylene, slowly but completely decomposes the gas giving hydrogen and C_2HK. Sodium gives a similar compound when sealed up with liquid acetylene, and this C_2HNa, heated in a vacuum, gives up pure acetylene, leaving sodium carbide C_2Na_2 behind; at a red heat this is decomposed into carbon and sodium. The potassium compound behaves similarly, neither sodium, potassium, nor magnesium carbides being able to exist at the temperature of the electric furnace.—Histological mechanism of cicatrisation; on true immediate reunion, by M. L. Ranvier. In wounds caused by cutting the cornea of the rabbit, two modes of closing up of the tissue can be noted, an immediate synaptic joining, and a true immediate joining, the former due to the cuts being filled with epithelial cells arising from the neighbouring epithelium, and the latter noticeable only in wounds forty-eight hours after the incision had been made, and where, owing to the lips of the cut happening to touch, no epithelial cells had penetrated.—The enlargement of the right auricle of the heart during inspiration demonstrated by radioscopy, by M. Ch. Bouchard.—On the fourth voyage of the *Princesse-Alice*, by S.A.S. Albert I., Prince of Monaco. The chief work was done on the western coast of Morocco, round Madeira and the Azores, and comprised sounding operations, together with zoological study of the fauna of the Princesse-Alice bank. A chart of this bank accompanies the paper.—Remarks by M. Edmond Perrier on his work on animal colonies and the formation of organisms.—Shooting-stars in the months of November and December 1897, observed at Basse-Terre (Guadeloupe), by M. Ch. Duprat.—On the development of uniform or holomorphic functions in any field, by M. Paul Painlevé.—On the types of increase and on complete functions, by M. Émile Borel.—On systems of partial differential equations analogous to equations of the first order, by M. Jules Beudon.—On the geometry of magnetic fields and of motion with two degrees of freedom in a plane or on a sphere, by M. René de Saussure.—Law of deformation of commercial metals, by M. Marcel Brillouin. A mathematical expression is given which includes all the known facts regarding permanent changes of shape in metals.—On an interference spectroscope, by MM. Ch. Fabry and A. Perot. The method consists in observing rings produced by transmission through a layer of air contained between two perfectly parallel silvered glass faces. Full details of the adjustments necessary are given in the present paper.—On the part played by diffraction in the effects produced with gratings, by M. Ch. Féry.—Study of chemical and physical equilibria by the osmotic method, by M. A. Ponsot.—On the law of mixture of gases by M. Paul Sacerdote, giving the experimental results of mixing equal volumes of gases. The observed changes of pressure for a mixture of nitrous oxide and carbon dioxide, and of the latter gas with sulphur dioxide, are compared with those deduced from the densities by M. Leduc. The results of the two methods are in general agreement.—On the separation of thorium and the cerite earths, by MM. G. Wyrouboff and A. Verneuil.—The method proposed is based upon the fact that in a mixture of nitrates of the rare earths, as free as possible from excess of acid, heating with excess of hydrogen peroxide to 60° completely precipitates all the thoria in the solution.—Hydramides and the isomeric glyoxalidines, by M. Marcel Delépine. A thermochemical paper.—Researches on ouabaïne, by M. Arnaud.—Synthesis of terebic acid, by M. E. E. Blaise.—Manufacture of acetone oil, in particular of methyl-ethyl-ketone, by means of the liquors from the desuintage of wool, by MM. A. and P. Buisine. The calcium salts of the mixture of fatty acids obtained from wool is submitted to dry distillation. The resulting liquid yields on fractionation 60 per cent. of methyl-ethyl-ketone. —On the estimation of gastric juice, by M. L. Cordier. The free acid is converted into lithium chloride by treatment with lithium carbonate, and this separated from the sodium chloride by extracting the incinerated residue with a mixture of equal parts of absolute alcohol and dry ether, in which the lithium chloride only is soluble.—Ergographical experiments for measuring the maximum power of a muscle regularly stretched, by MM. André Broca and Charles Richet.—The fungus *Sporotrichum globuliferum*, by M. Trabut.—On the anhydrous calcium sulphate produced by the complete dehydration of gypsum, by M. A. Lacroix. The dehydration of gypsum gives rise to a calcium sulphate dimorphous with anhydrite, probably triclinic. When the drying was not quite carried to completion another form of crystal was observed, possibly $2CaSO_4.H_2O$.—On the Callovian of Woëvre, by M. René Nicklès.—On the third international ascent of experimental balloons, by M. Ed. Stelling. Two ascents were made, one with two observers, the other balloon carrying self-registering instruments only. The temperature variation with the height is given in full.

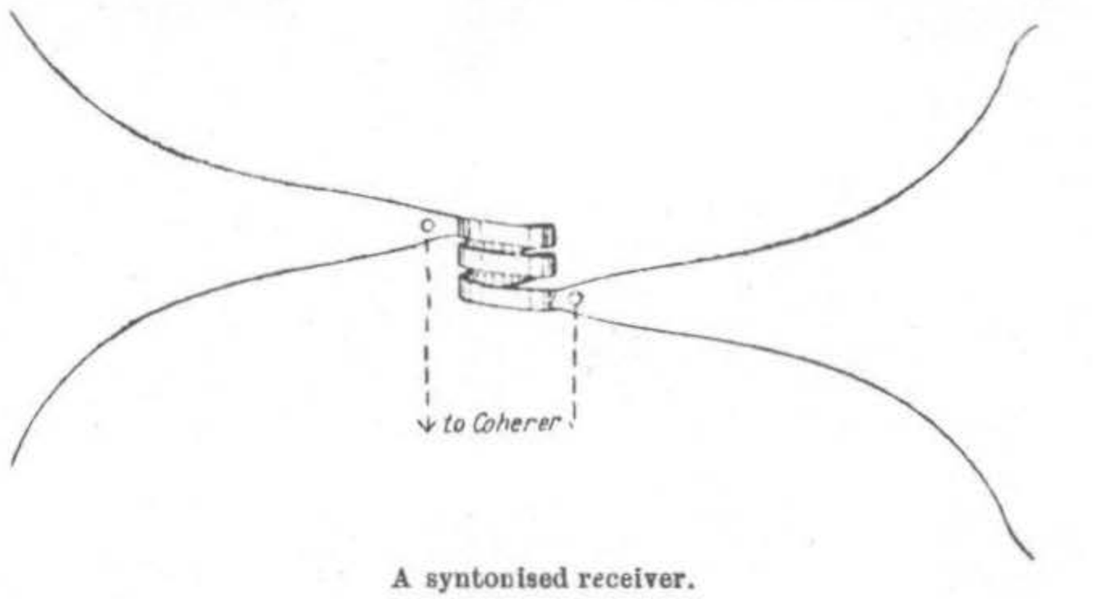
PHYSICAL SOCIETY.

[The illustrations given herewith were made from sketches kindly lent us by Dr. Oliver Lodge, and are explained by their footnotes. They are not referred to in the text of the official report.—Ed. *E. E.*]

At the ordinary meeting held on Jan. 21, 1898, Mr. Shelford Bidwell, president, in the chair,

Prof. Fitzgerald exhibited some photographs by Mr. Preston in illustration of the Zeeman effect for various cases, including those of iron, cadmium, zinc, and sodium. These photographs and the method of obtaining them have already been described. The cause of doubling is now attributed by Prof. Fitzgerald to absorption by the surrounding vapour. In a particular case he examined a double line that exists in one of the photographs. Under the polariser the two lines are at first distinctly seen, but when the polariser is turned, a thin line appears in the middle, and this central line is therefore circularly polarised in a direction opposite to that of the outer pair of lines. The reason for the appearance of doubling in the first position of the polariser is that the central line is there completely absorbed out by the surrounding vapour.

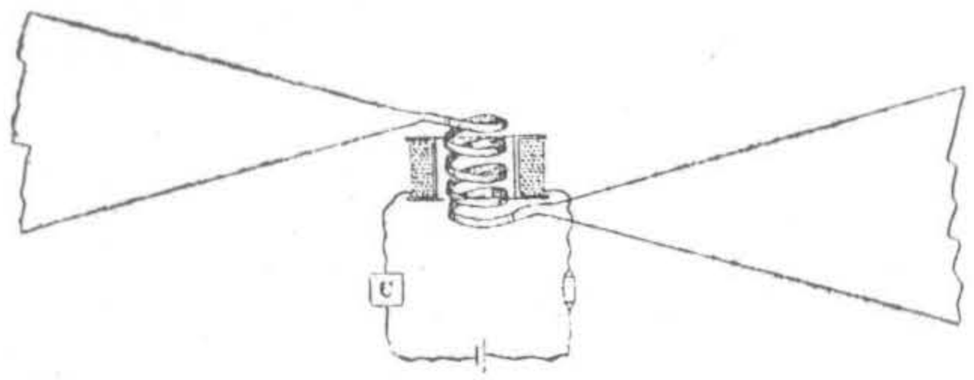
Prof. Oliver J. Lodge then gave a communication concerning his work on "**Electric Signalling without Connecting Wires.**" From the nature of the oscillatory disturbances emanating from any of the customary forms of Hertz vibrator, syntony has hitherto been only very partially available as a means for discriminating between receivers. There is, in fact, so rapid a decrease in the amplitude of the vibrations that almost any receiver can respond to some extent. Discrimination by syntony is possible with magnetic systems of space telegraphy where the



A syntonised receiver.

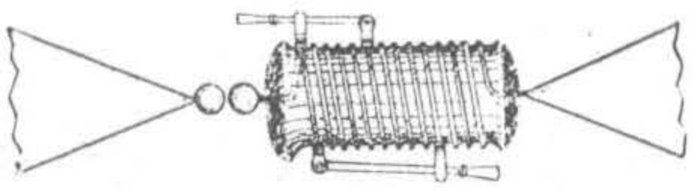
magnetic energy much exceeds the electric—*i.e.*, as between two separated inductive coils—and by the use of such coils, appropriately applied, the author has been able to attain fair syntony even with true Hertz waves—*i.e.*, he has constructed spark-gap oscillators, with sufficient persistence of vibration, and syntonised resonators. The "coherer" principle can be applied to either a purely magnetic or to the Hertzian system It was first used by Prof. Lodge in devising lightning guards, and afterwards in his magnetic system of telegraphy by inductive circuits, each in series with a Leyden jar, a pair of knobs in near contact, or other overflow gap, being provided in the receiving apparatus. This was the first meaning of a "coherer" in the electrical sense as used by Prof. Lodge: it referred to a single contact between two metal knobs. The term has since been extended by others to the filings tube of M. Branly, and some confusion has arisen, for M. Branly does not consider that simple coherence and break explains fully the behaviour of his instrument. Prof. Lodge is disposed to agree, for he finds that the resistance of almost any form of coherer varies in rough proportion to the received impulses, and that there are other peculiarities (to be mentioned later); he is therefore inclined to think that the action cannot,

after all, be entirely explained as due to mere "welding," but that there is something more to be learnt about it. The sensitiveness of a coherer depends upon the number of loose contacts; it is a maximum for a single contact—*i.e.*, for a needle point lightly touching a steel spring. With this sensitive coherer, hardly any "tapping back" is required for decoherence, but it wants delicate treatment when properly adjusted, and the greatest



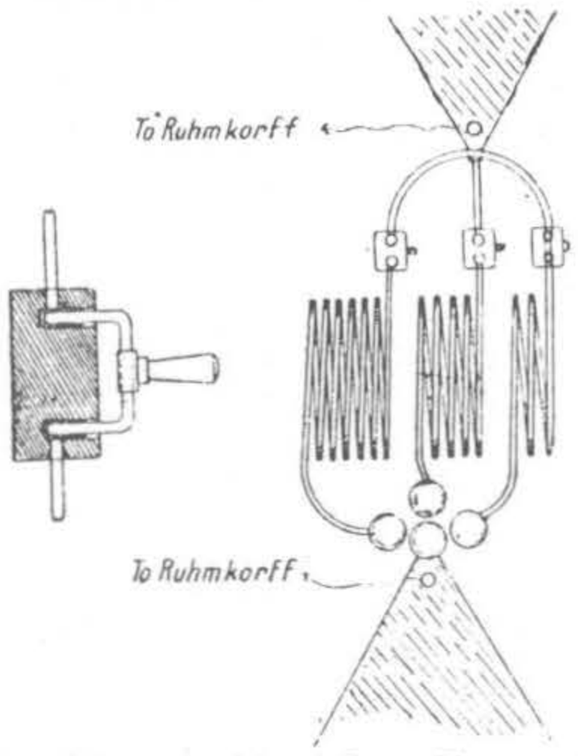
A syntonised receiver. Sketch showing a mode of stimulating coherer by means of currents induced in an outer coil with the simplest connections to coherer.

current through it should not approach a milliampere. On the other hand, a Branly tube rather improves under rough treatment. In such a tube the author prefers to use iron filings in the best possible vacuum; brass, too, is very good, but rather less easy to manage. Aluminium is thoroughly bad, and gold, for an opposite reason, will not work—its surface is too clean. Points, or small surfaces for making contact with the filings, are better than large surfaces. The usual method of connecting the coherer across the gap of an ordinary Hertz receiver, in parallel with the telegraph instrument and battery, has the unavoidable objection that they shunt away part of the received oscillations. With the syntonic receiver of



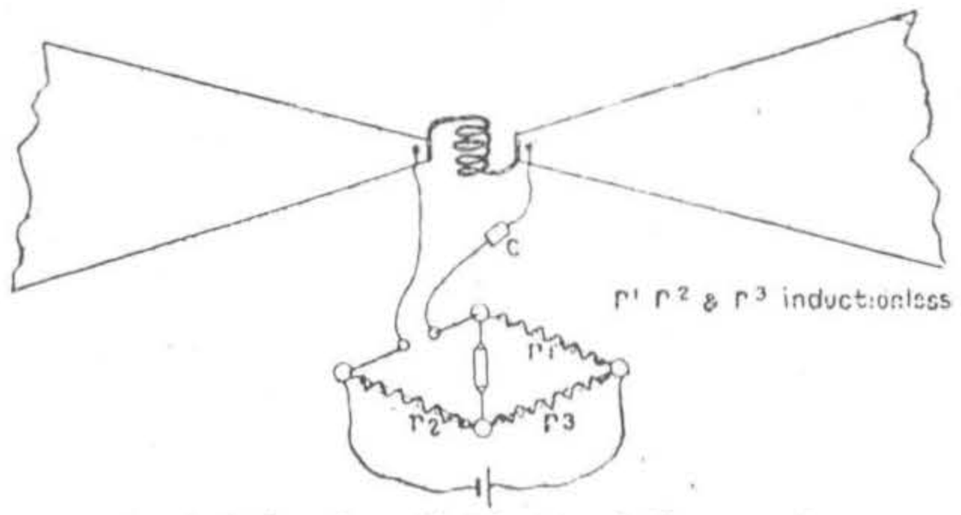
A method of tuning a receiver by means of a Hedgehog choking coil.

Prof. Lodge, which contains no gap but a closed wire coil instead, the difficulty no longer exists, for the coherer can now be in series with the detecting instrument, and in so far as these obstruct the oscillations they may be shunted out in various ways, as the author describes. The main feature of his new syntonised vibrators is this self-inductance coil, whose function it is to prolong the duration of the oscillations, and thereby to render syntony possible. Although such a coil acts disadvantageously in so far as it possesses resistance, the resistance does not increase so fast as the self-induction. The coil should consist of thick copper of highest conductivity, and it should have maximum inductance for given resistance. For similar reasons the capacity areas should also be of highest conductivity; their dimensions should increase outwards from the spark-gap, as triangles. The receiver must have no gap; it should be accurately bridged over when a transmitter is used as



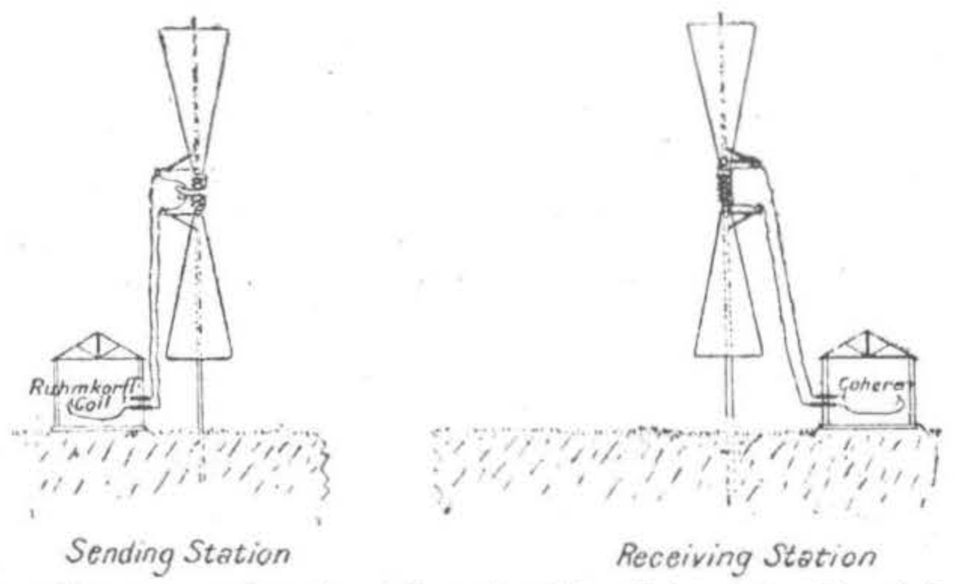
Emitter for three different receiving stations. The connections A, B, or C are plugged up according to station required.

receiver. The limit of speed of response depends upon the telegraphic instrument. Dr. Muirhead adapted a siphon recorder to the purpose, because it is one of the quickest responders. He arranged it so that it could be used with intermittent currents direct. Under these intermittent impulses the siphon trembles, and instead of the ordinary siphon signals the slip is marked with dots and dashes. Constant mechanical tremor is usually employed by decoherence, but the author finds that decoherence can be brought about by electrical means, without any mechanical tremor, by connecting the coherer momentarily to a circuit less effective as a collector than that of the proper capacity areas of the syntonised receiver. The battery and galvanometer detector circuit may be used for this purpose; the coherer being momentarily connected to it, and while so connected, letting it experience an impulse from a distance. Prof. Lodge has designed a revolving commutator, by means of which the coherer can be rapidly changed over from the resonating circuit to the instrument circuit, and finally to the "tapping-back" apparatus. A coherer is more sensitive when thus isolated and exposed to the full influence of the received



A syntonised receiver with Wheatstone bridge connections.

oscillations. The subsequent detection of the effect by altered connections is very convenient for laboratory measurements. A diagram of a series of plotted measurements showed that the resistance of an undisturbed filings tube is approximately a direct function of the intensity of the received stimulus, whether successive stimuli increased or decreased in strength. This electrical



General appearance of one form of a pair of long-distance signalling stations with syntonised emitter and receiver. The coils connecting the capacity areas are diagrammatically shown.

process of "tapping back" is to be depended upon, but the process long continued fatigues the tube until a mechanical shake is employed to restore it. Large-size apparatus made by Dr. Muirhead for actual distant syntonic work was exhibited, and means were shown for protecting and isolating the coherer when its receiving areas were being used as emitters; also a switch used for changing at one moment all the connections from "sending" to "receiving."



A long-distance sending and receiving station. The insulated metal roof is used as the capacity area, with all its parts well connected up to discharging rod.

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Mr. Rutherford also had found it best to work with long waves. He fully appreciated the advantage of increasing the capacity of the oscillator by extending the surface of the metallic plates.

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to annul the effect. He also asked whether Prof. Lodge had observed the extraordinary sensitiveness of coherers to small changes of current in neighbouring circuits.

Prof. Lodge, in reply, said he had observed the sensitiveness to slight sudden variations of current referred to by Mr. Campbell-Swinton—for instance, when electric lamps were switched on or off. The effect of mirrors had been studied by Prof. Fitzgerald. They required to be of large dimensions as compared to the oscillator and receiver, otherwise the true reflections were not obtained.

Dr. Silvanus Thompson afterwards exhibited a Tesla oscillator. This apparatus is intended to replace the two induction coils and spark-gap arrangements used by Mr. Tesla for high-frequency experiments. It consists of an induction coil with a separate self-inductance coil in the primary circuit. This self-inductance coil is also used as an electromagnet for the separate interrupter of the primary circuit. A condenser is connected between one end of the primary coil and one terminal of the interrupter, so as to include both of them between its terminals. The primary is a single turn of copper strip, 6in. wide. The secondary is one layer of thick wire; each turn separated from the next by an air space. The supply current, about half an ampere, may be taken from the electric light mains at almost any voltage from 50 to 200, direct or alternating.

Prof. Lodge said it would work quite well at 10 volts. He pointed out also that if the straight discharge rods at the spark gap were free to slide, the discharge drove them back into their sockets.

Prof. Fitzgerald said it was stated at Toronto that the spark was broken at the interrupter when the condenser was charged, and that by the time the condenser was ready to discharge the contact at the interrupter had been made again. It seemed to him that the condenser discharges and surgings must take place at a rate far higher than the period of the mechanical movement of the interrupter. The condenser charges and discharges were very rapid. It was not what is ordinarily called the "time constant" that was involved for that only referred to constant voltage. Here the voltage was changing very rapidly indeed.

Prof. Herschel asked if such an apparatus was suitable for work with Röntgen rays.

Dr. Thompson, in reply, congratulated Mr. Tesla upon the perfect working and compactness of his invention. The present form was not suited for Röntgen-ray experiments with the ordinary focussing tubes, but Mr. Tesla had designed a special tube which gave most excellent results with the coil.

The **President** proposed votes of thanks, and the meeting was adjourned until Feb. 11.

THE PHYSICAL SOCIETY.

AT the meeting of the Physical Society, held on January 21, Mr. Shelford Bidwell, President, in the chair, Professor Fitzgerald exhibited some photographs by Mr. Preston in illustration of the Zeeman effect, for various cases, including those of iron, cadmium, zinc, and sodium. These photographs and the method of obtaining them have already been described. The cause of doubling is now attributed by Professor Fitzgerald to absorption by the surrounding vapour. In a particular case he examined a double line that exists in one of the photographs. Under the polariser the two lines are at first distinctly seen; but when the polariser is turned, a thin line appears in the middle, and this central line is, therefore, circularly polarised in a direction opposite to that of the outer pair of lines. The reason for the appearance of doubling in the first position of the polariser is that the central line is there completely absorbed out by the surrounding vapour.

Professor Oliver Lodze then gave a communication concerning his work on "*Electric Signalling without Connecting-wires.*" From the nature of the oscillatory disturbances emanating from any of the customary forms of Hertz vibrator, syntony has hitherto been only very partially available as a means for discriminating between receivers. There is, in fact, so rapid a decrease in the amplitude of the virations that almost any receiver can respond to some extent. Discrimination by syntony is possible with magnetic systems of space telegraphy where the magnetic energy much exceeds the electric, *i.e.*, as between two separated inductive coils; and by the use of such coils, appropriately applied, the author has been able to obtain fair syntony even with true Hertz waves, *i.e.*, he has constructed spark-gap oscillators, with sufficient persistence of vibration and syntonised resonators. The "coherer" principle can be applied to either a purely magnetic or to the Hertzian system. It was first used by Professor Lodge in devising lightning-guards, and afterwards in his magnetic system of telegraphy by inductive

circuits, each in series with a Leyden jar; a pair of knobs in rear contact, or other overflow gap, being provided in the receiving apparatus. This was the first meaning of a "coherer" in the electrical sense, as used by Professor Lodge. It referred to a single contact between two metal knobs. The term has since been extended by others to the filings-tube of M. Branly, and some confusion has arisen, for M. Branly does not consider that simple coherence and break explains fully the behaviour of his instrument. Professor Lodge is disposed to agree, for he finds that the resistance of almost any form of coherer varies in rough proportion to the received impulses, and that there are other peculiarities (to be mentioned later); he is, therefore, inclined to think that the action cannot, after all, be entirely explained as due to mere "welding," but that there is something more to be learnt about it. The sensitiveness of a coherer depends upon the number of loose contacts; it is a maximum for a single contact, *i.e.*, for a needle-point lightly touching a steel spring. With this sensitive coherer, hardly any "tapping-back" is required for decoherence, but it wants delicate treatment when properly adjusted, and the greatest current through it should not approach a milliampere. On the other hand, a Branly tube rather improves under rough treatment; in such a tube the author prefers to use iron filings in the best possible vacuum; brass, too, is very good, but rather less easy to manage. Aluminium is thoroughly bad; and gold, for an opposite reason, will not work; its surface is too clean. Points, or small surfaces for making contact with the filings, are better than large surfaces. The usual method of connecting the coherer across the gap of an ordinary Hertz receiver, in parallel with the telegraph instrument and battery, has the unavoidable objection that they shunt away part of the received oscillations. With the syntonic receiver of Professor Lodge, which contains no gap, but a closed wire coil instead, the difficulty no longer exists: for the coherer can now be in series with the detecting instrument, and in so far as these obstruct the oscillations they may be shunted out in various ways, as the author describes. The main feature of his new syntonised vibrators is this self-inductance coil, whose function it is to prolong the duration of the oscillations, and thereby to render syntony possible. Although such a coil acts disadvantageously in so far as it possesses resistance, the resistance does not increase so fast as the self-induction. The coil should consist of thick copper of highest conductivity, and it should have maximum inductance for given resistance. For similar reasons, the capacity-areas should also be of highest conductivity, their dimensions should increase outwards from the spark-gap, as triangles. The receiver must have no gap, it should be accurately bridged over when a transmitter is used as receiver. The limit of speed of response depends upon the telegraphic instrument. Dr. Muirhead adapted a syphon-recorder to the purpose, because it is one of the quickest responders; he arranged it so that it could be used with intermittent currents, direct. Under these intermittent impulses the syphon trembles; and instead of the ordinary syphon signals, the slip is marked with dots and dashes. Constant mechanical tremor is usually employed for decoherence, but the author finds that decoherence can be brought about by electrical means, without any mechanical tremor, by connecting the coherer momentarily to a circuit less effective as a collector than that of the proper capacity-areas of the syntonised receiver. The battery and galvanometer detector-circuit may be used for this purpose; the coherer being momentarily connected to it, and while so connected letting it experience an impulse from a distance. Professor Lodge has designed a revolving commutator by means of which the coherer can be rapidly changed over from the resonating circuit to the instrument circuit, and finally to the "tapping-back" apparatus. A coherer is more sensitive when thus isolated and exposed to the full influence of the received oscillations; the subsequent detection of the effect by altered connections is very convenient for laboratory measurements. A diagram of a series of plotted measurements shows that the resistance of an undisturbed filings-tube is approximately a direct function of the intensity of the received stimulus, whether successive stimuli increase or decrease in strength. This electrical process of "tapping-back" is to be depended upon, but the process long continued fatigues the tubes until a mechanical shake is employed to restore it. Large-size apparatus made by Dr. Muirhead for actual distant syntonic work was exhibited, and means were shown for protecting and isolating the coherer when its receiving areas were being used as emitters; also a switch used for changing at one moment all the connections from "sending" to "receiving."

Professor Threlfall said he had come to the same conclusion as Professor Lodge as to the advisability of diminishing the number of contact points in the coherer. He had endeavoured to produce longer and more persistent waves, and thus to set afield greater effective energy. It was desirable to keep the waves as parallel as possible. He thought there was some probability that the wave-points could be altered and rendered more conformable by a process of diffraction.

Mr. Rutherford also had found it best to work with long waves. He fully appreciated the advantage of increasing the capacity of the oscillator by extending the surface of the metallic plates.

Mr. Campbell Swinton asked whether experiments had been made to verify Hertz results as to the influence of reflectors behind oscillators and receivers. He had found them disadvantageous. A single wire behind either apparatus seemed partially to annul the effect. He also asked whether Professor Lodge had observed the extraordinary sensitiveness of coherers to small changes of current in neighbouring circuits.

Professor Lodge, in reply, said he had observed the sensitiveness to slight sudden variations of current referred to by Mr. Campbell Swinton; for instance, when electric lamps were switched on or off. The effect of mirrors had been studied by Professor Fitzgerald. They required to be of large dimensions as compared to the oscillator and receiver, otherwise the true reflections were not obtained.

Dr. Silvanus Thompson afterwards exhibited a Tesla oscillator. This apparatus is intended to replace the two induction coils and spark-gap arrangements used by Mr. Tesla for high-frequency experiments. It consists of an induction coil with a separate self-inductance coil in the primary circuit. This self-inductance coil is also used as an electro-magnet for the separate interrupter of the primary circuit. A condenser is connected between one end of the primary coil and one terminal of the interrupter, so as to include both of them between its terminals. The primary is a single turn of copper strip, 6 in. wide. The secondary is one layer of thick wire; each turn separated from the next by an air space. The supply current, about half an ampere, may be taken from the electric light mains at almost any voltage from 50 to 200, direct or alternating.

Professor Lodge said it would work quite well at 10 volts. He pointed out also that if the straight discharge rods at the spark-gap were free to slide, the discharge drove them back into their sockets.

Professor Fitzgerald said it was stated at Toronto that the spark was broken at the interrupter when the condenser was charged, and that by the time the condenser was ready to discharge, the contact at the interrupter had been made again. It seemed to him that the condenser discharges and surgings must take place at a rate far higher than the period of the mechanical movement of the interrupter. The condenser charges and discharges were very rapid. It was not what is ordinarily called the "time constant" that was involved, for that only referred to constant voltage. Here the voltage was changing very rapidly indeed.

Professor Herschel asked if such an apparatus was suitable for work with Röntgen rays.

Dr. Thompson, in reply, congratulated Mr. Tesla upon the perfect working and compactness of his invention. The present form was not suited for Röntgen ray experiments, but Mr. Tesla had designed a special coil that was excellent for that purpose.

The President proposed votes of thanks, and the meeting was adjourned until February 11.

The New York Journal And Advertiser February 6, 1898

ELECTRICITY TO TAME WILD BEASTS.

Nicola Tesla Writes of the Interesting Possibilities of This New and Successful Device of Animal Trainers in Europe.

How the "Electric Subjugator" Shocks a Lion Into Submission When He Attacks the Trainer In His Cage.

TESLA ON ANIMAL TRAINING BY ELECTRICITY.

To the Editor of the Journal:

IT seems to me that there are interesting possibilities in the training of animals by electricity. Of course, it's rather out of my province, but the idea of the electrical subjugator appears feasible when one knows the power of electricity and the instinctive fear that brutes have of the unknown. And the electric method seems more humane than those I believe are in use—the whip, red hot irons and drugs, which are likely to do permanent injury, while the physical effects of an electric shock are soon gone, only the moral ones remaining.

The subjugator referred to will do the work, but I think an apparatus could be designed that would be less dangerous to the man. I do not desire to be understood as giving the matter deep thought, but I believe that if, instead of the armored backpad, the trainer used a wand with two prongs at one end, better results would follow. This wand would be connected with the supply cables and could be applied to any part of the animal's body at will. Its operation would be precisely the same as the subjugator here illustrated, the two prongs supplying the positive and negative poles of contact found in the flattened wires. With this wand an animal could be simply shocked, stunned or killed, as required.

To cure animals of jumping at men in cages, a screen of stout but flexible wire could be stretched between the trainer and his subject, the wires to be alternately positive and negative, and connected through the regulator with the dynamo. After a couple of springs which would hurl him half insensible back into his corner, the taste for unexpected jumps would leave the brute.



ROENTGEN-RAY NOTES.

BY WILLIAM ROLLINS.

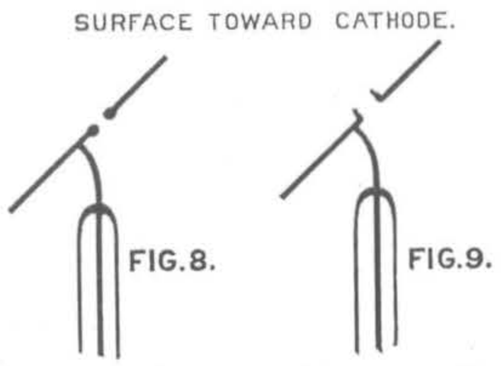
XXI—THE APPEARANCE OF AN UNCOOLED ANODE IN A ROENTGEN REFLECTING FOCUS TUBE.

In my attempts to find out what happens in a Roentgen tube I have spent considerable time in studying the appearances of anodes spoiled in use. Through the courtesy of Kirmayer & Oelling I have been able to examine the tubes returned to them for new anodes. Where the force has been only sufficient to gently melt the anodes, the edges of the holes are rounded as shown in section in Fig. 8. If the force has been enough to quickly give the molecules a freer range, the holes made in the platinum have edges toward the cathode, and are rough and jagged where the metal stiffened into points and ridges, as shown in section in Fig. 9. The bombarding molecules from the cathode have not driven the platinum in front of them, as we might suppose when our minds are fixed upon the cathode. They have been opposed by another force operating in a contrary direction. As this force increases with the degree of excitement in the tube and operates perpendicularly with the surface of the anode even when, as in a focus tube of the reflecting type, this is at an angle with the cathode, I have no doubt it is the molecular rush of the forgotten anode.

XXII—DR. WILLIAMS'S TUBE.

Dr. F. H. Williams has recently shown me the tube illustrated in Fig. 10. It consists of an aluminum bulb, with a rubber stopper, through which passes a glass tube with the anode sealed in. Inside the glass tube is a rubber tube, through which water was admitted, the waste escaping between the tubes. This tube goes back to the time when only newspaper accounts of Roentgen's discovery had reached this country, showing that cooled anodes had been thought of before I invented my A–W–L tube. The inventions are in a way different, because at that early day the amount of force used was too small to injure the anode, the object being to prevent the warmth of the anode from injuring the rubber stopper, while in my tube the target on which the anode discharge is received is cooled, because, with the great force I frequently apply, it would otherwise promptly melt. Using these tubes, I have been able to approach the conditions long ago reached by Mr. Tesla and described in paragraph 139 of Thompson and Anthony's invaluable work on X-rays, where the action of the generator is alone sufficient to produce a vacuum in a tube, and where in practice the vacuum rises so quickly that none of the commercial methods of adjusting are efficient.

Now, after allowing due weight to the other reasons already mentioned in these notes for the vacuum rising, we are brought face to face with that other extraordinary truth of Mr. Tesla's that molecules of residual air go out through the glass walls of a vacuum tube. So it becomes interesting to offer all the experimental evidence we can to illustrate this truth, and in a future note I shall give what I have accumulated as appearing to bear on the subject. Meanwhile it is worth while to point out where work should be done to find the best means of keeping a vacuum steady. Potash is not efficient, because when it has parted with its water it is inoperative, and this is soon when a powerful generator is used. First, we should leave only inert gas in the tube. Then we need a substance which, under heat or electricity, will give large controllable volumes of a suitable gas. This gas should have a high molecular weight in order that the momentum of the molecules may cause them to strike the target with force. As this will be treated more fully in a future note dealing with the means of using the velocity of the cathode discharge, I turn now to mechanical methods of controlling the vacuum. On some of my tubes I have used a special form of stop-cock invented by Dr. F. H. Williams. It is tight when not in use, and when the tube is running we can admit microscopic amounts of air by turning a valve a few times. When it is connected with a small bulb of suitable gas and used with a tube containing only gas which does not combine with the terminals, we have eliminated some of the causes of the rise, and have only to consider the Tesla effect. In some of my direct-acting tubes, shown in previous figures, instead of using a sealed-in window, I have gone back to Lenard's aluminum window, which has not yet been made tight by any plan suggested, so in running the leak compensates for the rise. But this method is not under control, and, when not in use, the end must be kept plunged under mercury.



UNCOOLED ANODES IN ROENTGEN REFLECTING FOCUS TUBES.

XXIII—OXYGEN IN A VACUUM TUBE.

In searching for new lights by which to see that remarkable fact of Mr. Tesla's that molecules of the residual gases went out through the glass walls, I tried a number of experiments with different gases. Oxygen was chosen for one of these on account of its reasonably high molecular weight, and because I had reason to believe these molecules would be easier than some others to break under electric stress into electro-negative and positive groups, a matter of importance, because Roentgen light and smashed molecules go together. Whatever may be thought of this statement and of another, that it is broken molecules which go out through the glass, the experiments are of interest, for a Roentgen tube, in which the residual molecules are largely oxygen, is very bright and easy to exhaust, and also we have in stored-up oxygen the best means now known of regulating the vacuum. A simple way to prepare this stored-up oxygen is this: Mix four parts of chlorate of potash with one part of manganese dioxide. Heat them gently in a test tube until they form a coke-like mass. When cool, this is broken up into suitable pieces and placed in another tube, the end being sealed to exclude water vapor and gases. When required for use the tube is opened, a few grains of the mixture taken out and placed in a small bulb attached to a vacuum tube, which is then placed on the pump and exhausted to a high vacuum; heated to lower the vacuum, again pumped and heated, and this process continued until heating no longer lowers the vacuum. Then the little reservoir of stored oxygen is gently heated until the vacuum comes down. The pump is worked to raise the vacuum and the process repeated a few times. The tube is then sealed off. When in use the vacuum has risen, the reservoir of oxygen is gently heated while the tube is excited, until the vacuum is at the degree required for the special work on hand. Such a tube phosphoresces strongly after the current is turned off, and presents several interesting appearances which will be described if suitable half-tones can be made.

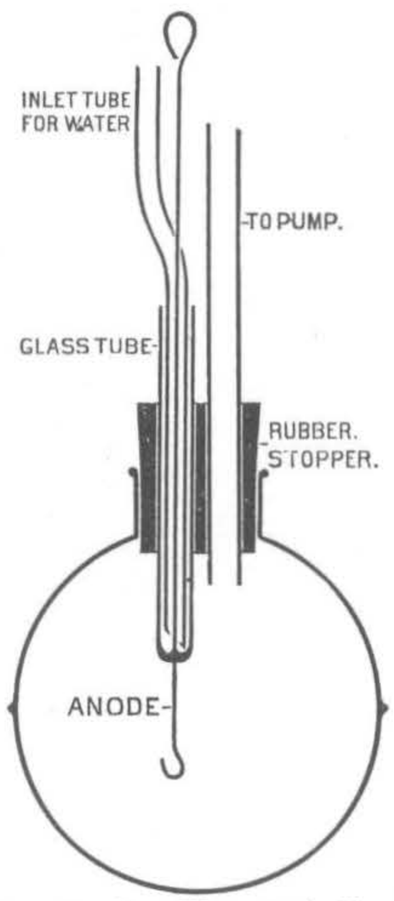


FIG. 10.—DR. WILLIAMS'S TUBE.

Tesla's Latest Advances in Vacuum Tube Lighting.

IN a letter to the *Electrical Review*, N.Y., Tesla describes the results of some recent experiments he has made in vacuum tube lamps, and in their application to photography and other purposes. Along with the letter are published copies of photographs taken with Tesla's new vacuum. One is a portrait taken by the light of a single vacuum lamp at a distance of 5 feet with an exposure of five seconds. Another is a page of letterpress taken by a single vacuum tube at a distance of 4 feet with an exposure of two seconds. The photographs are not equal to sunlight photographs, but resemble more those taken with a single magnesium flash light, the shadows being very harsh, but the amount of detail is considerable. It is difficult to say from Tesla's letter in what his improvements exactly consist. He appears to have reduced the size of the vacuum tube, and thereby, as he says, considerably reduced the dissipation of energy from its surface. The illuminating power of the lamp with which the photographs were taken he estimates at 1,000 candles. The great superiority in efficiency of his system over earlier attempts at vacuum tube lighting he considers is principally due to the use of his improved apparatus for "producing economically harmonical electrical vibrations of extreme rapidity," referring, no doubt, to his oscillator recently described in the ELECTRICAL REVIEW. Tesla promises soon to give further details of his system. The well known originality of nearly all Tesla's investigations leads us to look forward to the publication of the full description of his new system.

OUR NOTE-BOOK

BY EDGAR SALTUS

FROM THALES TO TESLA

Thales—Franklin, Franklin—Volta, Volta—Faraday, Faraday—Morse, Morse—Tesla. There is a formula not algebraic but convenient, which, imagination aiding, represents the diminishing leaps that electricity has taken in avoiding capture by man. The archaic and monstrous reptile is not wholly fanged as yet. But its elusiveness is clipped. In the processes to which it has been yoked the world is assisting at the domestication of an enigma. Presently it will be quite tame. Meanwhile from the garrulities of its purr the solution of multiple mysteries is obtainable. Wherever thought is, there, too, are sentries of science, a hand to the ear, listening. Among them is Moissan. Recently the monitions which he intercepted were so luminous that he saw diamonds, he saw more, he saw nature in her laboratory, and, following her method, with little else than iron, a crucible, electricity and brains, he produced solid sparks, little gems which are real diamonds. Memory aided, of course. He knew that Sir Humphry Davy had shown that the diamond is formed of but two elements—time and carbon. But though Sir Humphry could dissolve he could not construct. Carbon he could manage, yet not time. For time Moissan substituted electricity; or, more exactly, an electric furnace in which the heat equals that of the sun, the bowels of the earth, the throne of Satan—four thousand degrees Centigrade. Into it the iron went. The result was dissolved carbon in a crystalline form, and behold! the chemist had assisted at the birth of a diamond. Similarly from silica opals come. The receipt for a ruby reads, First get your aluminium. Given now an oven and a little cook-book and we won't have to go to Tiffany for our groceries any more. To such feminine uses will the reptile come.

TESLA'S ORIGINAL WORK.

[*From the London Electrical Review.*]

In a letter to the ELECTRICAL REVIEW, New York, Tesla describes the results of some recent experiments he has made in vacuum tube lamps, and in their application to photography and other purposes. Along with the letter are published copies of photographs taken with Tesla's new vacuum. One is a portrait taken by the light of a single vacuum lamp at a distance of five feet with an exposure of five seconds. Another is a page of letter-press taken by a single vacuum tube at a distance of four feet with an exposure of two seconds. The photographs are not equal to sunlight photographs, but resemble more those taken with a single magnesium flash-light, the shadows being very harsh, but the amount of detail is considerable. * * * The great superiority in efficiency of his system over earlier attempts at vacuum tube lighting he considers is principally due to the use of his improved apparatus for "producing economically harmonical electrical vibrations of extreme rapidity," referring, no doubt, to his oscillator recently described in the *Electrical Review*. Tesla promises soon to give further details of his system. The well known originality of nearly all Tesla's investigations leads us to look forward to the publication of the full description of his new system.

Century Magazine April 1898

THE NEW TELEGRAPHY.

RECENT EXPERIMENTS IN TELEGRAPHY WITH SPARKS.

BY A. SLABY.[1]

IN the early months of 1897, when the news appeared in the papers that it had been possible to carry out practically the sending of telegraphic messages without a wire for distances of a mile or more, there were many doubters on both sides of the ocean. People thought it nothing more than the sensational imaginings of some able writer for the press, who wished to present to readers hungry for novelties in electrical matters a particularly toothsome dish. On the contrary, those who have followed with attention and understanding the science of electricity, came to quite a different conclusion; for these knew that a German scientist, Heinrich Hertz, had proved ten years ago by convincing experiments that the electrical forces spread themselves through space like the rays of light—so much so, in fact, that there exists between these two phenomena (of electricity and of light) no difference of quality, but merely one of quantity.

To be sure, these electrical forces do not emanate from electrical phenomena of every kind, but only from such as we designate as quick-pulsating or oscillating streams. From this Nikola Tesla first made the most interesting practical deductions, and performed those wonderful experiments in which the electrical rays transform themselves directly into the desired rays of light, without taking the roundabout way over heat, and without the strength-devouring agency of metal wires. Nature, that unapproachable schoolmistress, furnished him a shining example; for she had already solved the great problem thousands of years before. In the body of the glow-worm, which delights us on warm summer evenings with the magic of its greenish glow, she employs her whole strength in the selective radiance of light. Nikola Tesla followed Nature's footsteps and came upon the banks of a new river, into which the springs of Nature pour her energies of light in broad streams. It fell to the lot of the young Italian Guglielmo Marconi to bring to realization the transfer of forces through space with the help of electrical rays, and in a form within reach of practical application.

First let us consider the means and apparatus wherewith he produced an efficient working radiation of electrical waves.

An electrical phenomenon observed long ago, the springing of sparks from one loaded conductor to another, furnishes the most powerful electrical radiation.

Hitherto we saw in such a discharge a simple passage of the electricity from one body to another, and hardly considered that the phenomenon, which is accompanied by brilliant crackling sparks, is more remarkable than any other electrical phenomenon. To-day we know that this discharge is an intermittent one, in such wise that unnumbered other discharges follow the first discharge of electricity, and in changing direction and with diminishing strength. The whole phenomenon passes with such enormous swiftness that the movements to and fro of the electrical forces are concealed from sight. On the contrary, the eye is capable of receiving as a completed fact only the impression of one single spark.

As an originator of sparks Nature shows to our view bounds that lie very far apart. It is a tremendous jump from the faint crackling that we hear on cold winter days when, in a heated room, we pass a rubber comb through our hair, to the flashing of gigantic lightning-bolts; and yet both consist of the same phenomena; from both the same invisible forces emanate. Marconi uses an artificial producer of sparks, the strength of which occupies a moderate middle place between the extremes that Nature shows. He employs the well-known induction apparatus, that important instrument for the production of Roentgen rays, and connects its binding-clamp with two spheres of brass,

[1] Privy Councilor Dr. Slaby is a professor in the Technical High School at Charlottenburg, near Berlin.

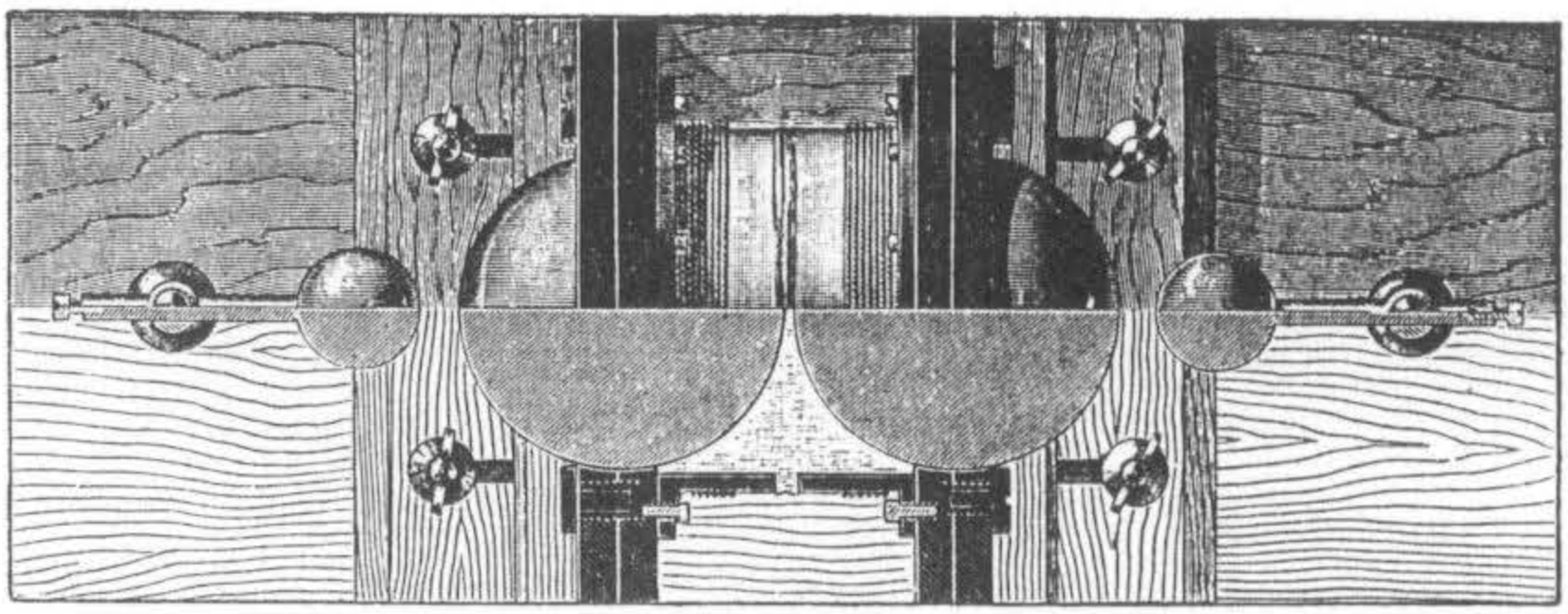


FIG. 1A. MARCONI'S SPARK-GENERATOR. FROM ABOVE.

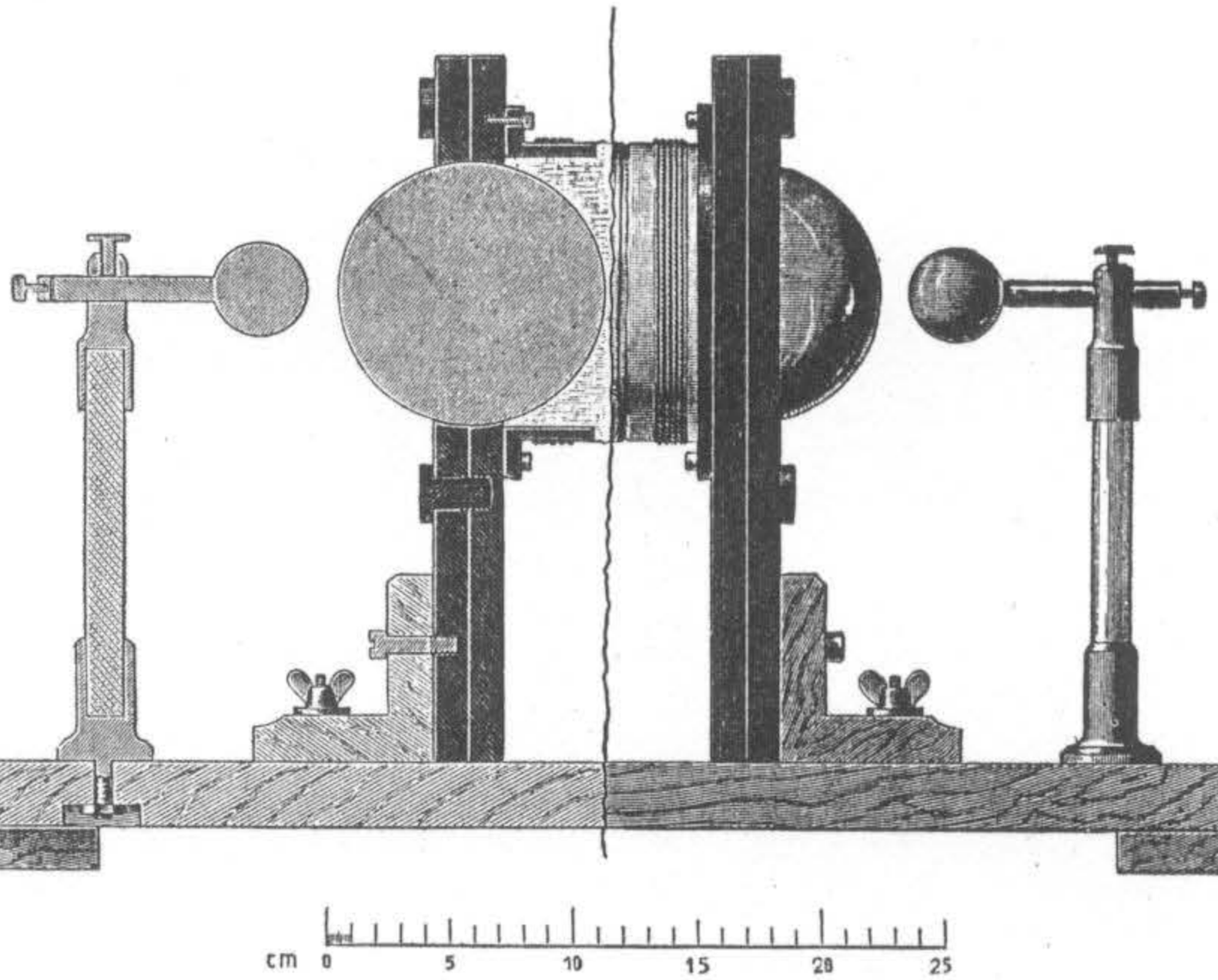


FIG. 1B. MARCONI'S SPARK-GENERATOR. CROSS SECTION, SIDE VIEW.

which are placed opposite each other at a distance of only a few millimeters (Fig. 1). When the inductorium is set in action we get an uninterrupted sequence of thick, white, shining sparks, the power of radiation of which is strengthened if the place of the sparks is filled with oil. In accordance with a process first used by Righi, he does not bind these brass spheres directly together with the binding-clamp of the induction apparatus, but charges them with the aid of smaller spheres which are placed at proper distance opposite the outer half of each of the larger spheres, which, in order to contain the oil, are surrounded with a shell of vellum.

From this apparatus for the production of sparks emanate the rays of electrical force. Heinrich Hertz was the first to make the arrangement whereby it is possible to establish their presence. For this purpose he employed the so-called resonators (Fig. 2), which are open circuits of wire the ends of which are provided with little polished balls of brass. By means of an isolated graduator, the air-space between the balls can be exactly fixed to very small fractions of a millimeter. When such a resonator is placed in the path of electric waves an electrical sympathetic ringing is roused therein, which shows itself in the passage of sparks at the point of non-contact or interruption in somewhat the same way that a tuning-fork is brought to sympathetic sounding by waves of sound. To be sure, the sparks are so minute that they can be seen only in a darkened room.

With the simple resource of this resonator Heinrich Hertz examined into the laws which the electric forces follow in their radiation.

The most remarkable among his experiments showed that the electric waves were reflected from a metal surface exactly in the same way that light is thrown back from a mirror. Moreover, by means of ingenious arrangements he discovered that the velocity with which the electric forces spread themselves through space is the same as the velocity of light—namely, three hundred thousand kilometers in a second.

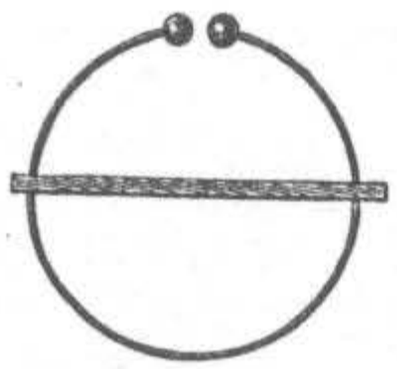


FIG. 2. HERTZ RESONATOR.

So far as it has in any case been possible, these and further experiments have brought us the certainty that light and electric rays are phenomena of the same kind, which differ from each other only in relations of size.

The retina of the eye is the sensitive instrument which permits us to become aware of the presence of rays of light; in the same way we may hereafter call the apparatus which shows us the electric rays an electrical eye. The resonator of Hertz is an eye which is still incomplete. It is weak and short-sighted. We can perceive with it only the most dazzling effects of the electric rays, and can, if I may so express myself, calculate only approximately the degree of their illuminating power.

The electrical eye which Marconi uses is essentially more sensitive; we may call it a clever improvement on the resonator of Hertz. The chief characteristic of the latter was the interruption of a metallic circuit by an air-space of uncommonly short width. The working of an electric ray impact showed itself in the appearance of visible sparks. But we can bring other means of assistance to bear in order to recognize the presence of infinitely small sparks which the human eye fails to see. The most sensitive means are always electrical; therefore we choose a continuous electrical current, the slightest traces of which can be detected by the galvanometer.

Let us imagine that the metal knobs of a resonator of Hertz have been so closely brought together that the air-space between them can be no longer detected even with the most delicate optical means; nevertheless, it is not necessary that a complete metallic contact has yet taken place. If we introduce into the wire circuit of the resonator a little galvanic battery (Fig. 3), say, in the nature of a desiccator, and a very sensitive galvanometer, then, as long as the electric stream is obstructed at the knobs, the needle of the galvanometer will remain at rest. But if the impact of an electrical discharge falls upon the circuit, electric effects tremble through it which are not barred by the air-space between the knobs, very much as a wave of water may spurt its way over an obstacle when it is turned into millions of little spray-drops. In this fashion is it that fine sparks spurt across; and though they are hidden from the keenest methods of optical reinforcement, yet for an instant they are there, and every spark of them fills the air-space with metallic steam. These guide the continuous current, and close the circuit. The result is a perceptible movement of the needle of the galvanometer. Either the needle swings back after the impact is finished,—then the isolating air-space has reëstablished itself as it was, and the electrical eye is ready to react to another impact,—or (and this is most commonly the case) fine scattered particles of metal, which have been consolidated again after evaporation, fill the air-space and build a metal bridge, whereupon the movement of the galvanometer's needle is permanent. But the slightest shock is sufficient to bring this bridge to a fall, and thus to break the metallic contact.

In the same way, as Branly first discovered, works a tube of glass when filled with iron or copper filings. Such a tube presents an insuperable resistance to the passage of an electrical stream, so that we can clamp it to the pole of a galvanic battery with metal fasteners without receiving a charge. But if this tube receives the impact of electric rays, then it conducts the main circuit, and the needle of the galvanometer moves. After the electrical radiation upon the tube is finished, a light shock given to the tube reëstablishes once more the complete resistance to the main circuit.

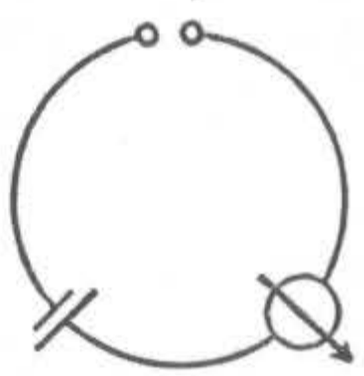


FIG. 3. RESONATOR WITH GALVANOMETER ATTACHED.

Fig. 4 shows an apparatus of this kind, in which the metal filings are replaced with iron nails loosely piled up one upon another. There are countless points of contact present having insulating surfaces. The radiation of electric waves excites among them an electric vibration, and countless invisible sparks at the points of interruption cause metallic contact.

Lodge of Liverpool appears to have been the first to use such tubes as electrical eyes for the study of the Hertz rays. In his ab-

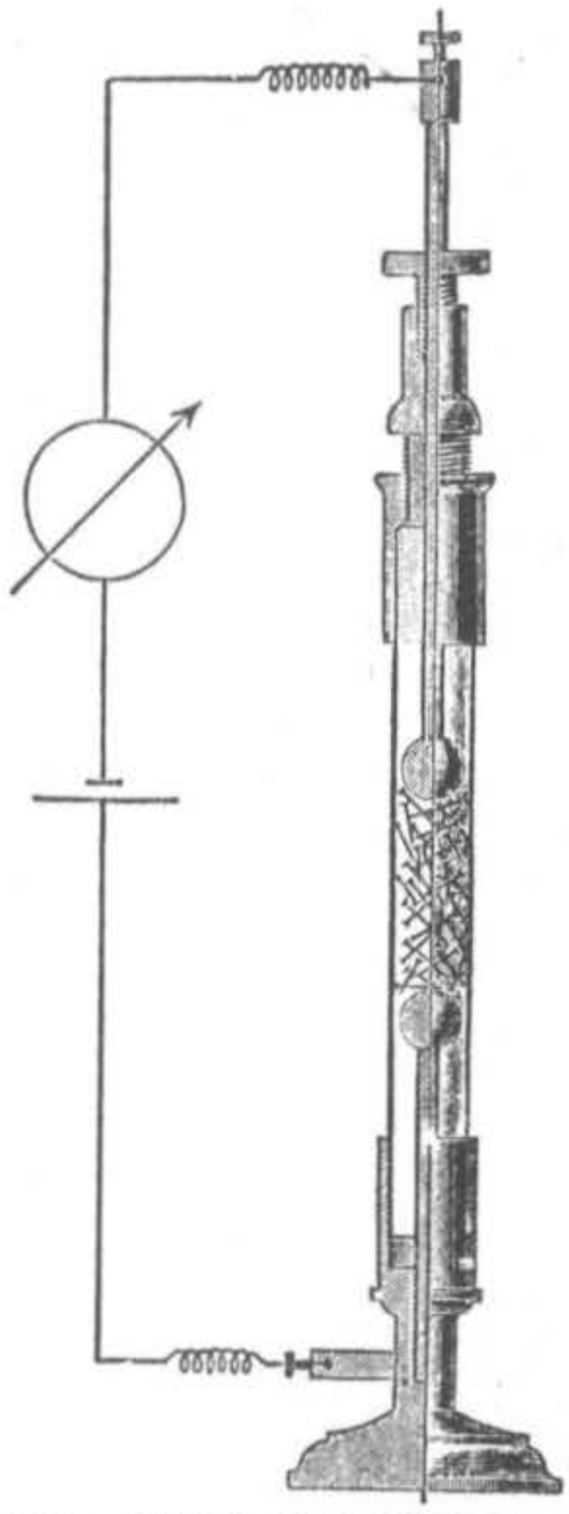


FIG. 4. THE LODGE COHERER AND BRANLY'S TUBE WITH METAL FILINGS TO REGISTER IMPACT OF AËRIAL ELECTRICITY.

sorbing book, «The Work of Hertz and Some of his Successors,» he describes various arrangements of this and of other kinds, which he had been using as early as 1889. From him came the term «coherer,» which he chose because a more intimate connection, as it were a cohesion, of the metal filings was produced by the electrical waves. One may also fairly consider Lodge the father of the idea of telegraphing with electric rays and such tubes; but he fixes as the farthest distance that can be reached one half an English mile (eight hundred meters), without ever having given any practical proof of the theory.

Marconi's electrical eye is pictured in Fig. 5. He uses a metallic powder, or, more correctly, a mixture of metallic powders, which consist of ninety-six per cent. nickel and four per cent. silver. This mixture is sealed up in a little glass tube between two knobs of silver, the meeting surfaces of which knobs are amalgamated by a trace of quicksilver. After it is filled, the tube is cleansed and soldered up; wires of platinum effect the passage of electricity, and are soldered on to the silver knobs; the tube is fastened with marine glue to a stick or pillar of glass, which serves as a support.

Fig. 6 shows the arrangement of Marconi's receiver. The main circuit, strongly drawn out, contains a desiccator (*A*), a sensitive relay (*B*), and the coherer (*C*). It is well known that a transferrer commonly used in telegraphy is called a relay. It reacts to very slender streams of electricity, and moves at the same time a tongue which conducts a second circuit with stronger batteries. When the coherer is cut off, the circuit is broken, and the tongue of the circuitless relay points to contact of rest. After the impact of the waves, cohesion in *C* permits the establishment of a current which turns the tongue of the relay on the working contact. Therewith the circuit of the battery (*a*) is closed, and the Morse indicator (*b*), which has been inserted therein, as well as the ticker (*c*), are set to work. At the first stroke of the ticker against the coherer the particles in the latter must fall asunder; thereby the first circuit becomes at rest, and the tongue of the relay lays itself at the point of rest and cuts off the battery (*a*). At a renewed subjection to the electric waves this action repeats itself. It is evident that by subjection of the coherer to intermittent radiation one can produce the Morse alphabet.

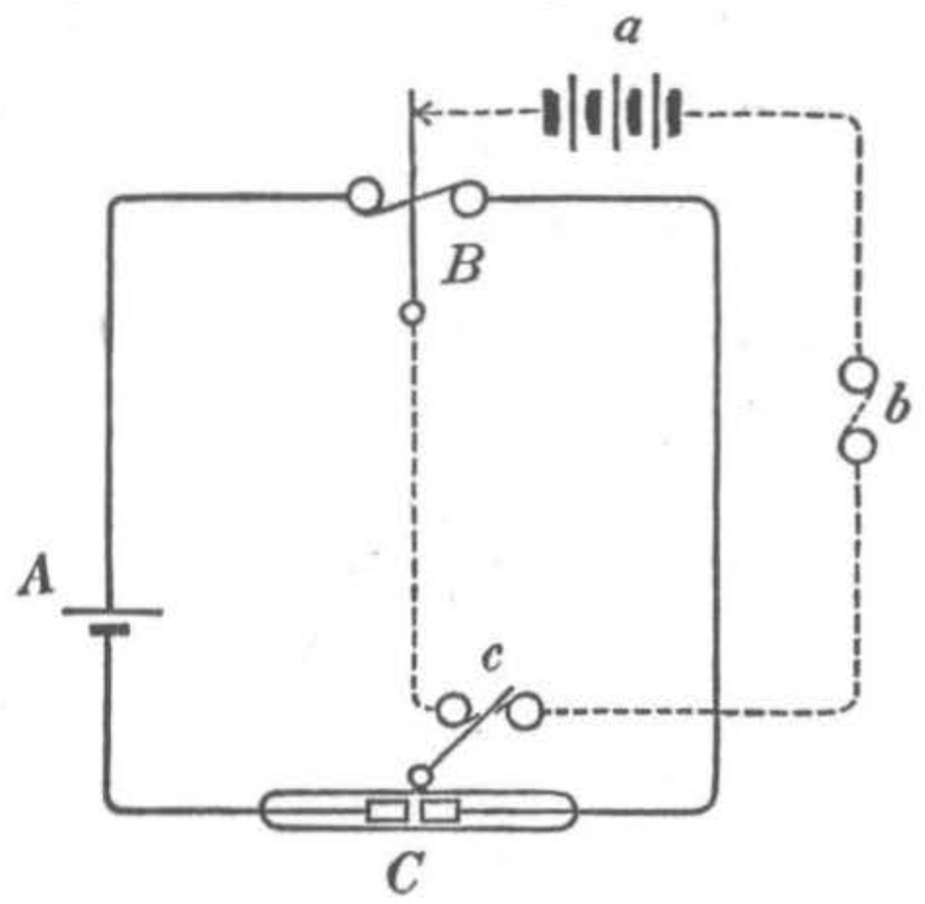


FIG. 6. MARCONI'S RECEIVER.

A—Desiccator. *a*—Battery.
B—Relay. *b*—Morse indicator.
C—Coherer. *c*—Ticker.

In January, 1897, when the news of Marconi's first successes ran through the newspapers, I myself was earnestly occupied with similar problems. I had not been able to telegraph more than one hundred meters through the air. It was at once clear to me that Marconi must have added something else—something new—to what was already known, whereby he had been able to attain to lengths measured by kilometers. Quickly making up my mind, I traveled to England, where the Bureau of Telegraphs was under-

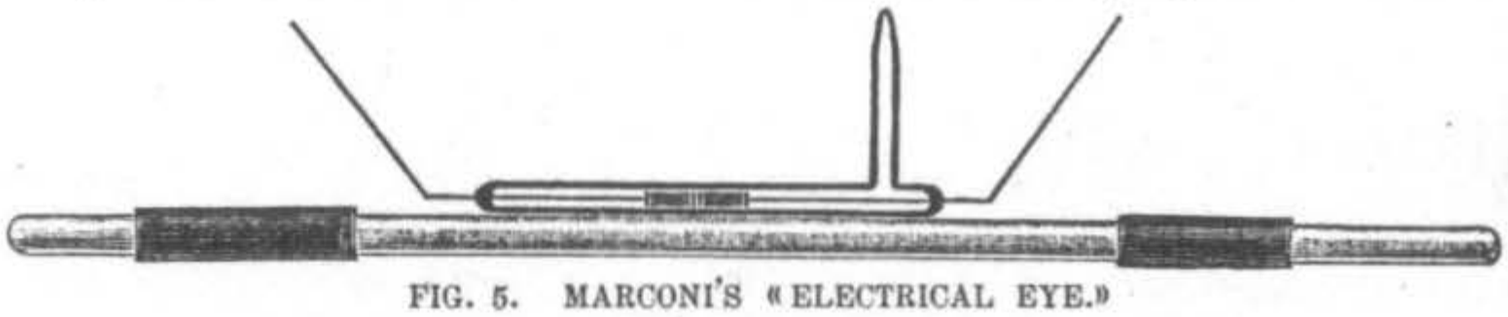


FIG. 5. MARCONI'S «ELECTRICAL EYE.»

taking experiments on a large scale. Mr. Preece, the celebrated engineer-in-chief of the General Post-Office, in the most courteous and hospitable way, permitted me to take part in these; and in truth what I there saw was something quite new. Marconi had made a discovery. He was working with means the entire meaning of which no one before him had recognized. Only in that way can we explain the secret of his success. In the English professional journals an attempt has been made to deny novelty to the method of Marconi. It was urged that the production of Hertz rays, their radiation through space, the construction of his electrical eye—all this was known before. True; all this had been known to me also, and yet I never was able to exceed one hundred meters.

In the first place, Marconi has worked out a clever arrangement for the apparatus which by the use of the simplest means produces a sure technical result. Then he has shown that such telegraphy (writing from afar) was to be made possible only through, on the one hand, earth connection between the apparatus and, on the other, the use of long extended upright wires. By this simple but extraordinarily effective method he raised the power of radiation in the electric forces a hundredfold. The upright extended wires work like the pierced tube of a watering-cart; the rays of electric force spurt, as it were, in every direction upright to the wire; they cause a great part of space to be drawn into sympathy.[1]

Now, since these wires are the essence of Marconi's discovery, the term «telegraphy without wires» is really erroneous; more correctly should it be called telegraphy by sparks, in opposition to the term used hitherto, «telegraphy by circuit» (*Stromtelegraphie*).

The experiments in England were carried out in the Bristol Channel. A mast thirty meters high was erected on the cliff near Lavernock Point—a cliff twenty meters high, one hour from the pleasant little bathing village of Penarth. Over the top of the mast was a cylindrical hood of zinc, two meters high and one meter in diameter. An insulated copper wire passed from the zinc cylinder to the foot of the mast to meet one pole of the receiver. The other pole was connected with the ocean by a long wire which ran down the face of the cliff. In the midst of Bristol Channel, five kilometers distant from Lavernock Point, lies the little island called Flatholm. There was the place for transmission. The apparatus to engender the sparks was in a little wooden cabin. Its knobs were connected, one with a zinc hood on a mast of the same height as that on Lavernock Point, the other with the sea.

After a few preliminary experiments, the sending of messages was perfectly successful. It will always be an unforgettable recollection how, on the morning of May 13, 1897, our party of five, cowering together in a big wooden case, because of the heavy wind, our ears and eyes bent with the most anxious care upon the receiving apparatus, suddenly, after the raising of the signal-flag agreed upon, perceived the first tickings, the first clear Morse letters on the tape! Silently and invisibly the message had been borne across the space from the rocky coast, ferried across by that mysterious medium, the ether.

After my departure the experiments were continued. It was possible to make clear telegraphic communications between Lavernock Point and Brean Down, straight across the entire breadth of Bristol Channel, fourteen and a half kilometers.

Having returned to my home, I went to work at once to repeat the experiments with my own instruments, with the use of Marconi's wires. Success was instant. I set up telegraphic communication between my laboratory and a factory about two kilometers away, where a water-tower was placed at my disposal for the placing of the wire of transmission. I resolved, however, to discontinue the connection, because there came a query from the office of the telephone company, whether in that district any local meteorological storm existed, since all the telephone-lines there were out of order.

Meantime the attention of the German Emperor had been drawn to the new form of telegraphy. It is known with what a lively interest and with what a depth of technical knowledge the Emperor follows the progress of applied science. Hardly a tract of this great field is foreign to him, and it is not un-

[1] The reader will find in THE CENTURY for April, 1895, in an article on Mr. Tesla's inventions, a quotation from his lecture, delivered at Philadelphia in February, 1893, and at St. Louis in March, 1893, in which he expressed confidence in the practicability of telegraphy without wires. In the same lecture will be found a description of the scheme, the connections, and the arrangement of transmitting- and receiving-instruments used later in Signor Marconi's experiments. (See «Inventions, Researches, and Writings of Nikola Tesla,» by Thomas Commerford Martin; New York, «The Electrical Engineer,» 1894, pp. 346–349.) A number of scientific men have already called attention to this fact. This does not detract from the distinct merit of Signor Marconi in having effected the transmission to a five- or sixfold distance by an application of devices which were thought capable only of a transmission of a mile or two.—THE EDITOR.

frequently the case that the reading of technical reports, foreign and German, is, as it were, a rest for him from the wearisome exertions of state affairs.

For carrying out extensive experiments, the waters of the Havel River near Potsdam were put at my disposal, as well as the surrounding royal parks—an actual laboratory of nature under a laughing sky, in surroundings of paradise! The imperial family delight to sail and row on the lakes formed by the Havel; therefore a detachment of sailors is stationed there during the summer, and I was permitted to employ the crews as helpers.

I placed the receiving apparatus in the sailors' barracks. The flagstaff there was considerably heightened, so that the highest point of the clear receiving wire was twenty-six meters above the level of the ground. For my first transmitting-station I chose a church lying on the other shore of the Havel, which was built by Frederick William IV, called the Saviour's Church at Sacrow, distant one and six tenth kilometers in an air-line. Fig. 7 shows the edifice. On one side of the basilica stands the clock-tower, which has a platform immediately below its roof. There a mast was placed, and from its highest point, twenty-three meters above the ground, a copper wire was suspended by means of a porcelain insulator. I had chosen the nave of the church as the place for my spark-generator, in order to be protected during rainy weather. The telegrams transmitted from Sacrow reached the sailors' barracks with unimpeachable clearness and exactness. To be sure, I was on one occasion in a state of lively dismay because of the indistinctness of the marks on the tape. It was the very day on which the Emperor desired to inspect the arrangements. It was only a short time before the doors closed that I was able to discover the origin of the interference and to suppress it. I had withdrawn the transmitting or spark-generating apparatus farther than was my wont within the entrance of the church, and thus it had got too near the stone flooring. By pulling the wires tighter the trouble was overcome. The sending of messages was very successful. The Emperor himself sent a telegram, and on his return to the sailors' station could convince himself of its safe arrival there.

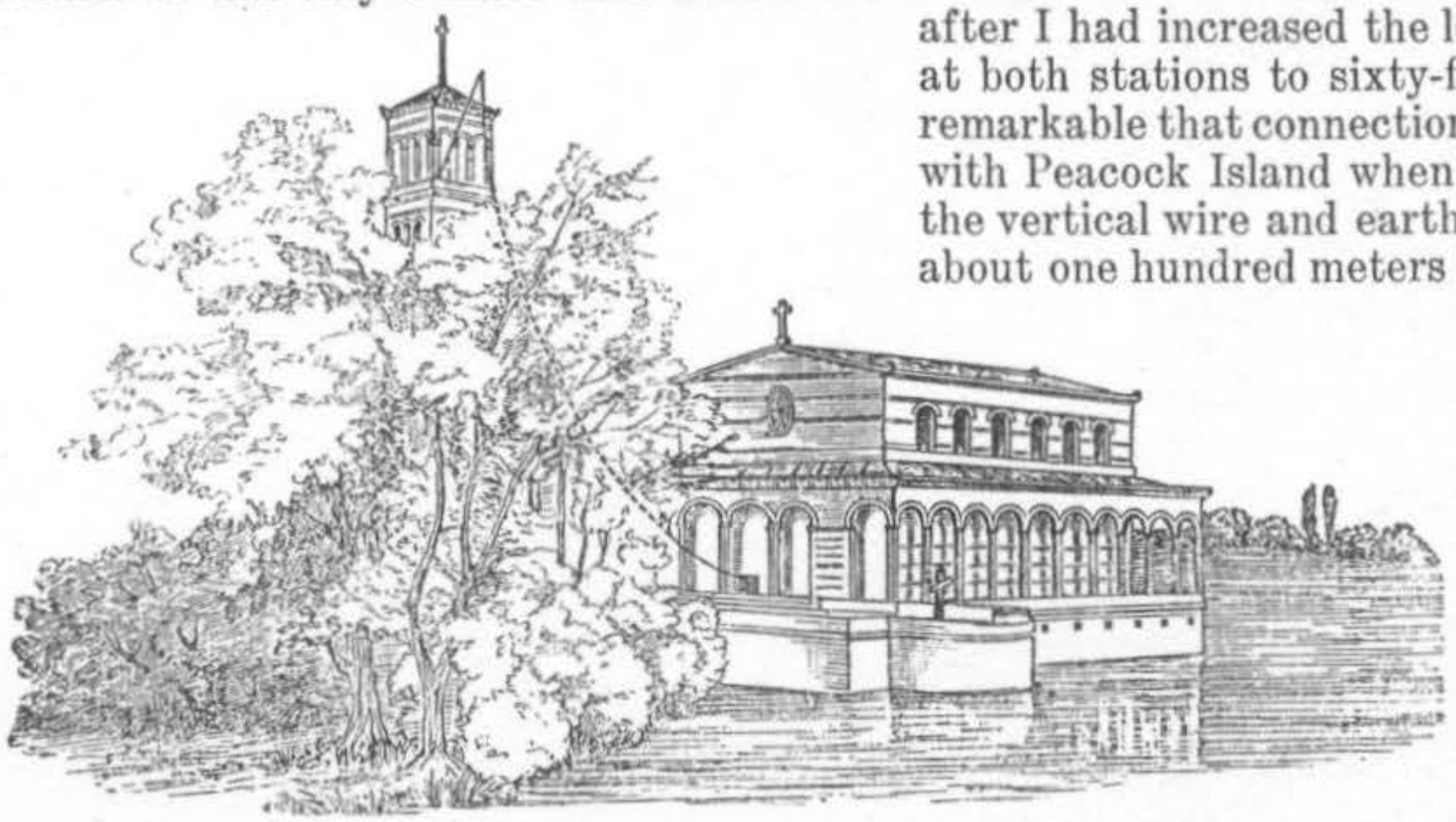


FIG. 7. FIRST TRANSMITTING-STATION, SACROW CHURCH, NEAR POTSDAM.

Further experiments at the Sacrow church gave an important result. When I carried the transmitter wire perpendicularly down the clock-tower to the entrance of the church and to the spark-generator placed there, the signs entirely failed to appear at the receiving-station. After a good deal of experimenting the obstacle was discovered. In the immediate neighborhood of the clock-tower are clumps of trees (see Fig. 7) which almost entirely concealed the vertical wire, so that from the sailors' station with the telescope one could only make out the upper section of the wire. The rays emanating from the wire were swallowed up by the group of trees as rays of light might be, or else led off toward the ground. The chief condition for success with telegraphy by sparks is that all obstacles which are found in front of the transmitter wire must be cleared away.

This fact was particularly felt when I wished to open telegraphic communication between the sailors' station and Peacock Island, three kilometers apart. The air-line between the two stations is crossed by a hilly, wooded tongue of land in the Glienicke Park, which is covered with houses. The electrical rays had to pass through these houses. It was successful, truly, but only after I had increased the length of the wire at both stations to sixty-five meters. It is remarkable that connection could also be had with Peacock Island when I substituted for the vertical wire and earth connection wires about one hundred meters in length, which I stretched parallel to each other, about two meters above the level of the ground.

The experiments in Potsdam had for their object the discovery of the basal conditions on which to predi-

cate success in spark telegraphy. In order to overcome greater distances, more auspicious places and methods had been considered.

In the meantime Marconi, while conducting experiments at Spezia which he carried out with the support of the Italian navy, had succeeded in telegraphing from a moving battle-ship, the *San Martino*, sixteen and three tenth kilometers to the arsenal of San Bartolommeo, and at a distance of eighteen kilometers in deciphering a few signals.

I resolved to attempt still greater distances.

The Emperor had ordered the balloon department of the army to assist in these experiments. The practice-ground of the military balloonists lies in Schöneberg, near Berlin, and a military railway runs thence directly south. At a distance of twenty-one kilometers in an air-line lies the village of Rangsdorf, on the railway itself. The sending apparatus was arranged there, and the necessary guard and balloon material were sent down.

After a few experiments, we succeeded on the 7th of October in establishing communication between the two posts. There was a cold, raw northwest wind, so that both the balloons, anchored at the two places, were driven about. At both stations thin copper wire was fastened to the baskets of the balloons, reaching two hundred and fifty meters to the apparatus. Connection with the earth was made by means of swords stuck in the ground.

The first telegram received under these conditions is reproduced by the autotype process in Fig. 8. The clearness of the Morse characters seems all the more noticeable because the electrical condition of the atmosphere on that day was as unfavorable as one could imagine. The electricity of the air was so strong that one could not touch the wires hanging down from the balloons without getting the severest electrical shocks. When one of the wires broke loose from the apparatus by reason of the strong wind, a lively jumping about took place among the soldiers standing near, for fear that they might be hit by the wires whipping to and fro. Nevertheless, the effect of those electrical interferences in the air are to be seen on the Morse tape only in a few points which did not mar the legibility of the Morse characters, consisting of short and long lines.

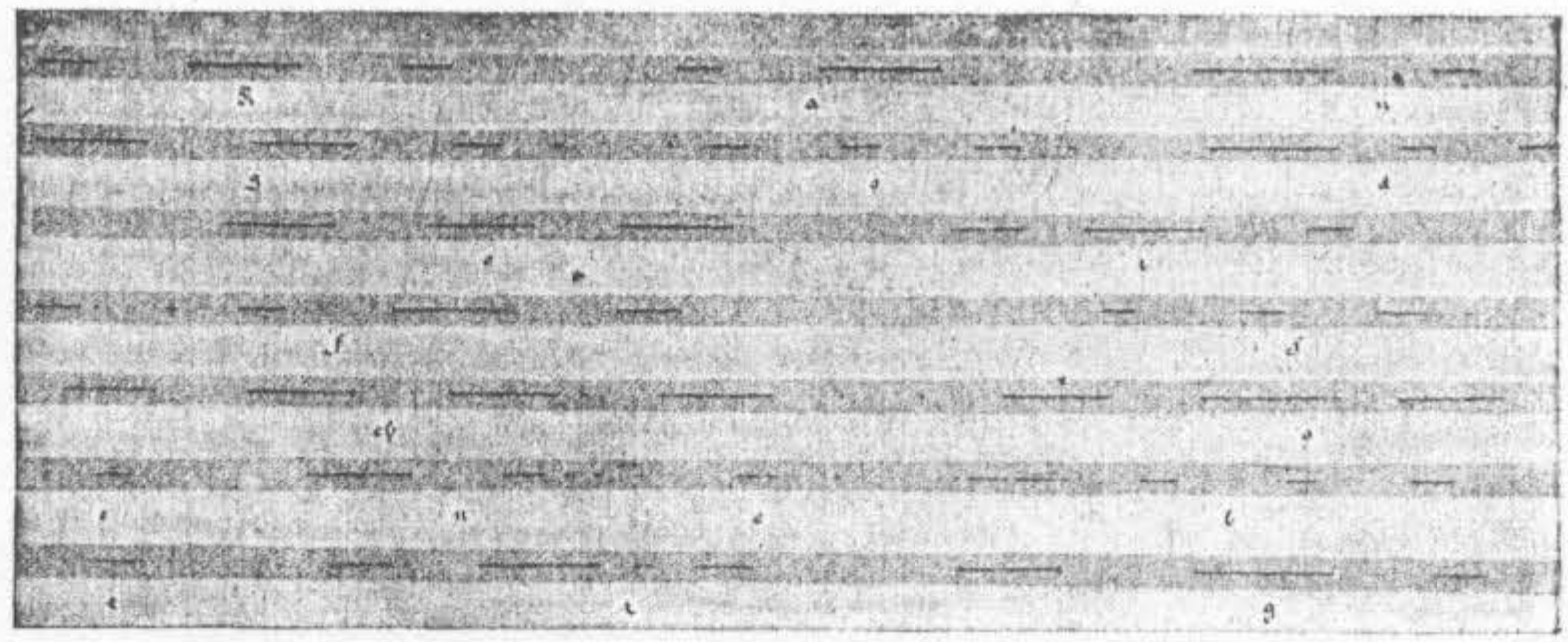


FIG. 8. FIRST TELEGRAM THROUGH THE AIR BETWEEN BALLOONS—«RANGSDORF, SCHOENEBERG.»

I have often been asked in what directions and in what field the use of spark telegraphy might be employed. Our knowledge of the phenomenon in question is, so far, a very modest thing; we are really in the very opening chapters. Who would care to say to-day how far, and whither, the path will lead us? I do not purpose to paint pictures of the future, but I believe I can state with emphasis that for certain purposes the new telegraphy is ripe to-day, and well worthy of consideration. The most important appear to me to lie in the military field. Besieged fortresses, and advancing armies which have the enemy between them, could make use of spark telegraphy to-day as a method of communication. The system works just as surely on a bright day as by night and in fog, though, to be sure, only in cases where balloons can be employed, since the distances reached when towers, masts, and high trees were used would hardly suffice in cases of this kind.

Quite as important is the usefulness of the discovery for the navy. Experiments of last summer have made perfectly certain the possibility of using captive balloons on the high sea. In place of balloons, without doubt, one might use the modern kites, brought to such a pitch of perfection in America, as those of Hargrave and others. I owe it to the kindness of an acquaintance in New York that I know something of these excellent kites, and a few experiments have already shown me that they are perfectly adapted to the carrying of thin wires.

There is a future for the use of spark telegraphy for lighthouses and light-ships. The receiving apparatus can easily be made in a handy form, not bulkier than a chronometer. On the approach to a lighthouse it

would not only give signs, but would tick out the name of the lighthouse; it appears even possible to provide the receiving apparatus with a regulator, to be adjusted at will according to whether a greater or smaller sensitiveness is desired, whereby the distance of the lighthouse can be read off.

An undeniable weakness of spark telegraphy is this: every telegram is imparted to the whole world; every receiver can take it up. Owing to this reason, for the present its application will have to be confined to particular cases. For practical purposes, if one desires to protect one's self from having despatches read by others, there remains always the use of signs arranged beforehand. In war, to be sure, telegraphy would become impossible as soon as a hostile spark-generator should cause a permanent disturbance of the characters. A very interesting battle might occur in the waves of ether.

Notwithstanding these undeniable shortcomings, let us not allow ourselves to be deprived of joy at the discovery of the new telegraphy. We are face to face with very peculiar phenomena. Nature has opened a new door for us. It is the mission of science at present to bring light into the opened room. After that we shall not have to wait long for the necessary technical progress.

TELEGRAPHY ACROSS SPACE.*

BY SILVANUS P. THOMPSON, F.R.S.

There is no such thing as wireless telegraphy. True, one can send signals for a distance of a yard or two without any wires, but in all the recent successful attempts to telegraph across space, whether by electric waves or by other means, wires are used. They do not, indeed, run from the sending station to the receiving station, but are used as base lines. For example, in the case of the longest distance yet reached in telegraphing by electric waves—13 miles over open country—the maximum distance attained in the recent experiments of Prof. Slaby, the length of the wires used as base lines at each end was nearly 1,000ft. As will be seen, in every case, wires or their equiva-

* Paper read before the Society of Arts, March 30, 1898.

lent are used to serve either as base lines or as base areas in the transmission.

Setting aside the mediæval myth of a sympathetic magnetic telegraph with two mere compass needles to point to letters ranged around a dial, there are three generic methods by which it has been found possible to signal across space without any directly communicating wire or cable. These may be conveniently classified as follows: (1) conduction methods; (2) induction methods; (3) wave methods.

I.—Conduction Methods.

These methods depend upon the use of water or earth as a means of conducting a fraction of the electric current from the base line at the sending end to the base line at the receiving end.

From the earliest days of telegraphy it has been a familiar fact that either earth or water might serve as a return circuit for an electric current, and, under certain circumstances, that signals could be sent even with an absolute gap in the metallic line, if there were provided by means of earth or water a sufficiently good path to enable current in adequate amount to be received beyond the gap in the line. This method has sometimes been called the leakage method, since it depends upon the circumstance that electric currents flowing in a conducting medium, such as water or moist earth, do not flow exclusively or even mainly along the path of least resistance, but spread out, some flowing along paths of greater resistance. If current enters a conducting stratum at any point by a single electrode, A, and leaves it at some other point by another suitable electrode, B, some of the current will certainly flow straight from A to B; yet the greater part will not so flow, but will stream around from A to B in long curving paths. If, then, two other electrodes, C and D, are inserted in one of these stream paths at a distance from A and B, some of the current—perhaps only a small percentage of it— may be picked up by a metallic line joining C to D. Hence it is possible, using A B as a sending base line, to signal to C D as a receiving base line at a distant place. The only limits to this method of telegraphy across space are (1) the strength of the original currents used in the sending base line, A B; (2) the sensitiveness of the apparatus used in the receiving base line, C D; (3) the ratio between the space distance from A B to C D and the lengths of the two base lines. This system of telegraphing across space has been proposed at various times. It has been used by Mr. Preece in several of those many experiments which he has made from time to time, and which will entitle him to be regarded as one of the foremost pioneers in this entire branch of telegraphic enterprise.

Morse himself—as recorded in Vail's early work on telegraphy—worked at this subject, and made experiments in 1842 on the Susquehanna river, about a mile wide. He engaged Prof. Gale to investigate the best conditions, and came to the conclusion that the base lines should be three times as long as the distance to be crossed. Mr. Dering, an English telegraph engineer, and Mr. Lindsay, of Dundee, have also worked in this direction.

After the introduction in 1877-78 of the Bell telephone it was found that the extraordinary sensitiveness of that instrument furnished a new means of picking up currents that would otherwise be too feeble to produce intelligible signals. The importance of this circumstance in extending the possibilities of distance telegraphy was not lost upon Mr. Preece. In 1882 he conducted a series of researches upon the establishment of telegraphic communication between the Isle of Wight and the Hampshire coast without any connecting cable across the Solent. An account of these experiments will be found in the report of the British Association for that year. Large metal plates to serve as electrodes were immersed in the sea at the ends of the two base lines. On the Hampshire coast the base line extended from Portsmouth through Southampton to Hurst Castle, a length of 20 miles. On the island the base line extended from Ryde through Newport to Sconce Point, and was about 16 miles long. From Portsmouth to Ryde the breadth of the sea is six miles, while Hurst Castle is only about a mile from Sconce Point. Hence in this case the length of the base lines considerably exceeded the average distance to be crossed. With this arrangement signals were passed in dot and dash which could be read on the Morse system with ease; but telephonic speech was not feasible. After many other experiments to be mentioned under the next heading, Mr. Preece established communication in the winter of 1893-4 across the Kilbrannen Sound between the Isle of Arran and Kintyre, a distance of over four miles. He also maintained telephonic speech across Loch Ness, a distance of 1¼ miles.

In the experiments from Arran to Kintyre, parallel wires about three miles long were used as base lines along the coast, while in some of the experiments two other base lines were used, being insulated wires laid along each coast at a height of about 500ft. above sea-level. A detailed account of these experiments will be found in the report of the British Association for 1894.

A year earlier Mr. Preece had made some striking experiments in the Bristol Channel between Lavernock Point on the South Wales coast and the islands of the Flat Holm and the Steep Holm, the distances of which are respectively 3·1 and 5·35 miles. His base line on the shore at Lavernock Point was a pair of copper wires weighing 400lb. per mile, suspended on poles for a length of 1,267 yards, their circuit being completed through earth. An alternating current was sent into this base line by an alternator worked by a 2-h.p. steam-engine, the voltage being 150 volts, the frequency 192 periods per second, and the current (maximum) 15 amperes. These alternations were broken up into dots and dashes by use of a Morse key. The signals were read on a pair of receiving telephones inserted in the distant base line, which in each case ran across the island and dipped into the sea. The length of these is not stated. Mr. Preece received messages easily over the three miles separating the mainland from the Flat Holm. But at the Steep Holm, 5·35 miles away, though the signals were feebly perceptible, telegraphic conversation was impracticable, as the sound could not be differentiated into dots and dashes. Mr. Preece came to the conclusion that with two base lines, each 10 miles long, he could with ease signal across a distance of 10 miles.

Prof. Trowbridge, of Harvard, has also investigated the possibility of transmitting signals through the earth by conduction, using a rapidly interrupted primary current and a telephonic receiving apparatus.

Many experiments have been made under accidental circumstances, all tending to prove the possibility of this mode of transmitting signals through the earth itself. The instruments in Greenwich Observatory are affected by the stray currents that escape into the earth from the badly-insulated return circuit of the City and South London Electric Railway, 4½ miles away. Another example is afforded by an accident which occurred some 10 years since at the Ferranti electric lighting station at Deptford, when one night one of the dynamos by some derangement became connected to earth. The whole of the railway telegraphs in the signal boxes of the railways in South London were temporarily put of order and rendered inoperative, while the currents flowing in the earth were perceived in the telegraph instruments so far northwards as Leicester, and so far south as in Paris. If this could occur as a mere accident, it is obvious that with properly-thought-out arrangements signals could easily be sent from one part of the globe to another by conduction through earth or water.

Most striking of all the cases of distance signalling by conductive methods is that presented by the transmission of signals over nearly three miles, which was carried out in 1894 by Dr. W. Rathenau, Mr. E. Rathenau, and Prof. Rubens. They selected as a suitable place for operations the open water of the Wannsee, which opens into the Havel, near Potsdam. Here at the south end, near the Friedrich-Wilhelmsbrücke, they immersed two metal electrodes, each having about 15 square metres of surface, at the two ends of a base line about 550ft. long. With 75 accumulators and a rotating interruptor giving about 150 currents per second, and a Morse key, they injected signals into the base line. At a distance of 4½ km., or nearly three miles across the water, near the shore at Neu Cladow, they set up the secondary base line, having electrodes of about four square metres each. These were hung in the water from two boats between which the connecting line—about 330ft. long—was stretched. In this line was inserted a telephone receiver of usual pattern. The current used was about three amperes, and there was not the slightest difficulty in hearing the dot-and-dash messages. Several situations for the receiving base line were tried, and it appeared that the interposition of a large sandbank between the two stations made very little difference.

II.—Induction Methods.

Induction methods are of two varieties. An electric charge upon a conductor may induce another electric charge upon another conductor at a distance by influence, or electrostatic induction. An electric current in a wire, during such time as it is increasing or diminishing, may induce another electric current in another wire in its neighbourhood by electromagnetic induction.

So far as I am aware, the only case in which electrostatic induction has been used in electric signalling is that of telegraphing (or telephoning) to trains in motion, as suggested about 13 years ago by Mr. Wiley Smith, of Kansas City. If a wire suspended over a train is electrified, either positively or negatively, charges are induced upon the metallic roofs of the cars, and if these are suitably connected to instruments on board the train, signals may be exchanged between train and wire without any metallic connection between the two. This suggestion was further developed, about the year 1886, by Mr. Phelps, and by Messrs. Gilliland and Edison. Descriptions of their methods will be found in the American electrical journals of that date. The system was successful both for telegraphing and telephoning, and was, indeed, adopted for a time by the Lehigh Valley Railroad Company. But it has been abandoned for a very simple reason. One of the consolations of railway travelling is that one is free from being disturbed by telegraph or telephone. No one on board an express wants to telegraph or be telegraphed to.

Electromagnetic induction has played so important a part in distance telegraphy that it must receive a more extended notice. Very early after the introduction of the commercial telephone, troubles arose from the exceeding sensitiveness of the instrument. Conversations in one line were overheard in another, while the ear was disturbed by an incessant buzz or rattle from the interference of stray currents from neighbouring telegraph lines. All these were at first attributed to induction—that is to say, to the electromagnetic influence of the currents in one line upon the neighbouring line. No doubt in some cases this is a cause, but unquestionably in many of the cases the disturbance was due not to induction at all, but either to leakage of currents across the surfaces of the insulating supports, over films of dirt or moisture, or else to leakage of currents from one line into the other through the earth-plates or earth connections. Unless circuits with metallic returns are used it is certain that the earth return will afford a means for stray currents to find their way into the telephone lines. Mr. Preece has narrated many cases in which telegraph or telephone messages that are being transmitted along some line have been heard, or rather overheard, in telephonic instruments in some totally disconnected and distant line. Many of these are due doubtless to stray currents through earth, but some are unquestionably due to true induction. A line or circuit absolutely insulated from any earth contact or earth return may yet act inductively. During the brief instant while the current in it is growing that current is setting up a magnetic field in the surrounding region, extending indefinitely but feebly into space. As the current dies away again this magnetic field also dies away. If in its growth or decrease this magnetic field encounters other wires it sets up E.M.F.'s in them, and thus originates disturbances. For the propagation of this effect from wire to wire no contact is needed. It is an effect that is dependent upon the properties of the intervening medium, and is proportional to its magnetic permeability. The ether of space itself—air, water, soil, and rock—are all of about equal permeability. Hence this kind of induction may be propagated from circuit to circuit whatever natural material intervenes. Mr. Preece has made repeated researches with a view of utilising this effect for the purpose of distance telegraphy. He has erected parallel base lines, sometimes in South Wales, sometimes near the mouth of the Dee, sometimes in Scotland. He has laid out, flat on the ground, great squares of insulated wire to test the inductive transmission from one area to another. On Newcastle town moor, and on the sands at Penarth, he has thus operated. It is not always easy in his experiments, particularly in those where earth connections were used, to be certain how much of the effect was due to true induction and how much to earth conduction. But in some of the cases there can be no doubt whatever. An excellent *résumé* of his work was given by him at the Chicago Congress in 1893. In this he describes how in one series of experiments he laid out on a level plain two quarter-mile squares of copper wire insulated with guttapercha, the distances between the two nearest sides of the two squares being also a quarter of a mile. In this case, using rapidly-interrupted or vibratory currents, and a Morse key to break them up into Morse signals, and applying in the other circuit a receiving telephone, conversation in the Morse code could be held readily between the two operators. This arrangement precluded all idea of earth conduction. In effect, Mr. Preece was working with a strange species of transformer, of which his two squares constituted respectively the "primary" and the "secondary," the "core" of the transformer being in this case partly of earth and partly of air. Mr. A. W. Heaviside has described an analogous case in which, wishing to establish telephonic communication to the bottom of a colliery in the North of England, he arranged a circuit in a triangular form along galleries about $2\frac{1}{4}$ miles in total length at a depth of 60 fathoms. On the surface of the colliery another circuit was laid out in triangular lines of equal size over and parallel to the underground line. Here, again, telephonic speech was perfectly clear by induction from line to line; or rather, in this case, from area to area. Each area enclosed something like 700,000 square yards, an ample base area when the distance to be penetrated was but 120 yards.

Earlier than the date of either of these experiments, the late Mr. Willoughby Smith had shown how, using two coiled circuits of wire at a distance of some yards apart, telephonic messages could be sent across air, or even through walls and floors.

The greatest distance to which Mr. Preece's experiments upon telegraph lines have been carried is 40 miles—namely, between the telegraph lines that run across the Scottish border by the east and west coasts respectively. Sounds produced in the Newcastle and Jedburgh line were distinctly heard on the parallel line at Gretna, though there was no line connecting the two places. Here, however, since both lines used earth returns, it is probable that most of the effect was due to conduction, not to true induction.

Instruments which operate by means of alternating currents of high frequency, like Mr. Langdon-Davies's phonophore, are peculiarly liable to set up disturbance in other circuits. A single phonophore circuit can be heard in lines 100 miles away. When this first came to my notice it impressed me greatly, and, coupled in my mind with the Ferranti incident mentioned above, caused me to offer to one of my financial friends in the City, some eight years ago, to undertake seriously to establish telegraphic communication with the Cape, provided £10,000 were forthcoming to establish the necessary basal circuits in the two countries, and the instruments for creating the currents. My offer was deemed too visionary for acceptance. The thing, however, is quite feasible. The one necessary thing is the adequate base lines or areas. All the rest is detail.

(*To be continued.*)

TELEGRAPHING ACROSS SPACE.*

BY SILVANUS P. THOMPSON.

II.—Induction Methods.

(Continued from page 468.)

One must not close this section without reverting to a most pregnant point of advance made about 1888 or 1889 by Dr. Oliver Lodge. When experimenting upon the oscillatory discharge, he conceived the happy idea of turning two circuits into resonance, or, as he termed it, "syntony" with one another, in such a way that when an oscillating electric spark occurred in one of the circuits, the inductive effect on the other immediately set up in it electric oscillations which manifested themselves by an overflow spark. I call this experiment pregnant because it affords a hint of another possibility—namely, that of signalling inductively from one area to another, and using around those areas, not merely circuits of wires, but syntonic circuits, which, therefore, are necessarily much more sensitive in their response one to the other. Some of Tesla's high-frequency experiments also have an obvious bearing on this point.

III.—Electric Wave Methods.

After Clerk Maxwell had predicted the existence of electromagnetic waves, and had shown that their speed of propagation is identical with that of light, it required, in reality, very little to demonstrate by experiment the existence of such waves. But that very little was not actually achieved until the year 1888, when the lamented Prof. Heinrich Hertz showed simple methods of producing, detecting, and measuring these waves. It had been known for many years, from the predictions of Kelvin and Von Helmholtz, and confirmed by the experiments of Fedderssen, that in many cases an electric discharge is of an oscillatory character. In the years 1887-8, Lodge, Fitzgerald, and others were investigating the nature of these oscillations, and the manner in which they are guided by conducting wires, when Hertz conceived the idea of investigating the disturbances which such oscillatory discharges set up in the surrounding space. He showed that, given a simple apparatus, which he called an "oscillator," consisting of two metal plates or conductors, connected by a conductor interrupted at one intermediate point by a "spark-gap," the oscillator on the appearance of each spark emitted a train of electric waves into the surrounding space. He further showed that if a mere circuit or ring of wire of suitable size, the continuity of which is interrupted at one point by a minute gap, is placed in the path of these travelling waves in a suitable position, the waves as they reach it set up electric surgings in this wire, and if sufficiently energetic cause it to show a small spark in the gap. This simple detecting device he termed a "resonator." Armed with these apparently primitive pieces of apparatus, he then devoted himself to the task of exploring the propagation of the waves. He found that, like waves of light, they could be reflected by metallic surfaces, could be refracted by prisms, concentrated by lenses, and even could be polarised. He measured their wave-length and velocity of propagation. He found that they could pass readily through walls of wood, stone, or brick, which are opaque to ordinary light-waves. Metals and other conductors of electricity, on the contrary, absorbed them, and were consequently opaque.

In these researches of Hertz we meet, for the first time,† with the recognition of a true travelling wave. With this immense discovery there was opened out an entirely new field of possibilities. Hitherto there had been inductive actions known which might reach out from wire to wire, only to fall back again when their excitant cause died away. But now the electric wave, once started on its path, did not collapse back into the wire when the spark ceased; on the contrary, it went travelling on. And just as the javelin, which can travel on after the impulse has ceased, can act at greater range than the sword, whose thrust is limited by the length of arm and blade, so the true electric wave, by the very fact that it is a true travelling wave, can carry signals to greater distances than the mere inductive influence that simply extends outwards from a wire or from a coil.

The work which Hertz had begun, was, after his death, carried on by a whole army of investigators. Of these, and of their achievements, the best account that has yet appeared is Prof. Lodge's little book on "The Work of Hertz and his Successors." To that book enquirers must be recommended for details. Suffice it here to say much has been done in perfecting both the oscillator and the detector. Notable amongst these matters have been the forms of oscillator designed by Lodge and by Righi; the latter having the spark gap immersed in oil or vaseline between two metal balls. Many forms of detector have been proposed. Very early Lodge produced one under the name of "coherer," consisting of a metallic point very lightly pressed against a metal plate, and connected in circuit with a galvanometer and a local cell. The light contact constitutes an imperfect joint, which is practically non-conductive until caused to cohere and conduct by the impact of an electric wave; or, perhaps more accurately, by the stimulus of the minute surging electric current which results from the impact of an electric wave. Subsequently, taking a hint from M. Branly, Lodge substituted as a detector a new kind of coherer, consisting of a small glass tube partly filled with loose metallic filings—iron or nickel by preference—joined in the circuit. Such a coherer acts as a species of relay, by means of which an electric wave, incapable in itself of affecting a galvanometer or other instrument, is enabled to do so indirectly by setting into operation a local current. After the coherer has thus operated, it usually remains in the conductive state until subjected to some mechanical jar or shock. Lodge proposed to apply for this purpose a mechanical tapper worked either by clockwork or by a trembling electric mechanism. On several occasions, and notably at Oxford in 1894, he showed how such coherers could be used in transmitting telegraphic signals to a distance. He showed that they would work through solid walls. Lodge's greatest distance at that time had not exceeded some 100 or 150 yards. Communication was thus made between the University Museum and the adjacent building of the Clarendon Laboratory. For more than 18 months the Rev. F. Jervis Smith, of Oxford, using a carbon powder coherer, has maintained communication between his house and the Millard Engineering Laboratory, over a mile away.

Even before this Mr. Nikola Tesla, in a lecture delivered at St. Louis in 1893, had made a further suggestion of great importance. He proposed to transmit electric energy by oscillations to any distance, without communicating wires, by erecting at each end of the stretch a vertical conductor joined at its lower part to the earth, and at its upper to a conducting body of large surface. This constitutes a vertical base line from which to disseminate the oscillating disturbances.

About two years ago a young Italian, Mr. Marconi, came to this country, and succeeded in inducing the British Telegraph Department to give him facilities for experimenting upon wave-method of transmission. First upon Salisbury Plain, and then across the Bristol Channel, he succeeded in transmitting Morse signals to greater distances than anyone had previously attained. He sent signals from Lavernock Point to Bream Down—about nine miles as the crow flies over the open channel. To accomplish this he used as base lines two vertical conductors earthed at their lower ends, and carrying at the top extended surfaces, He used a Righi transmitter. As receiver he employed the special form of Lodge-Branly coherer presently to be described. This was connected in the manner Lodge had recommended in a local circuit, and was tapped by a mechanical tapper operated by a vibrating electric mechanism. The local circuit operated a Post Office relay connected to a Morse instrument signalling the dots and dashes. The coherer was itself included in the vertical base line. So far all is old. The special coherer used in these experiments by Marconi has very fine metallic powder, chiefly of nickel and silver, in a small glass tube exhausted of air. He also applied shunting resistances to the relay contacts, and interposed a fine iron wire closely coiled, as an impedance in the local circuit on each side of the coherer.

In 1897, some further experiments were carried out by Prof. Slaby, of Charlottenburg, on an even larger scale. He abandoned everyone of the novelties introduced by Marconi, and fell back upon the methods previously known. He used a simple Lodge-Branly coherer, employed elevated conductors as base lines, discarded the useless little iron wire impedance coils in the local circuit, and substituted for the Post Office polarised relay one made out of a Weston galvanometer. His success shows that all that is essential can be thus attained. He chose as the scene of his operations the Havel, and set up elevated conductors upon the castle of the Pfaueninsel, and on the campanile of the church at Sacrow. Thus equipped, he transmitted signals, at first about three-quarters of a mile, then three miles across the water. He found trees and masts to interfere with the signals to some degree. He then proceeded, with the aid of the military authorities, to experiment over an open stretch of country—from Rangsdorf to Schöneberg. The elevated conductors were wires raised by means of hydrogen balloons to heights of nearly 1,000ft. Signals were obtained at a distance of 21 km., or over 13 miles. Neither in Marconi's nor in Slaby's successful operations were syntonic devices employed. The following table summarises the results of Marconi's and Slaby's work.

Commenting on these results, Slaby notes how over open sea a much greater distance appears to be attained from a base line of given length. Assuming Marconi's best proportion, he calcu-

* Paper read before the Society of Arts, March 30, 1898.

† Many years before, Prof. Joseph Henry had transmitted induced electric sparks from one circuit to another in different floors of a building. Doubtless, these were oscillatory; but it is impossible, at this time, to determine whether the arrangements were such as to produce true travelling waves, or whether the action was (like Lodge's later experiment of the two syntonic circuits) merely one of electromagnetic induction.

lates the vertical length of base line needed for communicating across the English channel at Dover to be 265ft., while from London to Paris, over land and sea, would require 4,700ft. He even estimates base lines of 6,600ft. as sufficient, were it not for the curvature of the globe, to serve for communication across the Atlantic.

	Distance. Miles.	Base line. Feet.	Ratio.
Marconi—			
Flat Holm (sea)	3¼	150	100
Bream Down (sea)	9	200(?)	250(?)
Spezia (land and sea)	4¼	100	200
Spezia (open sea)	11	100	500
Slaby—			
Sacrow (water and trees)	¾	80	70
Pfaueninsel (water and buildings)	3	200	50
Rangsdorf (land)	13½	950	70

The most recent improvements made towards perfecting this method of transmission are those of Dr. Oliver Lodge, whose labours, continnued during the past few months, are still in progress. He has first reorganised the transmitter apparatus so as to make it a more persistent radiator. It emits longer trains of waves. This has been accomplished by introducing in the path of the oscillations, between the spark-gap and the wings, a few turns of stout wire to act as an impedance coil. By this means the oscillations can be accurately tuned. The receiving apparatus is also tuned ; in fact, each apparatus is made to operate both as emitter and as receiver, in turn, as required. Lodge has also modified the arrangements of the coherer circuits, to render them more certain of operation, no local current being allowed to pass through the coherer until after it had been affected by the waves. He has, in fact, thoroughly redesigned the sending and receiving instruments upon a rational basis, so that they shall be both less sensitive to stray impulses, and more sensitive to properly attuned waves. The results obtained with these have not yet been made public ; but, employing a siphon recorder as the receiving instrument, remarkable precision of signalling has been attained. Further developments in this direction will doubtless be awaited with much interest. Meantime, in other countries—the United States, Russia, and France—other experimenters are at work. Any account given at the present time will, therefore, be necessarily incomplete.

In passing finally from a review of that which has already been attained to that which may reasonably be contemplated as within reach of attainment in the near future, I have no wish to assume the *rôle* of the prophet. Still less would I desire to emulate the example of the imaginative *litterateur* who, whether his name be Jules Verne or H. G. Wells, stimulates the public curiosity by amazing speculations, and in doing so renders the dis-service that the public so stimulated is made less capable than before of distinguishing between that which is and that which is not within the bounds of reasonable possibility.

It has been shown that there are three general methods of transmitting electric signals across space. All of them require base lines or base areas. The first—conduction—requires moist earth or water as a medium, and is for distances under three miles the most effective of the three. The second—induction—is not dependent upon earth or water, but will equally well cross air or dry rock. The third—electric wave propagation—requires no medium beyond that of the ether of space, and is, indeed, interfered with by interposed things such as masts or trees. Given proper base lines or base areas, given adequate methods of throwing electric energy into the transmitting system, and sufficiently sensitive instruments to pick up and translate the signals, it is possible, in my opinion, so to develop each of the three methods, that by any one of them it will be possible to establish electric communication between England and America across the intervening space. It is certainly possible, either by conduction or by induction ; whether by waves I am somewhat less certain. Conduction might very seriously interfere with other electric agencies, since the waste currents in the neighbourhood of the primary base line would be very great. It is certainly possible either by conduction or induction to establish direct communication across space with either the Cape, or India, or Australia (under the same assumptions as before), and at a far less cost than that of a connecting submarine cable. I doubt very greatly whether the wave method can be made applicable at all to these so-distant parts of the globe. But whether by conduction, by induction, or by waves, I am firmly convinced that the immediate road to commercial success lies in two things. Firstly, we must frankly recognise that there is no such thing as telegraphing without wires—that the base line, or the base area surrounded by wires, is a fundamental necessity. Secondly, we must look to establishing real syntony between the sending and the receiving parts of the apparatus to render it, as far as possible, sensitive and independent, without which conditions such systems will become too costly and too unmanageable for commercial ends.

[The paper was illustrated by numerous slides illustrating the methods and instruments used by Hertz, Lodge, Righi, Marconi, and Slaby in their investigations, and the newest syntonic apparatus of Lodge. Experiments were also shown illustrating the transmission of electric waves and their reception and detection. A small Lodge apparatus, constructed by Mr. Miller, was also exhibited in operation.]

Discussion.

The Chairman said no doubt all present had come with great expectations, anticipating much pleasure in hearing of the latest developments of one of the most interesting and valuable applications of modern science to useful purposes—electric telegraphy. But whatever their expectations they must have been more than realised by the exceedingly lucid exposition by Prof. Thompson of a most intricate and difficult subject ; so lucid, in fact, had it been that probably few realised how intricate it was. He felt with Prof. Thompson that perhaps in the immediate future the application of wireless telegraphy to practical purposes was not quite so wide as some might have anticipated and hoped ; but at the same time there were purposes to which they might reasonably hope it might be applied, such, for example, as communication between the shore and lightships, and possibly between ship and ship. It was satisfactory to learn that means were being sought for, and had been to some extent found, of differentiating one telegraphic signal sent through space from another by tuning. That was to him a particularly interesting point, and the explanations which had been given of the methods adopted by Prof. Oliver Lodge for obtaining the transmission of a particular message, and the receipt of that message by the particular person intended to receive it were specially valuable. Obviously it would be very inconvenient if messages sent through space were indifferently receivable by everyone who chose to play the part of an eavesdropper. That condition of things would somewhat resemble that described in one of Hans Christian Andersen's stories, where the fumes coming from a pipkin revealed to everyone who chose to smell them what each particular person was having for dinner. It was not very desirable that that kind of curiosity should be gratified in connection with telegraphy, and it seemed to him that the uses of telegraphy through space would be very much limited if this sort of thing could not be prevented. Prof. Lodge's line of experiment, however, seemed to tend in that direction, and to show the means of confining a message to the person intended to receive it. He was sure Prof. Thompson would be pleased to answer any questions on any point that had not been made clear if there were any such, any questions which could arise having been already answered in anticipation. If no one had any such query to put he would conclude by proposing a hearty vote of thanks to Prof. Thompson for his paper.

The vote of thanks was carried unanimously.

The New York Herald April 27, 1898

ELECTRIC SPARKS TO BLOW UP WAR SHIPS

Tesla Figuring on Exploding the Enemy's Magazines by an Air Current.

War without explosives may come eventually if the hopes of Nikola Tesla are realized. Experiments now being made by the famous inventor may prove that an electric spark can be sent miles and miles through the air to lodge in the powder magazine of an enemy's ship and cause the instant destruction of the vessel.

It is not a new invention Mr. Tesla is working on, rather a perfection of one already found practicable—his oscillator, that marvellous electrical machine with which he was able to transmit messages without wires or artificial conductors of any kind. This instrument, with the aid of powerful machinery, may be able to start a vibratory wave that accumulates force as it progresses and, finally striking the object against which the wave is directed, does so with such a percussion as to set off any explosives it comes in contact with. None of the ammunition in the magazine of an enemy's ship would be safe from this vibratory wave. All that would be necessary to insure the success of Mr. Tesla's operations, should his scheme prove practicable, would be to know the location of the vessel to be destroyed, and the oscillator is to have an appliance for locating it. If this engine of death should be perfected before the end of the present hostilities it would be safer for Spanish war ships to leave their powder at home, for Mr. Tesla intends to offer the use of his invention to the United States.

Mr. Tesla at present refuses to give any details. He merely admits that he is working on the plan.

"I cannot say when my plans will be perfected," said he yesterday, "or whether they will be of any use in the present war. I wish you would merely say that I am trying to be useful to the United States."

Oscillatory Currents and Some of Their Phenomena—I.

BY PROF. E. F. NORTHRUP.

Intense interest has of late been aroused in the many striking phenomena connected with oscillatory currents. This interest was first awakened among professional electricians and physicists by the extraordinary experiments of Hertz, later the general public became excited over the fairy-like effects obtained by Tesla, with his currents of high potential and high frequency, and now comes the production of the X-rays, which have forced a large body of scientists, the doctors and surgeons, to give their attention to electrical matters. Marconi's wireless telegraphy, an outgrowth of the experiments of Hertz and Lodge with oscillatory currents, is likewise exciting general attention. The interest felt in these matters is extended, but people's notions are in general vague as to the methods used for obtaining the effects, or the principles upon which they depend.

It is, however, surprising to note how many of the phenomena of oscillatory currents may be explained and connected by a right application of a very few simple physical principles with which everyone is instinctively acquainted. Furthermore many of the most interesting results may be obtained by any one who has a little ingenuity, clear physical conceptions, a few dollars and a room in which to experiment. It is feasible for every doctor using X-ray apparatus, and station-tender who has the disposal of alternating or direct currents, to rig up the necessary simple apparatus to repeat experiments along this line and to materially contribute to the general fund of knowledge upon the subject.

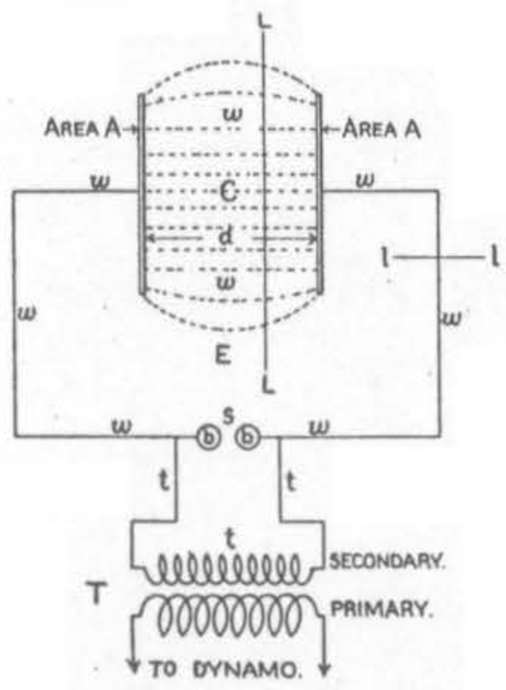


FIG. 1.

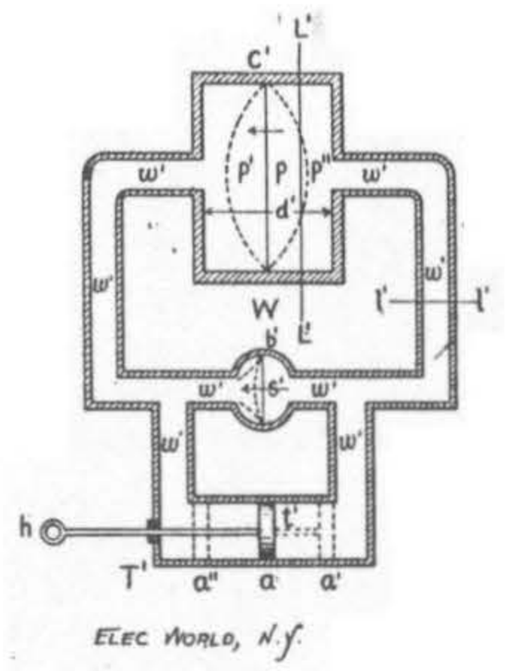


FIG. 2.

The writer will try and describe for the above class of readers of THE ELECTRICAL WORLD, in a simple non-mathematical manner and as far as possible non-technical form, the general methods and the construction of the necessary apparatus for obtaining oscillatory currents and their effects. He shall feel well repaid for his undertaking if doctors and others are induced to try for themselves some of the experiments to be described, and if they derive from their efforts a share of the delight which he felt when experimenting along the same line.

A clear physical conception of what constitutes an oscillatory current should be obtained before the attempt is made to describe what may be done with such currents. This may justify the somewhat lengthy description which follows:

A common arrangement for obtaining an oscillatory current is diagrammatically illustrated in Fig. 1. Here C is a condenser, which may be considered as consisting of two square brass plates, having each an area A parallel and separated from each other by a distance d. T is a transformer, from the secondary of which a high-potential current, of 20,000 volts, say, may be obtained. b b are two metal balls, separated from each other about one-quarter inch. When a low-voltage slowly alternating current is sent through the primary of the transformer, the high voltage induced in the secondary of the transformer causes a discharge to pass across the air gap s, and an oscillatory current, that is, a current which, so to speak, swings back and forth in opposite directions like a pendulum, is found to exist in the circuit w (including the insulating space between the plates of the condenser). In the circuit t the current is slowly alternating, while in the circuit w the current is rapidly oscillating.

Several important characteristics of this oscillatory current may be understood by any one not an electrician by considering the water analogue which is illustrated in Fig. 2. Here the arrangement to be described is shown in section. w' w', etc., is a system of iron pipes. C' is an iron box, its dimension perpendicular to the plane of the paper being, say, the same as its width, d'. Dividing this box into two compartments is an elastic rubber partition, P. This partition under pressure may be strained so as to take the position P' or P''. Across the enlarged portion of the pipe, b', is a partition, s'. This partition is likewise supposed to consist of rubber which will yield a trifle under moderate pressure and suddenly break when the pressure becomes great. The piston t' may be moved by the handle h back and forth in the cylinder T'. At the start let the piston have the position a, let s' be intact and P in its normal position. Conceive the whole system, pipe, cylinder and box, completely filled with water, which is a practically incompressible fluid. Now grasp the handle and push the piston toward the right. The water pressure upon the left hand side of the diaphragms P and s' will be decreased and the pressure upon the right hand side will be increased. As the piston approaches nearer to the position a', shown in dotted lines, the elastic diaphragms P and s' will be strained more and more to the left. When the piston has reached a' suppose P to be strained into the position P' and suppose the strain upon s' to have become so great that it very suddenly breaks. The instant s' breaks the pressure is released upon the right hand side of P', and hence the water is forced to move out of the right hand side of the box, through the circuit of pipe w', around into the left hand side of the box. Note that the velocity with which the water flows in the pipe circuit continues to increase until the force urging the water on ceases to act. This force is the elastic reaction of the partition P. The velocity will evidently be greatest when the diaphragm is in its normal position P. Since, however, the water is now in rapid motion it cannot suddenly come to rest, hence it continues to move in the same direction until it has forced the elastic diaphragm into the position P''. The direction of motion of the water is then reversed. It surges back again in the opposite direction; the original motion is then repeated and so on. These back and forth oscillations of the mass of water, however, grow less and less extended, on account of the decay of the motion due to the friction of the water against the sides of the pipe, until after a greater or less time the water comes to rest. Now imagine that a new diaphragm s' is suddenly created and that the piston continues to be moved very slowly back and forth. In whatever direction this piston is moved a pressure must finally be produced on s' which will burst it, and the above series of oscillations of the water be repeated. If the piston continues to move back and forth with a regular motion and the diaphragm s' is magically restored whenever the surging water comes to rest, there will be a continued series of oscillations of a mass of water, which illustrate and obey many of the laws of the oscillations of electricity which occur in the electric circuit illustrated in Fig. 1.

The principal points of similarity between the electric and the water circuits are as follows: The rougher is the interior surface of the water pipe w' the greater will be the friction of the water against this surface and the more rapidly will the oscillations of the water die out. This roughness of the pipe corresponds to the quality of the wire forming the electric circuit, one of the factors which determines its ohmic resistance. The electric oscillations would die out quicker in a circuit made of iron wire than in one made of copper wire. If the ohmic resistance of the electric circuit is greater than a certain amount the oscillations will not exist at all.

The time which it takes for the column of water to make one complete oscillation, that is, for the diaphragm P to move from its position P' to P'' and back again to P', is seen plainly to be dependent upon two circumstances, the mass of water which moves back and forth and the elasticity, as well as the area of the partition P. If the pipes in which the water oscillates are long, the oscillations are necessarily slower than if they are short. The time for a complete oscillation to take place will also be greater when the diaphragm P is very yielding than when it is les so. A stiff diaphragm of small area will urge the water back and forth more quickly than one of large area and very elastic.

In the electric circuit there is something which corresponds to the mass of the water in the water circuit in determining the time which is required for a complete oscillation of the electricity to take place. This something is the medium surrounding the circuit and bears no resemblance to the water except in having inertia. When the electricity is said to flow in the wire more or less of this medium is in motion. The mass of this medium which is in motion when a current of electricity flows depends upon the length of the wire and

the way in which it is coiled up, just as the mass of the water depends upon the length and diameter of the water pipe. The velocity of the motion of the medium is proportional to the strength of the electric current which is said to flow in the wire. This motion of the medium which surrounds the circuit is made manifest in the so-called lines of magnetic force. When a unit quantity of current sets in motion a certain mass of the medium surrounding the electric circuit, the circuit is said to have a certain inductance or coefficient of self induction. This inductance of the circuit then is represented in the water analogue by the mass of the water, and as the period of oscillation of the water is proportional to its mass, so the period of oscillation of the electricity is proportional to the self inductance of the electric circuit. The longer the wire and the more it is coiled up the greater this will be.

In the electric circuit just before the E. M. F. or force which urges electricity into motion becomes great enough to break down the thin air gap between the balls, this being represented by the partition s' in the water analogue, there is a strained condition of the medium between the two condenser plates. This is produced by the E. M. F. acting across the space between these plates just as the water-pressure force acts on the diaphragm P to strain it.

Now a particular thickness of medium or dielectric, as it is called, will be strained out of its normal condition by a certain E. M. F. by an amount which depends upon its nature, the same as a certain thickness of rubber diaphragm will be strained from its normal position under a given water pressure by an amount depending upon its flexibility. The amount of strain produced in both cases will be less the greater is the thickness of the substance strained. Evidently then the nearer the condenser plates are together the greater will

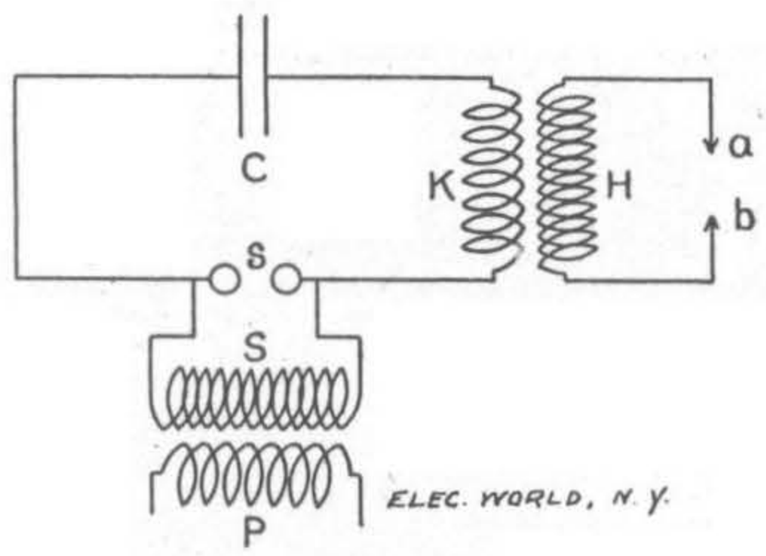


FIG. 3.

the dielectric between the plates be strained or displaced and the greater will be the quantity of electricity which will have been moved across any imaginary plane, as L L. Likewise a greater quantity of water will move across any imaginary plane L' L' under a given pressure when the rubber partition is made more yielding. Note also the important fact that under a given pressure of the piston as large a quantity of water is forced across any imaginary plane l' l' as across any other imaginary plane, as L' L'. In the same way as large a quantity of electricity crosses one section of the circuit as any other. In short, as much electricity moves across the portion of the circuit which is made up of a so-called insulator as moves across any section of the conducting portion.

We may tabulate as follows the conditions which govern alike the oscillations in the water circuit and the electric circuit:

WATER CIRCUIT.	ELECTRIC CIRCUIT.
Roughness of interior of pipe.	Resistance of wire due to quality.
These determine the rate at which the oscillations die out.	
WATER CIRCUIT.	ELECTRIC CIRCUIT.
Mass of water in circuit.	Mass of medium in motion when current flows or self inductance of the circuit.
Flexibility of diaphragm P.	Capacity of electric condenser.
These determine the time during which a complete oscillation occurs.	
WATER CIRCUIT.	ELECTRIC CIRCUIT.
Pressure which piston can produce.	E. M. F. of transformer.
Length of air gap S'.	Strength of partition S

From the above comparisons it is seen that greatness of area of the condenser plates and their nearness together, or in electrical language, greatness of capacity, corresponds to greatness of elasticity and area of the rubber diaphragm, and hence the greater is the capacity of the electric condenser the slower will be the oscillations in the electric circuit. The sudden restorations supposed for the diaphragm s' are actually accomplished in the electric circuit by the inrush of cold non-conducting air as often as the oscillations in the circuit w have died out.

Let a circuit now be arranged as in Fig. 3. This circuit is supposed to be like that of Fig. 1 in all respects, except that at K the wire is wound into a coil or solenoid of eight or ten turns. Another coil of fine wire, H, is supposed to be wound around the coil K. When an oscillatory current now passes through the coil K a current is induced in the coil H. No known mechanical analogue can well illustrate of explain why a varying current of electricity in one circuit will induce or cause a current to flow in a neighboring circuit. Such, however, is the fact, the discovery of which added lustre to the already immortal name of Faraday. What concerns us here is that the force with which the electricity in the coil H is urged forward is, in the case illustrated above, very great. The high E. M. F. which is induced in the coil H is due to the very rapid rate at which its turns are cut by the magnetic lines which are produced by the oscillating current flowing in the coil K. When the circuit in the coil K has its maximum value there is a maximum number of lines of induction in the space about the two coils. When the condenser C is fully charged, and there is no current in the coil K then there are no lines of induction in the field. Now, if the two coils are wound so as to be close together and well insulated from each other, the lines of induction, which come into and go out of the field as the current in K rapidly changes its value and direction must all cut the turns of the coil H. These turns will be cut twice every time the current in the inducing circuit makes a swing in one direction; once as the current rises from zero to its maximum value and once as it again sinks to zero. Since the oscillations of the current take place with enormous rapidity, the turns of H are cut by the magnetic lines of induction with a like rapidity. It is an experimentally determined fact that the E. M. F. set up in a circuit which is being cut by lines of induction is proportional to the number of such lines per second which cut it, or as usually expressed, to the rate of change of induction through the circuit; hence in the circuit which includes the coil H the E. M. F. induced is very great. For example, the E. M. F. induced in H will be sufficient to produce an 8 or even a 10-inch discharge through air between the terminals a and b, when the circuits have approximately the following proportions: From the secondary S, of the transformer T, a sufficient E. M. F. must be obtained to discharge across the discharge gap s when a quarter of an inch long. The condenser C must have a capacity of about one two-hundredth of a microfarad, or a capacity such as would be obtained by stacking up about forty sheets of double thick window glass 10 by 10 inches and thirty-nine sheets of tin or copper. The coil K may have about ten turns of heavy wire and the coil H about 500 turns of fine wire. The current in H, of course, changes its direction with the same frequency as the current in K; that is, some millions of time in a second. The discharge from the coil H is what has been popularly called the Tesla current of high potential and high frequency. It may be remarked here, however, that phenomena of this class have been studied and developed in quite as able a manner by Prof. Elihu Thomson.

Before attempting to explain the effects, uses and practical methods of producing oscillatory currents it may be well to show diagrammatically the various arrangements of circuits which will give rise to such currents.

In Fig. 4 D is a direct current dynamo. The higher the voltage of this dynamo the better, for the effects to be described are increased in proportion to the square of the voltage; 500 volt machines used to operate electric street lines will give powerful effects. C is a condenser made of paper and tinfoil soaked in wax and having a very great capacity. P is a coil of a dozen or more turns, and S is a coil of several thousand turns. K is a device for alternating, allowing the condenser C to be charged by the dynamo, and for closing the circuit through the coil P, so the charged condenser can discharge through the coil. It operates as follows: a a and b b are strips of metal fastened on a cylinder of wood or hard rubber and cross-connected as shown. n' n' n n are four brushes which bear upon the cylinder, and have the relative positions shown in the

diagram. It will be easily seen that if the cylinder is made to rapidly rotate in the direction of the arrow that when the brushes *n n* bear on two conducting pieces the condenser is in circuit with the dynamo and is being charged, and that the coil *P* is out of circuit, and that when the two brushes *n' n'* bear upon conducting pieces the condenser is in circuit with the coil *P*, and that it will then discharge through the coil, the dynamo then being out of circuit with the condenser. When, however, the condenser discharges an oscillation of electricity will take place through the coil *P* in the same way and for the same reason that it did in Fig. 1.

The oscillatory current in *P* will induce an oscillatory current of the same frequency in the coil *S*. If the coil *S* has many turns the current induced in it will be urged forward with a very high E. M. F., so that a long discharge may be obtained between the terminals *p p'*. Since, however, the condenser *C*, for reasons to be explained, must be made very large, the oscillations in the coil *P* will be very much slower than in the case of the circuit of Fig. 1, which is supposed to contain a condenser of small capacity, but charged to such a high degree or potential that it can discharge across an air gap.

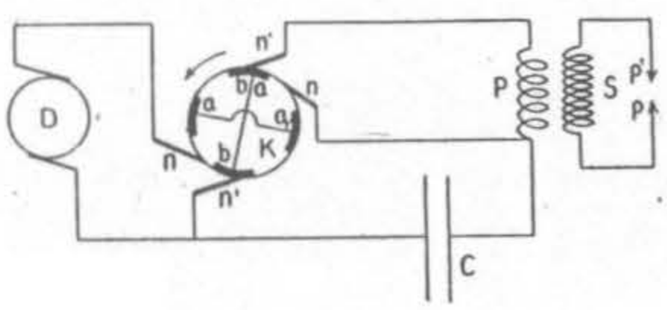


Fig. 4.

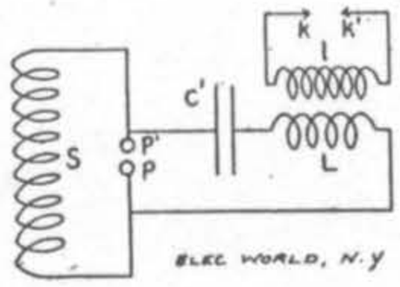


Fig. 5

Since the current swings slowly back and forth through the coil *P*, the rate at which the coil *S* is cut by lines of induction is not very great, and to obtain a high E. M. F. in the coil *S* this coil must have a great many turns of wire. This follows from the well-known principle that the E. M. F. set up in each turn by the inductive action is added to that set up in the other turns. The oscillatory current in the coil *S*, while having a very high potential, or in other words the power to discharge through a considerable length of air, oscillates with comparative slowness. To obtain an extremely rapid oscillation we may modify the circuit as illustrated in Fig. 5.

The terminals of the secondary coil *S* end in two balls, separated from each other about a quarter of an inch. A condenser of small capacity in series with a coil of a half dozen turns is joined to the opposite sides of the discharge gap *p p'*. If *S* then has potential enough to discharge across this gap an oscillatory current of very great frequency will flow in the coil *L*, which, by means of the coil *l*, can be raised or lowered in potential.

The condenser *C*, Fig. 4, must have a very large capacity, for the following reason: The quantity of electricity which any charged condenser contains is proportional to the potential to which it has been charged or to the force, so to speak, with which electricity was forced into it. Referring to Fig. 2 it is evident that the excess of water in the box on one side of the partition *P* over that on the other side will be proportional to the force exerted upon the handle *h* of the piston *t'*. Now this excess of water on one side of the partition *P* corresponds to the quantity of electricity in the condenser *C* of Fig. 1, and the force exerted upon the handle *h* to the potential or E. M. F. of the secondary of the transformer *T* which charges the condenser *C*. Such being the case, if the condenser *C* in Fig. 4 had a small capacity and was only charged by the low E. M. F. of the dynamo *D*, it would contain very little electricity. which, when discharged through the coils *P*, makes a rapid oscillation but produce a current having very little intensity. In short, the condenser *C* would have very little energy stored up in it, and however the relations of the two coils *P* and *S* are adjusted, only a small display of energy could be obtained from the terminals *p p'*. If we attempted to make the discharge between *p p'* long it would be found to be very thin, and if a condenser, *C'*, were connected across its terminals the discharge would be very much shortened, if not eliminated altogether. It can be shown that the energy contained in any condenser is proportional to its capacity and to the square of the potential to which it is charged, so that when working with low potentials very large condensers must be used to obtain effects which exhibit much energy.

Oscillatory Curves and Some of Their Phenomena—II.

BY PROF. E. F. NORTHRUP.

In the circuits shown above the condensers have been considered as consisting of two or more sheets of metal separated a short distance from each other by insulating material. Any such condenser, even when the separate sheets have a small area, will have a capacity large enough to make the oscillations much slower than is desirable for many forms of experiments which may be performed with oscillatory currents. When therefore it is desired to obtain the most rapid oscillations, such as are used for the production of electric waves (about which more will be said later), it will be found convenient to arrange the circuit as indicated in Fig. 6.

Here *S S* are two sheets or spheres of metal; *s* is the discharge gap and *l l* is the wire along which the very rapidly oscillatory currents flow. The two metal sheets, together with the surrounding air, form a condenser in all respects like the condenser in *E*, Fig. 1, except that it has a very much smaller capacity on account of the great distance that the plates are separated from each other and

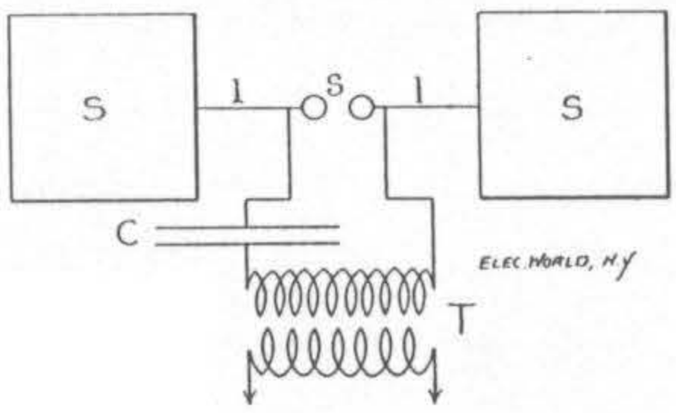


FIG. 6.

from other conducting matter. Another condenser, *C*, is indicated as placed in series with the secondary of the transformer *T*. The importance of this condenser rests on a practical point in the operation of the contrivance, as shown. The author has found that the secondary of a transformer generally gives such a large current that when the air gap *s* breaks down an arc of very low resistance is permanently established across this gap if the condenser *C* is left out, and that no true oscillations take place in the wire *l l*. By inserting a small condenser, as *C*, in the circuit of the secondary of the transformer the current becomes cut down to a low value, while the distance that the spark can jump in the spark gap *s* is not diminished. In this case the arc does not form permanently across *s* and

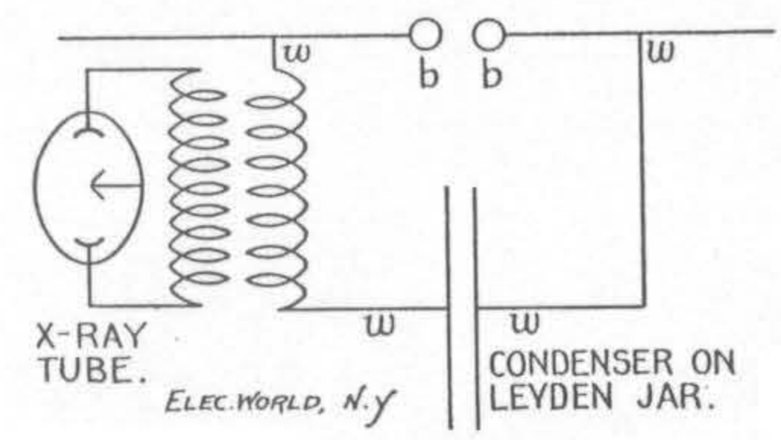


FIG. 8.

good oscillations are obtained. A blower or polished balls or other devices often used to break the arc will then often not be required.

The customary way of exciting oscillations in a circuit like the above is to employ in place of a transformer an induction coil, as shown in Fig. 7. This is the arrangement first used by Hertz in his experiments on electrical waves. An induction coil will not, however, give as good or as powerful effects as a transformer. The chief reason for this is that the induction coil only supplies energy to the circuit in which the oscillations take place, at comparatively long intervals, the discharge from an induction coil not being continuous, as it practically is from a high-potential transformer.

Oscillatory currents may be obtained also from a Holtz or influence machine. Arranging the circuits as in Fig. 8, where *b b* are the terminals of the influence machine, very rapid oscillatory currents of small energy may be obtained in the circuit *W W W W*, but of sufficient power in the case of a large machine to excite vacuum tubes and X-rays. In the case shown the induced current will pass through the vacuum or X-ray tube when the spark passes between *b b*.

I shall now show some devices which ought to give oscillatory currents of great power, although I have never had an opportunity to actually test the matter. I offer the devices as of sufficient interest to be worth testing by experiment.

In Fig. 9 *D* is a direct-current dynamo of any voltage, *I* is a coil of a great many turns of heavy wire wound on an iron core, *c c*. *C* is a condenser, *s* a spark gap between balls about an eighth of an inch apart. *P* is a coil of a few turns of large wire and *f* a coil of fine wire. *K* is a device by means of which two carbons may be made to touch each other and then be drawn quickly apart until the arc which forms on separating them is broken. Now it is well known that when a direct current is passing through a coil wound on an iron core and of a great many turns, that on suddenly breaking the circuit the current which is flowing in the coil tends to keep on flowing in the same direction with such persistency that a spark of considerable length will occur at the point where the circuit is broken. Hence if the carbon points at *K* are brought into contact and a large current flows through *I*, on quickly separating them an arc of low resistance will first form between the points and, when the separation becomes

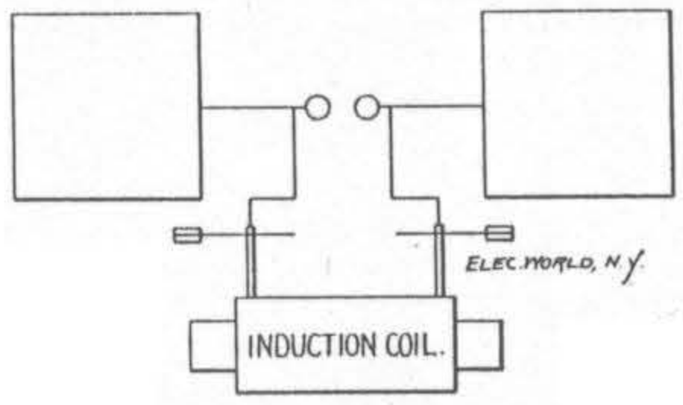


FIG. 7.

great enough, will quite suddenly break. The current in *I* will, however, tend to keep on flowing and as it has no other path to take will flow into the condenser *C*, charging this to a high potential, and, if matters are rightly arranged, this potential may be made great enough to cause a discharge to take place across the air gap *s*. If this occurs the condenser wil discharge through the coil *P* with an oscillatory current which will induce a current in the coil *f*. Thus a long discharge between the terminals *a a* may be obtained. It would be desirable to have the break in the circuit which is supposed to occur at *K* made at a number of different points at once. Devices for accomplishing this anyone can readly design.

In Fig. 10 *A* is an alternating current dynamo, *T* a commercial

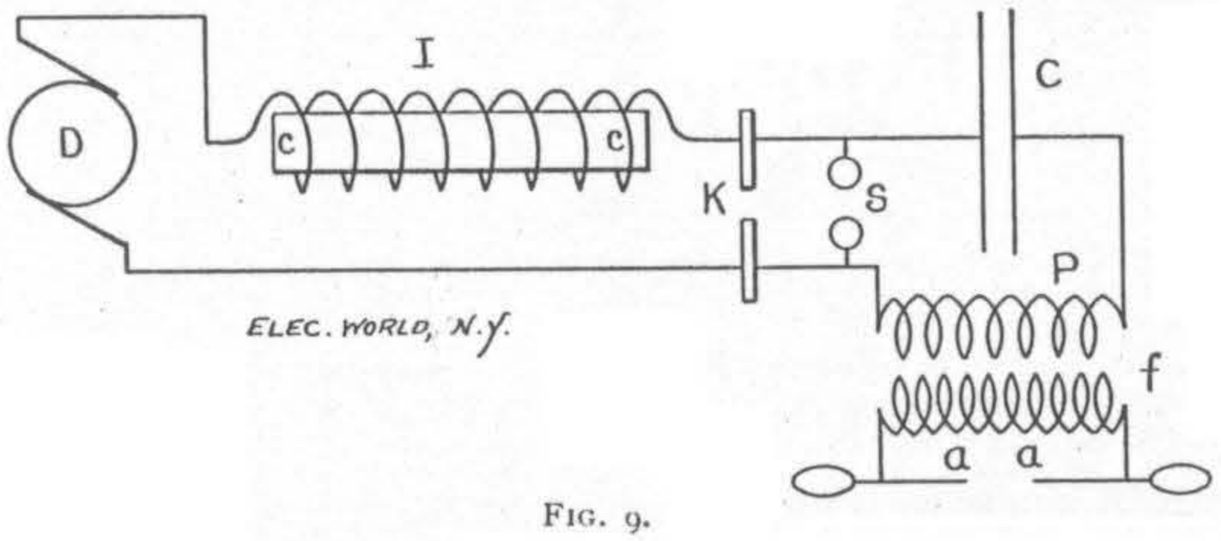


FIG. 9.

transformer which will give across the terminals of its secondary a potential of 100 volts. *L* is a very large coil of wire wound on an iron core, or what would serve the purpose as well, the secondaries of several transformers connected in series. *C* is a condenser of moderate capacity, *P* a coil of a few turns of heavy wire, *f* a coil of fine wire and *s* a spark gap. Suppose that a momentary current flows through the primary of the transformer *T*, then a momentary E. M. F. will act in the secondary of the transformer, tending to start a current flowing through the circuit, including *L*, *C* and *P*. The condenser *C* will be charged to a low potential and will then immediately discharge, causing a weak oscillatory current to circulate in the condenser circuit, Assume now that each time this oscillatory current starts to flow in one direction or the other a new current is sent through the primary of the transformer in such a direction that the E. M. F. induced in the secondary of the transformer helps the current which is already flowing in the secondary along in the same direction. This current will then evidently be increased. If we start a rocking chair rocking and each time it starts to go back in one direction give it a slight push it will be made

by very slight impulses to rock back and forth a great way. If the impulses given to the chair are not rightly timed it will almost be brought to rest. Just so in the above electric circuit. If the oscillatory current has a natural rate of swing back and forth in the circuit and the alternating current through the primary of the transformer changes its direction at the same rate as the oscillatory current naturally swings, the surgings of this latter current will become very great and the condenser *C* will become charged to a very high potential and with a large quantity of electricity. The potential to which the condenser may be charged, by rightly varying the natural period of its circuit until it is the same as the period of the alternating current through the primary of the transformer, may be made fifty times as great as the potential which could be obtained from the secondary of the transformer alone. Or, in other words, the potential

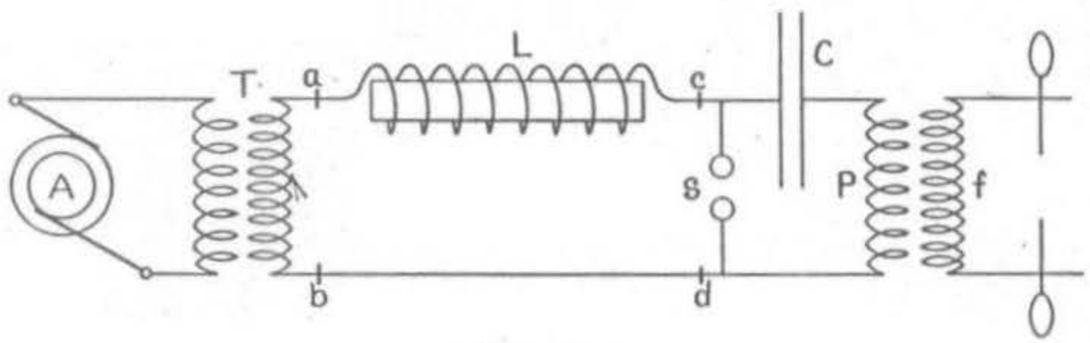


FIG. 10

between the points *c* and *d* may be made fifty times as great as the potential between the points *a* and *b*. If the potential between *a* and *b* is 100 volts the potential between *c* and *d* would be great enough to cause a discharge to take place across the air gap *s*, and this would cause a much more rapid series of oscillations to take place through the coil *P*. These could be used to induce a very high potential in the coil *f*. The circuit may be adjusted to resonance, as it is called, with the alternating E. M. F. in the transformer, by varying the number of turns in the coil *L* or the amount of iron in this coil, the capacity of the condenser, or, where it can be managed, by varying the speed of the alternator *A*.

Oscillatory Currents and Some of Their Phenomena—III.

BY PROF. E. F. NORTHRUP.

PRACTICAL HINTS FOR CONSTRUCTING OSCILLATOR.

The chief and almost the sole difficulty encountered in the construction of efficient oscillatory current apparatus of reasonable size is in obtaining sufficient and permanent insulation. The liking of a high-potential high-frequency current for any path of discharge beside that between the terminals will often drive the experimenter to despair. A few general facts therefore in regard to the subject of insulators and insulation will not be out of place.

As Professor Fessenden has pointed out in a recent paper read before the American Institute of Electrical Engineers and printed in THE ELECTRICAL WORLD April 2, 1898, we may speak of an insulating substance as that which will more or less effectually prevent a slow leakage of the electric current or as a substance which, permitting more or less leakage, will prevent a disruptive or sudden discharge. These two aspects of an insulator may be very prettily illustrated as follows: Provide a glass tube about an inch in diameter with a tight fitting cork for each end. Insert a pointed wire through each cork, so that the two wires will come within the tube and be capable of meeting at its centre. Fill the tube with ordinary water and pull the two ends of the wire a short distance apart. If a high-frequency high-potential current source be attached to the ends of the wires outside the tube, it will be found that the water has considerable insulating power against a disruptive discharge. When the ends of the wires are sufficiently near, however, the discharge will pass through the water, giving a beautiful light. It will be observed, also, that bubbles come off everywhere from the sides of the wire. These show that considerable current is flowing through the water in the ordinary way, while the water is behaving as a highly insulating substance to the disruptive discharge. After the water becomes thoroughly fouled no disruptive discharge can be obtained, the current all passing through the water by electrolysis. The kind of insulation required for oscillatory currents is that which will prevent the disruptive discharge. For reasons to be shown an insulator may have enormous strength for an E. M. F. which acts for only an instant and yet be very weak for the same E. M. F. applied for a considerable time.

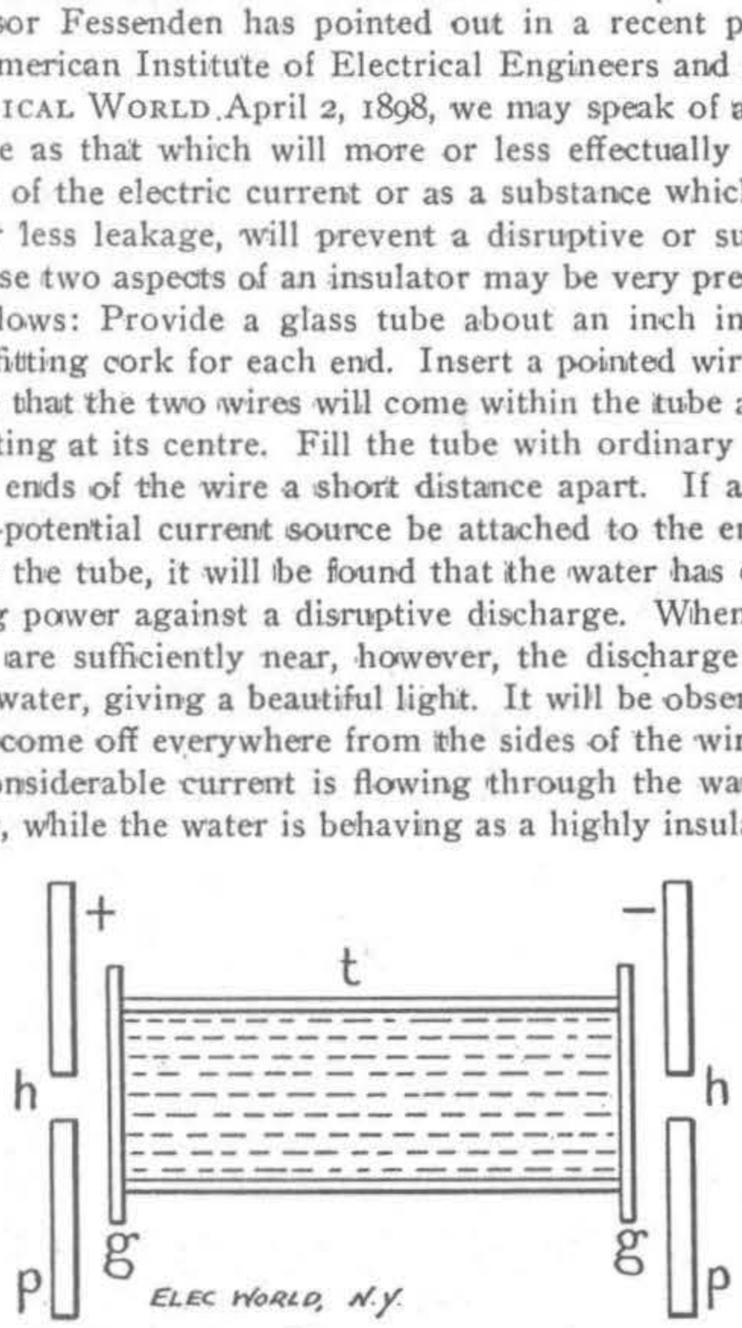


FIG. 11.

An experiment first performed by Faraday will teach us much about insulators. The experiment is illustrated in Fig. 11. *p p* are two circular brass plates with small holes *h h* in their centre. *t* is a tube with glass ends *g g*. Such a tube Faraday filled with carbon bisulphide and a great many short pieces of silk thread. By applying the eye to one of the holes *h h* he could not see through the tube because the short pieces of silk were turned in all directions. When, however, *p p* were given opposite charges of electricity the threads all arranged themselves in line and he obtained clear vision through the tube lengthwise. This shows that the silk is a better conductor of the lines of electric stress than the liquid in the tube. Now assume the silk to be also a poorer insulator than the liquid, and that the difference of potential of the two plates is so great that a discharge is just on the point of taking place between the plates through the liquid alone. At the first instant that the plates are charged the particles, supposedly of weak insulating power, will not be lined up, but after a greater or less time they will become so, when the path for the current to pass through being weakened by this alignment of the particles the discharge will occur. Thus we have one case in which an instantaneously applied E. M. F. would not break down an insulator, while one longer applied of the same value would. The same will hold true in a like measure if the two plates are being alternately charged with electricity of opposite signs. Now there are few oils or other insulating liquids which are perfectly pure and free from foreign particles, and the very effect here described often takes place, especially with high-potential currents of a moderate frequency. I have found oil, which had an instantaneous insulating value for the current from a high-potential transformer several times stronger than air, prove actually weaker than air for a long applied electric pressure. By making the insulator a solid we ought to prevent this polarization of the particles, but, with high-frequency currents, we fall in two other difficulties which are harder still to eliminate.

Almost all solids become conducting when hot, glass, for example, being an excellent conductor when melted.

Now it is a well-known fact that a high-potential high-frequency current will eat its way through the best of solid insulators a distance that it could not begin to penetrate at once, and that, too, when no air is present, the terminals being perfectly imbedded in the solid insulator. My own conception (formed probably by reading Professor Fessenden's article on insulators) of one cause of this will be made plain by referring to Fig. 12. Let *P* and *P'* be two metal plates of indefinite area. Suppose black fibre to be an insulating material between these plates and suppose this to be impure, having particles of some better insulating substance, but of higher specific inductive capacity than the fibre imbedded in it. Let *p*, *m* and *n* be three such particles. If *P* is charged positive and *P'* negative the lines of electric stress, finding an easier passage through these particles, will be bent out of their course somewhat, as shown in the diagram. Since a charge of electricity is nothing but the locus of the ends of such lines of stress, *p*, *m* and *n* will have by induction small apparent charges of electricity upon their ends, as indicated in the diagram. Suppose *m* and *n* are near enough together so that a discharge may pass between their approximated ends. Now if *P* and *P'* are charged to a steady potential, such a discharge between the particles taking

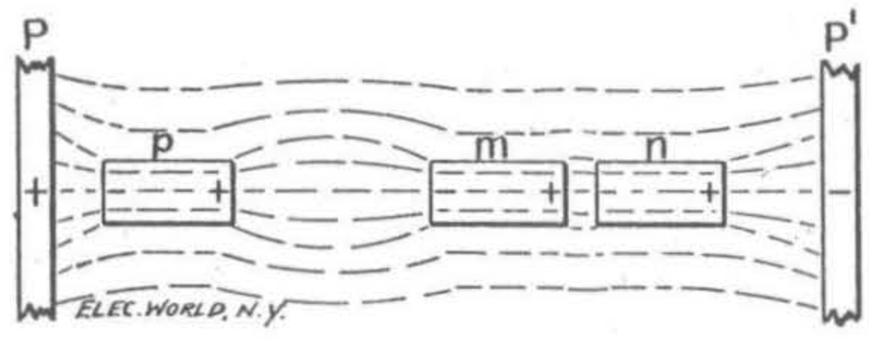


FIG. 12.

place but once might produce no visible effect, but if the two plates are rapidly charged alternately positive and negative by means of an oscillatory E. M. F. the discharges between the particles would be rapidly repeated, and since heat is always the accompaniment of discharge the insulating medium about the particles would become heated and thereby greatly weakened, so that the local discharges in its substance would become more and more numerous, and finally the discharge would find its way directly from plate to plate. Very few solids are so homogeneous that the above effect will be entirely absent. Substances which readily conduct lines of electric stress or, as the term is, have a high inductive capacity are usually very poor insulators for oscillatory currents. High specific inductive capacity may be a quality inherent to the substance itself or merely a result of impurities scattered through the substance. Referring to Fig. 12 we may suppose that the insulating medium between the plates is solid sulphur, which has a small specific inductive capacity, that is, it conducts lines of electric stress only a little better than air does. Suppose now the particles, such as *p*, *m* and *n*, to be of metal and extremely numerous. The lines of electric stress would find an easy passage through these particles and the actual path which they would have to travel through sulphur would be small, hence the sulphur would appear to have a great specific inductive capacity. In this case, however, the apparent specific inductive capacity is obtained at the expense of dielectric strength. It would therefore be folly to use such a contaminated substance as an insulator between the metal plates of a condenser. The apparently high specific inductive capacity of the substance would make the capacity of the condenser great for its size, but only at the expense of insulation. The apparent specific inductive capacity of many substances may be greatly lessened by drying out the moisture which is occluded in the pores.

Aother potent cause of dielectrics or insulators breaking down

under a continued strain of rapidly alternating potentials is what Tesla terms molecular bombardment. To observe this effect fill a box containing a high-frequency high-potential coil with a very viscous insulator, as a mixture of resin and machine oil. Place in the bottom of this box a piece of asbestos or any substance which contains a quantity of air in its pores. On account of the thickness of the insulating compound this air would ordinarily remain permanently entrapped. When, however, the coil is in action the air bubbles are agitated with great violence. They heat the insulator surrounding them and soon work their way to the top of the box through a substance so thick that a stick could hardly be pushed into it. It is useless to try to insulate high-frequency currents with homogeneous solids unless every trace of air can be avoided, for this molecular bombardment, which heats and destroys the insulating property of the solid, will eventually destroy success. Tesla remarks that a solid insulator containing a particle of air will in time be as surely eaten through by the high-frequency discharge as a stone let go will fall to the ground.

I have observed another property of insulators for high-potential high-frequency discharges which is quite remarkable, and which I shall not here attempt to explain, but merely to state the fact as I have observed it, hoping only that some experimenter will investigate the matter thoroughly. A high-frequency coil was constructed with a separation between the primary and the secondary which was calculated as being quite sufficient to prevent breakdown when machine oil was used as the insulator. It was thought that the insulating power of the oil would not be lessened by dissolving pure resin in it. This was accordingly done, the proportions being such that when the mixture became cold it would scarcely flow, but yet was not a solid. This mixture when very hot was poured over the coil, which was immediately set in operation for two hours without a sign of a breakdown. Every particle of air had been expelled, and yet when the coil was tried the following day under exactly similar conditions, except that the insulator had become cold, it broke down in many places between the primary and the secondary coils. This observation leads me to believe that under certain conditions a substance becomes a better insulator as it is made more fluid, though the fluidity is gained by raising the temperature. I may add that tests show that the more fluid oils are much better insulators for high-frequency high-potential currents than the thick oils, kerosene being especially superior.

It is a remarkable fact that while engine and other kinds of oil may be taken as from eighteen to twenty-four times as strong as air for the high-potential high-frequency currents, it can only be taken as about equal to air for the discharge from a high-potential transformer capable of giving an inch discharge through air. (See The Electrical World, April 2, 1897.) Solid dielectrics, such as a mixture of beeswax one part and resin three parts, or resin softened a little by a small portion of engine oil, hold up the high-potential slowly alternating E. M. F. of a high-potential transformer much better than oil, while the reverse holds true with high-frequency E. M. Fs.

Micanite is the best all around solid dielectric to employ where it can be used with slowly alternating E. M. Fs. that I have found. A sheet 1-1000-inch thick will hold up about 1000 volts if it does not become heated. The best solid dielectric for slowly alternating E. M. Fs., which can be melted and poured over the parts of the apparatus, is resin with a very small portion of a good quality of engine oil melted with it and thoroughly stirred in. Paraffin that has been heated a long time is also very good. For the high-frequency currents I would recommend after much experimenting a good quality of clear, well-strained engine oil, and that it should be heated quite hot before being poured over the apparatus. Oil is the only insulator for these currents which can be counted as safe for all time. As a rule it is advisable to avoid the use of substances which have a high specific inductive capacity. A 5-inch high-frequency discharge will quickly eat a hole through an eighth of an inch of glass.

I will now give a somewhat detailed account of how to construct the separate parts of a high-frequency apparatus which will run on a 104 or a 52-volt alternating-current city circuit, and be capable of giving a copious high-frequency discharge 8 inches long. The apparatus will be especially designed with a view to exciting X-ray tubes.

It is often customary to use an ordinary induction coil for the high-potential transformer. If such is used the condenser is cut out of circuit and the primary of the coil connected through an inductive resistance to the alternating current mains of the lighting circuit. An induction coil, since it has an open magnetic circuit, is an extremely inefficient form of transformer to employ. There is moreover a very important reason why it is desirable to employ a transformer of high efficiency. When resistance is thrown in circuit with the primary of the induction coil the effect on the discharge across the gap in the circuit of the condenser is merely to shorten it. The high frequency discharge is likewise shortened, but is of the same thickness or quantity. If, however, the transformer is of an efficient type, adding inductive resistance to the primary has the curious effect of causing the discharges in the condenser circuit across the gap to take place less frequently and the high frequency discharge, while remaining of the same length, is much thinner, and, by a proper adjustment of the inductive resistance and of the length of the spark gap in the condenser circuit, the high frequency discharge may be made to assume the appearance of a discharge from a Holtz machine or to become so fine and threadlike as to be scarcely visible. This ability to adjust the thickness of the high frequency discharge without changing its length has great value in working with X-ray tubes.

In Fig. 13 is shown a design of an efficient form of a high-potential transformer, which experience has shown to be admirably adapted to the work for which it is intended. Consideration has been given to cheapness and ease of construction. The secondary requires but 3 pounds of double silk covered No. 32 wire. It is intended to be used on an alternating circuit of about 125 alternations

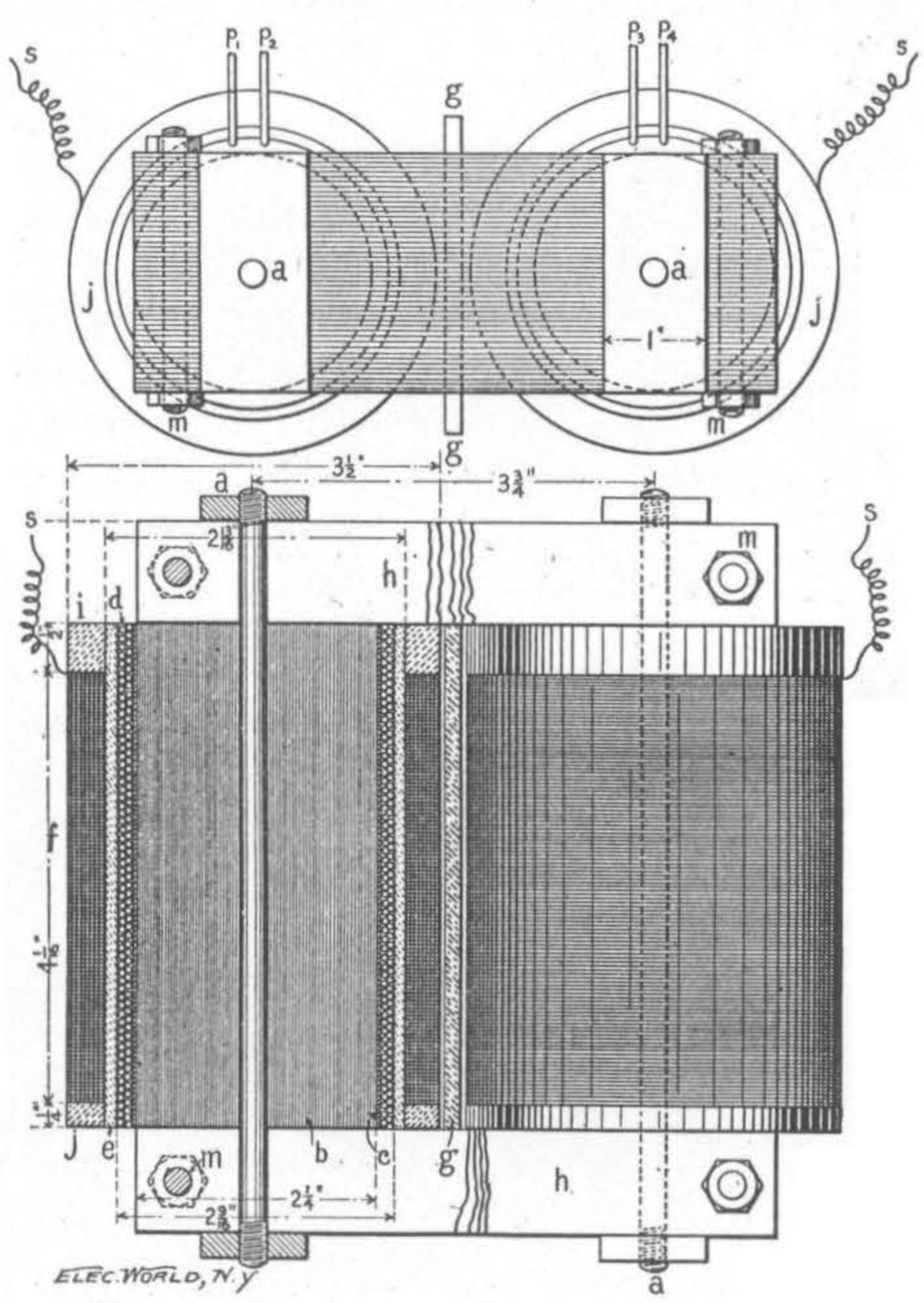


Fig. 13.

A = plan, *B* = section of elevation.

a a = bolts, *b b* = iron cores of No. 16 soft annealed wire.

c c = paper insulation $\frac{1}{32}$ of an inch thick.

d d = space for primary winding. This consists of 115 turns on each half of transformer, of No. 15 magnet wire wound in two layers.

e e = micanite tubes ⅛ of an inch thick to insulate secondary windings from primary.

f f = space for secondary windings which are wound in 26 sections for each side, 52 sections in all. Sections $\frac{3}{32}$ of an inch thick, $\frac{1}{16}$ of an inch of fiber insulation between each section. Depth of secondary winding may be increased if greater E. M. F. is required. Use double silk-covered No. 32 wire.

g = glass plate to prevent a discharge between the two halves of the transformer.

h h = iron yokes to complete magnetic circuit. These yokes should be built up of iron strips one inch wide and not over $\frac{1}{16}$ of an inch thick and bolted together with bolts *m m*.

i i = red fibre or micanite rings.

j j = red fibre or micanite rings.

p_1 p_2 p_3 p_4 = ends of primary windings, which may be connected in series or multiple.

s s = ends of secondary winding.

per second. By connecting the primary coils in series or in parallel it may be used on 104 or on 52 volts. An inductive resistance should be constructed to be connected in circuit with the primary of the transformer. If the condenser with which the transformer is used has the capacity of the one to be described the inductive resistance should consist of a closed magnetic circuit having two square inches of cross section of iron and 200 turns of No. 12 wire so arranged that more or less of the turns may be thrown in or out of circuit according to the voltage of the supply circuit and to the thickness of the high-frequency discharge which is required. The construction of the transformer will be plain from the description printed below the diagram. Since for insulating these high potential low frequency potentials micanite gives the best results of any thing which I have tried, it is worthy of remark that the firms which

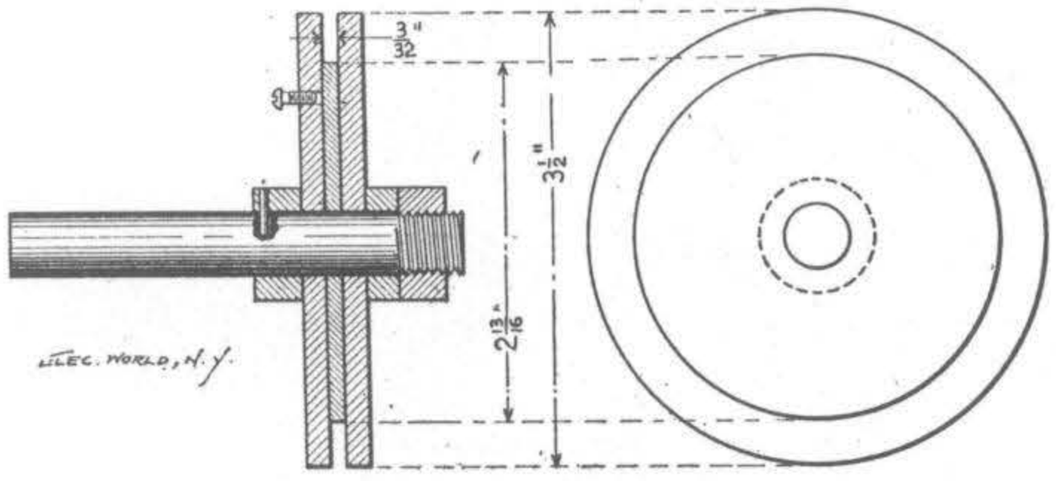


FIG. 14.

manufacture it will furnish it in most any conceivable form. It may also be remarked that black fibre should never be used, as it is useless as a high insulator. The red is much better, but is far inferior to micanite.

It is absolutely essential that the secondary of the transformer be wound in a large number of sections, and that these be thoroughly insulated from each other. The sections may be conveniently wound on a form like that shown in Fig. 14. The wire as it is being wound upon the form should run through a hot wax compound so that the coils will hold together when taken out of the form. Beeswax one part and resin four parts makes a very suitable wax. If the form is well oiled before the wire is wound upon it the coils will readily come off the form. The sections may be insulated from each other by rings of red fibre, one-sixteenth of an inch thick. The spark length of the transformer is about double when the condenser is placed in parallel with the gap. Three-eighths of an inch with the condenser connected in is sufficient for all practical purposes. If, however, a greater E. M. F. is required the sections may be wound a little deeper than those indicated in Fig. 13.

It is generally supposed that to obtain first-class oscillations and hence a smooth secondary discharge that the discharge across the gap in the condenser circuit must be blown out by a strong air blast or in some way mechanically interrupted. If, however, the capacity of the condenser is correctly proportioned to the transformer and a double discharge gap is employed the discharge will be automatically interrupted, and the oscillations will be as perfect without as with artificial interrupters.

A good condenser to go with the above transformer may be made as follows: Select about thirty sheets of a good quality of double thick window glass and examine these for flaws, casting out all defective sheets. For an eighth-inch discharge apparatus a suitable size for these sheets is 15 x 8½ inches x ⅛-inch thick. Very thin sheet copper or brass makes the best conducting material to use between these plates. The margin of glass between the edge of the copper and the edge of the glass along the sides of the plates should be one-half inch and the margin at the end of the plates should be 1 inch. At the other end the metal sheet may project one-half inch beyond the glass. Prepare a mixture of resin and oil by melting the resin and stirring into it a small quantity of engine oil. The proportions should be such that when the mixture is quite cold it will be hard, but not brittle like pure resin. Now dip one at a time all the metal sheets in the hot mixture so as to give them an even coating of the compound, and stack up the condenser. Hold the condenser plates in place with a light framework of wood. Place the condenser in an iron pan a little larger than the plates and about 5 inches deep. Fill the pan with the melted resin and oil and keep the whole hotter than boiling water for an hour or so, and press upon the condenser plates from time to time so as to expel as far as possible all air from between the glass plates.

When the air has been removed take the pan off the fire and allow the contents to become quite cold. Then by heating the pan on the outside with a gas flame the condenser will slide out as a solid cake. With a chisel the superfluous wax and the wooden frame are easily removed. The ends of the metal sheets which project beyond the ends of the glass plates may now be bent over flat and soldered together. Such a condenser will withstand potential difference which will give an inch discharge through air, and will show no brush discharge or glow in the dark. A still better condenser may be made of micanite sheets, each about one-thirty-second of an inch thick. The condenser made of this material should be stacked up and then placed in an oven till the micanite is softened and then be placed in a letter press and compressed while cooling. The only drawback to micanite is its expense. If it is intended to have the condenser in the same box with the high-frequency coil, which necessarily contains oil, no other insulation than the glass and oil is needed. Dry condensers like the above are, however, very convenient where the parts of the apparatus are in separate boxes, the box containing the high-frequency coil alone requiring oil.

The high-frequency transformer may be made in a great variety of ways. From theoretical considerations and after much experimenting I have arrived at the form shown in Fig. 15 as at the same time the most efficient and the easiest to construct. It can be shown that the potential obtainable at the terminals of the secondary or the length of discharge is practically independent of the number of turns in the primary coil, provided it has one turn and the total resistance (ohmic) of the primary coil is kept constant. The length

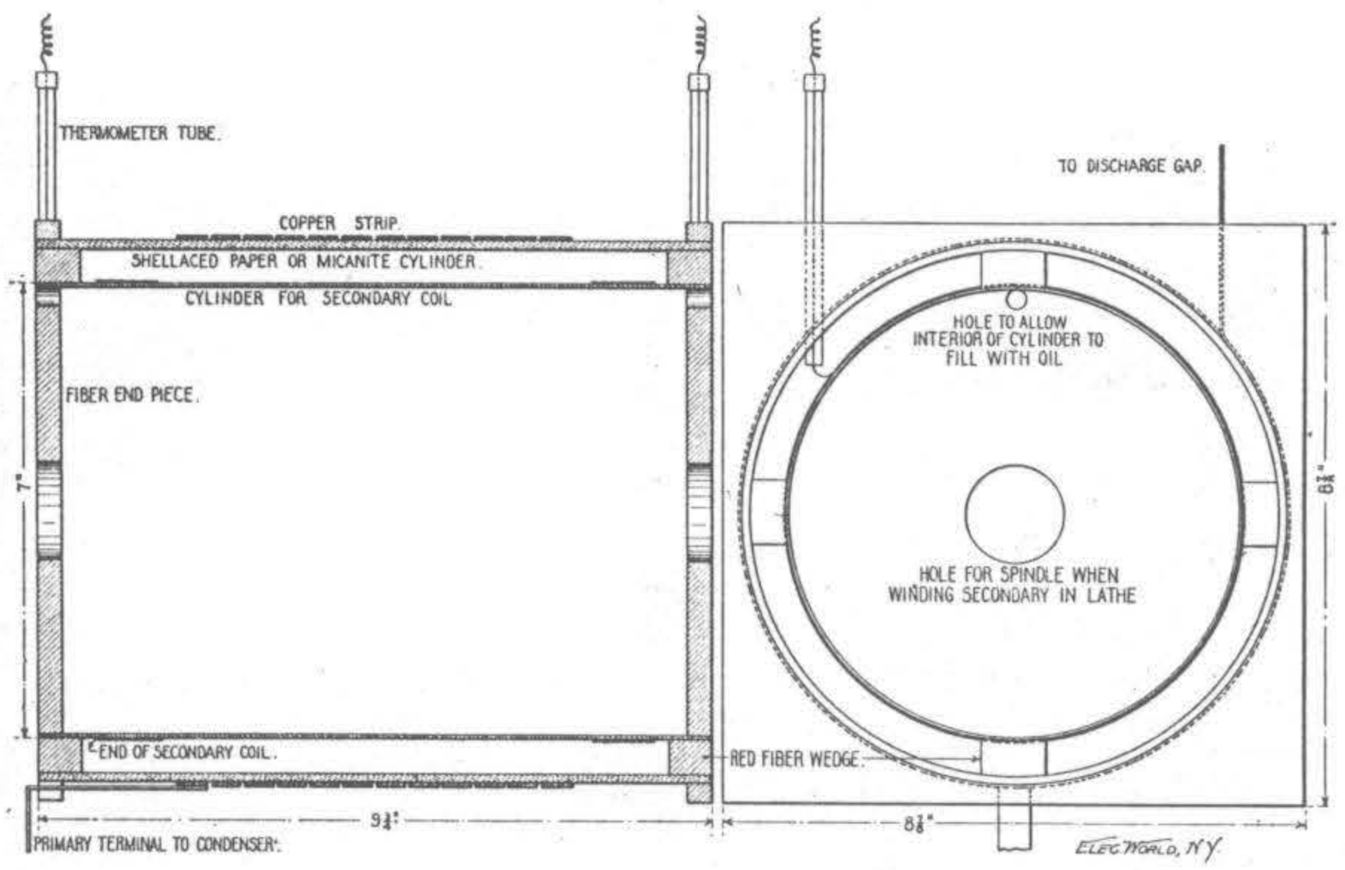


FIG. 15.

of discharge is proportional among other things to the number of turns per unit of length of the secondary coil, the length of this coil, and to its diameter. Experience shows that the secondary coil cannot be wound upon a solid cylinder of wood without greatly cutting down the spark length. In Fig. 15 the secondary coil is shown wound upon a cylinder made of thoroughly shellacked paper, or better still, upon a cylinder of micanite. No. 34 or 32 double silk covered, or even single silk covered copper wire is used for the secondary and is wound upon the cylinder sixty-four turns to the inch by means of a screw cutting lathe. After the wire is wound smoothly upon the cylinder it is covered with a thick coating of shellac poured over it. It is also well, while winding the wire on the cylinder, to have it run through shellac. Care must be exercised not to have any of the turns overlap each other. The primary is wound upon a larger cylinder, as shown in the diagram. The most advantageous material to employ is insulated copper strip such as is used in winding some kinds of dynamos. Strip about three-eighths of an inch wide and three sixty-fourths of an inch thick, triple cotton covered, is what I have used to advantage.

Since, however, most of the resistance of the circuit is encountered at the discharge gap most any kind of coper wire will answer for the primary. The turns should come nearly together and the completed coil should have about two-thirds the length of the secondary coil. The inside cylinder upon which the secondary is wound has a disc of hard wood or red fibre fitted into each end, and the ends of the outside cylinder fit into circular holes cut in square pieces of fibre, as shown in the diagram. The cylinder for the secondary is held centrally in the outside cylinder by fibre wedges so that it can be removed if required. The secondary terminals are brought up through thermometer tubing, as shown in the figure. It is almost needless to remark that no nails or metal should be used in the construction of this part of the apparatus. When the high-frequency transformer is placed in a box and covered with a good quality of engine oil a continuous 9-inch discharge may pass between the terminals without any danger of breakdown. If, however, any solid wax compound is used as an insulator, though it may hold up for a time, sooner or later the discharge will eat its way through the insulation and cause a breakdown. Unless the apparatus is made on an excessively large scale for the length of discharge to be obtained it is my belief that oil is the only insulator that can be *permanently* depended upon. Paraffin does not dissolve in engine oil and a box can be made oil tight by pouring into it boiling hot paraffin until the pores and cracks of the wood are well filled. If one is constructing a high-frequency apparatus for experimental purposes it is well to put the different parts of the apparatus in separate boxes. Only the box containing the high-frequency transformer need be filled with oil. If, however, it is desired to have all the parts of the apparatus in one box complete the best

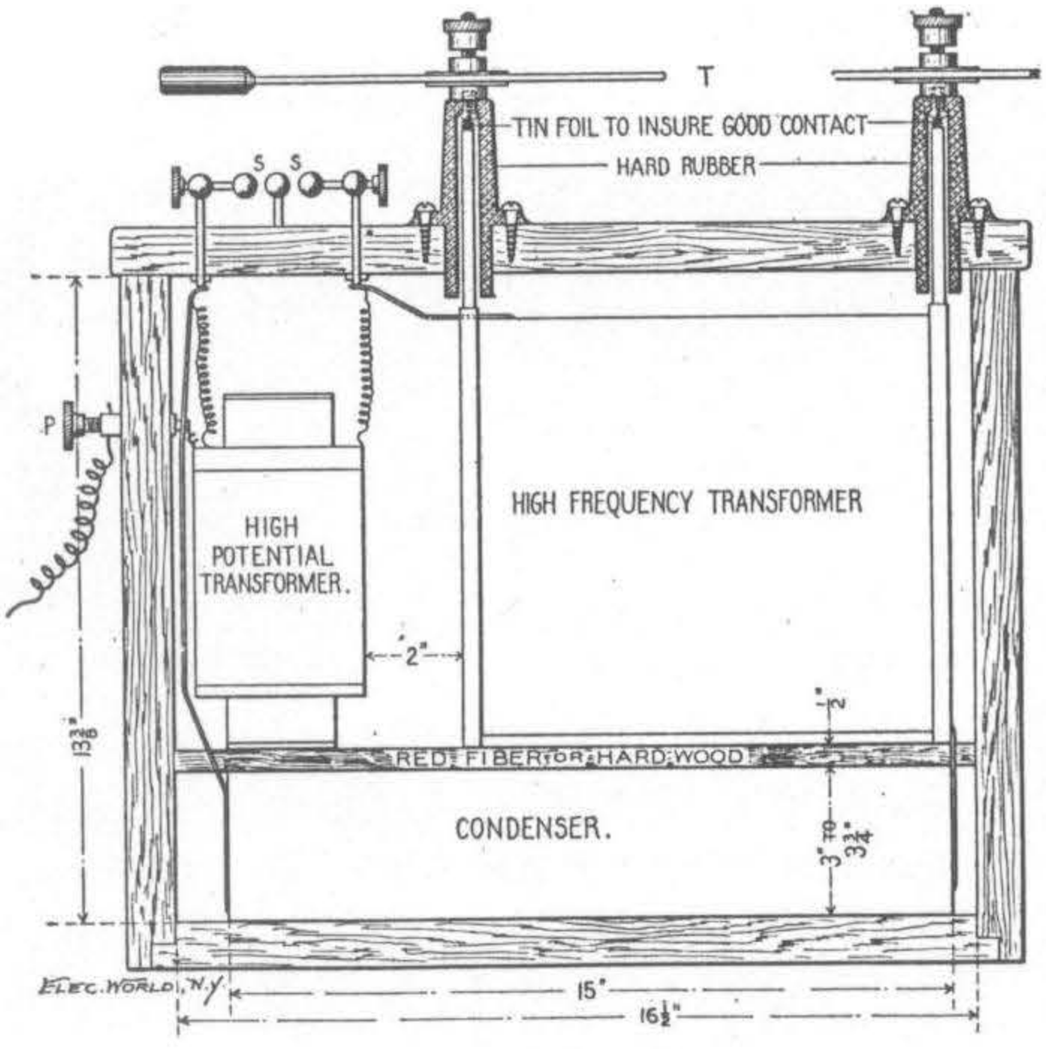


Fig. 16.

relative positions for the different parts of the apparatus and the necessary size of box to use so as to get the required insulation is shown in Fig. 16. The discharge across the gap *s s* is very noisy and it is an advantage to enclose this gap in a small box. This will greatly deaden the noise. The box must not be too small or it will get very hot from the heat generated at the discharge gap.

The large box may be filled to a level with the top of the condenser with melted resin and then filled the rest of the way with engine oil. The cover can be fitted on the top of the box, so as to be oil tight by laying a strip of asbestos soaked in paraffin on the top edge of the box and screwing the cover down tight while the asbestos strip is still hot. A vent hole must be left in the top of the box. When the terminal farthest from the transformer is connected to earth there is a great tendency for a discharge to take place to the iron of the transformer and to the binding post *p*. It is this which necessitates the separation of 2 inches between the high potential and the high-frequency transformer.

Oscillatory Currents and Some of Their Phenomena—IV.

BY PROF. E. F. NORTHRUP.

The high frequency apparatus, described above, is unquestionably the most powerful type of apparatus for the production of the X-rays. It has advantages over all other types of apparatus, such as induction coils and friction or Holtz machines, in giving a discharge of great quantity, which is practically continuous. Furthermore, the thickness of the discharge admits of being regulated through a wide range, the length of the discharge remaining unaltered.

With high-frequency currents produced, as described above, to excite the X-rays, the limit as to the quantity of rays which can be obtained is determined solely by the construction of the tube. A tube of any particular construction when exhausted for the production of X-rays is capable of dissipating only a certain maximum amount of energy. If more energy in the form of a discharge of greater quantity is sent through the tube the platinum upon which the cathode rays strike, as well as the walls of the tube, becomes dangerously hot. Obviously, if the high-frequency apparatus has sufficient power to furnish the largest and strongest tube upon the market with the maximum amount of energy which it is capable of taking, and this power can be controlled so that it may be diminished to an amount which smaller tubes require, then the apparatus is suited to every range and variety of X-ray work.

The apparatus described above will do all this.

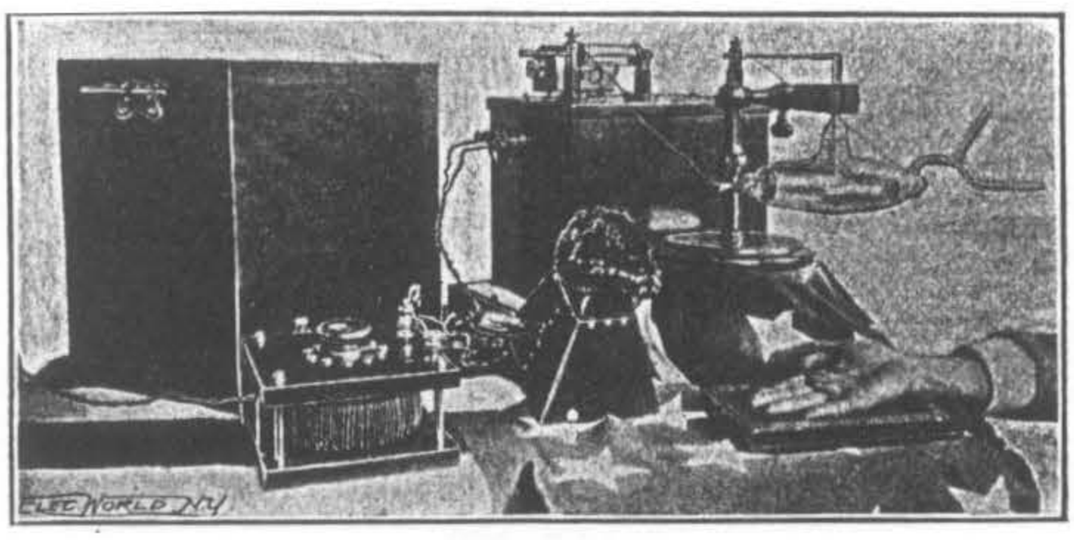


FIG. 17.

The X-rays are now known to be non-homogeneous; that is, as the exhaustion of the tube proceeds new rays are given off which have greater penetrative power than the rays which first make their appearance when the vacuum is lower. For obtaining the most penetrative rays, with which to view the ribs, the hip joint, etc., the vacuum should be very high. If, however, the exhaustion is carried too far the discharge will prefer the path around the glass outside the tube to the path through the tube. If then the distance between the terminals of the tube is, say, 9 inches, there is no object in having a machine to excite the tube which will give a discharge greater than 9 inches. In point of fact the discharge length need not be more than two-thirds of the distance between the terminals of the tube, because the discharge will run a greater distance over the surface of glass than it will through air. A Thompson double focus tube which has the distance between its terminals about 9 inches will be excited by an apparatus giving a 6-inch discharge of large quantity to its utmost limit.

The 8-inch discharge apparatus, described above, if intended only for X-ray work is, therefore, larger than will be required, although on account of the perfect manner in which the discharge may be regulated it will serve well for this work. If the apparatus is intended solely for X-ray work and it is desirable to have it portable, it may be considerably reduced in size over the one described above. Fig. 17 shows an apparatus made by the author which is intended only for producing X-rays and constructed so as to be portable. The picture shows the apparatus with its various auxiliary parts set up ready for taking an X-ray photograph. The box shown on the left of the picture is the case which is used for protection to the apparatus and for transporting it about. The entire outfit, including the variable inductive resistance and case, weighs 147 pounds. The apparatus is constructed essentially like the one described. The discharge gap of the condenser circuit is enclosed in a small box made of blackened brass on the sides and slate ends. Windows in this box allow the double discharge gap to be seen. The tube which appears on the front of the top of the box is to make the discharge through a series gap, which it is sometimes desirable to have in circuit with the tube, noiseless. The inside dimensions of the box are 12 x 8 x 12 inches deep. The transformer is made like the one described above. The condenser is made of thirty plates of glass, 7½ x 11 inches, and twenty-nine thin sheets of copper. The high-frequency transformer is made 6¾ inches long over all. The inside cylinder, on which the secondary of No. 34 wire is wound, sixty-four turns to the inch, is 5¾ inches in diameter. The outside cylinder, on which the primary of ten turns of copper strip is wound, is 6⅝ inches in diameter. The condenser would have been better if made of fourteen sheets of micanite one-thirty second of an inch thick. On 104 volts when the apparatus is giving its thickest discharge it takes less than five amperes. As the discharge is made thinner and more threadlike by adding inductive resistance in the primary circuit the amount of current required is much less. When the discharge has its maximum thickness it will heat the platinum radiant of a Thompson double focus tube white hot in five seconds.

By putting considerable resistance in the circuit of the primary of the high-potential transformer and increasing the length of the discharge gap enclosed in the small box till the discharge will just be able to pass, the high-frequency discharge may be made to simulate

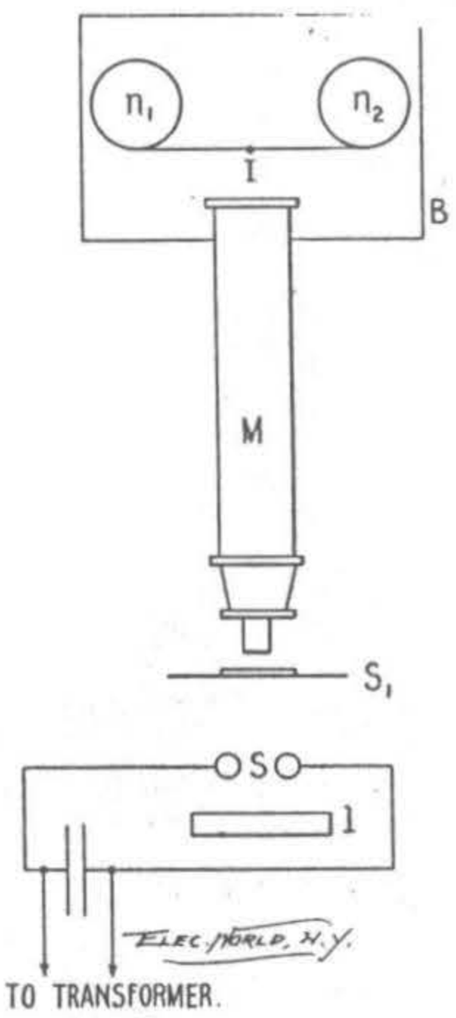


FIG. 21.

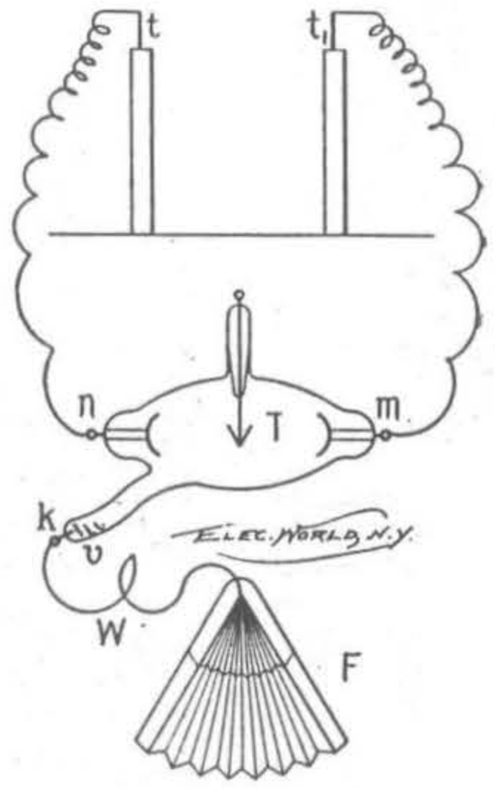


FIG. 18.

so perfectly the discharge from a friction machine that the eye can detect no difference. Now if the transformer had been made like an induction coil and the condenser had been of very much smaller capacity the discharge across the gap in the condenser circuit would have been of the nature of an arc and the high-frequency discharge could not have been obtained without suddenly interrupting this arc by an air blast or in some other mechanical way. I dwell upon this point, since it seems to be the universal notion that the most perfect form of high-frequency discharge can only be obtained by an artificial interruption of the discharge across the gap in the condenser circuit.

Though a discharge through air of 5 inches means a potential difference of about 250,000 volts the physiological effects of the high-frequency discharge are very mild. With an apparatus like the above, having a large condenser, the shock felt by taking hold of both terminals is quite severe, but not at all dangerous to even the life of a cat, as was determined by experiment. If one presents his hand to one terminal, the discharge will go between one-fourth and one-third of the total discharge length between the terminals to reach it, but with the exception of a very slight burn, is not felt. If a piece of metal is held in the hand and presented to the terminal no sensation whatever is noticed. A very severe but probably not fatal shock would be experienced if the current in the primary of the high-frequency transformer were to be passed through the body. It is therefore advisable never to attempt to adjust the discharge gap in this circuit while the machine is in operation.

The limits of this article will not permit of a description of the many striking experiments which can be performed with the high-frequency and high-potential currents. Only a few simple and

easily obtained effects may be mentioned, leaving the reader to pursue this fascinating subject by reading the lectures of Tesla and by his own experimenting.

The chief peculiarity of the high-frequency discharge is its ability to pass to an insulated object from one terminal.

Set the coil working and hold a small piece of metal suspended on a thread within an inch or two of one of the terminals. A fine thread-like discharge will pass to the metal, though this be no larger than a small nail. If the piece of metal is increased in size the thickness of the discharge which passes to it is much increased. Decreasing the distance between the terminals of the coil decreases the discharge to the piece of metal and the distance which it will pass. Thus the discharge to the insulated piece of metal depends for its strength upon the size of the metal piece and upon the air resistance which the discharge between the terminals of the coil has to pass through. This action of the high-frequency discharge finds an important application in regulating the vacuum of X-ray tubes. In Fig. 18 *t t* are the terminals of the high-frequency apparatus, to which the tube *T* is connected. The tube has a projection *v*, in the end of which is some caustic potash and a terminal *k*. *F* is an ordinary paper fan covered with tinfoil to make its surface conducting. *F* is attached by a small wire to *k*. If the vacuum of the tube is very low the potential of the points *n* and *k* is nearly that of the earth, and very little current will flow through the wire *W*. If, however, the vacuum of the tube becomes very high the potential of the points *n* and *k* reaches very high positive and negative values, the changes from positive to negative values occurring with great rapidity. In consequence of this the fan *F* is charged positive and negative alternately with a like rapidity, and a feeble current flows in the wire *W* and through the potash in the neck *v*. This current heats the potash and causes it to give off some of the moisture which is absorbed in it and the vacuum is thereby lowered. The amount of current in the wire *W* can be controlled by closing up the fan, thereby diminishing its surface. Thus by regulating the surface of the fan the vacuum of the tube may be maintained at a point best suited for the production of X-rays. An arrangement of this character will only operate with a high-frequency apparatus.

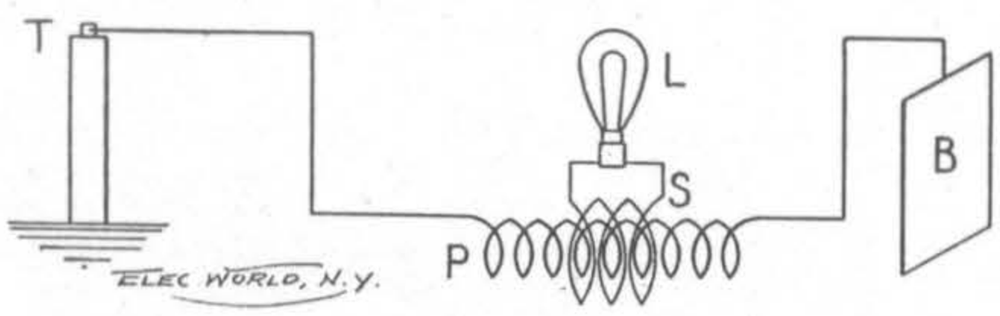


FIG. 19.

Connect a fine wire to each terminal of the high-frequency apparatus. Lead these wires to an insulating support about 10 feet away and adjust the wires so that they are parallel to one another and about 6 inches apart. The current being turned on a beautiful purple sheet of light will fill the space between the wires. In this and other light experiments the room should be darkened to observe the effects at their best. With a powerful apparatus a square metre or more of space may be covered with this purple sheet of electric flame. The effect may be varied by causing a cylinder of light to form between two circular discs of metal connected to the coil with short leads and made to face each other at a distance of a foot or 18 inches apart.

Take a plate of thick glass and paste on opposite sides of it two circular pieces of tinfoil about as large around as a dollar and connect one to one terminal of the machine and the other to the other terminal. The discharge will spread out in streamers some distance over the surface of the glass surrounding the tinfoil discs with a brilliant sheet of light. The high-frequency discharge will not puncture an ordinary window pane at once, but if the two terminals are placed on opposite sides of the pane the discharge spreading out over the surface of the glass will after a short time heat it, when, the glass becoming conducting, the discharge will pass through. The glass shows no hole, but only a spot where it has been melted and again solidified. A 10-inch discharge will in this way eat its way through a cake of paraffin 2 inches thick. If the discharge is passed through a capillary tube the tube becomes brilliantly lighted. If any kind of a vacuum tube is presented to only one terminal of the coil it is quite brightly illuminated. The illumination is much increased by hanging a piece of tinfoil on the free end of the tube. By touching any point of the tube with the finger the illumination of that spot is increased. An incandescent lamp may have its filament brought to incandescence by using only one terminal of the coil in the manner illustrated in Fig. 19. *T* is the terminal of the coil, to which a plate *B* is attached. *P* is a coil of fine wire and around this is wound a coil of a few turns of coarse wire, the ends of which are connected to the lamp *L*. This experiment may be modified in a variety of ways. But the reader who cares to pursue this side of the subject must be referred to Tesla's lectures.

Perhaps of all the striking phenomena of oscillatory currents the most remarkable are the phonomena of impedance which these currents exhibit. To show these arrange matters as shown in Fig. 20. Here *T* is a high-potential transformer, like the one described above. *C* is a condenser, preferably of small capacity. *s* is a double discharge gap, *w* is a heavy copper wire, *l l* are incandescent lamps of high resistance and l_1 l_1 are lamps of lower resistance. When the transformer is working discharges will take place across the air gap *s*, and the high-resistance lamps *l l* will burn more brightly than the lamps of lower resistance, l_1 l_1. These lamps burn in spite of the fact that they are short circuited by the heavy wire *w*. If the lamps are dispensed with and the points p_1 p_1 of the circuit are approached to within a small fraction of an inch of each other while the rest of the circuit to the right of these points forms a loop of some size a discharge will pass between the approximated points of the circuit, which indicates a potential difference between these points of several hundred volts. The wire *w*, which would offer scarcely any resistance to the passage of a direct current, impedes these oscillatory currents as if it were of dry wood.

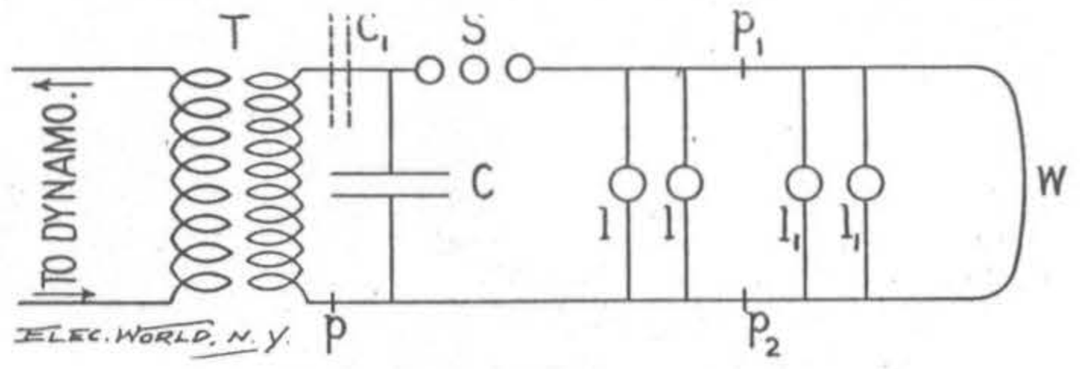


FIG. 20.

These impedance phenomena increase with the frequency of the oscillations, which must be made very great by making the condenser *C* of small capacity and the circuit of wire short. A Leyden jar will answer very well for the condenser and an induction coil may be used for the transformer. In this case, however, a continuous arc is apt to occur at the discharge gap, and as the resistance of an arc is small the condenser will not be highly charged and the oscillations will be poor. This difficulty may be overcome either by blowing out the arc with a moderate blast of air or sometimes by inserting another condenser, C_1 (shown in dotted line), in the circuit. This condenser should have a little greater capacity than the condenser *C*. In this way *C* can become charged to its full capacity while C_1 holds back the current from the transformer so that a flaming arc cannot occur across the discharge gap. In this and other experiments on the oscillatory discharge it is desirable to arrange matters so that the condenser in the circuit carrying the oscillatory discharge is supplied with electricity from the transformer more slowly than it empties itself of its charge when the air of the discharge gap breaks down. In this case the low-resistance arc at the gap is automatically broken. It is hard, however, to say just what conditions are required to produce the best oscillations in any particular case without blowing out the arc. This would be a very useful matter to experiment upon till the principles are determined clearly which govern the automatic interruption of the arc. It may be that adding a suitable ohmic or inductive resistance at the point *P*, Fig. 20, would serve the same purpose as the condenser C_1.

No mention has been made of the use of iron in the coils to increase the inductive action between a primary and a secondary circuit. A simple experiment will show why iron cannot with advantage be used. Take a glass tube and wind on it a few turns of wire and send through this wire, which will correspond to the primary of the high-frequency transformer, an oscillatory current. If now a fine iron wire is inserted in the tube it will in a few seconds become too hot to handle. A large number of wires put in the tube will also become very hot, but not so quickly as one. This

heating of the wires is probably due not only to hysteresis or molecular friction, which resists the rapid reversals of the magnetization, but also to currents which are induced in the metal. Heating of the iron represents a great loss of energy and as the inductive effects can be obtained without it nothing is to be gained by its use.

If the circuits are arranged like that shown in Fig. 1, the condenser being made of about fifteen glass plates a foot square, and the wire w is not over 6 inches long, when the oscillatory discharge is passing the short wire w_1, even if it is as large as No. 14, will become sufficiently hot to burn its insulation, while the No. 32 wire of the transformer supplying the energy to the transformer remains perfectly cool. This indicates that a very large current flows in the condenser circuit when oscillations are taking place. The discharge through the gap is entirely different in character from what it is when no condenser shunts the gap. In the latter case it is a species of flame, having a yellow hue and nearly noiseless. In the former case the discharge becomes very noisy, extremely brilliant and very blue. By waving a stick in the light of the discharge the light is seen to be discontinuous, as the moving stick gives rise to a large number of multiple images. As the balls of the gap are more and more separated the intervals between the separate discharges become greater. This light undoubtedly has powerful actinic properties, and the idea suggests itself that kinetoscopic views might be taken with its aid, especially of moving microscopic objects. An arrangement something like that shown in Fig. 21 might be adopted.

Here S is the discharge gap, giving rise to the brilliant rapidly interrupted light, l is a condensing lens, S_1 is the slide of the microscope containing the moving microscopic object, M the microscope; N_1 N_2 are two rolls, on which a sensitive film runs, B a box to exclude light. The microscope can be easily arranged to throw the magnified image on the film at I. If the film be now rolled from one roll to the other while the rapidly intermittent discharge is passing at S, kinetoscope views ought to be obtained on the film without great difficulty. At any rate the brilliant and intermittent character of the light ought to find useful application in some way similar to the above.

TESLA'S GREAT INVENTION TO BLOW UP HOSTILE WARSHIPS BY ELECTRIC WAVES.

"I am perfecting an electrical engine of war which I am ready to offer to the Government. It is to exert such a terrible force as to disable war ships and powerfully affect vast armies on land at great distances."--TESLA.



HOW TESLA'S OSCILLATOR WILL HURL DEATH AND DESTRUCTION INTO AN ENEMY'S SHIP BY MEANS OF ELECTRICAL VIBRATION.

The Terribly Destructive Electrical Engine of War.

BY NICOLA TESLA.

I AM perfecting an electrical engine of war which I am about to offer to the Government. It is to exert such a terrible force as to disable war ships and powerfully affect vast armies on land at great distances.

If this device acts as effectively on a large scale as it does in my laboratory, the results will be incalculable. When put into operation it will tend to bring war to a speedy end by reason of its unlimited power of extermination

It is the application of the principle of oscillating waves. By this means electrical currents of high potentials can be sent out in all directions and aimed against the vulnerable part of a hostile army or war ship.

Five years ago I discovered that electrical vibrations produced by a novel kind of apparatus, which I have since considerably improved, may be propagated through the earth and through the air, and from experimental data I have calculated that such vibrations can be propelled a distance equal to the diameter of the earth. To effect this an expenditure of energy of about five hundred horse-power is needed, although this estimate may not be quite true, as there are a number of uncertain quantities in the calculation.

I intended to use the principle primarily for the transmission of signals over great distances, but soon I saw that something of greater importance could be accomplished by its use.

The only way to insure the action was to construct apparatus on novel principles which would make possible the production of waves of many hundred times greater intensity.

I foresaw long ago that, despite the strenuous efforts of the President to maintain peace, war would break out and I have concentrated my energies upon perfecting these devices and rendering them immediately available.

This, in fact, is the only reason why I have not, up to this time, offered my services as a volunteer, which I would certainly have done under other circumstances. In this respect, I may say, I have already formed definite plans.

Although the United States have taken energetic measures, and are determined to bring the difficulty to a speedy termination, I fear that the war will be prolonged, and it will become all the more important to apply improved electrical measures and contrivances.

Electricity to Become Our Greatest Weapon.

BY W. J. CLARKE,
General Manager of the United States Electric Agency.

To fire a cannon and blow up a war ship by electricity without any connections may seem miraculous. Yet this is exactly what will be done on a small scale at the Electrical Agency. This spectacle is designed to show the newest and most wonderful development of electricity at the present it seems like this remarkable American achievement may be converted into the great military use by directing it against a hostile fleet or army.

In this way not only may approaching war ships be sunk far out at sea by the medium of torpedoes, but troops on land can repel invasion by firing the batteries of their own and then landing miles away from their exposed guns. All the appliances for this latter purpose have been developed.

At the present stage of development of this art it is necessary to have all the equipment on or close to the cannon or war ship to be acted upon by the electrical waves produced by pressing the key at the distant station, but the results of recent experiments indicate that we should be able to explode the powder in the magazine of our enemy's war ship without any corresponding electrical waves from such ship.

I also believe it possible to totally disarrange the electrical signal system in the ship by the same means and without allowing them to affect our signal system.

It will also be possible for the whole fleet to be at the absolute control with the mere pressing of a key by the Admiral being sufficient to stop or start the engines of every motorized china, to turn their lights on or off and to make them perform many other simultaneous actions

No. 141 East Twenty-fth street, New York, April 20, 1898.

As Described for the Journal by Prof. Garrett P. Serviss.

BY GARRETT P. SERVISS.

The Famous Scientist and Lecturer Describes Tesla's Wonderful Oscillator.

The great naval war between the United States and Spain, which bids fair to make the close of the nineteenth century forever memorable, may, if Mr. Nicola Tesla is able to fulfil his promises, also mark the greatest advance in the art and science of destruction that war has ever known.

For several years now the public has been familiar with the fact that Mr. Tesla, who in many respects is recognized as the foremost master of electrical science now living, has been able to produce by means of an instrument called the electrical oscillator a vibratory force capable of causing brilliant lights to burst forth in the centre of a room without material connection with any electrical instrument, and electro-magnetic phenomena to manifest themselves at great distance from the oscillator and without connection with it by wire or otherwise.

More recently great attention has been aroused by the experiments of Mr. Tesla of Senor Marconi, an Italian; of Mr. W. J. Clarke of this city, and others, in the transmission of telegraphic dispatches without wires. Dispatches of this kind have been sent from a distance of not less than twelve miles.

Electric Vibrations to Shatter Spanish Ships.

Mr. Tesla himself has repeatedly declared that it would be possible to send a current into the earth an electric vibration which would reach the planet Mars, in that if there were people and instruments there to receive it telegraphic communication might be opened up between the earth and that distant world.

The practical principle underlying all of these surprising experiments is one which is now invoked by Mr. Tesla in the invention of an instrument of arms quite as potent and wonderful as some of the devices which have recently been suggested in stories of mimic warfare. But up to the outbreak of the present hostilities with Spain no one had apparently thought of turning this tremendous and mysterious power to other than peaceful uses.

There seems good reason to hope that early in the coming century it might become possible to do away entirely with cumbersome telegraph wires, and that houses and city streets and squares might be filled with artificial daylight without the aid of the elaborate apparatus at present employed.

In fact, almost everybody familiar with the experiments going on in the laboratories of Mr. Tesla and the other great inventors has been looking forward to the dawn of a new era in electrical science, an era which would mark as great an advance in the condition of the world as anything that has ever occurred in its history.

But it now appears these new potencies are to be turned to an unexpected and even terrible employment. In the electrical exhibition to be given in this city the coming week the public will have an opportunity to see the application of the invisible electrical oscillations to the firing of cannon and the blowing up of models of ships. This is wireless telegraphy in a new form.

What the Electrical Oscillator Will Do.

The invisible waves of electricity, radiating from their source, carry not information, but destruction. It will only be necessary, according to the belief of the inventors, to increase the power and range of the oscillations in order that what is done with toy vessels in the exhibition hall may be accomplished with actual ships of war invading the harbor of New York or met in the open sea.

Mr. Goldwin Smith may find that he spoke far more truth than he was aware of the other day when he declared that Spain would be enormously overmatched in this war because the Spaniards had no mechanical genius. In the mechanical application of science it is not self-flattery to say that America stands foremost. Let Mr. Tesla turn his electrical oscillator into an engine of war and America will be more than foremost—there will be no second.

On account of the intense interest which Mr. Tesla's declaration is certain to awaken, it is important to point out how far the application of the electrical oscillator for use as an instrument of war has practically progressed and what remains yet to be done.

From a central station on the shore, or from a ship of war, it is possible to send forth without the aid of wires electrical oscillations in widening circles, like waves in water, to an effective distance of several miles. Anywhere within the radius of such waves an electric spark can be produced by means of a proper instrument or receiver. But an enemy's war ship cannot be expected to contain such a receiver, and particularly not in such a position that a spark from it could reach the ship's powder.

The problem remaining to be solved is how to produce electric sparks within the radius of influence of the oscillatory waves without the existence of a transforming instrument at the receiving end. Both Mr. Tesla and Mr. Clarke, who have worked independently upon this matter, assert their belief that it will be possible to produce such sparks. Not only so, but these gentlemen speak of the problem in a manner which gives reason to hope that the solution will not be long deferred.

Aiming Lightning Bolts at the Enemy.

It may even be possible to focus the oscillations on a particular ship. In that case all danger of exploding our own mines and magazines in the neighborhood would be eliminated.

Supposing this final problem solved, then the situation of affairs will be as follows: An enemy's fleet is seen approaching the harbor. One or more electric oscillators placed in a commanding position on headlands or on anchored ships of war are prepared for their deadly work.

The enemy approaches with ships flying, cleared for action, conscious of overpowering numbers in his favor, confident of success. Perhaps by means of some of the appliances now existing for that purpose he may have cleared the channels of mines, and believes he can enter the harbor in safety.

On come the battle ships, volumes of black smoke rolling backward in the breeze, their guns glittering, a fearful spectacle. They are prepared for hostile shots and expect them, but none comes. The great batteries of Sandy Hook are silent. There is no thunder from the gigantic mortars in the sandpits.

HOW THE OSCILLATOR AND THE ELECTRICAL EXPLODING [illegible]

"The Yankee pigs are afraid to shoot," says the Admiral of the Spanish Squadron, "the mere sight of a Spaniard has terrified them. In two hours, gentlemen of Spain, the great city of the New World will be ours.

But at this moment, unknown and invisible to the Spanish commander and his men, Mr. Tesla has touched an electric button. Likewise invisible, but with the speed of light, the electric oscillations expand over the bay. Unnoticed they penetrate the steel sides of one of the Spanish ships and little blue sparks play through its magazines

Bang! Boom! Bang!

The great steal hull leaps, bursts and is scattered far and wide on the foam beaten waters.

The Spanish commander does not understand what has happened. He believes the magazines of the ship have blown up of their own accord. Perhaps he recalls the insultin words of the Spanish "report" on the blowing up of the Maine, and wonders whether there has not been some "carelessness" on a Spanish warship.

Will Sink Spaniards.

And now suddenly the great batteries at the Hook begin to open. The smoke rolls over Atlantic Highlands; the piercing flashes of the guns are visible even in the broad daylight and the thundering reverberations shake the city miles away. Fort Wadworth and Fort Hamilton are next ablaze.

"The Spanish ships are still advancing," says the bulletins.

"The forts seem unable to sink them."

"They are nearing the Narrows."

"The oscillators! What are the oscillators doing?" cried the maddened crowd. "Will they never sink them? Will they never blow them up?"

But these things the Spaniards are prepared for. Their armoried sides are battered and smashed, but still their vitals are not touched and their great guns reply fiercely to the fire of the forts.

Three million hearts listen to the bellish uproar. "All work is abandoned. Houses and offices are deserted; the thronging multitudes in the streets are crazed with excitment. Ticking telegraph instruments transmit every instant the latest news of the fight and the men at the bulletin boards seem electrified, and write and rub out and write again amid the cheers and the shouts of the inlookers.

"Mr. Tesla has touched an electric button. . . . electric oscillations expand over the bay Bang! boom! bang! . . . . The great steel hall leaps, bursts, and is scattered far and wide on the foam beaten waters."

NIKOLA TESLA.



Nikola Tesla's

REVOLUTION IN

War Telegraphy.

He Believes He Will Be Able to Successfully Operate Without Wires from a Ship 100 Miles Away.

(Copyright, 1898, by Charles Culver Johnson.)

New York, April 30.—Nikola Tesla has made an instrument for telegraphing without wires by which a vessel a hundred miles from our coast will be able to send messages to the shore. Mr. Tesla tells me that he is ready to offer this invention to the Government for use in war. Its advantages are easy to understand. There has been much talk of telephoning to moving ships and some discussion of the feasibility of sending out a cable repair ship to pick up one of the great ocean cables and send us messages telling of the approach of an enemy.

The telephoning would be over a short range and the cable ship would be confined to observation along the line of cable communication. The wireless telegraph would enable any ship within 100 miles of a coast station to send messages to the shore. The ships of a fleet lying off Havana could receive their instructions from the Navy Department by way of Key West and telegraph to Secretary Long and the President just what was happening in Cuba.

Mr. Tesla is not prepared to make public the details of his invention. He always gives his conclusions to the world through articles in a scientific periodical, which he writes with the utmost care. But he said to me yesterday: "You may say that I have succeeded in making a machine a thousand times more powerful than any ever made before. With it I expect to send messages without wires over long distances—probably 100 miles."

I asked Mr. Tesla if his invention was so near perfection that it might be of use in the war with Spain.

"I think so," he said. "If it can be used, I have no desire for compensation. It is not for sale. But I will freely offer it to the Government. One reason I cannot tell you just what my machine is, is that if it can be used on our ships it will give us an advantage; and I shall be proud to have been of so much use to my country."

"Then you consider yourself a good American, Mr. Tesla?"

The inventor threw up his hands and looked incredulous at the suggestion of doubt.

"I a good American?" he said. "I was a good American before I ever saw this country. I had studied its government; I had met some of its people. I admired America. I was at heart an American before I thought of coming here to live.

"What opportunities this country offers a man! Its people are a thousand years, yes, a thousand years, ahead of the people of any other nation of the world. They are big, broad-minded, generous. I could not have accomplished in any other country what I have done here. I was in France for a time. I tried to work out some of my ideas there. But I could get no encouragement. I could find no one to back me. When I came here, I met men immediately who were ready to help me to develop my ideas. The American people are quick to hold out a helping hand and to give recognition. Yes, I am as good an American as there is. I have nothing to sell to the Government of the United States. If it needs my services in any way it is welcome to them.

"Of this invention I can tell you that it is the result of more than five years of hard work. The experiments, which have been carried on in Europe and which have attracted so much comment, follow the lines that I laid down some years ago. For a long time the experiments abroad did not follow these lines, and they were not successful. Signals could be sent, but only short distances. When they returned to my system they found that they could send messages to a much greater distance.

"Five years ago in the course of a lecture, speaking of the transmission of intelligible signals or perhaps even power to any distance without the use of wires, I said: 'I am becoming daily more convinced of the practicability of the scheme; and though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realized, yet I think that all consider the development in recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day.

"The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb by means of powerful machines the electrostatic condition of the earth and thus transmit intelligible signals and perhaps power.

"In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why then not try to avail ourselves of the earth for this purpose? We need not be frightened by the look of distance. To the weary wanderer counting the mile posts the earth may seem very large, but to that happiest of all men, the astronomer, who gazes at the heavens and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician, for when he considers the speed with which an electric disturbance is propagated through the earth, all his ideas of distance must completely vanish.'

"I have been working on that problem ever since. For a long time I experimented with delicately adjusted instruments, but I found them unreliable. I would send signals for a few blocks and then a strong current of electricity somewhere in the neighborhood or some atmospheric condition would interrupt them.

"After a time I saw that this would not do. I must have something reliable, then I set about making a machine which would give me more powerful vibrations. I have succeeded beyond my expectations. I have made a machine which is a thousand times as powerful as any now known. With it I could stop every electric current—every telegraph or telephone in this neighborhood." With a sweep of his arm the inventor suggested that populous district which surrounds the building in Houston Street, where his laboratory is.

"But could not some one else destroy the effectiveness of your signals with a counter-current?" I asked.

Mr. Tesla hesitated and answered rather slowly: "Yes, yes, he could. But he'd have to be a devil of a fellow." Which ingenious statement I interpreted as meaning that the "other fellow" would have as strong a machine as that of Mr. Tesla.

Mr. Tesla told me that the new machine filled very little space. "It is not so large as that table," he said, indicating a very small one which stood against the wall, covered with scientific magazines.

"It could be put aboard a ship without inconvenience, then?"

"Certainly."

"And how about the current to operate it?"

It could be had from a small dynamo such as they have aboard all the ships the navy."

Mr. Tesla says that his original theory concerning the transmission of signals, and possibly of power, without wires had been confirmed by his experiments. On this subject he said some years ago:—

"A point of great importance would be first to know what is the capacity of the earth, and what change does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair possibility that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation. If it be a charged body insulated in space its capacity should be extremely small, less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may retain an opposite charge.

"Then the capacity might be incomparably greater. In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is by means of electrical resonance. If ever we can ascertain at what period the earth's charge when disturbed oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric currents.

"One of the terminals of the source would be connected to earth, as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the water conducting air strata, or free space, contain an opposite charge and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible, and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body and watching for the disturbance at various neighboring points of the earth's surface, resonance might be detected.

"Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do and a proper electrical oscillator would have to be produced, and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface."

At the time he made this statement, Mr. Tesla proposed the following plan for signalling without wires:

Assume that a source of alternating currents be connected with one of its terminals to earth (conveniently to the water mains) and with the other to a body of large surface, P. When the electric oscillation is set up there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to or diverging from the point C, where the ground connection is made. In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion.

Since the body P is insulated in order to displace a considerable quantity, the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source S will set up, the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration at least of a certain low period upon the earth by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured.

At another place Mr. Tesla said that if it was at all possible to transmit signals through the earth or its environing medium, "distance does not mean anything." In fact, he not only suggested the wireless telegraph first, but he first suggested the means by which all after results have been achieved, and the fact that they could be made to cover great distances. The most that is claimed for Marconi by scientists is that he has succeeded in telegraphing without wires for a greater distance than any one before him. But if Mr. Tesla's new machine accomplishes what he confidently predicts, Marconi's laurels will be plucked very quickly from his brow.

What makes the new machine more important is its superiority to the influence of others. A recent writer on Marconi's system said that "in war telegraphy would become impossible as soon as a hostile spark generator should cause a permanent disturbance of the characters." If Mr. Tesla is not mistaken only "a devil of a fellow" will be able to disturb his signals; and if the Tesla system can be kept a secret there is no likelihood that any disturbing element will enter into the transmission of signals by our army and navy during the trouble with Spain.

CHARLES CULVER JOHNSON.

TESLA PERFECTING A WAR ENGINE.

Electrical Device to Destroy the Enemy's Fleets and Armies.

IS CONFIDENT OF SUCCESS.

He Will Offer the Destroying Agency to the Government—Another Scientist Comments Favorably on the Inventor's Scheme.

BY NICOLA TESLA.

REPUBLIC SPECIAL.

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BY PROF. SERVIS, SCIENTIST.

The great naval war between the United States and Spain, which bids fair to make the close of the Nineteenth Century forever memorable, may, if Mr. Nicola Tesla is able to fulfill his promise as stated above, also mark the greatest advance in the art and science of destruction that war has ever known. For several years now the public has been familiar with the fact that Mr. Tesla has been able to produce by means of an instrument called the electrical oscillator a vibratory force capable of causing brilliant lights to burst forth in the center of a room without material connection with any electrical instrument, and electro-magnetic phenomena to manifest themselves at a great distance from the oscillator and without connection with it by wire or otherwise.

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Almost everybody familiar with the experiments going on in the laboratories of Mr. Tesla and the other great inventors has been looking forward to the day of a new era in electrical science, an era which would mark as great an advance in the condition of the world as anything that has ever occurred in its history.

But it now appears these new potencies are to be turned to an unexpected and even terrible employment. In the electrical exhibition to be given in this city the coming week the public will have an opportunity to see the application of the invisible electrical oscillations to the firing of cannon and the blowing up of models of ships. This is wireless telegraphy in a new form.

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On come the battleships, volumes of black smoke rolling backward in the breeze, their guns glittering—a fearful spectacle. They are prepared for hostile shots, and expect them, but none comes. The great batteries of Sandy Hook are silent. There is no thunder from the gigantic mortars in the sandpits.

"The Yankee pigs are afraid to shoot," says the Admiral of the Spanish Squadron; "the mere sight of a Spaniard has terrified them. In two hours, gentlemen of Spain, the greatness of the New World will be ours."

But at this moment, unknown and invisible to the Spanish commander and his men, Mr. Tesla has touched an electric button. Likewise invisible, but with the speed of light, electric oscillations expand over the bay. Unnoticed they penetrate the steel sides of one of the Spanish ships, and little blue sparks play through its magazines.

Bang! Boom! Bang! The great steel hull leaps, bursts and is scattered far and wide on the foam-beaten waters.

The Spanish commander does not understand what has happened. He believes the magazines of the ship have blown up of their own accord. Perhaps he recalls the insulting words of the Spanish "report" on the blowing up of the Maine, and wonders whether there has not been some "carelessness" on a Spanish warship.

And now suddenly the great batteries at the Hook begin to open. The smoke rolls over Atlantic Highlands; the piercing flashes of the guns are visible even in the broad daylight, and the thundering reverberations shake the city miles away. Fort Wadsworth and Fort Hamilton are next ablaze.

But these things the Spaniards are prepared for. Their armored sides are battered and smashed, but still their vitals are not touched and their great guns reply fiercely to the fire of the forts.

Three million people listen to the hellish uproar with hearts beating at their throats. All work is abandoned. Houses and offices are deserted; the thronging multitudes in the streets are crazed with excitement. Ticking telegraph instruments transmit every instant the latest news of the fight and the men at the bulletin boards seem electrified, and write and rub out and write again amid the cheers and shouts of the onlookers.

"The Spanish ships are still advancing," say the bulletins.

"The forts seem unable to sink them."

"They are nearing the Narrows."

"The oscillators! What are the oscillators doing?" cried the maddened crowd. "Will they never sink them? Will they never blow them up?"

Already stray shots are coming across the sandhills and falling in the outskirts of Brooklyn. The confidence with which the assailed city had waited the attack in the morning, when the news of the approach of the enemy's fleet was heard, is rapidly turning to despair.

But the oscillators are all right. There has been a temporary disarrangement, but the trouble is rapidly remedied, and presently cut through the thickening battle smoke steal those invisible undulations, thrilling through the air, touching the red and yellow emblems of Spain, insolently flaunting from the mastheads of the ships, but not disturbing them. They have a deadlier mission. Through the hulls they penetrate, and once more little blue flames flicker among the magazines. And now not but one, but half a dozen Spanish warships suddenly leap, as the Maine leaped, and, like her, go to the bottom. But they have gone down in a fair fight.

The battle is over,

The Spanish armada has been blown into space.

Such is the picture of what we should expect to behold provided the inventors who have this problem in hand are able to achieve all that they now confidently expect to do.

Transmission

POLYPHASE INDUCTION MOTORS.

ALTERNATING current motors, although developed and perfected much later than direct current motors, were soon recognized to possess such great practical advantages that they have by rapid strides largely supplanted the latter in many important applications. They have, in fact, done more; being advantageously used in places where electric power could not be previously employed by reason of some of the inherent characteristics of direct current apparatus.

Alternating current apparatus, owing to the field which it originally occupied, was for a long time looked upon by many as applicable only to the transmission of power over long distances. The extreme simplicity and flexibility of the alternating system, however, added to the attractions of the polyphase motor, have led to the use of polyphase apparatus for the distribution of power in factories, mills, mines, and other industrial establishments where the distances are comparatively short. A large factor in the present popularity of alternating current power is due to the high state of perfection to which the improved polyphase motors have been brought; yet despite their practically exclusive use on all power transmissions, a knowledge of their mode of construction and principles of operation are not commonly understood. To give needed information on these points may best be done by describing distinctive forms of apparatus, for which the type "C" motor of the Tesla polyphase system, as brought out by the Westinghouse Electric and Manufacturing Company, is first selected for illustration and description. Tesla polyphase induction motors have two main elements; viz.: the primary, which is directly magnetized by the currents supplied from the line circuits; and the secondary, in which low potential currents are induced by the action of the primary. The windings of the primary are so arranged that when supplied with alternating currents differing in phase; *i. e.*, polyphase currents, a rotating magnet field is produced. This field acts upon the secondary winding and induces currents therein. Rotation is produced by the action between the secondary currents and the rotating field of the primary. The principle upon which motors of this class operate was discovered by Mr. Nikola Tesla, whence their name.

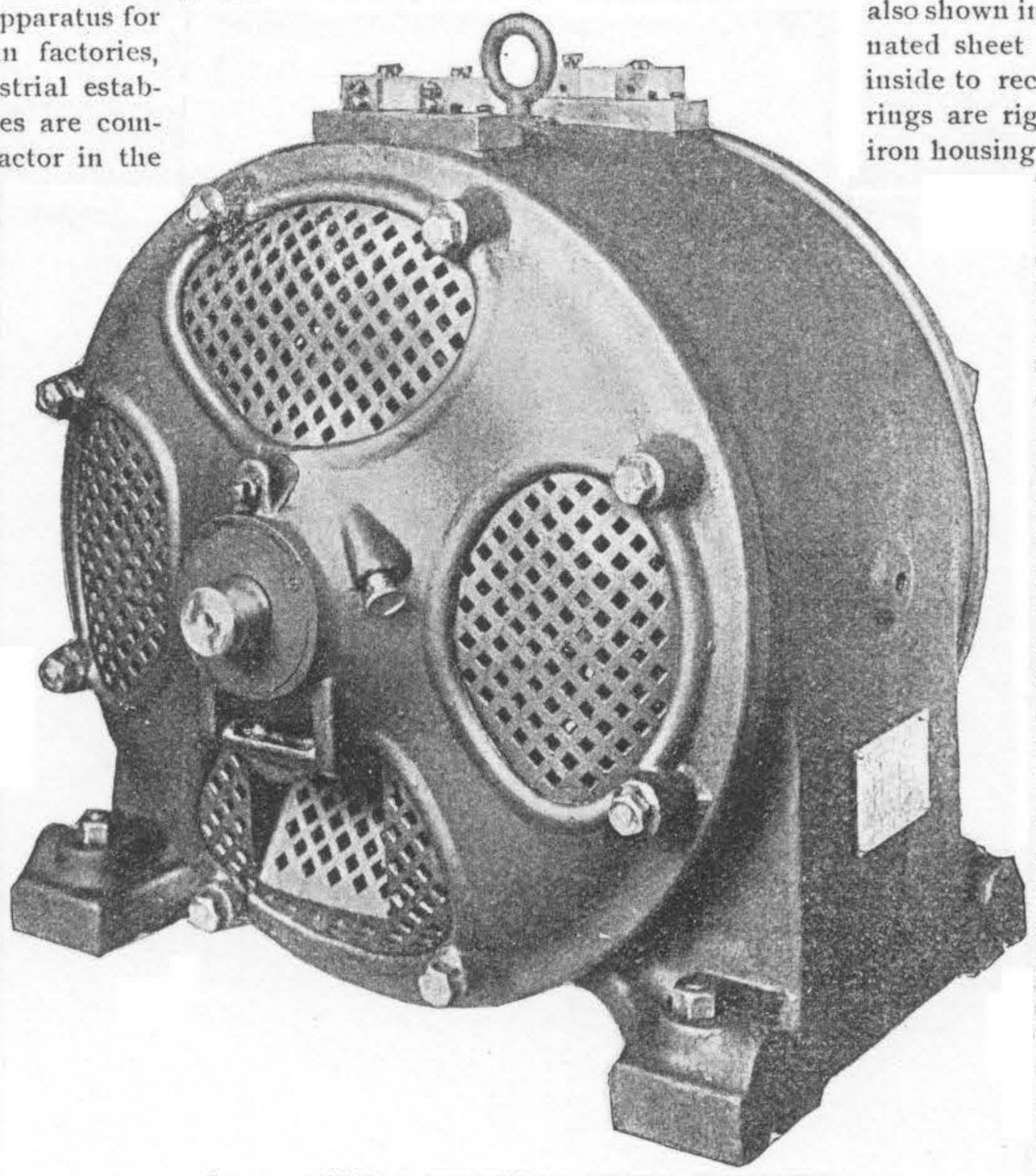


FIG. 1.—A TESLA INDUCTION MOTOR COMPLETE.

The revolving element of an induction motor may be either the primary or the secondary. In the motors described herein, the primary is stationary and the secondary revolves; hence, for purposes of comparison, the primary may be regarded as corresponding to the field magnets, and the secondary as corresponding to the armature of a direct current motor.

The form of the motor is shown in the accompanying illustrations, among which is that of a complete machine as shown in figure 1. It will be noted from the illustrations, that from a mechanical standpoint the induction motor is reduced to the simplest possible elements; *i. e.*, a stationary part, permanently connected to the main circuits, and a rotating part having no electrical connection with any other portion, and absolutely no electrical contacts or adjustments; in fact, no sliding or working friction except that of the shaft in the journals. It will therefore be observed that as a piece of moving machinery this type of motor is designed and built to operate for long periods of time with but a very small amount of cleaning and an occasional renewal of oil.

The hollow cylindrical frame of cast iron shown in figure 2, in which the primary is mounted, forms a base for the machine and also supports the two brackets carrying the self-oiling bearings. Ordinarily, perforated iron plates fitted into these brackets protect the rotating element and permit excellent ventilation, but they may be replaced by solid plates when it is desired to make the motor absolutely dust-proof. It will be noted that the housing compietely encloses the primary and secondary elements, and protects them from any external damage. The primary element, also shown in figure 2, is built up of laminated sheet iron rings, slotted on the inside to receive the conductors. These rings are rigidly supported by the cast iron housing which encloses the primary.

The conductors are machine wound coils, which are thoroughly insulated before being placed on the core. The secondary, which is shown in figure 3, is built up of laminated steel discs, made of a high grade of metal, mounted upon an open spider, and carrying in slots around the periphery the rectangular copper bars of the winding. The construction is such that the conductors cannot be thrown out by centrifugal force, the whole secondary being extremely simple, rigid and durable. Its conductors are all purposely short circuited, therefore it is evident that no accidental short circuit can possibly occur that will cause injury to the windings, and the danger of interruption to service from this cause, always a menace in direct current apparatus, is absolutely eliminated. The construction is also practically indestructible from heating, raising of coils, or mechanical injury in handling. This is undoubtedly the simplest and most durable form of secondary ever devised. Moreover, the end brackets may be bolted to the frame in any one of four different positions, so that the oil chambers in the brackets will be in the proper position whether the frame is bolted to the floor, the wall, the ceiling, or at a forty-five degree angle.

The type "C" motor is made with a variable speed for cranes, elevators, hoists, and similar classes of work, the variable speed motor being especially designed to give a proper speed curve, and is supplied with suitable regulating devices when necessary.

The power factor of an induction motor is found by dividing the real horse-power applied to the motor, by the apparent applied horse-power.

The energy supplied to a direct current motor is found by multiplying the current by the voltage; but in the case of an alternating induction motor, this product, designated the "apparent' energy, is greater than the real energy on account of the fact that

the current in such large motors "lags" behind the electromotive force, and hence the useful effect is less than would be the case if the current and electromotive force were coincident in phase. The current, however, exerts its full heating effect upon the conductors, and the excess current causes a corresponding drop of potential in the circuit. It is therefore desirable to reduce the lag as much as possible; *i. e.*, to bring the real and apparent energies

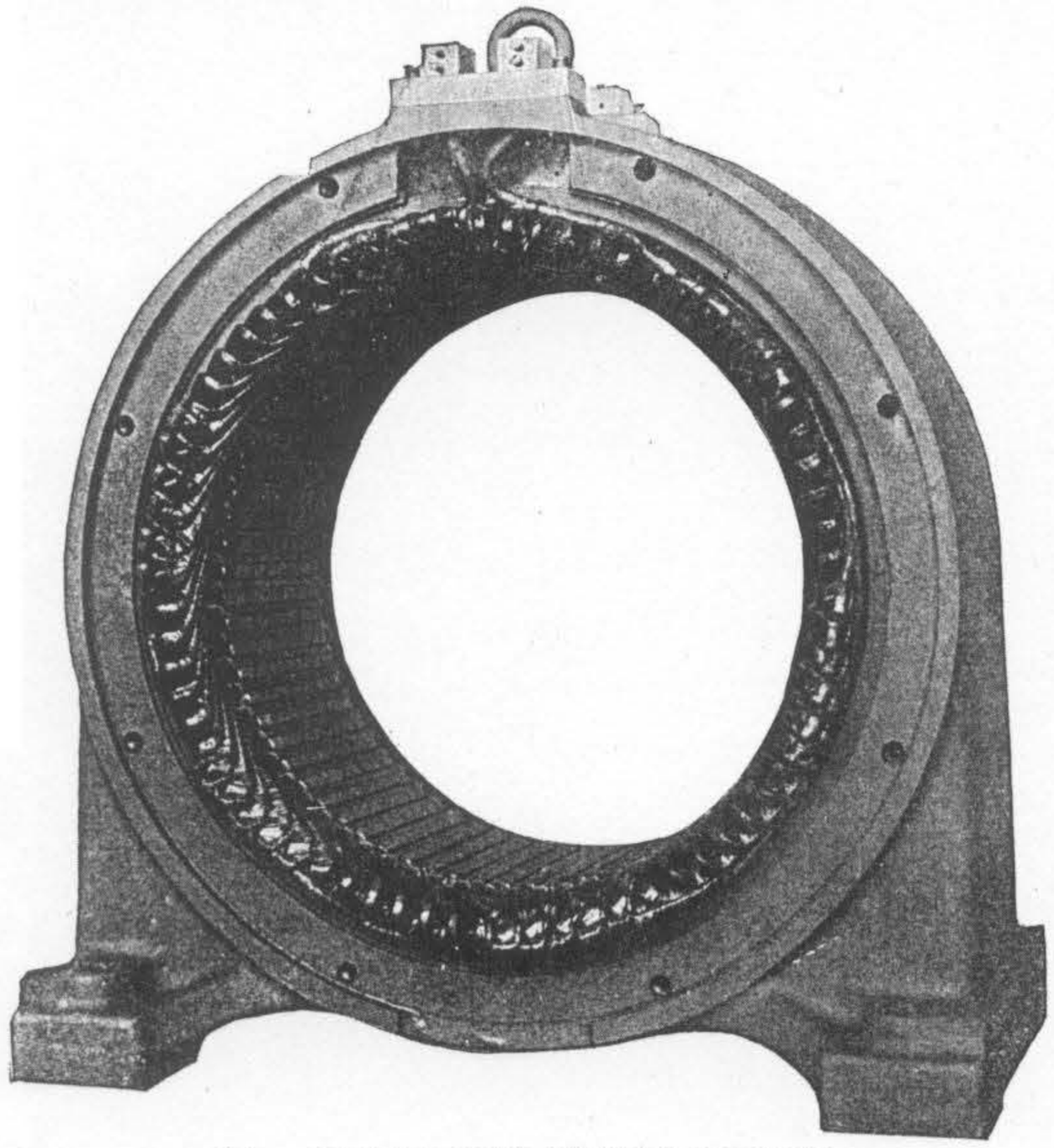


FIG. 2.—PRIMARY, WITH WINDING COMPLETE.

to coincide as near as we can. If it were possible to entirely eliminate the lag, the real and apparent horse-power would be equal, and the power factor would be 100. Special attention has been given to this matter in the designing of these machines, with the result that their power factors are very high.

The designs and principles governing the construction of the type "C" motor are fortunately favorable to a particularly attractive feature; *i. e.*, the maintaining of a high and almost constant efficiency from full load to one-half load. Under the conditions which prevail in a very large proportion of electric motor service, the motors are operated much of the time at considerably less than their full rated capacities. With the type "C" motor, therefore, by maintaining a constant efficiency, there can be secured to the user an all day or average efficiency very much above that heretofore possible, with either direct or alternating current motors. The variation of speed between no load and full load is small, being less than that found in direct current motor practice.

A polyphase induction motor may be started by connecting it directly to the circuit with an ordinary switch, and small motors are so started in practice. The larger motors, however, are started on a reduced voltage, the full electromotive force of the circuit not being applied until the motors have reached a considerable speed.

In the Westinghouse system, the low electromotive force is ordinarily obtained by the auto-starter, shown on page 37, and which consists of a double throw switch mounted on a cast-iron box in which are two auto-converters. When the switch is closed in the position shown in the cut, the auto-converters are connected across the circuits and deliver a low electromotive force to the motor, but when the switch is thrown in the opposite direction the auto-converters are cut out and the motor is connected directly to the circuit. Three or four wires are connected directly to the auto-starter, and the same number of wires connect the auto-starter to the motor. The auto-converters are arranged with loops so that one of several voltages may be applied for starting, thus adjusting the torque for the work the motor has to do. Thus a motor operating a machine having great inertia may be made to give a correspondingly strong starting torque, or one driving a light device may be adjusted for extremely light starting torque with a corresponding reduction of current.

On two-phase circuits in which there are four wires, different electromotive forces exist between the different pairs of wires, and in some cases this affords a simple way of obtaining a low electromotive force for starting. A simple double throw switch is required, by which the low electromotive force for starting is obtained by one connection, and the full electromotive force for running by throwing the switch to the opposite position.

When it is necessary to install motors in a grain elevator, a woolen mill, a mine, or in any place exposed to inflammable gases or floating particles, or not easily accessible, the starting devices may be located at a convenient point more or less remote from the motor, thus eliminating all danger from fire due to possible sparks.

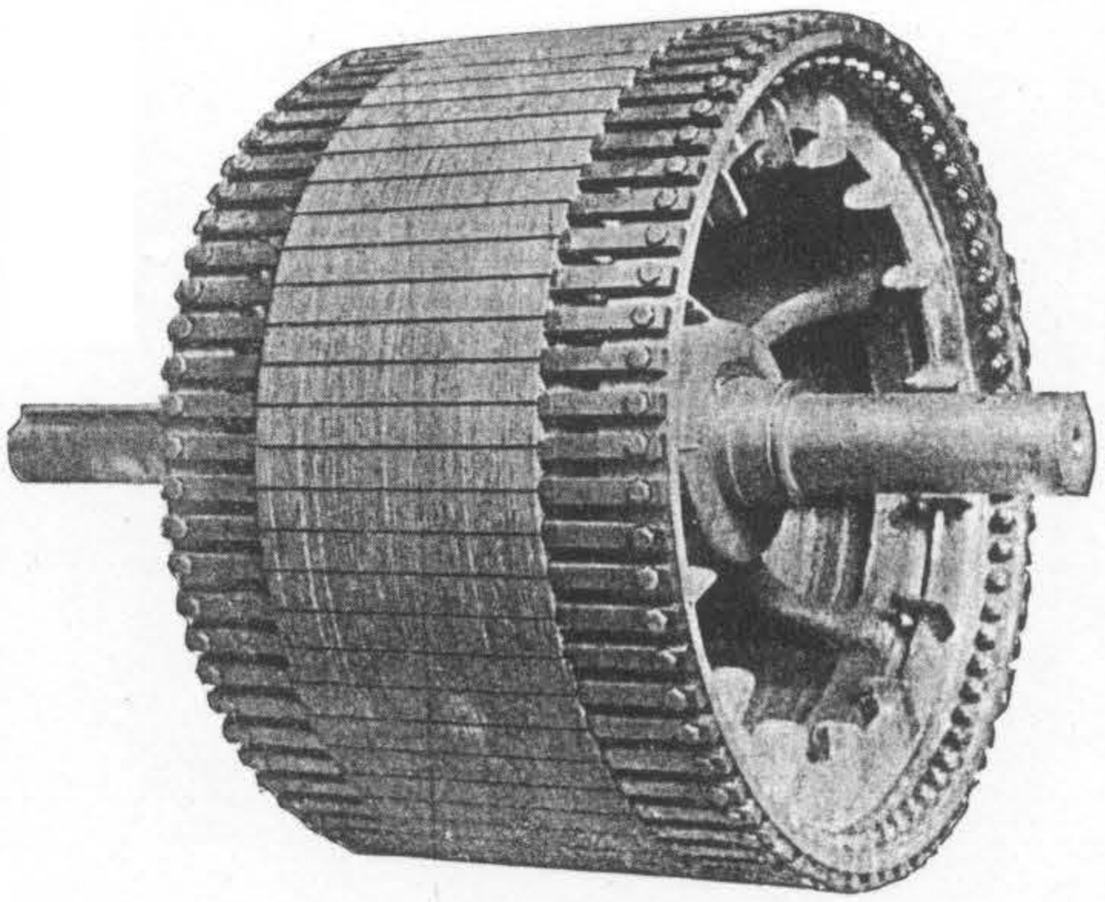


FIG. 3.—SECONDARY COMPLETE, SHOWING COPPER BARS CONNECTED TO END RINGS.

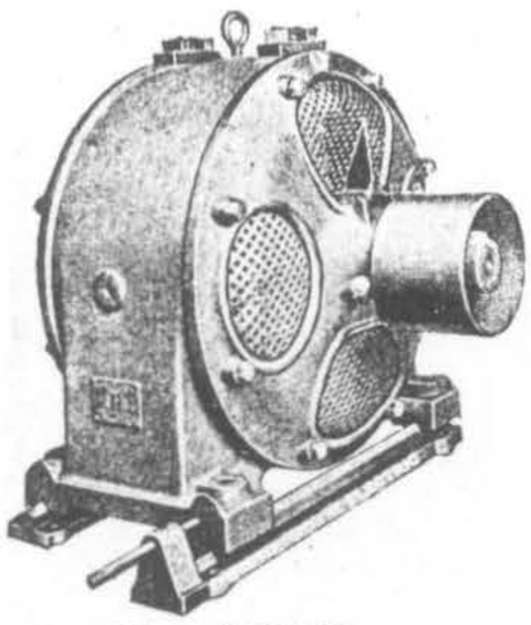
Tesla and Old Age.—According to the *Public Health Journal* of New York, Nikola Tesla has made a somewhat amusing contribution to medicine. He has found a way of warding off the ravages of time from the surface of the body. This is of especial interest to the ladies. He tells us that between 4,000 and 7,000 microbes fall on every square foot of the human body and settle there in 24 hours. If we could see the surface of the body with a microscope, we would see it swarming with millions of germs. This would not only, he says, be a hideous sight (he evidently pictures them in his mind's eye with heads and long claws), but they would be seen to be eating the skin and destroying its freshness at a rapid rate. The reason that old people are yellow and wrinkled is because the microbes have for years fed upon their skins. Tesla recommends, in the first place, thorough washing of the skin once a day with alcohol, and has invented a battery which shoots the microbes off into space with great violence, sometimes to the distance of 4ft. or 5ft. If this discovery of Tesla's leads people to wash who would otherwise not do so, it would be a boon indeed. We are afraid it will appeal more to those over-sensitive people who are already tottering under the weight of many more or less senseless fads.

WESTINGHOUSE ELECTRIC — THE NAME OF WESTINGHOUSE IS A GUARANTEE

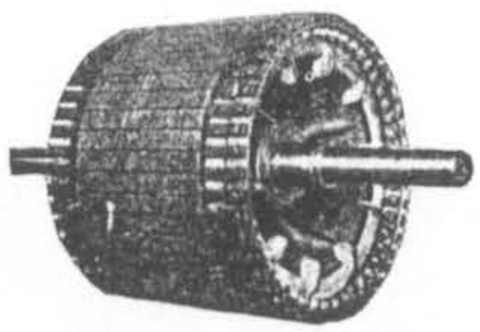
I-
-deal
in
Simplicity
of
Construction
and Operation

Builders of the Standard Induction Motors

Tesla Polyphase Induction Motor Type "C"



Type "C" Motor, complete.



Revolving Secondary, Type "C" Motor.



Stationary Primary. Type "C" Motor.

Westinghouse Electric
& Mfg. Co., Pittsburg, Pa.

have built more
H. P. Capacity in Polyphase Motors, as well as
in Polyphase Generators, than
All other Makers combined.

"Their work is giving perfect satisfaction."
Albert Vicker's Article, Electrical World, Feb. 12-'98.

New York, Atlanta, Austin, Boston, Buffalo, Chicago, Cincinnati, Philadelphia, St. Louis, San Francisco, Syracuse, Tacoma. Denver, Mountain Electric Co. For Canada, Ahearn & Soper, Ottawa. For Mexico, G. & O. Braniff & Co., City of Mexico. Westinghouse Electric Co., Ltd., 32 Victoria St., London.

EXPERIMENTS ON INDUCTION COIL CONDENSERS.

BY ALFRED G. DELL.

The following experiments were made to determine the relation between an induction coil and its condenser.

The apparatus used consists of an induction coil and a separate interrupter with a condenser in its base, so arranged with a separate contact that the breaks were made entirely independent of the battery strength passing into the induction coil, a separate cell of battery being used to run the interrupter. The separate interrupter has switches arranged to throw in or out of use the condenser connected to it. The induction coil has an interrupter and condenser of its own, but in making these experiments its interrupter was locked so it could not move, and, of consequence, its condenser was out of use.

I tried the arrangement as described above, and found I obtained from the secondary of the coil fair and vigorous sparks when the interrupter was in use, and the sparks at break of the primary were very small. On throwing out of use the condenser, I found exactly the opposite; the sparks from the secondary were very minute, and the sparks at the break of the primary were large and bright. I attached in the circuit of the secondary a Leyden jar in shunt with the spark gap, and then, after removing the jar, I attached a Tesla coil. In both cases the condenser was without any effect; the electrical energy received being the same whether the condenser was in or out of use.

I also attached a double cathode Crookes tube to the Tesla coil, and failed to distinguish from the light received in a fluoroscope whether the condenser was in or out of use.

I attached several very sensitive Geissler tubes, one at a time, and examined the anodes and cathodes, striæ, and intensity of the light obtained. I failed to discover any difference in any respect, whether the condenser was in or out of use. It is evident that if there are any discharges at make of interrupter, they are not affected by the condenser being in use; neither has the condenser any influence on the striæ, nor the intensity of light obtained.

I now come to experiments where I found a difference in the phenomena. I attached to the secondary of the coil a Geissler tube made of six feet of glass tubing one-quarter of an inch in diameter, wound into a spiral of five and one-half inches of diameter; there being no bulbs around the electrodes; of consequence the discharges were confined to rather small spaces. The tube is inclined to be refractory to quite small discharges. I having found sparks too small to light it up fully.

With this tube I discovered a slight difference in the light attained, but not in the striæ or the anode and cathode. I, as a last test, attached two Crookes tubes. The first used would not receive the discharges when the condenser was out of use, nothing appearing but a faint glow, which I attributed principally to the discharges from the electro-static field surrounding the connections of the tube.

The other tube contains a lower vacuum, it being more suitable for a

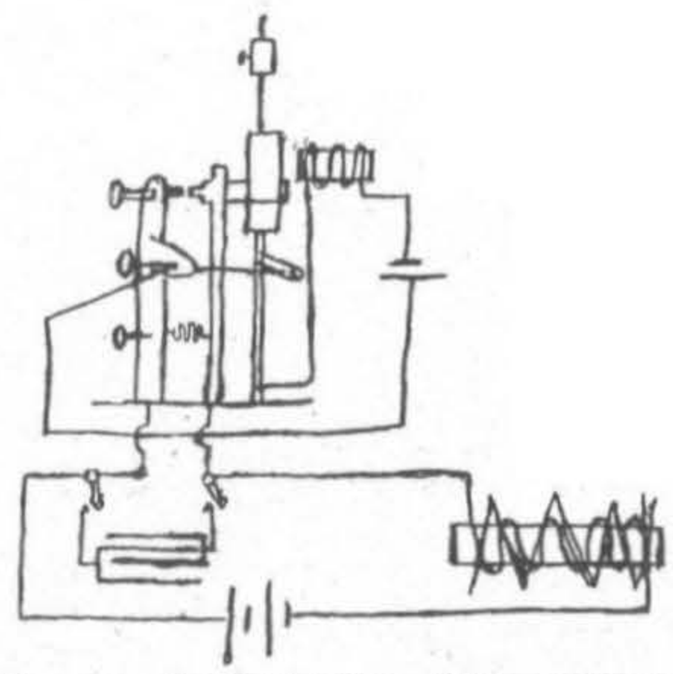


DIAGRAM ILLUSTRATING "EXPERIMENTS ON INDUCTION COIL CONDENSERS."

static machine, but with a spark-gap in series with the tube and coil, it gives X rays of considerable strength when the spark-gap is at its full length to hold the sparks, the X rays varying in strength with the length of spark-gap. This tube lighted up brightly with condenser out of use, but on opening a spark-gap in series I had, in a manner, no spark and the light disappeared. My deductions from the above experiments are that the condenser destroys the spark at break of the primary, which is necessary to preserve the platinum points and makes the spark in the secondary. If the arrangement used does not require a spark larger than the one obtained without condensers to break across an air space, the condenser is entirely without effect in the results obtained. Where an air-space has to be crossed the spark must be of sufficient length to pass it or there will be no discharge. I have noticed, sometimes, that in experimenting with Crookes tubes and a fluoroscope there would be a sudden dark space, a discharge having failed to pass, and I also noticed at such failures the spark at the break of primary was very bright.

From the above experiments, I think the cause of the dark spaces is fully explained. The extra discharges at break do not pass into the condenser; the dark discharges are the same as if there was no condenser in use. With Geissler tubes, that are sensitive, there are no dark spaces seen.

I will now give an experiment somewhat different from the above, hoping I will be pardoned for the digression. I have often noticed that when an interrupter, attached to the core of an induction coil, was in operation, and a spark-gap was in circuit with the secondary of the coil, that if the spark-gap was closed, or very nearly so, there was an interference of some nature with the running of the interrupter. I energized a coil from an exceedingly weak cell of battery, and found that the interrupter would run as long as the spark-gap was well open, but as soon as closed the interrupter would stop.

I do not propose to theorize concerning it; I only give it as a peculiar experiment. I depend upon experiments almost entirely for my information, believing they are the only reliable criteria.

If my experiments are of any benefit, my object in publishing them has been obtained.

TESLA AND OLD AGE.

NIKOLA TESLA has made a somewhat amusing contribution to medicine. He has found a way of warding off the ravages of time from the surface of the body. This is of especial interest to the ladies. He tells us that between 4,000 and 7,000 microbes fall on every square foot of the human body and settle there in 24 hours. If we could see the surface of the body with a microscope we would see it swarming with millions of germs. This would not only, he says, be a hideous sight (he evidently pictures them in his mind's eye with heads and long claws), but they would be seen to be eating the skin and destroying its freshness at a rapid rate. The reason that old people are yellow and wrinkled is because the microbes have for years fed upon their skins. Tesla recommends, in the first place, thorough washing of the skin once a day with alcohol, and has invented a battery which shoots the microbes off into space with great violence, sometimes to the distance of four or five feet. If this discovery of Tesla's leads people to wash who would otherwise not do so, it would be a boon indeed. We are afraid it will appeal more to those over-sensitive people who are already tottering under the weight of many other more or less senseless fads.



Concentration of Power by Electric Transmission at Taunton, Mass., Tack Works.

ONE of the most forcible of the advantages of electrical transmission of power is that this method often makes it possible to combine two or more steam plants into one, greatly diminishing the cost of labor and supplies. Such an advantage appeals especially to the mill owner, who may operate shafting in several buildings and departments by separate sources of power. A conspicuous example of a wasteful arrangement is in the works of one of the largest locomotive shops of the country, where part of the plant is operated by water power, part by steam power, and part by compressed air, the latter necessitating an extra engine and compressor.

Electric transmission, and notably the polyphase system, as developed by the Westinghouse Company, has made it possible to centralize the power in such shops. When Lieut. L. O. Garrett took charge of the affairs of the Atlas Tack Co., of Taunton, Mass., as manager, he instituted a thorough investigation as to the power required for the various classes of tack making machinery under normal conditions. The mills of this company at Taunton are three in number, located from 800 to 1,200 feet apart, and were until recently operated by three separate steam plants, with the accompanying wastefulness incident to small units. It was found that owing to variations in the amount of power required from day to day for the different classes of work, the duty of the three steam plants could be easily performed by a single steam plant of two-thirds their united capacity.

So large a saving in coal and labor as was expected from this arrangement induced Lieut. Garrett to engage the services of Mr. T. W. Sprague, of Boston, Mass., to investigate jointly with him the various systems of transmission. The parties interested inspected personally a number of the principal polyphase plants among the New England mills, and finally selected the Westinghouse three-phase system, 3,600 alternations, as best adapted to the work of the Atlas Tack Co. This system, in connection

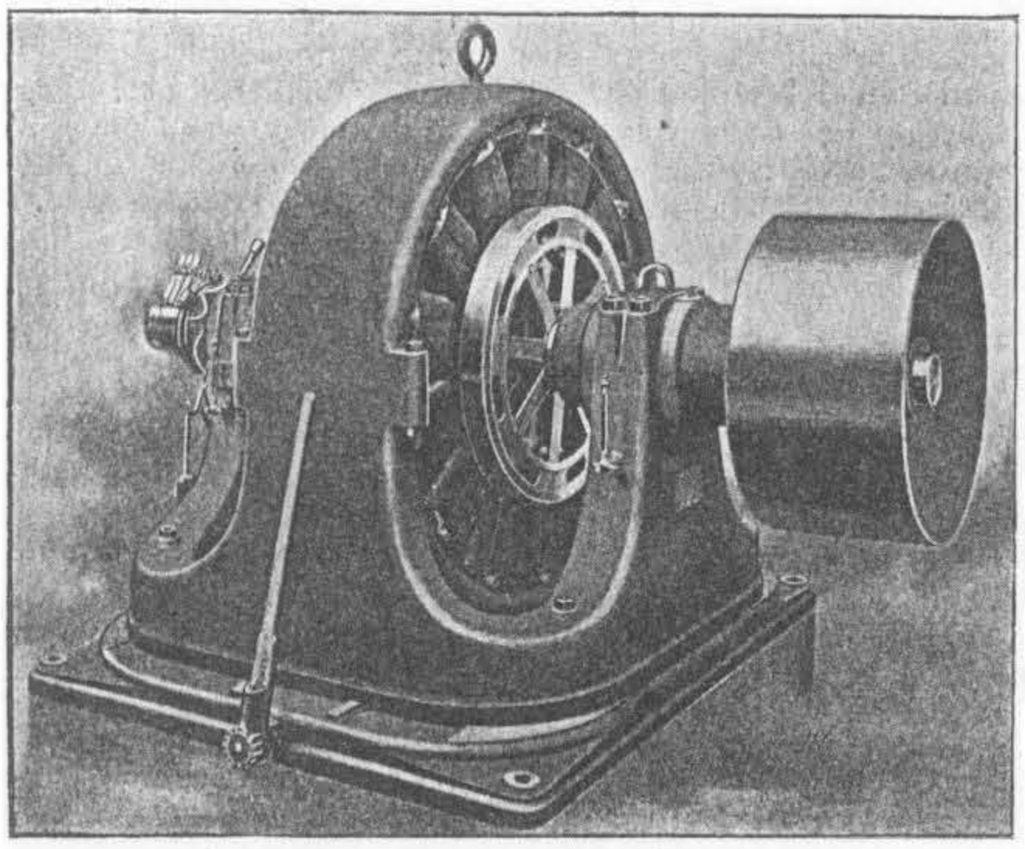


FIG. 1—150 K. W. WESTINGHOUSE GENERATOR.

with the Tesla "Type C" motors, made by the Westinghouse Electric and Manufacturing Co., has attained marked success in every instance in which a plant has adopted it, and the alternate current motor, though developed later than the direct current motor, has been favorably received in all such installations.

The Atlas Tack Co. are to use a 150-kilowatt Westinghouse generator, shown in Fig. 1, which will operate 9 Tesla induction motors of the above type, shown in Fig. 2, ranging from 3 to 50 horse power, in the various mills. The gas lighting system of the mills will be replaced by about 1,000 incandescent lights.

The company instituting these changes is one of the most progressive of manufacturing concerns, employing over 500 men,

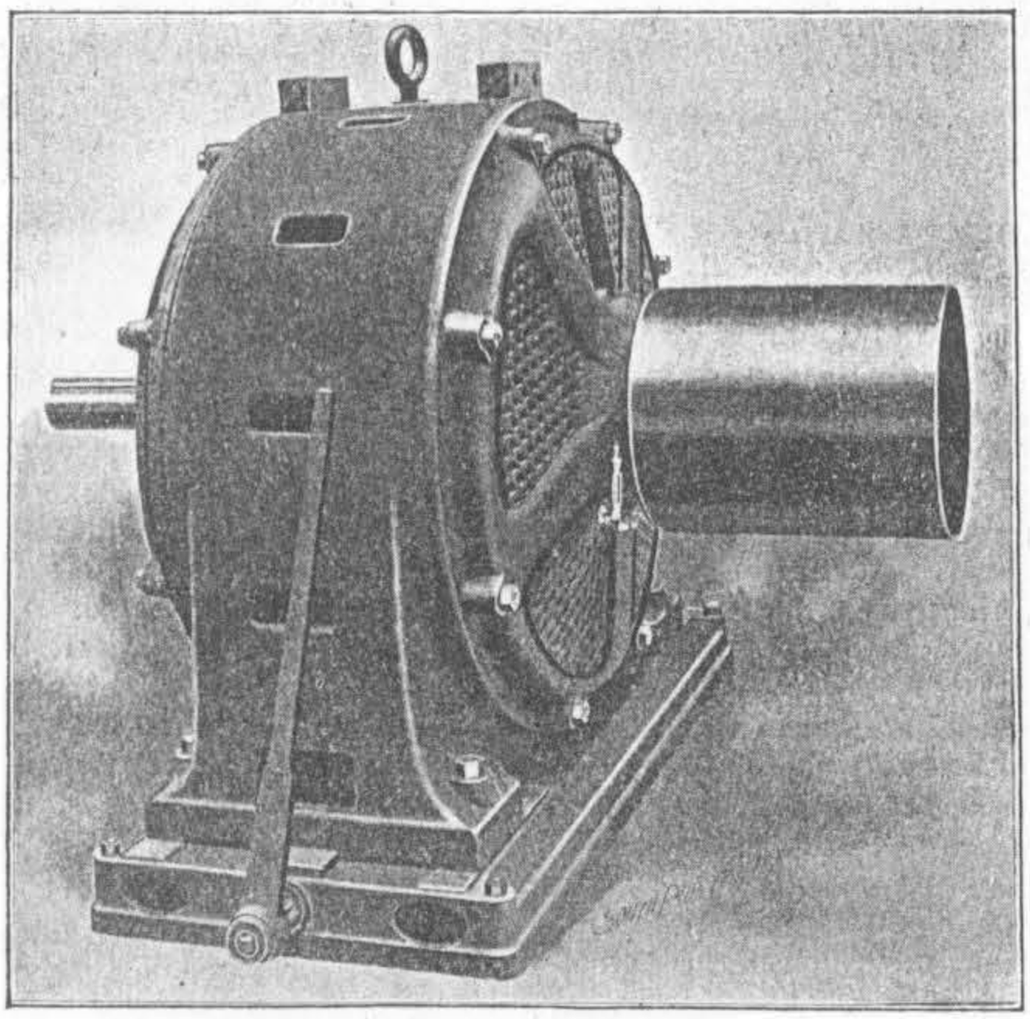


FIG. 2.—TESLA INDUCTION MOTOR.

and making some 10,000 brands of tacks, rivets, etc. Considerably over 50 per cent. of all the tacks and rivets made in the United States are produced at their shops, and their electrical equipment will be watched with interest, and no doubt imitated by many other concerns of the kind.

The adaptability of the "Type C" motor, as made by the Westinghouse company, to so many varied fields of usefulness, has surprised many, who have possibly been prejudiced against the alternating current motor; but the cause of their surprise constitutes one of the strongest proofs of the reliability of this new Westinghouse product.

THE DEVELOPMENT OF HIGH FREQUENCY CURRENTS FOR PRACTICAL APPLICATIONS.

There will be found in another part of this paper a description of an extensive line of interrupters or circuit make and break devices lately patented by Mr. Nikola Tesla for use in the production of high-frequency currents. Oscillatory currents with a frequency of several hundred thousand alternations per second are fortunately easily generated by the simple discharge of a condenser through an inductive path, the main difficulty in producing them being the means of again starting the oscillations whenever they die out, as, of course, they do in a very small fraction of a second. The electrical method by means of a discharge is, of course, extremely wasteful, and mechanical devices for this purpose have heretofore been very troublesome, particularly in the contacts.

Mr. Tesla has been working at this problem for some years, recognizing that its solution was essential to the success of the commercial application of such currents. The results of this work appear in these recently issued patents. In general he uses a jet contact for the make and break device or circuit interrupter similar to the jets used in laboratory work for brief contacts in the determination of the wave form of alternators, etc. Mercury is preferred, owing to the high specific resistance of its vapor, and the low resistance of the liquid and a form in which jet meets jet possesses advantages, as in this case there is no sparking to or from a solid metal. Further, the contacts are made in an inclosed chamber filled with some inert gas, if necessary under considerable pressure. If atmospheric pressure is used, the apparatus is simply hermetically sealed, the small amount of oxygen contained within being soon absorbed by oxidation, leaving an inert insulating medium of nitrogen. If pressure is desired—and high pressure cuts down the arcing of such devices even more than does a high vacuo—anhydrous liquid ammonia may be used, the minute sparks gradually dissociating the ammonia into its elements, hydrogen and nitrogen, the former diffusing through the containing walls, leaving inert nitrogen under pressure.

The designer states that these machines run satisfactorily, without apparent change in the liquid, and requiring a surprisingly small amount of attention, small instruments transforming several horse-power continuously for long periods with no attention whatever. More than this, he also states that the efficiency of conversion between the direct current supplied and the high frequency current obtained, the latter being measured by calorimetric methods, is as high as 95 per cent. This being the case, the use of such currents for lighting purposes may be expected as soon as the luminous efficiency of exhausted bulbs or tubes under the action of such currents approaches or exceeds that of the incandescent filament, the fulfillment of which condition Mr. Tesla confidently promises. Such currents may also find a wide application in other fields, one of which is the electro-chemical, for the production of such compounds as ozone, in which high-frequency currents are said to give a much greater output per unit of energy than those of frequencies now used. Other chemical conversions are also readily accomplished by the same means, a promising one being the oxidation of atmospheric nitrogen, giving, if commercially practicable, promise of an enormous use of electrical energy in the production of nitrates and other nitrogenous substances, for which there is a great demand in the arts.

Mr. Tesla's Circuit Interrupters.

For the production of intermittent currents for use in obtaining oscillatory currents of very high frequency by means of charging a circuit possessing capacity and self-induction, Mr. Nikola Tesla has designed a large number of interrupters or make and break devices embodying many ingenious features. These interrupters, or, as Mr. Tesla calls them, circuit controllers, were patented in a group of patents issued August 16, 1898.

In order to make clear the purpose of these devices it may be well to give an untechnical explanation of the means of producing high frequency or oscillatory currents. Whenever a charged condenser is short circuited through a circuit containing self-induction the sudden rush of current, by an action analogous with mechanical inertia, over-discharges the condenser, charging it up in the reverse direction; this again discharges the other way, again reversing the charge in the condenser, and so on, the oscillations gradually dying out at a rate dependent on the resistance of the circuit. With ordinary Leyden jars and the small self-induction obtained by a few turns in air, these oscillations have a frequency of several hundred thousand alternations per second, this frequency running up as the capacity of the condenser or the amount of the self-induction is diminished, being, in fact, inversely proportional to the square root of the product of the capacity and the self-induction. To start such an action the condenser must first be charged and then closed on its discharge circuit. The simplest way of accomplishing this, and the means most commonly used, is to insert a spark gap in the circuit and in shunt with this spark gap connect the secondary of a high-voltage transformer supplied with ordinary alternating current, or the secondary of an induction coil. The action, then, is as follows: As the voltage rises in the transformer the condenser is gradually charged until the pressure gets so high that it jumps across the spark gap. The spark or arc here formed is of such a low resistance that the condenser and its discharge circuit are practically short circuited through it, and the oscillations continue for a short while, until the arc dies out, the action being repeated at the next reversal of the alternating current supplied.

Such a method is extremely wasteful of power, for two reasons. First, because the secondary of the transformer is short circuited just at the peak of the wave; and, second, because the arc or spark offers some resistance to the high-frequency oscillations, which, therefore, die out more quickly than they would if they were not opposed in this way. A far better plan, therefore, is the use of a mechanical interrupter, such as those described below, the action of which can best be understood by a reference to Fig. 3. Here *A A* are the terminals of the source of supply, which may be either direct or alternating current at commercial pressures, 100, 200, 500 or 1000 volts. *A'* is a highly inductive coil which should be wound on iron. *A''* is the condenser, *B* a small self-induction, and *C* the interrupter. The action is as follows: When the circuit is open at *C*, the pressure applied from the source of supply acts through *A'* and *B* to charge the condenser, *A''*. Suddenly *A''* and *B* are short circuited through the interrupter, *C*, and the condenser discharges with oscillations, occurring perhaps several hundred thousand times per second. These gradually die out, becoming negligible after perhaps 200 or 300 oscillations, when the circuit is suddenly opened again at *C*. It should be noted that *C*, besides short circuiting the condenser through its slight self-induction, *B*, has also short circuited the source of supply connected to the terminals, *A A*, through the inductive coil, *A'*. This short circuit is so brief, however, that the incoming current has not had time to rise to an undesirable strength, but has been held back by the self-induction of *A'*. It has also while rising been storing up, so to speak, a certain amount of energy in the magnetic circuit of *A'*. Now, when the circuit at *C* is again opened, this current, passing through *A'*, tends to persist, owing to the self-induction therein, and charges the condenser *A''* up to a voltage considerably higher than that of the source of supply, the energy absorbed in the magnetic circuit of *A'* passing out thus into the condenser *A''*, charging it to a high voltage, the interrupter, *C*, afterward short circuiting this and allowing the current to oscillate again through the discharge circuit, *B*.

Thus the interrupter, *C*, inductive coil, *A'*, and the source of supply act to open the condenser circuit for a brief instant and charge the condenser by a sort of electrical blow, immediately short circuiting it again and allowing it to discharge in oscillations. If the condenser discharge circuit is tuned to a frequency of, say, 300,000 per second, and its resistance is such that 300 oscillations take place before they die down to a negligible value, the interrupter, *C*, should make and break the circuit about 1000 times a second. There will then exist in the condenser discharge circuit, *B*, a cycle somewhat as follows: A sudden surging charge followed by an oscillatory discharge, starting with high waves, which gradually die down until interrupted by the next surging charge, etc. Owing to the enormous frequency of these oscillatory discharges, they can be transformed by ordinary double-winding, stationary alternating transformers, with a very small amount of material for their capacity, since the capacity of any transformer is proportional to the rate of change of lines of force, and is hence proportional to the frequency of the alternating currents therein. So high is this frequency that an air magnetic circuit is all that is necessary, iron, in fact, being a disadvantage, owing to the energy lost within it in eddy currents and hysteresis, with such a high frequency. In the figure, *B* represents the primary of such a high-frequency air transformer, *B'* being the secondary, with a winding of more turns to obtain higher tension, the output of which is delivered to any translating devices, as *B''*.

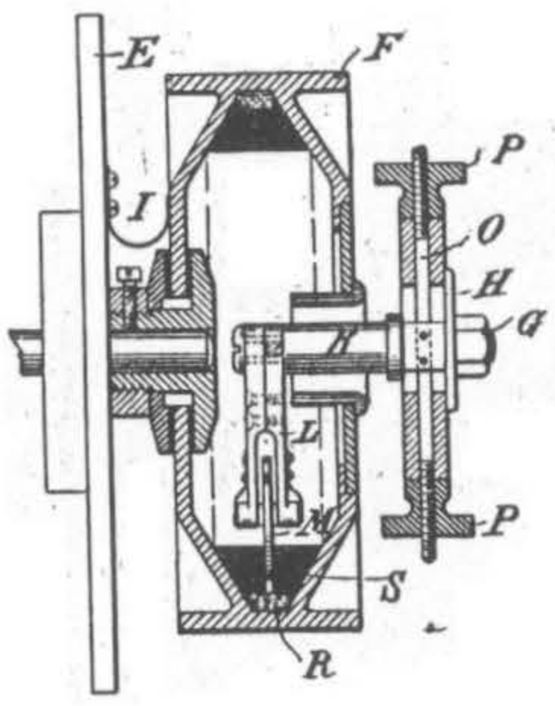


FIG. 1.

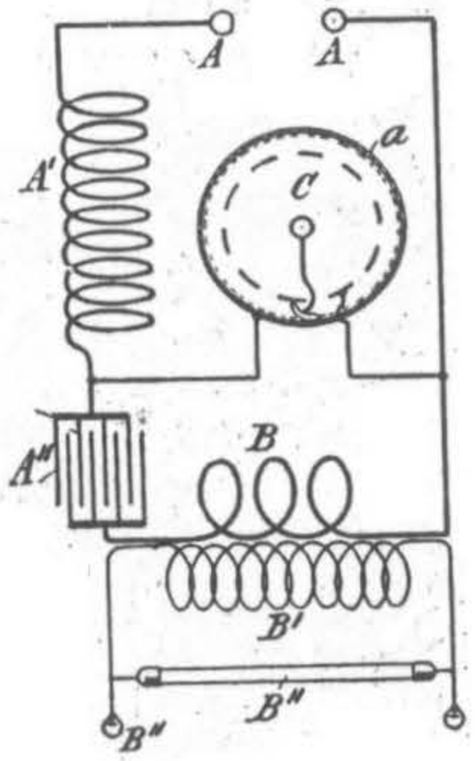


FIG. 3.

The distinguishing feature of the devices described below is the use of a liquid for one or both of the contacts of the make and break devices, this liquid preferably being mercury, acting in some instances in the form of a jet and in other cases as a surface with which a solid conductor makes and breaks a contact. Ingenious applications are also made of other principles, such as the use of a liquid dielectric between the contacts, inert gases under high pressure, jets meeting each other, etc.; and all the instruments are worked out with great perfection of detail for continuous and practically frictionless running, such as to require a minimum of attention.

The requirements of such an instrument are well stated in the patent specifications, as follows: The capability of effecting an extremely rapid interruption and completion of the circuit, the latter being positive and abrupt; the apparatus not to be liable to derangement, and capable of prolonged use without attention or adjustment.

Of the various types described the first is that shown in cross section in Fig. 1. This consists of an inclosing shell, *F*, arranged to be rapidly rotated by means of a motor coupled to the shaft shown at the left, and containing two liquids of different specific gravities, that with the higher specific gravity being a conductor and the other an insulator; preferably the conductor is mercury, the insulator being some hydrocarbon. When the shaft and shell mentioned are rapidly rotated the mercury flies to the periphery by centrifugal force and forms a ring shown at *R*, the other liquid forming an inner ring, as shown at *S*. Within the shell is an arm, *L*, supported on a non-rotating shaft, *H*, carrying a wheel, *M*, with projecting points sufficiently long to touch the mercury, *R*. As the liquids revolve they rotate this wheel at high speed, the points of which successively and repeatedly dip into the mercury rim and leave it again, the relative motion being a hypo-cycloid. The insulating liquid, under considerable pressure, owing to centrifugal action, forces itself between the mercury and the points as the lat-

ter recede and extinguishes the arcs which tend to form across these gaps. Other figures attached to the same patent show the machine assembled with a motor, condenser and transformer.

The next patent describes the waste of energy which occurs during the periods of make and break, or both, due to the passage of the current through an arc formed between the terminals; this loss of energy is said to be generally such as to render impossible a practical and economical conversion of considerable amounts of electrical energy by means of ordinary make and break devices, particularly in cases where a high frequency is required. Experiment and investigation have led Mr. Tesla to recognize the following laws governing this waste of energy: First, that the loss in any device for making and breaking a circuit, other conditions being the same, is inversely proportional rather to the square than to the first power of the relative velocity of the terminals in approaching and receding from one another in case the current curve is not so steep as to materially depart from one which may be represented by a simple sine function of the time; but such a case seldom obtains in practice; on the contrary, the current curve resulting from a make and break is generally very steep and particularly so when the circuit controller effects the charging and discharging of a condenser, and consequently the loss of energy is still more rapidly reduced by increased velocity of approach and separation.

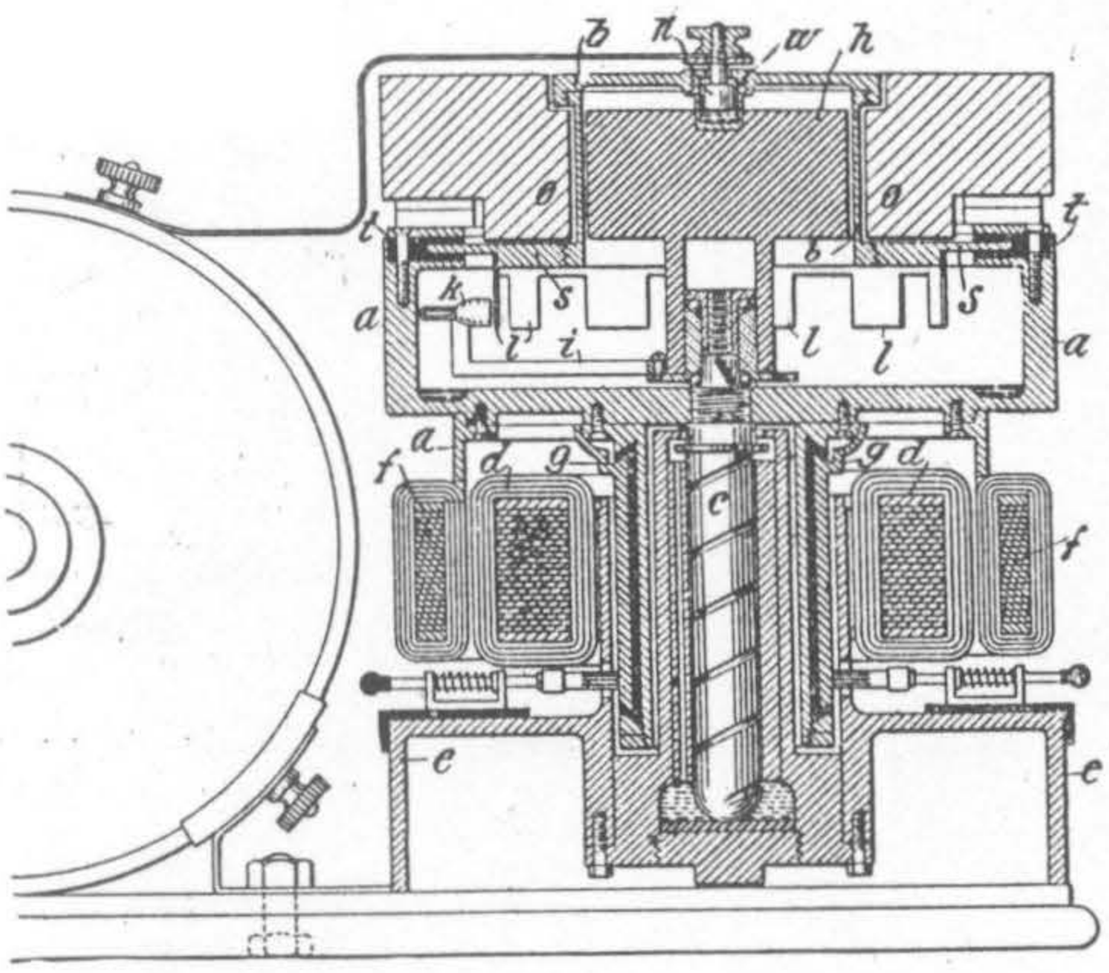


Fig. 2.

With a view to securing an interrupter in which not only the relative speed of the terminals but also the frequency of the interruption should be very high, the instrument shown in Fig. 2 was designed; this consists essentially of a shell, *a*, attached to the external armature, *f*, of a direct-current motor with a commutator, *g*, and field magnets, *d*, by which means the shell, *a*, is rotated at high speed on a self-oiling spindle, *c*. Projecting downward from the upper lid of the shell is a series of teeth, *l*, and within the case is a nozzle, *k*, arranged to throw a jet of mercury against these teeth; the nozzle is attached by means of an arm, *i*, to an armature, *h*, which is prevented from rotation by means of the field of force of an external non-rotating magnet, *o*, this field acting through the shell of the rotating case on the armature within. When mercury is placed within this case and the latter is revolved the mercury rises by centrifugal force against the outer wall and is caught by an open mouth or scoop attached to the non-rotating nozzle, *k*, and directed by the latter against the teeth, *l*. The main circuit is open between this nozzle and these teeth, and is intermittently closed by the jet of mercury.

For the further reduction of arcing others have used contacts made in a high vacuo, but Mr. Tesla claims that only a moderate improvement is secured in this manner, and this can be greatly exceeded by the use of certain fluids inert chemically maintained at a high pressure in the make and break chamber. It is found that in such a case the arc, when formed, is restricted to a small cross section or is, in other words, prevented from expanding laterally, and is therefore more quickly raised to a high resistance, choking back the current to such an extent that the arc is more promptly extinguished.

Fig. 4 shows an apparatus designed to make use of this principle. Here *F* is the laminated field ring or primary of a rotary field motor, the secondary of which is wound upon the rotatable core, *E*, mounted on the shaft, *D*, within the gas-tight shell, *A*, which is closed by the insulated and gas-tight cover, *B*. The rotating field of force obviously acts through the shell, *B*, which should be an insulating material or high-resistance metal, and rotates the parts within which carry a crown of downwardly pro-

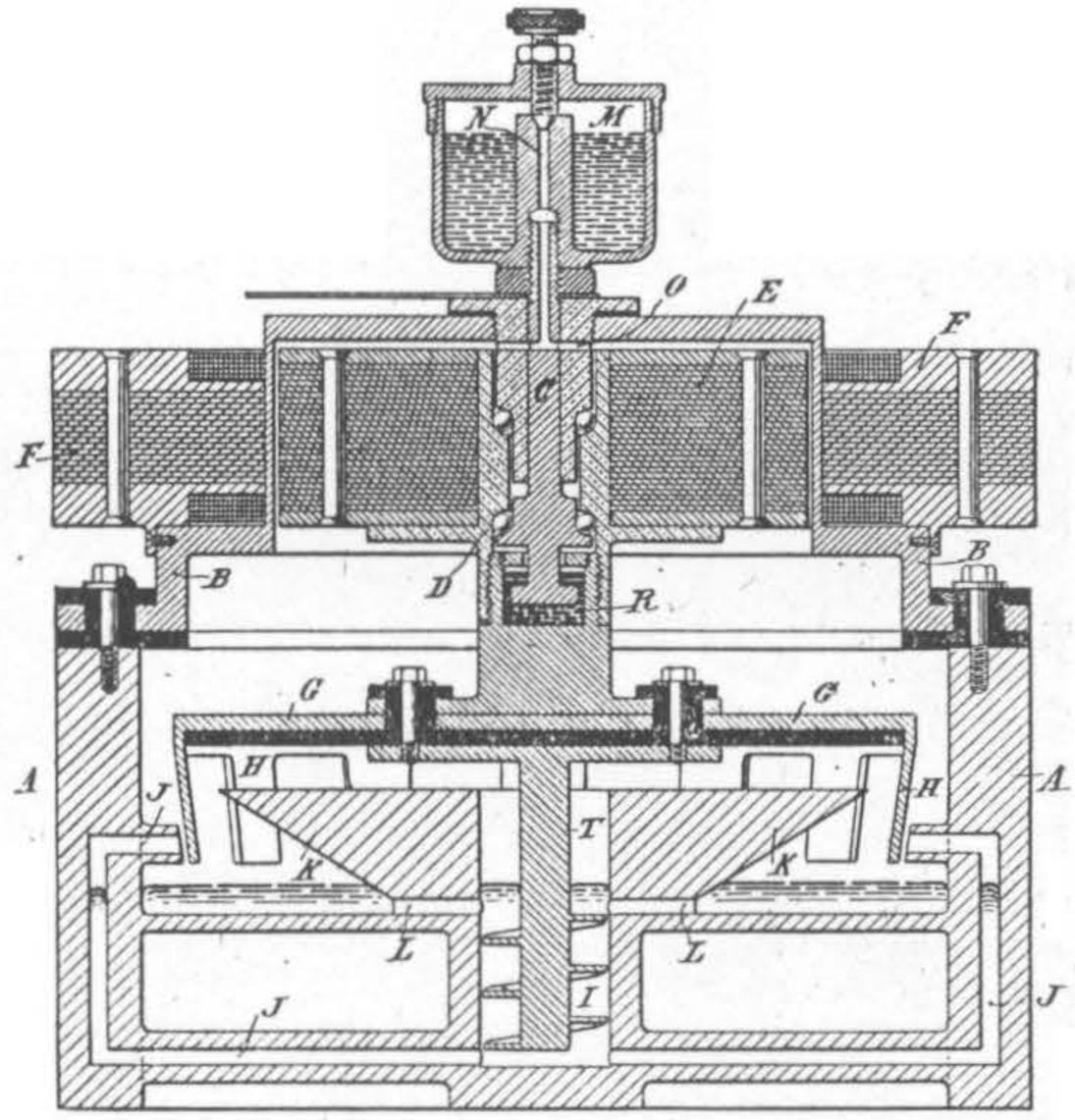


Fig. 4.

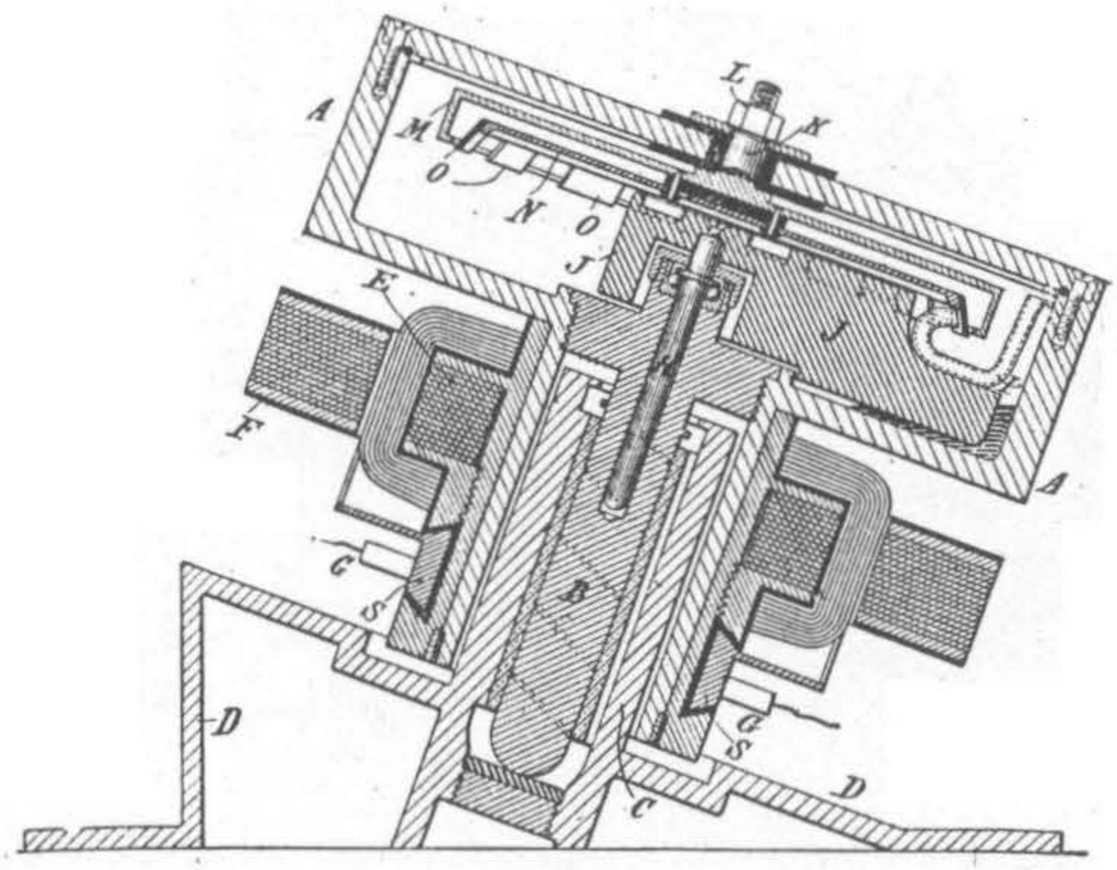


Fig. 5.

jecting teeth, *H*, and on the lower end of the shaft a screw pump, *I*. This screw pump acts upon the mercury in the lower part of the vessel, forcing it outwardly through tubes, *J*, from which it emerges in jets against the teeth, *H*; these jets and teeth make and break the circuit as in the apparatus described above, the whole being kept under pressure by an inert fluid shown in the cup, *M*, at the top of the apparatus; this liquid may be such a one as anhydrous ammonia, giving, at ordinary temperatures, a high pressure, due to its restricted evaporation and low boiling point. The gas is carried down into the chamber through the tube, *N*, in the fixed internal part of the ball bearing, *C*.

A means of accomplishing the same result without the use of a magnetic field acting through a fixed gas-tight wall, utilizing instead the force of gravity, is shown in Fig. 5, where *A* is again a gas-tight case supported upon an inclined spindle, *B*, and arranged to be rotated by a direct-current motor with outside armature similar to that shown in Fig. 2. Within this case is an eccentric weight, *K*, mounted on a self-oiling spindle, *J*, with a ball thrust bearing to avoid its being dragged around by friction. Owing to the inclination of the rotating axis of the system from the vertical, this weight, *K*, tends to remain at the low side and not to revolve with the case. Attached to this non-rotating weight, *K*, is an arm, *L*, carrying another ball bearing shaft, *N*, supporting a

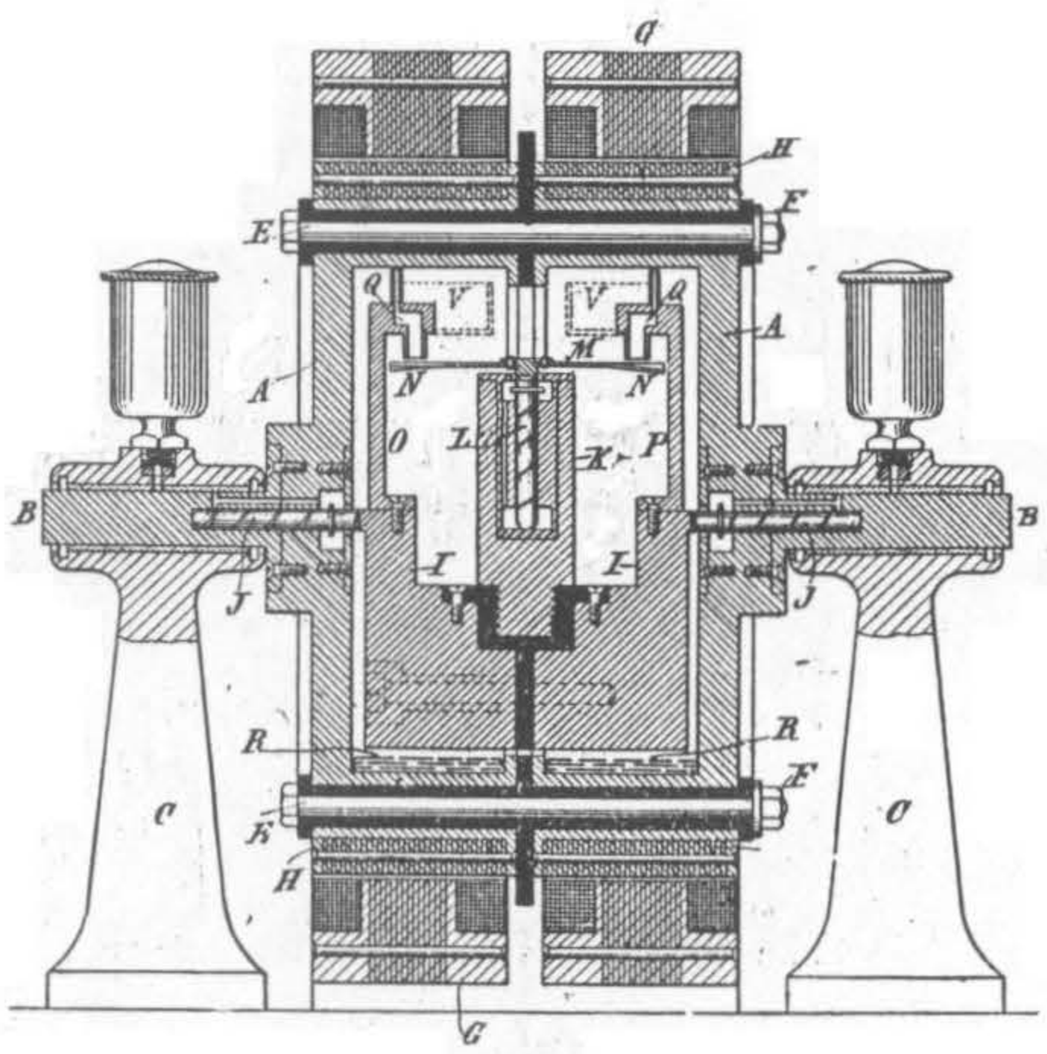


FIG. 6.

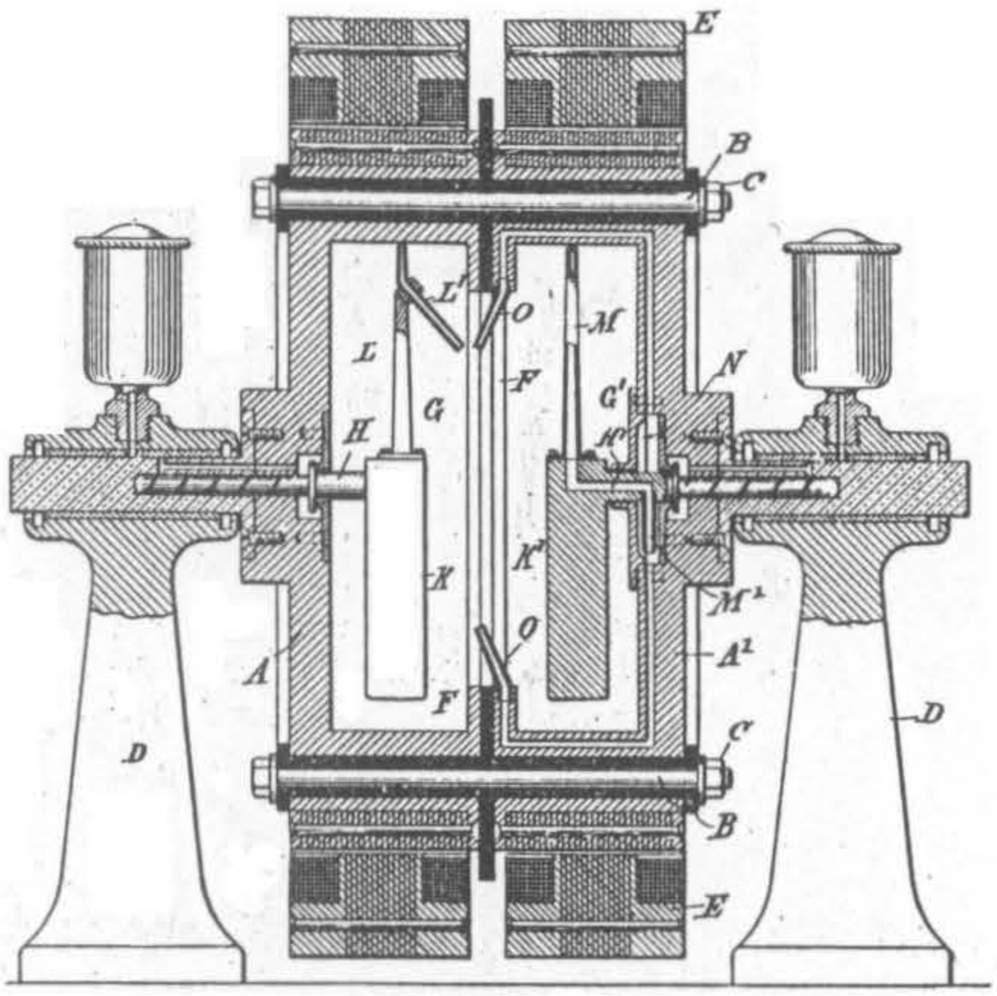


FIG. 7.

number of vanes, *Q*. When the case is revolved the mercury contained therein is maintained by centrifugal force in the form of a ring against the outside wall, into which ring the vanes, *Q*, dip and are rotated at high speed, making and breaking a contact between themselves and the mercury.

Still another device for obtaining a rapid make and break in a gas-tight chamber, this time utilizing both the rotary field and the eccentric weight, is shown in Fig. 6, where *G G* are two stationary primaries of the induction motor, which in this case is arranged in a vertical plane of rotation, *H H* being two secondary rotors, the necessity for two elements being the division of the rotating part by insulating gaskets into two sections. Within this rotating chamber, *A*, are mounted two eccentric weights, *I I*, fastened together by an insulating joint and supported on the spindles, *J J*. Fastened also to them is the central vertical journal, *K*, in which rotates the spindle, *L*, carrying a wheel, *M*, and inclined helically bent blades, *N N*. As before mercury placed in the revolving case is carried around by centrifugal force and, meeting the spouts attached to the nozzles, *Q*, is driven by its own inertia through them against the blades, *N N*, which, owing to their inclination, are given a rapid rotary motion about the spindle, *L*. The claims of novelty made for this combination are the facts that the action of the jets themselves puts in motion the solid terminals of the make and break device, with a speed very high compared with that of the shell, and that the motion of the vanes acts gyroscopically to prevent oscillation (and hence variation of the frequency) of the eccentric weights, *I I*.

A similar make and break device, in which, however, both terminals are liquid jets, is shown in Fig. 7. Here, as in Fig. 6, are the two rotary field motors rotating in a vertical plane with eccentric weights, *K K'*, the scoop attached to the former directing a jet from the nozzle, *L'*. The scoop attached to the other is intended to direct the liquid through the tube, *M*, to the axis of rotation, whence it is distributed through passages in the rotating case to the nozzels, *O O*. These jets striking that from *L'* make and break the circuit between the two insulated halves of the shell,

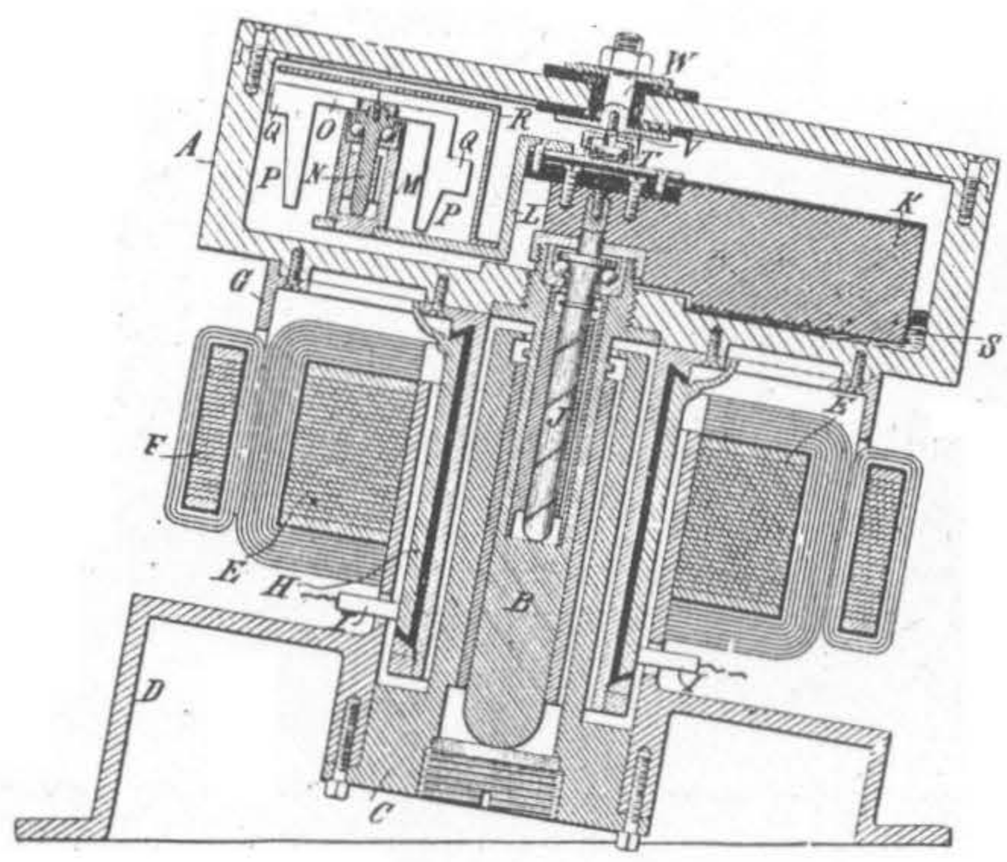


FIG. 8.

thus giving liquid contacts at both terminals of the make and break device.

Another interesting variation of the inclined axis arrangement shown in Fig. 5, giving mercury terminals in another way, is shown in Fig. 8, the essential features of which are a rotating shell, *A*, eccentric weight, *J*, carrying a tube, *P*, with scoop and nozzle and an unbroken solid metal terminal, *M*, with which the mercury makes contact. Rotating with the shell is a crown of downwardly projecting teeth, *O O*, these teeth being in this instance insulators preferably non-organic and vitreous. These insulating teeth cut off the stream of mercury intermittently, giving a rapid make and break with mercury terminals.

A further modification by which higher frequency is obtained is shown in Fig. 9, the frequency being doubled by means of rotating both terminals of the make and break device in opposite directions. This is effected by means of one rotary field generated by the primary, *H*, actuating the rotatable secondary, *G*, which carries on spindle, *C*, the gas-tight shell, *D*, through the upper part or cap of which, *F*, still another rotary field acts upon the secondary wound upon *Q*, which in turn is rotatable on spindle, *P*, and carries by means of arms, *T*, the mercury scoops and jets, *V*. These move in one direction while the teeth, *L L*, rotate with the case, *D*, in the opposite direction, thus giving double the frequency obtainable with the same angular velocity and one member stationary.

A most curious modification is shown in Fig. 10, in which the winding of the secondary of one of the elements, instead of being a copper short-circuited squirrel cage, as in the induction motors described above, consists of the mercury itself, this being arranged

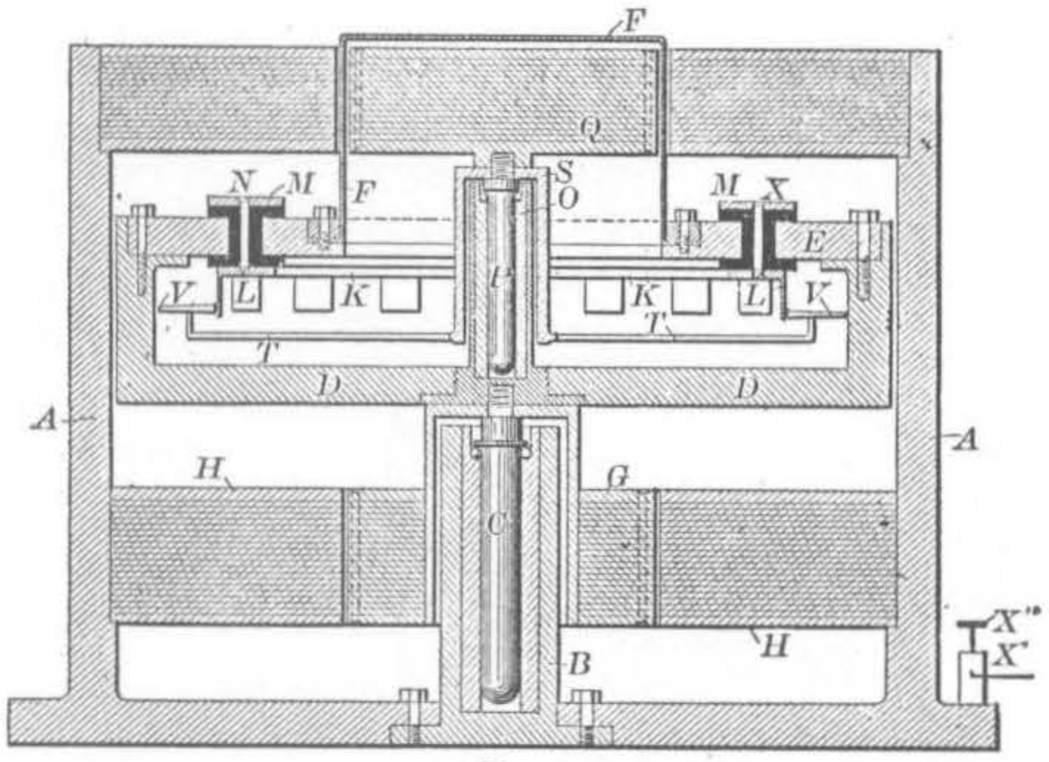


Fig. 9.

in two rings, *B B'*, forming the two terminals. A powerful rotating field, generating Foucault currents in these rings, will rotate them with a high velocity, the field completing itself through the stationary core, *E'*. Above is another rotary field actuating the secondary, *N'*, which carries the star wheels, *L' L''*, whose teeth

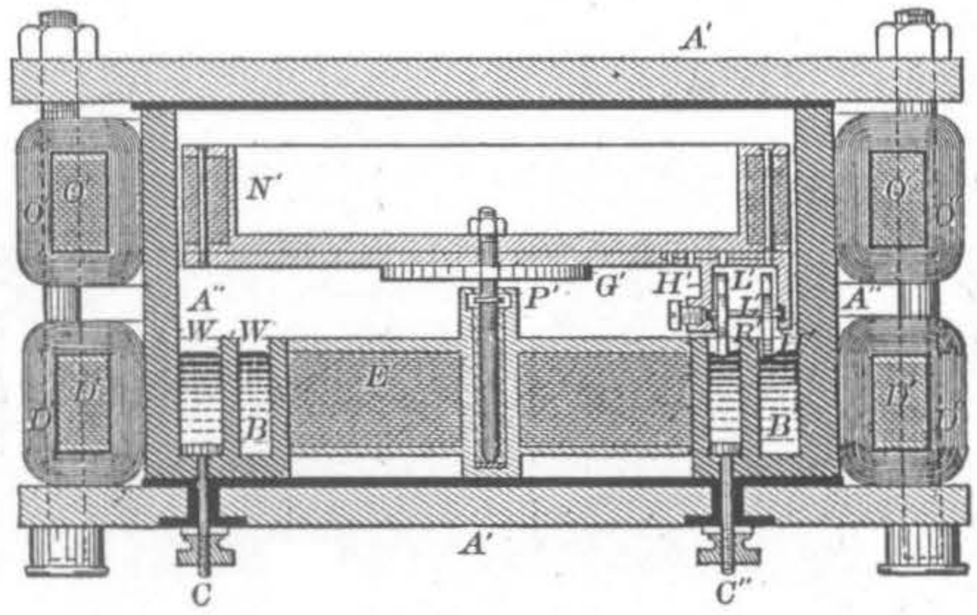


Fig. 10.

dip into the mercury rings below. The element carrying these wheels is supposed to rotate in the opposite direction from the rings of mercury, giving the star wheels a high peripheral velocity and a correspondingly high frequency of make and break.

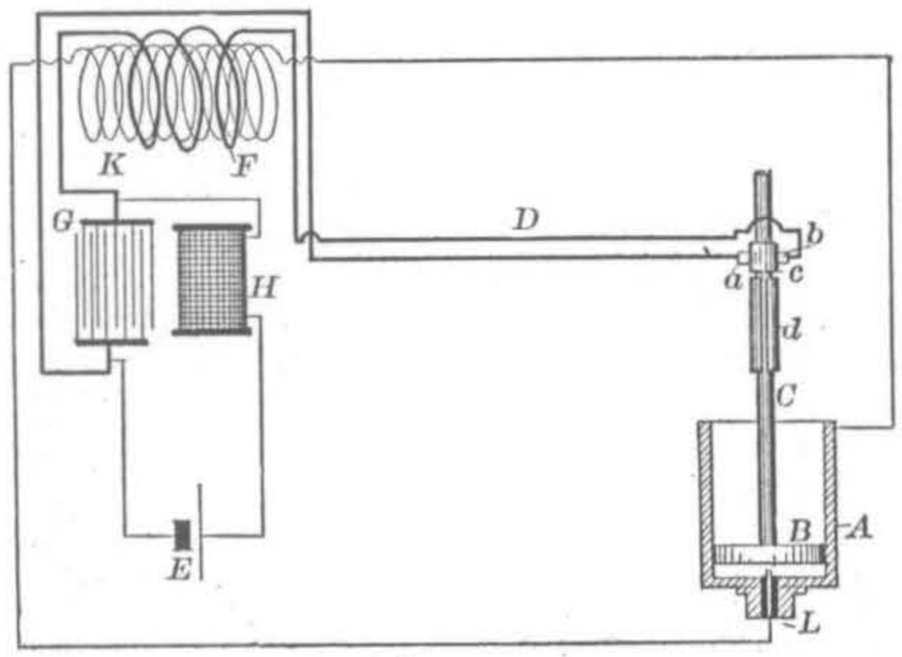


Fig. 11.

Another patent issued simultaneously with those described above and by the same inventor covers an improvement in electrical igniters for gas engines, as shown in Fig. 11, the principle being the use of an oscillatory discharge in the cylinder of the engine, the primary impulse being obtained at the proper instant from a contact actuated by the motion of the engine parts.

In the figure, *E* is the source of current, *H* an inductive coil, *G* a condenser, and *K* the transformer; at *a* is shown the contact for short-circuiting the primary and condenser at the proper time, thus causing a discharge from the secondary between the terminal, *L*, and the piston, *B*.

Remarkably broad claims on these various mechanical combinations have been obtained, the most important being briefly as follows: a rotating receptacle and independently mounted terminal, making contact with the fluid therein; a jet making contact with spaced conductors in combination with self-contained means for maintaining a circulation of the fluids (the use of a jet contact being well known in the art was not broadly patentable); an interrupter surrounded in a closed receptacle by an inert insulating medium under pressure; the use of jets for both terminals and the use of a jet intercepted intermittently by insulating solids.

MISCELLANEOUS

Tesla Circuit Controllers for Obtaining Oscillatory Currents of High Frequency.

ON August 16 a very ingenious and apparently significant group of patents was issued to Mr. Nikola Tesla, comprising several types of current-interrupting devices for obtaining oscillatory currents of very high frequency. Mr. Tesla has called them "electrical circuit controllers" and their use and construction may be understood by the following introductory remarks, taken from the patent specification referring to the class of circuits for which they were designed. We present also several illustrations showing the latest forms developed by Mr. Tesla, whose persistent investigations along the high frequency line entitle him to much praise and credit.

In every form of electrical apparatus involving a means for making and breaking more or less abruptly, a circuit, a waste of energy occurs during the periods of make or break, or both, due to the passage of the current through an arc formed between the receding or approaching terminals or contacts, or, more generally, through a path of high resistance. The tendency of the current to persist after the actual disjunction or to precede the conjunction of the terminals exists in varying degrees in different forms of apparatus, according to the special conditions

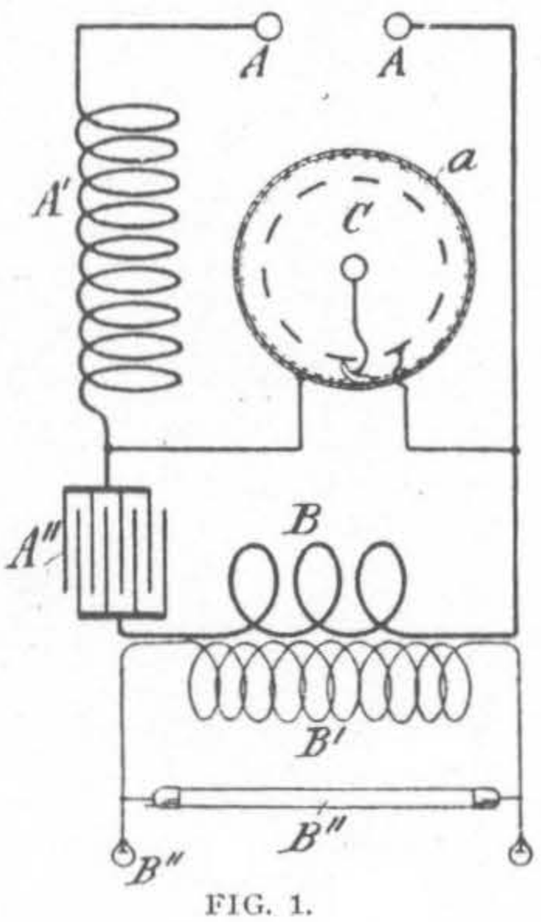


FIG. 1.

present. For example, in the case of an ordinary induction coil the tendency to the formation of an arc at the break is, as a rule, the greater, while in certain forms of apparatus in which the discharge of a condenser is utilized this tendency is greatest at the instant immediately preceding the conjunction of the contacts of the circuit-controller which effects the discharge of the condenser.

The loss of energy occasioned by the causes mentioned may be very considerable and is generally such as to greatly restrict the use of the circuit-controller and render impossible a practical and economical conversion of considerable amounts of electrical energy by its means, particularly in cases in which a high frequency of the makes and breaks is required.

Extended experiments and investigation conducted with the aim of discovering a means for avoiding the loss incident to the use of ordinary forms of circuit-controllers have led Mr. Tesla to recognize certain laws governing the waste of energy and making it dependent chiefly on the velocity with which the terminals approach and recede from one another and also more or less on the form of the current-wave. Briefly stated, from both theoretical considerations and practical experiment, it appears that the loss of energy in any device for making and breaking a circuit, other conditions being the same, is inversely proportional rather to the square than to the first power of the speed or relative velocity of the terminals in approaching and receding from one another in an instance in which the current-curve is not so steep as to materially depart from one which may be represented by a sine function of the time; but such a

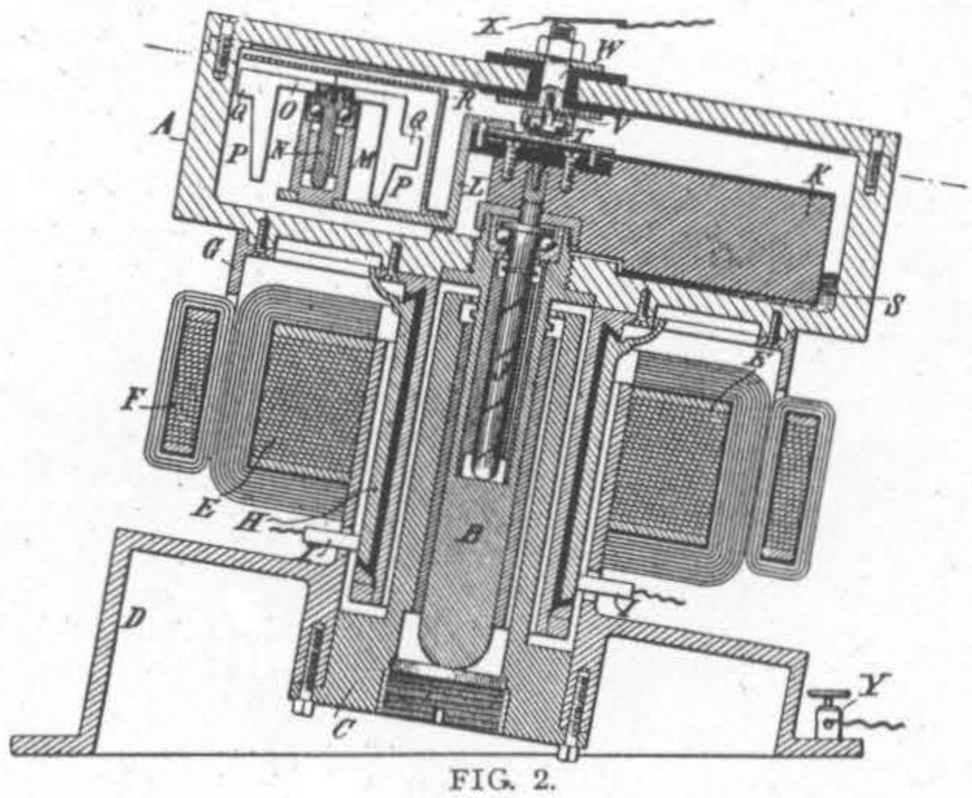


FIG. 2.

case seldom obtains in practice. On the contrary, the current-curve resulting from a make and break is generally very steep, and particularly so when, as in Mr. Tesla's system, the circuit-controller effects the charging and discharging of a condenser, and consequently the loss of energy is still more rapidly reduced by increased velocity of approach and separation. The demonstration of these facts and the recognition of the impossibility of attaining the desired results by using ordinary forms of circuit-controllers led Mr. Tesla to invent other means for making and breaking a circuit in which he has utilized a conducting fluid, such as mercury, as the material for one or both of the terminals and devised novel means for effecting a rapidly-intermittent contact between the fluid and a conductor or series of conductors forming the other terminal.

In this apparatus one of the members or terminals is a conducting fluid which is caused to issue from an orifice against a series of spaced conductors in rapid succession. For this purpose the series of conductors, or it may be a single conductor, is moved transversely through the stream or jet of fluid, or the jet is moved so as to impinge upon the conductors, or both jet and conductors are moved. This is preferably accomplished

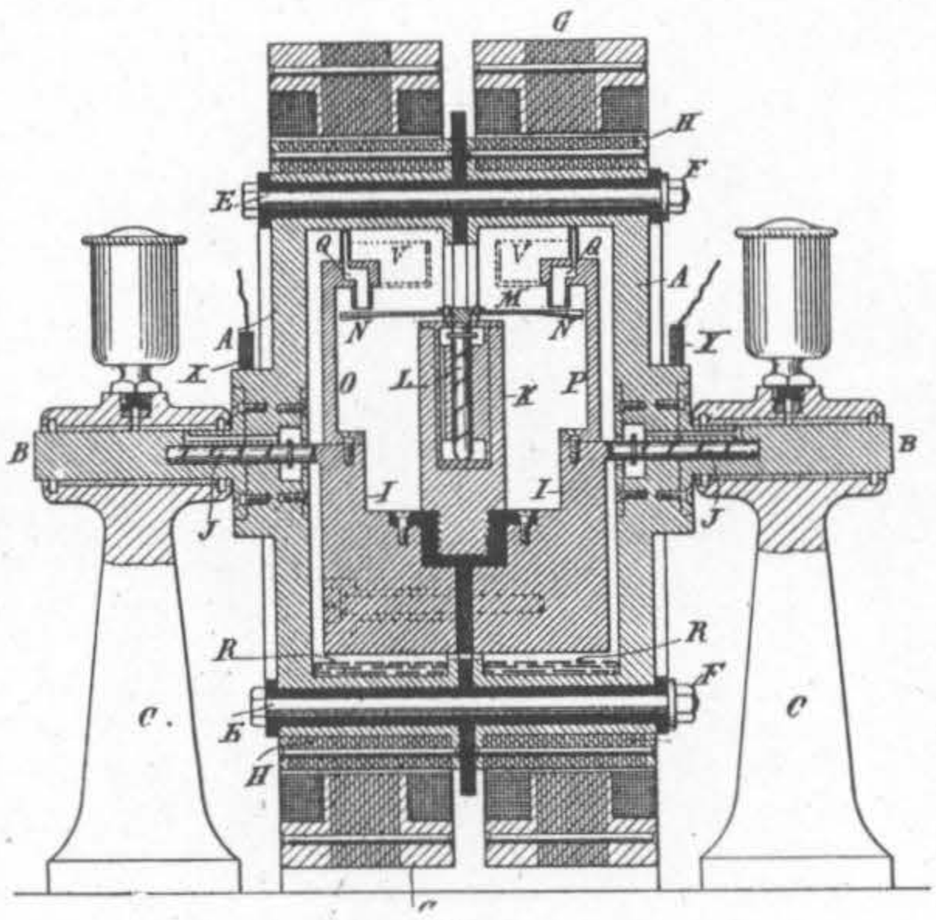


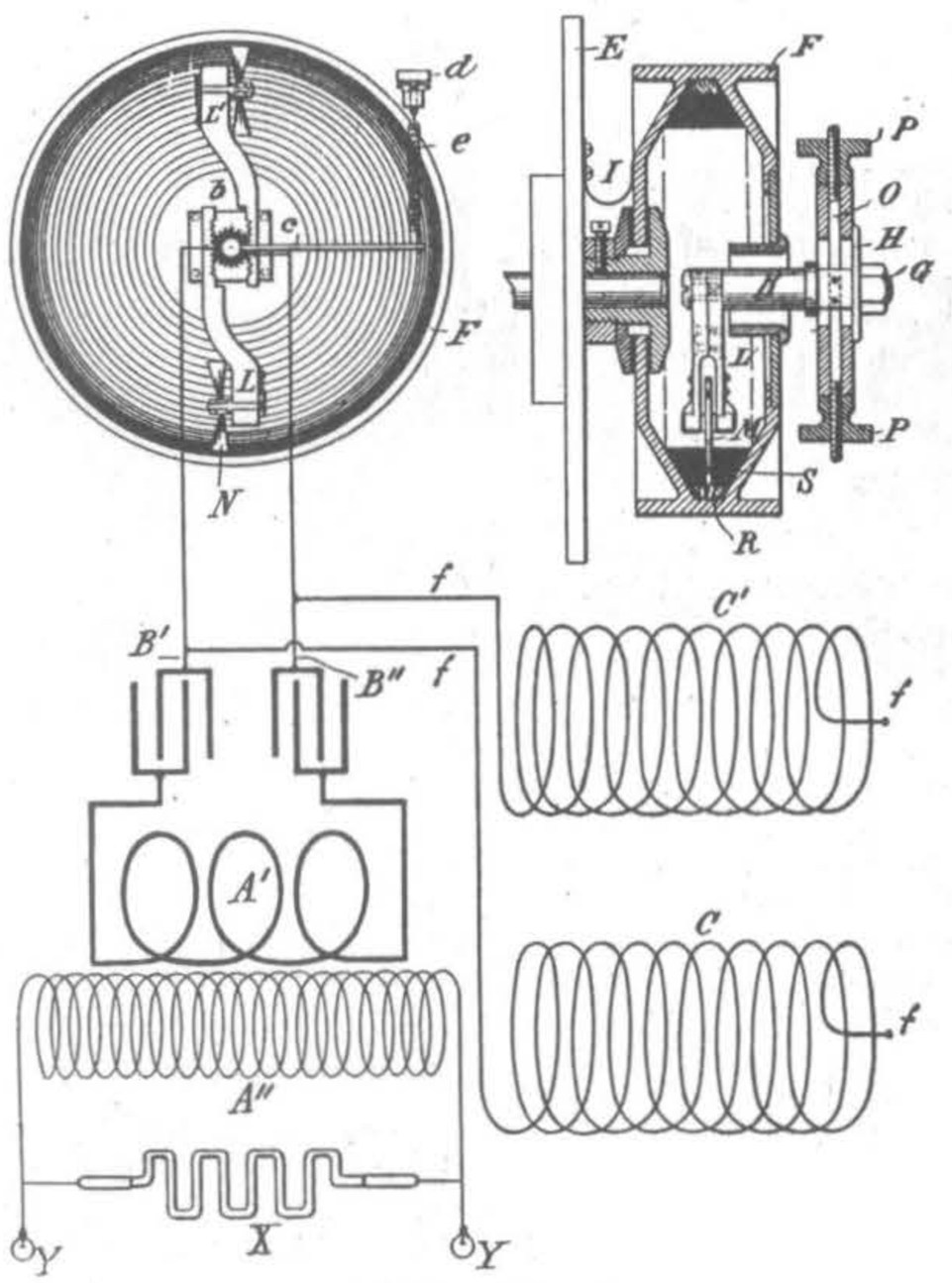
FIG. 3.

by mounting the conductors and the tube or duct from which the fluid issues concentrically and revolving one or both.

The plan adopted for maintaining the stream or jet of conducting fluid consists in utilizing the same power that actuates or drives the circuit-controller in effecting the necessary rela-

tive movement of its terminals to maintain the proper circulation of the conducting fluid by combining the two mechanisms (the controller and the means for maintaining a circulation of the conducting fluid) in one. This feature is of great practical advantage and may be effected in many ways. A typical arrangement for this purpose is to provide a tube or duct having an orifice at the end directed toward the spaced conductors and its other end in a position to take up a portion of the rapidly-rotating body of conducting fluid, divert it through the duct, and discharge it against the conductors. With this object when a closed receptacle is used a holder for the tube is employed, mounted within the receptacle and concentrically therewith, and this holder, when the receptacle is revolved, is held or influenced by any suitable means, as by magnetic attraction exerted from the outside or otherwise, in such manner as to keep it either in a fixed position or impress upon it a velocity different from that of the rotated fluid.

The general scheme of the system for use with which the circuit-controllers are more especially designed will be understood by referring to Fig. 1. In this figure A A represent the terminals of a source of current. A′ is a self-induction or choking coil included in one branch of the circuit and permanently connected to one side of a condenser A″. The opposite terminal of this condenser is connected to the other terminal of the source through the primary B of a transformer, the secondary B′ of which supplies the working circuit containing any suitable translating devices, as B″.



FIGS. 4 AND 5.

The circuit-controller C, which is represented conventionally, operates to make and break a bridge from one terminal of the source to a point between the choking-coil A′ and the condenser A″, from which it will result that when the circuit is completed through the controller the choking-coil A′ is short-circuited and stores energy which is discharged into the condenser when the controller-circuit is broken, to be in turn discharged from the condenser through the primary B when these two are short-circuited by the subsequent completion of the controller-circuit.

Six different constructions of circuit controllers have been patented by Mr. Tesla in this group referred to in the beginning of this article, but we have selected three of them which illustrate fairly well the various types for which patents were granted.

Referring to Fig. 2, the operative portions of the circuit-controlling mechanism are contained in a closed cylindrical receptacle A, of iron or steel, mounted on a spindle B in a suitable socket or support C to permit it to be freely and rapidly rotated. The socket C is secured to or forms a part of a base or stand D.

As a means of producing the proper rotation of the receptacle A, a field-magnet E is shown, mounted on or secured to the base D, and an armature F, supported by a bracket G from the under side of the receptacle A. The same bracket also carries a series of commutator-segments H, upon which bear brushes I, these parts being arranged to constitute an electromagnetic motor with stationary field and rotating armature. Any other suitable means, however, may be employed to rotate the receptacle and the fluid.

In the spindle B and concentric with its axis is a spindle J in bearings specially constructed to reduce friction in order that the spindle J may be as little as possible influenced by the rotation of the main spindle and receptacle which it carries. A suitable provision is made to oppose or prevent the rotation of the spindle J during the rotation of the receptacle. For this purpose the following has been devised.

The spindle B is held by its bearings at an angle to the vertical, and a weight K is secured eccentrically to the spindle J and tends to hold the spindle always in one position. The inclination of the axes of rotation necessary for this result may be as shown, and should not be greater, for the reason that it is especially advantageous to preserve the spindles and bearings as nearly as practicable vertical on account of lesser friction and easier lubrication.

Attached to the spindle J or weight K is an insulated bracket L, carrying a standard or socket M, in which is mounted on antifriction-bearings a spindle N. Secured to this latter is a plate with radial arms O, from which depend vanes or blades P, with projections Q extending radially from it. A shield or screen R incloses the vanes, except on the side adjacent to the inner periphery of the receptacle A.

A small quantity of a conducting fluid S is placed in the receptacle, and in order to secure a good electrical connection between the vanes P and a terminal on the outside of the receptacle a small mercury-cup T, in metallic contact with the vanes through the bracket L and socket M, is secured to the weight K. A metal stud V, set in an insulated bolt W, projects into the cup T through a packed opening in its cover. One terminal of the circuit-controlling mechanism will thus be any part of the metal receptacle and the other the insulated bolt W. The apparatus may be connected up in circuit by connecting the wires of the circuit to a brush X, bearing on the bolt W, and to a binding-post Y in contact with the base D.

To operate the apparatus, the receptacle is set in rotation, and as its speed increases the mercury or other conducting fluid which it contains is carried by centrifugal force up the sides of the inner wall, over which it spreads in a layer. When this layer rises sufficiently to encounter the projections Q on the blades or vanes P, the latter are set in rapid rotation, and the electrical connection between the terminal of the apparatus is thereby made and broken, it may be, with very great rapidity.

The projections Q are preferably placed at different heights on the vanes P, so as to secure greater certainty of good contact with the mercury film when in rapid rotation.

Fig. 3 is a central vertical cross-section of another type, which involves two salient features of novelty, one that it provides for maintaining in a rotating receptacle a stationary jet or jets which by impinging on a rigid conductor maintain the latter in rotation, thereby securing the requisite rapidly-intermittent contact between the two, and the other that it utilizes the rotation of such rigid conductor as a means for opposing or preventing the movement of its own supports in the direction of rotation of the receptacle, thereby securing, among other things, an approximately constant relative movement between the parts, a feature which in devices of this kind is often very desirable.

Referring to the figure, A designates a receptacle, usually of iron or steel and mounted in any suitable manner, as by trunnions B B, having bearings in standards C C, so as to be capable of rapid rotation about a horizontal axis.

The receptacle is divided into two parts insulated by a washer D and held together by insulated bolts E with nuts F. These two parts are electrically connected, respectively with the two terminals of the apparatus, and by means of brushes X Y, bearing at any suitable points on the two parts of the receptacle, the circuit-controller is connected with the wires of a circuit.

Any convenient means may be employed to rotate the receptacle; but a simple way to effect this is to surround the same with a field-magnet G and to make the receptacle itself the armature of an electric motor or else to secure to it armature-cores, as H.

A body I is supported by trunnions J, having bearings in the ends of the receptacle and concentric with the axis of rotation of the same. The weight of the body I being eccentric to this axis tends to oppose its turning about the axis when the receptacle is rotated.

Upon the body or support I, but insulated therefrom, is secured a vertical standard K, in which there is a freely-rotatable spindle L, carrying a disc M, with radial arms inclined to the plane of the disc, so as to form vanes N. Arms O P are also secured to the body I and are formed with or carry at their ends ducts or tubes Q, with one end directed toward and opening upon the vanes N, and the other end close to the inner wall of the receptacle and opening in the direction opposite to that of the rotation of the receptacle.

A suitable quantity of mercury R is placed in the receptacle before the latter is sealed or closed.

The operation of the device is as follows: The receptacle is started in rotation, and as it acquires a high velocity the mercury or other conducting fluid R is caused by centrifugal action to distribute itself in a layer over the inner peripheral surface of the receptacle. As the tubes or ducts Q do not take part in the rotation of the fluid, being held at the start by the weighted body I, they take up the mercury as soon as it is carried to the points where the ducts open and discharge it upon the vanes of the disc M. By this means the disc is set in rapid rotation, establishing the contact between the two sides of the receptacle which constitute the two terminals of the circuit-controller whenever the two streams or jets of fluid are simultaneously in contact with the vanes, but breaking the contact whenever the jets discharge through the spaces between the vanes. The chief object of employing more than one insulated jet is to secure a higher velocity of approach and separation. The disc M, having acquired a very rapid rotation, operates to prevent by gyrostatic action any tendency of the body I to rotate or oscillate, as such movement would change the plane of rotation of the disc. The movement of the parts, therefore, and the operation of the device as a whole are very steady and uniform, and a material practical advantage is thereby secured. The speed of the disc will be chiefly dependent on the velocity of the streams and pitch of the blades, and it is of course necessary in order to produce a constant speed of rotation of the disc that the velocity of the streams be constant. This is accomplished by rotating the receptacle with a constant speed; but when this is impracticable and the uniformity of motion of the disk very desirable special means are resorted to to secure this result, as by providing overflowing-reservoirs V V, as indicated by dotted lines, from which the fluid issues upon the vanes with constant velocity, though the speed of the receptacle may vary between wide limits.

In Fig. 4 is shown a central vertical section of an improved circuit controller and Fig. 5 represents the latest and most preferred form, showing it in connection with the remaining parts of the apparatus illustrated diagrammatically. In these forms the receptacle contains both a conducting and a non-conducting fluid, the former being the heavier, and the terminals are maintained in such relations that the electrical connection between them is made and broken by the successive immersion of the contact-points into and their withdrawal from the conducting through the non-conducting fluid. These relations are best maintained by such construction of the receptacle that the distribution of the two fluids necessary for the proper operation of the device may be preserved by centrifugal action and the rotation of the other terminal effected by the movement of the fluids in relation to it.

To secure the conditions necessary for the accomplishment of the objects of the invention, various mechanical expedients may be resorted to; but the best and most practicable device for the purpose appeared to Mr. Tesla to be a hollow wheel or drum mounted so as to be rotated at any desired speed and containing a conducting fluid, such as mercury or an electrolyte, which by the rotation of the drum is thrown by centrifugal force outward to the inner periphery of the same, and a sufficient quantity of a lighter non-conducting or poorly-conductive fluid, such as water or oil, which by the centrifugal action is maintained on the surface of the heavier conducting fluid and tends to prevent the occurrence of arcs between the contact-points and the conducting fluid.

A central opening is formed in one side of the drum, through which enters an arm carrying a disc with peripheral projections or vanes which when the drum is rotated project to a sufficient extent toward or into the conducting fluid to effect the makes and breaks of the circuit.

The motion of the fluid within the drum causes the disc to rotate and its projections or vanes to make and break the circuit with a rapidity which may be very great. In fact, when the drum is rotated at a high rate of speed, the fluid conductor may become in its effect similar to a solid body, upon which the conducting disc rolls so that the conducting fluid might be dispensed with.

In order to insure the proper immersion of the projections into the fluid to compensate for wear and at the same time to secure a yielding pressure between the fluid and the disc, it is desirable to employ for the disc some form of spring connection or support which will exert a force tending to force it in contact with the fluid.

Referring to Fig. 4, the various parts are mounted on a base, which contains the condenser, and comprise a transformer with primary and secondary coils, one or more self-induction coils, a small electromagnetic motor D, and the circuit-controller, which is driven by the motor.

The shaft of the motor D extends through a stationary disc E, and to its end is keyed a hollow wheel or drum F, which rotates with it. Two standards G are secured to the disc E and connected by a cross-bar H, from which extends an arm K into the interior of the drum F through a central opening in its side.

To the end of the arm K is secured an arm L, carrying at its free end a disc M with peripheral teeth or projections N. The disc is mounted on any suitable bearings in the arm L, so as to be capable of free rotation.

It is desirable that the disc should admit of adjustment with respect to the inner peripheral surface of the drum, and for this purpose the arm K is secured to a rod O, which passes through supports in the cross-bar H and is adjustable therein by means of threaded nuts P.

The interior of the drum F is tapered or contracted toward the periphery so as to form a narrow trough in which the fluid is confined when the drum is rotated.

R designates the conducting fluid, and S the lighter non-conducting fluid, which are used in the drum. If the proper quantities and proportions of these fluids be introduced into the drum and the latter set in rapid rotation, the two fluids will distribute themselves under the action of centrifugal force around the drum in the manner shown in the figure. The arm K is adjusted so that the teeth or projections on the disc M will just enter the conducting fluid, and by the action of either or both the disc will be rapidly rotated. Its teeth are so arranged that no two are simultaneously in contact with the conducting fluid, but come into the same successively. If, therefore, one part of the circuit be connected to the drum, as by a contact strip or brush T, and the other part to the disc M, or to any part, as the standards G, which are insulated from the frame of the apparatus and in metallic connection with the disc M, the circuit will be made and broken with a rapidity which may obviously be made enormously high. The presence of the non-conducting fluid on the surface of the other operates to prevent the occurrence of sparks as the teeth N leave the latter and also to prevent the current from leaping across the space between the teeth and the conductor as the two approach.

The diagram of circuit connections shown in Fig. 5 will serve to illustrate the purpose and mode of operation of the latest device. Let f f be the conductors from a source of current, each including a self-induction coil C C′ and connected with the arms L and L′ and with two conductors B′ B″, respectively. Then during the periods when the circuit is completed between the two arms L L′ the coils C C′ store energy, which on the interruption of said circuit rushes into and charges the condensers. These latter during the periods when the circuit is closed between arms L and L′ discharge through the primary A′ and induce by such discharge currents in the secondary A″, which are utilized for any purpose for which they may be suited, as in operating vacuum-tubes X or suitable lamps Y. It will be understood that the rotating drum may be mounted in a horizontal or other plane.

INJURIOUS EFFECTS OF THE ROENTGEN RAYS.

BY JOHN T. PITKIN, M. D

It is safe to say that no scientific discovery was ever received with greater rejoicing by suffering humanity than the enunciation by Professor Roentgen of the possibilities he had discovered that the x-ray possessed which could be utilized to photograph the living dense structures of the human body and thereby determine their physiological and pathological condition.

An army of scientific men including many of the medical profession hastened to become his disciples.

Static machines and induction coils or step up transformers of every conceivable size and description were suddenly very much in requisition.

An era of experimentation and investigation with x-rays galore was inaugurated, all of which was productive of many glowing accounts of what was seen and done through their instrumentality.

But this new variety or degree of light, too rapid in its rate of etherial vibrations to be perceived by the visual organs also failed to impress the nerves of tactile sensibility and thereby warn us of its dangerous and destructive qualities, consequently many untoward results have been experienced through which the ser-services of the Roentgenian have been brought into disrepute and his great field of usefulness thereby unduly limited.

Many who have been exposed to the Roentgen rays have suffered as sequelae all conceivable varieties and degrees of burns. The loss of an eye, the detachment of an external ear, the sloughing of a lower extremity, alopecia of a large portion of the head are among the alleged injuries sustained [redacted] one exposure of the brain to the rays for a period of thirty-minutes at a distance of one and one-half inches from the tube was in all probability contributory to death.

Although not any one operator of the rays may even hope to determine all of their mysterious properties, still each by careful observation may be able to add a little knowledge toward the enhancement of their usefulness on the one hand and the limitation of their destructiveness on the other. It is in this spirit that the writer who has had an experience from almost daily employment since their inception, nearly three years ago, concluded to communicate the tabulated results of his investigations.

DESCRIPTION OF THE X-RAY BURN.

Not any disagreeable feeling is experienced in the parts during the exposure, only a gentle breeze caused by bombardment of parts by the particles of electrified air repelled from the outer surface of the Crookes' tube. A period of incubation lasting from one to twenty-one or more days in which the parts functionate as usual and are devoid of discoloration or discomfort. Small erythematous spots with itching and dull pain deep seated become manifest, the redness extends, the pain increases in severity, is worse at night, and at times almost unbearable. The epidermis becomes separated from the derma by a transfusion of watery serum forming large blebs which coalesce, break down and discharge profusely. The epidermis desquamates layer after layer much as we can remove the outer coatings from an onion, the parts are much swollen, stiff, hot, angry looking, bleed easily and are very painful. If the fingers or toes are attacked the nails lose their brightness, as they grow out the line of demarkation between the new and old

texture becomes apparent. The stage of ulceration supervenes characterized by its indolence, severe pain and being usually devoid of suppuration, its depth depends upon the severity of the exposure and the vulnerability of the tissues, it may involve all of the subjacent structures even the bone participating in the inflammation. After several weeks or even months of chronicity, the parts very slowly repair, the destroyed parts are often regenerated and functional activity may be entirely restored but the new integument will be devoid of hair and hair follicles.

TREATMENT OF X-RAY INJURIES.

Treatment is of little avail—showering the parts with cold water reduces the temperature and for the time mitigates the pain. A rubber bandage loosely applied will hasten repair and afford a little relief, a solution of cocaine muriate will benumb the nerves, slightly raising the parts afford relief, but if raised too high, the suffering is intensified. Hot applications augment the discomfort of the patient.

THE CAUSE AND HOW TO AVOID THE DANGER.

If in accordance with the general consensus of opinion we concede that the rays in and of themselves are devoid of dangerous properties, that all of the bad results are attributable to the electricity unconsumed in their generation, it becomes obvious that as the x-ray can not be obtained without the electrical currents every precaution must be taken to keep the patient's body out of their field of operation.

In the atmosphere in the immediate neighborhood of every excited Crookes' tube two separate fields of force, the electrical and x-radial can be investigated, a portion of the former travels the dialectric air along the conductors to and from the tube, another portion which concerns us most is repelled from its exterior traveling a varying distance into space but incessantly tends to return to the generating apparatus by the path or paths of least resistance, this field of force constitutes the danger zone and can be explored by a floating feather or silken fabric which will travel through the areal electrical pathway. The x-radiance can be traced through this electrical field into the apartment by the aid of the fluoroscope, it will be observed to diverge from the deflecting target in the Crookes' tubes spreading out in a conoidal manner, rectilenear in propagation.

X-ray injuries may follow the employment of any variety of exciting apparatus but are by far more common from the unidirectioned than the oscillatory discharges, because the latter neutralizes its own potential with each pulsation in the immediate vicinity of the Crookes' tube, *i. e.*, has a smaller danger zone whereas, with the unidirectioned current the tendency is to select the patient's body as a path for a portion of the return flow.

Employment of the metallic grounded screen as recommended by Nikola Tesla as a protective measure is of extreme importance.* With the modern static machines capable of developing a pressure of several millions of volts, the employment of additional spark gaps increases the electrical dissemination, raises the resistance, developes amperage, increases the electrification of the patient and thereby adds to the danger.

Although it may seem paradoxical, the same strength of current from a large static machine delivering an electro-motor force of three million volts capable of causing severe x-ray injuries with the Crookes' tube attached, can be employed to bombard a patient's body placed directly in the circuit, after the tube has been removed, as a therapeutic proceed-

*See Electrical Review, May 5th, 1897.

ure, with only beneficial results, the skin may be reddened for a few hours immediately following the exposure, but no delayed impairment need be anticipated.

Insulating the body of the patient exposed to the x-rays, lessens his electrical transmissibility, and hence, decreases the danger.

Untoward results are in inverse ratio to the distance from the excited tube, the time of exposure and the efficiency of the apparatus—in other words the Crookes' tube, like the red hot stove, will not burn us unless we are brought into too close relationship therewith, but unlike the stove the excited tube will not warn us of its destructiveness and such manifestations are not immediate but delayed.

X-RAYS AND LUPUS.—It is reported from Vienna that Dr. Schiff has successfully treated cases of lupus vulgaris by means of the x-rays. His process is to set up an independent inflammation in the lupoid area by exposing the part to a very intense radiation. So far, investigations into the germicidal effects of the x-rays have gone to show that their activity in this respect is not greater than that of ordinary light. But Dr. Schiff's result is not a germicidal one, and we know that inflammation, and even necrosis may result from exposure in certain cases, although we do not know the determining factor which leads to iujury in some cases but not in others under apparently similar conditions. It is not, however, altogether improbable that Dr. Schiff's results may be due to a direct germicidal action of the x-rays on the tubercle-bacillus. Light, we know, is deleterious to this organism, and Dr. Finsen, of Copenhagan has reported cases of cure in lupus by protracted exposure to concentrated light, so arranged that the ultra-violet rays predominated.—*British Medical Journal.*

THE CAUSE OF THE EFFECTS PRODUCED BY EXPOSURE TO THE ROENTGEN RAYS.

BY ALFRED C. PRENTICE, A. M., NEW YORK.

When Dr. Wm. Konrad Roentgen discovered the x-rays he gave them this name because he did not know what they were, and the algebraic sign for an unknown quantity aptly signified his limited knowledge of their nature. It is significant that the name is still applicable. Dr. Roentgen's first reports were published in January, 1895, since which time scientists have eagerly crowded into this field of discovery. Much has been learned of the phenomena exhibited by the x-rays, but many difficult questions remain unanswered as yet by scientific facts. Very like the phenomena of electricity itself, the exact nature of which is still an enigma, the results produced by that form of electrical discharge in the vacuum tube, viz., the cathode rays and the x-rays, have found many new and varied applications in practical science, while many conflicting theories attempt to explain their action. Nor is the evidence brought forward as yet conclusive as to their exact nature.

The most important use of the x-rays is in medical and surgical diagnosis, but this has been involved with troublesome results in some cases. From their early use, and even now occasionally, there has followed a severe lesion at first apparently of the skin, but later involving the deep tissues as well. The constitutional disturbances have been most severe, and the process of healing is always protracted and exceedingly painful. Although cases of the "x-ray burns" so-called have become less frequent, and of the patients exposed to the rays, probably only a small fraction of one per cent experience any such results, nevertheless the uniform severity of the lesion and its obstinacy in healing can not but

qualify as more or less dangerous any exposure to their action. Notwithstanding these objections, the use of the x-rays in surgical diagnosis is destined to become general. Cases are on record (1) in which even the courts are required to accept the skiagraph as corroberative evidence of expert testimony.

The theories adduced to account for the injuries resulting from the application of the x-rays, inducing the "x-ray burn," have not as yet afforded either a remedy for the lesion or a way to avoid it.

The following series of experiments* have been conducted by the writer during the past six months in the study of the problem.

The x-rays were produced by means of the static electric current from a Wimshurst or influence machine having eight circular plates of blown glass each twenty-eight inches in diameter, revolv- at a high rate of speed between an equal number of stationary plates. The power was supplied by an one-half horse-power motor of the Crocker-Wheeler type connected with the current used for lighting the building. The apparatus is supplied with Leyden jars, in circuit or not, accessory spark gaps, and all adjustments for perfect regulation to secure the best results from the vacuum tubes. The tubes used were fourteen inches in length, having each a bulb three and one-half inches in diameter, enclosing aluminum cathodes and platinum anticathodes, also provided with an auxiliary potash tube to be connected in circuit by a shunt, so as to reduce the vacuum when it became too high. In this manner the tubes could be so adjusted to the potential of the current as to produce x-rays of the greatest brilliancy and penetration, and maintain their uniform production for an indefinite period without danger of breakage by perforation.

Two guinea pigs kept upon the same conditions of food, etc., were used—one for the experiments and one for the purpose of normal comparisons. Exposed a pig to the x-rays at a distance of three inches from the tube for a period of twenty minutes in order to accustom her to the slight annoyances of noise, etc., incident to the following experiments.

The only effect of the exposure was a slight drowsiness, which gradually passed away. No further effects of the exposure became apparent during the following week. Accordingly the pig was again exposed to a low vacuum tube giving x-rays of a poor quality, at a distance of one inch from the surface of the tube, for ten minutes; and again to a high vacuum tube emitting intensely brilliant x-rays, at the same distance, for a period of two hours. During this time the pig was confined in a pasteboard box perforated by a window one and one-half inches square, directly opposite the pig's right lateral thoracic wall. She remained quiet in her box except at intervals she would shift her position as if uncomfortable, but would immediately return to her former position. Three or four times she appeared to act as if something annoyed her belly and endeavored to reach the spot with her nose, but after some slight effort subsided into quiet.

During this time the table on which the pig rested became strongly electrified, and no doubt the pig was electrified as well.

She acted entirely normal, and no cutaneous or other effects were noticeable for one week after the exposure.

The fur was then clipped from a region one inch square, over the right lateral thoracic wall, which had been previously exposed, and again submitted to action of rays of greatest brilliancy for a

*The experiments mentioned in this paper were conducted in the photographic and x-ray laboratories of the Department of Pathology in the College of Physicians and Surgeons, Medical department of Columbia College in the City of New York, under the guidance of Dr. Edward M. Leaming, F.R P.S., instructor in photography, photomicography and skiagrapny in the above institution. The microscopic data here presented were supplied by the courtesy of Dr Frederick S. Ward, assistant in Normal Histology in the Department of Pathology.

period of seventy minutes at a distance of one inch.

In this exposure, although neither the pig nor table came in contact with the electrical apparatus, both became so strongly electrified that a spark was produced between the edge of the table and my finger held near; and the pig started and squirmed when I touched her, as if pricked with a pin, while I could feel the pricking sensations at the tips of my fingers, on touching her body. By the end of the week from the time of this exposure, there appeared on the clipped area two or three dry vesicles of exfoliating epidermis. The lesion gradually grew deeper and continually worse, until at the end of the second week the animal was very ill, showing marked ccnstitutional symptoms of fever and depression. Examination revealed a characteristic "x-ray burn." The skin had vesiculated and peeled off in flakes, leaving a pale, raw surface, moistened with serous exudation. Not much, if any, inflammation was evident, but the lesion was quite sensitive and apparently very painful. Only the small area which had been clipped was at first affected, but the injury rapidly extended, and on the night after the fifteenth day following the exposure the pig died.

On picking up the body by the fur at the back of the neck, a large bunch came out, permitting the body to fall. Body was dissected and portions were reserved for histological examination. The following is Dr. Ward's report:

Examination of Injury to Thoracic Wall of Guinea Pig Due to Prolonged Exposure to Action of X-Rays.

"*Macroscopical.*—Over a circular area of about four c. m. in diameter the hair and skin had been removed and the exposed surface was parched, the subcutaneous tissue and thoracic muscles feeling as though they were partially dried to the underlying ribs.

Microscopical.—Portion for examination taken through the seat of injury and including entire thickness of thoracic wall. Fixed in formalin five per cent; alcohol, ninety-seven per cent. Decalcified in acid. Imbedded in celloidin. Stained with Gage's haemotoxylin and alcoholic eosin. The skin and subcutaneous tissue had all disappeared. In the central portion the superficial layers of muscles did not stain. No striations were visible. The blood-vessels were shrunken and contained very little blood. Approaching the margin, the staining of the specimen improved, striations and cell nuclei of the connective tissue were visible. The deep, muscular layers of the central portion were slightly stained with eosin, and the nuclei took on a pale-purple color, but in neither case was the staining that of normal muscle. At the edge of the affected area, about blood-vessels and between muscles, there was a moderate amount of infiltration of small, round cells.

Anatomical diagnosis is that all the structures at the site of the injury have lost their vitality and have become dried. In the closely adjacent parts there is a very moderate amount of inflammation."

The sensation of drowsiness has been mentioned by other writers as following an exposure to x-rays. The statement of Professor J. J. Thomson that "all bodies traversed by Roentgen radiations become conductors of electricity" is perhaps a hint. It is supported by Professors Trowbridge and Burbank. (2) We know that twice were the animal and table charged in our experiments. Tesla states (3) that "by means of an enormous potential and high frequency, the tube was surrounded by a violet luminosity or halo," and that "Lenard also obtained a similar phenomenon in front of the aluminum window."

Mr. Rollin states (4) that the burning from vacuum tubes *not generating x-rays* may be severe, the tube being exhausted to such a degree that no Roentgen light could be produced with the voltage used.

Professor Thomson, of Harvard, demonstrates (5) by experiments upon himself that if the x-rays are ether vibrations of great rapidity, known as ultra-violet light, as we are now led to believe, they could not have produced the "burn" which he induced upon his finger by exposing at one and one-half inches distance from a vacuum tube of blue glass

in which was a transparent window of clear German glass, the injury which followed occurred only on that portion opposite the clear glass window, and the part covered, as it were, by the blue glass was unaffected, marked off by a sharp line of demarcation. He says the blue glass would have been transparent to the ultra-violet rays.

In another case (6) of purposely induced dermatitis, no effect was produced where the skin was covered with lead and tin foil, the lesion appearing only on the uncovered area, although exposed at a distance of only five-eighths of an inch. It would appear that only the electricity attacking the area covered by the foil was conducted away, while that attacking the uncovered area was the ultimate cause of the injury. Certainly the x-rays would have penetrated the foil as if it had been paper.

Dr. Monell is authority for the statement (7) that "nothing is more certain than that a sufficiently energetic electric current passing to tissues which it can reach and enter only after electrical energy has been transferred into heat by resistance, such as dry and hair-covered skin or clothing, will vesicate and can be made to produce intense and deep inflammatory action."

All these statements combined with the evidence of direct experiment tend to the conclusion that not the x-rays themselves, but the direct actions of the electric currents upon the fluids and tissues are the real factors in the damage done.

Tesla has stated (8) that he "believes the hurtful action is not due to the x-rays, but to the ozone generated in contact with the skin. Ozone," he says, "attacks the cutaneous surface, its action, no doubt, being heightened by the heat and moisture of the skin. This generation of ozone ceases at a definite distance from the electrical terminal, and the same is true regarding the production of this irritation." He also believes, or did believe that the electrodes became gradually disintegrated by the bombardment of the cathode rays, and that these metallic particles penetrate the walls of the tube. He said, (9) "I am getting more and more convinced that we have to deal with a stream of material particles which strike the sensitive plate with great velocities. If these observations be confirmed by men of keener insight, I shall be still more convinced that material streams of matter actually penetrate the skull. Thus it may be possible to project a suitable chemical into any part of the body."

Professor Ames (10) states: "The radiation in an x-ray tube may be divided provisionally into three classes: Ether waves, which may have wave-lengths from 150 to 800 m. m. approximately; cathode rays, which undoubtedly are streams of matter electrically charged; and x-rays, about whose nature there is no conclusive evidence at the present time. If the walls of the tube are thin enough, and of suitable material, all these radiations will emerge and pass into the surrounding air. It is a matter of doubt if the cathode rays observed outside the vacuum tube are the same as those inside; but the inner ones undoubtedly cause the outer ones. There is no evidence that the x-rays carry with them particles of matter, or that they directly cause a stream of particles; in fact, all known facts serve to point to the belief that they are ether waves of extreme shortness."

If this last statement holds true, then Professor Thompson has proven that the x-rays themselves do not burn. That the "cathode rays are streams of matter electrically charged," gives Dr. Gilchrist (11) sufficient reason to assume that the lesions may be due to the entrance of material particles—of platinum in his case—into the tissues, and that the cathode rays which accompany the x-rays, may be the cause of the trouble and not

the x-rays themselves. He endeavored to show that these particles had so accumulated in a given case as to produce an ostitis and periostitis, acting like foreign bodies in the tissues. He produced in evidence of this a skiagraph of the part taken after the injury was developed, which he said showed a marked increase in the density of the bones. He laid no emphasis on a chemical analysis of the exfoliated skin, which, however, gave a negative result.

Campbell Swinton, Esq., of London, writes: "Cathode rays are generally believed in this country to consist of atoms or molecules of risidual gas, which, being similarly electrified to the cathode, are repulsed by the latter, and travel at an average velocity not much less than one-twentieth that of light, the velocity depending upon the exact potential of the cathode and the molecule at the moment the latter leaves the former, and also upon the degree of the exhaustion of the tube, upon which depends the free path of the molecules, that is, the distance a molecule can travel without coming in contact with another molecule."

It seems strange that Dr. Gilchrist should have so confused the material particles of the cathode rays, which, as we have seen, can be nothing but residual gas, with the unique theory of Tesla, who spoke of metallic particles of the electrodes—aluminum or platinum, as the case might be—which he believed were projected through the walls of the tube and into the densest tissues. Tesla has also informed us (12) that if the part of the body exposed to the x-rays be placed between a metal plate and the tube, the injury would be on the side of the part on which was the metal plate. But that if a thin plate of aluminum, which is practically transparent to the x-rays, or a sheet of wire gauze, be placed between the tube and the exposed part, and at the same time the *metal screen be electrically connected with the ground*, the disturbance to the tissues will be avoided. His latest suggestion (13) is that it is possible for the "electro-static influence" which generates the ozone to "decompose the sodium chloride in the tissues, thus giving rise to irritants." It would appear that his statements of the violet halo or brush-discharge around the tube connected with the practical value of a metal screen in dispersing the injurious agents when electrically grounded, and its concentrative power, if placed on the far side of the part and not grounded, point directly to the action of electric currents and nothing else.

Dr. Charles a Lenard (14) states directly that the "burn" is the result of induced electric currents in the tissues, which will be induced capable of destroying their vitality, if the patient is approached sufficiently near to the x-ray tube.

Dr. Monell speaks of the "electrical energy transformed into heat by resistance of dry skin, etc., as causing dermatitis and inflammation. Professor E. Dorn (15) has demonstrated that x-rays do exert very slight heat effects, and he has measured their quantity, but this element is of so small amount as not to be appreciable.

A remarkable fact in nearly all cases of the "burn" is that no sensations of heat are felt at the time of exposure, and only in some cases is there noted any immediate symptoms whatever, as of "a sense of prickling heat, or a tingling followed by itching;" but there is uniformly no sensitiveness or pain. Another characteristic is the time which elapses from the exposure to the appearance of the first symptoms—usually a week to nine or ten days, or even a month or more in some cases. These facts have called forth the statement from several authorities (16) that the lesion is "not a burn," inasmuch as the accepted defini-

tion (17) of a burn is "an injury produced by the action of too great heat." It is also useful to note that ichthyol usually gives relief from pain in an ordinary burn, but Dr. Tuttle (18) found that it aggravated the pain of an x-ray injury. Cold water also proves soothing to burns, but in this case it was found the pain increased when moist dressings were applied of a temperature lower than 85 deg. Fahrenheit. Also, in certain cases, where skin grafting had been employed, the severe neuralgic pain still persisted after the part had healed.

It may not be improbable that electrical energy attacking the tissues is transformed into another form of energy than heat, as perhaps electrolysis of chemical substances. Dr. Bardeen (19) regards it justifiable to consider that one of the main causes of death after burns (ordinary) is to be sought in a toxaemia caused by alterations in the blood and tissues, the direct effect of the elevation of temperature; "a view which is further strengthened by chemical evidences and the experimental work of Kijanitzen and others." Since the pathological condition of the tissues in the "x-ray burn" correspond very nearly to, only are worse than those of a severe burn produced by heat, it does not seem unreasonable to suppose that similar chemical alterations and decompositions might be produced by electrical energy or electrolysis as are supposed to be produced by mere action of heat. Tesla hinted at this phase of the question in speaking of the decomposition of the sodium chloride.

It is well known that the static discharge in air produces ozone in a more or less considerable amount. The fact that a sufficient amount to detect by the odor is often produced and inhaled with impunity to the mucus lining of the respiratory passages would cast some discredit on the theory that it might irritate a warm and moist skin.

Tesla has demonstrated, however, that metallic particles of the anticathode do become deposited upon the inside of the tube, by breaking the tube and analyzing the deposit noticed. This deposit is especially noticeable in the tubes that have been in use for some time and at so high tension as to render the anticathode red or white hot. But whether these particles could penetrate the tube and enter the tissues to produce irritation as foreign bodies, is another question.

In order to test this matter, I exposed to the rays of maximum brilliancy four photographic plates superposed, so that if the metallic particles should strike the sensitive film or even pass through it, and one or more of the four glass plates and gelatine films, just as in human tissues Tesla supposed them to do, they would be apt to lodge, some of them at least, in one or more of the films. The exposure in this case was timed and adjusted exactly as in the last exposure of the guinea pig, viz., for seventy minutes at a distance of one inch. If the metallic particles caused the lesion which developed a week later in the case of the pig, they would certainly be deposited in the films of the plates. I therefore removed all the films, after having dissolved out the unchanged silver-salt in a solution of hyposulphite of sodium, and evaporated to dryness. Reduced the residue to an ash which was then digested in aqua regia (HCL, 3 parts to HNO_3 1 part, concentrated), forming from any metallic platinum present, soluble platinic chloride, $PtCl_4$. I then treated this solution with stannous chloride, $SNCl_2$ which reduces platinic salts to platinous salts. The latter are soluble in dilute hydrochloric acid, (HCl) giving a characteristic deep cherry red colored solution. I accordingly added HCl, but no color reaction took place. At the same time, for a check test, I dissolved in 10 c.c. of water two or three small granules of potassium, chloroplatinite,

and tested for platinum, as already indicated. The color reaction was characteristic, intense and permanent, in fully 20 c.c. of solution. This experiment proves conclusively that the particles of platinum are not projected into surrounding objects.

It is of quite recent demonstration (20) that the silver salt of the photographic plate which is sensitive to white light, is not affected by the x-rays. Experiments made upon the sensitized collodion film and the Daguerreotype plate produced no image whatever, while upon the gelatin coated plate or film the negative image was produced in the usual manner.

The conclusion drawn was that the x-rays did not produce an electrolytic effect upon the silver salt, nor even the partial decomposition as produced by ordinary light directly; but they did produce a fluorescence of the gelatine film and perhaps of the glass support, if it were of a fluorescent material, which in turn acted upon the silver salt suspended in it, just as ordinary light does. Incidentally the statement was made that plates most sensitive to ordinary light are not necessarily most sensitive to the x-rays, since the result depends upon the kind of gelatine used, and the period of cooking to which the emulsion was subjected. This fact was apparently confirmed by a series of comparative tests conducted by the writer in which he was convinced that the particular brand of plates which happened to be cheapest in the market produced the best x-ray negatives in the shortest time of exposure.

Little attention has been given to the comparative value of the static and induced currents in the production of the x-rays, and it may be worthy of note in this connection that in the great majority of cases reported as "x-ray burns," the current has been generated by the induction coil apparatus. Such an equipment of high potential, even a ten or twelve-inch spark-gap, requires less room, and is less expensive; but the current is characterized by much greater amperage than the static current of the same or even greater potential in volts. The amperage of the static current is very low, while the potential is almost unlimited under proper conditions. Also the distance of the exposed part from the tube in those reports which mention the distance has been invariably small, from three or four to six or eight inches.

The length of the spark-gap is directly proportional to the internal resistance of the tube (21), and is also directly dependent upon the voltage (22), and not the amperage. The greater the internal resistance, the more penetrative are the x-rays produced. Thus it is seen the production of x-rays of the highest penetrative value is directly dependent upon the voltage utilized. And consequently, the lower the amperage, the less danger attends the use of the tube, because a less quantity of electricity per unit of time is free to act upon the tissues; and with a current of higher potential and lower amperage the greater may be the distance from the tube, and only the voltage is important to produce x-rays.

Since the intensity of the x-rays varies inversely as the square of the distance, it follows that the higher the potential in volts, the greater may the distance be, to produce the same results of penetration. I have not been able to see any penetration by the skiascope, from a tube supplied by an induction coil having a six-inch spark gap at a distance of eight feet. While with a tube supplied by the static machine working at a similar sparking interval, the bones of my hand could be seen at a distance of thirty-six feet.

Professor Thomson has already demonstrated that a "burn" may be induced by the use of the static current in the vacuum tube, but no cases on record, to my knowledge, in which injuries have

been sustained at so short a distance as six inches, using the static current, while one case I recall was burned by the induction current x-ray tube at a distance of eighteen inches.

If the intensity of the brush discharge is governed by the same law as other form of radiated energy, it would require an exposure of some thirty-two hours at a distance of twelve inches, and fifty-seven hours at a distance of sixteen inches, to produce a lesion as Professor Thomson did while using the static current in his tube for half an hour at one and one-half inches distant, making no allowance, of course, for idiosyncrasies of patients.

The radical treatment that has been employed consists in a complete excision of the lifeless tissues, as in gangrene, thereby producing a healthy granulating surface in the wound, which rapidly heals. One surgeon claims to have cured twenty-five or thirty cases by cutting down clear through the affected part, and then dressing with carbolic acid until granulation sets in. Balsam of Peru was then applied, and healing took place by granulation. Of course the necrotic tissues had to be sloughed off in this latter treatment.

In noting the conclusions of this paper it will be valuable to compare results strikingly similar of a series of experiments (23) by Oudin, Barthelemy and Darier, of Paris.

CONCLUSIONS.

1. The general character of the tissues affected in the "x-ray burn" is that of absolute necrosis and more or lesss exudative inflammation. The resulting alopecia is more or less marked in lesions involving hair follicles.

2. The x-rays themselves exert no appreciable heating effects, and consequently do not burn. All evidence seems to point to the conclusion that the lesion is due to the direct effects of the electric currents upon the tissues and fluids. The nature of this effect is as yet wholly speculative.

3. The ozone irritation theory is not supported by evidence.

4. Metallic particles of the platinum anode are not projected into substances near to x-ray tube.

5. X-rays do not decompose the silver salt of the photographic plate directly, but produce in the gelatine film a fluorescence which in turn acts upon the silver salt as ordinary light.

6. The use of the static rather than the induced electric current in producing the x-rays is less liable to result harmfully, (*a*) because it is of low amperage, and (*b*) being of very high potential comparatively, does not necessitate so short distance between the tube and the exposed part.

7. In all cases where exposure is required at a distance less than twelve inches from the tube an aluminum screen, electrically grounded, should be placed between the tube and the exposed part.—*Medical Review of Reviews*, N. Y.

121 West Sixty-second Street.

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THEORY OF ROENTGEN RAYS. Lond. *Elec. Rev.*, May 13.—Stokes suggested a theory several years ago, according to which these rays are aperiodic electromagnetic waves caused by the impact against the anti-cathode of the charged particles in the cathode stream; this theory was recently developed by J. J. Thomson (*Phil. Mag.* page 172). Lord Rayleigh, in *Nature*, April 28, protests against the acceptance of this theory, as it does not carry with it some of the consequences which have been deduced as the distinction between Roentgen rays and ordinary luminous and non-luminous radiation; he does not agree that Roentgen rays are not very short waves, but impulses; he favors the view that the waves differ from ordinary light only in the shortness of their waves.

IF one wishes by a simple optical illusion to obtain an almost perfect imitation of the wonders of radiography, he may take a small turkey feather, and, holding it close to the eye, look through the radiating ribs at the end of the feather at the ends of the outstretched fingers of his hand, held against the window. This done, the flesh will appear to be transparent, with the opaque bone running down in the center as shown by true radiography. If gas light is used, a piece of ground glass must be held before the flame, to diffuse the light.—*Inter-Ocean.*

CATHODE AND ROENTGEN RAY TUBES. Villard. *L'Eclairage Elec.*, May 28; *Electrical World*, New York.—An abstract of a French Physical Society paper describing improvements. One of these is an anticathode which does not blacken the tubes; iridium is very satisfactory if quite pure, but the commercial variety is not pure enough; the new anti-cathode is in the form of a paraboloid with a lateral opening through which the cathode rays enter; this will not blacken the tube, because it never acts as a cathode for the reversed currents; the form of the anode, creating an electrical field which is practically zero in its interior, totally prevents the formation of these new rays. He also describes a tube which may be regenerated; part of the tube consists of a small tube of platinum closed at one end and joined at the open end with a glass tube; nickel or palladium will also answer; to regenerate the tube this metallic tip is heated in a Bunsen flame; at about 1,000 deg., hydrogen passes through the platinum, but it is absolutely impenetrable to air. He also mentions some magic screens on which the images are preserved, but the description is not quite clear.

TREATMENT OF LUPUS WITH ROENTGEN RAYS AND CONCENTRATED LIGHT.—Dr. Kummel (Hamburg) claimed that in selected cases these means were successful, but experience with them was yet too limited to absolutely state the indications and contraindications. He exhibited two advanced cases almost cured, in which he expected a continuance of the treatment to cure radically.

TRANSPORTABLE X-RAY APPARATUS. Levy. *Elec. Zeit.*, July 7.—A reprint of a brief, illustrated paper describing a simple, portable apparatus, devised by him.

Mr. Tesla's Circuit Interrupter.—When a charged condenser is discharged through a circuit possessing high induction and low resistance electrical oscillations are produced, the frequency of these being given by $2\pi\sqrt{KL}$, where K and L respectively represent the capacity of the condenser and the coefficient of self-induction in the charging circuit. Under the most favourable conditions which can be realised experimentally the train of waves produced by a single discharge is quickly damped, owing to the dissipation of energy due to the resistance of the circuit. Thus with oscillations possessing a frequency of several hundred thousand per second, if after 200 oscillations the electric waves have been so far damped as to be negligible, there will be a current flowing through the circuit for only an inappreciable fraction of the whole time, unless the condenser be charged and discharged many times per second. The primary object of several recent patents due to Mr. Tesla is to obtain an arrangement which is capable of doing this in an efficient manner. The actual arrangement of the electrical apparatus is somewhat as follows: The terminals of a condenser of suitable capacity are connected with the electric mains, one terminal through a coil of wire possessing an iron core, the other terminal through a few turns of wire of small resistance, forming the primary of a trans former with an air core. The condenser is also capable of being short-circuited through the above-mentioned low-resistance coil by a mechanical contact-maker effecting as many as 1,000 contacts per second. As a consequence, electric oscillations will be produced in the condenser circuit, and these will be transformed to an exceedingly high voltage by means of the transformer. The general principles of the circuit interrupter employed may be understood from an example. An arm hangs vertically from a stationary horizontal spindle, a star wheel being attached to the end of the arm so as to be capable of free rotation. The spindle passes through the centre of an airtight case, which can be rotated at a high speed by means of a motor. Mercury is placed in this case, and will be driven, by centrifugal force, to form a ring around that part of the case furthest from the axis of rotation; a non-conducting liquid, less dense than mercury, forms an interior ring owing to the same cause. The quantity of mercury is so adjusted that the points of the star wheel alternately dip into it, and are withdrawn from it as the wheel revolves. The methods of using this arrangement to make and break a circuit are obvious. A number of other ingenious contrivances are also described, in some of which mercury jets are used to make contacts, whilst high-pressure gases are employed to diminish sparking. Important applications of the high-tension currents of great frequencies may be anticipated, both in regard to lighting and the formation of chemical substances, such as ozone.

The Buffalo Evening News September 13, 1898

DOCTORS IN CONVENTION.

Electro-Therapeutic Association Begins Its Sessions in the Library

The eighth annual convention of the American Electro-Therapeutic Association was called to order in the rooms of the society of Natural Sciences in the Library building this forenoon.

Although the attendance at this morning's session was small, it is expected that fully 100 men, who stand high in the medical profession in this country, will be here before night. They are coming on trains from the four points of the compass.

About 25 members were present in the Library building when Dr. Charles Rea Dickson of Toronto, president of the association, rapped for order at 10:30. He briefly announced the purpose of the association and outlined the important features of the meeting. Rev. O. P. Gifford of the Delaware Avenue Baptist Church was then introduced and delivered an eloquent prayer. The reading of the minutes of the last meeting was dispensed with and the report of the executive council was submitted by President Dickson.

On motion of Dr. William T. Bishop of Washington the privileges of the floor were extended to all members of the medical profession. Mayor Diehl was introduced and extended a warm welcome to the visitors. He spoke of the rapid strides that had been made in the growth and development of electrical treatment for disease. He referred to the way electricity was operating the street cars of this city and advisd the visiting phycians to inspect the plant of the Buffalo Railway Company. Dr. Bishop responded to the Mayor's welcome in fitting terms. Guests were then introduced. Dr. Henry McClure of Cromer, England; Dr. Holland of Hot Springs, Dr. A. D. Rockwell of New York and other physicians of note were presented and made short remarks. Letters were read from Dr. Georges Apostoli of Paris, Dr. Felice La Torre of Rome, Dr. Georges Gautier of Paris and several others, expressing their regret at being unable to attend the meeting.

Reports of committees were then presented and discussed. Dr. Margaret A. Cleaves read the report of the committee on meters, Dr. Dickson the report from the committee on electrodes, John J. Carty of New York the report on electric light apparatus for X rays.

Several physicians who were scheduled to read papers were not present and are expected later in the session. Dr. Cleaves read an interesting report on "Phlebitis; A Clinical Study." This afternoon several other papers will be read. Dr. Apostoli has sent a paper on "New Uses of the Sinusoidal Current in Gynaecology," Dr. La Torre on "Electricity in the Treatment of Uterine Fibromata," and Dr. Gautier on "Electro-Therapeutics in Gynaecology." These papers will be read by a member of the association.

Tonight a reception will be given at the University of Buffalo. Addresses will be delivered by Dr. Henry R. Hopkins, Dr. O. P. Gifford, Dr. Wende and others.

The Buffalo Evening News September 14, 1898

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(From Yesterday's Last Edition.)

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The Buffalo Evening News September 15, 1898

ELECTRICITY IN MEDICINE.

Electro-Therapeutic Physicians Close Their Session With an Excursion.

Dr. Charles R. Dickson of Toronto, president of the American Electro-Therapeutic Association, spoke at considerable length at yesterday afternoon's meeting of the association on the uses of electricity as a therapeutic agent. He declared that the necessity of such an association as the one in session was due to the fact that in the colleges nothing worthy of the subject is taught concerning electricity.

Electricity, he averred, is an agent powerful for weal or woe. Educators have hitherto been lethargic concerning it and the sooner they awake the better it will be for the reputation of surgery as an enlightened, progressive scientific profession. Electricity has too long been left to the charlatan, the incompetent and the unscrupulous. It is the association's aim to cultivate and promote knowledge of it wherever it can be of service to medicine.

Papers were read at the afternoon session by Dr. G. Betton Massey of Philadelphia, Dr. Robert Newman of New York, Dr. A. D. Rockwell of New York and others.

In the evening Dr. Lucien Howe entertained the delegates at dinner. Officers were elected at the night session as follows:

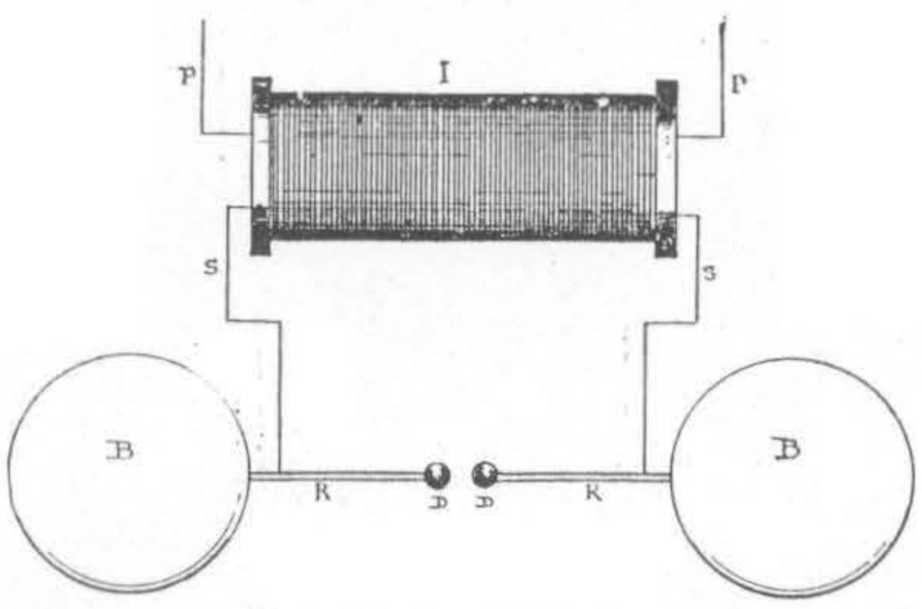
President, Dr. Francis B. Bishop of Washington; first vice-president, Dr. Ernest Wende of Buffalo; second vice-president, Dr. W. H. White of Boston; secretary, Dr. John Gerin of Auburn; treasurer, Dr. Richard T. Nunn of Savannah, Ga.; executive council, Dr. Robert Newman of New York and Dr. G. Belton Massey of Philadelphia (three years), Dr. A. D. Rockwell and Dr. William J. Morton of New York (two years), Dr. Charles R. Dickson of Toronto and Frederick Shavior of Stamford, Conn., (one year.)

This morning's sesssion ended the convention. The next annual gathering will be held at Washington a year hence. This afternoon the delegates go down the river on the yacht Huntress.

TESLA AND HERTZ EFFECTS.

The currents of high frequency used by Tesla in his researches are produced by electrical rather than mechanical means. The alternating current dynamo used by him renders a current of 10,000 alternations per second, but the actual current necessary to the performance of the luminous effects has a frequency of millions of oscillations per second, produced by the discharge of Leyden jars or condensers.

Dr. Oliver J. Lodge, in his "Modern Views of Electricity," shows that the discharge of the Leyden jar is in



Hertz Electric Resonator.

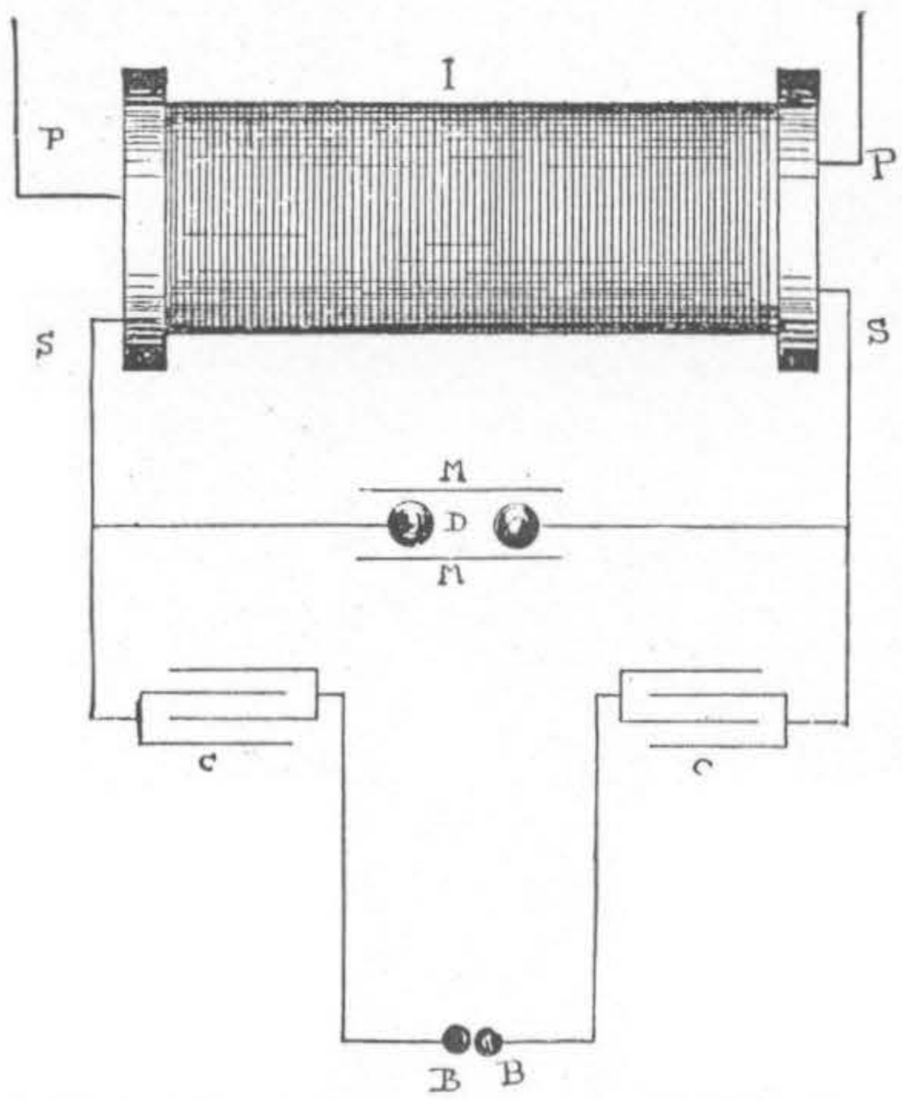
general oscillatory; the apparently single and momentary spark, when analyzed in a very rapidly rotating mirror, is shown to consist of a series of alternating flashes, rapidly succeeding one another and lasting individually less than one hundred thousandth of a second. The capacity of the condenser and inertia of the circuit regulate the rapidity of these oscillations. A 1 microfarad condenser discharging through a coil of large self-induction, such as one having an iron core, may oscillate only a few hundred times per second. On the other hand, a Leyden jar of the 1-pint size discharging through a short circuit will set up oscillations, perhaps ten million per second; and a still smaller jar would give oscillations away up in the billions. But these small jars are quickly discharged, and require a constant replenishing.

The discharge actually consists of a principal discharge in one direction, and then several reflex actions back and forth, becoming feebler until their cessation. In their vibration they generate waves in the surrounding medium, similar in many respects to sound waves, but of infinitely higher velocity. Their length depends on the rate of vibration of the source and their velocity. The microfarad discharge before mentioned will have a wave length of perhaps 1,200 miles, the small jar not over 70 feet; and yet the true light wave has only an average length of one fifty thousandth of one inch. These waves travel into space until they either die out from exhaustion or are absorbed by some suitable body; but they possess the quality of resonance in a degree like those of sound. Two tuning forks of the same pitch will influence one another—that is, one on being vibrated will start the other in vibration, even at a considerable distance, but the electric waves far surpass them in this respect.

Dr. Hertz made the first practical experiments in this direction with his electric resonator (Fig. 51). This apparatus consisted of a 3-inch spark induction coil, *I*, the secondary wires *S S* being connected to the copper rods *R R*, provided with metal balls *B B*, nearly 11 inches in diameter. The discharging balls *D D* were approximated until a satisfactory discharge passed between them. A large wire ring having a spark gap in its circuit was so influenced by the resonance as to show minute sparks passing across this gap, even when the ring was situated in a distant room. In many experiments with a rapidly vibrating induction coil current, a sparking has been noticed in metallic objects in the same room, in one instance it being discovered in the metallic designs on a wall-paper.

The "Tesla" Effects.

In exploring the comparatively new field opened up by Professor Crookes, Nikola Tesla has stimulated research



Tesla Arrangement with a Ruhmkorff Coil.

into the mysteries of high tension and frequency currents and their effects. In the majority of his experiments Tesla uses alternating currents generated by machinery of his own design, but in a large number of cases his effects can be duplicated with an induction coil suitably energized. In the latter case the apparatus consists of a battery, a Ruhmkorff coil, two condensers, and a second specially constructed induction or disruptive coil, with some few subsidiary implements. The contact-breaker or rheotome must be one giving interruptions of very rapid sequence.

Fig. 52 shows a diagram of the Tesla arrangement with a Ruhmkorff coil. The terminals of the secondary coil of the Ruhmkorff coil *I* terminate at the condensers *C. C.* Bridged across the wires before they reach the condensers is the discharger *D*. The second terminals of the condensers are led through the split primary of the disruptive coil, terminating at the points *B B* of the second discharger. The secondary of the disruptive coil is either outside or inside the primary coil. The condensers are of special design, being small, but of high insulation. They each consist of two plates of metal a few inches

square immersed in oil and arranged so they can be brought nearer together or further apart, as necessary. Within limits, the smaller these plates are the more frequent will be the oscillations of their discharge. They also fulfil another purpose; they help nullify the high self-induction of the secondary coil by adding capacity to it.

The discharger tips are preferably metal balls under 1 inch in diameter. Tesla uses various forms of dischargers, but for experimental purposes the two metal balls will answer. They are adjusted when the whole apparatus is working according to the results desired. The mica plates serve to establish an air current up through the gap, making the discharge more abrupt, an air blast being also used at times for the furtherance of this object. The device (Fig. 53)consists of an electro-magnet, *C*, set with its poles *P* across the air gap, helping to wipe out the spark, as in a well-known form of lightning arrester. This form, described by Tesla, has the pole pieces *P* shielded by mica plates *M* to prevent the sparks jumping into the magnets. Fig. 53 is an elevation and Fig. 54

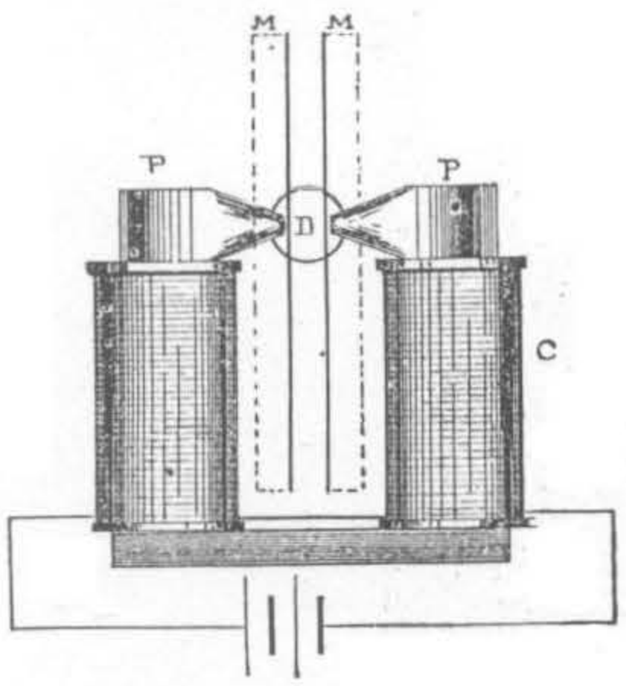


Fig. 53—Tesla's Spark Destroy r.

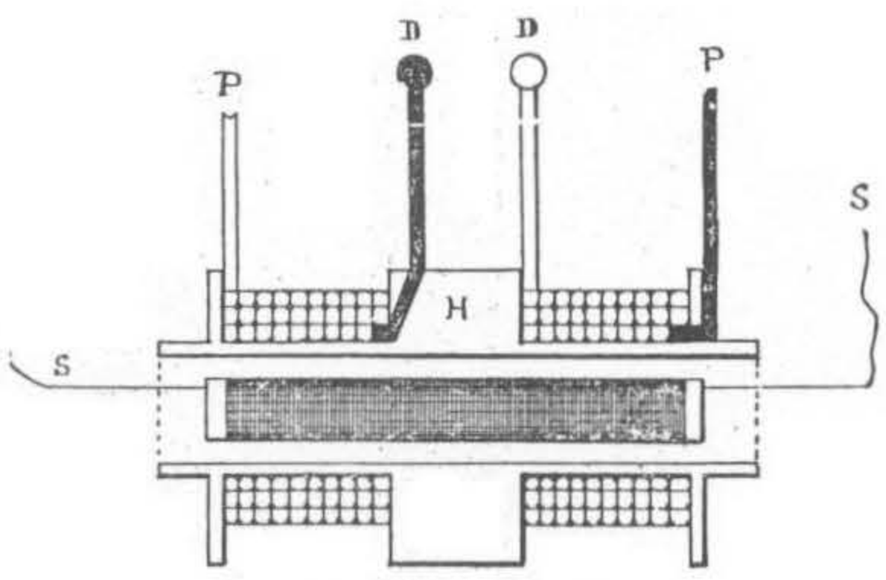
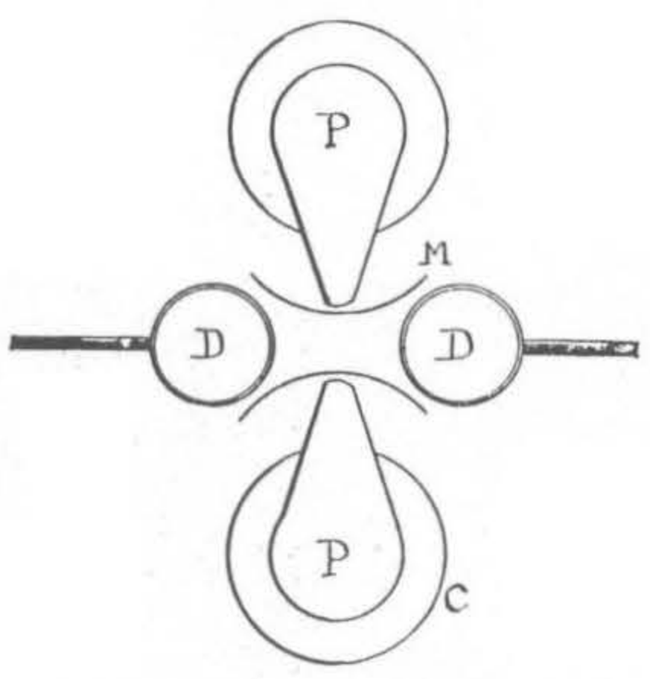


Fig. 55—Disruptive Coil.



Tesla's Spark Destroyer Shielded by Mica Plates, M M.

a plan of this device. The terminals from the condenser are led to the primary of the disruptive coil, or, as in Fig. 52, to two discharger balls *B B*. The disruptive coil (Fig. 55) is easily made, and will give good results with careful handling.

The secondary coil *S* of 300 turns of No. 30 silk-covered magnet wire, wound on a rubber tube or rod ½ inch in diameter, with the ends brought out in glass or rubber tubes. The primary coils are wound on a second rubber tube, *H*, at least 1-10 inch thick, and large enough inside to slip easily over the secondary coil S. It must be long enough to project 2 or 3 inches over the ends of the secondary coil turns. The primary has 50 turns in each coil of No. 18 B. & S. gutta-percha covered wire. The four ends, *P P P P*, of this coil are brought out in rubber or glass tubes, two to the condenser and two to the discharger *D D*. Each layer of these coils must be separated by rubber cloth or even cotton cloth. The further apart the layers the less the inductive effect, but the better the insulation. The whole coil is immersed in a glass or wooden vessel containing boiled-out linseed or petroleum oil. A perfect coil should have all the air bubbles drawn out of it after being immersed by putting it under an air-pump, but for many experimental uses this is not absolutely necessary; but extreme care must be taken to insulate the coils and their terminals. This will be apparent when the current is turned on.

The resonance effects obtained during the operation of a Tesla coil are very marked, and their study may lead to the solution of the problems of communication between distant points without the use of other conducting media than the atmosphere. But the main use to which the Tesla currents have been put is that of artificial illumination. These currents have enabled experimenters to obtain a high luminosity in vacua by the aid of only one conducting wire—in fact, in some cases without the utilization of any conductor than the air. An ordinary incandescent lamp connected to one terminal of the coil will show in a fair degree some of the luminescent phenomena. The brush effects from the terminals of the secondary coils are extremely marked and interesting; but to detail the experiments that can be performed with the Tesla disruptive coil would be an impossibility here. Reference is recommended to the published works of Nikila Tesla, which, happily, are readily procurable.

These currents of high frequency have of late been turned to account in electro-therapeutics, principally for the stimulation they exert on the nutritive process. They also exert a very great influence on the vasomotor centres, as is evidenced by the reddening of the skin and exudation of perspiration. This result is readily obtainable by placing the patient in connection with one electrode on an insulating stool, and terminating the other electrode at a large metal plate situated a few feet distant; or the patient may be surrounded by a coil of wire in connection with the coil of sufficient diameter, however, to prevent contact.—H. S. Norrie, in "Ruhmkorff Induction Coils," by permission of Spon & Chamberlain.

COMBINATION OF THE WALKER AND WESTINGHOUSE INTERESTS.

Two of the largest manufacturing concerns in this country, the Westinghouse Electric & Manufacturing Company, of Pittsburg, Pa., and the Walker Company, of Cleveland, O., have combined and formed what is probably the largest electrical combination in the world. The Walker Company has been very successful in obtaining large contracts for electric railway installations, but has been greatly hampered by litigation with the Westinghouse Company. The combination, therefore, of the two corporations will result in their working on a more profitable basis than heretofore, unhampered by ruinous competition.

Third Day—Thursday, September 15th.

The Alternating Dynamo Current.—Dr. F. B. Bishop presented a paper in which he described a simple step-down transformer for use in this connection. He said that he had treated several cases of writer's cramp with this current. The patients had been previously treated with the galvanic current, and of their own accord had spoken of how much easier they felt after the alternating current. By means of the transformer the voltage was reduced from 104 to 4. The patient placed both hands in jars containing warm water in which salt or soda had been dissolved.

The Electric Arc Bath: A Clinical Report.—Dr. Margaret A. Cleaves presented in this report detailed clinical accounts of cases treated by the electric arc bath. Among these were cases of eczema, psoriasis, bronchial asthma, and pulmonary phthisis. Her observations in connection with the last-named disease were especially interesting. As she very pertinently remarked, it had long been known that sunlight was inimical to the growth of tubercle bacilli, and the value of sun baths had been demonstrated again and again. The electric-light bath closely approximated the sun bath, and, in addition, there was the production of ozone. A greater quantity of ozone was generated from the alternating current. She preferred the arc light because of this production of ozone, and also because of the fact that the rays from this light embraced a large part of the violet end of the spectrum. There could be no doubt, she said, that in man, as in plants, protoplasmic activity was increased by exposure to electric light. Her cabinet, she said, was six feet long, two and one-half feet wide, and seven feet high, and was lined with zinc, painted white. At each end were glass compartments containing the electric arc lights. The patient reclined on a wire-mattress cot. Each lamp had a reflector which allowed focussing the light on special parts. The patient was preferably nude, and the eyes were protected by dark glasses. The maximum of nutritional activity was usually observed at the end of the second week, and this would be expected from theoretical considerations as to the action of ozone.

Dr. Nunn said that the paper was interesting as emphasizing the old-time truth regarding the sanitary value of sunshine. Of course, where sunshine could be readily obtained, it must be admitted to be superior to artificial light. As modern chemistry had shown the atmosphere to be such a complex substance, it did not seem to him wise to say very much regarding ozone.

Mr. John J. Carty, electrical engineer, suggested that some of the effect might be due to radiation and some to emanations from the arc. In the latter connection it should be borne in mind that the carbon rods were commonly of complex composition, and not pure carbon, and, furthermore, that they were coated with copper.

Dr. F. B. Bishop said that he had had an opportunity of seeing the working of Dr. Cleaves' cabinet, and had been impressed with the rapidity with which the ozone had been generated and its quantity. As he had himself secured some excellent results in the treatment of the early stages of pulmonary phthisis by means of the ozone bath, he was inclined to attribute Dr. Cleaves' success chiefly to the ozone generated in connection with the arc light.

Dr. Massey spoke of the striking effect of sunlight on the vegetable world, and the mistake of modern civilization in so generally excluding the sun from dwellings.

Dr. Cleaves, in closing the discussion, said that she wished it to be understood that she did not know what it was that gave her these good results, though the clinical fact remained. In only the one case reported had there been a complete disappearance of the tubercle bacilli, but in all of the cases so treated there had been gratifying improvement.

Some Suggestions on the Possibilities of Cataphoresis.—Mr. John J. Carty, E.E., of New York, presented this paper, which was founded on some experiments that he had made regarding the use of cataphoresis in the attempt to secure painless dentistry. It did not seem to him that there was any part of the body which physicians should despair of reaching by cataphoric medication. A novel suggestion which he made was to use an O'Dwyer tube as the positive pole, and apply the negative pole to the neck in the form of a collar in cases of diphtheritic laryngitis.

Dr. Massey said that cocaine cataphoresis never failed in dentistry if properly conducted. The principal causes of failure were: (1) improper apparatus; (2) imperfect technique, such as not properly drying the tooth cavity; and (3) lack of willingness on the part of dentists to give the necessary time to the use of this method. The suggestion about using the intubation tube seemed an excellent one, and if this tube was of zinc and was freshly amalgamated at the time, he thought it would prove still more efficient, as the oxychloride of mercury formed was one of the most powerful antiseptics known.

A High-Frequency Oscillation for Electro-Therapeutic Purposes.—Mr. Nikola Tesla, E.E., of New York, in a paper with this title described his now well-known experiments with high-frequency currents, dwelling particularly on the construction of the apparatus and the possibilities of the future in the therapeutic application of this form of electricity.

Officers.—The following officers of the association were elected: *President*, Dr. Francis B. Bishop, of Washington, D. C.; *Vice-Presidents*, Drs. Ernest Wende, of Buffalo, and W. H. White, of Boston; *Secretary*, Dr. John Gerin, of Auburn; *Treasurer*, Dr. R. J. Nunn, of Savannah, Ga.

The next meeting will be held in Washington, D. C., on September 19, 20, and 21, 1899.

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Wh. Sc., M.I. Mech. E., Assoc. M. Inst. C.E., M. Iron and Steel Inst., &c.

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Rival Systems of Electric Driving.

IT cannot be doubted that electric transmission of energy over long and short distances has made remarkable progress during the past few years. Even in this country, which is commonly reputed to be slow in adopting new methods, electric driving is being extensively used, and it will not be surprising to find the system eventually adopted in the majority of those works where the process of manufacture necessitates somewhat wide areas. The natural enthusiasm of the electrical engineer has infected to a great extent manufacturers and power users; but in spite of the obvious merits of electrical systems, and the very high efficiency that usually obtains, it must not be assumed that economy can be exhibited under all conditions.

A system of power transmission which embraces long lengths of steam pipes and small scattered engines would be clearly uneconomical, and it is not surprising when such a method is superseded by electric transmission that some very marked economies should ensue. In the case of Messrs. Richardson's works at West Hartlepool, where long steam pipes were carried through extensive shops and yards, electric transmission scored a complete triumph by demonstrating a saving of 100 tons of coal per week. Messrs. Dorman and Long again have, by adopting electricity, saved 32 tons of coal per week; while in the case of Messrs. Gray and Son the saving of fuel consequent upon introducing electric driving realised the large sum of £3,000 per annum. Electrical men could not be blamed for proclaiming such results to the whole world, but while these instances demonstrate beyond all cavil the economy of electricity, it clearly proves the extremely wasteful nature of the previous methods. It would be impossible to conceive a more inefficient means of transmitting energy than that formerly employed at Messrs. Richardson's, and almost any system of mechanical transmission, hydraulic or compressed air, would have shown marked economy over it. Therefore, without desiring in the least degree to depreciate the value of electricity as an economical transmitting agent, one is inclined to view the foregoing cases as somewhat extreme ones.

It is true that hydraulic systems are not very efficient at light loads, and that long distances and leakage considerably impair the efficiency of compressed air. Moreover, while the addition of 100 horse power to an existing installation on these systems would call for a much larger conductive agent, it would make but slight difference to the cross-section of an electric conductor. Notwithstanding these drawbacks, however, electrical engineers are somewhat prone to disregard the good features of rival systems. Moreover, we think they are apt to overstate the losses that arise in shafting, and frequently they have cited shafting losses, though doubtless unwittingly, which really represented the combined losses of shafting and gearing. This was especially noticeable in a recent paper presented by Mr. Geipel to the recent meeting of the British Association. There is undoubtedly a good deal of confusion as to the exact losses that arise in shafting. Probably there are cases where they may reach as high as 75 per cent, but it must not be forgotten that mill engineers have given considerable attention to the design of shafting, and on the whole we should be inclined to accept Prof. Kennedy's statement that for 100 horse power of useful work in shafting it required 145 indicated horse power at the engine. No doubt a well-designed electrical system could show better results than that, but it is, after all, only a series of links between the prime mover and the machine to be driven, and is, consequently, subject to certain losses of its own. The most efficient electrical plant could not show a much greater efficiency than 76 per cent at the place where power was demanded; there are the dynamo losses which might be 6 or 7 per cent; the conductors would absorb

2 per cent; while the motors would represent a loss of 12 per cent. It is true that the losses of an electric system are not continuous in the same sense as those of shafting, but even electric motors do not always abolish shafting.

While there is very properly a strong tendency among power users to accept electric driving as an economical agent, there is a disposition among electrical engineers to quarrel among themselves as to which is the best system, and the recent discussion at the British Association took a somewhat acrimonious tone. In fact, it seems to be a revival in a modified form of the old battle of the systems. These discussions, while highly diverting and even of some interest in an academic sense, might tend to somewhat perplex the prospective user of electric driving.

There is, after all, very little to quarrel about, for an unbiassed investigation into the various systems will show that each has its special sphere of usefulness. For practical purposes electric driving may be divided into three classes—continuous current, single-phase alternating, and three-phase alternating.

The continuous current motor has been widely adopted in this country, and it owes much of its development to the central station engineer, who, in an endeavour to obtain a day load for his lighting plant, has created quite a small revolution in the condition of small power users. How marked the development has been in this direction is shown in such towns as Manchester, where 257 motors, aggregating 696 horse power, are connected to the public mains, while even in a non-industrial centre, such as Edinburgh, 167 motors, aggregating 343 horse power, are employed. In the early days of electric lighting one heard a good deal as to the evil effects that would be created on the lighting circuits by the throwing on and off of electric motors, but though some trouble may have been originally experienced, a stage is soon reached when the trouble ceases. The interference caused by motors decreases in exact proportion to the increase of the load, and the starting and stopping of motors causes a minimum of disturbance; especially is this the case in three and five wire systems of distribution when the motors are connected across the outer wires. It is not alone on public supply circuits, however, that continuous current motors have been adopted; indeed, until comparatively recently the system was the only one employed on private systems in this country. Even now the greater proportion of new electric driving schemes embrace direct-current motors.

It is not easy to say what is the precise stage at which it pays to employ private plant to generate electricity for power purposes, rather than purchase from a public supply, if such be available. As a matter of fact, public supply companies and municipal authorities have not gone far beyond the small consumer, or one whose demand is greater than 50 horse power; but it is almost established that a public supply could even now supply electricity cheaper for power purposes than it could be generated even on a large scale by private plant. Many towns are now able to sell electricity for power purposes at 1½d. per Board of Trade unit, and that this is probably cheaper than it could be generated by a private plant is shown by the case of Messrs. Siemens Bros., of Charlton, who, employing electrical driving on a very large scale, find the cost to be 2d. per unit. In other words, if Messrs. Siemens were obtaining their supply of electricity from public mains they would probably save £2,000 per annum. With such apparent economies the development of a public supply of electricity for power purposes is bound to be rapid.

Considering the continuous current motor in a comparative sense, it can scarcely be denied, even by the most ardent advocate of three-phase principles, that it has the merit of simplicity. Theoretically the commutator and brushes ought to give trouble, but in practice they do not. With the general adoption of carbon brushes continuous current motors may be left for days, and even weeks, without any attention whatever. So reliable is this type considered to be in some works that it is frequently fixed in somewhat inaccessible places, a sufficient indication of the little attention required.

For all practical purposes the single-phase alternating current motor may be considered out of court. It is true that marked improvements have been effected during the past twelve months, but it is doubtful whether the problem has been really solved. We are inclined to agree with Mr. Alexander Siemens, when he says, "If a reliable alternate current motor had been invented there is little doubt that this system of transmitting power would be the dominating one at the present time, but unfortunately alternate current motors up to now refuse to start without being first synchronised by external means. They are liable to stop abruptly when they are overloaded, and their speed cannot be varied."

As a matter of fact, there are few motors on the mains of alternating supply stations, and those are of quite insignificant size; indeed the engineers of such stations do not, as a rule, countenance their introduction upon the lighting circuits. That the present alternating stations cannot satisfactorily meet a motor load is shown by the County of London and Brush Co., which, owning an alternating supply station in the City of London, has, in order to meet the demand that exists for motors, laid down continuous current machinery and special mains. The City of London Company has decided to proceed on almost similar lines.

When we come to speak of three-phase alternating motors, we are again in the region of practical accomplishment, for some of the most ambitious and most interesting electrical driving has been carried out on this system. The chief development, however, has taken place on the Continent, and when we say that three-phase motors of 1,000 horse power each have been erected, one obtains an indication of the possibilities that lie before electric transmission. Some of the objections urged in this country against three-phase motors were that it was impossible to overload them, and that it was difficult to place such motors on lighting circuits.

The Brooklyn Eagle October 4, 1898

WILL TESLA'S PATENTS BE USED EXCLUSIVELY?

Consolidation of the Electric Companies Said to Mean This.

THE COMBINATION ASSURED.

Over 90 Per Cent. of Edison Stockholders Have Deposited Their Shares and the Physical Consolidation Will Be Effected Within a Few Months—All Power Houses but the New Water Front Plant of Kings County to Be Closed—This Is Equipped With Tesla's Inventions—Financial Details.

The combination of the four principal electric light companies of this borough into one large corporation, and securing what is practically the control of that industry here, has now become assured through the formal consent of nearly the entire stock issue of the Edison Electric Company. According to Vice President Royal C. Peabody, over 91 per cent. of the capital stock of $5,000,000 has been deposited with the Central Trust Company and there is every reason to believe that every share will finally go in. This transfer makes the Kings County Electric Light and Power Company the owner of the Edison, the latter in turn controlling the Citizens' Lighting Company and the Municipal Lighting Company; or substantially all of the electric light business of Brooklyn.

While the consolidation of the electric interests is now practically settled, yet there are so many details and legal matters to be attended to that Vice President Peabody said this morning that it would be two or three months before the physical and actual combination of the companies would be effected. It would take at least this time, he said, to close up the financial questions and until that has been done, Mr. Peabody was not prepared to discuss the policy of the new consolidated company, how it would be operated, its new management, etc. In fact, Mr. Peabody added, these questions had not been definitely decided as yet, the financial matters engrossing so much of the attention of the men behind the consolidation.

When this consolidation becomes a fact the new company will find itself in control of three immense plants in addition to the sub-stations established throughout the borough and on Long Island by the Edison Company. It is not to be expected that all of these plants will be operated and a director of one of the companies is the authority for the statement that all the plants will be closed, when the new company takes hold, and that the new water front plant of the Kings County Company will be used to manufacture all the power necessary to supply Brooklyn. This, the reporter's informant said, it was well able to do and much cheaper than the power is now being manufactured by the present plants, including even the new million dollar South Brooklyn station of the Edison.

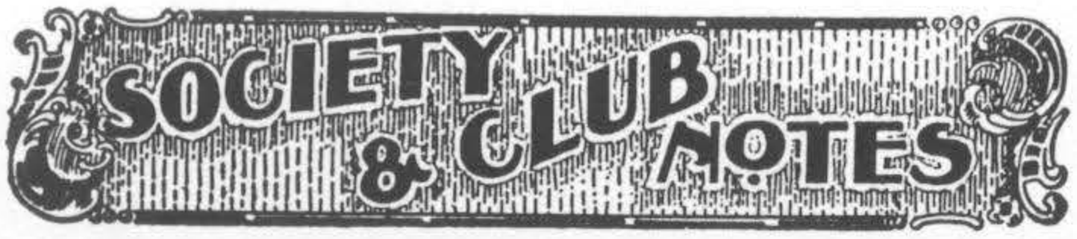
The water front plant of the Kings County Company has been completed for some time, but it has not been in operation; the consolidation deal of the companies making it unnecessary that there should be any actual competition. When the Kings County Company was organized and the construction of its power house was well advanced, it was currently reported that this new power house was going to be the perfection of electrical art and, through the fact that the company had secured control of a number of new patents by that well known expert, Tesla, it was said that they could manufacture power so cheaply that with the accompanying cut in rates that would be possible, the other electric companies would be driven to the wall. The men interested in the Kings County Company were in the habit of talking most mysteriously in regard to these new patents, but the only positive information ever obtained was to the effect that they did control a system which could greatly reduce the cost in transmitting power long distances.

If the consolidation company uses this new plant exclusively even to the abandonment of that admittedly modern South Brooklyn power house, men interested say it will be conclusive proof that there is something in the Tesla invention stories, which, by the way, have generally been regarded as bluffs, after all. It is certainly true that the Edison Company feared the competition of the Kings County, as the latter was able to bring about a consolidation on what is regarded as most favorable terms, especially after taking into consideration the large business and almost monopoly enjoyed by the Edison for so many years. There will be no change in the local electrical situation for several months and for the present it is impossible to secure any information as to executive heads of the consolidated company, the directors, etc., and the officers themselves say these questions have not even been discussed.

According to the terms of the agreement, the $5,000,000 of the Edison capital stock, which has lately been increased by an additional 25 per cent. of the original $4,000,000 issue, and for which the stockholders had the privilege of subscribing, is to be exchanged, par for par, for $5,000,000 second mortgage 99 year gold 6 per cent. bonds, to be issued by the Kings County Company.

These bonds of the Kings County Company will be secured by vendor's lien on the Edison shares to be reserved by the Central Trust Company and by a purchase money mortgage, which, beside being a first lien on the Edison shares, will be a general lien on property, present and future, of the Kings County Company, subject only to its present first mortgage for $2,500,000. They will also be secured by deposit with the Central Trust Company of $1,000,000 cash, to be invested in securities approved by the Edison stockholders' committee, which consists of George Foster Peabody, Ethan Allen Doty and Edwin M. Bulkley.

It is proposed that the Edison first consolidated mortgage, recently authorized for $5,000,000, in 5 per cent. bonds, shall be authorized instead to an amount not exceeding $10,000,000 in forty year 4 per cent. bonds. This mortgage will be secured by a first lien on all of the Edison property, subject only to the existing first mortgage bonds, which are to be paid off and canceled in 1900. The first issue of these Edison first consolidated bonds was of $2,000,000 to provide funds to pay for the stock of the municipal company. Of the remainder, $1,875,000 will be reserved to retire the $1,500,000 of existing first mortgage bonds, which will be called for payment at 110 and interest in 1900. The rest of the $10,000,000 of bonds will be issued from time to time as required, for extensions, additions and other property, which, when acquired, will become subject to the lien of the mortgage.



Eighth Annual Meeting of the American Electro-Therapeutic Association, Buffalo, N. Y., September 13, 14 and 15, 1898.

SHORTLY after 10 a. m. Dr. Charles Rea Dickson, of Toronto, Canada, president of the American Electro-Therapeutic Association, called together the eighth annual meeting of the association in the rooms of the Buffalo Society of Natural Sciences.

President Dickson introduced Dr. Conrad Diehl, Mayor of Buffalo, who extended to the members of the association the freedom of the city. He spoke of the growth and development of electrical treatment since the time it was first adopted by the medical profession, as an important part of the professional apparatus. Dr. Diehl said that the street cars of Buffalo were now run by electric power from Niagara Falls, and urged the members of the association to inspect the electrical plant of the Buffalo Railway Company.

Dr. Francis B. Bishop, of Washington, responded to the Mayor's welcome on behalf of the American Electro-Therapeutic Association.

Reports of standing committees on scientific questions were next in order. Dr. Margaret A. Cleaves, of New York, presented her report on meters. The report was accepted and the committee requested to continue its labors. Dr. Cleaves announced that the committee was not willing to continue its work, but desired the appointment of a new committee on meters.

On constant current generators and controllers the report was asked for from the chairman of the committee, Dr. William J. Herdman, of Ann Arbor, Mich., but in his absence an auxiliary report was presented by another member of the committee, Dr. Robert Newman, of New York, who in 1896 was president of the American Electro-Therapeutic Association.

John J. Carty, electrical engineer, of New York, made a brief report of progress. He is chairman of the committee on electric light apparatus for diagnosis and therapy and the Roentgen X-ray.

Dr. Margaret A. Cleaves, of New York, read a paper on "Phlebitis, a Clinical Study," in which she gave a number of instances which had come under her professional supervision.

Dr. A. D. Rockwell read his paper on "The Diagnostic and Therapeutic Relations of Electricity to Diseases of the Central Nervous System."

AFTERNOON SESSION.

Shortly after 2 p. m. the second session of the American Electro-Therapeutic Association was called to order by President Dickson. The first paper on the programme was by an honorary fellow of the society, Dr. Georges Apostoli, of Paris. The subject was "New Uses of the Undulatory Current in Gynaecology." The paper was translated from French into English and was read by Dr. G. Betton Massey, of Philadelphia.

"Electricity in the Treatment of Uterine Fibromata" was the subject of a paper by Dr. Felice La Torre, of Rome, Italy, read by Dr. John Gerin, of Auburn, secretary of the association. Then came a paper on "Electro-Therapeutics in Gynaecology," by Drs. Georges Gautier and J. Larat, of Paris, France, read in English by Dr. Dickson, president of the association, followed by "The Treatment of Uterine Fibroids by Small Currents, Administered Percutaneously," by Dr. Richard J. Nunn, of Savannah, Ga.

Dr. W. H. White, of Boston, read a paper by Dr. Adelstan de Martigny, of Montreal, on "Treatment of Menorrhagia by Weak Current and Silver Internal Electrode."

This was the concluding paper on the afternoon programme. An early adjournment was taken in order that members of the association might avail themselves of the tally-ho ride about the city, planned by the committee on arrangements.

An invitation to the association to visit the storage battery of the Buffalo Railway Company was sent by Superintendent Danforth at the request of Mayor Diehl.

RECEPTION FOR THE VISITORS.

At 8:30 p. m. a public reception in honor of the members of the American Electro-Therapeutic Association was held in Alumni Hall, University of Buffalo Building, which was largely attended, many medical men of Buffalo being present.

Dr. Henry R. Hopkins, of Buffalo, a member of the local committee on arrangements, spoke of the earnest work of the medical men in this country. Dr. Charles Rea Dickson, of Toronto, president of the American Electro-Therapeutic Association, made a few remarks, in which he spoke of the fraternal feeling existing between the two great English-speaking nations at the present time.

Dr. Robert Newman, of New York, made a brief address, as did Dr. G. Sterling Ryerson, of Toronto, Deputy Surgeon General of the Canadian Militia.

SECOND DAY'S SESSION.

An executive session of the American Electro-Therapeutic Association was held at 9 a. m.

The report of the executive council on the revision of the constitution and by-laws was adopted, making some important changes in the governing rules of the association.

The first paper was presented by Dr. Lucien Howe, of Buffalo, who represented the Erie County Medical Society and also the New York State Medical Society at the convention. Dr. Howe's subject was "The Method for Using Cataphoresis in Certain Forms of Conjunctival Inflammation."

Dr. Howe illustrated his address by means of a number of his patients. His lecture was received with great interest and considerable discussion followed. Many questions were asked Dr. Howe concerning his methods of treatment.

Dr. Robert Newman, of New York, presented an able paper on "Electricity in Deafness and Stricture of the Eustachian Tube." In his address Dr. Newman rehearsed the history of a peculiar case which came under his professional care. He also cited a number of other cases, which had been reported by other physicians.

The discussion which followed Dr. Newman's paper was led by Dr. Howe, followed by Dr. A. D. Rockwell, of New York.

Dr. Grover W. Wende, of Buffalo, read a paper on "Electricity in Acne Vulgaris and Acne Rosaceae."

Dr. G. Betton Massey, of Philadelphia, led the discussion of Dr. Wende's paper, followed by Dr. Margaret A. Cleaves, of New York.

Dr. G. Sterling Ryerson, of Toronto, Deputy Surgeon General of the Canadian Militia and the accredited delegate of the Ontario Medical Association, was introduced by President Dickson, and spoke briefly, giving a number of instances of the effect of lightning-stroke causing diseases of the eye, in which the results were not permanently serious.

Dr. Francis B. Bishop, of Washington, presented a paper on "High Tension Current in Neuritis," which was followed by considerable discussion.

The final paper of the morning session was by Dr. Charles Rea Dickson on "Electricity in the Treatment of Goitre."

At 1 o'clock the convention adjourned until 2 p .m.

AFTERNOON SESSION.

President Dickson delivered his annual address, a part of which is as follows:

"The necessity for the existence of such an association as ours has been questioned not only here, but elsewhere, hence it may be necessary to explain our position. It has been asked 'Why should there be such an association?' Electricity is only one of many therapeutic agents, and it would be absurd to have a separate association to consider each therapeutic agent. At first

glance this may seem a quite rational question. Our colleges teach us how to administer opium and its various derivatives, therefore the necessity for an opium society does not exist, but do our colleges teach us anything about electricity worthy of the subject? The answer to this question is quite unnecessary in the presence of the members of our association. Anyone should be depended upon to prescribe and administer the ordinary, or even extraordinary, remedies to carry out any regulation form of treatment. But I, for one, should fear to trust myself to the tender mercies of the general practitioner of to-day did he, in his wisdom, consider it necessary to use this agent, electricity, unless he had paid some special attention to the mastery of it. The contention is an absurdity unworthy of America, the vaunted land of progress, and of Buffalo, the Electrical City. In my own benighted land, even, we are more enlightened than that. This is an age of specialism.

"The old-time practitioner, then the physician and surgeon, seems passing away. Surgery is being divided and subdivided, until at one time we feared that we were to be confronted with an appendix surgeon. Our patients are reaping the benefit of all this. Why, then, should we call a halt? No! Let onward be our cry. The time is past when a physician, the proud possessor of a solitary magneto-electrical machine, turned by a crank, considered his armamentarium electricum quite complete. One has but to glance at our programme to see to what extent electricity may be used to advantage. A programme such as ours should prove a perfect revelation to him who has not kept well up to this progressive age. Could such a programme or one-hundredth part of it be intelligently discussed in any other existing society to-day not dealing distinctly with the subject? No, I greatly fear it would be a hidden book, a stumbling block.

"The hope of the future lies in those who are now thronging wisdom's halls, and it is a subject for congratulation that this association is to be asked to take action, bringing the needs of the hour before the authorities competent to deal with them. The student with mind as yet unwarped by prejudice must be in a position to obtain a comprehensive, intelligent grasp of the whole subject, that he may turn his theories to practical account in his professional career. But even he, unless endowed by these inestimable blessings, common sense, patience and gentleness, will find his efforts unavailing, and he must be a close observer of Nature and her laws, seeking to assist rather than to combat her. Electricity is an agent most powerful for weal or woe. A great responsibility rests upon our educators, and the sooner they awake from their strange lethargy the better will it be for our reputation as an enlightened, progressive, scientific profession. The commercial world has taken such advantage of the rapid strides of electricity as a science with fixed laws that we have laid ourselves open to the charge of neglect. Let us hasten to make amends for the past and remove some of the reproaches that rest on this, the noblest profession in this fair world.

"Our association was organized some eight years ago, because it was felt that the subject of electro-therapeutics could not be discussed in any existing society in a scientific and practical manner without controversial digressions of no value whatever. It was felt, and felt strongly, that electricity had been left too long to the charlatan, the incompetent and the unscrupulous. It was also felt that we had another foe of hardly less dangerous character, the over-zealous.

"To combat all these and cultivate and promote knowledge of electricity wherever it can be of service in medicine and surgery is the object of our association. It must be admitted that we are setting about this in the most practical manner possible. In fact, I know of no other association in which more practical or more useful work is being done. To carry out this idea successfully we have associated with us other than purely medical practitioners, and the association has proved a most happy one, and fruitful of nothing but good. Thus the electrical engineer and expert study electricity's laws and note its action upon inert matter. The biologist and physicist go a step farther and study these laws in their action upon living tissue, and their labors are turned to practical account by the physician and surgeon. The curative and palliative powers of the agent are available to all who have access to my clinics.

"The clouds are breaking on our horizon. On my side of that imaginary boundary line we find increasing interest being manifest, and it gives me the greatest satisfaction to say that my own warmest friends in the city of my adoption are the men who stand in the front ranks of medicine and surgery, and electrotherapy has a recognized standing, inasmuch as special departments devoted to it are to be found in our public hospitals. I have had the honor to organize and now to preside over four such departments in as many hospitals, and more intelligent inquiries are being made by the students of the various medical colleges, all of whom have access to my clinics.

"A rock we must avoid is that on which many a stronger society than our own has come to grief, the clique. And the furtherance of personal ambition or personal designs must be shunned."

All the suggestions embodied in the address were referred to the executive council of the association.

The programme for the afternoon was made up of a series of ten-minute talks on "Electro-Therapy," and the subject was one to attract a widespread interest among members of the medical fraternity.

Dr. G. Betton Massey, of Philadelphia, presented a paper on "The Galvanic Current in Gynaecology." The next paper was "Surgical Uses of Electricity," by Dr. Charles Rea Dickson, president of the association.

Dr. Robert Newman, of New York, presented a paper on "Electricity in Genito-Urinary Diseases." Dr. G. Betton Massey spoke on "Treatment of Malignant Growths by Means of Electricity."

A paper by Dr. Louis A. Weigel, of Rochester, on "Orthopædic Uses of Electricity," was followed by a paper by Dr. Rockwell on "Functional Diseases of the Nervous System Treated by Electricity."

The association adjourned at 4:30 p. m. and proceeded by special car to visit the power house and storage batteries of the Buffalo Railway Company.

A short business session of the American Electro-Therapeutic Association was held from 8 to 9 p. m., at which the following officers were elected: President, Dr. Francis B. Bishop, of Washington; first vice-president, Dr. Ernest Wende, of Buffalo; second vice-president, Dr. W. H. White, of Boston; secretary, Dr. John Gerin, of Auburn; treasurer, Dr. Richard T. Nunn, of Savannah, Ga.; executive council, Dr. Robert Newman, of New York, and Dr. G. Betton Massey, of Philadelphia, three years; Dr. A. D. Rockwell and Dr. William J. Morton, of New York, two years; Dr. Charles R. Dickson, of Toronto, and Dr. Frederick Schavoir, of Stamford, Conn., one year. Washington was selected for the convention next year, to be held September 19-21, 1899.

Dr. Lucien Howe entertained the men of the association at the conclusion of the business meeting. A smoker was given at Dr. Howe's home, corner of Delaware avenue and Huron street, which was largely attended.

THIRD DAY'S SESSIONS.

A vote of thanks was tendered to Dr. Wende, chairman of the local committee on arrangements; to the Buffalo Commercial for its kindness, not only during the convention, but in publishing the preliminary news of the association; to Dr. Howe, for his entertainment last evening; to Mayor Diehl, to the Buffalo Railway Company, Buffalo Historical Society, Fine Arts Academy, president and secretary of the association, and Dr. Newman, of New York, and to the press generally.

The congratulations of the American Electro-Therapeutic Association were extended to the University of Buffalo for its progress in establishing a chair of electro-therapeutics in the medical college.

A general vote of thanks was also adopted, expressing the association's deep appreciation of the courtesy and hospitality extended to the members during the convention in Buffalo.

At 10 o'clock the executive session adjourned and President Dickson called the scientific session to order. The first two papers on the programme were read by title. They were both by Drs. Georges Gautier and J. Larat, of Paris, France, the first on "The Hydro-Electric Bath with Sinusoidal Current in Disease," the second on "The Use of Hot Air and Light Bath in Disease."

A paper was read by the newly-elected president of the association, Dr. Francis B. Bishop, of Washington, on "Alternating Dynamo Currents."

Dr. Margaret A. Cleaves, of New York, read a paper on "The Electric Arc Bath."

A paper by Dr. J. H. Kellogg, of Battle Creek, Mich., on "The Electric Light Bath" was read by title. The next paper was by John J. Carty, of New York, on "Some Suggestions on

the Possibilities of Cataphoresis." Mr. Carty gave a short, practical talk, which was very interesting.

A paper by Dr. G. Herbert Burnham, of Toronto, Canada, on "Electricity in the Treatment of Certain Diseases of the Eye," was read by title.

Then came a paper by Nikola Tesla, read by Dr. White, of Boston. The subject was "A High Frequency Oscillator for Electro-Therapeutic Purposes."

The following papers were read by title: "The Effect of High Tension Discharges Upon Micro-Organisms," Drs. J. Inglis Parsons and C. Slater, London, England; "The Action of X-Rays Upon Tuberculosis," Dr. J. Bergonie, Bordeaux, France; "Two Years of Practice in Radiotherapy," Drs. Georges Gaultier and J. Larat, Paris, France.

Dr. Newman, of New York, and Dr. Nunn, of Savannah, Ga., were appointed a committee by the president to conduct the president-elect, Dr. Bishop, of Washington, to the chair. Before turning over to his successor the gavel and other insignia of office Dr. Dickson took occasion to thank the association for its kindness and courtesy to him during his term of office.

The afternoon was devoted to an excursion and reception under the direction of the local committee of arrangements.

On Friday afternoon the members were conducted over the power house of the Niagara Falls Power Company by Coleman Sellers, E. D., president and chief engineer, who made the visit a most interesting and instructive one. On returning to the hotel a meeting was held and Dr. C. R. Dickson was requested to convey to Dr. Sellers the thanks of the association for his courtesy.

Those who remained visited on Saturday morning Power Station No. 2 of the Niagara Falls Hydraulic Power and Manufacturing Company, being conducted over it by the chief electrician, who fully explained all the appliances.

A most interesting exhibition of electrical apparatus for diagnostic, therapeutic and radiographic purposes was held in the room adjoining the meeting hall. The following manufacturers exhibited: Van Houten & Ten Broeck, New York; Chloride of Silver Dry Cell Battery Company, Baltimore, Md.; Jerome Kidder Manufacturing Company, New York; Edison Manufacturing Company, New York; Waite & Bartlett Company, New York; Dow Electric Assistant Company, Boston, Mass.; the American Electro-Neurotone Company, Niagara Falls, N. Y.; the Standard Cold Electric Lamp Company, Washington, D. C.; the Spencer Lens Company, Buffalo, N. Y.; the Detwiller, Biddle Company, Buffalo, N. Y.; W. J. Shields & Co., New Wilmington, Pa.; Rochester Fluorometer Company, Rochester, N. Y.

The eighth annual meeting was unanimously conceded the most successful and enjoyable that has been held, and the prospects for the association were never brighter or more encouraging.

[94183.]—**Tesla's Experiments.**—By means of an induction coil or other transformer, which charges a condenser or Leyden jar, which, in its turn, sends its discharges through a second highly-insulated coil or transformer, which at once raises the potential and increases the frequency of the induced current. You will find illustrations of the necessary apparatus in the ENGLISH MECHANIC for Sept. 11, 1896. S. BOTTONE.

Electrical Review

[OLDEST ELECTRICAL WEEKLY IN THE UNITED STATES.]

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NEW ADVERTISEMENTS should be in the office not later than Saturday noon to insure publication the following week.

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MR. TESLA'S NEW CIRCUIT CONTROLLER.

Unusual interest attends all of the work of Mr. Nikola Tesla, but more particularly that in connection with his system of vacuum tube lighting. On another page we present a description of an electric circuit controller, one form of a series of developments in this line for which patents were recently issued to him, several of which were previously noted in the ELECTRICAL REVIEW. This invention seems to us to possess mechanical efficiency of a high order, and, like the author's work in general, marks an advanced step, and will undoubtedly possess a wide field of usefulness.

Improved Circuit-Controller for Vacuum Tube Lighting and Other Purposes.

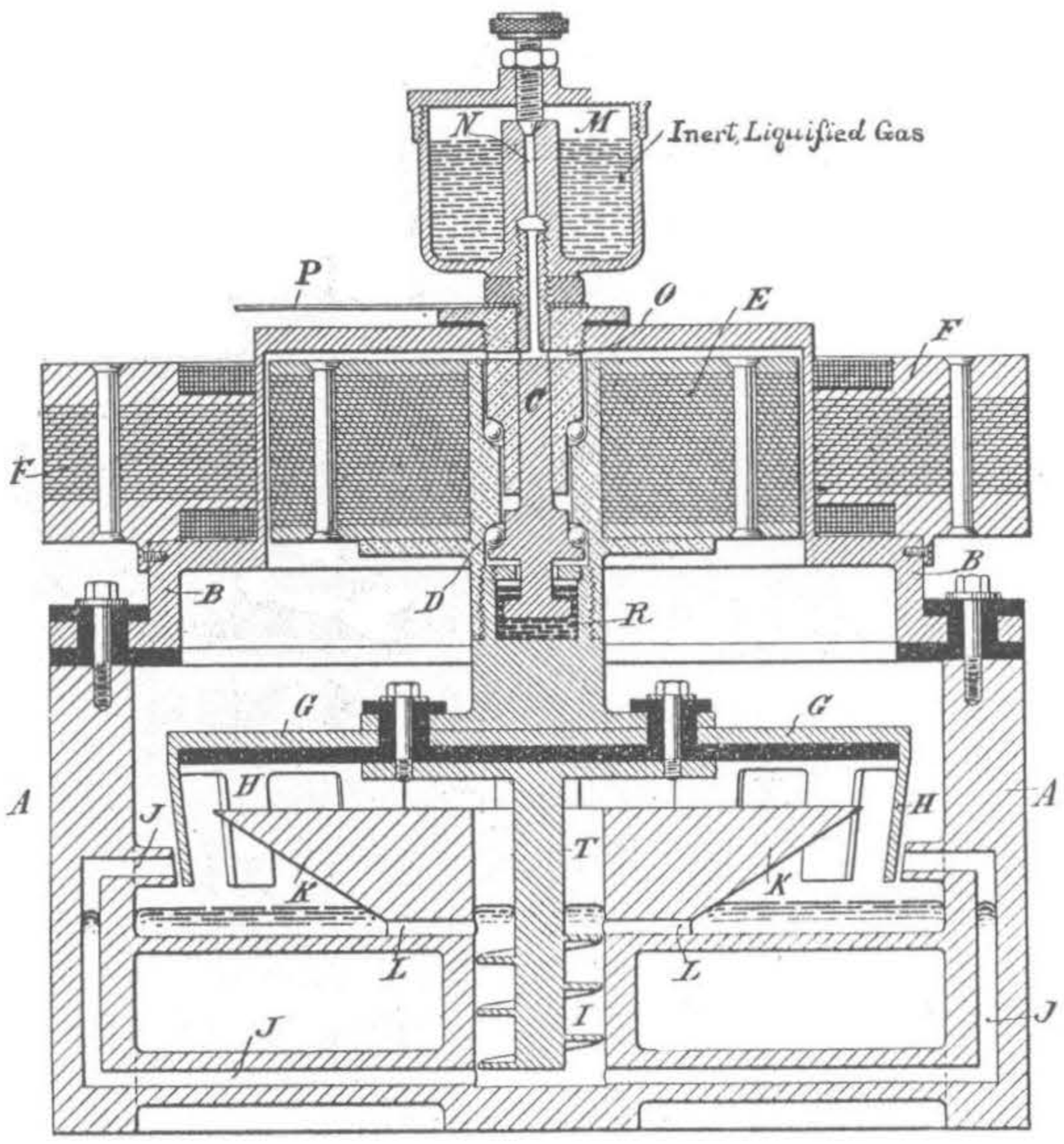
A patent was issued to Nikola Tesla October 4 relating to improvements in electric circuit controllers. The details of this invention are presented herewith, with illustration, the interesting description being in full in the language of the author, as follows:

In order to secure a more efficient working of circuit-controllers, particularly in their use in connection with my system of electrical-energy conversion by means of condenser discharges, I have devised certain novel forms of such appliances, comprising as essential elements a body of conducting fluid constituting one of the terminals, a conductor or series of conductors forming the other terminal, and means for bringing the two into rapidly-intermittent contact with each other. These devices possess many desirable qualities, particularly that of being eminently adapted for making and breaking at a very rapid rate an electric circuit and thus reducing to a minimum the time of passage of the current through an arc or path of high resistance and diminishing thereby the losses incident to the closure and interruption of the circuit. Continued experimentation with these appliances has led me to make further important improvements by causing the make-and-break to be effected in an inert medium of very high insulating power.

It is a fact, which was fully demonstrated by Poggendorff and utilized by him to improve the operation of induction-coils, that when the contact-points of a circuit-breaker are enclosed in a vessel, and the latter exhausted to a high degree, the interruption of the current is rendered more sudden, as if a condenser were connected around the break. Furthermore, my own investigations have shown that under such conditions the closure also is more sudden, and this to even a greater degree than the break, which result I attribute to the high insulating quality of the vacuous space, in consequence of which the electrodes may be brought in very close proximity before an arc can be formed between them. Obviously these facts may be utilized in connection with my novel circuit-controllers; but inasmuch as only a very moderate improvement is secured in this manner, and as the high vacuum required is quickly destroyed and can not be maintained, unless by a continuous process of rarefaction and other inconvenient measures, I have found it desirable to employ more effective and practical means to increase the efficiency of the devices in question. The measures I have adopted for this purpose have resulted from my recognition of certain ideal qualifications of the medium wherein to effect a make-and-break. These may be summed up as follows: First, the medium by which the contact-points are surrounded should have as high an insulating quality as possible, so that the terminals may be approached to an extremely short distance before the current leaps across the intervening space; second, the closing up or repair of the injured dielectric, or, in other words, the restoration of the insulating power, should be instantaneous in order to reduce to a minimum the time during which the waste principally occurs; third, the medium should be chemically inert, so as to diminish as much as possible the deterioration of the electrodes and to prevent chemical processes which might result in the development of heat, or, in general, in loss of energy; fourth, the giving way of the medium under the application of electrical pressures should not be of a yielding nature, but should be very sudden and in the nature of a crack, similar to that of a solid, such as a piece of glass when squeezed in a vice, and, fifth, most important, the medium ought to be such that the arc when formed is restricted to the smallest possible linear dimensions and is not allowed to spread or expand. As a step in the direction of these theoretical requirements I have employed in some of my circuit-controlling devices a fluid of high insulating qualities, such as liquid hydrocarbon, and caused the same to be forced, preferably with great speed, between the approaching and receding contact-points of the circuit-controller. By the use of such liquid insulator a very marked advantage was secured; but while some of the above requirements are attained in this manner, certain defects still exist, notably that due to the fact that the insulating liquid, in common with a vacuous space, though in a less degree, permits the arc to expand in length and thickness, and thus pass through all degrees of resistance and causing a more or less considerable waste of energy. To overcome this defect and to still more nearly attain the theoretical conditions required for most efficient working of the circuit-controlling devices, I have been finally led to use a fluid insulating medium subjected to great pressure.

The application of great pressure to the medium in which the make-and-break is made secures a number of specific advantages. One of these may be obviously inferred from well-established experiental facts, which demonstrate that the striking distance of an arc is approximately inversely proportional to the pressure of gaseous medium in which it occurs; but in view of the fact that in most cases occurring in practice the striking distance is very small, since the difference of potential between the electrodes is usually not more than a few hundred volts, the economical advantages resulting from the reduction of the striking distance, particularly on approach of the terminals, is not of very great practical consequence. By far the more important gain I have found to result from an effect which I have observed to follow from the action of such a medium when under pressure upon the arc—namely, that the cross-section of the latter is reduced approximately in an inverse ratio to the pressure. As under conditions in other respects the same the waste of energy in an arc is proportional to its cross-section, a very important gain in economy generally results. A feature of great practical value lies also in the fact that the insulating power of the compressed medium is not materially impaired even by considerable increase in temperature, and, furthermore, that variations of pressure between wide limits do not interfere notably with the operation of the circuit-controller, whereas such conditions are fatal drawbacks when, for instance, Poggendorff's method of insulating the terminals is used. In many other respects, however, a gas under great compression nearly fulfills the ideal requirements above mentioned, as in the sudden breaking down and quick restoration of the insulating power, and also in chemical inertness, which by proper selection of the gas is easily secured.

In carrying out my invention the medium under pressure may be produced or maintained in any proper manner, the improvement not being limited in this particular to any special means for the purpose. I prefer, however, to secure the desired result by enclosing the circuit-controller, or at least so much of the same as shall include the terminals, in a chamber or receptacle with which communicates a small reservoir containing a liquefied gas.



TESLA'S NEW CIRCUIT-CONTROLLER.

While the improvement is applicable generally to circuit-controllers, the best results will be secured by the use of devices in which a high relative speed between the terminals is obtainable, and with this special object in view I have devised a novel circuit-controller, which, though belonging to the class of which I have shown a typical form in my application for patent filed December 2, 1897, Serial No. 660,518, differs in certain particulars of construction, which will be understood from the following comparison: In the previously-described form of said circuit-controllers a rotary receptacle, carrying within it a series of spaced conductors, is driven at a high speed by a suitable motor. Mounted within and concentrically with the receptacle, but capable of free independent rotation with respect thereto, is a body which during the rotation of the receptacle is retarded or restrained against rotation by the application of a suitable force. This body carries a tube or duct, which takes up at one end a fluid conductor contained in the receptacle and rotating with the same, and discharges it from the other end against the rotating spaced conductors.

While an apparatus thus constructed is very efficient and performs the work required of it in a highly satisfactory manner, it is nevertheless subject to certain limitations, arising mainly from the amount of work which the conducting fluid is required to perform and which increases with the speed. With the object of overcoming objections that might lie to this form of circuit-controller in the particular referred to, I devised the form of instrument shown herein. The features which more particularly distinguish this form are the following: I employ a closed stationary receptacle within which is mounted a body that is capable of being rotated in any way—as, for example, by the drag or pull upon it of an external field of force or a magnet rotated bodily. The rotary body imparts rotation to a series of spaced conductors within the receptacle and also operates as a pump to maintain a flow of conducting fluid through one or more stationary ducts and from the same against the rotating conductors.

The details of this apparatus will be described by reference to the accompanying drawing, which is a vertical central section of the circuit-controller complete.

A is a receptacle, of iron, steel or other proper material, with a head B, secured by a gas-tight insulating-joint. Within this receptacle is contained the circuit-controller, which, in so far as the main feature of my present invention is concerned, may be of any desired construction, but which, for the reason stated above, is of the special character shown. A spindle C is screwed or otherwise secured centrally in the head B, and on this is mounted on antifriction-bearings a body to which rotary motion may be imparted. The construction of the device in this particular and the means for imparting rotation to the said body may be greatly varied; but a convenient means for accomplishing this is to secure to the rotary sleeve D a laminated magnetic core E and place around the portion of the head B which contains it a core F, provided with coils and constituting the primary element of a motor capable of producing a rotary field of force which will produce a rapid rotation of the secondary element or core E. To the depending end of the sleeve D is secured a conductor G, usually in the form of a disk with downwardly-extending teeth or peripheral projections H. To the sleeve or the disk G is also attached, but insulated therefrom, a shaft T having a spiral blade and extending down into a well or cylindrical recess in the bottom of the receptacle. One or more ducts or passages J lead from the bottom of this well to points near the path of the conducting teeth H, so that, by the rotation of the screw I, a conducting fluid, which runs into the well from the receptacle, will be forced up through the duct or ducts, from which it issues in a jet or jets against the rotating conductor. To facilitate this operation the well is surrounded by a flange K, containing passages L, which permit the conducting fluid to flow from the receptacle into the well, and having beveled sides, which serve as a shield to deflect the fluid expelled from the ducts through the spaces in the conductor to the bottom of the receptacle.

M is any suitable reservoir communicating with the interior of the main receptacle and containing a liquefied gas, such as ammonia which maintains a practically inert atmosphere under pressure in the receptacle.

Preferably, though mainly as a matter of convenience, the receptacle M is a metal cup with a hollow central stem N, the opening for the passage of gas being controlled by a screw valve in the top of the cup. The said cup is screwed onto the end of the spindle C, through which is a passage O, leading into the interior of the receptacle A.

The receptacle A and the conducting fluid, which is generally mercury, being normally insulated from the head B and the parts attached and supported thereby, are connected to one part of the circuit to be controlled. The other circuit connection is made by a conductor P to any part of the head, so that when the core E and conductor G are rotated the circuit will be completed between the two insulated parts of the receptacle through the jet or jets of conducting fluid whenever they impinge upon the said conductor.

To ensure a good electrical connection between the sleeve D and the spindle C, I provide in the former a small chamber R, which contains mercury, and into this the end of the spindle C extends.

RATED SUPPLEMENT—TESLA'S ELECTRIC POWER TRANSMISSION WITHOUT WIRES.

ECTRICAL REVIEW

AN ILLUSTRATED WEEKLY JOURNAL OF SCIENTIFIC AND ELECTRICAL PROGRESS.

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TESLA'S SYSTEM OF ELECTRIC POWER TRANSMISSION THROUGH NATURAL MEDIA.*

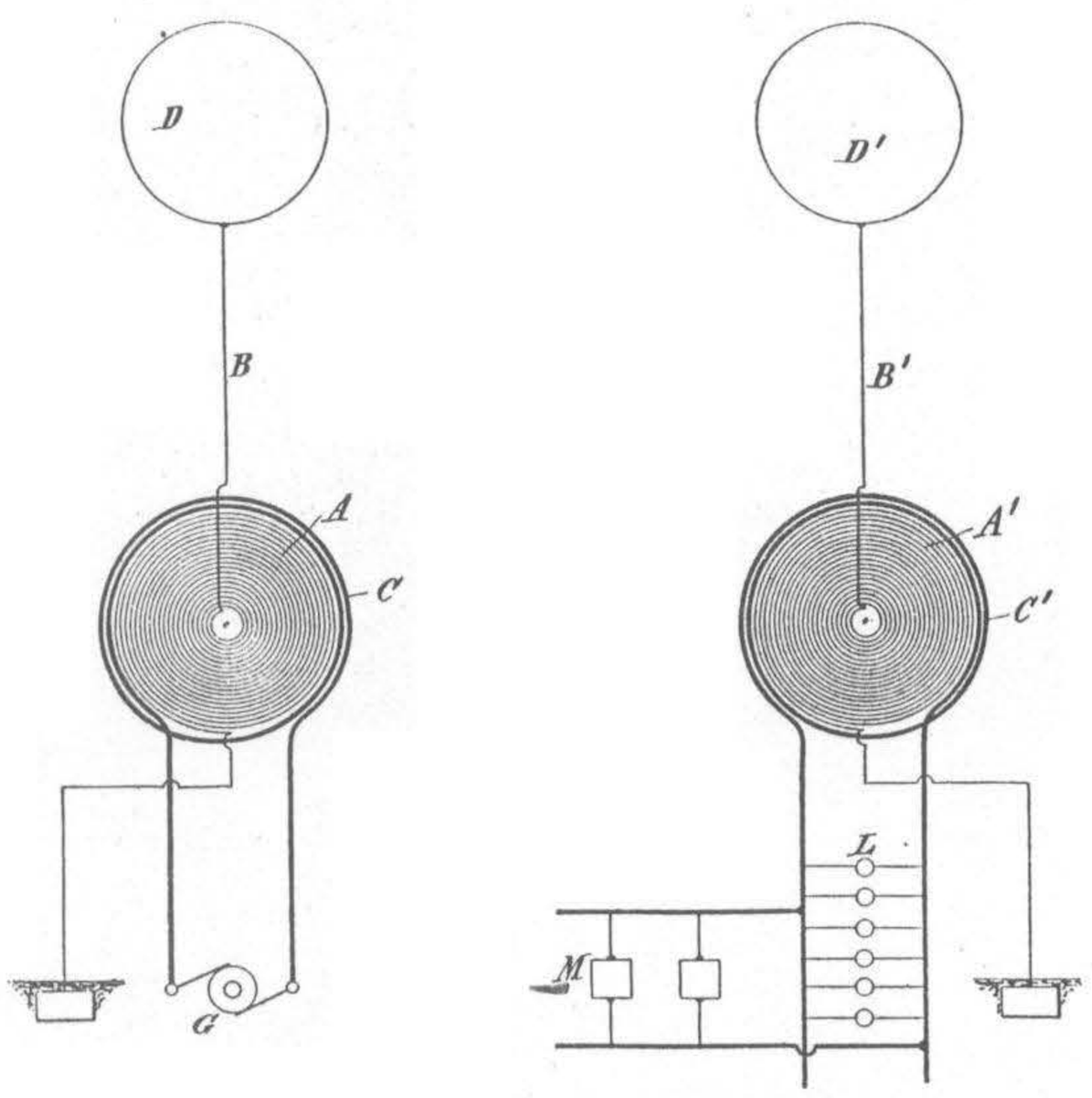
On this novel system patents have been obtained in various countries, and the following is freely quoted from the inventor's own text :

It has been well known heretofore, that if the air enclosed in a vessel be rarefied, its insulating properties are impaired to such an extent that it becomes what may be considered as a true conductor of electricity, although one of admittedly high resistance. The practical information in this matter, however, has been derived from observations manifestly subject to limitations imposed by the character of the apparatus or means heretofore known, and the quality of the electrical effects producible thereby.

It has also been known, particularly since the investigations of Heinrich Hertz, that certain transverse electrical waves or radiations may be transmitted through the atmosphere, and these have been found capable of affecting certain delicate receiving instruments at a limited distance from the source of the electrical disturbance.

The invention which forms the subject of the present application comprises a novel method or system for the transmission of electrical energy without the employment of metallic line conductors, and is primarily designed for use in cases where large amounts of electrical energy are to be transmitted to considerable distances, but the results arrived at are of such character and magnitude, as compared with any heretofore secured, as to render indispensable the employment of means and the utilization of effects essentially different in their characteristics and actions from those before used or investigated.

To be more explicit, the transmission of electrical energy, which forms a part of my present invention, demands for the attainment of practically useful results the production and conversion of excessively high electrical pressures. Heretofore, it has been possible, by means of the



DIAGRAMS ILLUSTRATING TESLA'S SYSTEM OF ELECTRIC POWER TRANSMISSION THROUGH THE AIR.

apparatus at command, to produce only moderate electrical pressures, and even these not without some risks and difficulties, but I have devised means whereby I am enabled to generate with safety and ease electrical pressures measured by hundreds of thousands, and even millions, of volts, and in pursuing investigations with such apparatus, I have discovered certain highly important and useful facts which render practicable the method of transmission of electrical energy hereinafter described.

Among these, and bearing directly upon the invention, are the following: First, that with electrical pressures of the magnitude and character which I have made it possible to produce, the ordinary atmosphere becomes, in a measure, capable of serving as a true conductor for the transmission of the current. Second, that the conductivity of the air increases so materially with the increase of electrical pressure and degree of rarefaction, that it becomes possible to transmit through even moderately rarefied strata of the atmosphere electrical energy up to practically any amount and to any distance.

The system of transmission comprised in my present invention and which, as above stated, was rendered possible only by the production of apparatus of a character radically new and different from any before known, and which is based upon discoveries made in the investigation of the results produced thereby, consists then in producing at a given point a very high electrical pressure, conducting the current caused thereby to earth and to a terminal at an elevation at which the atmosphere serves as a conductor therefor, and collecting the current by a second elevated terminal at a distance from the first.

In order to attain this result it is necessary to employ an apparatus capable of generating electrical pressures vastly in excess of any heretofore used, and to lead the current to earth and to a terminal maintained at an elevation where the rarefied atmosphere is capable of conducting freely the particular current produced; then, at a distant point, where the energy is to be utilized, to maintain a terminal at or about the same elevation to receive the current and to convey it to earth through suitable means for transforming and utilizing it.

The apparatus which I have invented, and by means of which this method of transmission may be effected, is represented in the accompanying drawing, which is a diagrammatic illustration of the system, each transformer comprising a spiral conductor with many turns shown in fine lines surrounded by a conductor indicated in heavy lines with a very few convolutions.

The secondary coil is built up as usual, the wire being wound around an insulating core or spool until its convolutions fill up the space and form one complete layer. The winding is continued in the same way until another layer is formed, and so on. When the desired length of secondary or high-tension coil is thus obtained, the primary or low-tension coil is wound outside of it, but this latter coil is composed of only a very few turns of wire or conductor, which is of much larger diameter of cross-section than the secondary wire.

The transformer thus consists simply of two concentric coils, the inner coil having very many turns of fine wire, the outer coil a very few turns of coarse wire.

From this plan of construction it follows that one of the high-tension terminals is at the center of the secondary coil, and in the use of the coil the other terminal, whether it be connected to ground or not, is electrically connected to the primary, in order that there may be no material difference of potential between the latter and the adjacent convolutions of the secondary.

Assuming that it appears from the above that, in the general plan of construction of the coils, only common and well known methods have been pursued, it remains then to consider the length of the secondary coil. This should be approximately one quarter of the wave length of the electrical disturbance in the circuit, and the reason for it is that the highest possible electrical pressures may be secured at the center terminals of the secondary coils.

A is a coil, generally of many turns and of very large diameter, wound in spiral form either about a magnetic core or not, as may be desired. C is a second coil formed by a conductor of much larger size and smaller length wound around in proximity to the coil A.

In the transmitting apparatus the coil A constitutes the high-tension secondary, and the coil C the primary of much lower tension of a transformer. In the circuit of the primary C is included a suitable source of current G.

One terminal of the secondary A is at the center of the spiral coil, and from this terminal the current is led by a conductor B to a terminal D, preferably of large surface, formed of or maintained by such means as a balloon at an elevation suitable for the purposes of transmission as before described. The other terminal of the secondary A is connected to earth and, preferably, to the primary also, in order that the latter may be of approximately the same potential as the adjacent portions of the secondary, thus insuring safety.

At the receiving station a transformer of similar construction is employed, but in this case the long coil A^1 constitutes the primary, and the short coil C^1 the secondary of the transformer. In the circuit of the latter are arranged lamps L, motors M, or other devices for utilizing the current. The elevated terminal D^1 connects with the center of the coil A, and the other terminal of said coil is connected to earth and preferably also to the coil C^1 for the reasons above stated.

The length of the high-tension coil of each apparatus should be approximately one-quarter of the wave length of the electrical disturbance in the circuit, this estimate being based on the velocity of propagation of the electrical disturbance through the coil itself and the circuit with which it is designed to be used. To illustrate, in accordance with accepted views, if the rate at which the current traverses the circuit, including the two high-tension coils, be 185,000 miles per second, then a frequency of 925 per second would maintain 925 stationary waves in a circuit 185,000 miles long, and each wave would be 200 miles in length. For such a frequency I should use in each high-tension coil a conductor 50 miles in length, or in general, with due allowance for the capacity of the leading wires and terminals, such length of conductor as would secure the highest electrical pressures at the terminals under the working conditions.

It will be observed that in coils of the character described the potential gradually increases with the number of turns, and the difference of potential between adjacent turns is comparatively small, and a very high potential, impracticable with ordinary coils, may be successfully obtained.

As the main object of the invention is to produce a current of extremely high potential, this object will be facilitated by using a primary current of very considerable frequency, but the frequency of the current is, in large measure, arbitrary, for if the potential be sufficiently high and the terminals of the coils be maintained at a proper elevation where the atmosphere is comparatively rarefied, the intermediate stratum of air will serve as a conductor for the current produced, and the latter will be transmitted through the air with, it may be, even less resistance than through an ordinary copper wire.

The apparatus described, it may be observed, is useful as a means for producing currents of very high potential for other purposes than that of the present system, as, for instance, the coils may be used singly for producing extremely high electrical potentials for any purpose, or used generally in the same manner as other electrical transformers for the conversion and transmission of electrical energy.

It will be understood that either or both of the coils or transformers and terminals may be movable, as, for instance, when carried by vessels floating in the air, or by ships at sea. In the former case the connection of one terminal with the ground might not be permanent, but might be intermittently or inductively established without departing from the spirit of the invention.

As to the elevation of the terminals D, D^1, it is obvious that this is a matter which will be determined not only by the condition of the atmosphere, but also by the character of the surrounding country.

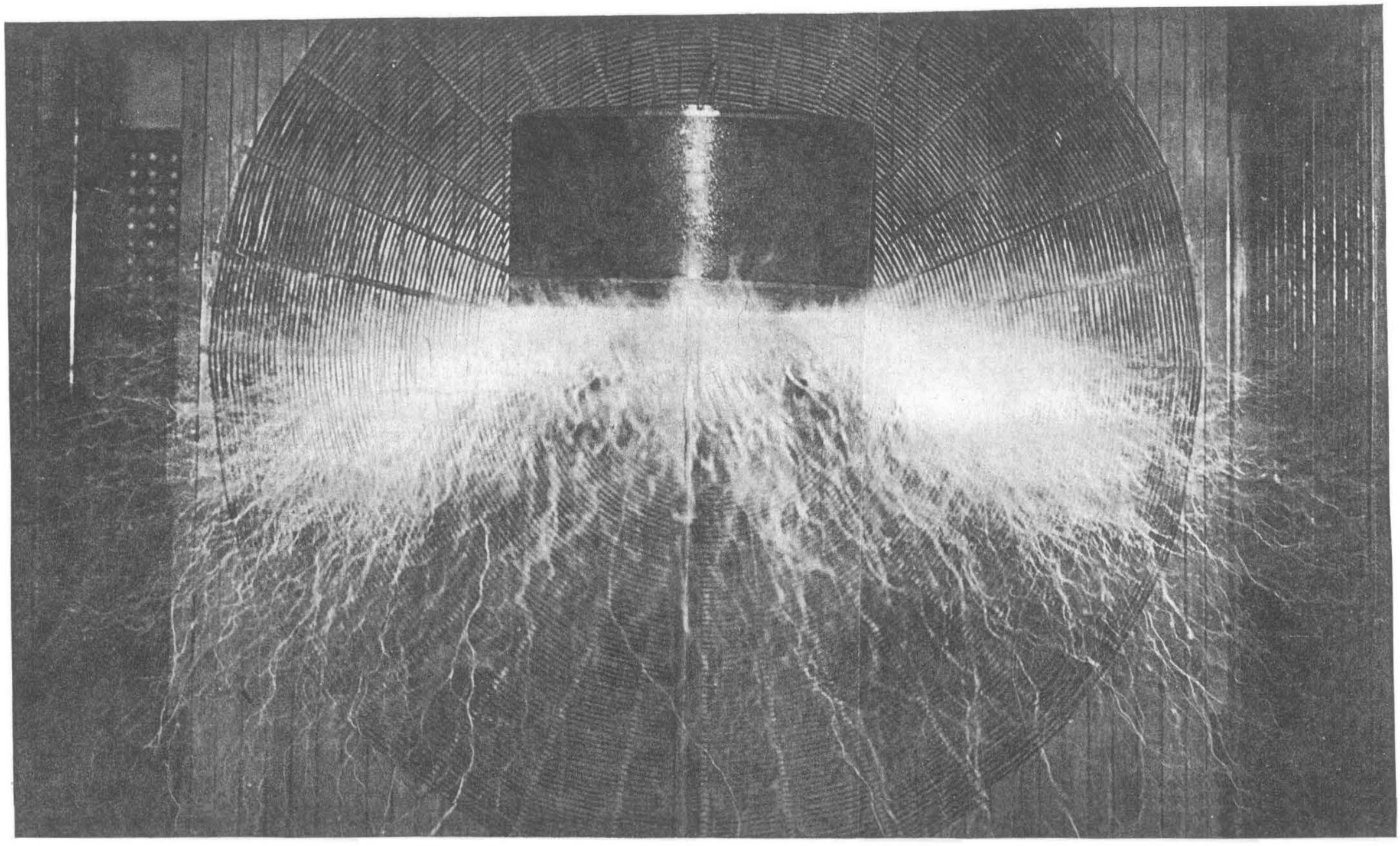
Thus, if there be high mountains in the vicinity the terminals should be at a greater height, and generally, they should always be at an altitude much greater than that of the highest objects near them in order to reduce the loss by leakage. Since, by the means described, practically any potential that is desired may be produced, the currents through the air strata may be very small, thus reducing the loss in the air.

It will be observed that the phenomenon here involved in the transmission of electrical energy is one of true conduction, and is not to be confounded with the phenomena of induction or of electrical radiation which have heretofore been observed and experimented with, and which, from their very nature and mode of propagation, would render practically impossible the transmission of any considerable amount of energy to such distances as would be of practical importance.

Of the claims the following may be quoted:

1. The method of transmitting electrical energy herein described, which consists in producing at a given point a very high electrical pressure, conducting the current caused thereby to earth and to a terminal at an elevation at which the atmosphere serves as a conductor therefor, and collecting the current by a second elevated terminal at a distance from the first, as set forth.

2. A system for the transmission of electrical energy, comprising in combination a source of current of very high pressure, connected respectively with the earth and with a terminal at an elevation where the atmosphere forms a conducting path for the current produced, a second elevated terminal at a distance from the first for receiving the current transmitted therefrom and means for utilizing the said current, as set forth.



"Tesla's System of Electric Power Transmission Through Natural Media."—View of Model Transformer, or "Oscillator," Photographed in Action.—Actual Width of Space Traversed by the Luminous Streams Issuing from a Circular Single Terminal over Sixteen Feet.—Area Covered by the Streamers Approximately Two Hundred Square Feet.—Estimated Effective Electrical Pressure Two and One-half Million Volts.

Electrical Review

OLDEST ELECTRICAL WEEKLY IN THE UNITED STATES.]

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While we are naturally pleased at the reiterated evidence that the ELECTRICAL REVIEW is the most widely quoted electrical publication in the world, we respectfully suggest to our daily contemporaries that care in assigning proper credit for borrowed matter will be appreciated, not only by ourselves, but by our electrical contemporaries.

A WONDERFUL POSSIBILITY IN ELECTRIC POWER TRANSMISSION.

As civilization advances and our needs multiply, the demands on the toilers in the various departments of science constantly increase, and naturally the activity in the direction of providing new resources becomes more and more intense. But the severest burden is undoubtedly on the engineer, mechanic or inventor, whose task it is to produce motive power. The problem of providing economical power has ever taxed the inventive mind, and with the introduction of electricity a great stride in advance has been effected. But still, many limitations were encountered in the difficulties of efficiently transmitting the energy of great sources of power, which exist in abundance in Nature, to remote places of utilization.

Here it is that Nikola Tesla did his first great work by discovering the rotating magnetic field, and applying it to a practical system of electric power transmission, now used in all parts of the world.

As we were then, so now we are privileged to record another forward step, which, if successful on a large scale, will prove of astounding consequences, for it will open up unlimited resources of practically costless power. Tesla now proposes to transmit, without the use of any wires, through the natural media—the earth and the air—great amounts of power to distances of thousands of miles. This will appear a dream—a tale from the Arabian Nights. But the extraordinary discoveries Tesla has made during a number of years of incessant labor, which are authoritatively described and illustrated in our present issue, make it evident that his work in this field has passed the stage of mere laboratory experiment, and is ready for a practical test on an industrial scale. The success of his efforts means that power from such sources as Niagara will become available in any part of the world regardless of distance.

The photographic reproduction contained in our present issue, which is explained in its title, illustrates one of the remarkable effects produced by Tesla's improved apparatus.

The New York Herald October 27, 1898

TESLA WOULD USE AIR AS CONDUCTOR

Announces Discovery of Method for Transmission of Electrical Energy Without Wires.

SAYS PLAN AVOIDS LOSS.

Terminals Raised Above All Surrounding Objects Communicate Through Rarefied Atmosphere.

Nikola Tesla, who has added much to the world's knowledge of electricity and electrical phenomena, announces in the current issue of the Electrical Review his discovery of a new method of transmitting large quantities of electrical energy to any distance without the employment of wires or other metallic conductors, and with a loss in transmission so small as to be practically inappreciable. The only conductor used is the atmosphere at great altitudes, where it is extremely rarified.

Mr. Tesla's discovery differs from others exploited as methods of telegraphing without wires and so forth, it is contended, in that it transmits any quantity of energy generated up to millions of volts, and without loss.

SAYS IT IS NOT INDUCTION.

He asserts that by his plan there is true conduction, and not, as in the case of other methods referred to, an induction or electrical radiation. Phenomena accompanying these methods preclude the transmission of any considerable quantity of energy and involve a great loss of power, so that, it is urged, they are of little practical importance.

It has long been known that if air enclosed in a vessel be rarefied it becomes a true conductor of electricity, though of high resistance. Mr. Tesla has discovered, however, that the conductivity of air increases rapidly with the increase of electrical pressure and its degree of rarefication, and the purpose of the apparatus which he has devised is to turn this discovery to account.

Stripped of technicalities, this apparatus comprises a line connecting a transformer, which communicates with the source of electrical energy, and a terminal high in the air. This terminal is a metallic globe of large surface.

SUSPENDED BY BALLOONS.

It is suspended by a balloon at such an altitude that the air is extremely rarefied and performs the function of projecting the electrical energy. If there be high mountains in the neighborhood the terminal must be above their crests to prevent leakage of energy. At the receiving end is a similar apparatus. Here, however, the terminal performs the function of collecting the energy projected from the first terminal mentioned and transmits it to the transformer, from which it can be distributed for use.

The transformer comprises an insulating core or spool, around which are wound many thicknesses of fine wire, forming in the transmitting apparatus the secondary or high tension coil, and around it are wound a few turns of coarse wire, forming the primary or low tension coil. In the receiving apparatus the fine wire constitutes the primary and the coarse wire the secondary coil.

No rule can be laid down as to the degree of elevation required for the terminals, which depends entirely on the condition of the atmosphere and the character of the country. They must, however, be much higher than the highest objects surrounding them.

This method of transmitting energy, Mr. Tesla says, can be used by ships at sea or by vessels floating in the air. It can be used to transmit power over high mountains when the stringing of wires or laying of other conductors would be difficult or impossible, or by projecting energy across rivers or lakes, saving the trouble and expense of submarine cables.

While not designed primarily for telegraphing, but for the transmission of power in large quantities, he says the method can be applied to telegraphic purposes also, as a current of very low power can be transmitted as easily and practically without loss.

TESLA'S LAST INVENTION.

TO TRANSMIT POWER GREAT DISTANCES BY NATURAL MEDIA.

Earth and Air the Only Means of Transmission—The Inventor Says He Can Generate with Safety and Ease Electrical Pressures Measured by Millions of Volts.

Tesla has pushed his investigations of the possibilities of electrical transmission through natural media far into the realm of what even in these days might almost be called fairyland since the public last heard of his then latest discoveries, inventions and visions. "Wireless telegraphy," luminous cylinders diffusing radiance throughout a room without visible wires, or familiar forms of illuminers, seem like tame achievements compared with what he now proposes, the transmission of great power, without other media than the earth and the air, to distances of hundreds of miles, over mountains, over sea—only a little less than launching thunderbolts in the ether to distribute their energy under men's guidance at remote points. This latest advance of the electrician in the possibilities of his science, the *Electrical Review*, in which he records it to-day, says "will, if successful on a large scale, open up unlimited sources of practically costless power. The success of his efforts means that power from such sources as Niagara will become available in any part of the world, regardless of distance."

His work in this field, the *Review* says, has passed the stage of mere laboratory experiment and is ready for a test on an industrial scale.

His last invention is, briefly, the apparatus for the production of great electric power and for the collection and utilization of that power at a point distant from the seat of its production after the power, or the electric current in which it is comprised, has traversed without wires the intervening atmosphere at an altitude such that the rarefaction has made the air of that stratum a conductor of the electric fluid.

The invention, he points out, was based partly upon, or was in part the outgrowth of, the observations heretofore recorded and well known, that the air in a closed vessel, if rarefied, suffered an impairment of its insulating properties to such an extent as to become a true conductor of electricity, though one of high resistance. This much known, with the fact of the rarefaction of the atmosphere high above the earth, and the further fact, which has before been demonstrated, "that certain transverse waves or radiations may be transmitted through the atmosphere, and have been found capable of affecting certain delicate receiving instruments at a limited distance from the source of the electrical disturbance," gave the groundwork upon which Tesla built his hypothesis and developed the invention that is its demonstration. The practical information at his command was necessarily derived from observations manifestly subject to limitations imposed by the character of the apparatus heretofore known, and the quality of the electrical effects producible by it. He needed high electrical pressures, for his problem involved the transmission of great electrical energy long distances.

"I have devised means whereby I am able to generate with safety and ease electrical pressure measured by hundreds of thousands and even millions of volts," he says, and adds that with pressures of such magnitude and character he has found that the ordinary atmosphere becomes in a measure capable of serving as a true conductor for the transmission of the current.

A second highly important fact which he came upon in pursuing his investigation was "that the conductivity of the air increases so materially with the increase of electrical pressure and degree of rarefaction that it becomes possible to transmit through even moderately rarefied strata of the atmosphere electrical energy up to practically any amount and to any distance."

With these facts he constructed his apparatus, a part to develop the electrical energy, of very high pressure, then to lead the current to earth and also "to a terminal at an altitude where the rarefied atmosphere is capable of conducting the particular current produced," and another part to provide and maintain another terminal, at or about the same elevation, at a distant point, "to receive the current and convey it to earth through suitable means for transforming and utilizing it."

The apparatus consists of "a transformer comprising a spiral conductor with many turns, surrounded by a conductor with a very few convolutions," or, in other words, a coil of fine wire wound in many layers, surrounded by a lesser coil of heavier wire, the former the secondary coil, the latter the primary. In the circuit of the primary is included the source of the current.

The outer terminal of the secondary coil is connected with the earth, the inner to a conductor which carries the current to a terminal up in the air, "maintained there by such means as a balloon." At the receiving point there is a similar contrivance; the high terminal there receiving the current that has been conducted to it by the rarefied air. The coils there perform reverse service, the long coil being the primary and the short one the secondary. In the circuit of the secondary are placed lamps or motors or such device as may be desired for utilizing the current. Tesla says: "It will be understood that either or both of the coils or transformers and terminals may be movable, as, for instance, when carried by vessels floating in the air or by ships at sea."

The New York Tribune October 27, 1898

TESLA'S LATEST INVENTION.

TRANSMITTING ELECTRICITY THROUGH THE AIR WITHOUT WIRES.

Extensive quotations are made by "The Electrical Review" this week from patents recently taken out by Nikola Tesla, the object of which is the transmission of large quantities of electricity from one point to another through the air without the aid of wires. Just now, to convey a current from the Niagara Falls dynamos to Buffalo a costly pole line is in service, the copper conductors being nearly or quite an inch in diameter, and three of them being used for each five thousand horse-power dynamo. Now, if this power could be sent without any such medium great economy would be secured. This is the central idea of Mr. Tesla's invention.

He has found from laboratory experiments that the conductivity of air, which is ordinarily so poor that it might be considered an insulator rather than a conductor, is improved if the air be rarefied. Hence, if a current of the right kind could be led up from the earth to a comparatively rare stratum, and then suitable receiving apparatus be placed at a distance, the current, he believes, would flow from the one piece of apparatus to the other. Then it would be conducted down to earth again and used at that point.

An essential part of the scheme is that the current, from any suitable source, shall be so manipulated as to acquire a very high "voltage," or "potential." The voltage is raised for this particular purpose by a transformer of original design, and the transformer is the chief feature of the new system. Those who are interested in technical details will find them in "The Electrical Review."

Mr. Tesla emphasizes the fact that his method involves the conduction of the current by the air, exactly as if metal were substituted. He does not make use of the imponderable ether which conveys the Hertzian waves in wireless telegraphy. He thinks that if the air is sufficiently rarefied, and the potential of the current is high enough, the conductivity will be at least as great as that of copper wire. He does not make it entirely clear how far apart he would have his stations, or how high above the earth he would put the terminals of his apparatus. But he talks about transmitting current for "considerable distances," by which he probably means scores, perhaps hundreds, of miles at one leap. Nor in the portion of the patent papers reproduced by "The Electrical Review" is there any suggestion as to the means by which he would suspend in air the terminals. He is, however, confident that there would be no leakage of electricity. The enterprising periodical that makes this announcement remarks that, "if successful on a large scale, this latest discovery will prove of astounding consequences. . . . The success of his efforts means that power from such sources as Niagara will become available in any part of the world, regardless of distance."

Tesla's Aerial Power Transmission.

TO THE EDITOR OF ELECTRICAL REVIEW:

This end of the century has been so replete with scientific discoveries, both electrical and otherwise, that the old motto, *nil admirari*, becomes revivified, and truly we wonder at nothing.

When one reads the account of Mr. Tesla's latest work in electric power transmission the mental question arises, "and why not?" Once he had accomplished wireless telegraphy, to his restless activity it was but a step to wireless transmission, merely devising ways and means for transmitting wagonloads instead of thimblefuls.

Nature herself has done this in what is probably her most awe-inspiring manifestation of power, the lightning. Who has not seen the tremendous bolt dart from one end of a long cloud to earth and at the other end flash back from earth as the "return stroke?" And who will say the cloud, though many miles in length, has not constituted an aerial circuit in such case?

It is my belief that the upper strata are constantly carrying electrical currents of high potential.

An old-fashioned apparatus for the study of electrical phenomena was a globe of sulphur or glass, which, when rotated under slight friction of the dry hands, produced the desired effect in the shape of a snappy spark. Such a globe was about one foot diameter. What, then, should be the effect of the earth rotating at its enormous speed under the friction of the atmosphere—a globe billions of times the surface of the archaic electric machine?

It is no wonder that our most advanced meteorologists go astray in their forecasts, when they have no means of learning what is going on in the upper strata.

Tesla's balloon terminals may prove a boon to meteorology, while serving their own purpose also; for they can be used as a source of information of the various phenomena continually taking place above us. And, as the ELECTRICAL REVIEW has often pointed out, meteorology will never reach the pedestal of an exact science till observations are regularly conducted at an elevation consistent with the conditions.

There is nothing inconceivable in Tesla's transmission scheme, wonderful as it may seem; on the contrary, it is consistent with all that has gone before. He has simply gone after tarpon when others have been content with sprats. T. J. M.

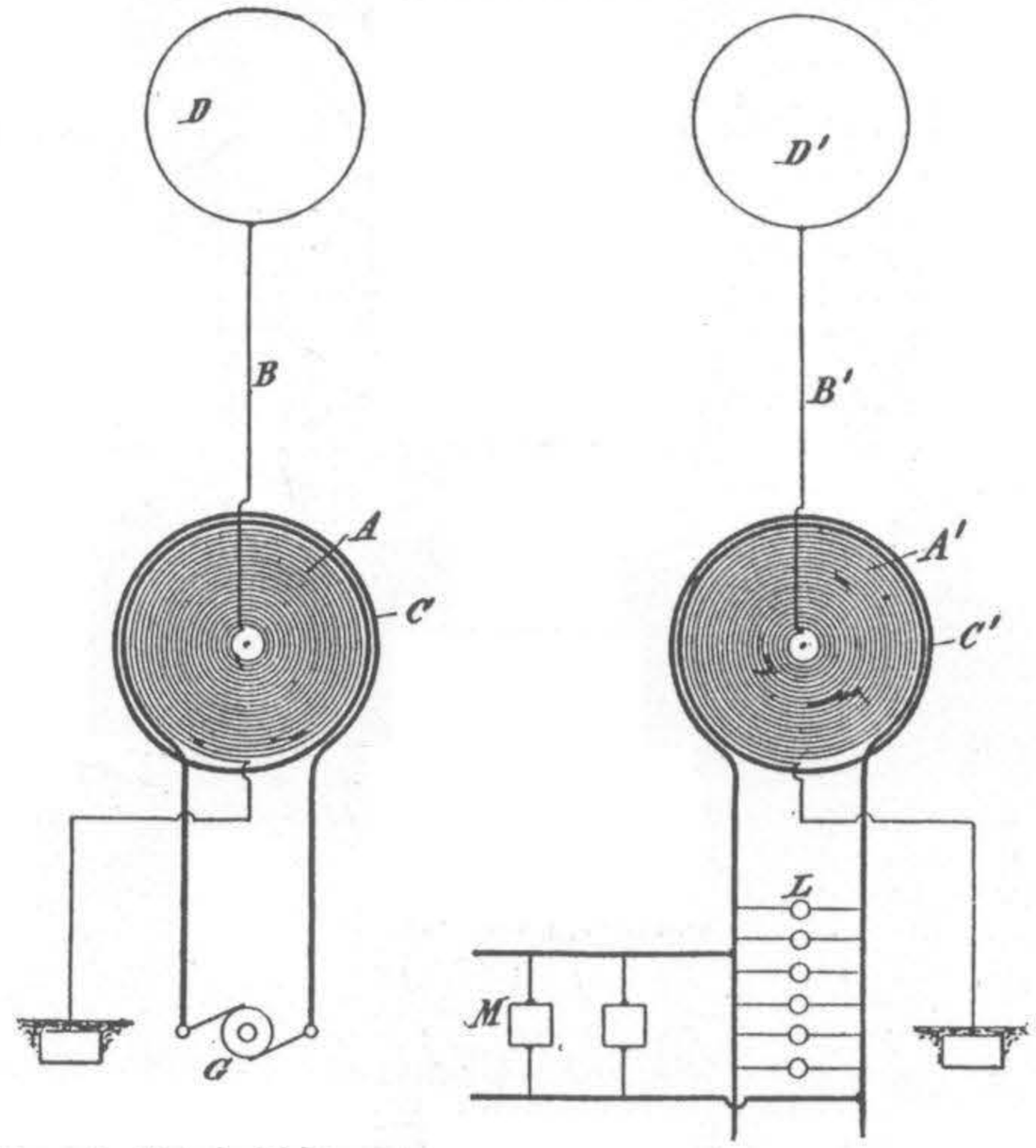
New York, October 29.

SCIENTIFIC

Tesla's New Marvel

NICOLA TESLA, in the *Electrical Review*, New York, October 26. Condensed for PUBLIC OPINION

My invention comprises a novel method or system for the transmission of electrical energy without the employment of metallic line conductors, and is primarily designed for use



From the Electrical Review.

DIAGRAM OF TESLA'S NEW TRANSMITTER

in cases where large amounts of electrical energy are to be transmitted to considerable distances, but the results arrived at are of such character and magnitude, as compared with any heretofore secured, as to render indispensable the employment of means and the utilization of effects essentially different in their characteristics and actions from those before used or investigated. I have devised means whereby I am enabled to generate with safety and ease electrical pressures measured by hundreds of thousands, and even millions, of volts, and in pursuing investigations with such apparatus, I have discovered certain highly important and useful facts which render practicable the method of transmission of electrical energy hereinafter described. Among these, and bearing directly upon the invention, are the following: First, that with electrical pressures of the magnitude and character which I have made it possible to produce, the ordinary atmosphere becomes, in a measure, capable of serving as a true conductor for the transmission of the current. Second, that the conductivity of the air increases so materially with the increase of electrical pressure and degree of rarefaction, that it becomes possible to transmit through even moderately rarefied strata of the atmosphere electrical energy up to practically any amount and to any distance.

The system of transmission comprised in my present invention and which, as above stated, was rendered possible only by the production of apparatus of a character radically new and different from any before known, and which is based upon discoveries made in the investigation of the results produced thereby, consists then in producing at a given point a very high electrical pressure, conducting the current caused thereby to earth and to a terminal at an elevation at which the atmosphere serves as a conductor therefor, and collecting the current by a second elevated terminal at a distance from the first. In order to attain this result it is necessary to employ

an apparatus capable of generating electrical pressures vastly in excess of any heretofore used, and to lead the current to earth and to a terminal maintained at an elevation where the rarefied atmosphere is capable of conducting freely the particular current produced; then, at a distant point, where the energy is to be utilized, to maintain a terminal at or about the same elevation to receive the current and to convey it to earth through suitable means for transforming and utilizing it. The apparatus which I have invented, and by means of which this method of transmission may be effected, is represented in the accompanying drawing, which is a diagrammatic illustration of the system, each transformer comprising a spiral conductor with many turns shown in fine lines surrounded by a conductor indicated in heavy lines with a very few convolutions.

The secondary coil is built up as usual, the wire being wound around an insulating core or spool until its convolutions fill up the space and form one complete layer. The winding is continued in the same way until another layer is formed, and so on. When the desired length of secondary or high-tension coil is thus obtained, the primary or low-tension coil is wound outside of it, but this latter coil is composed of only a very few turns of wire or conductor, which is of much larger diameter of cross-section than the secondary wire. The transformer thus consists simply of two concentric coils, the inner coil having very many turns of fine wire, the outer coil a very few turns of coarse wire. From this plan of construction it follows that one of the high-tension terminals is at the center of the secondary coil, and in the use of the coil the other terminal, whether it be connected to ground or not, is electrically connected to the primary, in order that there may be no material difference of potential between the latter and the adjacent convolutions of the secondary. It will be understood that either or both of the coils or transformers and terminals may be movable, as, for instance, when carried by vessels floating in the air, or by ships at sea. In the former case the connection of one terminal with the ground might not be permanent, but might be intermittently or inductively established without departing from the spirit of the invention.

TESLA AND POWER.

THE very latest from America is that Mr. Nikola Tesla has invented a means of transmitting electricity to the distance of thousands of miles without loss of power or the use of wires, and there seems to be no limit to the power so transmitted, for the announcement states that the power of Niagara will now be available in any part of the world. Of course, such statements as this are naturally received with a considerable amount of caution; in fact, would not be taken any notice of were not Mr. Tesla's name mentioned in connection with them. We are told, however, the why and the wherefore, and are given a considerable amount of detail. The rarefied air at high altitudes is said to be a conductor of electricity, though of very high resistance, but the resistance is said to decrease rapidly as the electrical pressure increases. Tesla proposes to use electricity of millions of volts pressure, and to conduct it to a large metallic globe kept suspended high in the air by means of a balloon, and to have another globe similarly suspended at a receiving station perhaps some thousands of miles away. We have seen and heard in this our generation so much of the ostensibly impossible becoming the usefully possible, that it would be rash to assert that Tesla, or his American interpreter, say the thing which is not. But we manifest no undue incredulity when we say that no method of generating electricity of millions of volts pressure has yet been devised; while there is not any conceivable means of insulating the necessary apparatus. To the scientific use of the imagination the world is indebted for much. Tesla may find himself anticipated by some one who, instead of making lightning by the aid of Niagara, will utilise it as we find it ready made by nature's own apparatus.

Our Modern Franklin==Nikola Tesla

He Tells "Success" the Story of his Struggles and Triumphs—The Firefly as a Model—Two Hundred Inventions and More Coming

FRANCIS LEON CHRISMAN

"THE secret of success is hard work." The speaker was Nikola Tesla, the great electrician; and the place, his laboratory, at 46 East Houston street, New York.

I had called upon Mr. Tesla in order to learn from his own lips, for the readers of SUCCESS, the secret of his rapid progress toward the pinnacle of fame.

"To be successful in this world," continued the great electrician, "one must perform the hardest kind of work. You must peg away night and day, and not stop a minute. There is no royal road. This has been the plan I have followed for years.

"Why! I am even blamed for being lazy by some people, because I do not perfect all my inventions; although I work from sixteen to twenty hours out of the twenty-four.

Replicating the Firefly's Light

"It may interest you to know that my system of vacuum-tube lighting is a success. It is now almost ready to be given to the public, and I expect soon to make an announcement on the subject. I have been watching very carefully what other inventors have been doing in this direction, and can assure you that my light will meet all requirements."

The aim and ambition of electricians is to actually manufacture artificial daylight. At first thought, it seems a very easy matter to duplicate the light of the firefly. Nevertheless, for ages, the little bug has successfully kept the secrets of its phosphorescent [illegible]on-house, baffled the brains of the world, and proved as elusive to electricians as the will-o'-the-wisp is to us all. Of late, several electricians have been making remarkable headway,—notably Tesla, Edison, [illegible]ore, and Haines. All have been devoting their time to vacuum tubes. Mr. Tesla showed his friends, a year or two ago, what he could accomplish with a single tube, and produced a good photograph made at a distance of four feet with only two minutes' exposure. It was while working on the problem presented by the firefly that he found time to harness Niagara Falls, and transmit its energy by an alternating current to the surrounding cities and towns. In the meantime, too, he developed the "Tesla Oscillator" for producing currents of tremendous potential, and at the same time made a machine for measuring the electric discharges from the earth, thus suggesting the possibility of "calling up" and communicating with the planet Mars one day by means of signals.

Modern Benjamin Franklin

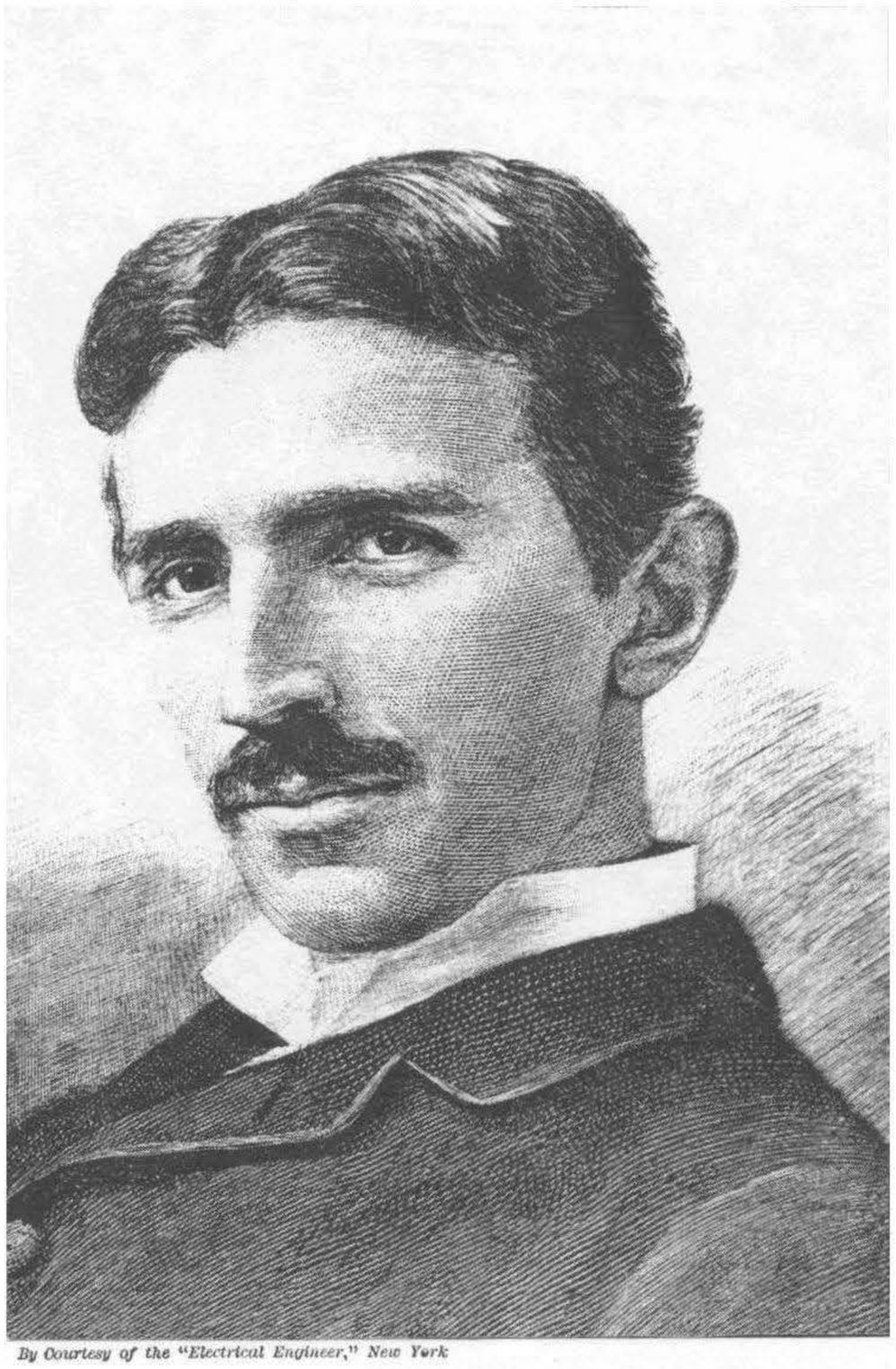
Mr. Tesla is the modern Benjamin Franklyn and has sent his electrical kite to the sky for studying the secret of light. That he has at last succeeded in producing artificial sunlight which will stream from long glass tubes, is not surprising, in view of the long years of patient experiment and field work. The points in favor of the Tesla light are beautiful illumination, the absence of deadly wires, and the non-employment of any kind of filament in the tubes.

Mr. Tesla's hours are crammed with experiments and scientific investigations. In personal appearance he is tall and commanding. Like Cassius, he has a "lean and hungry look," and "thinks too much." He has already patented some two hundred inventions, has a similar number in various stages of evolution in his laboratory, and is dreaming daily of new worlds to conquer.

The friends of Mr. Tesla say that he is even fonder of solitude than Lincoln was. Few ever cross the threshold of his laboratory, and you can nearly always find him dining alone at the Waldorf-Astoria any evening at nine o'clock.

The distinguished inventor was born in 1858, at smiljan, Lika, on the borderland of Austro-Hungary. His mother had great ingenuity, and delighted in the construction of looms and churns. His father was a clergyman in the Greek Church, and intended that his son should succeed him in the sacred office. There were many children in the family, of whom Nikola was one of the youngest, and the most remarkable. He always dominated his brothers and sisters in their home and at school he had a decided aptitude for his studies. At school, one day, the master was expermenting in mechanics before the class. The children were gathered round the desk, Nikola in the front row. The teacher proceeded to demonstrate what he considered one of the main principles of electricity. He explained just why the lever moved, and had almost finished when Nikola, who had been listening intently, interrupted him. "That can't be true," he said, quietly. The master looked at him in astonishment, and demanded an explanation of his words. "Well, I say that isn't true," said Nikola, again; "I can't tell you why to-day, but I will to-morrow."

The master dismissed the class, and warned Nikola that, if he did not prove his assertion before the week was out, he would have to answer for his impudence. The young student went home and confidently began his experiments to prove that the master was wrong. All night long he worked, becoming more hopeful every moment. Before daylight he had finished his model, and went to bed triumphant. He declares that, when he went up to the desk and showed his machine to the teacher, he felt more triumphant than he has ever felt since, and when he was openly commended before the school, his joy was supreme. It was not long before the whole town knew that Nikola Tesla was destined for a great electrician, and his career had begun.



By Courtesy of the "Electrical Engineer," New York

NIKOLA TESLA

The Race of Genius

Young Tesla's early studies were in electricity and magnetism. Later, he went to Prague and Buda-Pesth to study languages. He then entered the laboratory of a great inventor at Vienna; but, becoming dissatisfied, went to Paris, and engaged in the labor of furnishing that city with electric lights. Then he went to other cities, ever rising in his profession, making new improvements, new discoveries, and adding continually to his fame. His name became known all over the continent, and in London. The king of Servia, proud of such a subject, decorated him, and the emperor of Austria did likewise. His rise was almost phenomenal, and many places in Europe were open to him.

Tesla was a lover of liberty. He looked with longing eyes toward America, where there is such a promising field for electricians. He had read of Edison, and determined to come to New York and seek a place with the great inventor. Edison gladly received him, and for many years the two worked together, each relying to a certain extent on the other, and each profiting by the other's knowledge. Gradually their ideas began to differ, and it was decided that they would better separate.

Mr. Tesla is in his laboratory at half past eight every morning, and spends a long day there, planning, experimenting, and making models. He puts an enormous amount of energy into his work, and never stops until he has hit upon the idea he is after. He has a corps of clever assistants, but is careful to do all the important work himself.

Superior to Discouragement

On the morning of March 13, 1895, Mr. Tesla met with a bitter experience in the entire destruction of his fine laboratory on South Fifth Avenue by fire. It was a hard blow to the inventor, who cried like a child. The work of years had gone up in smoke, and two tottering walls, like tumbling monuments, marked the place where he had spent years of toil and tribulation in trying to wrest the secrets from nature. But before the ashes were fairly cold, he was planning for new quarters on East Houston street. While the valuable papers, notes, and data for years were destroyed, the man was still alive.

"More divine, the master of all these."

The new laboratory soon grew, and is now one of the best equipped in the country. Mr. Tesla's inventions cover many things, and are contained in big volumes. He believes that his discovery of the rotating magnetic field is the invention by which he will be best known. The "Oscillator" is a blending of the dynamo and the steam engine, the idea being to get the electric current directly from steam. He has also met with great success in experiments looking to the long-distance transmission of water-power. "Some day," he asserts confidently, "New York, Washington, Pittsburg, and Chicago, will be supplied with power generated from Niagara Falls."

Mr. Tesla has tried to harness the electrical discharge of the earth, and has made some interesting discoveries in this connection. Before he took up the subject, the alternating current had no recognized place. Now it is used everywhere, and has cheapened light and power. Mr. Tesla is a great genius, survey him as you will. To everyone he is courteous and Chesterfieldian. He always inspires you by his noble character, for he fully believes that "a firm faith is the best divinity;" a good life, the best philosophy; a clear conscience, the best law; honesty, the best policy; and temperance, the best physic. His achievements in electrical science have already marked him as one of the greatest benefactors to civilized society which our age has produced.

with the same conducting strata by means of any suitable device, such as that used by the illustrious Benjamin Franklin, or, preferably, as stated in the patent, by means of a balloon, the earth being utilized as a ground return.

The fact is set forth that the atmosphere at 15 pounds to the square inch, or other pressures common near the surface of this mundane sphere, is a good insulator, while at lower pressures, as is well known by manufacturers of 200-volt lamps, it becomes quite a fair conductor. By a rigid suppression of the reasoning faculties and a little freedom of the imagination, fancy pictures a conductor poked up through the insulating sheath at Niagara, establishing an alternating difference of potential between the superincumbent ether and this ball of solid matter below protected by an atmospheric dielectric, which difference of potential can be tapped, so to speak, at any desired location, such as the large cities, or by express trains with electric locomotives towing balloon trolleys, making contact with an overhead conductor from which they cannot readily slip off. The use of several great sources of natural power will, of course, necessitate generators of the same frequency running in synchronism with each other, as they are all, so to speak, connected across the same bus bars, and lacking the third bus bar, multiphase systems will go out of fashion.

The system might, however, give other results more valuable than those of power transmission. With transmitting and receiving stations at Niagara Falls and New York city, respectively, the State of New York would possibly be illuminated by a gigantic Geissler tube overhead that would turn night into day, put to shame the aurora borealis, and make the advocates of diffused illumination shout for joy.*

Mr. Tesla should certainly be enjoined from putting his polished ball terminals too high, or a Crookes-tube effect might be obtained, emitting a profusion of X-rays which would disclose altogether too much to anyone with fluorescent spectacles, and might make it necessary for mortals to carry leaden umbrellas to prevent the skin being burned from the tops of their heads.

The patent gives no data as to the estimated height to which it would be necessary to elevate the terminals. It is obvious that a height sufficient for a very marked difference in the specific resistance must be attained, otherwise the voltage would be necessarily so high that fatal leakage through the extended sheet of insulating medium would ensue. No such marked change of resistance occurs at the highest elevations yet attained by man, several miles upward, and the atmospheric pressure falls off somewhat more slowly even than by a logarithmic law, so that scores or hundreds of miles of elevation would be necessary. The methods of ballooning at this elevation and supporting conductors of this length are not explained in the patent.

With a circuit looped about so many square miles of space, it is not explained how the self-inductive choking of the comparatively high-frequency currents proposed (about 1000 cycles per second) could be eliminated, and no explanation is made of the precautions to be taken against lightning. The advocates of that light-weight material, aluminum, for current-conducting purposes must take a back seat, as the ether has a lower specific gravity than anything hitherto proposed for this service. Mr. Tesla, if correctly reported, previously proposed to wabble the earth's charge for man's ignoble uses, but he now, if these things can be taken seriously, has designs on the universe. The price of copper remains in the neighborhood of 11 cents. however.

*The writer reserves all rights to the use of interplanetary space as a vacuum tube for lighting purposes.

BOUNDLESS SPACE A BUS BAR.

One of the American electrical journals has recently taken some of Mr. Nikola Tesla's patents undoubtedly more seriously than the inventor himself intended them, and advanced the ideas there tentatively proposed as a revolutionary invention comparable with those of the same inventor in the rotary-field line, and has, with the aid of the gullible daily press, given the public in general another false impression of the wonders of electricity. The idea proposed comprises nothing more nor less than a high-tension step-up transformer feeding into a vertical conductor with a terminal at such an elevation above the earth as to reach a strata of rarefied atmosphere which has a comparatively low electrical resistance, a similar step-down transformer to be connected at any desired point

TESLA DECLARES HE WILL ABOLISH WAR.

Magician of Electricity Announces That He Has Perfected an Application of the Current Which Will Make Possible the Destruction of Battle Ships at Any Distance from an Operating Base.

PROJECTS CONTROLLING IMPULSES THROUGH ATMOSPHERE

Exhibits a Working Model, the Propelling, Steering and Exploding Mechanism of Which Are Controlled at Will from a Distance Without the Intervention of Wires.

SAYS WILL RENDER USELESS THE NAVIES OF THE WORLD.

At the Paris Exposition the Inventor Intends to Exhibit a Model of a Vessel, All the Manoeuvres of Which Will Be Directed by Him from His Office in New York.



WONDERS NIKOLA TESLA SAYS HE CAN PERFORM.

Shows How He Proposes by Electricity, Without Wires, to Control the Movements of a Model at the Paris Exposition from His Office in New York, and by Similar Methods Blow Up Ironclads and Send Lifeboats to Shipwrecked Vessels.

At the moment when all the world is ringing with rumors of an impending colossal conflict there comes from the laboratory of one of the great magicians of science the announcement of the development of a power which he believes is destined immediately to usher in the era of universal peace by the demonstration of its ability to destroy, without the possibility of defence, the mightiest armaments of all the naval powers.

In the words of Nikola Tesla, uttered yesterday morning:—"War will cease to be possible when all the world knows to-morrow that the most feeble of the nations can supply itself immediately with a weapon which will render its coast secure and its ports impregnable to the assaults of the united armadas of the world. Battle ships will cease to be built, and the mightiest armorclads and the most tremendous artillery afloat will be of no more use than so much scrap iron. And this irresistible power can be exerted at any distance by an agency of so delicate, so impalpable a quality that I feel that I am justified in predicting that the time will come, incredible as it may seem, when it can be called into action by the mere exercise of the human will."

Unlimited Destructive Powers.

In brief, Mr. Tesla's latest and most startling miracle consists in an application of electricity whereby, without the interposition of any artificial medium of communication, one man can control and direct, with absolute exactitude, the movements of any type of vessel, balloon or land vehicle, at any distance that may be desired. From a station on shore, or from the deck of a vessel under way, a torpedo boat equipped with Mr. Tesla's controlling device may be propelled either on or below the surface, manoeuvred at will in any direction, and finally brought into contact and exploded against the side of a hostile vessel at any point within the range of the vision of the operator.

More than this, assuming that it were possible to accurately locate the position of the vessel which it is desired to destroy, the torpedo boat could be directed to it, even if the ship lay in the harbor of Southampton and the operator were stationed at Sandy Hook. With such marvellous possibilities of destruction it is hardly to be wondered that Mr. Tesla firmly believes that the days of the supremacy of sea power are numbered.

Mr. Tesla told me that some months had elapsed since he had fully developed his device, for which he has applied for a patent. When it was learned that Admiral Cervera was bottled up at Santiago it was his intention to apply his mechanism to several launches and similar small craft loaded with high explosives and annihilate the fleet at anchor. Admiral Cervera, however, came out and met his fate under the guns of the American fleet before the necessary arrangements could be made. Then Mr. Tesla planned a raid on the Spanish vessels in Havana Harbor, only to be thwarted by the proclamation of the suspension of hostilities.

Ironclads Doomed.

While the most important application of the device is unquestionably in the direction of destruction, it will also have countless peaceful uses, and it is Mr. Tesla's highest pride that by making war too terrible it will render it impossible.

When I saw Mr. Tesla yesterday morning in his laboratory in East Houston street he said:—"It gives me the greatest pleasure to announce to the world my last and my greatest invention through the medium of the HERALD. My imagination fairly reels when I attempt to contemplate its countless possibilities. Already I hear the knell of the battle ship and the monster gun. Their day has passed with the advent of a new and irresistible power, which gives to all nations an absolute power of defence against any attack.

"England has until now boasted of her mastery of the seas, but her superiority has vanished and she is now no stronger than the weakest of the maritime nations, so far as her offensive power is concerned. England, who is now so diligently preparing for war, will awake to this unwelcome discovery tomorrow and will be utterly confounded, and France, against whom her armaments have been reported to be preparing, will rejoice in the discovery that she possesses an all powerful weapon of defence.

"Hitherto," continued Mr. Tesla, "the only means of controlling the movements of a vessel from a distance have been supplied through the medium of a flexible conductor such as an electric cable, but this system is subject to obvious limitations such as are imposed by the length, weight and strength of the conductor which can be practically used; by the difficulty of maintaining, with safety, the high speed of the vessel or changing the direction of her movements with rapidity; by the necessity of effecting the control from a point which is practically fixed, and from many other drawbacks which are inseparably connected with such a system.

No Wires Required.

"The plan which I have perfected involves none of these objections, for I am enabled by the use of my invention to employ any means of propulsion, to impart to the moving body or vessel the highest possible speed, to control the operation of its machinery and to direct its movements from either a fixed point or from a body moving and changing its direction, however rapidly, and to maintain this control over great distances, without any artificial connections between the vessel and the apparatus governing its movements, and without such restrictions as these must necessarily impose.

"In a broad sense, then, my invention differs from all of those systems which provide for the control of the mechanism carried by a moving object and governing its motion, in that I require no intermediate wires, cables or other form of electrical or mechanical connection with the object save the natural media in space. I accomplish, nevertheless, similar results and in a much more practical manner by producing waves, impulses or radiations which are received through the earth, water or atmosphere by suitable apparatus on the moving body and cause the desired actions, so long as the body remains within the active region or effective range of such currents, waves, impulses or radiations.

"Having explained to you some of the possibilities of the device," continued Mr. Tesla, "I will now give you a practical example of the workings of the model before going into a detailed description of how I am able to produce these results."

Illustrated by a Model.

Elevated on stocks on a table in the centre of the laboratory stood a model of a screw propelled craft, about four feet long and somewhat disproportionately wide and deep. Mr. Tesla explained that it was merely a working model which he had had made in order to exhibit to President McKinley, and that no attempt had been made to follow the usual sharp lines of a torpedo boat. The deck was slightly arched and surmounted by three slender standards, the centre one being considerably higher than the other two, which carried small incandescent bulbs, a third bulb being fixed at the bow.

The keel consisted of a massive copper plate, the propeller and rudder being in the usual positions. Mr. Tesla explained that the boat contained the propelling machinery, consisting of an electric motor actuated by a storage battery in the hold, another motor to actuate the rudder and the delicate mechanism which performs the function of receiving through the central standard the electric impulses sent through the atmosphere from the distant operating station, which set in motion the propelling and steering motors, and through them light or extinguish the electric bulbs and fire the exploding charge in a chamber in the bow in response to signals sent by the operator.

"Now, watch," said the inventor, and, going to a table on the other side of the room, on which lay a little switchbox, about five inches square, he gave the lever a sharp turn. Instantly the little bronze propeller began to revolve at a furious rate. "Now I will send the boat to starboard," he said, and another quick movement of the lever sent the helm sharp over, and another movement turned it as rapidly back again. At another signal the screw stopped and reversed.

Will Abolish War.

"During the day," continued Mr. Tesla, his hand still on the lever, "we should steer our course by keeping the two standards in line, but at night we should depend on the electric lights, which would, of course, be screened so as not to be visible to the enemy," and at a signal both the tiny bulbs were illuminated.

"Now we will assume that the boat has arrived within striking distance of the vessel to be destroyed, and the bulb in the bow will serve to show that the explosion has taken place."

As he spoke he touched the lever again and the light flashed and was extinguished.

"Imagine, if you can," said Mr. Tesla as he went back to his desk, "what an irresistible instrument of destruction we have in a torpedo boat thus controlled, which we can operate day or night, on the surface or below it, and from any distance that may be desired. A ship thus assailed would have no possibility of escape.

"I can apply this system of control to any type of vessel and of any size. It is not even necessary to make a close approach to the vessel to be destroyed. At the distance of 100 feet the explosion of 200 pounds of dynamite will exert a shattering effect on a battle ship, but there is no reason why we should not load a vessel with 200 or 300 tons, or even more, of dynamite, which, exploded even a mile or so away, would raise a wave that would overwhelm the biggest ship ever built.

"But I have no desire that my fame should rest on the invention of a merely destructive device, no matter how terrible. I prefer to be remembered as the inventor who succeeded in abolishing war. That will be my highest pride. But there are many peaceful uses to which my invention can be put, conspicuously that of rescuing the shipwrecked.

"It will be perfectly feasible to equip our life saving stations with life cars, or life boats, directed and controlled from the shore, which will approach stranded vessels and bring off the passengers and crews without risking the lives of the brave fellows who are now forced to fight their way to the rescue through the raging surf. It may also be used for the propulsion of pilot boats, for carrying letters or provisions or instruments to inaccessible regions, for killing whales and for many other commercial or scientific purposes."

Controlled from Any Distance.

"Is there any limit," I asked, "to the distance at which the controlling device can be operated?"

"In the operations of war," replied Mr. Tesla, "the radius of control would usually be limited by the range of the vision of the operator, whether afloat or ashore, but otherwise there is no limit to the distance. In order to give a practical illustration of this it is my intention to exhibit a model of a torpedo boat at the Paris Exposition and direct all its movements from my office in New York, precisely as I have shown you the working of the model here to-day, except that in Paris I intend to exhibit it afloat in a tank."

Coming to the description of the details of his device Mr. Tesla prefaced his remarks by the explanation that the electrical disturbances proceeding from the centre of control were of an infinitesimally feeble character, and then made the startling statement that he believed that the time would come when it would be possible to bring them into play by the mere exercise of the will.

"But that time," he continued, "is probably far distant. I only mention the fact as illustrative of the delicate character of the impulses, and because the possibility of exciting them by mere will power is logically in accordance with the development of the system."

Continuing his description, Mr. Tesla said:—"As to that part of my invention which involves the production of suitable waves or radiations and the conveying of the same to a remote receiving apparatus capable of being operated or controlled by their influence, it may be carried out in various ways which are at the present time more or less understood. For example, I may pass through a conducting bath, preferably enclosing a large area, a rapidly varying current, and by electro-magnetic induction of the same affect a circuit carried by the moving body.

Methods of Operating.

"In this case the action at a given distance will be the stronger the larger the area enclosed by the conductor and the greater the rate of change of the current. If the latter were generated in the ordinary ways, the rate of change, and consequently the distance at which the action would be practically available for the present purpose, would be very small, but by adopting such means as I have devised—that is, either by passing through the conducting path currents of a specially designed high frequency alternator, or, better still, those of a strongly charged condenser—a very high rate of change may be obtained, and the effective range of the influence thus extended over a vast area, and by carefully adjusting the circuit on the moving body so as to be in exact electro-magnetic synchronism with the primary disturbances this influence may be utilized at great distances.

"Another way to carry out my invention is to direct the currents or discharges of a high frequency machine or condenser through a circuit one terminal of which is connected directly or inductively with the ground and the other with a body, preferably of large surface and at an elevation. In this case, if the circuit on the moving body be similarly arranged or connected, differences of potential on the terminals of the circuit either by conduction or electrostatic induction are produced, and the same object is attained.

"Still another way is to pass the currents simply through the ground by connecting both the terminals of the source of high frequency currents to earth at different and remote points, and to utilize the currents spreading through the ground for affecting the receiving circuit properly placed and adjusted.

A Sensitive Device.

"Finally, I may avail myself, in carrying out my invention, of electrical oscillations which do not follow any particular conducting path, but propagate in straight lines through space, of rays, waves, pulses or disturbances of any kind, capable of bringing the mechanism of the moving body into action from a distance and at the will of the operator by their effect upon suitable controlling devices.

"In any event—that is to say, whichever of the above or similar plans I may adopt—and particularly when the influence exerted from a distance upon the receiving circuit be too small to directly and reliably affect and actuate the controlling apparatus, I employ auxiliary sensitive relays, or, generally speaking, means capable of being brought into action by the feeblest influences, in order to effect the control of the movements of the distant body with the least possible expenditure of energy and at the greatest practicable distance, thus extending the range and usefulness of my invention."

In describing the device used for detecting the presence of the impulse from the controlling station, and transmitting it to the propelling and other mechanism of the boat Mr. Tesla said a great variety of devices for the detection of vibrations were known to scientific men and artisans, and mentioned, among others, the familiar lightning arrester in use in telegraph offices.

He had demonstrated, he said, the practicability of providing a large number of receiving currents of a special design—fifty or a hundred or more—each of which might be called up, or brought into action, whenever desired without the others being interfered with. This made it possible for one operator to direct simultaneously the movements of many bodies, each of which might have a distinct duty to perform, as well as to control the action of various devices located on the same body, such as the propelling, steering and exploding mechanism of a torpedo boat.

The Problem Solved.

"In regard to these sensitive devices," he said, "which may be broadly considered as belonging to one class, inasmuch as the operation of all of them involves the breaking down of a minute thickness of highly strained dielectric, it is necessary to make some provision for automatically restoring to the dielectric its original, unimpaired insulating qualities in order to enable the device to be used in successive operations.

This is usually accomplished by a gentle tapping or vibration of the electrodes or particles, or continuous rotation of the same, but in long experience with many forms of these devices I have found that such procedures, while suitable in simple and comparatively unimportant operations, as ordinary signalling, when it is merely required that the succeeding effects produced in the receiving circuit should differ in regard to their relative duration only—in which case it is of little or no consequence if some of the individual effects be altered or incomplete or even entirely missed—do not yield satisfactory results in many instances when it may be very important that the effects produced should all be exactly such as desired and that none should fail.

"To illustrate, let it be supposed that an official, directing the movements of a vessel in the manner described, should find it necessary to bring into action a special device on the latter, or to perform a particular operation, perhaps of vital moment, at an instant's notice, and, possibly when, by design or accident, the vessel itself or any mark indicating its presence is hidden from his view.

Guarding Against Failure.

"In this instance a failure or defective action of any part of the apparatus might have disastrous consequences, and such cases, in which the sure and timely working of the machinery is of paramount importance, may often present themselves in practice, and this consideration has impressed me with the necessity of doing away with the defects in the present devices and of producing an apparatus which, while being sensitive, will also be most reliable and positive in its action.

"In this arrangement these defects are overcome in a most satisfactory manner, enabling thousands of successive operations in all respects alike being performed by the controlling apparatus without a single irregularity or miss being recorded.

"The apparatus by means of which the operation of both the propelling and steering mechanisms is controlled involves, primarily, a receiving circuit, which, for reasons before stated, is preferably both adjusted and rendered sensitive to the influence of waves or impulses emanating from a remote source, the adjustment being so that the period of oscillation of the circuit is either the same as that of the source or a harmonic thereof.

"The receiving circuit proper comprises a terminal affixed on the central standard conductor, a sensitive device, and a conductor leading to the ground, conveniently through a connection to the metal keel of the vessel.

"The terminal should present a large conducting surface and should be supported as high as practicable on the standard.

How the Current Flows.

"The circuit, or path, also a part of a local circuit, which latter includes a relay magnet and a battery, the electro-motive force of which is so determined that although the dielectric layers in the sensitive device are subjected to a great strain, yet normally they withstand the strain and no appreciable current flows through the local circuit. But when an electrical disturbance reaches the circuit the dielectric films are broken down, the resistance of the device is suddenly and greatly diminished, and a current traverses the relay magnet."

The sensitive device which Mr. Tesla employs, and on which dependence is placed to effect connection between the impulses from the controlling station and the mechanism proper of the boat, consists of a metal cylinder, provided with insulating heads, through which passes a metallic rod. A small quantity of metallic grains of conducting material, consisting of particles of exactly uniform size and carefully oxidized, is placed in the cylinder, which is placed in connection with a small battery and a train of clockwork.

This mechanism operates to turn the sensitive cylinder, end for end, after the passage of the impulse which has started the battery current. The normal position of the cylinder is vertical, and when turned over the grains in it are simply shifted from one end to the other. As they always fall through the same space and are subjected to the same agitation, they are brought after each operation of the relay to precisely the same electrical condition, and offer the same resistance to the flow of the battery current, until another impulse from afar reaches the receiving current.

In addition to the mechanism described the vessel may carry any other device or apparatus which may be required for any special object and which may be set in motion in the same manner as the propelling and steering machinery. In practice the switch box by which the generation of the electrical impulses is controlled is similar to the one used by Mr. Tesla in his demonstration with the model, signals being conveyed by simple movements of the lever.

TESLA'S NEW WAR WONDER

HAS MODEL OF SHIP OPERATED BY MAGNETIC WAVES FROM SHORE.

Applies Principle of Electrical Transmission Without Wires to New Invention—Magnet Controls the Machinery—Can Direct Balloon or Wagon in Same Way.

Nikola Tesla, whose original discoveries in electrical science during the last ten years have placed him in the foremost ranks of science, and whose applications of his discoveries have made him recognized as one of the world's greatest inventors, makes public to-day his latest discovery and invention, which he believes is also his greatest one. In brief, Mr. Tesla believes that this invention will not only answer many useful purposes in ordinary life, but that it would make war so terrible, as well as expensive, as to make it prohibitory, and thus to assure peace between all the nations.

Mr. Tesla's latest invention consists of a combination of his devices for producing and projecting into the air currents of electricity of enormous voltages which will reach out for many miles, and a means for using electric waves thus projected for controlling the driving, steering and other machinery of a moving body. By fitting out a vessel, a balloon, or a wagon with his special mechanical devices, Mr. Tesla can control their movements on land or sea or in the air by the projection without wires of currents of electricity to great distances. If desirable that such a vessel should carry great quantities of explosives, bombs or other destructive devices, the operator at the distant point can direct discharge and explode them at will.

The idea of the invention came to Mr. Tesla years ago, and he has never lost sight of it since, but it was not until the war with Spain came and stirred him with patriotism—for Mr. Tesla is American to the backbone—that the scheme took definite form and shape. Then the idea completely possessed him and gave him no rest until the problem was worked out in its entirety.

"Years ago," said Mr. Tesla, in explaining what led to this latest invention, "I used to argue that the human organism was but a thermo-electric machine, whose operations were controlled by the impressions which came to it through the medium of the eye, the ear, the nose, the palate or the touch. Light falls upon the retina, I would argue, and conveys an impression to certain nerves, and these transmit a signal to some part of the mechanism further back, which sets in motion certain muscles or perhaps sends signals further along. Could I but make a machine which could receive impressions as does my eye, my ear or my other organs of sense, then I could make it do anything which I wished almost as if it were a sensate being which could reason as well as act."

That is what Mr. Tesla has succeeded in doing. In his laboratory in West Houston street stands the working model of a vessel whose every movement Mr. Tesla can control by the simple turning of a crank in another part of the room, with no other connection between him and the vessel than that formed by the atmospheric air or the wooden floor. At one turn of the crank the vessel's screw begins to revolve, her rudder swings until it is in whatever position Mr. Tesla desires, and then with another touch the rudder remains fixed while the screw drives away. Another touch and the rudder moves either way, little or much as desired, and at the will of the operator signal lights flash out from staffs on the vessel to tell just what position the rudder is in. A green light tells that it is to port, a red light that it is a-starboard; and the flash of red and green together gives true word that it is amidship. The lamps remain dark unless their signal warning is ordered by the operator's touch, or they flash for a second or remain glowing, just as is desired. At another touch a white light forward glows or flashes, as may be desired, without interfering in any way with the other operations, and this is used by Mr. Tesla to signify that a giant charge of guncotton has been projected or exploded, or that any other operation that might be needed has been performed. When, with Mr. Tesla's guiding hand to help, one looks into the interior of the three-foot model vessel, and sees how these operations and the stopping of the machinery or regulation of its speed to either of three degrees of speed are produced, it is at once apparent that there is no operation which goes on aboard the greatest warship or merchant vessel, in a fort or workshop, where automatic machines could replace the hand of man that could not be controlled by the master hand at the tiny crank with as much certainty and precision as if that hand were on board the vessel and in direct touch with a master machine there. There might be a hundred, a thousand, ten thousand operations to be done, and all would be under the entire control of the operator miles away as certainly as the quartermaster steers our great ships, by the touching of a mechanism so frail that it breaks like a toy, or as surely as the men aboard a modern warship turn and handle her enormous turrets by the pressing of a key or turning of a stopcock.

Air, earth or water is all that is needed to make the connection between the operator and the moving mechanism, be it vessel, wagon or whatever, and even some of these might be done away with under certain circumstances. In the model which Mr. Tesla has the power which controls the moving mechanism is electricity, and Mr. Tesla declares that he can exercise the control from as far away as a telescope could enable the operator to keep watch of the vessel. But it is not necessary to use electricity even to exercise such control. With devices which any expert mechanic could make the same control could be exercised by the notes of a whistle, or by other means which would produce measurable vibrations. Electricity is, however, the necessary agent by which the primary control of the machinery within the controlled object is made obedient; although beyond the primary device steam, compressed air or any other source of power can be used. In the model vessel Mr. Tesla uses a combination of storage batteries and clockwork to produce the movements. The use of these, however, is but a minor detail of mechanics. Balloons can be controlled and directed as readily as any other vessel and sent hither and yon at will, or caused to drop explosives whenever the operator might desire, and yet be free from earth.

The possibilities of the new invention are thus modestly described by Mr. Tesla in the application for a patent which he filed at the Patent Office at Washington on July 1:

"The invention which I have described will prove useful in many ways. Vessels or vehicles of any suitable kind may be used, as life, despatch, or pilot boats, or the like, or for carrying letters, packages, provisions, instruments, objects or materials of any description, for establishing communication with inaccessible regions and exploring the conditions existing in the same, for killing or capturing whales or other animals of the sea, and for many other scientific, engineering, or commercial purposes. But the greatest value of my invention will result from its effects upon warfare and armaments, for, by reason of its certain and unlimited destructiveness, it will tend to bring about and maintain permanent peace among nations."

It was when Cervera's fleet took refuge in Santiago harbor that the invention assumed form in Mr. Tesla's mind. Almost by inspiration, he says, the thing shaped itself into a complete whole, embodying in the complete device the use of a number of his previous discoveries and inventions and the accepted science of the world.

"I was prepared," said Mr. Tesla yesterday, "to go to Santiago then and make such a demonstration as would have astounded the world and have made it impossible for an intelligent man like Cervera to have stood out for a day after he saw what could be done. It was not my idea to kill any one, but to send word to Cervera that at a certain time, despite all he might do to prevent it, we should produce such a destructive effect right under the guns of the fleet and fortifications and within the harbor as would if otherwise directed have destroyed his entire fleet or the town. I proposed to send a submerged vessel into the harbor carrying perhaps 10,000 pounds of wet guncotton and explode it. No intelligent commander, knowing that his enemy had at command such forces, would be justified in holding out for a day afterward. I was delayed for a few days in getting ready to explain and demonstrate what I could do to President McKinley, and then Cervera's fleet made the attempt to escape and was destroyed by Admiral Sampson's fleet. With victory already on our side, I decided to do nothing more at that time, but I went on and completed my arrangements for the making of such a demonstration at Havana in case we had to take that city. Fortunately for the country we were saved from having to take Havana, and so the necessity for the demonstration ceased."

Mr. Tesla declares that almost every part of the working devices for putting afloat a fleet of automatic vessels of war can be bought in the markets, and that in the case of a war, for instance between France and England or any of the other great powers, it would take but a few days or weeks for any of these nations to have ready quantities of engines of war that would make the guns and armor of the war fleets useless for offence and defence. One fast, unarmored vessel, without a gun aboard her, but supplied with a fleet of little vessels whose movements could be controlled by an operator aboard of the big vessel, could destroy the fleet of any enemy without ever coming anywhere within the range of any of the destructive engines of present warfare, or could send vast quantities of explosives into a hostile harbor where their explosion would be almost as destructive as an earthquake. Such are the visions which Mr. Tesla sees of the possibilities of his invention, and these he believes would insure a universal peace.

If war came it would be a war with machines on none of which was there a man. His moving automatons could be made, if needed, to discharge at the will of the operator, bombs, cannon, torpedoes, or any other offensive weapons. With a fleet of such little vessels directed from one vessel, each would answer to the signals meant for it alone, and it would be impossible for the enemy to control any of them, because each would be attuned to answer only to certain definite electrical vibrations, which could be known only to the proper operator. An attempt to interfere with their operation by others would be like the attempt of a burglar to find the combination of a safe lock.

In his application for a patent Mr. Tesla describes the various ways which have been heretofore used to control such moving objects as automobile torpedoes, and says:

"In a broad sense, then, my invention differs from all of those systems which provide for the control of the mechanism carried by a moving object and governing its motion in that I require no intermediate wires, cables or other form of electrical or mechanical connection with the object save the natural media in space. I accomplish, nevertheless, similar results and in a much more practicable manner by producing waves, impulses or radiations which are received through the earth, water or atmosphere by suitable apparatus on the moving body and cause the desired actions, so long as the body remains within the active region or effective range of such currents, waves, impulses or radiations. These actions necessitated the designing of devices and apparatus of a novel kind, in order to utilize to the best advantage various facts or results which, either through my own investigations or those of others, have been rendered practically available."

He then describes a number of ways, well known to electricians, by which an electric effect could be transmitted to a distance without direct connection and says: "But by adopting such means as I have devised, that is, either by passing through the conducting path currents of a specially designed high frequency alternator, or, better still, those of a strongly charged condenser, a very high rate of change may be obtained, and the effective range of the influence thus extended over a vast area, and by carefully adjusting the circuit on the moving body so as to be in exact electro-magnetic synchronism with the primary disturbances, this influence may be utilized at vast distances."

The device which he has adopted for his model demonstration consists of currents of enormous voltage, which can be projected in waves at the will of the operator by the turning of a little crank. Two waves go forth at each half turn. The effect of these is like that of the vibrations produced by the voice in a telephone. On the little vessel to be controlled is a broken electrical circuit, loose particles of a metallic oxide being at the point of separation. A current is always endeavoring to pass through these, but fails. The magnetic waves produced by the operator bring together by magnetic action those particles, which thus have power to conduct an electric current. When the operator sends out his signal, this current is enabled to pass through the oxide, and does so, bringing down an armature upon a magnet. With the first move of the armature a clockwork starts and prepares to set the machinery of the vessel into action by closing other electric circuits as soon as it may be released. A second magnetic wave moves the armature again and the vessel's machinery begins to move. Then by special devices combinations of impulses coming from the operator are made to operate each and every part of the machinery in the vessel at the will of the operator.

Among the new things designed by Mr. Tesla in carrying out his purposes is an agitator for shaking up the metallic oxide at the end of each impulse, to break its conductivity, and a new way of making the powder to insure its uniformity of composition and size of its grains. A vessel built after the manner described could be made to dive or rise at will and could be directed by a chart and kept out of sight if desired. If it were desired to watch her progress, and still have her under water, her position could be determined by a slender rod poking up above water in the daytime or at night by flashes of light made up into the air at the will of the operator.

Electrical Review

[LARGEST ELECTRICAL WEEKLY IN THE UNITED STATES.]

TIMES BUILDING, 41 PARK ROW,

BOX 2339. NEW YORK.

NEW YORK, NOVEMBER 9, 1898.

A NEW MARVEL.

As we go to press an invention of Tesla's is announced which must produce a profound impression all over the world. Tesla has already identified himself with a number of most remarkable scientific advances, and great things may still be confidently expected as the fruit of his earnest and persistent labors, but it is difficult for us to see how he could ever produce a more beautiful result than he now makes known through a United States patent issued this week.

To direct and control to the minutest detail, by a subtle agent, the operations of a mechanism however complicated and ponderous, to change its speed and direction at will, to make it perform an unlimited number of movements, without any tangible connection and from a great distance, is indeed an achievement worthy of the closing days of this century of wonders.

When Bell transmitted the human voice over a wire so that the faintest of its modulations could be recognized, it was a marvelous triumph; when Edison showed his fascinating invention of the phonograph, this, too, was justly looked upon as a wonder; when Tesla first showed the phenomena of the rotating magnetic field, or when he presented the magical effect of a tube of glass brilliantly lighted in his hand, the world stood astonished; when Roentgen announced the epoch-making discovery of the rays bearing his name, the scientific world was thrilled as never before; but we believe that the beauty and importance of the invention Tesla has just announced, in its ultimate developments, will be such as to place it among the most potent factors in the advance and civilization of mankind. The fact that the invention has been thoroughly and practically developed makes its immediate application sure.

In this issue we begin the publication of the clear and exhaustive wording of Tesla's own description of this invention, which will be concluded next week.

TESLA'S LATEST INVENTION.

The following is the text of a patent issued this week to Nikola Tesla, which will undoubtedly prove of world wide interest. The language of the author is given in full:

The problem, for which the invention forming the subject of the present application affords a complete and practicable solution, is that of controlling from a given point the operation of the propelling engines, the steering apparatus and other mechanism carried by a moving object, such as a boat, or any floating vessel, whereby the movements and course of such body or vessel may be directed and controlled from a distance, and any device carried by the same, brought into action at any desired time.

So far as I am aware, the only attempts to solve this problem, which have heretofore met with any measure of success, have been made in connection with a certain class of vessels, the machinery of which was governed by electric currents conveyed to the controlling apparatus through a flexible conductor. But this system is subject to such obvious limitations as are imposed by the length, weight and strength of the conductor which can be practically used, by the difficulty of maintaining with safety a high speed of the vessel or changing the direction of movement of the same with the desired rapidity, by the necessity for effecting the control from a point which is practically fixed, and by many well understood drawbacks inseparably connected with such a system.

The plan which I have perfected involves none of these objections, for I am enabled by the use of my invention to employ any means of propulsion, to impart to the moving body or vessel the highest possible speed, to control the operation of its machinery and to direct its movements from either a fixed point or from a body moving and changing its direction, however rapidly, and to maintain this control over great distances, without any artificial connections between the vessel and the apparatus governing its movements, and without such restrictions as these must necessarily impose.

In a broad sense, then, my invention differs from all of those systems which provide for the control of the mechanism carried by a moving object and governing its motion, in that I require no intermediate wires, cables or other form of electrical or mechanical connection with the object, save the natural media in space. I accomplish, nevertheless, similar results, and in a much more practicable manner, by producing waves, impulses or radiations, which are received through the earth, water or atmosphere by suitable apparatus on the moving body and cause the desired actions, so long as the body remains within the active region or effective range of such currents, waves, impulses or radiations.

The many and difficult requirements of the object here contemplated, involving peculiar means for transmitting to a considerable distance an influence capable of causing, in a positive and reliable manner, these actions, necessitated the designing of devices and apparatus of a novel kind in order to utilize to the best advantage various facts or results which, either through my own investigations or those of others, have been rendered practically available.

As to the part of my invention which involves the production of suitable waves or radiations and the conveying of the same to a remote receiving apparatus capable of being operated or controlled by their influence, it may be carried out in various ways which are at the present time more or less understood. For example, I may pass through a conducting path, preferably enclosing a large area, a rapidly varying current and by electro-magnetic induction of the same, affect a circuit carried by the moving body. In this case the action at a given distance will be the stronger the larger the area enclosed by the conductor and the greater the rate of change of the current. If the latter were generated in the ordinary ways, the rate of change, and consequently the distance at which the action would be practically available for the present purpose, would be very small; but by adopting such means as I have devised, that is, either by passing through the conducting path currents of a specially designed high-frequency alternator, or better still, those of a strongly charged condenser, a very high rate of change may be obtained, and the effective range of the influence thus extended over a vast area, and by carefully adjusting the circuit on the moving body so as to be in exact electro magnetic synchronism with the primary disturbances, this influence may be utilized at great distances.

Another way to carry out my invention is to direct the currents or discharges of a high-frequency machine or condenser through a circuit, one terminal of which is connected directly or inductively with the ground and the other to a body, preferably of large surface and at an elevation. In this case if the circuit on the moving body be similarly arranged or connected, differences of potential on the terminals of the circuit, either by conduction or electrostatic induction, are produced, and the same object is attained. Again, to secure the best action, the receiving circuit should be adjusted so as to be in electro-magnetic synchronism with the primary source as before, but in this instance it will be understood by those skilled in the art that, if the number of vibrations per unit of time be the same, the circuit should now have a length of conductor only one half of that used in the former case.

[Concluded next week.]

DOUBTS VALUE OF TESLA DISCOVERY

Professor C. F. Brackett Says Electrical Scientist's Invention Would Not Work in Practice.

DENIES ITS ORIGINALITY.

Asserts That Naval Warfare Cannot Be Terminated in the Manner Suggested by the Inventor.

A. S. BROWN LESS DOUBTFUL.

Declares He Has Full Faith in the Inventor's Ability to Carry Out His Ideas.

Nikola Tesla's declaration, made in yesterday's HERALD, that he had discovered a system of applying an electrical current whereby such marvellous results might be obtained as the destruction of battle ships, balloons or land vehicles at a great distance, attracted deep interest not only on the part of the general public, but among electrical experts and scientists. In some quarters doubt was expressed as to the possibility of Tesla putting his invention to practical use. Others were confident that the inventor would in time be able to make good his declaration by practical demonstration.

One of those inclined to question the value of Tesla's discovery was Cyrus F. Brackett, professor of physics in Princeton University and head of the Henry electrical school of Princeton, N. J., who is author of a treatise on physics.

When seen yesterday he said he placed no confidence in Tesla's claims that by means of his appliance naval warfare would, of necessity, be abandoned. He believes that Tesla is a theorist, that his discoveries are useless and for the most part the reproduction under another form of the inventions of other scientists.

NOT A NEW DISCOVERY.

Professor Brackett said:—"The shortest, most correct and most complete criticism which I can make in reference to this bold boast is that what is new about it is useless, while that which is useful had all been discovered by other scientists long before Tesla made this startling announcement. You will find the whole theory which he has applied in any up to date text book. What Tesla has done is simply to make theoretical application, which would prove to be absolutely ridiculous in application, of inventions which had already been discovered.

"There is nothing new about this. The theory is perfect, but the application absurd. So throughout Tesla's whole elaborate scheme, the theory is not at fault, although there is nothing original about it, but the circumstances under which its application would be necessitated are such that the only result would be failure.

THE SCHEME NOT PRACTICABLE.

"Do you suppose that in the din of battle it would be possible to put into execution those minute and carefully adjusted mechanical experiments, all of which are presupposed by his theory, which require the quiet of an uninterrupted laboratory to work successfully?

"Or do you think that the enemy would co-operate with the attack and place their vessels in exactly the correct position to be hit or that they would remain stationary while the torpedo boat approached?

"His theory would have to assume an affirmative answer in order to be a success, and moreover the torpedo boat would have to be seen from the base of operations in order to direct it. It would be discovered by the doomed vessel long before it reached its destination, and would be exploded on the spot, so how great an advance is this on the present mode of warfare?

"I do not doubt the validity of the scientific truth of the principles which the theory involves, for the experiments have been made repeatedly in physical laboratories, and I believe that on a small model the desired effects could be made. In my classroom I perform experiments by which the actions of a body fitted with the proper electrical mechanism can be controlled without metallic communication through wave motion by means of a lever which Tesla has utilized in controlling the action of his model vessel.

"In application the whole phase of the matter is changed and the thing becomes an absolute impossibility, owing to the mechanical and natural impediments which would have to be overcome."

HAS FAITH IN TESLA.

A. S. Brown, chief electrical expert of the Western Union Telegraph Company, does not agree with Professor Brackett. He believes that Tesla's discovery may prove most important. When I saw him yesterday he said:— I have not had an opportunity to read closely the HERALD article which sets forth Tesla's discovery, but I may say that he is such a wonderfully inventive genius that we need not question the value and practicability of anything which he may discover. His is a wonderful mind, and his contributions to the cause of science have been most valuable and important.

"It has for some time been possible to produce a movement of a telegraphic sounder for a distance of some twenty miles without making use of a wire, but whether it is possible to extend this principle to a distance of three or four thousand miles, or say from New York to Paris, France, as Mr. Tesla says he will be able to do, remains to be seen. I do not question his ability to do so, for I know what a wonderfully inventive genius he is."

The New York Herald November 10, 1898

CHARY ABOUT TESLA'S PLANS.

Professor Dolbeer Says the Electrician Has Made Startling Announcements Before Without Result.

BOSTON, Mass., Wednesday.—Professor Dolbeer, of Tufts College, said to me to-day:—"This last so called invention of Nikola Tesla's is a very pretentious affair, and it is so incredible that the story is not to be believed until the work is actually done. If Tesla said all that the HERALD quotes him as saying, then his whole scheme and his manner of working is unintelligible to me. He even says that 'this power can be exerted at any distance by an agency of so delicate, so impalpable a quality, that I feel I am justified in predicting that the time will come when it can be called into action by the mere exercise of the human will.'

"That is getting a little outside of science, but you will notice that Tesla himself is only predicting that this will come true. There has been no accomplishment. He proposes to do great things, but he does not tell how he is going to do them, and he hasn't done them himself yet.

"The announcement is most amazing, and, coming as it does from Tesla, scientists are all the more chary about accepting it. During the last six years he has made so many startling announcements and has performed so few of his promises that he is getting to be like the man who called 'Wolf! wolf!' until no one listened to him. Mr. Tesla has failed so often before that there is no call to believe these things until he really does them. Meantime, we are all waiting with much patience and without solicitude. We will believe them when they are done."

TESLA'S SYSTEM OF ELECTRIC POWER TRANSMISSION THROUGH NATURAL MEDIA.

The *Electrical Review*, N.Y., of October 26th, gives a description of a new method of electric power transmission invented and patented by Tesla, the well-known electrician. The description appears to be taken from Tesla's patent specification, and is of a somewhat general nature; but is sufficient to enable us to understand the principle of the startling novelty which Tesla proposes to introduce into our methods of transmitting power by electricity. The following is a summary of our contemporary's article:—

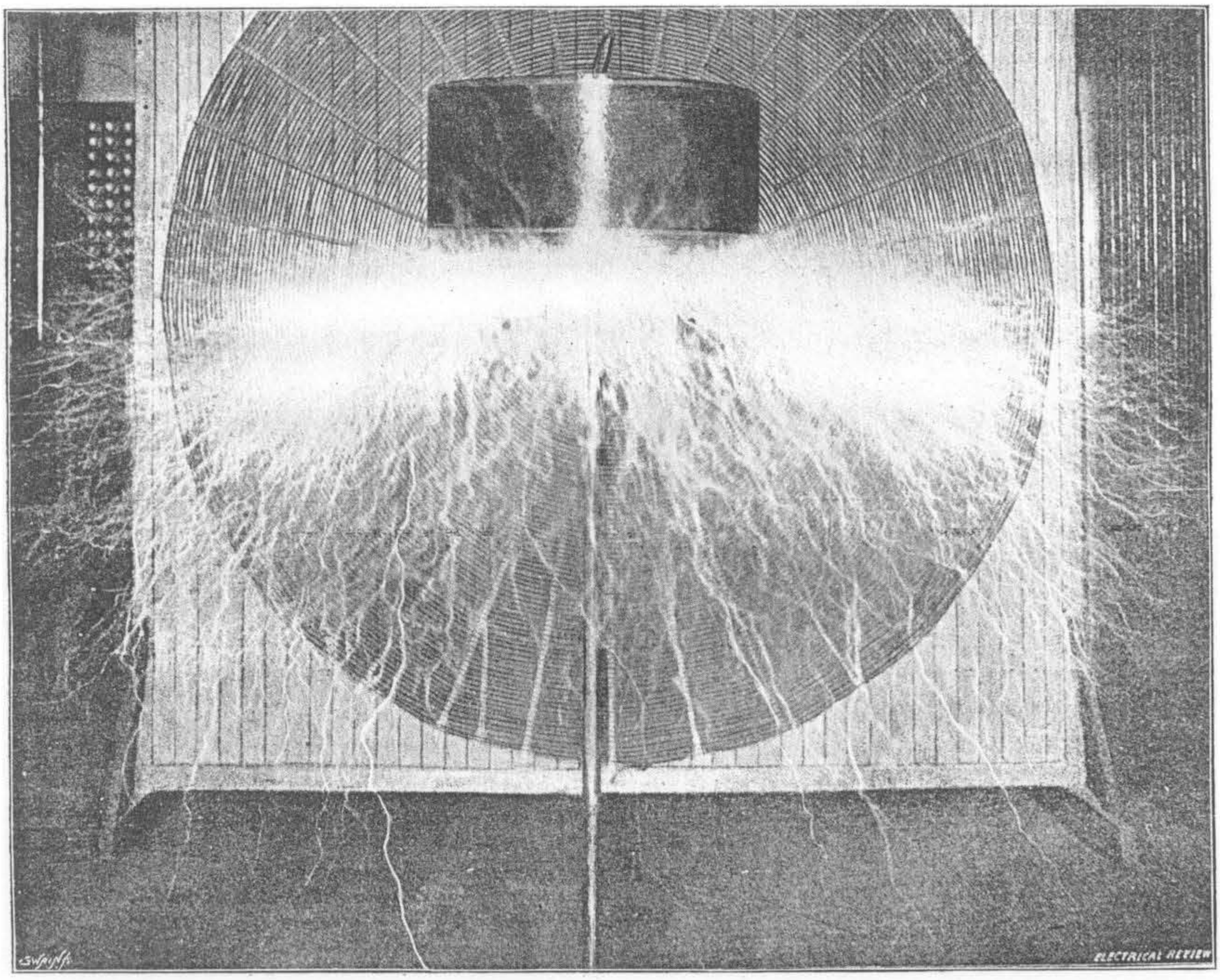
It has long been known, that if air enclosed in an insulating vessel is rarefied, its resistance is reduced to such an extent, that it may be considered a true conductor of electricity, though one of admittedly high resistance. The practical information on this subject, has, however, been derived from observations, manifestly subject to limitations imposed by the character of the apparatus or means heretofore known, and the kind of electrical effects which could be produced.

Tesla's invention consists in transmitting electrical power without the employment of metallic line conductors, by taking advantage of the conductivity of the layer of rarefied air which exists in the higher regions of the atmosphere. But in order to make this practicable, he has devised special apparatus for the production and conversion of excessively high electrical pressures.

Heretofore, it has been possible, by means of the apparatus at command, to produce only moderate electrical pressures, and even these, with considerable risks and difficulties. Tesla, however, claims that he has devised means, whereby he is enabled to generate with safety and ease, electrical pressures measured by hundreds of thousands, and even by millions of volts. He has also, during his investigations with such apparatus, discovered certain highly important and useful facts, which are said to render practicable his new system of transmitting electrical energy.

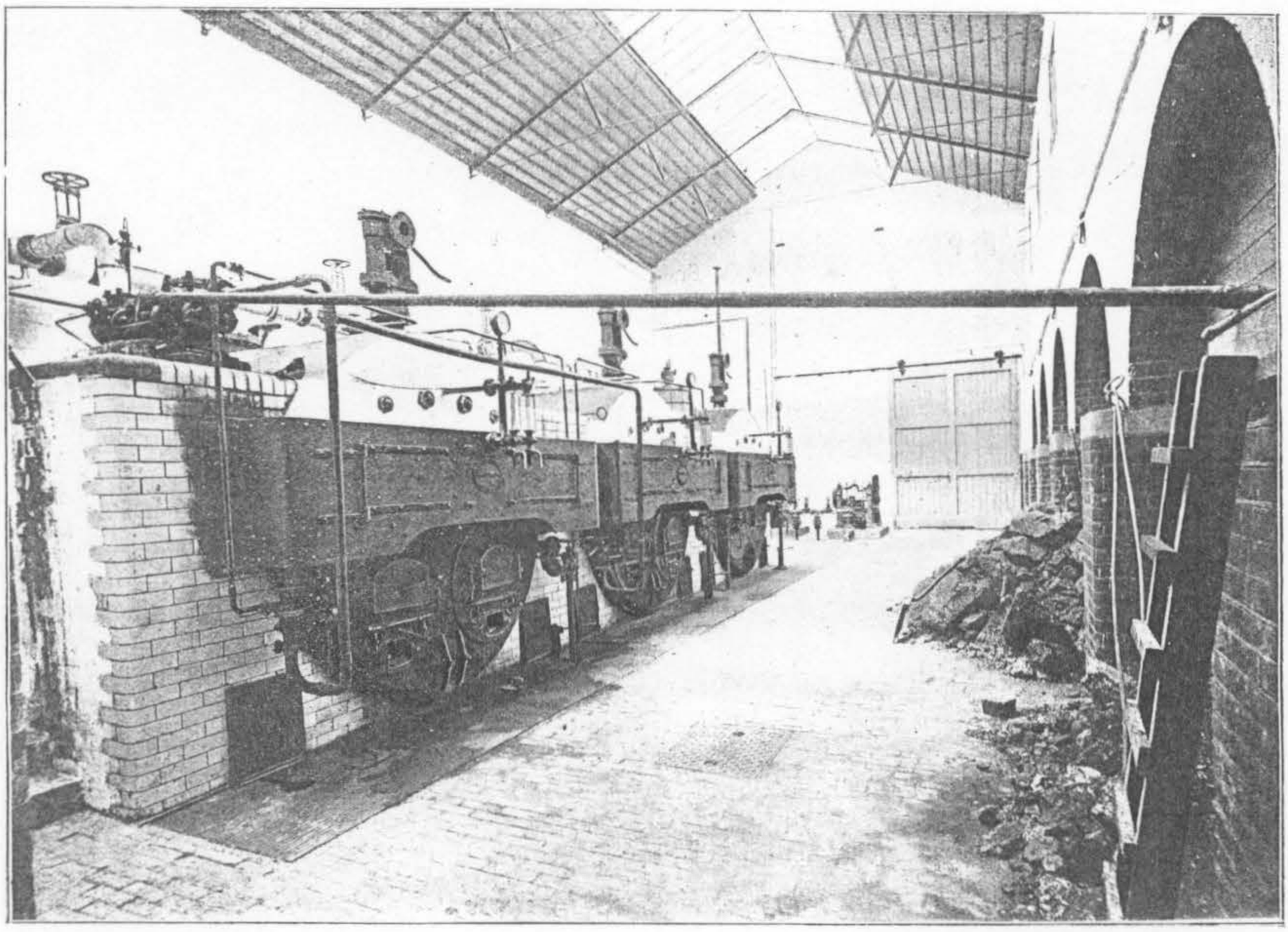
Among these are the following: first, that with electrical pressures of the magnitude and character which he has been able to produce, the ordinary atmosphere becomes, in a measure, capable of serving as a true conductor for the transmission of the current; second, that the conductivity of the air increases so materially with the increase of electrical pressure and the degree of exhaustion, that it becomes possible to transmit through even moderately rarefied strata of the atmosphere, electrical energy up to practically any amount and to any distance.

In order to carry out his system of power transmission, Tesla has designed special apparatus capable of generating electrical pressures vastly in excess of any hitherto made use of. One terminal of this generating apparatus is connected to earth, and the other terminal is maintained at an elevation, where the rarefied atmosphere is capable of conducting

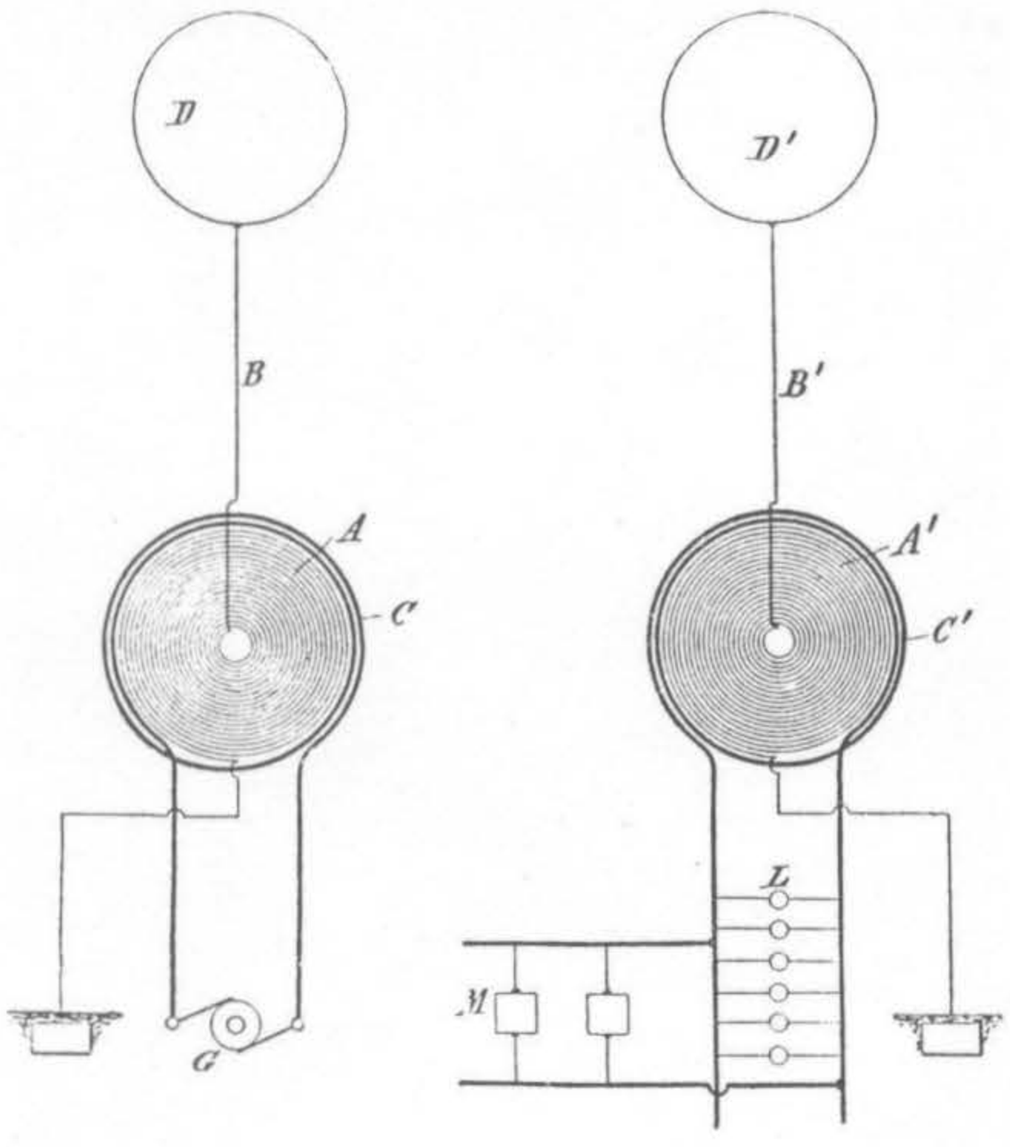


View of model transformer, or "oscillator," photographed in action.—Actual width of space traversed by the luminous streams issuing from a circular single terminal, over 16 feet.—Area covered by the streamers, approximately 200 square feet.—Estimated effective electrical pressure, 2½ million volts.

freely the particular kind of current produced. Then at the distant point where the energy is to be utilised, a terminal is maintained at an equally high elevation, to receive the current and to convey it to earth through suitable means for transforming and utilising it.



Folkestone.—View of Boilers.



The apparatus by means of which this method of transmission may be effected, is represented diagrammatically in the accompanying figure.

A is a coil, generally of many turns, and of very large diameter, wound in spiral form, either about a magnetic core or not, as desired. C is a second coil formed by a conductor of much larger size and smaller length, wound around in proximity to the coil A.

In the transmitting apparatus the coil A constitutes the high tension secondary, and the coil C the primary, of much lower tension, of a transformer. In the circuit of the primary, C, is included a suitable source of current G.

One terminal of the secondary, A, is at the centre of the spiral coil, and from this terminal the current is led by a conductor, B, to a terminal D, preferably of large surface, formed of, or maintained by such means as a balloon at an elevation suitable for the purposes of transmission as before described. The other terminal of the secondary, A, is connected to earth and, preferably, to the primary also, in order that the latter may be of approximately the same potential as the adjacent portions of the secondary, thus insuring safety.

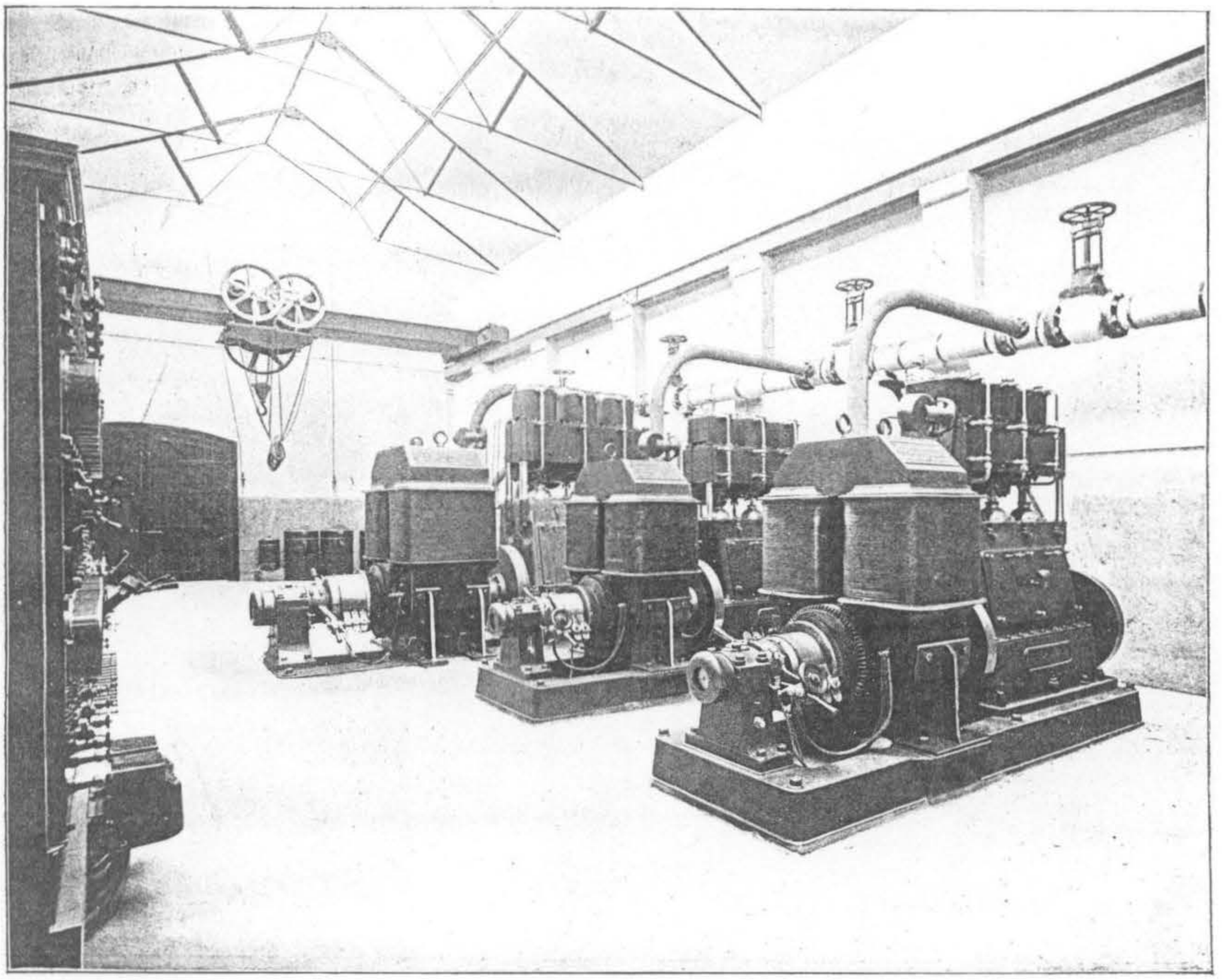
At the receiving station a transformer of similar construction is employed, but in this case the long coil, A', constitutes the primary, and the short coil, C', the secondary of the transformer. In the circuit of the latter are arranged lamps, L, motors, M, or other devices for utilising current. The elevated terminal, D', connects with the centre of the coil, A, and the other terminal of said coil is connected to earth, and preferably also to the coil C', for the reasons above stated.

The length of the high tension coil of each apparatus should be approximately one quarter of the wave length of the electrical disturbance in the circuit, this estimate being based on the velocity of propagation of the electrical disturbance through the coil itself, and the circuit with which it is designed to be used. To illustrate this in accordance with accepted views, if the rate at which the current traverses the circuit, including the two high tension coils, be 185,000 miles per second, then a frequency of 925 per second would maintain 925 stationary waves in a circuit 185,000

miles long, and each wave would be 200 miles in length. For such a frequency Tesla would use in each high tension coil a conductor 50 miles in length, or, in general, with due allowance for the capacity of the leading wires and terminals, such length of conductor as would secure the highest electrical pressures at the terminals under the working conditions.

It will be observed that in coils of the character described, the potential gradually increases with the number of turns, and the difference of potential between adjacent turns is comparatively small, and a very high potential, impracticable with ordinary coils, may be successfully maintained.

As the main object of the invention is to produce a current of extremely high potential, this object will be facilitated by using a primary current of very considerable frequency. But the frequency of the current is, in a large measure, arbitrary, for if the potential be sufficiently high and the terminals of the coils be maintained at a proper elevation



General View of Dynamo and Engine Room.

where the atmosphere is comparatively rarefied, the intermediate stratum will serve as a conductor for the current produced, and the latter will be transmitted through the air with, it may be, even less resistance than through an ordinary copper wire.

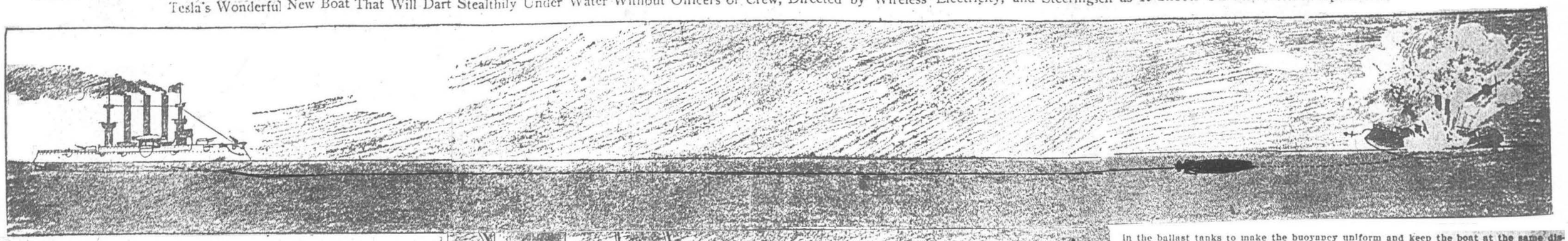
As to the elevation of the terminals D, D', it is obvious that this is a matter which will be determined not only by the condition of the atmosphere, but also by the character of the surrounding country. Thus if there be high mountains in the vicinity, the terminals should be at a great height, and generally, they should always be at an altitude much greater than that of the highest objects near them in order to reduce the loss by leakage. Since, by the means described, practically any potential that is desired may be produced, the currents through the air strata may be very small, thus reducing the loss in the air.

Tesla points out that the phenomenon involved in the transmission of electrical energy is one of true conduction, and is not to be confounded with the phenomena of induction or of electrical radiation which have heretofore been observed and experimented with, and which, from their very nature and mode of propagation, would render practically impossible the transmission of any considerable amount of energy to such distances as would be of practical importance.

Science

A SUBMARINE DESTROYER THAT REALLY DESTROYS—AND WITHOUT A SOUL ON BOARD TO GUIDE IT.

Tesla's Wonderful New Boat That Will Dart Stealthily Under Water Without Officers or Crew, Directed by Wireless Electricity, and Steeringself as It Shoots Off Its Terrific Explosives.



YESTERDAY Nikola Tesla gave to the Sunday Journal exclusively the news of his latest invention—a submarine torpedo boat. He has perfected his device after observing the defects of the torpedo boats in the recent war, and noting the fatalities of submarine boats invented up to date. His submarine boat will carry no lives to risk, but can be directed at a distance of miles from on shore or from the deck of a war ship. The power to do this will be the electric vibrations of the air used in wireless telegraphy. By this means a whole flotilla of submarine destroyers can be turned against a hostile fleet, and perhaps destroy it, without the enemy knowing how they were attacked. This seems almost incredible until the great magician of electricity explains his wonderful invention, point by point, in the following statement.

"My New Submarine Destroyer."

By Nikola Tesla.

I AM now prepared to announce through the Journal my invention of a submarine torpedo boat that I am confident will be the greatest weapon of the navy from this time on.

The almost utter uselessness of the present kind of torpedo boat has been conclusively demonstrated in the recent war. Neither the courage and skill of the Americans nor the desperate extremities of the Spaniards were able to bring the torpedo boats into successful action. These frail craft, of which so much was expected, simply made an easy target for land batteries and rapid-fire guns of opposing war ships.

The submarine boats, on the other hand, which have up to this time been built to carry torpedoes have proved death traps for men and were consequently ineffective. The submarine boat, or, more properly speaking, the submarine destroyer, which I have invented is as compact as a torpedo itself. In fact, it is simply an enlarged torpedo shell, thirty-six and a half feet long, loaded with other torpedoes to discharge. Like a torpedo, also, it has its own propelling device. But here the likeness stops. The ordinary torpedo, once launched, plunges head on blindly and no known power can turn it one way or another. It hits or misses, according to the trueness with which it is aimed at its launching.

But my submarine boat, loaded with its torpedoes, can start out from a protected bay or be dropped over a ship's side, make its devious way below the surface, through dangerous channels of mine beds, into protected harbors and attack a fleet at anchor, or go out to sea and circle about, watching for its prey, then dart upon it at a favorable moment, rush up to within a hundred feet if need be, discharge its deadly weapon and return to the hand that sent it. Yet all through these wonderful evolutions it will be under the absolute and instant control of a distant human hand on a far-off headland, or on a war ship whose hull is below the horizon and invisible to the enemy.

I am aware that this sounds almost incredible and I have refrained from making this invention public till I had worked out every practical detail of it. In my laboratory I now have such a model, and my plans and description at the Patent Office at Washington show the full specifications of it.

As to the mechanism which is to be stored in this submarine shell: The first and most essential thing is a motor, with storage battery to drive the propeller. Then there are smaller motors and batteries to operate the steering gear, on the same principle that an ordinary vessel is now steered by steam or electricity. Besides these there are still other storage batteries and motors to feed electric signal lights. But in order that the weight of machinery shall not be too great to destroy the buoyancy or make the boat go too deep in the water compressed air motors will also be used to perform certain functions, such as to fill and empty the water tanks which raise the boat to the surface or sink it to any required depth. Pneumatic air or motors will also fire the torpedoes and pump out the water that may leak in at any time.

This submarine destroyer will be equipped with six 14-foot Whitehead torpedoes. These will be arranged vertically in two rows in the bow. As one torpedo falls into position and is discharged by pneumatic force, another torpedo, by the force of gravity, falls into the position of the first one, the others above being held up by automatic arms. They can be fired as rapidly as a self-cocking revolver is emptied or at intervals of minutes or hours. The discharge takes place through a single tube, projecting straight ahead in the bow. The small amount of water which leaks through each time is caught by drain pipes and a compressed air pump instantly expels it. As each torpedo is expelled a buoyancy regulator will open the sea cocks and let enough water in the ballast tanks to make the buoyancy uniform and keep the boat at the same distance beneath the surface.

This submarine destroyer will carry a charge of torpedoes greater than that of the largest destroyers now in use. Those vessels of five hundred tons each which cost the Government $500,000, carry but three or four torpedoes, while this simple submarine destroyer, which can be built for $48,000 to $50,000 or less, will carry six torpedoes. It will have, also, the incalculable advantage of being absolutely invisible to an enemy, and have no human lives to risk or steam boilers to blow up and destroy itself.

All that is necessary to make this submarine boat subject to perfect control at any distance is to properly wire it, just like a modern house is wired so that a button here rings a bell, a lever there turns on the lights, a hidden wire somewhere else sets off a burglar alarm and a thermal device gives a fire alarm.

The only difference in the case of the submarine boat is in the delicacy of the instruments employed. To the propelling device, the steering gear, the signal apparatus and the mechanism for firing the torpedoes are attached little instruments which are attuned each to a certain electro-magnetic synchronism.

Then there is a similar set of synchronistic instruments all connected to one little switchboard, and placed either on shore or on an ordinary war ship. By moving the lever on the switchboard I can give the proper impulse to the submarine boat to go ahead, to reverse, throw the helm to port or starboard, rise, sink, discharge her torpedoes or return

It might be thought that some great power would be necessary to be projected across miles of distance and operate on the far-off boat. But no. The power is all stored in the submarine boat itself—in its storage batteries and compressed air. All that is needed to affect the synchronistic instruments is a set of high alternating currents, which can be produced by my oscillator attached to any ordinary dynamo situated on shore or on a war ship.

How such an apparently complicated mechanism can be operated and controlled at a distance of miles is no mystery. It is as simple as the messenger call to be found in almost any office. This is a little metal box with a lever on the outside. By moving the crank to a certain point it gives vibrating sounds and springs back into position, and its momentary buzzing calls a messenger. But move this same crank a third further round the dial and it buzzes still longer, and pretty soon a policeman appears, summoned by its mysterious call. Again, move the crank this time to the farthest limit of the circle and scarcely has its more prolonged hum of recoil sounded when the city fire apparatus dashes up to your place at its call.

Now, my device for controlling the motion of a distant submarine boat is exactly similar. Only I need no connecting wires between my switchboard and the distant submarine boat, for I make use of the now well-known principle of wireless telegraphy. As I move this little lever to points which I have marked on a circular dial I cause a different number of vibrations each time. In this case two waves go forth at each half turn of the lever and affect different parts of the distant destroyer's machinery.

How such submarine destroyers should actually be used in war I leave for naval tacticians to determine. But it seems to me that they could best be operated by taking a number on board a large fast auxiliary cruiser like the St. Louis or St. Paul, launch them, several at a time, like life boats, and direct their movements from a switch board placed in the forward fighting top.

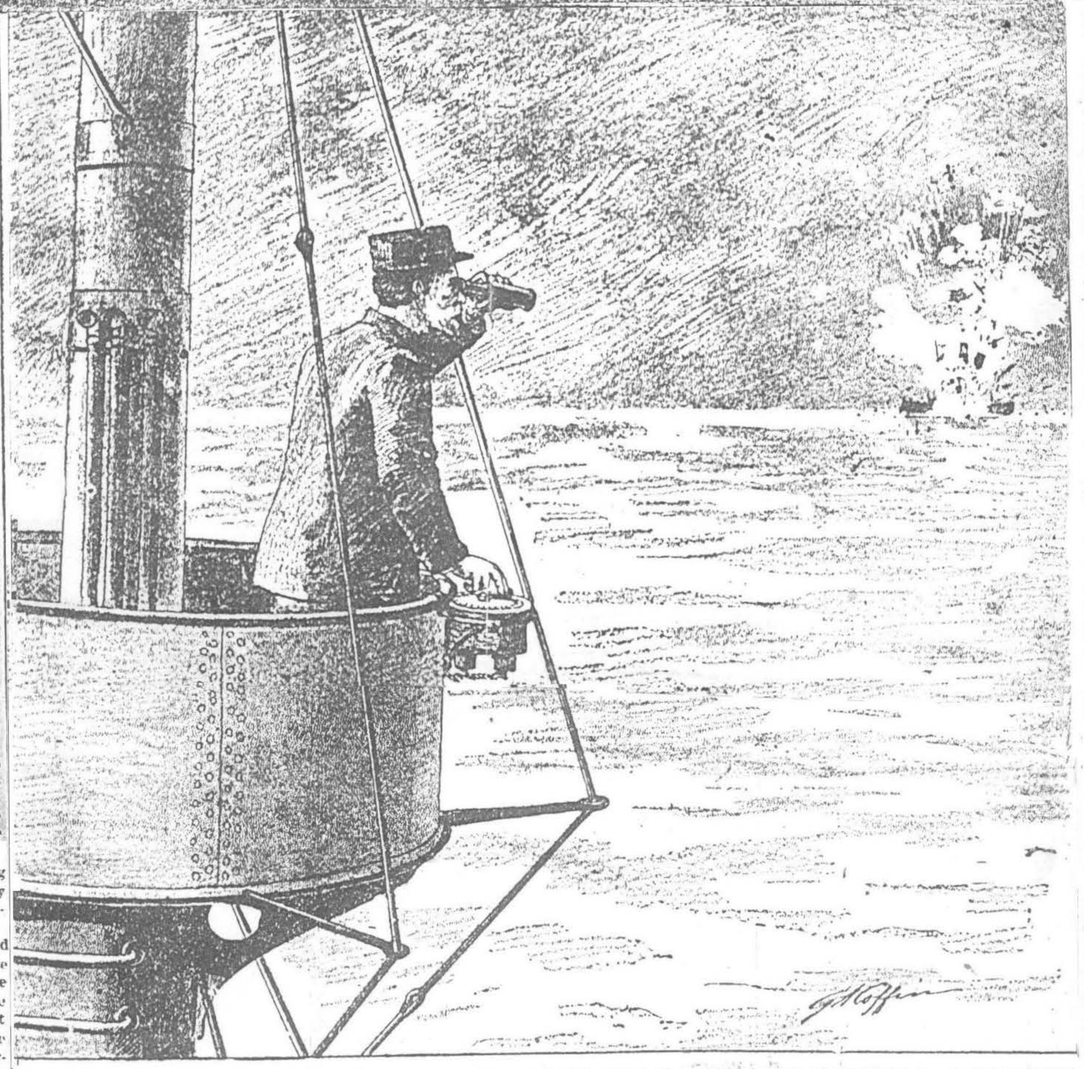
In order that the director of the submarine destroyer may know its exact position at every moment, two masts, at bow and stern, will project up just above the water, too minute to be seen or hit by an enemy's guns by day, and by night they will carry hooded lights.

The lookout placed in the fighting top could detect a hostile ship off on the horizon while the auxiliary cruiser's big hull is still invisible to the enemy. Starting these little destroyers out under direction of a man with a telescope, they could attack and destroy a whole armada—destroy it utterly—in an hour, and the enemy never have a sight of their antagonists or know what power destroyed them. A big auxiliary cruiser, used to carry these submarine destroyers, could also carry a cargo of torpedoes sufficient to conduct a long campaign and go half way around the world.

She could carry the gun cotton and other explosives needed to load the torpedoes in safe magazines below the water line, and do away with much of the danger of transporting loaded torpedoes. When necessary for use the war heads could be loaded, fitted to the torpedoes, and the submarine destroyers fully equipped.

A high, projecting headland overlooking a harbor and the sea would also be a good point on which to establish a station and have the destroyers laid up at docks below and ready to start.

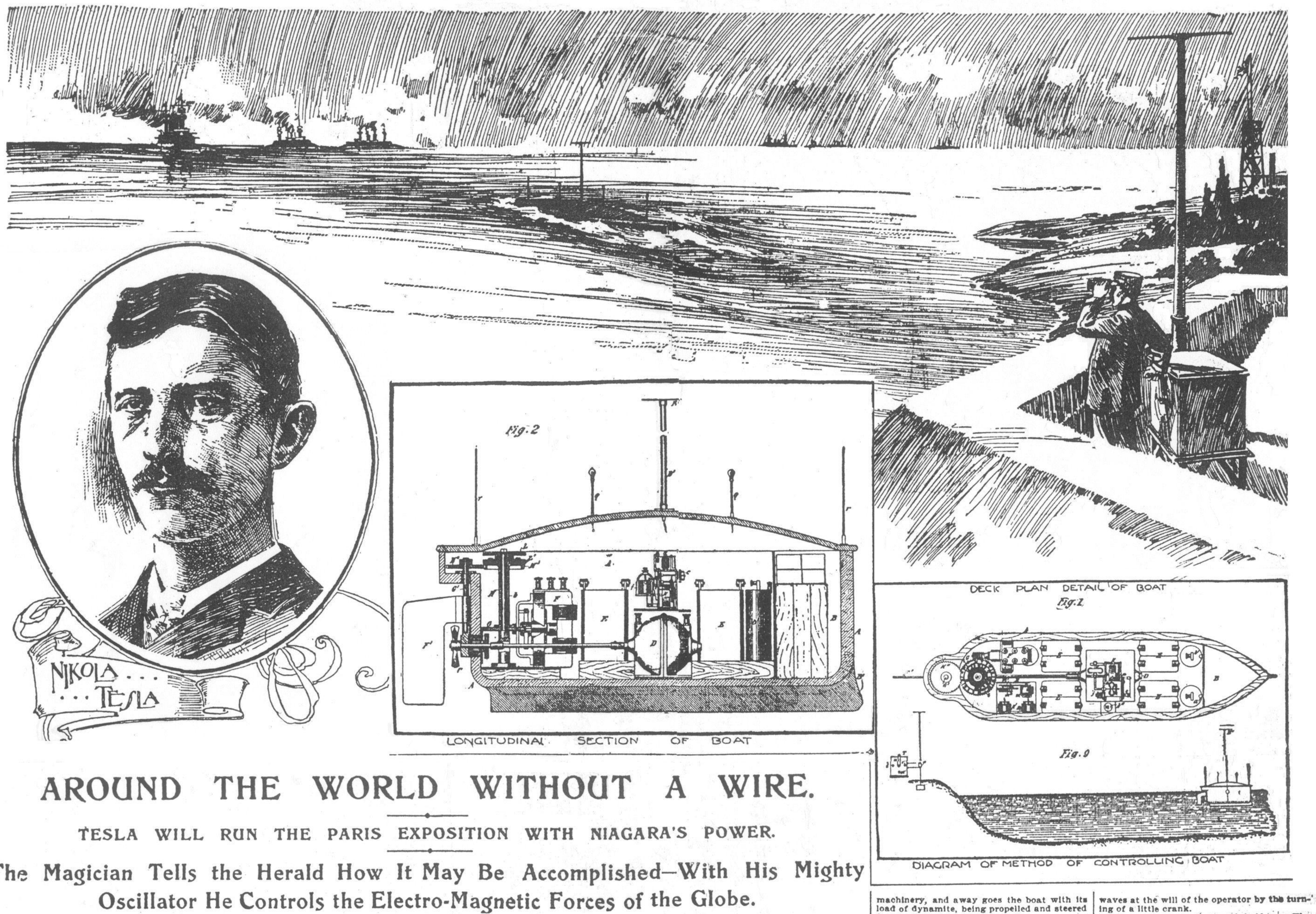
That is the whole story of my latest invention. It is simple enough, you say. Of course it is, because I have worked all my life to make each one of the details so simple that it will work as easily as the electric ticket in a stock broker's office.



STATION IN A FIGHTING TOP FROM WHICH THE SUBMARINE DESTROYER IS DIRECTED

TESLA TO DESTROY NAVIES AND SHOOT MOTIVE POWER FROM NIAGARA TO EUROPE.

All this is done without metallic conductors. A wonderful feature is that with a little pocket oscillator distant war ships, forts and cities may be annihilated.



AROUND THE WORLD WITHOUT A WIRE.

TESLA WILL RUN THE PARIS EXPOSITION WITH NIAGARA'S POWER.

The Magician Tells the Herald How It May Be Accomplished—With His Mighty Oscillator He Controls the Electro-Magnetic Forces of the Globe.

TESLA proposes to run the machinery of the Paris Exhibition with electric power sent instantly across the world from Niagara Falls.

It is an astounding statement.

He has just patented his machine for transmitting electricity without wires. He says he can shoot thousands of millions of volts around and through the globe without metallic conductors.

The Electrical Review says "It is like a tale from the 'Arabian Nights,' and, if successful, it will open up unlimited resources of practically costless power."

If successful, it means that from the great falls of Niagara, of the Yellowstone, of Alaska and of the canyons of Colorado unlimited power of millions of volts can be delivered in New York, London, Paris, St. Petersburg and Pekin in a second of time. Mountains, rivers and oceans would thus be annihilated.

Tesla says his machinery works perfectly; that he has demonstrated the seeming miracle beyond all possibility of failure.

He said to me yesterday:—"I will supply the Paris Exhibition with Niagara's power. I will send it across the ocean without a wire. My invention is the crowning success of long years of thought and labor.

Tesla went on to explain how he invents. He first discovers the natural laws governing the secret he is after. Then he can predict just what his mechanism, when constructed in a certain way, will accomplish.

When the laws controlling their appointed work in the universe have been once mastered the making of the proper machine to act in harmony with the laws is comparatively an easy task.

When Tesla discovered the laws leading up to the invention of his famous oscillator he was convinced that if he made certain wires in the machine exactly of the required length the electricity of the globe would stream forth in flame.

A New Marvel.

He worked long and persistently, with no satisfactory result. Still, he said, he knew to a mathematical certainty—a certainty on which he would stake his life—that the flames must appear when once he found the right measurements.

At last he hit it, and the world now marvels at the results announced. When Lord Kelvin, the Shakespeare of European science, saw this machine in action, its awful flames shooting and exploding in veritable thunderbolts, it is said that his emotion was profound, for above and beyond its spectacular features he realized that it sent its currents around and through our universe of matter. Between each terrifying lightning stroke the globe is penetrated and encircled by the million volted force. With this seemingly divinely endowed oscillator Tesla, it is declared, instantly brings Paris and Hong Kong within the reach of his hand.

I saw the machine yesterday. At the touch of Tesla's finger it blossomed into lightning flame. In color and shape it was like a celestial morning glory flower, twenty feet in diameter, fringed with ten thousand purple thunderbolts—shooting into daggers and tongues of fire, continuously exploding with the roar of a cyclone.

It was like the spectacle on Sinai.

And what is this electric force that moves cars and machinery?

"Invisible light," says Tesla.

To Abolish War.

A still greater marvel is claimed. Tesla will destroy navies and abolish war. His invention to accomplish this sublime end is the subject of wide discussion. General Grant said:—"Make war terrible enough and you will have peace." This Tesla claims to have accomplished with his astonishing machinery.

But it is not by raining artificial thunderbolts on the enemy nor throwing shells by electricity. Tesla's plan is to steer swift dynamite boats at express train speed along the surface or under water against a ship or a fleet, against a fort or a city, and blow them up—annihilate them.

Tesla will handle his destroyers from shore or a distant ship as skilfully as would a captain with a picked crew of experts. By electric devices alone the engines will be controlled and the boat steered and run at any speed, its guns fired or the boat exploded. If a submarine boat it will be made to dive and move below the surface at any depth, coming up at the desired point to blow the enemy out of the water. All this and a hundred other things will be done, he claims, by electricity, without wires or any artificial means of communication.

More Wonderful Than Fiction.

It is a staggering statement to make. But the electrical machinery for doing it is fully described in the twenty-four typewritten pages of specifications covering the patent. There are eight thousand words in the document, showing the invention as a veritable engine of power for peace or war. Its action is largely automatic, and under the manipulation of the operator, stationed a mile or fifty miles away, it would seem almost instinct with human intelligence.

Tesla shows that his machine not only has the capacity for executing any number of orders, but it exhibits what practically amounts to intelligence.

It distinguishes from any number of signals that particular vital one which it has been previously "instructed" to select and obey.

Herein lies the proof of its almost omnipotent power for civilization, for peace or war. By its use war becomes annihilation and peace is the inevitable consequence.

Already rivals in electricity are criticising the claims of the patent, calling Tesla a laboratory dreamer. As usual, they say that sending electrical currents without a wire is nothing new in theory; that it will be impossible to achieve anything of a practical character on sea or land with the enemy vigilant, the weather stormy, the sea boisterous and battles raging. They claim that dynamite boats can never be steered and fleets blown up by an operator stationed miles away with no metallic means of communication.

But Tesla is no ordinary inventor. According to the records he stands in the front rank of geniuses. He was associated with Edison and his achievements are a part of the marvellous history of electrical discov- the marvellous history of electrical discovery.

Tesla Too Busy to Bother with Critics.

When I showed Tesla some of the things the critics had written about this last invention he smiled and said life was too short to enter into a defence of his work. He preferred to devote every hour to perfecting his inventions, leaving the results to vindicate his skill and judgment.

"I was many years in perfecting my electrical apparatus for transmitting power," he said. "Many were at work in that direction, but I invented the machine now used in this country, in Europe, Asia, and even in Zululand. It has revolutionized the whole system of transmitting power. It was not difficult to transmit power a short distance. To transmit power successfully and cheaply long distances required years of study and demonstration.

"But in regard to my invention for destroying cities, forts and fleets, which I have just patented, that is altogether beyond any question of doubt. I know just what I can do.

"It is a mistake to imagine that fleets can be destroyed without the operator knowing where they are. That is absurd. I never made such a claim. He must see the war ships with his unaided eye or through a telescope, or they must be otherwise located that he may know exactly where they are, and then direct his attacking boat, filled with dynamite or gunpowder, against the enemy to accomplish their destruction."

How the Miracle Is Accomplished.

And how does Tesla propose to do this without wire or any artificial means of communication?

He uses the earth and the atmosphere as his double wire and thus secures a complete electrical circuit. He has a thunderbolt producing machine, his famous "Oscillator." Instead of producing the few thousand volts used for electric lighting, propelling trolley cars or killing murderers at Sing Sing, it manufactures millions of volts. But the electricity is of such a character that when the machine fills a room with jagged lightning, flashing and thundering in a tornado of fiery storm, it does not kill anybody, yet it develops a force thousands of times greater than the biggest ordinary dynamo can produce.

With this machine creating a pressure of millions of volts, Tesla lashes the vast ocean of electricity of the earth into a cyclonic storm. Instantly the waves spread in all directions through the universe of matter.

And this electricity is as rigid as steel. It cannot be compressed nor condensed. Yet it is thousands of millions times lighter than the lightest air of the highest mountain tops. It is everywhere in the universe, in the earth, in the sea, in the air and in the vast abyss above the air. With it your eye penetrates material substance, as in using the X ray. In the presence of this divine fluid, electricity, the earth and the universe of matter in a sense no longer exist, yet on a spider web wire, on a sunbeam, on a cloud you can send a thunderbolt or a human whisper hurling through space.

Like Aladdin's Famous Lamp.

All science stands aghast before the secret of this inexplicable power, yet it is obedient to the red freckled telephone girl who works in accordance with its laws. And yet old Archimedes' lever which moves the world cannot condense a volume of electricity to the extent of a hair's width. If you had a bag reaching from Tammany Hall to Chicago filled with electricity, and you dimpled the bag in New York with your fist, it would instantly be dimpled in Chicago, eight hundred miles away. It can encircle the globe sixteen times in a second.

All the universe is a big bag of electricity. When Tesla's thunderbolt machine bombards it in New York, rippling waves break on the most distant electric shores of the world—in Chicago, San Francisco, Siberia, New Zealand, in our Philippines, at the poles north and south. This is Tesla's claim, that the electro-magnetic waves thus made sweep around and through the world in an instant.

How the Machines Work.

Now how can he send his message aboard ship from distant lands—reaching one particular vessel?

By having two electric circuits, one on shore and one on the vessel, both adjusted to be in exact unison. They may be likened to a pair of violins in perfect accord and tune. You play one and the other takes up the strain of music.

One of the most wonderful features of this invention is that the oscillator for producing these tremendous, far reaching electric waves can be almost tucked away in one's pocket, like a cigarette case.

When Tesla on shore wants the ship's engines to start he touches the code signal, which goes flying on the billows of electric ether through all space. If these duplicate machines were in every city every city would receive the message to start the engine, fire the guns, steer "port" or "starboard," go ahead or back, or whatsoever the message sent might be.

But the machine is deaf and blind to all other messages. Hence the enemy is powerless to thwart any attack.

So one ship alone of a fleet receives the electric message, the current "impulse," or whatever it may be termed.

A little armature or lever is released, the electric circuit is complete, the clock starts a more powerful electric machine connecting with the engines, as it does with the steering machinery, and away goes the boat with its load of dynamite, being propelled and steered for the fleet at terrifying speed.

McKinley's Great Feat.

Didn't McKinley press a button and start the great machinery of the big fair?

Tesla touches his code signal and the distant boat starts for the enemy's fleet.

Every day a similar feat is performed in the big hotels of the country. The visitor on the fifteenth floor of the Imperial wants writing material and a steak. He sets the electric machine to the proper index in his room.

Down in the hotel office it rings and points to the same articles on the same kind of a dial—bearing all the "calls" and dishes, lettered exactly the same as the twin machine in his room in the fifteenth floor.

In the big hotel the electricity travels over a double wire. Tesla's electricity travels through air and earth. They are his double wires.

In your house you pull your district messenger call for boy, fire engine or policeman. It is because of the peculiarity of the machine that the electricity obeys you—calling for boy or policeman as you wish.

So again with Tesla. The secret is in the peculiarity of the machines. His machines not only enable him to control the distant ship, on which there is no human being, but they pick out only the vibratory current originally sent flying by the machine creating it.

With a glass Tesla sees the enemy's fleet fifteen miles away. He adjusts the two machines—one on shore, one on the boat. He starts it, steers it, increases speed, rushes it against the fleet with its cargo of dynamite blowing the war ships to destruction.

If it is a diving submarine boat, he knows its course by bars of colored electric light which shoot from the depths to the sky from the speeding boat. If, on the surface, he uses colored lamps.

Besides ships, Tesla says he can direct balloons, or wagons—steering them in the same way.

Atlantic travellers know how easily the pilot steers the big steamship by merely pressing a button, operating the machinery connected with the ponderous steering mechanism. In a similar way Tesla would set his dynamite boat's machinery in motion. What matters it whether he is one or twenty miles away. Electricity laughs at distance.

How Tesla Describes It.

Here is a section of his own technical description of how he does it:—

"In a broad sense, my invention differs from all of those systems which provide for the control of the mechanism carried by a moving object and governing its motion in that I require no intermediate wires, cables or other form of electrical or mechanical connection with the object, save the natural media in space.

"I accomplish, nevertheless, similar results and in a much more practicable manner by producing waves, impulses or radiations which are received through the earth, water or atmosphere by suitable apparatus on the moving body and cause the desired actions, so long as the body remains within the active region or effective range of such currents, waves, impulses or radiations.

"These actions necessitated the designing of devices and apparatus of a novel kind, in order to utilize to the best advantage various facts or results which, either through my own investigations or those of others, have been rendered practically available."

About the Electric Waves.

Tesla describes a number of ways, well known to electricians, by which an electric effect could be transmitted to a distance without direct connection, and says:—

"But by adopting such means as I have devised, that is, either by passing through the conducting path currents of a specially designed high frequency alternator, or, better still, those of a strongly charged condenser, a very high rate of change may be obtained, and the effective range of the influence thus extended over a vast area, and by carefully adjusting the circuit on the moving body so as to be in exact electro-magnetic synchronism with the primary disturbances, this influence may be utilized at vast distances."

An expert thus describes the working of the electrical machine:—

"The device which he has adopted for his model demonstration consists of currents of enormous voltage, which can be projected in waves at the will of the operator by the turning of a little crank.

"Two waves go forth at each half turn. The effect of these is like that of the vibrations produced by the voice in a telephone. On the vessel to be controlled is a broken electrical circuit, loose particles of a metallic oxide being at the point of separation. A current is always endeavoring to pass through these, but fails. The magnetic waves produced by the operator bring together by magnetic action these particles, which thus have power to conduct an electric current.

Working the Signals.

"When the operator sends out his signal current it is enabled to pass through the oxide, a magnet. With the first move of the armature a clockwork starts and prepares to set closing other electric circuits as soon as it may be released.

"A second magnetic wave moves the armature again, and the vessel's machinery begins to move. Then by special devices combinations of impulses coming from the operator are made to operate each and every part of the machinery in the vessel at the will of the operator."

Many astounding facts in electricity have been discovered. It originally cost thousands of dollars for copper wire alone to carry comparatively weak currents a few miles to move machinery. It was finally discovered that a tremendous voltage could be sent on a mere thread of wire, thus reducing the cost to a trifling expense. Tesla first succeeded in transmitting power over one wire, now he abolishes all wires.

Regarding the Diagrams.

The accompanying illustrations, taken from Tesla's patent specification, show a top and side of his boat, Nos. 1 and 2 respectively. Also a view showing the operating boat out at sea and the electrical wave generator and controller on shore, where the operator stands directing the course of the vessel. This latter operation Tesla thus describes:—

"In this figure S designates any source of electrical disturbance or oscillations, the generation of which is controlled by a suitable switch contained in box T. The handle of the switch is movable in one direction only, and stops on four points—t t^1 u u^1—so that as the handle passes from stop to stop oscillations are produced by the source during a very short time interval. There are thus produced four disturbances during one revolution, and the receiving circuit is affected four times, but the rudder is moved only twice—once to right and once to left. Now I preferably place the handle of the switch so that when it is arrested on points t t^1—that is, to the right or left of the operator—he is reminded that the vessel is being deflected to the right or left from its course, by which means the control is facilitated. The normal positions of the handle are therefore at u u^1 when the rudder is not acted upon, and it remains on the points t t^1 only so long as necessary. Since the working of the apparatus is very sure, the operator is enabled to perform any such operations as provision is made for without even seeing the vessel.

"To blow up the boat or ram it into the enemy's fleet, the switch handle of the entire wave controlling machine is simply turned by the operator continually round and round for, say, ten or twenty seconds, sufficiently to accomplish the work designed."

In summing up the various uses of this invention Tesla says it will be invaluable in saving life at sea and in shipwrecks along shore. The operator can send out a lifeboat, scoop in the struggling swimmers from the water, turn the boat about and bring them safely to shore.

In his own words Tesla says of its merits:—

"The invention which I have described will prove useful in many ways. Vessels or vehicles of any suitable kind may be used, as life, despatch or pilot boats or the like, or for carrying letters, packages, provisions, instruments, objects or materials of any description, for establishing communication with inaccessible regions and exploring the conditions existing in the same, for killing or capturing whales or other animals of the sea, and for many other scientific, engineering or commercial purposes."

And he adds the following significant and prophetic remarks:—"But the greatest value of my invention will result from its effect upon warfare and armaments, for, by reason of its certain and unlimited destructiveness it will tend to bring about and maintain permanent peace among nations."

The New York Sun November 13, 1898

Nikola Tesla and His Quest.

NIKOLA TESLA has just made public some facts about an invention intended to make war too terrible to be prosecuted, and thus to insure peace between nations. The war with Spain drew Mr. TESLA'S mind aside for the time from the line of studies which has engaged him for years. Inspired and fired by patriotism he has applied to a war engine some of the principles which he discovered in following his inquiries into new methods of applying energy to the purposes of peace.

The success or failure of Mr. TESLA'S latest invention will not turn him away from the great project which has possessed his mind for years. This, as he puts it, is to harness the sun's power to do the work of mankind. He does not mean to catch the power of the sun's rays directly, but to utilize that enormous portion of their power which is expended upon the earth's surface in sucking from sea and lake waters which are afterward precipitated upon the higher parts of the land.

That there are waterfalls upon the earth which are capable of producing all the energy which mankind uses for power, heat and light is well known. The use of water powers, however, is limited within narrow margins, partly because of the investment cost of installment, but chiefly because the great waterfalls are remote from the seats of population and trade. Before Mr. TESLA began his researches there was no method known by which the power generated at a remote place could be transmitted to where it was wanted except at a loss of efficiency which was prohibitory. Since that time, by the use of currents of from 10,000 to 20,000 volts, it has become possible to send electric power successfully over wires for thirty-five miles or more, and one plant is now building to transmit power eighty-five miles.

But to utilize the great water powers of the world, the transmittal of energy for a distance of from fifty to one hundred miles is hardly more useful than a reach of eight or ten miles. Mr. TESLA designs to annihilate space. He would take the power of a Niagara, transform it into an electric current, and send this without appreciable loss to any place on earth where it was needed for use. Mr. TESLA has, accordingly, devised an electric oscillator which will receive the electric current from its source and give it an intensity which, as the inventor calculates, would enable a copper thread to carry 50,000-horse power across the ocean. Mr. TESLA claims to have discovered, furthermore, that at an altitude easily reached by balloons the rarefied air has a conductivity equal to copper, while the denser layer of air below is a non-conductor. He proposes to suspend one pole of his electric circuit in the air at Niagara Falls and the other at Paris, and to forward his current through the upper air to France, whence it shall return through the earth when its active energy has been expended in work. He believes that he will be able to make this demonstration in 1900 as an exhibit at the coming world's fair at Paris, and to drive all the machinery at that exposition with the power from our great waterfall. The significance of his success would be that coal would become a convenience instead of a necessity, and water power and electricity would replace coal and steam for the work of the world.

Another great quest which Mr. TESLA has been conducting side by side with this, and in fact leading along the same lines, is for the means of producing light from electricity without heat. It was well known when TESLA began his studies that a Crookes vacuum tube could be made to glow by passing through it currents of electricity at a high tension, but no electrician could evolve from these tubes more than a phosphorescent glow. To turn this into a white light which should shine like the face of the sun itself was the problem to be solved. All his investigations led Mr. TESLA to conclude that the thing which was needed was to be able to give to electrical currents voltages enormously beyond any which had ever been produced, and then to be able to handle and control the currents thus transformed. From this need grew his electrical oscillator, with which Mr. TESLA proposes to produce a current with an intensity of 800,000 volts, capable of transmission across the Atlantic. In Mr. TESLA'S laboratory the vacuum tubes glow like sunshine, and their introduction for use is waiting only for a reduction of the cost of their light to a commercial basis, a reduction which he says is near at hand.

Since Mr. TESLA began investigating the possibilities of such high tension currents as he produces by means of his oscillator he has made some startling announcements, such as that of his ability to use the whole earth as a conductor, and to telegraph to any part of its surface from any other part, sending messages jointly to many stations or separately to each at will. Perhaps because none of these late triumphs of Mr. TESLA'S genius have yet been brought into practical use, there are many persons who declare that he is a visionary and impractical. It must be remembered that his discovery of the rotating electric field was of as great importance in its day as are his later discoveries now. That was announced in 1882, yet it was nearly ten years before its value was fully recognized.

The personality of NIKOLA TESLA is as interesting as are the results of his scientific labors. His ways of work differ radically from the methods of those who study by experiment and elimination. TESLA seldom experiments, and when he does it is to prove a theory, not to form one. In eleven years, he says, only one of his experiments has failed. His processes are mental, and at times, he declares, his mind reaches out into fields so vast that he is afraid, and recalls it. He verifies his conclusions afterward by figures and experiments.

No other great scientific genius ever turned aside from his work to devise means for putting an end to war. Others have invented guns, armor, explosives, and other accessories of war, but even in these cases the inventions were in a line with work in which the inventors were already engaged. Mr. TESLA'S first design was to apply his method of control to such engines as automobile torpedoes and to use these to destroy the Spanish fleets, but as he went on, the broader idea came to him to make his war machine so irresistible as to render war itself improbable.

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TESLA'S LATEST INVENTION.

DETAILS OF AN INVENTION WHICH MAY ASSURE THE PEACE OF THE WORLD.

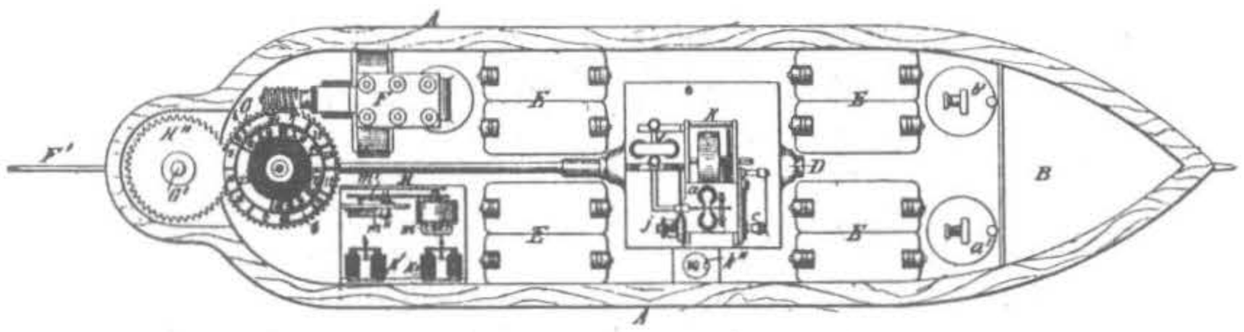


FIG. 1.—TESLA'S LATEST INVENTION—PLAN VIEW OF A VESSEL AND ITS CONTAINED MECHANISM.

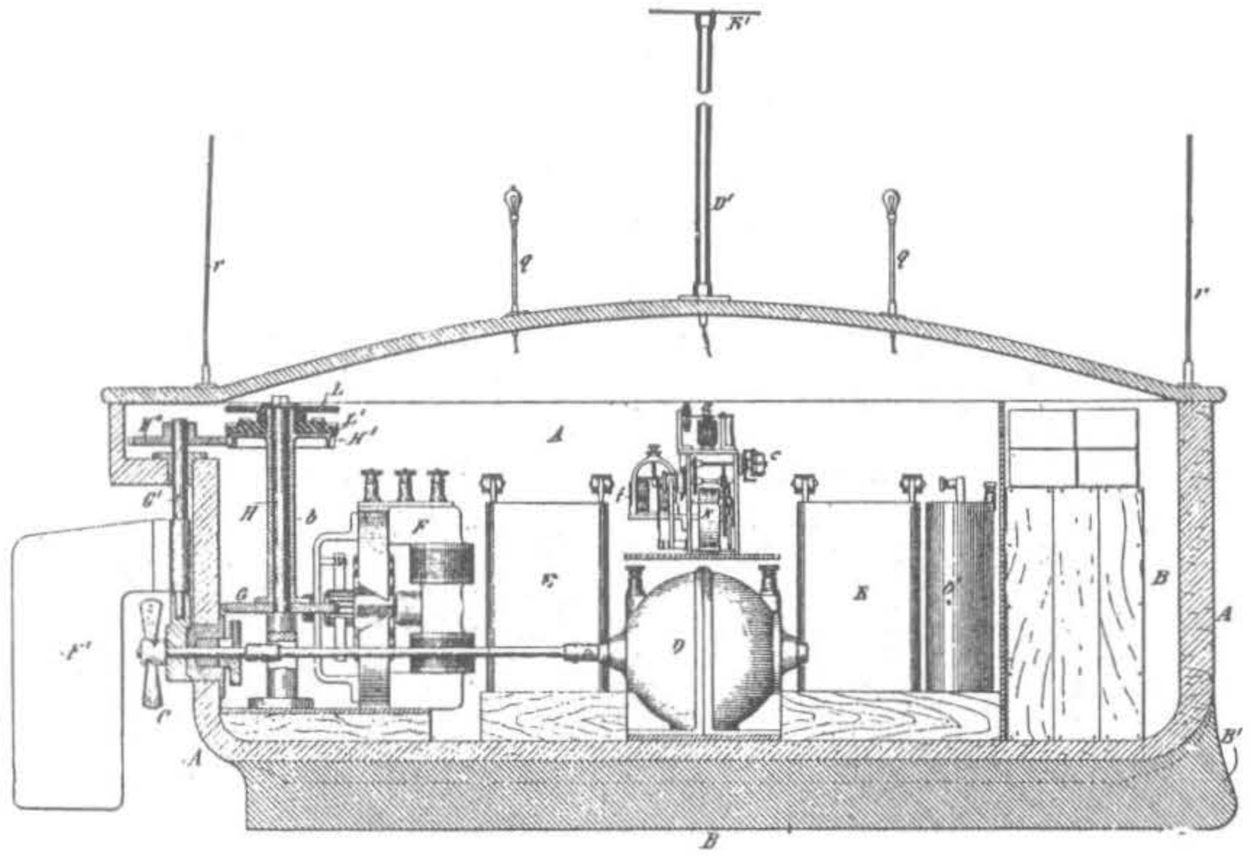


FIG. 2.—TESLA'S LATEST INVENTION—LONGITUDINAL SECTIONAL VIEW OF ELECTRICALLY CONTROLLED VESSEL AND ITS CONTAINED MECHANISM.

The ELECTRICAL REVIEW last week began the publication of a patent just issued to Nikola Tesla for the invention of means and apparatus for controlling from a given point the operation of the propelling engines, the steering apparatus and other mechanism carried by a moving object, such as a boat, or any floating vessel, whereby the movements and courses of the body or vessel may be directed and controlled from a distance, and any device carried by the same brought into action at any desired time. After stating that the production of suitable waves or radiations, and the conveying of the same to a remote receiving apparatus capable of being operated or controlled by their influence, may be carried out in various ways which are at the present time more or less understood, the specification, which is presented herewith in full, goes on to describe the apparatus used as follows:

Still another way is to pass the currents simply through the ground by connecting both the terminals of the source of high frequency currents to earth at different and remote points and to utilize the currents spreading through the ground for affecting a receiving circuit properly placed and adjusted. Again, in this instance, if only one of the terminals of the receiving circuit be connected to the ground—the other terminal being insulated—the adjustment as to synchronism with the source will require that under otherwise equal conditions the length of wire be half of that which would be used if both the terminals be connected or, generally, if the circuit be in the form of a closed loop or coil. Obviously also, in the latter case, the relative position of the receiving and transmitting circuits is of importance, whereas, if the circuit be of the former kind, that is, open, the relative position of the circuits is, as a rule, of little or no consequence.

Finally, I may avail myself, in carrying out my invention of electrical oscillations which do not follow any particular conducting path, but propagate in straight lines through space of rays, waves, pulses or disturbances

of any kind, capable of bringing the mechanism of the moving body into action from a distance and at the will of the operator by their effect upon suitable controlling devices.

In the following detailed description I shall confine myself to an explanation of that method and apparatus only which I have found to be the most practical and effectual, but obviously my invention, in its broad features, is not limited to the special mode and appliances which I have devised and shall here describe.

In any event, that is to say, whichever of the above or similar plans I may adopt, and particularly when the influence exerted from a distance upon the receiving circuit be too small to directly and reliably affect and actuate the controlling apparatus, I employ auxiliary sensitive relays, or, generally speaking, means capable of being brought into action by the feeblest influences, in order to effect the control of the movements of the distant body with the least possible expenditure of energy and at the greatest practicable distance, thus extending the range and usefulness of my invention.

A great variety of electrical and other devices, more or less suitable for the purpose of detecting and utilizing feeble actions, are now well known to scientific men and artisans, and need not be all enumerated here.

Confining myself merely to the electrical as the most practicable of such means, and referring only to those which, while not the most sensitive, are, perhaps, more readily available, from the more general knowledge which exists regarding them, I may state that a contrivance may be used which has long been known and used as a lightning arrester, in connection with telephone switchboards for operating annunciators and like devices, and comprises a battery, the poles of which are connected to two conducting terminals separated by a minute thickness of dielectric. The electromotive force of the battery should be such as to strain the thin dielectric layer very nearly to the point of breaking down, in order to increase the sensitiveness. When an electrical disturbance reaches a circuit so arranged and adjusted, additional strain is put upon the insulating film, which gives way and allows the passage of a current which can be utilized to operate any form of circuit-controlling apparatus.

Again, another contrivance capable of being utilized in detecting feeble electrical effects, consists of two conducting plates or terminals which have preferably wires of some length attached to them and are bridged by a mass of minute particles of metal or other conducting material. Normally, these particles, lying loose, do not connect the metal plates, but, under the influence of an electrical disturbance produced at a distance, evidently owing to electro-static attraction, they are pressed firmly against each other, thus establishing a good electrical connection between the two terminals. This change of state may be made use of in a number of ways for the above purpose.

Still another modified device, which may be said to embody the features of both the former, is obtained by connecting the two conducting plates or terminals, above referred to, permanently with the poles of a battery, which should be of very constant electro-motive force. In this arrangement a distant electrical disturbance produces a two-fold effect on the conducting particles and insulating films between them. The former are brought nearer to each other in consequence of the sudden increase of electro-static attraction, and the latter, owing to this as well as by being reduced in thickness or in number, are subjected to a much greater strain which they are unable to withstand.

It will be obviously noted from the preceding that, whichever of these or similar contrivances be used, the sensitiveness, and, what is often still more important, the reliability of operation is very materially increased by a close adjustment of the periods of vibration of the transmitting and receiving circuits, and, although such adjustment is in many cases unnecessary for the successful carrying out of my invention, I nevertheless make it a rule to bestow upon this feature the greatest possible care, not only because of the above mentioned advantages which are secured by the observance of the most favorable conditions in this respect, but also, and chiefly, with the object of preventing the receiving circuit from being affected by waves or disturbances emanating from sources not under the control of the operator. The narrower the range of vibrations, which are still capable o perceptibly affecting the receiving circuit, the safer will the latter b against extraneous disturbances. T secure the best result, it is necessary as is well known to experts, to con struct the receiving circuit, or tha part of the same in which the vibra tion chiefly occurs, so that it wil have the highest possible self-induc tion and at the same time the leas possible resistance. In this manne I have demonstrated the practicability of providing a great number of such receiving circuits—50 or 100 or more—each of which may be called up or brought into action whenever desired, without the other being interfered with. This result makes it possible for one operator to direct, simultaneously, the movements of a number of bodies, as well as to control the action of a number of devices located on the same body, each of which may have a distinct duty to fulfill. In the following description, however, I shall show a still further development in this direction; namely, how, by making use of merely one receiving circuit, a great variety of devices may be actuated and any number of different functions performed at the will and command of the distant operator.

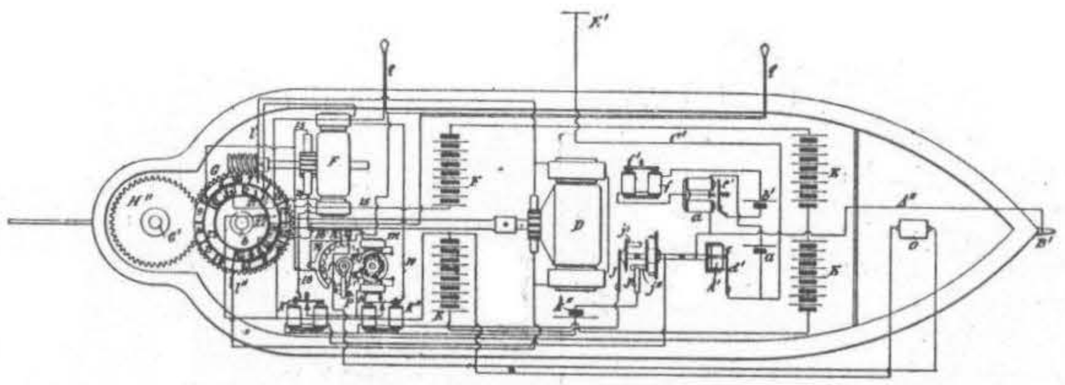
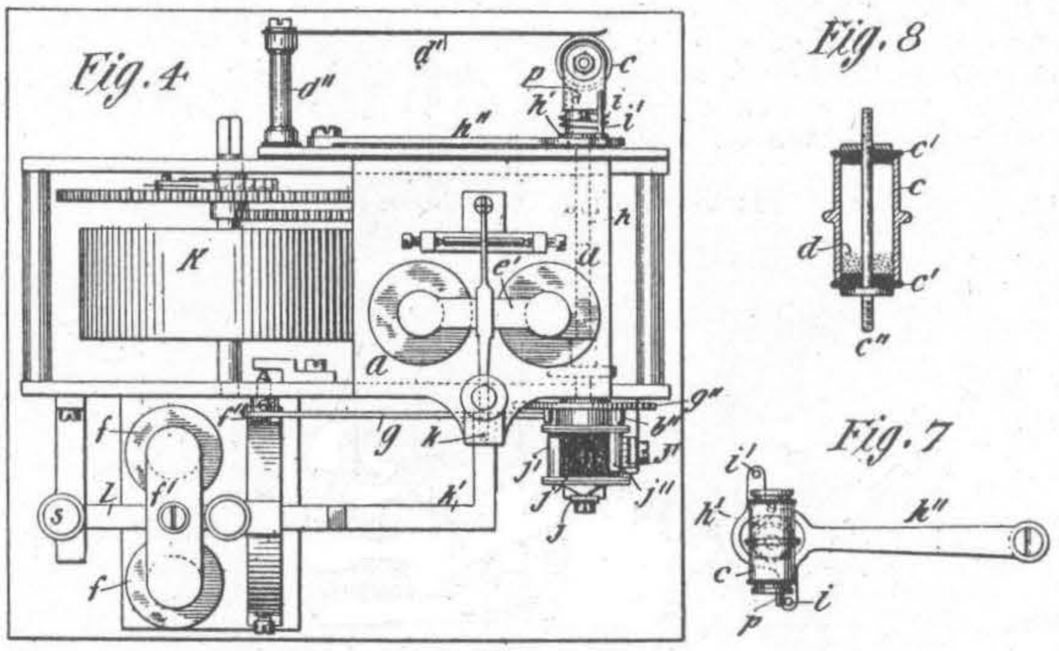


FIG. 3.—TESLA'S LATEST INVENTION—PLAN VIEW SHOWING ELECTRICAL CIRCUITS AND APPARATUS OF ELECTRICALLY CONTROLLED VESSEL.



FIGS. 4, 7 AND 8.—TESLA'S LATEST INVENTION.—DETAILS OF APPARATUS ON ELECTRICALLY CONTROLLED VESSEL.

It should be stated in advance, in regard to the sensitive devices above mentioned, which may be broadly considered as belonging to one class, inasmuch as the operation of all of them involves the breaking down of a minute thickness of highly strained dielectric, that it is necessary to make some provision for automatically restoring to the dielectric its original, unimpaired insulating qualities, in order to enable the device to be used in successive operations.

This is usually accomplished by a gentle tapping or vibration of the electrodes or particles, or continuous rotation of the same, but in long experience with many forms of these devices I have found that such procedures, while suitable in simple and comparatively unimportant operations, as ordinary signaling, when it is merely required that the succeeding effects produced in the receiving circuit should differ in regard to their relative duration only (in which case it is of little or no consequence if some of the individual effects be altered or incomplete or even entirely missed), do not yield satisfactory results in many instances, when it may be very important that the effects produced should all be exactly such as desired and that none should fail. To illustrate, let it be supposed that an official, directing the movements of a vessel in the manner described, should find it necessary to bring into action a special device on the latter, or to perform a particular operation, perhaps of vital moment, at an instant's notice, and possibly when, by design or accident, the vessel itself or any mark indicating its presence, is hidden from his view. In this instance a failure or defective action of any part of the apparatus might have disastrous consequences, and such cases, in which the sure and timely working of the machinery is of paramount importance, may often present themselves in practice, and this consideration has impressed me with the necessity of doing away with the defects in the present devices and procedures and of producing an apparatus which, while being sensitive, will also be most reliable and positive in its action. In the arrangement hereinafter described these defects are overcome in a most satisfactory manner, enabling thousands of successive operations, in all respects alike, being performed by the controlling apparatus without a single irregularity or miss being recorded. For a better understanding of these and other details of the invention as I now carry them out, I would refer to the accompanying drawings, in which

Fig. 1 is a plan view of a vessel and mechanism within the same.

Fig. 2 is a longitudinal section of the same showing the interior mechanism in side elevation.

Fig. 3 is a plan view, partially diagrammatical, of the vessel, apparatus and circuit connections of the same.

Fig. 4 is a plan view on an enlarged scale of a portion of the controlling mechanism.

Fig. 5 is an end view of the same.

Fig. 6 shows the same mechanism in side elevation.

Fig. 7 is a side view of a detail of the mechanism.

Fig. 8 is a central sectional view on a larger scale of a sensitive device forming part of the receiving circuit.

Fig. 9 is a diagrammatic illustration of the system in its preferred form.

Fig. 10 is a view of the various mechanisms employed, but on a larger scale and leaving out or indicating

conventionally certain parts of well understood character.

Referring to Fig. 1 and Fig. 2, A designates any type of vessel or vehicle which is capable of being propelled and directed, such as a boat, a balloon or a carriage. It may be designed to carry, in a suitable compartment B, objects of any kind, according to the nature of the uses to which it is to be applied. The vessel, in this instance a boat, is provided with suitable propelling machinery, which is shown as comprising a screw propeller C secured to the shaft of an electromagnetic motor D, which derives its power from storage batteries E, E, E, E.

In addition to the propelling engine or motor, the boat carries also a smaller steering motor F, the shaft of which is extended beyond its bearings and provided with a worm which meshes with a toothed wheel G. This latter is fixed to a sleeve *b*, freely movable on a vertical rod H, and is rotated in one or the other direction, according to the direction of rotation of the motor F.

The sleeve *b* on rod H is in gear through the cog wheels H′ and H″ with a spindle G′ mounted in vertical bearings at the stem of the boat and carrying the rudder F″.

The apparatus, by means of which the operation of both the propelling and steering mechanisms is controlled, involves, primarily, a receiving circuit which, for reasons before stated, is preferably both adjusted and rendered sensitive to the influence of waves or impulses emanating from a remote source, the adjustment being so that the period of oscillation of the circuit is either the same as that of the source or a harmonic thereof.

The receiving circuit proper, diagrammatically shown in Figs. 3 and 10, comprises a terminal E′, conductor C′, a sensitive device A′ and a conductor A″ leading to the ground, conveniently through a connection to the metal keel B′ of the vessel.

The terminal E′ should present a large conducting surface and should be supported as high as practicable on a standard D′, which is shown as broken in Fig. 2, but such provisions are not always necessary. It is important to insulate very well the conductor C′, in whatever manner it be supported.

The circuit or path just referred to forms also a part of a local circuit, which latter includes a relay magnet *a* and a battery *a′*, the electro-motive force of which is, as before explained, so determined that although the dielectric layers in the sensitive device A′ are subjected to a great strain, yet normally they withstand the strain and no appreciable current flows through the local circuit. But when an electrical disturbance reaches the circuit, the dielectric films are broken down, the resistance of the device A′ is suddenly and greatly diminished and a current traverses the relay magnet *a*.

The particular sensitive device employed is shown in general views and in detail in Figs. 4, 6, 7 and 8. It consists of a metal cylinder *c* with insulating heads *c′*, through which passes a central metallic rod *c″*. A small quantity of grains *d* of conducting material, such as an oxidized metal, is placed in the cylinder.

A metallic strip *d′*, secured to an insulating post *d″*, bears against the side of the cylinder *c*, connecting it with the conductor C′, forming one part of the circuit. The central rod *c″* is connected to the frame of the instrument and so to the other part of the circuit through the forked metal arm *e*, the ends of which are fastened with two nuts to the projecting ends of the rod, by which means the cylinder *c* is supported.

In order to interrupt the flow of battery current, which is started through the action of the sensitive device A′, special means are provided, which are as follows: The armature *e′* of the magnet *a*, when attracted by the latter, closes a circuit containing a battery *b′* and magnet *f*. The armature lever *f′* of this magnet is fixed to a rock shaft *f″*, to which is secured an anchor escapement *g*, which controls the movements of a spindle *g′*, driven by a clock train K.

The spindle *g′* has fixed to it a disk *g″*, with four pins *b″*, so that for each oscillation of the escapement *g* the spindle *g′* is turned through one-quarter of a revolution.

One of the spindles in the clock train, as *h*, is geared so as to make one-half of a revolution for each quarter revolution of spindle *g′*. The end of the former spindle extends through the side of the frame and carries an eccentric cylinder *h′*, which passes through a slot in a lever *h″*, pivoted to the side of the frame

The forked arm *e*, which supports the cylinder *c*, is pivoted to the end of an eccentric *h′*, and the eccentric and said arm are connected by a spiral spring *l*.

Two pins *i′ i″* extend out from the lever *h″*, and one of these is always in the path of a projection on arm *e*. They operate to prevent the turning of cylinder *c* with the spindle *h* and the eccentric. It will be evident that a half revolution of the spindle *h* will wind up the spring *i*, and at the same time raise or lower the lever *h″*, and these parts are so arranged that just before the half revolution of the spindle is completed, the pin *i″*, in engagement with projection or stop pin *p′*, is withdrawn from its path, and the cylinder *c*, obeying the force of the spring *i*, is suddenly turned end for end, its motion being checked by the other pin *i′*.

The adjustment relatively to armature *f′* of magnet *f* is furthermore so made that the pin *i″* is withdrawn at the moment when the armature has nearly reached its extreme position in its approach towards the magnet, that is, when the lever *l*, which carries the armature *f′*, almost touches the lower one of the two stops *ss*, Fig. 5, which limits its motion in both directions.

The arrangement just described has been the result of long experimenting with the object of overcoming certain defects in devices of this kind, to which reference has been made before.

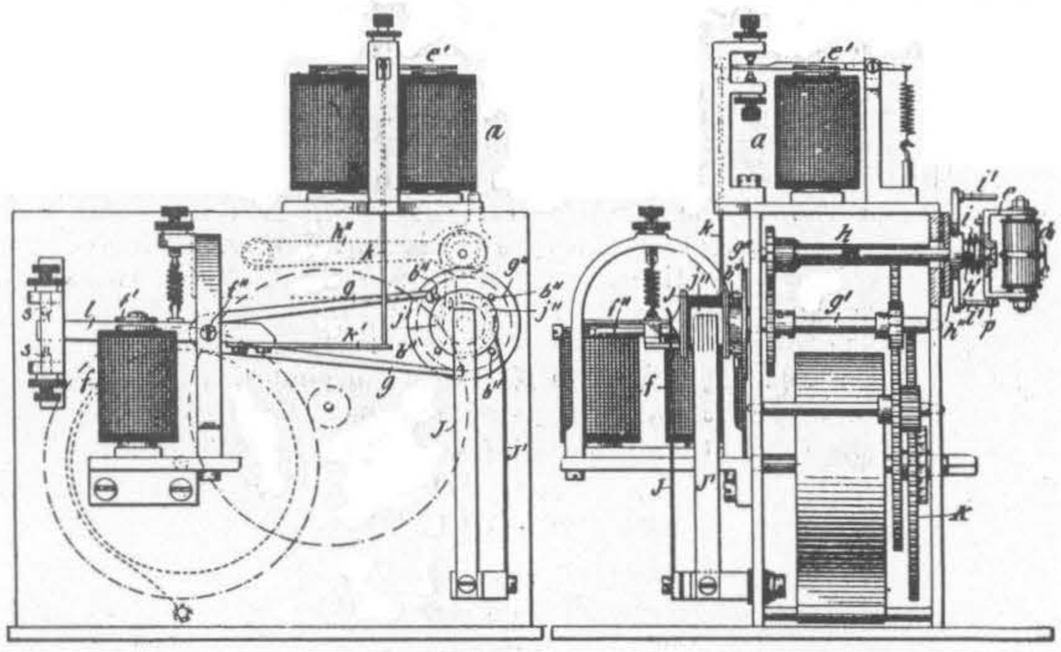
These defects I have found to be due to many causes, as the unequal size, weight and shape of the grains, the unequal pressure which results from this and from the manner in which the grains are usually agitated, the lack of uniformity in the conductivity of the surface of the particles, owing to the varying thickness of the superficial oxidized layer, the varying condition of the gas or atmosphere in which the particles are immersed and to certain deficiencies, well known to experts, of the transmitting apparatus as heretofore employed, which are in a large measure reduced by the use of my improved high-frequency coils. To do away with the defects in the sensitive device, I prepare the particles so that they will be in all respects as nearly alike as possible. They are manufactured by a special tool insuring their equality in size, weight and shape, and are then uniformly oxidized by placing them for a given time in an acid solution of predetermined strength. This secures equal conductivity of their surfaces and stops their further deterioration, thus preventing a change in the character of the gas in the space in which they are enclosed. I prefer not to rarefy the atmosphere within the sensitive device, as this has the effect of rendering the former less constant in regard to its dielectric properties, but merely secure an air-tight enclosure of the particles and rigorous absence of moisture, which is fatal to satisfactory working.

The normal position of the cylinder *c* is vertical, and when turned in the manner described, the grains in it are simply shifted from one end to the other. But inasmuch as they always fall through the same space and are subjected to the same agitation, they are brought, after each operation of the relay, to precisely the same electrical condition, and offer the same resistance to the flow of the battery current until another impulse from afar reaches the receiving circuit.

The relay magnet *a* should be of such character as to respond to a very weak current and yet be positive in its action. To insure the retraction of its armature *e′*, after the current has been established through the magnet *f* and interrupted by the inversion of the sensitive device *c*, a light rod *k* is supported in guides on the frame in position to be lifted by an extension *k′* of the armature lever *l* and to raise slightly the armature *e′*. As a feeble current may normally flow through the sensitive device and the relay magnet *a*, which would be sufficient to hold, though not draw, the armature down, it is well to observe this precaution.

The operation of the relay magnet *a* and the consequent operation of electro-magnet *f*, as above described, are utilized to control the operation of the propelling engine and the steering apparatus in the following manner:

On the spindle *g′*, which carries the escapement disk *g″*, Fig. 4 and Fig. 6, is a cylinder *j*, of insulating material with a conducting plate or head at each end. From these two heads respectively contact plates or segments *j′ j″* extend on diametrically opposite sides of the cylinder. The plate *j″* is in electrical connection



FIGS. 5 AND 6.—TESLA'S LATEST INVENTION.—SIDE VIEW AND SIDE ELEVATION OF A PORTION OF THE CONTROLLING MECHANISM ON AN ELCTRICALLY CONTROLLED VESSEL.

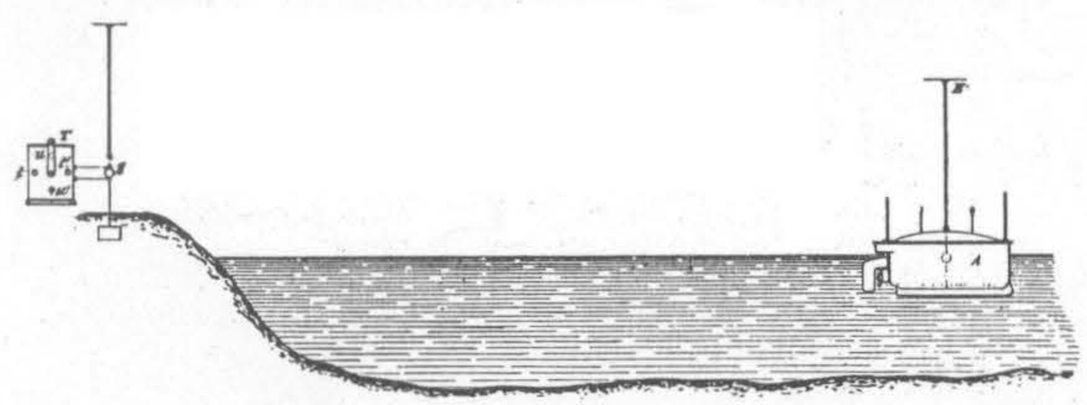


FIG. 9.—TESLA'S LATEST INVENTION.—DIAGRAM OF ELECTRICALLY CONTROLLED VESSEL SYSTEM.

with the frame of the instrument through the head from which it extends, while insulated strips or brushes J J' bear upon the free end or head of the cylinder and the periphery of the same respectively. Three terminals are thus provided, one always in connection with plate j', the other always in connection with the plate j'', and the third adapted to rest on the strips j' and j'' in succession or upon the intermediate insulating spaces, according to the position in which the commutator is brought by the clock train and the anchor escapement g.

K' K'', Figs. 1, 3 and 10, are two relay magnets, conveniently placed in the rear of the propelling engine. One terminal of a battery k'' is connected to one end of each of the relay coils; the opposite terminal to the brush J', and the opposite ends of the relay coils to the brush J, and to the frame of the instrument respectively. As a consequence of this arrangement either the relay K' or K'' will be energized, as the brush J' bears upon the plate j' or j'' respectively, or both relays will be inactive while the brush J' bears upon an insulating space between the plates j' and j''.

While one relay, as K', is energized, its armature closes a circuit through the motor F, which is rotated in a direction to throw the rudder to port. On the other hand, when relay K'' is active, another circuit through the motor F is closed, which reverses its direction of rotation and shifts the rudder to starboard. These circuits, however, are at the same time utilized for other purposes, and their course is, in part, through apparatus which I shall describe before tracing their course.

The fixed rod H carries an insulating disk or head L, Fig. 2, to the under line of which are secured six brushes, 1, 2, 3, 4, 5 and 6, Fig. 3. The sleeve b, which surrounds the rod and is turned by the steering motor F, carries a disk L', upon the upper face of which are two concentric circles of conducting contact plates Brushes 1, 2, 3 and 4 bear upon the inner circle of contacts, while the brushes 5 and 6 bear upon the outer circle of contacts.

The outer circle of contacts comprises two long plates, 7 and 8, on opposite sides of the disk, and a series of shorter plates, 9, 10, 11, 12, 13 and 14, in the front and rear. Flexible conductors l l' connect the plates 7 and 8 with the terminals of the propelling motor D, and the poles of the main battery E are connected to the brushes 5 and 6 respectively, so that, while the rudder is straight or turned up to a certain angle to either side, the current is conveyed through the brushes 5 and 6 and segments 7 and 8 to the propelling motor D.

The steering motor F is also driven by current taken from the main battery E in the following manner. A conductor 15, from one pole of the battery, leads to one of the commutator brushes, and from the other brush runs a conductor 16 to one of the contacts of each relay K' K''. When one of these relays, as K'', is active, it continues this circuit through a wire 19, through one field-coil or set of field coils on the motor F, and thence to the brush l. In a similar manner, when the other relay K' is active, the circuit is continued from wire 18, through a wire 20, the second or reversing set of field-coils, and to brush 2.

Both brushes 1 and 2, at all times when the rudder is not turned more than about 45 degrees to one side, are in contact with a long-conducting plate 21, and one brush, in any position of the rudder, is always in contact with said plate, and the latter is connected by a flexible conductor 22 with the opposite pole of the main battery. Hence the motor F may always be caused to rotate in one direction, whatever may be the position of the rudder, and may be caused to rotate in either direction whenever the position of the rudder is less than a predetermined angle, conveniently forty-five degrees from the center position.

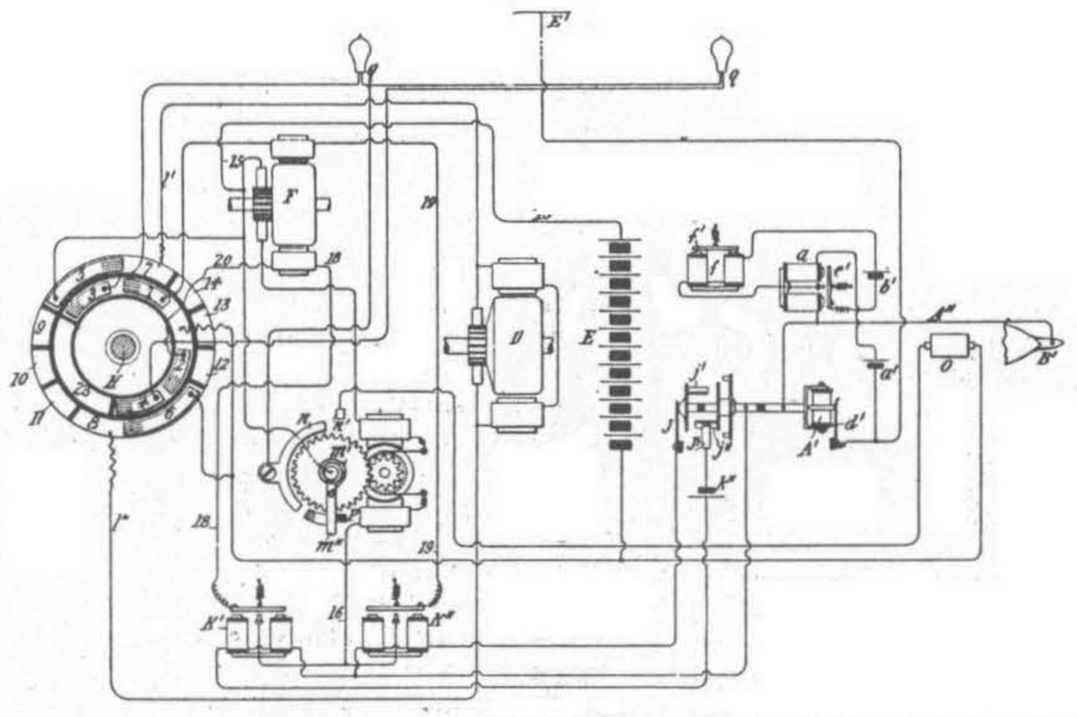


FIG. 10.—TESLA'S LATEST INVENTION—VIEW OF VARIOUS MECHANISMS EMPLOYED ON ELECTRICALLY CONTROLLED VESSEL.

In order, however, to prevent the rudder from being turned too far in either direction, the isolated plate 23 is used. Any movement of the rudder beyond a predetermined limit brings this plate under one or the other of the brushes 1, 2, and breaks the circuit of motor F, so that the rudder can be driven no further in that direction, but, as will be understood, the apparatus is in condition to turn the rudder over to the other side.

In like manner the circuit of the propelling motor D is controlled through brushes 5 and 6 and the segments on the outer circle of contacts of head L If the short segments on either side of the circle are insulated, the motor D will be stopped whenever one of the brushes 5 or 6 passes onto one of them from the larger segments 7, 8.

It is important to add that on all contact points where a break occurs, provision should be made to overcome the sparking and prevent the oscillation of electrical charges in the circuits, as such sparks and oscillations may affect the sensitive device. It is this consideration chiefly which makes it advisable to use the two relays K' K'', which otherwise might be dispensed with. They should be also placed as far as practicable from the sensitive device in order to guard the latter against any action of strong varying currents.

In addition to the mechanism described the vessel may carry any other device or apparatus as might be required for accomplishing any special object of more or less importance. By way of illustration, a small motor m is shown (Figs. 1 and 3), which conveniently serves for a number of purposes. This motor is shown connected in series with the armature of the steering motor F, so that, whenever either one of the circuits of the latter is closed through relays K' K'', the motor m is likewise rotated, but in all cases in the same direction. Its rotation is opposed by a spring m', so that, in normal operation, owing to the fact that the circuits of motor F are closed but a short time, the lever m'' which is fastened to one of the wheels of clockwork M, with which the armature of the motor is geared, will move but a short distance, and upon cessation of the current return to a stop P. But if the circuits of the motor F are closed and opened rapidly in succession, which operation leaves the rudder unaffected, then the lever m'' is moved to a greater angle, coming in contact with a metal plate n, and finally, if desired, with a post n'.

Upon the lever m'' coming in contact with plate n, the current of the main battery passes either through one or other or both of the lights supported on standards q q, according to the position of brushes 3 and 4 relatively to the insulating segment 23. But since the head L carrying the segments is geared to the rudder, the position of the latter is in a general way determined by observing the lights. Both of the lights may be colored, and by flashing them up whenever desired the operator may guide at night the vessel in its course. For such purposes also the standards r r are provided, which should be painted in lively colors, so as to be visible at great distances.

By opening and closing the circuits of motor F a greater number of times, preferably determined beforehand, the lever m'' is brought in contact with post n', thus closing the circuit of the main battery through a device o and bringing the latter into action at the moment desired. By similar contrivances, or such as will readily suggest themselves to mechanicians, any number of different devices may be operated.

Referring now to Fig. 9, which illustrates diagrammatically the system as practiced when directing the movements of a boat:

In this figure S designates any source of electrical disturbance or oscillations, the generation of which is controlled by a suitable switch contained in box T. The handle of the switch is movable in one direction only, and stops on four points, t, t', u, u', so that, as the handle passes from stop to stop, oscillations are produced by the source during a very short time interval. There are thus produced four disturbances during one revolution, and the receiving circuit is affected four times; but it will be understood from the foregoing description of the controlling devices on the vessel that the rudder will be moved twice, once to right and once to left. Now I preferably place the handle of the switch so that, when it is arrested on points t, t'—that is, to the right or left of the operator—he is reminded that the vessel is being deflected to the right or left from its course, by which means the control is facilitated. The normal positions of the handle are therefore at u, u' when the rudder is not acted upon, and it remains on the points t, t' only so long as necessary. Since, as before stated, the working of the apparatus is very sure, the operator is enabled to perform any such operations as provision is made for without even seeing the vessel.

The manner of using the apparatus and the operation of the several instrumentalities comprising the same is, in detail, as follows: Normally, the plate L' is turned so that brush 2 rests upon the insulated segment 23, and brush 6 upon one of the isolated short segments in the rear of the circle. Under these conditions the rudder will be turned to starboard and the circuit of motor D interrupted between brushes 5 and 6. At the same time, only one of the circuits of motor F—that controlled by relay K'—is capable of being closed, since brush 2, which connects with the other, is out of contact with the long segment 21.

Assuming now that it is desired to start the vessel and direct it to a given point. The handle T is turned from its normal position on u' to the point t on the switch-box. This sends out an electrical disturbance which, passing through the receiving circuit on the vessel, affects the sensitive device A' and starts the flow of current through the local circuit, including said device, the relay a and the battery a'. This, as has been previously explained, turns the cylinder j and causes the brush J' to pass from insulation onto the contact j'.

(Concluded on page 312.)

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(*Concluded from page 308.*)

The battery *k*'' is thus closed through relay K'', and the latter closes that circuit of the motor F which, starting from plate 22, which is permanently connected with one pole of the main battery, is completed through the brush 1, the field of motor F, wire 19, the armature of relay K'', wire 16, the motor *m*, the brushes and commutator of motor F, and wire 15 to the opposite terminal of the battery E. Motor F is thus set in operation to shift the rudder to port, but the movement of plate L', which follows, brings the brush 6 back onto segment 8 and closes the circuit of the propelling motor, which starts the vessel.

The motor F is permitted to run until the rudder has been turned sufficiently to steer the vessel in the desired direction, when the handle T is turned to the point *u*. This produces another action of the relay *a*, and brush J' is shifted onto insulation and both relays K' and K* are inactive.

The rudder remains in the position to which it has been shifted by the motor F. If it be then desired to shift it to starboard or in the opposite direction to that in which it was last moved, the handle T is simply turned to point *t'* and allowed to remain there until the motor F, which is now operated by relay K', the circuit of which is closed by strip J' coming into contact with plate *j**, has done its work.

The movement of handle T to the next point throws out both relays K' and K*, and the next movement causes a shifting of the rudder to port, and so on. Suppose, however, that after the rudder has been set at any angle to its middle position, it be desired to shift it still further in the same direction. In such case, the handle is moved quickly over two points, so that the circuit which would move the rudder in the opposite direction is closed for too short a time interval to produce an appreciable effect, and is allowed to rest on the third point until the rudder is shifted to the desired position, when the handle is moved to the next point, which again throws out both relays K' and K*. It will be understood that, if the handle be held for a sufficiently long time upon either point *t* or *t'*, the motor will simply turn the plate L' in one direction or the other until the circuits of motors D and F are broken. It is furthermore evident that one relay K' or K* will always be operative to start the motor F.

As previously explained the longest period of operation of which the motor F is capable, under ordinary conditions of use, does not permit the motor *m* to shift the arm *m'* into contact with the plate *n*. But if the handle T be turned with a certain rapidity a series of current impulses will be directed through motor *m*, but, as these tend to rotate the motor F in opposite directions, they do not sensibly affect the latter, but act to rotate the motor *m* against the force of the coiled spring.

The invention which I have described will prove useful in many ways. Vessels or vehicles of any suitable kind may be used as life, despatch or pilot boats or the like or for carrying letters, packages, provisions, instruments, objects or materials of any description, for establishing communication with inaccessible regions and exploring the conditions existing in the same, for killing or capturing whales or other animals of the sea, and for many other scientific, engineering or commercial purposes. But the greatest value of my invention will result from its effect upon warfare and armaments, for, by reason of its certain and unlimited destructiveness, it will tend to bring about and maintain permanent peace among nations.

Having now described my invention, what I claim is:

1. The improvement in the art of controlling the movements and operation of a vessel or vehicle herein described, which consists in producing waves or disturbances which are conveyed to the vessel by the natural media, actuating thereby suitable apparatus on the vessel and effecting the control of the propelling engine, the steering and other mechanism by the operation of the said apparatus, as set forth.

2. The improvement in the art of controlling the movements and operation of a vessel or vehicle, herein described, which consists in establishing a region of waves or disturbances, and, actuating by their influence exerted at a distance, the devices on such vessel or vehicle, which control the propelling, steering and other mechanism thereon, as set forth.

3. The improvement in the art of controlling the movements and operation of a vessel or vehicle, herein described, which consists in establishing a region of electrical waves or disturbances, and, actuating by their influence exerted at a distance, the devices on said vessel or vehicle, which control the propelling, steering and other mechanism thereon, as set forth.

4. The improvement in the art of controlling the movements and operation of a vessel or vehicle, herein described, which consists in providing on the vessel a circuit controlling the propelling, steering and other mechanism, adjusting or rendering such circuit sensitive to waves or disturbances of a definite character, establishing a region of such waves or disturbances, and rendering by their means the controlling circuit active or inactive, as set forth.

5. The combination with a source of electrical waves or disturbances of a moving vessel or vehicle, and mechanism thereon for propelling, steering or operating the same, and a controlling apparatus adapted to be actuated by the influence of the said waves or disturbances at a distance from the source, as set forth.

6. The combination with a source of electrical waves or disturbances of a moving vessel or vehicle, mechanism for propelling, steering or operating the same, a circuit and means therein for controlling said mechanism, and means for rendering said circuit active or inactive through the influence of the said waves or disturbances exerted at a distance from the source, as set forth.

7. The combination with a source of electrical waves or disturbances and means for starting and stopping the same, of a vessel or vehicle, propelling and steering mechanism carried thereby, a circuit containing or connected with means for controlling the operation of said mechanism and adjusted or rendered sensitive to the waves or disturbances of the source, as set forth.

8. The combination with a source of electrical waves or disturbances, and means for starting and stopping the operation of the same, of a vessel or vehicle, propelling and steering mechanism carried thereby, local circuits controlling said mechanisms, a circuit sensitive to the waves or disturbances of the source and means therein adapted to control the said local circuits, as and for the purpose set forth.

9. The sensitive device herein described comprising in construction a receptacle containing a material such as particles of oxidized metal forming a part of the circuit, and means for turning the same end for end when the material has been rendered sensitive by the passage through it of an electric discharge, as set forth.

10. The sensitive device herein described, comprising in combination a receptacle containing a material such as particles of oxidized metal forming a part of an electric circuit, an electromagnet in said circuit, and devices controlled thereby for turning the receptacle end for end when said magnet is energized, as set forth.

11. The sensitive device herein described, comprising in combination a receptacle containing a material such as particles of oxidized metal forming part of an electric circuit, a motor for rotating the receptacle, an electromagnet in circuit with the material, and an escapement controlled by said magnet and adapted to permit a half revolution of the receptacle when the said magnet is energized, as set forth.

12. The combination with a movable body or vehicle, of a propelling motor, a steering motor and electrical contacts carried by a moving portion of the steering mechanism, and adapted in certain positions of the latter to interrupt the circuit of the propelling motor, a local circuit and means connected therewith for controlling the steering motor, and a circuit controlling the local circuit and means for rendering said controlling circuit sensitive to the influence of electric waves or disturbances exerted at a distance from their source, as set forth.

13. The combination with the steering motor, a local circuit for directing current through the same in opposite directions, a controlling circuit rendered sensitive to the influence of electric waves or disturbances exerted at a distance from their source, a motor in circuit with the steering motor, but adapted to run always in the same direction, and a local circuit or circuits controlled by said motor, as set forth.

lectrical Review

D IST ELECTRICAL WEEKLY IN THE UNITED STATES.]

TIMES BUILDING, 41 PARK ROW,

BOX 2339. NEW YORK.

IEW YORK, NOVEMBER 16, 1898.

TESLA'S PEACE MANIFESTO.

We conclude in this issue the full text of the specifications of the patent issued to Nikola Tesla last week, and which excited such unusually widespread interest, more especially in military circles. Although Tesla contemplates in the description of his marvelous invention chiefly its uses in peace, its tremendous importance in regard to its powers in warfare did not escape the keen perceptions of our alert army and navy officials.

We think that the numerous press comments did not really bring out with sufficient clearness the revolutionary features of the invention, particularly in regard to the furtherance of the noble cause which the Czar of Russia voices in his stirring peace manifesto. Naturally our heroes are keenly disappointed at the prospect of having no wars, but the every-day citizen will hail with joy the success of Tesla's humane efforts.

The ability to control with precision, from a distance of a score of miles the movements of a vessel with no soul on board—to call any of its numerous appliances into play, at any desired moment—would of itself be a stupendous achievement. But when this vessel in addition has the power of distinguishing with almost human intelligence the orders which it receives from afar, though silent and invisible—obeying only those for which the builder designed it, and remaining unresponsive to all others—the imagination staggers when following the immediate consequences of such an unheard-of result. Inventions of a startling character have been made before, but most of them have been the result of gradual development. Here the inventor has given us an entirely new and wonderful art. There is something appalling, awe-inspiring in Tesla's invention.

The Electrical Engineer.

Vol. XXVI. NOVEMBER 17, 1898. No. 550.

MISCELLANEOUS

High Frequency Oscillators for Electro-therapeutic and Other Purposes.[1]

BY NIKOLA TESLA.

SOME theoretical possibilities offered by currents of very high frequency and observations which I casually made while pursuing experiments with alternating currents, as well as the stimulating influence of the work of Hertz and of views boldly put forth by Oliver Lodge, determined me some time during 1889 to enter a systematic investigation of high frequency phenomena, and the results soon reached were such as to justify further efforts towards providing the laboratory with efficient means for carrying on the research in this particular field, which has proved itself so fruitful since. As a consequence alternators of special design were constructed and various arrangements for converting ordinary into high frequency currents perfected, both of which were duly described and are now —I assume—familiar.

One of the early observed and remarkable features of the high frequency currents, and one which was chiefly of interest to the physician, was their apparent harmlessness which made it possible to pass relatively great amounts of electrical energy through the body of a person without causing pain or serious discomfort. This peculiarity which, together with other mostly unlooked-for properties of these currents I had the honor to bring to the attention of scientific men first in an article in a technical journal in February, 1891, and in subsequent contributions to scientific societies, made it at once evident, that these currents would lend themselves particularly to electro-therapeutic uses.

With regard to the electrical actions in general, and by analogy, it was reasonable to infer that the physiological effects, however complex, might be resolved in three classes. First the statical, that is, such as are chiefly dependent on the magnitude of electrical potential; second, the dynamical, that is, those principally dependent on the quality of electrical movement or current's strength through the body, and third, effects of a distinct nature due to electrical waves or oscillations, that is, impulses in which the electrical energy is alternately passing in more or less rapid succession through the static and dynamic forms.

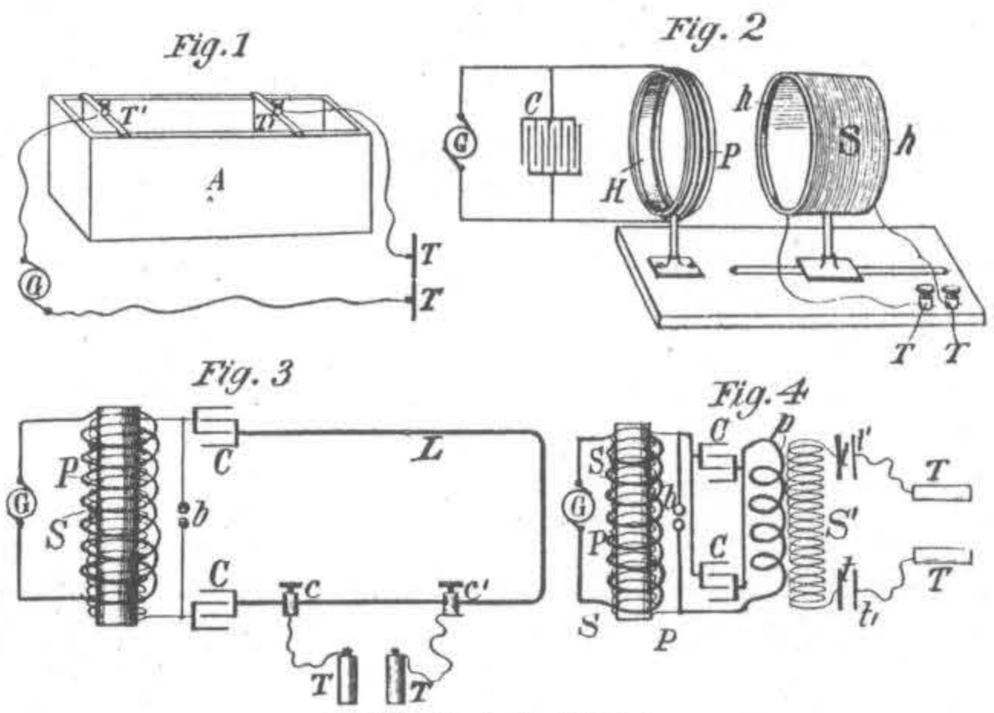
Most generally in practice these different actions are coexistent, but by a suitable selection of apparatus and observance of conditions the experimenter may make one or other of these effects predominate. Thus he may pass through the body, or any part of the same, currents of comparatively large volume under a small electrical pressure, or he may subject the body to a high electrical pressure while the current is negligibly small, or he may put the patient under the influence of electrical waves transmitted, if desired, at considerable distance through space.

While it remained for the physician to investigate the specific actions on the organism and indicate proper methods of treatment, the various ways of applying these currents to the body of a patient suggested themselves readily to the electrician.

As one cannot be too clear in describing a subject, a diagrammatic illustration of the several modes of connecting the circuits which I will enumerate, though obvious for the majority, is deemed of advantage.

The first and simplest method of applying the currents was to connect the body of the patient to two points of the generator, be it a dynamo or induction coil. Fig. 1 is intended to illustrate this case. The alternator G may be one giving from five to ten thousand complete vibrations per second, this number being still within the limit of practicability. The electromotive force—as measured by a hot wire instrument—may be from fifty to one hundred volts. To enable strong currents to be passed through the tissues, the terminals T T, which serve to establish contact with the patient's body should, of course, be of large area, and covered with cloth saturated with a solution of electrolyte harmless to the skin, or else the contacts are made by immersion. The regulation of the currents is best effected by means of an insulating trough A provided with two metal terminals T' T' of considerable surface, one of which, at least, should be movable. The trough is filled with water, and an electrolytic solution is added to the same, until a degree of conductivity is obtained suitable for the experiments.

When it is desired to use small currents of high tension, a secondary coil is resorted to, as illustrated in Fig. 2. I have found it from the outset convenient to make a departure from the ordinary ways of winding the coils with a considerable number of small turns. For many reasons the physician will find it better to provide a large hoop H of not less than, say, three feet in diameter and preferably more, and to wind upon it a few turns of stout cable P. The secondary coil S is easily prepared by taking two wooden hoops h h and joining them with stiff cardboard. One single layer of ordinary magnet wire, and not too thin at that, will be generally sufficient, the number of turns necessary for the particular use for which the coil is intended being easily ascertained by a few trials. Two plates of large surface, forming an adjustable condenser, may be used for the purpose of synchronizing the secondary with the primary circuit, but this is generally not necessary. In this manner a



FIGS. 1, 2, 3 AND 4.

cheap coil is obtained, and one which cannot be easily injured. Additional advantages, however, will be found in the perfect regulation which is effected merely by altering the distance between the primary and secondary, for which adjustment provision should be made, and, furthermore, in the occurrence of harmonics which are more pronounced in such large coils of thick wire, situated at some distance from the primary.

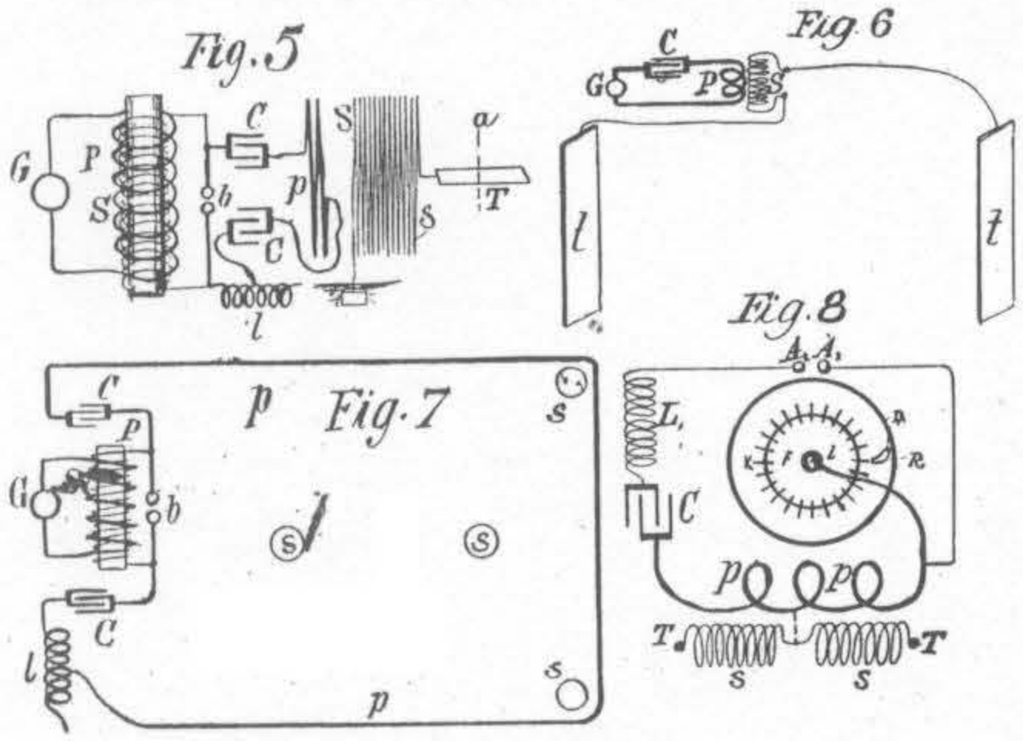
The preceding arrangements may also be used with alternating or interrupted currents of low frequency, but certain peculiar properties of high frequency currents make it possible to apply the latter in ways entirely impracticable with the former.

One of the prominent characteristics of high frequency or, to be more general, of rapidly varying currents, is that they pass with difficulty through stout conductors of high self-induction. So great is the obstruction which self-induction offers to their passage that it was found practicable, as shown in the early experiments to which reference has been made, to maintain differences of potential of many thousands of volts between two points—not more than a few inches apart—of a thick copper bar of inappreciable resistance. This observation naturally suggested the disposition illustrated in Fig. 3. The source of high frequency impulses is in this instance a familiar type of transformer which may be supplied from a generator G of ordinary direct or alternating currents. The transformer comprises a primary P, a secondary S, two condensers C C which are joined in series, a loop or coil of very thick wire L and a circuit interrupting device or break b. The currents are derived

[1]Read at the eighth annual meeting of The American Electro-Therapeutic Association, Buffalo, N. Y., Sept. 13 to 15, 1898.

from the loop L by two contacts c c', one or both of which are capable of displacement along the wire L. By varying the distance between these contacts, any difference of potential, from a few volts to many thousands, is readily obtained on the terminals or handles T T. This mode of using the currents is entirely safe and particularly convenient, but it requires a very uniform working of the break b employed for charging and discharging the condenser.

Another equally remarkable feature of high frequency impulses was found in the facility with which they are transmitted through condensers, moderate electromotive forces and very small capacities being required to enable currents of considerable volume to pass. This observation made it practicable to resort to a plan such as indicated in Fig. 4. Here the connections are similar to those shown in the preceding case, except that the condensers C C are joined in parallel. This lowers the frequency of the currents, but has the advantage of allowing the working with a much smaller difference of potential on the terminals of the secondary S. Since the latter is the chief item of expense of such apparatus and since its price rapidly increases with the number of turns required, the experimenter will find it generally cheaper to make a sacrifice in the frequency, which, however, will be high enough for most purposes. However, he only needs to reduce proportionately the number of turns or the length of primary p to obtain the same frequency as before, but the economy of transformation will be somewhat



FIGS. 5, 6, 7 AND 8.

reduced in so doing and the break b will require more attention. The secondary S^1 of the high frequency coil has two metal plates t t of considerable surface connected to its terminals, and the current for use is derived from two similar plates t' t' in proximity to the former. Both the tension and volume of the currents taken from terminals T T may be easily regulated and in a continuous manner by simply varying the distance between the two pair of plates t t and t' t' respectively.

A facility is also afforded in this disposition for raising or lowering the potential of one of the terminals T, irrespective of the changes produced on the other terminal, this making it possible to cause a stronger action on one or other part of the patient's body.

The physician may find it for some or other reason convenient to modify the arrangements in Figs. 2, 3 and 4 by connecting one terminal of the high frequency source to the ground. The effects will be in most respects the same, but certain peculiarities will be noted in each case. When a ground connection is made it may be of some consequence which of the terminals of the secondary is connected to the ground, as in high frequency discharges the impulses of one direction are generally preponderating.

Among the various noteworthy features of these currents there is one which lends itself especially to many valuable uses. It is the facility which they afford for conveying large amounts of electrical energy to a body entirely insulated in space. The practicability of this method of energy transmission, which is already receiving useful applications and promises to become of great importance in the near future, has helped to dispel the old notion assuming the necessity of a return circuit for the conveyance of electrical energy in any considerable amount. With novel appliances we are enabled to pass through a wire, entirely insulated on one end, currents strong enough to fuse it, or to convey through the wire any amount of energy to an insulated body. This mode of applying high frequency currents in medical treatment appears to me to offer the greatest possibilities at the hands of the physician. The effects produced in this manner possess features entirely distinct from those observed when the currents are applied in any of the before mentioned or similar ways.

The circuit connections as usually made are illustrated schematically in Fig. 5, which, with reference to the diagrams before shown, is self-explanatory. The condensers C C, connected in series, are preferably charged by a step-up transformer, but a high frequency alternator, static machine, or a direct current generator, if it be of sufficiently high tension to enable the use of small condensers, may be used with more or less success. The primary p, through which the high frequency discharges of the condensers are passed, consists of very few turns of cable of as low resistance as possible, and the secondary s, preferably at some distance from the primary to facilitate free oscillation, has one of its ends—that is the one which is nearer to the primary—connected to the ground, while the other end leads to an insulated terminal T, with which the body of the patient is connected. It is of importance in this case to establish synchronism between the oscillations in the primary and secondary circuits p and s respectively. This will be as a rule best effected by varying the self-induction of the circuit including the primary loop or coil p, for which purpose an adjustable self-induction e is provided; but in cases when the electromotive force of the generator is exceptionally high, as when a static machine is used and a condenser consisting of merely two plates offers sufficient capacity, it will be simpler to attain the same object by varying the distance of the plates.

The primary and secondary oscillations being in close synchronism, the points of highest potential will be on a part of terminal T, and the consumption of energy will occur chiefly there. The attachment of the patient's body to the terminal will in most cases very materially affect the period of oscillation in the secondary, making it longer, and a readjustment of the primary circuit will have to be made in each case to suit the capacity of the body connected with terminal T. Synchronism should always be preserved, and the intensity of the action varied by moving the secondary coil to or from the primary, as may be desired. I know of no method which would make it possible to subject the human body to such excessive electrical pressures as are practicable with this, or of one which would enable the conveying to and giving off from the body without serious injury amounts of electrical energy approximating even in a remote degree those which are entirely practicable when this manner of applying the energy is resorted to. This is evidently due to the fact that the action is chiefly superficial, the largest possible section being offered to the transfer of the current, or, to say more correctly, of the energy. With a very rapidly and smoothly working break I would not think it impossible to convey to the body of a person and to give off into the space energy at the rate of several horse power with impunity, while a small part of this amount applied in other ways could not fail to produce injury.

When a person is subjected to the action of such a coil, the proper adjustments being carefully observed, luminous streams are seen in the dark issuing from all parts of the body. These streams are short and of delicate texture when the number of breaks is very great and the action of the device b (Fig. 5) free of any irregularities, but when the number of breaks is small or the action of the device imperfect, long and noisy streams appear which cause some discomfort. The physiological effects produced with apparatus of this kind may be graduated from a hardly perceptible action when the secondary is at a great distance from the primary, to a most violent one when both coils are placed at a small distance. In the latter case only a few seconds are sufficient to cause a feeling of warmth all over the body, and soon after the person perspires freely. I have repeatedly, in demonstrations to friends, exposed myself longer to the action of the oscillations, and each time, after the lapse of an hour or so, an immense fatigue, of which it is difficult to give an idea, would take hold of me. It was greater than I experienced on some occasions after the most straining and prolonged bodily exertion. I could scarcely make a step and could keep the eyes open only with the greatest difficulty. I slept soundly afterward, and the after-effect was

certainly beneficial, but the medicine was manifestly too strong to be used frequently.

One should be cautious in performing such experiments for more than one reason. At or near the surface of the skin, where the most intense action takes place, various chemical products are formed, the chief being ozone and nitrogen compounds. The former is itself very destructive, this feature being illustrated by the fact that the rubber inslation of a wire is destroyed so quickly as to make the use of such insulation entirely impracticable. The compounds of nitrogen, when moisture is present, consists largely of nitric acid which might, by excessive application, prove hurtful to the skin. So far, I have not noted injuries which could be traced directly to this cause, though on several occasions burns were produced in all respects similar to those which were later observed and attributed to the Röntgen rays. This view is seemingly being abandoned, having not been substantiated by experimental facts, and so also is the notion that these rays are transverse vibrations. But while investigation is being turned in what appears to be the right direction, scientific men are still at sea. This state of things impedes the progress of the physicist in these new regions and makes the already hard task of the physician still more difficult and uncertain.

One or two observations made while pursuing experiments with the apparatus described might be found as deserving mention here. As before stated, when the oscillations in the primary and secondary cirucits are in synchronism, the points of highest potential are on some portion of the terminal T. The synchronism being perfect and the length of the secondary coil just equal to one-quarter of the wave length, these points will be exactly on the free end of terminal T, that is, the one situated farthest from the end of the wire attached to the terminal. If this be so and if now the period of the oscillations in the primary be shortened, the points of highest potential will recede towards the secondary coil, since the wave-length is reduced and since the attachment of one end of the secondary coil to the ground determines the position of the nodal points, that is, the points of least potential. Thus, by varying the period of vibration of the primary circuit in any manner, the points of highest potential may be shifted accordingly along the terminal T, which has been shown, designedly, long to illustrate this feature. The same phenomenon is, of course, produced if the body of a patient constitutes the terminal, and an assistant may by the motion of a handle cause the points of highest potential to shift along the body with any speed he may desire. When the action of the coil is vigorous, the region of highest potential is easily and unpleasantly located by the discomfort or pain experienced, and it is most curious to feel how the pain wanders up and down, or eventually across the body, from hand to hand, if the connection to the coil is accordingly made—in obedience to the movement of the handle controlling the oscillations. Though I have not observed any specific action in experiments of this kind, I have always felt that this effect might be capable of valuable use in electro-therapy.

Another observation which promises to lead to much more useful results is the following: As before remarked, by adopting the method described, the body of a person may be supjected without danger to electrical pressures vastly in excess of any producible by ordinary apparatus, for they may amount to several million volts, as has been shown in actual practice. Now, when a conducting body is electrified to so high a degree, small particles, which may be adhering firmly to its surface, are torn off with violence and thrown to distances which can be only conjectured. I find that not only firmly adhering matter, as paint, for instance, is thrown off, but even the particles of the toughest metals are torn off. Such actions have been thought to be restricted to a vacuous inclosure, but with a powerful coil they occur also in the ordinary atmosphere. The facts mentioned would make it reasonable to expect that this extraordinary effect which, in other ways, I have already usefully applied, will likewise prove to be of value in electro-therapy. The continuous improvement of the instruments and the study of the phenomenon may shortly lead to the establishment of a novel mode of hygienic treatment which would permit an instantaneous cleaning of the skin of a person, simply by connecting the same to, or possibly, by merely placing the person in the vicinity of a source of intense electrical oscillations, this having the effect of throwing off, in a twinkle of the eye, dust or particles of any extraneous matter adhering to the body. Such a result brought about in a practicable manner would, without doubt, be of incalculable value in hygiene and would be an efficient and time-saving substitute for a water bath, and particularly appreciated by those whose contentment consists in undertaking more than they can accomplish.

High frequency impulses produce powerful inductive actions and in virtue of this feature they lend themselves in other ways to the uses of the electro-therapeutist. These inductive effects are either electrostatic or electrodynamic. The former diminish much more rapidly with the distance—with the square of the same—the latter are reduced simply in proportion to the distance. On the other hand, the former grow with the square of intensity of the source, while the latter increase in a simple proportion with the intensity. Both of these effects may be utilized for establishing a field of strong action extending through considerable space, as through a large hall, and such an arrangement might be suitable for use in hospitals or institutions of this kind, where it is desirable to treat a number of patients at the same time.

Fig. 6 illustrates the manner, as I have shown it originally, in which such a field of electrostatic action is established. In this diagram G is a generator of currents of very high frequency, C a condenser for counteracting the self-induction of the circuit which includes the primary P of an induction coil, the secondary S of which has two plates t t of large surface connected

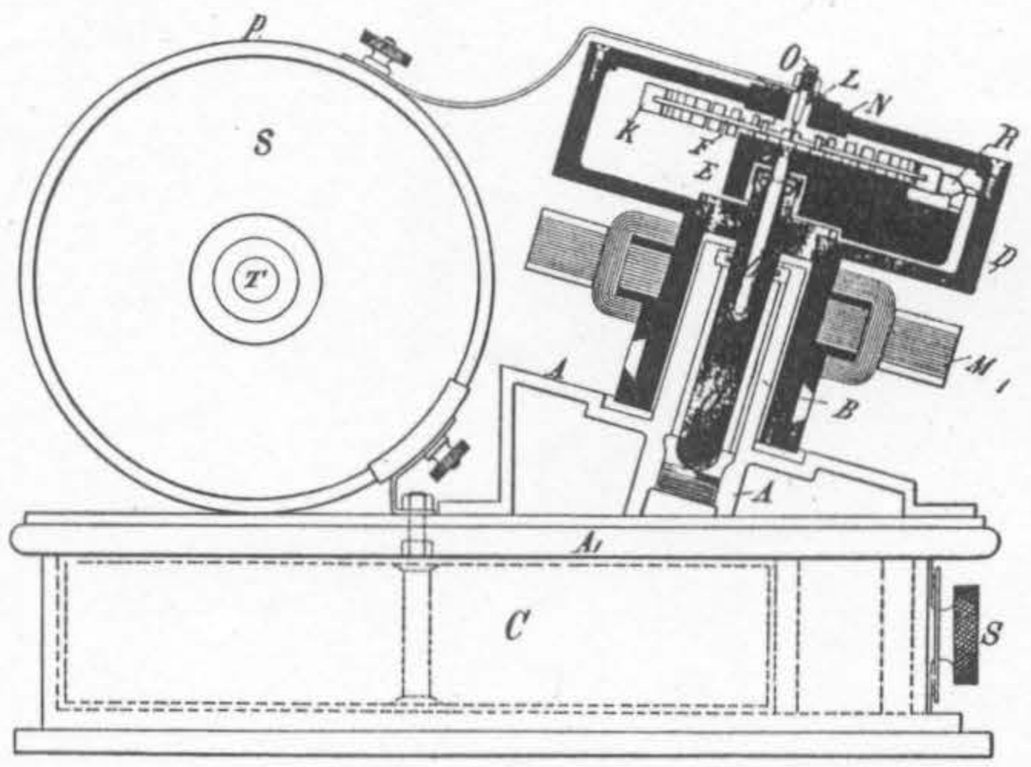


FIG. 9.

to its terminals. Well known adjustments being observed, a very strong action occurs chiefly in the space between the plates, and the body of a person is subjected to rapid variations of potential and surgings of current, which produce, even at a great distance, marked physiological effects. In my first experiments I used two metal plates as shown, but later I found it preferable to replace them by two large hollow spheres of brass covered with wax of a thickness of about two inches. The cables leading to the terminals of the secondary coil were similarly covered, so that any of them could be approached without danger of the insulation breaking down. In this manner the unpleasant shocks, to which the experimenter was exposed when using the plates, were prevented.

In Fig. 7 a plan for similarly utilizing the dynamic inductive effects of high frequency currents is illustrated. As the frequencies obtainable from an alternator are not as high as is desired, conversion by means of condensers is resorted to. The diagram will be understood at a glance from the foregoing description. It only need be stated that the primary p, through which the condensers are made to discharge, is formed by a thick stranded cable of low self-induction and resistance, and passes all around the hall. Any number of secondary coils s s s, each consisting generally of a single layer of rather thick wire, may be provided. I have found it practicable to use as many as one hundred, each being adjusted for a definite period and responding to a particular vibration passed through the primary. Such a plant I have had in use in my laboratory since 1892, and many times it has contributed to the pleasure of my visitors and also proved itself of practical utility. On a latter occasion I had the pleasure of entertaining some of the mem-

bers with experiments of this kind, and this opportunity I cannot let pass without expressing my thanks for the interest which was awakened in me by their visit, as well as for the generous acknowledgment of the courtesy by the Association. Since that time my apparatus has been very materially improved, and now I am able to create a field of such intense induction in the laboratory that a coil three feet in diameter, by careful adjustment, will deliver energy at the rate of one-quarter of a horse power, no matter where it is placed within the area inclosed by the primary loops. Long sparks, streamers and all other phenomena obtainable with induction coils are easily producible anywhere within the space, and such coils, though not connected to anything, may be utilized exactly as ordinary coils, and what is still more remarkable, they are more effective. For the past few years I have often been urged to show experiments in public, but, though I was desirous to comply with such requests, pressing work has so far made it impossible. These advances have been the result of slow but steady improvement in the details of the apparatus which I hope to be able to describe connectedly in the near future.

However remarkable the electrodynamic inductive effects, which I have mentioned, may appear, they may be still considerably intensified by concentrating the action upon a very small space. It is evident that since, as before stated, electromotive forces of many thousand volts are maintained between two points of a conducting bar or loop only a few inches long, electromotive forces of approximately the same magnitude will be set up in conductors situated near by. Indeed, I found that it was practicable in this manner to pass a discharge through a highly exhausted bulb, although the electromotive force required amounted to as much as ten or twenty thousand volts, and for a long time I followed up experiments in this direction with the object of producing light in a novel and more economical way. But the tests left no doubt that there was great energy consumption attendant to this mode of illumination, at least with the apparatus I had then at command, and, finding another method which promised a higher economy of transformation, my efforts turned in this new direction. Shortly afterward (some time in June, 1891,) Prof. J. J. Thomson described experiments which were evidently the outcome of long investigation, and in which he supplied much novel and interesting information, and this made me return with renewed zeal to my own experiments. Soon my efforts were centered upon producing in a small space the most intense inductive action, and by gradual improvement in the apparatus I obtained results of a surprising character. For instance, when the end of a heavy bar of iron was thrust within a loop powerfully energized, a few moments were sufficient to raise the bar to a high temperature. Even heavy lumps of other metals were heated as rapidly as though they were placed in a furnace. When a continuous band formed of a sheet of tin was thrust into the loop, the metal was fused instantly, the action being comparable to an explosion, and no wonder, for the frictional losses accumulated in it at the rate of possibly ten horse power. Masses of poorly conducting material behaved similarly, and when a highly exhausted bulb was pushed into the loop, the glass was heated in a few seconds nearly to the point of melting.

When I first observed these astonishing actions, I was interested to study their effects upon living tissues. As may be assumed, I proceeded with all the necessary caution, and well I might, for I had the evidence that in a turn of only a few inches in diameter an electromotive force of more than ten thousand volts was produced, and such high pressure would be more than sufficient to generate destructive currents in the tissue. This appeared all the more certain as bodies of comparatively poor conductivity were rapidly heated and even partially destroyed. One may imagine my astonishment when I found that I could thrust my hand or any other part of the body within the loop and hold it there with impunity. More than on one occasion, impelled by a desire to make some novel and useful observation, I have willingly or unconsciously performed an experiment connected with some risk, this being scarcely avoidable in laboratory experience, but I have always believed, and do so now, that I have never undertaken anything in which, according to my own estimation, the chances of being injured were so great as when I placed my head within the space in which such terribly destructive forces were at work. Yet I have done so, and repeatedly, and have felt nothing. But I am firmly convinced that there is great danger attending such an experiment, and some one going just a step farther than I have gone may be instantly destroyed. For, conditions may exist similar to those observable with a vacuum bulb. It may be placed in the field of the loop, however intensely energized, and so long as no path for the current is formed, it will remain cool and consume practically no energy. But the moment the first feeble current passes, most of the energy of the oscillations rushes to the place of consumption. If by any action whatever, a conducting path were formed within the living tissue or bones of the head, it would result in the instant destruction of these and death of the foolhardy experimenter. Such a method of killing, if it were rendered practicable, would be absolutely painless. Now, why is it that in a space in which such violent turmoil is going on living tissue remains uninjured? One might say the currents cannot pass because of the great self-induction offered by the large conducting mass. But this it cannot be, because a mass of metal offers a still higher self-induction and is heated just the same. One might argue the tissues offer too great a resistance. But this again cannot be the reason, for all evidence shows that the tissues conduct well enough, and besides, bodies of approximately the same resistance are raised to a high temperature. One might attribute the apparent harmlessness of the oscillations to the high specific heat of the tissue, but even a rough quantitative estimate from experiments with other bodies shows that this view is untenable. The only plausible explanation I have so far found is that the tissues are condensers. This only can account for the absence of injurious action. But it is remarkable that, as soon as a heterogeneous circuit is constituted, as by taking in the hands a bar of metal and forming a closed loop in this manner, the passage of the currents through the arms is felt, and other physiological effects are distinctly noted. The strongest action is, of course, secured when the exciting loop makes only one turn, unless the connections take up a considerable portion of the total length of the circuit, in which case the experimenter should settle upon the least number of turns by carefully estimating what he loses by increasing the number of turns, and what he gains by utilizing thus a greater proportion of the total length of the circuit. It should be borne in mind that, when the exciting coil has a considerable number of turns and is of some length, the effects of electrostatic induction may preponderate, as there may exist a very great difference of potential—a hundred thousand volts or more—between the first and last turn. However, these latter effects are always present even when a single turn is employed.

When a person is placed within such a loop, any pieces of metal, though of small bulk, are perceptibly warmed. Without doubt they would be also heated—particularly if they were of iron—when embedded in living tissue, and this suggests the possibility of surgical treatment by this method. It might be possible to sterilize wounds, or to locate, or even to extract metallic objects, or to perform other operations of this kind within the sphere of the surgeon's duties in this novel manner.

Most of the results enumerated, and many others still more remarkable, are made possible only by utilizing the discharges of a condenser. It is probable that but a very few—even among those who are working in these identical fields—fully appreciate what a wonderful instrument such a condenser is in reality. Let me convey an idea to this effect. One may take a condenser, small enough to go in one's vest pocket, and by skilfully using it he may create an electrical pressure vastly in excess—a hundred times greater if necessary—than any producible by the largest static machine ever constructed. Or, he may take the same condenser and, using it in a different way, he may obtain from it currents against which those of the most powerful welding machine are utterly insignificant. Those who are imbued with popular notions as to the pressures of static machines and currents obtainable with a commercial transformer, will be astonished at this statement—yet the truth of it is easy to see. Such results are obtainable, and easily, because the condenser can discharge the stored energy in an inconceivably short time. Nothing like this property is known in physical science. A compressed spring, or a storage battery, or any other form of device capable of storing energy, cannot do this; if they could, things undreamt of at present might be accomplished by their means. The nearest approach to a charged condenser is a high explosive, as dynamite. But even the most violent explosion of such a compound bears no comparison with the discharge or explosion of a condenser. For, while the pressures which are produced in the detonation of a chem-

ical compound are measured in tens of tons per square inch, those which may be caused by condenser discharges may amount to thousands of tons per square inch, and if a chemical could be made which would explode as quickly as a condenser can be discharged under conditions which are realizable—an ounce of it would quite certainly be sufficient to render useless the largest battleship.

That important realizations would follow from the use of an instrument possessing such ideal properties I have been convinced since long ago, but I also recognized early that great difficulties would have to be overcome before it could replace less perfect implements now used in the arts for the manifold transformations of electrical energy. These difficulties were many. The condensers themselves, as usually manufactured, were inefficient, the conductors wasteful, the best insulation inadequate, and the conditions for the most efficient conversion were hard to adjust and to maintain. One difficulty, however, which was more serious than the others, and to which I called attention when I first described this system of energy transformation, was found in the devices necessarily used for controlling the charges and discharges of the condenser. They were wanting in efficiency and reliability and threatened to prove a decided drawback, greatly restricting the use of the system and depriving it of many valuable features. For a number of years I have tried to master this difficulty. During this time a great number of such devices were experimented upon. Many of them promised well at first, only to prove inadequate in the end. Reluctantly, I came back upon an idea on which I had worked long before. It was to replace the ordinary brushes and commutator segments by fluid contacts. I had encountered difficulties then, but the intervening years in the laboratory were not spent in vain, and I made headway. First it was necessary to provide for a circulation of the fluid, but forcing it through by a pump proved itself impractical. Then the happy idea presented itself to make the pumping device an integral part of the circuit interrupter, inclosing both in a receptacle to prevent oxydation. Next some simple ways of maintaining the circulation, as by rotating a body of mercury, presented themselves. Then I learned how to reduce the wear and losses which still existed. I fear that these statements, indicating how much effort was spent in these seemingly insignificant details will not convey a high idea of my ability, but I confess that my patience was taxed to the utmost. Finally, though, I had the satisfaction of producing devices which are simple and reliable in their operation, which require practically no attention and which are capable of effecting a transformation of considerable amounts of energy with fair economy. It is not the best that can be done, by any means, but it is satisfactory, and I feel that the hardest task is done.

The physician will now be able to obtain an instrument suitable to fulfil many requirements. He will be able to use it in electro-therapeutic treatment in most of the ways enumerated. He will have the facility of providing himself with coils such as he may desire to have for any particular purpose, which will give him any current or any pressure he may wish to obtain. Such coils will consist of but a few turns of wire, and the expense of preparing them will be quite insignificant. The instrument will also enable him to generate Röntgen rays of much greater power than obtainable with ordinary apparatus. A tube must still be furnished by the manufacturers which will not deteriorate and which will allow to concentrate larger amounts of energy upon the electrodes. When this is done, nothing will stand in the way of an extensive and efficient application of this beautiful discovery which must ultimately prove itself of the highest value, not only at the hands of the surgeon, but also of the electro-therapist and, what is most important, of the bacteriologist.

To give a general idea of an instrument in which many of the latter improvements are embodied, I would refer to Fig. 9, which illustrates the chief parts of the same in side elevation and partially in vertical cross-section. The arrangement of the parts is the same as in the form of instrument exhibited on former occasions, only the exciting coil with the vibrating interrupter is replaced by one of the improved circuit breakers to which reference has been made.

This device comprises a casting A with a protruding sleeve B, which in a bushing supports a freely rotatable shaft a. The latter carries an armature within a stationary field magnet M and on the top, a hollow iron pulley D, which contains the break proper. Within the shaft a, and concentrically with the same, is placed a smaller shaft b, likewise freely movable on ball-bearings and supporting a weight E. This weight being on one side and the shafts a and b inclined to the vertical, the weight remains stationary as the pulley is rotated. Fastened to the weight E is a device R in the form of a scoop with very thin walls, narrow on the end nearer to the pulley and wider on the other end. A small quantity of mercury being placed in the pulley and the latter rotated against the narrow end of the scoop, a portion of the fluid is taken up and thrown in a thin and wide stream towards the centre of the pulley. The top of the latter is hermetically closed by an iron washer, as shown, this washer supporting on a steel rod L a disk F of the same metal provided with a number of thin contact blades K. The rod L is insulated by washers N from the pulley, and for the convenience of filling in the mercury a small screw o is provided. The bolt L forming one terminal of the circuit breaker is connected by a copper strip to the primary p. The other end of the primary coil leads to one of the terminals of the condenser C, contained in a compartment of a box A, another compartment of the same being reserved for switch S and terminals of the instrument. The other terminal of the condenser is connected to the casting A and through it to pulley D. When the pulley is rotated, the contact blades K are brought rapidly in and out of contact with the stream of mercury, thus closing and opening the circuit in quick succession. With such a device it is easy to obtain ten thousand makes and breaks per second and even more. The secondary s is made of two separate coils and so arranged that it can be slipped out, and a metal strip in its middle connects it to the primary coil. This is done to prevent the secondary from breaking down when one of the terminals is overloaded, as it often happens in working Röntgen bulbs. This form of coil will withstand a very much greater difference of potential than coils as ordinarily constructed.

The motor has both field and armature built of plates, so that it can be used on alternating as well as direct current supply circuits, and the shafts are as nearly as possible vertical, so as to require the least care in oiling. Thus, the only thing which really requires some attention is the commutator of the motor, but where alternating currents are always available, this source of possible trouble is easily done away with.

The circuit connections of the instrument have been already shown and the mode of operation explained in periodicals. The usual manner of connecting is illustrated in Fig. 8, in which A_2 A_2 are the terminals of the supply circuit, L, a self-induction coil for raising the pressure, which is connected in series with condenser C and primary P P. The remaining letters designate the parts correspondingly marked in Fig. 9 and will be understood with reference to the latter.

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Mr. Tesla and the Czar.

THE personality of Mr. Tesla is one of the most fascinating in the field of modern invention, and his work is such as to command the interest of both the lay and the scientific public whenever he chooses to give details of his investigations and researches. If he had never done more than develop the theory and practice of the multiphase system, his life would have been useful above the ordinary; and even should it happen that none of his other ideas ever get into practical shape, his discoveries in electricity must always be regarded as important. We cannot number ourselves among those who, like the distinguished scientists, Profs. Brackett and Dolbear, quoted in our columns this week, are impatient with his tendency to let imagination outrun achievement and who virtually class him as a humbug. Mr. Tesla fools himself, if he fools anybody, when he launches forth

into the dazzling theories and speculations associated with his name. That he should desire to benefit the human race in ways now unknown, and should avow out loud belief in his capacity to do so, is surely not discreditable, any more than it is unworthy in the head of his own poetic Slavic race to propose the disarmament of the world. Granted that there will still be wars, and granted that all these wonderful visions of new arts in peace do not fructify without the work of a score of later geniuses, why find fault either with the Czar or with Mr. Tesla? Their aims appear wholly noble, their thoughts are beautiful, and if they fail, as they probably will in some material and vital respects, the world is certainly none the worse off for what they actually accomplish.

Just of late Mr. Tesla has been giving publicity to some of his newest work, and it is peculiarly interesting. We should have been glad, personally, to see him finish up some of the many other things that have occupied his energies these ten years past, but none of which now claim any place. For example, his "oscillator," or combination of generator and steam engine, which was to wipe out all other methods of power generation and reduce vastly the cost of power, by steam and electric economies. The very name is now bestowed by Mr. Tesla on another piece of apparatus, and though illustrated in detail and brought before the Chicago Electrical Congress in 1893, the "oscillator" of the original brand is, for aught the public knows, in the scrap heap. Yet it was a lovely invention, of infinite possibilities. We can only regret its neglect and oblivion, but if Mr. Tesla has other things more appealing to his mind for the present, that is his own business.

Of late also Mr. Tesla has brought forward another plan of power generation and transmission. At one period he expressed his belief in ability to disturb the earth's charge and thus send currents through the earth. That does not appear to be so feasible or attractive now as the idea of using the upper strata of the air which he says have a very superior conductivity. He would tether up aloft balloons in those strata and deliver to them large quantities of current at such high potential that it would travel economically across the space without wires, say from Niagara Falls to Paris. By this facile distribution of water power, coal and steam would become unnecessary to industry. The new plan may explain why Mr. Tesla has abandoned his old steam oscillator. It is earnestly to be hoped that this novel idea will prove workable. Balloons were a dismal failure in our late war, but that is no criterion, and Mr. Tesla may have some superior gas for inflation and sustentation purposes. It will be remembered that Mr. Marconi has already telegraphed from balloon to balloon, without wires, a distance of over twenty miles, thus proving in advance the tenability of Mr. Tesla's proposition.

The tremendous hold that war has taken upon the public mind is shown by the fact that even a genius of Mr. Tesla's independence is compelled to invention in that field. A patent issued to him last week intimates that he believes that torpedos and torpedo boats which were so utterly useless and unmanageable in the late conflict with Spain can be made more valuable if controlled entirely from shore, by a Navy Board, and without any crew. Last spring the ability to explode floating torpedos under ships from a distance without any wires was brilliantly demonstrated at Madison Square Garden several times a day for a month. Taking that idea, Mr. Tesla has applied the same principle to the electro-mechanical steering of torpedos, just as it is now done with several types, but, of course, in his case, without the intervening wires from shore. He is very sanguine that this will stop war, and we pray heartily that it may. The article or patent digest we print in this issue on the subject suggests improvements of his on existing apparatus that may render it, in spite of its great delicacy, able to evade jarring and jolting, the perils of the open sea, the defensive network crinolines around the ships, the concussions of great guns, and the intentional explosion of defenses placed in its way thus to derange and negative its operation. During the late war, apparatus far less sensitive than coherers was rendered useless by the firing of the heavy artillery on the ships, and it must be a preternaturally tough coherer that would escape the same fate. So also it must be a very difficult problem for which Mr. Tesla cannot suggest half a dozen diagrammatic solutions.

While all these curious things are "in the air," so to speak, it is a distinct pleasure to be able to print, as we do in this issue, Mr. Tesla's able and thoughtful paper read before the Buffalo meeting of the American Electro-Therapeutic Association. It compensates for the disappointment experienced from his unfinished lecture two years ago before the New York Academy of Sciences, which has never found its way into print, but of which the opening passages indicated the covering of the same ground. We trust that the data given by Mr. Tesla may stimulate our medical friends to greater employment of electricity. It is unfortunately true that disastrous results from injudicious use by some of them of Prof. Röntgen's great discovery of the X-ray have made medical men fight shy of handling electricity themselves lately, and we do not know whether Mr. Tesla's experiments will altogether reassure them, so striking and farreaching are they. But the saving of human life is a sacred thing. Every means and instrumentality must be tried by the surgeon and the physician, and it is devoutly to be hoped that having stopped the slaughter due to war Mr. Tesla will revert at some time to this brilliant paper and give the doctors apparatus that will help prevent the slaughter due to accident and disease.

It is not our desire to pose as apologists or publicists for Mr. Tesla. He needs no assistance of that kind; and so long as he commands freely whole pages of the Sunday papers, for which Mr. Wanamaker pays gladly his thousands of dollars, the technical and scientific journals have, indeed, little to do with the matter. All we wish to say is that it is not fair to condemn, as so many do, Mr. Tesla as visionary and impractical. No man has finished his work till he is dead, and even then there are long, long centuries in which his ideas can prove themselves true. The visionaries are thus often, in the end, the most sordid of realists—something Mr. Tesla will never be.

NEWS & NOTES

Tesla's Electrical Control of Moving Vessels or Vehicles from a Distance.

IN view of the public interest of late in anything which has a warlike appearance or apparatus tending to render war less probable by making it more horrible and destructive, and in view also of numerous recent disasters at sea, the current descriptions in the daily papers of a new invention of Mr. Tesla and reported interviews with him have been received with widely differing comments. In Mr. Tesla's own words, the invention consists of a complete and practicable solution of the problem of controlling from a given point the operation of the propelling engines, the steering apparatus and other mechanism carried by a moving object, such as boat or floating vessel, whereby the movement and the course of such a vessel may be directed and controlled from a distance, and any device carried by the same brought into action at any desired time. The system is based on the use, upon the object to be exploded or steered, of a Branly coherer and Marconi agitator of novel form, toward which impulses are sent from a Hertzian radiator. It will be remembered that this is what was done in a small but very successful way at the Electrical Exhibition in Madison Square Garden last May, when miniature floating torpedos fastened on a board floating under the bottom of model men-of-war were thus blown up daily, without wires, by means of the same "wireless telegraph" methods, from a distance of not less than 50 or 60 feet. Mr. Tesla's application is dated in July. It was one of the intentions at the exhibition to place all the receiving apparatus on the boat in the water; but for obvious reason pertinent to the locality it was found desirable to run the boat connections to a temporary shelf at the top edge of the tank and rest the cohering apparatus there; so that the floating mines or torpedos could be renewed frequently and also to prevent the boat from floating about, as one or two people were hurt by flying pieces when the explosions took place too near the sides. Another object was to prevent the continuous destruction of the coherers, being delicate and expensive apparatus then not readily obtainable. Mr. Tesla in his scheme embodies the idea of placing the coherer on the floating torpedo, and proposes that the impulses taken up by the coherer shall also operate steering magnets, as in other dirigible torpedos, such as the Sims-Edison, but without the wires to shore. This method he elaborates with wonted ingenuity, although he does not include the firing of artillery, which was also done last May at the exhibition, and of course might be done with equal facility on a floating ship, without wires from the shore; or on a submerged fort or an uninhabited monitor at a harbor entrance. His patent is limited merely, it would appear, to devices or mechanism for steering, and does not claim either the discharge of explosives or selective signaling, or other features of that kind.

Referring to Fig. 1, A designates any type of vessel or vehicle which is capable of being propelled and directed, such as a boat, a balloon, or a carriage. It may be designed to carry in a suitable compartment B objects of any kind, according to the nature

of the uses to which it is to be applied. The vessel—in this instance a boat—is provided with suitable propelling machinery, which is shown as comprising a screw propeller C, secured to the shaft of an electromagnetic motor D, which derives its power from storage batteries E E E E. In addition to the propelling engine or motor the boat carries also a small steering motor F, the shaft of which is extended beyond its bearings and provided with a worm which meshes with a toothed wheel G. This latter is fixed to a sleeve b, freely movable on a vertical rod H, and is rotated in one or the other direction, according to the direction of rotation of the motor F.

The sleeve b on rod H is in gear, through the cog-wheels H′ and H″, with a spindle G, mounted in vertical bearings at the stem of the boat and carrying the rudder F′.

The apparatus by means of which the operation of both the

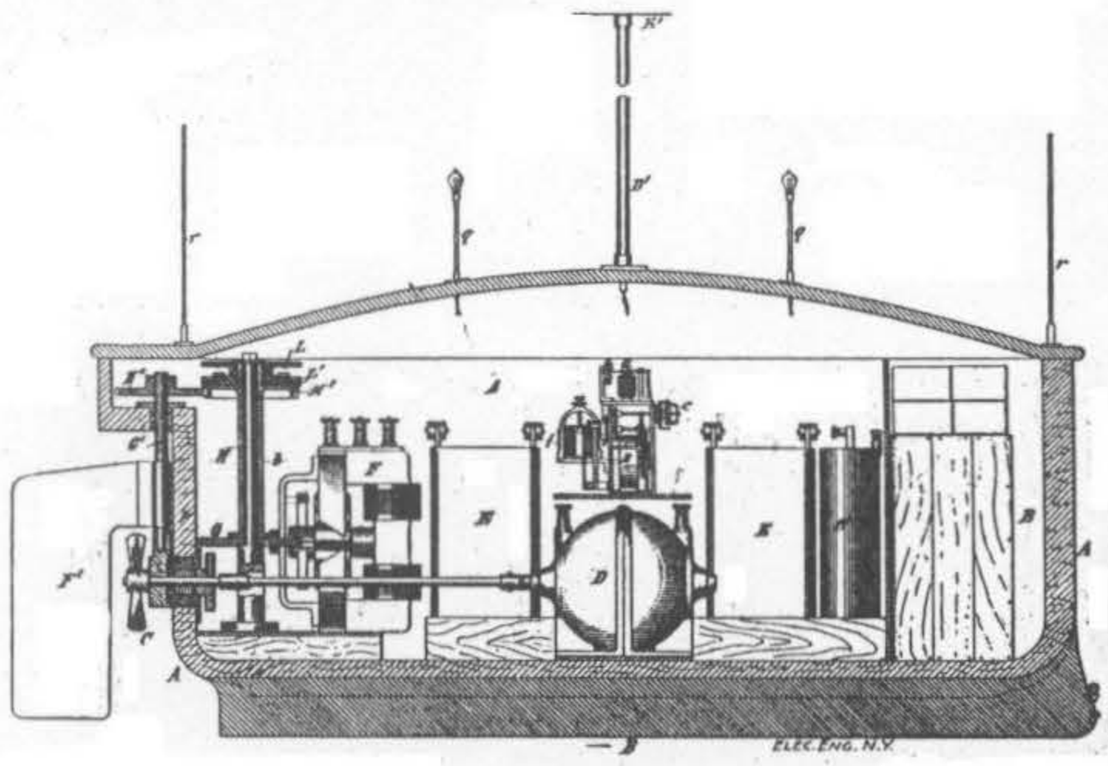


FIG. 1.

propelling and steering mechanisms is controlled involves a receiving circuit, adjusted and rendered sensitive to the influence of waves or impulses emanating from a remote source, the adjustment being so that the period of oscillation of the circuit is either the same as that of the source or a harmonic thereof.

The receiving circuit proper (diagrammatically shown in Fig. 2) comprises a terminal E′, conductor C′, a sensitive device A′, and a conductor A″, leading to the ground conveniently through a connection to the metal keel B′ of the vessel. The terminal E′ should present a large conducting surface and should be supported as high as practicable on a standard D′, which is shown as broken in Fig. 1; but such provisions are not always necessary. It is important to insulate very well the conductor C′ in whatever manner it be supported.

The circuit or path just referred to forms also a part of a local circuit, which latter includes a relay magnet a and a battery a′, the electromotive force of which is, as before explained, so determined that although the dielectric layers in the sensitive device A′ are subjected to a great strain, yet normally they withstand the strain and no appreciable current flows through the local circuit; but when an electrical disturbance reaches the circuit the dielectric films are broken down, the resistance of the device A′ is suddenly and greatly diminished, and a current traverses the relay magnet A.

The particular sensitive device employed consists of a metal cylinder, with insulating heads, through which passes a central metallic rod. A small quantity of grains of conducting material, such as an oxidized metal, is placed in the cylinder. A metallic strip, secured to an insulated post, bears against the side of the cylinder, connecting it with one part of the circuit. The central rod is connected to the frame of the instrument and so to the other part of the circuit. This instrument, which is similar in construction to the ordinary Branly coherer, differs from it only in the method used for restoring the particles to their original position after each impulse. Mr. Tesla uses for this purpose a spring device operated by the armature of an electromagnet. This is said to overcome all serious defects caused by the unequal size.

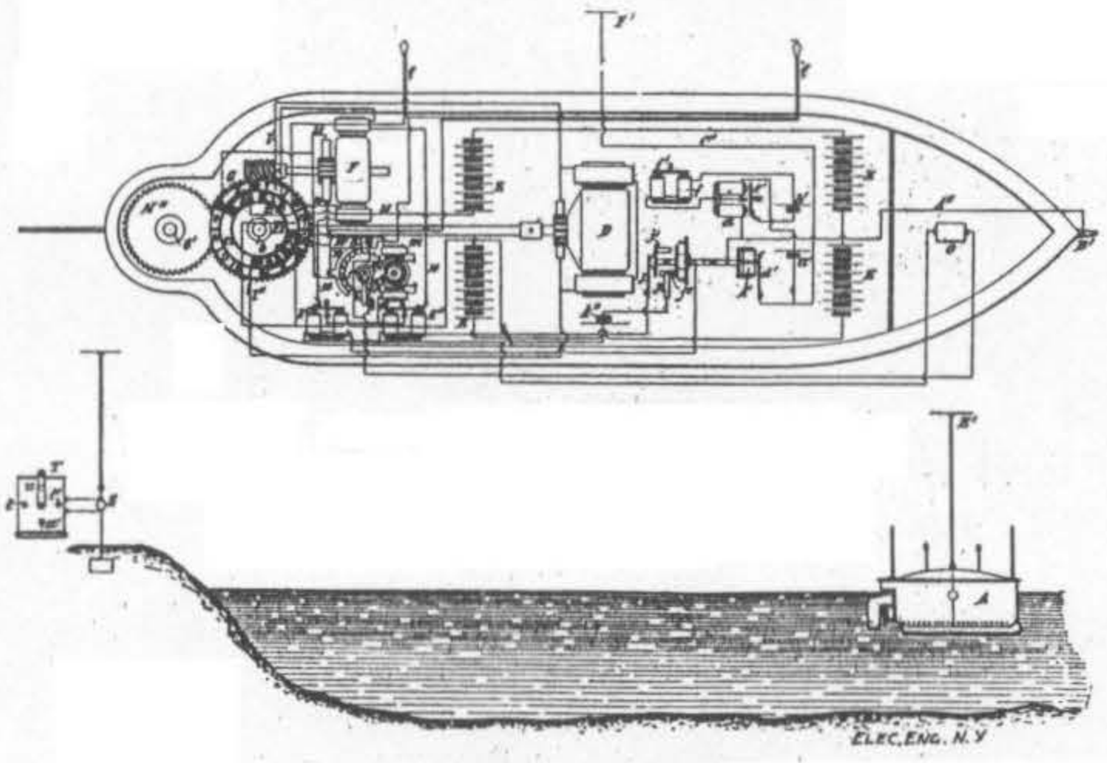
To do away with the defects in the sensitive device, Mr. Tesla makes the particles by a special tool, insuring their equality in size, weight and shape, and they are then uniformly oxidixed by placing them for a given time in an acid solution. This secures equal conductivity of their surfaces and stops their further deterioration, thus preventing a change in the character of the gas in the space in which they are enclosed. He prefers not to rarefy the atmosphere within the sensitive device, as this has the effect of rendering the former less constant in regard to its dielectric properties, but merely secures an airtight inclosure of the particles and rigorous absence of moisture, which is fatal to satisfactory working.

The normal position of the cylinder c is vertical, and when turned in the manner described, the grains in it are simply shifted from one end to the other; but inasmuch as they always fall through the same space and are subjected to the same agitation they are brought after each operation of the relay to precisely the same electrical condition and offer the same resistance to the flow of the battery current until another impulse from afar reaches the receiving current.

Referring again to Fig. 2, K′ K″ are two relay magnets conveniently placed in the rear of the propelling engine. One terminal of a battery k″ is connected to one end of each of the relay coils, the opposite terminal to the brush J′, and the opposite ends of the relay coils to the brush J and to the frame of the instrument, respectively. As a consequence of this arrangement either the relay K′ or K″ will be energized as the brush J′ bears upon the plate j′ or j″, respectively, or both relays will be inactive while the brush J′ bears upon an insulating space between the plates j′ and j″. While one relay, as K′, is energized, its armature closes a circuit through the motor F, which is rotated in a direction to throw the rudder to port. On the other hand, when relay K″ is active another circuit through the motor F is closed, which reverses its direction of rotation and shifts the rudder to starboard. These circuits, however, are at the same time utilized for other obvious purposes.

Mr. Tesla informs a "Herald" reporter that using his special apparatus for the production of electrical waves and impulses, he will operate from his laboratory in New York a model which he will exhibit at the Paris Exposition in 1900; from which it may be inferred that he does not expect immediate practical utilization of the idea beyond that with which the New York public has already been made familiar by the electrical exhibition of last May.

The reporters who have been allowed to enter the laboratory state that Mr. Tesla has there a model roughly outlined of a torpedo boat on stocks, the keel of copper plate, with rudder and propeller in the usual positions, and showing two small incandescent lamps on standards. With this he illustrates the operation of the steering gear and of the lights by means of the



FIGS. 2 AND 3.

apparatus for projecting and receiving the electrical waves or impulses. No details are given by them of the mechanism.

Discussing the subject Prof. C. F. Brackett, of Princeton University, says: "The shortest, most correct and most complete criticism which I can make in reference to this bold boast is that what is new about it is useless, while that which is useful had all been discovered by other scientists long before Tesla made this startling announcement. You will find the whole theory which he has applied in any up-to-date text book. What Tesla has done is simply to make theoretical application, which would prove to be absolutely ridiculous in application of inventions

which had already been discovered. There is nothing new about this. The theory is perfect, but the application absurd. So throughout Tesla's whole elaborate scheme, the theory is not at fault, although there is nothing original about it, but the circumstances under which its application would be necessitated are such that the only result would be failure. Do you suppose that in the din of battle it would be possible to put into execution those minute and carefully adjusted mechanical experiments, all of which are presupposed by his theory, which require the quiet of an uninterrupted laboratory to work successfully? Or do you think that the enemy would co-operate with the attack and place their vessels in exactly the correct position to be hit or that they would remain stationary while the torpedo boat approached? His theory would have to assume an affirmative answer in order to be a success, and moreover the torpedo boat would have to be seen from the base of operations in order to direct it. It would be discovered by the doomed vessel long before it reached its destination, and would be exploded on the spot, so how great an advance is this on the present mode of warfare?"

Prof. A. E. Dolbear, of Tufts College, Massachusetts, says: "This last so-called invention of Nikola Tesla's is a very pretentious affair, and it is so incredible that the story is not to be believed until the work is actually done. If Tesla said all that the 'Herald' quotes him as saying, then his whole scheme and his manner of working is unintelligible to me. He even says that 'this power can be exerted at any distance by an agency of so delicate, so impalpable a quality, that I feel I am justified in predicting that the time will come when it can be called into action by the mere exercise of the human will.'

"That is getting a little outside of science, but you will notice that Tesla himself is only predicting that this will come true. There has been no accomplishment. He proposes to do great things, but he does not tell how he is going to do them, and he hasn't done them himself yet.

"The announcement is most amazing, and, coming as it does from Tesla, scientists are all the more chary about accepting it. During the last six years he has made so many startling announcements and has performed so few of his promises that he is getting to be like the man who called 'Wolf! wolf!' until no one listened to him. Mr. Tesla has failed so often before that there is no call to believe these things until he really does them. Meantime, we are all waiting with much patience and without solicitude. We will believe them when they are done."

A FEW particulars of Mr. Nikola Tesla's new method of electric power transmission are given in the current uumber of the *Electrical Review*. From the article it appears that the invention consists in transmitting electrical power without the employment of metallic line conductors, by taking advantage of the conductivity of the rarefied air existing in the upper regions

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of the earth's atmosphere. In order to make this practicable, special apparatus has been devised for the production and conversion of excessively high electrical pressure. Heretofore, it has been possible, by means of the apparatus at command, to produce only moderate electrical pressures, and even these, with considerable risks and difficulties. Mr. Tesla, however, claims that he has devised means whereby he is enabled to generate, with safety and ease, electrical pressures measured by hundreds of thousands, and even by millions of volts. He has also, during his investigations with such apparatus, discovered certain highly important and useful facts, which are said to render practicable his new system of transmitting electrical energy. Among these are the following: first, that with electrical pressures of the magnitude and character which he has been able to produce, the ordinary atmosphere becomes, in a measure, capable of serving as a true conductor for the transmission of the current; second, that the conductivity of the air increases so materially with the increase of electrical pressure and the degree of exhaustion, that it becomes possible to transmit, through even moderately rarefied strata of the atmosphere, electrical energy up to practically any amount and to any distance.

Tesla Talks

And Confirms His Astounding Story.

A TALL, spare man entered from the side door. He had a keen face—the dome of the head seeming to overbalance the sensitive chin.

This was the man who jounced the reading world out of its usual apathy several days ago by declaring that war would be abolished—the means being an invention of his, by which a torpedo or boat could be controlled from shore, although entirely cut off from ordinary means of communication—the governing impulses to be sent through the air.

"You must excuse me," he said, with a pleasant foreign accent, "but I cannot be interviewed. There is so m' :h put down that I do not say, and the subject is of too great importance to be treated lightly."

"But, Mr. Tesla, am I to understand that your invention remains to be perfected, or is now ready for operation?"

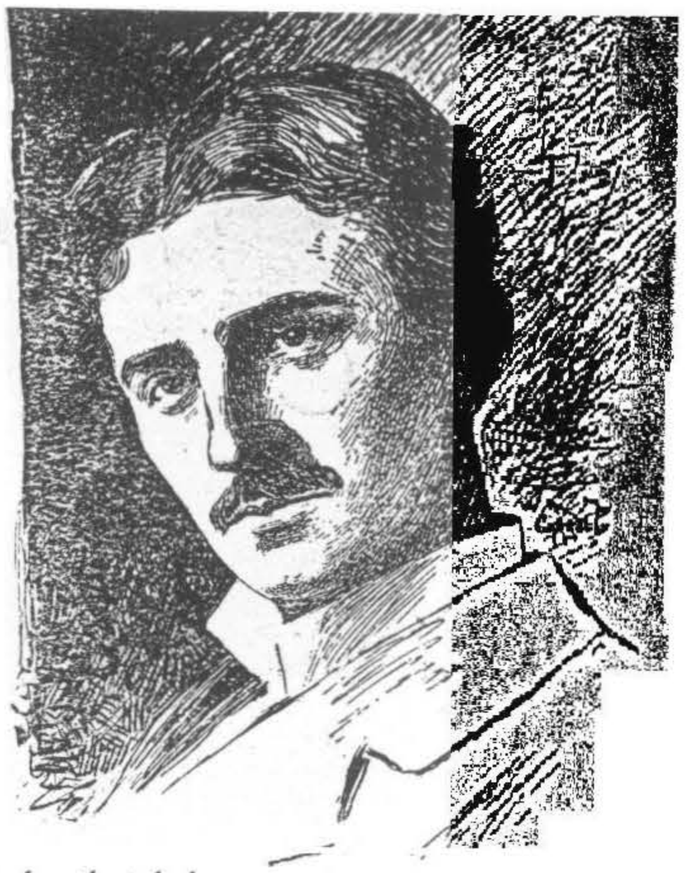
"It is now!" he answered, eagerly. "Within three days can be made ready a launch, torpedo boat, or what you will. There are four—five—men in the world who could apply these principles—not more—but they, by taking a piece here and something there, now that I have disclosed my idea, could utilize the invention at once. I do not care to make it quite so strong for publication, as every new idea arouses antagonism, and many people may call me fanatic, for that statement, but it is true."

"Could not a man-of-war have your sending apparatus on board, and thereby defeat the object of the people on shore, who send out the torpedo-boat?"

"No, they cannot thwart me. If they send signals they do it blind—as if shooting in the dark. Were there no protection but that, I should be safe, but I have a protection beyond that. It is an arrangement whereby the apparatus will recognize no signal but my own. If they attempt to thwart me they only hasten their own destruction, and, more than this, should they by any chance destroy the boat—what harm? Send out another four—ten—why not?"

"Would it not be difficult to hit a man-of-war at a distance of, say, twenty miles? It would be a good target close at hand, but a slight divergence caused by an ocean current, a draft of wind or any one of a number of things might cause your torpedo-boat to miss her mark."

"Great accuracy is not of necessity. A boat loaded with five hundred pounds of gun-cotton would shake a vessel sorely by exploding within five hundred yards of her—think, then, of exploding five hundred tons! The size of my vessel is not limited. Why, it would raise a wave four hundred feet high—sufficient to sink any ship afloat, more surely a man-of-war; they are all top-heavy."



"Then you think that this invention is a practical thing at the present time?"

"Yes, sir. It is so. I think, also, that it is the greatest discovery of the age. There is a something artistic—an appeal to the imagination in it that the telephone, phonograph and other fine inventions lack. Think of the abolishment of war! And the means of doing it—by a vessel which I can control merely by a touch on an instrument not connected with it in any way. No wire—nothing! More than that, I do not have to touch the instrument."

"Now there's something, Mr. Tesla, that brings us to the psychological part of it. The papers quoted you as saying that you——

"Could control the apparatus by an effort of will," broke in the inventor. "There it was they perverted my meaning. Now listen—I can stand two metres away from that instrument, and by a mere stiffening of my muscles cause it to send a signal. It is so delicate in its adjustment that the disturbance of the electrical equilibrium caused by my muscular action affects it. Inasmuch as Sir William Crookes, that distinguished scientist and my good friend, has not hesitated to state openly his belief in telepathy, it is a reasonable flight of fancy for me to say that my machine—so sensitive—may be affected by the human will. But that is all it is—merely a pleasant speculation, founded on logical grounds. I have no evidence to support it, but I have a perfect right to state it—understand me—as a possibility—no more."

"But is not an apparatus of such extreme delicacy little suited to the rough-and-ready usages of warfare?"

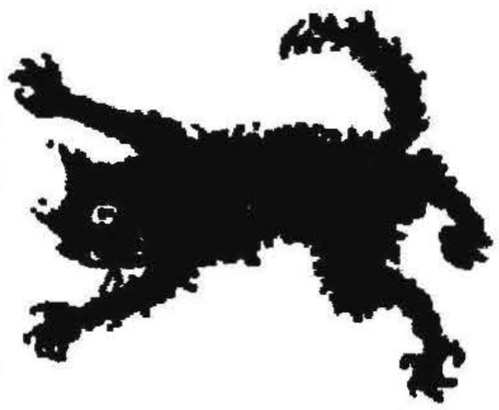
"No—that is provided for. True, it would take experts to handle it, but they could do it. It is a great invention. Had I nothing else to show for a life-work, this would put the laurels of everlasting fame on my head. The people at the Patent Office were astonished that so simple and reasonable an idea had not occurred to someone before. I am sick with working on it; but it is complete. It is strange, but when I have an inspiration, always it seems to me as if my mother were near me—at my bedside—during my work—all the time. She was an inventor. She invented a weaving machine, attending to all details herself. Yes, and many things of more importance. My father was a mathematician and linguist. He was a man of note in both studies, but from my mother comes the inventive faculty, and now, though she is dead, when the pressure of thought of some new idea is on me, I feel her presence. But, concerning the invention. It is my idea to have a submerged vessel, having two rods sticking above water, or two puffs of smoke coming out, whereby to steer it; then it would be safe from the projectiles of the enemy.

"My device can also be used to propel lifeboats—Oh! of course, for any kind of boat. It is a thing of the present time and a thing that will work a revolution of the politics of the whole world. At first the smaller nations may have a desire to bully in their new-found strength, but that will adjust itself—and now, as I am very busy——

"Just one moment—What is your nationality, Mr. Tesla?"

"I am a Servian—not from the Kingdom of Servia, but from the outskirts—near Montenegro, And now I must say good-morning."

H. W. Phillips.





Mr. Tesla's Application of Hertz-Wave Transmission.

Exercising their well-developed ability to make a startling piece of news of a very ordinary event, the daily papers have taken up Mr. Nikola Tesla's recent patent, No. 613,809, issued November 8, 1898, and made of it "the greatest marvel of the age." The facts, as set forth in the patent cited, are in brief as follows: Hitherto the only practical means of controlling the movements of a vessel, such as a torpedo or a torpedo boat, at a distance has been the use of a cable, the disadvantages of which are obvious. The plan proposed by the inventor is to provide any such craft with a coherer connected between the hull and an elevated terminal and to so arrange the propelling and steering mechanism, which is motor-driven with storage-battery supply, that it can be controlled by various relays and auxiliary devices actuated through the agency of the Hertz waves.

A single coherer is used, the inventor preferring this to a plurality of coherers respectively syntonized to respond to waves of different frequency, although he states that he has "demonstrated the practicability of providing a great number of such receiving circuits—50 or 100 or more—each of which may be called up or brought into action when desired, without the others being interfered with." This coherer possesses some elements of novelty designed to yield a more uniform de-cohering action. It consists of a metal cylinder with insulating ends and a metal rod passing lengthwise through it. The cylinder normally stands with its axis vertical, and the de-cohering action consists of inverting it, throwing the granules or particles, which, according to the illustration, occupy about one-fifth of its length, from one end to the other. The patent also describes these granules as "manufactured by a special tool, insuring their equality in size, weight and shape, and uniformly oxidized by placing them for a given time in an acid solution of pre-determined strength. This secures equal conductivity of their surfaces and stops their further deterioration, thus preventing a change in the character of the gas in the space in which they are enclosed. I prefer not to rarefy the atmosphere within the sensitive device, as this has an effect of rendering the former less constant in regard to its dielectric properties, but merely secure a water-tight enclosure of the particles and rigorous absence of moisture, which is fatal to satisfactory working."

The auxiliary devices consist of ordinary relays, actuating a simple step-by-step escapement wheel, which in turn rotates brushes and commutators, affecting the various internal circuits of the boat. These differ in no essential respect from the rosettes or circuit controllers of synchronous printing-telegraph instruments, and many other means of accomplishing the same results by a different arrangement of details could, of course, be devised. There is apparently nothing broadly new in this part of the invention. The claims upon it, however, are very broad, the first claim reading as follows: "The improvement in the art of controlling the movements and operation of a vessel or vehicle herein described, which consists in producing waves or disturbances, which are conveyed to the vessel by the natural media, actuating thereby suitable apparatus on the vessel and effecting the control of the propelling engine, the steering and other mechanism by the operation of the said apparatus, as set forth." It is doubtful if this claim would withstand litigation in case of infringement, if it ever became possible to make such a system operative, as it is simply the use of the coherer as a relay for actuating a step-by-step mechanism, instead of a simple sounder. It is obvious that, unless Mr. Tesla has made revolutionary improvements in Hertz-wave apparatus which have not yet been disclosed, the coherer and auxiliary apparatus working therewith are altogether too delicate for the service proposed.

Mr. Tesla is quoted by the daily press in this connection as follows:

"War will cease to be possible when all the world knows that the most feeble of the nations can supply itself immediately with a weapon which will render its coast secure and its ports impregnable to the assaults of the united armadas of the world. Battleships will cease to be built, and the mightiest armorclads and the most tremendous artillery afloat will be of no more use than so much scrap iron. And this irresistible power can be exerted at any distance by an agency of so delicate, so impalpable a quality that I feel that I am justified in predicting that the time will come, incredible as it may seem, when it can be called into action by the mere exercise of the human will.

"My imagination fairly reels when I attempt to contemplate its countless possibilities. Already I hear the knell of the battleship and the monster gun. Their day has passed with the advent of a new and irresistible power, which gives to all nations an absolute power of defense against any attack.

"England has until now boasted of her mastery of the seas, but her superiority has vanished and she is now no stronger than the weakest of the maritime nations, so far as her offensive power is concerned. England, who is now so diligently preparing for war, will awake to this unwelcome discovery to-morrow and will be utterly confounded; and France, against whom her armaments have been reported to be preparing, will rejoice in the discovery that she possesses an all-powerful weapon of defense.

* * * * * *

"But I have no desire that my fame should rest on the invention of a merely destructive device, no matter how terrible. I prefer to be remembered as the inventor who succeeded in abolishing war. That will be my highest pride. But there are many peaceful uses to which my invention can be put, conspicuously that of rescuing the shipwrecked.

"It will be perfectly feasible to equip our life-saving stations with life cars, or life boats, directed and controlled from the shore, which will approach stranded vessels and bring off the passengers and crews without risking the lives of the brave fellows who are now forced to fight their way to the rescue through the raging surf. It may also be used for the propulsion of pilot boats, for carrying letters or provisions or instruments to inaccessible regions, for killing whales and for many other commercial or scientific purposes.

"In order to give a practical illustration of this it is my intention to exhibit a model of a torpedo boat at the Paris Exposition and direct all its movements from my office in New York." * * *

It is probable that the movements will be directed by messages sent via the transatlantic cables; otherwise we would advise the use of the torpedo boat and its directing mechanism for trans-oceanic telegraphy.

Tesla's Latest Claim.

Following is a verbatim statement from Nikola Tesla, in his application for a patent which last week was issued to him:

The problem, for which the invention forming the subject of the present application affords a complete and practicable solution, is that of controlling from a given point the operation of the propelling engines, the steering apparatus and other mechanism carried by a moving object, such as a boat, or any floating vessel, whereby the movements and course of such body or vessel may be directed and controlled from a distance, and any device carried by the same, brought into action at any desired time.

So far as I am aware, the only attempts to solve this problem, which have heretofore met with any measure of success, have been made in connection with a certain class of vessels, the machinery of which was governed by electric currents conveyed to the controlling apparatus through a flexible conductor. But this system is subject to such obvious limitations as are imposed by the length, weight and strength of the conductor which can be practically used, by the difficulty of maintaining with safety a high speed of the vessel or changing the direction of movement of the same with the desired rapidity, by the necessity for effecting the control from a point which is practically fixed, and by many well understood drawbacks inseparably connected with such a system.

The plan which I have perfected involves none of these objections, for I am enabled by the use of my invention to employ any means of propulsion, to impart to the moving body or vessel the highest possible speed, to control the operation of its machinery and to direct its movements from either a fixed point or from a body moving and changing its direction, however rapidly, and to maintain this control over great distances, without any artificial connections between the vessel and the apparatus governing its movements, and without such restrictions as these must necessarily impose.

In a broad sense, then, my invention differs from all of those systems which provide for the control of the mechanism carried by a moving object and governing its motion, in that I require no intermediate wires, cables or other form of electrical or mechanical connection with the object, save the natural media in space. I accomplish, nevertheless, similar results, and in a much more practicable manner, by producing waves, impulses or radiations, which are received through the earth, water or atmosphere by suitable apparatus on the moving body and cause the desired actions, so long as the body remains within the active region or effective range of such currents, waves, impulses or radiations.

The many and difficult requirements of the object here contemplated, involving peculiar means for transmitting to a considerable distance an influence capable of causing, in a positive and reliable manner, these actions, necessitated the designing of devices and apparatus of a novel kind in order to utilize to the best advantage various facts or results which, either through my own investigations or those of others, have been rendered practically available.

As to the part of my invention which involves the production of suitable waves or radiations and the conveying of the same to a remote receiving apparatus capable of being operated or controlled by their influence, it may be carried out in various ways which are at the present time more or less understood. For example, I may pass through a conducting path, preferably enclosing a large area, a rapidly varying current and by electro-magnetic induction of the same, affect a circuit carried by the moving body. In this case the action at a given distance will be the stronger the larger the area enclosed by the conductor and the greater the rate of change of the current. If the latter were generated in the ordinary ways, the rate of change, and consequently the distance at which the action would be practically available for the present purpose, would be very small; but by adopting such means as I have devised, that is, either by passing through the conducting path currents of a specially designed high-frequency alternator, or better still, those of a strongly charged condenser, a very high rate of change may be obtained, and the effective range of the influence thus extended over a vast area, and by carefully adjusting the circuit on the moving body so as to be in exact electro-magnetic synchronism with the primary disturbances, this influence may be utilized at great distances.

Another way to carry out my invention is to direct the currents or discharges of a high-frequency machine or condenser through a circuit, one terminal of which is connected directly or inductively with the ground and the other to a body, preferably of large surface and at an elevation. In this case if the circuit on the moving body be similarly arranged or connected, differences of potential on the terminals of the circuit, either by conduction or electrostatic induction, are produced, and the same object is attained. Again, to secure the best action, the receiving circuit should be adjusted so as to be in electro-mangnetic synchronism with the primary source as before, but in this instance it will be understood by those skilled in the art that, if the number of vibrations per unit of time be the same, the circuit should now have a length of conductor only one half of that used in the former case.

(*To be Continued.*)

Tesla's Latest Claim.

NUMBER II.

In last week's issue appeared the first installment of a verbatim statement from Nikola Tesla in his application for a patent. After a detailed recital of the proposed method and device, he says: What I claim is—

1. The improvement in the art of controlling the movements and operation of a vessel or vehicle herein described, which consists in producing waves or disturbances which are conveyed to the vessel by the natural media, actuating thereby suitable apparatus on the vessel and effecting the control of the propelling engine, the steering and other mechanism by the operation of the said apparatus, as set forth.

2. The improvement in the art of controlling the movements and operation of a vessel or vehicle, herein described, which consists in establishing a region of waves or disturbances, and actuating, by their influence exerted at a distance, the devices on such vessel or vehicle, which control the propelling, steering and other mechanism thereon, as set forth.

3. The improvement in the art of controlling the movements and operation of a vessel or vehicle, herein described, which consists in establishing a region of electrical waves or disturbances, and actuating, by their influence exerted at a distance, the devices on said vessel or vehicle, which control the propelling, steering and other mechanism thereon, as set forth.

4. The improvement in the art of controlling the movements and operation of a vessel or vehicle, herein described, which consists in providing on the vessel a circuit controlling the propelling, steering and other mechanism, adjusting or rendering such circuit sensitive to waves or disturbances of a definite character, establishing a region of such waves or disturbances, and rendering by their means the controlling circuit active or inactive, as set forth.

5. The combination with a source of electrical waves or disturbances of a moving vessel or vehicle, and mechanism thereon for propelling, steering or operating the same, and a controlling apparatus adapted to be actuated by the influence of the said waves or disturbances at a distance from the source, as set forth.

6. The combination with a source of electrical waves or disturbances of a moving vessel or vehicle, mechanism for propelling, steering or operating the same, a circuit and means therein for controlling said mechanism and means for rendering said circuit active or inactive through the influence of the said waves or disturbances exerted at a distance from the source, as set forth.

7. The combination with a source of electrical waves or disturbances and means for starting and stopping the same of a vessel or vehicle, propelling and steering mechanism carried thereby, a circuit containing or connected with means for controlling the operation of said mechanism and adjusted or rendered sensitive to the waves or disturbances of the source, as set forth.

8. The combination with a source of electrical waves or disturbances and means for starting and stopping the operation of the same, of a vessel or vehicle, propelling and steering mechanism carried thereby, local circuits controlling said mechanisms, a circuit sensitive to the waves or disturbances of the source and means therein adapted to control the said local circuits, as and for the purpose set forth.

9. The sensitive device herein described comprising in construction a receptacle containing a material such as particles of oxidized metal forming a part of the circuit, and means for turning the same end for end when the material has been rendered sensitive by the passage through it of an electric discharge, as set forth.

10. The sensitive device herein described, comprising in combination a receptacle containing a material such as particles of oxidized metal forming a part of an electric circuit, an electro-magnet in said circuit and devices controlled thereby for turning the receptacle end for end when said magnet is energized, as set forth.

11. The sensitive device herein described, comprising in combination a receptacle containing a material such as particles of oxidized metal forming part of an electric circuit, a motor for rotating the receptacle, an electro-magnet in circuit with the material and an escapement controlled by said magnet and adapted to permit a half revolution of the receptacle when the said magnet is energized, as set forth.

12. The combination with a movable body or vehicle, of a propelling motor, a steering motor and electrical contacts carried by a moving portion of the steering mechanism, and adapted in certain positions of the latter to interrupt the circuit of the propelling motor, a local circuit and means connected therewith for controlling the steering motor, and a circuit controlling the local circuit and means for rendering said controlling circuit sensitive to the influence of electric waves or disturbances exerted at a distance from their source, as set forth.

13. The combination with the steering motor, a local circuit for directing current through the same in opposite directions, a controlling circuit rendered sensitive to the influence of electric waves or disturbances exerted at a distance from their source, a motor in circuit with the steering motor, but adapted to run always in the same direction, and a local circuit or circuits controlled by said motor, as set forth.

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FACT AND FANCY.

Mr. Nikola Tesla, of New York, has invented what is known in naval science as a dirigible torpedo, that is to say, a torpedo which, instead of being self-driven and self-steering, like the Whitehead and the Howell, now in use in our navy, is driven and steered by an operator on shore, who controls the torpedo through electrical connections. Of the latter kind are the Sims-Edison, the Brennan, and the Victoria.

The Sims-Edison torpedo is driven by an electric motor carried within the shell of the torpedo, and it is steered by exciting certain magnets which control the steering gear. Current for operating the motor and magnets is supplied through a flexible cable which is wound upon a reel carried within the shell of the torpedo, and has one end connected to the shore. As the torpedo travels through the water, the cable unwinds. The torpedo is maintained at the proper depth by attaching it to a canoe-shaped float. To enable the operator to follow the course of the torpedo, two small flagstaffs are carried at each end of the float, and by keeping his eye on these, the operator is supposed to be able to steer the deadly weapon unerringly on its course. By night two colored lights are carried at the ends of the flagstaffs, and are hooded in such a way that, while they are visible to the operator, they are invisible to the enemy.

The Victoria, an Australian invention, differs from the last-mentioned in being entirely submergible below the water and in using compressed air as its motive power. When first started, it hauls a cable after it, unwinding it off a reel on shore, and the first part of its course is covered at moderate speed. When the operator has guided it to within striking distance of the enemy, a current is sent through the cable, which releases the reel on the torpedo and allows its cable to unwind. At the same time the current starts the air engines at full speed, and the final dash for the ship is made. The Brennan is another torpedo of the dirigible type, which received considerable attention as the result of its being taken up by the British Admiralty and subjected to exhaustive experiments. Like all the torpedoes of the dirigible type, however, it has proved to be only moderately successful, and, in common with them, is not regarded with much favor by naval authorities, the Whitehead automobile being par excellence the torpedo of the present day.

The most characteristic feature in Mr. Tesla's torpedo as distinguished from the others of the dirigible class is that, whereas they use a connecting cable for transmitting the controlling power to the torpedo, he makes use of the Hertzian waves, dispensing with the cable. This method of transmission is more popularly known under the name of "wireless telegraphy," and as such attracted considerable public attention during the recent experiments by the British Post Office with the apparatus designed by the young Italian, Marconi. On another page we reproduce some of the drawings accompanying the patent which has recently been granted to Mr. Tesla, and these, together with the descriptive matter, will render this interesting device clear to our readers.

Regarding the merits of the invention and its practical value, it is altogether too early to make any predictions. The abolition of the connecting cables is, of course, greatly to be desired, and the Tesla torpedo will, presumably, be rid of the liability to accident due to several thousand yards of cable trailing in the water. On the other hand, since the propelling current can no longer be transmitted from the shore, it becomes necessary to provide batteries within the torpedo itself, thereby adding again the weight that was saved by abolishing the cable.

It is true the range of the torpedo is enlarged (according to the inventor, indefinitely); but as the Sims-Edison has an extreme range of two miles, at which distance it would be extremely difficult to follow the motion of the two small flagstaffs above referred to, we fail to see what advantages would ensue from being able to drive and control the torpedo at any greater distance.

Except so far as it dispenses with the cables, it is not evident what advantages the Tesla torpedo possesses over others of the dirigible type, and unless it proves far more effective in actual test than they have done, it cannot be considered as even a formidable weapon.

Unfortunately for its reception by the thinking public, Mr. Tesla's improvement has been introduced to the world with some of the most extravagant rhapsodies that ever threw discredit upon an untried invention. Under the "scare head" title "Tesla declares he will abolish war," one of the leading New York journals quotes Mr. Tesla as saying in an interview: "War will cease to be possible when all the world knows to-morrow that the most feeble of the nations can supply itself immediately with a weapon which will render its coast secure and its ports impregnable to the assaults of the united armadas of the world. Battleships will cease to be built, and the mightiest armorclads and the most tremendous artillery afloat will be of no more use than so much scrap iron. And this irresistible power can be exerted at any distance by an agency of so delicate, so impalpable, a quality that I feel that I am justified in predicting that the time will come, incredible as it may seem, when it can be called into action by the mere exercise of the human will."

Having thus oratorically blotted out the navies of the world, the interviewed descends to particulars, and the reader, whose faith in battleships and cruisers is thus so rudely assailed, is relieved to learn that the mighty agent of this naval cataclysm is no more nor less than our time-honored friend the torpedo (that ever verdant topic of the universal destructionalist); in new war paint and snorting strange and new defiance, it is true, but still—"a torpedo." Unlike its prosaic forbears, however, this prodigy is not content with smiting anything in the way of a warship that may be in sight; for so keen is it on the scent that it could strike, we are told, a vessel that lay at Southampton, England, while the operator was snugly ensconced in the forts at Sandy Hook.

"Mr. Tesla told me," says the reporter, "that some months had elapsed since he had fully developed his device, for which he has applied for a patent. When it was learned that Admiral Cervera was bottled up at Santiago, it was his intention to apply his mechanism to several launches and similar small craft loaded with high explosives and annihilate the fleet at anchor. Admiral Cervera, however, came out and met his fate under the guns of the American fleet before the necessary arrangements could be made. Then Mr. Tesla planned a raid on the Spanish vessels in Havana Harbor, only to be thwarted by the proclamation of the suspension of hostilities."

In view of these facts we can well believe the inventor when, according to the journal in question, he says of his dirigible torpedo:

"My imagination fairly reels when I attempt to contemplate its countless possibilities. Already I hear the knell of the battleship and the monster gun! . . . England is now no stronger than the weakest of the maritime nations. . . . She will be utterly confounded, . . . and France will rejoice."

Now all this extravaganza may or may not express the true state of the "reeling imagination" above referred to. We prefer, charitably, to hope it does not; but the question to be asked in all seriousness is, What possible good can be done either to the inventor himself or to the great cause of science, which he is presumably desirous to promote, by confusing the minds of the public by such unscientific exaggerations as we have quoted above?

The facts of Mr. Tesla's invention are creditable enough in themselves. Their practical value will be demonstrated, we presume, in due course under the fierce searchlight of a test by naval experts. Until that time it would be better to allow the navies of the world to enjoy to the full that short spell of life which yet remains to them.

NIKOLA TESLA'S LATEST INVENTION.

We have recently been informed by the public press in flamboyant rhetoric that Nikola Tesla has devised a boat which is destined to revolutionize the art of warfare. Apart from its value as an excellent subject for sensational newspaper articles, Mr. Tesla's invention presents certain aspects which are, perhaps, not uninteresting from a scientific point of view. We have therefore produced herewith diagrams of this vessel, from which it will be seen that, ingenious as the mechanism employed may be, no very decided advantage is presented over the dirigible torpedo.

Of the annexed diagrams, Fig. 1 is a plan view of Tesla's boat, presenting a general view of the apparatus employed, Fig. 2 is a sectional view of the Tesla system, and Fig. 3 is a longitudinal section of the boat showing the mechanism in side elevation.

Tesla claims that, in a broad sense, his invention differs from all other systems of controlling boats, in so far as he uses no intermediate wires, cables, or other form of electrical or mechanical connection with the object, save the natural media in space.

The boat itself is provided with a propelling mechanism comprising a screw propeller, *C*, secured to the shaft of an electric motor, *D*, driven by the storage battery, *E*. The vessel is steered by a rudder controlled by a steering motor, *F*. The apparatus by means of which the operation of both the propelling and steering is controlled, involves the use of a receiving circuit adjusted and rendered sensitive to the influence of the electrical waves or impulses emanating from a distant source, the adjustment being such that the oscillations of the circuit and of the source of disturbance shall occur in electromagnetic synchronism.

The receiving circuit consists of a terminal, *E'*, a conductor, an electric controller similar to that used in "wireless" telegraphy, and means by which the current may be led to the ground through the medium of the vessel's keel. The circuit in question forms part of a local circuit, in which are included a relay magnet, *a*, and a battery, *a'*, the electromotive force of which is so determined that although the dielectric layers in the electric controller are subjected to great tension, yet normally they withstand the strain, and no appreciable current flows through the circuit. When, however, an electric impulse reaches the dielectric layers, they are broken down, thus suddenly diminishing the resistance and permitting a current to pass through the relay magnet. The particular controller employed need not be described here, but is shown in side elevation over the motor, *D*, in Fig. 3. The relay magnet, *a*, is used to control the operation of the propelling engine and of the steering apparatus.

Placed in the circuit of the electric controller is a commutator, by means of which the direction of the current may be changed in order to influence one of the two relay-magnets, *K'* or *K''*, placed in the circuit of the battery, *k''*. While one relay, *K'*, for example, is in operation, its armature closes a circuit passing through the motor, *F*, in order to cause the rudder to be swung to port. The other relay, *K''*, causes the motor to throw the rudder to starboard. The steering apparatus, as shown in Figs. 1 and 3, consists, in addition to the steering motor, *F*, of a toothed wheel, *G*, engaged by a worm on the shaft of the motor, *F*. The wheel, *G*, controls the rudder, *F'*, through the medium of a sleeve, *b*, a toothed wheel, *H''*, and rod, *G'*. A fixed vertical rod, *H*, is mounted within the sleeve, *b*, and carries an insulating disk, *L*, to the under surface of which brushes are secured. The sleeve, *b*, surrounding the rod, *H*, and turned by the motor, *F*, carries a disk, *L'*, upon the upper face of which are secured two concentric circles of conducting contact plates interspersed with insulated plates. In certain positions of the disk, *L'*, the brushes are in electric connection with the contact plates. Conductors connect the contact plates with the terminals of the propelling motor, *D*; and the poles of the battery, *E*, are so connected with two of the brushes that when the rudder is in straight position or turned to either side, the current is conveyed through these two brushes and through the contact plates to the propelling motor, *D*. The steering motor is similarly driven by current taken from the battery, *E*, and conducted to two brushes of the plate, *L*. The motor, *F*, according to Mr. Tesla, may always be caused to rotate in one direction whatever may be the position of the rudder; and may be caused to rotate in either direction whenever the rudder is inclined less than 45° from the center position.

In addition to this mechanism the vessel carries a small auxiliary motor, *m* (Fig. 1), connected in series with the armature of the steering motor. By means of this auxiliary motor, lights on the ends of the standards, *q*, may be flashed in order to indicate the course of the vessel to the operator at night.

In Fig. 2, illustrating diagrammatically the operation of the system, *S* indicates any source of electrical wave energy controlled by a switch located in a box, *T*. The handle of the switch is movable in one direction only, and stops on four points, *t*, *t'*, *u*, *u'*, so that as the handle passes from stop to stop, oscillations are produced during a very short interval. Tesla places the handle of the switch so that when arrested on the points, *t t'*, the boat is deflected respectively to the left or to the right from its course. The normal positions of the handle are *u u'*. The impulses sent forth from *S* are, according to Tesla, received by the terminal, *E'*, transmitted to the commutator, *j*, to influence one of the relays, *K' K''*, and to cause the motor, *F*, to act on the brushes to turn the rudder in whichever direction it may please the operator. The motor of the rudder causes the second set of brushes to act on the propelling motor to drive the vessel.

Whether, as Mr. Tesla claims, his apparatus, by reason of its certain and unlimited destructiveness, will tend to bring about and maintain permanent peace, is a question discussed elsewhere.

Fig. 1.

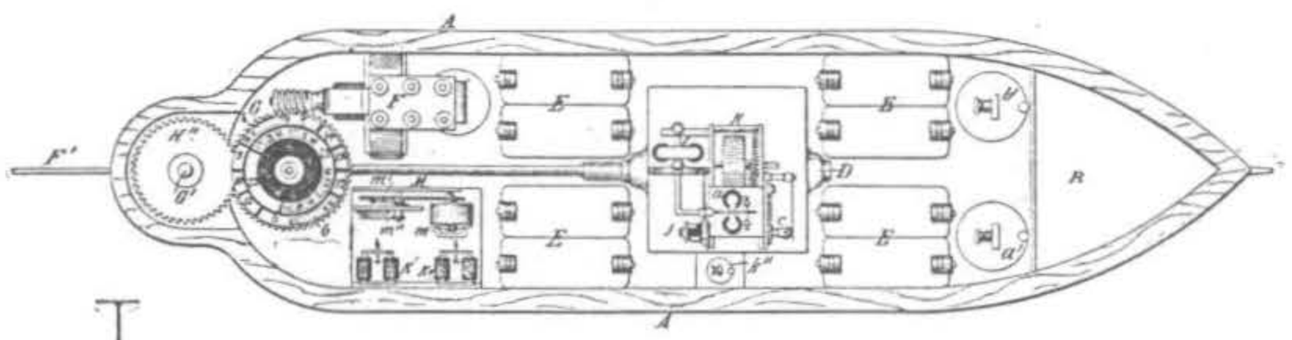


Fig. 2.

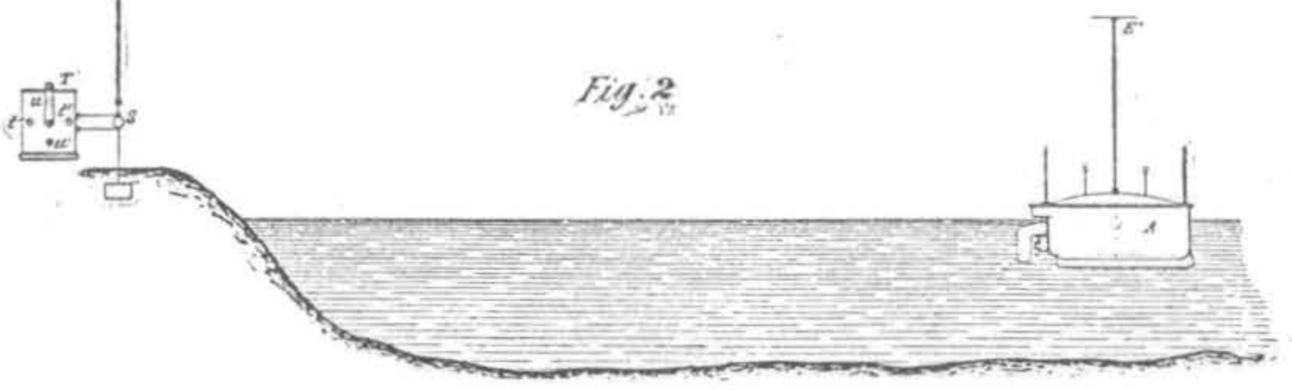
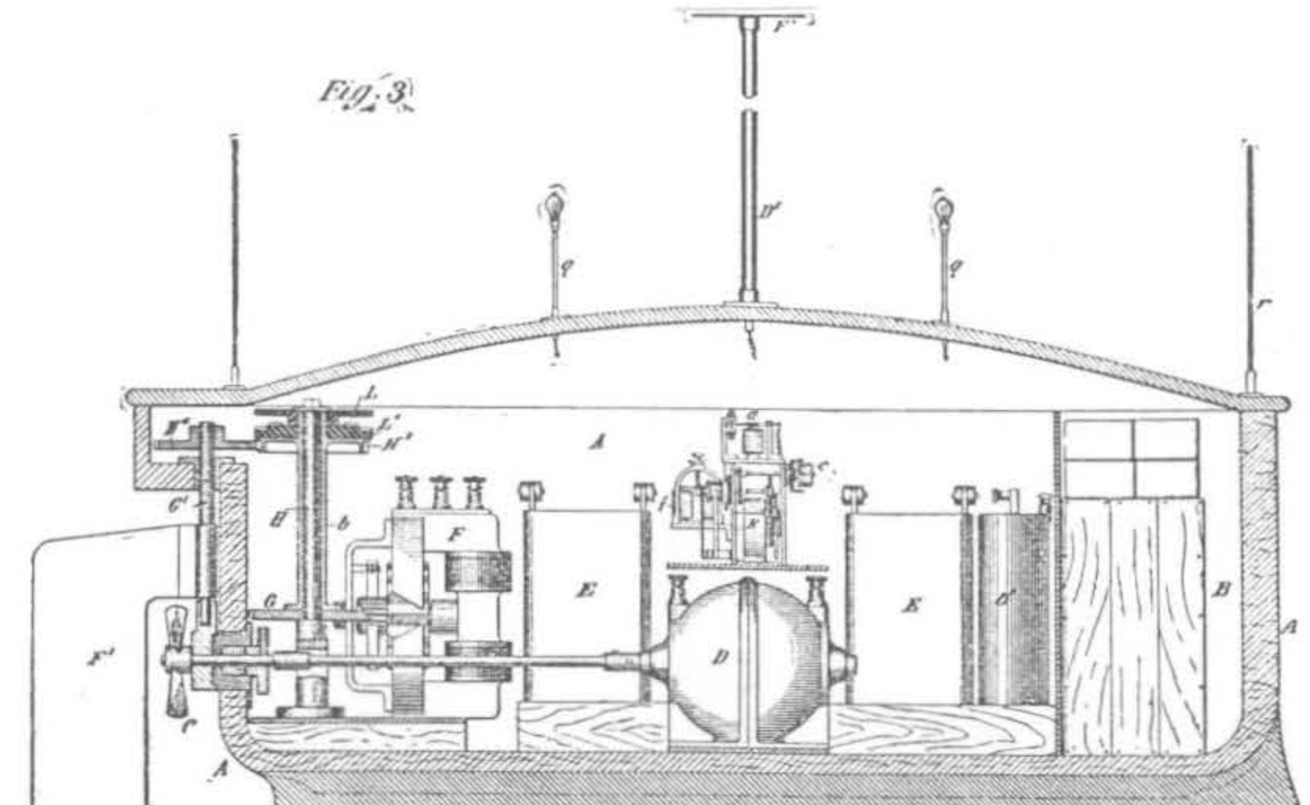


Fig. 3.



TESLA'S DIRIGIBLE BOAT.

Transmission of Power Through the Air Without Wires.

BY PROF. JOHN TROWBRIDGE.

Mr. Tesla has recently patented a method of transmitting power through the air without the use of wires. This method consists in producing a very great difference of potential between a high point in the atmosphere, reached by a wire connected to a balloon, and a distant point on a balloon, which in turn is connected through a stepdown transformer with the earth. A stepup transformer produces the high potential at the sending station, or at the first balloon, and the difference of potential thus created produces a current of conduction through the rarefied air to the second balloon and thence through the stepdown transformer to earth. Mr. Tesla relies upon the good conductivity of rarefied air to high electromotive force.

Some recent experiments I have made with high electromotive force are interesting in regard to the suggestion of Mr. Tesla, and are in continuation of those I described in the SCIENTIFIC AMERICAN for January 15, 1898. At that time my apparatus was capable of producing one million two hundred thousand volts. It now can produce three million.

Up to the point of one million and a half volts, the length of the electrical discharge in air appears to be closely proportional to the electromotive force. When this voltage is exceeded, the length of the spark no longer increases in proportion to this force, for instance, and electromotive force of approximately three million volts produces a spark of about seven feet in length, when it should excite one at least ten feet long. The reason of this diminution is readily seen when the operation of my apparatus is examined in the dark.

From both terminals and from the conductors to those terminals there is a luminous brush discharge to the walls and floor of the room. The main portion of the discharge is, so to speak, shunted through the air, which breaks down with facility at such high voltages. The high electromotive force exerts a similar action to that of diminished air pressure.

In the case of rarefied air, one sees the luminous area of discharge on the positive terminal extend farther and farther from the point of the terminal, thus indicating that there is an increased flow through the rarefied air. In ordinary atmospheric air the same increase of electrical conductivity takes place under the action of great electromotive force. When discharges produced by one million volts or more are excited between terminals six feet apart, in tubes filled with water, the tubes are speedily burst, and when the phenomenon is carefully examined, it is perceived that the disruptive sparks occur on the surface of the water inside the tubes which vaporize the water and thus lead to an explosion. The layer of air conducts more readily than the water. The same phenomenon can be shown by interposing a conductor made of plumbago and infusorial earth, making a resistance of about 10,000 ohms between the terminals of the apparatus. A spark passes over the surface of such a conductor through the air, if the length of such a conductor does not exceed ten or twelve inches.

I found also that the spark preferred to jump through five centimeters of air to passing through a thousand ohms of a copper sulphate solution. Thus the air evidently breaks down with increasing readiness when the electromotive force is increased beyond a certain limit.

One of the most striking experiments in this connection can be performed by coating a board with a thin layer of plumbago, which is polished upon the surface in such a manner as to make a resistance of about 1,000 ohms between broad terminal bands of copper. When a discharge under a difference of potential of 1,000,000 volts passes between the terminal bands, the entire surface of the conductor becomes luminous.

When my new apparatus was first set up, the coated surfaces of the Leyden jars were not more than a foot from the floor. On account of the great loss due to electrostatic induction, I determined to have the entire apparatus lifted three feet from the floor. A certain portion of the loss was thus obviated, but when discharge takes place, sparks an inch long can be drawn from the neighboring brick walls, and the entire room seems to be filled with brush discharges.

I believe, therefore, that beyond one million volts, the length of the spark is no longer proportional to the voltage, and that this departure from proportionality is due to the initial resistance of the neighboring air becoming less and less. In order to get the full effect of the voltage of my machine, I believe that it should be placed thirty or forty feet above the earth and at a distance from neighboring masses. The apparent length of lightning discharges at low altitudes is therefore no criterion of the voltage which produces these discharges; for there must be great leakage, which necessitates an excess of electromotive force to produce the discharge. On the other hand, the discharges in higher regions of the atmosphere are much lengthened on account of the increased conductivity of the medium.

In view of the experiments which I have described, I am led to believe that ordinary atmospheric air under very high voltage acts like a fairly good conductor, and I can conceive of such a high electromotive force that the initial resistance of air might not be more than the resistance of metals. The loss of electrical energy in producing difference of potential of three million volts at a distance of ten feet from the terminals of my machine is very great, and in employing such high voltages Mr. Tesla could only obviate great loss by lifting his entire generating apparatus far above the surface of the earth.

TESLA AND HIS WORK.

His Efforts in Various Fields of Investigation Described by Himself.

TO THE EDITOR OF THE SUN—*Sir:* Had it not been for other urgent duties, I would before this have acknowledged your highly appreciative editorial of Nov. 13. Such earnest comments and the frequent evidences of the highest appreciation of my labors by men who are the recognized leaders of this day in scientific speculation, discovery and invention are a powerful stimulus, and I am thankful for them. There is nothing that gives me so much strength and courage as the feeling that those who are competent to judge have faith in me.

Permit me on this occasion to make a few statements which will define my position in the various fields of investigation you have touched upon.

I cannot but gratefully acknowledge my indebtedness to earlier workers, as Dr. Hertz and Dr. Lodge, in my efforts to produce a practical and economical lighting system on the lines which I first disclosed in a lecture at Columbia College in 1891. There exists a popular error in regard to this light, inasmuch as it is believed that it can be obtained without generation of heat. The enthusiasm of Dr. Lodge is probably responsible for this error, which I have pointed out early by showing the impossibility of reaching a high vibration without going through the lower or fundamental tones. On purely theoretical grounds such a result is thinkable, but it would imply a device for starting the vibrations of unattainable qualities, inasmuch as it would have to be entirely devoid of inertia and other properties of matter. Though I have conceptions in this regard, I dismiss for the present this proposition as being impossible. We cannot produce light without heat, but we can surely produce a more efficient light than that obtained in the incandescent lamp, which, though a beautiful invention, is sadly lacking in the feature of efficiency. As the first step toward this realization I found it necessary to invent some method for transforming economically the ordinary currents as furnished from the lighting circuits into electrical vibrations of great rapidity. This was a difficult problem and it was only recently that I was able to announce its practical and thoroughly satisfactory solution. But this was not the only requirement in a system of this kind. It was necessary also to increase the intensity of the light, which at first was very feeble. In this direction, too, I met with complete success, so that at present I am producing a thoroughly serviceable and economical light of any desired intensity. I do not mean to say that this system will revolutionize those in use at present, which have resulted from the co-operation of many able men—I am only sure that it will have its fields of usefulness.

As to the idea of rendering the energy of the sun available for industrial purposes, it fascinated me early, but I must admit it was only long after I discovered the rotating magnetic field that it took a firm hold upon my mind. In assailing the problem I found two possible ways of solving it. Either power was to be developed on the spot by converting the energy of the sun's radiations or the energy of vast reservoirs was to be transmitted economically to any distance. Though there were other possible sources of economical power, only the two solutions mentioned offer the ideal feature of power being obtained without any consumption of material. After long thought I finally arrived at two solutions, but on the first of these, namely, that referring to the development of power in any locality from the sun's radiations, I cannot dwell at present. The system of power transmission without wires, in the form in which I have described it recently, originated in this manner. Starting from the two facts that the earth was a conductor insulated in space and that a body cannot be charged without causing an equivalent displacement of electricity in the earth, I undertook to construct a machine suited for creating as large a displacement as possible of the earth's electricity.

This machine was simply to charge and discharge in rapid succession a body insulated in space, thus altering periodically the amount of electricity in the earth, and consequently the pressure all over its surface. It was nothing but what in mechanics is a pump, forcing water from a large reservoir into a small one and back again. Primarily I contemplated only the sending of messages to great distances in this manner, and I described the scheme in detail, pointing out on that occasion the importance of ascertaining certain electrical conditions of the earth. The attractive feature of this plan was that the intensity of the signals should diminish very little with the distance, and, in fact, should not diminish at all, if it were not for certain losses occurring, chiefly in the atmosphere. As all my previous ideas, this one, too, received the treatment of Marsyas, but it forms, nevertheless, the basis of what is now known as "wireless telegraphy." This statement will bear rigorous examination, but it is not made with the intent of detracting from the merit of others. On the contrary, it is with great pleasure that I acknowledge the early work of Dr. Lodge, the brilliant experiments of Marconi, and of a later experimenter in this line, Dr. Slaby of Berlin. Now, this idea I extended to a system of power transmission, and I submitted it to Helmholtz on the occasion of his visit to this country. He unhesitatingly said that power could certainly be transmitted in this manner, but he doubted that I could ever produce an apparatus capable of creating the high pressures of a number of millions of volts, which were required to attack the problem with any chance of success, and that I could overcome the difficulties of insulation. Impossible as this problem seemed at first, I was fortunate to master it in a comparatively short time, and it was in perfecting this apparatus that I came to a turning point in the development of this idea. I, namely, at once observed that the air, which is a perfect insulator for currents produced by ordinary apparatus, was easily traversed by currents furnished by my improved machine, giving a tension of something like two and a half million volts. A further investigation in this direction led to another valuable fact, namely, that the conductivity of the air for these currents increased very rapidly with its degree of rarefaction, and at once the transmission of energy through the upper strata of the air, which, without such results as I have obtained, would be nothing more than a dream, became easily realizable. This appears all the more certain, as I found it quite practicable to transmit, under conditions such as exist in heights well explored, electrical energy in large amounts. I have thus overcome all the chief obstacles which originally stood in the way, and the success of my system now rests merely on engineering skill.

Referring to my latest invention, I wish to bring but a point which has been overlooked. I arrived, as has been stated, at the idea through entirely abstract speculations on the human organism, which I conceived to be a self-propelling machine, the motions of which are governed by impressions received through the eye. Endeavoring to construct a mechanical model resembling in its essential, material features the human body, I was led to combine a controlling device, or organ sensitive to certain waves, with a body provided with propelling and directing mechanism, and the rest naturally followed. Originally the idea interested me only from the scientific point of view, but soon I saw that I had made a departure which sooner or later must produce a profound change in things and conditions presently existing. I hope this change will be for the good only, for, if it were otherwise, I wish that I had never made the invention. The future may or may not bear out my present convictions, but I cannot refrain from saying that it is difficult for me to see at present how with such a principle brought to great perfection, as it undoubtedly will be in the course of time, guns can maintain themselves as weapons. We shall be able, by availing ourselves of this advance, to send a projectile at much greater distance, it will not be limited in any way by weight or amount of explosive charge, we shall be able to submerge it at command, to arrest it in its flight, and call it back, and to send it out again and explode it at will, and, more than this, it will never make a miss, since all chance in this regard, if hitting the object of attack were at all required, is eliminated. But the chief feature of such a weapon is still to be told, namely, it may be made to respond only to a certain note or tune, it may be endowed with selective power. Directly such an arm is produced, it becomes almost impossible to meet it with a corresponding development. It is in this feature, perhaps, more than in its power of destruction, that its tendency to arrest the development of arms and to stop warfare will reside. With renewed thanks, I remain, very truly, yours,

NEW YORK, Nov. 19, 1898. N. TESLA.

A Letter From Mr. Tesla.

NEW YORK, NOV. 18, 1898.
46 and 48 East Houston St.

TO THE EDITOR OF ELECTRICAL REVIEW—*Dear Sir:*

Under enclosure I forward a copy of a letter which is self-explanatory. If you consider it a justice to me to insert it in your next issue, kindly do so.

Yours very truly,
N. TESLA.

"THE ELECTRICAL ENGINEER" ASKED TO EXPLAIN.

NEW YORK, NOV. 18, 1898.
46 and 48 East Houston St.

EDITOR OF THE ELECTRICAL ENGINEER—*Sir:*

By publishing in your columns of November 17 my recent contribution to the Electro-Therapeutic Society, you have finally succeeded—after many vain attempts made during a number of years—in causing me a serious injury. It has cost me great pains to write that paper, and I have expected to see it appear among other dignified contributions of its kind, and, I confess, the wound is deep. But you will have no opportunity for inflicting a similar one, as I propose to take better care of my papers in the future. In what manner you have secured this one in advance of other electrical periodicals, who had an equal right to the same, rests with the secretary of the society to explain.

Your editorial comment would not concern me in the least, were it not my duty to take note of it. On more than one occasion you have offended me, but in my qualities both as Christian and philosopher, I have always forgiven you and have only pitied you for your errors. This time, though, your offense is graver than the previous ones, for you have dared to cast a shadow on my honor.

No doubt you must have in your possession, from the illustrious men whom you quote, tangible proofs in support of your statement reflecting on my honesty. Being a bearer of high honors from a number of American universities, it is my duty, in view of the slur thus cast upon them, to exact from you that, in your next issue, you produce these, together with this letter which, in justice to myself, I am forwarding to other electrical journals. In the absence of such proofs, which would put me in the position to seek redress elsewhere, I require that, together with the preceding, you publish instead a complete and humble apology for your insulting remark which reflects on me as well as on those who honor me.

On this condition I will again forgive you, but I would advise you to limit yourself in your future attacks to statements for which you are not liable to be punished by law.

N. TESLA.

TRANSMISSION OF POWER THROUGH THE AIR WITHOUT WIRES.

BY PROF. JOHN TROWBRIDGE IN THE "SCIENTIFIC AMERICAN."

Mr. Tesla has recently patented a method of transmitting power through the air without the use of wires. This method consists in producing a very great difference of potential between a high point in the atmosphere, reached by a wire connected to a balloon, and a distant point on a balloon, which in turn is connected through a step-down transformer with the earth. A step-up transformer produces the high potential at the sending station, or at the first balloon, and the difference of potential thus created produces a current of conduction through the rarefied air to the second balloon, and thence through the step-down transformer to earth. Mr. Tesla relies upon the good conductivity of rarefied air to high electro-motive force.

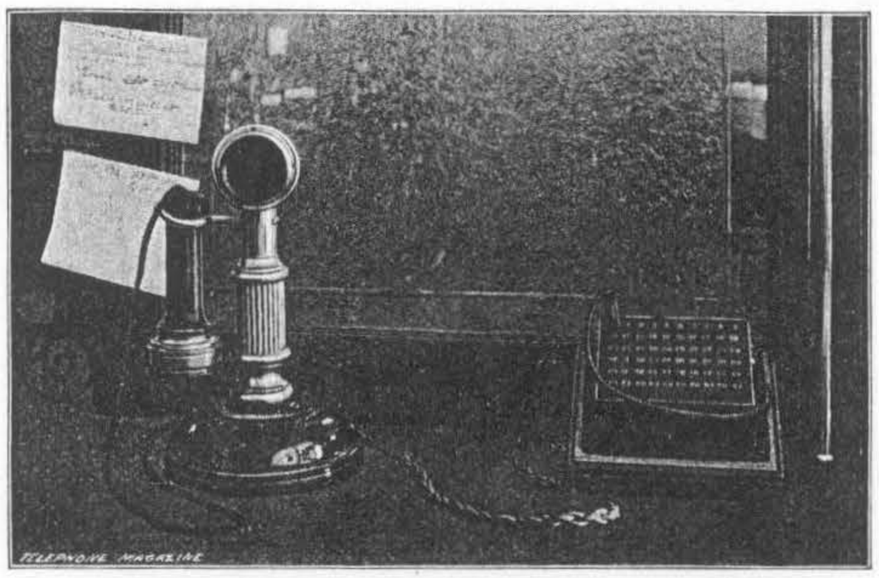


FIG. 1.—SIXTY-POINT STROMBERG-CARLSON TELEPHONE PLUG BOX.

Some recent experiments I have made with high electro-motive force are interesting in regard to the suggestion of Mr. Tesla, and are in continuation of those I described in the *Scientific American* for January 15, 1898. At that time my apparatus was capable of producing 1,200,000 volts. It can now produce 3,000,000.

Up to the point of 1,500,000 volts the length of the electrical discharge in air appears to be closely proportional to the electro-motive force. When this voltage is exceeded, the length of the spark no longer increases in proportion to this force, for instance, and electro-motive force of, approximately, 3,000,000 volts produces a spark of about seven feet in length, when it should excite one at least 10 feet long. The reason of this diminution is readily seen when the operation of my apparatus is examined in the dark.

From both terminals, and from the conductors to those terminals, there is a luminous brush discharge to the walls and floor of the room. The main portion of the discharge is, so to speak, shunted through the air, which breaks down with facility at such high voltages. The high electro-motive force exerts a similar action to that of diminished air pressure.

In the case of rarefied air, one sees the luminous area of discharge on the positive terminal extend farther and farther from the point of the terminal, thus indicating that there is an increased flow through the rarefied air. In ordinary atmospheric air the same increase of electrical conductivity takes place under the action of great electro-motive force. When discharges produced by 1,000,000 volts or more are excited between terminals six feet apart, in tubes filled with water, the tubes are speedily burst, and when the phenomenon is carefully examined, it is perceived that the disruptive sparks occur on the surface of the water inside the tubes, which vaporize the water and thus lead to an explosion. The layer of air conducts more readily than the water. The same phenomenon can be shown by interposing a conductor made of plumbago and infusorial earth, making a resistance of about 10,000 ohms between the terminals of the apparatus. A spark passes over the surface of such a conductor through the air, if the length of such a conductor does not exceed 10 or 12 inches.

I found also that the spark preferred to jump through five centimeters of air to passing through 1,000 ohms of a copper sulphate solution. Thus the air evidently breaks down with increasing readiness when the electro-motive force is increased beyond a certain limit.

One of the most striking experiments in this connection can be performed by coating a board with a thin layer of plumbago, which is polished upon the surface in such a manner as to make a resistance of about 1,000 ohms between broad terminal bands of copper. When a discharge under a difference of potential of 1,000,000 volts passes between the terminal bands, the entire surface of the conductor becomes luminous.

When my new apparatus was first set up, the coated surfaces of the Leyden jars were not more than a foot from the floor. On account of the great loss due to electrostatic induction, I determined to have the entire apparatus lifted three feet from the floor. A certain portion of the loss was thus obviated, but when discharge takes place, sparks an inch long can be drawn from the neighboring brick walls, and the entire room seems to be filled with brush discharges.

I believe, therefore, that beyond 1,000,000 volts, the length of the spark is no longer proportional to the voltage, and that this departure from proportionality is due to the initial resistance of the neighboring air becoming less and less. In order to get the full effect of the voltage of my machine, I believe that it should be placed 30 or 40 feet above the earth and at a distance from neighboring masses. The apparent length of lightning discharges at low altitudes is therefore no criterion of the voltage which produces these discharges; for there must be great leakage, which necessitates an excess of electro motive force to produce the discharge. On the other hand, the discharges in higher regions of the atmosphere are much lengthened on account of the increased conductivity of the medium.

In view of the experiments which I have described, I am led to believe that ordinary atmospheric air under very high voltage acts like a fairly good conductor, and I can conceive of such a high electro motive force that the initial resistance of air might not be more than the resistance of metals. The loss of electrical energy in producing difference of potential of 3,000,000 volts at a distance of 10 feet from the terminals of my machine is very great, and in employing such high voltages Mr. Tesla could only obviate great loss by lifting his entire generating apparatus far above the surface of the earth.

THE EARTH AND ITS ATMOSPHERE.

A CRITICISM AND ITS ANSWER.

AN INQUIRY.

To the Editor of Electrical Review:

In your issue of November 2, in an article dated New York, October 29, and entitled "Tesla's Aerial Power Transmission," T. J. M. says: "What, then, should be the effect of the earth rotating at its enormous speed *under the friction of the atmosphere*—a globe billions of times the surface of the archaic electric machine?"

If I am not mistaken, there is no "friction of the atmosphere" *with the earth*. The atmosphere moves with the earth. Did it not, we should be swept from its surface by the enormous velocity of our motion through the atmosphere.

There is no friction at the "*upper*" surface of the atmosphere, for there is absolutely nothing to cause friction.

It seems to me that T. J. M. must seek another explanation of the source of electricity that causes the electrical phenomena of the atmosphere.

S. R. M.

Ithaca, N. Y., November 4.

THE ANSWER.

To the Editor of Electrical Review:

If "S. R. M." had read discriminatingly he would have understood differently. As a whole, the earth and its atmosphere move together, or at least the text-books teach the student to consider the fact settled. But there are great disturbances constantly happening in the air and over vast areas and which can have tremendous effects capable of giving astonishing electrical manifestations, and in the upper strata electrical excitement of a most intense character would not, if manifested, cause any surprise to the modern thinker. What is a storm, if it be not a condition attended by the friction of the lower strata upon the earth's surface, and probably of the lower strata against the higher strata of air? Yet the storm may be, and often is, raging furiously over an area of a million square miles or more.

In the absence of the right sort of data, namely, observations and records of what is going on away up in our atmosphere, no one can say what is the primary cause of these great areas of high and low pressure.

Many days one can look up and observe several strata of clouds, each layer moving in an independent direction, proving the existence of stratum-friction, the clouds being merely the finger-boards or pointers, and having no relation to or bearing upon the fact of independently moving layers of air and the friction necessarily occurring.

And what is the cause of the steadily moving trade-winds in different parts of the world? Why is it that in a given locality the most destructive wind-storms always blow in the same direction? Text-books to the contrary, it is by no means demonstrated that there is no friction between the earth and its atmosphere. It is quite easy to conceive the idea of some friction, and easy to understand how the differential "winds" thus caused can take all sorts of directions. And a very little of that kind of disturbance could generate stupendous amounts of electricity. And it is quite as easy to believe—indeed, it would seem necessary to believe—that there are in the atmosphere movements just like the ocean tides, since air is as subject as water to the laws of gravitation.

T. J. M.

New York, November 12.

THE

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Mr. Tesla to His Friends.

New York, Nov. 18, 1898.
46 and 48 East Houston St.

Editor of The Electrical Engineer, 120 Liberty St., New York City.

Sir—By publishing in your columns of Nov. 17 my recent contribution to the Electro-Therapeutic Society you have finally succeeded—after many vain attempts made during a number of years—in causing me a serious injury. It has cost me great pains to write that paper, and I have expected to see it appear among other dignified contributions of its kind, and, I confess, the wound is deep. But you will have no opportunity for inflicting a similar one, as I propose to take better care of my papers in the future. In what manner you have secured this one in advance of other electrical periodicals who had an equal right to the same, rests with the secretary of the society to explain.

Your editorial comment would not concern me in the least, were it not my duty to take note of it. On more than one occasion you have offended me, but in my qualities both as Christian and philosopher I have always forgiven you and only pitied you for your errors. This time, though, your offence is graver than the previous ones, for you have dared to cast a shadow on my honor.

No doubt you must have in your possession, from the illustrious men whom you quote, tangible proofs in support of your statement reflecting on my honesty. Being a bearer of great honors from a number of American universities, it is my duty, in view of the slur thus cast upon them, to exact from you that in your next issue you produce these, together with this letter, which in justice to myself, I am forwarding to other electrical journals. In the absence of such proofs, which would put me in the position to seek redress elsewhere, I require that, together with the preceding, you publish instead a complete and humble apology for your insulting remark which reflects on me as well as on those who honor me.

On this condition I will again forgive you; but I would advise you to limit yourself in your future attacks to statements for which you are not liable to be punished by law.

N. TESLA.

His Friends to Mr. Tesla.

ONE of the foremost electrical inventors of this country, whose name is known around the world, has been kind enough to say that The Electrical Engineer made Mr. Tesla. This is an attribution that we naturally put aside, for it is a man's own work that makes or unmakes him, but we do plead guilty to the fact that for these ten years past we have done whatever mortals could do to bring Mr. Tesla forward and secure for him the recognition that was duly his. Not only in the columns of this and other journals, but in magazines and books we have striven with all the ability we possessed to explain Mr. Tesla's ideas. The record is before all men. If there is a line or a word in it that seeks to do Mr. Tesla "serious injury," we demand its production by him. The man, whoever he be, who says we have ever in word or deed or thought tried to do Mr. Tesla any sort of injury, lies.

Within the last year or two Mr. Tesla has, it seems to us, gone far beyond the possible in the ideas he has put forth, and he has to-day behind him a long trail of beautiful but unfinished inventions. By mild criticism and milder banter, not being able to lend Mr. Tesla the cordial support of earlier years of real achievement, we have only very lately endeavored to express our doubts and to urge him to the completion of some one of the many desirable or novel things promised. We believe this to be true friendship.

For example, take Mr. Tesla's latest and furthest enlargement of his newest idea, as presented by him in a signed letter in the New York "Sun," of Nov. 21, unfolding his plan to dispense with artillery of the present type. At this moment we have space only for the following passage:

"We shall be able, availing ourselves of this advance, TO SEND A PROJECTILE, at much greater distance, IT WILL NOT BE LIMITED IN ANY WAY BY WEIGHT or amount of explosive charge, we shall be able to submerge it at command, TO ARREST IT IN ITS FLIGHT AND CALL IT BACK, and to send it out again and explode it at will, and, more than this, IT WILL NEVER MAKE A MISS."

When we are expected, wide awake and in our sober senses, to accept in silence such an utterance as that quoted above or that which describes as "a possibility" the operation of a distant torpedo boat by the mere exercise of the will, we refuse point blank and we are willing to face the consequences. Our past admiration of Mr. Tesla's real, tangible work is on record, and stands; but we draw the line at such things as these. We are sorry Mr. Tesla feels it so keenly, but we cannot help it.

Now, as to the specific points raised in the above letter, which Mr. Tesla certainly would not have written had he been well advised. As to the manner in which we came to print Mr. Tesla's paper, the two letters herewith speak for themselves.

The American Electro-Therapeutic Association.
Dr. Charles R. Dickson, Ex-President.
296 Sherbourne St.
Toronto, Canada, Sept. 26, 1898.

T. Commerford Martin, Esq., 120 Liberty St., New York.

Dear Sir—I was quite surprised to hear on Saturday last from my friend, Dr. Robert Newman, of New York, that the editors of The Electrical Engineer had received no notices of the meeting of our association; I understood that the secretary had sent them. However, in case you might find space to say something of us, I have patched up an article drawn from various sources giving full particulars, which you can cut down to the desired dimensions. I fully appreciate all that you have done for the association in the past, or would not go to this trouble. I also send you a copy of the programme and of hand-book. In regard to latter, I am very sorry that the Buffalo committee had to retain for such a long time the electro of Mr. Tesla which you were so kind as to loan to them through Dr. Newman.

I have to thank you very sincerely for the loan of the electro, and hope that it reached you in good condition.

Wishing your esteemed journal continued and increasing success, very truly yours. CHARLES R. DICKSON.

The American Electro-Therapeutic Association.
Dr. Robert Newman, Chairman.
64 West 36th St.
New York City, Oct. 20, 1898.

Messrs. T. C. Martin and J. Wetzler.

Messrs. Editors—We have now the necessary vote for you publishing Tesla's paper in The Electrical Engineer, you lending us the cuts in proper size for our transactions.

The pages of our book are 7½ by 5 inches—if our secretary is not dilatory, you will receive the mss. and illustrations at once. Will call soon. Yours most truly, ROBERT NEWMAN.

These show our relations with a deserving association and our efforts to assist its work. We may add as a matter of fact, for which, if necessary, the proofs will be presented, that before printing the paper, we sent Dr. Newman to technical publishers, who refused to print the matter in book form because there was not, in their estimation, sufficient demand for it among scientific men. Failing this, we were undoubtedly glad to give it a place in our pages, as it struck us as good "copy."

We venture also to direct attention to the dates of the Dickson and Newman letters, one Sept. 26 and the other Oct. 20. The Tesla paper was read on Sept. 15 and appeared in our columns Nov. 17. Does this gap of over two months between reading and publication justify Mr. Tesla's insinuation that we took swift and mean advantage of him and of our contemporaries? Will anyone produce a letter to show that anyone of our contemporaries ever took the slightest interest in the Tesla paper or even asked for it? If such letters exist, now is the time to produce them. The paper was given to The Electrical Engineer because this journal takes a deep interest in the advance of electro-therapists and has a wide circulation among them, and according to universal custom, the paper once read became the property of the association to deal with as it chose. That, without any particular effort, we should have secured a "scoop"—to use the slang of journalism—is nothing to be ashamed of; we rather glory in it, for whatever it is worth.

It will be noted that we placed freely at the disposal of the association a portrait block of Mr. Tesla which we value highly. We were anxious, however, to do him honor in this way, and loaned the original. Since that time, we have loaned it, without charge, to Mr. Belford, of "Success," in whose November issue it appears by our courtesy; and we have within the past week placed it at the disposal of another publishing house. Perhaps these are the attempts to do him an injury about which Mr. Tesla has so unfortunately allowed himself to be persuaded.

Now as to the very depreciatory quotations from the distinguished scientists, Profs. Brackett and Dolbear. The passage from Prof. Brackett appeared in the New York "Herald" of Nov. 9. That from Prof. Dolbear appeared in the New York "Herald" of Nov. 10. They had not been contradicted or withdrawn when we called attention to them and objected to them. One of our electrical contemporaries last week quoted them both like ourselves, but said it was inclined to agree with Prof. Dolbear. We now beg to call Mr. Tesla's attention to the subjoined dispatches from both scientists, and would say that having already expressed dissent from the views of both Profs. Brackett and Dolbear, we do not see how it concerns us any further.

(Press Telegram.)

Princeton, N. J., Nov. 20, 1898.

T. C. Martin, Editor of The Electrical Engineer, New York.

Some of the language on pages 490 and 491 of The Electrical Engineer of Nov. 17, purporting to be quoted from me, is a fairly correct reproduction of what I said to a "Herald" reporter in reply to his question as to the probable practicability of Mr. Tesla's device for the abolishing war already presented in the "Herald," a copy of which he showed me.

In the language which you quote, there is much confusion and inaccuracy, due to the fact that the reporter took no notes of what I said, but trusted his memory.

No subject other than that proposed, viz.: Is the proposed plan practicable, was discussed. C. F. BRACKETT.

North Cambridge, Mass., Nov. 21.

The Electrical Engineer, New York.

Letter received this morning. The "Herald" report was substantially accurate. I will write more to you presently.

A. E. DOLBEAR.

"Greatest Discovery of the Age."

Mr. H. W. Phillips, in the "Criterion" of Nov. 19, has an illustrated interview with Mr. Tesla, whom he quotes as follows in regard to his use of the coherer as a relay for steering dirigible torpedoes: "I think that it is the greatest discovery of the age. There is something artistic—an appeal to the imagination—in it that the telephone, phonograph and other fine inventions lack." In reply to an inquiry as to his ability to operate the coherer by an effort of the will merely, Mr. Tesla said to Mr. Phillips: "I have no evidence to support it, but I have a perfect right to state it—understand me—as a possibility—no more." Mr. Tesla also remarked: "Had I nothing else to show for a lifework, this would put the laurels of everlasting fame on my head."

Rontgen Society.—The president of the Röntgen Society and Mrs. Mansell Moullin and the council entertained a large number of scientific gentlemen and their friends at a conversazione at the St. Martin's Town Hall on Monday night. While a most enjoyable programme by the London Concert Orchestra, with a couple of songs by Mr. Fitzroy Sheridan, and an excellent buffet supplied the wants of the inner man, those who wished that "this too solid flesh could melt" had no difficulty in gratifying their desire. In the main hall, which was filled with exhibits, Dr. Hedley presided over the London Hospital outfit, supplied by Isenthal, Potzler, and Co. A small portable dark-room was set up, and this cupboard was well patronised by those who wished to examine their friends skeletons or part of their own. Similar exhibitions were given in a large darkened room by Dr. Pepperdene, and Messrs. Webster, Watson Baker, Coldwell, Cox, and Dean. A number of patients in charge of nurses were similarly examined, under the supervision of Dr. Walsh, assisted by Mr. Fenton and Mr. Isenthal, a case of congenital clavicular malformation being especially easy to discern. Another patient lay on a stretcher in the main hall, and his bones could be distinctly seen by means of the fluoroscope, which consists of a fluorescent screen fitted with bellows like a camera, ending in an eyepiece bound in fur. This permits the exclusion of all extraneous light, and these appliances are very useful in simple cases, as the room need not be darkened during the examination of the patient. The phenomena of the Geissler tubes by Messrs. Corser, Gerard Smith, and Vesey, and the "white magic" by Prof. Silvanus P. Thompson, F.R.S., who demonstrated the

action of the Tesla oscillator upon vacuum tubes destitute of electrodes, drew such a large audience that it was almost impossible to get near. Mr. Harry W. Cox showed a large induction coil with his new type of contact-breaker. The coil required about six amperes and twelve volts when giving a 19in. spark. Mr. Isenthal had an apparatus fitted with double bulbs. These tubes consist of a very large bulb, about double the size hitherto used. The tube is continued vertically, then another bulb, about a quarter of the size, and a small sideward branch with another anode in it, is added. The advantage claimed for this arrangement is that a continuous supply of X-rays is produced without the necessity of heating the bulb every now and then, and that the current required is very low. A large selection of X-ray photographs lined the room, and we should suggest that another time the tablets should bear more definite inscriptions. It is rather puzzling at first to come across a female skeleton, and to read: "Mr. A—— B——," this being presumably the name of the exhibitor, and not of the exhibit.

Teslaic Transmissions.—The best criticism we have seen of the enormous potentialities claimed by the daily Press, both here and in the States, for Tesla's latest development in electric works, is contained in the *Electrical World*. Our contemporary, in a leader headed "Boundless Space a 'Bus Bar," states that at least one of the American electrical journals has taken Mr. Nikola Tesla's patents more seriously than the inventor intended them. The idea proposed comprises nothing more nor less than a high-tension step-up transformer feeding into a vertical conductor with a terminal at such an elevation above the earth as to reach a strata of rarefied atmosphere which has a comparatively low electrical resistance, a similar step-down transformer to be connected at any desired point with the same conducting strata by means of any suitable device, such as that used by the illustrious Benjamin Franklin, or, preferably, as stated in the patent, by means of a balloon, the earth being utilised as a ground return. The fact is set forth that the atmosphere at 15lb. to the square inch, or other pressures common near the surface of this mundane sphere, is a good insulator, while at lower pressures, as is well known by manufacturers of 200-volt lamps, it becomes quite a fair conductor. By a rigid suppression of the reasoning faculties, and a little freedom of the imagination, fancy pictures a conductor poked up through the insulating sheath at Niagara, establishing an alternating difference of potential between the superincumbent ether and this ball of solid matter below protected by an atmospheric dielectric, which difference of potential can be tapped, so to speak, at any desired location, such as the large cities, or by express trains with electric locomotive towing balloon trolleys, making contact with an overhead conductor, from which they cannot readily slip off. The use of several great sources of natural power will, of course, necessitate generators of the same frequency running in synchronism with each other, as they are all, so to speak, connected across the same 'bus bars, and lacking the third 'bus bar, multiphase systems will go out of fashion. The system might, however, give other results more valuable than those of power transmission. With transmitting and receiving stations at Niagara Falls and New York City respectively, the State of New York would possibly be illuminated by a gigantic Geissler tube overhead that would turn night into day, put to shame the aurora borealis, and make the advocates of diffused illumination shout for joy. (The writer reserves all rights to the use of interplanetary space as a vacuum tube for lighting purposes.) Mr. Tesla should certainly be enjoined from putting his polished ball terminals too high, or a Crookes tube effect might be obtained, emitting a profusion of X-rays which would disclose altogether too much to anyone with fluorescent spectacles, and might make it necessary for mortals to carry leaden umbrellas to prevent the skin being burned from the tops of their heads.

Mr. Tesla's Paper Before the Electro-Therapeutic Society.

The recent publication in an electrical journal of a paper presented before the Electro-Therapeutic Society by Mr. Tesla on "High-Frequency Oscillations for Therapeutic Applications" has elicited the following letter from Mr. Tesla to the editor of the paper making the reprint, with the request that the letter be published in the columns of The Electrical World. The letter, which is self-explanatory, is as follows:

"By publishing in your columns of Nov. 17 my recent contribution to the Electro-Therapeutic Society, you have finally succeeded—after many vain attempts made during a number of years—in causing me a serious injury. It has cost me great pains to write that paper, and I have expected to see it appear among other dignified contributions of its kind, and, I confess, the wound is deep. But you will have no opportunity for inflicting a similar one, as I propose to take better care of my papers in the future. In what manner you have secured this one in advance of other electrical periodicals, who had an equal right to the same, rests with the secretary of the society to explain.

"Your editorial comment would not concern me in the least were it not my duty to take note of it. On more than one occasion you have offended me, but in my qualities both as Christian and philosopher I have always forgiven you and have only pitied you for your errors. This time, though, your offense is graver than the previous ones, for you have dared to cast a shadow on my honor.

"No doubt you must have in your possession, from the illustrious men whom you quote, tangible proofs in support of your statement reflecting on my honesty. Being a bearer of high honors from a number of American universities, it is my duty, in view of the slur thus cast upon them, to exact from you that in your next issue you produce these, together with this letter, which, in justice to myself, I am forwarding to other electrical journals. In the absence of such proofs, which would put me in the position to seek redress elsewhere, I require that, together with the preceding, you publish instead a complete and humble apology for your insulting remark, which reflects on me as well as on those who honor me.

"On this condition I will again forgive you, but I would advise you to limit yourself in your future attacks to statements for which you are not liable to be punished by law. N. Tesla.

"New York, Nov. 18, 1898, 46 and 48 East Houston Street."

*See The Electrical World, October 29, 1898, page 440.

DIGEST OF CURRENT ELECTRICAL LITERATURE AMERICAN AND FOREIGN

By Carl Hering.

Power.

CONTROLLING MOTORS FROM A DISTANCE.—"Elec. Rev.," Nov. 16.—A reprint at considerable length, with the illustration, of Tesla's recent patent for controlling from a distant point, the operation of the propelling engines, starting apparatus, or other mechanism carried by a moving object, such as a vessel, and for bringing into action at any desired time any device carried by it.

Scientific American.

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NEW YORK, SATURDAY, NOVEMBER 26, 1898.

SCIENCE AND SENSATIONALISM.

One of the most astonishing features in the development of modern journalism is the magnitude and successful audacity of the Sunday issues of the great daily papers, and among these there are none quite so successful in self-advertisement, with the unthinking half of the public at least, as those issues which are marked by the distinctive characteristics of yellow journalism.

Now, the yellow journal is nothing if it is not sensational, and in its quest for startling novelties to whet the palate of its readers, it invades every possible sphere of human life and interest and every branch of human knowledge. Science, which, one would have thought, would be severely let alone, is a favorite hunting ground of the reporter, and whole pages of the yellow journal seventh-day editions are loaded down with pseudo-scientific pabulum, upon which the Sunday reader is supposed to satisfy his hunger for scientific knowledge. The reporters for these journals are apparently sent out into the domains of science charged with a commission to magnify mole hills into mountains and use such facts as they may pick up as texts for exuberant essays, in which rhetoric gorges itself with superlatives and becomes positively tipsy with the fumes of its own wild imaginings.

Hence it is by the merest promptings of self-respect that the average man of science shuns the noisy notoriety of a Sunday paper "write-up," and reserves his announcements for the columns of the technical and scientific journals, or a lecture desk in the auditorium of the learned associations. The practice, the etiquette, we had almost said the ethics, of scientific research agree in rebuking the former and approving the latter method of making public announcement of results actually accomplished.

We shall not soon forget the extreme mortification exhibited in our presence on a recent occasion by a medical expert when he discovered, through our application to him for the true facts of the case, that the details of a difficult operation just performed by him had been published, with flattering encomiums and the inevitable inaccuracies, in a certain daily paper, thereby anticipating a paper on the subject that was to be duly presented in the columns of the medical journals.

This is the true professional spirit, and every departure from it tends in some degree to subvert the interest of science, and throw a stumbling block in the way of the honest seeker after knowledge.

We note with considerable regret that subsequently to his first extraordinary interviews, Mr. Tesla has seen fit to place himself at the service of those New York Sunday papers that are more or less notoriously sensational, with the result that the "annihilator" has taken on fresh terrors. It is now illumined by the flaming brush of the artist, and the public is diverted with realistic scenes in which the nine days' wonder is depicted as speeding, now above, now beneath the surface of a sea which is always propitiously calm, under a sky and in an atmosphere that are ever opportunely bright and clear, against a ship that is ever fortuitously within easy range, and always with the inevitable and unutterable result!

Judging from the comments of the scientific and technical press, we are not alone in our expressions of regret that any one of Mr. Tesla's undoubted ability should indulge in such obvious and questionable self-advertisement. That the author of the multiphase system of transmission should, at this late day, be flooding the press with rhetorical bombast that recalls the wildest days of the Keely motor mania is inconsistent and inexplicable to the last degree.

The facts of Mr. Tesla's invention are as few and simple as the fancies which have been woven around it are many and extravagant. The principles of the invention are not new, nor was Tesla even their original discoverer. While the present application of these principles is novel, there is nothing whatever in the device to warrant the sweeping claims which have been made in regard to its destructive powers. The connecting cable in the dirigible torpedo is only one of many insuperable obstacles to its success. Mr. Tesla has removed (or rather believes that he has) this one defect; let him now apply himself to mastering the others. Before he announces his ability to blot the navies of the world out of existence, let him answer a few pertinent questions, as follows:

If the torpedo must be seen to be controlled, and is scarcely visible at a distance of over a mile, even in a calm sea, how, in view of the great range, rapidity and accuracy of modern rifles, is the operator to keep within striking distance of the enemy? If the course of the torpedo can with difficulty be followed in calm weather, how will it be traced when the surface is disturbed even by a moderate sea, to say nothing of more boisterous water? Furthermore, what becomes of its accuracy in thick or foggy weather? The apparatus employed by Tesla is extremely sensitive to shock; how then will it fare amid the terrific concussion of a modern sea fight? If one of these weapons should be lost sight of in its course, does it not at once threaten friend and foe alike, and is not the operator himself in danger of being incontinently "hoist with his own petard"?

Lastly, and most pertinent question of all: What is to prevent the enemy from installing a transmitter on his own ship and himself sending out waves to act upon the receiver in the torpedo? We fail to find any provision made for this contingency, either in the patent or in any of the published interviews of the inventor. With a transmitter in the hands of the enemy the proper sequence of the motions of the torpedo could be destroyed, and the control of it prevented.

Tesla Demands an Apology.

Nikola Tesla has a grievance. He resents the imputation that he is a humbug, and proclaims himself a "Christian and philosopher," citing in support of this assertion the fact that numerous offenses against his dignity and personal wishes have been committed by those who have posed as his friends, but that in every case he has forgiven them freely. In further proof of his forbearance he declares his willingness to extend pardon for the last offense and restore the erring ones to favor, conditioned, however, upon the publication of a "complete and humble apology." Mr. Tesla has furnished the Western Electrician the following copy of a letter upon this subject which is self-explanatory:

To the Editor of the Electrical Engineer:

By publishing in your columns of November 17th my recent contribution to the Electro-therapeutic society you have finally succeeded—after many vain attempts made during a number of years—in causing me a serious injury. It has cost me great pains to write that paper and I have expected to see it appear among other dignified contributions of its kind, and, I confess, the wound is deep. But you will have no opportunity for inflicting a similar one, as I propose to take better care of my papers in the future. In what manner you have secured this one in advance of other electrical periodicals who had an equal right to the same rests with the secretary of the society to explain.

Your editorial comment would not concern me in the least were it not my duty to take note of it. On more than one occasion you have offended me, but in my qualities both as Christian and philosopher I have always forgiven you and have only pitied you for your errors. This time, though, your offense is graver than the previous ones, for you have dared to cast a shadow on my honor.

No doubt you must have in your possession, from the illustrious men whom you quote, tangible proofs in support of your statement reflecting on my honesty. Being a bearer of great honors from a number of American universities, it is my duty, in view of the slur thus cast upon them, to exact from you that in your next issue you produce these, together with this letter, which, in justice to myself, I am forwarding to other electrical journals. In the absence of such proofs, which would put me in the position to seek redress elsewhere, I require that, together with the preceding, you publish instead a complete and humble apology for your insulting remark, which reflects on me as well as on those who honor me.

On this condition I will again forgive you, but I would advise you to limit yourself in your future attacks to statements for which you are not liable to be punished by law.

New York, November 18, 1898. N. TESLA.

Transmission of Power Through the Air Without Wires.[1]

By Prof. John Trowbridge.

Mr. Tesla has recently patented a method of transmitting power through the air without the use of wires. This method consists in producing a very great difference of potential between a high point in the atmosphere, reached by a wire connected to a balloon, and a distant point on a balloon, which in turn is connected through a step-down transformer with the earth. A step-up transformer produces the high potential at the sending station, or at the first balloon, and the difference of potential thus created produces a current of conduction through the rarefied air to the second balloon and thence through the step-down transformer to earth. Mr. Tesla relies upon the good conductivity of rarefied air to high electromotive force.

Some recent experiments I have made with high electromotive force are interesting in regard to the suggestion of Mr. Tesla, and are in continuation of those I described in the Scientific American for January 15, 1898. At that time my apparatus was capable of producing 1,200,000 volts. It can now produce 3,000,000.

Up to the point of one million and a half volts, the length of the electrical discharge in air appears to be closely proportional to the electromotive force. When this voltage is exceeded, the length of the spark no longer increases in proportion to this force, for instance, and electromotive force of approximately 3,000,000 volts produces a spark of about seven feet in length, when it should excite one at least 10 feet long. The reason of this diminution is readily seen when the operation of my apparatus is examined in the dark.

From both terminals and from the conductors to those terminals there is a luminous brush discharge to the walls and floor of the room. The main portion of the discharge is, so to speak, shunted through the air, which breaks down with facility at such high voltages. The high electromotive force exerts a similar action to that of diminished air pressure.

In the case of rarefied air, one sees the luminous area of discharge on the positive terminal extend farther and farther from the point of the terminal, thus indicating that there is an increased flow through the rarefied air. In ordinary atmospheric air the same increase of electrical conductivity takes place under the action of great electromotive force. When discharges produced by 1,000,000 volts or more are excited between terminals six feet apart, in tubes filled with water, the tubes are speedily burst, and when the phenomenon is carefully examined, it is perceived that the disruptive sparks occur on the surface of the water inside the tubes, which vaporize the water and thus lead to an explosion. The layer of air conducts more readily than the water. The same phenomenon can be shown by interposing a conductor made of plumbago and infusorial earth, making a resistance of about 10,000 ohms between the terminals of the apparatus. A spark passes over the surface of such a conductor through the air, if the length of such a conductor does not exceed 10 or 12 inches.

I found also that the spark preferred to jump through five centimeters of air to passing through a thousand ohms of a copper-sulphate solution. Thus the air evidently breaks down with increasing readiness when the electromotive force is increased beyond a certain limit.

One of the most striking experiments in this connection can be performed by coating a board with a thin layer of plumbago, which is polished upon the surface in such a manner as to make a resistance of about 1,000 ohms between broad terminal bands of copper. When a discharge under a difference of potential of 1,000,000 volts passes between the terminal bands, the entire surface of the conductor becomes luminous.

When my new apparatus was first set up, the coated surfaces of the Leyden jars were not more than a foot from the floor. On account of the great loss due to electrostatic induction, I determined to have the entire apparatus lifted three feet from the floor. A certain portion of the loss was thus obviated, but when discharge takes place, sparks an inch long can be drawn from the neighboring brick walls, and the entire room seems to be filled with brush discharges.

I believe, therefore, that beyond 1,000,000 volts, the length of the spark is no longer proportional to the voltage, and that this departure from proportionality is due to the initial resistance of the neighboring air becoming less and less. In order to get the full effect of the voltage of my machine, I believe that it should be placed 30 or 40 feet above the earth and at a distance from neighboring masses. The apparent length of lightning discharges at low altitudes is therefore no criterion of the voltage which produces these discharges, for there must be great leakage, which necessitates an excess of electromotive force to produce the discharge. On the other hand, the discharges in higher regions of the atmosphere are much lengthened on account of the increased conductivity of the medium.

In view of the experiments which I have described, I am led to believe that ordinary atmospheric air under very high voltage acts like a fairly good conductor, and I can conceive of such a high electromotive force that the initial resistance of air might not be more than the resistance of metals. The loss of electrical energy in producing difference of potential of 3,000,000 volts at a distance of 10 feet from the terminals of my machine is very great, and in employing such high voltages Mr. Tesla could only obviate great loss by lifting his entire generating apparatus far above the surface of the earth.

1. From the Scientific American.

Tesla Describes His Investigations.

[From the New York Sun.]

I cannot but gratefully acknowledge my indebtedness to earlier workers, as Dr. Hertz and Dr. Lodge, in my efforts to produce a practical and economical lighting system on the lines which I first disclosed in a lecture at Columbia College in 1891. There exists a popular error in regard to this light, inasmuch as it is believed that it can be obtained without generation of heat. The enthusiasm of Dr. Lodge is probably responsible for this error, which I have pointed out early by showing the impossibility of reaching a high vibration without going through the lower or fundamental tones. On purely theoretical grounds such a result is thinkable, but it would imply a device for starting the vibrations of unattainable qualities, inasmuch as it would have to be entirely devoid of inertia and other properties of matter. Though I have conceptions in this regard, I dismiss for the present this proposition as being impossible. We cannot produce light without heat, but we can surely produce a more efficient light than that obtained in the incandescent lamp, which, though a beautiful invention, is sadly lacking in the feature of efficiency. As the first step toward this realization I found it necessary to invent some method for transforming economically the ordinary currents as furnished from the lighting circuits into electrical vibrations of great rapidity. This was a difficult problem, and it was only recently that I was able to announce its practical and thoroughly satisfactory solution. But this was not the only requirement in a system of this kind. It was necessary also to increase the intensity of the light, which at first was very feeble. In this direction, too, I met with complete success, so that at present I am producing a thoroughly serviceable and economical light of any desired intensity. I do not mean to say that this system will revolutionize those in use at present, which have resulted from the co-operation of many able men; I am only sure that it will have its fields of usefulness.

As to the idea of rendering the energy of the sun available for industrial purposes, it fascinated me early, but I must admit it was only long after I discovered the rotating magnetic field that it took a firm hold upon my mind. In assailing the problem I found two possible ways of solving it. Either power was to be developed on the spot by converting the energy of the sun's radiations or the energy of vast reservoirs was to be transmitted economically to any distance. Though there were other possible sources of economical power, only the two solutions mentioned offer the ideal feature of power being obtained without any consumption of material. After long thought I finally arrived at two solutions, but on the first of these, namely, that referring to the development of power in any locality from the sun's radiations, I cannot dwell at present. The system of power transmisson without wires, in the form in which I have described it recently, originated in this manner: Starting from the two facts that the earth was a conductor insulated in space and that a body cannot be charged without causing an equivalent displacement of electricity in the earth, I undertook to construct a machine suited for creating as large a displacement as possible of the earth's electricity.

This machine was simply to charge and discharge in rapid succession a body insulated in space, thus altering periodically the amount of electricity in the earth, and, consequently, the pressure all over its surface. It was nothing but what in mechanics is a pump, forcing water from a large reservoir into a small one and back again. Primarily, I contemplated only the sending of messages to great distances in this manner, and I described the scheme in detail, pointing out on that occasion the importance of ascertaining certain electrical conditions of the earth. The attractive feature of this plan was that the intensity of the signals should diminish very little with the distance, and, in fact, should not diminish at all, if it were not for certain losses occurring chiefly in the atmosphere. As all my previous ideas, this one, too, received the treatment of Marsyas, but it forms, nevertheless, the basis of what is now know as "wireless telegraphy." This statement will bear rigorous examination, but it is not made with the intent of detracting from the merit of others. On the contrary, it is with great pleasure that I acknowledge the early work of Dr. Lodge, the brilliant experiments of Marconi, and of a later experimenter in this line, Dr. Slaby of Berlin. Now, this idea I extended to a system of power transmission, and I submitted it to Helmholtz on the occasion of his visit to this country. He unhesitatingly said that power could certainly be transmitted in this manner, but he doubted that I could ever produce an apparatus capable of creating the high pressures of a number of millions of volts which were required to attack the problem with any chance of success, and that I could overcome the difficulties of insulation. Impossible as this problem seemed at first, I was fortunate to master it in a comparatively short time, and it was in perfecting this apparatus that I came to a turning point in the development of this idea. I, namely, at once observed that the air, which is a perfect insulator for currents produced by ordinary apparatus, was easily traversed by currents furnished by my improved machine, giving a tension of something like two and a half million volts. A further investigation in this direction led to another valuable fact, namely, that the conductivity of the air for these currents increased very rapidly with its degree of rarefaction, and at once the transmission of energy through the upper strata of the air, which, without such results as I have obtained, would be nothing more than a dream, became easily realizable. This appears all the more certain, as I found it quite practicable to transmit, under conditions such as exist in heights well explored, electrical energy in large amounts. I have thus overcome all the chief obstacles which originally stood in the way, and the success of my system now rests merely on engineering skill.

Referring to my latest invention, I wish to bring out a point which has been overlooked. I arrived, as has been stated, at the idea through entirely abstract speculations on the human organism, which I conceived to be a self-propelling machine, the motions of which are governed by impressions received through the eye. Endeavoring to construct a mechanical model resembling in its essential, material features the human body, I was led to combine a controlling device, or organ sensitive to certain waves, with a body provided with propelling and directing mechanism, and the rest naturally followed. Originally the idea interested me only from the scientific point of view, but I soon saw that I had made a departure which sooner or later must produce a profound change in things and conditions presently existing. I hope this change will be for the good only, for, if it were otherwise, I wish that I had never made the invention. The future may or may not bear out my present convictions, but I cannot refrain from saying that it is difficult for me to see at present how, with such a principle brought to great perfection, as it undoubtedly will be in the course of time, guns can maintain themselves as weapons. We shall be able, by availing ourselves of this advance, to send a projectile at much greater distance; it will not be limited in any way by weight or amount of explosive charge; we shall be able to submerge it at command, to arrest it in its flight, and call it back, and to send it out again and explode it at will, and, more than this, it will never make a miss, since all chance in this regard, if hitting the object of attack were at all required, is eliminated. But the chief feature of such a weapon is still to be told, namely, it may be made to respond only to a certain note or tune; it may be endowed with selective power. Directly such an arm is produced, it becomes almost impossible to meet it with a corresponding development. It is in this feature, perhaps, more than in its power of destruction, that its tendency to arrest the development of arms and to stop warfare will reside.

With renewed thanks, I remain, very truly yours,

N. TESLA.

New York, November 19, 1898.

Tesla and Job.

[From the Indianapolis Journal.]

When Job was asked, "Who hath divided a watercourse for the overflowing of waters, or a way for the lightning of thunder?" it is not recorded what answer was made; but if the same question were addressed to Nikola Tesla he would promptly reply, "I, Lord." And to the query, "Canst thou send lightnings, that they may go and say unto thee, 'Here we are?'" he would answer: "Yea, verily, that can I." But Job, it must be remembered, was a modest man.

An Inquiry about Tesla's Electrically Controlled Vessel.

TO THE EDITOR OF ELECTRICAL REVIEW:

I have read some of the newspaper effusions relative to Mr. Nikola Tesla's latest invention, and have noted the articles and your editorial in the issue dated the 16th instant of your valued paper. In connection therewith permit me to inquire: Has not a very serious and important consideration in the operation of Mr. Tesla's apparatus been overlooked? It occurred to me that, while the vessel is controlled primarily by means of a "coherer" which receives the "waves" from the "transmitter" on shore, this same "coherer" can also be influenced by "waves" set up and transmitted *from the vessel menaced*, and the movements of the Tesla craft made uncontrollable. The Tesla vessel would, when nearer the vessel attacked, be within a stronger field of the radiations from the latter vessel's transmitter than from the controlling transmitter on shore or elsewhere. It will be necessary for Mr. Tesla to devise some method of control that can not be counter-influenced by the enemy.

Yours truly,

N. G. WORTH.

Indianapolis, November 21.

AN ANALYSIS OF TESLA'S WORK.

SOME NON-TECHNICAL VIEWS AND A RESPONSE BY TESLA DESCRIBING HIS EFFORTS IN SEVERAL FIELDS OF WORK.

The articles published below are taken from the New York *Sun*, a journal that is conservatively and ably conducted in all its scientific discussions. We consider its editorial review of Tesla's efforts and ambitions the best that has appeared, and Tesla's letter that follows will be read with interest by every one acquainted with modern electrical work. It is the first communication of this kind ever sent to the lay press by Tesla, who has been the victim of probably more forged interviews and sensational articles appearing without authority than any other inventor.

The *Sun* editorial is as follows:

NIKOLA TESLA AND HIS QUEST.

[*From The Sun, New York, November 13, 1898*]

Nikola Tesla has just made public some facts about an invention intended to make war too terrible to be prosecuted, and thus to insure peace between nations. The war with Spain drew Mr. Tesla's mind aside for the time from the line of studies which has engaged him for years. Inspired and fired by patriotism, he has applied to a war engine some of the principles which he discovered in following his inquiries into new methods of applying energy to the purposes of peace.

The success or failure of Mr. Tesla's latest invention will not turn him away from the great project which has possessed his mind for years. This, as he puts it, is to harness the sun's power to do the work of mankind. He does not mean to catch the power of the sun's rays directly, but to utilize that enormous portion of their power which is expended upon the earth's surface in sucking from sea and lake waters which are afterward precipitated upon the higher parts of the land.

That there are waterfalls upon the earth which are capable of producing all the energy which mankind uses for power, heat and light is well known. The use of water-powers, however, is limited within narrow margins, partly because of the investment cost of instalment, but chiefly because the great waterfalls are remote from the seats of population and trade. Before Mr. Tesla began his researches there was no method known by which the power generated at a remote place could be transmitted to where it was wanted except at a loss of efficiency which was prohibitory. Since that time, by the use of currents of from 10,000 to 20,000 volts, it has become possible to send electric power successfully over wires for 35 miles or more, and one plant is now building to transmit power 85 miles.

But to utilize the great water-powers of the world, the transmittal of energy for a distance of from 50 to 100 miles is hardly more useful than a reach of eight or ten miles. Mr. Tesla designs to annihilate space. He would take the power of a Niagara, transform it into an electric current, and send this without appreciable loss to any place on earth where it was needed for use. Mr. Tesla has, accordingly, devised an electric oscillator which will receive the electric current from its source and give it an intensity which, as the inventor calculates, would enable a copper thread to carry 50,000 horse-power across the ocean. Mr. Tesla claims to have discovered, furthermore, that at an altitude easily reached by balloons the rarefied air has a conductivity equal to copper, while the denser layer of air below is a non-conductor. He proposes to suspend one pole of his electric circuit in the air at Niagara Falls and the other at Paris, and to forward his current through the upper air to France, whence it shall return through the earth when its active energy has been expended in work. He believes that he will be able to make this demonstration in 1900 as an exhibit at the coming world's fair at Paris, and to drive all the machinery at that exposition with the power from our great waterfall. The significance of his success would be that coal would become a convenience instead of a necessity, and water-power and electricity would replace coal and steam for the work of the world.

Another great quest which Mr. Tesla has been conducting side by side with this—and, in fact, leading along the same lines—is for the means of producing light from electricity without heat. It was well known when Tesla began his studies that a Crookes vacuum tube could be made to glow by passing through it currents of electricity at a high tension, but no electrician could evolve from these tubes more than a phosphorescent glow. To turn this into a white light which should shine like the face of the sun itself was the problem to be solved. All his investigations led Mr. Tesla to conclude that the thing which was needed was to be able to give to electrical currents voltages enormously beyond any which had ever been produced, and then to be able to handle and control the currents thus transformed. From this need grew his electrical oscillator, with which Mr. Tesla proposes to produce a current with an intensity of 800,000 volts, capable of transmission across the Atlantic. In Mr. Tesla's laboratory the vacuum tubes glow like sunshine, and their introduction for use is waiting only for a reduction of the cost of their light to a commercial basis, a reduction which he says is near at hand.

Since Mr. Tesla began investigating the possibilities of such high-tension currents as he produces by means of his oscillator he has made some startling announcements, such as that of his ability to use the whole earth as a conductor, and to telegraph to any part of its surface from any other part, sending messages jointly to many stations, or separately to each, at will. Perhaps because none of these late triumphs of Mr. Tesla's genius have yet been brought into practical use, there are many persons who declare that he is a visionary and impractical. It must be remembered that his discovery of the rotating electric field was of as great importance in its day as are his later discoveries now. That was announced in 1882, yet it was nearly 10 years before its value was fully recognized.

The personality of Nikola Tesla is as interesting as are the results of his scientific labors. His ways of work differ radically from the methods of those who study by experiment and elimination. Tesla seldom experiments, and when he does it is to prove a theory, not to form one. In 11 years, he says, only one of his experiments has failed. His processes are mental, and at times, he declares, his mind reaches out into fields so vast that he is afraid, and recalls it. He verifies his conclusions afterward by figures and experiments.

No other great scientific genius ever turned aside from his work to devise means for putting an end to war. Others have invented guns, armor, explosives and other accessories of war, but even in these cases the inventions were in a line with work in which the inventors were already engaged. Mr. Tesla's first design was to apply his method of control to such engines as automible torpedoes, and to use these to destroy the Spanish fleets, but as he went on, the broader idea came to him to make his war machine so irresistible as to render war itself improbable.

TESLA DESCRIBES HIS EFFORTS IN VARIOUS FIELDS OF WORK.

[*From The Sun, New York, November 21, 1898*]

TO THE EDITOR OF THE SUN—SIR: Had it not been for other urgent duties, I would before this have acknowledged your highly appreciative editorial of November 13. Such earnest comments and the frequent evidences of the highest appreciation of my labors by men who are the recognized leaders of this day in scientific speculation, discovery and invention are a powerful stimulus, and I am thankful for them. There is nothing that gives me so much strength and courage as the feeling that those who are competent to judge have faith in me.

Permit me on this occasion to make a few statements which will define my position in the various fields of investigation you have touched upon.

I can not but gratefully acknowledge my indebtedness to earlier workers, as Dr. Hertz and Dr. Lodge, in my efforts to produce a practical and economical lighting system on the lines which I first disclosed in a lecture at Columbia College in 1891. There exists a popular error in regard to this light, inasmuch as it is believed that it can be obtained without generation of heat. The enthusiasm of Dr. Lodge is probably responsible for this error, which I have pointed out early by showing the impossibility of reaching a high vibration without going through the lower or fundamental tones. On purely theoretical grounds such a result is thinkable, but it would imply a device for starting the vibrations of unattainable qualities, inasmuch as it would have to be entirely devoid of inertia and other properties of matter. Though I have conceptions in this regard, I dismiss for the present this proposition as being impossible. We can not produce light without heat, but we can surely produce a more efficient light than that obtained in the incandescent lamp, which, though a beautiful invention, is sadly lacking in the feature of efficiency. As the first step toward this realization, I found it necessary to invent some method for transforming economically the ordinary currents as furnished from the lighting circuits into electrical vibrations of great rapidity. This was a difficult problem, and it was only recently that I was able to announce its practical and thoroughly satisfactory solution. But this was not the only requirement in a system of this kind. It was necessary also to increase the intensity of the light, which at first was very feeble. In this direction, too, I met with complete success, so that at present I am producing a thoroughly serviceable and economical light of any desired intensity. I do not mean to say that this system will revolutionize those in use at present, which have resulted from the co operation of many able men. I am only sure that it will have its fields of usefulness.

As to the idea of rendering the energy of the sun available for industrial purposes, it fascinated me early, but I must admit it was only long after I discovered the rotating magnetic field that it took a firm hold upon my mind. In assailing the problem I found two possible ways of solving it. Either power was to be developed on the spot by converting the energy of the sun's radiations or the energy of vast reservoirs was to be transmitted economically to any distance. Though there were other possible sources of economical power, only the two solutions mentioned offer the ideal feature of power being obtained without any consumption of material. After long thought I finally arrived at two solutions, but on the first of these, namely, that referring to the development of power in any locality from the sun's radiations, I can not dwell at present. The system of power transmission without wires, in the form in which I have described it recently, originated in this manner. Starting from the two facts that the earth was a conductor insulated in space, and that a body can not be charged without causing an equivalent displacement of electricity in the earth, I undertook to construct a machine suited for creating as large a displacement as possible of the earth's electricity.

This machine was simply to charge and discharge in rapid succession a body insulated in space, thus altering periodically the amount of electricity in the earth, and consequently the

pressure all over its surface. It was nothing but what in mechanics is a pump, forcing water from a large reservoir into a small one and back again. Primarily I contemplated only the sending of messages to great distances in this manner, and I described the scheme in detail, pointing out on that occasion the importance of ascertaining certain electrical conditions of the earth. The attractive feature of this plan was that the intensity of the signals should diminish very little with the distance, and, in fact, should not diminish at all, if it were not for certain losses occurring, chiefly in the atmosphere. As all my previous ideas, this one, too, received the treatment of Marsyas, but it forms, nevertheless, the basis of what is now known as "wireless telegraphy." This statement will bear rigorous examination, but it is not made with the intent of detracting from the merit of others. On the contrary, it is with great pleasure that I acknowledge the early work of Dr. Lodge, the brilliant experiments of Marconi, and of a later experimenter in this line, Dr. Slaby, of Berlin Now, this idea I extended to a system of power transmission, and I submitted it to Helmholtz on the occasion of his visit to this country. He unhesitatingly said that power could certainly be transmitted in this manner, but he doubted that I could ever produce an apparatus capable of creating the high pressures of a number of millions of volts, which were required to attack the problem with any chance of success, and that I could overcome the difficulties of insulation. Impossible as this problem seemed at first, I was fortunate to master it in a comparatively short time, and it was in perfecting this apparatus that I came to a turning point in the development of this idea. I, namely, at once observed that the air, which is a perfect insulator for currents produced by ordinary apparatus, was easily traversed by currents furnished by my improved machine, giving a tension of something like 2,500,000 volts. A further investigation in this direction led to another valuable fact; namely, that the conductivity of the air for these currents increased very rapidly with its degree of rarefaction, and at once the transmission of energy through the upper strata of the air, which, without such results as I have obtained, would be nothing more than a dream, became easily realizable. This appears all the more certain, as I found it quite practicable to transmit, under conditions such as exist in heights well explored, electrical energy in large amounts. I have thus overcome all the chief obstacles which originally stood in the way, and the success of my system now rests merely on engineering skill.

Referring to my latest invention, I wish to bring out a point which has been overlooked. I arrived, as has been stated, at the idea through entirely abstract speculations on the human organism, which I conceived to be a self-propelling machine, the motions of which are governed by impressions received through the eye. Endeavoring to construct a mechanical model resembling in its essential, material features the human body, I was led to combine a controlling device, or organ sensitive to certain waves, with a body provided with propelling and directing mechanism, and the rest naturally followed. Originally the idea interested me only from the scientific point of view, but soon I saw that I had made a departure which sooner or later must produce a profound change in things and conditions presently existing. I hope this change will be for the good only, for, if it were otherwise, I wish that I had never made the invention The future may or may not bear out my present convictions, but I can not refrain from saying that it is difficult for me to see at present how, with such a principle brought to great perfection, as it undoubtedly will be in the course of time, guns can maintain themselves as weapons. We shall be able, by availing ourselves of this advance, to send a projectile at much greater distance, it will not be limited in any way by weight or amount of explosive charge, we shall be able to submerge it at command, to arrest it in its flight, and call it back, and to send it out again and explode it at will, and, more than this, it will never make a miss, since all chance in this regard, if hitting the object of attack were at all required, is eliminated. But the chief feature of such a weapon is still to be told; namely, it may be made to respond only to a certain note or tune, it may be endowed with selective power. Directly such an arm is produced, it becomes almost impossible to meet it with a corresponding development. It is in this feature, perhaps, more than in its power of destruction, that its tendency to arrest the development of arms and to stop warfare will reside. With renewed thanks, I remain,

Very truly, yours,

N. TESLA.

New York, November 19.

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Tesla and His Critics.

We have received from Mr. Nikola Tesla, with a request that it be printed in our columns, a letter containing a personal attack on the editor of one of our electrical contemporaries. Owing to the personalities contained, which form the greater part of the letter, we regret that our editorial policy will not permit us to print the communication in full, and we will therefore only notice such parts as may be considered to have a journalistic or public bearing.

Mr. Tesla accuses our contemporary of having done him an injury by reprinting in its columns a paper read by him before a medical society; and of having cast a shadow on his honor and attacked his honesty in an editorial comment apropos of the said paper. Aside from their personal bearing, these charges involve the right of a journal to reprint matter that has passed out of the hands of a writer and become, through publication, the property of the

world at large; and the right to criticise, as a professional journal, public announcements of scientific discoveries pertaining to the profession which it represents.

As to the first charge, our contemporary in answer prints satisfactory evidence that the republication in its columns of the paper in question was authorized by the chairman of the medical society before which it was read. Even in the absence of such authorization, however, it is difficult to see what justification there can be for Mr. Tesla's statement: "By publishing in your columns of Nov. 17 my recent contribution to the Electro-Therapeutic Society, you have finally succeeded * * * in causing me a serious injury." The paper was presented before a national professional body, and, therefore, it is to be presumed, was maturely composed by its author with a knowledge that such presentation constituted publication to the world, and laid the statements contained open for comment or criticism from any source—not even excluding an electrical journal.

As to the second charge, a careful reading of the editorial upon which it is based leaves only the impression that the writer was actuated by a kindly motive in reminding Mr. Tesla of the many unfilled promises he has made to the public in recent years—promises of light without heat, a revolution by means of his "oscillator" in the generation of electrical energy, the transmission of electricity without wires, the destruction of fleets by means of an application of the coherer—to which list might have been added the expulsion of microbes by means of an electrification of the body and other announcements which, with those noted, have earned for Mr. Tesla the popular title of "The Wizard." Surely this constituted a legitimate subject for editorial comment by an electrical journal, and the manner in which the warning was conveyed—that Tesla had arrived at the stage when fulfillment of some of the many promises made had become vitally necessary to his reputation—was not such as to call for a violent attack on his critic.

The truth plainly stated is, that for several years Mr. Tesla has only escaped similar criticism in professional and scientific journals on account of the high esteem in which he is held personally, and through recollection of the magnificent boon he bestowed on the world by the invention early in his career of the polyphased system. The manner in which he has permitted himself to be exploited by the sensational newspaper press has been a source of pain to his friends, and has largely alienated from him the sympathy of the electrical profession. Moreover, his periodical promise of being on the point of accomplishing some wonder that would revolutionize electrical science has had an untoward effect on the electrical industry, for among laymen it has tended to produce the belief that at any moment one of Tesla's great discoveries may materialize and destroy all present investments.

SCIENTIFIC PROBLEMS, PROGRESS AND PROPHECY

Tesla's Latest Discovery.....Electrical Review

As civilization advances and our needs multiply, the demands on the toilers in the various departments of science constantly increase, and naturally the activity in the direction of providing new resources becomes more and more intense. But the severest burden is undoubtedly on the engineer, mechanic or inventor, whose task it is to produce motive power. The problem of providing economical power has ever taxed the inventive mind, and with the introduction of electricity a great stride in advance has been effected. But still, many limitations were encountered in the difficulties of efficiently transmitting the energy of great sources of power, which exist in abundance in Nature, to remote places of utilization. Here it is that Nikola Tesla did his first great work by discovering the rotating magnetic field, and applying it to a practical system of electric power transmission, now used in all parts of the world. As we were then, so now we are privileged to record another forward step, which, if successful on a large scale, will prove of astounding consequences, for it will open up unlimited resources of practically costless power. Tesla now proposes to transmit, without the use of any wires, through the natural media—the earth and the air—great amounts of power to distances of thousands of miles. This will appear a dream—a tale from the Arabian Nights. But the extraordinary discoveries Tesla has made during a number of years of incessant labor, make it evident that his work in this field has passed the stage of mere laboratory experiment, and is ready for a practical test on an industrial scale. The success of his efforts means that power from such sources as Niagara will become available in any part of the world regardless of distance.

Passing Comment

An Editorial Review of Current Events and Comtemporary Publications.

TESLA'S LINELESS POWER TRANSMISSION SYSTEM.

Nikola Tesla, to whose lines of research and invention the electrical world owes much, has secured patents on a novel system "of electric power transmission through natural media," and which, briefly described, consists in the generation of extremely high electromotive forces, even up into millions of volts, and the transmission of electrical energy from point to point thereby through the rarified atmosphere of the high altitudes. A description of the proposed system will be found in the *Electrical Review*, (N. Y.) for October 26th, together with a full page view of a Tesla oscillator, photographed in action, showing that the actual width of space traversed by the luminous streams issuing from a single terminal is over sixteen feet; that the area covered by the streamers is approximately two hundred square feet, and that the estimated effective electric pressure is two and one-half million volts. From the description, which is taken from the patent specifications, it appears that the generating and receiving stations do not differ from present practices in power transmission plants of today; but the novel features consist in the spirally wound coils of the raising and lowering transformers, and the conduction of the high potentials named to rarified strata of atmosphere as by balloons, a grounded return being used.

The times are not ripe for the acceptance of the views implied by the inventor. More than that, other ideas suggested and patented by him bear to a marked extent the imprint of day dreaming and unhealthful pandering "to the gallery" through the lurid columns of Sunday papers, and his once great name has suffered a possibly irreparable injury. Still, as stated, the engineering world owes much to his fertile brain, and its seeming degeneration can only excite pity and regret.

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Science and Sensationalism

Mr. Tesla's recently announced invention (see PUBLIC OPINION, November 10) has given rise to considerable criticism of his work and methods, the New York *Electrical Engineer* being especially severe in its comments upon the extravagance of the inventor's claims. The issue of this journal for November 24 prints a letter from Mr. Tesla bitterly complaining of the treatment he has received. The *Engineer* replies:

Within the last year or two Mr. Tesla has, it seems to us, gone far beyond the possible in the ideas he has put forth, and he has to-day behind him a long trail of beautiful but unfinished inventions. By mild criticism and milder banter, not being able to lend Mr. Tesla the cordial support of earlier years of real achievement, we have only very lately endeavored to express our doubts and to urge him to the completion of some one of the many desirable or novel things promised. We believe this to be true friendship. For example, take Mr. Tesla's latest and furthest enlargement of his newest idea, as presented by him in a signed letter in the New York *Sun*, of November 21, unfolding his plan to dispense with artillery of the present type. At this moment we have space only for the following passage:

> We shall be able, availing ourselves of this advance, to send a projectile, at much greater distance, it will not be limited in any way by weight or amount of explosive charge, we shall be able to submerge it at command, to arrest it in its flight and call it back, and to send it out again and explode it at will, and, more than this, it will never make a miss.

When we are expected, wide awake and in our sober senses, to accept in silence such an utterance as that quoted above or that which describes as "a possibility" the operation of a distant torpedo boat by the mere exercise of the will, we refuse point blank and we are willing to face the consequences. Our past admiration of Mr. Tesla's real, tangible work is on record, and stands; but we draw the line at such things as these. We are sorry Mr. Tesla feels it so keenly, but we can not help it.

Scientific American, New York, November 26

We note with considerable regret that subsequently to his first extraordinary interviews, Mr. Tesla has seen fit to place himself at the service of those New York Sunday papers that are more or less notoriously sensational, with the result that the "annihilator" has taken on fresh terrors. It is now illumined by the flaming brush of the artist, and the public is diverted with realistic scenes in which the nine days' wonder is depicted as speeding, now above, now beneath the surface of a sea which is always propitiously calm, under a sky and in an atmosphere that are ever opportunely bright and clear, against a ship that is ever fortuitously within easy range, and always with the inevitable and unutterable result! Judging from the

comments of the scientific and technical press, we are not alone in our expressions of regret that any one of Mr. Tesla's undoubted ability should indulge in such obvious and questionable self-advertisement. That the author of the multiphase system of transmission should, at this late day, be flooding the press with rhetorical bombast that recalls the wildest days of the Keely motor mania is inconsistent and inexplicable to the last degree.

The facts of Mr. Tesla's invention are as few and simple as the fancies which have been woven around it are many and extravagant. The principles of the invention are not new, nor was Tesla even their original discoverer. While the present application of these principles is novel, there is nothing whatever in the device to warrant the sweeping claims which have been made in regard to its destructive powers. The connecting cable in the dirigible torpedo is only one of many insuperable obstacles to its success. Mr. Tesla has removed (or rather believes that he has) this one defect; let him now apply himself to mastering the others. Before he announces his ability to blot the navies of the world out of existence, let him answer a few pertinent questions, as follows:

If the torpedo must be seen to be controlled, and is scarcely visible at a distance of over a mile, even in a calm sea, how, in view of the great range, rapidity, and accuracy of modern rifles, is the operator to keep within striking distance of the enemy? If the course of the torpedo can with difficulty be followed in calm weather, how will it be traced when the surface is disturbed even by a moderate sea, to say nothing of more boisterous water? Furthermore, what becomes of its accuracy in thick or foggy weather? The apparatus employed by Tesla is extremely sensitive to shock; how then will it fare amid the terrific concussion of a modern sea fight? If one of these weapons should be lost sight of in its course, does it not at once threaten friend and foe alike, and is not the operator himself in danger of being incontinently "hoist by his own petard"? Lastly, and most pertinent question of all: What is to prevent the enemy from installing a transmitter on his own ship and himself sending out waves to act upon the receiver in the torpedo? We fail to find any provision made for this contingency, either in the patent or in any of the published interviews of the inventor. With a transmitter in the hands of the enemy the proper sequence of the motions of the torpedo could be destroyed, and the control of it prevented.

Tesla's Dirigible Boat.—Several American journals have now published extracts of Tesla's patent for the construction of a vessel which can be controlled from a distance without conducting wires. We have carefully read the accounts which have appeared, and, curiously, it is a fact that in each case the real innovation or invention is not described. In fact, the details published are obvious ones which would suggest themselves to the youngest electrician. The wireless system of telegraphy is used as a means of communication to the crewless vessel, and one receiver only is provided. This receiver works four different relays for steering and stopping and starting. These relays are comparatively simple, but not a word has yet been published as to how four differentiating signals are transmitted to the one receiver. Surely this must be disclosed in the patent; but why are the technical papers so lax in their extracting?

AMERICAN NOTES.

(FROM OUR OWN CORRESPONDENT.)

NEW YORK, *November 18.*

A Recent Patent of Nikola Tesla.—The daily papers within the past week, by means of startling headlines, announced that Mr. Nikola Tesla would make war so horrible that no nation would care to undertake it. The basis of the story rested on a patent issued to Mr. Tesla on November 8th. The facts, as set forth in the patent, are in brief as follows :—Hitherto the only practical means of controlling the movements of a vessel, such as a torpedo or torpedo boat, at a distance, has been by the use of a cable, the disadvantages of which are obvious. The plan proposed by the inventor is to provide any such craft with a coherer connected between the hull and an elevated terminal, and to so arrange the propelling and steering mechanism which is motor-driven with storage battery supply, that it can be controlled by various relays and auxiliary devices actuated through the agency of the Hertz waves. A single coherer is used. It possesses some elements of novelty designed to yield a more uniform decohering action. It consists of a metal cylinder, with insulating ends and a metal rod passing lengthwise through it. The cylinder normally stands with its axis vertical, and the decohering action consists in inverting it, throwing the particles, which occupy one-fifth of its length, from one end to the other. According to the patent, these granules are manufactured by a special tool, insuring their equality in size, weight and shape, and are uniformly oxidised. This secures equal conductivity of their surfaces, and stops their further deterioration, thus preventing a change in the character of the gas in the space in which they are enclosed. The auxiliary devices consist of ordinary relays, actuating a multiple step-by-step escapement wheel, which, in turn, rotates the brushes and commutators, affecting the various internal circuits of the boat.

ANSWER TO AN INQUIRY CONCERNING TESLA'S LATEST INVENTION.

In the ELECTRICAL REVIEW last week appeared an inquiry from Mr. N. G. Worth, of Indianapolis, relating to a probable defect in the electrically-controlled vessel recently patented by Nikola Tesla. Mr. Worth inquired if the ship or fort menaced could not set up a counter-influence by means of similar apparatus, which would be more powerful at a nearer radiation than that transmitted to the attacking vessel from the distant point where the original and controlling influence was created. A number of electrical experts and the inventor himself have been consulted on this point, in addition to a careful perusal by the writer of the technical description of the invention which appeared in full exclusively in this journal on November 9 and 16. The following passage from the patent, in which the italics are our own, is republished as bearing on this question:

"It will be obviously noted from the preceding that, whichever of these or similar contrivances be used, the sensitiveness and, what is often still more important, the reliability of operation are very materially increased by a close adjustment of periods of vibration of the transmitting and receiving circuits, and, although such adjustment is in many cases unnecessary for the successful carrying out of my invention [Tesla evidently refers here to the many uses of his invention in peace—ED.] I nevertheless make it a rule to bestow on this feature the greatest possible care, not only because of the above-mentioned advantages, which are secured by the observance of the most favorable conditions in this respect, but also, and chiefly, with the object of *preventing the receiving circuit from being affected by waves or disturbances emanating from sources not under the control of the operator*. The narrower the range of vibrations, which are still capable of perceptibly affecting the receiving circuit, the safer will the latter be against extraneous disturbances. To secure the best result it is necessary, as is well known to experts, to construct the receiving circuit, or that part of the same in which the vibration chiefly occurs, so that it will have the highest possible self-induction and, at the same time, the least possible resistance. *In this manner I have demonstrated the practicability of providing a great number of such receiving circuits—50 or 100 or more—each of which may be called up or brought into action whenever desired without the other being interfered with.*

The above statement answers part of the question to the point, for, if the sending and receiving circuits are skillfully adjusted, the enemy attacked would be practically powerless, as he could only by the barest chance strike the vibration to which the receiving circuit on the vessel would respond. It is difficult enough, even for the best expert, to make an exact adjustment of two such circuits, let alone the far more difficult problem which in this respect would confront the enemy attacked. Granted he had an apparatus on board capable of developing electrical waves of any pitch, still he would never be able to know which of the notes struck is affecting the circuit on the assailing vessel, since this effect would be only momentary and speedily counteracted by the sending apparatus which the operator guiding the vessel in its course is controlling.

But, quite apart from the above, let it be assumed that such adjustment of the sending and receiving circuits was not at all observed, and that no agents were known capable of affecting a sensitive device on the Tesla vessel, which agent, by its very nature, made it impossible for the enemy to ward off the attack. The latter supposition is manifestly untrue, since any radiation propagating in straight lines, as light or short Hertzian waves, may be used for operating the vessel, and such radiations may be screened off on the side towards the enemy, so that the latter could not affect the controlling device on the attacking vessel. Still, even in such an extreme case, it would seem to us that, while it might be easy to disturb the dot and dash signals in wireless telegraphy, it would be quite a different matter to prevent an operator from directing his vessel to wherever he desires, for *he* only would know precisely how the signals affect the mechanism, whereas the supposed opponent would have no knowledge whatever in this respect and could never tell whether, in working his apparatus, he is aiding or thwarting the efforts of his assailant. However, his signals would be of telling effect only after the assailing vessel had reached a point at which the signals from both the sources are of equal intensity. Now it would be quite easy, in our opinion, for the operator controlling the course of the vessel and the operation of the apparatus on board of the same, to direct it straight upon the enemy, put the machines at top speed, release the exploding mechanism and render all further signals inactive. Since the vessel can carry any amount of explosive, it would not be necessary to come very close to the enemy to insure his destruction.

How about the intensity of the signals? Can the signals from a man-of-war be made as strong as from a vessel especially fitted for this purpose? Would it be advisable to have such a powerful apparatus on board of a warship when the experts tell us that powerful electrical vibrations are apt to make large sparks fly about in any part of the structure, thus becoming liable to short-circuit the light mains and injure any of the important electrical apparatus on board, and, worst of all, inflame the stores of explosives? Would any commander undertake the responsibility of operating such a powerful apparatus on board of his ship under such conditions? And anyway, how is he to know to what kind of influence the controlling device on the assailing vessel is designed to respond? And granted he does, will he feel sure to start his apparatus going when there might be a vessel submerged in the neighborhood responsive to his signals and ready to ignite a great quantity of explosive, and to so annihilate his costly ship and living crew? How would he know that, by his own signals, he is not drawing upon his ship one of the vessels especially adapted for such purpose, thus bringing destruction upon himself through his very efforts to ward off the danger? Would he not expose himself to such liabilities, particularly at night? A great many more of such arguments might be made if they were needed, and all of this, it seems to us, has been overlooked in the various comments we have perused. It is well known that most of the naval engagements must of necessity take place near the coast. Now it is not difficult to employ on shore a sending apparatus, fixed or portable, of great power, against which any on board of a warship would be ineffective, and we ask again how could a commander of a fleet possibly venture to approach the coast within 10 or 15 miles when he would know that in so doing he is risking not one but all of his vessels?

Our inquirer is mistaken in the belief that the use of the coherer is indispensable in Tesla's invention. The inventor is very explicit on this point, as will be observed by perusing his text. To cite only one passage, he states:

"A great variety of electrical and other devices, more or less suitable for the purpose of detecting and utilizing feeble actions, are now well known to scientific men and artisans, and need not be all enumerated here. Confining myself merely to the electrical * * *"

Those who have criticized this important advance seem to confound a special means for carrying out the invention for the invention itself. The latter is not limited to any particular mode of signaling, and on this point Tesla expresses himself clearly, as may be seen from the following quotation:

"Finally, I may avail myself, in carrying out my invention, of electrical oscillations which do not follow any particular conducting path, but propagate in straight lines through space, of rays, waves, pulses, or disturbances of any kind, capable of bringing the mechanism of the moving body into action, from a distance and at the will of the operator, by their effect upon suitable controlling devices."

Signaling without wires, in some way or other, is very old—in fact, ancient—whereas Tesla, as we have before stated, has created an art entirely novel, for there never was such a thing as guiding the movements of a distant body and controlling all of its appliances without any artificial connection whatever.

It is, perhaps, astonishing that this epochal idea has not been evolved in times long past, for it would seem that it might have been carried into effect, without the use of any electrical means whatever, by some scientific men of old, like Archimedes. He must have known, for instance, that by striking a shrill note he could set into vibration a delicate reed or diaphragm at a distance of as much as two or three miles, and he might have known that the force so developed could be utilized, in many ways, to control the movements of a rudder or other device on a vessel, and that by such control the vessel could be guided upon the enemy's ship and the latter destroyed, as by ramming into it, or by causing, for example, a large quantity of inflammable fluid to flow on the water and then igniting the fluid through a contrivance actuated by the signal from a distance, far out of the reach of the enemy's weapons. When gunpowder was discovered, and when we gained knowledge of voltaic electricity, it became still more easy to carry out the idea. When the action of light on a selenium cell was observed, a simple means was offered for effecting the control at great distances. The observation that currents are propagated through the ground to considerable distances and that inductive effects take place between circuits widely apart, again enlarged the possibilities, until finally the science of electrical vibrations and synchronized circuits afforded the best means for carrying the idea into practice. These means, which are accessories in this invention, will, in all probability, multiply and be further improved as time goes on, and, with every advance in this direction, this new art will be brought to greater perfection.

To one who considers that for centuries past a large proportion of human effort has been spent in devising and producing the most efficient means for destroying an enemy, the tremendous importance of this new departure is instantly impressive. The weapon is no longer one dependent on the chance of hitting, nor one subject to the limitations of the modern projectile, nor one which can be rendered inoffensive by armor protection, however thick. The mere moral effect of a weapon of unlimited powers of destruction must be so great as to lead to a radical change in warfare, first on sea and next on land, but its success in the end can not help compelling the nations, for the sake of humanity, to stop the slaughtering of men and sacrifice of property.

The Genius of Destruction.

[*Translated from "L'Évenément."*]

Man is born a vandal. His instinctive joy, his first pleasure is to destroy. From the reminiscences of his primitive savagery, throughout the process of civilization, this barbarous atavism which incites him to destruction and strife adheres to him. War, apart from the sacred causes which arise from the right of legitimate defense, is often nothing else than a manifestation of this instinct. It seems that Man, in imitation of Nature, and even oftener than Nature, offers an example, wants to create cataclysms in obeyance to this fatal heredity. His very genius provokes or produces them; for, since it is a question of catastrophes, the ambition of his knowledge knows no limits, and, devoured by the spirit of Evil, he perfects his engines of disaster and ruin.

Thus Nikola Tesla, a learned American, a rival of the illustrious Edison, has just made a discovery which, when applied to the art of warfare on sea or land, is to furnish to the armies a power of destruction so formidable that one scarcely dares to contemplate its practical results. The secret of this discovery resides in the transmission of electrical energy to distances which, until now, nobody could surmise. By simple atmospheric conduction, and without any wire whatever, the current is to traverse thousands of kilometers, bring mourning and desolation and carry death, silently, invisibly, into the ranks of the enemy, who will not even be aware of the approach of the Camarde and able to defend himself against its unforeseen blow.

It is with such exploits that human wisdom taxes its ingenuity, and one still dares to praise the moral effect of philosophy.

According to Nikola Tesla, the problem solved by him consists in producing and projecting currents of an enormous voltage heretofore unknown to electricians.

By means of this discovery an operator may, in the shelter of his laboratory, his person not exposed to the least danger, in perfect security blow up out at sea boats carrying explosives at incalculable distances and beyond the range of the most powerful guns.

A simple unarmored, unprotected vessel, having not even a cannon on board, but capable of great speed, may become the most terrible adversary of a whole fleet. A single operator in command of a flotilla of small boats, the evolutions of which are controlled by him with mathematic precision, may destroy the enemy's squadrons without having himself run any risk. In the same manner, and with as little danger, he may send into the enemy's port explosives which would produce a disaster similar to an earthquake.

In order to cause the credit to be given to such prophecies to be appreciated, the learned Yankee has constructed a small model of a boat which performs all the evolutions of his prescription. It is terrible in its precision. An electric motor placed at a distance, in another room, controls all its movements automatically and in a reliable manner. And in this way an electrician on board of a flagship seeming quite inoffensive may, with a simplicity which would eclipse the knowledge of the most profound strategists, direct against the enemy small vessels intended to spread death around themselves—death which nobody suspects, which calls unawares and from afar, with the prophetic surprise of a cataclysm prepared by man.

This is terrible, and causes one to shudder when contemplating this power of destruction brought to the height of its terror.

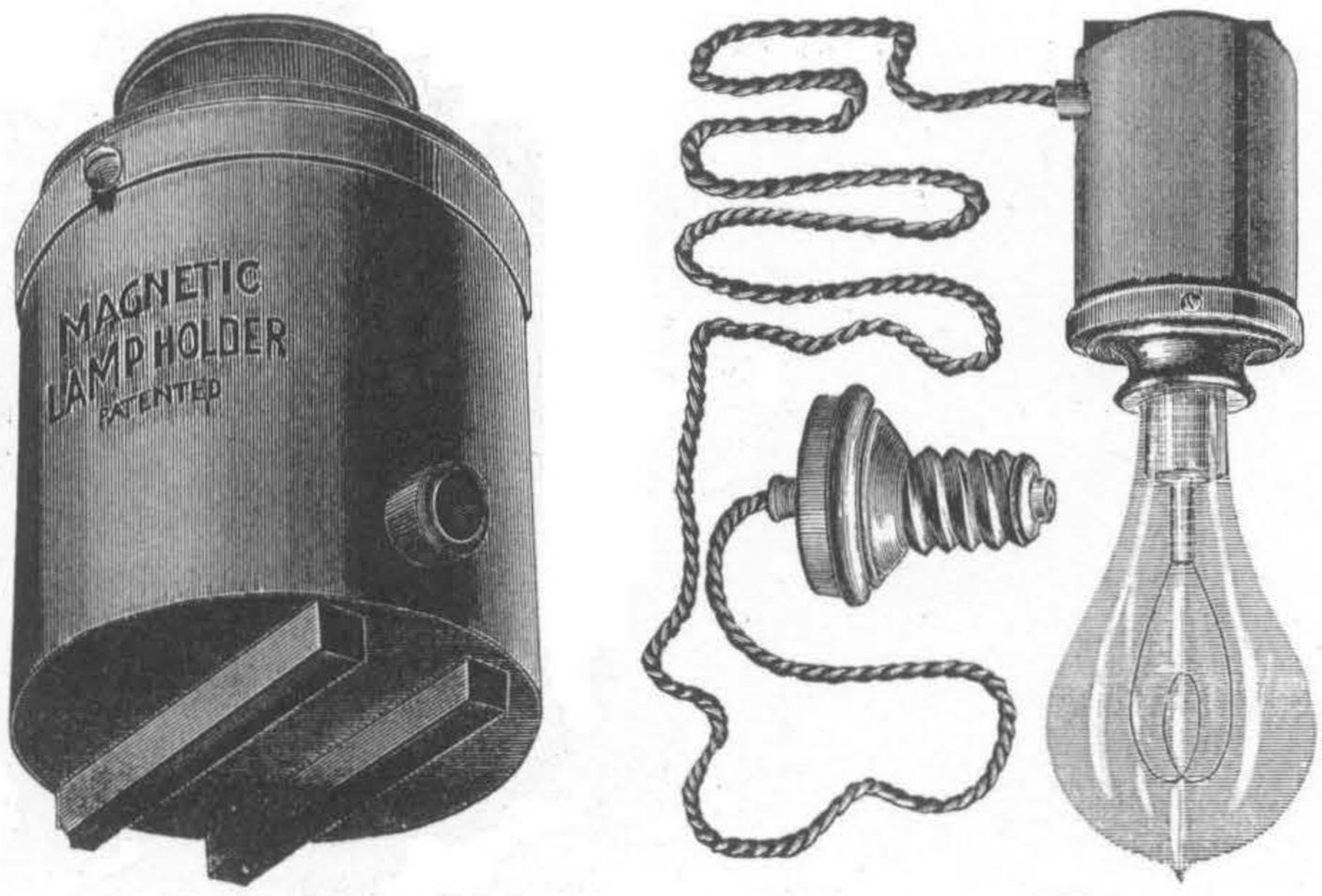
We must not be incredulous, however. Nikola Tesla proposes to instruct the most intellectual and skeptical people on earth. He intends to exhibit at the exposition in 1900 a torpedo of his invention. He will himself direct its movements from New York, without a conducting wire, by simple electric transmission through the high regions of the atmosphere.

And when we have been entertained what will be the result for humanity, thus threatened with the worst catastrophes, at the mercy of an infernal operator endowed with fiendish, almost diabolical power?

The man who could make this discovery knows how to reassure us in this regard. Like all inventors of destructive machines, he claims that his instrument will make the governments which are inclined to create international conflagrations hesitate. The power of destruction of which he disposes is, he says, so unlimited and its employment in war would endow an army with such an instrument of victory, that no country being concerned about the lives of human beings would dare to assume before civilization, before history, the terrible responsibility of a scientific war. On this account Nikola Tesla claims a right to be called a benefactor of humanity.

Posterity will, perhaps, accord him this claim, as well as to others who have, like him, perfected the art of destroying in bulk and at wholesale, dreaming of such numbers of deaths that nobody would want to boast the tragic glory of ever having caused them.

The genius of destruction would seem to have, then, two aims. It creates evil, but mostly good. Through its help the abolition of wars may no longer be a utopia of generous dreamers, an empty dream of enlightened, altruistic thinkers who have compassion with their fellowmen. A blessed era will open up to the people, whose quarrels will be settled in view of the terror of the cataclysms promised by science, views radiant with peace, which has at last conquered over centuries of barbarism, and there will be definite harmony in the entirely pacified universe!



FIGS. 1 AND 2.—A MAGNETIC INCANDESCENT LAMP HOLDER.

What contradictions of conception is the human mind subject to? At the moment when, thanks to the magnanimous initiative of Czar Nicholas II, the problem of universal disarmament is attracting the attention, the solicitude, of the diplomats of all nations, an inventor, a physicist of the New World, promises us the end of the barbarous international duels by the tragical horror of the work of Death, by an unheard-of improvement in the processes of destruction.

Will the universal peace result, then, from the excess of evil, or from the moral philosophy which springs out of modern civilization? Who can predict it to a certainty?

What does it matter, after all, whether we owe it to the former or the latter, if only some day this sublime utopian dream, this dawn of new times announced by the prophets of humanity, will realize, perhaps, at the beginning of the century which is about to be born. MARCEL HUART.

Paris, November 12.

Tesla's Views on his Critic.—The *Electrical Engineer* of New York in a recent issue printed the full text of a lecture by Mr. Nikola Tesla before the American Electro-Therapeutic Association. This course, and their leader on the subject, has drawn forth the following letter from this noted inventor: "Sir,—By publishing in your columns of Nov. 17 my recent contribution to the Electro-Therapeutic Society you have finally succeeded—after many vain attemp made during a number of years—in causing me a serious injury. It has cost me great pains to write that paper, and I have expected to see it appear among other dignified contributions of its kind, and I confess the wound is deep. But you will have no opportunity for inflicting a similar one, as I propose to take better care of my papers in the future. In what manner you have secured this one in advance of other electrical periodicals who had an equal right to the same, rests with the secretary of the society to explain. Your editorial comment would not concern me in the least were it not my duty to take note of it. On more than one occasion you have offended me, but in my qualities both as Christian and philospher I have always forgiven you, and have only pitied you for your errors. This time, though, your offence is graver than the previous ones, for you have dared to cast a shadow on my honour. No doubt you must have in your possession, from the illustrious men whom you quote, tangible proofs in support of your statement reflecting on my honesty. Being a bearer of great honours from a number of American universities, it is my duty, in view of the slur thus cast upon them, to exact from you that in your next issue you produce these, together with this letter, which, in justice to myself, I am forwarding to other electrical journals. In the absence of such proofs, which would put me in the position to seek redress elsewhere, I require that, together with the preceding, you publish instead a complete and humble apology for your insulting remark, which reflects on me as well as those who honour me. On this condition I will again forgive you, but I would advise you to limit yourself in your future attacks to statements for which you are not liable to be punished by law.—N. TESLA." Our contemporary's leader in question does not, in our opinion, warrant the tone of Mr. Tesla's letter, and the justification both for publishing the lecture and for criticising Mr. Tesla's statements in the American Sunday papers are ample.

NOTES.

More Tesla Marvels.—The *New York Herald* of November 13th contains a sensational article on Tesla's recent inventions in wireless transmission of power. The article is full of inaccuracies evolved from the unscientific imagination of the reporter. Here are some of the gems :— Speaking of Tesla's new generator, it is said : "With a machine creating a pressure of millions of volts, Tesla lashes the vast ocean of electricity of the earth into a cyclonic storm. Instantly the waves spread in all directions through the universe of matter." By this we are led to believe that Tesla transmits power by means of electric waves. This may, as a matter of fact, be true, but, nevertheless, Tesla expressly repudiates this mode of transmission in his specification. A description, with an illustration, is given of Tesla's new torpedo boat, which, however, appears to be merely controlled from the shore by Tesla currents. The motive power is an old-fashioned battery of accumulators on board. Moreover, the controlling is not done by the new Tesla currents, but by a species of Marconi telegraphy. At least, there is a coherer on board the boat, and this is affected by electric waves sent by an oscillator "which may be tucked away in one's pocket like a cigarette case." Since the generator of Tesla's high pressure air-piercing currents contains 50 miles of wires, it is not very suitable for carrying in the pocket. On turning a little crank, the generator gives forth two waves at each half-turn. "The effect of these is like that of the vibrations produced by the voice in a telephone. On the vessel to be controlled is a broken electric circuit, loose metallic particles of a metallic oxide being at the point of separation." By means of the coherer, which is evidently what the reporter is describing, electric circuits are closed on board the torpedo boat, which control the rudder and the battery which furnishes the motive power. We imagine Tesla is not the first to propose the application of electric wave telegraphy to control the movements of an electric torpedo boat.

"The Greatest Discovery of the Age."

When England set her navy afloat upon the sea,
She had no anticipation of my great discovery,
For 'tis I, the only I, that have made her ships but scrap.
Any nation now may whip her, e'en the smallest on the map,
By "the greatest discovery of the age."

For the blowing up of navies will now be only fun.
An exertion of my will or thought and, lo! the thing is done!
I've combined a wireless telegraph and torpedo dirigible
In so evident a fashion, some say not patentable,
My "greatest discovery of the age."

I care not if the whole shebang was generally known,
I'll be very much *offended* if 'tis not *now* my own.
I'm a Christian and philosopher, as I have truly said;
The laurels of undying fame are resting on my head
For "the greatest discovery of the age."

And when I *am* offended, my forgiveness is complete
When I get a full apology, with humbleness replete.
I've put a stop to wars, but do not rest my claim
On such a simple act as that for everlasting fame.
My super-extra glory rests upon the arts of peace,
I'm in for killing whales and sich and getting at their grease
By my "greatest discovery of the age."

I'm so struck on this my latest that my brain it fairly reels,
And my head it gets to spinning as if 'twere hung on wheels.
I had an oscillator once, a tuneful dynamo,
A revolution 'twas to make, by vibrating to and fro.
'Twas a very great discovery of the age.

But it died ere it was born and resteth as a myth,
And its name now means some coils I experimented with
As another great invention of the age.

To shake the charge of mother earth, another scheme of mine
Beats thunderstorms and earthquakes, all along the line.
But wait till 1900. O, won't the people talk,
When I blow up stuff at Paris, when I think so at New York,
By my "greatest discovery of the age!"

I've labored with high frequency to publish and proclaim
That I own some great discoveries, connected with my name;
By high-potential discourse I've tried to bring to light
That there weren't any others who contributed a mite
To such very great discoveries of the age.

But the shade of Cabanellas, and of many others too,
Are upsetting my endeavors, and proving my hoodoo.
I content myself in this, that the papers of the day
Will print my schemes sensational and boom me by the way
As "the greatest discovery of the age."

Electricity's Mystery.

[From Collier's Weekly.]

Mr. Tesla's announcement that he is prepared to destroy a ship by means of electricity, yet not by means of wires, has been received with cheerful incredulity. It is a bountiful Providence which has enabled man to ridicule what he does not understand. Ridicule has been the prelude of every great invention. It has crooned at its cradle. But though it came to jeer, again and again it has remained to stare. That is as it should be. The beginning of truth is amazement. But in this case, as in all others, the proof of the pudding is in the eating. The value of Mr. Tesla's process remains to be shown. Just at present it is a mystery. Yet, so also is electricity. No marvel which electricity has worked is as marvelous as electricity itself. To call it a mystery, though, is a misuse of language. Correctly speaking, there is no such thing; but there is ignorance, and it is in a manner both delightful and flattering to general self-esteem that the one is confused with the other. In the chartless morrow which the future has in charge it is not extravagant to assume that ignorance will evaporate, knowledge become exact, that electricity will yield its secret, and perhaps for those who then live fathom the recesses of the sky. From a servant it may develop into a confidant; it may tell of its wanderings, of its conception, of its sudden avatars and all that it has seen. But this is conjecture. The point is, that in manipulating it, with a wire or without, there is a difference in degree rather than in kind.

Treatment of Inventors.

[From the Mansfield, O., News.]

Tesla, the electrician, whose promises excel his performances, has been having a few words with the editor of an electrical journal and has come out second best. If he thus fares with one of the brethren in his own line troublous times are ahead for him if he tackles the laymen of the press, who are ever ready to give the glad hand to an inventor who invents, but who are rather merciless on those long on talk and short on deeds, whether they be inventors or politicians.

Tesla's Fears.

[From the Anaconda, Mont., Standard.]

Tesla has satisfied himself and is trying to satisfy others that he has discovered a principle, the application of which "must produce a profound change in things and conditions presently existing." Tesla's only fear is that his invention will be used by men for evil purposes—that, like the invention of gunpowder, it will not be an unmixed good to the world. But it is a comfort to him to know that, for one thing, it will abolish war.

Tesla's Romances.

[From the Minneapolis Times.]

Tesla has administered a severe scolding to the editor of an electrical journal, who intimated that Mr. Tesla might find it profitable to give his imagination a rest and finish up some of the wonderful things he has set out to do. In these days of scientific miracles it isn't safe to be skeptical, but some of those announcements of Tesla's read as if they might have been inspired by the product of the poppy in the pipe.

NOTES.

Tesla and his Critics.—Our contemporary the *Electrical Engineer* (N.Y.) has given offence to Mr. Tesla by an article entitled "Mr. Tesla and the Czar." The connection between these two famous personages is not at first sight apparent, but it appears that both are Slavs, and Tesla's new scheme for aerial power transmission strikes our contemporary as belonging to the same class as the Disarmament scheme of the Czar. The aims of both Tesla and the Czar, says our contemporary, "appear wholly noble, their thoughts are beautiful, and if they fail, as they probably will in some material and vital respects, the world is certainly none the worse off for what they actually accomplish." Though the article is not wholly unappreciative of the good work which Tesla has accomplished, it twits Tesla with the number of his unfinished inventions, and unnecessarily perhaps emphasises the assertion that Profs. Brackett and Dolbear have virtually classed him as a humbug. Tesla has written in reply that by this last straw our contemporary has strained his Christianity and philosophy to the breaking point, demands proofs of the animadversions of the distinguished professors, which he says reflect on his honour and honesty, and through him upon a number of American Universities, who have conferred great honours upon him. The *Electrical Engineer* replies by pointing out the support that it has given to Mr. Tesla and his inventions since the beginning of his career, and professes that its mild criticism and mild banter was a sign of true friendship. We confess that we don't think that there was anything much in what our contemporary said, but the way in which it was put might be expected to give offence to a man of Tesla's poetic sensibility.

Tesla and His Complaints.—Our contemporary the *American Electrician* sums up the points at issue between Mr. Nikola Tesla and another American journal in the following concise terms: "The truth plainly stated is, that for several years Mr. Tesla has only escaped similar criticism in professional and scientific journals on account of the high esteem in which he is held personally, and through recollection of the magnificent boon he bestowed on the world by the invention early in his career of the polyphased system. The manner in which he has permitted himself to be exploited by the sensational newspaper Press has been a source of pain to his friends, and has largely alienated from him the sympathy of the electrical profession. Moreover, his periodical promise of being on the point of accomplishing some wonder that would revolutionise electrical science has had an untoward effect on the electrical industry, for among laymen it has tended to produce the belief that at any moment one of Tesla's great discoveries may materialise and destroy all present investments."



Tesla Polyphase Patents Declared Invalid in Germany.

The Reichsgericht of Germany has confirmed the decision of the lower courts declaring the Tesla polyphase motor patents invalid. The court reviewing the case, holds that the patents are void owing to their not having been worked according to the requirements of the German patent law. The court goes on to say, however, that even if the patent had been sustained on that ground, it would have been, nevertheless, invalidated owing to the fact that the invention was not adequately described in the German patent specification, whereas the American patent specification is clear. It is understood that the Helios Co., of Cologne, who control the Tesla patents in Germany, will no longer contest the suits which it has brought against several parties in Germany.

TELEGRAPHING WITHOUT WIRES.

TESLA'S LATEST INVENTION.

C. D. Wood, in the "Yale Scientific Monthly."

For many years there was but one man to whom our country could look for its advancement in electricity. Thomas A. Edison was the undisputed leader, and his word was law in the world of applied electricity. In the past few years there has been another man to step to the front, and through his skill and persistent mastering of difficulties he has obtained a similar or even higher position in the world of science.

Nicola Tesla is not an American by birth, but as his name implies, was born in Austria. Thinking that an opening was in store for him in this country, he made it his home, and to it he has contributed the results of his discoveries. Tesla's career has been one of difficulty. On two different occasions his laboratory has been on fire, and several important models were destroyed, on which he was still working.

For the past year the young inventor has been studying the problem of conveying electric currents without visible conductors. He has proved the theory concerning the ability of waves of ether to carry electricity, and has brought it to a practical test by making luminous, without the aid of wire, cylinders suspended in the middle of a room. He now claims that it is possible, without the aid of other media than the earth and the atmosphere in a certain state to transmit large quantities of electricity an indefinite distance. The transmission of such currents for long distances would open up a field of electrical engineering the extent of which would be hard to conceive. It is well known that air, when enclosed in a vessel, can be so rarified as to destroy its insulating properties, and become a fair conductor. If the so-called electrical pressure at a certain point is sufficient, and that point be elevated so as to obtain the proper rarefaction, the electrical energy at the point can be conveyed to an indefinite distance.

Tesla has invented a machine (if it may be called that) by which, without danger to the human body, he can produce an electrical pressure to the amount of 2,500,000 volts. As the conductivity of the air increases directly as the pressure, the more current produced, the greater is the efficiency of the air to carry the particular current.

Tesla's generating apparatus or transformer, as he calls it, consists of a secondary coil, built up as usual around an iron core and wound with a large number of convolutions. This coil is surrounded by another, having wire of heavier diameter, but wound with fewer convolutions. This comprises the primary or low-tension coil, and is electrically connected to the secondary, in order that there may be no difference of potential. The length of the secondary coil is now to be considered. That the greatest possible electrical pressure may be obtained, the length of coil should be equal to one-quarter of the wa length of the electrical disturbance in the circuit.

The current in this case may be supposed to travel 182,000 miles per second; there a frequency of 925 per second would maintain 925 stationary waves; hence, each wave should be 200 miles long. Tesla proposes that his coil shall be 50 miles in length. The current coming from the terminal connected with the earth traverses the transformer, and is led by an ordinary conductor to an elevated station. This elevated terminal is generally a rounded surface suspended at a height which insures the rarefaction of the air necessary to conduct that particular current. If the potential is high enough and the surrounding conditions of the country favorable, the air will offer less resistance than an ordinary copper conductor. If there were mountains in the vicinity, the elevated terminals would have to be placed upon them, for a large portion of the electricity would otherwise escape to the higher ground.

Situated at an equal elevation at the receiving station, we have a terminal similar to the one just described, and connected with the receiving transformer. The machi resembles the first transformer, except that the coils are in a reversed position. The inner coil with the greater number of convolutions acts as a primary, and the low tension coil takes the part of the secondary. Another conductor completes the circuit by carrying the current to the earth. In the circuit of the transformer lamps, motors or any other machines for the utilization of current are placed. Such is the practical application of the new theory. These elevated terminals might be suspended from balloons, or placed upon high promonitories, provided the elevation is sufficient.

This scheme of transmitting electricity appeals to the business man as well as to the scientist, for he can readily see what large incomes could be realized with comparatively moderate expense. If the Kings County Electric Power Company of Long Island, which is now the largest electrical concern in the United States, could utilize the power of Niagara by this new method, they could do away with their several power houses and cut down their expenses one-half. This invention has not been the product of a small amount of work, but the outcome of long series of experiments and careful study on the part of the inventor. Tesla is purely a man of science. His connection with Edison was severed because he did not believe in a scientific life for the money that was to be found therein. He believed in giving his inventions to the world with unrestricted freedom, differing from his older partner, who was the business man, as well as the inventor.

Telegraphing Without Line Wires*—I.

BY WILLIAM BISSING.

It will be seen from the patents hereinafter cited that the present subject is not new. It has occupied the attention of inventors for at least fifty years; and, indeed, if we include signaling by flashlight or by sound, it will be found that for thousands of years man has been endeavoring to communicate to distant points without the intervention of artificial connecting media. It would, however, go beyond the limits of this article to mention all the experiments and applications of the various forms of signaling by light and other natural agents that have been tried for so many years. In view of the renewed interest in the subject that has been aroused by recent experiments of English and Continental physicists, who have used electrical methods for accomplishing the above result, and in view of the close relationship which exists in this country between the work of the theoretical scientist and the work of the practical inventor, it may be of interest to give a review of the electrical development of the patented art bearing on this form of signaling.

The electrical methods which have been used to transmit intelligence without intervening wires may be broadly divided into three distinct classes, i. e., conduction methods, in which battery currents are used and in which the earth serves as a conductor; methods in which the transmission is effected by induction, and electrical wave methods. Induction methods may be again subdivided into two classes, to wit: Electromagnetic and electrostatic methods.

CONDUCTION METHODS.

About the earliest patent in which the earth is used as a conductor to effect transmission is the English patent to Lindsay, No. 1242, of 1854. This patent contains all the essentials which enter into this means of telegraphing, and is open to all the objections that accompany this system. In it, as shown in Fig. 1, the patentee telegraphs across an intervening water course by using on one side of the water a battery, *B*, connected to two plates which are placed a considerable distance apart in the stream or lake. On the opposite side of the water course are placed two corresponding plates connected by wires which include a galvanometer and another battery. The patentee states that "the distance between the two plates on one side of the water course is greater than the distance across the water or to the plates of the opposite battery. Suitable keys, *K*, may be placed in the circuits. On closing the key in one circuit the electric current will pass into the water at *C*, through the wire or wires which are on the opposite side of the water, and re-cross at *F*; or, more correctly speaking, the electric current divides between the two courses in an inverse ratio to their resistances, so that a portion of it takes the circuitous course." It will, of course, be evident that the distance between the plates of one circuit may be diminished, if at the same time the e. m. f. of the battery connected to these plates be increased.

In the conduction system we are dealing with two plates buried in a conducting medium and kept at a suitable difference of potential. We may imagine the current distributed through the medium along certain stream lines, a fall of potential resulting along the different lines of flow. If the two ends of a receiving circuit be grounded at two points between which there is a sufficient difference of potential, enough current will be shunted through this circuit to actuate a recorder. An analogous case is afforded by the laboratory experiment, in which the lines of flow of the current from a battery are determined, when its poles are placed in contact with a sheet of tin foil. One end of a circuit which includes a galvanometer and a battery is touched to the sheet of foil, and the other end moved until a position is found for which the galvanometer gives no deflection. The former end of the circuit is then kept in its original fixed position on the tin foil, and the latter end moved until another point is found for which the galvanometer deflection is zero and so on. These points are then plotted and enough pairs of points found to locate the equipotential curves, which are normal to the lines of flow. It will be seen therefore that in the conduction system, the receiver might have its terminals so located that no current from the transmitter will be shunted through it and that the best position for the terminals of the receiving circuit is in a stream line of maximum intensity and at right angles to the equipotential curves. It will also be desirable to curve the end plates of the receiving circuit to fit the equipotential curves at the points where they are buried in the earth so that all the points of each plate may be at the same potential. This will avoid local circuits in the plates. Usually such curvature will be unnecessary, since the plates are small and the stream lines are straight at the points where the receiving terminals are located, and plane plates may consequently be substituted.

The objections to this method of transmission are many and obvious. Nowadays, when, in all large cities, currents from railway circuits and lighting systems are constantly leaking to earth, great disturbances of the instruments used in this system must be expected. Secrecy is impossible, since anyone may ground his instrument, and thus receive the signals intended for another. Only a small portion of the current generated by the battery will pass through the receiving instrument. This instrument must, therefore, be quite sensitive, which in turn may render it subject to the disturbances above referred to. The battery current, moreover, is short circuited by street-car rails, gas pipes and water pipes, so that very little current will reach the recorder.

It is interesting to notice, however, that this particular method has been many times revived, even as late as 1894, when it appeared in "Cosmos," Paris, March 3, 1894, republished by the "Electrical Review," Vol. 24, p. 193, which described some experiments by the Abbé L. Michel, in which telephones were used as receiving

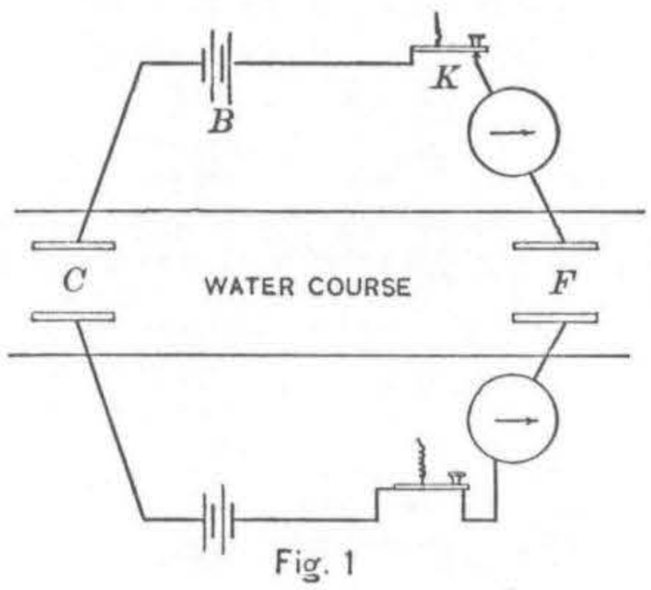


Fig. 1

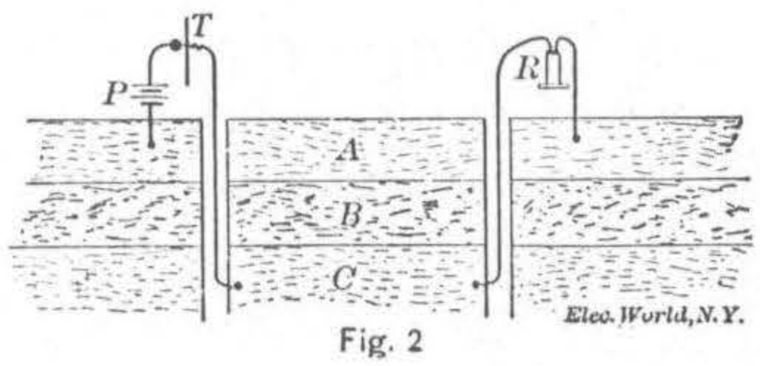


Fig. 2

and transmitting instruments. See Fig. 2. Five accumulators *P* were used in the transmitter circuit, and with the receiver *R* placed in a building about 3000 feet away, telegraphic dispatches were heard quite distinctly. In these experiments two distinct paths may be arranged for the electric current, according to the position of the plates in each circuit. If a plate is placed at the bottom of a well at *C*, and the other plate of the same circuit is placed in the surface soil *A*, and if there is an intervening layer *B* of high resistance soil between the transmitter plates, the plates of the receiving instrument *R* being similarly located, then the path of the current will be from one plate of the transmitter through the surface soil to the corresponding plate of the receiver, then through the receiving instrument and back by the bottom layer of earth. The intervening high resistance stratum will prevent short circuiting of each instrument. The other method would be to locate the plates of each instrument a suitable distance apart, but all of them in the surface soil, which is substantially the method of the English patent to Lindsay.

Between the dates of Lindsay's invention and the "Cosmos" article a number of patents have been taken out, all based on the principle of the resistances of branched circuits. Among them may be enumerated the following: In Great Britain—Haworth, No. 843, of 1862, and No. 2682, of 1863; Smith, No. 8159, of 1887;

*The classification adopted in this article has been followed by the patented art in its development, and is also that which has been used by Prof. S. P. Thompson in a review of the literature of the subject in the "Journal of the Society of Arts," London, April 1, 1898.

Stevenson, No. 5498, of 1892; Smith et al., No. 10,706, of 1892; and in the United States the following: Ader, No. 377,879, February 14, 1888; Blake, No. 526,609, September 25, 1894.

The Smith patents show a means of communicating from the shore to a lighthouse on an island by the use of submerged plates, one pair being connected to a receiving instrument in the lighthouse, and another pair arranged to include the former pair between them, the latter pair being connected by wires to a transmitting battery and key on the shore. In the last cited patent to Smith step-down transformers are used to energize the plates located in the signaling circuit. These, of course, generate heavy currents, so that an appreciable part of them may flow through the receiving instrument in the lighthouse. It is evident that devices of the last-named character can transmit signals through a short distance only without intervening wires. The advantages that result from their use are due to the ability of dispensing with shore connections for the cables on rocky coasts where lighthouses are usually situated. In heavy gales the ordinary cable is often torn from its bed and communication between the shore and the lighthouse is interrupted. By burying one of the plates of a conduction system in the ocean sufficiently below the surface of the water to avoid the disturbing action of the waves on the signals, and its neighbor in a well on the lighthouse shore, the necessity of bringing a cable end on land is avoided, and a fairly satisfactory means of communication is established.

An application of this method to ship signaling seems to offer a chance of success, owing to the short distance between the ship and the signal transmitting circuit. In this connection the following

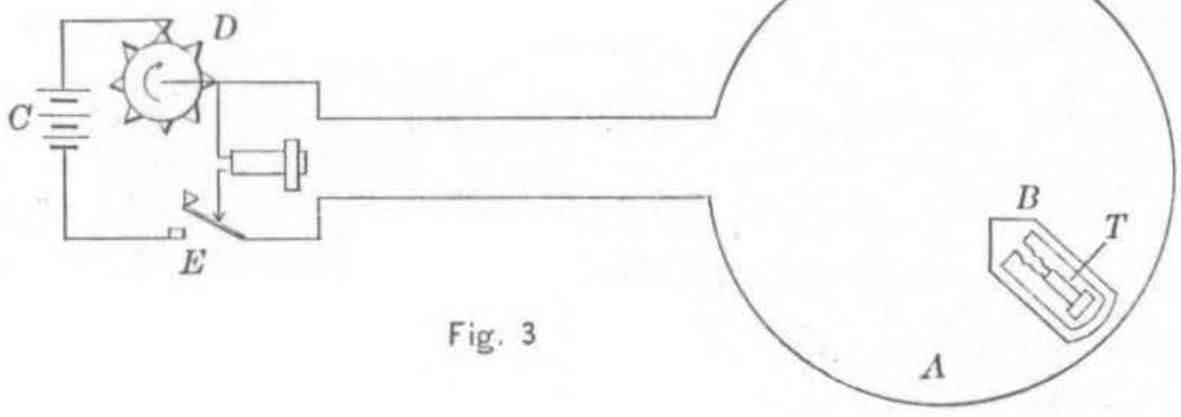


Fig. 3

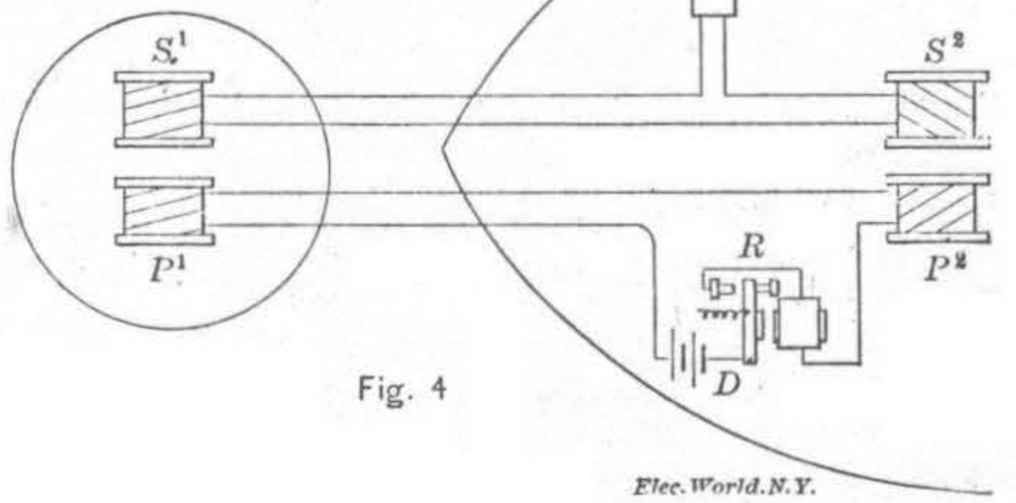


Fig. 4

patents may be cited, which illustrate a means of avoiding collisions of ships with each other, or of preventing them from running ashore: In Germany, Somzee, No. 44,101, of 1888; in Great Britain, Stevenson, No. 5498, of 1892, and in the United States, Blake, No. 526,609, September 25, 1894.

In Somzee's invention each ship carries a pair of plates submerged in the water, one at the bow, the other at the stern, the plates being connected by wires which include a signal-receiving instrument, such as a telephone or galvanometer. Shoals may be indicated by suitably energized stationary plates, the current from which is diverted into the receiving circuit on the ship whenever the vessel approaches shallow water. A similar method is used in the Stevenson and Blake patents. The conduction system of transmission is fully explained by Rathenau in a report to the General Electric Society in the "Elektrotechnische Zeitschrift," for November 8, 1894, in which it was suggested that a telephone receiver be used to receive the signals. The metallic diaphragm of the telephone was to be replaced by a light tongue, which should be tuned to respond to the predetermined rate of vibration of the transmitting circuit. This rate was to be imposed upon the circuit by a suitable tuning fork operating a circuit breaker. The investigator stated that communication had been effected over a distance of 3 miles.

INDUCTION METHODS.

These methods have already been classified into electromagnetic and electrostatic systems. The difference between them is largely one of degree, inasmuch as in each both kinds of induction may play a part, although usually the effect of one preponderates over that of the other. The intimate relationship which exists between the two methods is explained by the modern theories of inductive action. Maxwell's theory assumes that an e. m. f. which acts upon a dielectric produces an electric displacement, and that the change in electric displacement is an electric current called the displacement current. This displacement current in dielectrics is accompanied by magnetic force. It originates a field of magnetic lines of induction which surround it just as a wire carrying a current is surrounded by lines of force. The converse propositions whereby displacement currents are created by the change in the intensity of a magnetic field readily follow from the original assumption.

According to the J. J. Thomson theory, both kinds of induction are produced by electrostatic tubes of force, called by him Faraday tubes, some of them open and some closed, which are distributed through the ether. Each open tube which starts from a positive charge of electricity terminates on an equal and opposite negative charge. This gives rise to the ordinary phenomenon of electrostatic induction. The phenomena of the electromagnetic field are due to the motion of the Faraday tubes, or to changes in their position or shape; if, for example, a moving tube cuts a closed conductor, a current is induced in it.

The differences in the two methods above referred to result from the relative importance of the induction coil and the condenser in the particular circuit under consideration. In electromagnetic induction methods the magnetic field of the circuit supplied by the induction coil is the important element, in the so-called electrostatic system the effects are due to the condenser which gives rise to the electrostatic field of force.

The term electrostatic induction, which has been freely used, seems to be a misnomer when applied to phenomena which are due to electricity in motion. The appearance and disappearance of the induction tubes which accompany the charge and discharge of a condenser give rise to the induced current, and the effect is not one of electrostatics but of electrokinetics. It would be more accurate therefore, to apply the term capacity or condenser methods to the class called electrostatic induction, and the phrase mutual-induction system to the electromagnetic-induction methods. The older terms have been retained for convenience.

ELECTROMAGNETIC INDUCTION METHODS.

About 1893 Mr. W. H. Preece gave a renewed impetus to the electromagnetic induction class by some experiments performed in England, in which the inductive method was exhaustively tried. In previous experiments by the same investigator in which buried plates were connected to two parallel wires a considerable distance apart, the effects were attributed largely to earth conduction, and it was necessary to prove that the action in the later trials was electromagnetic in its nature. This was unquestionably true in some of the experiments, but there is still some doubt as to the nature of the action in all the tests. One method was to use insulated copper wires in quarter-mile squares laid on a level plain, a quarter of a mile apart. Alternating currents were sent through the transmitting circuit, and these, when interrupted by means of a telegraph key, gave Morse signals which were received in suitable telephones. The data are given in full in the Proceedings of the Electrical Congress at the World's Fair for 1893, published by the American Institute of Electrical Engineers.

The electromagnetic induction method has been the subject of a number of patents, attention being called to the following: In the United States—Phelps, No. 307,984, Nov. 11, 1884; 312,506, Feb. 17, 1885; Woods, No. 373,915, Nov. 29, 1887; Ader, No. 377,879, Feb.

14, 1888. In England—Evershed, No. 10,161, of 1892; Sennett, No. 13,415, of 1892, and Evershed, No. 18,312, of 1896. In Germany the patent to Somzee above cited.

The patents to Phelps and to Woods furnish applications of the method of transmitting signals to or from a moving railway train. A coil of wire, including in its circuit a transmitting key and a receiving instrument, is located on the car so that the coil may pass in close proximity to a telegraph wire strung upon poles or on the roadbed. These devices necessitate the presence of a telegraph operator upon the car, and inasmuch as it is an easy matter to dispatch telegrams at the nearest stopping point which may be written out on the train, it will readily be seen why this system has not gone into extensive use.

The English patents to Evershed and to Sennett above cited disclose methods of signaling from the shore to lightships or other vessels approaching the shore. An inductive circuit is arranged with a coil A, see Fig. 3, located in the ocean in a horizontal plane, the coil being supported, if desired, by suitable buoys so as to bring the magnetic field produced by the coil near the surface of the water below the vessel B which sails over it. The signaling circuit may be produced by an alternating-current dynamo, or by means of a battery C and revolving contact wheel D, which rapidly interrupts the battery current. A telegraph key E is used, by means of which signals of short and long duration are given according to the Morse or other code. The receiving instrument may be a telephone receiver T or an electromagnet acting on a reed of metal tuned to correspond in pitch to the frequency of the secondary currents. A call bell may be rung by means of a local battery in the circuit of a relay, the relay consisting of a tuning fork designed to respond to the timed impulses of the transmitting circuit.

In the German patent to Somzee, which has been discussed above, a modification is used which adopts the principle of the Hughes induction balance. See Fig. 4. In this method the balance is formed by two circuits, each including a pair of coils, one circuit being completed through a battery D, and automatic circuit breaker R, and the other through a bell. One pair of coils $P^2 S^2$ is placed upon the ship, the other pair $P^1 S^1$ is located upon a float which is dragged by the ship. The inductive effect of P^2 on S^2 is normally balanced by that of P^1 on S^1. When the vessel approaches a shoal, which should be marked by means of a large metal buoy, the balance of the currents is destroyed by the metal of the buoy and the bell rings. The method employed by Somzee has been used by Huskisson in patent No. 542,732, July 16, 1895, for the automatic firing of mines located in a harbor. The induction balance is connected to the mine, and when the ship passes over it the current balance being destroyed by the inductive action of the metal of the ship, the mine is fired.

In the methods which have just been described the effects are due to mutual induction. The current flowing through the signaling circuit creates a magnetic field of force, the lines of which penetrate the receiving circuit. Any change in the intensity of the current produces a corresponding change of the field, and this gives rise to an induced current in the receiving circuit, whose e. m. f. is measured by the rate of decrease of magnetic induction through it. This gives the equation

$$E = - M \frac{di}{dt}$$

in which E is the induced e. m. f. at any instant, M is the coefficient of mutual induction of the two circuits, and i is the current in the inducing circuit at any instant.

If, as in some of the cases discussed above, we have an alternate current flowing through the primary circuit whose equation is

$$i = I \sin a$$

in which I is the maximum value of the primary current, we have for the value of the induced e. m. f.:

$$E = M I \cos a \frac{da}{dt}.$$

The effective secondary induced e. m. f. is therefore:

$$E' = 2 \pi f M I'$$

in which I' is the effective primary current, f is the frequency of the primary current wave, and M is the coefficient of mutual induction.

It follows from this equation that in order to make this method of signaling as sensitive as possible we must use large currents of high frequency in the signaling circuit, as many turns of wire as possible in both circuits and increase the permeability of the intervening medium by introducing magnetic materials therein.

(To be Continued.)

Telegraphing Without Line Wires—II.

By William Bissing.

ELECTROSTATIC INDUCTION METHODS.

The electrostatic system may be said to represent an intermediate stage in the development of the art of telegraphing without line wires. Some of the difficulties which are met and overcome in this method of signaling, e. g., the dampening effect of intervening obstacles, occur in the modern or Hertzian wave method. In some of the patents that used electrostatic induction for their effects electrical waves occur, but, as will appear more fully below, the wave effect is lost or inconsiderable. Some of the electrostatic methods have been used, a number of years ago, in railroad signaling, examples of which are furnished by the following patents: Smith, 247,127, September 13, 1881; Phelps, 334,188, January 12, 1886; Edison et al, 486,634, November 22, 1892.

The patent to Smith was the first to describe a means of signaling by induction to a moving railway train. The metallic roof of the car which should be insulated is connected to a wire which leads to one terminal of a telephone receiver, the other terminal of the receiver being grounded through the wheels and rails. A telegraph line is strung along the track in closer proximity to the car than is customary for Morse signaling. On telephoning over the line from a station on the road the car roof is affected inductively, and a current is produced in the receiver on the car, the line and the roof forming the two plates of a condenser. An advantage of this method of transmitting signals is that the line wire along the track may be used for telegraphing according to the ordinary Morse system, without disturbing the telephonic signals. The current induced in the car circuit in this patent is probably due to both electromagnetic and electrostatic induction.

In the patent to Edison, et al, No. 486,634, see Fig. 5, a pair of suitably insulated plates *aa* are placed upon the car roof, and a wire *1* connects them to one terminal of the secondary of an induction coil *E*, the other terminal of which is connected to the telephone *F*, from which a wire *2* runs to ground at the car wheel. The primary of the induction coil is connected through a switch *e* to an electromagnetic circuit breaker *I* and battery *H*. Sparking at the circuit breaker is prevented by the condenser *K*. A switch *G* normally short-circuits the secondary of *E*. A similar apparatus is placed at the sending station. In receiving signals the switch *e* is opened, and *G* is left in its short-circuiting position. The signal will then be received at *F*, the telephone taking the place of the Morse sounder. In sending signals *e* is closed and *G* depressed at intervals to produce dots and dashes according to the length of depression of the key, a series of impulses which produces a rattle in the telephone receiver being sent to line each time the key is closed. The system used in this patent resembles that used by Edison in patent No. 465,971, which will be described below. Both patents were applied for in the same year, viz., 1885.

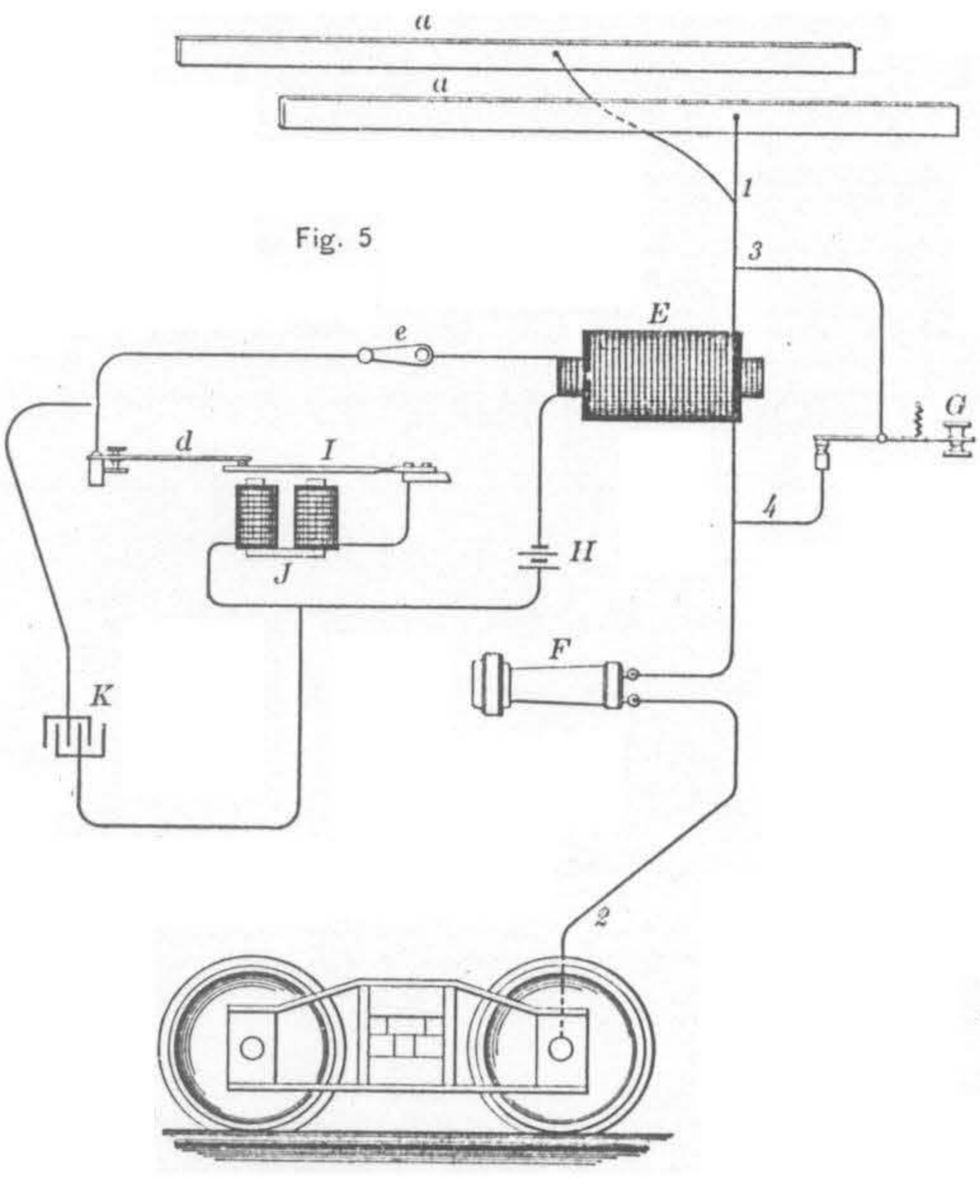


Fig. 5

In the patents which use induction methods treated in the preceding part of this paper the distances over which transmission is effected are comparatively short. A class of devices will now be investigated in which the inventors attempt to signal through a considerable space without using line wires. These inventions are described in the following patents: Dolbear, 350,299, October 5, 1886; Edison, 465,971, December 29, 1891; and Kitsee, 550,510, November 26, 1895.

In the patent to Dolbear, see Fig. 6, the transmitting circuit is shown at *A*, the receiving station at *B*. The induction coil *G* contains but one winding, which forms both its primary and secondary. One convolution of the coil is cut, the ends thus formed being connected with the poles of the battery f^1, which has a number of cells sufficient to establish a potential difference of 100 volts between the condenser H^1, which is attached to one terminal of the induction coil *G* and the wire *C*, which grounds the other end of the coil. A microphone transmitter *T* is included in the primary circuit. At *B* are located a magnetic telephone receiver *R*, condensers *H* and H^2, and a battery which the inventor says is arranged to charge the ground at *D* to an opposite potential from that at *C*.

Fig. 6

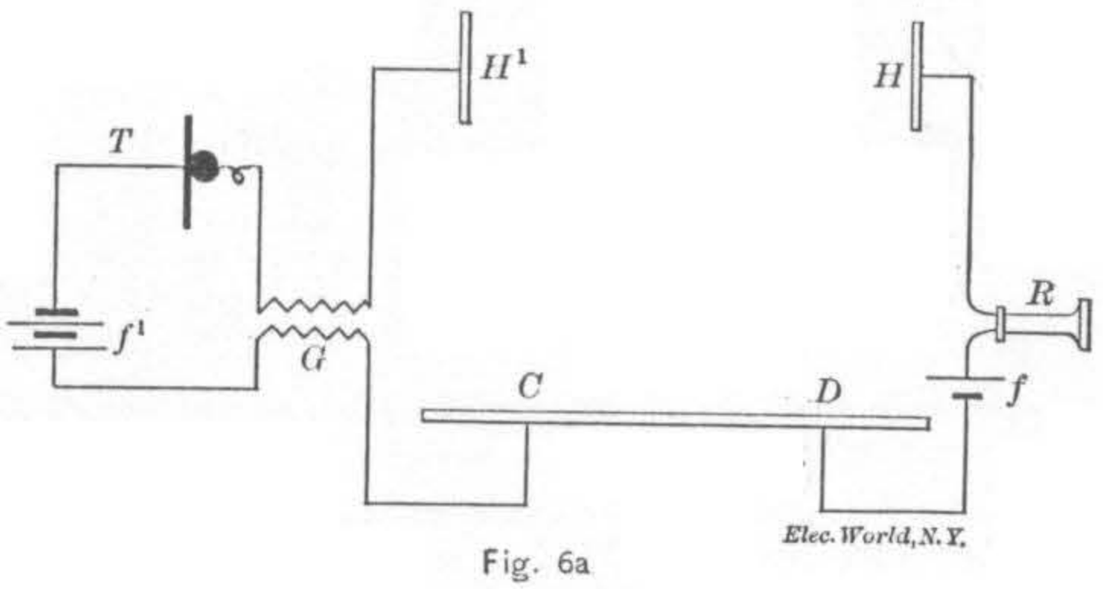


Fig. 6a

It would appear that several of the elements used by the patentee are unnecessary; he himself states that the condensers *H* and H^2 are not essential. Inasmuch as all the condensers are shown with one coating insulated, the capacity which they give to the system is small and their effect must be slight. The diagram, Fig. 6a, omits what appear to be inessentials, and gives perhaps a clearer idea of what occurs when the variable resistance transmitter *T* is vibrated. *G* represents the induction coil. H^1 and *H* form the two coatings of a condenser of small capacity. In addition to this condenser we have to take account of the fact that owing to the proximity of H^1 and *H* to the earth these plates form respectively the coatings of a pair of condensers, whose other plates are formed by the earth.

The capacity of this last-named pair is considerably greater than that of the condenser $H H^1$, for the capacity of a condenser varies inversely as the distance between the plates, and the distance from H or H^1 to earth is much less than from H to H^1. Consider now the circuit $C\ G\ f^1\ T\ G\ H^1\ H\ R\ D\ C$, in which a variable e. m. f. is produced by the vibration of T. There will be two paths for the alternating current produced by the change in the variable resistance T; one circuit beginning at the battery f^1 leads to the transmitter, then through one-half of the induction coil to H^1 to earth at C, and returns through the other half of the induction coil to the battery; the other circuit goes from H^1 to H, through the receiver R, and returns by way of the earth and through the path of the first circuit to H^1. It is the latter circuit that transmits the signals from T to R. Knowing the resistance, self-induction and capacity of each of these circuits, the amount of the e. m. f. of the battery and the variation in the resistance of T, the strength of the current in each of the two branches may be calculated. It will be seen that only a small proportion of the current produced in the local circuit $f^1\ T\ G\ H^1\ C\ f^1$ will be diverted into the receiving circuit at R. The battery at f, which is connected in series with the battery at f^1, increases the total e. m. f. in the signaling circuit, so that by means of it a given change in the resistance T will increase the current through the receiver R.

The apparatus used by Edison in his patent No. 465,971 is shown in Figs 7, 7a and 7b. In these figures two capacity areas C are placed at a suitable elevation and connected by wires l through his electromotograph receivers D and the secondary of the induction coil F to the earth. The electromotograph is a revolving chalk cylinder upon which a metal brush rests, giving a note of definite pitch (see patent No. 221,957 to Edison). When the current flows through the instrument the friction between the brush and cylinder changes, and this produces a note of different pitch. Any other form of receiver, which can be operated by alternate currents, may be substituted. A revolving circuit breaker, G, normally short-circuited by the key H, is placed in the primary of each induction coil. When the key is depressed a large number of impulses are produced in the primary, and by means of the secondary corresponding impulses are produced at the elevated condensing surface. These electrostatic impulses are transmitted inductively to the distant surface C, and are made audible by the current generated in the electromotograph connected in the ground circuit with the distant condenser plate. The intervening body of air forms the dielectric of the condenser, so that we again have the case of a circuit containing resistance, self-induction and capacity in series in which an alternating current is generated by a series of impulses of low frequency. It may be well to remark that Edison was one of the first to note the advantage of elevation for the condenser plate, as is shown by his statement in the patent; "that it is necessary on land to increase the elevation in order to reduce to a minimum the induction absorbing effect of houses, trees and elevations in the land itself."

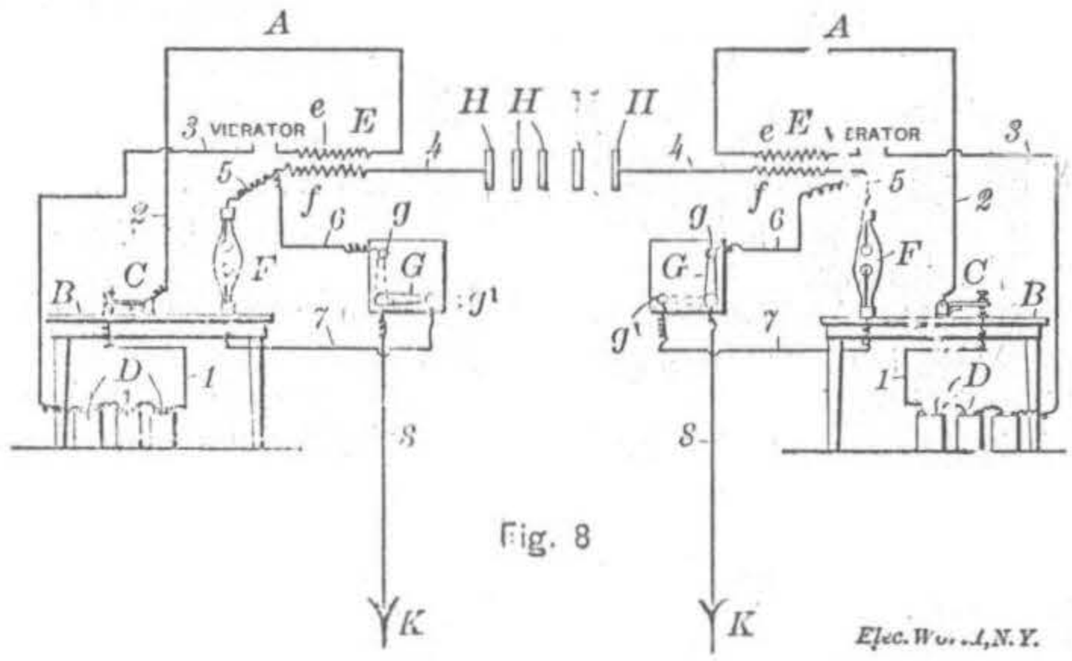


Fig. 8

The patent to Kitsee, which forms the last one of the electrostatic induction series, resembles the Edison patent in many respects, but uses a Geissler or vacuum tube for a receiving instrument. The closing of the key, in sending a current through the wire in which the Geissler tube is intercalated, causes a discharge in the tube which produces a continuous glow as long as the key is depressed. This permits the use of a dot and dash system of telegraphy. Referring to Fig. 8, a wire leads from the earth at K, through the switch G, and then either through the secondary f or through the Geissler tube F, and secondary to the line, according as the switch G is in the transmitting or receiving position. The local or signaling circuits consists of batteries D, a key C, a vibrator and primary e. With the switches in the position shown, on depressing the key C at the right-hand station, the vibrator is started, and the current induced in the secondary f, which alternately charges and discharges the plate H. These charges act inductively on the intermediate plates H, and finally induce a charge on the left-hand plate which creates a current in the secondary f which flows through the Geissler tube F, through the switch G to earth, thus causing a glow in the tube.

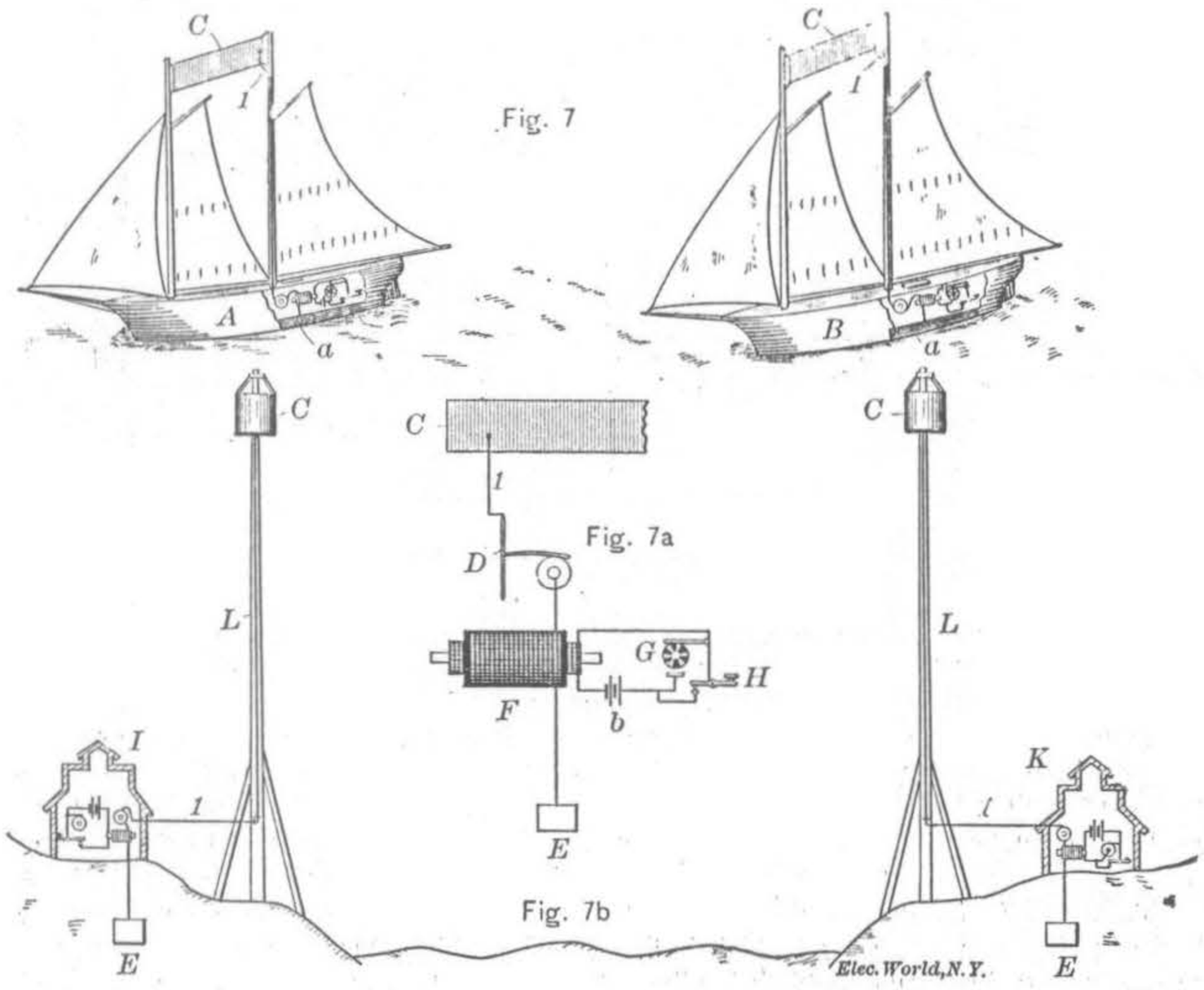


Fig. 7

Fig. 7a

Fig. 7b

WAVE METHODS.

It seems difficult at first to separate wave methods from some of the electrostatic systems used by Dolbear, Edison and Kitsee, and indeed both may be regarded as belonging to the same generic class of induction as distinguished from conduction methods. It will serve to bring out the differences that exist between them if we digress somewhat in order to consult the examples furnished by other undulatory fields.

When sound waves are sent through the air, for instance, a great difference is recognized by the ear between a noise like the report of a cannon and a musical note. The former is produced by one or more shocks or sudden impulses, the latter by a series of waves of definite frequency and amplitude.

A similar distinction may be recognized when solid or liquid bodies are set in vibration. If a string is fastened at one end and the other held in the hand a single impulse may be sent along it by jerking the hand to one side, or a series of impulses or waves following each other in definite order, and at a uniform distance apart, may be formed by shaking the string transversely in timed sequence.

It is difficult to imagine an impulse formed by light or heat, for the period of such a wave is so short that a great number of them are sent out before the radian source can be eclipsed. A flash of light, which corresponds in its effect on the retina to the shock produced by a sound impulse or noise upon the tympanum, is, it

reality made up of a great number of waves, and is not due to a single light impulse. The persistence of impressions on the retina, the duration of which is about half a second, permits 250,000,000,000,000 light waves to act upon it before the sensation due to the first wave has died out.

In all these cases an impulse may be regarded as a single wave, but differing in shape and sometimes in velocity from the wave that exists in a train or series of undulations emitted by a suitable source of energy. In the electrical induction methods which have been described a single impulse or a number of them is generated, and these impulses produce their separate effects upon the receiver. One impulse dies out and an interval of time elapses before another is created. Their effect may be cumulative, as in the case of the Kitsee apparatus, where a series of impulses produced by depressing a key causes a continuous glow in the vacuum tube owing to the persistence of the impression on the retina, but the impulses themselves are separated by a distinct interval of time. This will more fully appear from the following considerations.

Suppose, as in the patent to Edison, 465,971, a Rhumkorff coil is used to charge the inducing plate, and assume that the current interrupter G is driven at a speed which will produce 100 breaks of the primary current per second. In each one-hundredth of a second two distinct charges of opposite sign are produced at the end of the open secondary; the one due to the make of the primary, the other to its break. In addition there are a number of oscillations of the make-induced charge as well as of the break charge. The shape of the curve which shows the charge of the ends of the secondary may be roughly indicated as in Fig. 9. This shape depends on a number of conditions, which include the resistance, self-induction and capacity of the two circuits, and is particularly affected by the presence of a condenser in the primary circuit[1]. For the present purpose it is sufficient to say that the curve is made up of two predominant impulses A and B, one positive and the other negative, each accompanied by a few considerable oscillations a and b, with a large number of neglible waves, a' and b', and a period of zero charge C between them. In some experiments by Bernstein[2] the frequency of the oscillation was as high as 20,000 per second. If the interrupter breaks the primary 100 times a second 200 oscillations will have time to die out between two breaks. Only a few of these can be effective owing to the large dampening factor of the circuits, and in the experiments referred to perhaps thirty oscillations were measurable, of which the first two or three alone may be regarded as of the same order of intensity as that of the initially induced wave. In pure wave methods on the contrary each wave of the train exerts its influence and is as effective as any other.

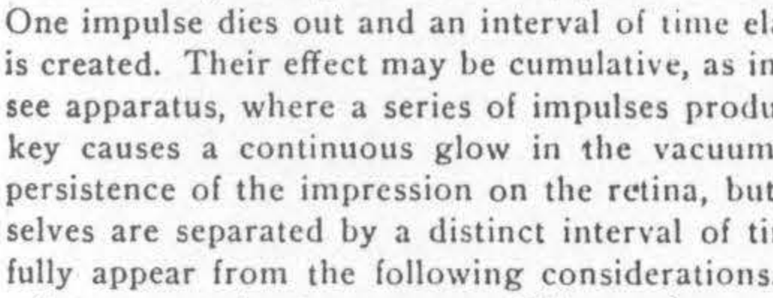


Fig. 9

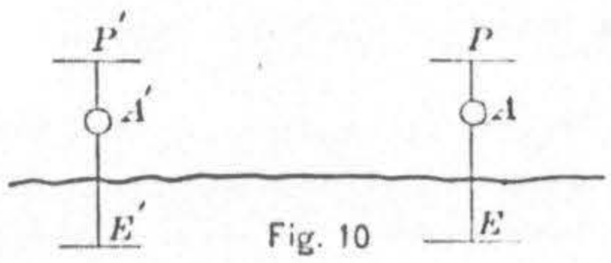


Fig. 10

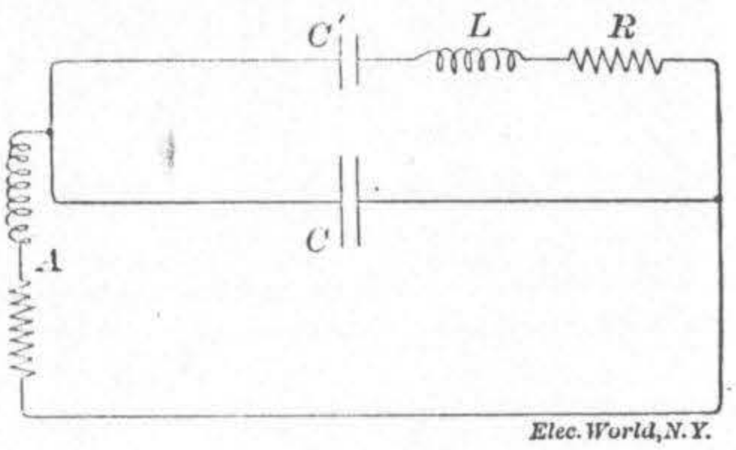


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Fig. 10 a

Another distinction which exists between impulse and wave methods is brought out by the principle of resonance. As is well known an oscillatory disturbance of definite period will exert a much greater effect upon a system tuned to the same period than upon one differing even slightly from it. A train of waves sent out by a sounding body will set a tuning fork of the same pitch into sympathetic vibration, but will leave undisturbed a fork of slightly different pitch.

A pendulum may be made to oscillate through a large arc by a series of weak forces if we so time their application that the interval between them is equal to the period of the pendulum. This has been used in a telephone selective signal system, in which each station is provided with a single pendulum of a definite time of vibration, which is determined by the position of a weight along its length. A number of electromagnets connected in series with a battery are arranged one at each station and each in position to attract its pendulum. Each subscriber can close the magnet circuit in suitable time sequence by means of a make and break pendulum whose period can be made equal to that of the call of any of the subscribers wanted. The magnets are thus all energized at each closure of the circuit, but the pendulum at the call station is the only one that responds, since its period is equal to that of the calling pendulum.

In optics, as is well known, a ray of light of a fixed wave length emitted by the sun will be absorbed by an incandescent gas in its photo sphere, which sends out waves of the same wave length, thus produced a so-called dark line in the solar spectrum. This has enabled physicists to determine the composition of the sun and "fixed" stars.

So an electrical oscillation of a definite period will exert, other conditions being the same, a much greater inductive effect upon one of equal period than upon one differing even slightly from it. The phenomenon of resonance is absent from electrical circuits in which impulses only are produced, for in them there is either an entire absence of period or this is not fixed but variable. Or as Lodge puts it[1], almost anything will respond equally well or equally ill to a dead-beat or strongly damped exciter.

Before proceeding to the discussion of the patents that have been granted for applications of wave methods it will be desirable to consider briefly a suggestion of Tesla which relates to a method of signaling by means of high frequency currents. The scheme, which is illustrated in Fig. 10, is described in his researches edited by T. C. Martin, 1894. Assume that a source of alternating currents of high frequency A be connected with one of its terminals to earth and the other to a body of large surface P When an electrical oscillation is set up at P this acts inductively on P', which constitutes a receiver. At any point within a certain radius of the source A a properly adjusted self-induction and capacity can be set in action by resonance. This method of signaling resembles that of the Edison patent 465,971, but an alternator is used without an induction coil, whose period, if we take for granted that a Tesla generator is referred to, may be as high as 20,000 reversals per second. No coherer is necessary, and the period of the waves emitted by the alternator, which is equal to that of the oscillations created in some of the induction methods described above, is of a much lower order than that of the Marconi and Lodge patents referred to below, in which waves are produced whose frequency may equal 10,000,000 per second. It will be seen that this device occupies an intermediate position in the development of the art.

The diagram in Fig. 10a shows the arrangements of the constants of the circuit. The generator A has a given self-induction and resistance; C' denotes the condenser at the receiving station in series with a suitable relay of resistance R and self-induction L. C is the condenser formed by the sending plate with the earth. It is shown as connected across the receiving circuit.

The case may be solved by the geometrical method, if the values of the constants are known. The calculation of the latter is a matter of some difficulty, since alowance must be made for the proximity of the condensing plates to the earth. The formula for calculating the capacity of two parallel plates

$$S = \frac{A}{4\pi d}$$

assumes that the field between them is uniform, which is only true when the distance between the plates is small compared to the distance of the plates from a foreign inducing body. This condition is just the reverse of the present case in which the earth acts inductively on the plate, increasing its capacity. In the absence of any experimental data it will be misleading to calculate a theoretical effect whose value in practice may be very different. Attention is

[1] See Colley, "Wied. Ann.," vol. 280, p. 109, and Lemstrom, "Pogg. Ann.," vol. 147, p. 354.

[2] "Pogg. Ann.," vol. 142, p. 54, 1871.

[1] See "The Work of Herz and Some of His Successes."

called to the fact, however, that the earth condenser C is of much larger capacity than C', so that very little current will be diverted through the receiving circuit. The capacity of the condenser C', moreover, is very minute, so that to secure resonance the self-induction of the circuit must also be made very small according to the formula

$$T = 2\pi\sqrt{LC}.$$

It is impossible to fix the value of self-induction by calculation when its value is so small; a cut-and-try method must be used until the proper length of wire is obtained which will neutralize the capacity.

The method used by Tesla, which has been described, resembles his proposed means for transmitting power at high altitudes, for which British patent 24,421 of 1897, and Swiss patent, 15,542 of 1897, have been granted to him, and is a step in the direction of his recent United States patent, 613,809, November 8, 1898, for controlling the movements and operation of a vessel or vehicle. Although both of these inventions relate to a different art, namely, that of transmitting power as distinguished from that of transmitting signals, yet by reason of their analogy to the present subject matter a brief description of them will be given. In the patent for transmitting power step-up and step-down transformers of high converting power are used, the former at the sending and the latter at the receiving station. One end of the secondary of the step-up transformer is connected to earth, the other to an insulated metallic sphere or condensing surface at a high elevation in the atmosphere. A similar arrangement is adopted at the receiving end and power is transmitted from one condenser plate to the other. The conditions which effect this method of transmission have been pointed out above.

In the patent, No. 613,809, for steering and propelling vessels a coherer circuit is used and local circuits which are energized by storage batteries for controlling the propelling and steering mechanisms. A steering motor is made to run in one direction by a local circuit thrown in by a relay and is driven in the reverse direction by another circuit and relay. The relays are energized by the coherer circuit, which includes a commutator and battery. The coherer circuit is made effective by the oscillator on shore. The boat is put into the water with the rudder to starboard, for example, the oscillator is started, the coherer is put into operation and the local circuit is thrown in which drives the rudder to port. This continues until the rudder reaches the port side. The coherer is then again operated which turns the commutator in the coherer circuit so as to throw in the local circuit which drives the rudder to starboard. The boat is thus made to steer its path in a series of zig zags. Signal lights may be flashed each time the coherer is operated to imitate the course of the vessel.

(To be continued.)

Telegraphing Without Line Wires—III.

By William Bissing.

(Concluded from last issue.)

Two patents have been granted in this country which make use of the method of signaling by electrical waves. One is the familiar patent to Marconi, 586,193, July 13, 1897, and the other is the patent to Lodge, 609,154, August 16, 1898.

In the patent to Marconi, Figs. 11 and 12 represent the transmitter and receiving apparatus when used for short distances. In them *c* indicates the induction coil, whose secondary is connected to the balls *d;* the primary is closed through the key *b*. *f* is a reflecting mirror of metal, and the sparking apparatus is placed at its focus. The spheres *e* lie between the knobs *d*, and when the induction coil sparks across at *d* it also of course produces sparking at *e*. This spark is the result of an oscillatory charge which is induced on the sphere *e*, and which sends out waves through the ether to the receiver, Fig. 12. This receiver consists of the coherer *j*, a glass tube containing metallic powder, each end of the column of powder being connected to a metallic plate *k* of suitable length to cause the system to syntonize electrically with the electrical oscillation transmitted. The tube *j* may be replaced by other forms of imperfect electrical contacts, examples of which are given by Lodge in the monograph above cited.* See the chapter on microphonic detectors. The reflector *l* collects the oscillations and projects them upon the coherer. There are two circuits at the receiver; one is the circuit embracing the coherer, the plates *k*, the battery *g*, and the magnet of the relay *n*; the other includes the battery *r*, the armature of the relay *n* and the trembler *p*. These correspond respectively to the line and local circuit of the ordinary Morse telegraph

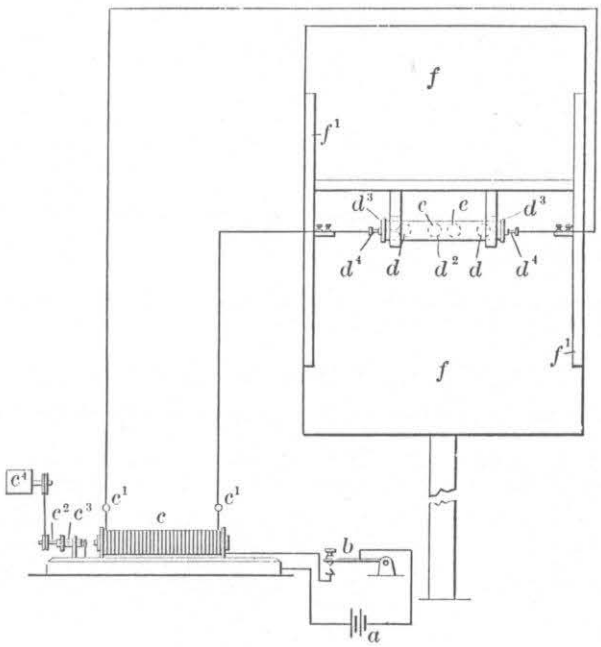

Fig. 11

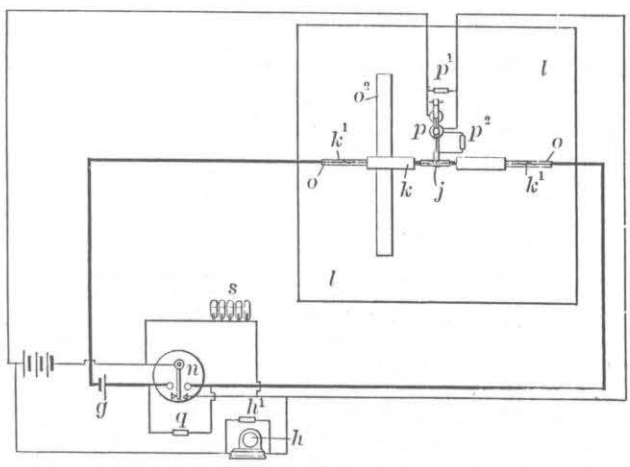

Fig. 12

The object of the trembler or decoherer is to disturb the filings after the spark has passed, and thus once more make their resistance too high to permit the passage of the current of the battery *g*. This decoherer is usually an electromagnetic bell, whose hammer is arranged to strike the coherer tube. The tapping is thus done automatically by the current started by the spark in the tube. In addition to these generic features of the invention there are a number of details which are shown in the figures. A telegraphic receiver *h* is placed in a circuit derived from the trembler bell circuit. The other devices shown at p^1 p^2 h^1 *q* and *s* are non-inductive resistances shunted about the electromagnets or circuit closures to counteract self-induction or prevent sparking. The arrangement usually adopted by Marconi is shown in Figs. 13 and 14, which are taken from Figs. 10 and 11 of the patent. One of the spheres *d* is connected to earth *E* and the other to a plate *u* suspended on a pole *v* and insulated from the earth. At the receiving station, Fig. 14, one terminal of the sensitive tube *j* is connected to the earth

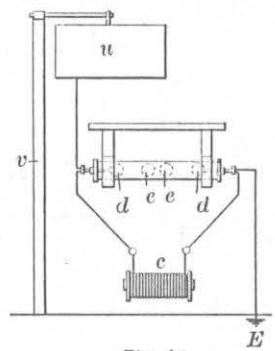

Fig. 13

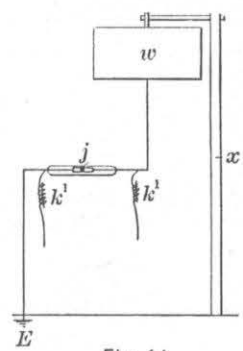

Fig. 14

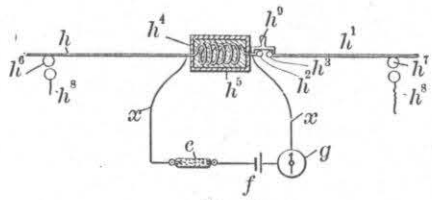

Fig. 15

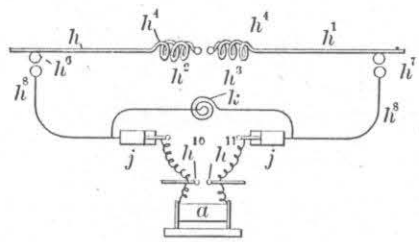

Fig. 16

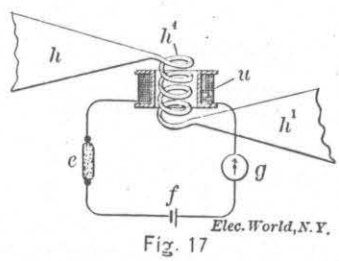

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Fig. 17

E and the other to an insulated plate *w* suspended on a pole *x*. The larger the plates of the receiver and transmitter and the higher the plates are suspended from the earth the greater is the distance through which it is possible to communicate. It was pointed out above that this elevation of the plates increased the proportion of the capacity of the plates with respect to each other to their capacity with respect to the earth, which augments the inductive action of one plate on the other. The theory of the coherer has been explained in several ways. The explanation given by Lodge in the monograph above referred to is that a kind of welding action between the particles takes place when the spark passes, which, of course, diminishes the resistance of the body of filings to the passage of the battery current.

*See "The Work of Herz and Some of His Successes."

Marconi describes in the specification a means of adjusting the capacity areas *k* so that the receiving circuit may syntonise electrically with the oscillations of the transmitter. In most of the experiments carried out by him with this apparatus, however, no tuning was attempted, and in the latest results that have been obtained by Slaby, circuits out of tune were used and a number of the minor features of the invention, such as the high shunted resistances to avoid sparking were omitted.

The patent to Lodge marks an important step in advance in this art. In the first place the waves emitted by the transmitter last longer, i. e., a greater number of waves are sent out at each discharge of the transmitter before they are damped out. Secondly, the receiver can be more effectively tuned or syntonized to respond to a definite pitch of the signaling instrument. Lodge's invention is shown in Figs. 15, 16 and 17, which are copies of Figs. 3, 4 and 13 of the patent.

Fig. 15 shows a combined radiator and receiver. In it h^8 indicates wires leading to the Ruhmkorff or high potential coil: *h* and h^1 constitute the capacity areas, h^4 is the syntonizing self-induction coil embedded in insulation h^5; h^9 is a sort of circuiting switch; *e* is the coherer, *f* the battery and *g* the receiving instrument. When in use as a radiator the gap between the discharge knobs h^2 and h^3 is left open; when utilized as a receiver the gap is closed by the switch and the coherer, battery and receiving instrument *g* are connected through a thin wire *x* from each end of the coil h^4. The above arrangement permits one instrument to be used as a transmitter or receiver by simply throwing a switch. In Fig. 16 a Leyden jar or other suitable condenser *j*, able to stand a high potential, is interposed in the wires h^8, leading from the Ruhmkorff coil, so that the knobs are supplied from the outer, that is, the uninsulated coat of each jar, while between the inner coats a third spark gap is arranged, called the starting gap, which consists of suitable knobs, h^{10} h^{11}. The outer coats of the jars are joined by an induction coil of thin wire, *k*, so as to permit thorough charging. When the discharge occurs this wire acts as an alternative path or bypass, but does not prevent the sparks at the supply gap.

In Fig. 17 the syntonizing coil of the resonator is surrounded with another or secondary coil *u*, constituting a species of transformer. This latter coil is made a part of the coherer circuit, so that it is secondarily affected by the alternating currents excited in the conductor of the resonator. The coherer is thus stimulated by the current in this secondary coil rather than primarily by the currents in the syntonising coil itself, the idea being to thus leave the resonator freer to vibrate electrically without disturbance from attached wires.

The persistance of vibration of the waves of the transmitter is due to the self-induction coil which is inserted between the capacity areas of the radiator. This effect is analogous to that due to increasing the weight, and therefore the moment of inertia of a flywheel which prolongs the number of revolutions the wheel makes, beginning with a given angular velocity, before it comes to rest. The following extract from Helmholtz's "Sencations of Tone," page 62, may make the action of the induction coil clearer by setting forth the parallel case for sounding bodies:

"Bodies of small mass which readily communicate their motion to the air and quickly cease to sound, as for example stretched membranes or violin strings, are readily set in sympathetic vibration. The limits of pitch capable of exciting sympathetic vibration in such bodies are somewhat broad. Massive elastic bodies, on the other hand, such as bells and plates, are not so easily excited. It is necessary to hit the pitch of their tone with much greater nicety in order to make them vibrate sympathetically. They will, of course, continue to vibrate for a longer period than the others."

Attention is called to the persistency of the sounds of heavy elastic bodies and nicety of regulation, which is required to set them in sympathetic vibration, just as in an electric circuit containing an induction coil, as used by Lodge, the oscillations last longer and the syntony is more accurate than when the coil is omitted.

With the patent to Lodge it will be necessary to bring this article to an end. It will be readily granted that there are still numerous problems to be solved in the art of wireless telegraphy. It will be necessary to increase the distance over which transmission may be effected, to add to the certainty and secrecy of the message, to prevent the disturbing and absorptive effects of the intervening media, to increase the sensitiveness without impairing the efficiency of the receiving instrument, before we can hope to replace the Atlantic cable and its costly appurtenances with a pair of syntonized radiators and receivers.

October, 1898.

The New York Herald January 15, 1898

ELECTRIC CURRENT TO KILL BACILLI

Nikola Tesla Proposes to Annihilate Disease by Using Millions of Volts.

RESULT, NEW LEASE OF LIFE

How This Tremendous Force Is To Be Generated Has Not Yet Been Revealed.

NO INSULATOR FOR PATIENTS.

Even Consumption, It Is Asserted, Will Be Routed by the New Discovery.

Nikola Tesla, whose boldness in conceiving astonishing uses to which electricity may be put, has given the scientific world surprises from time to time, has a new proposal, and one which will arouse widespread interest and comment.

He now proposes to destroy the bacilli of all diseases by applying millions of volts of electricity to persons afflicted. The tremendous force is to be applied in such a manner that the vital organs will be free from harmful effects and so that the bacilli will be drawn from the system.

The tremendous current which Tesla proposes to apply will not be sent through the body, as in the cases of persons executed by electricity, but will run along the surface.

The new plan for destroying disease germs, including even those of consumption, was outlined recently in an exhaustive paper which the electrician read before the Electro-Therapeutic Society, and created deep interest.

TO USE MILLIONS OF VOLTS.

It had been supposed that Tesla's feat in generating a current of fifty thousand volts, announced some time ago, was the limit, but he told me last evening that the cure proposed involved the use of millions of volts, applied in such a manner as not only not to harm the patient but to remove from his system all the bacilli lodged there and renew his store of energy.

The matter became public yesterday, when in despatches from Washington it was announced that a New York lawyer was filing with the patent office the papers necessary to protect the discovery. Mr. Tesla said yesterday that he had applied for no patent and that no one was acting for him in that respect, but he added that the news contained in the Washington despatches was probably based upon new features in the use of electricity of which he treated in the paper he read recently in this city.

Inquiry was made at the patent office by the HERALD'S Washington correspondent, and he was told that as yet no patent for any electrical process for germ destroying had been applied for, and that nothing was known of any application for a patent protecting any contrivance intended for such uses.

NO GLASS CASE.

Mr. Tesla told me that the Washington accounts of his discovery were incorrect in some particulars. It was said, for instance, that it was proposed to place the patient in a glass case and to apply the tremendous current from without, the glass, not being an absolute non-conductor, serving to permit the application of the current without causing too great a shock and to distribute it so that the repeated charges of static electricity would destroy the various forms of bacilli without injury to the patient. Mr. Tesla said of this description of his process:—

"That is wrong, technically. There will be no glass case such as is spoken of. I have no time to go into the matter in detail now, beyond telling you that it is my plan to apply several millions of volts of electricity to the surface of the body and draw out the germs.

"No, death would not follow the use of a current so tremendous. The patient would not be injured, but would receive a new store of energy. I think the reports from Washington are a result of my recent presentation of new features in the use of electricity for the cure of disease."

Just how Mr. Tesla proposes to generate a force so mighty he did not say. That is his secret. While a current of 1,500 or 1,800 volts suffices to kill a man instantly when applied in a certain way, a vastly greater amount of electricity applied in a manner altogether different, it is explained, may be of beneficial effect, and the patient may became practically a new man as far as his store of vital energy is concerned.

WHAT OTHER EXPERTS SAY.

Lack of details concerning the manner in which Mr. Tesla proposes to apply static electricity for curative purposes prevented a discussion of the value of the alleged discovery by medical men yesterday. Dr. Cyrus Edson pointed out that it is physically impossible to make static electricity permeate all parts of the human body, as it does not penetrate beyond the surface. If it did, the germs of disease might be destroyed by it.

Thomas A. Edison, when the matter was brought to his attention, in Orange, N. J., yesterday, said he had applied for no patent in connection with the use of electricity for germ destroying, and knew nothing about the discovery.

Dr. F. S. Kolle, who is in charge of the electro-therapeutic department of the Electrical Engineer Institute, at No. 120 Liberty street, and who has written extensively of the Roentgen discovery and kindred matters, was much interested when told of the discovery of Tesla yesterday. He told me that Tesla and others had produced apparatus that would generate two and a half million volts of electricity, and continued:—

"I see no reason why a glass case should be used. Any man can take a million volts direct into his body and not be injured by it, but benefited instead. The reason that 50,000 volts did not kill Tesla when he took that strength of current is that the cells in his body did not have time to contract in response to it. Much less would have killed him instantly. Much more is all the safer.

"It is just such a case as that of a bullet going through a window pane. At high speed it will cut a clean hole and will not crack the glass. The particles have not time to spread during the period of impact.

WHY ELECTRICITY IS LIFE.

"As to the benefit of so great a current, we say it as a proverb that electricity is life, and the scientific meaning of that saying is that it oxidizes the tissue.

"I have long held the theory, though I have never made it public before, that the renewal of energy and vitality which follows eating long before the three or four hours necessary for ordinary digestion have passed, is directly due to the production of a small electrical current generated by the action of the acid secreted by the stomach's mucous membrane upon the metallic elements which make up the food ingested.

"The exterior application of an oscillatory current of high frequency would have a similar effect, greater as the current went higher, but whether proportionately greater I cannot say. So, therefore, the use of such a current would restore vitality and be an ally and aid to the food taken into the stomach. It could never take the place of food, of course, for, while it could supply oxygen, it could not give the carbo-hydrates necessary to existence. Therefore its use would not diminish the amount of food needed. The person using it, however, would have a greater ability to work and a more brilliant intellectuality.

"Would a million volt current kill the bacili of disease in the body? I do not know. I do not know whether a fifty thousand volt current can do it. I am not aware that any experiments of that kind have been made. But oxidization does kill bacilli of all kinds, and as those currents produce it there is good reason to believe that part of the claim for this discovery. What has not been heretofore known is how much oxidization of tissue will kill bacilli therein. Perhaps that has now been found out. It all seems feasible, except the talk about a glass cage."

A PAPER read by Mr. Nikola Tesla at a meeting of the Electro-Therapeutic Society in Buffalo not long ago, suggesting a method of killing disease germs in the human body by means of static electricity, has again been brought to public notice by the rumor that a New York attorney was a day or two ago in Washington filing with the Patent Office the necessary papers for protecting the invention. In a word, Mr. Tesla's idea is to apply a current at everal millions of volts to the surface of the body, and by oxidizing the tissue kill all bacilli that may be present. The details of the process, as for instance how Mr. Tesla proposes to produce such a high potential current and how it would be applied for curative purposes, has as yet not been made public.

THE

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The Upper Regions of the Air as Current Conductors.

THERE are a number of striking and important electrical and magnetic phenomena, which though giving rise to speculation and hypotheses, have not yet been explained by generally accepted theories. Among these we may mention the earth's magnetism and electrical storms. A satisfactory explanation of the cause of these phenomena would indeed be a great step in advance on our present knowledge and might indeed lead to results now scarcely within the limits of legitimate speculation.

Undismayed by the numerous and conflicting theories of the past, Prof. W. P. Trowbridge has recently come forward with a new hypothesis which, even if not unassailable in all its details, is nevertheless highly interesting and deserving of more than passing notice. As explained by him in this month's "Forum," if we ascend a sufficient distance the layer of air which surrounds the earth we there find all the conditions requisite for the production of the two phenomena mentioned above, and incidentally a medium which can transmit X-rays. Having in mind the fact that at great altitudes the air is so rarefied as to constitute a good conductor and the further fact that the air absorbs numerous rays emanating from the sun, especially those of short wave length, Prof. Trowbridge asks: Can the disappearance of the short waves of light have anything to do with the production of electrical storms and the appearance of this weird new form of energy? and, Can this disappearance be connected in any way with the production of magnetism of the earth?

Starting with the proposition that the energy involved in the production of these phenomena emanates from the sun primarily, Prof. Trowbridge propounds the further question whether it is not possible that the short waves of energy may in some way produce electrical and magnetic effects in the upper regions of the air, and thus, being transformed, fail to manifest themselves as light at lower altitudes. It is Prof. Trowbridge's main contention that the sun's rays contain the short wave lengths assigned to the X-rays and that, though absorbed by the lower strata of the atmosphere, they exist at the higher altitudes; and that they are instrumental in producing the electricity of the atmosphere and the magnetism of the earth.

Fortifying himself by some recent researches Prof. Trowbridge holds that the solar X-rays give an electrical charge to our atmosphere. The rotation of the earth on its axis would then cause an accumulation of electricity on one side of the earth and a diminution of electricity on the other. We should, therefore, expect a fall of electric pressure between the regions just entering daylight and those in the full glare of the sun. This condition would direct the resulting electric current from east to west, or in the direction opposite to that of the earth's rotation.

The current thus established, according to Prof. Trowbridge, is sufficient to account for the main points of his thesis. The electrical disturbances, such as thunder storms, in the lower regions, might thus be accounted for as being the result of great commotions in the air which constitutes a vast atmospheric sea and due to a local descent of high electrical conditions prevailing in the upper regions. The Northern Lights, again, may, according to the same theory, be due to a dissipation of a portion of the electrical discharge, through layers of rarefied and well conducting air.

Reasoning in an analogous way, the currents existing in the upper well-conducting regions act as a solenoid upon the earth beneath and form the magnetic poles observed. In support of the solenoidal action, Prof. Trowbridge points out that on no other theory could the great distance between the north and south pole be explained; no permanent magnet could have any such length without exhibiting consequent poles. As no currents adequate to produce the poles of the earth have yet been discovered in or on the earth, they may, if they exist, circulate in the upper regions.

This entire reasoning depends of course upon the assumption of the great conductivity of the rarefied, upper regions of the air. This brings Prof. Trowbridge to the question of the practicability of Mr. Tesla's recent proposal to utilize those regions as a conducting medium for the electrical transmission of power. Prof. Trowbridge's experience, based on experiments in the laboratory, lead him to the belief that the method is impracticable. Thus, before one reached the height of ten miles—where there is greatly increased conductivity—the electricity would have deserted the terminal raised to that height and would have flowed to the ground, instead of taking the path of the air to the distant station! In the dark, one can see the reason for the diminished length; for luminous discharges are noted between the high tension apparatus and the floor of the room. The inductive effect is so great that sparks can be drawn from the brick walls and the neighboring gas pipes! The time when the upper regions of the air will be thus used commercially seems therefore to Prof. Trowbridge far distant.

As we have stated above, Prof. Trowbridge's hypothesis is not without objections. Thus, we may ask, how according to that theory, can the fact be accounted for that auroras have been observed within but a hundred yards of the surface of the earth, where there could be no possible adequate rarefaction of the air? Still the hypothesis is interesting and, at least, si non e vero e ben trovato.

Apropos of the suggestion of utilizing the upper strata of the atmosphere as a current conductor, we are reminded by some of our readers of the fact that the idea was put forth some twenty-five years ago by Mr. S. J. M. Bear for telegraph work. And now, Chicago, not to be outdone, has a claimant to the same region, in the person of Mr. Archibald J. Robertson, who claims to have covered the idea in a patent granted to him in 1892. From what he says, it looks as though we shall presently learn of a suit for infringement brought against Mr. Tesla. If a Chicago man can lay claim to giving the main idea of Cyrano de Bergerac to Rostand, why may not another from the same city of unlimited area and ideas claim all the upper atmosphere and its attributes as his own? To avoid strife and the establishment of a grinding monopoly in the future we would suggest that all claims in those regions be now staked and filed in a Government Air Bureau specially organized by Dr. Cleveland Abbe for that purpose, and to be called the Government Rarefied Air Office, with regulations patterned after those of the present Land Office. This might at once mitigate the coming wars with squatters and interlopers.

Tesla Polyphase Patents Declared Invalid in Germany.—The New York *Electrical Engineer* says that the Reichsgericht of Germany has confirmed the decision of the lower courts declaring the Tesla polyphase motor patents invalid. The court reviewing the case, holds that the patents are void owing to their not having been worked according to the requirements of the German patent law. The court goes on to say, however, that even if the patent had been sustained on that ground, it would have been, nevertheless, invalidated owing to the fact that the invention was not adequately described in the German patent specification, whereas the American patent specification is clear. It is understood that the Helios Company, of Cologne, who control the Tesla patents in Germany, will no longer contest the suits which it has brought against several parties in Germany.

ROENTGEN LIGHT NOTES.

BY WILLIAM ROLLINS.

NOTE XLII—ON GENERATOR TERMINALS IN OIL.

Soon after Roentgen's discovery was announced, Professor Trowbridge cooled the discharge tube by oil. Mr. Tesla developed the method and published a figure of the apparatus. Like most of the early work it has been lost, because the great experimenters will not take the time to say the same thing over and over. While using this method I noticed a phenomenon new to me. As I can not find it mentioned it is here described. At the anode end of the tube the oil fairly boiled, not in temperature but in appearance, the surface being raised and in constant motion. This was striking, for no bubbles were formed. At the cathode end there was less disturbance, though a match appeared alive, darting to the terminal and rushing back again, repeating the motion at short intervals. When the tube was removed and the terminals placed 15 inches apart the phenomena were very marked, the surface of the oil near the anode being raised a quarter of an inch. We had here in the liquid dielectric a similar process to what takes place in air; in other words, a liquid brush discharge.

NOTE XLIII—BURNING FROM ROENTGEN TUBES.

In Note 12 I showed that a severe burn could be produced by a tube giving no Roentgen light, the pressure being so low that, with the potential used, no discharge went through the tube. In this case, therefore, the burning was due to the electric discharge and not to Roentgen light. On the other hand I stated that prolonged exposure to the discharges from a vacuum tube did not burn me because I used a Tesla screen. I also tried the experiment in another way. The vacuum was made so high that the greater proportion of the Roentgen light was of short-wave length, what is commonly known as penetrating X rays. Using the same screen I could not burn myself. I then arranged the apparatus so that the radiation consisted chiefly of short waves, what is known as least penetrating X rays. I could not, with exposures of hours in a several day investigation, produce any effect with the screen to protect me. Now, as Roentgen rays are short ether vibrations, whose length depends upon the temperature to which the particles of the cathode discharge are raised by their impact on the target, we should not expect them to produce much more severe burns than sunlight, also an ether wave phenomenon; the chief difference, except in amount, being that in addition to the rays present in sunlight when it reaches us a tube gives off radiations of higher pitch. Prof. E. Thomson has said that the sun probably gives these short vibrations also, and Madame Curie, in attempting to reach the shore of that mysterious ocean of power from which evermore uranium and thorium draw force, started with the idea that all space is filled with more subtile radiations than those of Roentgen. Elster and Geitel doubt this, because carrying these metals to the bottom of a mine 3,000 feet below the surface did not affect them. To me this objection is without force, because I had previously stated in these notes that we could produce a vibration to which worlds would be transparent, the Roentgen rays being but an octave in the grand gamut. An eminent authority has stated, and repeated his statement, that burns are due to X rays of low penetrating power, which are most stopped by the tissues, and that a sheet of suitable material, in other words a Tesla screen, may prevent burns by stopping these waves. I, of course, do not know enough to criticize this view, but mention some facts which should be considered by those who hold it. I have always used a Tesla screen of wire netting, through whose open meshes all rays pass freely. This construction has been made necessary by the imperative need of being able to safely watch for hours the tubes with which I was experimenting. Moreover, the less penetrating rays are most stopped by bones, which on this theory should be affected.

NOTE XLIV—ON HYDROGEN AND OXYGEN.

In this journal for December 1, 1897, a tube was figured with an hydrogen vacuum, and in the number for February 9, 1898, one with an oxygen vacuum. As the latter type of vacuum is perhaps being made unduly prominent, the matter will bear speaking of again. When we wish to make most of the light of short waves use hydrogen, because the same electro-motive force causes its particles to strike the target at a higher velocity, and therefore they are raised to a higher temperature, producing more short waves. In this case the target should be of the most dense metal, because, as stated in Note XXXV, the shock of impact is more sudden, the heat in consequence reaching a higher degree. To generate light of mostly longer waves use oxygen, which, being heavier, strikes the target with less velocity when the electro-motive force is the same. The particles are therefore not raised to so high a temperature, the waves being in consequence longer. Oxygen has one advantage for a tube with an uncooled target—it does not disappear so rapidly, the vacuum requiring less frequent adjustment. These statements apply to the ordinary types of commercial apparatus. With generators of moderate electro-motive force, large amperage and enormous frequency, other considerations come in.

NOTE XLV—ON HARMONICS.

After reading the notes published in this journal it is desirable to add a few words on some points already touched upon. The wave length of the Roentgen light was said to depend upon the velocity with which the particles struck the target and upon the temperature to which they were raised by the force of impact. As these particles are small the heat declines rapidly, the train of waves being short, the length of the waves increasing as the heat declines. It was also stated that the amount of Roentgen light depended upon the amperage utilized at the target, and as this is not the same as saying that to increase the light it is only necessary to increase the amperage, I dwelt at some length upon the necessity of harmony between the tube and generator, a matter which each new day of experience showed to be of prime importance. For example, it is possible to use the entire output of my large Holtz machine, probably the most powerful of its type in America, and not get as much light from a tube as when it is excited by a very small machine of the same type. I do not believe that any electrician but Mr. Tesla realizes the imperative necessity for harmonics, if we wish to economically convert a long into a short vibration, and it appears to me that the remarkable photographs he has shown in this journal of electricity converted into light are due to his recognition of this principle.

The poets are the true seers, and the discoverers whose minds are most like theirs are those who first catch glimpses of remotest laws. I have already quoted Emerson as saying "the atoms march in tune," and again refer to this as showing the necessity of adjusting the apparatus so that the discharges from the concave terminal shall follow each other in regular order, and at periods which are harmonics of the wave length of the Roentgen light we wish to generate by the impact of these discharges on the target. Only in this way can we get the most light with the least amperage. Trowbridge has shown that an apparently single surge is composed of a multitude. We must adjust the rate of these, for so simple a thing as changing the condenser discharge with a static machine will make the difference between a well or badly lighted tube.

Torpedo Boat Without a Crew.....N. Tesla.....New York Journal

"My submarine boat, loaded with its torpedoes, can start out from a protected bay or be dropped over a ship side, make its devious way below the surface, through dangerous channels of mine beds, into protected harbors and attack a fleet at anchor, or go out to sea and circle about, watching for its prey, then dart upon it at a favorable moment, rush up to within a hundred feet if need be, discharge its deadly weapon and return to the hand that sent it. Yet all through these wonderful evolutions it will be under the absolute and instant control of a distant human hand on a far-off headland, or on a warship whose hull is below the horizon and invisible to the enemy.

"I am aware that this sounds almost incredible, and I have refrained from making this invention public till I had worked out every practical detail of it. In my laboratory I now have such a model, and my plans and description at the Patent Office at Washington show the full specifications of it.

"As to the mechanism which is to be stored in this submarine shell: The first and most essential thing is a motor, with storage battery to drive the propeller. Then there are smaller motors and batteries to operate the steering gear, on the same principle that an ordinary vessel is now steered by steam or electricity. Besides these there are still other storage batteries and motors to feed electric signal lights. But in order that the weight of machinery shall not be too great to destroy the buoyancy or make the boat go too deep in the water, compressed air motors will also be used to perform certain functions, such as to fill and empty the water tanks which raise the boat to the surface or sink it to any required depth. Pneumatic air or motors will also fire the torpedoes and pump out the water that may leak in at any time.

"This submarine destroyer will be equipped with six fourteen-foot Whitehead torpedoes. These will be arranged vertically in two rows in the bow. As one torpedo falls into position and is discharged by pneumatic force, another torpedo, by the force of gravity, falls into the position of the first one, the others above being held up by automatic arms. They can be fired as rapidly as a self-cocking revolver is emptied or at intervals of minutes or hours. The discharge takes place through a single tube, projecting straight in the bow. The small amount of water which leaks through each time is caught by drain pipes and a compressed air pump instantly expels it. As each torpedo is expelled a buoyancy regulator will open the sea cocks and let enough water in the ballast tanks to make the buoyancy uniform and keep the boat at the same distance beneath the surface.

"This submarine destroyer will carry a charge of torpedoes greater than that of the largest destroyers now in use. Those vessels of five hundred tons each, which cost the Government $500,000, carry but three or four torpedoes, while this simple submarine destroyer, which can be built for $48,000 to $50,000 or less, will carry six torpedoes. It will have also the incalculable advantage of being absolutely invisible to an enemy, and have no human lives to risk or steam boilers to blow up and destroy itself.

"All that is necessary to make this submarine boat subject to perfect control at any distance is to properly wire it, just like a modern house is wired so that a button here rings a bell, a lever there turns on the lights, a hidden wire somewhere else sets off a burglar alarm and a thermal device gives a fire alarm.

"The only difference in the case of the submarine boat is in the delicacy of the instruments employed. To the propelling device, the steering gear, the signal apparatus and the mechanism for firing the torpedoes are attached little instruments which are attuned each to a certain electro-magnetic synchronism.

"Then there is a similar set of synchronistic instruments all connected to one little switchboard, and placed either on shore or on an ordinary warship. By moving the lever on the switchboard I can give the proper impulse to the submarine boat to go ahead, to reverse, throw the helm to port or to go ahead, rise, sink, dsicharge her torpedo or return. It might seem that some great power would be necessary to be projected across the miles of distance and operate on the far-off boat. But no; the power is all stored in the submarine boat itself—in its storage batteries and compressed air. All that is needed to affect the synchronistic instruments is a set of high alternating currents, which can be produced by my oscillator attached to any ordinary dynamo situated on shore or on a warship.

"How such an apparently complicated mechanism can be operated and controlled at a distance of miles is no mystery. It is as simple as the mes-

senger call to be found in almost any office. This is a little metal box with a lever on the outside. By moving the crank to a certain point it gives vibrating sounds and springs back into position, and its momentary buzzing calls a messenger. But move the crank a third further round the dial and it buzzes still longer, and pretty soon a policeman appears, summoned by its mysterious call. Again, move the crank this time to the farthest limit of the circle, and scarcely has its more prolonged hum of recoil sounded when the city fire apparatus dashes up to your place at its call.

"Now, my device for controlling the motion of a distant submarine boat is exactly similar. Only I need no connecting wires between my switchboard and the distant submarine boat, for I make use of the now well-known principle of wireless telegraphy. As I move this little lever to points which I have marked on a circular dial I cause a different number of vibrations each time. In this case two waves go forth at each half turn of the lever and affect different parts of the distant destroyer's machinery.

"How such submarine destroyers should actually be used in war I leave for naval tacticians to determine. But it seems to me that they could best be operated by taking a number on board a large, fast auxiliary cruiser like the St. Louis or St. Paul, launch them, several at a time, like lifeboats, and direct their movements from a switchboard placed in the forward fighting top.

"In order that the director of the submarine destroyer may know its exact position at every movement, two masts, at bow and stern, will project up just above the water, too minute to be seen or hit by an enemy's guns by day, and by night they will carry hooded lights.

"The lookout placed in the fighting top could detect a hostile ship off on the horizon while the auxiliary cruiser's big hull is still invisible to the enemy. Starting these little destroyers out under direction of a man with a telescope, they could attack and destroy a whole armada—destroy it utterly—in an hour, and the enemy never have a sight of their antagonists or know what power destroyed them. A big auxiliary cruiser, used to carry these submarine destroyers, could also carry a cargo of torpedoes sufficient to conduct a long campaign and go half-way around the world.

"She could carry the gun-cotton and other explosives needed to load torpedoes in safe magazines below the water line, and do away with much of the danger of transporting loaded torpedoes. When necessary for use the war heads could be loaded, fitted to the torpedoes, and the submarine destroyers fully equipped.

"A high, projecting headland overlooking a harbor and the sea would also be a good point on which to establish a station and have the destroyers laid up at docks below and ready to start."

Mr. Tesla's New Theory of Artificial Light.

EVER since Mr. Tesla practically finished his multiphase motor work, now more than ten years ago, he is understood to have devoted much of his time to experimental work in the domain of electric lighting. His first attempts led him in the direction of the vacuum tube and his brilliant lectures on that subject, both here and abroad, must still be fresh in the minds of many of our readers. But even in those lectures Mr. Tesla devoted considerable space to the discussion of the employment of solid, refractory materials as light giving media under the influence of high frequency currents. It would seem, however, that of late Mr. Tesla has greatly modified his views as to what is a sine qua non in a successful electric illuminant. At least we are led to this belief after reading an interview had with him by Mr. Charles Culver Johnson, appearing in the "Philadelphia Press." We must confess at the outset that we are unable to follow the interviewer at all points, but we gather in general that Mr. Tesla has come to the conclusion that electricians have all been on the wrong track in the past in working on so-called non-refractory or heat proof materials as light giving bodies. There are, Mr. Tesla says, a few bodies which for a time seem to be indifferent to heat, but he has found that not one of them will endure a continuous strain. In this new discovery, we are told, vibrations play a most important part, Mr. Tesla having succeeded in obtaining more perfect control of the more rapid vibrations of light waves. Carbon is not employed as the light giver. As to the nature of the force employed the interviewer quotes Mr. Tesla as saying that he "will form an electric circuit and then with a file reduce the thickness of the wire a sixteenth of an inch and double the force of the current." The details of Mr. Tesla's work in this direction are unfortunately lacking, but Mr. Tesla promises to prepare a paper on the subject, "which he will read presently to a few scientific friends." Failing full details the information thus far vouchsafed is insufficient to permit of much comment, but we are glad to know that we may so soon expect a promised advance in electric lighting. All such work as this, or, in older directions, such as that on the Nernst lamp, is worthy of fullest encouragement.

The New York Tribune March 3, 1899

NIKOLA TESLA'S EXPERIMENTS.

DESCRIPTION OF HIS TRANSMITTING ELECTRICAL ENERGY WITHOUT WIRES.

The current issue of "The Electrical Review" contains the first extended description published of experiments carried on in Nikola Tesla's laboratory, and demonstrating, it is stated, his recently announced discoveries in the application of electricity to commercial purposes without the use of conducting wires. The experiments involve handling currents up to eight millions of volts, produced by his perfected oscillators with entire safety, it is said. Photographs of the experiments make it appear that the energy can be transmitted to any point desired. In one illustration the inventor appears to receive the electrical waves from a distance and to develop a pressure of 500,000 volts in a coil which he holds in his hand, preserving himself against injury by maintaining a fixed position, where the pressure developed is small. Another photograph shows an assistant receiving in his body the currents from an electrical oscillator, which pass through his body and make a metal bar glow in his hands, also lighting a vacuum tube on the ceiling.

In closing his communication to "The Electrical Review," Mr. Tesla says:

To the scientific experts, who are familiar, in theory and experiment, with electrical vibrations, the results here shown will, I believe, speak in eloquent language. But those readers to whom they are naturally less intelligible will ask: What are they good for, and what do they or have they demonstrated? To them it may be said that they have shown and proved among many other things: That ordinary currents can be transformed with high economy into electrical vibrations of any pitch, which are needed in many novel arts; they have shown that electrical energy in great amounts can be efficiently and safely transmitted without the use of wires to any point of the globe, however distant; they have furnished proof that the movements and operation of bodies and machinery carried by the same can be controlled from a great distance without any tangible connection whatever and with absolute precision; they have proved the practicability of a system of signalling without wires, not with the imperfect appliances as before attempted, which cannot be tuned, and are rendered useless by the play of a small induction coil, but by means of apparatus producing powerful oscillations and circuits in exact synchronism, with which it is impossible to interfere; they have shown that atmospheric nitrogen can be readily combined and valuable products manufactured, merely by the application of cheap water power, and that light, diffusive, like that of the sun, can be produced with an economy greater than is obtainable in the usual ways, and with lamps that never consume.

"The Electrical Review," in its editorial comment, says:

The experiments on which Tesla dwells, and which are evidently the result of years of patient labor, are, in our opinion, the most striking and promising that have been shown in years, and they cannot fail to create a profound impression on scientific minds.

The Reichsgericht, of Germany, has confirmed the decision of the lower courts declaring the Tesla polyphase motor patents invalid. The court reviewing the case holds that the patents are void, owing to their not having been worked according to the requirements of the German patent law. The court goes on to say, however, that even if the patent had been sustained on that ground, it would have been, nevertheless, invalidated, owing to the fact that the invention was not adequately described in the German patent specification, whereas the American patent specification is clear. It is understood, says The Electrical Engineer, of New York, that the Helios Company, of Cologne, who control the Tesla patents in Germany, will no longer contest the suits which it has brought against several parties in Germany.

TESLA ON CURRENT INTERRUPTERS.

To the Editor of Electrical Review:

I wish to acknowledge the receipt of your favor of March 11, and thank you for calling my attention to the matter of the "electrolytic current interrupter." Pressing work has for the past few weeks claimed all my time, and I have been unable to peruse the technical periodicals; and it is only a few days ago that I noticed an article descriptive of the device. Upon receiving your note I have gone over the journals and have read the articles and comments that have appeared. Most of them are indicative of time ill-spent for the purpose of comprehending the requirements of such an apparatus.

To stimulate the ardor of the zealous experimenters, who believe in the revolutionary character of this discovery, it might be well to suggest one or two such simple devices for interrupting the current For instance, a very primitive contrivance of this kind comprises a poker—yes, an ordinary poker, connected by means of a flexible cable to one of the mains of the generator, and a bathtub filled with conducting fluid which is connected in any suitable manner, through the primary of an induction coil, to the other pole of the generator. When the experimenter desires to take a Roentgen picture, he brings the end of the poker to white heat, and, thrusting the same into the bathtub, he will at once witness an astonishing phenomenon, the seething and boiling liquid making and breaking the current in rapid succession, and the powerful rays generated will at once convince him of the great practical value of this discovery. I might further suggest that the poker may be conveniently heated by means of a welding machine.

Another device, entirely automatic, and probably suitable for use in suburban districts, comprises two insulated metal plates, supported in any convenient manner, in close proximity to each other. These plates are connected through the primary of an induction coil with the terminals of a generator, and are bridged by two movable contacts joined by a flexible cable. The two contacts are both attached to the legs of a good-sized chicken standing astride on the plates. Heat being applied to the latter, muscular contractions are produced in the legs of the chicken, which thus makes and breaks the current through the induction coil. Any number of such chickens may be provided and the contacts connected in series or multiple arc, as may be desired, thus increasing the frequency of the impulses. In this manner fierce sparks, suitable for most purposes, may be obtained, and vacuum tubes may be operated, and these contrivances will be found a notable improvement on certain circuit-breakers of old, with which two enterprising editors undertook some years ago to revolutionize the systems of electric lighting. The enterprising editors are wiser now. They are to be congratulated, and their readers, scientific societies and the profession, all ought to be congratulated, and—"all is well that ends well." The observant experimenter will not fail to note that the fierce sparks frighten the chickens, which are thus put into more violent spasms and muscular contractions, this again increasing the fierceness of the sparks, which, in return, causes a greater fright of the chickens and increased speed of interruptions; it is, in fact, as Kipling says:

"Interdependence absolute, foreseen, ordained, decreed.
To work, ye'll note, at any tilt an' every rate o' speed."

But to return, in all earnestness, to the "electrolytic interrupter" described, this is a device with which I am perfectly familiar, having carried on extensive experiments with the same two or three years ago. It was one of many devices which I invented in my efforts to produce an economical contrivance of this kind. The name is really not appropriate, inasmuch as any fluid, either conducting or made so in any manner, as by being rendered acid or alkaline, or by being heated, may be used. I have even found it possible, under certain conditions, to operate with mercury. The device is extremely simple, but the great waste of energy attendant upon its operation and certain other defects make it entirely unsuitable for any valuable, practical purpose, and as far as those instances are concerned, in which a small amount of energy is needed, much better results are obtained by a properly designed mechanical circuit-breaker. The experimenters are very likely deceived by finding that an induction coil gives longer sparks when this device is inserted in place of the ordinary break, but this is due merely to the fact that the break is not properly designed. Of the total energy supplied from the mains, scarcely one-fourth is obtainable of that amount, which a well constructed mechanical break furnishes in the secondary, and although I have designed many improved forms, I have found it impossible to increase materially the economy. Two improvements, however, which I found at that time necessary to introduce, I may mention for the benefit of those who are using the device. As will be readily noted, the small terminal is surrounded by a gaseous bubble, in which the makes and breaks are formed, generally in an irregular manner, by the liquid being driven towards the terminal at some point. The force which drives the liquid is evidently the pressure of the fluid column, and by increasing the fluid pressure in any manner the liquid is forced with greater speed towards the terminal and thus the frequency is increased. Another necessary improvement was to make a provision for preventing the acid or alkali from being carried off into the atmosphere, which always happens more or less, even if the liquid column be of some height. During my early experiments with the device I became so interested in it that I neglected this precaution, and I noted that the acid had attacked all the apparatus in my laboratory. The experimenter will conveniently carry out both of these improvements by taking a long glass tube of, say, six to eight feet in length, and arranging the interrupting device close to the bottom of the tube, with an outlet for eventually replacing the liquid. The high column will prevent the fumes from vitiating the atmosphere of the room, and the increased pressure will add materially to the effectiveness of the performance. If the liquid column be, say, nine times as high, the force driving the fluid towards the contact is nine times as great, and this force is capable, under the same conditions, of driving the fluid three times as fast, hence the frequency is increased in that ratio and, in fact, in a somewhat greater ratio, as the gaseous bubble, being compressed, is rendered smaller, and therefore the liquid is made to travel through a smaller distance. The electrode, of course, should be very small to insure the regularity of operation, and it is not necessary to use platinum. The pressure may, however, be increased in other ways, and I have obtained some results of interest in experiments of this kind.

As before stated, the device is very wasteful, and, while it may be used in in which by far better results are obtainable with devices equally simple, if not more so. I may mention one here, based on a different principle, which is incomparably more effective, more efficient and also simpler on the whole. It comprises a fine stream of conducting fluid which is made to issue, with any desired speed, from an orifice connected with one pole of a generator, through the primary of the induction coil, against the other terminal of the generator placed at a small distance. This device gives discharges of a remarkable suddenness, and the frequency may be brought within reasonable limits, almost to anything desired. I have used this device for a long time in connection with ordinary coils and in a form of my own coil with results greatly superior in every respect to those obtainable with the form of device discussed.

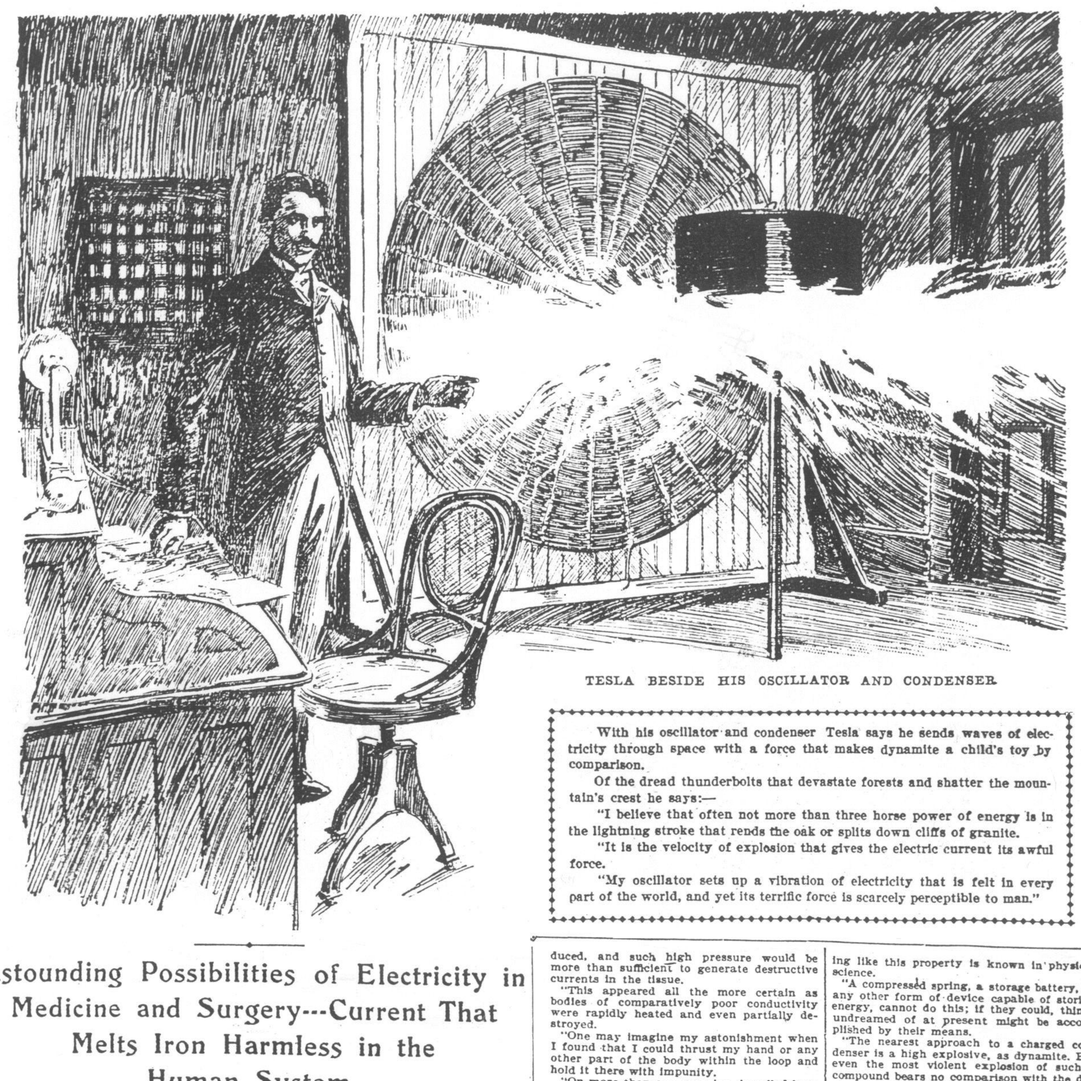
If time permits I shall, in compliance with the request expressed in your letter, make a few statements referring to such make and break devices in general, and various forms based on this new principle.

Yours very truly,

N. Tesla.

New York, March 13.

TESLA'S LIGHTNING TO FREE MAN FROM DISEASE.



TESLA BESIDE HIS OSCILLATOR AND CONDENSER.

With his oscillator and condenser Tesla says he sends waves of electricity through space with a force that makes dynamite a child's toy by comparison.

Of the dread thunderbolts that devastate forests and shatter the mountain's crest he says:—

"I believe that often not more than three horse power of energy is in the lightning stroke that rends the oak or splits down cliffs of granite.

"It is the velocity of explosion that gives the electric current its awful force.

"My oscillator sets up a vibration of electricity that is felt in every part of the world, and yet its terrific force is scarcely perceptible to man."

Astounding Possibilities of Electricity in Medicine and Surgery---Current That Melts Iron Harmless in the Human System.

HOW to use tremendous electrical forces, freeing us from microbes and disease," is the latest marvel of science.

Tesla has made some astonishing discoveries. He is able to shoot millions and tens of millions of volts of real thunder storm lightning through a man, that will melt glass and fuse metals, and yet give him no injury or pain.

More wonderful still is that all this mighty force which a human being can withstand will destroy microbic life and disease germs within, making one's system as clean and sweet as atmosphere after a thunder storm.

In view of these facts electro-medical scientists have shown great interest in Tesla's experiments with his machines for generating electricity that welds iron, tears steel bars to fragments, and yet plays harmlessly through the human system, creating new health and life for the microbe poisoned victim.

Tesla Rushing His Inventions.

A remarkable feature of it all is that Tesla has no patents to sell for manufacturing medicinal lightning, and he has no agents selling his all healing volts to the public.

He is working on a far loftier plane of achievement. He is pushing to completion his startling inventions for propelling and steering torpedo boats, war ships or any other kind of craft at a distance from land, with no person on board nor any connection by wire. He is also perfecting his machine for transmitting power from Niagara Falls to Paris or any other part of the world without a wire, by means of his electro-automatic instruments—each in perfect sympathy and unison with the other, so that electric currents leap across the intervening space of one or many thousands of miles.

Tesla's marvellous problems have now been solved, it is said, and he has only to perfect the necessary appliances to present them to the world in practical working form.

To this end a double force of skilled men are now engaged and the machines are being pushed with unceasing rapidity to completion.

Among the many discoveries made by Tesla none is more impressive than the fact that with a small volume of electricity he secures tremendous results.

How is it done?

By the velocity of the electrical explosions in his marvellous machine known as the condenser.

What giant can drive a hard wax candle into wood with blows from a hammer? But a boy can shoot a soft tallow dip through an oak plank with a shotgun. The powder gives the candle velocity.

A frontier teamster can split a board with his ox whip, which his child plays with and finds harmless. Sand blown from a powerful air blast machine cuts glass and steel like butter. Big steel rails are cut with a soft iron disc.

With the water that falls in gentle dew on the rose garden, the hydraulic miner in California beats down hills and mountains, because of the force—velocity—behind the water.

With his oscillator and condenser, Tesla says he sends waves of electricity through space with a force that makes dynamite a child's toy by comparison.

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"My oscillator sets up a vibration of electricity that is felt in every part of the world, and yet its terrific force is scarcely perceptible to man."

Tesla has been criticised severely by unthinking scientists, yet his invention of the "rotating magnetic field motor" has made those mighty machines at Niagara Falls possible. They light the city of Buffalo, twenty miles away, and run its street cars and the machinery of a thousand factories. Tesla's name in big letters of bronze cast on the plates of these world famed machines is a fitting monument to his genius.

His achievement in obtaining instantaneous force encircling the globe, omnipotent and everywhere present, borders on the miraculous—the infinite.

Tesla makes the unseen a visible, terrible manifestation in nature. He generates currents that would not disturb a fly on your sleeping babe, yet they are as devastating as a cyclone. He gives the faintest whispering current force—a force that disintegrates armor plate as quickly as you melt sugar with water.

In a way, he brings certainty out of chaos. He makes substance from "nothing." That which you can neither see, taste, hear nor smell, he lashes into a storm of fury, and you hear this "nothing" roar and thunder like Niagara.

It suggests to the contemplative mind that period when this great rolling globe of ours was "without form and void."

It suggests the phenomena of the original creation of matter made visible to man—the power of making substance out of thought. Of thinking "nothing" into substance, and perhaps the life principle itself. In this direction, toward this great end, science seems certainly drifting.

In one sense it may be said that the only sure thing to-day, the only thing that can be predicted with unfailing accuracy, is that which no man has seen with his naked eye nor touched, nor heard, nor tasted with his lips—the star which no one has beheld, but which science has already catalogued and which will appear next year or next century to the hour and minute.

Who dares stake his life on the sure arrival of to-morrow's five o'clock express at that hour? Yet all the world knows that to-morrow's eclipse will arrive on time to the second.

Working Toward Infinite Possibilities.

It is along these omnipotent, infallible lines of science that Tesla is apparently working.

Now to go back to his views on the use of electricity for disease.

Tesla has been before the highest scientific body of its kind in the country with his discovery. His address to the Electro-Therapeutic Association regarding the use of electricity by physicians in healing wounds and curing disease is soon to be published by the society.

In his carefully prepared paper he makes these interesting statements:—"The body of a person may be subjected without danger to electrical pressures vastly in excess of any producible by ordinary apparatus, for they may amount to several million volts, as has been shown in actual practice.

"Now, when a conducting body is electrified to go high a degree small particles, which may be adhering firmly to its surface, are torn off with violence and thrown to distances which can only be conjectured.

"The continuous improvement of the instruments and the study of the phenomenon may shortly lead to the establishment of a novel mode of hygienic treatment which would permit an instantaneous cleaning of the skin of a person, simply by connecting the same to, or possibly, by merely placing the person in the vicinity of, a source of intense electrical oscillations, this having the effect of throwing off, in a twinkle of the eye, dust or particles of any extraneous matter adhering to the body."

Of his experiments Tesla says:—

"Soon my efforts were centred upon producing in a small space the most intense inductive action, and by gradual improvement in the apparatus I obtained results of a surprising character.

"For instance, when the end of a heavy bar of iron was thrust within a loop powerfully energized, a few moments were sufficient to raise the bar to a high temperature.

Wonders of His Electricity.

"Even heavy lumps of other metals were heated as rapidly as though they were placed in a furnace.

"When a continuous band formed of a sheet of tin was thrust into the loop the metal was fused instantly, the action being comparable to an explosion, and no wonder, for the frictional losses accumulated in it at the rate of possibly ten horse power.

"Masses of poorly conducting material behaved similarly, and when a highly exhausted bulb was pushed into the loop the glass was heated in a few seconds nearly to the point of melting.

"When I first observed these astonishing actions I was interested to study their effects upon living tissues.

"As may be assumed, I proceeded with all the necessary caution, and well I might, for I had the evidence that in a turn of only a few inches in diameter an electromotive force of more than ten thousand volts was produced, and such high pressure would be more than sufficient to generate destructive currents in the tissue.

"This appeared all the more certain as bodies of comparatively poor conductivity were rapidly heated and even partially destroyed.

"One may imagine my astonishment when I found that I could thrust my hand or any other part of the body within the loop and hold it there with impunity.

"On more than one occasion, impelled by a desire to make some novel and useful observation, I have willingly or unconsciously performed an experiment connected with some risk, this being scarcely avoidable in laboratory experience.

"Now, why is it that in a space in which such violent turmoil is going on living tissue remains uninjured?

"One might say the currents cannot pass because of the great self-induction offered by the large conducting mass. But this it cannot be, because a mass of metal offers a still higher self-induction and is heated just the same.

"One might argue the tissues offer too great a resistance. But this, again, cannot be the reason, for all evidence shows that the tissues conduct well enough, and besides, bodies of approximately the same resistance are raised to a high temperature.

"One might attribute the apparent harmlessness of the oscillations to the high specific heat of the tissue, but even a rough quantitative estimate from experiments with other bodies shows that this view is untenable.

Human Tissues Are "Condensers."

"The only plausible explanation I have so far found is that the tissues are condensers. This only can account for the absence of injurious effects.

"But it is remarkable that, as soon as a heterogeneous circuit is constituted, as by taking in the hands a bar of metal and forming a closed loop in this manner, the passage of the currents through the arms is felt, and other physiological effects are distinctly noted.

"The strongest action is, of course, secured when the exciting loop makes only one turn, unless the connections take up a considerable portion of the total length of the circuit, in which case the experimenter should settle upon the least number of turns by carefully estimating what he loses by increasing the number of turns, and what he gains by utilizing thus a greater proportion of the total length of the circuit.

"It should be borne in mind that when the exciting coil has a considerable number of turns and is of some length, the effects of electrostatic induction may preponderate, as there may exist a very great difference of potential—a hundred thousand volts or more—between the first and last turn. However, these latter effects are always present even when a single turn is employed.

"When a person is placed within such a loop any pieces of metal, though of small bulk, are perceptibly warmed. Without doubt they would be also heated—particularly if they were of iron—when imbedded in living tissue, and this suggests the possibility of surgical treatment by this method.

To Sterilize Wounds Possible.

"It might be possible to sterilize wounds, or to locate, or even to extract metallic objects, or to perform other operations of this kind within the sphere of the surgeon's duties in this novel manner.

"Most of the results enumerated, and many others still more remarkable, are made possible only by utilizing the discharges of a condenser.

"It is probable that but a very few—even among those who are working in these identical fields—fully appreciate what a wonderful instrument such a condenser is in reality. Let me convey an idea to this effect.

"One may take a condenser, small enough to go in one's vest pocket, and by skilfully using it he may create an electrical pressure vastly in excess—a hundred times greater, if necessary—than any producible by the largest static machine ever constructed.

"Or he may take the same condenser, and, using it in a different way, he may obtain from it currents against which those of the most powerful welding machine are utterly insignificant.

"Or, again, he may avail himself of the same marvellous instrument, and, by suddenly discharging its stored electricity, he may create such a terrific commotion in the space that, though silent and invisible, it can be detected, as actually demonstrated, at distances much greater than those at which the sound of the largest gun is perceptible, distances which are measured in tens, perhaps hundreds, and even thousands, of miles.

"Those who are imbued with popular notions as to the pressures of static machines and currents obtainable with a commercial transformer will be astonished at this statement—yet the truth of it is easy to see.

His Method of Storing Electrical Force.

"Such results are obtainable, and easily, because the condenser can discharge the stored energy in an inconceivably short time. Nothing like this property is known in physical science.

"A compressed spring, a storage battery, or any other form of device capable of storing energy, cannot do this; if they could, things undreamed of at present might be accomplished by their means.

"The nearest approach to a charged condenser is a high explosive, as dynamite. But even the most violent explosion of such a compound bears no comparison with the discharge or explosion of a condenser.

"For, while the pressures that are produced in the detonation of a chemical compound are measured in tens of tons per square inch, those which may be caused by condenser discharges may amount to thousands of tons per square inch, and if a chemical could be made which would explode as quickly as a condenser can be discharged under conditions which are realizable an ounce of it would quite certainly be sufficient to render useless the largest battle ship.

"That important realizations would follow from the use of an instrument possessing such ideal properties I have been convinced since long ago, but I also recognized early that great difficulties would have to be overcome before it could replace less perfect implements now used in the arts for the manifold transformations of electrical energy.

"These difficulties were many. The condensers themselves, as usually manufactured, were inefficient, the conductors wasteful, the best insulation inadequate, and the conditions for the most efficient conversion were hard to adjust and to maintain.

Problem of Controlling Electricity.

"One difficulty, however, which was more serious than others, and to which I called attention when I first described this system of energy transformation, was found in the devices necessarily used for controlling the charges and discharges of the condenser.

"They were wanting in efficiency and reliability, and threatened to prove a decided drawback, greatly restricting the use of the system and depriving it of many valuable features.

"For a number of years I have tried to master this difficulty. During this time a great number of such devices were experimented upon. Many of them promised well at first, only to prove inadequate in the end.

"Reluctantly, I came back upon an idea on which I had worked long before. It was to replace the ordinary brushes and commutator segments by fluid contacts. I had encountered difficulties then, but the intervening years in the laboratory were not spent in vain, and I made headway.

"First it was necessary to provide for a circulation of the fluid, but forcing it through by a pump proved itself impractical.

"Then the happy idea, presented itself to make the pumping device an integral part of the circuit interrupter, enclosing both in a receptacle to prevent oxidation.

"Next some simple ways of maintaining the circulation, as by rotating a body of mercury, presented themselves. Then I learned how to reduce the wear and losses which still existed. I fear that these statements, indicating how much effort was spent in these seemingly insignificant details, will not convey a high idea of my ability, but I confess that my patience was taxed to the utmost.

Success for the Physician of Science.

Finally, though, I had the satisfaction of producing devices which are simple and reliable in their operation, which require practically no attention, and which are capable of effecting a transformation of considerable amounts of energy with fair economy.

"The physician will not be able to obtain an instrument suitable to fulfil many requirements. He will be able to use it in electro-therapeutic treatment in most of the ways enumerated. He will have the facility of providing himself with coils such as he may desire to have for any particular purpose, which will give him any current or any pressure he may wish to obtain.

"Such coils will consist of but a few turns of wire, and the expense of preparing them will be quite insignificant.

"The instrument will also enable him to generate Rönigen rays of much greater power than obtainable with ordinary apparatus.

"A tube must still be furnished by the manufacturers which will not deteriorate, and which will allow to concentrate larger amounts of energy upon the electrodes.

"When this is done nothing will stand in the way of an extensive and efficient application of this beautiful discovery, which must ultimately prove itself of the highest value, not only at the hands of the surgeon, but also of the electrotherapist, and, what is most important, of the bacteriologist."

"The first and simplest method of applying the currents was to connect the body of the patient to two points of the generator, be it a dynamo or an induction coil. The alternator may be one giving from five to ten thousand complete vibrations per second, this number being still within the limit of practicability.

WESTINGHOUSE SUES GENERAL ELECTRIC ON THE TESLA PATENTS.

The following important information is received by the ELECTRICAL REVIEW just as it goes to press. It would indicate that some new features have entered into the big electric lighting deal in New York city. There is also a rumor that this is an entering wedge in the split that is said to be likely to come between the General Electric and Westinghouse interests in the matter of their patent agreement. The electrical field will view with much interest and concern this new move. The statement the ELECTRICAL REVIEW has received is as follows:

The suit referred to in your inquiry is doubtless the suit which the Westinghouse company has instituted in the Circuit Court of the United States for the Northern District of New York, to enjoin the General Electric Company from delivering multiphase apparatus covered by the Tesla patents to the Edison Electric Illuminating Company of New York. The suit is brought under the agreement relating to patents which the General Electric and Westinghouse companies entered into in March, 1896, and the Westinghouse company contends that the apparatus in question can not be delivered by the General Electric Company to the New York Edison company because of the exclusive license under the Tesla patents which the Westinghouse Company's licensee in New York city, the United Electric Light and Power Company, has held for many years. The bill was filed at Utica, Tuesday, March 21, and the motion for a preliminary injunction is returnable Tuesday, April 4.

ELECTRICAL REVIEW

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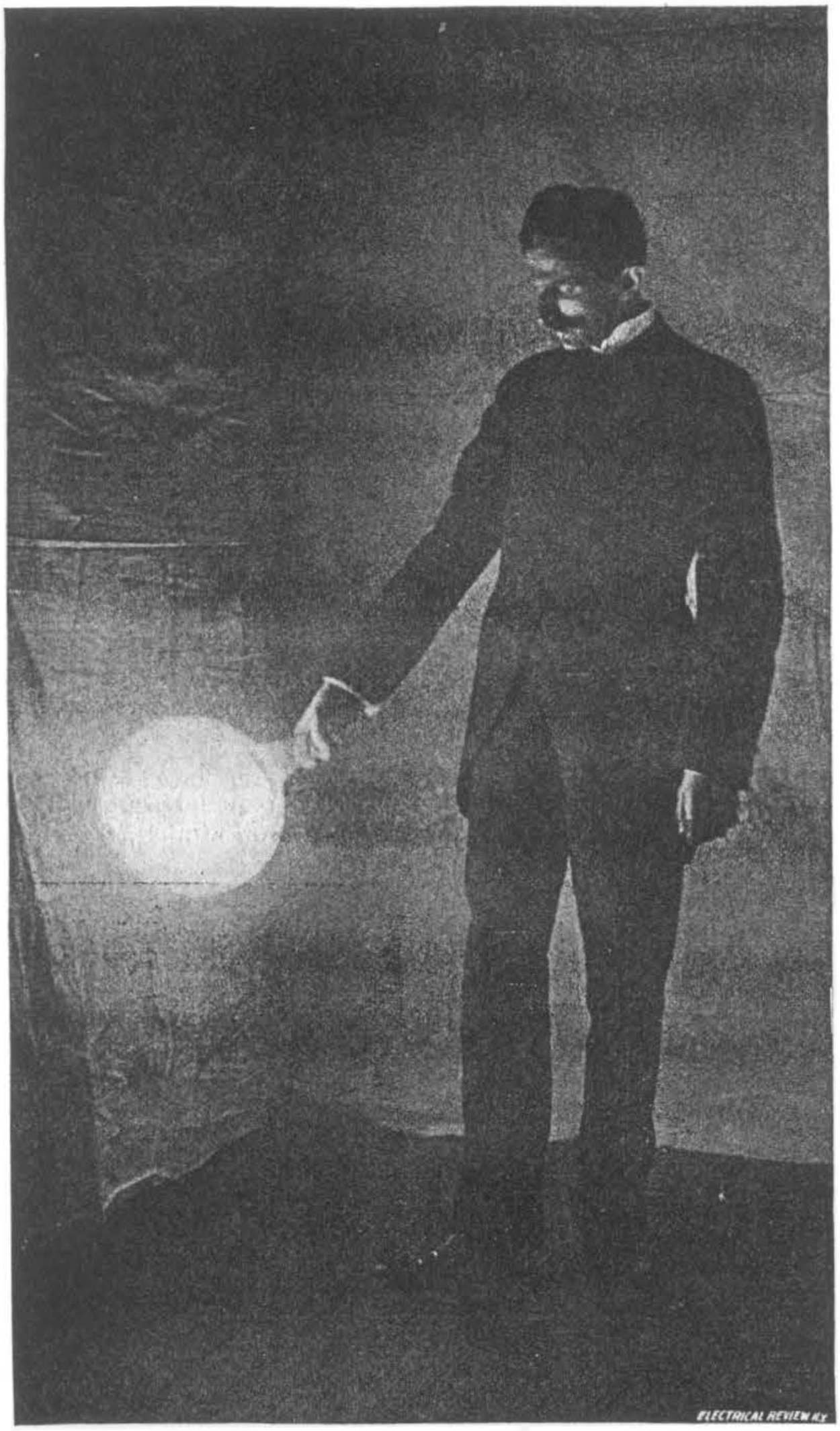

FIG. 1.—"SOME EXPERIMENTS IN TESLA'S LABORATORY WITH CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY"—LIGHTING A DISCONNECTED VACUUM BULB OF 1,500 CANDLE-POWER BY HIGH-FREQUENCY CURRENTS—PHOTOGRAPH TAKEN BY THE LIGHT OF THE BULB ITSELF, EXPOSURE ABOUT TWO SECONDS.

SOME EXPERIMENTS IN TESLA'S LABORATORY WITH CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.

TO THE EDITOR OF ELECTRICAL REVIEW:

Since the unfortunate accident of four years ago, which crippled and delayed my labors in a number of lines so seriously, I have had but little time to devote to the fulfillment of a duty which, next to that of turning his best efforts to diligent inquiry in the fields he has chosen, is the most important to a scientific man; namely, that of giving an exact record of the results obtained. I realize with sorrow every day that, despite of all pains taken to this end, I am gaining but very slowly on the material accumulated. Ideas come through a happy inspiration, apparently without much exertion, but it is the working out of the many harassing details and putting into a presentable form which consumes time and energy. It was impossible to abandon research in new directions, in which I have felt myself irresistibly drawn, and it was equally impossible to do full justice to the work partially completed, and I can only hope to gradually retrieve my losses by the only expedient available, which is to redouble the zeal. It is not the best plan to follow, I confess, and is in radical opposition to the kindly advice given to me by a great philosopher, but this admission may serve to refute the statements attributed to me to the effect that I intended to live 200 years by sleeping most of the time! It may also show that it is not this mode of life which is responsible for the delay in the commercial introduction of my system of vacuum tube lighting, as has been asserted by some people who have found a singular satisfaction in dwelling extensively in their columns on my proposed glass house on Long Island, which was to cover acres of ground, and which was to be built for the purpose of catching the sun's rays; on my claims of the discoveries

of Roentgen; on my invention enabling me to move and explode torpedo boats by will power, and on my efforts to annihilate the entire British navy. It is to be hoped that the limit of patience of the readers has been finally reached.

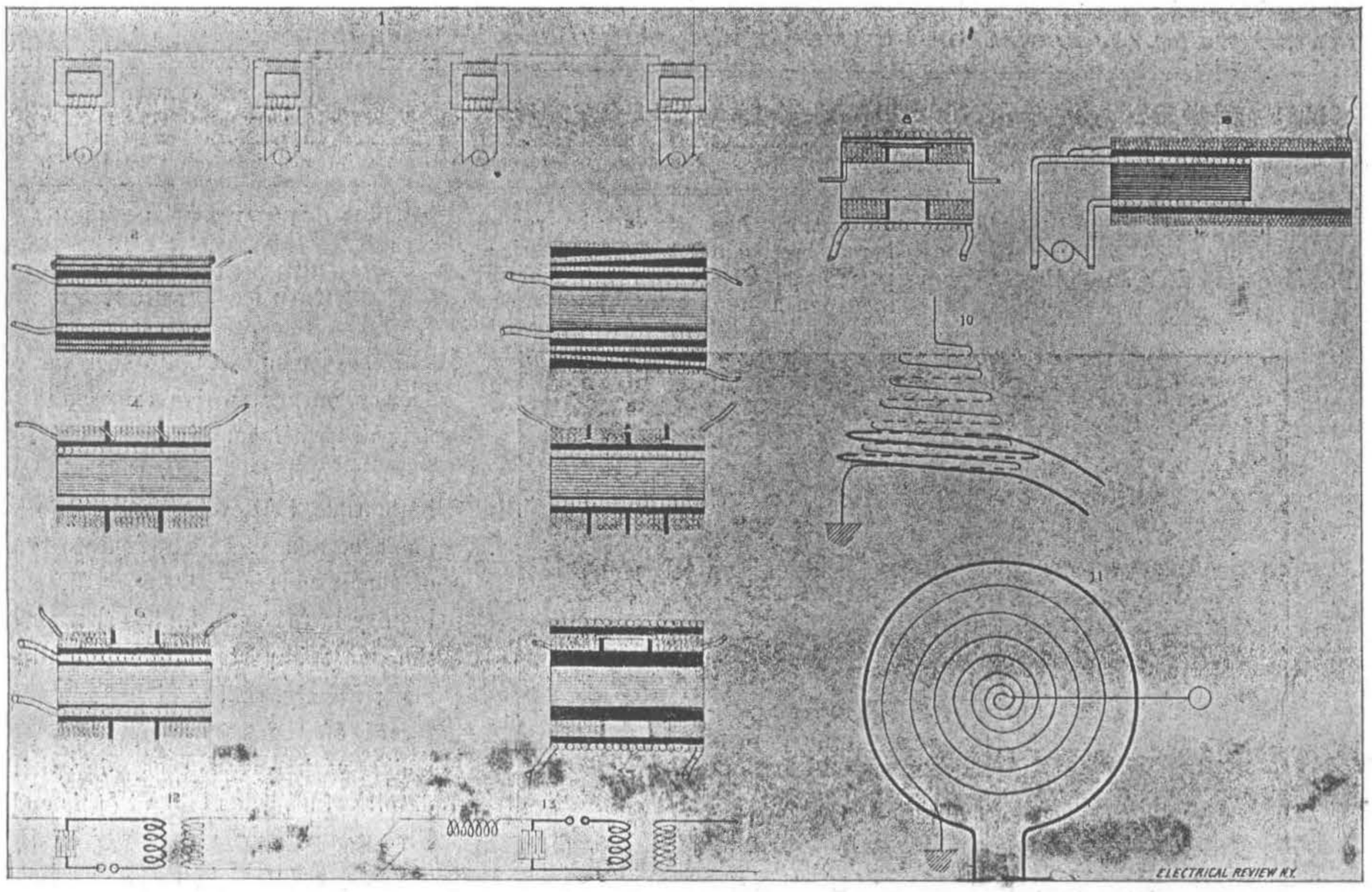

FIG. 2.—"SOME EXPERIMENTS IN TESLA'S LABORATORY WITH CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY."—TABLE OF DIAGRAMS ILLUSTRATING THE EVOLUTION OF A HIGH-TENSION TRANSFORMER ENABLING THE PRODUCTION OF ELECTRO-MOTIVE FORCES OF MANY MILLIONS OF VOLTS.

At that time, still painfully remembered, my energies were taken up principally by some mechanical problems of great importance, and the few observations in electricity which I was fortunate to make came like ever so many refreshing berries found on the road by a weary wanderer. The journey is not finished yet, and the wanderer is well-nigh exhausted. He longs for more sweet berries, and anxiously asks, "Did any one pass this road before?"

It was chiefly in three directions that electrical investigation was attractive and promising: There were the excessive electrical pressures of millions of volts, which opened up wonderful possibilities if producible in practical ways; there were the currents of many hundreds of thousands of amperes, which appealed to the imagination by their astonishing effects, and, most interesting and inviting of all, there were the powerful electrical vibrations with their mysterious actions at a distance. What better work could one do than inventing methods and devising means for enabling scientific men to push investigation far out into these practically unknown regions? This work was difficult and tedious and involved a certain amount of material sacrifice, but promised a higher reward if successfully accomplished—the gratitude of those many who exercise their gifts in different directions and are compelled to rely on the expert for providing them with implements suitable for their special purpose. Who can estimate how much science has been advanced by the beautiful instruments of measure which Lord Kelvin has given us? Unfortunately, in many of the new fields such instruments are yet to be invented. Still more unfortunately, information seems to be more needful than instruments, if one is to judge from statements frequently made in technical periodicals on a variety of subjects. An experimenter, for instance, measures the current through a make-and-break device, and, finding it small, he infers that the conversion is economical. Another suggests to determine the efficiency of conversion through such a device by the calorimetric method. Now, as a matter of fact, if there was such a contrivance, absolutely perfect in its action, which would behave as I have explained on another occasion, and change the resistance of a gap from zero to infinity without any loss in the gap itself, which separates the terminals, it still might happen that 99 per cent of the energy supplied to the circuit would be wasted in radiations, useless for the purpose contemplated. The calorimetric method would in this, or generally in any other instance, in which the disturbances produced are very sudden, entirely fail in giving an approximation as to the energy dissipated in the circuit, for the simple reason that the friction encountered by a wave in its passage through a medium, which determines the amount of heat generated, is no measure whatever of the energy of the wave. Thus, certain well understood cases excepted, the only method at present available in such estimates is to take account of the energy consumed by the source of supply. This remark alone will show that the economical conversion of currents by make and break devices is a much more difficult problem than it appears to those who have studied it superficially. Not only must the devices used in the transformation possess certain characteristics, but the entire circuit must be properly designed. One can not help admiring the confidence and self-possession of experimenters, who put



FIG. 4.—PHOTOGRAPH SHOWING AN INCANDESCENT LAMP LIGHTED BY A SYNCHRONIZED CIRCUIT COMPOSED OF A WIRE LOOP AND CONDENSER, AND ENERGIZED BY WAVES TRANSMITTED FROM A DISTANCE.

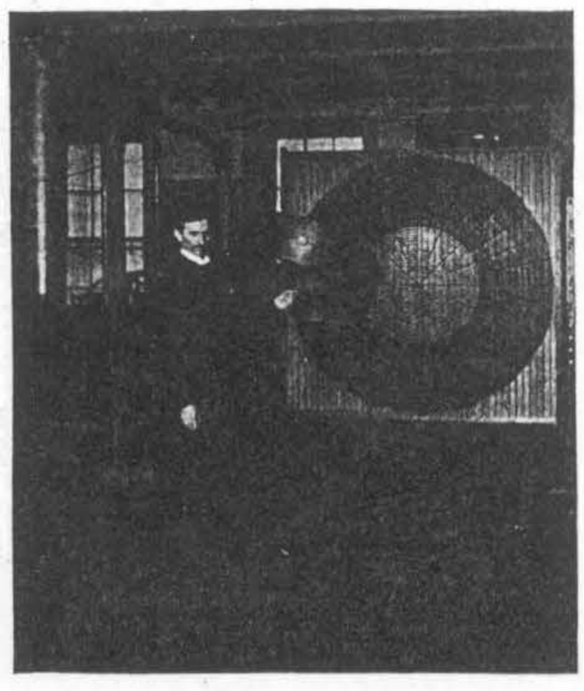

FIG. 5.—PHOTOGRAPH SHOWING AN INCANDESCENT LAMP LIGHTED BY MEANS OF WAVES TRANSMITTED THROUGH SPACE TO A COIL SYNCHRONIZED WITHOUT A CONDENSER.

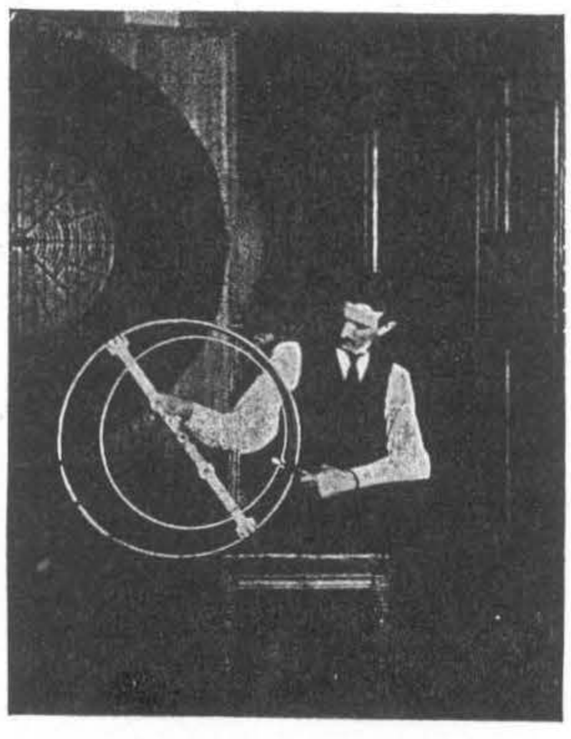

FIG. 6.—EXPERIMENT ILLUSTRATING THE ACTION OF A SYNCHRONIZED CIRCUIT ENERGIZED BY WAVES TRANSMITTED FROM A DISTANT OSCILLATOR — THE ENERGY RECEIVED IS TRANSFERRED UPON ANOTHER UNRESPONSIVE CIRCUIT, LIGHTING THE INCANDESCENT LAMP ATTACHED TO THE SAME.

forth carelessly such views and who, with but a few days', not to say hours', experience with a device, venture before scientific societies, apparently unmindful of the responsibility of such a step, and advance their imperfect results and opinions hastily formed. The sparks may be long and brilliant, the display interesting to witness, and the audience may be delighted, but one must doubt the value of such demonstrations. There is so little novelty in them, that one might easily perform a practical joke on the lecturer by describing in advance all his drawings, apparatus, experiments and theories, thus placing him in an awful predicament. Though such a course would be naturally impolite, it might be found justified and excused by the circumstances, for premature expressions of opinion and demonstrations of this kind are responsible for much evil, one of these being the erroneous idea which they create in scientific circles as to the importance of an advance made. It grieves one to observe that, for example, such great work as that of Professor Dewar, which he turns out with clock regularity, is scarcely commented upon in the technical columns, whereas a worthless trap for interrupting currents, which usually consumes nine-tenths of the energy, and is, besides, useless for other reasons, and just suitable for the amusement of small boys, who are beginning their electrical experience with Leclanche batteries and $1.50 induction coils, is hailed as an important scientific discovery. An agreeable contrast is afforded by those few who patiently investigate, contented to lose the credit for advances made rather than to present them to the world in an imperfect state, who form their opinions conscientiously, after a long and careful study, and have little to correct afterward.

The importance of the task of providing proper implements for research in these various fields once recognized, it became the question in what line the efforts to this end would be likely to be most profitable. A little thought showed that it was in investigating high electrical pressures, for these were needed in most instances. More than a passing thought was given to static electricity, with the experiments of Franklin as starting point. Various forms of generators of static electricity were experimented upon, and some new ones designed, to which I hope to revert some time, as they present some features of interest. The most valuable outcome of these experiments was a method of conversion which I have described, and which enables the operation of any kind of devices of low tension from such a high-pressure source with perfect ease and safety, no matter how high the tension. Soon, however, it was recognized that with the above object in view generators of steady pressure were entirely impractical, quite apart from their incidental limitations. It was exactly as if one attempted to drive piles into the ground by the application of continuous pressure. This would require cumbersome and powerful machinery, and would be very inconvenient. An incomparably better way of developing high pressure is by delivering violent blows as with a hammer. In such a case the motion of the hammer being suddenly arrested pressure is developed on the point of impact, which is all the greater the smaller the displacement caused, and if there were material absolutely rigid, incompressible and inelastic, an infinite pressure might thus be developed by a small blow.

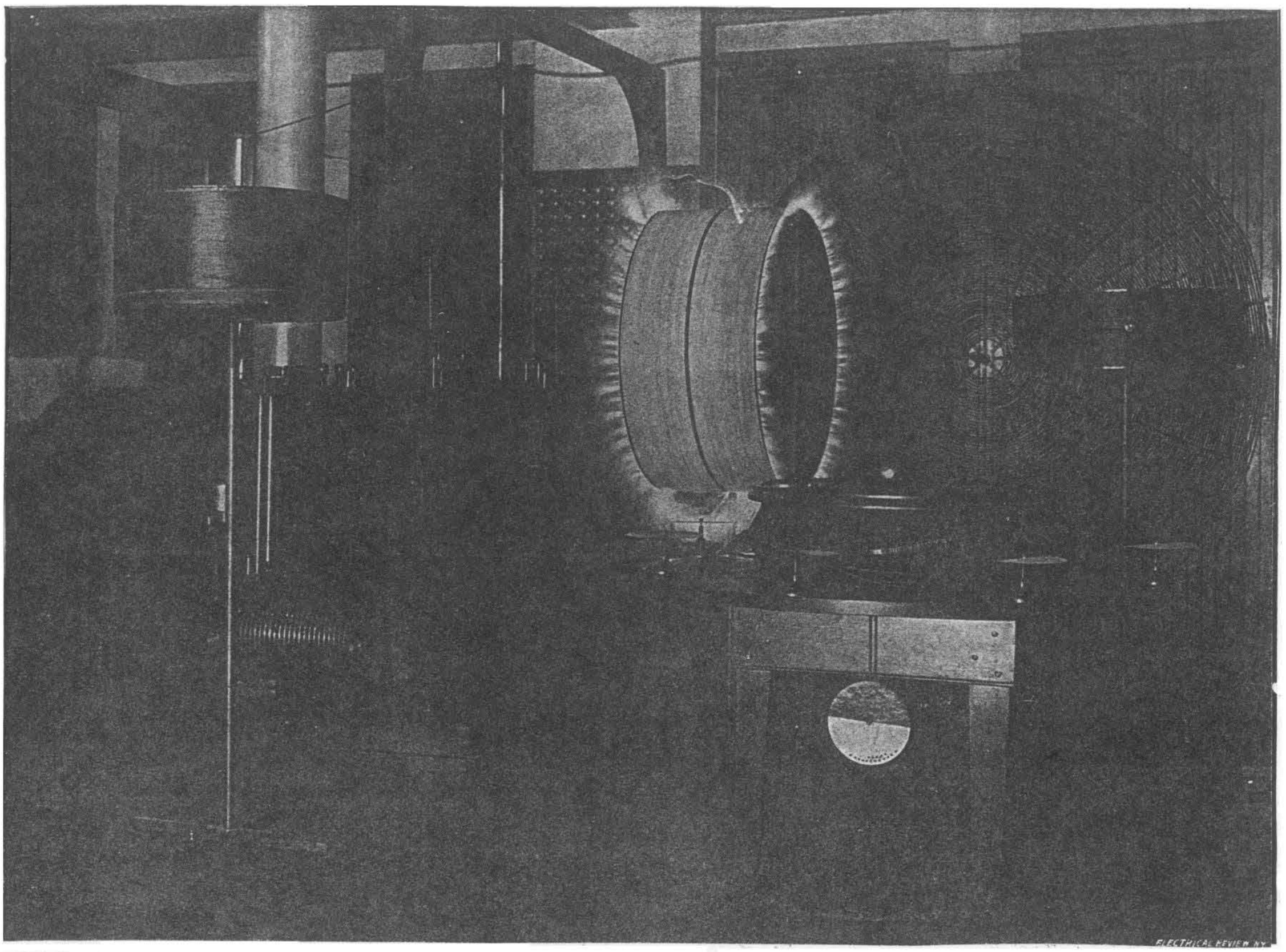

FIG. 3.—"SOME EXPERIMENTS IN TESLA'S LABORATORY WITH CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY"—PHOTOGRAPH SHOWING A PART OF THE LABORATORY, WITH A DISCONNECTED RESONATING COIL SUPPORTED ON AN INSULATING STAND, AND ILLUMINATED BY THE STREAMERS PRODUCED, OTHER COILS REMAINING UNAFFECTED—THE PRESSURE DEVELOPED IN THE RESONATING COIL IS OVER HALF A MILLION VOLTS.

Hence one is forcibly driven to the use of a transformer or induction coil as means for producing great electrical pressures. The first difficulty encountered was that of insulation, and it might be interesting and useful to show, chiefly to those who are less familiar with this special subject, how by gradual improvement, from the ordinary inductorium capable of furnishing currents of very moderate electro-motive force, an apparatus was finally evolved in which there is practically no limit as to the pressure obtainable.

Selecting first the closed core transformer, one easily recognizes that it is unsuitable for the attainment of the object in view for obvious reasons. Nevertheless, by adopting the plan illustrated in the first diagram of Fig. 2. I succeeded in obtaining nearly 200,000 volts, and I think that more than twice this tension is practicable by means of such an arrangement, which involves the use of independent and entirely insulated sources for supplying the primaries, as will be understood from an inspection of the diagram without further explanation. The evident limitations of the closed-core type in the way of insulation, rate of change and frequency of the current impulses, led to the adoption of an open-core type,



FIG. 8. — PHOTOGRAPH OF THE EXPERIMENTER STANDING IN THE MIDDLE OF THE LABORATORY AND LIGHTING A VACUUM BULB BY WAVES FROM A DISTANT OSCILLATOR—HIS BODY IS, IN THIS CASE, SUBJECTED TO GREAT ELECTRICAL PRESSURE.

as a matter of course, and the various diagrams of the figure referred to illustrate the modifications as they were gradually made in the manner of insulating and winding of the coils. In diagram 2 the old, primitive method of insulation is indicated. In diagram 3 the succeeding layers are insulated by material increasing in thickness gradually from one end to the other, being thickest on the place of greatest difference of potential. The thickness is easily calculated beforehand, and is such that all the insulation is as nearly as possible uniformly strained. As it was impracticable to pile up many layers in the manner illustrated in diagram 3, naturally the modification illustrated in diagram 4 was made, which led to a further improvement, indicated in diagram 5. It was recognized, however, that there was no advantage in winding many coils, and that all that was needed were two secondary coils joined in the middle, as illustrated in diagram 6, the secondaries being, of course, wound as shown in diagram 3. Next, in order to increase the output of the coil and gain other advantages, the relative customary position of the primary and secondary windings was reversed and the coil as shown in diagram 7 produced, the two secondary coils being joined on their outer, instead of on their inner ends, as before. This construction was considerably better than that illustrated in diagram 6, as the primary and secondary coils were placed in closer inductive relation. But when with this coil the tension had been pushed far enough, it was found that the iron core limited the spark length, and then two insulated cores, one in each coil, were resorted to, which were finally discarded, and so the coil shown in diagram 8 resulted, which I have described on several occasions and which, of all other constructions, permits the obtainment of the highest possible tension with a two-terminal coil in a given space.

But even in this perfected type it was not possible to go beyond a certain potential difference, and a further investigation led to a new type, which I have called a single terminal coil, and which is illustrated in diagram 9 and is now well known. In this coil the adjustment is so made that the secondary is nearly equal to a quarter of the wave length, the highest potential being, under these conditions, produced on the free terminal. Subsequently I extended such adjustment also to the coils in diagram 8, improving the same materially.

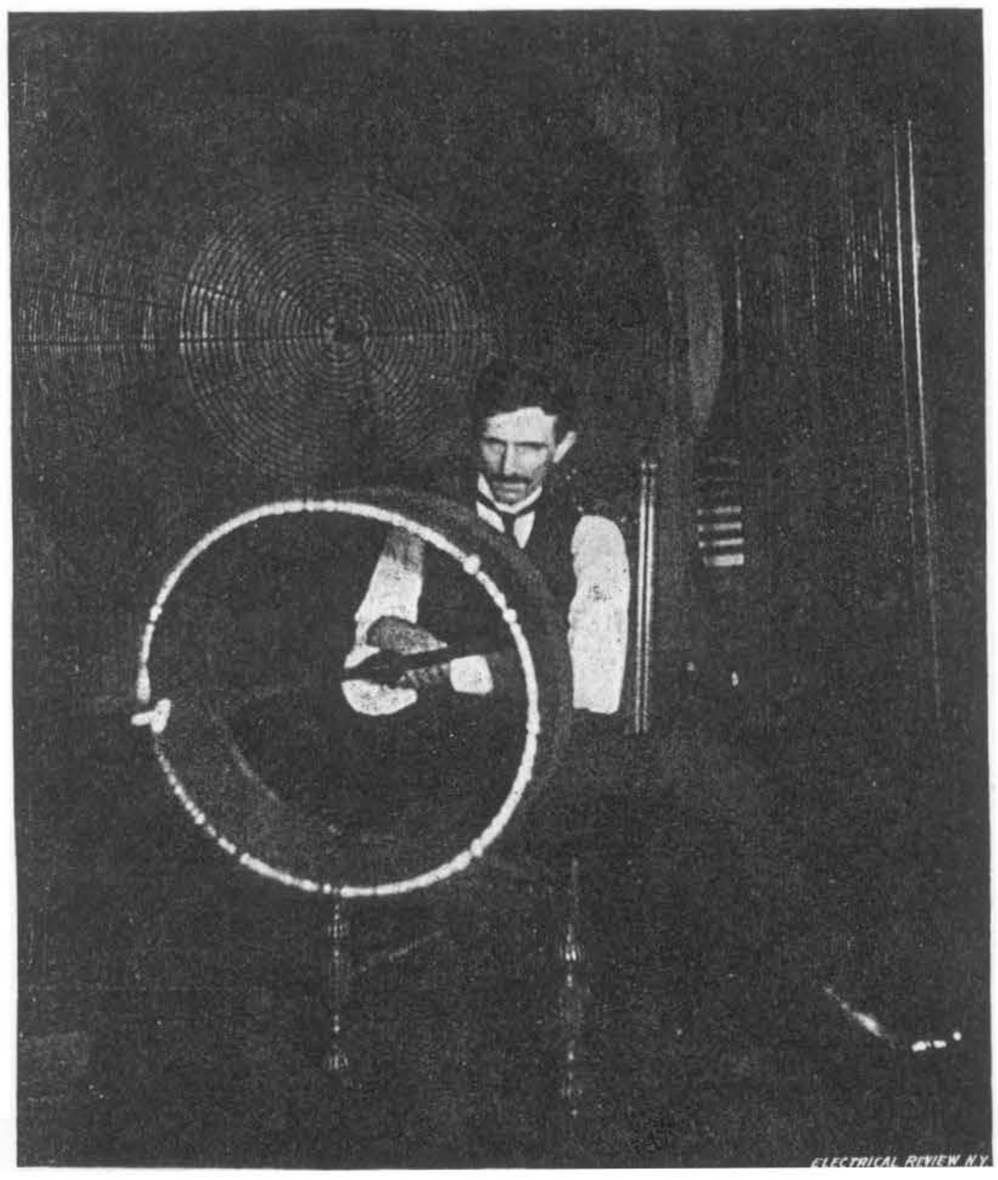

FIG. 7.—"SOME EXPERIMENTS IN TESLA'S LABORATORY WITH CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY"—EXPERIMENT SHOWING A COIL ENERGIZED BY THE WAVES OF A DISTANT OSCILLATOR AND ADJUSTED TO THE CAPACITY OF THE BODY OF THE OPERATOR, WHO PRESERVES HIMSELF FROM INJURY BY MAINTAINING A POSITION AT THE NODAL POINT, WHERE THE INTENSE VIBRATION IS LITTLE FELT—THE PRESSURE ON THE END OF THE COIL TOWARDS THE READER, WHICH IS ILLUMINATED BY THE POWERFUL STREAMERS, IS NEARLY HALF A MILLION VOLTS.

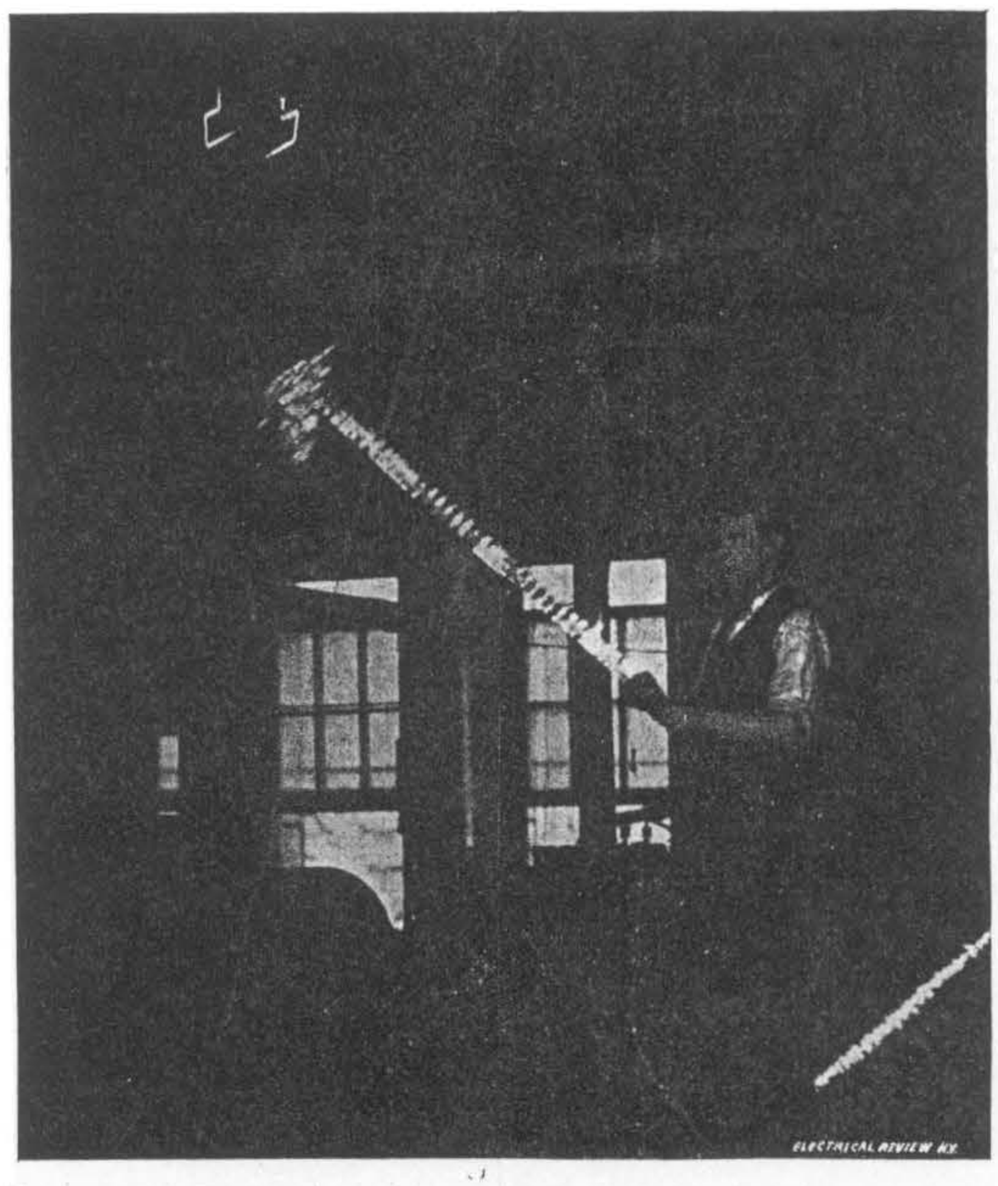

FIG. 10.—IN THIS EXPERIMENT THE OPERATOR'S BODY IS CHARGED TO A GREAT PRESSURE BY A DIRECT CONNECTION WITH AN OSCILLATOR—THE PHOTOGRAPH SHOWS A CONDUCTING BAR, CARRYING ON THE END A SHEET OF TIN OF DETERMINED SIZE, HELD IN HAND—THE OPERATOR IS ON THE TOP OF A STATIONARY ELECTRICAL WAVE AND THE BAR AND SHEET ARE BOTH ILLUMINATED BY THE VIOLENTLY AGITATED AIR SURROUNDING THEM—ONE OF THE VACUUM TUBES USED IN LIGHTING THE LABORATORY, THOUGH AT CONSIDERABLE DISTANCE ON THE CEILING, GLOWS BRIGHTLY, BEING AFFECTED BY THE VIBRATIONS TRANSMITTED TO IT FROM THE OPERATOR'S BODY.

During these efforts I fortunately discovered the important part which air played in the breaking down of the insulation, and by adopting proper methods for the exclusion of gaseous matter, I was able to increase the electro-motive force to more than 10 times the value without breaking down the secondary. I have described this method since, which I am using in the manufacture of coils and condensers, and without which it would be entirely impossible to reach any such results as I have obtained. The industrial world has profited by the recognition of the action of the air, for it has helped to extend power transmission to greater distances than heretofore practicable. It has also been useful in determining the limits of the electro-motive forces with ordinary apparatus used in power transmission, but I see that no attempt is yet made to overcome the streamers by a suitable construction of the cables, as I have indicated, and thus make higher electro-motive forces available.

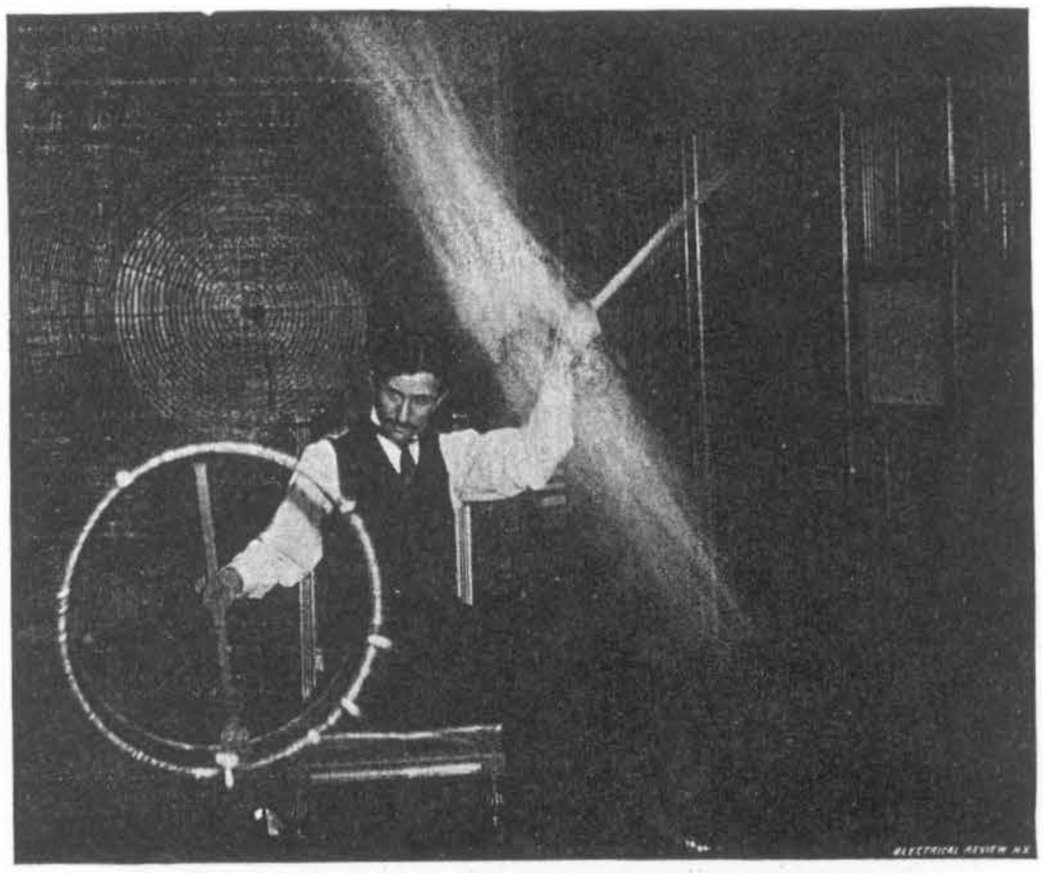

FIG. 9.—"SOME EXPERIMENTS IN TESLA'S LABORATORY WITH CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY"—THE OPERATOR'S BODY, IN THIS EXPERIMENT, IS CHARGED TO A HIGH POTENTIAL BY MEANS OF A COIL RESPONSIVE TO THE WAVES TRANSMITTED TO IT FROM A DISTANT OSCILLATOR, AND A LONG GLASS TUBE WAVED IN THE HAND IS LIGHTED TO GREAT BRILLIANCY BY THE ELECTRICAL CHARGES CONVEYED TO IT THROUGH THE BODY.

Further experimentation with the original single-terminal coil, before referred to, finally led step by step to the adoption of a coil of large dimensions, which, in two typical forms, is illustrated in diagrams 10 and 11. With such a coil I found that there was practically no limit to the tension obtainable, and it is by its means that I discovered the most important of all facts arrived at in the course of my investigation in these fields. One of these was that the atmospheric air, though ordinarily a perfect insulator, conducted freely the currents of immense electro-motive force producible by such coils and suitable accessories. So great is the conductivity of the air, that the discharge issuing from a single terminal behaves as if the atmosphere were rarefied. Another fact is that this conductivity increases very rapidly with the rarefaction of the atmosphere and augmentation of the electrical pressure, to such an extent that at barometric pressures which permit of no transit of ordinary currents, those generated by such a coil pass with great freedom through the air as through a copper wire. Following up these promising revelations I demonstrated conclusively by experiments that great amounts of electrical energy can be transmitted to any distance through upper air strata which are easily accessible, and since this truth has been recognized every fiber has been strained to realize such a transmission on a large scale. These two observations explain clearly the silent discharges noted frequently in dense air strata, but three or four miles above the earth's surface. One more equally important fact I may mention, which was simultaneously observed. The discharges of such a coil, when of an electro-motive force of a few millions of volts, excite powerful affinities in the atmospheric nitrogen, causing it to combine readily with the oxygen and other elements, particularly in the presence of aqueous vapor. So energetic are these actions and so strangely do such powerful discharges behave, that I have often experienced a fear that the atmosphere might be ignited, a terrible possibility, which Sir William Crookes, with his piercing intellect, has already considered. Who knows but such a calamity is possible? And who can tell with certitude that periodical cessations of organic life on the globe might not be caused by ignition of the air and destruction of its life-sustaining qualities, accidentally or as a consequence of some accumulative change? A lump of coal will lie for centuries unaffected in contact with oxygen, but the combustion once started, the process continues as long as there are elements to combine.

While improving the construction of the transformers, every effort was made to perfect the apparatus for generating the currents. The objective point from the outset was to obtain the greatest possible rate of variation. High-frequency alternators were first used, but their limitations were soon apparent. I then turned again to make and break devices, chiefly with the object of using them in connection with a novel form of transformer, which I have previously described, and which is now well known and understood. In its original form, as I first showed it, it is illustrated in diagram 12, which need not be dwelt upon, beyond saying that one of the characteristic features of such an instrument is the energizing of the primary of the induction coil by the rapidly succeeding discharges of a condenser. In a more recent type, specially adapted for ordinary supply circuits, which I have described and shown before several scientific societies, the transformer comprises, as indicated in diagram 13, three coils, there being, in addition to the primary and secondary coils, one which receives the currents from the supply circuit, and is designated the charging coil. Pref-

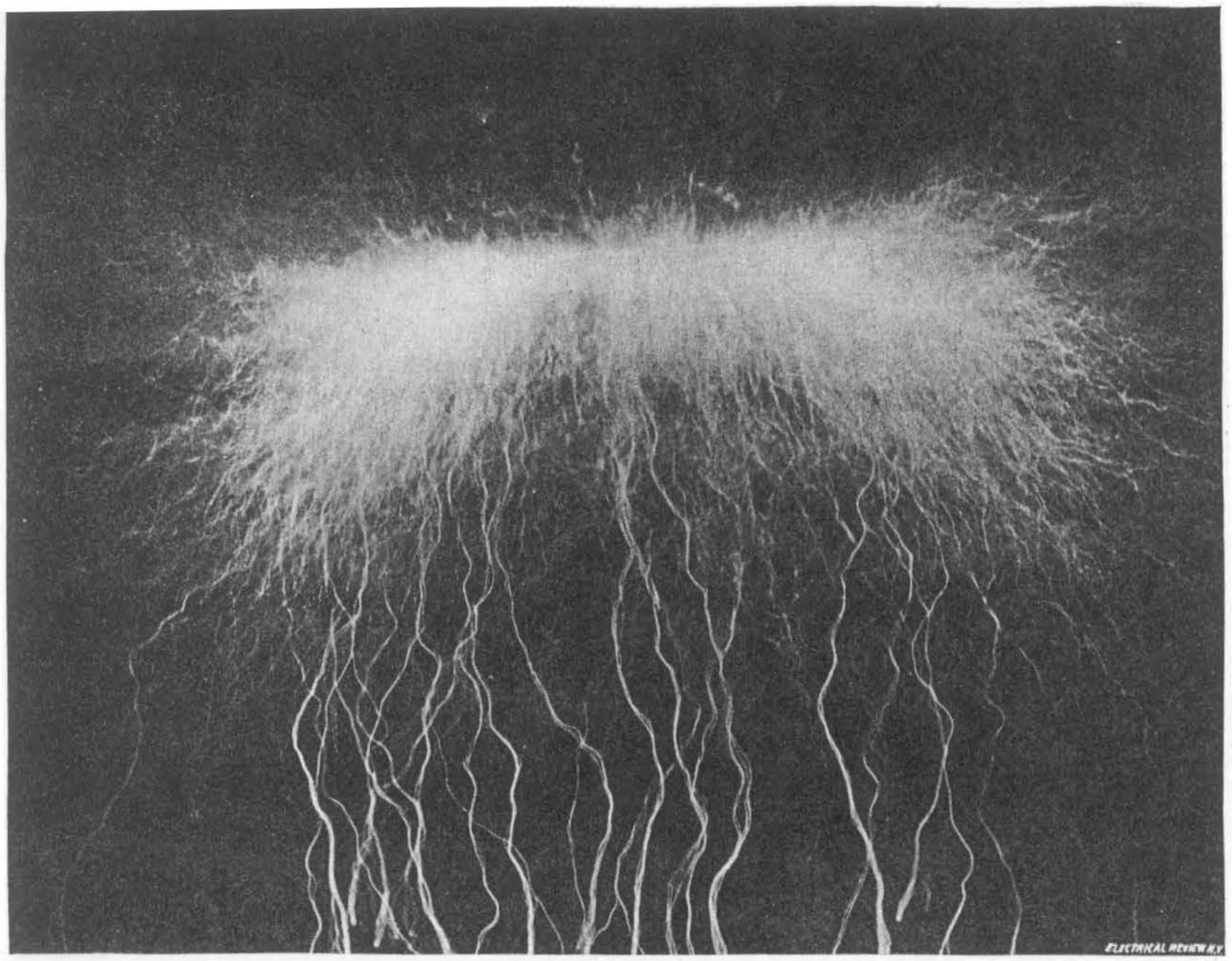

FIG. 11.—PHOTOGRAPH OF AN ACTIVE TERMINAL OF AN IMPROVED OSCILLATOR, USED IN TESLA'S EXPERIMENTS FOR TRANSMITTING ELECTRICAL ENERGY TO GREAT DISTANCES WITHOUT WIRES—WIDTH OF ILLUMINATED SPACE IS 18 FEET—THE PRESSURE ON THE TERMINAL IS ABOUT EIGHT MILLION VOLTS.

(Concluded on page 204.)

TESLA'S LABORATORY EXPERIMENTS.

(*Concluded from page 197.*)

erably the latter is not in inductive relation with the former. On a number of occasions I have described high-frequency apparatus embodying this beautiful method, which has already been of great value to science in my hands as well as in those of others. But a defect, to which I called attention early, still confronted me. It lay in the make and break devices which performed the function of charging and discharging the condenser. Many of such devices, based on a variety of principles, formed the subject of experiments carried on with the aim of doing away with this imperfection. To cite one of these, the current from the source of supply was passed through a minute column of conducting liquid maintained in a variety of ways, and in this simple manner rapidly succeeding impulses were obtained. Incidentally, some useful results were secured with these contrivances, as, for example, the generation of currents of differing phase and the production of rotating fields moving with constant velocity; but, interesting as these simple devices were, they naturally precluded the possibility of economical conversion. Their study, however, was useful as a means of recognizing the requirements of such make and break apparatus, and, finally, led to forms based on scientific and economical principles. A number of these were recently described in technical periodicals and, as stated on a former occasion, they fulfill their difficult duty surprisingly well and make it possible to obtain currents of very high frequency from ordinary supply circuits with great economy. These novel contrivances lend themselves well also to the uses of the ordinary induction coil, and I have employed them with equal success in a form of Planté's rheostatic machine and for many other useful purposes. Thus, after a continuous effort extending through a number of years, I have the supreme satisfaction of having carried this hard and important task to a satisfactory end.

The annexed photographs will serve to convey an idea of what can be done with these perfected implements. Referring to Fig. 1, illustrative of the high rate of change obtained in the current, a vacuum bulb of about 12 inches in diameter is held in front of a coil of four turns of specially constructed heavy cable, through which a condenser is discharging, and, although at a distance of several inches from the coil, the gas in the bulb is brought to intense incandescence, the light emitted being fully equal to 1,500 candles. Such a powerfully energized coil, when the frequency, as in this instance, is measured in millions per second, shows little repellent action, but when the frequency of the impulses is low, closed conductors, as washers of conducting material, are thrown off with a force of a magnitude which can be only explained on the assumption that the currents have maximum values of many hundred thousand amperes.

The remaining photographs will be understood from the titles, which are made explicit for this purpose. I hope to have in the near future an opportunity for describing more of such experiments, and dwelling in detail on the apparatus used. For the present I am compelled, for want of time, to merely state that the vibrations used in most of them were from 400,000 to 800,000 per second.

In conclusion I wish to apologize for the frequent appearance of my likeness in these photographs, which is distasteful to me, but was unavoidable. Most of the advances indicated, and a number of others, have resulted from the application of the beautiful principle upon which the operation of this apparatus is based. Scientific men have honored me by identifying it with my name, and I have earnestly endeavored to show myself worthier of this great distinction by devoting to it much of my energies. No desire for material advantages has animated me in all this work, though I hope, for the sake of the continuance of my labors, that these will soon follow, naturally, as a compensation for valuable services rendered to science and industry. To the scientific experts, who are familiar, in theory and experiment, with electrical vibrations, the results here shown will, I believe, speak in eloquent language. But those readers to whom they are naturally less intelligible will ask: What are they good for, and what do they or have they demonstrated? To them it may be said that they have shown and proved among many other things: That ordinary currents can be transformed with high economy into electrical vibrations of any pitch, which are needed in many novel arts; they have shown that electrical energy in great amounts can be efficiently and safely transmitted without the use of wires to any point of the globe, however distant; they have furnished proof that the movements and operation of bodies and machinery carried by the same can be controlled from a great distance without any tangible connection whatever and with absolute precision; they have proved the practicability of a system of signaling without wires, not with the imperfect appliances as before attempted, which can not be tuned and are rendered useless by the play of a small induction coil, but by means of apparatus producing powerful oscillations and circuits in exact synchronism, with which it is impossible to interfere; they have shown that atmospheric nitrogen can be readily combined and valuable products manufactured, merely by the application of cheap water power, and that light, diffusive like that of the sun, can be produced with an economy greater than obtainable in the usual ways and with lamps that never consume. N. TESLA.

New York, March 26.

TESLA'S LABORATORY EXPERIMENTS.

It is with great pleasure that we present to our readers, in this issue, the extraordinary results obtained by Mr. Tesla. The photographs taken in his laboratory are, we believe, the first of this kind that he has ever permitted to be published. The experiments on which he dwells, and which are evidently the result of years of patient labor, are, in our opinion, the most striking and promising that have been shown in years, and they can not fail to create a profound impression on scientific minds.

The New York Herald March 30, 1899

MORE WONDERS WORKED BY TESLA

Inventor Makes Marvellous Progress in Transmitting Electrical Energy Without the Use of Wires.

CONTROLS DEADLY CURRENT

Eight Million Volts of the Fluid Handled with Safety by Means of Oscillator.

SPARK AROUND THE GLOBE.

Nikola Tesla has further advanced his extraordinary experiments in transmitting electrical energy for commercial purposes without the use of wires. I called on him at the Waldorf-Astoria last night to learn the progress which he has made, and which amounts to this:—

The inventor can handle currents up to eight millions of volts, produced by his perfected oscillators; the current can be directed to any point at which arrangements have been made to receive it, and this can be accomplished without regard to distance or surrounding conditions.

These advances have been made since October, 1898, when the HERALD published an account of Mr. Tesla's discovery. Then the inventor thought environment would have a potent influence on the transmission. Now, he says, that handicap has been done away with.

MARVELS SHOWN IN PHOTOGRAPHS.

Referring to photographs, the current issue of the Electrical Review says:—

"In one illustration the inventor receives the electrical waves from a distance and develops a pressure of half a million volts in a coil which he holds in his hand, preserving himself against injury by maintaining a fixed position on the electrical wave, where the pressure developed is small. Another photograph shows an assistant receiving in his body the currents from an electrical oscillator, which pass through his body and make a metal bar glow in his hands, also lighting a vaccum tube on the ceiling."

"To the scientific experts who are familiar, in theory and experiment, with electrical vibration, the results here shown will, I believe, speak in eloquent language," said Mr. Tesla, in a communication to the Review, "but those readers to whom they are naturally less intelligible will ask:—'What are they good for, and what do they or have they demonstrated?'

"To them it may be said that they have shown and proved, among many other things, that ordinary currents can be transformed with high economy into electrical vibrations of any pitch, which are needed in many novel arts; they have shown that electrical energy in great amounts can be efficiently and safely transmitted without the use of wires to any point of the globe, however distant; they have furnished proof that the movements and operation of bodies and machinery carried by the same can be controlled from a great distance without any tangible connection whatever and with absolute precision.

SIGNALLING WITHOUT WIRES.

"They have also proved the practicability of a system of signalling without wires, not with the imperfect appliances as before attempted, which cannot be tuned and are rendered useless by the play of a small induction coil, but by means of apparatus producing powerful oscillations and circuits in exact synchronism, with which it is impossible to interfere. They have shown that atmospheric nitrogen can be readily combined and valuable products manufactured merely by the application of cheap water power, and that light, diffusive like that of the sun, can be produced with an economy greater than obtainable in the usual ways, and with lamps that never consume."

The Review, in its editorial comment, says:—

"The experiments on which Tesla dwells and which are evidently the result of years of patient labor, are, in our opinion, the most striking and promising that have been shown in years, and they cannot fail to create profound impression on scientific minds."

The New York Times March 30, 1899

TESLA'S ELECTRIC DISCOVERY.

The Electrical Review Pronounces His Experiments the Most Striking and Promising in Years.

The current issue of the Electrical Review contains the first elaborate description published of experiments carried on in Nikola Tesla's laboratory demonstrating his recently announced discoveries in the application of electricity to commercial purposes without the use of conducting wires. The experiments involve the handling of currents up to 8,000,000 volts produced by his perfected oscillators, with entire safety. Photographs of the experiments performed make it appear that the energy can be directed to any point desired, regardless of distance and environment.

In one illustration the inventor receives the electrical waves from a distance, and develops a pressure of half a million volts in a coil which he holds in his hand, preserving himself against injury by maintaining a fixed position on the electrical wave where the pressure developed is small. Another photograph shows an assistant receiving in his body the currents from an electrical oscillator, which pass through his body and make a metal bar glow in his hands, also lighting a vacuum tube on the ceiling.

In concluding his communication to The Electrical Review, Tesla says that it is proved, among many other things, that ordinary currents can be transformed with high economy into electrical vibrations of any pitch, which are needed in many novel arts; that electrical energy in great amounts can be efficiently and safely transmitted without the use of wires to any point of the globe, however distant; that the movements and operation of bodies and machinery carried by the same can be controlled from a great distance, without any tangible connection whatever and with absolute precision; the practicability of a system of signaling without wires; that atmospheric nitrogen can be readily combined and valuable products manufactured merely by the application of cheap water power, and that light, diffusive like that of the sun, can be produced with an economy greater than obtainable in the usual ways, and with lamps that never consume.

The Electrical Review in its editorial comment, says: "The experiments on which Tesla dwells, and which are evidently the result of years of patient labor, are, in our opinion, the most striking and promising that have been shown in years, and they cannot fail to create a profound impression on scientific minds.

Wireless Telegraphy for Yacht Races.

LONDON, March 30.—According to a dispatch to The Daily Chronicle from Dover Signor Marconi, whose brilliantly successful experiments with wireless telegraphy across the Strait of Dover have excited the liveliest interest, says he has received an offer to report the American Cup races for certain American newspapers.

Electrical Review

[OLDEST ELECTRICAL WEEKLY IN THE UNITED STATES.]
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HIGH PRESSURES AND HIGH FREQUENCIES.

There is no department of electrical study so fascinating as that dealing with high pressures and frequencies. While the first knowledge of electricity came through the study of high-pressure phenomena, interest in these waned and almost disappeared after the introduction of current electricity as a working force. The almost incredible development of knowledge in this department, the great industrial evolution it accomplished, the vast benefits arising from the completion of each step in advance, so accelerated the progress of the electrical arts that, to-day, application of the ordinary forms of electric current —direct, alternating, polyphase— may almost be said to be a finished subject. Its era of rapid progress is passed; it can only improve by the little betterments of detail suggested by experience.

But the really great field of electrical study remains, for the most part, unexplored. It is to electricity at high pressures and at high rates of vibration, or both, that we must look for new progress. So little is known of the beautiful phenomena of electrical action under such circumstances, so much can be imagined, that the least attempt at prophecy is dangerous.

The very few enthusiastic investigators who have left the beaten track to explore this fascinating region have already produced amazing results. In these pages, last week, was an account of the remarkable work of Mr. Tesla with currents of high potential and frequency. Such results as this patient and earnest experimentalist in the field of science has accomplished lie so far without the range of usual experience that no comparison of other results with them is possible. They stand apart, and it must be left to the future to judge of the value of their accomplishment.

Still; it is certain that every new fact of Nature discovered is finally beneficial, whether or not its utilitarian application is immediate. There seems vast promise in the new facts that Tesla presents; still vaster possibilities lie scattered through the new and interesting field to which he points. To this work must be given the large credit due to any effort to add to the world's store of knowledge. Its results may not always be immediate, but they can not fail to be extremely valuable — perhaps even revolutionary.

TESLA, America's Own and Only Non-Inventing Inventor, the Scientist of the Delmonico Café and Waldorf-Astoria Palm Garden, has been at it again. This time the news of young Marconi's success in telegraphing through space fired Tesla to feats hitherto undreamed of, and he filled columns in the *Herald*—which paper, I much fear me, inclines to help Tesla make a guy of himself—with profound droolings about volts and resistances and circuits and ampères and things and things. Tesla says he can do everything that Marconi has done. Of course he doesn't really do them, but that may be because he is afraid someone else may find out how they are done. He knows all about the theory and the practical machinery of Marconi's messages through miles of space, and could prove it too—if old Bill Jones was alive. Indeed, the actual results of the methods of the two inventors show only this slight difference: Marconi telegraphs through space and Tesla talks through space.

The New York Tribune April 9, 1899

IF THE AIR SHOULD BURN UP

A STARTLING AND INCENDIARY POSSIBILITY, SUGGESTED BY MR. TESLA.

In a paper which Mr. Tesla recently contributed to the pages of "The Electrical Review" he mentioned a striking possibility. He was discussing his own apparatus for raising the potential, or pressure, of an electric current, when it is intended to transmit it through rarefied air from one point to another. He noted, in passing, the increased sensitiveness of atmospheric nitrogen when subjected to the influence of electricity at a high potential. That is to say, a gas which is ordinarily rather sluggish about combining with other chemical elements exhibits a more sociable disposition when a powerful current is passing through it.

This fact led Mr. Tesla to contemplate the contingency of a sudden union between the nitrogen of the air, along the route traversed by a high-pressure current, and the oxygen with which it is mechanically intermingled. Such an operation, it must be noted, would really amount to combustion. When any substance burns—wood, for instance—the inflammable part of it combines chemically with oxygen. A material that is burned is oxidized. Hence a chemical combination of the nitrogen with its principal fellow-constituent of the atmosphere would really be a burning process.

Now, if anything of this sort should ever happen, the combustion would be confined at first to the immediate vicinity of the path of the current. But many things, like a stick of wood or a piece of coal, when once ignited, continue to burn for a considerable period, the fire gradually extending from the place at which it began until the whole object is consumed. In like manner, Mr. Tesla suggested, if the earth's aerial envelope is ever set ablaze at all, it may keep on burning until it is altogether converted into something else. The best-known chemical combinations of oxygen and nitrogen are nitrous or nitric acids, and one or both of these would doubtless result from a conflagration of the kind here indicated. A complete removal of the atmosphere from the earth would put an end to winds, rain and weather in general. But inasmuch as it would also extinguish all animal life, the weather would not be missed.

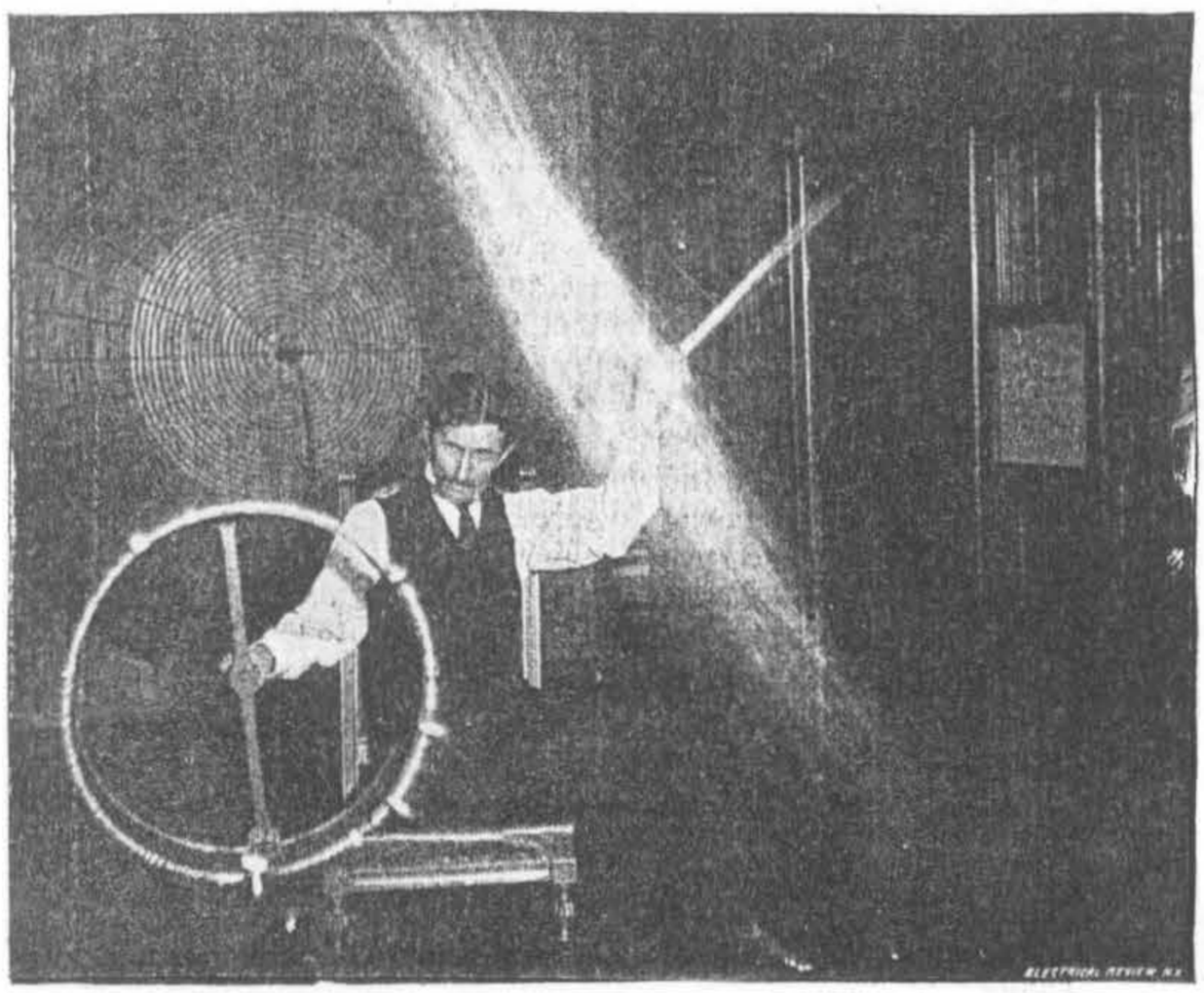
The fact that lightning is attended with very high potentials, and has been at work in the atmosphere for thousands—probably millions—of years without having produced any result of this kind, so far as scientists know, is somewhat reassuring as to the future; but, after all, it does not absolutely guarantee humanity against the possibility to which Mr. Tesla calls attention. It is doubtful whether the voltages of an ordinary stroke of lightning are as great as those which Mr. Tesla secures with his new transformer. Setting the North River on fire is conceded to be an unattainable bit of incendiarism; but if Mr. Tesla is not cautious he may give the world an infinitely vaster display of fireworks.

Teslaic Experiments.—In the issue of the *Electrical Review* of New York for March 29 there is an illustrated article written by Mr. Nikola Tesla on some experiments he has carried out with currents of high potential and high frequency. The value of the description in question is much enhanced by the numerous illustrations in which Mr. Tesla himself appears very frequently as operating or supporting the various luminous bodies. The article is chiefly devoted to vacuum-tube lighting, and in the first illustration a bulb 12in. in diameter is shown held in the hand of its inventor, in which a light equal to 1,500 c.p. is said to be generated by the vacuum bulb being held in front of a coil of four turns through which a condenser is discharging. Mr. Tesla adds that "such a powerfully energised coil, when the frequency, as in this instance, is measured in millions per second, shows little repellent action, but when the frequency of the impulses is low, closed conductors, as washers of conducting material, are thrown off with a force of a magnitude which can be only explained on the assumption that the currents have maximum values of many hundred thousand amperes." In the second illustrations a series of diagrams showing the connections adopted by Mr. Tesla in the construction of his high-frequency coils are clearly illustrated, the object being to produce one pole of exceedingly high potential so that it will discharge freely into the atmosphere. This type of coil Mr. Tesla calls the single-terminal coil, and a number of illustrations are given in which it is seen to be discharging very freely. For instance, in Fig. 11 a photograph of the actual terminal is shown such as Mr. Tesla wishes to use for the transmission of electrical energy to great distances without the use of wires. In this case, with a pressure on the terminal of about 8,000,000 volts, the width of space illuminated by the discharge is some 18ft. A good deal of attention is also drawn to the way in which such apparatus can be handled without danger. The author also claims that the energy developed in the bulbs is comparatively small. But no figures are given to enable one to judge whether the high candle-power obtained in several cases is more economically produced than by, say, arc lighting. Another point taken up is the action of these discharges into the air, in which E.M.F. is measured in millions of volts. Mr. Tesla states that such discharges excited powerful affinities in the atmospheric nitrogen, causing it to combine readily with the oxygen and other elements present in the air. This is particularly the case when aqueous vapour is present. In fact, to quote the author verbatim, "so energetic are these actions and so strangely do such powerful discharges behave, that I have often experienced a fear that the atmosphere might be ignited, a terrible possibility which Sir William Crookes, with his piercing intellect, has already considered. Who knows but such a calamity is possible? And who can tell with certitude that periodical cessations of organic life on the globe might not be caused by ignition of the air and destruction of its life-sustaining qualities, accidentally or as a consequence of some accumulative change?" One pleasing feature in the reproduction of the photographs taken in Mr. Tesla's laboratory is that a description of the apparatus used is placed underneath each of these. The author in certain parts of the article refers to his labours in other directions, such as an invention of a means for the annihilation of the English fleet. One cannot help wishing, however, that he would devote his attention more to the development of vacuum-tube lighting until its commercial possibility is either proved or disproved.

SCIENCE AND INVENTION.

RECENT EXPERIMENTS BY TESLA.

NIKOLA TESLA contributes to *The Electrical Review* (March 29) an illustrated account of some of his latest experiments in the building of improved induction-coils for the development of great electrical pressure. Mr. Tesla says that it is



SOME EXPERIMENTS IN TESLA'S LABORATORY WITH CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY.

The operator's body, in this experiment, is charged to a high potential by means of a coil responsive to the waves transmitted to it from a distant oscillator, and a long glass tube waved in the hand is lighted to great brilliancy by the electrical charges conveyed to it through the body.

Courtesy of *The Electrical Review.*

easier for him to invent than it is to perfect and to record his inventions. He puts it thus:

"Ideas come through a happy inspiration, apparently without much exertion; but it is the working out of the many harassing details and putting into a presentable form which consumes time and energy. It was impossible to abandon research in new directions, in which I have felt myself irresistibly drawn, and it was equally impossible to do full justice to the work partially completed, and I can only hope gradually to retrieve my losses by the only expedient available, which is to redouble the zeal."

The author pays his respects to the sensation-loving public, which at intervals attributes to his genius some new miracle, to the disgust of sober and slow-going, native-born scientists. "Some people," he says,

"have found a singular satisfaction in dwelling extensively in their columns on my proposed glass-house on Long Island, which was to cover acres of ground, and which was to be built for the purpose of catching the sun's rays; on my claims of the discoveries of Roentgen; on my invention enabling me to move and explode torpedo-boats by will power, and on my efforts to annihilate the entire British navy. It is to be hoped that the limits of patience of the readers have been finally reached."

The inventor next describes the process of thought that led him to devote special attention to the improvement of induction-coils. He says:

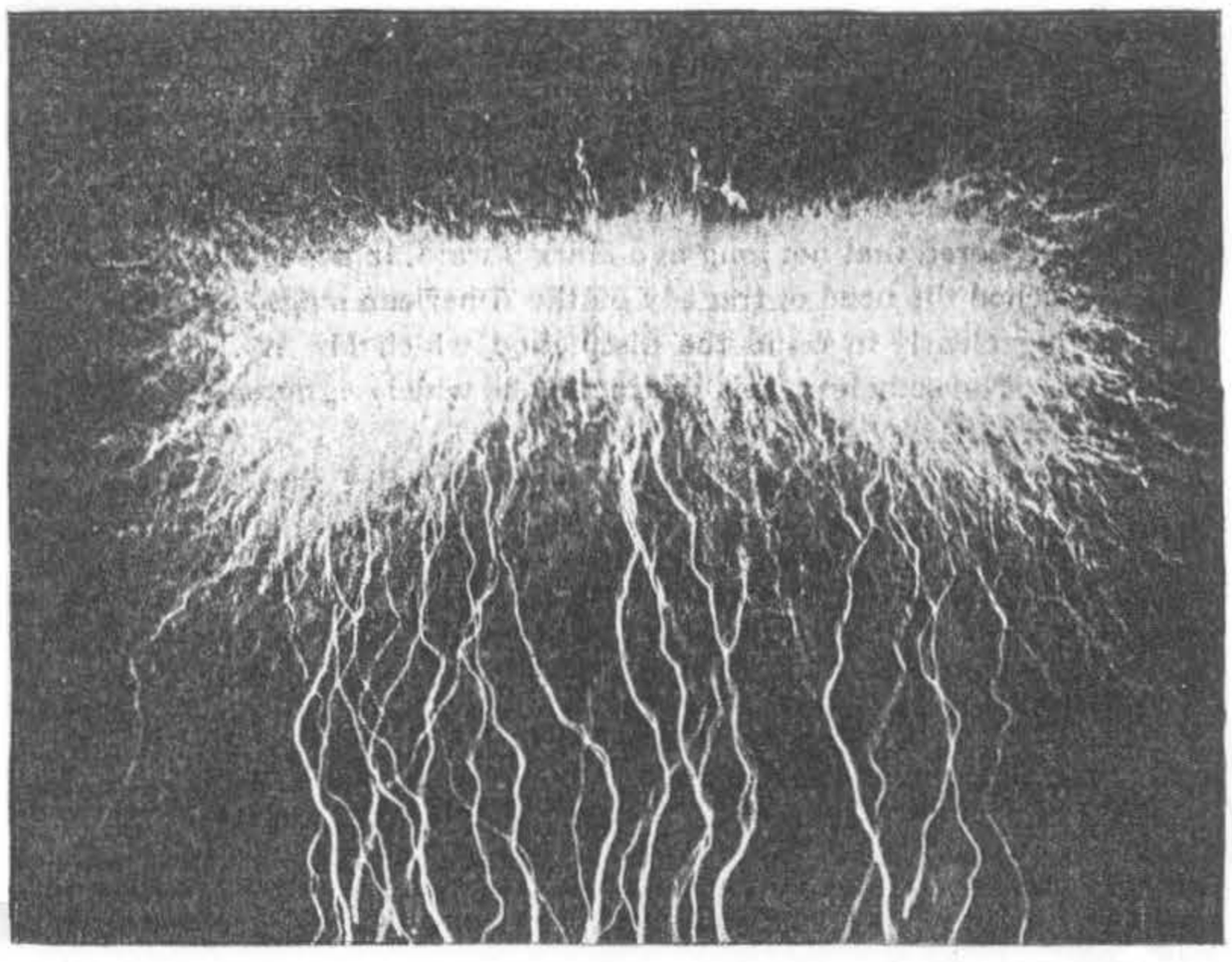
"The importance of the task of providing proper implements for research in these various fields once recognized, it became the question in what line the efforts to this end would be likely to be most profitable. A little thought showed that it was in investigating high electrical pressures, for these were needed in most instances. . . . . .

"Soon it was recognized that . . . generators of steady pressure were entirely impractical, quite apart from their incidental limitations. It was exactly as if one attempted to drive piles into the ground by the application of continuous pressure. This would require cumbersome and powerful machinery, and would be very inconvenient. An incomparably better way of developing high pressure is by delivering violent blows as with a hammer. In such a case the motion of the hammer being suddenly arrested pressure is developed on the point of impact, which is all the greater the smaller the displacement caused; and if there were material absolutely rigid, incompressible, and inelastic, an infinite pressure might thus be developed by a small blow. Hence one is forcibly driven to the use of a transformer or induction-coil as a means for producing great electrical pressures."

We can not follow the inventor in his detailed description of his work. The first difficulty he encountered was that of insulation, but by clever devices and by various alterations of position and arrangement in his primary and secondary coils, he finally attained remarkable results. His final and most radical improvement is thus described:

"During these efforts I fortunately discovered the important part which air played in the breaking down of the insulation, and by adopting proper methods for the exclusion of gaseous matter, I was able to increase the electromotive force to more than ten times the value without breaking down the secondary. I have described this method since, which I am using in the manufacture of coils and condensers, and without which it would be entirely impossible to reach any such results as I have obtained. The industrial world has profited by the recognition of the action of the air, for it has helped to extend power transmission to greater distances than heretofore practicable. . . . . .

"Further experimentation . . . finally led step by step to the adoption of a coil of large dimensions. . . . With such a coil I found that there was practically no limit to the tension obtain-



PHOTOGRAPH OF AN ACTIVE TERMINAL OF AN IMPROVED OSCILLATOR, USED IN TESLA'S EXPERIMENTS FOR TRANSMITTING ELECTRICAL ENERGY TO GREAT DISTANCES WITHOUT WIRES.

Width of illuminated space is 18 feet—the pressure on the terminal is about eight million volts.

Courtesy of *The Electrical Review.*

able, and it is by its means that I discovered the most important of all facts arrived at in the course of my investigation in these fields. One of these was that the atmospheric air, tho ordinarily a perfect insulator, conducted freely the currents of immense electromotive force producible by such coils and suitable accessories. So great is the conductivity of the air that the discharge issuing from a single terminal behaves as if the atmosphere were rarefied. Another fact is that this conductivity increases very rapidly with the rarefaction of the atmosphere and augmentation of the electrical pressure, to such an extent that at barometric pressures which permit of no transit of ordinary currents, those generated by such a coil pass with great freedom through the air as through a copper wire. Following up these promising revelations I demonstrated conclusively by experiments that great amounts of electrical energy can be transmitted to any distance through upper-air strata which are easily accessible, and since this truth has been recognized every fiber has been strained to realize such a transmission on a large scale. These two observations explain clearly the silent discharges noted frequently in dense-air strata, but three or four miles above the earth's surface. One more equally important fact I may mention, which was simultaneously observed. The discharges of such a coil, when of an electromotive force of a few millions of volts, excite powerful affinities in the atmospheric nitrogen, causing it to combine readily with the oxygen and other elements, particularly in the presence of aqueous vapor. So energetic are these actions and so strangely do such powerful discharges behave, that I have often experienced a fear that the atmosphere might be ignited, a terrible possibility, which Sir William Crookes, with his piercing intellect, has already considered. Who knows but such a calamity is possible? And who can tell with certitude that periodical cessations of organic life on the globe might not be caused by ignition of the air and destruction of its life-sustaining qualities, accidentally or as a consequence of some accumulative change? A lump of coal will lie for centuries unaffected in contact with oxygen, but the combustion once started, the process continues as long as there are elements to combine."

Tesla on the Wehnelt Interrupter.—Tesla lets himself out on the Wehnelt interrupter in the *Electrical Review*, (New York), March 15th. He invented this device two or three years ago. This belated publication in our contemporary would not, according to the generally accepted code, secure to Tesla the credit of being the inventor, but Tesla evidently does not regret this, since he considers there is no merit in the invention. It wastes, in his opinion, 90 per cent. of the energy, and is objectionable for other reasons which he does not specify. He mentions another interrupter based on a different principle which is incomparably more efficient, and also simpler on the whole. It comprises a fine stream of conducting fluid which is made to issue, with any desired speed, from an orifice connected with one pole of a generator, through the primary of the induction coil, against the other terminal of the generator placed at a small distance. This device gives discharges of a remarkable suddenness, and the frequency may be brought within reasonable limits, almost to anything desired. He has used this device for a long time in connection with ordinary coils and in a form of coil of his own with results greatly superior in every respect to those obtainable with the form of device discussed.

The New York Tribune April 23, 1899

ACTION AT A DISTANCE.

MODERN WONDERS WROUGHT BY ELECTRICITY.

A SUGGESTION TO TESLA—HIS SYSTEM OF CONTROLLING VESSELS—POWER TRANSMISSION.

The suggestion was made not long ago by Szczepanik, the inventor of the telectroscope, that Mr. Tesla might find a flying machine a good subject for experiment in testing his apparatus for controlling the movements of a vehicle at a distance. The idea is not a bad one; but it involves difficulties which the young Pole probably has not considered.

Mr. Tesla had in view, when he worked on his scheme last summer, the control of marine vessels capable of carrying a storage battery and propelled and steered electrically. But a storage battery is heavy, and, although it has been tried on a small scale in aerial navigation, the tendency of late years has been toward the construction and use of extremely light steam or gasolene engines instead of electric motors. In this manner it seems to be practicable to reduce the weight of the machinery in proportion to the power developed. In so dense a medium as sea water a craft laden with a considerable number of accumulator cells would easily preserve its buoyancy, but the case is different with an airship. Again, it is the ambition of the aerial navigator to traverse scores, even hundreds of miles, after once launching out upon a voyage, whereas Mr. Tesla, while studying how to project against an enemy's warship a more formidable quantity of high explosives than has hitherto been used, apparently contemplated shorter trips.

In view of the lively interest now taken by the enlightened public in electrical action at a distance without wires a fresh consideration of Mr. Tesla's plan is not out of place. In his patent, applied for last July, and taken out in November, he says:

> The invention which I have described may prove useful in many ways. Vessels or vehicles of any suitable kind may be used, as life, dispatch or pilot boats or the like, or for carrying letters, packages, provisions, instruments, objects or materials of any description, for establishing communication with inaccessible regions and exploring conditions existing in the same, for killing or capturing whales or other animals of the sea, and for many other scientific engineering or commercial purposes. But the greatest value of my invention will result from its effect upon warfare and armaments; for, by reason of its certain and unlimited destructiveness, it will tend to bring about and maintain permanent peace among nations.

Mr. Tesla provides for a base of operations on the shore or on a big ship at sea. Here the man who controls the movements of the crewless torpedo-boat has before him a rotating device or switch, one complete turn of which admits four momentary impulses to a vertical wire and sends them off into the earth or other conducting medium. The wire leads down into the earth and upward along a pole, terminating overhead in a flat metal plate. Several forms of apparatus for generating the electric waves are mentioned as available for this service. They resemble in general the appliances which Mr. Tesla has proposed to use for wireless telegraphy.

The small boat is equipped with an uplifted metal plate, a wire running down from it into the vessel, a sensitive device through which any impulse excited in this "receiving circuit" must flow, and, finally, a wire leading to the keel of the boat and thus to the sea. As has been mentioned already, the boat carries a storage battery, and there are several wire circuits, each leading to a different set of instruments. These wires behave much like pipes on a steamship which conduct steam along various routes to perform different kinds of work. In each auxiliary circuit, acting like a valve to admit or shut off current, is the familiar "relay" of the telegrapher. This mechanism is so constructed that an exceedingly faint current, passing through one part of it, automatically opens up the way for the flow of another current through another channel.

But the master instrument is the sensitive device in the receiving circut. This is so arranged that it already has a weak current trying to flow through it, and needing only the least imaginable additional stimulus to promote success. The needed impulse is derived from the vibrations emitted from the distant land station, and communicated through the ether, sea or earth. The sensitive device performs somewhat the same function as the "coherer" of a Marconi telegraphic system, but is an original affair in design. Mr. Tesla regards it as much more trustworthy and efficient.

It is not necessary to describe in detail the apparatus inside the boat. It suffices to say that it has been tried in a model and works to perfection. The distant operator, by his manner of moving the switch, can start the boat ahead, stop it, and steer it to the right or the left. Automobile torpedoes carry a charge of one hundred or two hundred pounds of guncotton. A boat like this of Mr. Tesla might bear tons of explosive and work the instantaneous ruin of the stoutest war vessel ever conceived. No wonder that he regards himself as the ally of the Czar of Russia in putting an end to war!

The plan of producing action at a distance should not be confounded with that other startling project which Mr. Tesla broached last summer—the transmission of power through the upper air. In the work just described, only a very small quantity of energy is employed, and it unlocks another store of energy already existing at the distant point. Moreover, the vibrations are transmitted, not by the air, but by the land, sea or what the scientist, not the poet, means when he uses the word "ether." But Mr. Tesla's new power-transmission scheme contemplates such work as is now being done between Niagara and Buffalo, where several thousand horse-power in the form of electricity are sent over costly copper rods, mounted on a pole line and carefully insulated.

Not only is it proposed to convey enormous quantities of energy from one place to another over distances of hundreds of miles, but to dispense altogether with the metallic conductor and use the air instead. At ordinary densities, especially when dry, the air is an insulator, and not a conductor. But when sufficiently rarefied it will conduct admirably; and as the atmosphere grows more rare as the distance above the earth increases, one needs only to get up to a certain elevation to find the right degree of rarefaction.

The current which Mr. Tesla would use for this purpose would possess a very high potential or voltage, and this would be secured by a newly invented apparatus of his, a peculiar type of "transformer." Every schoolboy knows nowadays that when a current is transformed upward, the voltage increases, but the quantity, as expressed in amperes, is reduced. The total amount of energy is unchanged. A current of 300 amperes, sent at 25,000 volts, is equivalent to 7,500,000 watts or 10,000 horse-power. But if this current were transformed into one of a single ampere and 7,500,000 volts, it would still be equal to 10,000 horse-power.

Now, Mr. Tesla has already experimented with a voltage of several millions, and he believes that he could transform up to 100,000,000 volts. If, at such a potential, he had one whole ampere, he would be handling 133,333 horse-power! He conceives it possible to transmit a current like this for hundreds, not to say thousands, of miles, with the air as a conductor in the same sense that copper wire is.

At the present time, however, he is not ready to explain how he would support in the upper air the terminal apparatus of his sending and receiving station, nor to talk about plans for making a commercial application of this remarkable idea

NOTES ON LIGHT.

BY WILLIAM ROLLINS.

NOTE LIX—INTERMOLECULAR JOURNEYS.

I wish to state concisely what some who have read my previous notes have failed to understand; namely, that material particles can be made by electricity to pass between the molecules of cold, dense, homogeneous metals. This is true of even the densest metals I have been able to obtain for experiment. Mr. Tesla, who always sees everything in the direction he is looking, stated, I find in this journal three years ago, that particles of gas from the interior of a vacuum tube passed outward through the glass. These outward journeys left the tube in too exhausted a condition to do its work. Of return journeys through glass I shall speak later. I mention them now, hoping others will also give us practical solutions of the problem.

NOTE LX—SYMMETRY IN TUBES.

In designing the aim should be to combine efficiency with beauty. As before mentioned, a regulator on the side of a vacuum tube is not pleasing. I have, therefore, aimed to find better positions and have shown some of my results as applied to cooled terminal tubes. In Fig. 56 the same plan is applied to a tube with an uncooled target. The regulator is on one end of the tube serving also as a support for the anode stem and as a place to attach a wire from the generator. I have selected one of my rotary target tubes for the illustration, because these are in use in a large hospital where there is an apparatus that soon perforates a stationary uncooled target of the usual kind. It is now three years since I made a tube with a cooled target, which would bear 10 times the power of the generators in use. I hoped then to soon see such a rapid development that such tubes would be necessary, but, even at the present time, there is no commercial apparatus where the power is sufficient to make them essential. One can form no clear idea of the possibilities of this invaluable method of medical diagnosis from the results obtained with the best commercial apparatus. With the best generators available, no better results can be obtained in photography than the remarkable ones shown by Professor Goodspeed three years ago. We must turn to the experimental results of Tesla and Trowbridge to see what may be done. Take, for example, the fact that the latter has made a photograph of the bones of the hand in a millionth of a second. Why, it would tax the best commercial generator to the utmost to do this in less than 2,000,000 times as long. What a vista this opens. If we concentrate all the power of an ordinary generator on an oval spot on the target two millimeters long, a thin bit of platinum will stand the full force of the Crookes's stream without melting. This gives some idea of how feeble such an apparatus is. Speaking of the Crookes's stream reminds me that this was discovered by Varley, who published his work in 1871. He not only observed the cathode stream, but also its effect on a pivoted mica vane. This is another illustration of what I mentioned in Note LVII. As I learn more about vacuum tube research I am constantly finding similar cases, and, even with my present limited knowledge, could make quite a list of them. But to return to my subject. Is it not singular that three years after Roentgen's discovery of the transparency of the human body to some of Lenard's rays that this most important method of diagnosis should not have come into general use? Not one physician in a hundred employs it regularly, and yet with some diseases it enables us to make the earliest diagnosis. To show how important this is, take consumption, which is responsible for one-seventh of the deaths from disease. If every one would be regularly examined, a matter taking only a short time, most of the cases could be saved, for Williams has proved that the signs can be detected so early that treatment is followed by prompt recovery, many cases not even requiring a change of climate. This latter is of the utmost importance as consumption is a disease of the poor, who can not often give up their work and go away. The fluoroscope in Dr. Williams's hands is constantly showing evidences of old tubercle scars in patients who never suspected they had been attacked by the disease. This is a point of great interest, for if in so many cases nature has unaided effected a cure, we may expect, with a little help from medicine, that almost every case can be saved. These details may seem out of place in a non-medical journal, but they are introduced for a purpose, as I am convinced that outside pressure is needed to hasten the adoption of the most important method of diagnosis discovered in my lifetime. Although my own work in medicine is in a limited field, I am in a position to see the prime importance of the method and to be distressed at its slow adoption. I know that at present efficient apparatus must be built at home and that it is large and expensive, but if Mr. Tesla could be induced to work on the problem it would be quickly solved, the apparatus being made efficient, compact, powerful and not expensive. As stated in previous notes it is only a matter of harmonics—a little generator if we knew how to tune it could accomplish great results.

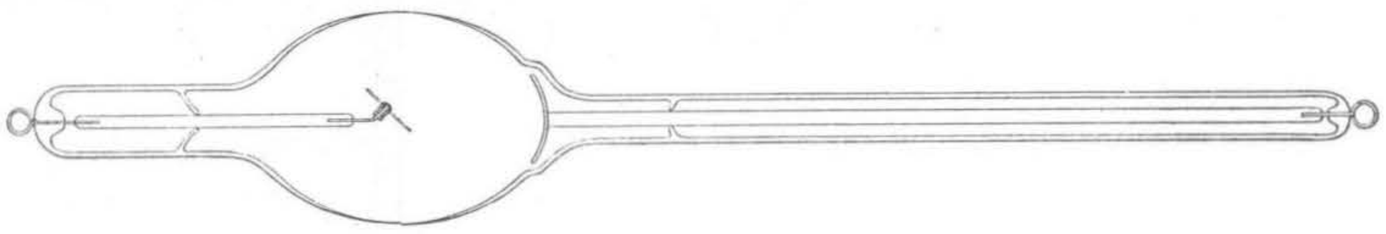


FIG. 56.—"NOTES ON LIGHT"—ROTARY TARGET TUBE WITH INTERMOLECULAR VACUUM REGULATOR AND TERMINALS WITH BARE STEMS.

NOTE LXI—ON GLASS WRAPPINGS.

Wrappings may have been appropriate for anything so old and dead as a mummy, but for vacuum tubes which are young and should be vigorous they are out of place. They are fetiches we have worshipped long enough. With any considerable force they get knocked from their pedestals, falling down as discolored fragments in the tube. As the glass wrapping about the anode stem was the first to go I tried the effect of shortening the stem, and finding this was an improvement, I also reduced the length of the wrapping, finally removing it entirely as in the tube here shown December 1, 1897. I next shortened that about the cathode stem and should have early abandoned it if two great experimenters, Lenard and Tesla, had not definitely stated that it was of value. I have now for some time discarded any covering for either terminal, not only without injury to the tube but to its distinct advantage. A tube of this kind is shown in Fig. 56. The method of supporting the bare stems is excellent and when these are of large diameter, three-sixteenths of an inch, the tube will bear any reasonable amount of jar in use or transportation. There is also another point about this tube which is of practical value—the large size of the wire loop forming the connection with the leading wire. These are usually small and delicate. They break easily and are difficult to find in a darkened room. It is irritating to hunt for the place to connect a wire, or to need to use care in its attachment. In some commercial tubes the danger of breaking the little wires is overcome by attaching brass caps on the ends, but these are objectionable as they prevent heating the tube, a process which should always be gone through with before exciting, to diminish the danger of puncture from the powerful current needed to overcome the high vacuums which are required for some work. Even with lower vacuums this preliminary heating is desirable, because with our present knowledge we can not make a tube which will give the same wave-length to the light when the tube is cold as when it has been run and become hot. A tube such as here shown is a small though distinct advance upon the usual commercial types.

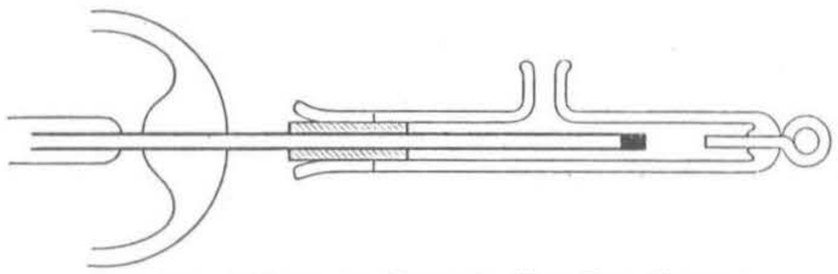


FIG. 57.—"NOTES ON LIGHT"—THE BON FEEDER.

NOTE LXII—THE BON FEEDER.

A friend having shown me a nursing tube of his invention, that had saved the life of a grandchild, I wanted to see if I also could not devise something new in this field. Having no grandchildren whose lives needed saving, it seemed best to construct it for a vacuum tube, which at that time was in a very exhausted condition. Fig. 57 shows the result. It is a bit of glass tubing partly filled with acidulated water held in by the rubber cork, which serves also as the support. To charge the regulator tube with hydrogen, connect the current in such a way that the gas will be liberated at the surface of the regulator tube, which should be of some metal that rapidly absorbs the gas. The device has amused me and may be of use to some one.

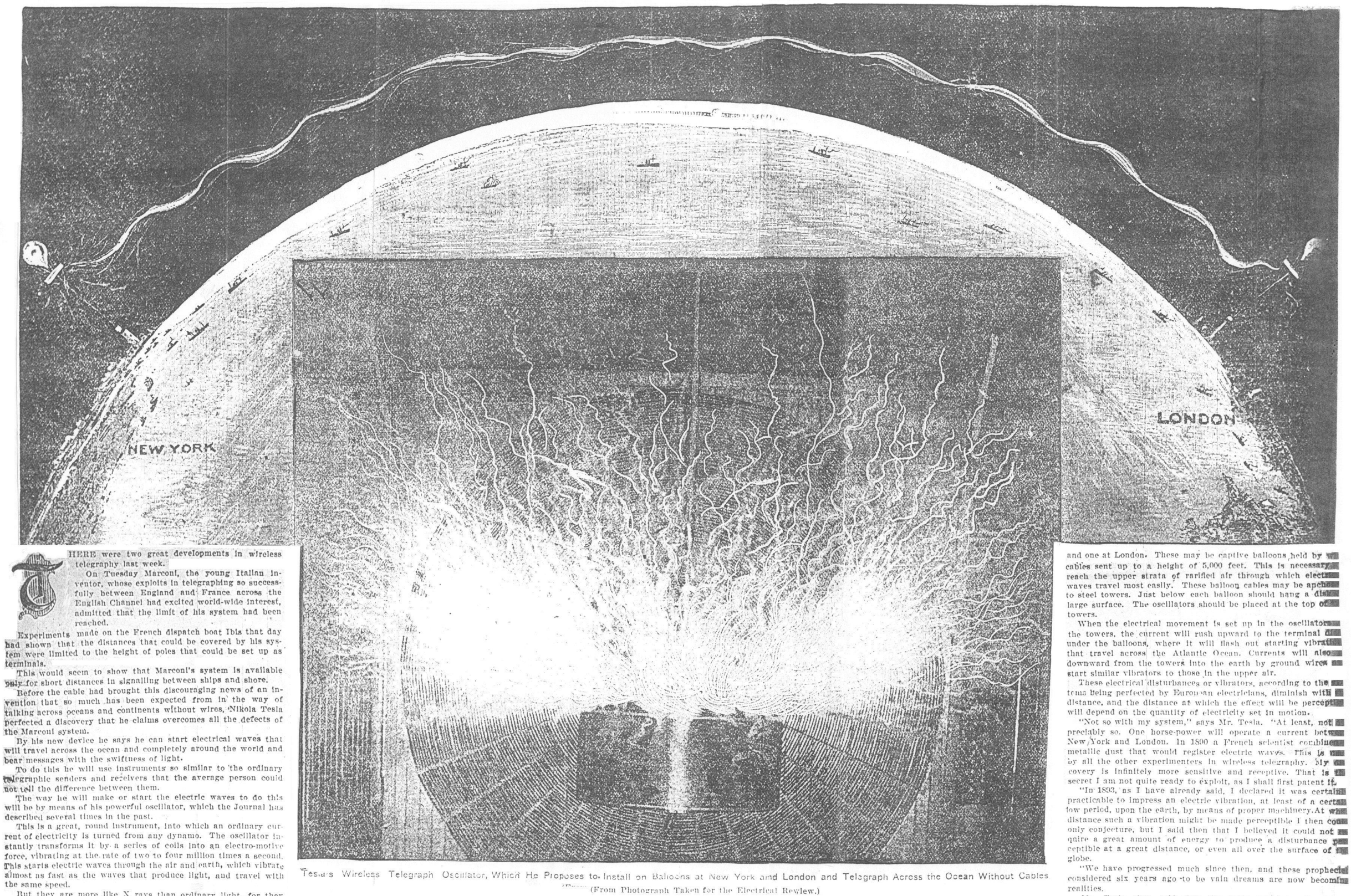
(Copyright, 1899, by the New York Journal and Advertiser.)

TESLA SAYS:

"Wireless telegraphy is a system of flashing signals by means of a light that is invisible, similar to the X-rays. Circles of this unseen, mysterious ligh instantly to any distance, even to Mars and Jupiter. If receiving terminals could be erected there the message could be intelligently and faithfully transmitted.

"To flash 2,000 or 3,000 words per minute to any part of the earth by the highly sensitized terminals I have perfected will be a common thing. It is nothing. inevitable. Distance no longer intimidates the electrician. I have demonstrated this week that messages may be sent with equal facility through the earth as by induc through the air. Neither distance nor the density of intervening objects will affect the speed or accuracy of the transmission of messages.

"THE PEOPLE OF NEW YORK CAN HAVE THEIR PRIVATE WIRELESS COMMUNICATION WITH FRIENDS AND ACQUAN ANCES IN VARIOUS PARTS OF THE GLOBE. IT WILL BE NO GREATER WONDER TO HAVE A CABLE TOWER ON YOUR RO THAN IT IS NOW TO HAVE A TELEPHONE IN YOUR HOUSE."---Nicola Tesla, the Distinguished Electrician, to the Journal.



Tesla's Wireless Telegraph Oscillator, Which He Proposes to Install on Balloons at New York and London and Telegraph Across the Ocean Without Cables
(From Photograph Taken for the Electrical Rewiew.)

THERE were two great developments in wireless telegraphy last week.

On Tuesday Marconi, the young Italian inventor, whose exploits in telegraphing so successfully between England and France across the English Channel had excited world-wide interest, admitted that the limit of his system had been reached.

Experiments made on the French dispatch boat Ibis that day had shown that the distances that could be covered by his system were limited to the height of poles that could be set up as terminals.

This would seem to show that Marconi's system is available only for short distances in signalling between ships and shore.

Before the cable had brought this discouraging news of an invention that so much has been expected from in the way of talking across oceans and continents without wires, Nikola Tesla perfected a discovery that he claims overcomes all the defects of the Marconi system.

By his new device he says he can start electrical waves that will travel across the ocean and completely around the world and bear messages with the swiftness of light.

To do this he will use instruments so similar to the ordinary telegraphic senders and receivers that the average person could not tell the difference between them.

The way he will make or start the electric waves to do this will be by means of his powerful oscillator, which the Journal has described several times in the past.

This is a great, round instrument, into which an ordinary current of electricity is turned from any dynamo. The oscillator instantly transforms it by a series of coils into an electro-motive force, vibrating at the rate of two to four million times a second. This starts electric waves through the air and earth, which vibrate almost as fast as the waves that produce light, and travel with the same speed.

But they are more like X rays than ordinary light, for they pass through dense things, like earth, stone and water, as easily as through the air and ether of space.

Mr. Nicola Tesla, who next to Thomas Edison is the foremost electrician in America, made this discovery six years ago. He has been at work perfecting it ever since. To make this of use in wireless telegraphy, one thing was needed. Last Tuesday Mr. Tesla exclaimed triumphantly that he had supplied the last link necessary for this purpose.

Nothing, Mr. Tesla says, can now obstruct or divert messages sent by this marvellous device. Words in incredible rapidity will be flashed across the broadest oceans and the widest continents. In fact, there is, according to the statements of the celebrated electrician, nothing to prevent the transmission of messages directly through the earth.

The construction of the wireless system is so simple and will be so inexpensive, that commercial firms and the great newspapers will have their own exclusive cable service.

"The people of New York," says Mr. Tesla, "can have their private wireless communication with friends and acquaintances in various parts of the globe.

"It will be no greater wonder to have a cable tower on your roof than it is now to have a telephone in your house.

"You will be able to send a 2,000-word dispatch from New York to London, Paris, Vienna, Constantinople, Bombay, Singapore, Tokio or Manila in less time than it takes now to ring up 'central.'

From a tower in Manila to a tower in New York City a message by wireless telegraphy, could be sent at no expense at all, in comparison with present cable rates, and without the danger of a moment's delay."

At his laboratory in East Houston street, surrounded by wires and motors and generators, Nikola Tesla was found yesterday by a representative of the Sunday Journal. The inventor was deep in the evolution of his great project.

"In 1893," said the inventor, "I predicted that messages would be sent throughout the world without wires. In an address delivered before the Franklin Institute, Philadelphia, in February of that year, I said a few words on this subject which even then constantly filled my thoughts. It was not a new idea—this wireless communication by signals. These demonstrations to-day in Europe by Marconi and others, and these triumphs in my laboratory had their crude genesis in the signal systems in vogue as early as the middle ages.

"Wireless telegraphy, to speak in unscientific terms, is a system of flashing signals, but by means of a light that is invisible, similar to the X rays. Circles of this unseen, mysterious light may be sped instantly to any distance—even to Mars and Jupiter, and if receiving terminals could be erected there, the message could be intelligently and faithfully transmitted.

"To flash 2,000 or 3,000 words per minute to any part of the earth by the highly sensitized terminals I have perfected will be a common thing. It is nothing. It is inevitable. Distance no longer intimidates the electrician. I have demonstrated, this week, that messages may be sent with equal facility through the earth as by induction through the air. The delicate and sensitive receiving device registers accurately every vibration of the transmitter. Neither distance or the density of intervening objects will affect the speed or accuracy of the transmission of messages.

"Accuracy and the avoidance of delay is secured by adjusting the receiving and transmitting contrivance to a common electric multiple. Then only the receiver prearranged and pre-adjusted, will record the message intended for it.

"By an understanding between operators in distant parts of the planet, code cipher messages will be sent with accuracy and with far greater speed than at present.

"Understand that I am not using scientific language. People generally misunderstand the system of wireless telegraphy, and I use ordinary expressions to make my meaning clear."

In more technical terms Mr. Tesla explained his rapid transmission of words by wireless telegraphy, and told how it could be put in operation between New York and London.

Two terminal stations should be established—one at New York and one at London. These may be captive balloons held by wi cables sent up to a height of 5,000 feet. This is necessary reach the upper strata of rarified air through which electr waves travel most easily. These balloon cables may be anch to steel towers. Just below each balloon should hang a dis large surface. The oscillators should be placed at the top o towers.

When the electrical movement is set up in the oscillator the towers, the current will rush upward to the terminal d under the balloons, where it will flash out starting vibrati that travel across the Atlantic Ocean. Currents will also downward from the towers into the earth by ground wires start similar vibrators to those in the upper air.

These electrical disturbances or vibrators, according to the tems being perfected by European electricians, diminish with distance, and the distance at which the effect will be percept will depend on the quantity of electricity set in motion.

"Not so with my system," says Mr. Tesla. "At least, not preciably so. One horse-power will operate a current betw New York and London. In 1890 a French scientist combine metallic dust that would register electric waves. This is by all the other experimenters in wireless telegraphy. My covery is infinitely more sensitive and receptive. That is secret I am not quite ready to exploit, as I shall first patent it.

"In 1893, as I have already said, I declared it was certain practicable to impress an electric vibration, at least of a certa low period, upon the earth, by means of proper machinery. At wh distance such a vibration might be made perceptible I then co only conjecture, but I said then that I believed it could not quire a great amount of energy to produce a disturbance p ceptible at a great distance, or even all over the surface of globe.

"We have progressed much since then, and these prophecie considered six years ago to be vain dreams are now becomin realities.

Mr. Tesla then said that the basic principle of wireless telegraphy given out by himself six years ago without being patented now makes it a free field for inventors and capitalists to enter.

"What effect will the general establishing of wireless tele graph stations throughout the world have?" Mr. Tesla was asked.

"The effect will be as pronounced, if not more so, than that produced by the introduction of ordinary telegraphy. We see now that time and space have been annihilated on this globe, but they have not been. They have been somewhat overcome. The complexity of transmission, the scarcity of wires in times of great happenings, congests the system. The tolls are excessive, absolutely prohibitive to millions of people. Under the system I have perfected companies will be able to send a message from New York to San Francisco, or London, or even far points like Zanzibar and Cape Town, for little more than we now pay for letter postage."

The introduction of wireless telegraphy on the scale contemplated by Mr. Tesla will be a great boon to the struggling country paper, but it will rob the big metropolitan papers of the glory of their fabulous cable bills. When it requires only the salary of two telegraph operators to secure news from central Siberia or northern China or from the remotest frontiers of all the earth, and when these far-sent messages flash into the office at the rate of 2,000 or 3,000 words per minute, the day of displaying achievements by cable shall have passed.

One operator in a tower above the Journal office could, in a few minutes, call up the principal cities of the world and learn of the day's doings of the race. To get news from Europe would be less of an undertaking than it is now to get a story by telephone from Bensonhurst.

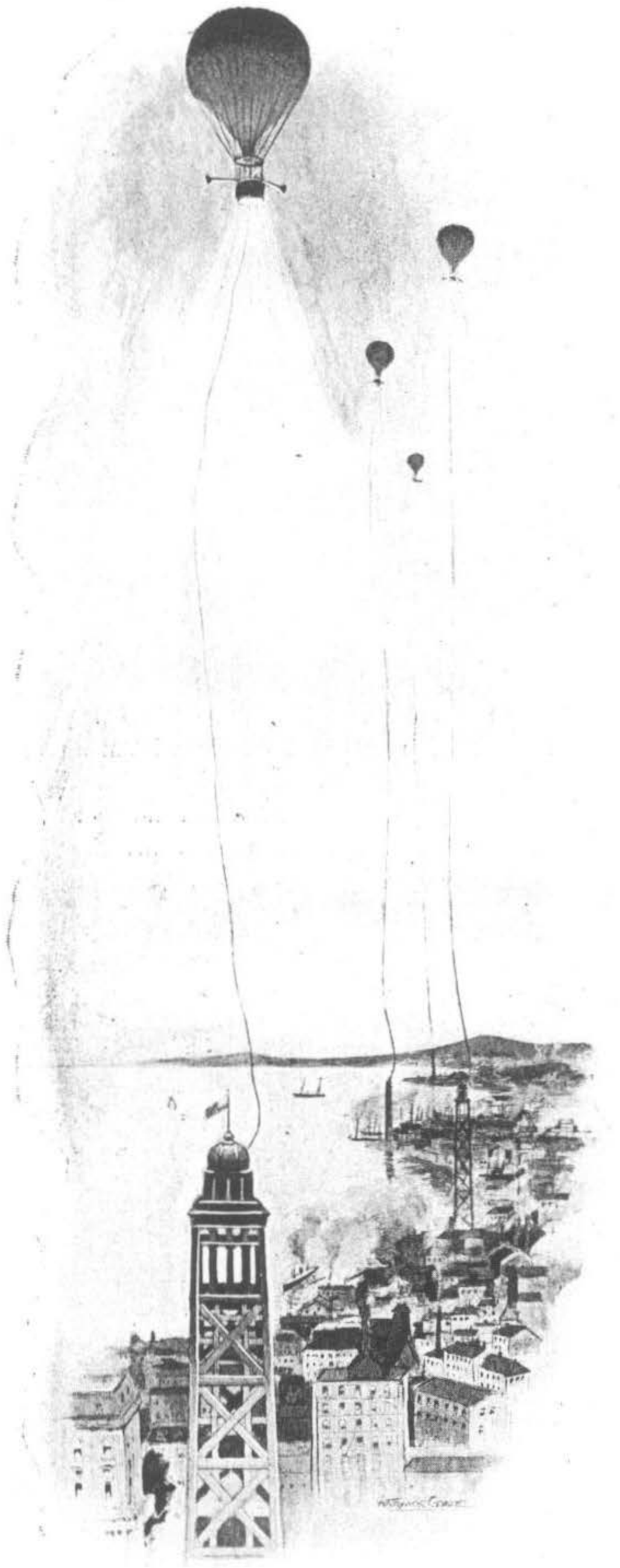
Mr. Tesla thinks that many newspapers will enlarge their business under this system by furnishing news tickers to be placed in the towers of private houses. A family could thus read the Journal's telegraphic news and cables in brief as fast as they ticked into the telegraph editor's room. What a convenience at elections and times of wars in different parts of the world!

Already the common telegraph has done much to avert wars, making it possible for men to live in London, Paris, Berlin or New York and operate in every commercial capital. It has made many kinds of business international that were formerly confined to a single nation or city.

"Every city, every empire, will be nothing more than a suburb of the city in which you live," said its inventor.

Mr. Tesla says he is now ready to put his wireless telegraph system into operation between New York and London as soon as the practical details of the undertaking can be arranged.

Pearson's Magazine May 1899



Tesla's proposed arrangement of balloon stations for transmitting electricity without wires.

THE NEW WIZARD OF THE WEST.

An Interview with Tesla, the Modern Miracle-worker, who is Harnessing the Rays of the Sun; has Discovered Ways of Transmitting Power without Wires and of Seeing by Telephone; has Invented a Means of Employing Electricity as a Fertiliser; and, Finally, is Able to Manufacture Artificial Daylight.

By Chauncey Montgomery M'Govern.

Not to stagger on being shown through the laboratory of Nikola Tesla requires the possession of an uncommonly sturdy mind. No person can escape a feeling of giddiness when permitted to pass into this miracle-factory and contemplate for a moment the amazing feats which this young man can accomplish by the mere turning of a hand.

Fancy yourself seated in a large, well-lighted room, with mountains of curious-looking machinery on all sides. A tall, thin young man walks up to you, and by merely snapping his fingers creates instantaneously a ball of leaping red flame, and holds it calmly in his hands. As you gaze you are surprised to see it does not burn his fingers. He lets it fall upon his clothing, on his hair, into your lap, and, finally, puts the ball of flame into a wooden box. You are amazed to see that nowhere does the flame leave the slightest trace, and you rub your eyes to make sure you are not asleep.

The odd flame having been extinguished as miraculously as it appeared, the tall, thin young man next signals to his assistants to close up all the windows. When this has been done the room is as dark as a cave. A moment later you hear the young man say in the laboured accentuation of the foreigner: "Now, my friends, I will make for you some daylight." Quick as a flash the whole laboratory is filled with a strange light as beautiful as that of the moon, but as strong as that of old Sol. As you glance up at the closed shutters on each window, you see that each of them is as tight as a vice, and that no rays are coming through them. Cast your eyes wherever you will you can see no trace of the source of the odd light.

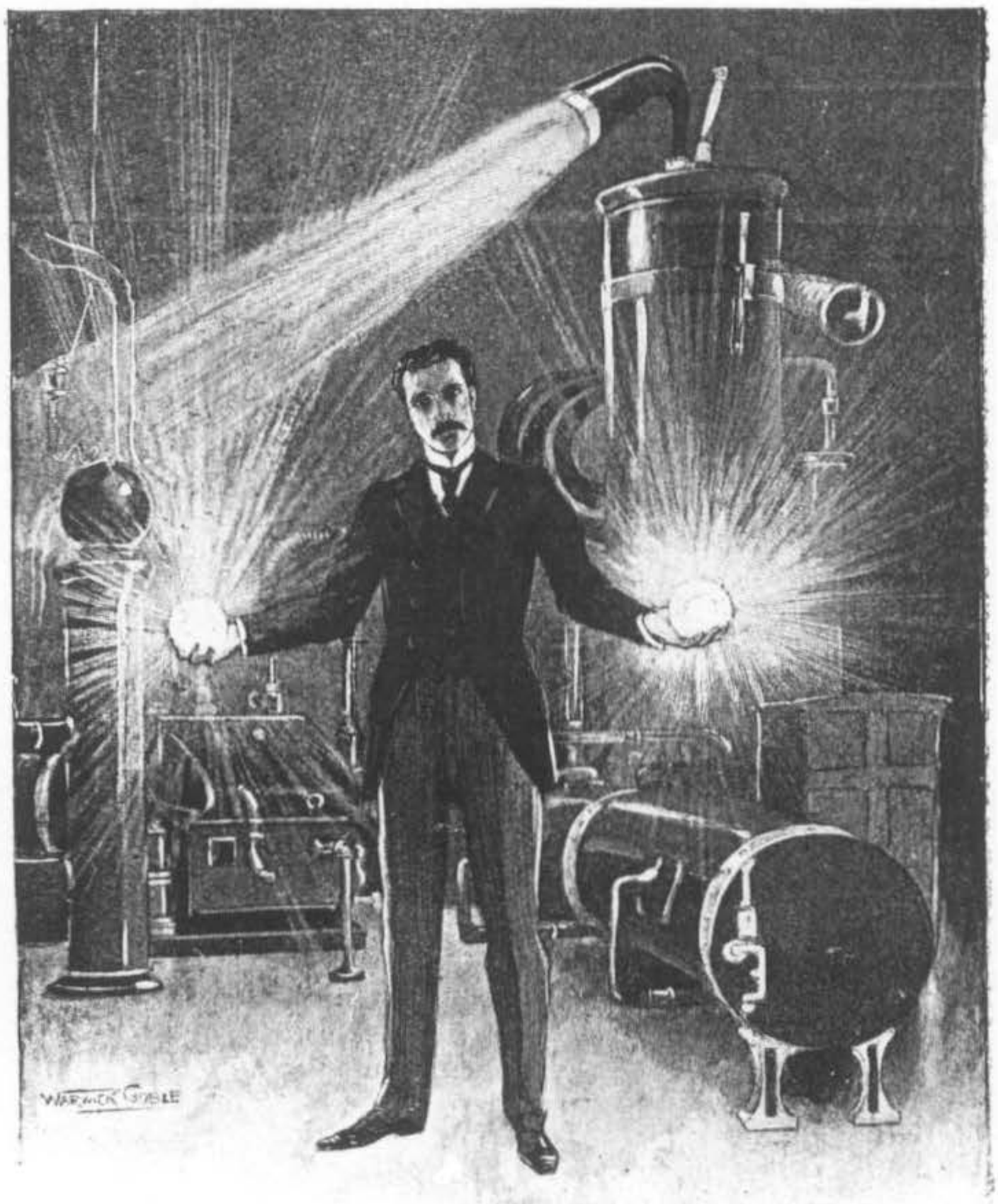
Scarcely have you begun to marvel when the light goes out by a touch on a button by the young man's hand. The room is in darkness again until the same laboured accentuation causes the reopening of all the shutters. Some animal is now brought out from a cage, it is tied to a platform, an electric current is applied to its body and in a second the animal is dead. The tall young man calls your attention to the fact that the indicator registers only one thousand volts, and the dead animal being removed, he jumps upon the platform himself, and his assistants apply the same current to the dismay of the spectators.

You feel a creeping sensation course up your back, and you see the indicator slowly mounting up to nine hundred, and then one thousand volts, and you involuntarily close your eyes, expecting the young man to fall dead before you the very next minute. But he does not budge. Quickly the indicator goes up, up, up, until presently it shows that ten thousand volts, then two million volts of electricity are pouring through the frame of the tall young man, who does not move a muscle.

At a sign, the current is stopped, the room is again made dark as night, and presently the visitor sees the sharply-defined black silhouette of the young man, with a beautiful halo of electricity in the background, formed by myriads of tongues of electric flame which are darting out from every quarter of the tall, thin frame. The place is lighted once more, and as the young man comes up to you and shakes your hand, you twist it about in the same fashion as you have seen people do who hold the handles of a strong electric battery. The young man is literally a human electric "live wire."

To tell of these and a thousand other wonders that Tesla does in a trice gives only a faint conception of their effect on the visitor. To really appreciate them one must see, hear, and feel them in the flesh. It is a scientific treat of a lifetime, but it is a treat that few can enjoy, for the laboratory of Tesla is securely locked against everyone not provided with an introduction from a personal friend of the audacious wizard.

"Oh, pshaw! these are only a few playthings," Nikola Tesla replies when the visitor puts into words the astonishment he has experienced; "none of these amount to anything—they are of no value to the great world of science. But come over here and I will show you something that will make a big



Nikola Tesla holding in his hands balls of flame



Nikola Tesla.

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revolution in every business and home as soon as I am able to get the thing into working form," and then he leads the way through a forest of queer-looking discs and mysterious coils of copper and steel, until the party reaches a raised wall of masonry, on which reposes a long cylinder of glass filled with water, and surrounded by a circle of large mirrors. The roof over this apparatus is of glass, and as the sun pours its rays through this, the rays strike the mirrors and are reflected again towards the glass cylinder, magnifying glasses intensifying the heat of the rays before they strike the cylinder.

"This is the experimental model of the apparatus with which I hope some day to so harness the rays of the sun that that heavenly body will operate every machine in our factories, propel every train and carriage in our streets, and do all the cooking in our homes, as well as furnish all the light that man may need by night as well as by day. It will, in short, replace all wood and coal as a producer of motive power and heat and electric lighting."

The plan of Nikola Tesla to harness the rays of the sun to do man's bidding is probably the boldest engineering feat that he or anyone else has ever attempted. Though the idea is so great, its principle is so simple that a schoolboy can readily comprehend it. It consists of concentrating the heat of the sun on one spot (the glass cylinder) by the series of complicated mirrors and magnifying glasses until the resulting heat is something terrific.

This manufactured heat is directed upon the cylinder filled with water. This water is chemically prepared so that in a short time the water has evaporated into steam and has passed from the cylinder through a pipe and into another chamber. In the latter place this sun-made steam is made to operate a steam-engine of ordinary construction, the horse-power of which will be determined by the size of the apparatus by which the sun generates steam in that spot. This steam-engine is used to generate electricity. And this electricity can be either used at once or else stored up in storage batteries to be used on days when there is no sunlight.

It will be seen that the object of this plan of Tesla is to do away with coal, wood, or other fuel, in the manufacture of steam. The remainder of his invention calls for the use of this sun-made steam-pressure, as steam-pressure made from coal is at present in use

throughout the world. The advantage of this Tesla invention is that the cost of manufacturing steam to generate electricity, which would propel say one hundred tram cars, would be infinitely smaller than the cost of the coal required to produce the power to do the same work. The cost of manufacturing the electricity to operate these one hundred tram cars by the Tesla plan, when once the sun-station has been completed, would only be a sufficient amount to pay the salaries of a few engineers in charge of the sun-station.

"In this way electricity will be so cheapened," says Mr. Tesla, "that it will be possible for the poorest factory-owner to use it as a power at a smaller cost than steam. Electricity will in this way supplant steam as a motive power on all railways and—in the shape of storage batteries—on all water vessels. And the humblest citizen will profit by the new system of producing electricity; for he can have it in his home to do all his cooking and lighting and heating, and it will be even cheaper for him than coal, wood, or petroleum."

It is, of course, not the intention of Mr. Tesla that one sun-station will provide all the electricity for the whole world. His scheme is that in every city and town the local authorities shall build one or more of these sun-stations by public taxation for the use of the whole population, just as these cities now have waterworks and gas plants. Each factory and home will then get its supply of electricity from the nearest sun-station by ordinary electric wires.

Any person can appreciate the big boon that Tesla will confer on humanity by the early completion of this master task. Among other things it will solve a question that has been occupying the minds of scientific men for a long time, viz: "As the supply of coal in the earth will be exhausted in about a thousand years, what are we going to do for fuel?" It was when Tesla first thought about the question that he turned his mind to the invention of some form of making power that would not depend upon coal. The plan to harness the sun's rays is the result.

Quite independent of his scheme to harness old Sol, but yet capable of co-operation with it, is Tesla's invention to transmit electrical power without the use of wires. This consists of a means of generating electricity in one spot, where it can be done with little cost, and transmitting the electricity to some other spot where it is impossible to generate electricity except at a big outlay of money.

Of course, it is now possible to transmit electrical power from one place to another by the use of electrical cables, but the cost of these transmitting cables is nearly as great as would be the cost of generating the electricity itself in the locality to which it is desired to transmit it. By the use of Tesla's invention, the atmosphere takes the place of the electrical cables in the transmission of the power, and as the use of the atmosphere would be free, the cost of the transmission of electricity from one city to another would be merely nominal.

To make the atmosphere take the part of the costly cables, Tesla's plan is to erect large power stations at every spot where a great waterfall like Niagara, for instance, makes the cost of generating electricity only trifling when the apparatus has once been constructed.

Above each of the stations Tesla wants to build a high tower, over which will be suspended a large balloon. As the electricity is generated in the station below it is conveyed by cables to the tower, and thence to the balloon, where the electricity is set free into the atmosphere. As the atmosphere at this height is much rarefied, and as Tesla has demonstrated rarefied atmosphere to be a good conductor of electricity, the electricity which is thus set free will be carried on by the atmosphere to any indefinite distance.

The second part of the Tesla plan for transmitting electrical power without wires calls for the erection of receiving stations wherever desired. These will act as sort of receivers and storage houses for the electricity set free into the atmosphere at the generating station miles away. Over each of the receiving stations will be put up a tower and a balloon, which will be equipped with the apparatus necessary to absorb the free electricity in the atmosphere and send it to the receiving station below, from which it can be sent out on wires to light the surrounding

country and drive all the machinery of that particular district.

It will be observed that in this scheme Tesla depends on getting his electricity through the agency of the waterfalls, while in the previous scheme he depends upon the agency of the sun for the same purpose. But the inventor is far from believing that the two schemes will conflict. He believes that when both inventions come into popular use they will work together for the common good of man. "The agency of waterfalls to generate electricity could be used when that agency is most convenient in view of natural conditions," says Tesla, "and the agency of the sun could be used in all other cases. But my scheme of transmitting electrical energy without wires can be applied with equally good results to both systems."

Of all the great inventions which Tesla has well on the way towards that point where they can be given to the world for every-day use, his wireless telegraphy invention is the furthest advanced. All that is necessary now is the formation of a company to put up the public station. The principle of this invention is almost too well known now to bear extended explanation. Briefly described, it consists of constructing an apparatus to stir up the electric currents in the earth in such a way that their disturbance will be felt on a second apparatus fitted up in a different part of the world. Different disturbances of the electric currents produce correspondingly different impressions on the second apparatus —the receiver—and in this way an intelligible code is readily arranged.

For the benefit of non-scientific people the great inventor has described for me his wireless telegraphy invention in the following words:

"Imagine you have on a table before you an immense rubber bag snugly filled with water. I take a rubber tube with a piston-rod in it and insert the tube into the rubber bag. When I press on the piston-rod I compress the water in the bag so that it expands the bag.

"When I withdraw the piston," continued Tesla, "the bag will shrink just so much as there is water drawn up into my tube: and now if I put a second tube with a piston-rod into the bag at the other end, at every pressure of the first piston-rod the effect will be felt and measured in the second tube. Now if a certain action of one piston-rod indicates a certain word or a certain sentence, if you watch the other piston-rod carefully you may easily read it. This is exactly what takes place in wireless telegraphy," concluded Tesla: "let the rubber bag stand for the earth, the water for the electric currents in the earth, and the two tubes and piston-rods for a sending oscillator and receiving oscillator. One sort of disturbance by one oscillator means a certain sentence, and when this particular disturbance is recorded on the second oscillator the operator there knows exactly how to interpret it."

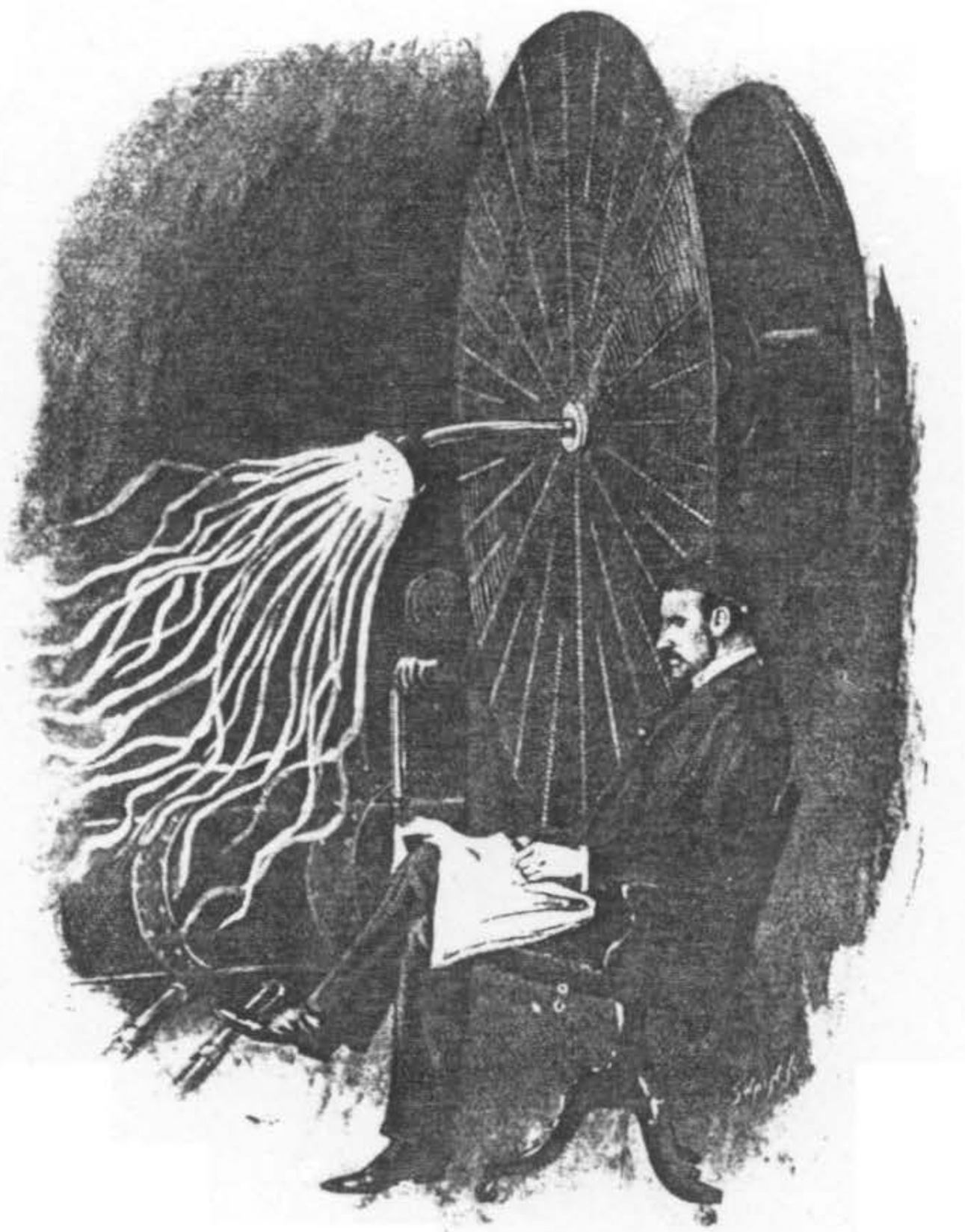
The "oscillators" to which the inventor refers are huge discs on which are insulated hundreds of coils of copper wire whose ends connect with the centre of the disc, where there is a huge round copper ball. They are really the only apparatus required for wireless telegraphy. To operate them Tesla simply turns the transmitting oscillator face downwards, and turns on a current which causes immense tongues of visible electric flashes to leap from the ball into the ground. The receiving oscillator has a delicate contrivance which throbs with each disturbance of the earth's electric currents and records them on a specially contrived apparatus.

Not the least fascinating of Tesla's numerous inventions is one to which he has given the name of "visual telegraphy." With this apparatus one person has only to look into the receiver of an ordinary telephone in one city, and, while talking to a friend a thousand miles away, he can watch the expression on the other's face, criticise the cut of his new suit of clothing, or advise him what to do for that tired look about the eyes. In this invention the experimental apparatus has proved thoroughly successful. The principle of this invention is that just as much as sound-waves make an impression on the immediate atmosphere, so do light waves make their impression.

"Now, as sound waves of the human voice are transmitted miles and miles yb the present telephone after their impression is made on the telephone transmitter," says

Mr. Tesla. "just so my experiments have demonstrated that the light waves of the human body can be transmitted by a different sort of telephone miles and miles away. All we need is the invention of a new transmitter. As the impressions of light waves are so many times more delicate than the impressions of sound waves, it follows that to transmit the impression of the human face, for instance, we require a transmitter many times more delicate. Now, selenium being an extremely sensitive substance, I have utilised this material in the construction of the transmitter which I have just described, and I have found it to be perfectly satisfactory."

To make our homes, our offices, and the streets at midnight as light as day, is another of the great tasks which Mr. Tesla set out for himself many years ago. His hope was to invent a new kind of electric light which would have the strong, steady glow of sunlight.



Nikola Tesla's wireless telegraphy apparatus.

That Tesla has succeeded in his dream to make artificial daylight there can be no doubt. To every visitor of his laboratory he shows numerous balls of glass of different sizes which look like miniature suns. The glass balls are perfectly empty, there are no wires in them, nor are there any wires on the outside of them. They do not burn the fingers when they are touched. The light does not hurt the eyes as sunlight and ordinary electric light do.

By the time this article is published, a number of the leading New York and Chicago photographers will have their studios supplied with the new artificial daylight.

"The reason I have chosen to introduce the new daylight to the photographers first," says the inventor, "is that I believe them to be the severest critics, and most hard to please in the matter of light. If it succeeds with them, a new light will succeed everywhere."

Not the least ingenious of Tesla's great schemes is his invention to fertilise impoverished land by electricity. When Tesla has a company formed to put this invention on the market it will no longer be necessary for the farmer to spend half his year's receipts in purchasing fertilisers. He has only to buy an electric fertiliser of his own, which he can secure for a trifle at the nearest town.

Dumping a few loads of loose earth into the fertiliser, it comes out at the other end ready to be spread over the surface of the impoverished ground, where it will insure for the following season the luxurious crop of the virgin soil.

The explanation which Mr. Tesla gives of just why so simple a piece of work should be productive of such wonderful results is not difficult to comprehend. "Everyone knows," says he, "that the constituent of a fertiliser which makes the ground productive is its nitrogen. Everybody knows also that nitrogen forms four-fifths of the volume of the atmosphere above that piece of unfertile land. This being the case it occurred to me: 'Where is the sense in the farmer buying expensive nitrogen when he has it free of cost at his own door? All the agriculturist needs is some method by which he can separate some of this nitrogen from the atmosphere above the ground and place it on the surface.' And it was to discover this means that I set to work."



The hand of Nikola Tesla, taken by his wonderful artificial daylight, just perfected. This is the first photograph made by the light of the future.

As far as the non-technical eye can perceive, the working model of the electric fertiliser consists of nothing but an upright copper cylinder with a removable top, with a spiral coil of wire running throughout the length of the cylinder. Through the bottom of the cylinder are two wires, which connect with a specially constructed dynamo. A quantity of loose earth, treated by a secret chemical preparation in liquid form, is shovelled into the cylinder, an electric current is passed through the confined atmosphere; the oxygen and hydrogen are thus expelled, and the nitrogen which remains is absorbed into the loose earth. There is thus produced as strong a fertiliser for a nominal price at home as it is possible to purchase at a large cost miles and miles away.

Mention is made in this paper of only those inventions of Mr. Tesla which have passed beyond the experimental stage. But there are hundreds of other promised wonders in the yet incipient stage of development in the great inventor's miracle-factory. As I have heard one of his admirers express it, an enumeration of these "sounds like the dream of a half-intoxicated god." Signalling to other planets, raising of certain of the dead by electricity, ending all wars by a terrible machine—these are a few suggestions selected at random.

Nikola Tesla is a young man yet, and on this account many of his promises have been looked upon by older scientists as but fanciful dreams of a youthful mind. He has scarcely ever made any invention which the scientific world has accepted as possible on the first public announcement. But sooner or later the scientific wiseacres have been compelled to admit that Tesla has proven their theories to be wrong.

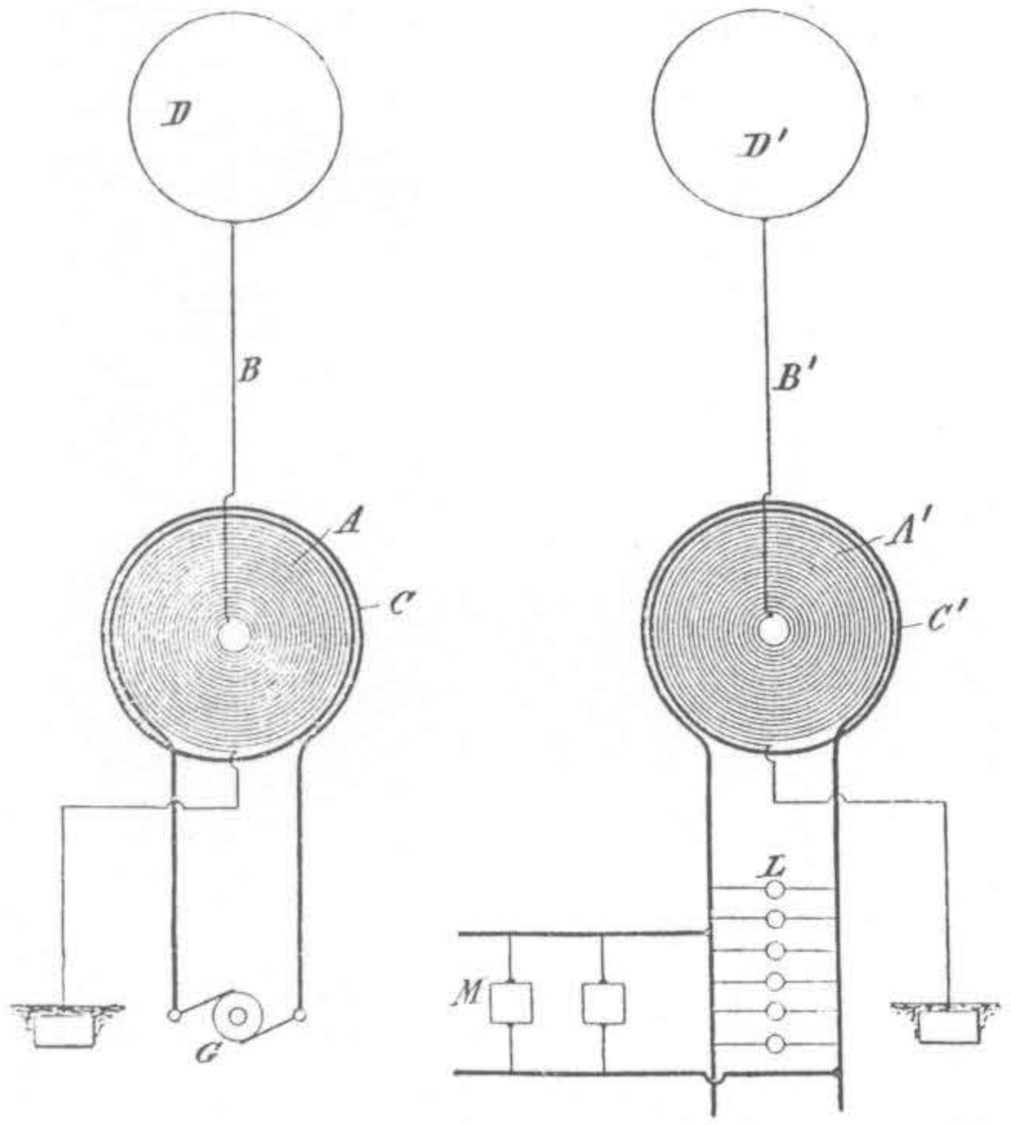
How these conservative scientists sneered at Tesla's "Utopian audacity" when he first suggested that man should harness the great Niagara Falls! But they humbled their pride sufficiently to be present when the enterprise was formally completed. Again, when he announced the invention of the "Tesla coil" they set him down as "pipe-dreamer." But a few of the brightest of them set to work seriously on the "coil," with the result that one of them—Röntgen—discovered his famous X-Rays.

No one who is privileged to know Tesla personally, to have heard him explain his plans, and to have been shown through his unique workshop, has the slightest doubt that every one of his promises will be fulfilled in an equally successful way.

ELECTRICAL REVIEW May 3, 1899 Vol. 34—No. 18

Suit on Tesla Patents.

In the United States Circuit Court at Philadelphia, on April 24, Judge McPherson heard argument in the equity suit of the Tesla Electric Company, of New York, against Gordon J. Scott and others, of Philadelphia, in which it is sought to have the defendants enjoined from the making of alleged infringements on the plaintiff's patented improvements in electro-magnetic motors.



Tesla's High Potential and High Frequency Work.—Fig. 1.

TESLA'S HIGH POTENTIAL AND HIGH FREQUENCY WORK.

Few inventors, in this last decade of a century of invention, have made a greater impression on the popular imagination than Nikola Tesla. Though by race a Southern Slav, he has now been settled for many years in the United States of America. From his race, it is to be presumed, he inherits his soaring scientific imagination, while from his environment he no doubt receives an extra stimulus to carry his fancies into practical effect.

Tesla, in the early part of his career, did some good work in connection with polyphase currents, but some 10 years ago he turned his attention to a comparatively new and unexplored field, namely, the production and utilisation of alternating currents of high frequency and high potential. Tesla's labours in this field have up to date revealed many new and startling phenomena, which, though they have as yet not found much practical application, may yet lead to the most astounding social and industrial revolutions.

A letter from Tesla, giving a sketch of his work and describing some recent experiments, appears in the *Electrical Review* (N.Y.), March 29th, 1899. From this and other sources we have derived the material for the following account of Tesla's investigations on the production of currents of extremely high potential:—

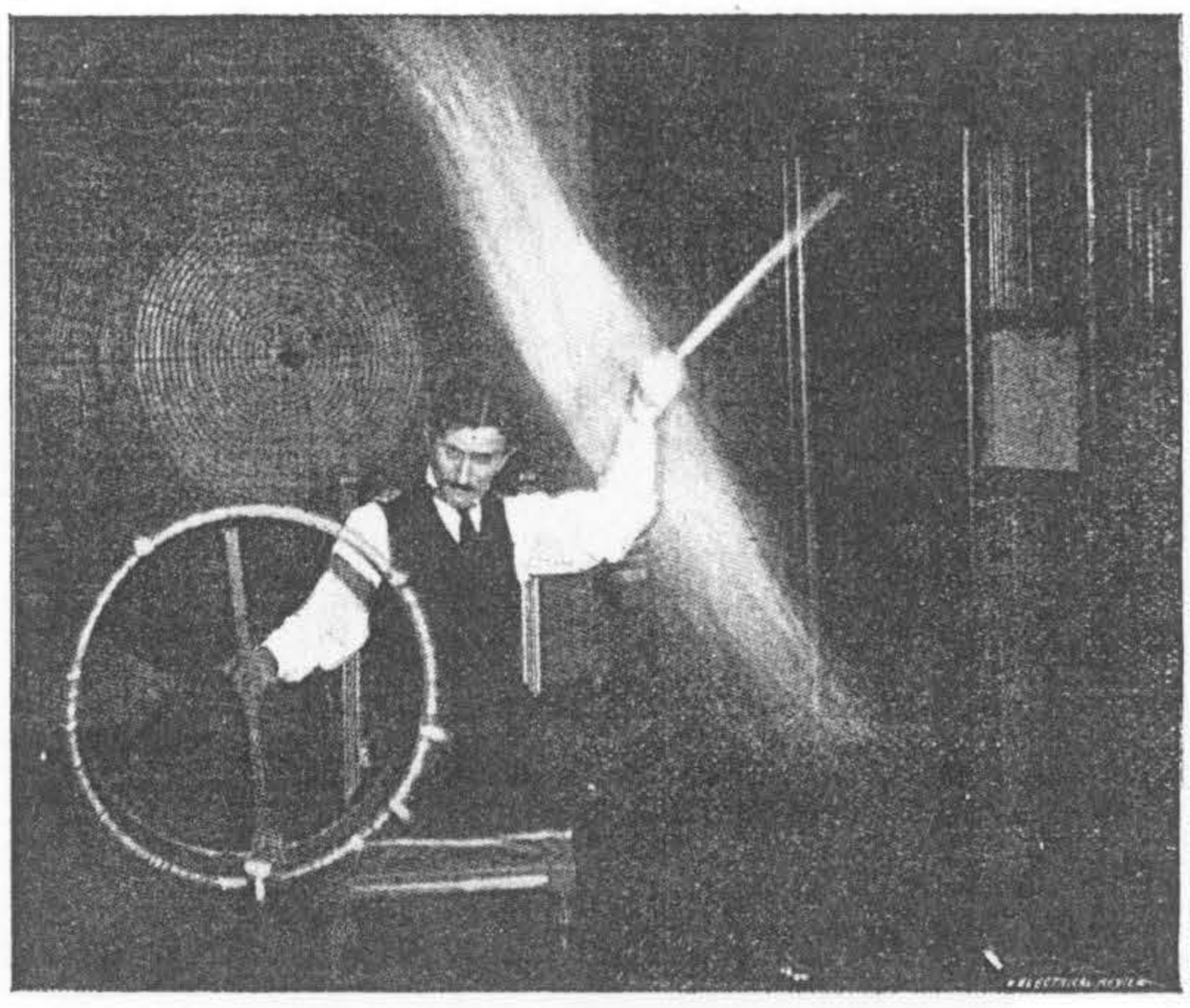


Fig. 4.—"Some Experiments in Tesla's Laboratory with Currents of High Potential and High Frequency."

The operator's body, in this experiment, is charged to a high potential by means of a coil responsive to the waves transmitted to it from a distant oscillator, and a long glass tube waved in the hand is lighted to great brilliancy by the electrical charges conveyed to it through the body.

At the beginning of his work Tesla found himself con-

fronted by three attractive lines of investigation; "there were the excessive electrical pressures of millions of volts, which opened up wonderful possibilities, if producible, in practical ways; there were the currents of many hundreds of thousands of amperes which appealed to the imagination by their astonishing effects; and, most interesting and inviting of all, there were the powerful electrical vibrations with their mysterious actions at a distance."

The production of high electrical pressures was finally chosen as, necessarily, the first step in the exploration of the whole field. Some attention was given to static electricity with the experiments of Franklin as a starting point. Various generators of static electricity were tried, and some new ones were designed. Tesla has not as yet published any account of these static generators which he has designed; it is to be hoped he will do so soon. The most valuable outcome of these experiments was the discovery of a method of operating any kind of low tension devices from such high pressure sources with perfect ease and safety.

Tesla, however, soon convinced himself that his object was not to be attained by the use of the steady pressures produced by static machines. "It was exactly," he says, "as if one attempted to drive piles into the ground by the application of continuous pressure. This would require cumbersome and powerful machinery, and would be very inconvenient. An incomparably better way of developing high pressure is by delivering violent blows as with a hammer." The kinetic energy of a hammer, when suddenly arrested, develops very high pressures, proportional to the rigidity of the body struck. In the same way, reasoned Tesla, enormously high potentials will be developed in the most convenient way by the electro-magnetic energy of a suddenly arrested current. This turned Tesla's attention to the use of transformers and induction coils for obtaining his high pressures. Those already in existence were evidently not adequate for the end in view, so Tesla set about improving them. First he tried the closed core transformer. This type was soon found to have several drawbacks; the insulation could not be made very high, and a very high frequency was impossible. Nevertheless, an arrangement of several of these transformers in series was devised, by which a pressure of 200,000 volts was attained. The secondary coils of several ring transformers were connected in series, while the primaries of all, except the first, were excited by insulated dynamos. This, however, was found to be practically a very inconvenient arrangement.

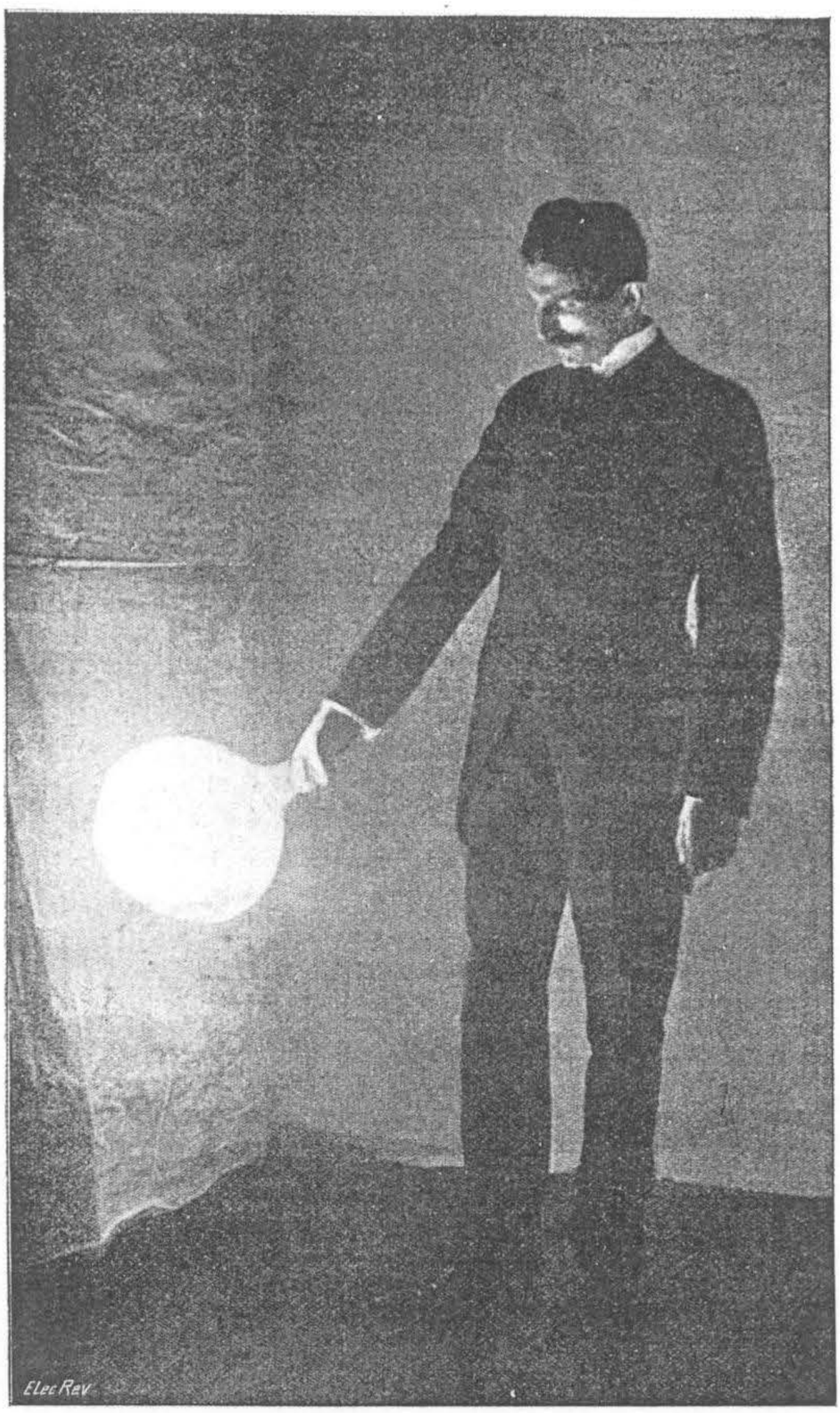


Fig. 2.—"Some Experiments in Tesla's Laboratory with Currents of High Potential and High Frequency."

Lighting a disconnected vacuum bulb of 1,500 C.P. by high-frequency currents—photograph taken by the light of the bulb itself, exposure about two seconds.

The straight open core type was then tried; several improvements in the insulation and arrangement of coils were tried, which appear to have been much the same as what has long been known to the makers of induction coils, such as winding in compartments, making the insulation thicker where a greater D.P. existed between adjacent parts of the coil, and so on. The first real advance made by Tesla appears to be his coil with a unipolar secondary. One terminal of the secondary wire is connected to the primary, the free terminal, as far distant as possible from the primary, being used for the discharge. A curious discovery made by Tesla in connection with this type of coil, was that the best results were got when the secondary wire was equal to a quarter of the wave length, as calculated from the frequency and velocity of light. This discovery Tesla has utilised in his most recent induction apparatus, with which he proposes to transmit electric currents through the air. It is difficult to explain this result; it appears as if something of the nature of a stationary wave of potential, with anode at the earthed terminal, was generated in the secondary wire.

During these experiments Tesla discovered that air played an important part in the breaking down of insulation, and by the exclusion of air, and the use of insulating liquids, he was able to increase the potential to 10 times the amount, without breaking down the insulation of the secondary. Tesla complains that the industrial world does not appear to have profited by the recognition of this discovery, since no attempt has been made to utilise it in cables for high potential transmission, to prevent streamers. It is a fact that the liquid insulation is less in favour in practice than when attention was first called to it by Tesla's experiments. It appears to have many practical inconveniences, and it is doubtful whether it is really superior to the solid insulation except for the high frequencies employed in the Tesla apparatus. An induction coil with viscous insulation was brought out a short time ago by Rochefort and Wydts,* and was said to be

* Electrical Review, 42, p. 165.

a great advance in efficiency, but it, like all the rest of such apparatus, has apparently dropped into disuse.

The final result of Tesla experiments with high tension generators was the coil or transformer illustrated in adjacent figure. In this coil the secondary coil is wound in a spiral lying practically in one plane perpendicular to its axis; its external terminal is earthed, and its length is made equal to a quarter wave length. The primary consists of a few turns of thick wire wound outside the secondary, lying thus adjacent to the part of the secondary whose potential is zero. It is with this apparatus that Tesla has made his experiments in the transmission of power through the atmosphere. The figure shows two transformers, a transmitter, and a receiver. The central terminals are connected to elevated plates, D, D', which require to be supported at a considerable height on a kite or a balloon. Tesla thinks a height of four miles will be sufficient. The air at such a height is supposed to break down under the enormous potentials developed, and become dissociated into a good conductor. This system of Tesla's has yet only appeared on paper, or, at least, no experiments on a large scale have been carried out in public. The criticisms with which this scheme was received when announced last November were by no means favourable. But Tesla is a pioneer in this field, and probably knows more about it than his critics. It is to be hoped that we shall soon see such a practical trial of his system as will finally determine its true value.

Tesla hints at a fearful catastrophe which might result from the introduction of his system of wireless transmission of power. The discharges of his coil when of an electromotive force of a few million volts, excite powerful affinities in the atmospheric nitrogen, causing it to combine readily with the oxygen and other elements, particularly in the presence of aqueous vapour. So energetic are these actions, and so strangely do such powerful discharges behave, that, says Tesla, "I have often experienced a fear that the atmosphere might be ignited." Can Tesla seriously believe in the possibility of such a calamity and yet go on with his experiments? Evidently the Tesla transformer is what Sir William Crookes wants to increase our supply of nitrates, and keep the wheat crop up to the demands of the world's increasing population; it is to be hoped Tesla's experiments will not solve the food problem in another way by reducing the population to zero.

The large size illustrations we publish show some remarkable results obtained in Tesla's laboratory by this coil. Fig. 2 shows a vacuum tube giving 1,500 C.P. illuminated by electric waves from a Tesla oscillator. Fig. 3 is a photograph showing a part of the laboratory with a disconnected resonating coil supported on an insulating stand, and illuminated by the streamers produced, other coils remaining unaffected. The pressure developed in the resonating coil is over half a million volts. In a similar experiment

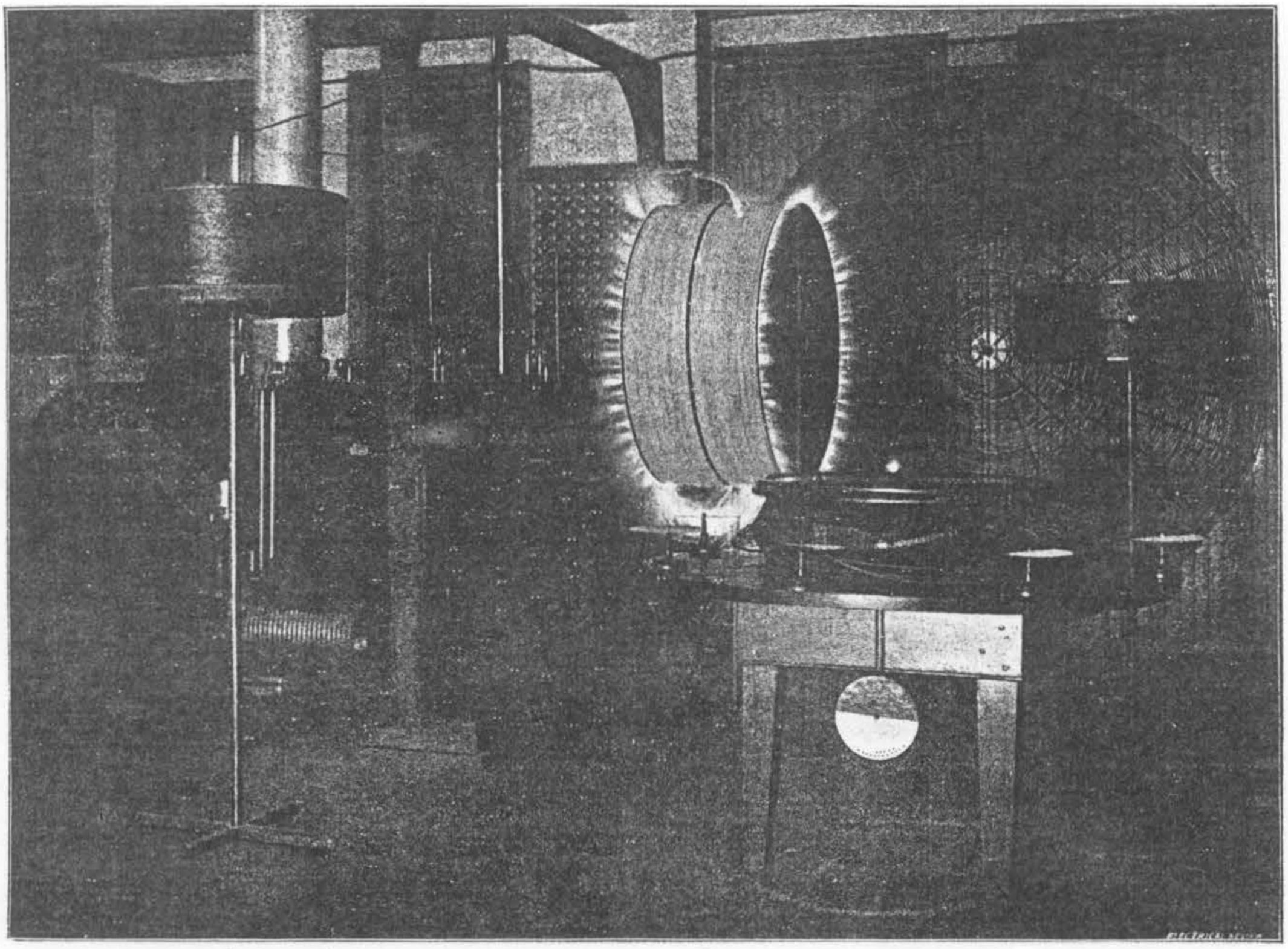


Fig. 3.—"Some Experiments in Tesla's Laboratory with Currents of High Potential and High Frequency."
Photograph showing a part of the laboratory, with a disconnected resonating coil supported on an insulating stand, and illuminated by the streamers produced, other coils remaining unaffected—the pressure developed in the resonating coil is over half a million volts.

Tesla grasped, without danger, a nodal point in a coil developing half a million volts. Fig. 4 shows a receiving coil illuminating a vacuum tube through the human body.

Very few details of the construction and operation of these latest fruits of Tesla's inventive genius have yet been published. For instance, we are left in the dark as to whether Tesla excites his high tension transformer by an alternating dynamo, or by a continuous current and a contact breaker. It is evident that lately he has been giving considerable attention to the latter device, in connection with an induction coil which has been exhibited in this country, and is generally known as Tesla's oscillator.

In 1891 Tesla patented a method of producing high frequency and high potential currents, in which an alternating generator sends currents through a primary, the secondary of which is in circuit with a condenser. This condenser lies also in a shunt circuit containing the primary of a second coil and a spark gap. The discharge of the condenser across this spark gap produces high frequency oscillations in the shunt circuit, and these oscillations are raised to an exceedingly high potential in a secondary coil wound round the

second primary. It was with an arrangement such as this that Tesla obtained the marvellous results which he showed before the Institution of Electrical Engineers at the Royal Institution in 1892. The discharge from his apparatus appear to penetrate with ease the best insulators; electrodeless vacuum tubes were illuminated at a distance of several yards from the poles of his coil; unipolar lamps gave out a light of dazzling whiteness, but unfortunately of very small candle-power. It appears to be one of these unipolar lamps that is held in Tesla's hand in fig. 2. If so, very considerable progress has been made since the Royal Institution lecture in 1892.

It is a coil of the above type that is generally used for producing Tesla currents for electro-medical purposes. Their use for certain purposes in electro-therapeutics is said to have been highly successful. It is a curious fact that such discharges of a potential of tens of thousands of volts can be passed through the body without any injury. A satisfactory explanation of this strange phenomenon has not yet been given; it has been suggested that it is because these rapidly varying currents must be purely superficial; it may, perhaps, be due to the fact that such currents are almost completely wattless, owing to the displacement of phase between the current and the electromotive force being almost a maximum.

In 1896 Tesla patented an improved generator of high frequency currents, which is known in this country, at least, as Tesla's oscillator. The spark gap in his first type of generator was replaced by a mechanical contact breaker, and the arrangement of the circuits was somewhat different. A condenser is connected in shunt in a circuit containing a continuous current generator, choking coils, the primary of the coil, and a contact breaker. When the circuit is closed by the contact breaker a direct current flows through the circuit. The circuit is then suddenly broken, and the condenser is charged to a very high potential by the self-induction of the choking coils. The contact breaker again closes the circuit, and the condenser discharges through the primary, which, being of few turns, has a comparatively small self-induction. The result is, that the frequency is considerably higher than in the ordinary induction coil where the choking coils would form part of the primary coil. This oscillator has been shown more than once in this country; it can be worked from lighting mains, and its working appears to be highly satisfactory.

It is apparently in connection with this oscillator that Tesla has devoted himself to the improvement of the mechanical contact breaker. In his original patent for the oscillator (No. 20,981, A.D. 1896) he describes a rotary contact breaker, which creates by its motion a current of air about the contact points, with the view apparently of removing the dissociated air, and improving the insulation of the spark gap. It is in a more recent patent (No. 12,866, A.D. 1898) on electric circuit controllers that we find embodied Tesla's latest discoveries in this field. The contact breakers there described are mechanical, of a very elaborate construction; too elaborate, we should think, for general use with induction coils, unless their superiority to the present simpler forms is very great. Two new ideas appear to be embodied in these interrupters; first, the break takes place in compressed air or other suitable gas, and second, a jet of mercury discharged against a metal plate, or another jet of mercury is used to complete the circuit. The metal plate is rotated by an electro-motor, and is notched on the periphery where the jet of mercury impinges, so that contact is broken when the jet passes through one of the notches between the teeth. Tesla has expressed a somewhat ungenerous contempt for the Wehnelt break, which has recently given such remarkable results in the hands of experimenters here and abroad. Its inferiority to Tesla's break appears to be known as yet only to Tesla; in simplicity, at least, it is certainly superior.

We, however, wish Tesla success in the working out of his grandly conceived, and if realised in practice, undoubtedly epoch-making ideas.

TESLA AS "THE WIZARD."

EXPOUNDS ELECTRICITY AS THE GUEST OF COMMERCIAL CLUB.

Astounds His Hearers with Predictions of What the Subtle Fluid May Yet Accomplish in the Arts and Industries and Thrills Them with Demonstrations Along the Line of His Novel Experiments—Work of His Oscillator—Wireless Torpedo.

Nikola Tesla was introduced to the members of the Commercial club last night as "the magician of the electrical world." Mr. Tesla then proceeded to astound, if not appal, his auditors by telling them of the things he would do when he had completed his devices for making Niagaras of nitric acid out of the atmosphere and converting what remained of this breathing material into a substance for the transmission of light and heat and power around the world.

Among Those Present.

Among those present were:

C. H. McCormick,
H. H. Kohlsaat,
H. G. Selfridge,
George B. Swift,
Edwin A. Potter,
M. E. Stone,
W. G. Collins,
C. H. Wacker,
F. S. Winston,
George E. Adams,
T. C. Chamberlain,
A. V. Abbott,
Bruce Clark,
J. C. Whitney,
Benjamin Allen,
S. B. Downing,
B. L. Smith,
N. B. Ream,
Robert T. Lincoln,
C. F. Kimball,
John J. Jones,
Granger Farwell,
Edward L. Brewster,
Marshall Field,
N. K. Fairbank,
A. S. Hibbard,
John M. Clark,
W. A. Fuller,
Victor F. Lawson,
S. J. McPherson,
E. H. Ellicott,
A. D. Wheeler,
H. H. Belfield,
Carl Keith,
E. O. Keith,
Henry Crew,
A. F. Seeberger,
A. A. Carpenter,
P. Carus,
Rev. Dr. Notman,
J. C. Zeublin,
J. H. Eckels,
Eames MacVeagh,
C. W. Carman,
E. W. Blatchford,
C. H. Blatchford,
F. B. Peabody,
W. J. Chalmers,
Franklin MacVeagh,
Von Bismarck-Plitke,
Baron Cornelius von Heil,
Robert Hotz,
Dr. Henry Favill,
E. M. Barton,
Professor Stevens,
R. N. Fowler,
F. H. Head,
C. Hotz,
J. L. Houghteling,
Charles E. Scribner,
C. D. Crandall,
Eugene Cary,
H. J. MacFarland,
D. C. Jackson,
W. H. Merrill,
H. A. Knott,
A. T. Evans,
Jerome J. Green,
Henry N. Tuttle,
F. E. Drake,
J. H. Bradley,
E. B. Butler,
H. S. Carhart,
J. V. Farwell Jr.,
A. L. Farwell,
Benjamin Carpenter,
Marvin Hughitt,
John M. Whitman,
Rev. C. A. Lippincott
Ernst Proctor,
Charles Proctor,
J. A. Spoor,
H. N. Higinbotham,
H. D. Higinbotham,
William T. Baker,
Percy B. Eckhart,
B. A. Eckhart,
A. J. Earling,
E. S. Pike.

Some Remarkable Tests.

Mr. Tesla talked at length and illustrated what he said with demonstrations made with his invention of a wireless submarine torpedo, his oscillator, which it is promised will transmit power across the Atlantic without wires; and several other devices which contributed almost as much to put his hearers into a state of bewilderment and amazement.

One of the astounding things he did was to fire five guns on board a wooden torpedo boat, work the rudder at will, and start and stop the screw propeller by electric impulses transmitted across the room without wires—something which already had been done in New York, but which never had been seen in Chicago. It was this experiment which mystified the scientists present, as well as the Commercial club members, though some of them declared the mystery was wholly in the mechanics and not in the electricity.

Mr. Tesla displayed another of his discoveries before attempting the experiment with the torpedo boat. His scheme for creating light in vacuum tubes by "jarring" the molecular atoms inside was displayed to the wondering business-men by lighting the room with bright flashes of blue light. The tube was held and waved about in the air by various members of the Commercial club. There was no wire connection in this experiment, though the electric current was transmitted through the body of the person who held the tube.

Developing "Electrical Sense."

Mr. Tesla did not reach his most interesting experiments until almost midnight. Just before he began handling his apparatus he declared that, to his mind, human beings were developing an "electrical sense." In his own experience, he said, he had found himself intuitively shunning destructive electric currents, and he believed that ultimately a sense would be developed as strong as the "sense of gravity."

Then the vacuum tubes were taken up. The test with these which excited most interest was made with an ordinary glass tube about four feet long, exhausted to a vacuum and hermetically sealed at both ends. Connection was made with the oscillator and ground wire by holding a pair of steel nippers against one of the poles. The glass tube was held in the other hand, and when the current was turned on the interior of the tube glowed with an uncanny blue light that almost filled the room.

First H. H. Kohlsaat held the tube and swung it around his head. The lights having been turned out the vacuum tube lighted the room like a chandelier. Harry G. Selfridge and Mr. Tesla himself then swung the tube. Then Mr. Selfridge tried the experiment of running his hand up and down the tube while some one else held it, and it was discovered that the portion of the tube beyond his hand scarcely glowed at all, while the uncanny blue glow seemed to extend with his hand in a bunch.

Mind and Matter.

Mr. Tesla declared he believed that many so-called mental phenomena could be accounted for on physical grounds. He believed, he said, that it was only a question of time until suitable scientific instruments would be invented that would read people's minds.

Before trying the tests with the torpedo boat model Mr. Tesla declared that the system of transmitting signals without wires between two transmitting spheres (the Marconi wireless scheme) was his own and that he had discovered the method in 1893. "With other methods you need ten times the power for ten times the distance," he said. "With the discovery of mine distance makes no difference."

President McCormick made the only other speech. When the dinner was finished he announced there would be an intermission of ten minutes. During that intermission Mr. Tesla held a little informal levee. Members of the club crowded around the tall, angular man, whose slight black mustache, raven hair, and sallow complexion heightened the effect of his air.

President McCormick's Introduction.

After the intermission President McCormick introduced Mr. Tesla, saying:

"We shall be much interested to hear from Mr. Tesla of the realm in which he dwells, which seems to us so incomprehensible, and if we become puzzled at the relative importance of 'ampères,' 'volts,' 'ohms,' 'induction,' and 'polyphase currents,' Mr. Tesla must remember that, although we may know more about other things, we are still in the primary class in electricity.

"Since this great force of nature has been made subservient to the will of man, electrical progress has opened a wide field for both capital and labor. The Commercial club will be interested in knowing that in this country alone the capital employed in the manufacture of electrical apparatus is $50,000,000; the telegraph interests represent $100,000,000; the telephone systems $110,000,000; while the investment in electric lighting is $247,000,000; this statement does not include the electrical equipment for elevated or surface railways.

"If this is the position which applied electricity holds today, who can say what its limit will be in the future? When the power of Niagara's thundering tide shall be moving the looms of New England; when 'ships that pass in the night' shall telegraph messages to each other from distant horizons; when Tesla's 'oscillator' shall be sending electrical currents from the top of the Alleghenies to turn the shafts of the Paris exposition of 1900; then may we stand in awe as we realize what secrets the mind of man has wrung from these latent forces in nature, and we may exclaim with Morse in his first message sent over the telegraph wire, 'What hath God wrought?'"

Mr. Tesla talked in a low voice and with a defective accent. These two characteristics of his delivery prevented him from being as fully understood at all times as he might have desired. His first demonstration was of the force in what he called a simple piece of iron with a coil of wire around it. There were two of these, looking alike, about eight inches in height and consisting of a pedestal surmounted by a circle. To one of these he held a disk, which was fixed on an axis in a handle. The disk did not show any effect. He held it to the other and the disk whirled. It was colored black and white, so everybody could see that it whirled. That was done, Mr. Tesla said, to illustrate the statement he had just made that some things are animate and some inanimate. He said those that are animate have life and that iron may be animated and be therefore deserving of a place in the list of things science has declared to be living objects. The iron was connected by wire with a dynamo and the current was turned into it, when it showed its quality of "life."

He then declared it was not beyond hope that it would be possible to deprive matter of its latent powers, its heat, and its consequent energy. When that was done and absolute zero obtained the present wonders of the electrical world would look insignificant.

Work of the Oscillator.

Then he turned to the task of his oscillator. He said that in order to transmit force from one object to another there must be something between them. It might be something so attenuated that it was not easy to comprehend it, but it must be there if the energy is to be transmitted.

He said he had succeeded in converting a column of gas into a solid column with the rigidity of steel.

"I have produced a flame which offered resistance to bodies," he said. "It resisted their passage through it. That is an approach to solidity. I may yet produce at the end of a wire a solid body."

He then told of a method he had invented for the production of ozone, which could be made in commercial quantities for sterilization and for purposes of sanitation. It was made by the process he followed in the production of this flame which had the power of resistance.

Forces of the Air.

"The forces of the air may be utilized in a manner now that we have not learned to even contemplate. Nitric acid may be made from the components of the atmosphere."

"This nitric acid may be made to fill our reservoirs and then utilized to produce the energy we need and to transmit energy to almost unlimited distances."

His greatest invention, he said, was in utilizing the forces of the air.

"The air, which is an insulator," he said, "becomes a conductor by means of the millions of volts I am able to produce. It means the using of the air for all purposes and uses of men. Not only for the transmission of messages without wires, but for the transmission of power in any amount to any distance across the earth's surface."

Views of Scientific Men.

Not all the scientific men who saw the tests agreed with Mr. Tesla as to their practicability.

"Mr. Tesla has certainly worked out the mechanical details of the torpedo boat apparatus to perfection," said Arthur V. Abbott, chief engineer of the Chicago Telephone company. "But there is too great a waste of power for it to be utilized for more than a few feet. The apparatus would be absolutely useless from the Auditorium to a boat a few feet from shore in Lake Michigan. There is nothing new about it except the mechanical adaptation. It is the same coherer that Marconi uses, only Tesla's revolves instead of being hit by a small hammer. The vacuum tube lights may have some commercial value, but it has not yet been discovered."

Professor Jerome J. Green of Notre Dame University and Professor Carhart of Michigan University both looked skeptical when asked their views of the experiments. Each said:

"I should want to have him explain his 'sensitive' apparatus before I made any comment on the newness of what he has shown."

TESLA'S TASK OF TAMING AIR

The Inventor's Hopes of Building Fame on the Establishment of a New Art.

GREAT FORCE HIS TOY

Wants to Make Nature World's Utilitarian Agent.

TALKS OF SIGNALING MARS.

Transmission of Intelligence Feasible Assuming Equal Conditions Exist on the Other Planet.

NIKOLA TESLA has come to Chicago. One afternoon of busy work with his machinery, a lecture in the evening, a day of social visits. That was all. To-day he leaves for Colorado, where his busy mind will continue to work in the same channels as it follows when he is at home in New York.

But Chicago is left full of wonder. "What of Tesla?" is the question which everyone must ask who has come into contact with the man and been made to feel with personal force something of the scope of his ideas. That he lives in high regions of an atmosphere totally unfamiliar to practical Chicago business sense everyone must recognize. But whether it is an atmosphere of phantasma, bubbles, specters, or whether it is the breeding place of things all important for the practical world of the future, that is the question.

Belittles His Experiments.

It is a question which each man can answer as best suits his own disposition. Indeed to Tesla himself it is indifferent whether it is answered at all or not. But when he was approached yesterday by a reporter for THE TIMES-HERALD and asked questions about the nature of his work and its bearing on human affairs, he consented to talk quite freely. He said many things that throw further light upon his lecture of the night before, as well as having interest as expressions of a character unique among the men of genius of the day.

From what he said it was very clear that for him the little experiments he had performed at the dinner of the Commercial Club were simply trifling applications of the principle he is working out in his investigations. That he could transmit force to some distance without the use of wires, that he could make lights glow and wheels revolve and torpedoes explode without any contact with them except through the medium of air, was wonderful enough to the men who saw it. It filled their attention, for it was specific and immediately present.

But One Problem Before Him.

But to Tesla himself, however much pleasure he may have taken in seeing his experiments work so successfully, it was only a little illustration of one of the simplest forms of communication and transmission of power which he says he has discovered and become able to control.

This great problem, the transmission of force in quicker and more precise and more effective and economical ways, is the center of all Tesla's speculations at the present time. It has long been the great problem set by him for solution.

"The invention of the torpedo boat worked at a distance," he says, "and the discovery of the principles of wireless telegraphy are simply incidents in my progress. They are not ends which I deliberately set out to accomplish. For many years I have given myself over, to the problems involved in communication between individuals at distances and in the transmission of energy from one place to another. There are methods for these things which are as old as the human race, and there are others which are comparatively new.

Wants Fame for Something New.

"None of them is as effective as it might be. I have discovered other ways of transmitting force, and some of them are capable of great development. They will tend to revolutionize the human race in many of its doings.

"What I am doing is to develop a new art. Is that not more important than the attempt to elaborate an old art in some of its phases? I want to go down to posterity as the founder of a new method of communication. I do not care for practical results in the immediate present. Where I have time I stop to develop the application of the principles that I have announced, but that is a part of the work which it is usually safe to leave to others. They will do it because there is money in it. For myself I am content to find the new principles through the knowledge of which the applications become possible."

Suggests the Wizard in Face.

Tesla's bright eyes glowed as he spoke of his ends in his work. Leaning forward, peering almost each moment into the eyes of his interviewer to make sure that his meaning had been understood, he proved a talker from whose train of reasoning there was no escape while a man was under his influence. With close cropped mustache, high cheek bones, clean shaven face showing all over the signs of a beard struggling to assume complete control of his appearance, he is a man whom only the addition of a pointed beard would be needed to turn into a typical Mephistopheles.

He turned aside from his statement as to his general aims to answer some questions put to him about the agencies which he has developed for communication with Mars or any other planet. That is another application of his theories about ways of transmitting force.

Signal Can Reach Mars.

"Signaling to Mars?" he said. "I have apparatus which can accomplish it beyond any question. If I should wish to send a signal to that planet I could be perfectly certain that the electrical effects would be thrown exactly where I desire to have them and that the exact signals I desire to make would be made. Further than that, I have an instrument by which I can receive with precision any signal that might be made to this world from Mars. Of course that is not the same as saying that I could establish communication with beings on Mars, but if they should know that I was signaling them, and had intelligence approximately similar to ours, communication would not be impossible."

Then Tesla began to explain the difference between his methods and those that might be suggested at first hand for sending a signal. "Suppose," he said, "a ray of light should be sent out toward Mars. It would send its beams in all directions and only a very slight proportion of the energy would fall upon any particular spot on the planet. If there were sensitive enough instruments there that infinitesimal bit of force would affect them. But in order to make the sending of signals practicable what is needed is a way of condensing energy. It is thus that I have found out how to do, and for this I possess the proper instruments already.

Receiver and Sender Needed.

"Two sets of instruments are necessary—one of them to send, the other to receive. My oscillator is used to send out the electrical vibrations, and I have an exceedingly sensitive mechanism which I call the rotating brush to receive signals. By the use of 10 horse power with any oscillator I would be able to start the entire electricity of the earth in vibration and secure sufficient strength to take effect on an ordinary fine relay on Mars. The amount of electricity needed to affect a relay is perfectly well known. By the aid of astronomical data I have calculated exactly what is necessary to secure the desired results on another planet. I can send out in this way force amounting to a trillion times as much as could be sent from a 100-foot reflector, if such a big one could be made to send rays of light into space.

"Now, on the other hand, there is the receiving of the signal. This is accomplished by the rotating brush, which is incomparably the most sensitive device known to science. I described it in my lecture before the Royal Institution in 1892.

Gathers All the Force.

"Heretofore only a minute amount of energy falling on a planet from another would fall upon and affect the receiving instrument of whatever kind it might be. Now, through my device the entire amount of the energy falling on the receiving planet can be gathered together and made to take effect on the instrument which receives the signals. The sensitive instrument will harness the entire electricity which the planet gets. The calculations are exact and beyond question.

"There you have all that is needed for the sending of signals from one planet to another. The difficulty was to get enough force upon a given spot to make the signal marked enough to be appreciable. The two instruments I have described overcome all this difficulty."

Mr. Tesla has not yet attempted to signal to any point so far away as Mars, but he is using these very same instruments in other modifications in signaling between different parts of the earth. They are similar in many ways to the instruments which he used Saturday evening before the Commercial Club to transmit power the little distance across the room without the aid of wires.

Transmission From India.

The principle is the same. He says that his sensitive rotating brush, as he has it in operation in his laboratory, will detect any electrical disturbance or sudden physical commotion which occurs in any part of the planet. A sharp electrical storm in India would be made known to him, he says, by vibrations of his instrument.

When asked what particular problem was occupying his attention most of all at the present time Tesla said: "I am striving to find out the best means of getting power from nature. The use of waterfalls to develop electricity which can be conducted through the air to the places where it is needed for practical use is one of the sides of the investigation. There is still another method I am struggling with, but I would say anything about it. It is older in my thought than the electrical method, but harder to work out and much less developed.

"Central in these problems of the transmission of force is the use of air as a transmitter. I told in my lecture how by the application of tremendous pressure through an exceedingly high voltage of electricity I could turn air from an insulator to a conductor. I can make it act toward the power I want to transmit just like a copper wire."

Great Resources of Air.

Mr. Tesla could not say too much in enlargement of his opinion expressed in the lecture that the coming century would bring the world into what might appropriately be called the era of the atmosphere. He is a wonderful optimist in his way, believing implicitly in man's ability to attain all his ends with ever increasing effectiveness, and in the air he sees the factors which will rapidly be developed to make up for all the threatened deficiencies in other parts of the material environment, such as in the timber and coal supply. Out of air will come, he predicts, the food of the world. Through it all power will be transmitted. It will be the vehicle for the spread of intelligence and of energy. Persons will begin to transport themselves through it in flying machines. Finally by the process of liquefaction much may be accomplished for science and for industry.

In regard to the air as the source of the world's food supply he said: "I have discovered a form of electrical discharge which excites the affinity of nitrogen for other substances. As is well known, nitrogen, as we find it is inert and will not combine with other substances, not even with fluorine. By my process nitric acid and ammonia can be produced. These are the world's fertilizers. The barren parts of the earth can be reclaimed by them and made to produce with all the luxuriancy of past geological ages. There is much poetry in the idea that in this way the work of the sun on the earth can be made more effective."

Electricity for Motors.

Asked what he thought about the motors which would be most successful in the future for use in transportation Tesla said that the air motor had certain very beautiful features, but that his faith in electricity was very high and that he thought through it most of the work of the world would be accomplished.

In answer to a question as to the practical value of the things he had thus far accomplished Tesla claimed for the results of his investigations all the greater utility to the world because he had not patented them and attempted to derive personal gain from them. He threatened, however, to take steps to patent the next great invention he should make. "Wireless telegraphy," he said, "is something now that is free to all the world to experiment with. Nobody can hinder anyone from using a wireless instrument. I was the first man to announce the principle of the instruments now used by Marconi and others. I gave it to the world in a lecture in St. Louis in 1892. It may not be practical in your sense now, but it will be some time soon.

Alternating Currents His.

"Then there is the principle of alternating currents first announced by me and now universally applied in telegraphy. What could be more practical than that? At the lecture last night I was speaking of it and said that there was only one trouble with it from my point of view. 'What is that?' asked some one. 'That it won't work?' 'No,' I replied, 'that I didn't have it patented. It works for everybody.'"

In his view of what work is of the most value Tesla is consistent throughout. He believes thoroughly that work for the future is the work that counts. He believes that it is better to find out the general principles than to bother with the details of application. He threatens, however, to be in a position to make applications in many lines on an alarmingly big scale before many years have passed.

As to the methods of work which the inventor follows he said many things which were of interest. He boasted with a certain measure of pride that he had not for ten years performed an experiment which was a failure.

"Of course, there is sometimes a defective piece of machinery which has to be replaced, but when I make an experiment I know in advance always that it will succeed. Perhaps I have spent something like 99 per cent of my time thinking and 1 per cent experimenting. The experiment simply proves that there is no element in the situation which the thinking has overlooked. Then, too, there is a great pleasure in watching the actual accomplishment of what one has been able to predict by means of his science."

"Are you going to Colorado for a rest?" Mr. Tesla was asked.

"Rest? Oh, no," he answered. "I shall just keep on thinking on the same lines and will work as hard while there as if I were in New York."

Absorption in Study Complete.

Tesla told one or two stories tending to indicate his complete absorption in the investigation which he pursues. When speaking of the circumstances surrounding the invention of his sensitive rotating brush he said: "I had come back from attending the funeral of my mother, and was bowed down with grief, but I became absorbed in this study. After a time I forgot that my mother had died. I don't mean that I simply was so absorbed that I neglected to think of the fact, but I actually forgot it, and my mother was to me as one of the living. After a time I began to feel an overweening longing to visit her again. I felt that I could not resist it, and prepared to make the trip. Then something brought back to me the knowledge that she was dead, and I found that my work of investigation had actually stolen my memory on this point for a long time—months even."

Tesla says that his daily habits in New York City are such that he follows the same beaten track day after day. In all his years in that city he says that there have been only very few occasions when he walked on any other streets than those which lead from his lodgings to his laboratories, and he is perfectly satisfied with that limitation of his movements.

The Chicago Tribune May 15, 1899

TESLA TO "TALK WITH MARS."

Inventor Says He Has Discovered a Delicate Instrument That Will Communicate with the Planet.

Nicola Tesla, the electrical inventor, purposes to establish communication between the earth and the planet Mars. This is to be done by an instrument so sensitive that it will feel disturbances created anywhere on the globe. Mr. Tesla, last night at the Auditorium, said:

"One of the most wonderful things I have discovered is this instrument. With it I purpose to communicate with Mars."

"The coming century," said Mr. Tesla, elaborating on his lecture before the Commercial club Saturday night, "will be the era of the atmosphere. From the moment I discovered that the air under certain conditions was a better conductor than a brass rod I saw possibilities which made me grow fairly dizzy at their extent. The transmission of force and influence to any distance, the use of the sun's energy for all the needs of man, the possibility of controlling things with which there is no visible connection, these and an endless number of smaller achievements have become facts that in a short time will have their practical demonstrations.

"I am going on to perfect the ideas of transmission of energy which I have found in the new and measureless ocean of the atmosphere about us. The sun has furnished us eevrything, yet the energy it has to give is not used in the smallest part. The earth itself can be restored to the condition it was in when the ferns grew as large as trees. Distance, in the new method of transmission, amounts to little or nothing. The idea of wireless telegraphy which arouses such interest now because it is developed to a new basis is not wonderful at all compared to the principle of which it is one application."

Mr. Tesla declined to discuss the interviews on his work given by Arthur V. Abbott, Professor Jerome J. Green, and Professor Carhart after the talk before the Commercial club.

The Colorado Springs Evening Telegraph May 17, 1899

PRICE 5 CENTS. 50 CENTS PER MONTH

NIKOLA TESLA WILL "WIRE" TO FRANCE

The Wizard of Electricity Arrives in City at Noon and Will Carry on Extensive Experiments in Connection With Wireless Telegraphy and Upper Atmosphere.

Nikola Tesla, the wizard of electricity, arrived in the city at noon to-day.

At an altitude of over 14,000 feet he will harness the powers of the upper heavens and compel them to do his bidding. He will carry on extensive investigations in the realm of his chosen science—electricity, and with a view of solving the problem of sending a telegraphic message around the world, he will harness the Pegasus of the upper air to the chariot of science and bid it carry his messages whither he wills.

"I propose to send a message from Pike's Peak to Paris," said Mr. Tesla, in the corridor of the Alta Vista hotel this afternoon.

The Telegraph man asked him why he had chosen Colorado Springs as the basis of his operation. He replied: "I might as well tell you the truth. I have come here to carry on a series of exhaustive experiments in regard to wireless telegraphy. I will be here perhaps several months. I come here for work." He spoke quickly and softly and the cadence of a foreign tongue did not sound at all unpleasantly to one's ear.

"I see no reason why I should keep the thing a secret longer," he said. "I have been preparing for a long while to come here and carry on these experiments which have been so much to me. I am here to work out a system of transmission at a distance. I propose to propogate electrical disturbances without wires. I find it necessary to investigate the higher strata of air which I find so convenient to do in this altitude. I will also investigate electrical disturbances through the air and the earth.

"Are you going in the near future, to flash your message from Pike's Peak to Long's Peak or some other mountain of Colorado?" was asked.

HERE TO WORK.

"No," he replied, with quickness, almost approaching irritation. "I am here to work. It is not pleasure. I am very busy and life is short and there is a great deal to be done. I will attempt to design an apparatus to use in wireless telegraphy everywhere. Everything is crude yet. I hope to perfect it," he said, and he warmed up in his conversation, becoming very animated.

"Will you go Pike's Peak to-morrow?" was asked.

"I may go to-morrow or I may not. I am tired. I have been traveling, and may rest a few days. I have many experiments to make which will take several weeks. I must study the conditions of the upper strata of air and that will be my work. I have sent them already over distances and need not try that now. It is conditions I want to study. There are great laws which I want to discover and principles to command. When I have mastered this I will attempt my long distance signalling."

TWO ASSISTANTS.

"While here I shall make my headquarters at the Alta Vista hotel, where I have mu suite. Two of my assistants are coming and they will bring many instruments for the work. With these we will carry on our work and we will be very busy. There are conditions which I must study," he repeated, as if deeply impressed with some great thought or theory, which he was revolving in his brain. He lapsed into silence for a few seconds and then referred for a third time to the fact that he was here to study the upper strata of air.

He added: "In this high altitude there is much to be learned. The electrical conditions are more active than at the lower levels. Your air is charged with electricity. I hope for favorable results."

Tesla begged to be excused, saying he was wearied of the journey. He refused to state anything concerning his theories of signaling to Mars, or to some of the more distant planets except to reiterate his former statement that he was here for work in connection with wireless telegraphy.

WHO HE IS.

Nikola Tesla is a foreigner. His speech betrays it, yet he is a master of the English language, which he speaks remarkably well. His tones are soft and evenly modulated. He arrived from Denver at 1 o'clock to-day over the Gulf, and was met by his old time friend, Mr. Leonard Curtis, of the law firm of Hall, Preston & Babbitt. Mr. Curtis has known Mr. Tesla for the past fifteen years, and through Mr. Curtis' law firm in New York city then known as Kerr, Curtis and Page the business end of Mr. Tesla's affairs were conducted. All the great legal battles which Mr. Tesla has been compelled to wage in this country to protect his patent inventions have been carried on through Mr. Curtis' firm.

Mr. Tesla was Mr. Curtis' guest at lunch to-day at the El Paso club, and will be entertained by him for several days awaiting the arrival of Mr. Tesla's assistants.

As Tesla walked out of the Alta Vista to the El Paso club he took in the surroundings. As the breeze struck his cheek coming from the mountain, he glanced over to Pike's Peak and a look of preoccupation came into his eyes. The great electrician is wrapped up in his life work, and it apparently takes but little to throw him into a contemplative state from which he rouses himself with an effort. He, however, is a vigorous conversationalist and is very easy to approach. But when he once sets himself to his work he is difficult to see as his experiments require the closest watching and most intense application.

NIKOLA TESLA ON TOP OF PIKE'S PEAK

Wizard Who Works Without Wires Likely to Try Some Very Interesting Experiments.

Startled by the Amount of Latent Energy in the Atmosphere and Delighted Over the Prospects of Developing His Ideas.



NIKOLA TESLA, THE FAMOUS ELECTRICIAN.

Nikola Tesla, the noted electrician, has come to Colorado to make experiments in his chosen science. His tall and modest figure was to be seen last night in the corridor of the Brown Palace hotel, where the unassuming signature of "N. Tesla, New York," is registered to show that he is among the guests.

Mr. Tesla says that his objective point is Colorado Springs, from which he admits in an evasive manner that he may possibly take a trip to the summit of Pike's peak before he is done with his stay. What he intends to do on the top of the peak, however, the electrician would not say, nor would he admit that he attached more than ordinary importance to the possibility of making tests at that elevation. He carries with him some of his most delicate instruments, but this, he declared in his modest way, was always his habit and he thus evaded the assumption that he expected any important development from his visit to this state.

Impressions of the Air.

"Yes," said Mr. Tesla, "this is my first trip to this state, and I must say that I noticed the peculiar quality of the atmosphere as soon as I reached the altitude of the plains. It is very remarkable. You have so much electricity in the air. I felt it with my fingers the first thing, and when I handled the newspapers I noticed they clung to my hands. It shows that the atmosphere must be very dry, and you must all have good health here, do you not?"

The first impression of Mr. Tesla is his reserve, though there is not the least shyness about him. He is tall and rather straight and wears a slight dark moustache. There is a depth to his eyes that indicate a dreamy and more or less philosophic disposition. He is serious by rule, but occasionally he gives way to the sense of humor.

"You do not think I am here for pleasure, do you?" he asked, as if he felt hurt at a question. "I always work. Life is too short for anything else."

'Phoning to Mars.

The scientist denied a report that he had come to Colorado with the idea of carrying on investigations conected with his method of signaling to Mars and Venus. But he declared with a good deal of assurance that his investigations in this direction were correct. His instrument, he said, whereby the signals were given was of sufficient power to affect a receiving instrument on the sister planet with ten times the necessary force.

The details of this discovery had already been published.

"Cannot you tell the people of Denver why you have chosen Colorado as a place for your experiments and what you expect to derive from them in this atmosphere?" the electrician was asked.

"Of course you cannot expect me to expose my plans," Mr. Tesla replied in a serious voice. "That is not just. It is generally admitted that the air in this region is quite favorable to experiments of a certain class, and as I said I have been surprised at the quality of it, but I cannot say now what I am seeking. I intend to go to Colorado Springs soon and, since you ask, I may say that I shall probably visit Pike's peak. No, I have no intention of communicating with Mars from the top of that mountain. The instruments I have brought with me are used for the purpose of testing the electrical conditions of the atmosphere."

Always Working on It.

"Do you expect to do anything with the subject of wireless telegraphy?"

"My friend, I have been working on that subject for many years. I am always working on it."

"But, will you do any specific work upon it while you are here?"

"That is not a fair question. I cannot expose my plans."

The electrician spoke of some of his more practical inventions, and said he believed some of them were in use by electric light companies in this state. When asked if he would give forth the results of his work here in pamphlet form he said he rarely wrote books.

Nickola Tesla, the famous electrical inventor, as well known in these days as Edison for his remarkable electrical inventions, arrived in Denver last night. Just what his mission is none of the electricians of the city could tell yesterday, as there was no one in the city who had had any correspondence with him. J. W Stearns of the Mountain Electric company, said that he had known for several days that Mr. Tesla was coming to Denver, but he could only surmise what the object of his visit is.

The success of Marconi, the Italian inventor, in transmitting messages without wire, it is believed has aroused Tesla to an effort to outdo the Italian. Tesla claims that he made successful experiments in wireless telegraphy several years ago and that Marconi's work is but stealing his ideas. It is possible, however, that Marconi has simply been working on the same lines as Tesla and has arrived at a solution of the problem. It has often happened in electrical inventions that two or more men have reached the same result at almost the same time, neither knowing that the other was working on the same line. Notably was this the case some eight years ago when Tesla, Gaulard of France, and Gibbs of England perfected what has been known in this country as the Tesla transmitter for transmitting high potential energies to low and vice versa. Neither one of the men named knew that the other was working on the same line, and yet all three reached the same result at about the same time.

Tests in Rarified Air.

It is believed that Mr. Tesla's visit is for the purpose of making wireless experiments in the rarified air of Colorado. Mr. Tesla has already made experiments with the transmission of power as well as messages through air. These experiments have been made with his high tension generator. The central terminal of the generator is connected with elevated plates which require to be supported by kites or balloons. Here in Colorado the elevated terminals may be set on high mountains. Tesla thinks power can be transmitted at a height of about four miles. The air he believes will break at that height under the enormous potentials developed and become a good conductor. He hints, however, at dire results from the discharges of his coil when an electric motive force of a few million volts is discharged in the air. He says it may excite powerful affinities in the atmosphere, nitrogen causing it to combine readily with the oxygen and other elements, and the actions become so powerful as to ignite the atmosphere.

Specialties of the Inventor.

In practical use of electric power Tesla is best known for his methods of producing high frequencies and high potential currents in which an alternating generator sends currents through a primary, the secondary of which is in a circuit with a condenser. Practical application of this which every reader can understand is seen in the transmission of light into a house from an arc light current. The condenser or small transformer is placed outside the house and the current in transmission is reduced to the proper tension for an incandescent light circuit.

Tesla's high potential and high frequency pressure is seen in the recently constructed machines for the operation of mining plants, several of which are in operation in this state. In one plant of this kind set up by the Mountain Electric company a pressure of 60,000 volts is used. The arm for the switch board of this plant is over four feet long, the danger to human life in the use of this great power being such that a specially constructed switch board had to be made. Tesla in his experiments devised a series of transformers by which a pressure of 200,000 volts was attained.

Even as far back as 1894 Tesla declared to New York newspaper men that wireless telegraphy was a certainty of the near future, and if Marconi could successfully transmit a message across the English channel in the heavy and murky atmosphere of western Europe then much more successful should be experiments in the clear, rarified air of Colorado.

Tesla Lectures in Chicago.

Mr. Nikola Tesla was entertained by the Commercial Club, of Chicago, on May 13, and in the evening delivered an address before the club. Besides the members, many prominent scientists and educators attended the dinner in his honor, which was an elaborate affair. Mr. Tesla gave a number of interesting demonstrations, one of which was steering a boat from the shore, using a seven-foot model on a miniature lake, built in the banquet-hall for the occasion. His experiments did not begin until nearly midnight and lasted until a late hour.

OUR VISITORS.

Colorado Springs is to have its share of distinguished visitors this summer. Among those who are already expected with a considerable amount of certainty are Nikola Tesla, the electrician; Admiral Schley, and President Cleveland.

All these gentlemen will be welcomed, but we want a great many others, less distinguished perhaps but none the less desirable visitors to the foremost health and tourist resort of the Rocky mountain region. Hundreds of these people will come anyhow, for Colorado Springs is too well established in its reputation and acquaintances to lack for visitors, but there are many thousand others whom we might also have if proper means are taken to attract visitors and interest them in our climate, scenery and opportunities for profitable investments in mines and other branches of business.

NIKOLA TESLA AND HIS DISCOVERIES

The Great Electrician Will Communicate Without Wires

FROM NEW YORK CITY TO PARIS

Is In Colorado Springs for a Period of Several Weeks to Experiment In the Atmosphere of a High Altitude—Brought Forth the Principle Which Resulted in the Successful Subserving of Niagara to the Use of Man—Something of His Personal Appearance and Manner.

The one man who alone stands as a successful rival to Thomas A. Edison in the world of electrical research at the present day, Nikola Tesla, as the world knows him, is in Colorado Springs and will remain for several weeks. He is conducting experiments in which he desires to know the effect of the rarefied air of exceedingly high altitudes, with a view to the further perfection of his system of telegraphy without the agency of wires, the great object toward which all his ideas have been turning for some time, and for attainment of which the world of science and invention is looking to him today.

The Personality of Tesla.

Mr. Tesla is one of those men of great genius whom the world calls hard to fathom. It is generally supposed that he is averse to talking and very noncommital as to his purposes and aims. The Gazette reporter who called at the Alta Vista last evening, did not find him so. When the great master of the earth's greatest natural force is approached in an informal and interested manner he is a congenial and most interesting talker. He talks of his past work in a manner which is rather too technical for the comprehension of man of only ordinary education in the realm of electricity but is in no degree boastful.

The electrician spent part of the afternoon yesterday at the El Paso club and part of it at the Alta Vista hotel, which will be his headquarters while here. He is a man of more than ordinary height, probably measuring close to six feet. He is rather slender in build, has a pleasant face, with an eye that is quick and of keen perception, yet at times extremely meditative in expression. He has a black moustache. In dress he is not particularly striking, his whole make-up being that of a man who has a purpose of his own and who allows it to be uppermost in his thought during the greater part of the time.

Will Talk With Paris.

Tesla makes no secret of the fact that he is working at present to perfect his plan for wireless telegraphy. He stated in the interview last evening that he expected to remain in Colorado Springs for several week making experiments to ascertain the effect of the conditions peculiar to such a high altitude and that, having satisfied himself on the point, he will return to New York city, from which place he will apply his theories in an effort to communicate with the city of Paris without the use of wires. He thinks it will probably be a couple of months before he returns to the east to talk to France.

Has Harnessed Niagara.

Tesla has for some years been considered the coming man of the world interesting phenomena which have been the discoverer of some of the most interesting phenomena which has been brought out in the rapid onward march of progress in the great force. One of the greatest of his achievements was the proving of the basic principle which finally received its application in the great power plant which has brought the mighty Niagara into the service of man.

For years back men have known well that if they could successfully harness the water power of Niagara Falls they would have solved the problem of furnishing cheap, efficient and absolutely unlimited power for driving the machinery of practically the whole of New York state at one time. It was for Nikola Tesla, however, to come forth with that solution of the problem which all experts conceded to be practicable and which was eventually put into effect.

It was Tesla, although one or two others were working along the same line at the time, who put forth the practicability of polyphase currents which is the principle that makes Niagara a landmark in the journey through the field of electrical progress.

Discovered a Harmless Current.

It is well known that the current which gives the illumination in an ordinary electric light, although an alternating current, is a dangerous thing with which to come in contact and is practically the same force that is used for purposes of electrocution. Mr. Tesla several years ago made the interesting discovery that if the alternating currents could be made to alternate at a vastly increased speed over that which was then known, for instance at as great a frequency as 40,000 or 50,000 or 60,000 or even more times per minute, it would be harmless. He brought the discovery out publicly by making experiments on himself personally before an assembly of prominent electrical students and experimenters in London and the effect was extremely sensational.

It is also by the use of his greatly increased speed of aletrnation, that Mr. Tesla has succeeded in producing what is known as his electric light. It is for purposes of illumination and makes a far more beautiful glow than that of the ordinary light. At the World's Columbian Exposition in Chicago in '93 there was an exhibit of this light and it was considered one of the great features of the fair.

Mr. Tesla will remain in Colorado Springs for several weeks and upon finishing the desired experiments here, will return to his New York laboratories, where final arrangements for the application of his conclusions will be made.

The Denver Rocky Mountain News May 18, 1899

TESLA HERE FOR WORK

To Make Experiments in Electricity on Pike's Peak Summit.

Perfection in Wireless Telegraphy the Result That Is Hoped For.

Assistants On Way to Colorado Springs With Instruments—Resting After Tedious Trip From the East—Scientific Men Much Interested.

Special to The News.

COLORADO SPRINGS, Colo., May 17.—Nikola Tesla, the great electrician, is in this city. He arrived here at noon to-day and immediately engaged a suite of rooms at the Alta Vista hotel. In an interview Mr. Tesla stated that he would in all probability stay in this vicinity for some months, as he intended to make extensive experiments in this altitude, or rather, at the top of the peak. He said he had come here for work and not for pleasure nor for his health.

Two of his assistants are on their way here with instruments, and when they arrive the great electrician will ascend the historic peak and begin his experiments.

Mr. Tesla denied the report that he intended to attempt to send a message from Pike's Peak to Paris by means of wireless telegraphy. He admitted that he was here to perfect his system of wireless telegraphy and that when he had it perfected would try to send a message from New York to Paris by means of it. He said that he would not experiment from Pike's peak to Long's peak or to any of the other mountains in this state, saying that he was here for work and not pleasure.

As soon as it was learned that the great electrician was coming to this city great interest was taken in his visit, especially by the scientific men.

Mr. Tesla arrived in a very quiet way and reached the hotel without any display. At noon Mr. Leonard Curtis, who has known Mr. Tesla for the past fifteen years, took him to luncheon at the El Paso club and he will be Mr. Curtis' guest during the whole time that he is waiting for his assistants to come with instruments. The electrician was very much worn out by his trip from Chicago to this city and kept himself closely confined to his rooms most of the day, excusing himself to nearly all callers on the grounds of his weariness.

To-morrow, in all probability, he will receive the electricians of the college and others who are deeply interested in his work. It is not thought that Mr. Tesla will not ascend the peak until possibly the middle of next week.

The New York Journal And Advertiser May 18, 1899

MAYBE WE CAN TALK TO MARS.

TESLA AND SERVISS HOLD OUT HOPE.

COLORADO SPRINGS, Colo., May 17.—Nikola Tesla arrived in the city this afternoon from Chicago. He will carry on extensive investigations in wireless telegraphy on the top of Pike's Peak at an elevation of 14,000 feet.

"I am here to work out a system of transmission at a distance," he said. "I propose to propagate electrical disturbances without wires. I shall attempt to design an apparatus to use in wireless telegraphy everywhere. Everything is crude yet. I will go to the top of the Peak to-morrow. I have many experiments to make, which will take several months. The electrical conditions at high levels are more active than at lower. I hope to be able to send a message from New York to Paris."

Tesla purposes to establish communication between the earth and Mars. This is to be done by an instrument so sensitive that it will feel disturbances created anywhere on the globe.

Mr. Tesla said: "One of the most wonderful things I have discovered is this instrument. With it I purpose to communicate with Mars.

"The coming century," he continued, elaborating on his lecture before the Commercial Club, "will be the era of atmosphere. From the moment I discovered that air under certain conditions was a better conductor than a brass rod I saw possibilities which made me grow fairly dizzy at their extent.

"The transmission of force and influence to any distance; the use of the sun's energy for all the needs of man, the possibility of controlling things with which there is no visible connection—these and an endless number of smaller achievements have become facts that in a short time will have their practical demonstrations.

"I am going on to perfect the ideas of the transmission of energy which I have found in the new and measureless ocean of the atmosphere about us. The sun has furnished us everything, yet the energy it has to give is not used in the smallest part. The earth itself can be restored to the condition it was when the ferns grew as large as trees.

"Distance, in the new method of transmission, amounts to little or nothing. The idea of wireless telegraphy which arouses such interest now because it is developed to a new basis is not wonderful at all compared to the principle of which it is one application."

GARRETT P. SERVISS TELLS HOW MARS MAY BE SIGNALLED.

GARRETT P. SERVISS explained to a Journal reporter last night how, operating on Mr. Tesla's theory of wireless telegraphy, communication would be established with Mars or any other planet.

"Of course," Mr. Serviss said, "the explanation I give is based on the truth of Mr. Tesla's hypothesis that the possibilities of wireless telegraphy are infinite. This theory supposes that some intermedium conveys electrical waves, making a magnetic connection between the sun and earth. And the fact that there is such connection proves it.

"No doubt, when a great upheaval takes place on the sun (exactly what force causes these upheavals we don't know), an electrical impulse reaches the earth. Auroral displays and magnetic storms are the results of such impulses.

"The sun, under certain conditions, sends to the earth electrical waves which affect the electrical conditions of the atmosphere sufficiently to interfere with electrical and magnetic instruments.

"Now, suppose Mr. Tesla by some apparatus can generate on the earth an electrical impulse capable of being transferred to a certain planet, strong enough, I mean, just as the sun sends electrical impulses to the earth, then, of course, he could affect the electrical condition of the atmosphere of that planet. He could produce a series of interruptions and breaks on it, which, if there were any receiving instruments there, could be translated, as the Morse telegraph code is.

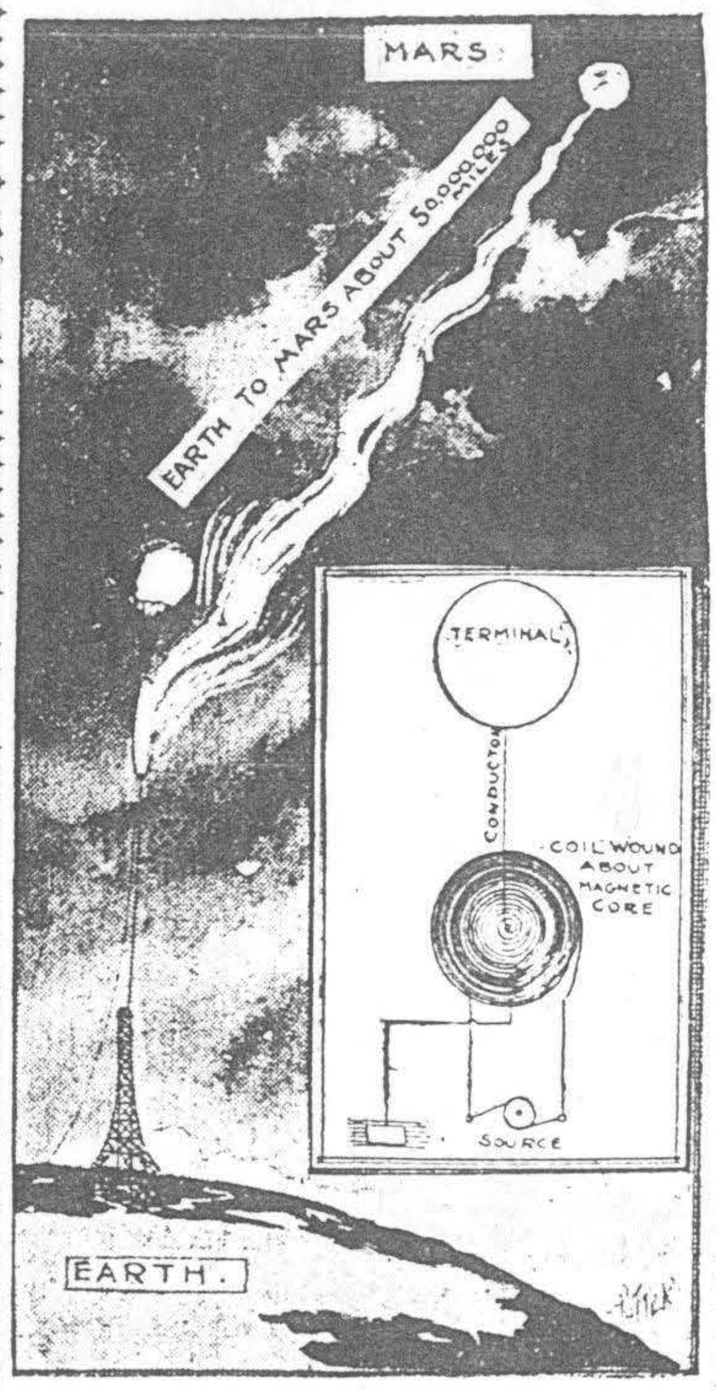
"Of course Mr. Tesla's scheme requires that Mars should have intelligent beings on it, who could respond to him, and as Mars is much older than the earth it is likely that this is the case.

"Assuming that this is so, let us suppose he could send an electrical impulse to Mars, which would produce some visible magnetic effect there. And let us suppose he could send this in the form of a code. Let him send three dots or dashes in rapid succession and after an interval another succession of dots and dashes. An intelligent person on Mars would see somebody was trying to talk with him. It might take years and years for him even to notice this, but, having once taken cognizance, he would set about putting the impressions into tangible shape.

"When the being on Mars decided that some one was trying to communicate with him he would set about translating the code. If Mr. Tesla should persist in following up the telegraphing, in time the receiver on Mars would undertake to find out where it came from. Having established this—not a difficult matter—he would send back, if he could, electrical impulses which would be in themselves a reply. If he could not send a return impulse at first he would reason out a plan, and in the end would find out how to do it. He would reply in a code of his own, just as Mr. Tesla would use his code. And as soon as an agrement of minds could be established it would be necessary only to invent a codal language which could be understood on both planets.

"This might take hundreds of years, but I may say the process would not be unlike the process followed when two men, thrown together and knowing nothing of each other's language, eventually invent a means of communication.

"If Mars's inhabitants are wholly incapable of understanding us, all efforts, of course, would be wasted. But, as I have said, the probability is that the mysterious planet's inhabitants are at least as far advanced as we are. It may be, indeed, that they have long understood these very principles we are just beginning to grasp, and have for years been trying to talk to us. It may be, indeed, that these initial efforts we are experimenting with are our first responses, unconscious that they are responses, to their attempts to communicate with us, and that, instead of making the first advances, we are being led on by them."



SIGNALLING FROM THE EARTH TO MARS BY ELECTRIC WAVES.

The New York Tribune May 19, 1899

TESLA'S COLORADO EXPERIMENTS.

MAY TRY TO TELEGRAPH WITHOUT WIRES FROM PIKE'S PEAK TO PARIS—TO STUDY UPPER-AIR STRATA IN COLORADO.

Colorado Springs, Col., May 18 (Special).—Nikola Tesla, the wizard of electricity, arrived here to-day, to spend three or four months in hard work from advantageous situations on mountain heights, ranging from 10,000 to 14,143 feet in altitude. He is in excellent health and spirits. Two assistants will arrive this week with a complete set of instruments for the investigations to be made.

"I have been preparing for a long time to visit Colorado Springs," said Mr. Tesla. "I have come to carry on a series of exhaustive experiments in wireless telegraphy. I find it necessary to investigate the higher strata of air, which I can well do in this altitude. I will also investigate electrical disturbances through the air and the earth. No, I shall not flash messages from Pike's Peak to Gray's Peak, or Long's, or any other. I am here to work. It is not a pleasure. I am exceedingly busy. Life is short, and there is a great deal to be done. I shall attempt to design an apparatus to be used everywhere in wireless telegraphy. Everything is crude yet. I hope to perfect it.

"I must study the conditions of the upper-air strata. There are great laws and principles which I want to study and command. When I master these I will attempt long-distance signalling.

"I may send a message from Pike's Peak to Paris. In these high altitudes there is much to be learned. The electrical conditions are more active than at the lower levels. This air is charged with electricity. I hope for favorable results."

An eighty-foot steel tower has been erected on the summit of Pike's Peak, which, while disclosing fifty thousand square miles of mountain and plain landscape to the tourists, secures Tesla 14,223 feet altitude. Sunset and moonlight trains, as well as two or more regular day trips over the cog road, make the summit easily accessible to the electrician under varying conditions, which otherwise he could not enjoy. Pike's Peak, while not the highest Colorado mountain, thus offers the most favorable conditions for electrical experiment.

Denver Rocky Mountain News May 20, 1899

TESLA READY FOR WORK

SECURES GROUND FOR AN EXPERIMENT STATION AT COLORADO SPRINGS.

Another Gift of $1,000 Made for a Room in Y. M. C. A. Building—Burglars Rob Warehouse at Noon—Hogeboome Sent to Reformatory.

Special to The News.

COLORADO SPRINGS, Colo., May 19.—Nikola Tesla, the electrician, keeps closely confined to his room and is practically unapproachable. It was learned to-day, however, that he has secured from W. S. Jackson the privilege of using a piece of high land in the rear of the State School for the Deaf and Blind east of the city, where he will construct a station for the purpose of carrying on his experiments. His assistants have not yet arrived with his instruments.

Facts

May 20, 1899



Nikola Tesla, the famous electrician, is now in the city, and will remain for some time. His reputation is world-wide, and he has accomplished wonderful feats in his chosen field of electricity, one of the greatest being the harnessing of Niagara. For some time past his special field of work has been in wireless telegraphy, and his visit here is for the purpose of making experiments in high altitudes. He is staying at the Alta Vista.

Tesla's Visit to Chicago.

Nikola Tesla's visit to Chicago and his published utterances have created a profound impression and have provoked no small amount of comment and criticism. Mr. Tesla came to this city as the guest of the Commercial Club of Chicago and delivered an address before that organization at the Auditorium, where a dinner was given in honor of the distinguished visitor.

The Commercial Club is a conservative organization, the membership being limited to 60 and composed of representatives of the leading commercial interests of the city. It was founded 32 years ago and has consistently adhered to the line of policy originally adopted. The dinner last Saturday evening at which Mr. Tesla was entertained was the 150th event of the kind in the history of the organization, and was therefore a red-letter day in the records of the society.

In addition to the members of the club there were several prominent men present by invitation, and a few electrical experts. Following is a list of those in attendance:

C. H. McCormick.
Nikola Tesla.
H. H. Kohlsaat.
H. G. Selfridge.
George B. Swift.
Edwin A. Potter.
Melville E. Stone.
W. G. Collins.
C. H. Wacker.
F. S. Winston.
George E. Adams.
T. C. Chamberlain.
A. V. Abbott.
Bruce Clark.
J. C. Whitney.
Benjamin Allen.
Samuel B. Downing.
Byron L. Smith.
N. B. Ream.
Robert T. Lincoln.
C. F. Kimball.
John J. Janes.
Granger Farwell.
Edward L. Brewster.
Marshall Field.
N. K. Fairbank.
A. S. Hibbard.
John M. Clark.
W. A. Fuller.
Victor F. Lawson.
S. J. McPherson.
Edward B. Ellicott.
Arthur D. Wheeler.
H. H Belfield.
Carl Keith.
E. G. Keith.
Henry Crew.
A. F. Seeberger.
A. A. Carpenter.
F. Carus.
Rev. Dr. Notman.
J C. Zeublin.
James H. Eckels.
James MacVeagh.
C. W. Corman.
E. W. Blatchford.
C. H. Blatchford.
F. B. Peabody
W. J. Chalmers.
Franklin MacVeagh.
Von Bismarck Plotke,
Baron Heyl.
Robert Hotz.
Henry Favell.
E. M. Barton.
Professor Stevens.
R. N. Fowler.
F. H. Head.
C. Hotz.
J. L. Houghteling.
C. E. Scribner.
C. D. Crandall.
Eugene Cary.
H. J. MacFarland.
D. C. Jackson.
W. H. Merrill, Jr.
Henry A. Knott.
A. T. Evans.
J J. Green.
Henry N. Tuttle.
F. E. Drake.
J. Harley Bradley.
Edward B Butler.
H. S. Carhart.
John V. Farwell, Jr.
Arthur L. Farwell.
Benjamin Carpenter.
Marvin Hughitt.
John M. Whitman.
C. A. Lippincott.
Ernest Proctor.
Charles Procter.
J A. Spoor.
H. N. Higinbotham.
H. D. Higinbotham.
William T. Baker.
Percy B. Eckhart.
B A. Eckhart.
A. J. Earling.
Eugene S. Pike.

At the conclusion of the dinner President McCormick addressed the company, saying:

"We shall be much interested to hear from Mr. Tesla of the realm in which he dwells, which seems to us so incomprehensible, and if we become puzzled at the relative importance of 'amperes,' 'volts,' 'ohms,' 'induction' and 'polyphase currents,' Mr. Tesla must remember that, although we may know more about other things, we are still in the primary class in electricity.

"Since this great force of nature has been made subservient to the will of man, electrical progress has opened a wide field for both capital and labor. The Commercial Club will be interested in knowing that in this country alone the capital employed in the manufacture of electrical apparatus is $50,000,000; the telegraph interests represent $100,000,000; the telephone systems $110,000,000; while the investment in electric lighting is $247,000,000; this statement does not include the electrical equipment for elevated or surface railways."

Mr. McCormick paid a compliment to Mr. Tesla and the work he has performed in this field, and predicted even greater results than those already accomplished.

Mr. Tesla's speech was rather disjointed and disconnected, due partly to the nature of the address, which was punctuated with experiments and side remarks, and partly to his apparent difficulty in expressing his ideas. He took particular pains to make himself clearly understood, however, and the members of the club were highly entertained, although it was evident that they were also greatly mystified by the lecture and the experiments.

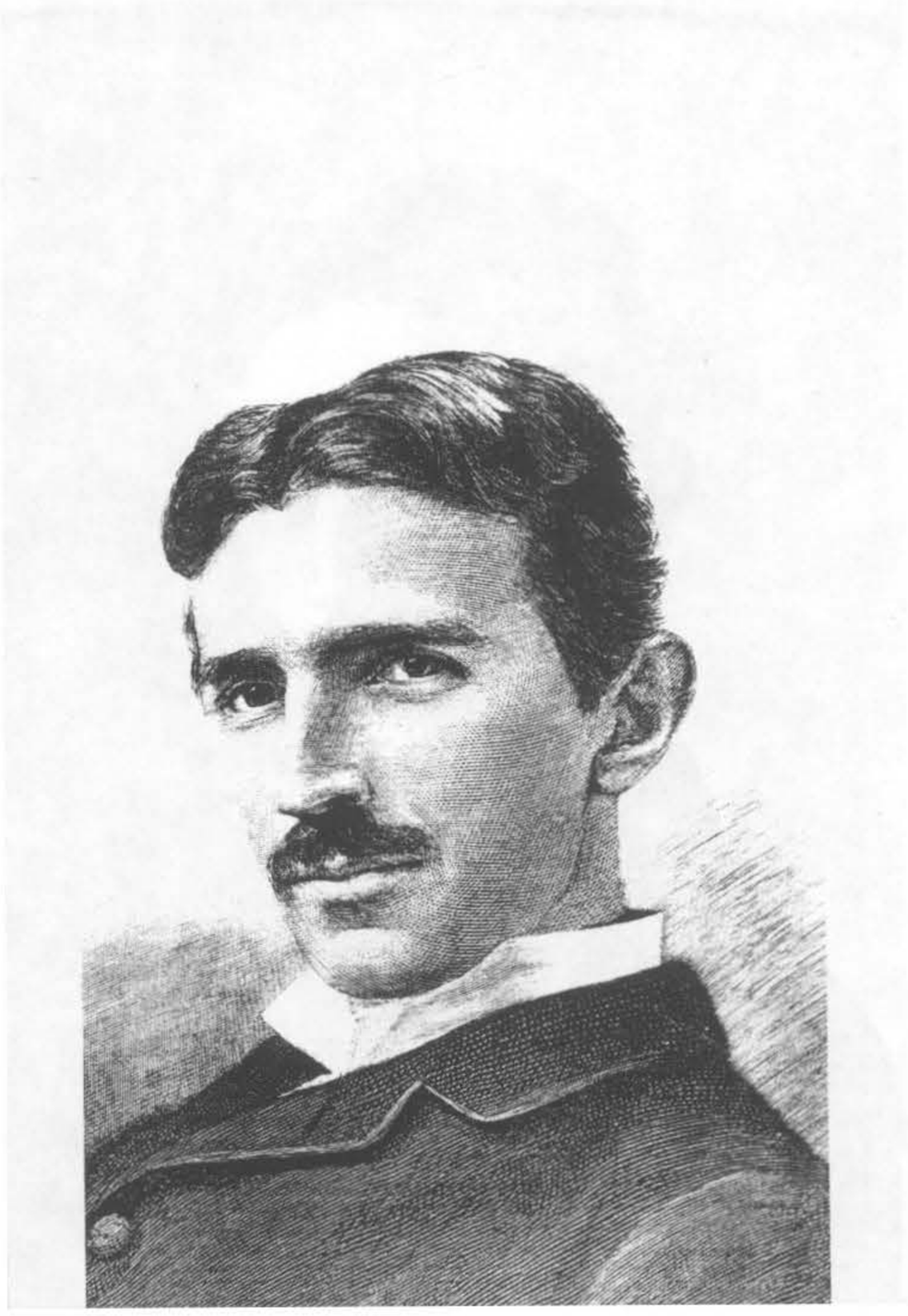
"There is no one," Mr. Tesla said, "who does not speculate about the questions of his existence, asking whence he comes, whither he is going and what in reality he is. Soul and matter and their relations have eternal interest for human beings. On the other side, there is always the desire to comprehend the marvelous manifestations of nature in all its phases. Let us talk of all of these."

With such a flexible subject it is not to be wondered that Mr. Tesla strayed from the paths of electrical science frequently during the evening and indulged in much speculation. He spoke for a time of the two terms, animate and inanimate, saying that he could distinguish between them in common language, but that for the scientist the case was not so simple, and he illustrated his meaning by an experiment with two disks, which he said were similarly constructed.

"One of these has life in it," he said, "and the other has not." Picking them up, he added: "Which is the active one I cannot tell, but we shall soon see." Then, while his assistant turned on a current, he tested each and determined which one was dead and which one was alive.

Then Tesla talked of the possibility of depriving a piece of iron of all its heat and energy until it had reached the absolute zero and the minimum of motion. "When the motion has ceased entirely," he said, "when the ultimate stage of condensation is reached, the matter would disappear. There may be going on in the infinite depths of space a process of appearance and disappearance of matter. We are working to test this by trying to reach the absolute zero. It may take centuries before we can reach this absolute zero, if ever, for the difficulties are very great."

Turning to another point, Tesla said: "It is necessary for us to assume a universal medium for the transmission of force. This results from the necessity of explaining the action of bodies at a distance. Energy is transmitted from the sun to the earth through some very attenuated medium. To show how such medium may be used under



NIKOLA TESLA.

certain conditions I may refer to a feat I once accomplished of converting a column of gas into a solid body by the application of electricity in a certain manner. The gas became rigid and vibrated like a steel wire. Scientific men have not noticed the importance of this as yet. Again, I have produced a solid body in the air on the end of a wire. I made a flame which consumed nothing and which showed signs of solidification, for it offered resistance to the passage of bodies through it."

He then told of a method he had invented for the production of ozone, which could be made in commercial quantities for sterilization and for purposes of sanitation. It was made by the process he followed in the production of this flame which had the power of resistance.

"The forces of the air may be utilized in a manner now that we have not learned to even contemplate. Nitric acid may be made from the components of the atmosphere."

"This nitric acid may be made to fill our reservoirs and then utilized to produce the energy we need and to transmit energy to almost unlimited distances."

His greatest invention, he said, was in utilizing the forces of the air.

"The air, which is an insulator," he said, "becomes a conductor by means of the millions of volts I am able to produce. It means the using of the air for all purposes and uses of men. Not only for the transmission of messages without wires, but for the transmission of power in any amount to any distance across the earth's surface."

Turning again to the distinction between living and dead objects, he said the two were not antithetic, but that the distinction was one in consciousness. He criticized the superficiality of the ordinary idea of life, saying that if our senses were keener we would entirely lose the feeling of individuality. He said that there were experiments which could prove scientifically the question of the continuation of individual existence, but that these experiments were impossible to perform. They would consist, he said, in demonstrating that any atom in the body behaved differently toward atoms in the same body than toward atoms on the outside. He next described the stages in the appearance of life on the globe, saying that all life was originally generated in the water. Ranging all the way from the lowest forms of animal life to the most complex, he pointed out the impossibility of showing the exact point at which life can be said to appear. Then he discussed the distinction between the phenomena of cause and effect and phenomena which mystify us. He gave his hearers something to see, flashing light in vacuum tubes without the aid of wires. Then he took a long tube in his hand and waved it like a flaming sword in the air before the machinery.

Describing many of the phenomena of his life and experience, he told how he had come to the conclusion that he was nothing else but an automaton in every act and sense. He explained how memory could be regarded as automatic, and told his hearers that some time he would write a philosophical treatise based on the facts he had observed.

"If I am an automaton," he said, "why should I not construct an automaton like unto me? What are the elements necessary? I am a heat-generating being, with powers of locomotion, with machinery to direct my movements, with a sensitive mechanism to provide data, and with a governing mind. My automaton must have all these qualities."

Mr. Tesla performed many of the experiments with which his name has been associated, showed his oscillator and explained its principle and operation, and then produced a model of a boat which he used to demonstrate in miniature his system of firing torpedoes and controlling the operation of machinery at a distance by means of electricity without connecting wires. In this connection Mr. Tesla recorded his claim to the invention of the system of "wireless telegraphy" with which Marconi's name is now generally associated.

At the conclusion of his address Mr. Tesla was the recipient of many compliments from members of the organization. Much curiosity was shown over the apparatus employed, especially that used in directing the boat and exploding torpedoes. Owing to the lateness of the hour it was impossible to examine it closely. The electricians who were present refrained from commenting upon the exhibition and the apparatus employed, as they did not have an opportunity to go into the matter thoroughly.

On Monday morning the Chicago Tribune printed an interview with Tesla, in which he was quoted as saying that he proposed to establish communication between the earth and the planet Mars by means of an instrument so sensitive that it will feel disturbances created anywhere on the globe. Mr. Tesla pronounced this instrument "one of the most wonderful things I have discovered."

"The coming century," said Mr. Tesla, elaborating on his lecture before the Commercial Club, "will be the era of the atmosphere. From the moment I discovered that the air under certain conditions was a better conductor than a brass rod, I saw possibilities which made me grow fairly dizzy at their extent. The transmission of force and influence to any distance, the use of the sun's energy for all the needs of man, the possibility of controlling things with which there is no visible connection—these and an endless number of smaller achievements have become facts that in a short time will have their practical demonstrations.

"I am going on to perfect the ideas of transmission of energy which I have found in the new and measureless ocean of the atmosphere about us. The sun has furnished us everything, yet the energy it has to give is not used in the smallest part. The earth itself can be restored to the condition it was in when the ferns grew as large as trees. Distance, in the new method of transmission, amounts to little or nothing. The idea of wireless telegraphy which arouses such interest now because it is developed to a new basis, is not wonderful at all, compared to the principle of which it is one application."

The Denver Rocky Mountain News May 21, 1899

TESLA HAS A RIVAL

Denver Man Has Invented Plan for Overcoming Induction.

Says He Can Telephone or Telegraph From Trains Moving Rapidly.

Astonishes All Experimenters by Saying That Oil Is a Good Conductor of Electricity and Other Inventors Make Mistake in This Respect.

Denver has a modern Tesla who out-Teslas even the wizard himself and who treats the impossible with a lightness that would easily confuse the experimenter at Colorado Springs. And Denver's Tesla has cropped out all because Tesla, the real, has achieved some favorable notoriety. There is one difference, however, between the two men. One has invented "things" and put them into use. The other promises to do so.

William Fremont Parker was at the Albany hotel last evening. He received his friends there, but his name didn't appear on the register. He replied when asked for his residence address that he was "in and out all the time."

About a year ago Mr. Parker experimented with telegraphing from moving trains. He stretched a few hundred feet of wire near a side track at Parker's station on the Colorado road and rigged up a little trolley to a car loaned by the company. The car was moved backward and forward and Mr. Parker sent a short message to Superintendent Dunaway. All this was by no means new, for several eastern roads have long been taking and receiving messages from moving trains, but not by the trolley method, however.

Mr. Parker last night told of the great benefit his invention would be to mankind. "Why, it will save the lives of 1,500 people each year who are killed in railroad wrecks." His idea is to put a bell in each of the coaches to alarm the passengers just before an accident happens.

But incidentally, Mr. Parker said he had discovered a method for overcoming induction from wires and making each line work without interference from others. This is entirely new, for electricians have for years considered this possible only by impracticable methods.

Then, Mr. Parker said his invention would permit the use of telephones from moving trains, but he would be compelled he said, to build insulated and sound proof rooms on the trains.

"How fast will your trolley work?" was asked.

"Oh, with a carriage well oiled and built of gutta percha and six-inch aluminum wheels with three-inch slots it will easily run 100 miles an hour and maintain a solid contact with the wires at exactly ten pounds pressure."

Then Mr. Parker said he had discovered that oil is a good conductor of electricity. That was entirely new, inasmuch as Tesla seems to have made the mistake of using oil to insulate his high potential converters in which currents of 40,000 volts are employed.

"Yes, it's a fact. Oil is a good conductor. Any street car man will tell you that," continued the inventor. He further explained that since his test he had done nothing with his inventions, but that he had written to the heads of several railroads and the Burlington had promised to permit him to build a hundred miles of wires along its road—under certain conditions.

THE arrival of Nikola Tesla at Colorado Springs, Col., on the 18th inst. has been announced in dispatches to the daily papers. Mr. Tesla has taken the trip to Colorado for the purpose, as he states, of carrying on "exhaustive experiments in wireless telegraphy." He has found it necessary, he says, to investigate the higher strata of air, and has chosen Pike's Peak as the location most suitable for his experiments. An eighty foot steel tower has been erected on the summit of the Peak, which, while disclosing fifty thousand square miles of mountain and plain landscape to the tourist, secures Tesla 14,223 feet altitude. Sunset and moonlight trains, as well as two or more regular day trips over the cog road, make the summit easily accessible to the electrician under varying conditions which otherwise he could not enjoy. Mr. Tesla is quoted in the dispatches as saying: "I must study the conditions of the upper-air strata. There are great laws and principles which I want to study and command. When I master these I will attempt long-distance signaling. I may send a message from Pike's Peak to Paris. In these high altitudes there is much to be learned. The electrical conditions are more active than at the lower levels. This air is charged with electricity. I hope for favorable results."

THE Chicago *Journal* has some facetious comments on Mr. Tesla's lecture before the Commercial Club at the Auditorium. It says: "Such a little thing as a quiet chat with inhabitants of the planet Mars will, if Tesla is sincere, be an everyday occurrence, and when you hang up the receiver of your Mars-communicating instrument, you may go out in the back yard and watch the weeds grow as large as poplars before you can say Jack Robinson. The vegetable kingdom will so abound with the two essential constituents, nitric acid and ammonia, that the luxuriant growth of the prehistoric eras will thrive again. Bananas will be as large as telegraph poles and peanuts like pumpkins, if Tesla can thus help the sun along."

Facts

May 27, 1899



The banquet given at the El Paso Club last Tuesday evening by Mr. Leonard E. Curtis was a memorable occasion. It was in honor of the distinguished electrician, Nikola Tesla, who is now in the city for a long visit. The eminent inventor is an old friend and client of Mr. Curtis and the host invited about twenty prominent men to meet him at dinner. After a few introductory remarks by the host, the noted guest talked entertainingly of his early life and ambition and of his latest successful achievements. The wonderful possibilities of wireless telegraphy and transmission of power were commented upon and his hearers were convinced that they were listening to one who is a thorough master of his subject and without a peer in his chosen field of investigation and invention. Governor Thomas, in a few well-chosen remarks, expressed his pleasure at being present and in meeting the guest of honor. Mr. Tesla is of a very retiring disposition and abhors notoriety of every kind. Like most men who have achieved greatness in any field of work, he is averse to talking of his successes. As his visit to Colorado Springs is for the purpose of special experiments in a high altitude, much interest is felt in his movements and operations.

In Society

Society has had a chance to do some lionizing;
And that the thing was carried out in style, is not surprising.

There's Tesla, who on Pike's high peak, will lure the lurid lightning
That with its jagged flash, forever common men is fright'ning.

There's Schley, the gallant admiral, a hero of the nation,
Who on the briny deep at Santiago won high station.

They're both aware that this fair town is famed for entertaining
Any guest who hereabouts, perchance, may be remaining.

Mr. Leonard E. Curtis entertained at dinner on Tuesday evening at the El Paso club in honor of Mr. Nikola Tesla, the eminent scientist. Twenty gentlemen were present, including Governor Thomas.

The Colorado Springs Evening Telegraph June 2, 1899

TESLA'S STATION IS READY

The building in which Nickola Tesla will conduct his experiments has been almost completed and will soon be ready for the use of that scientist and for the reception of such apparatus as he may deem necessary to the success of his trials. The building is a rough board structure and has been located on the north side of East Pike's Peak avenue, not far from the balcony which has been built on top a magnificent view of the grand old peak may be obtained. Nor have the plains been neglected. Mr. Tesla has, with the assistance of several friends here, endeavored to locate his experimental station as advantageously as possible in order to obtain the full benefit form mountain and plain, both of which the great electrician believes to be necessary to secure the best results from the tests that he will make within the next month or so.

The building is roughly boarded up, and is about 50 by 60 feet, with a lean-to in on the west, or front, in which are two windows and a big double door, the latter secured by a padlock. The structure is about 18 feet high, with a 12-foot roof, which slopes from near the center toward the four corners, thus enabling the carpenters to construct a fairly large platform or stand on the roof. The center of the building has not been covered, and Mr. Tesla will place his apparatus in the middle of the one big room, allowing it o extend upward out through the roof and above the platform which has been built around the aperture. That he intends to make use of the plains as well as the peak there is no doubt, as the magnificent view which can be obtained of both from the building clearly indicates Mr. Tesla's intention in this direction which he has also expressed to his friends. It is possible that he will make experiments in sending messages without wires from the top of Pike's Peak to the station and then endeavor to continue the system out across the plains. Or, if he intends to make experiments in the new and almost untried field of the transmission of motive electrical power without the aid of wires, the plains will also be of advantage to him in order to ascertain from how far a current, generated on the peak, can be utilized on the plains below, or vice versa. There is no doubt that Mr. Tesla intends to conduct experiments in one and perhaps both of these fields, and the whole civilized world will await with interest the result of his tests. If successful in either field it will completely revolutionize the present method of transmitting messages and motive power, and a new era in so far as the uses of electricity is concerned will have been ushered in with the new century.

Mr. Tesla is living very quietly at the Alta Vista hotel. He seldom sees any but his most intimate friends, and being naturally of a retiring disposition shirks as much as possible the many social calls that are made upon him. He has visited the new station and has expressed himself as being pleased with it, declaring that he believed the best results could be obtained there from the experiments that he desired to make. The building, which is exceedingly simple in design and architecture, was constructed after plans furnished by Mr. Tesla himself. After the building was completed Mr. Tesla feared that owing to a lack of sufficient foundation it might be wrecked by some high wind or gale, and at his suggestion the structure was securely braced on all sides except the west, and there is now hardly any likelihood of it blowing away, from which it may be inferred that Mr. Tesla is a great scientist, but a poor architect.

It is understood that the apparatus will be placed in position as soon as it arrives from the east, and that Mr. Tesla will then devote himself to daily work in the station.

A SPRINGS YOUTH MAY BE A TESLA

Is Transmitting Telegraphic Messages Without Wires

STATIONS ARE 60 FEET APART

Burnell Ford, a Clerk Employed by Mr. W. N. Burgess, is Working With Some Considerable Success at Wireless Telegraphy — Began With His Stations Only a Foot Apart — Almost All His Work is Done at Night and With Equipment Which He Has Made Himself—Will Now Erect a Pole on His House and Go Further.

Nikola Tesla, the world famed electrical discoverer and experimenter is not the only man in Colorado Springs who is exerting himself to perfect a system of wireless telegraphy. The world looks to Tesla and it is to be expected that either he or some other experimenter of long years of experience will be the first to proclaim to the world his success in what is the great problem in electrical research at the present day.

Notwithstanding this fact there is a young man in Colorado Springs who is laboring along the same line or for the same end and who has attained at least some degrees of success. He is Mr. B. R. Ford, a young man of about 22 or 23 years of age, who has been for some time employed in the store of W. N. Burgess.

What He Has Accomplished.

Mr. Ford resides at 712 East Huerfano street, and it is there that his efforts are being put forth and that he has achieved his present success. He has a laboratory which he has himself fitted up and although it does not contain the vast amount of equipment that is available for the use of experimenters who have unnumbered thousands at their disposal, it has been sufficient for him to have made progress which is, to say the least, encouraging.

Mr. Ford has been at work for several months. At first he applied his theories with his stations only one or two feet apart. Finding himself successful he moved them apart to a distance of eight or ten feet and was soon transmitting messages successfully from one to the other. He has continued in his efforts until now he is successfully transmitting messages from a station in his laboratory, through the walls of the building, to another station 60 feet distant.

To Direct the Rays.

As is the case with all experts who are endeavoring to perfect a system of wireless telegraphy, Mr. Ford is directing his study and effort toward securing control of the direction of the rays of electricity. In his experiments he is using an Edison battery to excite his coils and an ordinary salammoniac battery on his condenser. While not making any big claims as to what he is going to do or pretending that his present success is anything that should startle the world, Mr. Ford is extremely enthusiastic in his work and belives that his progress toward the goal will continue.

He will immediately erect on the roof of his house a pole about 30 feet in height and from a station on that pole will endeavor to communicate with different points.

His Instrument Clicked.

The young Colorado Springs experimenter has brought about his present success as a result of hard and careful work at such times as he could devote to it. Being engaged as he is during the entire day the most of his work must be done at night and it has been so.

He states that a few days ago he was sitting in his laboratory watching the instrument by his side when all at once he heard it begin to tick. The signals came clear and distinct but were too rapid for Mr. Ford to catch and he does not know what was the story told by his instrument. He staid beside it, however, and heard it click more or less for two hours and a half. He has not yet discovered what was the source of the rays which operated his instrument. Were it not for the failure to have heard it at other times he would believe that the source was in the Santa Fe depot which is near his home.

Will Continue the Work.

Mr. Ford expects to continue the work along the lines of his present activity. He is compelled to make a considerable portion of his equipment and to gather up different parts anywhere he can but the result of what he has thus far done would indicate that he knows how to use what he gets. Doubtless his work will be watched with great interest by all Colorado Springs.

Nikola Tesla.—We notice in the *Western Electrician* an account of a lecture given by Nikola Tesla before the Commercial College, Chicago. Our contemporary remarks that Mr. Tesla's speech was rather disjointed, partly owing to the nature of his address, which was punctuated with expressions and side remarks, and partly through his apparent difficulty in expressing his ideas. "There is no one," Mr. Tesla said, "who does not speculate about the questions of his existence, asking whence he comes, whither he is going, and what in reality he is. Soul and matter and their relatiors have eternal interest for human beings. On the other side, there is always the desire to comprehend the marvellous manifestations of nature in all its phases. Let us talk of all these." We quite agree with our contemporary, if the following remarks are correctly reported. For instance, we are told that Mr. Tesla talked of the possibility of depriving a piece of iron of all its heat and energy until it had reached the absolute zero and the minimum of motion. "When the motion has ceased entirely," he said, "when the ultimate stage of condensation is reached, the matter would disappear. There may be going on in the infinite depths of space a process of appearance and disappearance of matter. We are working to test this by trying to reach the absolute zero. It may take centuries before we can reach this absolute zero, if ever, for the difficulties are very great." Again, Mr. Tesla referred to an experiment in which he said he converted a column of gas into a solid body by the application of electricity in a certain manner. The gas became rigid and vibrated like a steel wire. We can quite conceive that the lecture was exceedingly difficult to follow, but we think that Mr. Nikola Tesla would enhance his reputation more by delivering a lecture which was clear and comprehensive rather than by delivering himself to utterances which were evidently intended to mystify those to whom he was speaking.

BURNELL FORD AND WIRELESS TELEGRAPHY

Colorado Springs' Young Experimenter and His System

DESCRIPTION OF HIS LABORATORY

Has It Equipped For Experiments in Electricity and Chemistry---Lighted With Acetylene Gas — Has Erected a Forty Foot Pole on the Roof and Will Experiment at Increased Distance.

As stated in the Gazette a few weeks ago, there is in Colorado Springs a young man who is making some remarkable strides toward success in wireless telegraphy. Since that announcement of his achievements it has been the privilege of the Gazette to make further investigation of his work and to witness the results which he is able to bring about.

Ford's Success to Date.

Since that time, also, the young man in question, Mr. Burnell Russell Ford, of 712 East Huerfano street, has been continuing his experiments and has attained even more gratifying results than were then announced. He is now transmitting messages a distance of 75 feet and through the walls of a brick house and is perfectly confident that when he can get his stations farther apart he can successfully transmit messages by telegraph through greatly increased distances. By reason of the necessity of removing a considerable weight of apparatus with his receiving instrument each time that he removes the receiver, he has been unable to ascertain the full extent of his success. He has now erected a 40-foot pole on his laboratory and will try for greater distance, sendind out his electro-magnetic waves from a plate on this pole.

Mr. Ford and a reporter for the Gazette spent an hour and a half in the young electrician's laboratory the other evening and the experiments were tried and the reporter was astonished beyond expression. There was something more than admiration in the thrill which passed through him as he watched the youthful experimenter operate a little key similar to that which is used in transmitting any telegraph message, saw a little spark fly from one wire to another each time the key was pressed and heard a receiving instrument stationed at the extreme far end of the room, entirely disconnected from the transmitter, respond with its sharp, quick click as regularly as the sender pressed his key.

Concerning the Laboratory.

The scene of the operations of this young man is a very interesting place. He has built in the back of his yard a small house, probably 10 by 10 feet in size. In this he has a corner for photography; on the wall there is a small library of electrical works including the leading scientific papers and many up-to-date books; one corner is devoted to chemistry, and is well equipped for the study of that science. On one wall there is a big plate which comes into use in many of his electrical experiments; a long bench for general utility is upon one side of the room, and wires and batteries and parts of different instruments may been seen on any part of the walls or the shelves. In one corner there are four Edison-Lalande batteries and upon a small stand made for the purpose there is an induction coil about 10 inches in height and 10 in diameter. This coil was made by Mr. Ford and took all his spare time for about three months.

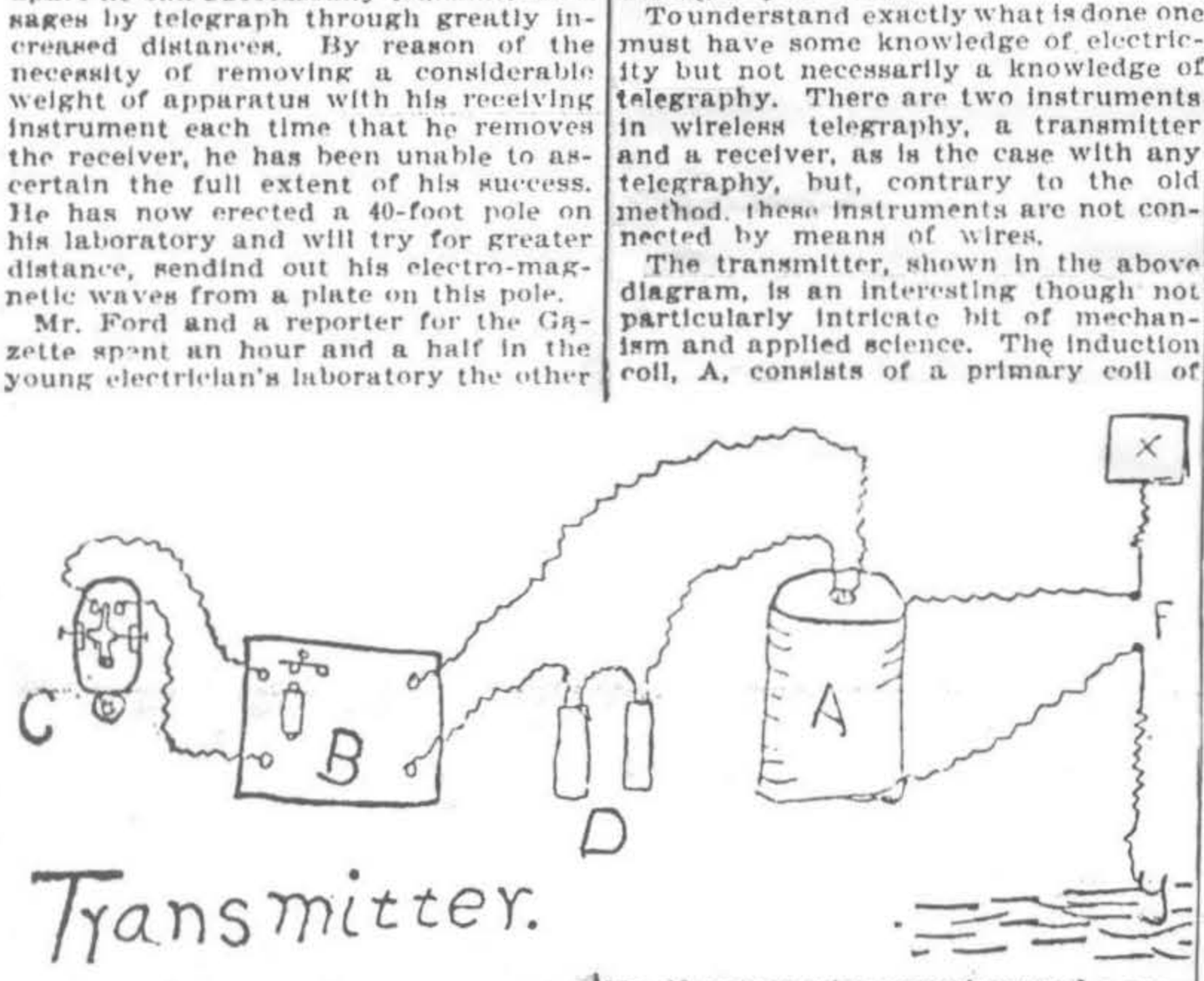
One of the extremely novel features of the laboratory is its light. Mr. Ford has succeeded in making Acetylene gas, generating it with an automatic generator of his own manufacture.

Detail of the System.

While there are a hundred things of interest in this little "den," the greatest interest centers in the subject which takes one to the place—the transmission of telegraphic messages without the agency of wires.

To understand exactly what is done one must have some knowledge of electricity but not necessarily a knowledge of telegraphy. There are two instruments in wireless telegraphy, a transmitter and a receiver, as is the case with any telegraphy, but, contrary to the old method, these instruments are not connected by means of wires.

The transmitter, shown in the above diagram, is an interesting though not particularly intricate bit of mechanism and applied science. The induction coil, A, consists of a primary coil of No. 18 copper wire wound around a core of soft iron pipes. Around this is wound several miles of No. 36 silk-covered copper wires, which form the secondary. The secondary is insulated from the primary by a thick wax tube. B is an automatic circuit breaker with a condenser in the base. C is a common telegraph key. D represents four Edison Lalande batteries.



Transmitter.

The sender of a message, by pressing the key at C, causes a stream of sparks to pass in rapid succession between the two points at F, these sparks sending out electro-magnetic waves through the air in all directions. In sending a message all that is necessary is for the operator to use a key at C, just as he would in sending an ordinary telegram. A spark at the points, F, responds to every touch of the key at C. One terminal of the secondary connects with the plate, X, which is hanging on the pole above the roof of the laboratory. The other terminal is connected with the ground, Y.

The coherer, which is the detecter of the electro-magnetic waves, and really the secret of the system, is a discovery of Marconi's to a great extent. It is really, however, a comparatively simple bit of apparatus. Mr. Ford's coherer is a small glass tube filled with a mixture of iron and brass filings, the iron having been exposed for some days to the air. Running down into the filings are the two copper wires, H and I, H being connected to a metal plate, J, and also being connected to one pole of the battery, L. The wire that then connects I with the ground is connected through the relay, M, and back to the battery, L.

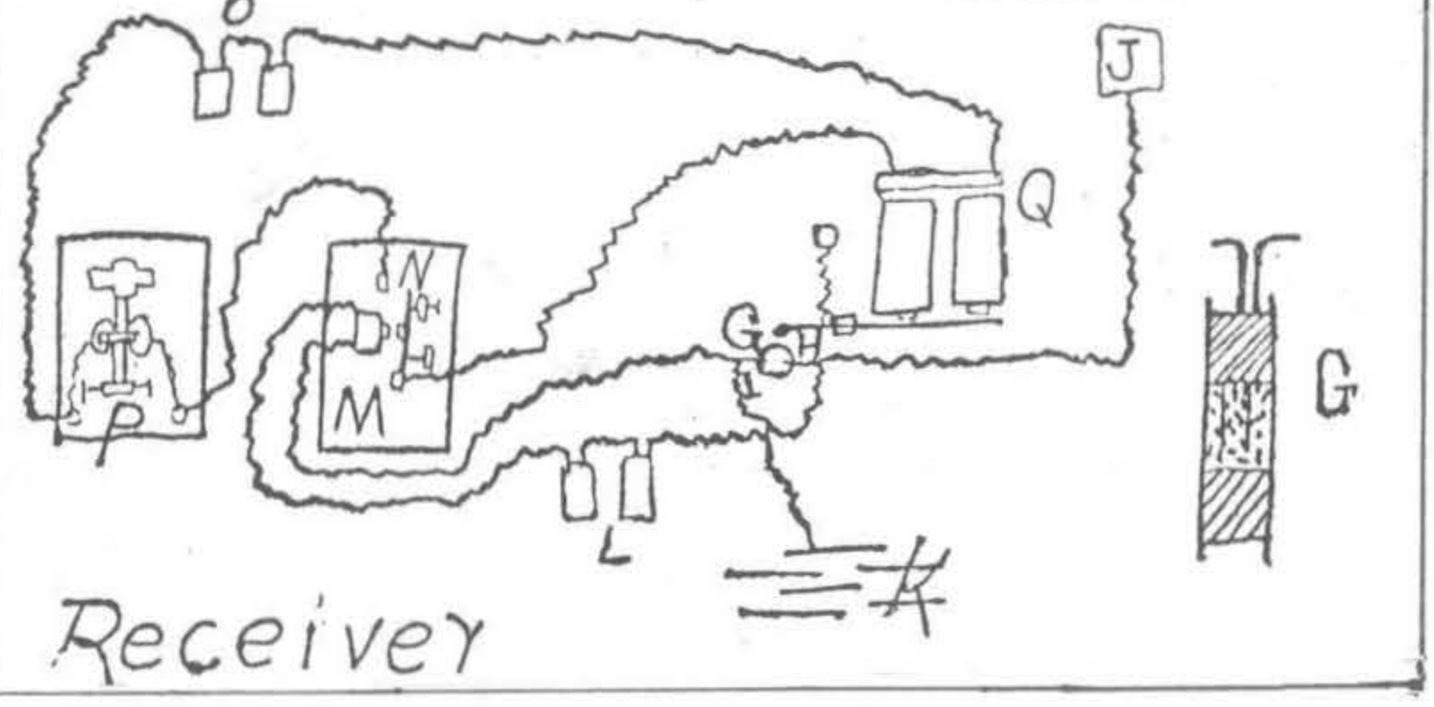
When no electro-magnetic waves are passing through the air the resistance of the filings in the coherer, G, is so great that the battery current cannot pass. But immediately upon the pressing of the key, C, of the transmitter, a spark passes between the points at F and the electro-magnetic waves, being sent out through the air, arrange the filings in the coherer, G, in such a position that the resistance is considerably reduced and sufficient current from the battery, L, passes through to work the relay, M, which is in the same circuit. The relay, in turn, closes the circuit at N and a current flows from the battery, O, through the ordinary telegraph sounder, P, through the contact point which was closed by the relay, thence through an electro-magnet, Q, which causes a small brass ball to tap the coherer, G, thus disarranging the iron and brass filings inside and breaking the relay circuit. The receiver is then ready for another electro-magnetic wave from the transmitter. At the instant the key at the transmitter is pressed the coherer and relay act, the sounder clicks, the coherer receives a little tap and the receiver is ready for another pressure on the key. Thus messages may be sent by the same code used in ordinary telegraphic work, but somewhat more slowly.

Some Other Experiments.

While the wireless telegraphy is the most important experiment at which Mr. Ford is working, as, in fact, is the case with electricians who are known far more widely, it is not the only line along which he has been thinking. He has found that an ordinary incandescent light bulb, when held in proximity to but entirely separated from almost any part of the transmitter, will show a beautiful effulgence. It is rendered much more beautiful and interesting if the ends of the bulb be wrapped in common tinfoil. A stranke fact is that no two bulbs will give the same kind of a light. One will show a pale, greenish, misty light; another shows figures and squirmers which remind the beholder of Eugene Field's "Seein' Things at Night;" another shows perfectly-formed stars and other shapes, and other queer fancies of just as diverse nature can be seen.

The young man is applying in his experiments much that he has learned in his studies under the International Correspondence school of Scranton, Pa. All his work must be done at night and at spare moments, as he is in the employ of W. N. Burgess and is busy during the day.

"That is one of the things I do not understand," said Mr. Ford, as he put another incandescent light globe up to the plate and brought out some new pictures, "but it's the kind of thing I meet with all the time. I have a few ideas that I am working on that I hope may prove interesting, but I do not care to tell much about them, as they may not amount to anything. I have put up this 40-foot pole to get bigger results with the telegraph. The greater the distance through which the message is to travel the higher the plate needs to be. At least that seems to me to be the case, but I don't know why it is. The ground may short circuit it if it is too low, or there may be some other force that I do not know of. At any rate, it is a very fascinating study."



Receiver

In Society

Nikola Tesla was visited by Herr Baumgart, of Frankfort-on-the-Main, Germany. He is an electrician of considerable renown.

The Colorado Springs Evening Telegraph June 21, 1899

TESLA IN HIS WORK ROOM

All the apparatus necessary to successfully conduct his experiments, has been received by Nickoln Tesla, and his experimental station near the Printers' Home is rapidly taking on an air of activity. The rough frame structure is filled with dynamos, electric wires, switches, generators, motors, and almost every conceivable invention known to electricians, and through this mass of intricate and dangerous mechanism Mr. Tesla walks as fearlessly as if on the streets of the city. He knows, perhaps, better than anyone else, just how deadly his appliances are, but he works with them without the least fear, though the least bit of carelessness on his part would result in instant and awful death.

He has several assistants, all of whom handle the various electrical appliances with great caution, but Mr. Tesla seems to know the exact condition of every wire and every dynamo in the house. He has no fear of grasping a "live" wire, and handles the powerful machines which are to generate the currents of electricity that are to be transmitted to Pike's Peak in the form of intelligible messages, without scarcely a thought as to the great danger.

Mr Tesla's experiments have not progressed very far, as yet, and though he is averse to talking for publication, it is known that he has done nothing that would warrant him in asserting that wireless telegraphy, as he conceives it, can be devoted to practical use. Mr. Tesla has two little rooms on each side of the main work-room which he has fitted up in a plain manner, and in these he plans out the details of his work and his experiments. The main apparatus is ,of course, in the center of the big building, and is very complicated. It was put in place by the assistants upder the personal direction of Tesla, and while it is in good order, nothing has been accomplished of enough importance to be given to the public.

Within the next week, however, it is hoped that something tangible will be accomplished, and that Colorado, and Colorado Springs in particular, will again be the center of all eyes in the civilized world, in having been the place where Tesla successfully demonstrated that wireless telegraphy was an assured fact and that electric motive power can be transmitted for a considerable distance without the aid of wires.

NIKOLA TESLA EXPERIMENTS IN THE MOUNTAINS.

ABOUT a quarter of a century past, books of "Familiar Science" were popular in certain of our institutions of learning, together with "Chronology," taught as a separate branch, disassociated from events,—and Magnall's Questions. The exhaustive study of "Ancient Geography" was also commended, and " a page of dictionary" was the invariable spelling lesson. Walker was the standard authority, and in his pages the present writer learned to spell music, "musick," and sundry extra "u's" and doubled consonants, which are fine old historical English, Isaac Pitman to the contrary notwithstanding. It was the special privilege of the book of "Familiar Science" to hurl disconnected facts at the scholar's head—to pelt him with the arbitrary processes of nature—"Why does dew fall?" paraded arm in arm with "Why does a cat's fur emit sparks when you stroke her in the dark?"

But the chief glory of the "Book of Familiar Science" was a full-page wood-cut of placid Benjamin Franklin, in broad-brim and gaiters, flying his scientific kite, and bringing lightning down from the skies by the aid of a large door key. The experiment marked the beginning of electrical science in America. "The knowledge of this world passeth away."
away."

In the first years of 1800, Lieutenant Pike camped at the foot of his great "Mexican mountain"—that "far blue cloud" which allured him over many a mile of wilderness march, and from his reports of discovery of Pike's Peak and exploration at the head-waters of the Platte and Arkansas, began the exodus from the Missouri river—first over the Santa Fe trail direct—and then gradually diverted to the north, where "Pike's Peak or Bust!" became the motto of the "'59er."

The years to be dated 1800 are fast drawing to a close, and in spanning them in thought, with all their stirring happenings and marvellous achievements, not a hundred years later than Zebulon Pike, we find another discoverer camped at the foot of Pike's Peak, armed with a more mighty key to electrical science than that of Poor Richard.

Nikola Tesla, the Servian scientist, whose electrical discoveries are not of one nation, but the pride of the world, has taken up his abode in Colorado Springs, where he will remain for some time conducting experiments in the medium of light air, and perpetual sunshine.

On East Pike's Peak avenue, with limitless plains stretching to the eastward, and a panorama of mighty mountains sweeping away north and south, to the west—Tesla has caused to be constructed a station for scientific research. It is a building, which, when complete, will cover an area of from 50 to 60 feet, with an extension with two windows and a large door. The structure is about 18 feet high, and crowned with a large platform. The center of the building remains unroofed to permit the scientific apparatus to project above, and to be inspected and regulated from the surrounding balcony. The structure has been built according to Mr. Tesla's own plans, and in telegraphing without wires from plain to mountain, or from mountain to plain, it would occupy an equally central situation.

It is said that Mr. Tesla's experiments will take this direction, though he is, naturally, reticent upon these points, until he is assured, by the success of his experiments, that the results are prepared to meet the demands of the scientific world.

With Tesla's wireless telegraph oscillator, he affirms he could talk to the inhabitants of the planet Mars, and will talk to the people of this earth, at any distance away, without the assistance of wires. Into the great oscillator Tesla will turn an ordinary current of electricity. The os-

cillator instantly transforms this electric current, by a series of coils, into an electro-motive force, vibrating at the rate of 2,000,000 to 4,000,000 times a second. This starts electric waves through the air and earth, which vibrate almost as fast as the waves that produce light, and travel with the same speed. These waves, like X-rays, pass through any dense substances, and, according to Tesla, there is nothing to prevent the transmission of messages by their aid directly through the earth. Tesla's plan for cabling across the Atlantic is to erect two terminal stations, one in London and one in New York, with the oscillators placed at the top of high towers, communicating thence with great disks suspended in captive balloons floating 5,000 feet above the earth to catch the strata of rarefied air through which electrical waves travel most easily. A message could be flashed instantly by these lightning rays from the oscillator to the disk in the balloon, and across the thousands of miles of intervening space to the second disk. Cable tolls would be reduced to a minimum ,and messages flashed around the world at little more than letter postage rates. Mr. Tesla says he is ready to put his wireless system into operation as soon as the practical details can be arranged.

In inter-planetary communication, however, it would be necessary to have a receiver upon the objective star, and it is also a pre-requisite that the inhabitant of Venus or Mars (if there he be) should—unlike some who wear the uniform in this sublunary sphere—"know enough to take a message."

The oscillator, charged, seems like a vivid sphere, fairly radiating light and glorious possibilities. Who that has looked into the soft green depths of light, in the heart of which lies hidden the X-ray (to which matter is no longer opaque and impenetrable), has not felt that under the touch of electric light and force, power is limitless and the future boundless?

In Bulwer-Lytton's novel of "The Coming Race," the heroine was a "perfect woman, nobly planned," on a superhuman scale. She and her sisters took the initiative in all good and wise achievement, while the men of the coming race somewhat lagged in the rear. By means of the "vril" staff, power was transmitted or arrested, in an incredible degree. The labor of the coming race was performed by automata, vivified and directed by the action of "vril," according to the mind of him who held the staff. In the spirit of the woman who wished that "posterity was here —right now," the employer of the present longs for the "vril" staff. There are so many, who, upon attempt of direction by the guiding mind, do the thing that is not wanted, in just the way that is not desirable or right.

Colorado, with her enfranchised women, opens a future for the sisterhood of the coming race. Tesla, in an interview with a representative of the Denver Republican, indicates that the day of "vril power" is not far distant.

"I would," said Tesla, "light whole cities and give to mere machines all the motions of intelligence. I have given demonstrations of this discovery of mine before bodies of men of science many times, but they have found it difficult to believe me. I gave a demonstration of one experiment, which I think is the most beautiful I have ever tried. I think if I live a long life and work all the time I shall never have a more beautiful experiment than that. I had a boat without crew or captain, which I controlled merely by the force of my intelligence. I would will 'turn,' and it would turn, 'go to the right,' and it would go to the right, 'to the left,' it would go to the left. The beautiful thing about it was that it seemed to be instinct with life, and, as a dog obeys the commands of his master, so this machine obeyed mind. And yet, it was governed simply by electrical waves striking upon a receiver. And so with any machine.

"Why, I could make an automaton in the shape of a man that could walk, move, perform all the motions of a man, except wherein the fact of its not being an organic being would make a difference. All this theory is developed from my idea that the actions of all animate beings are governed by impressions of outside objects received upon the eye.

"My idea is that people are simply automata, governed by the transmission of circumstances surrounding them upon the eye. This," said Nikola Tesla, solemnly, and with the greatest simplicity, "is the greatest idea of the age. The relations of nations will be affected by it. It will revolutionize thought. It may take years, but it will gradually come about. Men of science find it difficult to accept this idea. They cannot comprehend it. It is stupendous, and yet it is very simple."

Colorado may be the theatre of the first exhibition of "vril."

Mr. Tesla announces that he is at Colorado Springs, simply collecting experimental data. His instruments will shortly be mounted, and scientific work will begin. He has made similar experiments at different atmospheric levels, and the work here will be comparative.

Nikola Tesla is from the mountains of Servia, and his native tongue is Montenegrin. To those familiar with foreign types, he suggests the Pole —the grave and gentle temperament illumined by the flash of fire. He is very tall and slight, with thin and delicate features, black hair and mustache, and clear gray eyes. He speaks of himself and his work with simple modesty and reticence, in perfect English, with a slight foreign accent.

Mr. Leonard E. Curtis, a well-known member of the bar, who has been Tesla's legal adviser, gave a banquet to the famous electrician at the El Paso Club, where twenty gentlemen of Colorado Springs were invited to meet him, including Governor Thomas, of Colorado. Tesla was in his happiest vein and spoke of his life and work. When first he heard of the great Niagara of the western hemisphere, he was impressed with its power—mighty, resistless force! Some day he would turn it to account. Years after he went to Buffalo, and in the great power plant at Niagara he saw machinery bearing the name of Tesla.

All who were present at the banquet felt, if it may be so stated without bathos, that they had "soared toward the empyrean," for a glimpse of the glory that excelleth; the man in the midst of the fire; the controlling power,

"Half spirit and half bird.
And all a wonder and a wild desire."

DESIRE STANTON.

"Now shine your very brightest," said Dame Nature to the Sun;
"Appear, ye flowers and leaflets, for winter's course is run;
Let every rugged mountain peak in added grandeur rear;
Let everything look pleasant—for the tourist season's near."

("Gazette," Colorado Springs.)

POLYPHASE INDUCTION MOTORS.

In the Tesla motors of this type, made by the Westinghouse Company, the stationary part is permanently connected to the main circuits, and the rotating part has no electrical contacts or adjustments, and no wearing parts except the shaft and its bearings. The bearings are self-oiling. The primary element consists of a hollow cylinder built up of laminated rings of sheet steel, mounted on the inside to receive the conductors. The rings are rigidly supported by the cast iron housing which encloses the primary and forms the frame of the motor. In motors of large sizes the rings are not continuous, but are made up of segments which are dovetailed and are fitted into corresponding slots in a hollow cylindrical shell of cast iron. This shell is held in the cast iron frame of the motor. The conductors are usually machine-wound coils of wire which are thoroughly insulated before being slipped into the slots of the primary iron core. In some of the larger motors a copper strap bent into the proper form is used, instead of wire, for forming the coils. In large motors wound for low voltages, in which the large current requires a large conductor, a copper bar is placed in each slot ; the insulated bars are slipped in at one end and the proper connections between bars are made by short lengths of copper strap. This bar winding is considered to be the simplest and most desirable type of winding. The terminal blocks, through which the leads bring the current to the motor, are connected to the primary winding, and are located at the top of the motor, except in motors of the larger sizes, in which they are located at one side. The secondary is built up of laminated steel discs, made of a high grade of metal, mounted upon an open spider, and carrying in slots around the periphery the rectangular copper bars of the winding. The construction is such that the conductors cannot be thrown out by centrifugal force, the whole secondary being extremely simple, rigid, and durable.

The same general form of construction is used for motors from 1-horse power to 500-horse power. The conductors of the secondary are all purposely short-circuited ; therefore it is evident that no accidental short circuit can possibly occur that will cause injury to the windings. The construction is practically indestructible from heating, raising of coils, or mechanical injury in handling. The constant-speed motors are built for two-phase or three-phase circuits, for 7200 or 3600 alternations per minute, and for capacities ranging from 1-horse power upwards. The voltage is 100 volts for motors up to 3-horse power, 200 and 400 volts for motors up to 200-horse power, and 400 volts for all motors from 200-horse power to 500-horse power. Variable-speed motors are also made, and are used on cranes, &c. The variation of speed between full-load and no-load is very small, and is less than that in direct-current motors. There are no commutators, and no moving contacts of any kind.

The Colorado Springs Evening Telegraph July 29, 1899

TESLA TALKS TO THE TELEGRAPH

"When am I going to make an experiment with wireless telegraphy? Why I don't intend to make such an experiment."

This is what Nickola Tesla, the great electrician, said to a Telegraph reporter this morning when asked how long it would be before he would be ready to make his final experiment. It has been generally supposed that Mr. Tesla built his station for the purpose of telegraphing to the summit of Pike's Peak without the use of wires, but he has evidently changed his plans during his stay here, and has given up the idea of experimenting with wireless telegraphy.

"No, I have worked long enough on wireless telegraphy," continued Mr. Tesla, and I am not experimenting with it now." When asked about the experiments he is making, Mr. Tesla said he would prefer not to make any statements to the public concerning them. The workmen at the station east of town are still busy working on the large induction coil which occupies nearly the entire building. The coil is one of the largest in the world, and when finished will send out over 3,000,000 volts of electricity when necessary. Another smaller induction coil is also in the building, and will be used when a smaller volume of electricity is desired. Twelve large storage batteries were placed around the transmitter today.

When Mr. Tesla was asked when he would make some experiments he replied: "Why, I am making them all the time, and have been experimenting ever since I have been in the city. I think that is about all I wish to say this morning about my work." Mr. Tesla then walked back into his private room in one corner of the station and commenced to figure some problem. Mr. Tesla spends nearly all his time at the station, and several times has been seen with his instruments during the night hours. The electric power which he uses is furnished by the City Electric company, and he is generally unable to get the power in the daytime, and is required to use it at night. The experiments are still conducted with the utmost secrecy, and no one but his employes are allowed near the building.

The Brooklyn Eagle September 7, 1899

TO TEST TESLA'S SYSTEM.

Lighthouse Board to Ask Congress for an Appropriation.

(Special to the Eagle.)

Washington, September 7—The members of the Lighthouse Board intend to ask Congress for an apropriation during the coming session of Congress to enable them to conduct some extensive experiments with wireless telegraphy at Fire Island. This scheme is a popular one with Admiral Higginson and the other members of this board who believe that it will eventually figure prominently in the lighthouse and life saving systems.

Admiral Higginson has already had some correspondence with Tesla, the electrical expert, and others in New York who are interested in this subject, and it is possible that some semi-official tests may take place this fall. The members of the board will work from either Nantucket or Fire Island and the mainland. The greatest difficulty now in the way is lack of funds, no appropriation being available for experiments of any kind.

The New York Tribune September 20, 1899

TESLA'S WORK IN COLORADO.

TO GET ELECTRICAL POWER FROM THE UPPER AIR—EXPERIMENTING ON MACHINE FOR SENDING WIRELESS MESSAGES TO PARIS.

Colorado Springs, Col., Sept. 19.—When Nikola Tesla, the wizard of the electrical world, arrived here early in June for experiments in upper air strata, definite results were expected soon by the general public. Mr. Tesla himself said he might remain here all summer. He now says he has just fairly begun his work, and that he is not contemplating a return to New-York before December, if then, unless it is on urgent business, the trip being just as brief as possible.

"Two objects brought me here," said he. "First, to develop, perfect and manufacture a machine for transmitting messages to Paris next year without the use of wires; second, to work out a theory on which I have been experimenting for five or six years, that there are electrical currents in the strata of air at various altitudes, from which tremendous power can be generated. Some years ago I discovered the principle that power can be transmitted to any distance without wires. The transmission of messages followed close after. Then I discovered a principle to be made of more service. I am only at the beginning, but I was never more confident of success. I never fail."

Tesla has an experiment station just east of Colorado City. He spends there the daylight hours, not stopping for luncheon, and frequently works after nightfall. He has not yet ascended Pike's Peak, which may become important in his experiments. He confidently expects to talk to Paris next year without the aid of wires. He hopes also to perfect inventions for general use in wireless telegraphy.

NOTES AND MEMORANDA.

IN the Tesla Interrupter, the interruptions are obtained by a stream of mercury impinging upon a rotating disc having projecting teeth. The interruptions take place in a gas under pressure, thus permitting a much higher frequency than would otherwise be possible.

Time and space do not permit the discussion of the many other factors which give Colorado Springs its unique climatic possession; for instance, the influence of the far-distant Pacific Ocean on the West and the Gulf of Mexico on the south. There is, moreover, a wide field for speculation as to the influence of the peculiar and intense electrical phenomena exhibited in this vicinity, which we hope that our distinguished visitor, Nikola Tesla, will shortly elucidate for us. We physicians are cognizant of many nervous disturbances of the human economy of whose exact causes we can but vaguely guess. Those who come to us in depressed health usually experience the effects of a powerful climatic tonic, while those who seek these regions for rest and recreation at all seasons of the year, if they have been prudent in their food and exercise, as a rule return to their homes refreshed and strengthened and with pleasant memories of their sojourn in this happy clime.

S. E. Solly, M. D.

The Colorado Springs Evening Telegraph October 7, 1899

NIKOLA TESLA TALKS OF MARCONI'S WORK

Nikola Tesla is about to be heard from again in away that will interest the entire world.

This he says himself, but not in the boastful spirit stated above. He admitted, rather than made the assertion, that he was about to launch a new device for wireless telegraphy.

"My new theory will obviate the difficulty, or rather will not have the defect, that characterizes the present system," he said this morning to an Evening Telegraph reporter.

"You mean the Marconi system?"

"I mean all systems that I know of. I do not wish to disparage, therefore I will not specify. I am familiar with all the devices now being tried, and the defect common is that no operations can be conducted where there is another inductive instrument within a radius of 200 or even 300 miles.

"This is the fatal point with wireless telegraphy, as it now is," continued the great electrician. "It is absolutely impossible where there are other instruments to interfere. Therefore I see no practical value in wireless telegraphy as it is now.

"Another point not at all satisfactory about the present system," said Mr. Tesla "is the number of words that can be transmitted per minute—only twelve," and he smiled.

"I hope," said he, "to perfect a system by which 1,500 or 2,000 words can be telegraphed each minute," and he spoke with that confidence which lends faith.

This most important announcement that Mr. Tesla is about to introduce a system of wireless telegraphy that will be without the defects of the systems now being tried was made by the inventor himself in the lobby of the Alta Vista hotel this morning. When he came down from his room preparatory to going out to his experiment station on Knob Hill, he was asked his opinion of the experiments which Marconi has been making in reporting the movements of the Columbia and the Shamrock race. But the great inventor had already been asked the question. The prominent newspapers from all over the country have wired him for a statement regarding these experiments. To all their invitations he has turned a deaf ear.

"I have no time," he said, " to go into this matter. But I am glad to see the interest that is being manifested. There is really nothing novel, you understand, about what Marconi is doing. The experiments are interesting, that is all. I am glad they are so successful as reported, but the system, all devices, in fact, that I have seen described, have this fatal defect—they are of no value where powerful inductive instruments are stationed within a radius of 200 miles of the point of operations. Under such circumstances it is impossible to exchange signals."

Then it was that Tesla told, in a very modest way, about his hopes of a perfect system; more than hopes, in fact; he actually stated that in a short time he would submit a plan to the scientific world in which these defects would be overcome.

"I have already overcome the great defect," he said, ::and I will have something to say very shortly."

The constant and nerve-straining work which Tesla has been doing at his experiment station is telling on his health in this high altitude. He has been feeling ill of late and regrets that the corditions are somewhat unfavorable to his health.

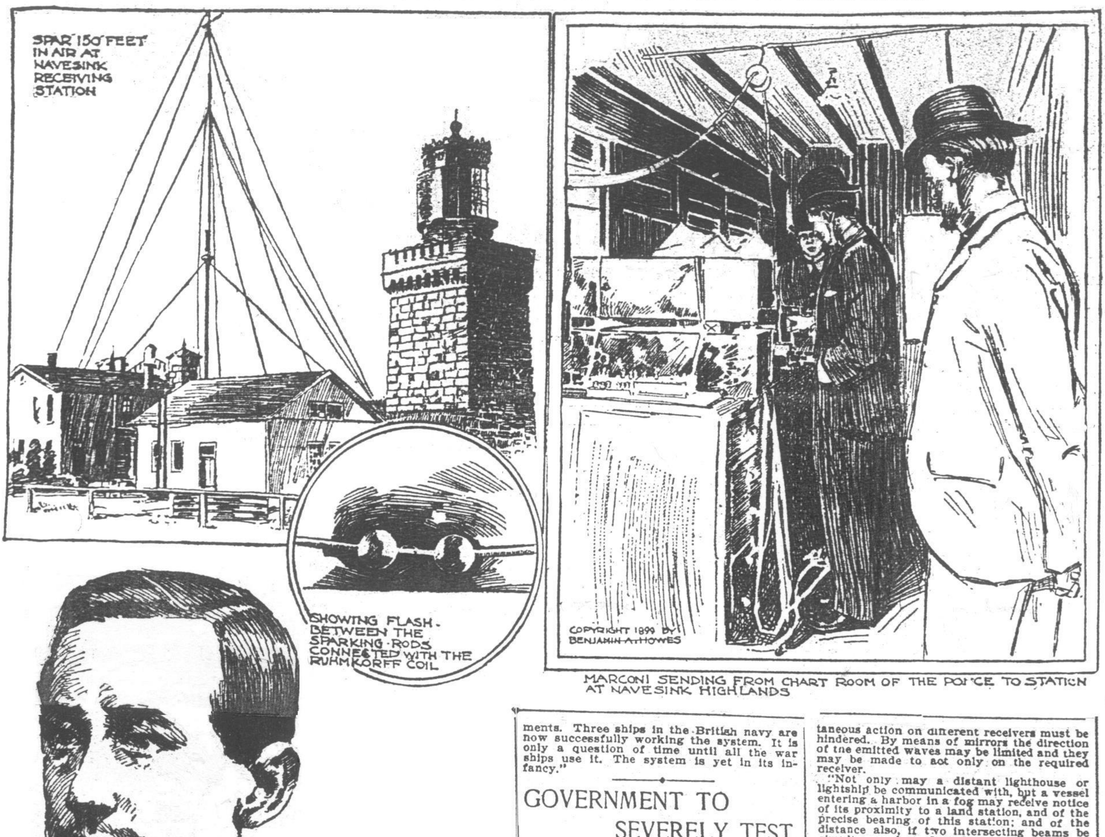
"It is the hours I keep," he said, "but I cannot change them. The night is my workday. It was in New York until 2 and 3 o'clock every morning, and I cannot cannot change my habits here, even though they are so unfavorable. I think the best time for working here would be early in the morning, say about 4 o'clock, and then retire early at night, but I could not accustom myself to those hours."

There is probably no more interesting character in the scientific world than Nikola Tesla. He has already astonished it with several inventions of a most important nature, and he is yet confident of doing the greatest things it is possible to imagine. While all Colorado Springs, indeed half the world, is sleeping, Tesla is manipulating electric currents in a little place out on the prairies east of town. There is something wierd and yet nothing unreal about this man who manufactures lightning bolts, whose happiest moments are during an electrical storm when the wires about him snap and light up on all sides, when it would seem his life is in danger. No one will doubt a man like this when he says:

"I will be heard from."

WIRELESS SYSTEM MAY BE USED IN PHILIPPINES

MARCONI AND PART OF HIS WIRELESS TELEGRAPHY APPARATUS.



MARCONI SENDING FROM CHART ROOM OF THE POLICE STATION AT NAVESINK HIGHLANDS



have always referred them to the police, as I have had full confidence in my ability to protect myself from interference. I can so individualize my stations that it would be almost impossible to disturb them.

"On the other hand, I am convinced that it would be possible to start in the atmosphere an electric commotion that would demoralize the entire telephonic system of any city. Indeed, it was done in Glasgow by an experimenter. He had an idea of using coils of wire from which to send signals through the air. His success was not entirely satisfactory, but, without intending to do so, he temporarily put the telephone system of the city out of business.

Not Afraid of Interference.

"It has been said that this is one of the weak points of the wireless telegraph. I can answer that our machines are less easily affected than are telephones. The currents that would play havoc with the telephone would make no impression upon the wireless telegraph.

"Have I ever given study to any other branch of practical electricity? Certainly I have, but I have dropped it all for the present. After the wireless telegraph has been fully developed I will take up something else with which to busy myself. I have many crude plans in mind, but of that I would rather not talk at present."

EDISON PREDICTS A GREAT FUTURE.

Sure of System Being Valuable at Sea—Suggests Use of Kites.

"He succeeded where I failed." This is the tribute paid to Signor Marconi by Thomas A. Edison. I called on Mr. Edison yesterday, at his home, in Llewellyn Park, and, although it is his general rule never to grant interviews on Sunday, reserving that day for himself, he consented to talk about wireless telegraphy for the HERALD. When asked what he thought of the system, Mr. Edison said:—

"There is certainly a great future ahead of it. What that future may be no one can say. It would seem as if we were approaching the limit, but then, so it was thought a long time ago. What that limit will be no one knows.

"Mr. Marconi has proved that the electrical waves can be jumped around the curvature of the earth, and this has heretofore been an insuperable obstacle. With this accomplished there is apparently no end to the distances that can be overcome. So far it seems as if about two hundred miles was the limit, but yet even this distance may be as nothing in the future."

"Is the system a new one or is it only an adaptation of old principles?"

"The idea is not new, and others have been experimenting along that line. I had patents out on this line long before we heard of Marconi. I tried experiments at Menlo years ago and kept at it for a long time, but I could not get over the obstacle of the curvature of the earth, and about two miles was the limit that I could reach. Telegraphing from moving trains was the line of my invention, but I and all others ran up against obstacles that could not be overcome."

"What is your estimate of the practical value of the invention?"

"Well, it will prove of great value in a maritime direction, but I cannot see that, as at present developed, it will be of much value in land operations. The system can be made of great practical use in sea service by stationing vessels or tugs a certain number of miles apart, but near enough to each other to come within the sphere of electrical influence. In this way lines of communication could be established for a thousand miles or more. Islands could be connected in this way, or, perhaps, groups of such islands brought into close communication with each other.

"It is possible that some valuable use might be made of the system on land, and, indeed, some time ago in the manœuvres of the British army and fleet the wireless system worked well. Possibly the use of aeroplane kites in connection with the system may be found to have a practical value. All this is yet to be developed."

"Are you working at all on this line?" the inventor was asked.

"No," he replied. "I gave the whole thing up years ago and have dismissed it from my mind. Perhaps one of these days I may take it up again, but that is a contingency too remote to speak of."

FIELD ENTIRELY NEW AND ITS OWN.

New York Experts Predict Many Practical Uses for System.

That wireless telegraphy has been brought to a practical stage and will soon be used as an additional means of communication on land and sea was the unanimous opinion of electrical experts who viewed its workings Saturday on board the Mackay-Bennett off Sandy Hook. There was some difference of opinion as to the extent of its application, but all agreed that it would take an important place in commerce and warfare.

Charles Cuttriss, an expert of the Commercial Cable Company, said:—"The wireless telegraph is one of the greatest inventions of the age. As to its practical applications, it will have a field entirely its own. Wireless telegraphy will not interfere with existing systems of telegraph communication. It will never take the place of the submarine cable or land telegraph lines.

"It will afford an invaluable means of communication, however, between points where the maintenance of telegraph wires would be impracticable. Wireless telegraph stations could be established on outlying points and islands. Passing ships that had the wireless equipment could send messages to these stations, and they in turn could send them to their destinations by the ordinary method. Vessels could receive messages from shore and could communicate with one another and give warning if in distress. In this way alone the system would be of inestimable value.

"The cost of equipping vessels would not be great. It would be a great convenience and great safeguard if all ocean liners were provided with instruments."

Thomas Commerford Martin, editor of the Electrical World and Engineer, said:—

"In view of the tests to which the wireless system has been submitted it seems safe to assume that it has reached an entirely practical stage and is ready for application to everyday work. The successful results obtained during the yacht races are the more interesting because the work has not been undertaken as a test of the system, but as an application of its practical purposes, not differing in this respect from the arrangement made to transmit the messages by cable from the receiving ship to the shore. There can no longer be any doubt as to the success of wireless telegraphy."

Charles Priest, electrician of the Mackay-Bennett, said:—"Wireless telegraphy will no doubt fill an important place in a field distinctly its own. It will never take the place of cable or land wire communication, but as a means of communication between ships and between points on shore which it would not be practicable to connect by wire it will be invaluable."

Minor M. Davis, traffic manager of the Postal Telegraph Company, said:—"The application that is being made of wireless telegraphy during the yacht races has proven that it is practicable. There is no doubt that there is a great field open to it. If ships are to use it as a means of communication it will be necessary to synchronize the instruments, so that different ships within the same radius can communicate with one another simultaneously, without the messages being confused."

T. Bowden, who receives the wireless messages on the Mackay-Bennett, said it was not claimed that wireless telegraphy would take the place of the great telegraph systems. He added:—

"Its greatest service will be as a means of communication between ship and ship, and ship and shore. It will prove a great safeguard to navigation. Fog does not interfere in the slightest with the wireless communication.

"The cost of equipping ships would be comparatively light. Experts are not required to work the instruments. Ordinary lightship men are now working it in England. So there is no reason why freight as well as passenger ships should not have the instruments. Three ships in the British navy are now successfully working the system. It is only a question of time until all the war ships use it. The system is yet in its infancy."

GOVERNMENT TO SEVERELY TEST.

Important Experiments Will Be Made by the Army and Navy Authorities.

HERALD BUREAU, CORNER FIFTEENTH AND G STREETS, N. W., WASHINGTON, D. C., Sunday.

Convinced of the practical value of wireless telegraphy by the successful reporting of the yacht races, arrangements have been made by the government for experimenting with the system which may lead to its adoption in several important services.

After the yacht races Rear Admiral Bradford, chief of the Naval Bureau of Equipment, expects to confer with Mr. Marconi relative to the naval experiments. It is understood that the cruiser New York and battle ship Texas will be equipped with instruments and a shore station will be established at Atlantic Highlands.

Negotiations are in progress also between the Signal Corps of the army and Mr. Marconi for experiments to demonstrate the use of the system on land.

Experiments have already been made by the life saving service, but the result has not been decisive. If satisfactory, life saving stations and lighthouses will probably be equipped with instruments.

The experiments to be made by the army and navy will be exhaustive. To quote officials with whom I talked, the yacht race reports have shown that the system is practicable for general operation at sea; it only remains to prove whether it will be satisfactory for naval and military purposes. If a success it will be adopted by the navy, and the army in the Philippines will be equipped with instruments. The lighthouse and life saving services will also adopt it, and merchantmen will be advised to equip their ships in order that they may communicate with the shore in case of disaster.

The naval experiments will be made under the general direction of Rear Admiral Farquhar, who will succeed Rear Admiral Sampson in command of the North Atlantic squadron. The officers now witnessing the operations of the system in connection with the yacht races will conduct the experiments at sea. Speaking of the matter to-day, Admiral Bradford said:—

"There is no question of its prospective value. I am not yet prepared, however, to say how great that value will be. The officers who are witnessing the present trials have not submitted their reports."

Colonel James Allen, acting chief signal officer of the army, states that two automobiles recently bought will be used in the army experiments. Small balloons and kites will be employed, and their use may increase the distance over which a message can be sent. He said:—

"The value of wireless telegraphy increases as the square of distance. Thus, if a message can be sent fifty miles and given a value, for instance, of two, its despatch over one hundred miles would make the system worth four. Should the system operate satisfactorily over one hundred miles, communication by wireless telegraphy could be maintained between Key West and Cuba, between the islands of the Hawaiian group and between some of the islands of the Philippine archipelago.

"The best results with the system have thus far been obtained over water. No satisfactory results have been secured over wooded country. Naturally we are hopeful that the experiments will show that the system can be operated on land. It will then be highly valuable in maintaining communication between operating columns, between such columns and their base and between besieged and their friends. In case the system proves successful, instruments and the necessary appliances will be sent to Manila."

Chief Moore, of the Weather Bureau, is another government official who is watching the experiments with wireless telegraphy with much interest. The officials of the bureau look forward to the possible use of the invention in gathering information regarding the weather and sending out forecasts and storm warnings.

WILL SUPPLEMENT EXISTING SYSTEMS.

Professor Suggests That News May Yet Reach Steamer in Midocean.

PHILADELPHIA, Pa., Sunday.—Dr. George F. Barker, professor of physics in the University of Pennsylvania, says of wireless telegraphy:—

"So far as my investigations have gone, they lead me to the conclusion that while wireless telegraphy is entirely possible practically, it is adapted to supplement rather than to displace the existing telegraph systems.

"The possibility of transmitting intelligence electrically through space between distant points without having these points connected by metallic conductors is beyond question. Moreover, improvements are rapidly being made. As transmitters multiply, their simultaneous action on different receivers must be hindered. By means of mirrors the direction of the emitted waves may be limited and they may be made to act only on the required receiver.

"Not only may a distant lighthouse or lightship be communicated with, but a vessel entering a harbor in a fog may receive notice of its proximity to a land station, and of the precise bearing of this station; and of the distance also, if two intersecting beams be simultaneously reflected.

"In the very near future the news of both continents may be received in midocean on our Atlantic liners, and so a newspaper may be published daily."

WILL FIND MUCH USE IN WARFARE.

Chicago Electricians Point Out Value of System in Military Plans.

CHICAGO, Ill., Saturday.—It is the opinion of leading electrical experts in Chicago that wireless telegraphy is one of the most valuable scientific discoveries ever given to the world. B. E. Sunny, manager of the General Electric Company, in speaking of the system said:—

"To say that it will affect the present system of telegraphy would be wrong, in my opinion. It will occupy a distinct field of its own, as the present methods of transmission of intelligence are near perfection.

"The wireless system will prove of inestimable value for the signalling of ships at sea, and will be of great service to armies and navies, and for sending messages over land and water where telegraph wires cannot be run. Railroads will find use for the new system in the emergency of a disaster between stations, but for commercial purposes the wireless telegraphy will never displace the obtaining methods."

Professor Francis B. Badt said:—

"I have unbounded faith in the success and practicability of the wireless system. The idea, though, in my opinion, is only in the first stages of development. The very satisfactory results from the experiments at the yacht races demonstrates the possibilities of the device for use over short distances, and whenever a method is found by which the energy lost in the wave current can be conserved the distance will be extended accordingly. I expect that this improvement will come before long.

"There will be no revolution in the old system of telegraphy. The wireless method would not be practicable in settled localities, where obstructions would interfere with the passage of the current. In all kinds of signalling on the water the service will be of great help. Military movements will be facilitated by the use of the wireless system. It will have a world of its own in which to operate.

IMPORTANT ADJUNCT FOR LIGHTHOUSES.

Professor Dolbear Thinks Wireless Telegraphy Is in Its Infancy.

BOSTON, Mass., Sunday.—Professor Amos E. Dolbear, of Tufts College, is sanguine as to the future of wireless telegraphy. He said in an interview:—

"The art of electrical communication without the use of wires or other conductors stands to-day where the art of telephoning stood in 1877. At that time the telephone was a demonstrated success, but needed improvements in the apparatus to make it available for commercial use. In 1877 it was possible to telephone twenty-five miles, but beyond that distance no satisfactory results could be obtained. Soon afterward, by the means of the Blake transmitter and other improvements, the efficiency of the telephone was increased, until it can now be used for talking a thousand miles.

"There is no storm, in my judgment, which would prevent the use of wireless telegraphy.

"Of course, the commercial use of wireless communication will greatly increase when the message can be individualized and the waves concentrated, as the light waves are in a searchlight. This, I believe, will be speedily done."

Professor John Trowbridge, of Harvard College, said:—

"As a scientific man, I would not take the position that great progress in this means of communication was impossible. At present it is possible to use wireless transmission for a limited amount of work, if there is no opposition. The waves are like light waves, travelling with the same velocity, but of greater length, sa, two or three feet long. By using poles 200 feet high, messages can be sent eighty or one hundred miles, but beyond that distance the curve of the earth's surface sends the waves floating off into space. If the suggestion is made to raise the height of the pole beyond 200 feet, the work of transmission meets with great difficulties in the more active electrical conditions that exist in the higher air.

"It is impossible to relay wireless telegraphy, so that one hundred miles may be taken as the extreme limit of its work. Restricted to this distance, it cannot compete with the regular telegraph in speed or certainty. Wireless telegraphy would undoubtedly be affected by thunder storms and other electrical disturbances, although wind, rain or snow would not disturb it. For use on lightships and other isolated points it will have a practical value, and also in some cases for use between ships at sea."

The New York Herald October 9, 1899

FRIENDS OF TESLA SAID TO FEAR FOR HIS HEALTH.

Inventor, Who Is at Colorado Springs, Says He Hopes Within a Short Time to Announce a Perfect System of Wireless Telegraphy.

DENVER, Col., Sunday.—"I hope within a week or two to announce to the world a system of wireless telegraphy that will be nearly perfect," said Nikola Tesla last night at Colorado Springs. Mr. Tesla has been working between fifteen and twenty hours a day for several weeks. Mr. Tesla's health is plainly impaired, and he announces with satisfaction that his task is almost completed.

"I will not disparage the Marconi system," continued the scientist, "but every system in use at the present time has a serious defect in that its action is disturbed by similar instruments within a radius of a greater or less number of miles. Besides, twelve words a minute seems to be very fast time.

"With the system I have about completed I hope, to attain by mechanical methods a speed of fifteen hundred or two thousand words a minute, and further, to have instruments absolutely free from extraneous disturbances. I have succeeded in eliminating outside influences and can make one set of instruments work free from another almost within touch.

"Marconi's experiments are interesting, but they are not new. I am glad they are being so successfully employed in the yacht races, but it is by no means improbable that before the next international race is pulled off, boats, propelled by wireless power transmission will followed the races, and I hope the yachts themselves will have wireless telephones on board."

Mr. Tesla's experiments with the wireless transmission of power seems to have passed beyond the experimental stage, but he refuses to talk about the subject until after the announcement of his wireless telegraph system.

Among the friends of Tesla much concern is felt for his health, which, they fear, breaking down under the strain of only four or five hours' rest daily. They think there are signs of lung trouble.

Tesla ridicules such ideas, except to admit that he is very tired, but says he expects to take a rest by working only twelve or fourteen hours a day after his wireless telegraph system is completed.

Personal.

NIKOLA TESLA is still experimenting with wireless telegraphy at Colorado City, Colo.

NOTES.

Tesla Patents.—The Tesla Electric Company of New York have recently been successful in a lawsuit against a Philadelphia firm for infringement of the Tesla patents for multiphase motors.

Tesla Patent Case Decided.

An opinion has been handed down by Judge McPherson of Philadelphia in favor of the Tesla Electric company in the equity proceedings which it brought against Scott & Janney and others. The bill charged the defendants with infringing letters patent Nos. 511,915 and 555,190, relating to polyphase motors, granted to the plaintiff as assignee of Nikola Tesla. The first patent was granted for a method of electrical transmission and the second for an alternating motor, but both patents stand upon the same application and were attacked together on the ground that they were void for want of invention. It was argued that in view of the prior state of the art, and especially in view of an earlier patent of Tesla, the step from obtaining separately from the generator the two alternating currents, different in phase, that are required to operate the motor described in the earlier patent, to obtaining only one of such currents from the generator, while the other is obtained by induction from the primary current, was an obvious step, easy to be taken by anyone possessed of skill in electrical engineering, and therefore did not involve invention. Judge McPherson concluded that the step was taken in the exercise of invention. In concluding his opinion on this point of the defense he said: "So far as I can realize the situation, the two patents now attacked seem to me to be so connected with the earlier group that the same faculties that were necessary to produce those that are first in point of time must have continued in exercise to produce those that followed. It is often very difficult to draw the line between invention and skill, and different minds may draw it at different points. I submit my own conclusion for what it may be worth."

Judge McPherson held that none of the defenses submitted to the court could be sustained and that the motor of the defendants infringed all of the disputed claims involved in the suit. The patents in question are now owned and controlled by the Westinghouse Electric and Manufacturing company.

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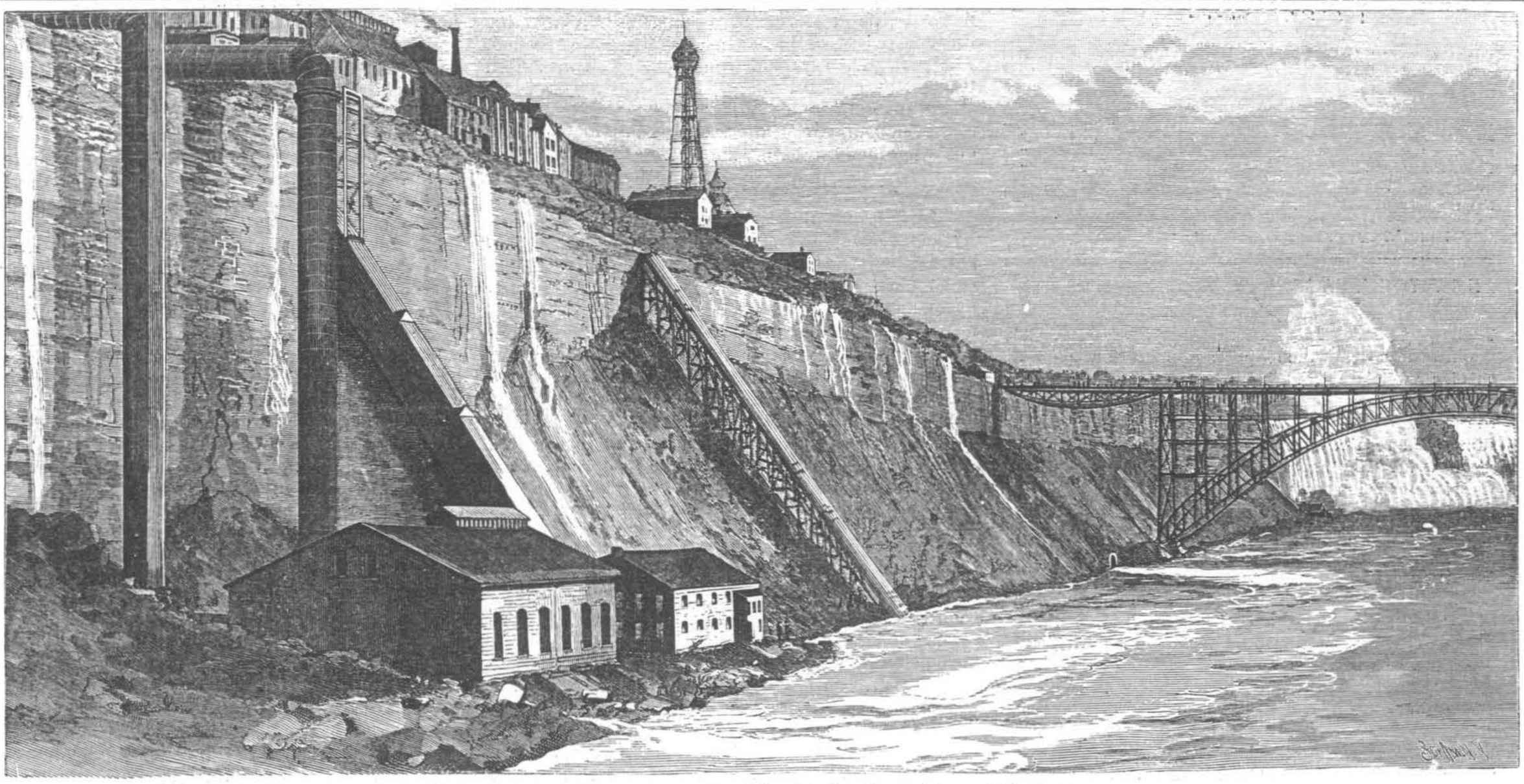
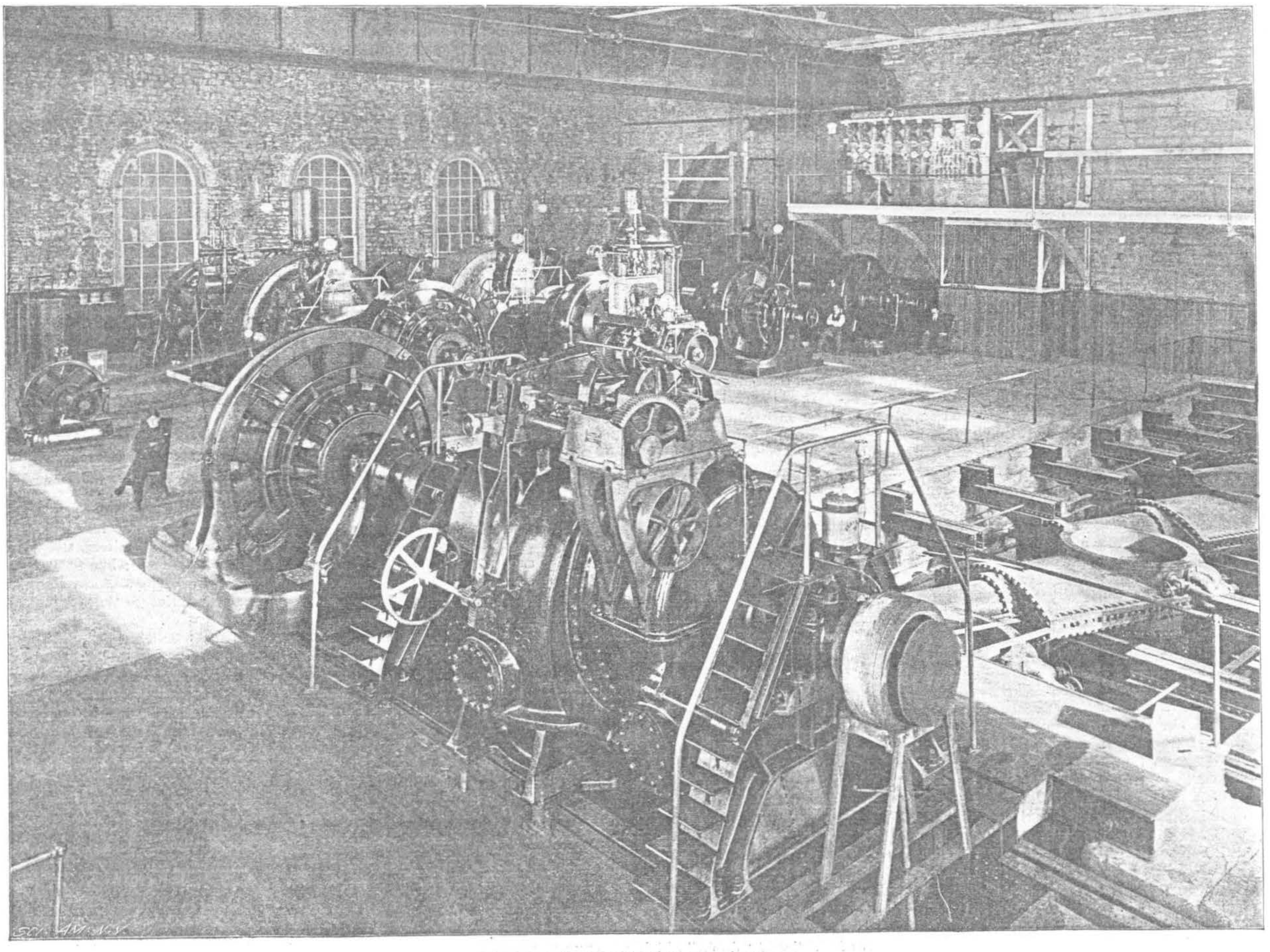


View of the Power House, Looking Up the Gorge Toward the Falls.



Interior of the 20,000 H. P. Power House.

NIAGARA FALLS HYDRAULIC POWER PLANT.—[See page 310.]

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THE ELECTRIC POWER PROBLEM OF NIAGARA.

With the article which appears on another page of this issue we close the series, on Niagara Falls as an industrial center, which has appeared at intervals during the present year, and it will now be opportune to sum up the results which have been accomplished, and see how far they agree with the expectations which were formed when the "harnessing" of the Falls on the present extensive scale was seriously undertaken.

In the first place it must be understood that the generation of fifty thousand electrical horse power was not attempted primarily with the expectation of transmitting it to far distant centers, there to be redistributed for local use. It is true that this was popularly supposed to be the object aimed at in the Niagara Falls Power Plant, and in the early days of its construction, writers were accustomed fairly to revel in picturesque descriptions of the silent flow of Niagara's energy to cities as far distant as Chicago and New York, where it was to displace every existing form of power by virtue of its extraordinary cheapness and convenience.

As a matter of fact, however, the eminent specialists and financiers who had the courage to build such a vast electrical plant did not undertake to generate this unprecedented amount of electrical energy with the idea of transmitting it *in toto* to far distant centers. Not only was the art of long distance transmission at that period in its comparative infancy, but it was foreseen that better economic results would be achieved in bringing the industries to the source of power rather than in carrying the power to the industries. As between the two alternatives, there were on the one hand the great cost and losses of transmission, and, on the other, the question of cheap railway and steamship transportation both for the raw materials and the finished product. The original promoters considered that, in respect of transportation facilities, the proximity of the Great Lakes and the convergence of several important railroads at Niagara rendered this an ideal manufacturing center, and, acting upon the conviction, they purchased large blocks of land contiguous to the power station, with the intention of renting the same for the erection of industrial establishments, which in the course of time were certain to be attracted by such an abundant electrical supply. At the same time, the company wisely determined to design the electric installation with a view to meeting the varied needs of its customers, and arrangements were made to supply, within reasonable limits, any kind of electric current that might be required.

That the expectations of the company were well founded is seen from a study of the facts presented in the series of articles in the SCIENTIFIC AMERICAN above referred to. In the few years that have intervened since the water was first turned into the wheelpit of the Niagara Falls Power Plant, a large number of entirely new industries have sprung up around, or within easy touch of, the station; while establishments that were already existing have become extensive users of the power. That the tendency is for the industries to gravitate to the power rather than the power to be transmitted to the industries is shown by the fact that out of a total of 35,000 horse power delivered from the station, over three-fourths are consumed in its vicinity, as against less than one-fourth that is transmitted to a distance—the principal long distance transmission being that of 8,000 horse power to Buffalo, for the use of the Cataract Power and Conduit Company.

Although the natural trend of events, controlled by well understood economic laws, has brought about a centralization of industries at the falls, it is not to be inferred that long distance transmission will not enter largely into the ultimate utilization of the energy of Niagara. In the few years since construction was first started a great stride has been made in art of generating and manipulating electrical currents for transmission, and the remarkable installation recently opened in Southern California, where a transmission of 83 miles has been successfully accomplished, suggests that a large part of the 7½ millions of hydraulic horse power available at the falls may yet be transformed and transmitted to the large cities of the East. The present indications are, however, that for some time to come transmissions are not likely to be attempted for distances of over 100 miles. The difficulties are not now so much of a physical nature (thanks to the alternating current of high potential), but are largely economical—the great cost of the line rapidly offsetting the cheap cost of production at the power station. The power from the falls could to-day be transmitted to a distance of 100 miles with a loss of 20 per cent; and in spite of this loss and the great cost of the line, it could compete successfully with steam power at a cost of $60 per horse power per annum.

NIAGARA FALLS HYDRAULIC POWER PLANT.

In the present number we conclude a series of articles on Niagara, the first of which, on "Niagara as an Industrial Center," appeared in our issue of May 27. On June 17 we illustrated the many handsome bridges which have been thrown across the Niagara gorge in the past fifty years, and on July 22 we gave a lengthy description of the 50,000 horse power electric plant of the Niagara Falls Power Company. In the first-named article it was shown that taking into account all the turbines that are at present in use, big and little, of the total theoretical horse power of 7,500,000 at the falls, only about 50,000 horse power is at present being developed and actually utilized, either as hydraulic or electrical power, for industrial and transportation purposes. This total, however, is constantly being increased, as the various additions which are being made to existing plants are brought into operation; and it will not be many months before the total amount of power developed will have increased by fifty per cent.

So much attention has been directed to the Niagara Falls Power Plant, with its present capacity of 40,000 horse power and actual output of from 20,000 to 30,000 horse power, that the public has not realized the size and rapidly growing importance of the Niagara Falls Hydraulic Power Plant, which has at present a capacity of 13,000 horse power, and has an enlargement under way which will increase its total capacity to 20,000 horse power. The method of developing the hydraulic power differs widely from that which has been employed with the Niagara Falls Power Plant, where, it will be remembered, the water is led in from the river above the falls by a short length of canal to the power house, and delivered through penstocks to a set of turbines which work under a head of 135 feet. The tailrace for the latter consists of a great tunnel with a fall of 50 feet in a length of 7,000 feet, and the water is finally discharged into the lower river at a point below the falls.

In the case of the Niagara Falls Hydraulic Power Plant, the water is taken from the river above the falls by an open canal and led to a point about a mile below the falls, where it passes through penstocks to turbines that are situated within a power house, which is built close to the water's edge at the bottom of the gorge, as shown in the two illustrations on the first page. The advantage of the latter system is that the effective head is considerably increased, the loss of the head in the tunnel being 50 feet and in the canal only 2 feet. By suitably constructing the tailrace, an additional head of several feet is secured below the turbines, with the result that the total effective head of the hydraulic power plant is 210 feet. The total length of the surface canal is 4,400 feet, its present width at the entrance is 250 feet, and in 400 feet the width narrows down to 70 feet. At this width it continues into a basin which is located about 300 feet back from the edge of the gorge above the power house. The basin runs parallel with the edge of the cliff and is about 400 feet long by 70 feet wide. The company owns sufficient right of way to increase the width of the canal to 100 feet, if it desires to do so. For 40 feet of the present width of the canal the channel is 14 feet deep, and for the remaining 30 feet it is 8 feet deep. The work of widening the canal is now in progress.

The power house is a substantial building of stone with a steel truss roof. Water is led down to the power house by means of two penstocks, one of which is 8 feet and the other 11 feet in diameter. The original section of the building was completed in 1896, and an 8-foot penstock serves to convey water to four Leffel turbines, of 2,250 horse power each, which operate eight generators, six of which supply power to the lower works of the Pittsburg Reduction Company, while the other two furnish power for the operation of the Niagara Falls and Lewiston Railway, better known as the "Great Gorge" route, illustrations of which will be found in the SCIENTIFIC AMERICAN of March 28, 1896. The operation of the original installation was so satisfactory that a large addition was immediately commenced, and the building was increased

to the size shown in our illustration. It now measures 100 feet by 120 feet. The addition to the plant consists of five wheels of the Jonval-Geyelin type, each of 2,500 horse power. Our illustrations show one of the new wheels in place. These wheels are fed by a new 11-foot penstock, which has a capacity of 12,000 horse power. It leaves the forebay with an elliptical bell mouth which measures about 20 feet by 11 feet, and is carried out horizontally from the cliff, supported on two heavy steel beams for a distance of 60 feet, and then drops vertically nearly 200 feet to the power house. For about fifty feet of its length beneath the power house floor it is 13 feet in diameter, and, after passing beneath two of the wheels, its diameter is reduced to 7 feet, beyond which point it tapers off into a cone 18 inches in diameter, and finally ends in an air-chamber, which is 4 feet in diameter by 15 feet in height. The object of the air-chamber is to cushion the vertical movement of such a great mass of water and prevent injurious shocks to the machinery. The steel used in the construction of the penstock varies from a thickness of $\frac{5}{8}$ of an inch at the top to $1\frac{1}{8}$ inches at the bottom.

Above the horizontal portion of the penstock beneath the floor are carried a series of five 60-inch hydraulic valves which are placed horizontally and serve to conduct the water from the penstock up to the five turbines which are placed immediately above them. These valves, with their supporting girders, are shown in the lower illustration of our first page. The water flows through the valves to the turbines and is admitted by a gate to the guide-wheels, and through them to the runners. From the sides of the turbine the discharge pipes project laterally and then downwardly to connect with draught tubes 22 feet 8 inches in length, the use of which makes it possible to utilize in part the atmospheric pressure, and increase the effective head of the turbines accordingly. The turbine wheels are made of bronze, and they are located in the draught-tube casing, one on each side of the casing proper. The pair weighs 5.095 pounds. They are mounted upon a horizontal shaft and are directly connected to a general electric generator, which supplies current to the new chlorate of potash plant of the National Electrolytic Company, located on the top of the cliff.

A walking-beam, working over the main casing, operates the gate which is connected to the beam by $2\frac{1}{2}$-inch rods extending down through the glands into the casing. Above the walking-beam is an air cylinder 36 inches in height, with a diameter of $20\frac{1}{2}$ inches. The turbine is controlled by a Reynolds governor. It should be mentioned that there are thirty-four buckets on the runners with a total area of 140·25 square inches. On the guide-wheel there are twenty buckets with a total area of 149·53 square inches. The General Electric Company's generator is shown in our illustration. It has fourteen poles and runs at 257 revolutions per minute, giving an output of 5,000 amperes at 175 volts. This represents a capacity of 875 kilowatts or about 1,200 horse power. The current is carried to the chlorate of potash works on aluminium cables, the lower part of which is made in bar form and the upper part in the form of well insulated cables. The dynamo for the Buffalo and Niagara Falls Electric Light and Power Company is of 700 kilowatts output capacity at 2,200 volts pressure.

The completion of the five Jonval-Geyelin turbines will raise the total horse power at this station to 20,000, but it is intended to build another 11-foot penstock and increase the total horse power of the plant to 30,000, which will be the maximum that can be developed from the present upper basin. Ultimately, however, it is intended to extend the basin along the cliff beyond the present factories of the small users of the company's water power, and carry down other penstocks to a new power house at the edge of the river. The company has sufficient room to install a total of 100,000 horse power, which is well within their grant of 125,000 horse power. The present capacity of the canal is about 40,000 horse power, but the company has a force of dredges which are continually at work enlarging and deepening it.

Visitors to Niagara will have noticed the cascades of water which fall from the side of the cliff in varying quantities in the immediate neighborhood of the company's power house. These streams are the tailraces of the various smaller factories which are built at the edge of the cliff, and take water from the company's basin behind them. The turbines operate under heads of from 60 to 100 feet In some cases they are sunk in wheel-pits and discharge through tunnels, while in others a cutting is made through the face of the cliff. The total hydraulic power thus developed is about 7,500.

This brings us to the close of a subject which we have treated at considerable length because we believe that there is a great demand for complete information upon a matter of such importance as the utilization of the energy of the falls.

Isolated statements of work done in this or that establishment at Niagara Falls have been published from time to time, but these are not sufficient to give such a comprehensive view of the subject as we have endeavored to set forth in these articles. While the work of developing this great source of hydraulic power has not gone forward with the rapidity which was popularly expected, it must at least be admitted that what has been done has been carried out on conservative lines and with such a measure of success as promises well for the future.

TESLA Hopes to Telegraph from New York to Paris Without Wires.

After Months of Experimenting in Colorado Says He Has Solved the Problem.

NIKOLA TESLA, who opened an experimental station in Colorado Springs, Col., in May last for the purpose of making scientific measurements and observations with wireless telegraphy in high altitudes, has successfully concluded his work and will soon return to this city to continue his work here. He has perfected a machine by which he intends to send messages to Paris next year, and his experiments here will be in communication by means of the machine with Paris, without the use of a wire.

"I have been successful in my experiments beyond anything I ever accomplished," he said to a correspondent for the HERALD. "I am glad I have come to Colorado. I am delighted with the results. I am not at liberty to give out the details of my work at this time, but you can say the system of wireless telegraphy has been successfully demonstrated in this altitude, which is 6,000 feet above sea level."

Since the establishment of his laboratory in Colorado Springs Mr. Tesla has lived at the Alta Vista Hotel, but he is seldom seen there.

The Colorado Springs laboratory in which Tesla has been so successful is located about a mile from the centre of the city, on the highest point of land in that vicinity, and is on a direct line east from Pike's Peak. It is about two hundred feet higher than the town proper, affording an unobstructed view of the Rocky Mountains.

It is not enclosed, and although located only a few hundred feet from a street, Mr. Tesla has obtained all the privacy desired, as he has placed about the building numerous signs bearing the following inscription:—

GREAT DANGER! KEEP OUT!

The laboratory is a queer looking structure and has been an object of interest to the townfolk, who have gazed at it long and often, but who, as a rule, never ventured closer than fifty feet, the sign being a sufficient warning to keep away the curious.

The most noticeable features about the barnlike building are the numerous electric wires running into the place, the scaffoldlike contrivances on the roof, and the pole in the centre of the building, rising to a height of 250 feet, and surmounted by a large ball.

Few persons looking at the ball suspended at the top of the innocent looking pole would imagine that it has played the important part in high altitude experiments. The ball, which is about one and a half feet in diameter, is used to transmit and receive messages. There is a wire on the inside of the pole which runs to the instrument in the building.

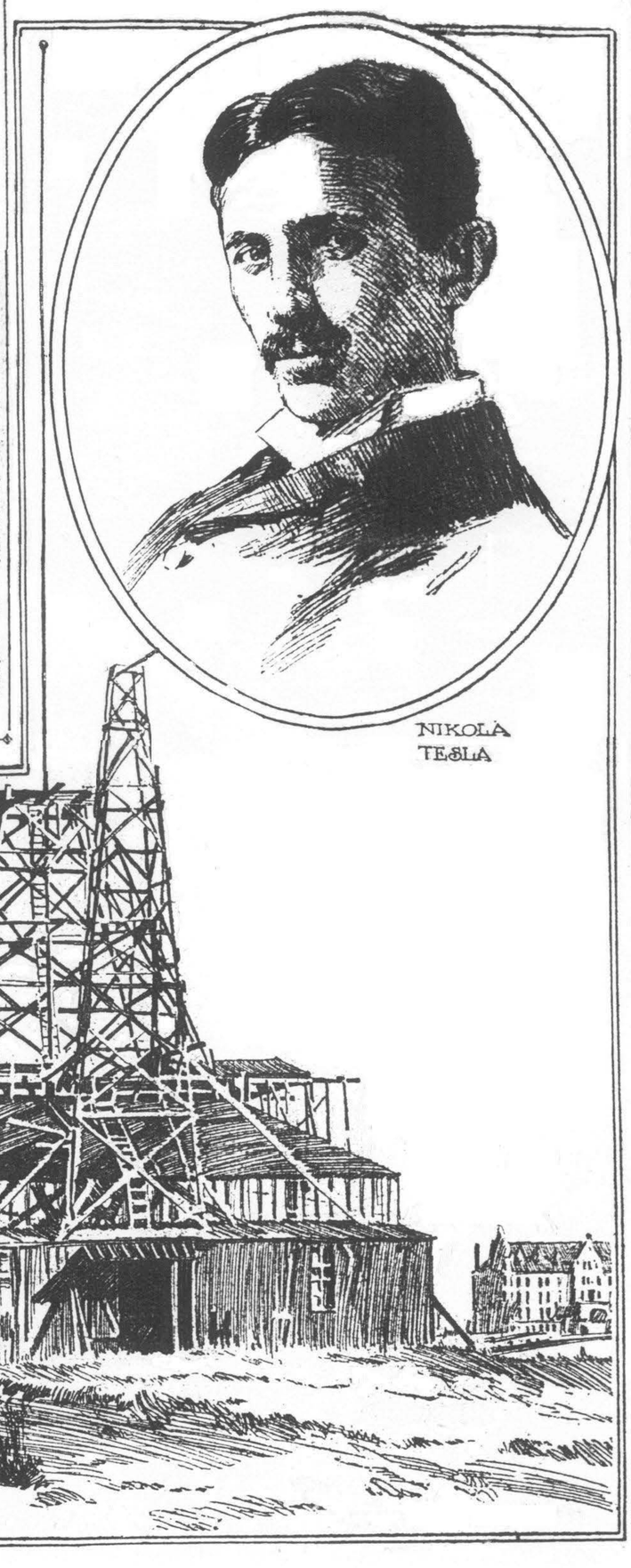
Tesla zealously guards all approaches to the laboratory. There is a small engine near the entrance. The laboratory proper is located back of the engine, and is enclosed by a circular partition, so that employes will not come in contact with "live" wires.

The laboratory consists of two large cylindrical shaped contrivances. One reaches from the floor to the roof, and is made entirely of wood. Surrounding it is one which is encircled by "live" wires, and it is here where Mr. Tesla has accomplished his scientific experiments in a high altitude.

The building, from an exterior point of view, is of peculiar design. It is a low, wooden building thirty feet square, and rises to a height of only twenty feet. The building to the right is the Printers' Home, founded by Messrs. Childs and Drexel, and maintained by the International Typographical Union.

Rising from the rof of the Tesla laboratory are two wooden scaffoldlike arrangements, one being over the centre of the building and the other over the doorway.

As Mr. Tesla was conversing with the HERALD correspondent a man entered with a sample of paint. Tesla smiled and said, "I wish I had had that paint before, as my laboratory here has been on fire five times and has been struck by lightning six times. Happily no damage was done."



NIKOLA TESLA

EXPERIMENTAL STATION AT COLORADO SPRINGS.

PRIMITIVE WIRELESS TELEGRAPHY.

System Used in Warfare by Oriental Tribes, Who Know of Enemy's Movements Hundreds of Miles Away.

THE army and navy might avail themselves of a system of wireless telegraphy perfected in an entirely unsuspected quarter of the world," said a well known psychic the other day. "It is a system destined to become universally employed for military, commercial and social communication.

"The other day there arrived in this country a little yellow book, by Richard Kerr, Fellow of the British Geographical Society, entitled 'Wireless Telegraphy,' which treats of the history of that art which now has the civilized world by the ears.

"Here are given well authenticated facts concerning mysterious war signals and reports of movements of troops despatched by certain Eastern natives across distances of hundreds of miles without visible electrical or other mechanical appliances. The facts are presented on authority of many officers of European armies engaged in Eastern wars.

"This wonderful system was noticed particularly during the recent war in Afghanistan. Whenever the British officers conveyed to their subordinates particulars as to their intentions to operate at a certain point fifty or a hundred miles away, the natives in those distant quarters were immediately acquainted with all of their plans. This fact was proved by constant repetitions of the feat, and it was seen to our satisfaction that none of our mechanical methods of communication or transportation were used.

"There were no connecting railroad or telegraph lines, and not even the fleetest horseman could have made the trip in the space occupied by the mysterious transmission of intelligence. The outlying hilltops were watched day and night for possible signals, but disclosed nothing.

Secret Well Kept.

"A fund was subscribed among the British officers with which to bribe the natives. Although they acknowledged their power, money could not purchase the secret. They said it was a religious heritage, which could not be imparted to the heretics of the West.

"Kerr publishes statements of British officers that on the day when England lost the illustrious General Gordon at Khartoum several people in the streets and bazaars of Cairo knew of his death. Yet there was no railway or telegraph between these cities. The distance in a direct line was one thousand miles or more.

"A Dutch official now in Amsterdam is quoted as saying that in the Dutch East Indies the natives of any one island knew everything of importance that occurred in any of the other islands, situated, as they all were, miles apart. If there occurred an earthquake or storm involving shipwreck and loss of life, or if a murder had been committed many miles away, the natives on the island on which this official resided would know all of the particulars long before the tidings could be conveyed by the ordinary channels.

"My explanation? Well, it is the same as that of Professor Kerr. He says that these Oriental methods of wireless telegraphy must rest entirely upon a highly trained mental effort. That is just it in a nutshell. Can you estimate the value which a corps of those Eastern wireless telegraphers would be to our government?

"To be sure, the Orientals give more attention to this kind of mental training than do the Occidentals, and it is as a result of this peculiar training alone that they are able to accomplish the wonderful feats of telegraphing attributed to them. Of course there is a class of ignorant sceptics who brand a man accepting such a hypothesis as a spiritualist or a gullible convert to voudoo art, but ghosts and spooks and haunts, or whatever you choose to call them, have no bearing upon this question at all.

"It will take us perhaps years to learn this new art, but instruments for such practice and training have already been devised. Between them thoughts and intelligence can be transmitted without regard to distance and intervening matter by means of inconceivably minute and rapid ether waves. It is simply an extension of the well known natural law under which sound is conveyed by vibrations of the atmosphere and light is transmitted by those of the thinner ether.

Experiments of Interest.

"One of these instruments is a delicate little scale balance, somewhat like those for weighing letters. Instead of the flat stand for supporting the letters there is a disk covered with a thin membranous material. The recording pointer moves against a revolving cylinder of record paper and writes in a waved line such as is understood by scientists.

"Now, Sir William Crookes, the celebrated English chemist, carried on some experiments with this and proved to his satisfaction that the human mind exerted at a distance could will the disk to move up or down. The subject was only a few feet away, to be sure, but this was only the beginning. Why could not there be made an instrument with sufficient delicacy to catch every vibration of the brain, just as Marconi's 'coherer' catches his electric waves, likewise thrown out in ether?

"There are mechanical means for practice of concentration and relaxation, the one condition needed by the transmitter and the other by the receiver. One of the more interesting transmitting devices consists of an alphabet printed in huge black letters upon large circular disks of white cardboard, a black screen and a small projector for throwing light rays. A darkened room is essential to thorough concentration. Suppose you wish to transmit the message 'Come' to your receiver. You would take each letter at a time and hang it upon the centre of the black screen, within focus of the projector, which may be a very strong bull's-eye lamp throwing a circle of light like that of a stereopticon. The mind is concentrated upon each letter until all external consciousness is definitely eliminated.

"The receiver, wherever he may be, sits in a similarly darkened room, keeps his mind in a perfectly passive state and gazes blindly into space. Gradually there appears before his eyes a wavy cloud followed by a pale bluish light, very bright in the centre. As he continues to gaze, the letters impressed upon the mind of the transmitter focus themselves into view.

"Perhaps money will sometime buy the secrets of the wireless telegraphy of the Orientals, or perhaps we Occidentals shall ourselves become masters in an equal art of our own perfection. At any rate, the day is not infinitely distant when all such mechanical devices as employed by Marconi, Tesla and the other workers along the electric line, shall have become obsolete and corps of selected operators will transmit our military, commercial and social despatches with no other instruments than their own heads, and with no expense save that of their own gray matter."

Argument For the Fundamental Tesla Polyphase Patents.

During the past few weeks, argument has been heard by the U. S. Circuit Court for the District of Connecticut, at New Haven, in the case of the Westinghouse Electric & Manufacturing Company against the New England Granite Company, et al., for infringement of the Tesla polyphase patents, Nos. 381,968, 382,279 and 382,280, the first of these dating back to May 1, 1888. The defendant concern has been using a polyphase plant alleged to infringe these patents. For plaintiffs the case was argued by Messrs. F. H. Betts, L. E. Curtis, and T. B. Kerr, and for the defendant by Messrs. C. E. Mitchell and H. B. Brownell. The motor sued on is a Cushman supplied with current from a General Electric three-phase generator.

In his argument, Mr. Betts asserted that with the publication of Mr. Tesla of his invention before the American Institute of Electrical Engineers in May, 1888, and with the simultaneous grant of his patents, "a new thought, a new era of construction, and even a new department of electrical terminology" came into the world, and that these facts were at once admiringly conceded by electrical engineers everywhere. The expression of contemporaneous opinion as to the character of a step in an art has always been deemed by the courts, in patent cases, as of great significance (see the Telephone Case, 126 U. S., p. 1; New Process Fermentation Co. vs. Maus, 122 U. S., p. 413; Electric Accumulator Co. vs. Julien Co., 38 F. R., p. 132). Mr. Tesla had found existing systems of power generation and transmission inadequate for their work. Direct current was not available in large quantities for long distances and was cumbered by the use of a commutator. Single-phase alternating current had failed because of the troubles due to obtaining synchronism between generator and motor, and the art was virtually at a standstill, except in regard to the use of current in small areas or small quantities. This then, was the state of the art as Tesla found it. Alternating currents were the only long distance power currents anywhere generated. But alternating currents could not be used as such successfully, for transmission of power, or, in other words, in "motors," because the alternations for the effective transmission of power were too fast. The motor could not keep up with them. It might be brought up to synchronous speed and would continue to run as long as such synchronism was substantially maintained. If a load was put on the machine which impaired synchronism the motor stopped. Mr. Tesla set himself to work to reconcile contradictions and to overcome difficulties which had blocked the way of the use of alternating currents in their initial condition. In doing this he turned the difficulties into means of success.

His new conception was that alternating currents could be made a source of power, notwithstanding the rapidity of alternation, or rather by reason of the rapidity of their alteration of direction (for, other things being equal and within practical limits, the higher the rate of alternation, the higher the efficiency of the machine). He perceived that by combining two or more of such currents, displaced in period of arriving at each point in their cycle of changes, the rising potential of one would accompany the falling potential of the other, and their joint effect would be to produce between them a "resultant pole" (which was the result of the combination of the magnetism of both), which would be constantly and progressively shifting its position around a circle, and which thereby produced a "whirling field." This met every difficulty by creating a continuous force in one circular direction, which tends continuously to drag the armature after the point of greatest attraction in the "whirling field," and thereby produces a source of power which becomes more effective the more rapidly it whirled; that is, the more rapid the alternations in direction.

The whirling field produces a condition in the motor which will always tend to start the armature, and will, in fact, start it, if the armature be of proper construction, and will cause the armature to run faster and faster to endeavor to catch up with the swiftly whirling pole. In this way "power" is generated. A practical alternating current motor (i. e., something that would move something else) was made. A motor capable of carrying large loads at high speeds was produced, the efficiency depending, so far as the "whirling" field was concerned, upon the rapidity of alternations in the generator, and the starting capacity and mutual attraction between such field and the armature, depending upon the particular construction of the armature. This, then, is the gist of the Tesla method and apparatus for transmitting power.

The "method" consists of the generation and utilization of two or more alternating currents of different periodicity to produce in a motor having corresponding circuits, a whirling field, or source of power. The "apparatus" consists, essentially, of a motor having a plurality of circuits, in which alternating currents of differing phase are produced, without mingling or interfering with each other, combined with a generator of alternating currents of differing phase, connected to the motor by transmission conductors of such a character as to preserve the independence and proper succession of phases, and thereby produce the whirling field. The method of operation just described is fully set forth in the Tesla Patent No. 382,280. The primary patent for the apparatus is No. 381,968.

But Mr. Tesla, having laid his foundation, said Mr. Betts, made other and supplementary inventions, and one of these is embodied in the third patent, No. 382,279, in which an armature of great capacity for developing a condition of structural attraction between it and the field is described. The gist of this is the construction of the motor with an armature (or moving member) wound with "closed coils." The effect of these closed coils is that the attraction between the moving armature and the field is increased by any lagging behind in speed of the armature with reference to the "whirling field" of force. There are subordinate claims in Patent No. 381,968 and No. 382,279, for improvements in the form of construction of the field magnet in a multiphase alternating current apparatus. These claims are founded upon the superiority of the "annular" or "ring" type of field magnet in the apparatus of the multiphase type.

Mr. Betts went on to point out that the utility of the invention, as such, was never contested, and deprecated the defendant's contention that it was merely an "invention on paper." Mr. Tesla built such motors and showed them, and his system had come largely into use. Moreover, attacks upon the degree of utility of machines made in exact accordance with the drawings of a patent have been so often characterized by the courts as futile that there should be an end of such defences. The Supreme Court of the United States in the Bell Telephone Case swept away a far more vigorous contention of the contestants, because based upon the fact that Prof. Bell had never in fact utilized the exact instrument of his patent for the successful transmission of a single articulate word (126 U. S., 1.). In Loom Co. vs. Higgins, 105 U. S., 586, the court said: "When the question is whether a thing can be done or not it is always easy to find persons ready to show how not to do it." Judge Coxe, in the Mergenthaler Case, 57 F. R., p. 502, satisfactorily disposed of all such defences, and in the latter case of Rynear Co. vs. Evans, 83, F. R., p. 697, he sarcastically remarked that a judicial experience of many years had convinced him "that when an expert undertakes to prove that his adversary's process or machine is a failure he always scored a success."

Mr. Betts then discussed four publications which were assumed by the defendant to anticipate Tesla. The first of these was by Mr. W. Bailey, in 1879, on a mode of producing Arago's rotation. But Bailey made not the faintest suggestion of the use of two "alternating" currents of differing phase generated by an alternating-current generator, and used to produce a shifting of the magnetic field in a motor. Bailey's paper describes no phenomenon except the ordinary one always present in every direct-circuit machine, of intermittently shifting the attractive poles by the reversal of a straight current by means of a commutator. Tesla does not claim, of course, to have been the first to produce a progressive shifting of the poles of a motor by any and all means. What he describes and claims is the method of progressively shifting such poles by combining two true alternating currents of differing phase. In his paper of May, 1888, he distinctly states this.

The next publication was that of Deprez in December, 1883, and later. But all that he demonstrated as a mere theoretical abstraction was that, if a machine were made in which the field magnet varied in position with reference to the brushes, the variation would be indicated by the needle of another machine. The needle of another machine would move so that whenever the angle between the brushes of the first machine moved, it would stop and indicate on a scale, attached to the second machine, the new angle which was subtended between the brushes and magnet. The only practical application of this thought was to indicate upon a ship's compass the position of the magnetic pole with reference to the course of the ship. It was said by the expert for the defendants that if the machine described by Deprez, which was constructed with a magnet and brushes capable of changing their angle with reference to each other, had been so used as to rotate the brushes continuously, the machine would have produced currents, not only differing in period of maximum and minimum potential, but also alternating in direction at proper intervals.

But certainly Deprez did not describe this, and had not the remotest idea of utilizing either the alternations of direction or the rapidity of such alternations, or the progressive and regular sequence of cyclic changes produced by continuous alternations. The only suggestion which Deprez makes is that the theorem of the parallelogram of forces can be employed to produce an indicator of position. The idea of utilizing that law, as exemplified in a two-phase alternating-current machine as a source of power, never dawned upon his mind. In fact, he pronounced alternating currents to be useless for power purposes, and in his famous Paris to Creil experiments resorted to direct current.

Next came the Siemens and Von Alteneck English patent of 1878, but Mr. Betts contended that all that could be asserted of the Siemens patent was that, in the case of a single one of the machines the position and connection of coils is such that the machine would initially generate two alternating currents of differing phase, but the inventors do not mention this fact. Nor if they had it, would such distinguished inventors have allowed such a useful invention to slumber for ten years in oblivion. Moreover, every machine described was equipped with commutators to straighten out the current.

The last defence in the shape of publication was Bradley's application of 1887, culminating in a patent of October, 1888. It was claimed that only the application could be considered, and that most assuredly was only a thing on paper. But the Bradley application, even if it were competent by itself, presents nothing of material importance. True, it describes a generator which is capable of producing not only direct currents—by means of a "commutator"—but also one or more alternating currents, and there is a general statement near the end of the specification, that "It is obvious that my machine may be used as a motor as well as a generator, and that it may when so used be fed or actuated either by continuous or alternating currents or both." But this is very far from a statement that two or more alternating currents, as initially produced in a generator, are deliberately and intentionally not to be "commutated" or straightened, but, on the contrary, are to be conducted by proper circuits, which preserve their initial independence of phase, and then, without "commutation" are to be utilized in corresponding circuits of the motor. True, Bradley claims in his original third claim an "alternating current dynamo-electric machine with windings to produce currents of differing phase." But Siemens had described such a machine in 1878, and Bradley does not claim, and nowhere even suggests, the use of such a machine as a motor by means of uncommutated currents of different phase. So, in his fourth claim, he claims an "alternating current dynamo-electric machine" having its armature wound with a closed coil, and utilized by means of complete contact rings, and such contact devices as are shown. But he fails to point out anywhere in his specification, or suggest in his claim, the combination of such a generator with such a motor, by means of circuits which will preserve independence of generated phase and utilize the same, as such, in the motor.

Mr. Betts asserted that Bradley's application and description is too vague. He had no thought of utilizing the difference of phase as a source of power. This, he thought, is conclusively shown by the fact that the only specific description contained in his original application, in connection with the initial production of two phases, is accompanied by the description of the running together of such phases and the production of "one single alternating current" by combining the two currents "by induction" by means of a converter.

When Bradley came to patent his device, five months after Tesla's patent had been granted, he erased the figure illustrating the transformer for running together the two phases by induction, so as to produce "one single alternating current," and he struck out that part of his description. This action was significant and decisive against the contention that he had knowledge of, or described, any use of two-phase currents generated and propagated and utilized as such.

Coming to the broad question of infringement, Mr. Betts noted that the principal contention of the defendants was that they did not use the "independent" circuits of Tesla, and also that the interposition of converters for letting down the current was a differentiation. The latter point he dismissed as idle, Tesla's system

being devised for the very purpose of high potential transmission and low potential use. The contest hinged upon the meaning of "independent circuits." Mr. Betts argued that the language used in a patent is almost necessarily less than the idea. The invention is larger than the form in which it is expressed, and the courts have even gone so far in carrying out that rule—when an invention before them is of an important character, and is important and valuable because it is capable of being expressed and embodied in a great variety of forms—as to disregard the literal wording of the claims if the substance of the invention has really been appropriated by an infringer. Nothing can be more pertinent on that point than the ruling of the Supreme Court in Hoyt vs. Horne.

It was true that the defendants connect the circuits of their generator at one end to each other, and the circuits of their motor in delta form, and that they use three transmitting wires in place of the six which Tesla illustrates in his several figures. But, none the less, the circuits of their generator and transmission circuits and the motor circuits, act independently, in so far as they preserve and utilize independence of phase, precisely in the same way as do the isolated circuits used in Tesla's illustrations. Besides, the defendants did not invent the "three-wire" system of electrical transmission, nor the practice of utilizing, in independent circuit systems, such parts of connected circuits whose use did not interfere with the appropriate work of those portions of the circuit which were in fact separate. Mr. Betts cited the proposal of three wires, with phase difference of 120 degrees, for the Lauffen-Frankfort transmission in 1891, and pointed out that Tesla himself in his paper of May, 1888, said of the economy of wires in connection with the two-phase system, "Instead of using four wires with like result, three wires may be used, one forming a common return for both circuits." In other words, and, in short, "independence" did not mean "isolation," and it was the phases of potential or varying pressures that were to be kept separate from each other, not the "currents." The defendants admitted that the generator which supplies their motor system with energy generates three alternating currents of differing phase of potential—that is, the time of reaching maximum and minimum potential in the circuits is 120 degrees apart. The potential thus generated in the three circuits of the generator is transmitted with the "independence" of phase, and time relation thereof, unimpaired, to the motor, and such potential, acting in the circuits of the motor, generates in such circuits three alternating currents of differing phase 120 degrees apart, and such currents in the motor produce a whirling field of exactly the same character as would be produced if the wires were six in number, instead of three.

No one could tag an atom of water any more than they can tag a vibration of electricity, and assert that it is the same atom or the same vibration which generated the pressure initially, which also transmitted and utilized it finally. "Pressure," or "potential," is the vital thing, and, if potentials of three different phases be produced and transmitted independently and utilized in a motor, it is of no importance whether such pressure was transmitted through three pipes or three wires, or six pipes or wires. The statement that the electromotive forces "so cancel out," when opposing each other, that there is in each circuit nothing but a current differing in phase by 120 degrees from the current in other circuits, is easily illustrated by diagrams.

As to the patents in suit, No. 381,968, was in dispute as to claims 1 and 3, touching the use of the word "independent," and as to the employment of an annular or ring shaped field magnet as a unit, the core and the winding to be regarded as a whole. Patent No. 382,280 was a claim for the "method." Mr. Betts remarked that a method of operation may be patented as a distinct invention from the apparatus which operates thereby. In the Bell Telephone case, the claim was for both the method and apparatus. The apparatus described by Bell was entirely different from that of the defendants in the several suits, and there was no infringement of the claim, so far as it was a claim for an apparatus, but the Supreme Court sustained the claim for the method and held that defendant infringed. This could not have been if the two inventions were exactly the same. In 94 F. R., p. 868, Judge Shipman, in a case on another Tesla patent, relating to a modification of the same system as that of the patent in suit, ruled that a claim for the "method" of operation was not void as covering merely a mode of operation or function of certain machines.

Patent No. 382,279 was for a motor having closed coils or closed inducing circuits on its armature. Infringement was not denied as to the first and second claims, unless the word "independent" is given the restricted meaning which was held to be untenable.

Infringement of the third claim was denied on the ground that the defendants' magnet is not "an annular field magnet," but this was due to the misapprehension of the meaning of the phrase, as noted above.

Mr. Betts touched last upon the decision of the Imperial Court of Germany, under which Tesla had been compelled to erase his broader claims and take refuge in limited phraseology. With regard to this, Tesla, admitting that the invention had not been "worked," in a strict sense, sought to have his default excused, on the ground that he had offered to license some one, and that infringers had adopted his method and claims by utilizing what is termed the "rotary current system," with three conductors instead of six. The court held that, in view of the limitations of his patents, and in view of the striking out of his claims as first presented, and in view of the substitution of narrow ones, and in view of the fact that certain explanatory language, as to what was meant by "independent" circuits, having been originally in the specifications, but stricken out, they would not give to the patents the broad construction which would enable Tesla to save them by relying upon the work of infringers as a statutory "working" of his invention. The German court went on to say that, even if the explanatory sentences had been left in, they would, nevertheless, have come to the same conclusion. But this was obviously a mere obiter dictum. No such question was before the United States Court, as the sentences had, in fact, been erased before the patent was issued.

But a more important fact came up in the German case, namely, the Ferraris publication in April, 1888, at Turin, of analogous ideas. This pamphlet had been distributed abroad, and was therefore part of the prior art there, and the German patents of Tesla could only be valid if at all, for specific construction. But the Ferraris lecture had no place in the prior art in the United States, and had not been invoked here by the defendants. "Here," concluded Mr. Betts, "Tesla is a primary inventor, being the actual originator of a new method of electrical transmission of power, which has revolutionized industry."

NOTES ON LIGHT.

BY WILLIAM ROLLINS.

NOTE LXXVIII—HYDROGEN IN TESLA-LIGHT TUBES.

Tesla, the father of vacuum-tube lighting, has said the higher the vacuum the better the light. This is an important fact in a system which is to be a light of the future. A second is this: The vacuum should be hydrogen and adjustable. This obvious deduction from what I have shown about this gas and X-light is mentioned now rather than later, when I shall describe experiments with Tesla light, because I should not like to see the idea patented for those of us "who serve the dream" know them unwise.

NOTE LXXIX—CHEMICAL HYDROGEN REGULATORS OF CHEAP X-LIGHT TUBES.

It is possible to buy an X-light tube for $5, which leaves the makers so small a profit they have to reduce the platinum to the lowest. They are, therefore, unable to use my intermolecular regulators of platinum or palladium, and either have none or the ordinary potash or the oxygen bulb, the life of these tubes is in consequence very short as they die of cathode exhaustion. I gave my tube-makers two years ago a formula for a chemical regulator which liberated hydrogen, but as their work is chiefly in furnishing the finest tubes to hospitals they have little use for it. I now publish the method, as it is worthy of extended use in connection with low-cost tubes, as it increases their price only five cents. I have shown in other notes that X-light was a hydrogen phenomenon for practical purposes and that in consequence it was necessary to introduce this gas. What therefore is necessary to revive cheap tubes is to have some chemical in a small supplementary bulb which will liberate hydrogen at a temperature low enough so the glass bulb will not soften in the process.

Sodium formate will do this.

NOTE LXXX—SUPPORTING THE STEMS OF X-LIGHT TUBES.

In Note lxi, it was said that the universally-used glass wrappings about the stems of the terminals in a vacuum tube were not only unnecessary but undesirable. In Fig. 56 a tube was shown with strong, bare stems supported by diaphragms blown in the glass. As I aim to make a tube which will be easy to construct, as well as durable, graceful and efficient, this kind of support has been abandoned, for it took a good workman to make it, and sometimes the glass would crack at the seal. The stems are now supported by collars of mica, or what may prove better, by rings of molded lava, as suggested by Mr. Heinze. This construction applied to my rotary and cooled target tubes is shown in Figs. 64 and 65, and in detail in Figs. 66 and 67. In these illustrations the electrolytic regulators are shown forming the support for the cathode stems, thus doing away with one piece of platinum wire. I have used this position for the platinum heat regulator for a long time, but, on account of the length of the platinum, it has been criticised as making the vacuum tube more liable to injury than when the regulator is placed on the side. The electrolytic regulator is now so short that this objection is without force. Fig. 68 shows the details of such a regulator.

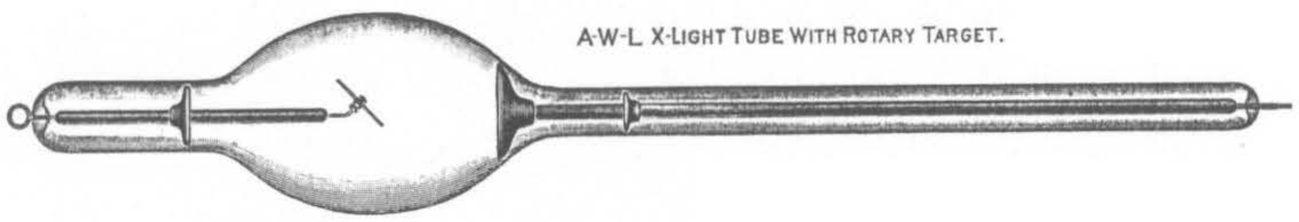
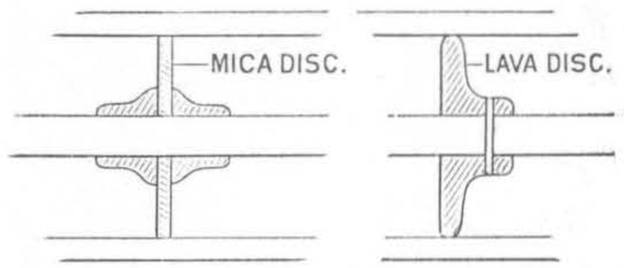


FIG. 64.—NOTES ON LIGHT—SCALE ONE-QUARTER SIZE. TUBE WITH ROTARY TARGET.



FIG. 65.—NOTES ON LIGHT—SCALE ONE-QUARTER SIZE. TUBE WITH WATER-COOLED ANODE.



FIGS. 66 AND 67.—NOTES ON LIGHT—SCALE FULL SIZE. DETAILS OF FIGS. 64 AND 65.

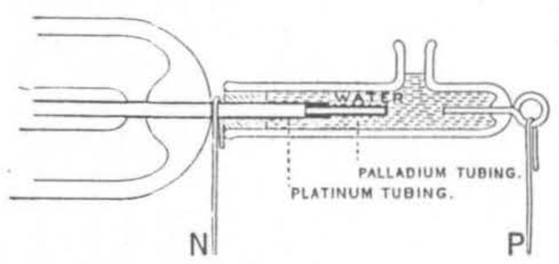


FIG. 68.—NOTES ON LIGHT—DETAILS OF ELECTROLYTIC REGULATOR.

TESLA IS NOT SICK

And He Says He is Going to Telegraph from New York to Paris Without Wires.

DENVER, Col., Jan. 14.—Nikola Tesla proposes to telegraph from New York to Paris without wires. He arrived yesterday from Colorado Springs, where he has been working secretly, and announced that he had perfected a system of wireless telegraphy vastly superior to that of Marconi. He left for New York last night.

Said Mr. Tesla: "I didn't come to Colorado for my health, but to learn the effect of dry air and high altitude upon the machine I have perfected. The benefits of my machine during a sea fight cannot be estimated. It will aid in doing deadly work.

"The beauty of my machine is that it can transmit power over several thousands of miles without wires. Now the Marconi system is useless at distances of more than one hundred miles. Any operator can read a message in transit by the Marconi system. It is impossible to do this with my machine. I expect to send messages to Paris during the Fair."

A SPECIAL cable dispatch to the N. Y. "Sun" from London states that the Secretary of the Wireless Telegraphy Company says that Inventor Marconi will make extensive tests in England in 1900 in behalf of the United States Government, with which negotiations are merely in abeyance. Marconi thinks that the present limit of eighty-six miles in communication will shortly be raised to 150 miles. He has no belief in Nicola Tesla's promise to communicate across the Atlantic. He believes that science, while gradually progressing, will be unable to obtain such great results before the preliminary difficulties have been surmounted. Personally, he does not expect, yet, to girdle the Atlantic. Meanwhile, the "Daily News" reports that Emilion Guarini, a native of Puglia, Italy, who is little more than 20 years of age, has discovered a means of utilizing Marconi's invention at the greatest distances. He accomplishes this by means of his own invention, which is called a repeater and which he says receives the electric waves and is capable of transmitting them to other repeaters for continuous repetition. He says he needs a repeater only at every five-hundredth mile. He further claims that his invention will enable polar expeditions to keep in constant communication with civilization.

WE announced some time ago that NIKOLA TESLA had gone to the top of a high mountain in Colorado to experiment not only in wireless telegraphy, but also in the wireless transmis sion of energy over a long distance. He has now returned to New York evidently well pleased with the result of his experiments, and the following remarks of his to a New York reporter convey his views and anticipations as to future developments :—

My experiments have been most successful, and I am now convinced that I shall be able to communicate by means of wireless telegraphy not only with Paris during the Exhibition, but in a very short time with every city in the world. My terminal instruments will be absolutely immune from extraneous disturbances, and I hope to obtain a speed of from 1,500 to 2,000 words a minute. I have returned to New York to pursue a series of experiments with a view to solving the greater problem of transmitting power without using wires.

Personal.

NIKOLA TESLA says he will remove his laboratory from New York City to Colorado Springs, Colo., and there make his permanent residence. This time he "has perfected a machine by which he can transmit power several thousand miles without wires." N. T. is a good thing for the "science" supplements of the Sunday papers.

Queries and Answers

What are the dimensions of the core, size of wire and number of turns for a Tesla coil to work with a 6-inch induction coil? What means may be used for regulating the same when supplied with alternating current?

S, J. S.

Tesla coils have no cores and must be very highly insulated. One of the easiest ways of making one is to take a large cylindrical battery jar 8 inches in diameter by 12 inches long, and wind over it about 60 or 80 turns of No. 18 magnet wire. This may then be fixed to the jar by a coating of shellac. The primary should be made of 8 or 10 turns of No. 4 or No. 6 wire, made sufficiently small to slip inside the jar. The whole should be enclosed in a big earthenware tub and filled with mineral seal, linseed or transil oil. For regulation the ordinary means of choking back the current in the primary of the induction coil may be used.

CONTEMPORARY CELEBRITIES

Nikola Tesla

Tesla has seemed to be under a cloud of late, but in the Philadelphia North American he is brought out once more, with his characteristics as a man, by Julian Hawthorne:

Tesla, the papers say, has left his eyrie on the flank of Pike's Peak in Colorado, and is on his way East with a new wireless telegraphy invention in his pocket. It is hard to realize how much the contents of this man's mind may mean for the world. I met him a few years ago in a famous but now obsolete cafe, near Madison Square, in New York, and we dined together there. I saw a tall, slender young man, with long arms and fingers, whose rather languid movements veiled extraordinary muscular power. His face was oval, broad at the temples and strong at the lips and chin; with long eyes, whose lids were seldom fully lifted, as if he were in a waking dream, seeing visions which were not revealed to the generality. He had a slow smile, as if awakening to actualities, and finding a humorous quality in them. Withal, he manifested a courtesy and amiability which were almost feminine, and beneath all were the simplicity and integrity of a child. Tesla is, I believe, a Herzegovinian. The Greek type prevails in him. He has abundant wavy brown hair, blue eyes and a fair skin. He was a trifle shy at first; or perhaps it was merely that he did not at once arrive from the regions in which his mind is wont to reside, and adjust himself to the requirements of his actual environment. But his social instincts were of the royal order; as the host of the occasion, he wished that his guest should be entertained as became the hospitality of princes. There was a reminiscence of the Oriental about it; and if the scene had been a tent in the desert, one would soon have imagined it a palace. But oh, how far it was from the oppressiveness which renders some of the best-intended courtesies a burden! To be with Tesla is to enter a domain of freedom even more free than solitude, because the horizon enlarges so. His mind cast out genial rays that illuminated distances, and made the great and marvelous seem near and beautifully familiar. You have felt the power of good music to make you seem more than yourself; and similar was the influence of this ingenuous but profound student. My own deficiency in the technicalities of science seemed to offer no impediment to our intercourse; partly because, like other men of really sound attainments, he was easily able to make intelligible to my untrained comprehension the spiritual essence of his own speculations and discoveries; and partly because he turned out to be quite as much at home in my own little specialties as I was. He knew all English poetry, much of it by heart; nor was he less familiar with the literature of Germany and France, not to speak of more recondite branches of literary culture in which I was not proficient. He knew the art of ancient and modern times, and had thoughts on the subject that were not merely critical, but creative. With music he stood on the terms of a musician; and one can imagine the kind of transcendental symphony that a mind of his calibre and sympathies might compose. Meanwhile, he was one of the first, if not the foremost, scientific investigators of his epoch, which is the most scientific in human history; and when it was question of the vintage of a wine, or the condition and cooking of an ortolan, he knew that, too, though his own eating and drinking were of the most abstemious order. The total impression which I derived from his manifestations was not, however, of an intelligence divided off into chambers, from one or another of which the treasures were brought forth as needed; but it seemed to be always the same entire and perfect chrysolite of intellectual ability, directed this way or that, focused far or near, as occasion served. Naturally it was toward the possibilities of the future in the way of ascertaining and controlling natural laws that I was most solicitous to direct the conversation. Tesla is the most modest of men, but also one of the most generously communicative when his confidence is secured; and I drew from him the wonderful story of his early experiences, his student days in a great European university—which I will not repeat here, not being authorized to do so. Then he went on to outline the nature and expected outcome of some of his dealings with electricity and other obscure forces of nature. As he spoke, mankind seemed to arise a Titan, and grasp the secrets of the skies. I saw a coming time when the race would no longer be forced to labor for the means of livelihood, when the terms rich and poor would no longer mean difference of material condition, but of spiritual capacity and ambition; a time when intercommunication all over the earth should be immediate and universal, and even when knowledge should be derived from sources now hardly imagined.

[97683.]—Tesla Coil.—The use of the oil is to insure good insulation. Even if a leak momentarily occurs in the coil, the oil oozes in and restores the insulation. The object of the jar is to increase the number of oscillations or "frequency" of the currents.

S. BOTTONE.

The New York Herald March 9, 1900

TESLA HAS NARROW ESCAPE.

Fire did $3,000 damage yesterday in the cellar of the seven story building Nos. 46 and 48 East Houston street. Nikola Tesla occupies three floors in the building. Five years ago his laboratory in West Broadway was destroyed by fire. The firemen said that if yesterday's blaze had not been promptly discovered Tesla probably would have been burned out a second time.

MR. TESLA'S LABORATORY IN DANGER.—One day last week the building on East Houston Street, New York, in which Mr. Nikola Tesla has his laboratory, was damaged by fire. The flames, however, were confined to the basement and did not reach Mr. Tesla's quarters. It will be remembered that Mr. Tesla's laboratory on South Fifth Avenue was burned out a few years ago.

A TESLA PATENT.—A patent issued March 20 to Nikola Tesla relates to the production at one point of an electrical pressure of such character and magnitude as to cause thereby a current to traverse elevated strata of the air between the point of generation and a distant point at which the energy is to be received and utilized. As illustrated, the apparatus consists of a generator supplying current to the primary of a transformer; the secondary consists of many turns and is connected at one side to the earth and at the other side to a terminal of large surface, maintained by such means as a balloon at a high elevation. The receiver duplicates this apparatus, except that instead of a generator being in one circuit of the transformer, receiving devices such as lamps and motors take its place. The transformer consists of a coil of very large diameter wound in spiral form, either with or without a magnetic core. The inventor claims that this furnishes a practical method or system of transmission of energy through natural media without the use of wires.

The Wireless Transmission System for electric energy which Mr. Nikola Tesla has been working out for such a long time has been covered by a patent granted to him recently, although the application was filed more than three years ago. Its general scheme is indicated by the ninth claim, which reads: "The method of transmitting electrical energy through the natural media, which consists in generating current impulses of relatively-low electromotive force at a generating-station, utilizing such impulses to energize the primary of a transformer, generating by means of such primary circuit impulses in a secondary surrounded by the primary and connected to the earth and to an elevated terminal, of sufficiently-high electromotive force to render elevated air strata conducting, causing thereby impulses to be propagated through the air strata, collecting or receiving the energy of such impulses, at a point distant from the generating-station, by means of a receiving-circuit connected to the earth and to an elevated terminal, and utilizing the energy so received to energize a secondary circuit of low potential surrounding the receiving-circuit."

Tesla Telegraphy.—As the outcome of Mr. Nikola Tesla's experiments on wireless telegraphy at high altitudes a patent has recently been issued to him in America, which is briefly summarised in the *Electrical World* as follows: "The patent relates to the production at one point of an electrical pressure of such character and magnitude as to cause thereby a current to traverse elevated strata of the air between the point of generation and a distant point at which the energy is to be received and utilised. As illustrated, the apparatus consists of a generator supplying current to the primary of a transformer; the secondary consists of many turns, and is connected at one side to the earth and at the other side to a terminal of large surface, maintained by such means as a balloon at a high elevation. The receiver duplicates this apparatus, except that instead of a generator being in one circuit of the transformer, receiving devices such as lamps and motors take its place. The transformer consists of a coil of very large diameter wound in spiral form, either with or without a magnetic core. The inventor claims that this furnishes a practical method or system of transmission of energy through natural media without the use of wires."

Wireless Electrical Transmission.—As is well known, Mr. Nikola Tesla has been giving much attention and time lately to the problem of transmitting electric energy between distant points through the air. A patent was issued in the United States to that gentleman on March 20th, which relates to the production at one point of an electrical pressure of such character and magnitude as to cause thereby a current to traverse elevated strata of the air between the point of generation and a distant point at which the energy is to be received and utilised. As illustrated, the apparatus consists of a generator supplying current to the primary of a transformer: the secondary consists of many turns, and is connected at one side to the earth and at the other side to a terminal of large surface maintained by such means as a balloon at a high elevation. The receiver duplicates this apparatus, except that instead of a generator being in one circuit of the transformer, receiving devices such as lamps and motors take its place. The transformer consists of a coil of very large diameter wound in spiral form, either with or without magnetic core. The inventor claims that this furnishes a practical method or system of transmission of energy through natural media without the use of wires.

Nikola Tesla Power Transmission. — Another patent by Mr. Nikola Tesla for the electric transmission of power by means of the upper strata of the atmosphere has now been published in America. The inventor proposes to use balloons to lift his sending and receiving conductors, and to employ such high electric pressures as millions of volts with a frequency of several thousand per second. The earth is to be used as a return, but we are not quite clear how the inventor will be able to prevent earth troubles with his return. In the patent the experimental apparatus is described for generating E.M.F.'s of from two to four million volts, and it is stated that current from such a machine can be sent through a glass tube 50ft. long with a barometric pressure of from one-third to one-fifth of an atmosphere. The estimated height of the captive balloons is put at from four to seven miles above sea-level, and Mr. Nikola Tesla proceeds to claim broadly the propagation of electrical energy by conduction through earth and air. The theoretical difficulties, let alone the practical difficulties, are so great in connection with this proposed scheme, that we do not propose to criticise it further until some actual results of experiments are published.

dition of the atmosphere, and also by the character of the surrounding country. The aerial conductors to these terminals are connected to the secondary of a spiral coil, the other end of the coil being connected to earth.

It is stated that the length of the thin wire in each of these coils should be approximately one-quarter of the wave length of the electric disturbance in the circuit, this estimate being based on the velocity of the propagation of the disturbance through the coil itself and the circuit with which it is to be used. For example, if the rate at which the current traverses the circuit including the coil be 185,000 miles per second, then the frequency of 925 miles per second would maintain 925 "stationary moves" in a circuit of 185 miles long, and each wave would be 200 miles in length. For such a low frequency, a secondary 50 miles in length would be used.

As will be noted from the illustration, the primary of the transmitting coil is supplied with a current by a dynamo, and the large coil of the receiver is connected with a circuit including lamps and motors. It is stated that the phenomenon involved in the apparatus is one of true conductions and not to be confounded with the phenomena of electrical radiation which have heretofore been observed, and which from the very nature and mode of propagation will render practically impossible the transmission of any appreciable amount of energy to such distances as are of practical importance. The specification states that if the potential is sufficiently high and the terminals of the coil be maintained at the proper elevation where the atmosphere is rarefied, the stratum of air will serve as a conducting medium for the current produced, and the latter will be transmitted through the air "with, it may be, even less resistance than through an ordinary conductor."

A Tesla Patent.

The accompanying illustration is reproduced from a patent granted May 15 to a Nikola Tesla on an "apparatus for transmission of electrical energy." *D D'* are terminals of large surface maintained by such means as a balloon at a high elevation, the elevation depending upon the amount and quality of the work to be preformed, the con-

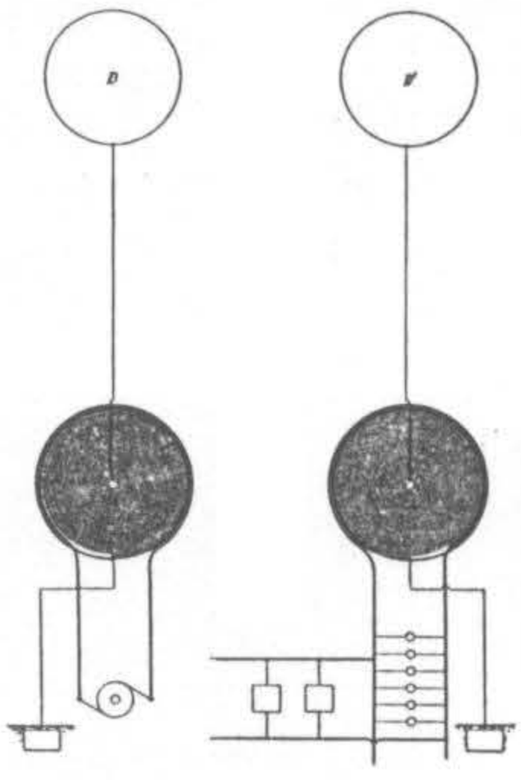
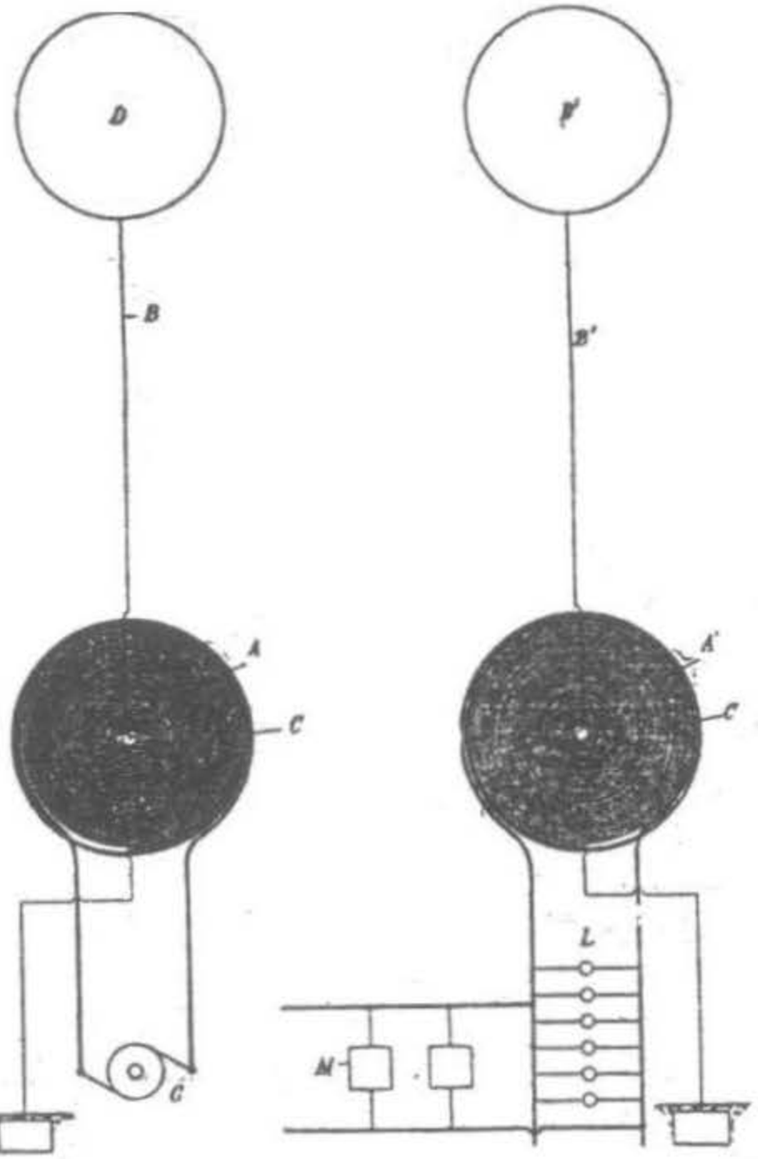


DIAGRAM OF TESLA APPARATUS.

APPARATUS FOR TRANSMISSION OF ELECTRICAL ENERGY.—No. 649,621; N. Tesla, New York, N. Y.



Combination with transmitting instrument comprising electrical transformer having its secondary connected to ground and to an elevated terminal respectively, and means for impressing electrica oscillations upon its primary, of receiving instrument comprising transformer having its primary similarly connected to ground and to an elevated terminal, and a translating device connected with its secondary, capacity and inductance of secondary of transmitting and primary of receiving intruments having such values as to secure synchronism with impessed oscillations.

MR. NIKOLA TESLA'S RECENT ELECTRICAL EXPERIMENTS.

A REMARKABLE paper, by Mr. Nikola Tesla, appears in the June number of the *Century Magazine*. The subject is "The Problem of Increasing Human Energy, with Special Reference to the Harnessing of the Sun's Energy"; and though metaphysical and sociological questions receive a large share of attention, the article contains an account of some very interesting electrical experiments, now described for the first time, illustrated by several very striking photographs, two of which are here reproduced. Mr. Tesla has been engaged for several years in further investigating the properties of alternate currents of high potential and frequency, with which he astonished audiences at the Royal Institution in 1892 (see NATURE, vol. xlv. p. 345). The following abstract of a part of his paper shows that his work has led to results of scientific interest and significance.

Electrical discharges capable of making atmospheric nitrogen combine with oxygen have recently been produced. Experiments made since 1891 showed that the chemical activity

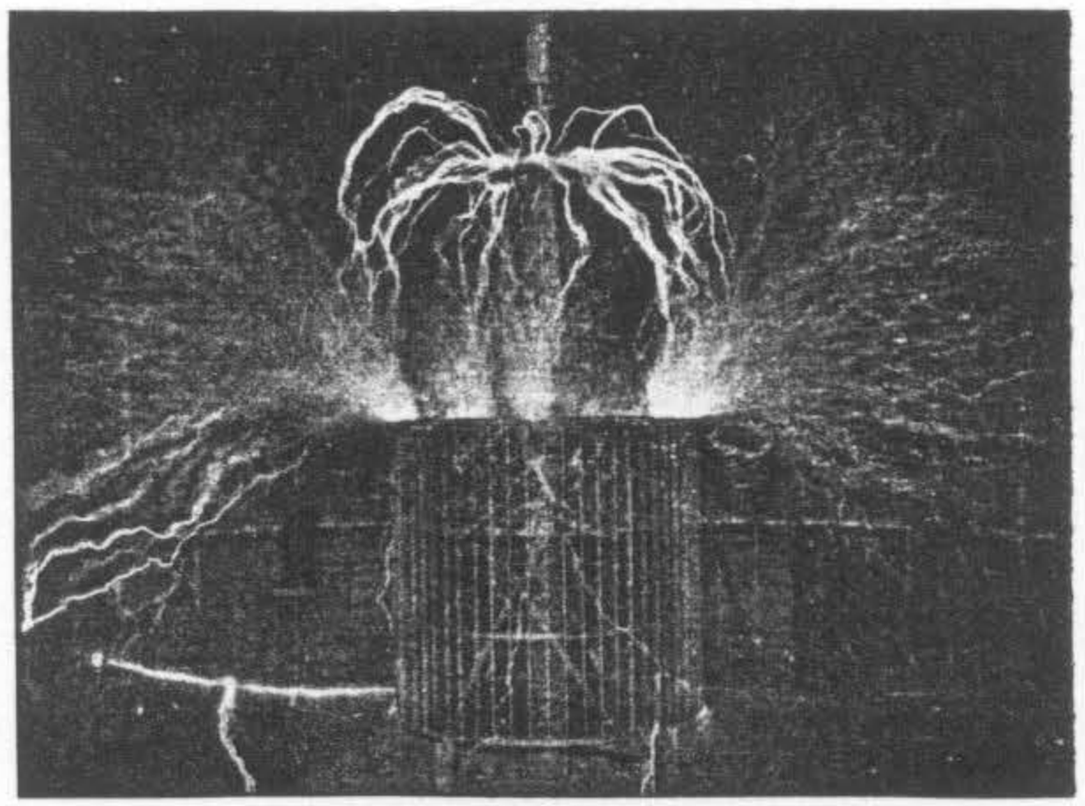


FIG. 1.—Combustion of atmospheric nitrogen by the discharge of an electrical oscillator giving twelve million volts and alternating 100,000 times per second. The flame-like discharge shown in the photograph measured 65 feet across.

of the electrical discharge was very considerably increased by using currents of extremely high frequency or rate of vibration. This was an important improvement, but practical considerations soon set a definite limit to the progress in this direction. Next, the effects of the electrical pressure of the current impulses, of their wave-form and other characteristic features, were investigated. Then the influence of the atmospheric pressure and temperature and of the presence of water and other bodies was studied, and thus the best conditions for causing the most intense chemical action of the discharge and securing the highest efficiency of the process were gradually ascertained. The flame grew larger and larger, and its oxidising action more and more intense. From an insignificant brush-discharge a few inches long it developed into a marvellous electrical phenomenon, a roaring blaze, devouring the nitrogen of the atmosphere and measuring sixty or seventy feet across (Fig. 1). The flame-like discharge visible is produced by the

intense electrical oscillations which pass through the coil shown, and violently agitate the electrified molecules of the air. By this means a strong affinity is created between the two normally indifferent constituents of the atmosphere, and they combine readily, even if no further provision is made for intensifying the chemical action of the discharge.

Under certain conditions the atmosphere, which is normally a high insulator, assumes conducting properties, and so becomes capable of conveying any amount of electrical energy. The discovery of the conducting properties of the air, though unexpected, was only a natural result of experiments in a special field carried on for some years previously. It was during 1889 that certain possibilities, offered by extremely rapid electrical oscillations, led to the design of a number of special machines adapted for their investigation. One of the earliest observations made with these new machines was that electrical oscillations of an extremely high rate act in an extraordinary manner upon the human organism. Thus, for instance, powerful electrical discharges of several hundred thousand volts, which at that time were considered absolutely deadly, could be passed through the body without inconvenience or hurtful consequences. Another observation was that by means of such oscillations light could be produced in a novel and more economical manner, which promised to lead to an ideal system of electric illumination by vacuum-tubes, dispensing with the necessity of renewal of lamps or incandescent filaments, and possibly also with the use of wires in the interior of buildings.

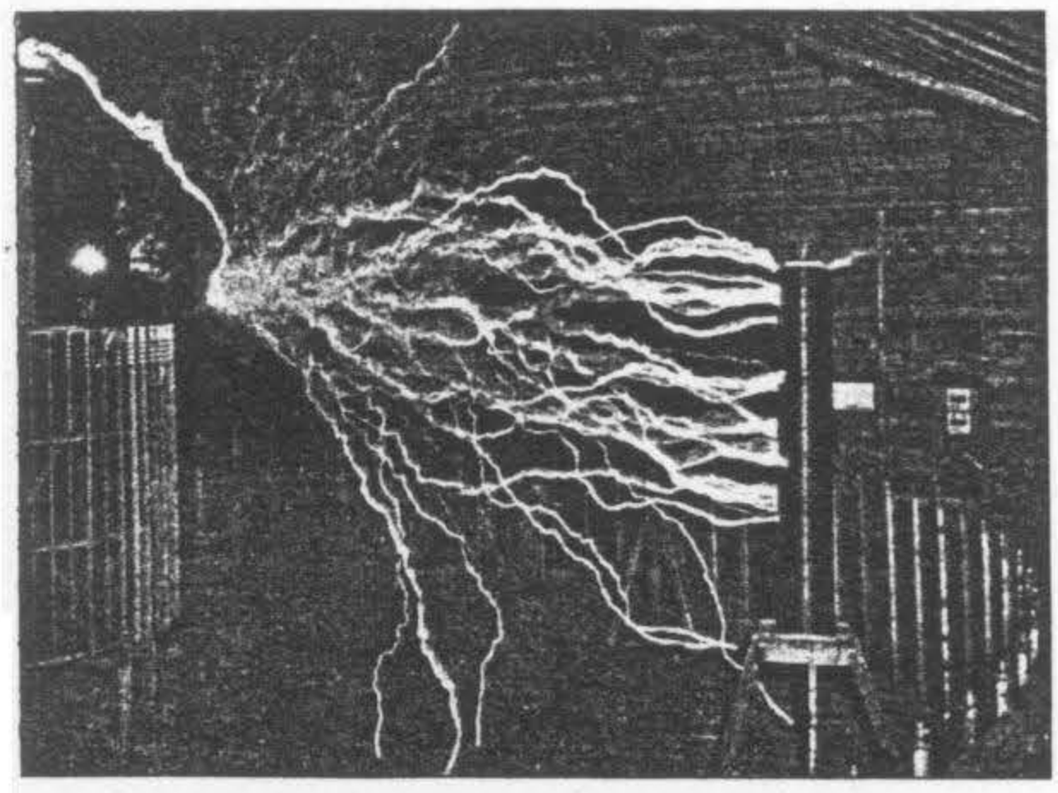


FIG. 2.—The coil, partly shown in the photograph, creates an alternating current of electricity at the rate of 100,000 alternations per second. The discharge escapes with a deafening noise, striking an unconnected coil 22 feet away, and creating such an electrical disturbance that sparks an inch long can be drawn from a water-main at a distance of 300 feet from the laboratory.

The investigations led to other valuable observations and results, one of the more important of which was the demonstration of the practicability of supplying electrical energy through one wire without return. To what a degree the appliances have been perfected since the demonstrations in 1892, when the apparatus was barely capable of lighting one lamp, will appear from the fact that as many as four or five hundred lamps have been lighted in this manner.

The success of this method of transmission suggested that the earth could be used as a conductor, thus dispensing with wires. The earth was regarded as an immense reservoir of electricity, which could be disturbed effectively by a properly designed electrical machine. Accordingly efforts were directed toward perfecting a special apparatus which would be highly effective in creating a disturbance of electricity in the earth, and a novel kind of transformer or induction-coil, particularly suited for this special purpose, was designed. By means of this apparatus, it is practicable, not only to transmit minute amounts of electrical energy for operating delicate electrical devices, but also electrical energy in appreciable quantities.

However extraordinary the results exemplified by Fig. 2 may appear, they are but trifling compared with those which are attainable by apparatus designed on these same principles. Electrical discharges have been produced, the actual path of which, from end to end, was probably more than one hundred feet long; but it would not be difficult to reach lengths one hundred times as great. Electrical movements occurring at the rate of approximately one hundred thousand horse-power have been obtained, but rates of one, five, or ten million horse-power are easily practicable.

The most valuable observation made in the course of these investigations was the extraordinary behaviour of the atmosphere toward electric impulses of excessive electromotive force. The experiments showed that the air at the ordinary pressure became distinctly conducting, and this opened up the wonderful prospect of transmitting large amounts of electrical energy for industrial purposes to great distances without wires, a possibility which, up to that time, was thought of only as a scientific dream. Further investigation revealed the important fact that the conductivity imparted to the air by these electrical impulses of many millions of volts increased very rapidly with the degree of rarefaction, so that air strata at very moderate altitudes, which are easily accessible, offer, to all experimental evidence, a perfect conducting path, better than a copper wire, for currents of this character.

The experiments have indicated that, with two terminals maintained at an elevation of not more than thirty thousand to thirty-five thousand feet above sea-level, and with an electrical pressure of fifteen to twenty million volts, the energy of thousands of horse-power can be transmitted over distances which may be hundreds and, if necessary, thousands of miles. Investigations are now being carried on with the object of reducing considerably the height of the terminals now required.

The Century Magazine June 1900

THE PROBLEM OF INCREASING HUMAN ENERGY.

WITH SPECIAL REFERENCE TO THE HARNESSING OF THE SUN'S ENERGY.

BY NIKOLA TESLA.

ILLUSTRATED BY THE WRITER'S ELECTRICAL EXPERIMENTS, NOW FIRST PUBLISHED.

THE ONWARD MOVEMENT OF MAN—THE ENERGY OF THE MOVEMENT—THE THREE WAYS OF INCREASING HUMAN ENERGY.

OF all the endless variety of phenomena which nature presents to our senses, there is none that fills our minds with greater wonder than that inconceivably complex movement which, in its entirety, we designate as human life. Its mysterious origin is veiled in the forever impenetrable mist of the past, its character is rendered incomprehensible by its infinite intricacy, and its destination is hidden in the unfathomable depths of the future. Whence does it come? What is it? Whither does it tend? are the great questions which the sages of all times have endeavored to answer.

Modern science says: The sun is the past, the earth is the present, the moon is the future. From an incandescent mass we have originated, and into a frozen mass we shall turn. Merciless is the law of nature, and rapidly and irresistibly we are drawn to our doom. Lord Kelvin, in his profound meditations, allows us only a short span of life, something like six million years, after which time the sun's bright light will have ceased to shine, and its life-giving heat will have ebbed away, and our own earth will be a lump of ice, hurrying on through the eternal night. But do not let us despair. There will still be left on it a glimmering spark of life, and there will be a chance to kindle a new fire on some distant star. This wonderful possibility seems, indeed, to exist, judging from Professor Dewar's beautiful experiments with liquid air, which show that germs of organic life are not destroyed by cold, no matter how intense; consequently they may be transmitted through the interstellar space. Meanwhile the cheering lights of science and art, ever increasing in intensity, illuminate our path, and the marvels they disclose, and the enjoyments they offer, make us measurably forgetful of the gloomy future.

Though we may never be able to comprehend human life, we know certainly that it is a movement, of whatever nature it be. The existence of a movement unavoidably implies a body which is being moved and a force which is moving it. Hence, wherever there is life, there is a mass moved by a force. All mass possesses inertia, all force tends to persist. Owing to this universal property and condition, a body, be it at rest or in motion, tends to remain in the same state, and a force, manifesting itself anywhere and through whatever cause, produces an equivalent opposing force, and as an absolute necessity of this it follows that every movement in nature must be rhythmical. Long ago this simple truth was clearly pointed out by Herbert Spencer, who arrived at it through a somewhat different process of reasoning. It is borne out in everything we perceive—in the movement of a planet, in the surging and ebbing of the tide, in the reverberations of the air, the swinging of a pendulum, the oscillations of an electric current, and in the infinitely varied phenomena of organic life. Does not the whole of human life attest it? Birth, growth, old age, and death of an individual, family, race, or nation, what is it all but a rhythm? All life-manifestation, then, even in its most intricate form, as exemplified in man, however involved and inscrutable, is only a movement, to which the same general laws of movement which govern throughout the physical universe must be applicable.

When we speak of man, we have a conception of humanity as a whole, and before applying scientific methods to the investigation of his movement, we must accept this as a physical fact. But can any one doubt to-day that all the millions of individuals and all the innumerable types and characters constitute an entity, a unit? Though free to

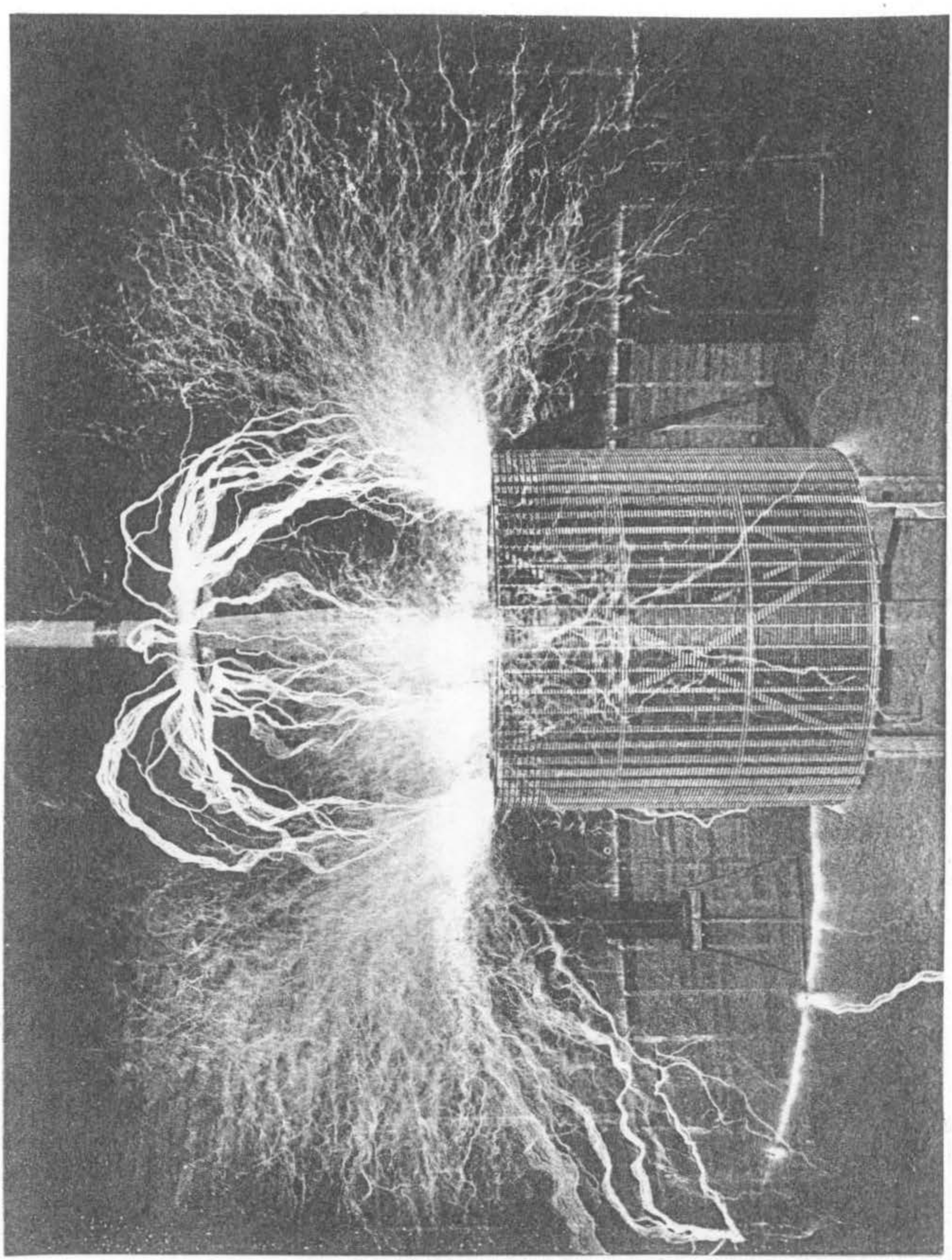


FIG. 1. BURNING THE NITROGEN OF THE ATMOSPHERE.

NOTE TO FIG. 1.—This result is produced by the discharge of an electrical oscillator giving twelve million volts. The electrical pressure, alternating one hundred thousand times per second, excites the normally inert nitrogen, causing it to combine with the oxygen. The flame-like discharge shown in the photograph measures sixty-five feet across.

think and act, we are held together, like the stars in the firmament, with ties inseparable. These ties we cannot see, but we can feel them. I cut myself in the finger, and it pains me: this finger is a part of me. I see a friend hurt, and it hurts me, too: my friend and I are one. And now I see stricken down an enemy, a lump of matter which, of all the lumps of matter in the universe, I care least for, and still it grieves me. Does this not prove that each of us is only a part of a whole?

For ages this idea has been proclaimed in the consummately wise teachings of religion, probably not alone as a means of insuring peace and harmony among men, but as a deeply founded truth. The Buddhist expresses it in one way, the Christian in another, but both say the same: We are all one. Metaphysical proofs are, however, not the only ones which we are able to bring forth in support of this idea. Science, too, recognizes this connectedness of separate individuals, though not quite in the same sense as it admits that the suns, planets, and moons of a constellation are one body, and there can be no doubt that it will be experimentally confirmed in times to come, when our means and methods for investigating psychical and other states and phenomena shall have been brought to great perfection. Still more: this one human being lives on and on. The individual is ephemeral, races and nations come and pass away, but man remains. Therein lies the profound difference between the individual and the whole. Therein, too, is to be found the partial explanation of many of those marvelous phenomena of heredity which are the result of countless centuries of feeble but persistent influence.

Conceive, then, man as a mass urged on by a force. Though this movement is not of a translatory character, implying change of place, yet the general laws of mechanical movement are applicable to it, and the energy associated with this mass can be measured, in accordance with well-known principles, by half the product of the mass with the square of a certain velocity. So, for instance, a cannon-ball which is at rest possesses a certain amount of energy in the form of heat, which we measure in a similar way. We imagine the ball to consist of innumerable minute particles, called atoms or molecules, which vibrate or whirl around one another. We determine their masses and velocities, and from them the energy of each of these minute systems, and adding them all together, we get an idea of the total heat-energy contained in the ball, which is only seemingly at rest. In this purely theoretical estimate this energy may then be calculated by multiplying half of the total mass—that is, half of the sum of all the small masses—with the square of a velocity which is determined from the velocities of the separate particles. In like manner we may conceive of human energy being measured by half the human mass multiplied with the square of a velocity which we are not yet able to compute. But our deficiency in this knowledge will not vitiate the truth of the deductions I shall draw, which rest on the firm basis that the same laws of mass and force govern throughout nature.

Man, however, is not an ordinary mass, consisting of spinning atoms and molecules, and containing merely heat-energy. He is a mass possessed of certain higher qualities by reason of the creative principle of life with which he is endowed. His mass, as the water in an ocean wave, is being continuously exchanged, new taking the place of the old. Not only this, but he grows, propagates, and dies, thus altering his mass independently, both in bulk and density. What is most wonderful of all, he is capable of increasing or diminishing his velocity of movement by the mysterious power he possesses of appropriating more or less energy from other substance, and turning it into motive energy. But in any given moment we may ignore these slow changes and assume that human energy is measured by half the product of man's mass with the square of a certain hypothetical velocity. However we may compute this velocity, and whatever we may take as the standard of its measure, we must, in harmony with this conception, come to the conclusion that the great problem of science is, and always will be, to increase the energy thus defined. Many years ago, stimulated by the perusal of that deeply interesting work, Draper's "History of the Intellectual Development of Europe," depicting so vividly human movement, I recognized that to solve this eternal problem must ever be the chief task of the man of science. Some results of my own efforts to this end I shall endeavor briefly to describe here.

Let, then, in diagram *a*, *M* represent the mass of man. This mass is impelled in one direction by a force *f*, which is resisted by another partly frictional and partly negative force *R*, acting in a direction exactly opposite, and retarding the movement of the mass. Such an antagonistic force is present

in every movement, and must be taken into consideration. The difference between these two forces is the effective force which imparts a velocity V to the mass M in the direction of the arrow on the line representing the force f. In accordance with the pre-

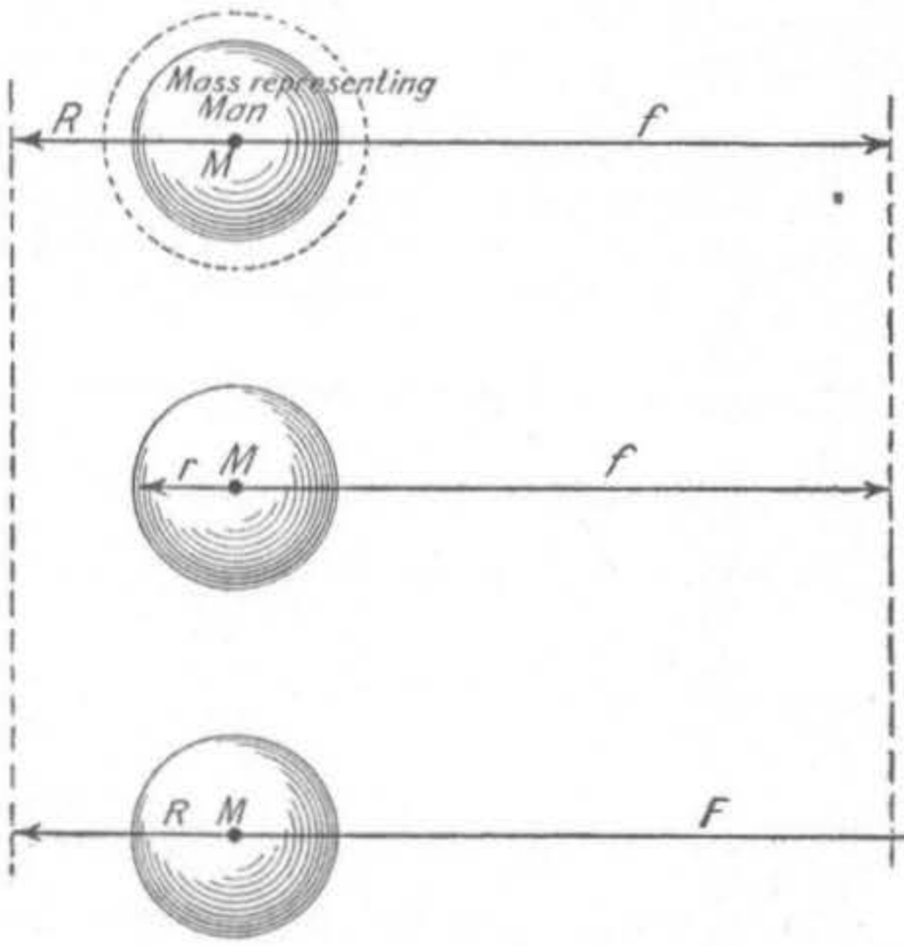


DIAGRAM *a*. THE THREE WAYS OF INCREASING HUMAN ENERGY.

ceding, the human energy will then be given by the product $\frac{1}{2} MV^2 = \frac{1}{2} MV \times V$, in which M is the total mass of man in the ordinary interpretation of the term "mass," and V is a certain hypothetical velocity, which, in the present state of science, we are unable exactly to define and determine. To increase the human energy is, therefore, equivalent to increasing this product, and there are, as will readily be seen, only three ways possible to attain this result, which are illustrated in the above diagram. The first way, shown in the top figure, is to increase the mass (as indicated by the dotted circle), leaving the two opposing forces the same. The second way is to reduce the retarding force R to a smaller value r, leaving the mass and the impelling force the same, as diagrammatically shown in the middle figure. The third way, which is illustrated in the last figure, is to increase the impelling force f to a higher value F, while the mass and the retarding force R remain unaltered. Evidently fixed limits exist as regards increase of mass and reduction of retarding force, but the impelling force can be increased indefinitely. Each of these three possible solutions presents a different aspect of the main problem of increasing human energy, which is thus divided into three distinct problems, to be successively considered.

THE FIRST PROBLEM: HOW TO INCREASE THE HUMAN MASS—THE BURNING OF ATMOSPHERIC NITROGEN.

VIEWED generally, there are obviously two ways of increasing the mass of mankind: first, by aiding and maintaining those forces and conditions which tend to increase it; and, second, by opposing and reducing those which tend to diminish it. The mass will be increased by careful attention to health, by substantial food, by moderation, by regularity of habits, by the promotion of marriage, by conscientious attention to the children, and, generally stated, by the observance of all the many precepts and laws of religion and hygiene. But in adding new mass to the old, three cases again present themselves. Either the mass added is of the same velocity as the old, or it is of a smaller or of a higher velocity. To gain an idea of the relative importance of these cases, imagine a train composed of, say, one hundred locomotives running on a track, and suppose that, to increase the energy of the moving mass, four more locomotives are added to the train. If these four move at the same velocity at which the train is going, the total energy will be increased four per cent.; if they are moving at only one half of that velocity, the increase will amount to only one per cent.; if they are moving at twice that velocity, the increase of energy will be sixteen per cent. This simple illustration shows that it is of the greatest importance to add mass of a higher velocity. Stated more to the point, if, for example, the children be of the same degree of enlightenment as the parents,—that is, mass of the "same velocity,"—the energy will simply increase proportionately to the number added. If they are less intelligent or advanced, or mass of "smaller velocity," there will be a very slight gain in the energy; but if they are further advanced, or mass of "higher velocity," then the new generation will add very considerably to the sum total of human energy. Any addition of mass of "smaller velocity," beyond that indispensable amount required by the law expressed in the proverb, "Mens sana in corpore sano," should be strenuously opposed. For instance, the mere development of muscle, as aimed at in some of our colleges, I consider equivalent to adding mass of "smaller velocity," and I would not commend it, although my views were different when I was a student myself. Moderate exercise, insuring the right balance between

mind and body, and the highest efficiency of performance, is, of course, a prime requirement. The above example shows that the most important result to be attained is the education, or the increase of the "velocity," of the mass newly added.

Conversely, it scarcely need be stated that everything that is against the teachings of religion and the laws of hygiene is tending to decrease the mass. Whisky, wine, tea, coffee, tobacco, and other such stimulants are responsible for the shortening of the lives of many, and ought to be used with moderation. But I do not think that rigorous measures of suppression of habits followed through many generations are commendable. It is wiser to preach moderation than abstinence. We have become accustomed to these stimulants, and if such reforms are to be effected, they must be slow and gradual. Those who are devoting their energies to such ends could make themselves far more useful by turning their efforts in other directions, as, for instance, toward providing pure water.

For every person who perishes from the effects of a stimulant, at least a thousand die from the consequences of drinking impure water. This precious fluid, which daily infuses new life into us, is likewise the chief vehicle through which disease and death enter our bodies. The germs of destruction it conveys are enemies all the more terrible as they perform their fatal work unperceived. They seal our doom while we live and enjoy. The majority of people are so ignorant or careless in drinking water, and the consequences of this are so disastrous, that a philanthropist can scarcely use his efforts better than by endeavoring to enlighten those who are thus injuring themselves. By systematic purification and sterilization of the drinking-water the human mass would be very considerably increased. It should be made a rigid rule—which might be enforced by law—to boil or to sterilize otherwise the drinking-water in every household and public place. The mere filtering does not afford sufficient security against infection. All ice for internal uses should be artificially prepared from water thoroughly sterilized. The importance of eliminating germs of disease from the city water is generally recognized, but little is being done to improve the existing conditions, as no satisfactory method of sterilizing great quantities of water has as yet been brought forward. By improved electrical appliances we are now enabled to produce ozone cheaply and in large amounts, and this ideal disinfectant seems to offer a happy solution of the important question.

Gambling, business rush, and excitement, particularly on the exchanges, are causes of much mass-reduction, all the more so because the individuals concerned represent units of higher value. Incapacity of observing the first symptoms of an illness, and careless neglect of the same, are important factors of mortality. In noting carefully every new sign of approaching danger, and making conscientiously every possible effort to avert it, we are not only following wise laws of hygiene in the interest of our well-being and the success of our labors, but we are also complying with a higher moral duty. Every one should consider his body as a priceless gift from one whom he loves above all, as a marvelous work of art, of undescribable beauty and mastery beyond human conception, and so delicate and frail that a word, a breath, a look, nay, a thought, may injure it. Uncleanliness, which breeds disease and death, is not only a self-destructive but a highly immoral habit. In keeping our bodies free from infection, healthful, and pure, we are expressing our reverence for the high principle with which they are endowed. He who follows the precepts of hygiene in this spirit is proving himself, so far, truly religious. Laxity of morals is a terrible evil, which poisons both mind and body, and which is responsible for a great reduction of the human mass in some countries. Many of the present customs and tendencies are productive of similar hurtful results. For example, the society life, modern education and pursuits of women, tending to draw them away from their household duties and make men out of them, must needs detract from the elevating ideal they represent, diminish the artistic creative power, and cause sterility and a general weakening of the race. A thousand other evils might be mentioned, but all put together, in their bearing upon the problem under discussion, they would not equal a single one, the want of food, brought on by poverty, destitution, and famine. Millions of individuals die yearly for want of food, thus keeping down the mass. Even in our enlightened communities, and notwithstanding the many charitable efforts, this is still, in all probability, the chief evil. I do not mean here absolute want of food, but want of healthful nutriment.

How to provide good and plentiful food is, therefore, a most important question of the day. On general principles the raising of cattle as a means of providing food is

objectionable, because, in the sense interpreted above, it must undoubtedly tend to the addition of mass of a "smaller velocity." It is certainly preferable to raise vegetables, and I think, therefore, that vegetarianism is a commendable departure from the established barbarous habit. That we can subsist on plant food and perform our work even to advantage is not a theory, but a well-demonstrated fact. Many races living almost exclusively on vegetables are of superior physique and strength. There is no doubt that some plant food, such as oatmeal, is more economical than meat, and superior to it in regard to both mechanical and mental performance. Such food, moreover, taxes our digestive organs decidedly less, and, in making us more contented and sociable, produces an amount of good difficult to estimate. In view of these facts every effort should be made to stop the wanton and cruel slaughter of animals, which must be destructive to our morals. To free ourselves from animal instincts and appetites, which keep us down, we should begin at the very root from which they spring: we should effect a radical reform in the character of the food.

There seems to be no *philosophical* necessity for food. We can conceive of organized beings living without nourishment, and deriving all the energy they need for the performance of their life-functions from the ambient medium. In a crystal we have the clear evidence of the existence of a formative life-principle, and though we cannot understand the life of a crystal, it is none the less a living being. There may be, besides crystals, other such individualized, material systems of beings, perhaps of gaseous constitution, or composed of substance still more tenuous. In view of this possibility,—nay, probability,—we cannot apodictically deny the existence of organized beings on a planet merely because the conditions on the same are unsuitable for the existence of life as we conceive it. We cannot even, with positive assurance, assert that some of them might not be present here, in this our world, in the very midst of us, for their constitution and life-manifestation may be such that we are unable to perceive them.

The production of artificial food as a means for causing an increase of the human mass naturally suggests itself, but a direct attempt of this kind to provide nourishment does not appear to me rational, at least not for the present. Whether we could thrive on such food is very doubtful. We are the result of ages of continuous adaptation, and we cannot radically change without unforeseen and, in all probability, disastrous consequences. So uncertain an experiment should not be tried. By far the best way, it seems to me, to meet the ravages of the evil, would be to find ways of increasing the productivity of the soil. With this object the preservation of forests is of an importance which cannot be overestimated, and in this connection, also, the utilization of water-power for purposes of electrical transmission, dispensing in many ways with the necessity of burning wood, and tending thereby to forest preservation, is to be strongly advocated. But there are limits in the improvement to be effected in this and similar ways.

To increase materially the productivity of the soil, it must be more effectively fertilized by artificial means. The question of food-production resolves itself, then, into the question how best to fertilize the soil. What it is that made the soil is still a mystery. To explain its origin is probably equivalent to explaining the origin of life itself. The rocks, disintegrated by moisture and heat and wind and weather, were in themselves not capable of maintaining life. Some unexplained condition arose, and some new principle came into effect, and the first layer capable of sustaining low organisms, like mosses, was formed. These, by their life and death, added more of the life-sustaining quality to the soil, and higher organisms could then subsist, and so on and on, until at last highly developed plant and animal life could flourish. But though the theories are, even now, not in agreement as to how fertilization is effected, it is a fact, only too well ascertained, that the soil cannot indefinitely sustain life, and some way must be found to supply it with the substances which have been abstracted from it by the plants. The chief and most valuable among these substances are compounds of nitrogen, and the cheap production of these is, therefore, the key for the solution of the all-important food problem. Our atmosphere contains an inexhaustible amount of nitrogen, and could we but oxidize it and produce these compounds, an incalculable benefit for mankind would follow.

Long ago this idea took a powerful hold on the imagination of scientific men, but an efficient means for accomplishing this result could not be devised. The problem was rendered extremely difficult by the extraordinary inertness of the nitrogen, which refuses to

combine even with oxygen. But here electricity comes to our aid: the dormant affinities of the element are awakened by an electric current of the proper quality. As a lump of coal which has been in contact with oxygen for centuries without burning will combine with it when once ignited, so nitrogen, excited by electricity, will burn. I did not succeed, however, in producing electrical discharges exciting very effectively the atmospheric nitrogen until a comparatively recent date, although I showed, in May, 1891, in a scientific lecture, a novel form of discharge or electrical flame named "St. Elmo's hotfire," which, besides being capable of generating ozone in abundance, also possessed, as I pointed out on that occasion, distinctly the quality of exciting chemical affinities. This discharge or flame was then only three or four inches long, its chemical action was likewise very feeble, and consequently the process of oxidation of the nitrogen was wasteful. How to intensify this action was the question. Evidently electric currents of a peculiar kind had to be produced in order to render the process of nitrogen combustion more efficient.

The first advance was made in ascertaining that the chemical activity of the discharge was very considerably increased by using currents of extremely high frequency or rate of vibration. This was an important improvement, but practical considerations soon set a definite limit to the progress in this direction. Next, the effects of the electrical pressure of the current impulses, of their wave-form and other characteristic features, were investigated. Then the influence of the atmospheric pressure and temperature and of the presence of water and other bodies was studied, and thus the best conditions for causing the most intense chemical action of the discharge and securing the highest efficiency of the process were gradually ascertained. Naturally, the improvements were not quick in coming; still, little by little, I advanced. The flame grew larger and larger, and its oxidizing action more and more intense. From an insignificant brush-discharge a few inches long it developed into a marvelous electrical phenomenon, a roaring blaze, devouring the nitrogen of the atmosphere and measuring sixty or seventy feet across. Thus slowly, almost imperceptibly, possibility became accomplishment. All is not yet done, by any means, but to what a degree my efforts have been rewarded an idea may be gained from an inspection of Fig. 1 (p. 176), which, with its title, is self-explanatory. The flame-like discharge visible is produced by the intense electrical oscillations which pass through the coil shown, and violently agitate the electrified molecules of the air. By this means a strong affinity is created between the two normally indifferent constituents of the atmosphere, and they combine readily, even if no further provision is made for intensifying the chemical action of the discharge. In the manufacture of nitrogen compounds by this method, of course, every possible means bearing upon the intensity of this action and the efficiency of the process will be taken advantage of, and, besides, special arrangements will be provided for the fixation of the compounds formed, as they are generally unstable, the nitrogen becoming again inert after a little lapse of time. Steam is a simple and effective means for fixing permanently the compounds. The result illustrated makes it practicable to oxidize the atmospheric nitrogen in unlimited quantities, merely by the use of cheap mechanical power and simple electrical apparatus. In this manner many compounds of nitrogen may be manufactured all over the world, at a small cost, and in any desired amount, and by means of these compounds the soil can be fertilized and its productiveness indefinitely increased. An abundance of cheap and healthful food, not artificial, but such as we are accustomed to, may thus be obtained. This new and inexhaustible source of food-supply will be of incalculable benefit to mankind, for it will enormously contribute to the increase of the human mass, and thus add immensely to human energy. Soon, I hope, the world will see the beginning of an industry which, in time to come, will, I believe, be in importance next to that of iron.

THE SECOND PROBLEM: HOW TO REDUCE THE FORCE RETARDING THE HUMAN MASS—THE ART OF TELAUTOMATICS.

As before stated, the force which retards the onward movement of man is partly frictional and partly negative. To illustrate this distinction I may name, for example, ignorance, stupidity, and imbecility as some of the purely frictional forces, or resistances devoid of any directive tendency. On the other hand, visionariness, insanity, self-destructive tendency, religious fanaticism, and the like, are all forces of a negative character, acting in definite directions. To reduce or entirely to overcome these dissimilar retarding forces, radically different methods must be employed. One knows, for instance, what

a fanatic may do, and one can take preventive measures, can enlighten, convince, and possibly direct him, turn his vice into virtue; but one does not know, and never can know, what a brute or an imbecile may do, and one must deal with him as with a mass, inert, without mind, let loose by the mad elements. A negative force always implies some quality, not infrequently a high one, though badly directed, which it is possible to turn to good advantage; but a directionless, frictional force involves unavoidable loss. Evidently, then, the first and general answer to the above question is: turn all negative force in the right direction and reduce all frictional force.

There can be no doubt that, of all the frictional resistances, the one that most retards human movement is ignorance. Not without reason said that man of wisdom, Buddha: "Ignorance is the greatest evil in the world." The friction which results from ignorance, and which is greatly increased owing to the numerous languages and nationalities, can be reduced only by the spread of knowledge and the unification of the heterogeneous elements of humanity. No effort could be better spent. But however ignorance may have retarded the onward movement of man in times past, it is certain that, nowadays, negative forces have become of greater importance. Among these there is one of far greater moment than any other. It is called organized warfare. When we consider the millions of individuals, often the ablest in mind and body, the flower of humanity, who are compelled to a life of inactivity and unproductiveness, the immense sums of money daily required for the maintenance of armies and war apparatus, representing ever so much of human energy, all the effort uselessly spent in the production of arms and implements of destruction, the loss of life and the fostering of a barbarous spirit, we are appalled at the inestimable loss to mankind which the existence of these deplorable conditions must involve. What can we do to combat best this great evil?

Law and order absolutely require the maintenance of organized force. No community can exist and prosper without rigid discipline. Every country must be able to defend itself, should the necessity arise. The conditions of to-day are not the result of yesterday, and a radical change cannot be effected to-morrow. If the nations would at once disarm, it is more than likely that a state of things worse than war itself would follow. Universal peace is a beautiful dream, but not at once realizable. We have seen recently that even the noble effort of the man invested with the greatest worldly power has been virtually without effect. And no wonder, for the establishment of universal peace is, for the time being, a physical impossibility. War is a negative force, and cannot be turned in a positive direction without passing through the intermediate phases. It is the problem of making a wheel, rotating one way, turn in the opposite direction without slowing it down, stopping it, and speeding it up again the other way.

It has been argued that the perfection of guns of great destructive power will stop warfare. So I myself thought for a long time, but now I believe this to be a profound mistake. Such developments will greatly modify, but not arrest it. On the contrary, I think that every new arm that is invented, every new departure that is made in this direction, merely invites new talent and skill, engages new effort, offers a new incentive, and so only gives a fresh impetus to further development. Think of the discovery of gunpowder. Can we conceive of any more radical departure than was effected by this innovation? Let us imagine ourselves living in that period: would we not have thought then that warfare was at an end, when the armor of the knight became an object of ridicule, when bodily strength and skill, meaning so much before, became of comparatively little value? Yet gunpowder did not stop warfare; quite the opposite—it acted as a most powerful incentive. Nor do I believe that warfare can ever be arrested by any scientific or ideal development, so long as similar conditions to those now prevailing exist, because war has itself become a science, and because war involves some of the most sacred sentiments of which man is capable. In fact, it is doubtful whether men who would not be ready to fight for a high principle would be good for anything at all. It is not the mind which makes man, nor is it the body; it is mind and body. Our virtues and our failings are inseparable, like force and matter. When they separate, man is no more.

Another argument, which carries considerable force, is frequently made, namely, that war must soon become impossible because the means of defense are outstripping the means of attack. This is only in accordance with a fundamental law which may be expressed by the statement that it is easier to destroy than to build. This law defines human capacities and human conditions.

Were these such that it would be easier to build than to destroy, man would go on unresisted, creating and accumulating without limit. Such conditions are not of this earth. A being which could do this would not be a man; it might be a god. Defense will always have the advantage over attack, but this alone, it seems to me, can never stop war. By the use of new principles of defense we can render harbors impregnable against attack, but we cannot by such means prevent two war-ships meeting in battle on the high sea. And then, if we follow this idea to its ultimate development, we are led to the conclusion that it would be better for mankind if attack and defense were just oppositely related; for if every country, even the smallest, could surround itself with a wall absolutely impenetrable, and could defy the rest of the world, a state of things would surely be brought on which would be extremely unfavorable to human progress. It is by abolishing all the barriers which separate nations and countries that civilization is best furthered.

Again, it is contended by some that the advent of the flying-machine must bring on universal peace. This, too, I believe to be an entirely erroneous view. The flying-machine is certainly coming, and very soon, but the conditions will remain the same as before. In fact, I see no reason why a ruling power, like Great Britain, might not govern the air as well as the sea. Without wishing to put myself on record as a prophet, I do not hesitate to say that the next years will see the establishment of an "air-power," and its center may not be far from New York. But, for all that, men will fight on merrily.

The ideal development of the war principle would ultimately lead to the transformation of the whole energy of war into purely potential, explosive energy, like that of an electrical condenser. In this form the war-energy could be maintained without effort; it would need to be much smaller in amount, while incomparably more effective.

As regards the security of a country against foreign invasion, it is interesting to note that it depends only on the relative, and not on the absolute, number of the individuals or magnitude of the forces, and that, if every country should reduce the war-force in the same ratio, the security would remain unaltered. An international agreement with the object of reducing to a minimum the war-force which, in view of the present still imperfect education of the masses, is absolutely indispensable, would, therefore, seem to be the first rational step to take toward diminishing the force retarding human movement.

Fortunately, the existing conditions cannot continue indefinitely, for a new element is beginning to assert itself. A change for the better is imminent, and I shall now endeavor to show what, according to my ideas, will be the first advance toward the establishment of peaceful relations between nations, and by what means it will eventually be accomplished.

Let us go back to the early beginning, when the law of the stronger was the only law. The light of reason was not yet kindled, and the weak was entirely at the mercy of the strong. The weak individual then began to learn how to defend himself. He made use of a club, stone, spear, sling, or bow and arrow, and in the course of time, instead of physical strength, intelligence became the chief deciding factor in the battle. The wild character was gradually softened by the awakening of noble sentiments, and so, imperceptibly, after ages of continued progress, we have come from the brutal fight of the unreasoning animal to what we call the "civilized warfare" of to-day, in which the combatants shake hands, talk in a friendly way, and smoke cigars in the entr'actes, ready to engage again in deadly conflict at a signal. Let pessimists say what they like, here is an absolute evidence of great and gratifying advance.

But now, what is the next phase in this evolution? Not peace as yet, by any means. The next change which should naturally follow from modern developments should be the continuous diminution of the number of individuals engaged in battle. The apparatus will be one of specifically great power, but only a few individuals will be required to operate it. This evolution will bring more and more into prominence a machine or mechanism with the fewest individuals as an element of warfare, and the absolutely unavoidable consequence of this will be the abandonment of large, clumsy, slowly moving, and unmanageable units. Greatest possible speed and maximum rate of energy-delivery by the war apparatus will be the main object. The loss of life will become smaller and smaller, and finally, the number of the individuals continuously diminishing, merely machines will meet in a contest without bloodshed, the nations being simply interested, ambitious spectators. When this happy condition is realized, peace will be assured. But, no matter to what degree of perfection rapid-

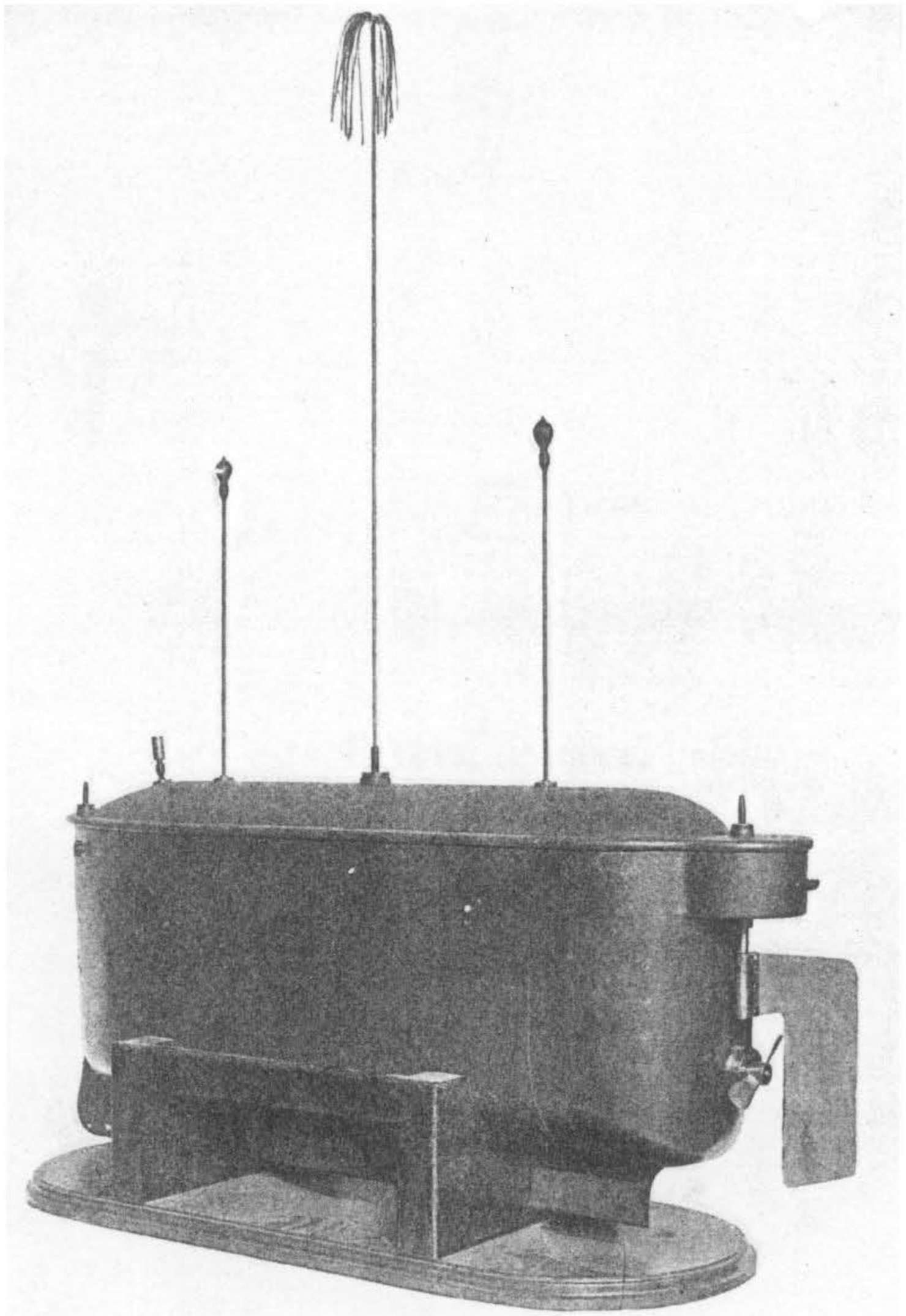


FIG. 2. THE FIRST PRACTICAL TELAUTOMATON.

A machine having all its bodily or translatory movements and the operations of the interior mechanism controlled from a distance without wires. The crewless boat shown in the photograph contains its own motive power, propelling- and steering-machinery, and numerous other accessories, all of which are controlled by transmitting from a distance, without wires, electrical oscillations to a circuit carried by the boat and adjusted to respond only to these oscillations.

speak. As to the capacity for propagation, it could likewise be left out of consideration, for in the mechanical model it merely signified a process of manufacture. Whether the automaton be of flesh and bone, or of wood and steel, it mattered little, provided it could perform all the duties required of it like an intelligent being. To do so, it had to have an element corresponding to the mind, which would effect the control of all its movements and operations, and cause it to act, in any unforeseen case that might present itself, with knowledge, reason, judgment, and experience. But this element I could easily embody in it by conveying to it my own intelligence, my own understanding. So this invention was evolved, and so a new art came into existence, for which the name

fire guns, high-power cannon, explosive projectiles, torpedo-boats, or other implements of war may be brought, no matter how destructive they may be made, that condition can never be reached through any such development. All such implements require men for their operation; men are indispensable parts of the machinery. Their object is to kill and to destroy. Their power resides in their capacity for doing evil. So long as men meet in battle, there will be bloodshed. Bloodshed will ever keep up barbarous passion. To break this fierce spirit, a radical departure must be made, an entirely new principle must be introduced, something that never existed before in warfare—a principle which will forcibly, unavoidably, turn the battle into a mere spectacle, a play, a contest without loss of blood. To bring on this result men must be dispensed with: machine must fight machine. But how accomplish that which seems impossible? The answer is simple enough: produce a machine capable of acting as though it were part of a human being—no mere mechanical contrivance, comprising levers, screws, wheels, clutches, and nothing more, but a machine embodying a higher principle, which will enable it to perform its duties as though it had intelligence, experience, reason, judgment, a mind! This conclusion is the result of my thoughts and observations which have extended through virtually my whole life, and I shall now briefly describe how I came to accomplish that which at first seemed an unrealizable dream.

A long time ago, when I was a boy, I was afflicted with a singular trouble, which seems to have been due to an extraordinary excitability of the retina. It was the appearance of images which, by their persistence, marred the vision of real objects and interfered with thought. When a word was said to me, the image of the object which it designated would appear vividly before my eyes, and many times it was impossible for me to tell whether the object I saw was real or not. This caused me great discomfort and anxiety, and I tried hard to free myself of the spell. But for a long time I tried in vain, and it was not, as I still clearly recollect, until I was about twelve years old that I succeeded for the first time, by an effort of the will, in banishing an image which presented itself. My happiness will never be as complete as it was then, but, unfortunately (as I thought at that time), the old trouble returned, and with it my anxiety. Here it was that the observations to which I refer began. I noted, namely, that whenever the image of an object appeared before my eyes I had seen something which reminded me of it. In the first instances I thought this to be purely accidental, but soon I convinced myself that it was not so. A visual impression, consciously or unconsciously received, invariably preceded the appearance of the image. Gradually the desire arose in me to find out, every time, what caused the images to appear, and the satisfaction of this desire soon became a necessity. The next observation I made was that, just as these images followed as a result of something I had seen, so also the thoughts which I conceived were suggested in like manner. Again, I experienced the same desire to locate the image which caused the thought, and this search for the original visual impression soon grew to be a second nature. My mind became automatic, as it were, and in the course of years of continued, almost unconscious performance, I acquired the ability of locating every time and, as a rule, instantly the visual impression which started the thought. Nor is this all. It was not long before I was aware that also all my movements were prompted in the same way, and so, searching, observing, and verifying continuously, year after year, I have, by every thought and every act of mine, demonstrated, and do so daily, to my absolute satisfaction, that I am an automaton endowed with power of movement, which merely responds to external stimuli beating upon my sense organs, and thinks and acts and moves accordingly. I remember only one or two cases in all my life in which I was unable to locate the first impression which prompted a movement or a thought, or even a dream.

With these experiences it was only natural that, long ago, I conceived the idea of constructing an automaton which would mechanically represent me, and which would respond, as I do myself, but, of course, in a much more primitive manner, to external influences. Such an automaton evidently had to have motive power, organs for locomotion, directive organs, and one or more sensitive organs so adapted as to be excited by external stimuli. This machine would, I reasoned, perform its movements in the manner of a living being, for it would have all the chief mechanical characteristics or elements of the same. There was still the capacity for growth, propagation, and, above all, the mind which would be wanting to make the model complete. But growth was not necessary in this case, since a machine could be manufactured full-grown, so to

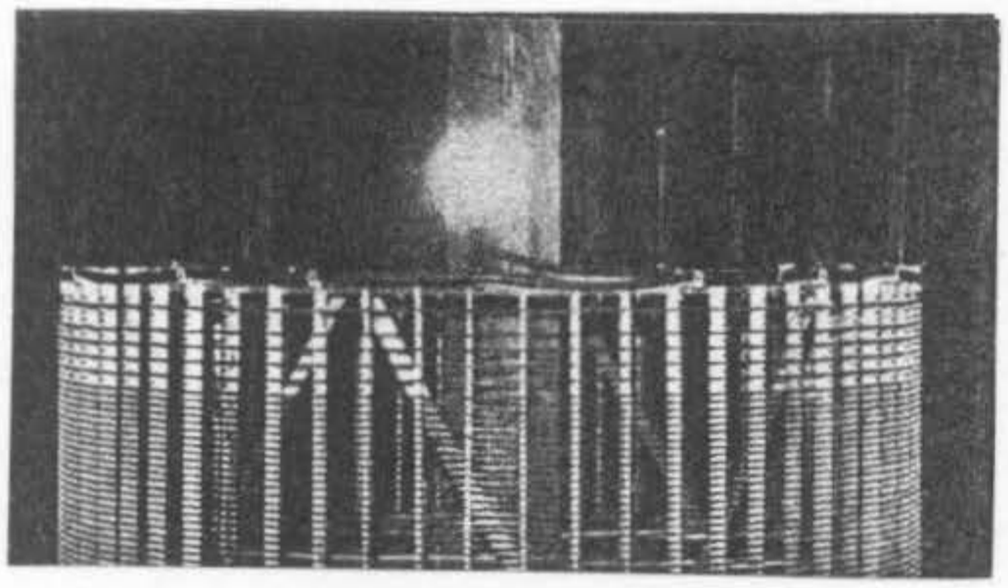


FIG. 3. EXPERIMENT TO ILLUSTRATE THE SUPPLYING OF ELECTRICAL ENERGY THROUGH A SINGLE WIRE WITHOUT RETURN.

An ordinary incandescent lamp, connected with one or both of its terminals to the wire forming the upper free end of the coil shown in the photograph, is lighted by electrical vibrations conveyed to it through the coil from an electrical oscillator, which is worked only to one fifth of one per cent. of its full capacity.

"telautomatics" has been suggested, which means the art of controlling the movements and operations of distant automatons.

This principle evidently was applicable to any kind of machine that moves on land or in the water or in the air. In applying it practically for the first time, I selected a boat (see Fig. 2). A storage battery placed within it furnished the motive power. The propeller, driven by a motor, represented the locomotive organs. The rudder, controlled by another motor likewise driven by the battery, took the place of the directive organs. As to the sensitive organ, obviously the first thought was to utilize a device responsive to rays of light, like a selenium cell, to represent the human eye. But upon closer inquiry I found that, owing to experimental and other difficulties, no thoroughly satisfactory control of the automaton could be effected by light, radiant heat, Hertzian radiations, or by rays in general, that is, disturbances which pass in straight lines through space. One of the reasons was that any obstacle coming between the operator and the distant automaton would place it beyond his control. Another reason was that the sensitive device representing the eye would have to be in a definite position with respect to the distant controlling apparatus, and this necessity would impose great limitations in the control. Still another and very important reason was that, in using rays, it would be difficult, if not impossible, to give to the automaton individual features or characteristics distinguishing it from other machines of this kind. Evidently the automaton should respond only to an individual call, as a person responds to a name. Such considerations led me to conclude that the sensitive device of the machine should correspond to the ear rather than to the eye of a human being, for in this case its actions could be controlled irrespective of intervening obstacles, regardless of its position relative to the distant controlling apparatus, and, last, but not least, it would remain deaf and unresponsive, like a faithful servant, to all calls but that of its master. These requirements made it imperative to use, in the control of the automaton, instead of light- or other rays, waves or disturbances which propagate in all directions through space, like sound, or which follow a path of least resistance, however curved. I attained the result aimed at by means of an electric circuit placed within the boat, and adjusted, or "tuned," exactly to electrical vibrations of the proper kind transmitted to it from a

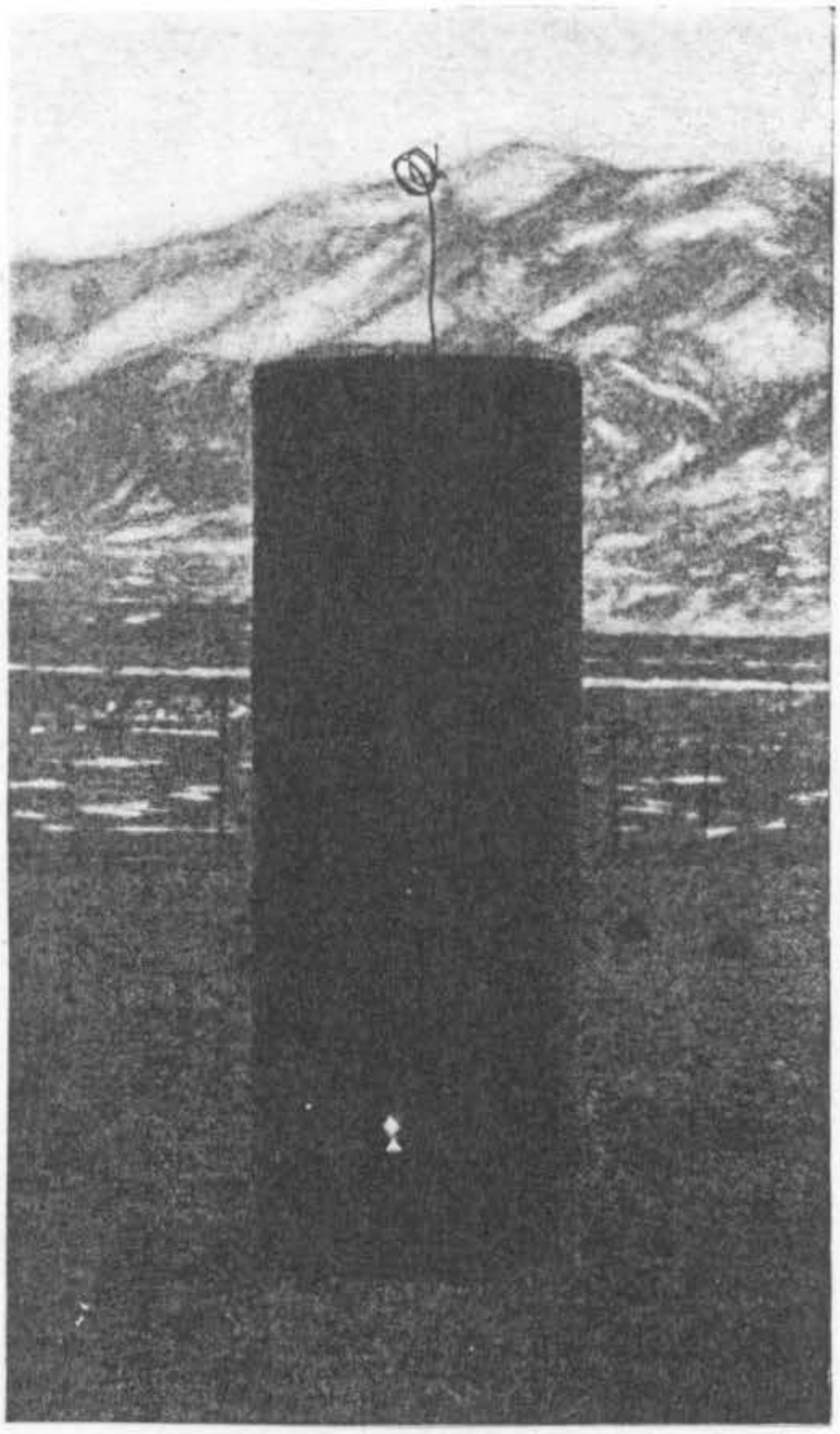


FIG. 4. EXPERIMENT TO ILLUSTRATE THE TRANSMISSION OF ELECTRICAL ENERGY THROUGH THE EARTH WITHOUT WIRE.

The coil shown in the photograph has its lower end or terminal connected to the ground, and is exactly attuned to the vibrations of a distant electrical oscillator. The lamp lighted is in an independent wire loop, energized by induction from the coil excited by the electrical vibrations transmitted to it through the ground from the oscillator, which is worked only to five per cent. of its full capacity.

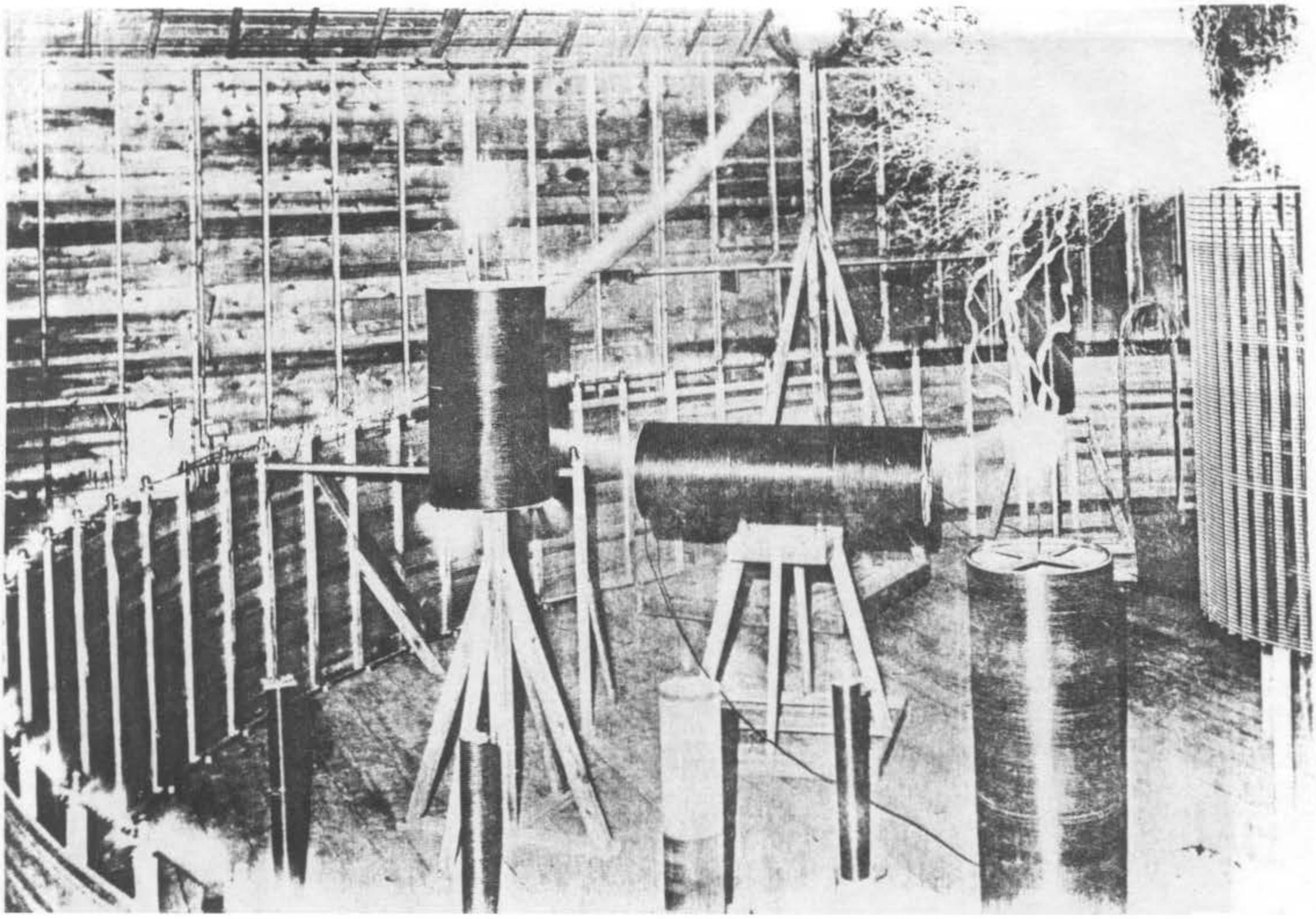


FIG. 5. PHOTOGRAPHIC VIEW OF COILS RESPONDING TO ELECTRICAL OSCILLATIONS.

The picture shows a number of coils, differently attuned and responding to the vibrations transmitted to them through the earth from an electrical oscillator. The large coil on the right, discharging strongly, is tuned to the fundamental vibration, which is fifty thousand per second; the two larger vertical coils to twice that number; the smaller white wire coil to four times that number, and the remaining small coils to higher tones. The vibrations produced by the oscillator were so intense that they affected perceptibly a small coil tuned to the twenty-sixth higher tone.

distant "electrical oscillator." This circuit, in responding, however feebly, to the transmitted vibrations, affected magnets and other contrivances, through the medium of which were controlled the movements of the propeller and rudder, and also the operations of numerous other appliances.

By the simple means described the knowledge, experience, judgment—the mind, so to speak—of the distant operator were embodied in that machine, which was thus enabled to move and to perform all its operations with reason and intelligence. It behaved just like a blindfolded person obeying directions received through the ear.

The automatons so far constructed had "borrowed minds," so to speak, as each merely formed part of the distant operator who conveyed to it his intelligent orders; but this art is only in the beginning. I purpose to show that, however impossible it may now seem, an automaton may be contrived which will have its "own mind," and by this I mean that it will be able, independent of any operator, left entirely to itself, to perform, in response to external influences affecting its sensitive organs, a great variety of acts and operations as if it had intelligence. It will be able to follow a course laid out or to obey orders given far in advance; it will be capable of distinguishing between what it ought and what it ought not to do, and of making experiences or, otherwise stated, of recording impressions which will definitely affect its subsequent actions. In fact, I have already conceived such a plan.

Although I evolved this invention many years ago and explained it to my visitors very frequently in my laboratory demonstrations, it was not until much later, long after I had perfected it, that it became known, when, naturally enough, it gave rise to much discussion and to sensational reports. But the true significance of this new art was not grasped by the majority, nor was the great force of the underlying principle recognized. As nearly as I could judge from the numerous comments which then appeared, the results I had obtained were considered as entirely impossible. Even the few who were disposed to admit the practicability of the

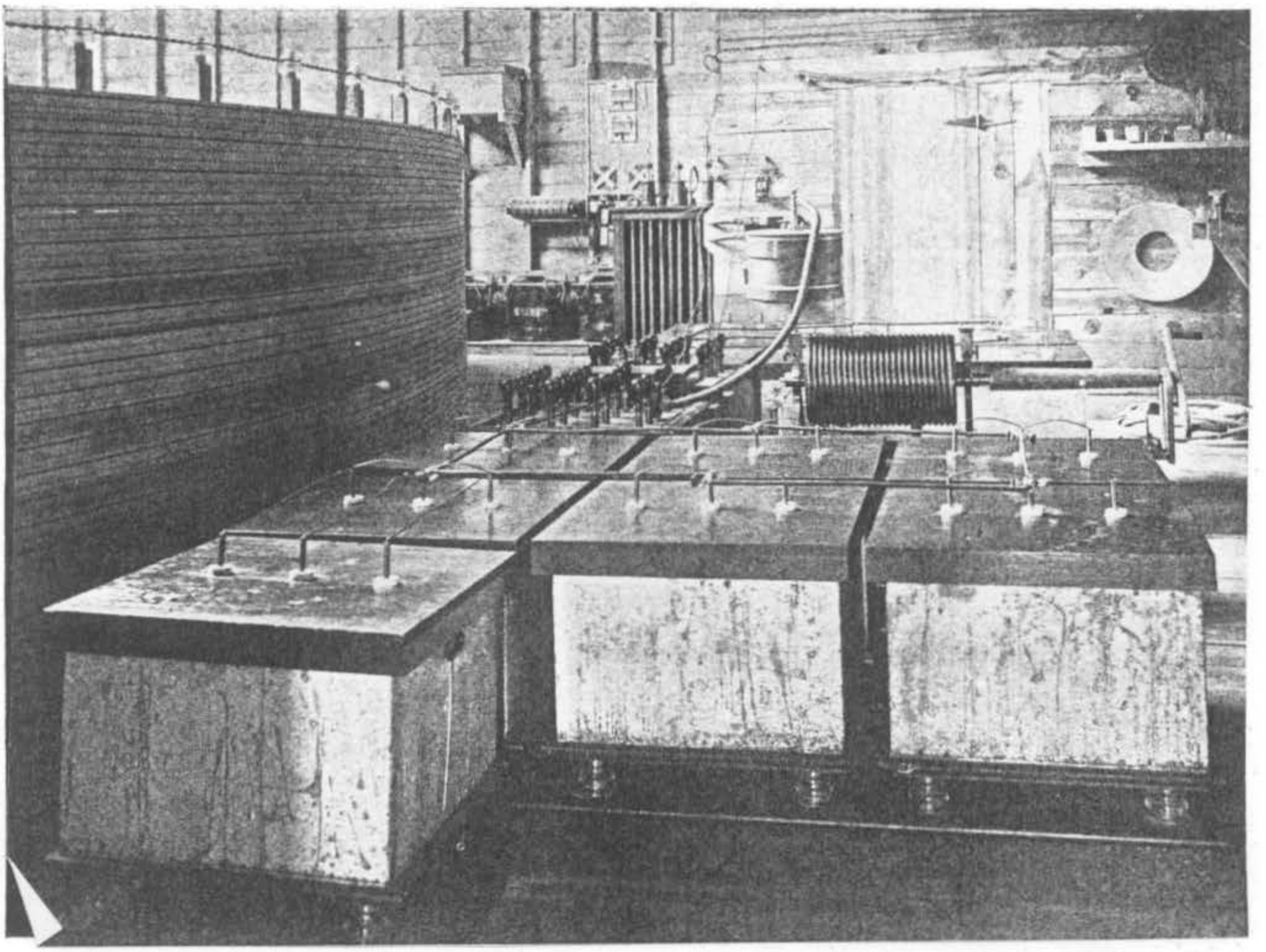


FIG. 6. PHOTOGRAPHIC VIEW OF THE ESSENTIAL PARTS OF THE ELECTRICAL OSCILLATOR USED IN THE EXPERIMENTS DESCRIBED.

invention saw in it merely an automobile torpedo, which was to be used for the purpose of blowing up battle-ships, with doubtful success. The general impression was that I contemplated simply the steering of such a vessel by means of Hertzian or other rays. There are torpedoes steered electrically by wires, and there are means of communicating without wires, and the above was, of course, an obvious inference. Had I accomplished nothing more than this, I should have made a small advance indeed. But the art I have evolved does not contemplate merely the change of direction of a moving vessel; it affords a means of absolutely controlling, in every respect, all the innumerable translatory movements, as well as the operations of all the internal organs, no matter how many, of an individualized automaton. Criticisms to the effect that the control of the automaton could be interfered with were made by people who do not even dream of the wonderful results which can be accomplished by the use of electrical vibrations. The world moves slowly, and new truths are difficult to see. Certainly, by the use of this principle, an arm for attack as well as defense may be provided, of a destructiveness all the greater as the principle is applicable to submarine and aërial vessels. There is virtually no restriction as to the amount of explosive it can carry, or as to the distance at which it can strike, and failure is almost impossible. But the force of this new principle does not wholly reside in its destructiveness. Its advent introduces into warfare an element which never existed before—a fighting-machine without men as a means of attack and defense. The continuous development in this direction must ultimately make war a mere contest of machines without men and without loss of life—a condition which would have been impossible without this new departure, and which, in my opinion, must be reached as preliminary to permanent peace. The future will either bear out or disprove these views. My ideas on this subject have been put forth with deep conviction, but in a humble spirit.

The establishment of permanent peaceful relations between nations would most effectively reduce the force retarding the human mass, and would be the best solution of this great human problem. But will the dream of universal peace ever be realized? Let us hope that it will. When all darkness shall be dissipated by the light of science, when all nations shall be merged into one, and

patriotism shall be identical with religion, when there shall be one language, one country, one end, then the dream will have become reality.

THE THIRD PROBLEM: HOW TO INCREASE THE FORCE ACCELERATING THE HUMAN MASS—THE HARNESSING OF THE SUN'S ENERGY.

Of the three possible solutions of the main problem of increasing human energy, this is by far the most important to consider, not only because of its intrinsic significance, but also because of its intimate bearing on all the many elements and conditions which determine the movement of humanity. In order to proceed systematically, it would be necessary for me to dwell on all those considerations which have guided me from the outset in my efforts to arrive at a solution, and which have led me, step by step, to the results I shall now describe. As a preliminary study of the problem an analytical investigation, such as I have made, of the chief forces which determine the onward movement, would be of advantage, particularly in conveying an idea of that hypothetical "velocity" which, as explained in the beginning, is a measure of human energy; but to deal with this specifically here, as I would desire, would lead me far beyond the scope of the present subject. Suffice it to state that the resultant of all these forces is always in the direction of reason, which, therefore, determines, at any time, the direction of human movement. This is to say that every effort which is scientifically applied, rational, useful, or practical, must be in the direction in which the mass is moving. The practical, rational man, the observer, the man of business, he who reasons, calculates, or determines in advance, carefully applies his effort so that when coming into effect it will be in the direction of the movement, making it thus most efficient, and in this knowledge and ability lies the secret of his success. Every new fact discovered, every new experience or new element added to our knowledge and entering into the domain of reason, affects the same and, therefore, changes

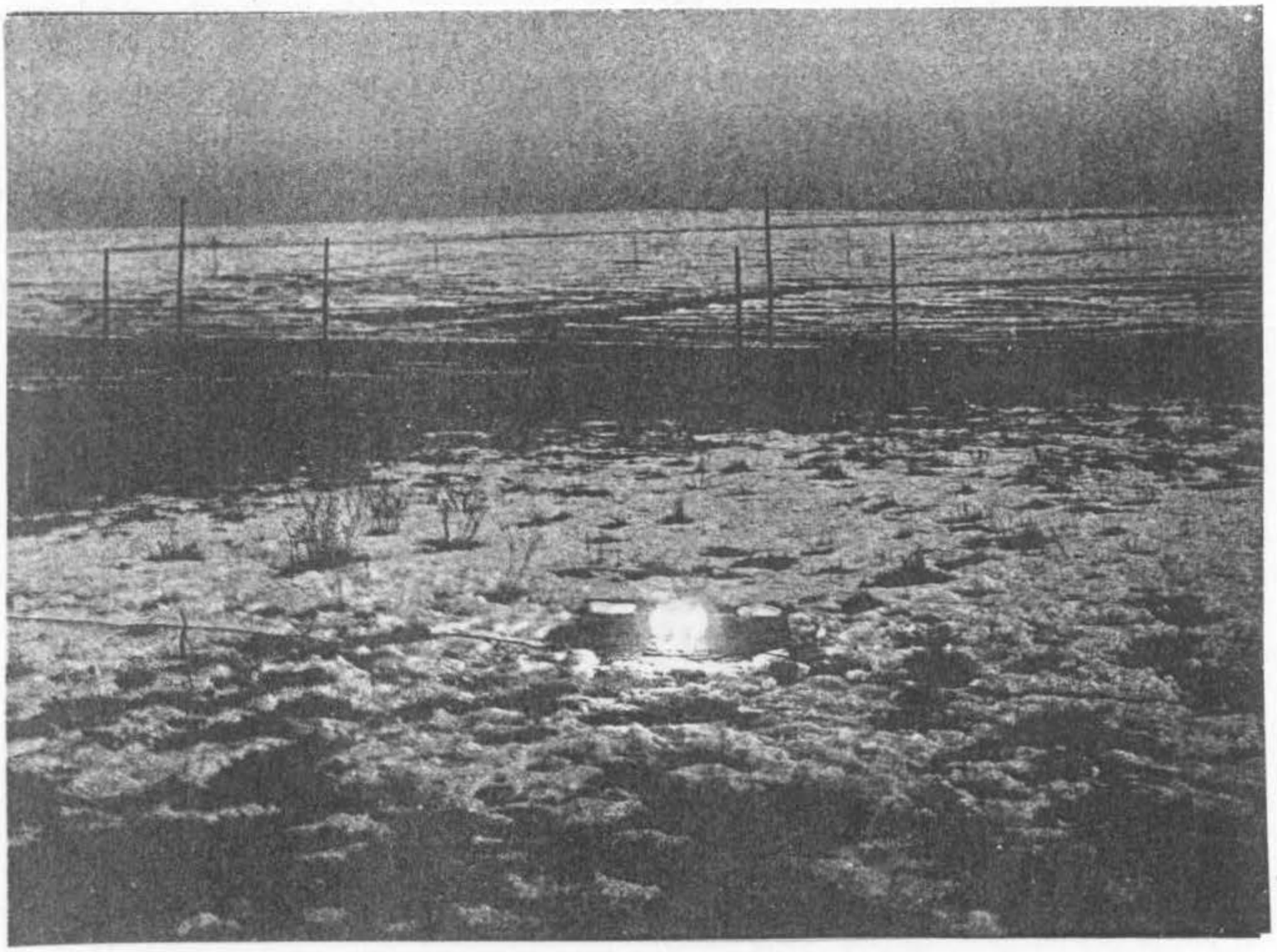


FIG. 7. EXPERIMENT TO ILLUSTRATE AN INDUCTIVE EFFECT OF AN ELECTRICAL OSCILLATOR OF GREAT POWER.

The photograph shows three ordinary incandescent lamps lighted to full candle-power by currents induced in a local loop consisting of a single wire forming a square of fifty feet each side, which includes the lamps, and which is at a distance of one hundred feet from the primary circuit energized by the oscillator. The loop likewise includes an electrical condenser, and is exactly attuned to the vibrations of the oscillator, which is worked at less than five per cent. of its total capacity.

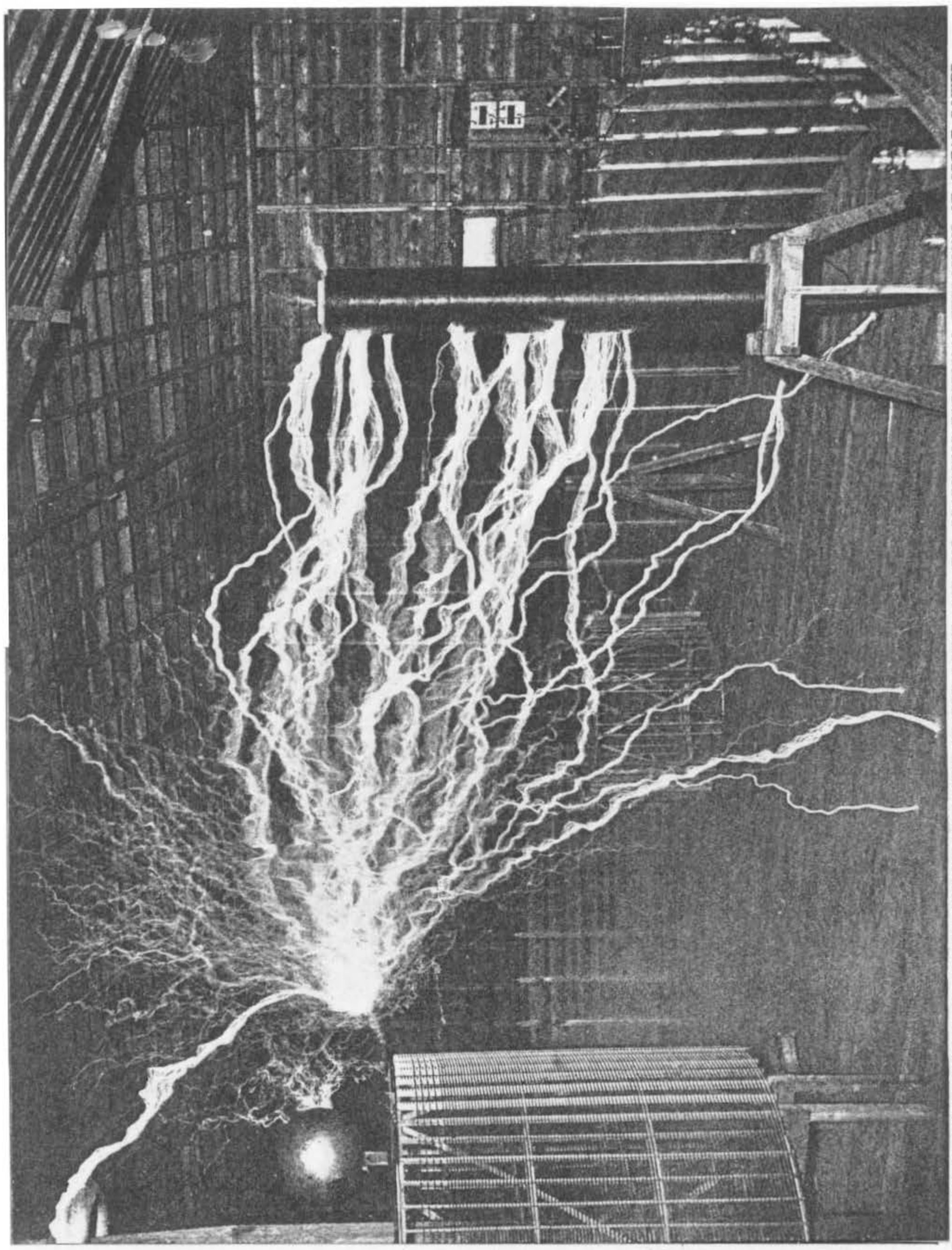


FIG. 8. EXPERIMENT TO ILLUSTRATE THE CAPACITY OF THE OSCILLATOR FOR PRODUCING ELECTRICAL EXPLOSIONS OF GREAT POWER.

NOTE TO FIG. 8.—The coil, partly shown in the photograph, creates an alternative movement of electricity from the earth into a large reservoir and back at the rate of one hundred thousand alternations per second. The adjustments are such that the reservoir is filled full and bursts at each alternation just at the moment when the electrical pressure reaches the maximum. The discharge escapes with a deafening noise, striking an unconnected coil twenty-two feet away, and creating such a commotion of electricity in the earth that sparks an inch long can be drawn from a water-main at a distance of three hundred feet from the laboratory.

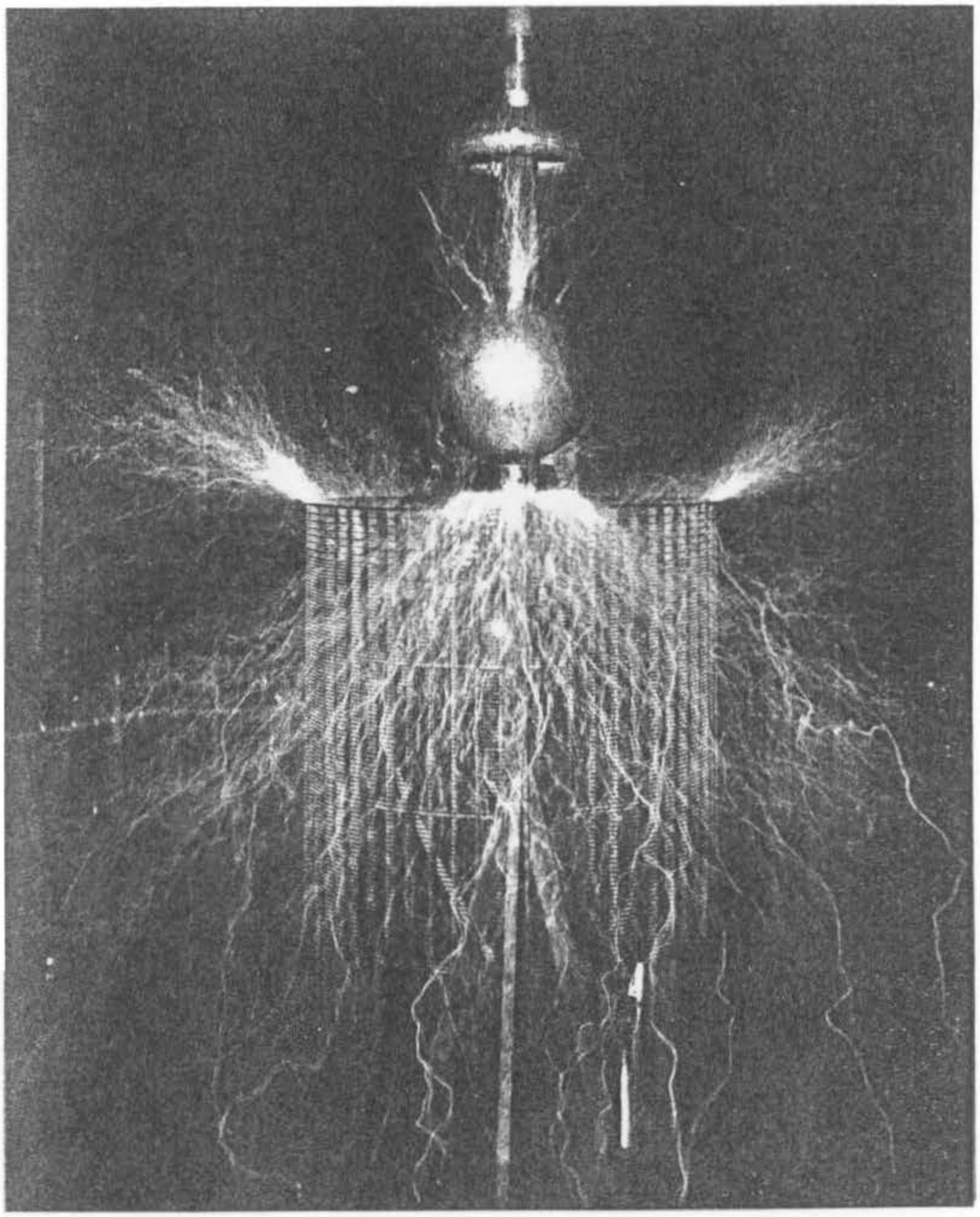


FIG. 9. EXPERIMENT TO ILLUSTRATE THE CAPACITY OF THE OSCILLATOR FOR CREATING A GREAT ELECTRICAL MOVEMENT.

The ball shown in the photograph, covered with a polished metallic coating of twenty square feet of surface, represents a large reservoir of electricity, and the inverted tin pan underneath, with a sharp rim, a big opening through which the electricity can escape before filling the reservoir. The quantity of electricity set in movement is so great that, although most of it escapes through the rim of the pan or opening provided, the ball or reservoir is nevertheless alternately emptied and filled to overflowing (as is evident from the discharge escaping on the top of the ball) one hundred and fifty thousand times per second.

the direction of the movement, which, however, must always take place along the resultant of all those efforts which, at that time, we designate as reasonable, that is, self-preserving, useful, profitable, or practical. These efforts concern our daily life, our necessities and comforts, our work and business, and it is these which drive man onward.

But looking at all this busy world about us, on all this complex mass as it daily throbs and moves, what is it but an immense clockwork driven by a spring? In the morning, when we rise, we cannot fail to note that all the objects about us are manufactured by machinery: the water we use is lifted by steam-power; the trains bring our breakfast from distant localities; the elevators in our dwelling and in our office building, the cars that carry us there, are all driven by power; in all our daily errands, and in our very life-pursuit, we depend upon it; all the objects we see tell us of it; and when we return to our machine-made dwelling at night, lest we should forget it, all the material comforts of our home, our cheering stove and lamp, remind us how much we depend on power. And when there is an accidental stoppage of the machinery, when the city is snow-bound, or the life-sustaining movement otherwise temporarily arrested, we are affrighted to realize

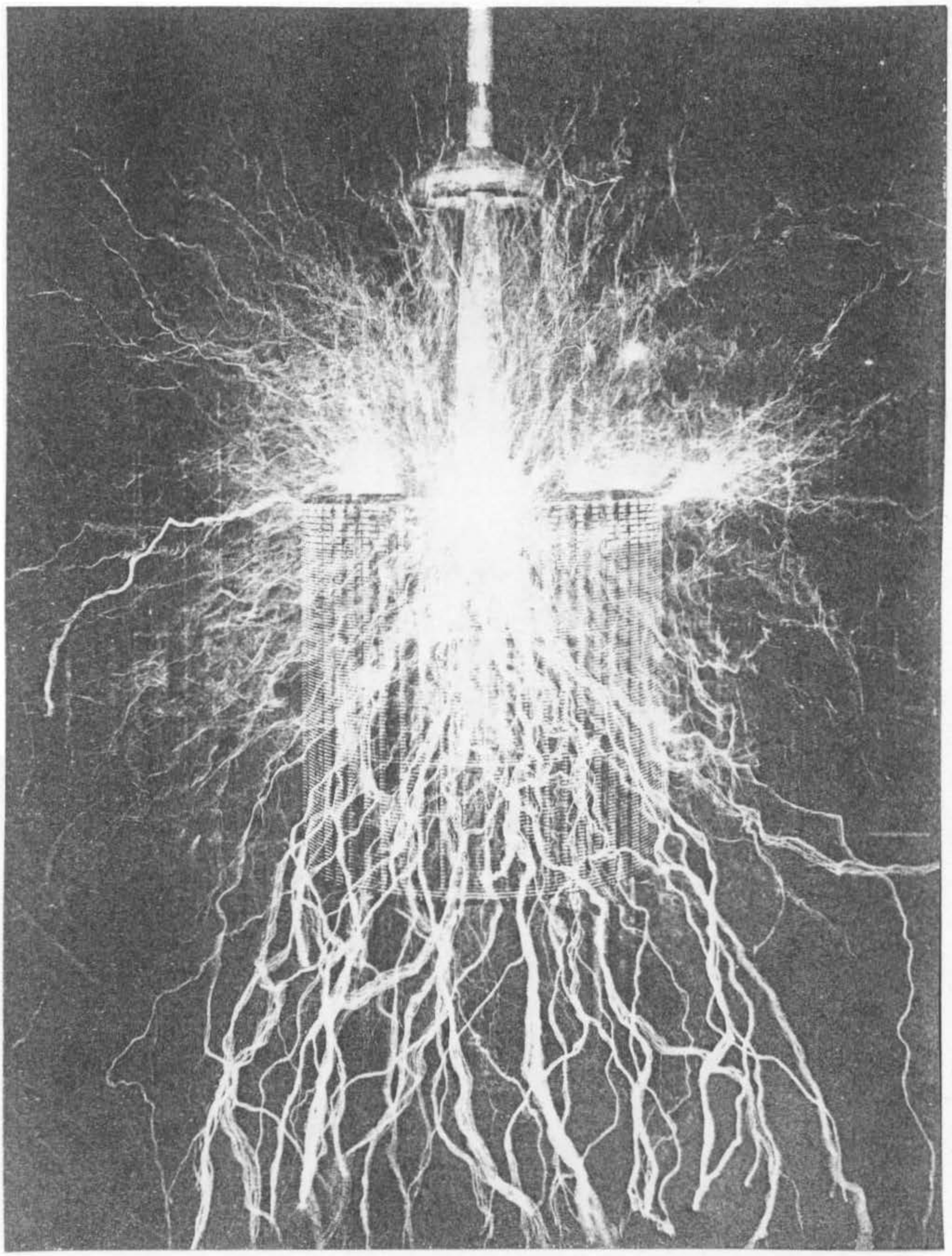


FIG. 10. PHOTOGRAPHIC VIEW OF AN EXPERIMENT TO ILLUSTRATE AN EFFECT OF AN ELECTRICAL OSCILLATOR DELIVERING ENERGY AT A RATE OF SEVENTY-FIVE THOUSAND HORSE-POWER.

The discharge, creating a strong draft owing to the heating of the air, is carried upward through the open roof of the building. The greatest width across is nearly seventy feet. The pressure is over twelve million volts, and the current alternates one hundred and thirty thousand times per second.

how impossible it would be for us to live the life we live without motive power. Motive power means work. To increase the force accelerating human movement means, therefore, to perform more work.

So we find that the three possible solutions of the great problem of increasing human energy are answered by the three words: *food*, *peace*, *work*. Many a year I have thought and pondered, lost myself in

speculations and theories, considering man as a mass moved by a force, viewing his inexplicable movement in the light of a mechanical one, and applying the simple principles of mechanics to the analysis of the same until I arrived at these solutions, only to realize that they were taught to me in my early childhood. These three words sound the key-notes of the Christian religion. Their scientific meaning and purpose are now clear to me: food to increase the mass, peace to diminish the retarding force, and work to increase the force accelerating human movement. These are the only three solutions which are possible of that great problem, and all of them have one object, one end, namely, to increase human energy. When we recognize this, we cannot help wondering how profoundly wise and scientific and how immensely practical the Christian religion is, and in what a marked contrast it stands in this respect to other religions. It is unmistakably the result of practical experiment and scientific observation which have extended through ages, while other religions seem to be the outcome of merely abstract reasoning. Work, untiring effort, useful and accumulative, with periods of rest and recuperation aiming at higher efficiency, is its chief and ever-recurring command. Thus we are inspired both by Christianity and Science to do our utmost toward increasing the performance of mankind. This most important of human problems I shall now specifically consider.

THE SOURCE OF HUMAN ENERGY—THE THREE WAYS OF DRAWING ENERGY FROM THE SUN.

FIRST let us ask: Whence comes all the motive power? What is the spring that drives all? We see the ocean rise and fall, the rivers flow, the wind, rain, hail, and snow beat on our windows, the trains and steamers come and go; we hear the rattling noise of carriages, the voices from the street; we feel, smell, and taste; and we think of all this. And all this movement, from the surging of the mighty ocean to that subtle movement concerned in our thought, has but one common cause. All this energy emanates from one single center, one single source—the sun. The sun is the spring that drives all. The sun maintains all human life and supplies all human energy. Another answer we have now found to the above great question: To increase the force accelerating human movement means to turn to the uses of man more of the sun's energy. We honor and revere those great men of bygone times whose names are linked with immortal achievements, who have proved themselves benefactors of humanity—the religious reformer with his wise maxims of life, the philosopher with his deep truths, the mathematician with his formulæ, the physicist with his laws, the discoverer with his principles and secrets wrested from nature, the artist with his forms of the beautiful; but who honors him, the greatest of all,—who can tell the name of him,—who first turned to use the sun's energy to save the effort of a weak fellow-creature? That was man's first act of scientific philanthropy, and its consequences have been incalculable.

From the very beginning three ways of drawing energy from the sun were open to man. The savage, when he warmed his frozen limbs at a fire kindled in some way, availed himself of the energy of the sun stored in the burning material. When he carried a bundle of branches to his cave and burned them there, he made use of the sun's stored energy transported from one to another locality. When he set sail to his canoe, he utilized the energy of the sun supplied to the atmosphere or ambient medium. There can be no doubt that the first is the oldest way. A fire, found accidentally, taught the savage to appreciate its beneficial heat. He then very likely conceived the idea of carrying the glowing embers to his abode. Finally he learned to use the force of a swift current of water or air. It is characteristic of modern development that progress has been effected in the same order. The utilization of the energy stored in wood or coal, or, generally speaking, fuel, led to the steam-engine. Next a great stride in advance was made in energy-transportation by the use of electricity, which permitted the transfer of energy from one locality to another without transporting the material. But as to the utilization of the energy of the ambient medium, no radical step forward has as yet been made known.

The ultimate results of development in these three directions are: first, the burning of coal by a cold process in a battery; second, the efficient utilization of the energy of the ambient medium; and, third, the transmission without wires of electrical energy to any distance. In whatever way these results may be arrived at, their practical application will necessarily involve an extensive use of iron, and this invaluable metal will undoubtedly be an essential element in the further de-

velopment along these three lines. If we succeed in burning coal by a cold process and thus obtaining electrical energy in an efficient and inexpensive manner, we shall require in many practical uses of this energy electric motors—that is, iron. If we are successful in deriving energy from the ambient medium, we shall need, both in the obtainment and utilization of the energy, machinery—again, iron. If we realize the transmission of electrical energy without wires on an industrial scale, we shall be compelled to use extensively electric generators—once more, iron. Whatever we may do, iron will probably be the chief means of accomplishment in the near future, possibly more so than in the past. How long its reign will last is difficult to tell, for even now aluminium is looming up as a threatening competitor. But for the time being, next to providing new resources of energy, it is of the greatest importance to make improvements in the manufacture and utilization of iron. Great advances are possible in these latter directions, which, if brought about, would enormously increase the useful performance of mankind.

GREAT POSSIBILITIES OFFERED BY IRON FOR INCREASING HUMAN PERFORMANCE—ENORMOUS WASTE IN IRON MANUFACTURE.

IRON is by far the most important factor in modern progress. It contributes more than any other industrial product to the force accelerating human movement. So general is the use of this metal, and so intimately is it connected with all that concerns our life, that it has become as indispensable to us as the very air we breathe. Its name is synonymous with usefulness. But, however great the influence of iron may be on the present human development, it does not add to the force urging man onward nearly as much as it might. First of all, its manufacture as now carried on is connected with an appalling waste of fuel—that is, waste of energy. Then, again, only a part of all the iron produced is applied for useful purposes. A good part of it goes to create frictional resistances, while still another large part is the means of developing negative forces greatly retarding human movement. Thus the negative force of war is almost wholly represented in iron. It is impossible to estimate with any degree of accuracy the magnitude of this greatest of all retarding forces, but it is certainly very considerable. If the present positive impelling force due to all useful applications of iron be represented by ten, for instance, I should not think it exaggeration to estimate the negative force of war, with due consideration of all its retarding influences and results, at, say, six. On the basis of this estimate the effective impelling force of iron in the positive direction would be measured by the difference of these two numbers, which is four. But if, through the establishment of universal peace, the manufacture of war machinery should cease, and all struggle for supremacy between nations should be turned into healthful, ever active and productive commercial competition, then the positive impelling force due to iron would be measured by the sum of those two numbers, which is sixteen—that is, this force would have four times its present value. This example is, of course, merely intended to give an idea of the immense increase in the useful performance of mankind which would result from a radical reform of the iron industries supplying the implements of warfare.

A similar inestimable advantage in the saving of energy available to man would be secured by obviating the great waste of coal which is inseparably connected with the present methods of manufacturing iron. In some countries, as in Great Britain, the hurtful effects of this squandering of fuel are beginning to be felt. The price of coal is constantly rising, and the poor are made to suffer more and more. Though we are still far from the dreaded "exhaustion of the coal-fields," philanthropy commands us to invent novel methods of manufacturing iron, which will not involve such barbarous waste of this valuable material from which we derive at present most of our energy. It is our duty to coming generations to leave this store of energy intact for them, or at least not to touch it until we shall have perfected processes for burning coal more efficiently. Those who are to come after us will need fuel more than we do. We should be able to manufacture the iron we require by using the sun's energy, without wasting any coal at all. As an effort to this end the idea of smelting iron ores by electric currents obtained from the energy of falling water has naturally suggested itself to many. I have myself spent much time in endeavoring to evolve such a practical process, which would enable iron to be manufactured at small cost. After a prolonged investigation of the subject, finding that it was unprofitable to use the currents generated directly for smelting the ore, I devised a method which is far more economical.

ECONOMICAL PRODUCTION OF IRON BY A NEW PROCESS.

THE industrial project, as I worked it out six years ago, contemplated the employment of the electric currents derived from the energy of a waterfall, not directly for smelting the ore, but for decomposing water, as a preliminary step. To lessen the cost of the plant, I proposed to generate the currents in exceptionally cheap and simple dynamos, which I designed for this sole purpose. The hydrogen liberated in the electrolytic decomposition was to be burned or recombined with oxygen, not with that from which it was separated, but with that of the atmosphere. Thus very nearly the total electrical energy used up in the decomposition of the water would be recovered in the form of heat resulting from the recombination of the hydrogen. This heat was to be applied to the smelting of the ore. The oxygen gained as a by-product in the decomposition of the water I intended to use for certain other industrial purposes, which would probably yield good financial returns, inasmuch as this is the cheapest way of obtaining this gas in large quantities. In any event, it could be employed to burn all kinds of refuse, cheap hydrocarbon, or coal of the most inferior quality which could not be burned in air or be otherwise utilized to advantage, and thus again a considerable amount of heat would be made available for the smelting of the ore. To increase the economy of the process I contemplated, furthermore, using an arrangement such that the hot metal and the products of combustion, coming out of the furnace, would give up their heat upon the cold ore going into the furnace, so that comparatively little of the heat-energy would be lost in the smelting. I calculated that probably forty thousand pounds of iron could be produced per horse-power per annum by this method. Liberal allowances were made for those losses which are unavoidable, the above quantity being about half of that theoretically obtainable. Relying on this estimate and on practical data with reference to a certain kind of sand ore existing in abundance in the region of the Great Lakes, including cost of transportation and labor, I found that in some localities iron could be manufactured in this manner cheaper than by any of the adopted methods. This result would be attained all the more surely if the oxygen obtained from the water, instead of being used for smelting the ore, as assumed, should be more profitably employed. Any new demand for this gas would secure a higher revenue from the plant, thus cheapening the iron. This project was advanced merely in the interest of industry. Some day, I hope, a beautiful industrial butterfly will come out of the dusty and shriveled chrysalis.

The production of iron from sand ores by a process of magnetic separation is highly commendable in principle, since it involves no waste of coal; but the usefulness of this method is largely reduced by the necessity of melting the iron afterward. As to the crushing of iron ore, I would consider it rational only if done by water-power, or by energy otherwise obtained without consumption of fuel. An electrolytic cold process, which would make it possible to extract iron cheaply, and also to mold it into the required forms without any fuel consumption, would, in my opinion, be a very great advance in iron manufacture. In common with some other metals, iron has so far resisted electrolytic treatment, but there can be no doubt that such a cold process will ultimately replace in metallurgy the present crude method of casting, and thus obviate the enormous waste of fuel necessitated by the repeated heating of metal in the foundries.

Up to a few decades ago the usefulness of iron was based almost wholly on its remarkable mechanical properties, but since the advent of the commercial dynamo and electric motor its value to mankind has been greatly increased by its unique magnetic qualities. As regards the latter, iron has been greatly improved of late. The signal progress began about thirteen years ago, when I discovered that in using soft Bessemer steel instead of wrought iron, as then customary, in an alternating motor, the performance of the machine was doubled. I brought this fact to the attention of Mr. Albert Schmid, to whose untiring efforts and ability is largely due the supremacy of American electrical machinery, and who was then superintendent of an industrial corporation engaged in this field. Following my suggestion, he constructed transformers of steel, and they showed the same marked improvement. The investigation was then systematically continued under Mr. Schmid's guidance, the impurities being gradually eliminated from the "steel" (which was only such in name, for in reality it was pure soft iron), and soon a product resulted which admitted of little further improvement.

THE COMING AGE OF ALUMINIUM—DOOM OF THE COPPER INDUSTRY—THE GREAT CIVILIZING POTENCY OF THE NEW METAL.

WITH the advances made in iron of late years we have arrived virtually at the limits of improvement. We cannot hope to increase very materially its tensile strength, elasticity, hardness, or malleability, nor can we expect to make it much better as regards its magnetic qualities. More recently a notable gain was secured by the mixture of a small percentage of nickel with the iron, but there is not much room for further advance in this direction. New discoveries may be expected, but they cannot greatly add to the valuable properties of the metal, though they may considerably reduce the cost of manufacture. The immediate future of iron is assured by its cheapness and its unrivaled mechanical and magnetic qualities. These are such that no other product can compete with it now. But there can be no doubt that, at a time not very distant, iron, in many of its now uncontested domains, will have to pass the scepter to another: the coming age will be the age of aluminium. It is only seventy years since this wonderful metal was discovered by Woehler, and the aluminium industry, scarcely forty years old, commands already the attention of the entire world. Such rapid growth has not been recorded in the history of civilization before. Not long ago aluminium was sold at the fanciful price of thirty or forty dollars per pound; to-day it can be had in any desired amount for as many cents. What is more, the time is not far off when this price, too, will be considered fanciful, for great improvements are possible in the methods of its manufacture. Most of the metal is now produced in the electric furnace by a process combining fusion and electrolysis, which offers a number of advantageous features, but involves naturally a great waste of the electrical energy of the current. My estimates show that the price of aluminium could be considerably reduced by adopting in its manufacture a method similar to that proposed by me for the production of iron. A pound of aluminium requires for fusion only about seventy per cent. of the heat needed for melting a pound of iron, and inasmuch as its weight is only about one third of that of the latter, a volume of aluminium four times that of iron could be obtained from a given amount of heat-energy. But a cold electrolytic process of manufacture is the ideal solution, and on this I have placed my hope.

The absolutely unavoidable consequence of the advance of the aluminium industry will be the annihilation of the copper industry. They cannot exist and prosper together, and the latter is doomed beyond any hope of recovery. Even now it is cheaper to convey an electric current through aluminium wires than through copper wires; aluminium castings cost less, and in many domestic and other uses copper has no chance of successfully competing. A further material reduction of the price of aluminium cannot but be fatal to copper. But the progress of the former will not go on unchecked, for, as it ever happens in such cases, the larger industry will absorb the smaller one: the giant copper interests will control the pygmy aluminium interests, and the slow-pacing copper will reduce the lively gait of aluminium. This will only delay, not avoid, the impending catastrophe.

Aluminium, however, will not stop at downing copper. Before many years have passed it will be engaged in a fierce struggle with iron, and in the latter it will find an adversary not easy to conquer. The issue of the contest will largely depend on whether iron shall be indispensable in electric machinery. This the future alone can decide. The magnetism as exhibited in iron is an isolated phenomenon in nature. What it is that makes this metal behave so radically different from all other materials in this respect has not yet been ascertained, though many theories have been suggested. As regards magnetism, the molecules of the various bodies behave like hollow beams partly filled with a heavy fluid and balanced in the middle in the manner of a see-saw. Evidently some disturbing influence exists in nature which causes each molecule, like such a beam, to tilt either one or the other way. If the molecules are tilted one way, the body is magnetic; if they are tilted the other way, the body is non-magnetic; but both positions are stable, as they would be in the case of the hollow beam, owing to the rushing of the fluid to the lower end. Now, the wonderful thing is that the molecules of all known bodies went one way, while those of iron went the other way. This metal, it would seem, has an origin entirely different from that of the rest of the globe. It is highly improbable that we shall discover some other and cheaper material which will equal or surpass iron in magnetic qualities.

Unless we should make a radical departure in the character of the electric currents employed, iron will be indispensable. Yet

the advantages it offers are only apparent. So long as we use feeble magnetic forces it is by far superior to any other material; but if we find ways of producing great magnetic forces, then better results will be obtainable without it. In fact, I have already produced electric transformers in which no iron is employed, and which are capable of performing ten times as much work per pound of weight as those with iron. This result is attained by using electric currents of a very high rate of vibration, produced in novel ways, instead of the ordinary currents now employed in the industries. I have also succeeded in operating electric motors without iron by such rapidly vibrating currents, but the results, so far, have been inferior to those obtained with ordinary motors constructed of iron, although theoretically the former should be capable of performing incomparably more work per unit of weight than the latter. But the seemingly insuperable difficulties which are now in the way may be overcome in the end, and then iron will be done away with, and all electric machinery will be manufactured of aluminium, in all probability, at prices ridiculously low. This would be a severe, if not a fatal, blow to iron. In many other branches of industry, as ship-building, or wherever lightness of structure is required, the progress of the new metal will be much quicker. For such uses it is eminently suitable, and is sure to supersede iron sooner or later. It is highly probable that in the course of time we shall be able to give it many of those qualities which make iron so valuable.

While it is impossible to tell when this industrial revolution will be consummated, there can be no doubt that the future belongs to aluminium, and that in times to come it will be the chief means of increasing human performance. It has in this respect capacities greater by far than those of any other metal. I should estimate its civilizing potency at fully one hundred times that of iron. This estimate, though it may astonish, is not at all exaggerated. First of all, we must remember that there is thirty times as much aluminium as iron in bulk, available for the uses of man. This in itself offers great possibilities. Then, again, the new metal is much more easily workable, which adds to its value. In many of its properties it partakes of the character of a precious metal, which gives it additional worth. Its electric conductivity, which, for a given weight, is greater than that of any other metal, would be alone sufficient to make it one of the most important factors in future human progress. Its extreme lightness makes it far more easy to transport the objects manufactured. By virtue of this property it will revolutionize naval construction, and in facilitating transport and travel it will add enormously to the useful performance of mankind. But its greatest civilizing potency will be, I believe, in aërial travel, which is sure to be brought about by means of it. Telegraphic instruments will slowly enlighten the barbarian. Electric motors and lamps will do it more quickly, but quicker than anything else the flying-machine will do it. By rendering travel ideally easy it will be the best means for unifying the heterogeneous elements of humanity. As the first step toward this realization we should produce a lighter storage-battery or get more energy from coal.

EFFORTS TOWARD OBTAINING MORE ENERGY FROM COAL—THE ELECTRIC TRANSMISSION—THE GAS-ENGINE—THE COLD-COAL BATTERY.

I REMEMBER that at one time I considered the production of electricity by burning coal in a battery as the greatest achievement toward advancing civilization, and I am surprised to find how much the continuous study of these subjects has modified my views. It now seems to me that to burn coal, however efficiently, in a battery would be a mere makeshift, a phase in the evolution toward something much more perfect. After all, in generating electricity in this manner, we should be destroying material, and this would be a barbarous process. We ought to be able to obtain the energy we need without consumption of material. But I am far from underrating the value of such an efficient method of burning fuel. At the present time most motive power comes from coal, and, either directly or by its products, it adds vastly to human energy. Unfortunately, in all the processes now adopted, the larger portion of the energy of the coal is uselessly dissipated. The best steam-engines utilize only a small part of the total energy. Even in gas-engines, in which, particularly of late, better results are obtainable, there is still a barbarous waste going on. In our electric-lighting systems we scarcely utilize one third of one per cent., and in lighting by gas a much smaller fraction, of the total energy of the coal. Considering the various uses of coal throughout the world, we certainly do not utilize more than two per cent. of its energy theoretically available. The man who should stop this senseless waste would be a great

benefactor of humanity, though the solution he would offer could not be a permanent one, since it would ultimately lead to the exhaustion of the store of material. Efforts toward obtaining more energy from coal are now being made chiefly in two directions—by generating electricity and by producing gas for motive-power purposes. In both of these lines notable success has already been achieved.

The advent of the alternating-current system of electric power-transmission marks an epoch in the economy of energy available to man from coal. Evidently all electrical energy obtained from a waterfall, saving so much fuel, is a net gain to mankind, which is all the more effective as it is secured with little expenditure of human effort, and as this most perfect of all known methods of deriving energy from the sun contributes in many ways to the advancement of civilization. But electricity enables us also to get from coal much more energy than was practicable in the old ways. Instead of transporting the coal to distant places of consumption, we burn it near the mine, develop electricity in the dynamos, and transmit the current to remote localities, thus effecting a considerable saving. Instead of driving the machinery in a factory in the old wasteful way by belts and shafting, we generate electricity by steam-power and operate electric motors. In this manner it is not uncommon to obtain two or three times as much effective motive power from the fuel, besides securing many other important advantages. It is in this field as much as in the transmission of energy to great distances that the alternating system, with its ideally simple machinery, is bringing about an industrial revolution. But in many lines this progress has not yet been felt. For example, steamers and trains are still being propelled by the direct application of steam-power to shafts or axles. A much greater percentage of the heat-energy of the fuel could be transformed in motive energy by using, in place of the adopted marine engines and locomotives, dynamos driven by specially designed high-pressure steam- or gas-engines and by utilizing the electricity generated for the propulsion. A gain of fifty to one hundred per cent. in the effective energy derived from the coal could be secured in this manner. It is difficult to understand why a fact so plain and obvious is not receiving more attention from engineers. In ocean steamers such an improvement would be particularly desirable, as it would do away with noise and increase materially the speed and the carrying capacity of the liners.

Still more energy is now being obtained from coal by the latest improved gas-engine, the economy of which is, on the average, probably twice that of the best steam-engine. The introduction of the gas-engine is very much facilitated by the importance of the gas industry. With the increasing use of the electric light more and more of the gas is utilized for heating and motive-power purposes. In many instances gas is manufactured close to the coal-mine and conveyed to distant places of consumption, a considerable saving both in the cost of transportation and in utilization of the energy of the fuel being thus effected. In the present state of the mechanical and electrical arts the most rational way of deriving energy from coal is evidently to manufacture gas close to the coal store, and to utilize it, either on the spot or elsewhere, to generate electricity for industrial uses in dynamos driven by gas-engines. The commercial success of such a plant is largely dependent upon the production of gas-engines of great nominal horse-power, which, judging from the keen activity in this field, will soon be forthcoming. Instead of consuming coal directly, as usual, gas should be manufactured from it and burned to economize energy.

But all such improvements cannot be more than passing phases in the evolution toward something far more perfect, for ultimately we must succeed in obtaining electricity from coal in a more direct way, involving no great loss of its heat-energy. Whether coal can be oxidized by a cold process is still a question. Its combination with oxygen always evolves heat, and whether the energy of the combination of the carbon with another element can be turned directly into electrical energy has not yet been determined. Under certain conditions nitric acid will burn the carbon, generating an electric current, but the solution does not remain cold. Other means of oxidizing coal have been proposed, but they have offered no promise of leading to an efficient process. My own lack of success has been complete, though perhaps not quite so complete as that of some who have "perfected" the cold-coal battery. This problem is essentially one for the chemist to solve. It is not for the physicist, who determines all his results in advance, so that, when the experiment is tried, it cannot fail. Chemistry, though a positive science, does not yet admit of a solution by

such positive methods as those which are available in the treatment of many physical problems. The result, if possible, will be arrived at through patient trying rather than through deduction or calculation. The time will soon come, however, when the chemist will be able to follow a course clearly mapped out beforehand, and when the process of his arriving at a desired result will be purely constructive. The cold-coal battery would give a great impetus to electrical development; it would lead very shortly to a practical flying-machine, and would enormously enhance the introduction of the automobile. But these and many other problems will be better solved, and in a more scientific manner, by a light-storage battery.

ENERGY FROM THE MEDIUM—THE WINDMILL AND THE SOLAR ENGINE—MOTIVE POWER FROM TERRESTRIAL HEAT—ELECTRICITY FROM NATURAL SOURCES.

BESIDES fuel, there is abundant material from which we might eventually derive power. An immense amount of energy is locked up in limestone, for instance, and machines can be driven by liberating the carbonic acid through sulphuric acid or otherwise. I once constructed such an engine, and it operated satisfactorily.

But, whatever our resources of primary energy may be in the future, we must, to be rational, obtain it without consumption of any material. Long ago I came to this conclusion, and to arrive at this result only two ways, as before indicated, appeared possible—either to turn to use the energy of the sun stored in the ambient medium, or to transmit, through the medium, the sun's energy to distant places from some locality where it was obtainable without consumption of material. At that time I at once rejected the latter method as entirely impracticable, and turned to examine the possibilities of the former.

It is difficult to believe, but it is, nevertheless, a fact, that since time immemorial man has had at his disposal a fairly good machine which has enabled him to utilize the energy of the ambient medium. This machine is the windmill. Contrary to popular belief, the power obtainable from wind is very considerable. Many a deluded inventor has spent years of his life in endeavoring to "harness the tides," and some have even proposed to compress air by tide- or wave-power for supplying energy, never understanding the signs of the old windmill on the hill, as it sorrowfully waved its arms about and bade them stop. The fact is that a wave- or tide-motor would have, as a rule, but a small chance of competing commercially with the windmill, which is by far the better machine, allowing a much greater amount of energy to be obtained in a simpler way. Wind-power has been, in old times, of inestimable value to man, if for nothing else but for enabling him to cross the seas, and it is even now a very important factor in travel and transportation. But there are great limitations in this ideally simple method of utilizing the sun's energy. The machines are large for a given output, and the power is intermittent, thus necessitating the storage of energy and increasing the cost of the plant.

A far better way, however, to obtain power would be to avail ourselves of the sun's rays, which beat the earth incessantly and supply energy at a maximum rate of over four million horse-power per square mile. Although the average energy received per square mile in any locality during the year is only a small fraction of that amount, yet an inexhaustible source of power would be opened up by the discovery of some efficient method of utilizing the energy of the rays. The only rational way known to me at the time when I began the study of this subject was to employ some kind of heat- or thermodynamic engine, driven by a volatile fluid evaporated in a boiler by the heat of the rays. But closer investigation of this method, and calculation, showed that, notwithstanding the apparently vast amount of energy received from the sun's rays, only a small fraction of that energy could be actually utilized in this manner. Furthermore, the energy supplied through the sun's radiations is periodical, and the same limitations as in the use of the windmill I found to exist here also. After a long study of this mode of obtaining motive power from the sun, taking into account the necessarily large bulk of the boiler, the low efficiency of the heat-engine, the additional cost of storing the energy, and other drawbacks, I came to the conclusion that the "solar engine," a few instances excepted, could not be industrially exploited with success.

Another way of getting motive power from the medium without consuming any material would be to utilize the heat contained in the earth, the water, or the air for driving an engine. It is a well-known fact that the interior portions of the globe are very hot, the temperature rising, as observa-

tions show, with the approach to the center at the rate of approximately 1° C. for every hundred feet of depth. The difficulties of sinking shafts and placing boilers at depths of, say, twelve thousand feet, corresponding to an increase in temperature of about 120° C., are not insuperable, and we could certainly avail ourselves in this way of the internal heat of the globe. In fact, it would not be necessary to go to any depth at all in order to derive energy from the stored terrestrial heat. The superficial layers of the earth and the air strata close to the same are at a temperature sufficiently high to evaporate some extremely volatile substances, which we might use in our boilers instead of water. There is no doubt that a vessel might be propelled on the ocean by an engine driven by such a volatile fluid, no other energy being used but the heat abstracted from the water. But the amount of power which could be obtained in this manner would be, without further provision, very small.

Electricity produced by natural causes is another source of energy which might be rendered available. Lightning discharges involve great amounts of electrical energy, which we could utilize by transforming and storing it. Some years ago I made known a method of electrical transformation which renders the first part of this task easy, but the storing of the energy of lightning discharges will be difficult to accomplish. It is well known, furthermore, that electric currents circulate constantly through the earth, and that there exists between the earth and any air stratum a difference of electrical pressure, which varies in proportion to the height.

In recent experiments I have discovered two novel facts of importance in this connection. One of these facts is that an electric current is generated in a wire extending from the ground to a great height by the axial, and probably also by the translatory, movement of the earth. No appreciable current, however, will flow continuously in the wire unless the electricity is allowed to leak out into the air. Its escape is greatly facilitated by providing at the elevated end of the wire a conducting terminal of great surface, with many sharp edges or points. We are thus enabled to get a continuous supply of electrical energy by merely supporting a wire at a height, but, unfortunately, the amount of electricity which can be so obtained is small.

The second fact which I have ascertained is that the upper air strata are permanently charged with electricity opposite to that of the earth. So, at least, I have interpreted my observations, from which it appears that the earth, with its adjacent insulating and outer conducting envelop, constitutes a highly charged electrical condenser containing, in all probability, a great amount of electrical energy which might be turned to the uses of man, if it were possible to reach with a wire to great altitudes.

It is possible, and even probable, that there will be, in time, other resources of energy opened up, of which we have no knowledge now. We may even find ways of applying forces such as magnetism or gravity for driving machinery without using any other means. Such realizations, though highly improbable, are not impossible. An example will best convey an idea of what we can hope to attain and what we can never attain. Imagine a disk of some homogeneous material turned perfectly true and arranged to turn in frictionless bearings on a horizontal shaft above the ground. This disk, being under the above conditions perfectly balanced, would rest in any position. Now, it is possible that we may learn how to make such a disk rotate continuously and perform work by the force of gravity without any further effort on our part; but it is perfectly impossible for the disk to turn and to do work without any force from the outside. If it could do so, it would be what is designated scientifically as a "perpetuum mobile," a machine creating its own motive power. To make the disk rotate by the force of gravity we have only to invent a screen against this force. By such a screen we could prevent this force from acting on one half of the disk, and the rotation of the latter would follow. At least, we cannot deny such a possibility until we know exactly the nature of the force of gravity. Suppose that this force were due to a movement comparable to that of a stream of air passing from above toward the center of the earth. The effect of such a stream upon both halves of the disk would be equal, and the latter would not rotate ordinarily; but if one half should be guarded by a plate arresting the movement, then it would turn.

A DEPARTURE FROM KNOWN METHODS—POSSIBILITY OF A "SELF-ACTING" ENGINE OR MACHINE, INANIMATE, YET CAPABLE, LIKE A LIVING BEING, OF DERIVING ENERGY FROM THE MEDIUM—THE IDEAL WAY OF OBTAINING MOTIVE POWER.

WHEN I began the investigation of the subject under consideration, and when the preceding or similar ideas presented themselves

to me for the first time, though I was then unacquainted with a number of the facts mentioned, a survey of the various ways of utilizing the energy of the medium convinced me, nevertheless, that to arrive at a thoroughly satisfactory practical solution a radical departure from the methods then known had to be made. The windmill, the solar engine, the engine driven by terrestrial heat, had their limitations in the amount of power obtainable. Some new way had to be discovered which would enable us to get more energy. There was enough heat-energy in the medium, but only a small part of it was available for the operation of an engine in the ways then known. Besides, the energy was obtainable only at a very slow rate. Clearly, then, the problem was to discover some new method which would make it possible both to utilize more of the heat-energy of the medium and also to draw it away from the same at a more rapid rate.

I was vainly endeavoring to form an idea of how this might be accomplished, when I read some statements from Carnot and Lord Kelvin (then Sir William Thomson) which meant virtually that it is impossible for an inanimate mechanism or self-acting machine to cool a portion of the medium below the temperature of the surrounding, and operate by the heat abstracted. These statements interested me intensely. Evidently a living being could do this very thing, and since the experiences of my early life which I have related had convinced me that a living being is only an automaton, or, otherwise stated, a "self-acting engine," I came to the conclusion that it was possible to construct a machine which would do the same. As the first step toward this realization I conceived the following mechanism. Imagine a thermopile consisting of a number of bars of metal extending from the earth to the outer space beyond the atmosphere. The heat from below, conducted upward along these metal bars, would cool the earth or the sea or the air, according to the location of the lower parts of the bars, and the result, as is well known, would be an electric current circulating in these bars. The two terminals of the thermopile could now be joined through an electric motor, and, theoretically, this motor would run on and on, until the media below would be cooled down to the temperature of the outer space. This would be an inanimate engine which, to all evidence, would be cooling a portion of the medium below the temperature of the surrounding, and operating by the heat abstracted.

But was it not possible to realize a similar condition without necessarily going to a height? Conceive, for the sake of illustration, an inclosure T, as illustrated in diagram b, such that energy could not be transferred across it except through a channel or path O, and that, by some means or other, in this inclosure a medium were maintained which would have little energy, and that on the outer side of the same there would be the ordinary ambient medium with much energy. Under these assumptions the energy would flow through the path O, as indicated by the arrow, and might then be converted on its passage into some other form of energy. The question was, Could such a condition be attained? Could we produce artificially such a "sink" for the energy of the ambient medium to flow in? Suppose that an extremely low temperature could be maintained by some process in a given space; the surrounding medium would then be compelled to give off heat, which could be converted into mechanical or other form of energy, and utilized. By realizing such a plan, we should be enabled to get at any point of the globe a continuous supply of energy, day and night. More than this, reasoning in the abstract, it would seem possible to cause a quick circulation of the medium, and thus draw the energy at a very rapid rate.

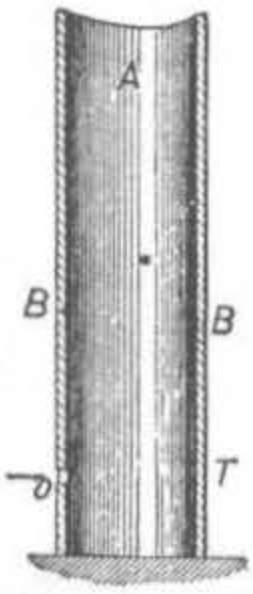


DIAGRAM *b*. OBTAINING ENERGY FROM THE AMBIENT MEDIUM.

A, medium with little energy; *B*, *B*, ambient medium with much energy; *O*, path of the energy.

Here, then, was an idea which, if realizable, afforded a happy solution of the problem of getting energy from the medium. But was it realizable? I convinced myself that it was so in a number of ways, of which one is the following. As regards heat, we are at a high level, which may be represented by the surface of a mountain lake considerably above the sea, the level of which may mark the absolute zero of temperature existing in the interstellar space. Heat, like water, flows

from high to low level, and, consequently, just as we can let the water of the lake run down to the sea, so we are able to let heat from the earth's surface travel up into the cold region above. Heat, like water, can perform work in flowing down, and if we had any doubt as to whether we could derive energy from the medium by means of a thermopile, as before described, it would be dispelled by this analogue. But can we produce cold in a given portion of the space and cause the heat to flow in continually? To create such a "sink," or "cold hole," as we might say, in the medium, would be equivalent to producing in the lake a space either empty or filled with something much lighter than water. This we could do by placing in the lake a tank, and pumping all the water out of the latter. We know, then, that the water, if allowed to flow back into the tank, would, theoretically, be able to perform exactly the same amount of work which was used in pumping it out, but not a bit more. Consequently nothing could be gained in this double operation of first raising the water and then letting it fall down. This would mean that it is impossible to create such a sink in the medium. But let us reflect a moment. Heat, though following certain general laws of mechanics, like a fluid, is not such; it is energy which may be converted into other forms of energy as it passes from a high to a low level. To make our mechanical analogy complete and true, we must, therefore, assume that the water, in its passage into the tank, is converted into something else, which may be taken out of it without using any, or by using very little, power. For example, if heat be represented in this analogue by the water of the lake, the oxygen and hydrogen composing the water may illustrate other forms of energy into which the heat is transformed in passing from hot to cold. If the process of heat-transformation were absolutely perfect, no heat at all would arrive at the low level, since all of it would be converted into other forms of energy. Corresponding to this ideal case, all the water flowing into the tank would be decomposed into oxygen and hydrogen before reaching the bottom, and the result would be that water would continually flow in, and yet the tank would remain entirely empty, the gases formed escaping. We would thus produce, by expending initially a certain amount of work to create a sink for the heat or, respectively, the water to flow in, a condition enabling us to get any amount of energy without further effort. This would be an ideal way of obtaining motive power. We do not know of any such absolutely perfect process of heat-conversion, and consequently some heat will generally reach the low level, which means to say, in our mechanical analogue, that some water will arrive at the bottom of the tank, and a gradual and slow filling of the latter will take place, necessitating continuous pumping out. But evidently there will be less to pump out than flows in, or, in other words, less energy will be needed to maintain the initial condition than is developed by the fall, and this is to say that some energy will be gained from the medium. What is not converted in flowing down can just be raised up with its own energy, and what is converted is clear gain. Thus the virtue of the principle I have discovered resides wholly in the conversion of the energy on the downward flow.

FIRST EFFORTS TO PRODUCE THE SELF-ACTING ENGINE—THE MECHANICAL OSCILLATOR—WORK OF DEWAR AND LINDE—LIQUID AIR.

HAVING recognized this truth, I began to devise means for carrying out my idea, and, after long thought, I finally conceived a combination of apparatus which should make possible the obtaining of power from the medium by a process of continuous cooling of atmospheric air. This apparatus, by continually transforming heat into mechanical work, tended to become colder and colder, and if it only were practicable to reach a very low temperature in this manner, then a sink for the heat could be produced, and energy could be derived from the medium. This seemed to be contrary to the statements of Carnot and Lord Kelvin before referred to, but I concluded from the theory of the process that such a result could be attained. This conclusion I reached, I think, in the latter part of 1883, when I was in Paris, and it was at a time when my mind was being more and more dominated by an invention which I had evolved during the preceding year, and which has since become known under the name of the "rotating magnetic field." During the few years which followed I elaborated further the plan I had imagined, and studied the working conditions, but made little headway. The commercial introduction in this country of the invention before referred to required most of my energies until 1889, when I again took up the idea of the self-acting machine. A closer in-

vestigation of the principles involved, and calculation, now showed that the result I aimed at could not be reached in a practical manner by ordinary machinery, as I had in the beginning expected. This led me, as a next step, to the study of a type of engine generally designated as "turbine," which at first seemed to offer better chances for a realization of the idea. Soon I found, however, that the turbine, too, was unsuitable. But my conclusions showed that if an engine of a peculiar kind could be brought to a high degree of perfection, the plan I had conceived was realizable, and I resolved to proceed with the development of such an engine, the primary object of which was to secure the greatest economy of transformation of heat into mechanical energy. A characteristic feature of the engine was that the work-performing piston was not connected with anything else, but was perfectly free to vibrate at an enormous rate. The mechanical difficulties encountered in the construction of this engine were greater than I had anticipated, and I made slow progress. This work was continued until early in 1892, when I went to London, where I saw Professor Dewar's admirable experiments with liquefied gases. Others had liquefied gases before, and notably Ozlewski and Pictet had performed creditable early experiments in this line, but there was such a vigor about the work of Dewar that even the old appeared new. His experiments showed, though in a way different from that I had imagined, that it was possible to reach a very low temperature by transforming heat into mechanical work, and I returned, deeply impressed with what I had seen, and more than ever convinced that my plan was practicable. The work temporarily interrupted was taken up anew, and soon I had in a fair state of perfection the engine which I have named "the mechanical oscillator." In this machine I succeeded in doing away with all packings, valves, and lubrication, and in producing so rapid a vibration of the piston that shafts of tough steel, fastened to the same and vibrated longitudinally, were torn asunder. By combining this engine with a dynamo of special design I produced a highly efficient electrical generator, invaluable in measurements and determinations of physical quantities on account of the unvarying rate of oscillation obtainable by its means. I exhibited several types of this machine, named "mechanical and electrical oscillator," before the Electrical Congress at the World's Fair in Chicago during the summer of 1893, in a lecture which, on account of other pressing work, I was unable to prepare for publication. On that occasion I exposed the principles of the mechanical oscillator, but the original purpose of this machine is explained here for the first time.

In the process, as I had primarily conceived it, for the utilization of the energy of the ambient medium, there were five essential elements in combination, and each of these had to be newly designed and perfected, as no such machines existed. The mechanical oscillator was the first element of this combination, and having perfected this, I turned to the next, which was an air-compressor of a design in certain respects resembling that of the mechanical oscillator. Similar difficulties in the construction were again encountered, but the work was pushed vigorously, and at the close of 1894 I had completed these two elements of the combination, and thus produced an apparatus for compressing air, virtually to any desired pressure, incomparably simpler, smaller, and more efficient than the ordinary. I was just beginning work on the third element, which together with the first two would give a refrigerating machine of exceptional efficiency and simplicity, when a misfortune befell me in the burning of my laboratory, which crippled my labors and delayed me. Shortly afterward Dr. Carl Linde announced the liquefaction of air by a self-cooling process, demonstrating that it was practicable to proceed with the cooling until liquefaction of the air took place. This was the only experimental proof which I was still wanting that energy was obtainable from the medium in the manner contemplated by me.

The liquefaction of air by a self-cooling process was not, as popularly believed, an accidental discovery, but a scientific result which could not have been delayed much longer, and which, in all probability, could not have escaped Dewar. This fascinating advance, I believe, is largely due to the powerful work of this great Scotchman. Nevertheless, Linde's is an immortal achievement. The manufacture of liquid air has been carried on for four years in Germany, on a scale much larger than in any other country, and this strange product has been applied for a variety of purposes. Much was expected of it in the beginning, but so far it has been an industrial ignis fatuus. By the use of such machinery as I am perfecting, its cost will probably be greatly lessened, but even then its commercial success will be ques-

tionable. When used as a refrigerant it is uneconomical, as its temperature is unnecessarily low. It is as expensive to maintain a body at a very low temperature as it is to keep it very hot; it takes coal to keep air cold. In oxygen manufacture it cannot yet compete with the electrolytic method. For use as an explosive it is unsuitable, because its low temperature again condemns it to a small efficiency, and for motive-power purposes its cost is still by far too high. It is of interest to note, however, that in driving an engine by liquid air a certain amount of energy may be gained from the engine, or, stated otherwise, from the ambient medium which keeps the engine warm, each two hundred pounds of iron-casting of the latter contributing energy at the rate of about one effective horse-power during one hour. But this gain of the consumer is offset by an equal loss of the producer.

Much of this task on which I have labored so long remains to be done. A number of mechanical details are still to be perfected and some difficulties of a different nature to be mastered, and I cannot hope to produce a self-acting machine deriving energy from the ambient medium for a long time yet, even if all my expectations should materialize. Many circumstances have occurred which have retarded my work of late, but for several reasons the delay was beneficial.

One of these reasons was that I had ample time to consider what the ultimate possibilities of this development might be. I worked for a long time fully convinced that the practical realization of this method of obtaining energy from the sun would be of incalculable industrial value, but the continued study of the subject revealed the fact that while it will be commercially profitable if my expectations are well founded, it will not be so to an extraordinary degree.

DISCOVERY OF UNEXPECTED PROPERTIES OF THE ATMOSPHERE—STRANGE EXPERIMENTS—TRANSMISSION OF ELECTRICAL ENERGY THROUGH ONE WIRE WITHOUT RETURN—TRANSMISSION THROUGH THE EARTH WITHOUT ANY WIRE.

ANOTHER of these reasons was that I was led to recognize the transmission of electrical energy to any distance through the media as by far the best solution of the great problem of harnessing the sun's energy for the uses of man. For a long time I was convinced that such a transmission on an industrial scale could never be realized, but a discovery which I made changed my view. I observed that under certain conditions the atmosphere, which is normally a high insulator, assumes conducting properties, and so becomes capable of conveying any amount of electrical energy. But the difficulties in the way of a practical utilization of this discovery for the purpose of transmitting electrical energy without wires were seemingly insuperable. Electrical pressures of many millions of volts had to be produced and handled; generating apparatus of a novel kind, capable of withstanding the immense electrical stresses, had to be invented and perfected, and a complete safety against the dangers of the high-tension currents had to be attained in the system before its practical introduction could be even thought of. All this could not be done in a few weeks or months, or even years. The work required patience and constant application, but the improvements came, though slowly. Other valuable results were, however, arrived at in the course of this long-continued work, of which I shall endeavor to give a brief account, enumerating the chief advances as they were successively effected.

The discovery of the conducting properties of the air, though unexpected, was only a natural result of experiments in a special field which I had carried on for some years before. It was, I believe, during 1889 that certain possibilities offered by extremely rapid electrical oscillations determined me to design a number of special machines adapted for their investigation. Owing to the peculiar requirements, the construction of these machines was very difficult, and consumed much time and effort; but my work on them was generously rewarded, for I reached by their means several novel and important results. One of the earliest observations I made with these new machines was that electrical oscillations of an extremely high rate act in an extraordinary manner upon the human organism. Thus, for instance, I demonstrated that powerful electrical discharges of several hundred thousand volts, which at that time were considered absolutely deadly, could be passed through the body without inconvenience or hurtful consequences. These oscillations produced other specific physiological effects, which, upon my announcement, were eagerly taken up by skilled physicians and further investigated. This new field has proved itself fruitful beyond expectation, and in the few years which have passed since, it has been

developed to such an extent that it now forms a legitimate and important department of medical science. Many results, thought impossible at that time, are now readily obtainable with these oscillations, and many experiments undreamed of then can now be readily performed by their means. I still remember with pleasure how, nine years ago, I passed the discharge of a powerful induction-coil through my body to demonstrate before a scientific society the comparative harmlessness of very rapidly vibrating electric currents, and I can still recall the astonishment of my audience. I would now undertake, with much less apprehension than I had in that experiment, to transmit through my body with such currents the entire electrical energy of the dynamos now working at Niagara—forty or fifty thousand horsepower. I have produced electrical oscillations which were of such intensity that when circulating through my arms and chest they have melted wires which joined my hands, and still I felt no inconvenience. I have energized with such oscillations a loop of heavy copper wire so powerfully that masses of metal, and even objects of an electrical resistance specifically greater than that of human tissue, brought close to or placed within the loop, were heated to a high temperature and melted, often with the violence of an explosion, and yet into this very space in which this terribly destructive turmoil was going on I have repeatedly thrust my head without feeling anything or experiencing injurious after-effects.

Another observation was that by means of such oscillations light could be produced in a novel and more economical manner, which promised to lead to an ideal system of electric illumination by vacuum-tubes, dispensing with the necessity of renewal of lamps or incandescent filaments, and possibly also with the use of wires in the interior of buildings. The efficiency of this light increases in proportion to the rate of the oscillations, and its commercial success is, therefore, dependent on the economical production of electrical vibrations of transcending rates. In this direction I have met with gratifying success of late, and the practical introduction of this new system of illumination is not far off.

The investigations led to many other valuable observations and results, one of the more important of which was the demonstration of the practicability of supplying electrical energy through one wire without return. At first I was able to transmit in this novel manner only very small amounts of electrical energy, but in this line also my efforts have been rewarded with similar success.

The photograph shown in Fig. 3 (see p. 186) illustrates, as its title explains, an actual transmission of this kind effected with apparatus used in other experiments here described. To what a degree the appliances have been perfected since my first demonstrations early in 1891 before a scientific society, when my apparatus was barely capable of lighting one lamp (which result was considered wonderful), will appear when I state that I have now no difficulty in lighting in this manner four or five hundred lamps, and could light many more. In fact, there is no limit to the amount of energy which may in this way be supplied to operate any kind of electrical device.

After demonstrating the practicability of this method of transmission, the thought naturally occurred to me to use the earth as a conductor, thus dispensing with all wires. Whatever electricity may be, it is a fact that it behaves like an incompressible fluid, and the earth may be looked upon as an immense reservoir of electricity, which, I thought, could be disturbed effectively by a properly designed electrical machine. Accordingly, my next efforts were directed toward perfecting a special apparatus which would be highly effective in creating a disturbance of electricity in the earth. The progress in this new direction was necessarily very slow and the work discouraging, until I finally succeeded in perfecting a novel kind of transformer or induction-coil, particularly suited for this special purpose. That it is practicable, in this manner, not only to transmit minute amounts of electrical energy for operating delicate electrical devices, as I contemplated at first, but also electrical energy in appreciable quantities, will appear from an inspection of Fig. 4 (see p. 186), which illustrates an actual experiment of this kind performed with the same apparatus. The result obtained was all the more remarkable as the top end of the coil was not connected to a wire or plate for magnifying the effect.

"WIRELESS" TELEGRAPHY—THE SECRET OF TUNING—ERRORS IN THE HERTZIAN INVESTIGATIONS—A RECEIVER OF WONDERFUL SENSITIVENESS.

As the first valuable result of my experiments in this latter line a system of telegraphy without wires resulted, which I described in two

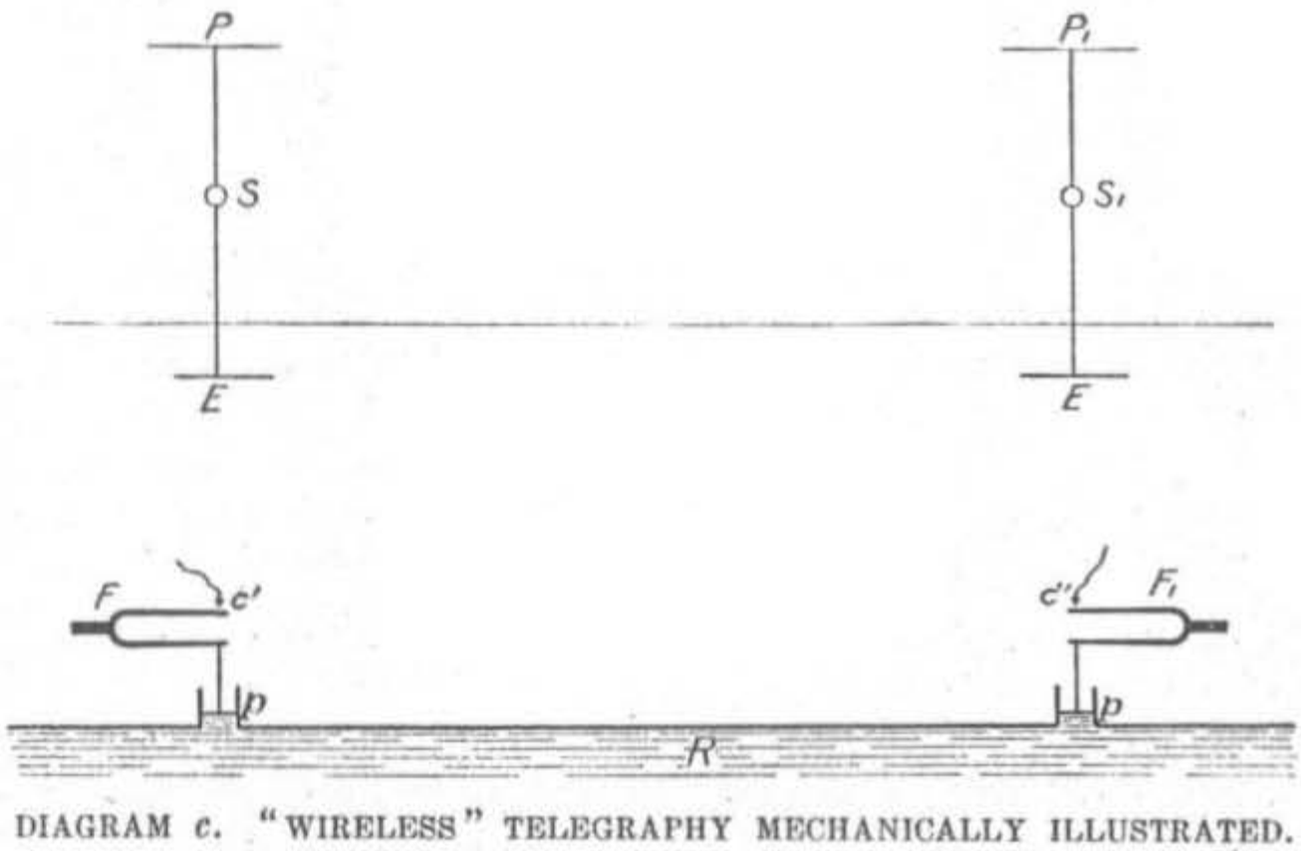


DIAGRAM *c*. "WIRELESS" TELEGRAPHY MECHANICALLY ILLUSTRATED.

scientific lectures in February and March, 1893. It is mechanically illustrated in diagram *c*, the upper part of which shows the electrical arrangement as I described it then, while the lower part illustrates its mechanical analogue. The system is extremely simple in principle. Imagine two tuning-forks *F*, F_1, one at the sending- and the other at the receiving-station respectively, each having attached to its lower prong a minute piston *p*, fitting in a cylinder. Both the cylinders communicate with a large reservoir *R*, with elastic walls, which is supposed to be closed and filled with a light and incompressible fluid. By striking repeatedly one of the prongs of the tuning-fork *F*, the small piston *p* below would be vibrated, and its vibrations, transmitted through the fluid, would reach the distant fork F_1, which is "tuned" to the fork *F*, or, stated otherwise, of exactly the same note as the latter. The fork F_1 would now be set vibrating, and its vibration would be intensified by the continued action of the distant fork *F* until its upper prong, swinging far out, would make an electrical connection with a stationary contact *c''*, starting in this manner some electrical or other appliances which may be used for recording the signals. In this simple way messages could be exchanged between the two stations, a similar contact *c'* being provided for this purpose, close to the upper prong of the fork *F*, so that the apparatus at each station could be employed in turn as receiver and transmitter.

The electrical system illustrated in the upper figure of diagram *c* is exactly the same in principle, the two wires or circuits *ESP* and $E_1S_1P_1$, which extend vertically to a height, representing the two tuning-forks with the pistons attached to them. These circuits are connected with the ground by plates *E*, E_1, and to two elevated metal sheets *P*, P_1, which store electricity and thus magnify considerably the effect. The closed reservoir *R*, with elastic walls, is in this case replaced by the earth, and the fluid by electricity. Both of these circuits are "tuned" and operate just like the two tuning-forks. Instead of striking the fork *F* at the sending-station, electrical oscillations are produced in the vertical sending- or transmitting-wire *ESP*, as by the action of a source *S*, included in this wire, which spread through the ground and reach the distant vertical receiving-wire $E_1S_1P_1$, exciting corresponding electrical oscillations in the same. In the latter wire or circuit is included a sensitive device or receiver S_1, which is thus set in action and made to operate a relay or other appliance. Each station is, of course, provided both with a source of electrical oscillations *S* and a sensitive receiver S_1, and a simple provision is made for using each of the two wires alternately to send and to receive the messages.

The exact attunement of the two circuits secures great advantages, and, in fact, it is essential in the practical use of the system. In this respect many popular errors exist, and, as a rule, in the technical reports on this subject circuits and appliances are described as affording these advantages when from their very nature it is evident that this is impossible. In order to attain the best results it is essential that the length of each wire or circuit, from the ground connection to the top, should be equal to one quarter of the wave-length of the electrical vibration in the wire, or else equal to that length multiplied by an odd number. Without the observation of this rule it is virtually impossible to prevent the interference and insure the privacy of messages. Therein lies the secret of tuning. To obtain the most satisfactory results it is, however, necessary to resort to electrical vibrations of low pitch. The Hertzian spark apparatus, used generally by experimenters, which produces oscillations of a very high rate, permits no effective tuning, and slight disturbances are sufficient to render an exchange of messages impracticable. But scientifically designed, efficient appliances allow nearly perfect adjustment. An experiment performed with the improved apparatus repeatedly referred to, and intended to convey an idea of this feature, is

illustrated in Fig. 5 (p. 187), which is sufficiently explained by its note.

Since I described these simple principles of telegraphy without wires I have had frequent occasion to note that the identical features and elements have been used, in the evident belief that the signals are being transmitted to considerable distances by "Hertzian" radiations. This is only one of many misapprehensions to which the investigations of the lamented physicist have given rise. About thirty-three years ago Maxwell, following up a suggestive experiment made by Faraday in 1845, evolved an ideally simple theory which intimately connected light, radiant heat, and electrical phenomena, interpreting them as being all due to vibrations of a hypothetical fluid of inconceivable tenuity, called the ether. No experimental verification was arrived at until Hertz, at the suggestion of Helmholtz, undertook a series of experiments to this effect. Hertz proceeded with extraordinary ingenuity and insight, but devoted little energy to the perfection of his old-fashioned apparatus. The consequence was that he failed to observe the important function which the air played in his experiments, and which I subsequently discovered. Repeating his experiments and reaching different results, I ventured to point out this oversight. The strength of the proofs brought forward by Hertz in support of Maxwell's theory resided in the correct estimate of the rates of vibration of the circuits he used. But I ascertained that he could not have obtained the rates he thought he was getting. The vibrations with identical apparatus he employed are, as a rule, much slower, this being due to the presence of air, which produces a dampening effect upon a rapidly vibrating electric circuit of high pressure, as a fluid does upon a vibrating tuning-fork. I have, however, discovered since that time other causes of error, and I have long ago ceased to look upon his results as being an experimental verification of the poetical conceptions of Maxwell. The work of the great German physicist has acted as an immense stimulus to contemporary electrical research, but it has likewise, in a measure, by its fascination, paralyzed the scientific mind, and thus hampered independent inquiry. Every new phenomenon which was discovered was made to fit the theory, and so very often the truth has been unconsciously distorted.

When I advanced this system of telegraphy, my mind was dominated by the idea of effecting communication to any distance through the earth or environing medium, the practical consummation of which I considered of transcendent importance, chiefly on account of the moral effect which it could not fail to produce universally. As the first effort to this end I proposed, at that time, to employ relay-stations with tuned circuits, in the hope of making thus practicable signaling over vast distances, even with apparatus of very moderate power then at my command. I was confident, however, that with properly designed machinery signals could be transmitted to any point of the globe, no matter what the distance, without the necessity of using such intermediate stations. I gained this conviction through the discovery of a singular electrical phenomenon, which I described early in 1892, in lectures delivered before some scientific societies abroad, and which I have called a "rotating brush." This is a bundle of light which is formed, under certain conditions, in a vacuum-bulb, and which is of a sensitiveness to magnetic and electric influences bordering, so to speak, on the supernatural. This light-bundle is rapidly rotated by the earth's magnetism as many as twenty thousand times per second, the rotation in these parts being opposite to what it would be in the southern hemisphere, while in the region of the magnetic equator it should not rotate at all. In its most sensitive state, which is difficult to attain, it is responsive to electric or magnetic influences to an incredible degree. The mere stiffening of the muscles of the arm and consequent slight electrical change in the body of an observer standing at some distance from it, will perceptibly affect it. When in this highly sensitive state it is capable of indicating the slightest magnetic and electric changes taking place in the earth. The observation of this wonderful phenomenon impressed me strongly that communication at any distance could be easily effected by its means, provided that apparatus could be perfected capable of producing an electric or magnetic change of state, however small, in the terrestrial globe or environing medium.

DEVELOPMENT OF A NEW PRINCIPLE—THE ELECTRICAL OSCILLATOR—PRODUCTION OF IMMENSE ELECTRICAL MOVEMENTS—THE EARTH RESPONDS TO MAN—INTERPLANETARY COMMUNICATION NOW PROBABLE.

I RESOLVED to concentrate my efforts upon this venturesome task, though it involved

great sacrifice, for the difficulties to be mastered were such that I could hope to consummate it only after years of labor. It meant delay of other work to which I would have preferred to devote myself, but I gained the conviction that my energies could not be more usefully employed; for I recognized that an efficient apparatus for the production of powerful electrical oscillations, as was needed for that specific purpose, was the key to the solution of other most important electrical and, in fact, human problems. Not only was communication, to any distance, without wires possible by its means, but, likewise, the transmission of energy in great amounts, the burning of the atmospheric nitrogen, the production of an efficient illuminant, and many other results of inestimable scientific and industrial value. Finally, however, I had the satisfaction of accomplishing the task undertaken by the use of a new principle, the virtue of which is based on the marvelous properties of the electrical condenser. One of these is that it can discharge or explode its stored energy in an inconceivably short time. Owing to this it is unequaled in explosive violence. The explosion of dynamite is only the breath of a consumptive compared with its discharge. It is the means of producing the strongest current, the highest electrical pressure, the greatest commotion in the medium. Another of its properties, equally valuable, is that its discharge may vibrate at any rate desired up to many millions per second.

I had arrived at the limit of rates obtainable in other ways when the happy idea presented itself to me to resort to the condenser. I arranged such an instrument so as to be charged and discharged alternately in rapid succession through a coil with a few turns of stout wire, forming the primary of a transformer or induction-coil. Each time the condenser was discharged the current would quiver in the primary wire and induce corresponding oscillations in the secondary. Thus a transformer or induction-coil on new principles was evolved, which I have called "the electrical oscillator," partaking of those unique qualities which characterize the condenser, and enabling results to be attained impossible by other means. Electrical effects of any desired character and of intensities undreamed of before are now easily producible by perfected apparatus of this kind, to which frequent reference has been made, and the essential parts of which are shown in Fig. 6 (p. 188). For certain purposes a strong inductive effect is required; for others the greatest possible suddenness; for others again, an exceptionally high rate of vibration or extreme pressure; while for certain other objects immense electrical movements are necessary. The photographs in Figs. 7, 8, 9, and 10, of experiments performed with such an oscillator, may serve to illustrate some of these features and convey an idea of the magnitude of the effects actually produced. The completeness of the titles of the figures referred to makes a further description of them unnecessary.

However extraordinary the results shown may appear, they are but trifling compared with those which are attainable by apparatus designed on these same principles. I have produced electrical discharges the actual path of which, from end to end, was probably more than one hundred feet long; but it would not be difficult to reach lengths one hundred times as great. I have produced electrical movements occurring at the rate of approximately one hundred thousand horse-power, but rates of one, five, or ten million horse-power are easily practicable. In these experiments effects were developed incomparably greater than any ever produced by human agencies, and yet these results are but an embryo of what is to be.

That communication without wires to any point of the globe is practicable with such apparatus would need no demonstration, but through a discovery which I made I obtained absolute certitude. Popularly explained, it is exactly this: When we raise the voice and hear an echo in reply, we know that the sound of the voice must have reached a distant wall, or boundary, and must have been reflected from the same. Exactly as the sound, so an electrical wave is reflected, and the same evidence which is afforded by an echo is offered by an electrical phenomenon known as a "stationary" wave—that is, a wave with fixed nodal and ventral regions. Instead of sending sound-vibrations toward a distant wall, I have sent electrical vibrations toward the remote boundaries of the earth, and instead of the wall the earth has replied. In place of an echo I have obtained a stationary electrical wave, a wave reflected from afar.

Stationary waves in the earth mean something more than mere telegraphy without wires to any distance. They will enable us to attain many important specific results impossible otherwise. For instance, by their use we may produce at will, from a sending-station, an electrical effect in any particular

region of the globe; we may determine the relative position or course of a moving object, such as a vessel at sea, the distance traversed by the same, or its speed; or we may send over the earth a wave of electricity traveling at any rate we desire, from the pace of a turtle up to lightning speed.

With these developments we have every reason to anticipate that in a time not very distant most telegraphic messages across the oceans will be transmitted without cables. For short distances we need a "wireless" telephone, which requires no expert operators. The greater the spaces to be bridged, the more rational becomes communication without wires. The cable is not only an easily damaged and costly instrument, but it limits us in the speed of transmission by reason of a certain electrical property inseparable from its construction. A properly designed plant for effecting communication without wires ought to have many times the working capacity of a cable, while it will involve incomparably less expense. Not a long time will pass, I believe, before communication by cable will become obsolete, for not only will signaling by this new method be quicker and cheaper, but also much safer. By using some new means for isolating the messages which I have contrived, an almost perfect privacy can be secured.

I have observed the above effects so far only up to a limited distance of about six hundred miles, but inasmuch as there is virtually no limit to the power of the vibrations producible with such an oscillator, I feel quite confident of the success of such a plant for effecting transoceanic communication. Nor is this all. My measurements and calculations have shown that it is perfectly practicable to produce on our globe, by the use of these principles, an electrical movement of such magnitude that, without the slightest doubt, its effect will be perceptible on some of our nearer planets, as Venus and Mars. Thus from mere possibility interplanetary communication has entered the stage of probability. In fact, that we can produce a distinct effect on one of these planets in this novel manner, namely, by disturbing the electrical condition of the earth, is beyond any doubt. This way of effecting such communication is, however, essentially different from all others which have so far been proposed by scientific men. In all the previous instances only a minute fraction of the total energy reaching the planet—as much as it would be possible to concentrate in a reflector—could be utilized by the supposed observer in his instrument. But by the means I have developed he would be enabled to concentrate the larger portion of the entire energy transmitted to the planet in his instrument, and the chances of affecting the latter are thereby increased many millionfold.

Besides machinery for producing vibrations of the required power, we must have delicate means capable of revealing the effects of feeble influences exerted upon the earth. For such purposes, too, I have perfected new methods. By their use we shall likewise be able, among other things, to detect at considerable distance the presence of an iceberg or other object at sea. By their use, also, I have discovered some terrestrial phenomena still unexplained. That we can send a message to a planet is certain, that we can get an answer is probable: man is not the only being in the Infinite gifted with a mind.

TRANSMISSION OF ELECTRICAL ENERGY TO ANY DISTANCE WITHOUT WIRES—NOW PRACTICABLE—THE BEST MEANS OF INCREASING THE FORCE ACCELERATING THE HUMAN MASS.

THE most valuable observation made in the course of these investigations was the extraordinary behavior of the atmosphere toward electric impulses of excessive electromotive force. The experiments showed that the air at the ordinary pressure became distinctly conducting, and this opened up the wonderful prospect of transmitting large amounts of electrical energy for industrial purposes to great distances without wires, a possibility which, up to that time, was thought of only as a scientific dream. Further investigation revealed the important fact that the conductivity imparted to the air by these electrical impulses of many millions of volts increased very rapidly with the degree of rarefaction, so that air strata at very moderate altitudes, which are easily accessible, offer, to all experimental evidence, a perfect conducting path, better than a copper wire, for currents of this character.

Thus the discovery of these new properties of the atmosphere not only opened up the possibility of transmitting, without wires, energy in large amounts, but, what was still more significant, it afforded the certitude that energy could be transmitted in this manner economically. In this new system it matters little—in fact, almost

nothing—whether the transmission is effected at a distance of a few miles or of a few thousand miles.

While I have not, as yet, actually effected a transmission of a considerable amount of energy, such as would be of industrial importance, to a great distance by this new method, I have operated several model plants under exactly the same conditions which will exist in a large plant of this kind, and the practicability of the system is thoroughly demonstrated. The experiments have shown conclusively that, with two terminals maintained at an elevation of not more than thirty thousand to thirty-five thousand feet above sea-level, and with an electrical pressure of fifteen to twenty million volts, the energy of thousands of horse-power can be transmitted over distances which may be hundreds and, if necessary, thousands of miles. I am hopeful, however, that I may be able to reduce very considerably the elevation of the terminals now required, and with this object I am following up an idea which promises such a realization. There is, of course, a popular prejudice against using an electrical pressure of millions of volts, which may cause sparks to fly at distances of hundreds of feet, but, paradoxical as it may seem, the system, as I have described it in a technical publication, offers greater personal safety than most of the ordinary distribution circuits now used in the cities. This is, in a measure, borne out by the fact that, although I have carried on such experiments for a number of years, no injury has been sustained either by me or any of my assistants.

But to enable a practical introduction of the system, a number of essential requirements are still to be fulfilled. It is not enough to develop appliances by means of which such a transmission can be effected. The machinery must be such as to allow the transformation and transmission of electrical energy under highly economical and practical conditions. Furthermore, an inducement must be offered to those who are engaged in the industrial exploitation of natural sources of power, as waterfalls, by guaranteeing greater returns on the capital invested than they can secure by local development of the property.

From that moment when it was observed that, contrary to the established opinion, low and easily accessible strata of the atmosphere are capable of conducting electricity, the transmission of electrical energy without wires has become a rational task of the engineer, and one surpassing all others in importance. Its practical consummation would mean that energy would be available for the uses of man at any point of the globe, not in small amounts such as might be derived from the ambient medium by suitable machinery, but in quantities virtually unlimited, from waterfalls. Export of power would then become the chief source of income for many happily situated countries, as the United States, Canada, Central and South America, Switzerland, and Sweden. Men could settle down everywhere, fertilize and irrigate the soil with little effort, and convert barren deserts into gardens, and thus the entire globe could be transformed and made a fitter abode for mankind. It is highly probable that if there are intelligent beings on Mars they have long ago realized this very idea, which would explain the changes on its surface noted by astronomers. The atmosphere on that planet, being of considerably smaller density than that of the earth, would make the task much more easy.

It is probable that we shall soon have a self-acting heat-engine capable of deriving moderate amounts of energy from the ambient medium. There is also a possibility—though a small one—that we may obtain electrical energy direct from the sun. This might be the case if the Maxwellian theory is true, according to which electrical vibrations of all rates should emanate from the sun. I am still investigating this subject. Sir William Crookes has shown in his beautiful invention known as the "radiometer" that rays may produce by impact a mechanical effect, and this may lead to some important revelation as to the utilization of the sun's rays in novel ways. Other sources of energy may be opened up, and new methods of deriving energy from the sun discovered, but none of these or similar achievements would equal in importance the transmission of power to any distance through the medium. I can conceive of no technical advance which would tend to unite the various elements of humanity more effectively than this one, or of one which would more add to and more economize human energy. It would be the best means of increasing the force accelerating the human mass. The mere moral influence of such a radical departure would be incalculable. On the other hand, if at any point of the globe energy can be obtained in limited quantities from the ambient medium by means of a self-acting heat-engine or otherwise, the conditions will remain the same as before. Human performance will be increased, but men will remain strangers as they were.

I anticipate that many, unprepared for these results, which, through long familiarity, appear to me simple and obvious, will consider them still far from practical application. Such reserve, and even opposition, of some is as useful a quality and as necessary an element in human progress as the quick receptivity and enthusiasm of others. Thus, a mass which resists the force at first, once set in movement, adds to the energy. The scientific man does not aim at an immediate result. He does not expect that his advanced ideas will be readily taken up. His work is like that of the planter—for the future. His duty is to lay the foundation for those who are to come, and point the way. He lives and labors and hopes with the poet who says:

Schaff', das Tagwerk meiner Hände,
Hohes Glück, dass ich's vollende!
Lass, o lass mich nicht ermatten!
Nein, es sind nicht leere Träume:
Jetzt nur Stangen, diese Bäume
Geben einst noch Frucht und Schatten.[1]

[1] Daily work—my hands' employment,
To complete is pure enjoyment!
Let, oh, let me never falter!
No! there is no empty dreaming:
Lo! these trees, but bare poles seeming,
Yet will yield both fruit and shelter!
Goethe's "Hope,"
Translated by William Gibson, Com. U. S. N.

Mr. Tesla's Announcements.

IT is well known that for many years Mr. Tesla has been addressing himself to the largest problems connected with the increase of human energy by electrical means, and in the eyes of the great number of eager investigators in the general field of electricity this fact will give piquancy to the important narrative of his work which he contributes to the present number of THE CENTURY. Happily, the paper is addressed also to the comprehension of the untechnical reader, who will find some of the ideas and results there set forth little short of the incredible. In general, much that must seem speculative to the layman can take its proper place only in the purview of the scientist, who knows what a part the imagination has played both as a forerunner and as a stimulus of discovery. In Sir Isaac Newton's day no doubt there were wiseacres who would have considered that eminent "dreamer" much more worthy of their respect if the fall of the historic apple had suggested to him not a mere trifle like the law of gravita-

tion, but some new and important device in cider-mills. The dullest observer is not likely to blink the practical bearings of Mr. Tesla's paper on manufactures, mining, invention, agriculture, commerce, transportation, war—in short, on modern life itself.

For the general reader, Mr. Tesla does what he confesses the author of "The Intellectual Development of Europe" did for him—namely, presents a new and never-to-be-forgotten conception of humanity moving as a mass. To follow his vivid introduction is like looking down from a great height and seeing familiar and new regions in their true relationship. It begets the feeling of being a spectator at the progress of the world, of listening to the grandest of symphonies. It awakens in one a new interest in his fellow-men and a sobering and devout sense of his relation to the universe, helping him to realize the poet's vision:

> One God, one law, one element,
> And one far-off divine event,
> To which the whole creation moves.

Human Energy Increased.—Once again we hear of remarkable inventions and aspirations from Mr. Nikola Tesla. This time the problem which occupies his attention is that of increasing human energy, and his views are published in the *Century Magazine*. He gives three ways in which his problem may be solved—namely, "to increase the human mass," "to reduce the retarding force," and "to increase the impelling force." The first is accomplished by attention to hygiene and good food. Ignorance and stupidity form a retarding force that people are continually endeavouring to improve out of existence, but there are other retarding forces, the greatest being warfare, and to overcome some of these the writer invented the telautomaton, "a machine having all its bodily or translatory movements and the operations of the interior mechanism controlled from a distance without wires." The possibilities of this machine are amazing, "and the continuous development in this direction must ultimately make war a mere contest of machines without men and without loss of life." The third problem—"how to increase the force accelerating the human mass"—is to be solved by the application of the power of the sun. Wireless telephony and wireless electrical power transmission are also among the castles which Mr. Tesla has built in the air.

SCIENTIFIC

Mr. Tesla's Experiments

The Problem of Increasing Human Energy is the title of an article in the June *Century,* by Nicola Tesla, the inventor. Mr. Tesla gives us glimpses of many of his recent experiments, having in view the increase of human energy, but a very small part of the article is intelligible to the lay reader, and it is, furthermore, largely speculative. Below we quote a part of the article describing the discovery of some new properties of the atmosphere and interesting experiments made by Mr. Tesla in connection therewith:

I was led to recognize the transmission of electrical energy to any distance through the media as by far the best solution of the great problem of harnessing the sun's energy for the uses of man. For a long time I was convinced that such a transmission on an industrial scale could never be realized, but a discovery which I made changed my view. I observed that under certain conditions the atmosphere, which is normally a high insulator, assumes conducting properties, and so becomes capable of conveying any amount of electrical energy. But the difficulties in the way of a practical utilization of this discovery for the purpose of transmitting electrical energy without wires were seemingly insuperable. The work required patience and constant application, but the improvements came, though slowly. Other valuable results were, however, arrived at in the course of this long-continued work, of which I shall endeavor to give a brief account, enumerating the chief advances as they were successively effected.

The discovery of the conducting properties of the air, though unexpected, was only a natural result of experiments in a special field which I had carried on for some years before. It was, I believe, during 1889 that certain possibilities offered by extremely rapid electrical oscillations determined me to design a number of special machines adapted for their investigation. One of the earliest observations I made with these new machines was that electrical oscillations of an extremely high rate act in an extraordinary manner upon the human organism. Thus, for instance, I demonstrated that powerful electrical discharges of several hundred thousand volts, which at that time were considered absolutely deadly, could be passed through the body without inconvenience or hurtful consequences. I still remember with pleasure how, nine years ago, I passed the discharge of a powerful induction-coil through my body to demonstrate before a scientific society the comparative harmlessness of very rapidly vibrating electric currents, and I can still recall the astonishment of my audience. I would now undertake, with much less apprehension than I had in that experiment, to transmit through my body with such currents the entire electrical energy of the dynamos now working at Niagara—forty or fifty thousand horse-power. I have produced electrical oscillations which were of such intensity that when circulating through my arms and chest they have melted wires which joined my hands, and still I felt no inconvenience.

Another observation was that by means of such oscillations light could be produced in a novel and more economical manner, which promised to lead to an ideal system of electric illumination by vacuum-tubes, dispensing with the necessity of renewal of lamps or incandescent filaments, and possibly also with the use of wires in the interior of buildings. The efficiency of this light increases in proportion to the rate of the

oscillations, and its commercial success is, therefore, dependent on the economical production of electrical vibrations of transcending rates. In this direction I have met with gratifying success of late, and the practical introduction of this new system of illumination is not far off.

The investigations led to many other valuable observations and results, one of the more important of which was the demonstration of the practicability of supplying electrical energy through one wire without return. At first I was able to transmit in this novel manner only very small amounts of electrical energy, but in this line also my efforts have been rewarded with similar success. To what a degree the appliances have been perfected since my first demonstrations early in 1891 before a scientific society, when my apparatus was barely capable of lighting one lamp (which result was considered wonderful), will appear when I state that I have now no difficulty in lighting in this manner four or five hundred lamps, and could light many more. In fact, there is no limit to the amount of energy which may in this way be supplied to operate any kind of electrical device.

After demonstrating the practicability of this method of transmission, the thought naturally occurred to me to use the earth as a conductor, thus dispensing with all wires. Whatever electricity may be, it is a fact that it behaves like an incompressible fluid, and the earth may be looked upon as an immense reservoir of electricity, which, I thought, could be disturbed effectively by a properly designed electrical machine. Accordingly, my next efforts were directed toward perfecting a special apparatus which would be highly effective in creating a disturbance of electricity in the earth. The progress in this new direction was necessarily very slow and the work discouraging, until I finally succeeded in perfecting a novel kind of transformer or induction-coil, particularly suited for this special purpose. It is practicable, in this manner, not only to transmit minute amounts of electrical energy for operating delicate electrical devices, as I contemplated at first, but also electrical energy in appreciable quantities.



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NOTES.

THE sensational announcements in the American press with regard to Mr. NIKOLA TESLA'S wonderful doings and still more wonderful prophecies, have been attributed in a large measure to the highly developed power of imaginative embroidery possessed by some Western newspaper reporters. An article by Mr. TESLA himself, in the current number of the *Century Magazine*, shows that an injustice has been done to that class of individuals, for this contribution equals in wild speculation anything hitherto attributed to the eminent inventor. The article is headed "The Problem of Increasing Human Energy, with Special Reference to the Harnessing of the Sun's Energy." The writer begins by postulating that human life is a movement. The existence of a body in motion unavoidably implies a force which is moving it. Consequently Mr. TESLA chooses to consider human energy as denotable by the expression $MV^2/2$, and proceeds to consider how it may be increased. M he takes as the "total mass of man in the ordinary interpretation of the term 'mass,'" and V is "a certain hypothetical velocity." He warns his readers against reducing their mass by intemperance, impure drinking water, or laxity of morals—digressing on the subject of food supply, and the production of artificial

fertilisers by causing the nitrogen of the air to combine chemically with the oxygen in a high-pressure electric discharge.

ORGANISED warfare, Mr. TESLA thinks, is what tends mostly to the reduction of the hypothetical velocity V, and he proceeds to describe a means, he has not yet perfected, of rendering warfare less harmful in this direction. This simple means is the substitution of "telautomatics" for men. So far he has only succeeded in constructing one such apparatus—a boat controlled by electrical oscillations—with a "borrowed mind"; but, he says "I purpose to show that, however impossible it may now seem, an automaton may be contrived which will have its 'own mind' and . . . be capable of distinguishing between what it ought to do and what it ought not to do. . . . . In fact, I have already conceived such a plan." On the other hand, to deal fully with the methods of increasing the force "accelerating the human mass" would lead Mr. TESLA too far. "Suffice it to state that the resultant of all these forces is always in the direction of reason. . ." A "telautomatic" is then presumably not one of the components.

LACK of space precludes us also from dealing more fully with Mr. TESLA'S dreams—or are they nightmares?—with their bright pictures of high-pressure phenomena. We can only mention briefly some of his schemes for the advantage of mankind. He intends to smelt iron by first electrolysing water, burning the hydrogen in air to produce the heat for smelting, and selling the pure oxygen as a by-product. He suggests other methods than windmills of obtaining energy from "the ambient medium," some of which he no longer considers likely to be commercially profitable, and others with regard to which he is more hopeful. He next deals with the transmission of energy through space without wires. The proposal to transmit electricity at high pressure through the upper strata of the atmosphere we have alluded to on a former occasion, but the following bears repetition. Mr. TESLA has discovered causes of error in HERTZ'S researches, with the result that he has "long ago ceased to look upon his [HERTZ'S] results as being an experimental verification of the poetical conceptions of MAXWELL."

TESLA ON ENERGY.

By T. H. MURAS.

IN the *Century Magazine* for June there appears an article of 36 pages by Nikola Tesla on "The Problem of Increasing Human Energy, with Special Reference to the Harnessing of the Sun's Energy." Human energy here means the total power available to humanity. Increase of it is to be obtained in the first place by adding to and improving the condition of humanity, and for this purpose the author emphasises the necessity of increasing the productivity of the soil. He states: "the key for the solution of the all-important food problem" to be the cheap production of compounds of nitrogen to replace that withdrawn from the soil by crops, and proposes to produce such compounds by the use of electric discharges of high frequency in air, and, in fact, to develop Cavendish's experiment on the production of nitric acid into a manufacture. The necessary electrical energy is to be obtained from waterfalls. In this proposal the author appears to suffer from the incomplete knowledge with which a scientific man is sometimes unconsciously afflicted when he looks over the paling surrounding the little scientific plot that he has laboriously cultivated. Mr. Tesla does not mention, and apparently is unaware of the fact, that any necessary amount of nitrogen can be "fixed" in the soil by the prosaic agricultural method of growing leguminous plants, such as clover, as one of the crops in a rotation, these co-operating with special bacteria, which fix and supply nitrogen to their roots by means of energy derived in carbon compounds from the plants. In this practically simple process the energy used is obtained by the plant directly from the sun's radiation, and to anyone whose vision is not absolutely bounded by the walls of a laboratory, the proposed production of nitrogen compounds by the waterfall and electric method must appear a very crude substitute. It is true that agricultural methods are inefficient in various ways, and especially as regards the proportion of the sun's available power utilised; but this appears comparatively unimportant, in view of the almost unlimited supply of such power. It would appear to a commonplace individual that patient work in the scientific study of such bacteria and crops, with a view to their more efficient working, with the help of artificial selection or otherwise, is a far more promising "key for the solution of the all-important food problem" than any new method at present in prospect for obtaining human energy from the sun's radiation or otherwise.

In the second place, Tesla proposes to substitute mechanical automata, more or less controlled by high frequency electromagnetic radiations, for human beings in warfare. Judging from recent events, the supply of "human energy" for this purpose does not appear to be limited, in this country at any rate; the real demand appears to be for an outlet for existing energy, and warfare in South Africa is preferred to office work in England.

The remainder of the article contains a number of suggestions as to obtaining energy for mechanical and chemical purposes directly from sunlight, and from the heat of the earth and atmosphere; and its transmission by high frequency electric currents through the upper part of the atmosphere. The article does not contain one exact measurement or statement of an attained result, but it is accompanied by photographs of remarkable electric discharges, extending to 100 feet long, in the air. These are apparently obtained by high frequency currents in large inductive circuits, tuned by means of condensers to rates from 50,000 to 130,000 ~ per second, the pressure obtained being about 12 million volts! No indication is given as to how these figures are arrived at, but Mr. Tesla is obviously not a believer in the hypothesis (based on experiments) that a pressure much exceeding 100,000 volts cannot exist between any two conductors at any distance apart in air, on account of discharge occurring in brush or "spark" form. Electricians, and probably other people, would have been grateful if a few pages of the article had been devoted to a precise account of these electrical experiments, especially as his experiments have caused Mr. Tesla to state, relative to the work of Hertz, "I have long since ceased to look upon his results as being an experimental verification of the poetical conceptions of Maxwell." As it is, the article is mainly of interest on account of the pretty and somewhat startling photographs.

DIRECT APPLICATION OF ELECTRICITY TO THE PROPULSION OF SHIPS.

A Reply to Certain of the Statements Made by Nikola Tesla in the June, 1900, Issue of "The Century Magazine."

BY WILLIAM F. DURAND.

In the June number of *The Century Magazine* is found an article from the pen of Mr. Nikola Tesla, in which the author discusses in a decidedly transcendental manner the problem of "increasing human energy." It would not be difficult to join issue with Mr. Tesla regarding some of the fundamental assumptions made, as for example, that *mechanical energy,* expressible by formula $MV^2 \div 2$, or in terms of mass and velocity as we know them, can fully represent the quality of the operations of the human mind. This is simply begging a question regarding which we are profoundly ignorant, a question regarding which we have no sure facts, and therefore in regard to which it is in the last degree unscientific to make the assumptions implied by the author.

The chief interest lies, however, with the transcendental and hypothetical conclusions drawn from these assumptions, and among them are found two or three relative to the application of electricity to marine propulsion. These conclusions are utterly incorrect and in direct antagonism with the laws of nature, and taking into account the standing in literary circles usually accredited to *The Century Magazine* and the popular reputation as an electrician usually accredited to the author, it would seem proper to point out the nature of these errors, lest by those not technically qualified to judge, such absurdities might be considered as having some foundation in fact.

On page 198 are found the following statements:

> Instead of driving the machinery in a factory in the old wasteful way by belts and shafting, we generate electricity by steam power and operate electric motors. In this manner it is not uncommon to obtain two or three times as much effective motive power from the fuel, besides securing many other important advantages. It is in this field as much as in the transmission of energy to great distances that the alternating system, with its ideally simple machinery, is bringing about an industrial revolution. But in many lines this progress has not yet been felt. For example, steamers and trains are still being propelled by the direct application of steam power to shafts and axles. A much greater percentage of the heat-energy of the fuel could be transformed in motive energy by using, in place of the adopted marine engines and locomotives, dynamos driven by specially designed high-pressure steam or gas-engines, and by utilizing the electricity generated for propulsion. A gain of fifty to one hundred per cent in the effective energy derived from the coal could be secured in this manner. It is difficult to understand why a fact so plain and obvious is

> not receiving more attention from engineers. In ocean steamers such an improvement would be particularly desirable, as it would do away with noise and increase materially the speed and the carrying capacity of the liners.

It is more especially with respect to the latter part of the quotation that we are here concerned. The proposition in brief is to displace the usual type of marine engine by "specially designed high-pressure steam or gas engines," driving electric generators, the electrical energy thus developed being then carried to an electric motor attached to the propeller shaft. In other words, an electric generator and motor are to be interposed between the engine and the propeller-shaft. Now let us examine this proposition, regarding the likelihood of an increase of efficiency similar to that promised in the quotation given above.

In the first place not the slightest grain of superiority or improvement in efficiency due to the use of the "specially designed high-pressure steam or gas engine will be conceded. Any such motor which can be used to operate an electric generator can also be used to operate a propeller direct, and without the interposition of the generator and motor. Screw propellers are designed and operated at speeds of revolution from 100 per minute and less to 2,000 per minute and over, and as an instrument of propulsion it is as fully capable of utilizing any gain in the efficiency of the prime-mover as is an electric generator. In any event the use of a screw propeller is assumed, and it is evident that it will be an element of equal value in either scheme of powering and propulsion.

Further, as to the high pressure steam engine, where shall we find anything higher than the 300 to 400 lbs., which is accepted and involved in present day practice with torpedo boats, fast launches, yachts and cruisers? Again, with regard to engine efficiency, where in present practice shall we go to better the record of the S. S. *Kensington*, 8,000 I. H. P., with her service record of about 1.00 lb. of coal per I. H. P. for the main engines? Again, regarding gas engines on board ship, the weight which present practice seems to find necessary for their safe construction and efficient operation is entirely prohibitive of their use when the highest results are to be attained. Then as a practical problem how would a designer of gas engines like to undertake the design and guarantee performance of a gas engine of, say, 10,000 I. H. P.? Or if, otherwise, such total power were to be split up into a number of small units the whole scheme immediately breaks down by reason of its complexity and weight. Then there is the further question of the cost of gasoline or other hydrocarbon, and of the enormous increase of output which would be required in order to make possible its use on any large scale; or if the gas is to be made from coal, is each ship to carry gas works in the fore hold, or is the gas to be stored in the bunkers and double bottoms?

All these considerations of detail, however, are beside the main point, which, as already noted, is that no claim of superiority whatever can be admitted for the use of any special type of prime-mover, since for utilizing the increased efficiency of any such improved steam or gas engine, the propeller is quite as capable as the electric generator.

The question simplifies therefore to the following: Given two steam engines or other prime-movers of equal efficiency, to compare the two schemes for ship propulsion in one of which the prime-mover is attached directly to the propeller shaft; and in the other, of which there is interposed between the two an electric generator and motor. If the gain of from 50 to 100 per cent promised by Mr. Tesla is to be realized at all, it must therefore come in as a result of these additional transformations of energy. Now, one of the first things which the engineer learns in his dealings with energy is that all transformations are sources of loss. This is a fact so simple and so fundamental that it cannot be overlooked, least of all by one who has given his life to the study of problems involving the transformation and use of energy in various forms. Yet here we find a proposition to interpose between the steam engine and the propeller two transformations or changes of energy, one from the mechanical form in the engine to the electrical form in the generator, and the other a change back to the mechanical form in the motor. There will also be a further loss due to transmission from the generator to the motor, but on board ship this will be very small and may be neglected. Taking as a basis of estimate the actual achievements of electrical engineering at the present day, the best combined efficiency which could be expected for this double transformation would be perhaps 90 per cent, though probably 85 per cent might be a safer estimate. In other words, of the energy supplied by the steam engine from 10 to 15 per cent would be lost as a result of the electrical transformations. So to take the more favorable case, for every 100 horse power delivered by the engine, 90 will reach the shaft instead of 100 as in the case of direct connection between engine and propeller. Yet to these transformations of energy which by the law of the conservation of energy must result in a loss, we are to look, if anywhere, for a gain of from 50 to 100 per cent, so that in the preceding case instead of 90 delivered horse power or thereabouts, as would actually be the case, we are to look for from 150 to 200. This would mean simply the creation of energy, and is a dream of perpetual motion in its baldest form. Such a proposition is a not unworthy fellow to those which have but recently been put before the public in connection with the liquid air absurdities.

Mr. Tesla knows, however, too well the doctrine of the conservation of energy to base any expectation of gain upon transformations which he knows must give rise to a loss, and it is therefore only fair to assume that his faith was pinned to the gain expected from the "specially designed high-pressure steam or gas engine," a gain which would reduce the cost of power in terms of fuel to one-half or two-thirds of the figures representing the best present practice. This especially designed engine would apparently also be of such peculiar type that while available for operating an electrical generator it could not be used for turning a screw-propeller. It may perhaps be in order to suggest that the design for such a prime-mover should be forthcoming in order to substantiate the claim, and until such an engine is produced all such claims for possible gain must be considered as without foundation, and instead of gain there is the certainty of loss. There may also have been some

expectation of gain by a shortening of the line shafting, or in greater uniformity of turning effort in the propeller. There is ground for expecting small gains due to these features, but so small as to be utterly inconsiderable and without practical influence on the main features of the problem. These points only merit mention in order that all sources of gain for the electrical scheme may be noted.

The author's naive curiosity as to why a method which promises so great a saving should have received so little attention from engineers is at the least amusing. Does he suppose that marine engineers are ignorant of the trend of advancement in the electrical field? Does he suppose that if there were any reasonable hope of increasing the efficiency by 50 to 100 per cent that it would not receive some attention from those most interested? If there were any likelihood of cutting the consumption of coal per day on a "liner" from, say, 400 tons to 200 or 275; that is a saving from 125 to 200 tons per day, and of increasing the cargo capacity by perhaps 1,000 tons for the trip, would those most interested long delay the adoption of such means? The truth seems to be that this so-called "fact," plain and obvious as it may seem to Mr. Tesla, is less plain and less obvious to those who are actually doing the world's work in the field of marine design and construction. If there is any one fact that is plain and obvious to them it is that a multiplication of changes of energy means a loss, and the proposition to interpose additional changes between the prime-mover and the propeller will be apt to receive from them small consideration so long as the laws of nature remain as they now are.

There is still another interesting side to this proposition, and that is, the price which must be paid for the apparatus; that is, for the generators and motors. The first point to be made is that the price is two-fold; one the price in terms of money, and the other the price in terms of weight.

If we confine ourselves to actual achievement in electrical engineering we shall hardly find builders of generators and motors ready to guarantee results for much less than 20 to 30 lb. per H. P., and these figures will require most careful design and might easily rise to 50 lb. and over. The installation of generators and motors will therefore mean the addition of, say, 50 lb. and upward per H. P. This would just about double the weight of machinery on a modern torpedo boat, for which in recent practice the engines and boilers together weigh 50 lb. or less per I. H. P. Let us compare the figures for a torpedo boat with 3,000 I. H. P.:

	STEAM EQUIPMENT.	STEAM AND ELECTRICAL EQUIPMENT.
Hull	56 tons	56 tons.
Coal, ordnance and stores	37 "	37 "
Machinery	67 "	134 "
Total	160	227

The displacement of the boat would thus be increased by about 67 tons, or from 160 to 227, while the power delivered to the propeller shaft would be decreased by, say, 300 H. P. The joint effect of these would be a reduction in the speed of the boat by about 3 knots, or from, say, 25 knots to 22. These results are hardly such as would be apt to commend themselves to naval designers.

Again, with a "liner" having, say, 25,000 I. H. P., the addition of electrical machinery of suitable type would result in adding perhaps 1,500,000 lb., or about 700 tons to the machinery weights. For the same total displacement this would mean the loss of about 700 tons of paying cargo, and a further loss of about 2,500 horse power as a result of the electrical transformations, decreasing the speed by from 1-2 to 3-4 knot. When we remember that on the modern "liner" the margin of weight left for paying cargo is quite small, usually not exceeding a maximum of 2,000 tons, it is apparent that the loss of 700 tons or more would result in a most serious reduction in the earning capacity of the vessel. The "increase" of carrying capacity referred to at the close of the quotation would be therefore of a character not likely to commend itself to the stockholders or board of directors.

The price to be paid in cash will depend on the current prices for electrical machinery of such types and sizes as may be required, but it will not be far wrong to say that the cost of the electrical equipment would be not less than that of the steam equipment, and that the cost of the total equipment would therefore be not less than double what it is with the present methods of powering and propulsion. The interest on this added first cost would make a most serious inroad upon the small margin of profit now obtainable from investments in this field of commerce.

A passing reference may also be made to the statements in the early part of the quotation relating to the substitution of electric generators and motors for lines of shafting and belting, whereby it is claimed that two or three times as much effective power may be obtained as by the old and wasteful methods. From what has preceded it is clear that the substitution of electric generators and motors for shafting and belting is a substitution of one form of loss for another, and the final balance will depend on which is the greater of the two. If the belting and shafting scheme is long and complicated and perhaps in poor mechanical condition as well, there will undoubtedly result a gain in efficiency for the electrical scheme. If it is short and direct and in good condition, the advantage will remain with the mechanical transmission. In no normal or ordinary case, however, will the gain amount to anything approaching 100 to 200 per cent. In fact, the question of fuel economy in such cases is only one of many considerations, and not always the most important. In cases where such installations have been made it is probable that other considerations have weighed quite as much as that of economy of fuel. Among such special advantages for the electrical scheme are the following: Independence of operation, entire freedom in locating machines without reference to lines of shafting, etc., absence of line shafting, countershafts, etc., and consequent greater freedom for the operation of cranes and handling gear.

not of a translatory character, yet the general laws of mechanical movement are applicable to it;" "That we can send a message to a planet is certain, that we can get an answer is probable;" "It is highly probable that if there are intelligent beings on Mars they have long ago realized this very idea [the transmission of electrical energy for industrial purposes without wires], *which would explain the changes on its surface noted by astronomers.*" (The italics are our own.)

Mr. Tesla's doctrine of human energy is in some ways as original as the inventions and discoveries which he expects to make. Each of us is, he says, a part of a unitary whole, 'man.' "This one human being lives on and on. . . . Therein . . . . is to be found the partial explanation of many of those marvelous phenomena of heredity which are the result of countless centuries of feeble but persistent influence." Now we may "assume that human energy is measured by half the product of man's mass with the square of a certain hypothetical velocity. . . . . the great problem of science is, and always will be, to increase the energy thus defined. . . . This mass is impelled in one direction by a force F, which is resisted by another partly frictional and partly negative force R, acting in a direction exactly opposite, and retarding the movement of the mass."

Unhappily Mr. Tesla in his enthusiasm to progress to recommendations of religion, vegetarianism, the old régime for women and the artificial preparation of nitrogen compounds, neglects to state which direction is the proper one for the human mass to follow, north, south, east, west, toward the moon or Sirius or to Dante's Satan in the centre of the earth. Nor does he explain how 'enlightenment' makes the mass of human bodies go in an exactly opposite direction to that toward which 'visionariness' impels them, nor reveal why, if his account be true, he and a 'visionary' can walk in the same direction. Of course the whole notion that the 'velocity' of the human 'mass,' *i.e.* the space it traverses in a given time, has any connection with human progress or is of any value to anybody or anything, is absurd.

Mr. Tesla has enjoyed considerable, excellent repute as a gifted student of certain electrical phenomena and one expects a good deal from his "electrical experiments, now first published." Mr. Tesla, too, expects a good deal from them. It would take too long to even note here all the important scientific discoveries which Mr. Tesla expects to make or all the benefits which he expects to thereby confer upon mankind in general and in particular upon those who exploit his inventions. Some samples may be given. War will be rendered harmless by being reduced to a sort of game between 'telautaumata,' machines which behave "just like a blind-folded person obeying instructions received through the ear," any one of which is "enabled to move and to perform all its operations with reason and intelligence."

Says Mr. Tesla: "I purpose to show that, however impossible it may now seem, an automaton may be contrived which will have its 'own mind,' and by this I mean that it will be able, independent of any operator, left entirely to itself, to perform, in response to external influences affecting its sensitive organs, a great variety of acts and operations as if it had intelligence. It will be able to follow a course laid out or to obey orders given far in advance; it will be capable of distinguishing between what it ought and what it ought not to do, and of making experiences or, otherwise stated, of recording impressions which will definitely affect its subsequent actions. In fact, I have already conceived such a plan."

Inasmuch as the interest in this telautomatic warfare is to be purely æsthetic, it would seem as if international bull-fights or kite-flying or spelling matches or potato-races might do as well, and have the added advantage of leaving Mr. Tesla's expectations free to wander among the following prospective discoveries.

New sources of energy, Mr. Tesla thinks, may be opened up, such as a wheel which shall perform work without any further effort on our part than that of constructing it. "Imagine a disc of some homogeneous material turned perfectly true and arranged to turn in frictionless bearings on a horizontal shaft above the ground. This disk, being under the above conditions perfectly balanced, would rest in any position. Now, it is possible that we may learn how to make such a disk rotate continuously and perform work by the force of gravity without any further effort on our part. . . . . To make the disk rotate by the force of gravity we have only to invent a screen against this force. By such a screen we could prevent this force from acting on one half of the disk, and the rotation of the latter would follow."

Into further particulars concerning the nature of such a screen Mr. Tesla does not enter, though it would seem a matter well fitted to engage his peculiar gifts. The 'screen against gravity' idea has already entered into a popular story, but scientific men have probably not given it much consideration.

By producing a 'sink' or reservoir of a low temperature, thereby inducing the heat of the ambient medium to transform itself in part into other forms of energy *(e.g.* electrical), Mr. Tesla hopes to "get any amount of energy without further effort" beyond the amount needed to create the 'sink.' We should thus employ "an ideal way of obtaining motor power," and incidentally rebuke the narrow-minded physics of Carnot and Lord Kelvin.

By means of his electrical oscillator Mr. Tesla has satisfied himself that he can transmit electrical energy in large quantities without wires. He expects that this can be done to great economic advantage. Then would come the golden age. "Men could settle down everywhere, fertilize and irrigate the soil

SCIENCE AND FICTION.

The leading article of the June number of the *Century Magazine* is entitled "The Problem of increasing Human Energy," and is written by Nikola Tesla. Mr. Tesla offers the reader some naive verbal analogies between the causes of human progress and the 'energy' of theoretical physics, and a eulogy of a number of inventions which he expects to make. He intersperses these with sundry remarkable statements such as, "our own earth will be a lump of ice;" "Though this movement is

with little effort, and convert barren deserts into gardens, and thus the entire globe could be transformed and made a fitter abode for mankind."

The golden age figures largely in Mr. Tesla's article; he offers us all that is entrancing and wonderful. He is generous. We ask for the bread of definite facts of science and intelligible evidence, but he gives us the amethyst and topaz and diamonds of an ambient medium doing all our work and the atmosphere transporting all our motive power and the tyrant gravity held powerless by a screen, and Mr. Tesla correcting Lord Kelvin's errors. Still amethyst and topaz and diamonds are only stones. They may dazzle the magazine reader, but they do not nourish the student of science.

The editorial department of the *Century Magazine* perhaps felt that these jewels were a bit too bright. We read there that "much that must seem speculative to the layman can take its proper place only in the purview of the scientist." Some conservative scientists will feel like growling, "And much that must seem bosh to the man of science can take its proper place only in the purview of the editorial departments of popular magazines." Leaving aside the present case, it is a fact that the same care which is exercised by editors to secure in their contributions excellence of style and syntax, a proper moral tone and freedom from advertisement of business ventures, is not exercised to secure accuracy in statements of fact or decent credibility in matters of theory. The editors apparently impute to their readers a desire to be entertained at all costs. They descend to a footing with the Sunday newspaper instead of trying to rise to the level of such scientific literature as Huxley or Tyndall gave us. They evidently often do not know science from rubbish and apparently seldom make any effort to find out the difference. They should at least submit their scientific literature to competent men for criticism and revision.

The general public is helpless before any supposedly scientific statement. It may judge vaguely by the standing of the paper or magazine or book containing it, by the name of the writer or by the general tone in which the article is written. But it cannot judge definitely by comparison with relevant facts or by critically examining the logic of the deductions, for the general public lacks both knowledge of the relevant facts and training in logical criticism. That a man should invent a microscope which will enable one to see objects a million times as small as can be seen with the naked eye seems no more questionable to the general public than that a man should cause unfertilized eggs to develop. Yet the first would be impossible while the second has been possible, probable, and still more lately proved. Guidance in scientific matters should be welcome if only for the protection thus given against fraudulent medicines, bogus inventions and nonsensical enterprises.

PHYSICIST.

Tesla and the Electric Propulsion of Ships.—In a recent number of the "Century Maganzine" an article by Mr. Nikola Tesla was printed, in which some statements were made that drew caustic comment from our contemporary, "Marine Engineering." In the July number of the latter magazine the editor refers to the article as the "handiwork of a cerebrose individual * * * a bombastical genius who has illumined unknown fields of imaginative science with his intellectual searchlight and is willing to permit the gaping world of ignorance or complaisance to peep in and wonder, the credulous editor drawing the curtain. This dazzling contribution to modern unscientific research," he continues, "reads like nothing so much as an essay on Christian Science, so profound is it in the ambiguous nothingness whereby it leads through the intricacies of incoherency into the climax of absolute asininity." The particular statements made by Mr. Tesla which most aroused the editor of "Marine Engineering" were:

"Steamers and trains are still being propelled by direct application of steam power to shafts and axles. A much greater percentage of the heat energy of the fuel could be transformed in motive energy by using in place of the adopted marine engines and locomotives, dynamos driven by specially-designed high-pressure steam engines or gas engines, and by utilizing the electricity generated for the propulsion. A gain of from 50 to 100 per cent in the effective energy derived from the coal could be secured in this manner. In ocean steamers such an improvement would be particularly desirable as it would do away with noise and increase materially the speed and carrying capacity of the liners."

In the same issue of "Marine Engineering" also appears an article by Prof. W. F. Durand commenting upon Mr. Tesla's reckless statement. Mr. Durand argues, and of course soundly, that any especially efficient prime mover which can be used to drive an electric generator can also be used to drive a propeller direct so that interposing a generator and motor between the prime mover and the propeller shaft would be a gratuitous waste of energy. Mr. Durand further points out that the addition of an electrical equipment in the case of a liner having 25,000 horse-power of driving machinery would result in a loss of about one-third of the freight-carrying capacity of the ship, besides the loss of about 2500 horse-power due to the two transformations of energy, entailing a reduction in speed from half to three-quarters of a knot. "The increase of carrying capacity referred to at the close of the quotation," says Mr. Durand, "would be, therefore, of a character not likely to commend itself to the stockholders or board of directors."

ELECTRICITY A CURE FOR TUBERCULOSIS

Wonderful Results Said To Have Been Effected by Means of Tesla's Oscillator.

TOLD OF THEIR CURES

Physician and Clergyman at Dr. Carroll's Clinic Declared Treatment Had Saved Them.

Current Thus Applied, It Is Said, Does Not Produce Death, Because Waves Are Synchronous with Life Force.

"Electrical oscillation" as a new treatment for tuberculosis, was demonstrated, and the immediate benefits derived from it by men in the last stages of the disease were testified to at an interesting clinic yesterday in the offices of Dr. Craft C. Carroll, No. 21 East Twenty-fourth street. Dr. Carroll declares that by the application of a new principle evolved by Nikola Tesla he can cure the worst cases of acute tuberculosis. Dr. E. P. Iliff, of Newark, a specialist in lung diseases, who, three weeks ago, was declared to be dying of consumption by his brother physicians, received his third treatment of "electrical oscillation" yesterday at the clinic, and then ran to catch a car on his way back to Newark. The Rev. S. W. Switzer, pastor of the Baptist Tabernacle, in Harrison, N. J., who had been sent to Dr. Carroll in the last stages of consumption, told of his remarkable cure. Dr. John B. Rich, president of the American Microscopical Society, declared that it was the most wonderful demonstration of positive beneficial results that he had ever seen in the treatment of germ diseases.

CHARGE WOULD KILL ORDINARILY.

Nikola Tesla had worked for two years on the apparatus which Dr. Carroll used yesterday in his first public clinic. It was Dr. Carroll's idea to apply the new principle in electricity evolved by Tesla to the treatment of consumption. Mr. Tesla had predicted that oscillation would accomplish wonders, but he had not thought of using it as a germ killer.

By applying the electrode of the Tesla machine, Dr. Carroll drives through the affected part a quantity of electricity, which if applied in any other way would cause instant death. With the Tesla "oscillator" he handles between two and three thousand volts of electricity with impunity. Dr. Carroll says that after the oscillation treatment all tubercular matter is eliminated from the system by the emunctories—the liver, kidneys, bowels and general glandular system. The treatment is one of destruction to the germs.

Dr. Iliff told how he had contracted tuberculosis from his patients about a year ago It had developed in the aorta, which is the artery leading from the heart to the pulmonary system. Stenosis of the aorta resulted. The tubercular matter had clogged the aorta about one inch from the entrance to the heart, so finally the heart could not pump blood to the extremities. A dropsical condition ensued. Dr. Iliff said that in forty-eight hours fo[illegible] weeks ago he increased in weight thirty pounds.

PHYSICIANS HAD GIVEN HIM UP.

"I was removed to Dr. Carroll's office in New York ten days ago," said Dr. Iliff. "My brother physicians protested against my being removed. They said there was not the slightest chance of recovery. They even predicted the hour I was to die. I took my third oscillation treatment to-day. I am now attending to my practice again in Newark and am on the speedy road to complete recovery."

The testimony given by the Rev. Mr. Switzer was almost as remarkable. He had contracted acute tuberculosis four years ago. When he was moved to Dr. Carroll's house the physicians of Newark and Harrison told him he had six weeks to live. He was back attending to his pastoral duties in less than three weeks, and declared yesterday that he had completely recovered.

Henry J. Rice, a patient who had been put under the electrical treatment for the first time on July 9, when he had a respiration of 36, yesterday, it was said, had the full use of his lungs. His respiration was 12. He had had tuberculosis of the lungs for five years. The lower third of the right and left lungs was hepatic. There had been a cavity at the left of the heart bone, so Dr. Carroll said, as large as a silver dollar.

Dr. Carroll says that the cavity has entirely disappeared, and is refilled with new lung tissue

LIFE FORCE ELECTRICAL FORCE.

Asked for an explanation of the treatment, Dr. Carroll said:—

"All life is a force manifestation in which electricity plays a part. Life force, spirit force and electrical force I believe to be one and the same force. Disease or unhealth is only a difference of potential that requires to be brought into a state of equilibrium in order to be brought into a state of health.

"The reason why this high oscillation does not take life is because the wave motions of the machine are in synchronous harmony with the life force in the body."

Dr. Carroll declined to allow the Tesla machine to be seen. All of the apparatus that was visible was the glass electrode, which was spon shaped and hollow. While the current was on there was an opalescent blaze or a series of big sparks in the electrode, which was applied directly to the part affected.

Dr. William F. Holcombe, of No. 78 Lexington avenue, who was present, was unwilling to give a definite opinion as to the treatment until he had attended other clinics.

"Most doctors frown on anything new, but I believe in investigation. It may be that Dr. Carroll has hit on a valuable discovery."

SOME NOVEL INVENTIONS OF NIKOLA TESLA.

BY J. WRIGHT.

Most members of the electrical profession associate the name of Nikola Tesla with high-frequency and high-potential currents, and few are acquainted with the fact that he has also invented several novelties for use in other branches of the profession. It is of some of these extraneous productions that I purpose treating in the course of this paper.

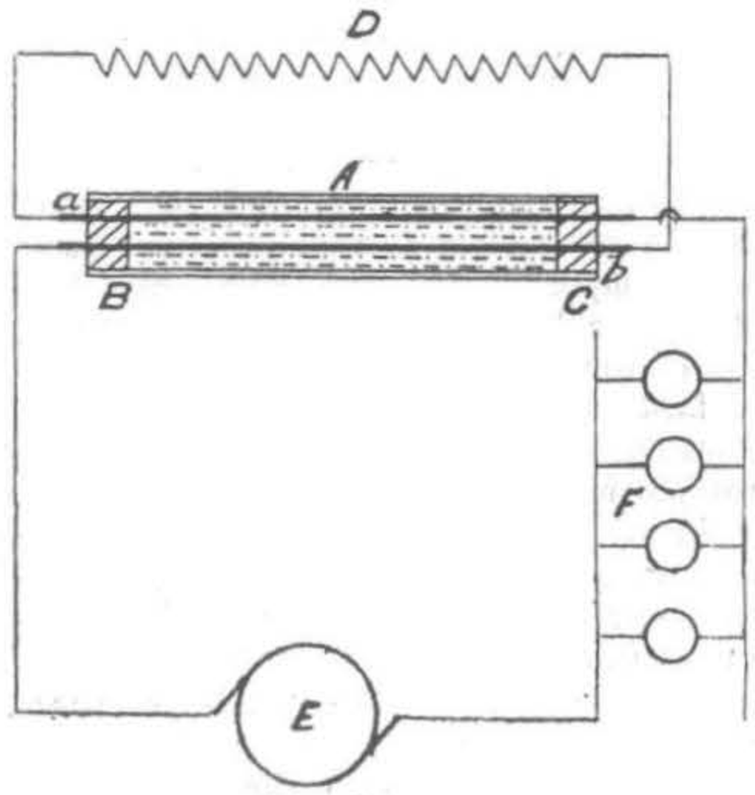


FIG. 1.

The first item consists of an electrolytic meter, the principle underlying the action of which is as follows: A conductor is immersed in a metallic solution, and the current to be measured is passed through it. The action of the current in passing is to remove from or deposit on the conductor a certain quantity of metal, and by so doing alter the electrical resistance of the conductor, which can thus, if necessary, be caused to register automatically when the current passing rises above or falls below certain limits. Fig. 1 is a diagrammatic view of the apparatus. A is the glass containing tube of cylindrical form, sealed at each end by an insulating and watertight plug, B C, through which pass the leading-in wires; *a b* are the active conductors of the apparatus. They are placed parallel to one another throughout the length of the tube, A, and are connected in series through a resistance, D, with the generator, E, and energy-consuming circuits, F, in such a manner that there is an equal difference of potential between them throughout their whole length.

Under the conditions described above a current passing through *a* and *b* will establish a difference of potential between them proportional to the current strength. This gives rise to a leakage between them which is proportional to the potential difference, and therefore to the strength of the current passing through the conductors. Again, owing to the fact that there is a constant difference of potential between the two conductors throughout their entire length, the current density through the electrolyte will also be uniform, and as a natural consequence the metal will be removed at a uniform rate from one conductor and deposited at an equal rate on the opposite one, thus causing an alteration in their electrical resistances proportional to the strength of the current passing through them, from which given quantity the value of the latter can be readily ascertained—in the first instance by experiment, and in the second by comparison. It will be seen that this apparatus is somewhat similar in principle to that of Edison, with this difference—that the results depend in one case on electrical resistance, and in the other on actual weight.

The *modus operandi* of the apparatus is as follows: The two conductors, *a* and *b*, are first accurately gauged and measured for resistance, the results being carefully noted. A fixed current is then passed through the instrument for a certain time, and the respective diminution and increase in the resistance of *a* and *b* is then ascertained. From the facts thus gathered a constant is obtained whereby the instrument is rendered capable of accurately recording any succeeding currents which may traverse the active conductors, *a* and *b*. A test of its accuracy is provided by the separate measurement of the two conductors, when the gain in the resistance of one should equal the simultaneous loss in the other, or, as a further proof, the resistance of the two conductors measured in series with the resistance, D, should be a constant quantity. It is hardly necessary to mention that at certain intervals the direction of the current in the two conductors, *a* and *b*, must be reversed in order to equalise the metallic reduction and deposition respectively. The advantages appertaining to this form of meter are obvious: The readings can be made directly by means of an ohmmeter; the whole of the current may be passed through it provided that the gauge of the two wires, *a* and *b*, be sufficiently large, thus rendering the use of shunts and attendant inaccuracies unnecessary. The accuracy of the instrument is not impaired to any appreciable extent by temperature variations. Above all, it is a cheap form of apparatus for the purpose.

The next inventions with which I purpose dealing are

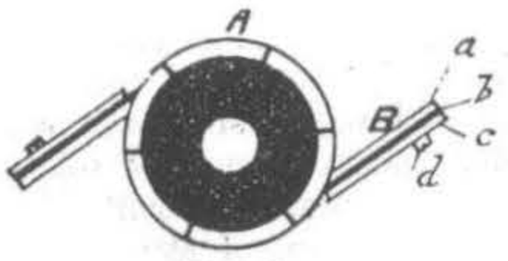


FIG. 2.

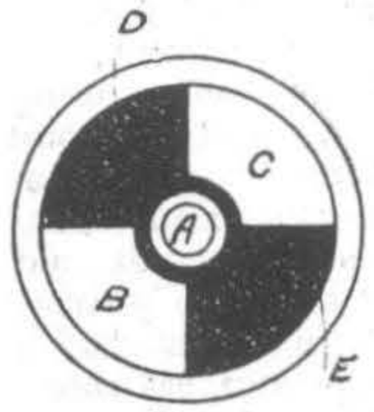


FIG. 3.

those involved in the manufacture of dynamo commutators and brushes, in which sparking is reduced to a minimum or even rendered impossible. Devices for the reduction of this generally necessary evil were no doubt suggested to Mr. Tesla by his marked antipathy to commutators of any description, brought to light by a consideration of his commutatorless motors. Fig. 2, which is a diagram of an anti-sparking brush device designed by him, will help to explain its principle. A is the end view of an ordinary continuous-current dynamo commutator, B being the brush, which is divided into three principal parts: *a*, the metallic brush, as usual; *b*, a plate of mica or other suitable insulating material, such as asbestos paper; and *c*, a flexible spring, which regulates the pressure of *b*, and is governed by the set screw, *d*. The principle of the device will no doubt be understood from its construction. The formation of an arc or spark between the brush, *a*, and the commutator segment which is just leaving it is prevented by the contact made between the insulating strip, *b*, and the corresponding insulating material of the commutator. In some forms of this brush two separate strips of insulating material have been introduced at *b*, instead of one, with advantage.

In another device designed with the same object in

view—viz., the elimination of sparking between commutator segments and collectors—both apparatus take the form of discs with their faces well surfaced revolving accurately against one another. Fig. 3 is a diagrammatic end view of the commutator disc of one of these devices. A is the dynamo shaft; B and C are the metallic sectors; D and E the corresponding sectors of insulating material, this being only a simple two-part commutator. The whole surface of the disc in Fig. 3 is accurately faced and smoothed, so that both metallic and insulating sectors are flush with one another. The collector disc is the facsimile of that shown in Fig. 3, but is not keyed to the shaft of the dynamo.

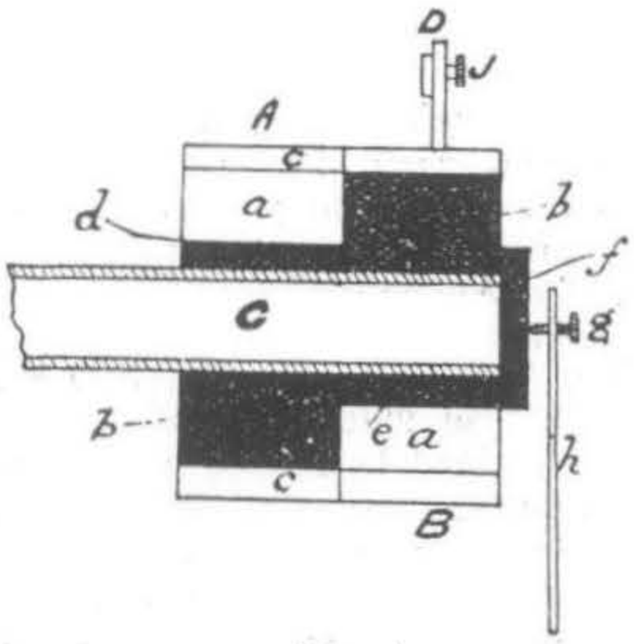


FIG. 4.

A general idea of the complete apparatus may be gained by a study of Fig. 4, which represents a longitudinal section of the commutator, A, and B, the collector; *a a* represent two metallic and *b b* two insulating sectors; *c c* are insulating rings which surround the outside edges of the sectors, and prevent a dissolution of partnership on the ground of centrifugal force; C is the dynamo shaft, through the tubular extremity of which are brought the wires from the armature coils; *d* is an insulating collar placed between the sectors and the shaft to prevent contact, and revolving with the latter; *e* is a similar insulating sleeve for the collector, and the dynamo shaft revolves inside it; a cap, *f*, is screwed on the end of this movable sleeve, and the pressure of a set screw, *g*, on the end of a stiff steel spring, *h*, serves to maintain good surface contact, between the commutator and collector surfaces; D is a quadrant for adjustment with a set screw, *j*, which takes the place of the ordinary brush-rocker, and serves to set the angle of the collectors. The advantages of this form of dynamo commutation will also be readily seen. The short-circuiting interval is reduced to a minimum by the simultaneous "make" and "break" of the sectors, which reduces sparking, besides increasing the efficiency of the machine.

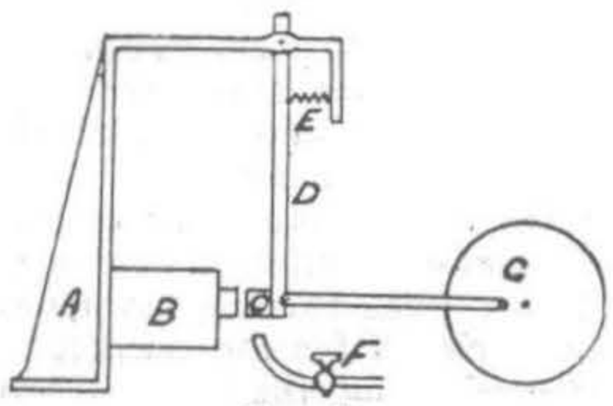


FIG. 5.

In another form of the same device a liquid—mercury, to wit—takes the place of the solid metallic sectors. The two discs are built completely of insulating material in this case, and in place of the solid metallic sectors cavities are left in their faces. The terminals of the collector end in airtight spring plungers or buffers, which serve to regulate the pressure of the mercury under the action of centrifugal force, and also to ensure a good contact between it and the terminal screws. In both forms the insulating blocks should be constructed of some durable material, such as glass or marble, whilst in the solid form the efficiency and durability may be augmented by facing the edges of the metal segments, between which the major portion of the sparking would tend to take place with some durable conducting material, such as platinum.

In the course of his electrical research, Tesla has not failed to study the subject of thermomagnetism, and as a result he constructed one or two rather ingenious forms of thermomagnetic motor, which are, however, for obvious reasons, still in an experimental stage. They are founded on the fact proved by Dr. William Gilbert at the beginning of the seventeenth century, that a magnet or lodestone when heated to redness is deprived of its magnetism. The principle underlying the device is illustrated in Fig. 5, in which A is a standard or support carrying a magnet, B, permanent or otherwise. C is an armature of the latter, forming the bob of a pendulum rod, D, supported above; E is a spiral spring which comes into play when the armature is demagnetised; F is a gas-burner or other suitable source of heat; and G is a wheel and connecting rod by which the power is converted into the ordinary form of rotary motion. Its action is as follows: The armature, C, is in the first instance attracted by the magnet against the tension of the spring, E. On heating C by means of the burner, F, it loses its magnetism and is drawn back by the spring out of the flame. On cooling, the magnetism again comes into play, and the armature returns to its original position, to be again heated, and so it goes on, the motion being of necessity somewhat slow.

There are several modifications of this motor, all working on the same main principle. In one the core of the electromagnet is made movable, and takes the place of the swinging armature, C, which is fixed. To the end of the magnet core it attached a shield, which, when the armature loses its magnetism and the core is drawn back by the spring in consequence, comes between the armature and the flame, and allows the former to cool by intercepting the heat rays. In another form the armature rocks over the two pole-faces of a permanent horseshoe magnet spanned by a sheet-iron keeper, which latter is heated by a burner whose tap valve is controlled by the rocking armature itself.

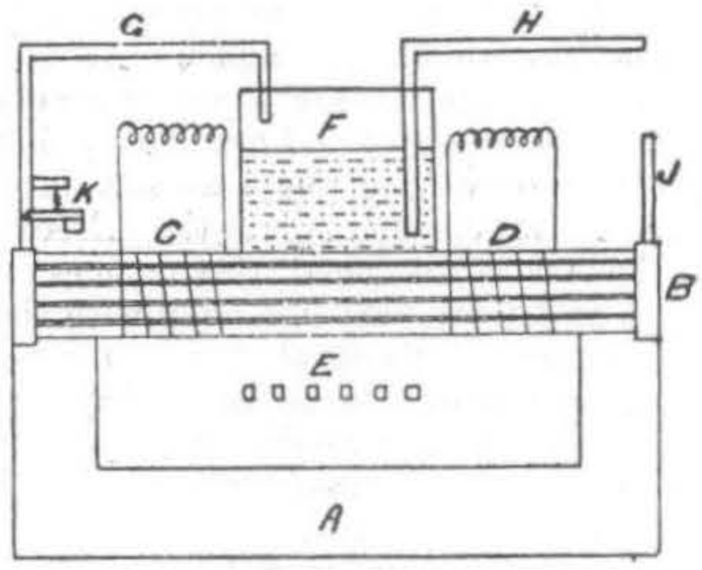


FIG. 6.

A study of the reverse of these conditions also led Mr. Tesla to construct a pyro-magnetic generator based on the undermentioned laws: "Electricity, or electrical energy, is developed in any conducting body by subjecting such body to a varying magnetic influence. The magnetic properties of iron or other magnetic material may be partially or entirely destroyed or caused to disappear by raising it to a certain temperature, but restored and caused to reappear by again lowering its temperature to a certain degree." Tesla's apparatus for practically applying these laws is represented diagrammatically in Fig. 6. A is a permanent magnet, the poles of which are bridged across by a casing containing a number of iron tubes, B. Round this compound bridging-piece are wound the collecting coils, C and D, which serve to collect the current generated. E is a closed furnace surrounding the central portion of the bridging-piece, and surmounted by a boiler, F, the steam generated in which is conveyed to the tubes, B, in the bridging-piece by the pipe, G. H is the water-supply pipe, and J the exhaust. The admission of steam is regulated by a valve, K, under the control of the magnet, A.

From the several inventions dealt with above, it will be seen that Mr. Tesla has not confined his labours solely to the field of high frequencies.

Tesla Apparatus Tried on Tuberculosis.

Although technical information has not been given out concerning it, the report is that Tesla oscillators, or something of the kind, are being tried by Dr. Croft C. Carroll of 21 East Twenty-fourth street, New York, and the result on two notably bad cases of tuberculosis is said to have been remarkably beneficial. Dr. Carroll is using the apparatus in his public clinic. Dr. John B. Rich, president of the American Microscopical society, is quoted as declaring it the most wonderful demonstration of positive beneficial results that he had ever seen in the treatment of germ diseases. One of the most notable cases cured was that of Dr. E. P. Iliff of Newark, N. J., a specialist in lung diseases, who contracted tuberculosis from one of his patients. He was given up for lost by his brother physicians, and in ten days after being treated was out attending to his practice. Rev. S. W. Switzer, of the Baptist tabernacle, Harrison, N. J., was very low with consumption, but was so helped that he was back on duty in less than three weeks. The principle of the apparatus is said to be the driving through the affected parts of a sufficient quantity of electricity to kill the germs, which are then eliminated from the system by nature.

NIAGARA'S POWER FOR CITY WHEELS

Only One Result of the Plan Which Nikola Tesla Holds Will Revolutionize Industries.

ELECTRICITY TO BE CARRIED IN ICE

Inventor Declares That It Can Be Transmitted Across Continent Without Loss.

AMAZING IN SIMPLICITY

After Seven Years of Work and Experiment the Idea Came Upon Student Like a Flash.

Methods of transmitting electrical currents will be revolutionized if the results anticipated by Nikola Tesla from his most recent invention for the insulation of wires meet with the success in practice indicated by his experiments. There will then be no danger of deaths or injury by contact with live wires. It will be possible to transmit a current of high voltage hundreds of miles with no appreciable loss.

By cheapening the cost of electricity at the place where it is to be used all industries dependent upon electricity for their motive power may be carried on at a vastly less expense. These results will be accomplished by using an insulation of ice or other frozen material.

Mr. Tesla was informed yesterday that his application for a patent covering this ground had been granted.

When I saw him, last night, at the Waldorf-Astoria, Mr. Tesla said that he was greatly pleased with the outcome of the experiments, upon which he had been working for seven years.

Amazed by Its Simplicity.

"Professor Dewar, of the Royal Institute, gave me the suggestion," said he, "which set me thinking along this line. That was in 1893. Realizing the great practical value of such an invention, I thought much about the subject, until a few weeks ago, when the complete system by which the desired end might be attained suddenly flashed across my mind as I was pondering upon the problem in my laboratory. Then the simplicity of the plan amazed me.

"Let me describe this method of insulation to you in its most comprehensive form. All wires will, of course, be placed under ground before my cold air insulation can be used.

"Imagine, now, a great trough extending, if you wish, across the continent. It must contain a quantity of water or some other substance which will freeze. From my experiments I judge that sawdust and water will prove most effective. For the purpose of transmitting the current long distances I shall use a thin metal tube, capable of resisting three hundred pounds' pressure to the square inch. This tube will be submerged in the substance which I intend to freeze.

Most Interesting Feature.

"In the whole discovery the most interesting feature is the method I have devised for freezing the material in the trough. Five or six feet below the surface the ground itself is very cold. Here the trough would be buried. Through the tube there will then be forced a current of gas—probably hydrogen—reduced to a temperature of minus 200 degrees or thereabouts.

"This, under ordinary circumstances, will be sufficient to freeze the material surrounding the tube in the trough, and also to neutralize the heat which would be generated by the electricity.

"It has been known since the days of Faraday that an electrical current cannot break through an insulation of ice. My success lies in discovering how to practically apply this truth. To show of what gigantic worth it may be needs but a moment. Grant that the invention has, as I believe, given to the world an almost perfect insulator, immediately there follow results which will directly or indirectly affect every manufacturing industry which in any way uses electricity.

No Loss in Transmission.

"This will follow from the fact that no electricity will be lost in transmission. The cost of the new insulation will in the end be cheaper than that now used, and so it follows that the electricity which is to be utilized in a thousand different ways can be produced at a less cost. To telephone and telegraph companies, therefore, you see that my invention will be indispensable.

"Water power converted into electricity can by the new method of insulation be carried thousands of miles. At present the loss of electricity due to unsatisfactory insulation makes this impossible. I have been considering the possibility of carrying the power of Niagara to this city, and find that it can be done with a loss of not more than one-half per cent to one per cent.

"For the first time in history a power will be used for insulation instead of a property. Deaths from contact with exposed wires will be prevented by the new method. The increase in the speed of exchange of telephone and telegraph messages will be pronounced after the adoption of my discovery.

"These are the important changes in the electrical world which will be wrought by this invention. There will be also innumerable indirect results."

Mr. Tesla said that he hoped to apply his new discovery to electric surface railways. He said that he was working upon a plan by which the cars could be propelled without direct contact with the wire. This plan is still in an embryotic condition, and for this reason Mr. Tesla declined to discuss it in detail.

500,000 VOLTS OF ELECTRICITY PASSED THROUGH THE BODY TO CURE CONSUMPTION---TESLA'S IDEA.

800 Volts Ordinarily a Fatal Current, but by the Marvellous Oscillator Which the Electrician Has Devised the Vaster Current May Be Made as Harmless as Sunlight.



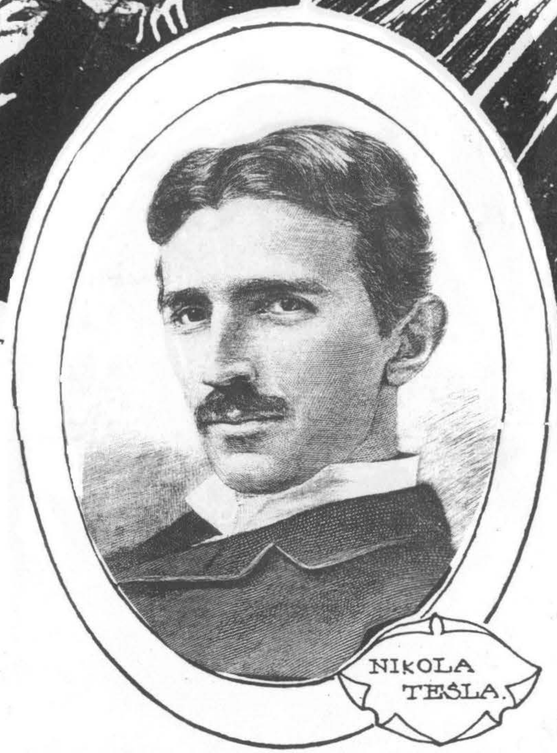
APPLYING THE TESLA ELECTRODE OVER THE HEART--FEATURE OF THE TREATMENT TO CURE CONSUMPTION.



APPLYING THE TESLA ELECTRODE ON SIDE OF FACE TO CURE NEURALGIA.

APPLYING THE TESLA ELECTRODE TO BACK OF NECK TO CURE SPINAL MININGITES.





NIKOLA TESLA has recently invented an electrical instrument which he thinks will revolutionize the science of medicine. By means of an oscillator he proposes to cure consumption, cancer and other forms of disease which have hitherto resisted all the efforts of medical science.

Ordinarily, 800 volts of electricity passed through the body of a man by means of the dry-cell method are sufficient to kill him.

By Tesla's machine half a million volts can be administered to a patient without ill effect. One scarcely feels the subtle fluid, which, in another form, would instantly annihilate him.

A peculiar property claimed for the Tesla electricity is that it affects the germs of the disease without destroying the cells of the tissues of the body. Many doctors could cure consumption if they had only the disease bacillus to deal with. But they have to consider the cell structure of the human body. A germicide powerful enough to kill the consumption germ would also destroy the tissues in which this germ is conducting its operations. Ordinary electricity passed through the tissue would reduce it to its elemental state.

The Tesla oscillator is now in use by New York physicians, who record marvellous results. Patients suffering from chronic consumption have been cured permanently. Men whose hours have been numbered have taken up their beds and walked.

The Tesla oscillator not only cures consumption. Its effect in fevers has been pronounced marvellous. In four seconds the temperature has been brought down from 105 degrees to normal—98 2-5. The pulse, racing at fatal speed, has been checked and made to beat time to perfect health. The breath, short and gasping, has been sustained, and all pain from the lungs has been eliminated.

Should Tesla's new discovery prove all that the inventor claims for it, physic may be thrown to the dogs. A few days of Tesla's treatment, painless and pleasant, will suffice.

BY NIKOLA TESLA.

My new oscillator is based on a principle which I discovered some time ago. It involves the use of vibrations of an electrical condenser which stores electrical energy. This energy is of an explosive nature, like the power locked up in dynamite, only it is many times more powerful.

When this energy is suddenly released, as in my machine, it produces quickly varying oscillations which are able to penetrate through bodies. Though this energy may be enormous in amount, it is not harmful in nature.

By means of this machine I may pass at least half a million volts of electricity through a man without injury. Indeed, it may be utilized with beneficial effect.

I am of opinion that electricity in this form may be used as a means of stamping out internal disease. When you stand in the sunlight your body is receiving millions of volts of electricity; and yet, this is not of a harmful kind. It is the same way with my new electric energy. If you hold up your hand in the light you will see that certain portions of it are illuminated. The rays have passed into the flesh. Sunlight, as is well known, helps to cure many diseases.

The germs of consumption and kindred diseases grow in darkness. Almost all organic growths develop under the absence of sunlight and electrical energy. Now, if these portions of the body in which germs are growing are subjected to electricity the diseases will be unable to live in the changed atmosphere, as it were, and the disease will disappear. This has long been recognized in medical science; but electricity could not be administered in sufficiently powerful quantities to affect germs without hurting the tissues themselves.

My oscillator enables this to be done. That is why I base such hopes on its career as a therapeutic agent. It has already been tried and remarkable results have been obtained.

Tesla's oscillator is a small, drum-like object, oblong in form. It is about two feet long by one foot wide. It is connected with the ordinary street wires, setting up its wonderful oscillatory electricity as soon as the current is turned on.

The current is applied to the patient by means of a glass electrode which is spoon-shaped. The patient feels no sensation whatever, and would be unconscious of the treatment were it not indicated by a redness about the part to which the current is applied. When the patient is undergoing treatment and the oscillator is working in full force sparks may be obtained from any portion of the body.

We are now in the midst of what is sometimes called the "silly season" in the newspaper world. It is a long time, however, since we have seen anything more egregiously silly than the announcement in the *Daily Mail* of last Saturday as to an alleged new discovery by Nikola Tesla. We do not know what proportion of the startling announcements frequently made in connection with the name of this electrician is authorised by him, but we hope that for his sake it is a very small one. In the present instance Tesla is reported to have discovered a method of perfectly insulating an electrical conductor by surrounding it with a frozen mixture of water and sawdust in a thin metal tube. This amazing insulator, Tesla is reported to declare, renders possible the transmission of electric power from New York to London. A short while ago Tesla's schemes were in the ether above the earth's atmosphere. Now they appear to be at the bottom of the Atlantic ocean. We wonder where they will turn up next.

Tesla's Latest Scheme.

As noted in this week's patent record of the Western Electrician, a patent has been granted to Nikola Tesla on the method of insulating conductors which consists in freezing water or other mixture by artificial means around the conductor to be insulated and maintaining the insulator in its frozen condition. Much has been said about the revolutionizing character of the invention by the daily press. Just how the system which requires the maintenance of a set of refrigerating plants along a transmission line is to be superior to present systems is not pointed out.

ELECTRICITY UP TO DATE—AND BEYOND.

Fearful and wonderful as are many of the attributes of electricity to the man in the street, the *ultima Thule* has now been reached, according to our esteemed contemporary the *Daily Mail*.

"TESLA'S LATEST MARVEL.—Transmitting Electricity without Loss,"

form the headlines of an article which begins with the words—"Niagara Falls to light the streets of London, and cook the dinners of its 5 million inhabitants," and ends with the brutally practical consideration that "the cost of the insulation is the only factor to be considered." How electricity is to be transmitted without loss is explained with that airy indifference to such trifling obstacles as physical impossibilities that is characteristic of the efforts of the lay press when dealing with technical questions. In the early days of electric lighting it used to be said that most electrical engineers could lawfully claim descent from Ananias and Sapphira, but even the expert witness might be expected to develop a conscience if called upon to substantiate some of the means suggested by the *Daily Mail* by which electricity is to be transmitted without loss. For instance, the following gems of thought are worth quoting:—

"The chief difficulty to be faced in the long-distance transmission of electricity is the power lost in the line by reason of its resistance, which fritters the current down to heat." Apparently the E.M.F. is spared this indignity.

But how wonderful is the intelligence which, in the description of a difficulty, contrives to imply the way of escape! Of course, we can see with half an eye from this delphic utterance, that all that has to be done is to eliminate the resistance, and the difficulty will vanish. Then the master mind that prompted the article, in a few pithy sentences, shows how simply this may be done.

"A trough will extend across the entire continent of America, or across the Atlantic. In the trough will be placed sawdust and water." [It may reasonably be assumed that the act of "placing" the water when crossing the bottom of the Atlantic will be a work of supererogation.]

"A thin metal tube, capable of resisting a pressure of 300 lbs. to the square inch, will be used for the purpose of transmitting the current to long distances." [Note, only *one* tube—so simple.]

"The trough is to be buried 5 or 6 feet below the surface." [Presumably below the surface of the bottom of the Atlantic; but "buried" is a horribly suggestive word.]

"A current of gas, probably hydrogen, will be forced through a pipe submerged in the substance to be frozen,

The hydrogen will be reduced to — 200° C., which will suffice to freeze the material, and *neutralise the heat generated by the passage of the electricity*."

The italics are ours. Why is any heat generated? Transmission without loss means conductors without resistance, hence absence of heat. But if heat be generated, the neutralisation comes a day after the fair, as far as any saving is concerned. It would be better, if we might hazard a suggestion, to neutralise the resistance.

Nothing is said about the cost of producing the "gas at — 200° C.," or the quantity that will be required, nor is the somewhat delicate subject touched upon of labour troubles which might ensue if workmen were asked to break up and make good the bottom of the Atlantic under a pressure of anything from 2 tons per square inch upwards. What would the fish say to a cold streak at the bottom of their home? They might strike, and be joined by horses and birds out of sympathy. The possible prospect of fish refusing to be caught, horses refusing to move, and birds declining to fly, ought surely to awaken some sense of responsibility in Mr. Tesla's breast!

But we have not exhausted the possibilities of this system. Mr. Tesla is stated to believe that his new system of insulation is "indispensable to telephone and telegraph companies." The inclusion of each telephone wire in a trough filled with sawdust and water, and reduced to — 200° C., opens up some pleasing prospects on the overhead system.

Mr. Tesla is stated to believe, further, that no electricity will be wasted in transmission, and that "water-power converted into electricity will be carried thousands of miles." Query, in a trough?

The *Daily Mail*, in concluding, points out that, "by Mr. Tesla's invention, there is now practically no limit to the distance to which electricity may be conveyed."

The *Daily Mail* has spoken. We have, therefore, reached finality, and we may imagine interplanetary space mapped out, in the near future, into districts by troughs of sawdust and water at — 200° C., and agencies appointed in each of the more important planets for the supply of electricity on sale or return. Why not? it would be just as easy as to "trough" the bottom of the Atlantic.

THE SLABY-ARCO SYSTEM OF WIRELESS TELEGRAPHY.

The Slaby-Arco system, as described in a pamphlet issued by the General Electric Company of Berlin, though based on essentially the same principles as the Marconi system, differs

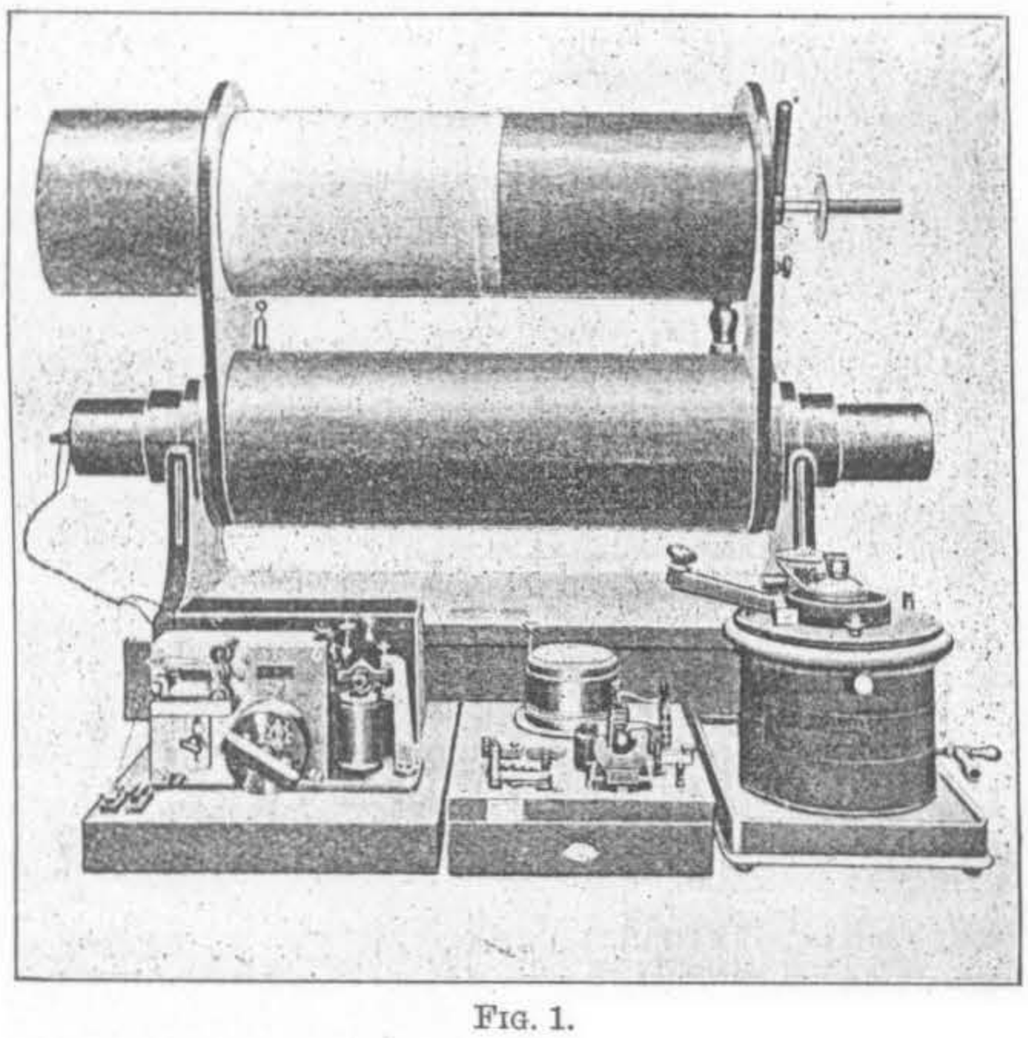


Fig. 1.

from the latter in some important respects. The vertical wire, for example, which is insulated in the Marconi arrangement, is in the Slaby-Arco system connected with earth for both transmitting and receiving.

The connections of the transmitting apparatus are shown in diagram 1. A condenser, C, is charged with high tension

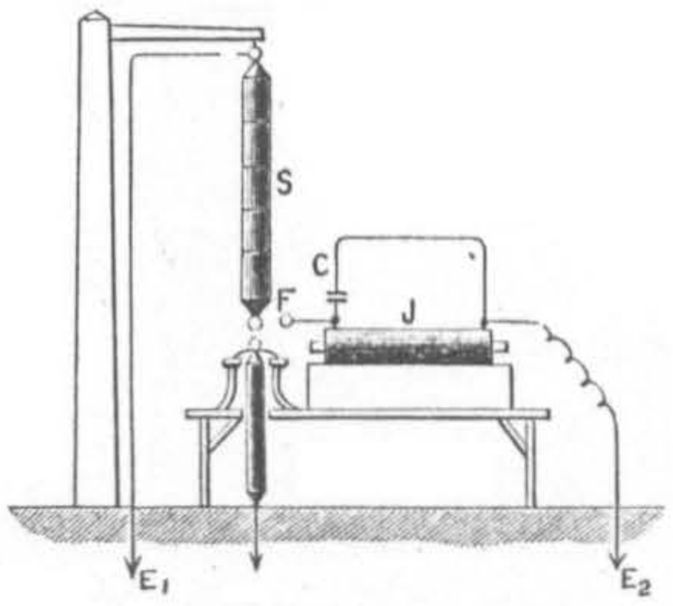


Diagram 1.

electricity by the induction coil, J, and discharges itself on one side through the spark-gap, F, and the transmitting wire, and on the other side through E_2 direct to earth. According to the inventors the technical advantages of this arrangement are very decided, for as only one of the condenser plates and one knob of the radiator—parts which can be permanently insulated, and from which danger to the operators can be completely prevented—are at a high potential relative to the earth, difficulties of insulating the transmitting wire are obviated; and even on taking hold of the wire scarcely perceptible shocks are felt.

For the production of the high potential the inventors ordinarily use a 40 or 50 cm. induction coil with a mercury turbine contact breaker; the coil may be directly connected with an electric light circuit thus dispensing with accumulators or dry cells. The use of a special Morse key is rendered unnecessary by a suitable appliance fitted to the turbine contact breaker. If an alternating current is available the arrangement becomes still simpler and more convenient, since in that case the contact breaker can be wholly dispensed with, and the induction coil can be directly connected with the alternating current circuit. The condensers used are made of "micanite," and are mounted on the induction coil itself, this being done in such a way that the high tension pole of the induction coil and of the condenser is protected from contact. (See fig. 1.)

The arrangement of the receiving apparatus is shown in diagram 2. In this figure S is the aerial wire netting, F the coherer, R the relay of the Morse instrument, and B the battery.

The action of the receiver is such that, when the initial high resistance of the coherer has been reduced by the etheric waves, the battery, B, is enabled to send a current through the relay, the aerial wire, and earth.

It is a characteristic feature of the receiving apparatus that the pulsating magnetic field produced by the transmitter may be received not only on a simple aerial wire, but also on an earthed wire cage or netting, whereas in previous arrangements the waves which reached the coherer, F, were shunted by the local circuit, and their effect was thereby weakened; in the Slaby-Arco system the series arrangement adopted completely removes this defect; atmospheric disturbances are also greatly diminished by the series arrangement.

Another improvement in the receiver consists in the introduction of an automatic interruption of the coherer circuit. Matters are so arranged that the blow of the tapper is only given to the coherer tube after the tension of the coherer elements is taken off. By this means not only is easy and satisfactory decoherence effected, but the life of the coherer is said to be considerably prolonged, since the sparks on breaking circuit, which would otherwise occur in the interior and would gradually destroy the coherer powder, are caused to take place externally.

A further improvement is claimed in the construction of the coherer, a variation in the sensitiveness of which is rendered possible by means of hermetically sealed leads. The

coherers are all tested for long distances, but each receiver for movable stations is furnished with an appliance for diminishing the intensity, so that the apparatus, in spite of its great sensitiveness, will work perfectly even at very short distances.

It is claimed that the system is particularly useful for communications between ships at sea or ships and the coast,

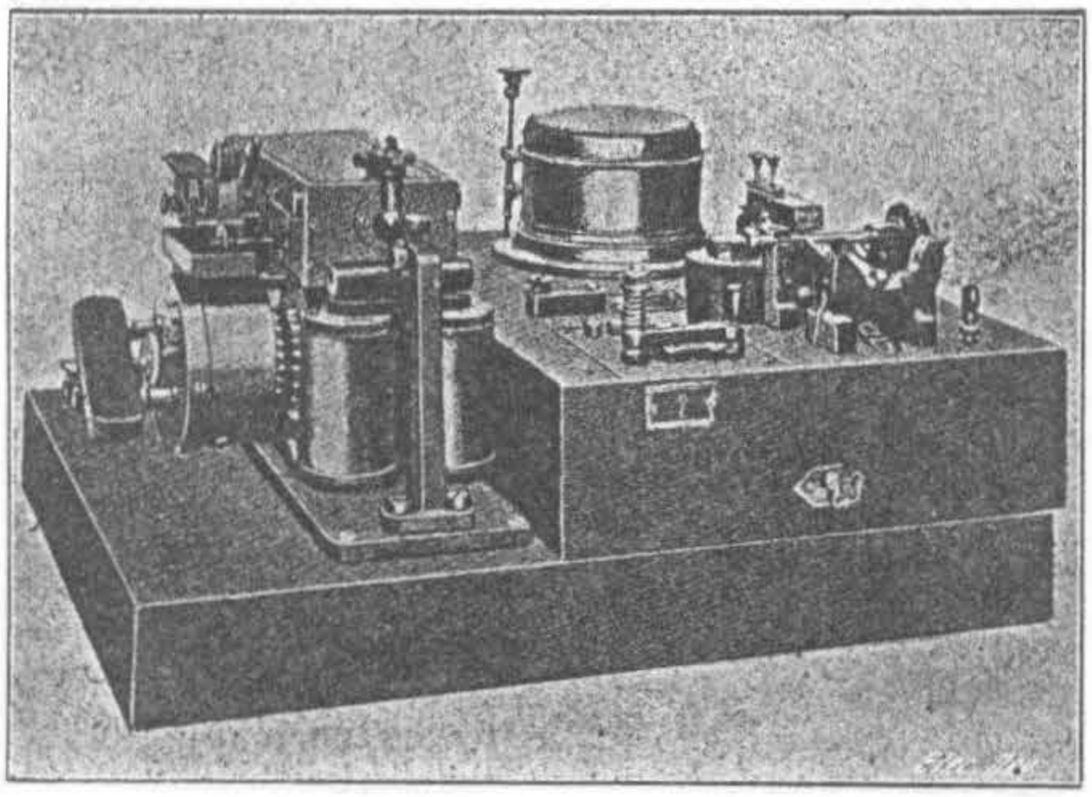


Fig. 2.—Receiving Apparatus.

and that experiments carried out by the German Navy prove that for such purposes the system is perfectly reliable.

At present the radiating power and sensitiveness of the apparatus is such that signals can be *safely* transmitted to distances of 25 to 28 miles over sea with vertical wires 38 to 44 yards high.

On land the General Electric Company maintain communication between their cable factory at Oberschöneweide and their central office in Berlin, a distance of 9⅓ miles. The vertical wires, about 55 yards high, are supported by two tall chimneys.

The advantages of the Slaby-Arco system, as compared with other systems, consists, it is stated, not so much in its

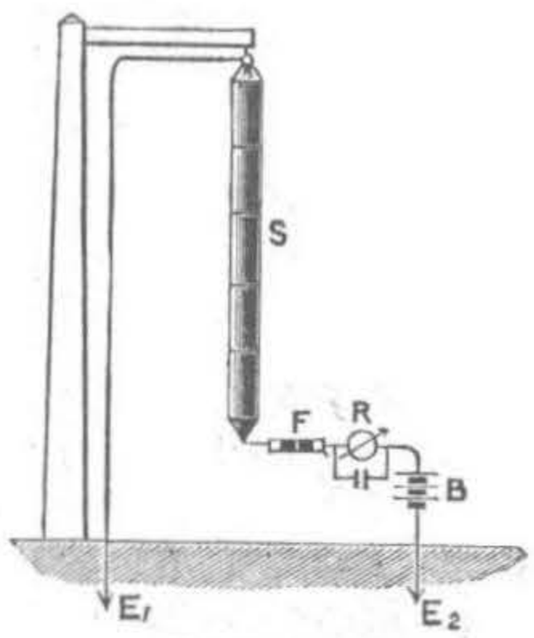


Diagram 2.

superiority in respect of the distances, as in its practical serviceability, prevention of danger from high pressures, avoidance of difficulties of insulation in the transmitter, and of atmospheric disturbances in the receiver, together with a greater solidity and simpler manipulation of the whole receiving apparatus. It is for these qualities that the system has been adopted by the German Navy.

TESLA ROTATING FIELD PATENTS SUSTAINED.

Judge Townsend, of the United States Circuit Court for the District of Connecticut, rendered a decision on August 29th sustaining the Westinghouse Electric and Manufacturing Company in its suit against the New England Granite Company for alleged infringement of the Tesla polyphase patents Nos. 381,968, 382,279 and 382,280, granted in 1888.

These are the fundamental Tesla polyphase patents, and in granting the injunction prayed for the court orders an accounting as to all the claims in suit. A synopsis of the argument of the case can be found in the *Electrical World and Engineer*, Vol. XXXIV, page 782, Nov. 18, 1899.

*See *Electrical Review* (N. Y.), Vol. XXXVII, No. 12, page 277.

Tesla.—WRIGHT.—An illustrated article on "Some Novel Inventions of Nicola Tesla." He describes an electrolytic meter, several anti-sparking brush devices, and models of a thermomagnetic motor and of a pyro-magnetic generator.—*Lond. Elec. Eng.*, Aug. 10.

TESLA'S ELECTRICAL METHOD OF CURING CONSUMPTION.

FROM an American paper we learn that "Tesla's Idea" for curing consumption is to pass 500,000 "volts of electricity" through the body. Thus we read :—Nikola Tesla has recently invented an electrical instrument which he thinks will revolutionise the science of medicine. By means of an oscillator he proposes to cure consumption, cancer, and other forms of disease which have hitherto resisted all the efforts of medical science. Ordinarily, 800 volts of electricity passed through the body of a man by means of the dry-cell method are sufficient to kill him. By Tesla's machine half a million volts can be administered to a patient without ill effect. One scarcely feels the subtle fluid, which, in another form, would instantly annihilate him. A peculiar property claimed for the Tesla electricity is that it affects the germs of the disease without destroying the cells of the tissues of the body. Many doctors could cure consumption if they had only the disease bacillus to deal with. But they have to consider the cell structure of the human body. A germicide powerful enough to kill the consumption germ would also destroy the tissues in which this germ is conducting its operations. Ordinary electricity passed through the tissue would reduce it to its elemental state.

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The following is given as from Tesla himself: "My new oscillator is based on a principle which I discovered some time ago. It involves the use of vibrations of an electrical condenser which stores electrical energy. This energy is of an explosive nature, like the power locked up in dynamite, only it is many times more powerful. When this energy is suddenly released, as in my machine, it produces quickly varying oscillations which are able to penetrate through bodies. Though this energy may be enormous in amount, it is not harmful in nature. By means of this machine I may pass at least half a million volts of electricity through a man without injury. Indeed, it may be utilised with beneficial effect. I am of opinion that electricity in this form may be used as a means of stamping out internal disease. When you stand in the sunlight your body is receiving millions of volts of electricity; and yet, this is not of a harmful kind. It is the same way with my new electric energy. If you hold up your hand in the light you will see that certain portions of it are illuminated. The rays have passed into the flesh. Sunlight, as is well known, helps to cure many diseases.

The germs of consumption and kindred diseases grow in darkness. Almost all organic growths develop under the absence of sunlight and electrical energy. Now, if these portions of the body in which germs are growing are subjected to electricity, the diseases will be unable to live in the changed atmosphere, as it were, and the disease will disappear. This has long been recognised in medical science; but electricity could not be administered in sufficiently powerful quantities to affect germs without hurting the tissues themselves.

My oscillator enables this to be done. That is why I base such hopes on its career as a therapeutic agent. It has already been tried, and remarkable results have been obtained.

The description given is as follows :—Tesla's oscillator is a small, drum-like object, oblong in form. It is about 2ft. long by 1ft. wide. It is connected with the ordinary street wires, setting up its wonderful oscillatory electricity as soon as the current is turned on. The current is applied to the patient by means of a glass electrode which is spoon-shaped. The patient feels no sensation whatever, and would be unconscious of the treatment were it not indicated by a redness about the part to which the current is applied. When the patient is undergoing treatment, and the oscillator is work-in full force, sparks may be obtained from any portion of the body.

The comment is that possibly Tesla has never said anything to warrant these statements.

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THE TESLA DECISION.

Elsewhere in this issue will be found a very full abstract of the Townsend decision, mentioned by us last week, in favor of the Tesla rotating magnetic field patents which have been in suit for some few years past. It will be seen that the judge treated as insufficient anticipations the work of Baily, Siemens, Deprez and Bradley, all of which had been relied upon and much of which was admittedly of a prophetic character, to say the least. The judge took occasion to compliment Mr. Tesla on the high value of his work to the art, in view of the enormous extension given to the transmission of power by such methods since the distinguished inventor read his memorable paper before the American Institute of Electrical Engineers.

General News.

Decision in Favor of the Tesla Rotating Magnetic Field Patents.

As announced in these pages last week, Judge Townsend in the U. S. Circuit Court for the District of Connecticut has handed down a decision sustaining three broad Tesla patents—Nos. 381,968, 382,279 and 382,280—of May 1, 1888, in the suit of the Westinghouse Electric & Manufacturing Company against the New England Granite Company, which had been using a Cushman phase motor operated from a General Electric three-phase generator. The case was reviewed at considerable length in the ELECTRICAL WORLD AND ENGINEER of Nov. 18, 1899, when the chief points in contention were brought out. The full text of the decision has now been handed down, which follows closely the lines then noted.

The claims in issue in patent No. 381,968 are as follows:

"1. The combination, with a motor containing separate or independent circuits on the armature or field-magnet, or both, of an alternating-current generator containing induced circuits connected independently to corresponding circuits in the motor, whereby a rotation of the generator produces a progressive shifting of the poles of the motor, as herein described.

"3. The combination, with a motor having an annular or ring-shaped field-magnet and a cylindrical or equivalent armature, and independent coils on the field-magnet or armature, or both, of an alternating current generator having correspondingly independent coils, and circuits including the generator-coils and corresponding motor-coils in such manner that the rotation of the generator causes a progressive shifting of the poles of the motor in the manner set forth."

That of patent No. 382,280 is as follows:

"1. The method herein described of electrically transmitting power, which consists in producing a continuously progressive shifting of the polarities of either or both elements (the armature or field-magnets or magnets) of a motor by developing alternating currents in independent circuits, including the magnetizing coils of either or both elements, as herein set forth."

The claims in issue of patent No. 382,279 are as follows:

"1. The combination, with a motor containing independent inducing or energizing circuits and closed induced circuits, of an alternating-current generator having induced or generating circuits corresponding to and connected with the energizing circuits of the motor, as set forth.

"2. An electro-magnetic motor having its field magnets wound with independent coils and its armature with independent closed coils, in combination with a source of alternating currents connected to the field coils and capable of progressively shifting the poles of the field magnet, as set forth.

"3. A motor constructed with an annular field magnet wound with independent coils and a cylindrical or disk armature wound with closed coils, in combination with a source of alternating currents connected with the field-magnet coils and acting to progressively shift or rotate the poles of the field, as herein set forth."

The complainant's theory of the invention was that the gist of it was the utilization of the alternating currents generated by an alternating-current dynamo or generator for effecting such shifting of the magnetic poles or resultant attractive forces upon the armature of a motor, and thus causing such armature to rotate in response thereto. His broad invention was the production in a motor of a progressively shifting magnetic field (or pole) by means of two or more independent alternating currents, differing in phase, and circuits which preserve the independent character and phase relation of such currents."

By way of defence, the decision goes on, the defendants relied upon four prior publications, namely, the Baily article of 1879; the Siemens patents of 1878; Deprez's article of 1880-4, and the Bradley application of May 9, 1887. As to Baily the court says: "Baily merely showed how to apply a series of successive impulses to the disk by an intermittent rotation of the field and thus produce Arago's rotation field with stationary magnets instead of a moving magnet, and he showed how the motion of the disk could be reversed. He conceived the idea of a uniform rotation by a manifestly imposible and impracticable construction. He did not claim to have established a continuous rotating field or to know any way in which a uniform rotation could be produced. He did not use alternating currents, but reversed currents. He was not dealing with the subject of the transmission of power. Defendants' expert admitted that his paper merely describes a laboratory experiment."

As to the allegation that the Siemens patent of 1878 was an anticipation, the Court says: "This patent is chiefly for means to convert motive power into electricity. It does not specificaly relate to or describe or fully show a system of apparatus for the transmission of power. It not only fails to refer to any difference of phase, or to point out how the armature and overlapping coils are to be coupled together to produce such phase, but it repeatedly describes the use of commutators in order to create a continuous or direct current. At this date it was not known that an alternating current machine could be used as a motor. Motors then were operated only by a direct or continuous current so far as the record shows. The 'suitable modifications' to change this machine into a motor are nowhere described; in view of the repeated reference to commutators, the modifications must be presumed to relate to such continuous current machines; and in view of the then state of the art such suitable modifications would have required such a series of experiments and such a departure from the existing theories and such development and application of devices in unexpected and non-analogous ways as would in themselves have constituted invention. Siemens himself, as late as 1884, and Alteneck, the other inventor of said Siemens patent, in 1881, admitted that they did not know that alternating currents could be used as motors. This evidence was objected to on the ground that the publications containing said statements are not duly proved, but the fact is established by other sufficient evidence."

The Court then takes up the Bradley application filed six months before the Tesla application, but regards it also as inadequate. "The single specific object of Bradley's construction stated in said specification was to obviate 'difficulties and limitations' in prior constructions wherein the machine was idle during a part of the time. He suggests that this may be done by rectifying one of the alternating currents by a commutator and then combining the two or by connecting each with a separate circuit. He does not show how he would use them in the latter case to operate a motor, nor did he indicate any combination of the alternate currents for a single motor or show that he had any conception of their use, if at all, otherwise than separately in single-phase motors.

"A comparison of the Bradley application prior to Tesla with the Bradley patent, issued subsequent to Tesla, shows that in the former he described a method and illustrated an apparatus designed to obviate the objections to a two-phase alternating currrent by combining both currents in one by means of a transformer, while from the latter he omitted this description and method and inserted figures which, while strikingly suggestive of the apparatus shown by Tesla, failed to show that he conceived the Tesla idea or sought to secure the object of Tesla's invention. For this reason, and further because Bradley's application is limited in scope, and ambiguous and indefinite; because it fails to show that he had any conception of the Tesla idea of 'the utilization of the motor for the purpose of progressively shifting the magnetic poles of a plurality of alternating currents by circuits which preserved the independence and differing time relation of their phases;' because, even if the idea had been first conceived by Bradley, it was not sufficiently described to disclose the principle or method of operation; because Tesla was the first to reduce this principle to practice, Bradley does not anticipate or limit."

As to the publications of Marcel Deprez of 1880-84, the Court concedes that Deprez not only disclosed the principle which Tesla utilized, but he gave a mathematical demonstration of the rotating field. But the only device possible to Deprez's mind was an electric compass. "All that Deprez demonstrated, therefore, was that if a field was made in which the field magnet varied relative to the brushes, or *vice versa*, the angle of variation would be indicated by the needle in another machine which would move quickly or slowly as the brushes and magnets shifted relative to each other and would indicate the new angle subtended between the brushes and the magnet. The only useful, practical application of this device was to attach it to a machine which would produce currents, and to use the earth or a ship to indicate the shift of position by means of a needle on top of the mast. This apparatus failed to teach any one that alternating currents could be used as a source of power in a motor. It was a mere indicator. It did not involve the utilization of two alternating currents differing in phase as a source of power in producing a continuous magnetic field. It did not depend upon any constant, regular, progressive currents, and, so far as the evidence shows, it was like the apparatus of Baily, confessedly a mere laboratory experiment. That Deprez did not conceive of the Tesla idea of utilizing regular, progressive, constant alternations of current is conclusively shown by his own statement in 1884 after the publication of this paper and after the invention of the Gaulard and Gibbs alternating current systems for lighting, when he published another paper in which he criticised the system and stated that one of the most serious objections to it was that it was not applicable to the transmission of power and adds: 'I must further remark that alternating currents are of no use in the transmission of power; they are suitable only for lighting purposes.' In fine, the evidence shows that, as Prof. Sylvanus Thompson says in his work on this general subject: 'Deprez's theorem bore no fruit; it remained a geometrical abstraction.'"

Judge Townsend then reviews the state of the art up to the time of Tesla's invention, and says that prior to it no alternating-current motors were in use, although there was an urgent demand for them. Six months later Tesla read his paper before the American Institute of Electrical Engineers and announced that previous efforts to utilize alternate currents had failed; that he had brought forth a novel system for the tarnsmission of power, and explained its theory and demonstrated its operation by exhibiting a working motor; and no one of the electricians present questioned his claim or criticized his apparatus.

Tesla first stated the discovery how these alternations could be thus utilized and showed the machine and method adapted for this purpose. He is entitled to a patent for this discovery as were the discoverers of the use of anthracite coal instead of bituminous coal, or of the hot blast instead of the cold blast, in the manufacture of iron, or of the practical application of electricity to the telegraph or telephone. Judge Blatchford once sustained a patent for insulating electric wires by means of gutta-percha, and said:

"The gist of the invention is the discovery of the fact that gutta-percha is a non-conductor of electricity, and the application of the fact to practical use. The claim is valid, even though a metallic wire covered with gutta-percha existed before the plaintiff's invention, if it was not known that gutta-percha was a non-conductor of electricity, and could be used to insulate the wire."—Colgate vs. Western Union Telegraph Company, 6 Fed. Cases, 86.

It is not necessary to go to this extent in sustaining these patents. The complainant may safely rest its case on the general principles laid down in the various decisions of the Supreme Court and extended and developed in Potts vs. Creager, *supra*.

Further than this, the Court says: "But if the evidence already considered be disregarded and it should be assumed that alternating and alternated currents were theoretically known equivalents, even then the argument of counsel for defendants does not appear to be sound. They contend that a superior result, by reason of the substitution of one known equivalent for another, does not constitute invention. But the first substitution or application of such theoretical equivalent to produce a new or non-analogous or unexpected result may involve invention. Tesla applied the alter*nating* current to do what the alter*nated* current had never before done, namely, to produce a new, unexpected and practical system of transmision of power. A careful study of the evidence has led to the conclusion that Tesla made a new and brilliant discovery. But even if this be incorrect, it is proved that by a new combination and arrangement of known elements, he produced a new and beneficial result never attained before. The technical defense of non-infringement by reason of the fact that defendants use only a motor, and that there is no allegation or proof of con-

spiracy with the owners of the plant which supplies the power, was not pressed on the argument, and as six days were spent in the discussion of the questions on the merits this point will not be discussed. If any amendment is necessary to cover these points it should be allowed. The contention of defendants that Tesla does not describe an operative machine is not satisfactorily proved. It is proved that in fact various practical motors have been manufactured according to his invention."

The question was urged by the defence as to the point that "independent" in the patents meant separated or "isolated." The Court held that "the claims, confessedly, cannot be read as requiring isolation of the circuits, but at most only such independence as is necessary for the purpose of producing a rotary field; that is, the connections must be such as not to interfere with the independency of the circuits which operate to shift the poles. The only practical result from defendants' use of three conductors instead of six is an improvement 'to regulate the action of the motor,' which result was anticipated by Tesla, and it is proved that it was known in the prior art that one of these arrangements was a substitute for the other. Inasmuch as the defendants have not invented any new idea, but have adopted an old contrivance which performs the same result in substantially the same way by a formal and unsubstantial change in means, and by circuits which while in some sense interdependent are operatively independent, and which preserve and utilize the vital element, independence of phase, these circuits must be held to be the equivalents of the independent circuits of the patent, the word independent being interpreted to mean *comparatively independent*, so as to embrace the true spirit and essence of the Tesla invention.

"This conclusion is supported by a great number of illustrations of similar uses of such independent conductors in the general field of the arts. As the expert for complainant has pointed out, in railroads, cash carriers, electric telegraphs, the tracks, the earth or a single wire, will serve as common but independently acting conductors. It does not seem necessary to further discuss this contention based on a technical verbal distinction. Defendants' three wires are operatively independent; they are actually independent while in action; they are independent enough to do the required work."

The Court touched briefly on the action of the Imperial Court of Germany presumed to affect adversely the Tesla patents, but saw no sufficient reason why the conclusion of that court should have any bearing on the question of infringement here.

Infringement of the first claim of patent No. 381,968 necessarily implies infringement of the method patent No. 382,280. The finding that the circuits of the defendants are independent, in the sense of the Tesla patents, is decisive against the defendants as to the infringement of the first and second claims of patent No. 382,279; and the field magnet of defendants' motor, while differing in some respects from that of the third claim of No. 381,968, is annular or ring-shaped within the meaning of said claim and infringes it.

The decision concludes as folows: "The search lights shed by defendants' exhibits upon the history of this art only serve to illumine the inventive conception of Tesla. The Arago rotation taught the school-boy 50 years ago to make a plaything which embodied the principle that a "rotating field could be used to rotate an armature." Baily dreamed of the application of the Arago theory by means of a confessedly impossible construction. Deprez worked out a problem which involved the development of the general theory in providing an indicator for a ship's compass. Siemens failed to disclose the "suitable modifications" whereby his electric light machine might be transferred into a motor, and Bradley is almost equally vague. Eminent electricians united in the view that by reason of reversals of direction and rapidity of alterations an alternating current motor was impracticable, and the future belonged to the commutated continuous current. It remained to the genius of Tesla to capture the unruly, unrestrained and hitherto opposing elements in the field of nature and art and to harness them to draw the machines of man. It was he who first showed how to transform the toy of Arago into an engine of power; the "laboratory experiment" of Baily into a practically successful motor; the indicator into a driver; he first conceived the idea that the very impediments of reversal in direction, the contradictions of alternations might be transformed into power producing rotations, a whirling field of force. What others looked upon as only invincible barriers, impassable currents and contradictory forces, he seized, and by harmonizing their directions utilized in practical motors in distant cities the power of Niagara.

"A decree may be entered for an injunction and an accounting as to all the claims in suit."

Messrs. F. H. Betts, Kerr, Page & Cooper, and L. E. Curtis, on the brief, appeared for the complainant; and Mitchell, Bartlett & Brownell for the defendants.

Tesla Patents Upheld.

An important electrical decision was handed down at New Haven, Conn., on August 29th by Judge Townsend, in the United States Circuit Court, in the case of the Westinghouse Electric and Manufacturing company against the New England Granite company.

It was on a final hearing on bill and answer raising questions of patentability and infringement of three patents granted to Nikola Tesla, May 1, 1888, for an electric-magnetic motor. The patents in suit relate to the art of electrical transmission of power by the use of mechanically generating alternating currents. They cover the rotating magnetic field.

A decree for an injunction and an accounting as to all claims in suit was granted.

INSULATION BY COLD.

THE discoveries and inventions of Nikola Tesla have of late been noticeable more for their ingenuity than for their practicality. Whether the latest belongs to this category or not, it is not our place to determine. It is a method for the insulation of electric conductors by immersing them in some medium that insulates when frozen, and by then keeping this below the freezing-point. Mr. Tesla thus describes his invention in a newspaper interview:

"Imagine a great trough extending, if you wish, across the continent. It must contain a quantity of water or some other substance which will freeze. From my experiments I judge that sawdust and water will prove most effective. For the purpose of transmitting the current long distances I shall use a thin metal tube capable of resisting three hundred pounds pressure to the square inch. This tube will be submerged in the substance which I intend to freeze.

"In the whole discovery the most interesting feature is the method I have devised for freezing the material in the trough. Five or six feet below the surface the ground itself is very cold. Here the trough would be buried. Through the tube there will then be forced a current of gas—probably hydrogen—reduced to a temperature of minus 200 degrees or thereabouts.

"This, under ordinary circumstances, will be sufficient to freeze the material surrounding the tube in the trough, and also to neutralize the heat which would be generated by the electricity."

Referring to the advantages that might be derived from this new system of insulation the inventor said:

"It has been known since the days of Faraday that an electrical current can not break through an insulation of ice. My success lies in discovering how practically to apply this truth. To show of what gigantic worth it may be needs but a moment. Grant that the invention has, as I believe, given to the world an almost perfect insulator, immediately there follow results which will directly or indirectly affect every manufacturing industry which in any way uses electricity.

"This will follow from the fact that no electricity will be lost in transmission. The cost of the new insulation will in the end be cheaper than that now used, and so it follows that the electricity which is to be utilized in a thousand different ways can be produced at a less cost. To telephone and telegraph companies, therefore, you see that my invention will be indispensable.

"Water-power converted into electricity can by the new method of insulation be carried thousands of miles. At present the loss of electricity due to unsatisfactory insulation makes this impossible. I have been considering the possibility of carrying the power of Niagara to this city, and find that it can be done with a loss of not more than one-half per cent. to one per cent.

"For the first time in history a power will be used for insula-

tion instead of a property. Deaths from contact with exposed wires will be prevented by the new method. The increase in the speed of exchange of telephone and telegraph messages will be pronounced after the adoption of my discovery.

"These are the important changes in the electrical world which will be wrought by this invention. There will be also innumerable indirect results."

Commenting upon all this *Electricity* (August 22) says editorially:

"This system of insulation, as will readily be seen, would entail the digging of trenches and laying of tubing, to say nothing of forcing a current of gas through the whole system, which, over a long distance, would entail an enormous initial expenditure of money. This would seem to be the principal objection to the system and one which would prohibit its adoption in carrying power to localities situated a hundred or more miles distant, where fuel could be obtained at reasonable prices. That such a system, if found practicable, would have its field of usefulness there is not the slightest doubt, but that field would be limited or not sufficiently extensive to warrant insulation manufacturers looking about for some other means of earning an honest living."

The Tesla Patent Decision.

Further details of the decision of Judge Townsend of the United States Circuit Court for the District of Connecticut, upholding the Tesla rotary-magnetic field patents in the case of the Westinghouse Electric and Manufacturing company against the New England Granite company, are of interest.

Judge Townsend, in sustaining Tesla's claims, directed attention to the sweeping changes brought about in the electrical arts by Tesla's inventions, and paid a strong tribute to the inventor's genius. In reviewing the history of electrical power transmission, the court referred to the earlier state of electrical science when direct current was alone used for the transmission of power, and pointed out the limitations which characterized this method. He then showed that efforts had been made to transmit power by the simple alternating current and that this system had proved inadequate, especially for variable loads. He then went on to state that at this stage of electric science, marked by the limitations of direct-current systems on the one hand and the impracticability of alternating-current systems on the other, Tesla's brilliant conception of the rotating field placed the transmission of power over considerable distances for the first time on a practical basis.

The court then took up in detail Tesla's three fundamental patents (Nos. 381,968, 382,280 and 382,279), covering respectively an electromagnetic motor, the transmission of power therefor, and specific designs of induction apparatus, and reviewed the respective position of the litigants. The defendant alleged that magnetic progression or rotation was not a new principle, but had been known in essence since Argo caused a copper disk to rotate by the rotation of an adjacent horseshoe magnet, subsequent to which Bailey had produced rotation in a similar disk by "an intermittent rotation of the field affected [effected?] by means of electromagnets."

Upon this point the court made an exhaustive analysis of the state of the art at that time, showing that Bailey had not used alternating currents to operate this motor, which was admitted by the defendant to be only a laboratory experiment.

The Westinghouse experts compared the operation of Bailey's intermittent field to the action of "propelling a boat with oars hung on pins so as to be incapable of feathering, and which are held rigidly in the water for a considerable time after each stroke before they are advanced for the next. It is evident that this method of propulsion would involve a large waste of power, since the oars would act alternately to propel and to stop the boat, and the method would be practically useless. Using the same analogy, the action of Tesla's continuously rotating field would be like that of the ordinary screw propeller, in which all the power is applied in a continuous push forward."

With reference to the Siemens and Gramme multiple-circuit machines and other early apparatus, the court cited the contentions of the defendant that these machines embodied in themselves the elements necessary to their operation as motors, and that with "suitable modifications," they would have shown the essential qualities of the Tesla apparatus. On this point the court held that whatever elements of this character these earlier machines may have possessed, such elements were at no time developed, and that their development would have required such a series of experiments, such a departure from then existing theories, and such development and application of devices in unexpected and non-analogous ways, as would in themselves have constituted invention. The court further said, "Siemens himself as late as 1884, and Alteneck, the other inventor of said Siemens' patent, admitted in 1881 that they did not know that alternating currents could be used as (in) motors," this statement being substantiated by sufficient evidence.

In 1887 C. B. Bradley made application for a patent on a dynamo-electric machine, which, the defendant contends, was a two-phase machine; but the court declared that the single specific object of Bradley in this construction was to "obviate difficulties and limitations" in prior constructions, and that he did not indicate any combination of the alternate currents for a single motor or show that he had any conception of their use, if at all, otherwise than separately in single-phase motors.

The court further held that Bradley's claims were limited in scope, were ambiguous and indefinite, and failed in showing any conception, on the inventor's part, of the Tesla idea of the production in a motor of a progressively shifting magnetic field by means of two or more independent alternating currents, differing in phase, and circuits which preserve the independent character and phase relation of such currets and added: "Even if the idea had been first conceived by Bradley, it was not sufficiently described to disclose the principle or method of operation. * * * Tesla was the first to reduce this principle to practice. Bradley does not anticipate or limit."

The defendant's chief reliance was upon the Marcel Deprez publications of 1880-84. In these Deprez had shown a device called a "comparer," in which a stationary ring of iron, carrying two independent windings, was employed. Into these two circuits currents of different strength were simultaneously thrown, the resultant polarity of the ring depending upon the ratio between the two current strengths. As a practical application of this device, Deprez describes the construction of a new form of compass, the needle of which was to respond to the varying current strengths induced in the two windings by changes in their position relative to the earth's magnetic axis. Deprez did not conceive even now of the Tesla idea of utilizing regular, progressive alternations of current, as is conclusively shown by his own statement, made in 1884, that "alternating currents are of no use in the transmission of power; they are suitable only for lighting purposes."

The court stated that, on the other hand, Tesla's underlying thought was "the use of the rapidly successive opposing alternation of the alternating current, regularly and constantly recurring in such differing phases as would not only prevent the alternations from stopping the armature, but would become a source of power. It was essential to the practical development of this idea that the alternations should rise and fall and succeed each other progressively and constantly and should be arranged, as counsel for complainant puts it, 'like the crank on a locomotive in which there is no dead center, but one crank is always pushing forward.'"

Such, then, was the status of the art in 1887, when Tesla filed his applications for patents. Prior to his invention alternating-current motors were not in use, although there had been an urgent demand for some practical means of utilizing alternating currents for power transmission. This demand had been emphasized by the rapid development of the electrical art in other directions, but the leading electricians of the day concurred with Deprez in his declaration that alternating currents could not be used for the transmission of power.

It was at this juncture that Tesla patented his invention, introducing a new method, a new means and a new terminology into the art. The prompt recognition of Tesla among electricians, as the original inventor of a new system and of means for its practical application is abundantly supported by the literature of that day. Tesla did not originate the parallelogram of forces or discover the rotary field, but he was the first to do practically what Bailey had said could be done by an impracticable, if not impossible, apparatus, and what others had vaguely said could be done without indicating the means.

Judge Townsend declared that Tesla, having stated the discovery by himself of a method whereby alternating current could be utilized for power, and having shown the actual machine and method, was as much entitled to a patent for this discovery as were the discoverers of the application of electricity to the telegraph and the telephone, and he added: "A careful study of the evidence has led to the conclusion that Tesla made a new and brilliant discovery. But even if this be incorrect, it is proved that by a new combination and arrangement of known elements, he produced a new and beneficial result never attained before."

The defendant tried to establish a point by showing that in the construction defended none of the transmitting circuits of the system consisted of two conductors specially devoted to any one of the differing phase currents, whereas the patents show two line conductors especially devoted to a single one of the differing phase currents. The court, in commenting upon this point, called attention to the question as to the construction to be placed upon the word "independent" in the Tesla patents, the complainant contending that Tesla's broad invention was the production in a motor of a progressively shifting magnetic field by means of independent alternating currents differing in phase and circuits which preserve the independent character and phase relation of the currents, while the defendant alleged that the words used in Tesla's patent ("induced circuits connected independently to corresponding circuits in the motor") referred to the physical relations which exist, and not to any result produced. But in Tesla's original specification he says: "By 'independent' I do not mean to imply that the circuits are necessarily isolated from one another, for in some instances there might be electrical connections between them to regulate or modify the action of the motor without necessarily producing a new or different action." This clause of Tesla's specification fully answers the last contention of the defendant, who is shown not to have invented any new idea but to have adopted an old contrivance which performs the same result in substantially the same way by a formal and unsubstantial change in means.

In conclusion, Judge Townsend referred eloquently to the genius of Tesla in seizing and adapting to purposes of utility what others had long looked upon as contradictory forces and impassable barriers. He said: "The searchlights shed by defendant's exhibits upon the history of this art only serve to illumine the inventive conception of Tesla. The Arago rotation taught the schoolboy 50 years ago to make a plaything which embodied the principle that a rotating field could be used to rotate an armature. Bailey dreamed of the application of the Arago theory by means of a confessedly impossible construction. Deprez worked out a problem which involved the development of the general theory in providing an indicator for a ship's compass. Siemens failed to disclose the 'suitable modifications' whereby his electric-light machine might be transferred [transformed] into a motor, and Bradley is almost equally vague. Eminent electricians united in the view that by reason of reversals of direction and rapidity of alternations, an alternating-current motor was impracticable, and the future belonged to the commutated continuous current.

"It remained to the genius of Tesla to capture the unruly, unrestrained and hitherto opposing elements in the field of nature and art and to harness them to draw the machines of man. It was he who first showed how to transform the toy of Arago into an engine of power, the 'laboratory experiment' of Bailey into a practically successful motor, the indicator into a driver. He first conceived the idea that the very impediments of reversal in direction, the contradictions of alternations, might be transformed into power-producing rotations, a whirling field of force. * * * A decree may be entered for an injunction and accounting as to all the claims in suit."

,lectrical Review

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On another page of this issue is given, practically in full, the text of the decision lately rendered by Judge Townsend, of the United States Circuit Court, in a suit alleging infringement of the patents granted to Mr. Nikola Tesla, upon the polyphase system of electrical transmission of power. The opinion reflects no little credit upon the learned judge's knowledge of electro-technical subjects. Whatever may be the history of the development of the polyphase system, there is no doubt that it has done more than any other single invention in the field of electrotechnics in the last fifteen years to advance and make possible the greater exploitation of electrical industries that we see about us to-day. The recognition given by Judge Townsend to Mr. Tesla is one that must be gratifying to him, and the text of the opinion, even to those not interested in the particular features of the matter in litigation, will be of peculiar interest as bearing upon the importance of the newer applications of the alternating current.

THE TESLA PATENTS.

SWEEPING DECISION IN FAVOR OF THESE PATENTS BY THE UNITED STATES CIRCUIT COURT.

Judge Townsend of the United States Circuit Court of Connecticut, recently handed down the decision sustaining the three Tesla patents of May 1, 1888. These patents are numbered 381,968, 382,280 and 382,279. The suit was that of the Westinghouse Electric and Manufacturing Company against the New England Granite Company.

The decision is a very sweeping and interesting one to the entire electrical fraternity, and we present it almost in full herewith.

TOWNSEND, District Judge.

The patents in suit relate to the art of electrical transmission of power by the use of mechanically generated alternating electric currents.

It is, of course, understood that the real nature of electricity is still unknown, and that the nomenclature used herein, such as "currents," "flowing," etc., are merely convenient technical terms to indicate certain known results.

The electric current induced by a mechanical generator—a dynamo—is necessarily alternating in character; that is, alternating in direction, so that the current, acting on an armature, first tends to actuate it in one direction and then reverses said effect and neutralizes such actuation. Such a current flows uninterruptedly and regularly, but rises in intensity from zero to maximum and falls from maximum to zero, and then repeats said variations in the opposite direction. Its curve of increase or decrease of strength is indicated by a wave line or sine curve.

Every mechanically generated current is naturally and originally an alternating current. Formerly it was not considered practicable to use mechanically generated currents until their alternations were straightened out by means of commutators which reversed the direction of the current so as to make it flow continually through the conductors. A current which is periodically reversed by a commutator which thus breaks the current between the changes in direction and takes off the current in sections, is known as a reversed or alternating current. This distinction between an alternating and an alternated current should be carefully noted. An alternating current continues to act in opposite directions as originally generated. An alternated current has been so reversed that the whole flows in one direction and is then known as a continuous current. When so reversed by commutators as to become continuous, the current loses certain characteristics essential to its highest efficiency.

Prior to the Tesla inventions, only reversed or alternated electric currents were used for the transmission of power. The application of this system for the transmission of power was limited, for various reasons; among others because a large current could not be safely used at sufficiently high pressure for long distances. On the other hand, the pure alternating current was practically unlimited in volume and pressure, and a change of pressure could be economically effected by the use of a transformer.

Prior to Tesla's inventions, however, these rapid alternations of the alternating current prevented the motor from starting its revolution and interfered with its continuing in operation, except when in synchronism with the generator. It was therefore impracticable for varying loads.

The problem which was presented to Nikola Tesla, and which he successfully solved was: How to overcome the difficulties attendant upon the use of the alternating currents so that their inherent vitality and untrammeled energy might be utilized for the unlimited transmission of power.

In an electric motor, the tendency of the armature is always toward the pole or point of maximum magnetic intensity. If a loosely-pivoted or freely-moving magnetic bar or armature be suspended midway between two coils of insulated wire wound in opposite directions on a soft-iron bar, and one of the coils is electrically energized, north and south poles will be formed at the ends of the soft iron bar—their location depending upon which coil is energized; but if both coils be equally energized, the two poles will neutralize each other and cause a resultant north pole midway between the coils. If, now, the current in one coil be made weaker than in the other, said pole will move toward the coil of greater electrical energy. The magnetic bar or armature will follow the shifting position of the pole, and by thus gradually varying the energy in the coils, the armature may be alternately caused to move from the pole of one coil along toward the pole of the other coil.

The alternating current generated by an electrical machine, as before stated, constantly varies from maximum intensity to zero in one direction, and then from zero to maximum intensity in the opposite direction.

In the invention of the patents in suit, Tesla availed himself of this characteristic feature of alternating currents in the following way:

In constructing a motor, he arranged on an annular soft-iron core, two pairs of magnetizing coils, each pair at right angles to the other, that is, one coil of one pair at the top and one at the bottom, and one coil of the other pair at each opposite side of said core, and mounted an armature in the centre. Then, connecting them with an alternating-current generator, he caused a current from one pole of said generator to pass through one pair of coils and a current from the other to pass through the other pair.

If the cycles of alternating currents be regarded as divided into 360 degrees, then, as shown in the Tesla illustrations, they will have a relative displacement of 90 degrees. In such position the lines of magnetic force traversing the two coils will be at maximum in one while at minimum in the other. This relative displacement marks the differing phase or time relation of the two currents.

The effect of passing two equal currents through said coils would be to cause the pole of maximum intensity to pass midway between the poles of the respective pairs of coils. But the effect of the ordinary operation of the generator as before explained was to cause the current in each pair of coils to vary from zero to maximum and to zero and then to shift in the opposite direction, the intensity of the current flowing to one pair of coils being at maximum while that of the other was at zero and one increasing while the other decreased, and the result being to shift said poles so as to make them travel entirely around said core.

Fifteen days after the issue of the patents in suit, Tesla read before the American Institute of Electrical Engineers a paper entitled "A New System of Alternate-Current Motors and Transformers," in which *inter alia*, he said:

"The transmission of power, on the contrary, has been almost entirely confined to the use of continuous currents, and, notwithstanding that many efforts have been made to utilize alternate currents for this purpose, they have, up to the present, at least as far as known, failed to give the result desired."

"The subject which I now have the pleasure of bringing to your notice is a novel system of electric distribution and transmission of power by means of alternate currents, affording peculiar advantages, particularly in the way of motors, which I am confident will at once establish the superior adaptability of these currents to the transmission of power and will show that many results heretofore unattainable can be reached by their use; results which are very much desired in the practical operation of such systems and which can not be accomplished by means of continuous currents.

"Before going into a detailed description of this system, I think it necessary to make a few remarks with reference to certain conditions existing in continuous-current generators and motors, which, although generally known, are frequently disregarded.

"In our dynamo machines, it is well known, we generate alternate currents which we direct by means of a commutator, a complicated device, and, it may be justly said, the source of most of the troubles experienced in the operation of the machines. Now, the currents so directed can not be utilized in the motor, but they must—again by means of a similar unreliable device—be reconverted into their original state of alternate currents. The function of the commutator is entirely external, and in no way does it affect the internal working of the machines. In reality, therefore, all machines are alternate-current machines, the currents appearing as continuous only in the external circuit during their transit from generator to motor. In view simply of this fact, alternate currents would commend themselves as a more direct application of electrical energy, and the employment of continuous currents would only be justified if we had dynamos which would primarily generate, and motors which would be directly actuated by such currents.

"But the operation of a commutator on a motor is two-fold; firstly, it reverses the currents through the motor; and, secondly, it effects, automatically, a progressive shifting of the poles of one of its magnetic constituents. Assuming, therefore, that both of the useless operations in the system, that is to say, the directing of the alternate currents on the generator and reversing the direct currents on the motor be eliminated, it would still be necessary, in order to cause a rotation of the motor, to produce a progressive shifting of the poles of one of its elements, and the question presented itself: How to perform this operation by the direct action of alternate currents? I will now proceed to show how this result was accomplished.

The claims in issue in Patent No. 381,968 are as follows:

"1. The combination, with a motor containing separate or independent circuits on the armature or field magnet, or both, of an alternating-current generator containing induced circuits connected independently to corresponding circuits in the motor, whereby a rotation of the generator produces a progressive shifting of the poles of the motor, as herein described.

"3. The combination, with a motor having an annular or ring-shaped field magnet and a cylindrical or equivalent armature, and independent coils on the field magnet or armature, or both, of an alternating-current generator having correspondingly independent coils, and circuits including the generator coils and corresponding motor coils in such manner that the rotation of the generator causes a progressive shifting of the poles of the motor in the manner set forth."

That of Patent No. 382,280, is as follows:

"The method herein described of electrically transmitting power, which consists in producing a continuously-progressive shifting of the polarities of either or both elements (the armature or field magnets or magnets) of a motor by developing alternating currents in independent circuits, including the magnetizing coils of either or both elements, as herein set forth."

The claims in issue of Patent No. 382,279, are as follows:

"1. The combination, with a motor containing independent inducing or energizing circuits and closed induced circuits, of an alternating-current generator having induced or generating circuits corresponding to and connected with the energizing circuits of the motor, as set forth.

"2. An electro-magnetic motor having its field magnets wound with independent coils and its armature with independent closed coils, in combination with a source of alternating currents connected to the field coils and capable of progressively shifting the poles of the field magnet, as set forth.

"3. A motor constructed with an annular field magnet wound with independent coils and a cylindrical or disk armature wound with closed coils, in combination with a source of alternating currents connected with the field-magnet coils and acting to progressively shift or rotate the poles of the field, as herein set forth."

Complainant's theory of the Tesla invention is shown in the following citation from the brief:

"It will be observed that to produce a shifting of the magnetic pole in one case, and a consequent movement of an armature corresponding thereto, each coil A and B must be traversed by a current of variable strength, and in order to secure uniformity of the movement of the pole or resultant it follows that the variations in strength of current in the two coils must be gradual and preserve definite relations to each other, throughout the cycle of variation in strength which the two currents undergo.

"This principle lies at the foundation of Tesla's brilliant discovery, the gist of which was the utilization of the alternating currents generated by an alternating-current dynamo or generator for effecting such shifting of the magnetic poles or resultant attractive forces upon the armature of a motor, and thus causing such armature to rotate in response thereto.

"His broad invention, expressed in a few words, was the production in a motor of a progressively-shifting magnetic field (or pole) by means of two

or more independent alternating currents, differing in phase, and circuits which preserve the independent character and phase relation of such currents."

Defendant's position is shown by the following extract from their briefs:

"Referring further to the apparatus of Tesla, Waterman says (Rec., p. 52): 'Briefly then, the apparatus consists of a ring held magnet having one set of coils tending to magnetize it on one diameter and another tending to magnetize it on a diameter at right angles to the first, and these sets of coils or circuits are so connected to a proper generator as to be traversed by currents such as would be generated by two coils at right angles to one another rotating in a two-pole field.' It will be seen from this that complainants claim a broad discovery and a broad invention based thereon. Defendants, on the other hand, contend that the alleged discovery was old, that its application was old, and that, since the days of Arago, there was never any room for a broad invention in the 'obvious' application of the alleged 'discovery;' and that the present state of the art has been developed from the earlier art including Arago's rotation by the mere application of engineering skill possessed by skilled electricians who have applied their knowledge as the progressive demands of the times called for it, supplemented by inventions special to the motor or the generator or the connecting circuits severally, and in no way entitling Tesla or any other patentee to prevent the sale of generators and motors through the ownership of an all-controlling patented 'system.'"

The well-known Arago rotation is described as follows:

"Arago's method of producing rotation in a copper disk consists of suspending it by its centre so as to make it lie horizontally above the poles of a horseshoe magnet and then rotating the magnet about a vertical axis. The rotation of the disk is due to that of the magnetic field in which it is suspended; and we should expect that if a similar motion of the field could be produced by any other means the result would be a similar motion of the disk."

The chief contention of the defendants is that there is no substantial difference in character between alternating and reversed currents and that the art of electric lighting illustrated in the alleged anticipations showed such an analogous use of reversed currents that the substitution of alternating for reversed currents did not involve invention.

Defendant further contends that the principle of reversibility was well known in the art, and as the inventors of electric lighting apparatus state that by a reversal of their action, power may be produced, Tesla is deprived of all claim to the exercise of the inventive faculty. That is, that the same apparatus may be used as a generator or dynamo-electric machine or may be reversed and used as a motor or electro-dynamic machine.

(This word "reversibility" has no relation in this connection to the word "reversed" as applied to currents.)

In support of their contentions defendants chiefly rely upon four prior publications, namely, the Baily article, of 1879; the Siemens patents, of 1878; Deprez's article of 1880-1884, and the Bradley application of May 9, 1887.

[The decision at this point quotes from different authorities at some length, from Siemen's British patent of 1878 for improvement in apparatus for dynamical production of electricity and its regulation when applied for illumination. The statement is also made that on May 9, 1887, about six months before the filing of the Tesla patents, Charles S. Bradley filed his application for his dynamo-electric machine, a generator for converting power into electricity. Judge Townsend continues as follows:]

A comparison of the Bradley application prior to Tesla with the Bradley patent issued subsequent to Tesla shows that in the former he described a method and illustrated an apparatus designed to obviate the objections to a two-phase alternating current by combining both currents in one by means of a transformer, while from the latter he omitted this description and method and inserted figures which, while strikingly suggestive of the apparatus shown by Tesla, failed to show that he conceived the Tesla idea or sought to secure the object of Tesla's invention.

For this reason, and further because Bradley's application is limited in scope, and ambiguous and indefinite; because it fails to show that he had any conception of the Tesla idea of "the utilization of the motor for the purpose of progressively shifting the magnetic poles of a plurality of alternating currents by circuits which preserved the independence and differing time relation of their phases;" because, even if the idea had been first conceived by Bradley, it was not sufficiently described to disclose the principle or method of operation; because Tesla was the first to reduce this principle to practice, Bradley does not anticipate or limit.

Defendants' chief reliance is on the Marcel Deprez publications of 1880-1884, and rightly so, for Deprez not only disclosed the principle which Tesla utilized, but he gave a mathematical demonstration of the rotating field. Complainant's expert's admission on this point is as follows:

"The article demonstrated mathematically the fact, which is also stated in the Tesla patents, that the polar line of an annular magnet may be shifted about through the entire circumference of the ring by the action of two magnetizing forces properly related."

[Judge Townsend here quotes from Deprez's writings, and then says:]

All that Deprez demonstrated, therefore, was that if a field was made in which the field magnet varied relative to the brushes, or *vice versa*, the angle of variation would be indicated by the needle in another machine which would move quickly or slowly as the brushes and magnets shifted relative to each other and would indicate the new angle subtended between the brushes and the magnet. The only useful, practical application of this device was to attach it to a machine which would produce currents, and to use the earth or a ship to indicate the shift of position by means of a needle on top of the mast. This apparatus failed to teach any one that alternating currents could be used as a source of power in a motor. It was a mere indicator. It did not involve the utilization of two alternating currents differing in phase as a source of power in producing a continuous magnetic field. It did not depend upon any constant, regular, progressive currents, and, so far as the evidence shows, it was like the apparatus of Baily, confessedly a mere laboratory experiment. That Deprez did not conceive of the Tesla idea of utilizing regular, progressive, constant alternations of current is conclusively shown by his own statement in 1884, after the publication of this paper and after the invention of the Gaulard and Gibbs alternating-current systems for lighting, when he published another paper in which he criticised the system and stated that one of the most serious objections to it was that it was not applicable to the transmission of power, and adds: "I must further remark that alternating currents are of no use in the transmission of power; they are suitable only for lighting purposes."

In fine, the evidence shows that, as Professor Silvanus Thompson says in his work on this general subject: "Deprez's theorem bore no fruit; it remained a geometrical abstraction."

The underlying thought disclosed and applied in the Tesla patents is such a use of the rapidly successive opposing alternations of the alternating current regularly and constantly recurring in such differing phases as would not only prevent the alternations from stopping the armature, but would become a source of power. It was essential to the practical development of this idea that the alternations should rise and fall and succeed each other progressively and constantly should be arranged, as counsel for complainant puts it, "like the crank on a locomotive in which there is no dead centre, but one crank is always pushing forward." Tesla's invention, considered in its essence, was the production of a constantly rotating or whirling field of magnetic forces for power purposes by generating two or more displaced or differing phases of the alternating current, transmitting such phases, with their independence preserved, to the motor, and utilizing the displaced phases as such in the motor.

Baily does not describe the use, with alternating currents, of displaced phases. He only describes the producing of intermittently shifting poles by means of a commutator or reverser which is just what Tesla disclaims. Neither Siemens nor Bradley describes the utilization of such displaced phases of alternating currents with their independence preserved in a motor.

Deprez describes a parallelogram of forces and its application to indicate at any given moment the angle between two parts of a source of current. He did not contemplate the use of alternating currents nor utilize their continuous and constant movement nor did he utilize said current to produce power, nor did he have any idea of a whirling field of forces to propel a motor.

What then was the status of the art in 1887 when Tesla filed these applications?

Nine years had elapsed since the grant of the Siemens patent which, according to counsel for defendants, "is a full disclosure of the subject matter in issue in Patents Nos. 381,968 and 382,280," and its "references . . . at the hands of the skilled electrician . . . would naturally, and as a matter of course, have resulted in an organization of elements constituting a system for the electrical transmission of power and embodying essentially the system" of said patents. Eight years had elapsed since Baily. It was four years since Marcel Deprez's article, according to defendant's counsel, "described the very thing that complainant claims is Tesla's discovery and explained the theory of operation," of an apparatus which "is an operative two-phase alternating-current generator supplying two-phase alternating currents to produce a rotating field in a motor" similar to the Tesla motor.

Prior to Tesla's invention no alternating-current motors were in use.

Although there has been an urgent demand for some practical means of utilizing alternating currents for transmission of power none had been found.

The continuous and unparalleled development of the electric art had for years increasingly emphasized the want of an electric motor capable of distributing power for long distances and had vainly called for the solution of the problem of the use of alternating currents for this purpose; the leading electricians of the day concurred with Deprez in his declaration after he had devised his comparateur that alternating currents could not be utilized in the transmission of power and that the future belonged to continuous currents.

In these circumstances Tesla patented his invention and thus first disclosed the method and apparatus, now generally known as the Tesla polyphase inventions, and introduced a new method, a new means and a new terminology into the art. Six months later he read his paper before the American Institute of Electrical Engineers and announced that previous efforts to utilize alternate currents had failed; that he had brought forth a novel system for the transmission of power, and explained its theory and demonstrated its operation by exhibiting a working motor; and no one of the electricians present questioned his claim or criticised his apparatus.

The statements made by electricians at said meeting are supported by abundant quotations from the contemporaneous literature of the day, and it does not appear that the recognition of Tesla as an original inventor of said system and of the means for its practical application was ever disputed until this suit was brought.

There is nothing in the record to detract from the claims then made. Tesla did not discover the parallelogram of forces; he did not discover the rotary field; but he was the first to explain how to do practically what Baily had said could be done by an impracticable infinity of magnets, and others had said it could be done, but without showing how it could be done. He harmonized the hitherto opposing alternations, while preserving their character and power.

Since the date of the Tesla patents in suit

there has been a revolution in the art due to the utilization of the means therein described.

The contention that the transfer from the electric light art to the electric power art did not involve invention can not be maintained.

Even if it be assumed that the art of electric lighting is in a sense analogous to that of electrical transmission of power, the result was new and unexpected. It has been already shown in what respects a reversed current differs from an alternating current. The question as to how far they are alike is of minor importance because it is admitted that the reversed or broken current is not the same for the practical purposes to which this invention is especially adapted. Therefore, although Deprez, in one of his publications, suggested that his system might be used for an impracticable and almost infinitesimal amount of power, the fact that these currents had never been practically used for any such purpose and can not, even now, be practically used for currents of high potential, shows that it required invention to select from an art that particular kind of current which was necessary for the production of the best results, and to adapt the mechanism of an art analogous or non-analogous, to its practical application.

The very fact that all the earlier electricians assumed or asserted that reversed and alternating currents were the equivalents of each other, was one of the errors which retarded the Tesla discovery, and the practical application of the polyphase principle.

The view most favorable to the contention of the defendants upon all the evidence presented, may be fairly stated thus:

Prior inventors had stated that electric light machines could be so reversed as to furnish power, although it is not proved that any one had shown a method for their use or the practical application thereof, or had ever made such practical application.

No prior publication explained how to utilize this alleged well-known reversibility and no prior machine applied it.

To the question why, if it was so obvious that the operation of the apparatus might be reversed and alternating currents then used, such method was not put in practical operation, the only answer of defendants is that "there had been up to 1885 no commercial system of distribution of alternating currents." But if this is so, is it not because the foremost electrical experts throughout the world had united in the opinion after repeated futile experiments that alternating currents were useless for the transmission of power and that the future belonged to continuous currents?

"The apparent simplicity of a new device often leads an inexperienced person to think that it would have occurred to any one familiar with the subject, but the decisive answer is that with dozens and perhaps hundreds of others laboring in the same field, it had never occurred to any one before." Potts *vs.* Creager, 155 U. S., 597.

Siemens, chiefly relied on to support this contention, does not describe any mode of using alternating currents, does not refer to the use of commutators, and only refers to the use of said apparatus as an electro-dynamic machine "with suitable modifications" which are nowhere described.

The impracticability as motors of reversed currents induced by commutators, shows that Siemens, Baily and others did not discover the Tesla invention; they were discussing electric light machines with commutators.

Tesla first stated the discovery how these alternations could be thus utilized and showed the machine and method adapted for this purpose. He is entitled to a patent for this discovery as were the discoverers of the use of anthracite coal instead of bituminous coal, or of the hot blast instead of the cold blast, in the manufacture of iron, or of the practical application of electricity to the telegraph or telephone. Judge Blacthford once sustained a patent for insulating electric wires by means of gutta-percha, and said:

"The gist of the invention is the discovery of the fact that gutta-percha is a non-conductor of electricity, and the application of the fact to practical use. The claim is valid, even though a metallic wire covered with gutta-percha existed before the plaintiff's invention, if it was not known that gutta-percha was a non-conductor of electricity, and could be used to insulate the wire." Colgate *vs.* Western Union Telegraph Company, 6 Fed. Cases, 86.

It is not necessary to go to this extent in sustaining these patents. The complainant may safely rest its case on the general principles laid down in the various decisions of the Supreme Court and extended and developed in Potts *vs.* Creager, *supra.*

But if the evidence already considered be disregarded, and it should be assumed that alternating and alternated currents were theoretically-known equivalents, even then the argument for counsel for defendants does not appear to be sound. They contend that a superior result, by reason of the substitution of one known equivalent for another, does not constitute invention. But the first substitution or application of such theoretical equivalent to produce a new or non-analogous or unexpected result, may involve invention. Tesla applied the alternating current to do what the alternated current had never before done; namely, to produce a new, unexpected and practical system of transmission of power.

A careful study of the evidence has led to the conclusion that Tesla made a new and brilliant discovery. But even if this be incorrect, it is proved that by a new combination and arrangement of known elements, he produced a new and beneficial result never attained before.

The technical defense of non-infringement by reason of the fact that defendants use only a motor, and that there is no allegation or proof of conspiracy with the owners of the plant which supplies the power, was not pressed on the argument, and, as six days were spent in the discussion of the questions on the merits, this point will not be discussed.

If any amendment is necessary to cover these points it should be allowed.

The contention of defendants that Tesla does not describe an operative machine, is not satisfactorily proved. It is proved that, in fact, several practical motors have been manufactured according to his invention.

The model of the particular patented construction selected for this proof, claimed to correspond most nearly to defendants' construction, failed to show a capacity of self-starting, and, when once started, revolved in either direction; but complainant showed on the hearing various differences between the construction shown in the drawing of the patent and the model, which, it was claimed, accounted for the failure.

The defendants use a three-phase transmitting system comprising a three-phase generator, three transformers and a three-phase motor. The argument based on the use of transformers was not pressed. . . .

The serious question raised in this branch of the case is as to the construction of the word " independent" in the patents. Counsel for defendants contends that "the word used in the patent evidently refers to the physical relations which exist and not to any result produced." Counsel for complainant contends that Tesla's "broad invention . . . was the production in a motor of a progressively shifting magnetic field by means of . . . independent alternating currents differing in phase, and circuits which preserve the independent character and phase relation of such currents."

The specifications and drawings of said patents describe and show six independent transmitting wires which are repeatedly referred to as constituting independent circuits, and the claims emphasize this independency. In defendants' motor the coils of generator and motor are so interconnected that each line wire not only serves as a conductor for its own phase, but also for the other currents.

Defendants' contention is fairly stated by counsel for complainant as follows:

"The defendants contend that currents of electricity belonging to each of the circuits are, therefore, at times all flowing in the same wire or wires, and that at certain instants in the operation of the same; *i. e.,* when each of the single transmission wires is, for an incredibly short period, transmitting no potential (*i. e.,* change from plus to minus)—two of the coils of the motor are supplying current to the third. . . . They cite the admission of Mr. Waterman that 'analytically' it is perfectly true that currents of electricity of differing phase may be at times regarded as simultaneously flowing in the same circuit."

This statement of Waterman, however, should be read in connection with his further statement, as follows:

"The net result of it all is that in a manner more or less complex to follow, these electromotive forces so cancel out that there is in each circuit a current differing in phase by 120 degrees from the current in each of the others, so that in the motor it is not possible to tell how the current got there, or over what kind of a circuit. (*i. e.,* whether over a three-wire or a six-wire circuit.)"

Counsel for defendants argue:

"That the term independent as used by Tesla means such separation as is consistent with having the complete circuits traversed by the same currents—currents which at any and every point are of the same quantity, intensity and phase, so that, as Mr. Clarke puts it, each motor circuit receives its current from a corresponding generator circuit and from no other. It can not refer to circuits which are interdependent in such sense that two of the circuits are at times strictly in series with one another and in multiple with the third, and so are not 'independent' in any sense. The whole system is an interdependent and not an independent system."

The following significant statement, however, is found near the end of the specification of the first patent, No. 381,968:

"By 'independent' I do not mean to imply that the circuits are necessarily isolated from one another, for, in some instances there might be electrical connections between them to regulate or modify the action of the motor without necessarily producing a new or different action."

The claims, therefore, confessedly can not be read as requiring isolation of the circuits but at most only such independence as is necessary for the purpose of producing a rotary field; that is, the connections must be such as not to interfere with the independency of the circuits which operate to shift the poles.

The only practical result from defendants' use of three conductors instead of six is an improvement "to regulate the action of the motor," which result was anticipated by Tesla as above, and it is proved that it was known in the prior art that one of these arrangements was a substitute for the other.

Inasmuch as the defendants have not invented any new idea, but have adopted an old contrivance which performs the same result in substantially the same way by a formal and unsubstantial change in means, and by circuits which, while in some sense interdependent, are operatively independent, and which preserve and utilize the vital element independence of phase, these circuits must be held to be the equivalents of the independent circuits of the patent, the word independent being interpreted to mean operatively independent, so as to embrace the true spirit and essence of the Tesla invention.

This conclusion is supported by a great number of illustrations of similar uses of such independent conductors in the general field of the arts. As the expert for complainant has pointed out, in railroads, cash carriers, electric telegraphs, the tracks, the earth or a single wire, will serve as common but independently-acting conductors.

It does not seem necessary to further discuss this contention based on a technical verbal distinction.

Defendants' three wires are operatively independent; they are actually independent while in action; they are independent enough to do the required work.

This case involves a diversity of complicated questions of the scope and effect of certain language, of the prior art, and of the operation of electrical apparatus. All these questions have been exhaustively discussed with singular ability and learning by the able counsel herein.

If the contentions of defendants as to the scope of the patents in suit are proved the question of infringement of the patented independent circuits is not free from difficulty. If independence means isolation the patents are valueless. But if complainant's contention is correct, and if Tesla is entitled now

to the broad claim which no one denied when he announced it to the American Institute of Electrical Engineers as his "novel system of electrical distribution and transmission of power by means of alternate currents . . . which will at once establish the superior adaptability of these currents to the transmission of power and will show that many results heretofore unattainable can be reached by their use," then there can be no question that defendants have infringed. The foregoing language has been again quoted in order to emphasize how consistently at the end of 10 years after a review of all possible questions Tesla stands upon his original statement of invention.

Infringement of the first claim of Patent No. 381,968, necessarily implies infringement of the method Patent No. 382,280. The finding that the circuits of the defendants are independent, in the sense of the Tesla patents, is decisive against the defendants as to the infringement of the first and second claims of Patent No. 382,279; and the field magnet of defendants' motor, while differing in some respects from that of the third claim of No. 381,968, is annular or ring-shaped within the meaning of said claim and infringes it.

At the close of the defendants' brief is printed the "Decision of the Imperial Court of Germany on Tesla Patent." The only reference thereto in said brief is in the statement that in said suit "brought to obtain a cancellation of Tesla's patents, that a German patent to one Haselwander (including the rotary-current system employed by defendants) was partially annulled because of the publication of this American patent to Bradley" and in the following statement:

"It should also be mentioned that the Imperial Court held that the system employed by defendants does not infringe the German Tesla patent corresponding to the patents involved in this suit —that court holding with us that our system is a dependent system and not having the independent circuits of the Tesla patents and inventions."

It is somewhat difficult to determine, from said opinion, the scope of the issues involved, but it appears that some German firm had applied to have two Tesla German patents canceled on the ground that they have not been worked, but "have only been used to the disturbance of the electro-technical industry in Germany." Tesla, as defendant, admitted that he had not actually worked his invention, but had fulfilled his duty by a license to a firm which had pledged itself to work the patents, and, furthermore, that certain alleged infringers, by using a rotary-current, three-wire system, which seems to have been substantially like that of defendants herein, had "worked" his invention, and thereby saved him from the statutory penalty. The court held as follows:

"'By independent is not meant to be expressed that the circuits are necessarily insulated from each other, since in single cases electrical connections can exist between them in order to regulate the working of the motor, without necessarily producing a new or another manner of working,' then also nothing is gained for him thereby. Entirely disregarding the fact that after the striking out of the sentence, which clearly occurred in order to avoid unclearness, the independence of the circuits is only so to be understood as is shown from the drawing and description—namely, as conditioned by a completely independent outgoing and return conductor—there would also never be able to be read into the stricken-out sentence that therein the linking of the circuits in the meaning of the rotary-current system had been thought of, for this linking removes the independence of the circuits, while the erased sentence will only admit such connections as permit the independence of the circuits to exist."

But this statement is a mere *obiter dictum*. The explanatory language relied upon by complainant in the patent here in suit has been stricken out of said German patent. The decision was upon two patents not shown to be the same as those herein in suit; the applications therefor were not filed until May, 1888, and not until after the Tesla invention had been described in a printed publication. But even this decision is to be construed as insisting upon a construction unfavorable to that here contended for by complainant, it should only be considered in connection with the foregoing facts. Here, the question of independence is directly presented, on a different issue, in view of a different state of the art, upon a different patent, from which the explanation of the word "independent" has not been erased. No sufficient reason has been shown why the conclusion of the German court should be followed in determining the question of infringement herein.

The search lights shed by defendants' exhibits upon the history of this art only serve to illumine the inventive conception of Tesla. The Arago rotation taught the schoolboy 50 years ago to make a plaything which embodied the principle that a "rotating field could be used to rotate an armature." Baily dreamed of the application of the Arago theory by means of a confessedly impossible construction. Deprez worked out a problem which involved the development of the general theory in providing an indicator for a ship's compass. Siemens failed to disclose the "suitable modifications" whereby his electric light machine might be transferred into a motor, and Bradley is almost equally vague. Eminent electricians united in the view that by reason of reversals of direction and rapidity of alternations an alternating-current motor was impracticable, and the future belonged to the commutated continuous current.

It remained to the genius of Tesla to capture the unruly, unrestrained and hitherto opposing elements in the field of nature and art and to harness them to draw the machines of man. It was he who first showed how to transform the toy of Arago into an engine of power; the "laboratory experiment" of Baily into a practically successful motor; the indicator into a driver; he first conceived the idea that the very impediments of reversal in direction, the contradictions of alternations might be transformed into power-producing rotations, a whirling field of force.

What others looked upon as only invincible barriers, impassable currents and contradictory forces, he seized, and by harmonizing their directions utilized in practical motors in distant cities the power of Niagara.

A decree may be entered for an injunction and an accounting as to all the claims in suit.

DISCUSSION AND CORRESPONDENCE.

MR. TESLA AND THE UNIVERSE—HUMAN ENERGY AND HOW TO INCREASE IT—HIS PHILOSOPHIZING QUESTIONED.

MR. NIKOLA TESLA has written a long article in the *Century Magazine* for June with the title 'The problem of increasing human energy, with special reference to harnessing the sun's energy.' The paper is profusely illustrated with impressive cuts of electrical experiments which, at first sight, seem convincing. Most readers of the *Century* looked at the striking cuts and glanced at some of the head lines of the article such as 'Development of New Principle'; 'Production of Immense Electrical Movements'; 'The Earth responds to Man'; Interplanetary Communication now probable,' and accepted the headlines on the testimony of the cuts; or else took it frankly for granted that so long an article must certainly prove a great deal.

The present writer has lately gone over the text of the article, pen in hand, and herewith

presents a small portion of his notes. They seem to him to show that the article in question is composed, essentially, of three different kinds of writing. The first kind describes Mr. Tesla's experiments in electricity and shows what he has already accomplished. This work is, no doubt, important. Its value will be appraised by experts. The present writer has no claim to be considered an electrical expert and does not attempt to give an estimate of the achievements referred to. The second describes what Mr. Tesla expects to accomplish in the future. His prophecies are so sanguine, in many cases, that even a general reader may presume to compare them with the comparatively small things already accomplished and to point out how very unlikely it is that any great part of his expectations will be realized within any reasonable future—within Mr. Tesla's own lifetime, for example.

The third element of this article consists of philosophical arguments about things in general—about human life—what it is—the future of the solar system—the solidarity of the human race—the Christian religion—vegetable food—theoretical dynamics—athletics in colleges—drinking water—ozone—education of women—ice—fertilizers—insanity—warfare—flying machines—iron manufacture—aluminium—liquid air—self acting engines—the inhabitants of Mars—etc., etc., etc.

Now these and other matters are interesting in themselves. We are all anxious to obtain new light upon them. We are all more or less competent to judge the conclusions of other people regarding them. It is not too much to say that this portion of Mr. Tesla's paper is in the main so trivial, so superficial, so obviously weak, as to throw doubt upon the whole essay. Many of the subjects treated are the oldest problems of the human race. They have been discussed by every philosopher since Aristotle. It is fairly astonishing to see Mr. Tesla's reasonings in print at this day. They compare with the logic of giants like Spinoza, Kant, Lord Kelvin, Herbert Spencer, and the rest as a baby's prattle to the 'Summa Theologiæ.'

If this judgment seems too harsh the following paragraphs will fully confirm it. No discourtesy is meant to Mr. Tesla. But his paper has been printed. It now belongs to his readers. He must allow them to compare his philosophizing with that of his great predecessors and with the dicta of common sense.

The paper begins by asking profound questions with regard to human life. Whence comes it? What is it? Whither does it tend? "*Though we may never be able to comprehend human life, we know certainly that it is a movement, of whatever nature it may be,*" is Mr. Tesla's answer. A movement?—*one* movement? Are we sure it is a movement, and nothing else? "*Hence, wherever there is life, there is a mass moved by a force.*" A mass? A force? Why not masses, forces, hundreds of them? These beginnings which seem so definite lead to the conclusion that life is a *rhythm*, but this conclusion is at once dropped for the utterly antagonistic conception that man, mankind, is '*a mass urged on by a force.*' A force will urge a mass onward, not swing it rhythmically. We need not linger over this discrepancy, though there might be something to say, if it were worth while.

Mankind is then conceived as *one* physical mass; and Mr. Tesla's proof that this is a true conception is derived from the fact that every one of us feels sympathy with a friend who is hurt. Here is a mixing of two worlds—the world of matter and the world of feeling—which does not tend to clearness. The man born blind thought the sunset like a pleasing friendship. Swedenborg in his idea of the Grand Man who is the sum and integral of all individual men has put the question in a much truer light; but let us pass on. Man is, according to Mr. Tesla, '*a mass*,' one physical mass. Call this physical mass M. M is a quantity which can be expressed in tons or in ounces. Mankind is '*impelled in one direction*'—*one* direction!! by a force f, "*which is resisted by another force R, acting in a direction exactly opposite.*"

The idea in Mr. Tesla's mind is apparently that the force R is the reaction of the first force f. But every reaction is not only opposite to its action but equal to it, according to Newton. Not so in Mr. Tesla's universe. Reactions are opposite to, but less than actions. There is an effective force left over, which, in

his scheme, imparts a velocity V to mankind, M. "*Human energy will then be given* (measured) *by the product* $\frac{1}{2} MV^2$, *in which* M is the *total mass of man in the ordinary interpretation of the term 'mass,'* and V *is a certain hypothetical velocity which, in the present state of science, we are unable exactly to define and determine.*" How learned all this looks! and how foolish it all is! Mankind has a physical mass, no doubt. The *energy* of mankind is the sum of a million different energies, of very different *qualities* as well as of different amounts—spiritual as well as physical. These different energies, being of different kinds, cannot be expressed by a single term. Mr. Tesla's algebraic formula is mere solemn rubbish. It has absolutely no meaning.

There are three ways of increasing human energy, Mr. Tesla says: I. To increase the mass and energy of mankind more children must be born, fewer individuals must die, and the children must be of '*higher velocity*' than the parents (and *velocity* Mr. Tesla takes as exactly equivalent to *enlightenment*). Here Mr. Tesla pauses to discourage college athletics, and to say that although whisky, tea and tobacco shorten human life, yet he does not think that vigorous measures should be taken to suppress the habits of using them. On the contrary he would leave whisky alone, and improve the quality of drinking water. '*Gambling, business-rush, excitement * * * uncleanliness * * * laxity of morals * * * the society-life, modern education and the pursuits of women*' and other matters tend to diminish the mass of mankind, but want of food is the chief cause.

Cattle are food of '*low velocity*' (enlightenment) Mr. Tesla says, and he does not approve of raising cattle, therefore. '*It is certainly preferable to raise vegetables.*' Here he has forgotten his basic principle, unless, indeed, he is prepared to prove that turnips are food of 'high velocity,' *i. e.*, enlightenment. Here, again, as in the case of rhythmic motion, he no sooner lays down a principle than he abandons or neglects it for something quite different. However his vote is for vegetables, and more are wanted. To fertilize the soil more nitrogen is needed. He has an electric method for obtaining nitrogen from the atmosphere (so has Sir William Crookes) and the world's food supply is safe. All this is very well known. There is nothing new about it except the solemn manner in which it is said.

II. The second point is to reduce the force that retards the human mass. This force is a compound of ignorance, stupidity, imbecility, insanity, religious fanaticism, etc. It is not so simple then as Mr. Tesla's 'force R' with which he began. Warfare is a retarding force but Mr. Tesla thinks it will be with us for some time yet, and indulges in a short excursion on flying-machines. "*The flying-machine is certainly coming and very soon. I see no reason why a ruling power like Great Britain might not govern the air as well as the sea. I do not hesitate to say that the next years will see the establishment of an 'air-power,' and its center may not be far from New York*" (possibly in Mr. Tesla's laboratory?). After a couple of pages devoted to warfare, harbor-defense, flying-machines, foreign invasion, international agreements, eternal justice, prehistoric man and his weapons, Mr. Tesla concludes that future battles will be decided by matching one complicated machine (say British) against another (say Russian).

"*Machines will meet in a contest without bloodshed, the Nations being simply interested, ambitious spectators. When this happy condition is realized peace will be assured.*" "*Bloodshed,*" Mr. Tesla thinks, "*will ever keep up barbarous passions.*" Hence we must '*produce a machine capable of acting as though it were a part of a human being.*' Such a machine may be destroyed but no blood will flow. Mr. Tesla has not yet produced a machine of the sort but he means to do it.

He tells us that as a boy he noticed that whatever he thought of he saw. He visualized words in his mind. By attention he discovered that every occurrence in his mind was suggested by some previous outside occurrence or object. Hence, he was not a free agent, but played upon by his environment. He was the sport of the universe—an automaton. "*I have demonstrated, to my absolute satisfaction, that I am an automaton endowed with power of movement, which merely responds to external stimuli beating on its sense-organs, and thinks and acts and moves accordingly.*" He may be an automaton; but if he thinks that the foregoing argument proves

it, he is no logician. Being an automaton himself Mr. Tesla proceeded to make another automaton. He consented to make it full-grown to save time. It was also unnecessary to endow it with the power of propagating its kind, since Mr. Tesla himself could make more machines when he wanted them. He likewise consented to make it without a mind, because a mind '*I could easily embody in it by conveying to it my own intelligence.*'

With these slight differences from the Garden of Eden Mr. Tesla's workshop has turned out a kind of electrical boat or animated bath-tub (see the cut) whose movements can be controlled from a distance. This machine '*behaved just like a blindfolded person obeying directions received through the ear.*' It had a '*borrowed mind.*' In fact, it had no mind at all, except in Mr. Tesla's confused terminology. It had the same kind of a mind as a Waltham watch. It is now Mr. Tesla's intention to build an '*Automaton*' '*which will have its own mind.*' "*It will be capable of distinguishing between what it ought and what it ought not to do.*"

Of course, such words are merely quibbles. In exactly the same sense a steam-engine has its own mind, and distinguishes what it ought from what it ought not to do. So did Maelzel's mechanical duck. So did Babbage's calculating engine. So does every device. Either the words mean nothing new; or else they are deceptive quibbles. It does not mend matters to say: '*my ideas on this subject have been put forth with deep conviction, but in a humble spirit.*'

Universal peace will be realized, he says, "*when all darkness shall be dissipated by the light of science, when all nations shall be merged into one, and patriotism shall be identical with religion, when there shall be one language, one country, one end, then the dream will have become reality.*" To bring about these desirable conclusions, an automatic fighting machine is necessary. Mr. Tesla is now engaged on the question automatically.

III. But all this while the main point has been lost sight of in divagations. How to increase the forces moving the human mass is the question. For reasons not adduced Mr. Tesla declares that '*the resultant of all these forces is always in the direction of reason.*' Every individual man is an automaton, we have seen, and will act unreasonably if played upon by certain forces. But mankind, which is made up of men, always acts reasonably. 'Tis strange; one seems to recall instances from history that refute the assertion. And indeed, Mr. Tesla himself does not really believe it. What is this busy world, he asks, but 'an immense clock-work?' A 'reasonable' clock-work! He finds, finally that "*the great problem of increasing human energy is answered by the three words: Food, Peace, Work.*" "*These three words,*" he says "*sound the key-note of the Christian Religion.*" One had supposed that Faith, Hope and Charity were the key-notes of the Christian religion; and that this religion had no message at all to a world of automatic men.

With a touching little eulogy on iron, and the prediction that aluminum is soon to take its place, and a good word for coal and for gas-engines, he passes on to the question of obtaining energy direct from the sun, and discusses the "*possibility of a self-acting engine or machine, inanimate, yet capable, like a living being, of deriving energy from the medium.*" His conclusion is that it is possible though it cannot be produced for a long time yet. It is not pressing, then, to discuss his results. We will wait until some are forthcoming.

The next paragraphs of Mr. Tesla's long paper are taken up with the description of his experiments on electrical matters, wireless telegraphy (which Marconi independently discovered and has made practical), etc. Into these we will not follow him, except to say that he claims to be able to produce electrical effects on the planets Venus or Mars by methods which he is very careful not to explain. He expects an answer, too: "*That we can send a message to a planet is certain, that we can get an answer is probable; man is not the only being in the Infinite gifted with a mind.*"

We might go on page by page, pointing out error, extravagance and bathos like the preceding. There seems to be no special need to go further. It should be evident to any impartial reader that the value of Mr. Tesla's general philosophical speculations and opinions is exactly *nil*. The value of his work in elec-

tricity must be judged by experts. The weight of his predictions as to future discoveries would be greater if his judgment on things in general were less unsound. It is passing strange that such loose reasonings can find a publisher. It is to be hoped that they will gain little credence from his readers. A line from Plato's Republic applies here (changing a word) to wit: "I verily believe that it is a more venial offence to be the involuntary cause of death to a man than to deceive him concerning scientific truth."

* * *

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Mr. Tesla has made so many curious statements in relation to what he proposes to do that it is pleasing to note a generous recognition of the valuable work that he has actually accomplished. Such a tribute is paid in the recent opinion of Judge Townsend, upholding the rotating-field patents granted on Tesla's brilliant discovery. Through the daily and technical press this judicial decision has gained wide publicity and will serve to bring again to mind an important portion of Tesla's really beneficial work.

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TESLA has so injured his prestige by premature and impracticable assertions that his announcements in the field of electrical discovery do not attract the attention they formerly commanded. His latest claim is to have successfully overcome the cause of electrolysis, and he has an invention designed to prevent the escape of electricity from a wire. He claims that he can insulate the wire by passing through it or near it air kept at a low temperature, producing a coat of ice on the wire which cannot be broken through by the strongest currents, and at the same time gives an insulation that costs practically nothing. By means of this the loss of electricity or electrical energy in transmission, it is claimed, can be rendered so small as to be insignificant, and power can be transmitted to great distances by means of underground wires. So far it is only a claim, but on a subject of surpassing interest to the electrical world.

Tesla Patents Sustained.—The suit of the Westinghouse Electric & Manufacturing Company against the New England Granite Company upon an infringement of the three Tesla polyphase power-transmission patents issued May 1, 1888, was recently decided in favor of the Westinghouse Company. The decision is a very sweeping one and is phrased in part in vigorous verbiage. Other parts of the decision appear unnecessarily oratorical; a notable paragraph of this character reads as follows: "It remained to the genius of Tesla to capture the unruly, unrestrained and hitherto opposing elements in the field of nature and art and to harness them to draw the machines of man. It was he who first showed how to transform the toy of Arago into an engine of power; the 'laboratory experiment' of Baily into a practically successful motor; the indicator into a driver; he first conceived the idea that the very impediments of reversal in direction, the contradictions of alternations might be transformed into power-producing rotations, a whirling field of force."

The Tesla Patents.—A decision, considered to be of some importance on the other side of the Atlantic, has been given in the United States Circuit Court of Connecticut with regard to the three Tesla patents, Nos. 381,963, 382,280 and 382,279 of May 1, 1888. The following were the claims at issue in the three patents :—

Patent No. 381,968.

1. The combination, with a motor containing separate or independent circuits on the armature or field magnet, or both, of an alternating-current

generator containing induced circuits connected independently to corresponding circuits in the motor, whereby a rotation of the generator produces a progressive shifting of the poles of the motor, as herein described.

3. The combination, with a motor having an annular or ring-shaped field magnet and a cylindrical or equivalent armature, and independent coils on the field magnet or armature, or both, of an alternating-current generator having correspondingly independent coils, and circuits including the generator coils and corresponding motor coils in such manner that the rotation of the generator causes a progressive shifting of the poles of the motor in the manner set forth.

Patent No. 382,280.

The method herein described of electrically transmitting power, which consists in producing a continuously-progressive shifting of the polarities of either or both elements (the armature or field magnets or magnets) of a motor by developing alternating currents in independent circuits, including the magnetising coils of either or both elements, as herein set forth,

Patent No. 382,279.

1. The combination, with a motor containing independent inducing or energising circuits and closed induced circuits, of an alternating-current generator having induced or generating circuits corresponding to and connected with the energising circuits of the motor, as set forth.

2. An electro-magnetic motor having its field magnets wound with independent coils and its armature with independent closed coils, in combination with a source of alternating currents connected to the field coils, and capable of progressively shifting the poles of the field magnet, as set forth.

3. A motor constructed with an annular field magnet wound with independent coils and a cylindrical or disc armature wound with closed coils, in combination with a source of alternating currents connected with the field-magnet coils, and acting to progresively shift or rotate the poles of the field as herein set forth.

The action was brought by the Westinghouse Electric and Manufacturing Co., the owners of the Tesla patents, against the New England Granite Co., and the judge declared that the patents were valid, and had been infringed.

DISCUSSION AND CORRESPONDENCE.

NEWSPAPER SCIENCE.

TO THE EDITOR OF SCIENCE: I have had so much satisfaction in the review and criticism recently published in SCIENCE, of Mr. Tesla's magazine article on 'Human Energy' that I cannot avoid making public acknowledgment of my appreciation of its justice and timeliness, especially the latter. Is it not the imperative duty of men of science to do what the author of this review has done, more frequently than they have during the past ten years?

Within this decade there has been an enormous decrease in the cost of publication and especially in the expense of illustration, and this has brought about a deluge of reading matter of such infinite variety and general worthlessness that the formation of a society for its systematic suppression is worthy of serious consideration. With the daily newspapers it has been distinctly an era of sensationalism.

A reporter for a daily paper recently de-

clared that he was required by his chief to 'furnish at least two sensations a week.' Nearly all the more respectable and conservative magazines have yielded somewhat to this demand. The general reading public has recognized in an indistinct and uncertain way that much that is wonderful in this 'wonderful century' is due to scientific discovery, and it is apparently hungry for easy exposition of scientific work. It seems to like, at any rate it is largely fed upon, science of the 'head-line' variety, and those who can furnish this sort are in great demand. Unfortunately there are a few men, fortunately not many, who have done and are doing really excellent scientific work who are ready to cater to this morbid appetite, and there are many others, merely 'hack' writers with neither knowledge or reputation, who find it easy to imitate them. The result tends to dull the scientific sense and corrupt the judgment of the great majority of readers. What we see in print concerning what we do not understand we almost invariably accept as true unless it violently opposes our prejudices or accepted theories, and the general public, therefore, is in a very receptive mood towards announcements of scientific discoveries and accomplishments. That this is taken advantage of to reach the purse of the public no one can deny, and it is impossible not to find certain very respectable and otherwise conservative journals largely responsible for losses of thousands of dollars by comparatively poor people through stock subscriptions in schemes believed to be backed by scientific men. It is no valid defense to say that the editors of these journals were imposed upon, for if they were they need not have been. Other journals, including some daily papers, know very well how to avoid such imposition and have the courage to do it. It appears to be accepted as a fundamental principle of what is called 'journalism' in these days that any one who is gifted with a little facility in writing, a far-reaching imagination and a conscience without elastic limit may be properly 'assigned' to prepare an article on any subject whatever, and thus we are treated to weekly or monthly essays by one author covering, in fact sometimes rather more than covering, in a few months the whole area of human knowledge. Perhaps they, too, have their orders to produce a given number of 'sensations' in a given time.

Among many other evils growing out of what may be called 'Newspaper Science' not the least is the manufacturing and maintaining of false reputations. The constant appearance of a name in connection with the development of a given art, science, discovery or invention makes an impression which it is difficult to destroy, and this is true even among the most intelligent classes. To find who is really and truly eminent in any field of human activity one must go to the specialists in that field. The popular verdict is more than likely to be wrong because it is based on fictitious, newspaper-created renown. Is there not, indeed, some danger that in spite of the carefully selected and altogether able jury, the newly created roll of American honor may, in certain cases and for the lack of this appeal to specialists, become a Hall of Notoriety rather than Fame? The selection of S. F. B. Morse for a place therein must have been due to the general belief among the jurors that he was the inventor of the electro-magnetic telegraph. Yet it was long since proved beyond dispute that his share in that invention was among the least of the many who contributed to make the telegraph possible, and that he justly deserves only a relatively very small share of the honor belonging thereto.

T. C. M.

The New York Herald November 28, 1900

A "Wireless Telegraph" Rumor.

If what is said in the London *Express*—not by Marconi, but by an unnamed member of his staff—and is retold in our special cable is a foreshadowing of what the master of wireless telegraphy has succeeded—or is about to succeed—in doing, then Marconi has indeed made a marvellous stride beyond the point he had heretofore reached in his discoveries and inventions.

According to the *Express* story we shall soon have England and America in close communication without wires. Indeed, England and anywhere you like, if you can have a station there, can be in reach, for Marconi's staff member says in effect that his chief has 'discovered the secret he has long looked for and can annihilate the difficulties of distance and the earth's curvature.

All of which is of great importance and interest if Mr. Marconi confirms it.

The New York Herald December 30, 1900



NIKOLA TESLA Shows How MEN . . . . . of the Future May Become as GODS

BY NIKOLA TESLA.

WHEN a child is born, its sense organs are brought in contact with the outer world. The waves of sound, heat and light beat against its feeble body, its sensitive nerve fibres quiver, the muscles contract and relax in obedience—a gasp, a breath, and in this act a wonderful little engine, of inconceivable delicacy and complexity of structure, is hitched to the wheelwork of the universe. Left to itself the engine stops; it has no power to draw energy from Nature's inexhaustible store.

The little engine moves and works, changes size and shape, performs more and more varied operations, becomes sensitive to more and more different influences, and now there begins to manifest itself in it a mysterious force. It becomes capable of responding to stimuli of a more subtile nature and of drawing, for its own use, energy from the environment. Gradually the engine has been transformed into a being possessed of intelligence, which perceives, discerns, does like others of its kind.

The experiences multiply, the knowledge increases, the discernment becomes keener, the human being, responding to the faintest influences, is awakened to the consciousness of Nature and its grandeur, and in its breast there is kindled a desire to imitate Nature, to create, to work itself the wonders it perceives.

But the exercise of this power does not satisfy the mind, which rises to still higher, undefinable perceptions, not of this world, and inspired by them the artist, the inventor and the man of science give expression to the longing of the soul.

What can man, with his power of creating, in his striving toward the ideal, produce; what result can he attain which would be of the greatest consequence in this universe, his greatest achievment? A scientific idea which I advanced nearly two years ago in an unpublished address may serve to answer this question, from a point of view likely to be taken by an inventor or engineer.

According to the adopted theory, first clearly formulated by Lord Kelvin, all matter is composed of a primary substance of inconceivable tenuity, vaguely designated by the word "ether." The atom of an elementary body is differentiated from the rest of this substance, which fills all space, merely by movement, as a small whirl of water would be in a calm lake.

All matter, then, is merely whirling ether. By being set in movement, ether becomes matter perceptible to our senses; the movement arrested, the primary substance reverts to its normal state and becomes imperceptible. If this theory of the constitution of matter is not merely a beautiful conception, which in its essence is contained in the old philosophy of the Vedas, but a physical truth, then, if the ether whirl or atom be shattered by impact or slowed down and arrested by cold, any material, whatever it be, would vanish into seeming nothingness, and, conversely, if the ether be set in movement by some force, matter would again form. **Thus, by the help of a refrigerating machine or other means for arresting ether movement and an electrical or other force of great intensity for forming ether whirls, it appears possible for man to annihilate or to create at his will all we are able to perceive by our tactile sense.**

This conclusion, though startling, is not contradictory to the adopted doctrine of the indestructibility of matter, and in the light of modern views it may be considered as a scientific possibility. It does not require the exercise of great powers of imagination to conceive that by harnessing the sun's energy and making his machines self-acting these processes of creation and annihilation might be made to go on without human intervention other than the control.

Could he do this, man would then have god-like power, for he could create any kind of material substance, of any size and shape, seemingly out of nothing, and he could make all perceptible substance revert to its primary form, lose itself forever in the universe.

At his command, almost without an effort on his part, worlds would disappear and new worlds would be born. This, according to my ideas, would be the grandest feat which might be performed by man, the most consequential, his greatest achievement.

The New York Journal And Advertizer January 1, 1901

ASTRONOMERS NOW TALK OF SIGNALLING PLANET MARS.

HAS NIKOLA TESLA SPOKEN WITH MARS?

Chicago, Dec. 31.—Nikola Tesla, the great electrician, writes:

The retrospect is glorious, the prospect is inspiring; much might be said of both

But one idea dominates my mind. This—my best, my dearest—is for your noble cause. I have observed electrical actions which have appeared inexplicable, faint and uncertain though they were, and they have given me a deep conviction and foreknowledge that ere long all human beings on this globe, as one, will turn the eyes on the firmament above with feelings sof love and reverence, thrilled by the glad news:

"Brethren, we have a message from another world, unknown and remote. It reads: ONE—TWO—THREE."

(Signed) NIKOLA TESLA.

Several months ago Nikola Tesla made a journey to Colorado. He went up among the mountains, away from human habitation. There he made many experiments. His pet dream for years has been to ascertain if the planets are inhabited. Is it possible that in some mysterious way this electrical wizard has received a message from Mars?

TESLA'S CALL FROM MARS?

SOME PLANET, IT SEEMED TO HIM, AFFECTED HIS MACHINE.

Suggestive of Signalling, the Movements Recorded When He Was Noting Electrical Conditions on a Peak in Colorado—Why Shouldn't Mars Know Morse as Well as We?

Not quite two years ago Mr. Nikola Tesla went out to Colorado to conduct experiments in relation to the wireless transmission of energy, which has engaged his attention for several years. Mr. Tesla found it necessary, in order to carry on his investigations and his experiments to the extent he desired, to work at an altitude of several thousand feet. He found conditions suitable for his purposes in Colorado and went out there in the spring of 1899, built a laboratory about ten miles from Pike's Peak and went to work. What he accomplished in the eight or nine months while he was working there he has kept pretty well to himself, but [illegible] when the National Red Cross, which was arranging for the end of the century meetings of its various branches throughout the country, asked Mr. Tesla to indicate what, in his opinion, would be one of the most striking achievements of the coming century, he gave just a hint of one of the wonders he discovered in Colorado.

In a more elaborate way Mr. Tesla dwelt on his work to a SUN man yesterday afternoon. He regards his latest results as far and away the most important he has ever attained. Briefly, Tesla has been able to note a novel manifestation of energy, which he knows is not of solar or terrestrial origin, and, being neither, he concludes that it must emanate from one of the planets. While he was conducting his investigations in his Colorado laboratory one day the instrument he was using to observe the electrical condition of the earth was affected in an unaccountable manner. It recorded three distinct, though very faint movements, one after the other. These movements were observed not once, but many times, the number of impulses varying, and Mr. Tesla now firmly believes that, with improved apparatus, it will be quite possible for the people of the earth to communicate with the inhabitants of other planets. In talking about his work and his discoveries Mr. Tesla said:

"I went to Colorado early in May, 1899, and stayed there about eight months. I believe that during this time I did more work than I could have done in the city in three years on account of the marvellously invigorating climate. I was compelled to go either to Colorado or to California, as only in these two States could I obtain power at a high altitude, which was necessary for certain investigations I had in view relative to the transmission of power in accordance with a method I had invented. I had tested the conditions at sea level thoroughly, and wanted to know in how far my laboratory observations would agree with practical tests at high altitudes. Colorado was nearer than California and I had some friendly relations in Colorado Springs, and this determined me to select that neighborhood for my place of observation.

"A laboratory was erected on an elevation at a distance of about ten miles from Pike's Peak. I set out to carry on my experiments along three different lines: First, to ascertain the best conditions for transmitting power without wires; second, to develop apparatus for the transmission of messages across the Atlantic and Pacific oceans, on which problem I have been engaged for eight years, and, third, to work on another problem, which involves a still greater mastery of electrical forces and which, with my present knowledge, I consider of still greater importance than even the transmission of power without wires, and which I shall make known in due course. There were, however, numerous points to be found out about electrical vibrations, and there were actions on which I was still in doubt. In my laboratory in New York I was able to go only to electrical discharges of 16 feet in length and I had only reached effective electrical pressures of about 8,000,000 volts. To carry the problems on which I was working farther I had to master electrical pressures of at least 50,000,000 volts, and electrical discharges were necessary for some purposes measuring at least fifty or one hundred feet.

"The results I attained were far beyond any I had expected to reach, and this has forcibly brought to my mind the stimulating influence of nature in scientific research. I found that my mental vision was incomparably clearer, so much so that I could look back in thought to my laboratory in New York, and in examining familiar objects in the rooms there could notice the smallest scratches on them, and in examining the features of my assistants I could notice the slightest marks on their faces, as though they had been actually before me. Now in the city the mental images are much dimler.

"One of the first observations I made in Colorado was of great scientific importance and confirmatory of a result I had already obtained in New York. I refer to my discovery of the stationary electrical waves in the earth. The significance of this phenomenon has not yet been grasped by technical men, but it virtually amounts to a positive proof that, with proper apparatus, such as I have perfected, a wireless transmission of signals to any point on the globe is practicable. When I read statements to the effect that such a thing is impossible, and recall the numerous adverse comments of my expressed confidence that I can ultimately accomplish this, I experience a feeling of satisfaction.

"In perfecting my apparatus I encountered at first great difficulties. I had to fence narrow escapes from sudden sparks jumping out to great distance, and a number of times my laboratory caught fire, but I carried all the work through without a serious mishap. I gradually learned how to confine electrical currents of a pressure of 50,000,000 volts; how to produce electrical movements up to 110,000 horsepower and I succeeded in obtaining electrical discharges measuring from end to end 100 feet and more. These results were, however, rendered more valuable by the fact that they opened up still greater possibilities for the future.

"Parallel with the development of my machinery for the production of powerful effects I also perfected novel methods for detecting feeble electrical actions, which, I feel confident, will be important in a number of lines of scientific research. To illustrate the efficacy of these methods I need only say that, whereas in ordinary, finely adjusted Hertzian appliances a lightning disturbance could be detected at a distance of only 300 miles, with my methods it was easy to observe the effect in the receiving instrument at a distance of 1,100 miles. It was, in fact, in investigating feeble electrical actions transmitted through the earth that I made some observations which are to me the most gratifying. Chief among these were certain feeble electrical disturbances, which I could barely note at times and which by their character unmistakably showed that they were neither of solar origin nor produced by any causes known to me on the globe.

"What could they be? I have incessantly thought of this for months until finally I arrived at the conviction, amounting to almost knowledge, that they must be of planetary origin. As I think over it now it seems to me that only men absolutely stricken with blindness, insensible to the greatness of nature, can hold that this planet is the only one inhabited by intelligent beings. I have perfected my transmitting apparatus so far that I can undertake to construct a machine which will without the slightest doubt be fully competent to convey sufficient energy to the planet Mars to operate one of these delicate appliances which we are now using here, as, for instance, a very sensitive telegraph or telephone instrument. Now since we ourselves are already so far advanced is it unreasonable to at least believe in the possibility that of the twenty or twenty-five planets of the solar system one, if not more, might be ahead of us in the evolution? Where there is sun's heat and moisture, life must originate and must go on developing just as a stone must fall to earth.

"I would have abstained from making the observations known for some time yet, had I not been asked by the Red Cross Society to give a short expression of opinion for their meetings on New Year's Eve. I have entertained a profound respect for the Red Cross ever since my boyhood, when I was told that the mere appearance of this society in the Balkans has advanced those wild regions a hundred years. I believe it to be the noblest and worthiest association in existence, and there was nothing which I could have refused to them, and furthermore I desired to give them my best. This discovery, in my opinion, was my best. With improved means of investigation we shall soon be able to find out whether indeed these disturbances which I have noticed are what I feel they must be. The time has certainly arrived for the electrician to join the astronomer in the exploration of our neighboring worlds.

"With regard to my work in other lines which I have simultaneously carried on, my progress has been most satisfactory, and I hope that soon electrical energy may be turned to the uses of man in a way and for purposes such as to surpass in importance all that we have ever done heretofore. The difficulties are still enormous, to be sure, but not such that we could not look with confidence to overcoming them. What will retard progress unquestionably is the fact that the mastery of electrical vibrations requires, like other arts, not only a thorough technical knowledge but years of continuous performance. Our colleges are rapidly turning out skilled and talented young men, and, whatever remains undone by us will be carried further by them."

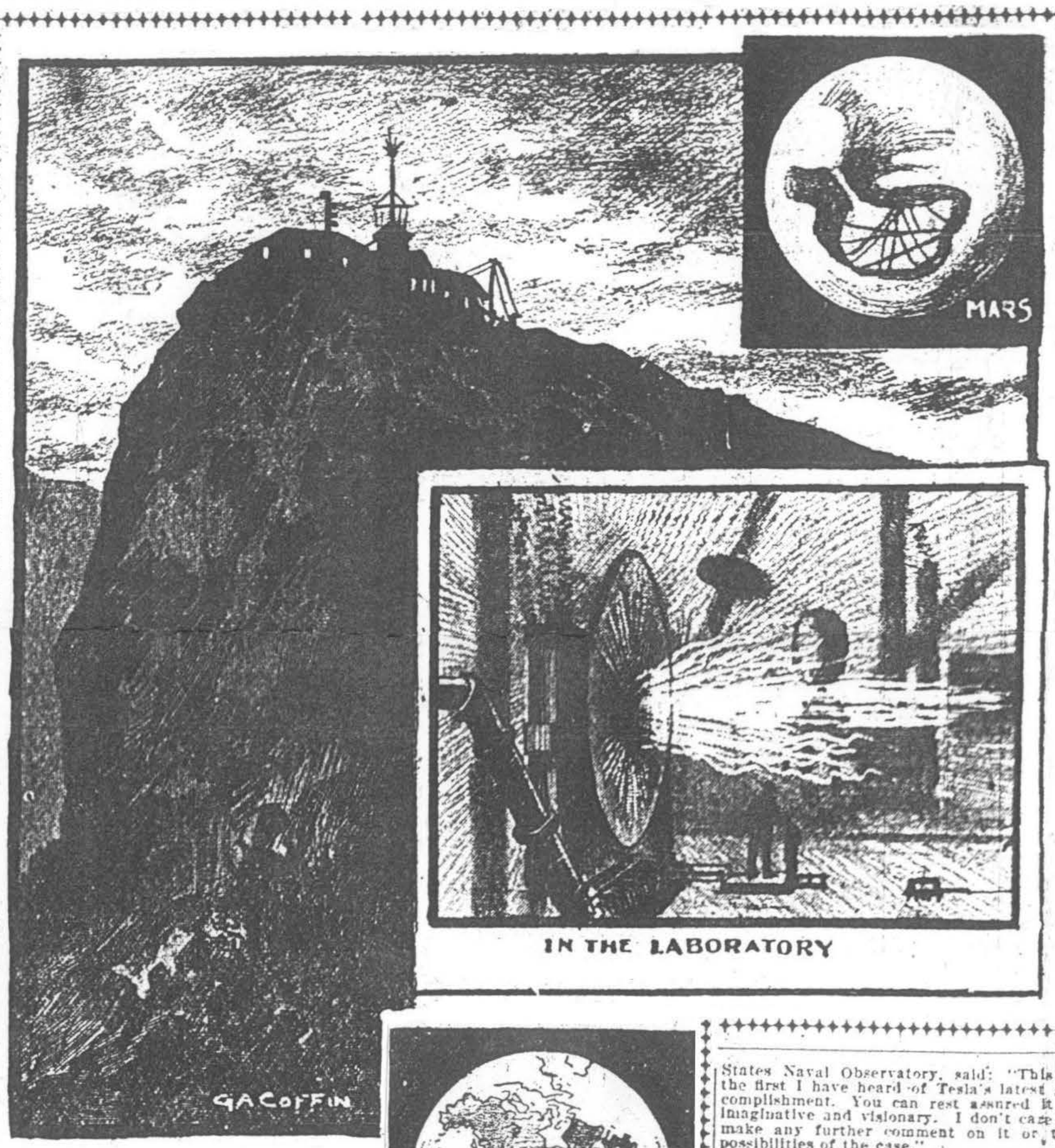
The New York Journal And Advertiser January 4, 1901

ASTRONOMERS DISCUSS TESLA'S ALLEGED MESSAGE FROM MARS.

They View Incredulously the Wizard's Claim That He Has Received Signals from Other Planet.

Inventor Says HE Can Construct Instrument That Will Establish Interplanet Communication.

Many Scientists Advance Arguments to Substantiate Their Skepticism of Tesla's Assertions.



NICOLA TESLA claims to have had the first call of the century from a neighboring planet.

He has communicated with Mars, he declares, while on Pike's Peak, delving into the mysteries of the wireless transmission of electrical energy.

The summons was faint, but, according to Tesla, not to be mistaken.

A new voice, from a planet thousands of miles removed, was speaking over one of the myriad unwired telephones of the Universe, and there, near the lonely mountain peak, in the fathomless calm of night, the voice at last found a listener and world spoke to world in language strange at first, but sure to be clearer, says Tesla, ere the twentieth century has finished its course. Here the Journal presents what Tesla himself says of this first manifestation:

"It was in investigating feeble electrical actions transmitted through the earth that I made some observations which are to me the most gratifying.

"Chief among these were certain feeble electrical disturbances which I could barely note at times, and which by their character unmistakably showed that they were neither of solar origin nor produced by any causes known to me on the globe. What could they be?

Will Talk to Mars.

"I have incessantly thought of this for months, until finally I arrived at the conviction, amounting almost to knowledge, that they must be of planetary origin. I have perfected my transmitting apparatus so far that I can construct a machine which will without the slightest doubt be fully competent **to convey sufficient energy to the planet Mars to operate one of these delicate appliances which we are now using here, as for instance a very sensitive telegraph or telephone instrument.**

"Now since we ourselves are already so far advanced, is it unreasonable to believe that of the twenty or twenty-five planets of the solar system one, if not more, might be ahead of us in the evolution? Where there is sun's heat and moisture life must originate and must go on developing just as a stone must fall to earth."

Tesla's almost incredible discovery was made by him in Colorado two years ago while he was conducting experiments in relation to the wireless transmission of energy. He worked in a laboratory specially constructed about ten miles from Pike's Peak.

When he was asked yesterday to give some visible form or notation to the message he had received he smiled enigmatically and said:

"As I have already said, one of the planets in the solar system may be ahead of us in the evolution. Their means of interplanetary communication may be perfect, **but we have yet to learn their sign language.** It is impossible at present, even to suggest a code and my observations to the Red Cross Society on New Year's Eve were purely speculative, but for purposes of illustration they will answer the purpose at present.

It is enough to say at this time that a message from Mars which might be a triangle to them would appear as some other form to us and vice-versa. These differences can only be reconciled by time and careful study. It is wonderful enough, is it not, that a beginning has been made.

"On Pike's Peak I set out to carry on my experiments along three different lines.

"One of the first observations I made in Colorado was of great scientific importance and confirmatory of a result I had already obtained in New York. I refer to my discovery of the stationary electrical waves in the earth. The significance of this phenomenon has not yet been grasped by technical men, but it virtually amounts to **a positive proof that, with proper apparatus, such as I have perfected, a wireless transmission of signals to any point on the globe is practicable.** When I read statements to the effect that such a thing is impossible, and recall the numerous adverse criticisms of my expressed confidence that I can ultimately accomplish this, I experience a feeling of satisfaction.

Difficulties Encountered.

"In perfecting my apparatus I encountered at first great difficulties. I had a few narrow escapes from sudden sparks jumping out to great distance, and a number of times my laboratory caught fire, but I carried all the work through without a serious mishap. I gradually learned how to confine electrical currents of a pressure of 50,000,000 volts; how to produce electrical movements up to 110,000 horse-power and I succeeded in obtaining electrical discharges measuring from end to end 100 feet and more. These results were, however, rendered more valuable by the fact that they opened up still greater possibilities for the future.

"As I think over it now it seems to me, that only men absolutely stricken with blindness, insensible to the greatness of nature, can hold that this planet is the only one inhabited by intelligent beings."

As to the practical details of establishing a system of inter-planetary communication, Mr. Tesla is not yet prepared to talk. **His suggestion, however, of an interchange of mathematical forms would indicate at once a practical basis of operations** by means of initiating electrical disturbances at the three angles of a vast triangle described over an immense area of the earth's surface.

Observers at these points with means at command for the transmission of powerful electrical energy could thus indicate to the inhabitants of Mars in unmistakable manner the species of form language in which it was desired to hold communication.

Thus, little by little, an intelligible code could be established containing possibilities for the acquisition of exact data concerning other worlds far beyond the wildest dreams of necromancers.

Tesla now firmly believes that with improved apparatus it is not only probable, but entirely possible; that we shall be able to communicate with the inhabitants of other planets.



The Pike's Peak Laboratory.

It was while working in this laboratory experimenting to perfect instruments for wireless telegraphy that Tesla claims to have observed the manifestations which, he asserts, were telegraphic signals from some other planet, presumably Mars.

ASTRONOMERS VOICE SCEPTICAL VIEWS.

Discuss with Considerable Incredulity the Story of Mr. Tesla's Alleged Discovery.

Washington, Jan. 3.—Professor S. I. Brown, of the United States Naval Observatory, said to-day: "Any proclamation coming from Tesla is likely to be received with considerable incredulity. I have been looking in vain for some practicable results to follow the extravagant claims that he has constantly made during the past half dozen years.

"His assertion that he has found that some planet is signalling to the earth is remote even to the point of impossibility. He contradicts himself so frequently that it is hard to tell what he really means.

"He indicates that Mars might be the world which is attempting to communicate with us. It is most peculiar that any discovery involving Mars should be made just now. Once in every fifteen years that planet reaches its greatest distance from the earth, when it is 62,000,000 miles away. The nearest that it ever gets is 36,000,000 miles. It happens that just now Mars is at the furthest distance that it ever gets from us.

"Tesla indicates that this method of communication is based upon wireless telegraphy. The power of the electric wave vibrations involved in wireless telegraphy is inversely as the square of the distance they have traversed. Thus the electrical power required on the planet Mars in order to communicate with this world would be 3,600,000,000,000,000 times as great as the power received here. Even the faintest sign of energy that might be received here, when multiplied by that sum, would represent an incredible force on the surface of the planet Mars."

Professor A. S. Skinner, of the United States Naval Observatory, said: "This is the first I have heard of Tesla's latest accomplishment. You can rest assured it is imaginative and visionary. I don't care to make any further comment on it or the possibilities of the case."

Father John B. Hagan, Professor of Astronomy at the Georgetown University, said: "Astronomers do not look forward to the discovery of communication between the planets, and in fact, take no interest in and pay no attention to experiments of this character. There is, of course, no internal contradiction to the problem, being only a question of means on our side and the possibility of inhabitants in Mars. I would prefer not to make any comment on this particular alleged discovery of Tesla."

Professor T. J. J. See, of the Naval Observatory, said: "I have read the story about this discovery. I do not care to say anything about it."

MAGNETISM, MAYBE, SAYS SCIENTIST.

Professor Hough, of Chicago, Gives Possible Explanation of Tesla's Phenomenon.

Chicago, Jan. 3.—Professor George W. Hough, director of the Dearborn Observatory and teacher of astronomy at Northwestern University, said: "Tesla asserts that his instrument was disturbed, and that he is positive that the disturbance was not caused by the sun, moon or earth, and then concludes that it comes from Mars or Venus. A dynamo when running will show a disturbance on any magnetic instrument located a block away, depending on the power of the dynamo. It is probably some such magnetic cause that produces the peculiar effect on the oscillator spoken of by Tesla.

"This idea of communicating with the planets is an old one. More than a half century ago Thomas Dick, an English philosopher, wrote a book called 'Celestial Scenery,' in which this theory is discussed thoroughly. I am convinced nothing new has been discovered on the subject up to the present time."

John H. Kedzie, author of "Solar Heat, Gravitation and Sun Spots," said: "The theory is utterly visionary and impossible. Tesla is a great genius, but is not recognized by scientific men as a safe authority on scientific subjects. When he presents something he can prove to be true, scientific men will be quick to give him the credit due. The nearest point to the earth which the planet Mars ever reaches is 40,000,000 miles. The making of an instrument sensitive enough to record waves at this distance is beyond the range of human possibilities."

Twenty-Five Great Names in Electrical Science and Invention During the Nineteenth Century.

The lists which appear on the opposite page were compiled from individual lists received in response to invitations sent to the membership of the American Institute of Electrical Engineers for an expression of opinion as to what names connected with electrical science and invention during the century just closed, should appear on a list of twenty-five greatest names; and an indication by numerals of the names which, in their opinion, should be assigned first, second and third rank, respectively.

In response to this invitation 277 ballots were received and from these the general list on the opposite page was compiled. In order that an interesting comparison might be made with the general list, the two other lists printed with it were compiled as follows: From the 277 ballots those of twenty-five professors of electrical engineering were selected; also twenty-five ballots signed by leaders in various branches of electrical application and others whose opinions were thought to have particular weight. From these two sets of selected ballots the comparative lists, "A" and "B" were prepared.

The closeness of the vote of the first thirty names on the tally sheets was quite remarkable; in a number of cases the vote was a tie and this is indicated on the lists by braces opposite the names. On the general list tally sheet there was a difference of but seven votes between the twenty-fifth and the thirty-first names, and had the list been extended to the latter number it would have included the following names in the order given: Weston, Hopkinson, S. P. Thompson, Weber, Ferraris and Gray. Similarly, the tally sheet of the ballots cast by twenty-five professors of electrical engineering, if extended to thirty names, would have included Gauss, Wheatstone, Ewing, Röntgen and Rowland, the three last mentioned having but three votes less than the twenty-fifth on the list. Had the selected engineers' list been extended to thirty names it would have included Hopkinson, Marconi, Heaviside, Pacinotti and Steinmetz—the difference between the vote of the last mentioned and number twenty-five on the list being also three.



FARADAY



MAXWELL



KELVIN



EDISON

On the general list, there were practically but seven selections for the first, second and third places, and in the following order: Faraday, Kelvin, Edison, Maxwell, Henry, Morse and Bell. Faraday received almost twice as many votes as any of the others, and the vote of the next three names was largely in excess of the final three. On the professors' tally sheet, Henry stood fourth, the other names below his receiving but a few votes each. On the engineers' list. Edison was fourth, the subsequent names also receiving but a few votes each.

The name Siemens should be accepted as standing for the family rather than for any particular member thereof.

Result of Vote Upon Twenty-five Greatest Names in Electrical Science and Invention During the Nineteenth Century

SELECTED LIST

A

Compiled from Ballots of 25 Professors of Electrical Engineering,

(Exclusive of Ballots in List B)

FARADAY
KELVIN
MAXWELL
EDISON
HENRY, HERTZ
E. THOMSON
BELL, MORSE
AMPÈRE, SIEMENS
DAVY, HELMHOLTZ, OHM
TESLA
HOPKINSON
BRUSH
OERSTED
FERRARIS, GRAMME, PLANTÉ, STEINMETZ
JOULE, SPRAGUE, WEBER

GENERAL LIST

Compiled from Ballots of 277 Members A. I. E. E.

(Inclusive of all Ballots)

FARADAY
KELVIN
EDISON
BELL
MORSE
HENRY
TESLA
E. THOMSON
MAXWELL
AMPERE
SIEMENS
OHM
HERTZ
DAVY
BRUSH
WHEATSTONE
HELMHOLTZ
GRAMME, STEINMETZ
ROENTGEN
SPRAGUE
PLANTÉ
MARCONI
OERSTED
JOULE

SELECTED LIST

B

Compiled from Ballots of 25 Prominent Members A. I. E. E.

(Exclusive of Ballots in List A)

FARADAY
MAXWELL
KELVIN
HENRY
BELL, EDISON
AMPÈRE
MORSE, OHM
DAVY, HERTZ, SIEMENS
TESLA
GRAMME, HELMHOLTZ
WHEATSTONE
PLANTÉ
E. THOMSON
ROENTGEN
BRUSH, GAUSS, WEBER, JOULE, OERSTED
FERRARIS

A New Century Call-Up from Mars.

It will be remembered that Mr. Nikola Tesla has for some time past insisted on the possibility of exchanging signals with Mars, as determined by the results of his interesting experiments on wireless transmission. The New York *Sun* publishes on Jan. 3 a column interview with him on the subject and in it asserts that he has recently seen some curious effects on his apparatus. We quote as follows: "When the National Red Cross, which was arranging for the end try, asked Mr. Tesla to indicate what, in his opinion, would be one of the century meetings of its various branches throughout the countransmission. The New York *Sun* publishes this week a column inof the great achievements of the coming century, he gave just a hint of one of the wonders he discovered in Colorado. In a more elaborate way Mr. Tesla dwelt on his work to a *Sun* man. He regards his latest results as far and away the most important he has ever attained. Briefly, Tesla has been able to note a novel manifestation of energy, which he knows is not of solar or terrestrial origin, and, being neither, he concludes that it must emanate from one of the planets. While he was conducting his investigations in his Colorado laboratory one day the instrument he was using to observe the electrical condition of the earth was affected in an unaccountable manner. It recorded three distinct, though very faint movements, one after the other. These movements were observed not once, but many times, the number of impulses varying, and Mr. Tesla now firmly believes that, with improved apparatus, it will be quite possible for the people of the earth to communicate with the inhabitants of other planets."

CURRENT NEWS AND NOTES.

TESLAIC TELEGRAPHY.—A special dispatch from Washington, of Dec. 29, says: "Nikola Tesla has been asked by Rear Admiral R. B. Bradford, Chief of the Bureau of Equipment, to submit for trial a wireless telegraphy system perfected by him. Mr. Tesla says that his system is equal to, and perhaps superior to that of Marconi, and has offered to install it on naval vessels. Admiral Bradford in his last annual report recommended that negotiations be entered into with Marconi to secure his system for American vessels of war, if a reasonable rate could be agreed on."

The New York Herald January 5, 1901

DISCREDITS TESLA'S MARTIAN THEORY

Mr. Marconi Attributes Alleged Messages from Mars to Local Atmospheric Disturbances.

[SPECIAL CABLE TO THE HERALD.]

The HERALD'S European edition publishes the following from its correspondent:—

LONDON, Saturday.—Nikola Tesla having set up the fascinating, or fantastic, theory as to the possibility of communicating with the people of Mars, the Daily Mail yesterday sought the opinion of Mr. Marconi, who is conducting experiments in wireless telegraphy near Poole, and Mr. Marconi gave the following reply:—

"In earlier experiments, before my apparatus was perfected, I often received signals apparently from nowhere. This was undoubtedly due to atmospheric electricity. One of the greatest difficulties has been to produce an apparatus which would eliminate them, but this I have lately succeeded in doing.

"I should attribute the alleged signals from Mars to local disturbances in the atmosphere."

Professor Fleming, F. R. S., of University College, laughed at the idea of communicating with Mars, even if there are any people there.

"Is this idea taken seriously?" was his first question. "I am afraid," added the distinguished authority on electrical science, "that Tesla has been led away by his own imagination. It is difficult, of course, to say that anything is beyond the ultimate reach of science, but at present I should say that the people of Mars are."

Tesla's Twentieth-Century Views.

Since, in 1887, Mr. Tesla conceived and applied the rotating magnetic field to alternating-current power transmission, this remarkable man has received a large share of public attention. He possesses what has been termed a "scientific imagination," and his bold views of natural phenomena have been given wide publicity. The subjoined interview was obtained exclusively for the Western Electrician by Mr. Frank L. Perry and was telegraphed to Chicago at the last moment for insertion in the Twentieth Century issue.

Nikola Tesla was seen at the Waldorf-Astoria in New York late on Friday evening, January 4th. He consented to answer one pertinent question relating to his researches, and his reply indicates a perfect confidence that astonishing, but, nevertheless, practical, results will be achieved during the earlier part of the twentieth century, through the skilful utilization of electric "tuning" or resonance effects, with circuits carrying oscillating currents of high frequency.

The question put to Mr. Tesla was this: "From your own investigations with high-frequency currents and the transmission of electrical energy through their aid, as revealed by you to date, it would seem that there was a great future along this line. Therefore, will you not tell me, Does not the question of syntony, or, as the layman would put it, 'electrical tuning,' of circuits become a most important one, and one that indicates the direction investigations must take during, say, the next 10 or 15 years? Will not the greatest progress be made with what could very properly be called 'resonance effects?'"

"You have put a question," answered Mr. Tesla, "which not only is of great importance in many arts of the present day, but also throughout the mechanism of the universe. The phenomena of sound and light afford striking examples. I believe that ultimately even nerve action will be proved to involve the principles of 'sympathetic response.' Spencer's idea of the unstable nerve matter is ingenious in its conception, but difficult to be admitted as a reality. The cones of the retina, with their fibers, must likewise behave as elastic systems, responding sympathetically. If this be so, the undulatory theory can hardly be true, because the periods of oscillation of these vibratory systems would be far too great for those of the light waves. Nor can we stop at the simple nerve action, for, in the entire complex movement of humanity, the same universal principle forces itself upon our observation as unmistakably as in the vibrations of a tuning fork.

"My own experiments in electrical and mechanical vibration have impressed me deeply with the tremendous possibilities in this direction. With a small engine capable of pressing a piston back and forth with a force of but two pounds, I have set an entire block of modern buildings, by careful attunement, into such a violent swaying that people rushed out affrighted. With an impressed force of only a fraction of a pound, I have caused steel rings of several square inches cross-section, capable of supporting several hundred tons, to vibrate and form loops like thin piano wires, until they finally broke.

"In electrical vibration I have frequently obtained results even more wonderful. The tuning of electric circuits is becoming more and more important with the advancement of the arts and refinement of methods. The layman can have but a vague idea of what can be accomplished in this line by men possessed of knowledge and skill. As to the former, it is acquired easily enough. The principles are very simple and do not require an exceptionally high scientific training. Perhaps the clearest expositions have been given by Dr. Oliver Lodge and Prof. Pupin. The latter, particularly, was fortunate in dealing with the subject, and a beginner can find no better source of information.

"But the skill is not acquired as quickly or as easily as the knowledge of the simple principles. It comes slowly, requires great patience and untiring application. Owing to this fact, of necessity but few are proficient in this art to-day. This is the reason why the greater part of contemporaneous literature on this subject is pervaded with the grossest errors. Many experimenters do not seem to realize that an electrical system cannot vibrate through an imperfect contact or path of high resistance. Still many more overlook the necessity of placing the excited system in a condition permitting free oscillation, yet everybody knows that if he grips a spring firmly and pushes it back and forth it cannot perform its own vibrations. Similarly, an excited electrical system, as the secondary of a transformer, cannot oscillate freely if the exciting primary circuit is linked closely with it.

"While the establishment of the best relations between the physical constants of electric circuits is imposed by economy, yet the chief object will be the attainment of specific results, as, for instance, a very high electromotive force, a current of great intensity or the magnification of feeble impulses. The transmission of electrical energy through the earth, for whatever purpose it may be, offers, in my opinion, the greatest possibilities of development.

"The time is not far off when electrical oscillations will speed in all directions through the globe, innumerable, yet each separate and distinct and each fulfilling its mission. The seemingly simple subject expands as one advances in its study, until he feels as if the wide ocean were opening up before his eyes. Some five years ago, to test the capacities of a system of telegraphy, I 'tuned' repeatedly 150 circuits, calling up each one in turn, without disturbing the others. And I thought then I had mastered the art. As I look back on those experiences now I realize that I was then only just beginning to learn."

The New York Herald January 6, 1901

TESLA CONFIDENT OF SPEAKING MARS

Impossible, He Says, for Other Experimenters to Note Effects Which He Has Discovered.

HAVE NOT PROPER DEVICES

Inventor Says with His Appliances He Can Observe Electrical Condition of 2,200 Miles.

NO DOUBT OF FINAL SUCCESS

Nikola Tesla in his recent experiments in atmospheric electricity obtained results which he believes will make possible communication with the people of Mars. Scientific investigators abroad were sceptical as to his new theory. Professor Fleming, F. R. S., of University College, London, laughed outright at the idea. Mr. Marconi, who is experimenting in wireless telegraphy near Poole, attributed the alleged signals from Mars to local disturbances in the atmosphere.

Following is Mr. Tesla's reply to his critics and his explanation of his theory:—

"Having no exact knowledge of the means of investigation used by other experimenters, I cannot judge of the value of their observations. I assume that the same circuit arrangements and devices have been employed which are described in patents and articles on Hertzian telegraphy. In these cases an aerial conductor, not directly connected with the ground, but separated from it by imperfect contacts or coils which prevent the passage of the current, receives the effects transmitted from a distance.

"The atmospheric disturbances in these arrangements, if I am to judge from my own experience, are so great that I have always doubted their practical value. In my investigations these disturbing atmospheric influences were almost wholly excluded. It would have been impossible for other experimenters to note the effects which I have discovered, for with the Hertzian devices only a very narrow region can be explored, whereas I was able to observe the electrical condition of a large portion of the globe, a stretch of land 2,200 miles in width and breadth. That these actions are due to causes heretofore unknown I am convinced.

"I feel that I have not been led away by my imagination, but that my sight was true as ever before, and I am confident that future investigation will confirm my statement

"Nor have I the slightest doubt, judging from my experiments and measurements, that with a properly constructed electrical oscillator an amount of energy can be transmitted to a planet, as Venus or Mars, even at their greatest distance, sufficient to bring into action a sensitive instrument, such as I have been using in my own observations.

"Furthermore, it is an error to believe that a great expenditure of power is necessary for interplanetary communication. What is needed is an effect specifically great—an enormous rate of energy delivery, but lasting each time only a fraction of a second, so that the total power used up is small. Now, with my oscillator I can make this rate equal to five million horse power and more, if necessary, and my calculations show that a small fraction of this rate is amply sufficient for conveying a message to Mars.

"Heretofore light was the only known agent for communicating with a planet. It is easy to show that by its means such a result is virtually impossible, owing to the rapid diminution of energy with the distance and the impossibility of concentrating in an instrument the energy falling upon a large area. By the method and machinery I have devised we are enabled to convey an immeasurably greater amount of energy to the planet, and the observer there, instead of utilizing in his instrument only an infinitesimal amount of the entire energy conveyed, can avail himself of a large portion of the same.

"A practical solution has thus been found both for transmitting and receiving messages, and we can only hope that there are beings as far advanced, and possibly further than we are ourselves. I see no harm in holding fast to this possibility. This thought cannot but make us better and give us a fresh interest in life."

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The next message Tesla gets from Mars will undoubtedly be "Advertise in the Gazette."

The Colorado Springs Gazette January 9, 1901

NIKOLA TESLA AND HIS TALK WITH OTHER WORLDS

Special to the Philadelphia Inquirer.

New York, Jan. 2.—Not quite two years ago, Mr. Nikola Tesla went out to Colorado to conduct experiments in relation to the wireless transmission of energy which has engaged his attention for several years.

Mr. Tesla dwelt on his work to an Inquirer man this afternoon. He regards his latest results as the most important he has ever attained. Briefly Tesla has been able to note a novel manifestation of energy which he knows is not of solar or terrestrial origin, and being neither, he concludes that it must emanate from one of the planets.

While he was conducting his investigations in his Colorado laboratory the instrument he was using to observe the electrical condition of the earth was affected in an unaccountable manner. It recorded three distinct, though very faint, movements, one after the other.

May Talk With Other Worlds.

These movements were observed not once but many times, the number of impulses varying, and Mr. Tesla now firmly believes that with improved apparatus it will be quite possible for the people of the earth to communicate with the inhabitants of other planets. In tetiling about his work and his discoveries, Mr. Tesla said:

"I set out to carry on my experiments along three different lines; first, to ascertain the best conditions for transmitting power without wires; second, to develop apparatus for the transmission of messages across the Atlantic and Pacific oceans, on which problem I have been engaged for eight years, and third, to work on another problem which involves a still greater mastery of electrical forces, and which, with my present knowledge, I consider of still greater importance than even the transmission of power without wires, and which I shall make known in due course.

Pressure of 50,000,000 Volts.

"There were, however, numerous points to be found out about electrical vibrations, and there were actions on which I was still in doubt. In my laboratory in New York I was able to go only to electrical discharges of 16 feet in length, and I had only reached effective electrical pressures of about 8,000,000 volts. To carry the problems on which I was working farther I had to master electrical pressures of at least 50,000,000 volts, and electrical discharges were necessary for some purposes measuring at least 50 or 100 feet.

"The results I attained were far beyond any I had expected to reach. One of the first observations I made in Colorado was of great scientific importance, and confirmatory of a result I had already obtained in New York. I refer to my discovery of the stationary electrical waves in the earth. The significance of this phenomenon has not yet been grasped by technical men, but it virtually amounts to a positive proof that with proper apparatus such as I have perfected a wireless transmission of signals to any point on the globe is practicable.

Sparks One Hundred Feet Long.

"In perfecting my apparatus I encountered at first great difficulties. I had a few narrow escapes from sudden sparks jumping out to great distance and a number of times my laboratory caught fire, but I carried all the work through without a serious mishap. I gradually learned how to confine electrical currents of a pressure of 50,000,000 volts to produce electrical movements up to 110,000-horse power, and I succeeded in obtaining electrical discharges measuring from end to end 100 feet and more. These results were, however, rendered more valuable by the fact that they opened up still greater possibilities for the future.

"It was in investigating feeble electrical actions transmitted through the earth that I made some observations which are to me the most gratifying. Chief among these certain feeble electrical disturbances which I could barely note occurred, and which by their character unmistakably showed that they were neither of solar origin nor produced by any causes known to me on the globe. What could they be?

"I have incessantly thought of this for months, until I finally arrived at the conviction, amounting to almost knowledge, that they must be of planetary origin. As I think over it now it seems to me that only men absolutely stricken with blindness, insensible to the greatness of nature, can hold that this planet is the only one inhabited by intelligent beings.

Communication With Mars.

"I have perfected my transmitting apparatus so far that I can undertake to construct a machine which will without the least doubt be fully competent to convey sufficient energy to the planet Mars to operate one of these delicate appliances which we are now using here, as, for instance, a very sensitive telephone instrument.

"With regard to my work in other lines which I have simultaneously carried on my progress has been most satisfactory, and I hope that soon electrical energy may be turned to the usages of man in a way and for purposes such as to surpass in importance all that we have ever done heretofore."

TESLA PREPARES TO SEND MESSAGES TO MARS.

The Electrician Says That He Will Soon Be Able to Establish Communication with That Planet.

Believes Martians Have Signalled Earth and That Unintelligible Messages Have Been Received.

Expects to Have Definite Results at an Early Date—Marconi Thinks the Scheme Is a Feasible One.

But one idea dominates my mind. That—my best and dearest—is for for your noble cause. Brethren, we have a message from another world, unknown and remote. It reads: ONE—TWO—THREE.—Nikola Tesla in the Journal, January 1, 1901.

Any proclamation coming from Tesla will be received with considerable incredulity. His assertion is remote to the point of impossibility.—Professor S. I. Brown, United States Naval Observatory, January 3, in the Journal.

You can rest assured that it is imaginative and visionary.—Professor A. S. Skinner, United States Naval Observatory, January 3, in the Journal.

I have read of the alleged discovery made by Tesla but would rather not spea kof it. Professor T. J. J. See, United States Naval Observatory, January 3, in the Journal.

NICOLA TESLA, the great electrical experimenter, is busy at work on a transmitter and a receiver that he believes will establish as an accomplished fact communication between this planet and Mars. When a reporter for the Journal saw him yesterday, in his laboratory, at No. 46 Houston street, he was drawing on paper zig-zag lines that looked like the teeth of an old-style up-and-down mill saw.

"I am preparing," he said, "for the greatest experiment that has ever been made on this planet. Sooner or later I shall establish communication with Mars. I am certain that the inhabitants of that planet have many times endeavored to signal this earth, but we have never had instruments of sufficient delicacy to receive their messages, nor instruments powerful enough to answer them. At last we have the former, and I will soon have the latter.

"It will remain then only to decipher their messages and answer them.

"Martians More Advanced."

"It is more than possible that the Martians will read our messages to them before we can read theirs, because I believe they are a more advanced people than we are.

"Already I have a transmitter that is, I am certain, of sufficient power to send a message to Mars with strength enough to operate a delicate telegraph instrument. A beginning has been made and the great result will soon be achieved."

Signor Guiseppe Marconi, the inventor of wireless telegraphy, said to the London correspondent of the Journal yesterday:

"It is not impossible to realize telegraphic communication between the earth and Mars, provided Mars is inhabited. Electrical science is able to overcome the millions of miles that interpose between us. Mr. Tesla is, I believe, sure to succeed in his efforts to establish this communication.

"With regard to wireless communication between London and New York, and messages flashed across the ocean for a half penny a word, I see no immediate prospect of such a consummation. At no very distant date, however, wireless communication between Europe and America will be a fact."

Only an Educated Guess.

Mr. Tesla shrugged his shoulders when a reporter for the Journal told him what Marconi had said.

"He knows nothing about what I have been doing, and if he has arrived at any conclusion it is but the conclusion of an educated guess. His wireless telegraphy has to do with this earth; mine deals with the stars. Let us both stick to our subjects.

"I see that Mr. Edison says he confines his thoughts below the apex of the Himalaya Mountains. Well, mine climb higher, and will reach their goal.

"Talking with Mars is not a new proposition. Other men than myself have received on delicate instruments messages they could not understand. My task is to receive them, to understand them and to reply to them.

"I will have some definite results soon, and when I get them I will explain all about them to the Journal."

The last remark appears to indicate that Mr. Tesla expects to receive the messages here in New York. When pressed to say whether he expected to establish Martian communication in this city he declined to answer.

MARS DESCRIBED BY C. FLAMMARION.

Great French Astronomer Says We Know More of Its Weather Than of the Earth's.

(Special Cable to the New York Journal and Advertiser.)

Paris, Jan. 9.—Camille Flammarion, the

nomical Society of France. After the lecture he summed it up for the Journal as follows:

"We know Mars better than the earth was known before the time of Columbus. We know the climatic conditions of Mars better than we know those of the earth today. We cannot tell what the weather will be to-morrow on the earth, but we all know what it will be on Mars, since it is always fair. Whereas no one has ever seen either the North or the South Pole of the earth, one pole of Mars is always observable. The conditions of observations are peculiarly favorable, on account of its proximity and because when Mars is in opposition it receives the full solar light.

"On Mars circulation of water takes place not by rain and rivers as on the earth, but by melted snows from the poles distributed over the planet by a system of canals. The circulation of water is horizontal instead of vertical as on the earth. Clouds on Mars are almost unknown. The canals as seen by astronomers are certainly water courses, but their dimensions are greatly exaggerated by growths of vegetation on each side, just as from a balloon the valley of a river on the earth appears to be the river itself.

"The melting of polar snows has a greater physical effect on Mars than on the earth. Here the polar seas are joined by oceans, and when there is a thaw at the Arctic Pole the rise of waters means a compensating depression at the Antarctic Pole. On Mars the great sea environing the South Pole has no connection with the seas about the North Pole, and the equilibrium of water in both hemispheres of Mars can be sustained only by canals. These canals run in straight lines for thousands of miles.

COMMUNICATION WITH THE PLANETS.

Mr. Tesla on Sir Norman Lockyer—Development of the Requisite Energy.

To THE EDITOR OF THE SUN—*Sir*. In your issue of Tuesday Sir Norman Lockyer, in commenting on my observations, is reported as having stated: "Communication with Mars is absolutely outside the domain of practical science."

Before I had obtained with electrical oscillations results such as were outlined in a recent article I would have unhesitatingly agreed to this statement, but now I have the unmistakable experimental evidence before me that the transmission of a message to that or some other planet is possible and, what is more, easily practicable.

Necessity of avoiding technical details, unintelligible to the general reader, compels me to illustrate the advantage of the new means of communication over the old by a comparison which, though not exact, is sufficiently correct to convey an approximate idea. Suppose that the entire available power of Niagara, about five million horse power, should be turned into an electric arc and transformed into an equivalent amount of radiant heat and light energy to be used for the purposes of signalling. Assume, further, that the observer in a planet at a distance of fifty million miles would be able to utilize integrally the energy falling upon one hundredth of a square mile of the planet's surface. This would be a difficult, if not impossible, task, but if he were successful, he would then only have 1—3,140,000,000,000,000,000th of that horse power available for the operation of his instrument.

On the other hand, let us examine how much energy could be conveyed by the methods and apparatus I have devised. In this case we should provide a conducting surface, connect it through a coil to the ground, and impress electrical oscillations upon this system. By availing ourselves of certain adjustments and artifices we should, according to my experiences, encounter no insuperable difficulties in setting up a movement of electrical energy equivalent to a rate of five million horse power, with but a small *actual* expenditure of energy. Supposing the observer in the planet should avail himself of similar means, we should then have, as in my system of energy transmission or telegraphy without wires, two resonating attuned circuits connected through a condenser. A great advantage would be at once secured, since the energy does not diminish with the square of the distance, as with light, heat or Hertzian rays, but in a linear proportion to the same.

Estimating the capacity of the condenser formed by the earth, the planet and the intervening medium, I find that we should be able to transmit in this manner to Mars, at intervals, energy at the rate of 1—50,000th of a horse power, which in the tuned circuit on the planet, by skilful construction and adjustment of the apparatus could be intensified to a rate of one-fifth of one horse power, and a considerable portion of this accumulated energy would be available for the operation of the receiving instrument.

The attainment of this enormous rate of energy delivery is made possible by the fact that in using these novel means we should not dissipate the energy of the transmitter uselessly in all directions through space, as we should when employing rays: We should simply transmit electrical stresses through the medium. It is as if we had a weightless, elastic bar extending from our globe to the planet, and as if we were transmitting energy by pushing this bar back and forth. The above rough estimate is obtained by ignoring the disturbing influences of the sun and of other planets, but by making all due allowances we could still convey to its place of destination an amount of energy many million times that possible with radiant light or heat. As far, then, as our ability of communicating with Mars is concerned, far from believing it impossible, we are justified in considering it practicable.

Why should Sir Norman Lockyer doubt that the energy would reach the planet? Does not the fact that electric disturbances are produced in the earth by changes in the sun offer a sufficient warrant? While I do not consider myself infallible, I feel confident that I am neither capable of mistaking earthquakes for novel electrical manifestations, nor incapable of noting what might have escaped the attention of others. I did not state that I had obtained a message from Mars. I only expressed my conviction that the disturbances I observed were of planetary origin. It does not follow that they could be detected by magnetic instruments. These are delicate only in a certain sense; in another sense they are very crude. Sir Norman Lockyer asks what ground I have for assuming Mars inhabited? I do not hesitate to admit that I am convinced of it. Perhaps part of my conviction is derived from the perusal of Sir Norman Lockyer's admirable papers. I am sorry he attaches no value whatever to my observations.

NIKOLA TESLA.

NEW YORK, Jan. 9.

Concentrates.

THE recent published vagaries of Nikola Tesla are not to be given serious attention and are interesting only for their notable absurdity.

The New York Tribune January 12, 1901

MARTIAN TELEGRAPHY DISCREDITED.

WASHINGTON SCIENTISTS CONSIDER TESLA'S CLAIMS ABSURD.

Washington, Jan. 11 (Special).—Scientists in Washington are inclined to regard the reports concerning recent experiments which are said to have facilitated the establishment of communication between the earth and Mars as wild theories, nor do they expect to hear of the success of such experiments. "It is a fanciful idea of Mr. Tesla's," said Professor Skinner, of the Naval Observatory, today, "and I do not think it is based on scientific principles. I believe that Tesla is an exceptionally brilliant man. He has done much wonderful work, but I take no stock in his new proposition, and, indeed, I have talked with no scientific men who do not consider Tesla's claim absurd."

Professor Eichelberger, also of the Naval Observatory, said that he first heard of Mr. Tesla's plans when a friend called his attention to a newspaper clipping. "Had I seen the story when it was first published I would very likely have glanced over it, thinking that it was not worth reading," he said. "I do not believe that anything is impossible which is to be performed in the future. At the same time I do not say that Tesla's claims are possible or even probable. Ten years ago no one would believe in some of the remarkable work he has since made practicable, therefore we cannot tell what is to happen in the future. Although wireless telegraphy has been so established that it must be recognized as a method of communication, as yet the science is in its infancy and great developments are to be expected as the outgrowth of the principles embodied in the Marconi and similar systems. All that I can say further is that we will be glad to hear of Mr. Tesla's success in fully establishing communication with the Martians, assuming, of course, that the planet is peopled. I think he will have no difficulty in convincing scientists of the practicability of such a scheme when he produces the proper evidence."

Father Hargan of Georgetown College, has been ill for several days with the grip, and was unable to talk about Tesla's plans to communicate with Mars, but he has been credited by other members of the faculty with having said that Tesla's plan was not an intrinsic impossibility. It is understood that he would not discuss the matter further.

Tesla Has a Message from the Stars.

Nikola Tesla gave to friends interested in the Red Cross movement this century greeting: "The retrospect is glorious, the prospect is inspiring. Much might be said of both. But one idea dominates my mind. This—my best, my dearest—is for your noble cause. I have observed electrical actions which have appeared inexplicable. Faint and uncertain though they were, they have given me a deep conviction and foreknowledge that ere long all human beings on this globe, as one, will turn their eyes to the firmament above with feelings of love and reverence, thrilled by the glad news: 'Brethren! We have a message from another world, unknown and remote. It reads: One—two—three—'"

Mr. Tesla states that in some experiments which he has been conducting for some time he has been noticing disturbances that have had a peculiar effect on his oscillatory instruments. "What these disturbances are caused by," says Mr. Tesla, "I am unable to say at present, but I am firmly convinced that they are the results of an attempt by some human beings, not of our world, to speak to us by signals. I am certain of some points in connection with these things I have noticed. I am absolutely certain that they are not caused by anything terrestrial. I know, too, that they are not caused by the sun or moon, and hence I am forced to the belief that they come from some other planet.

That we can send a message to a planet is certain. That we can get an answer is probable. Man on earth is not the only being in God's great system of worlds that is in possession of a mind."

The inventor sees no reason why communication cannot be opened in a comparatively short time with either Mars or Venus, or perhaps both, and suggests an electrical vibratory method of signal service.

Scientific American.

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NEW YORK, SATURDAY, JANUARY 19, 1901.

THAT MESSAGE FROM MARS.

It has been stated by an authority, whose weight will be determined by the mental attitude of his readers, that the day is near at hand when we shall be able to communicate with the other planets and preferably with Mars. It seems that in searching for a suitable location for a laboratory in which to conduct experiments in the wireless transmission of energy, Nicola Tesla found the desired conditions at a point some ten miles from Pike's Peak, at an altitude of several thousand feet above the sea. During the eight or nine months wherein Mr. Tesla was busy in the rarefied atmosphere of his laboratory, he seems to have produced some very spectacular effects; for, whereas in his New York laboratory, he was able to produce electrical discharges only 16 feet in length, and of 8,000,000 volts pressure, he here gradually "learned how to confine electrical currents of a pressure of 50,000,000 volts; how to produce electrical movements up to 110,000 horse power," and that he finally succeeded in "obtaining electrical discharges measuring from end to end 100 feet and more." Yet, in spite of his familiarity with 50,000,000-volt currents, Mr. Tesla did not disdain to study "certain feeble electrical disturbances which, by their character, unmistakably showed that they were neither of solar origin nor produced by any causes known to" him "on the globe." After deep thought upon the subject, he has finally "arrived at the conviction, amounting almost to knowledge, that they must be of planetary origin."

It would be interesting, and possibly vastly entertaining, to be supplied with the process of ratiocination by which Mr. Tesla deduces from the existence of certain puzzling electrical disturbances his "conviction, amounting almost to knowledge," that these disturbances had been launched at our particular planet from some other planet (preferably Mars), that was desirous of intercourse. Signor Marconi has suggested that these disturbances (which seem to have worked with such brilliant results upon Mr. Tesla's imagination) were due to atmospheric electricity which is especially active at such a high altitude as that of Mr. Tesla's laboratory; and Sir Norman Lockyer pertinently asks why, if electrical energy had been transmitted from Mars, it should have made its presence manifest in Colorado only; since all magnetic observatories in the world would have been simultaneously aware of it?

That some of the planets may be inhabited is possible, and there is nothing in our present knowledge of electricity absolutely to forbid the hope that in some future day we may learn how to fling forth intelligible electrical impulses into inter-planetary or even inter-stellar space; but it will certainly need something more than mere observations of some unexplained electrical impulses on a Colorado mountain to prove to a demonstration either the one proposition or the other.

A Canadian Rival of Tesla and Marconi.

Prof. E. S. Wiggins, of Ottawa, Canada, has just published a disquisition upon the subject of Tesla's experiments to establish telephonic communication with the planet Mars, in which the former makes a startling assertion in regard to Marconi's discovery, and expresses strong disbelief concerning Tesla's claim of having mechanical and electrical devices by which electrical energy can be forced through space. Prof. Wiggins, however, considered it quite possible for the earth to have electrical communication with Mars, but deprecates the idea of forcing a current of electricity from the earth to Mars. Electricity, he claims, exists only on the surface of bodies. The surface of our own planet's atmosphere is covered by a lake of electrical energy, and no little current, such as Tesla describes, could pass through it without being absorbed.

"Communication with Mars can be established," Prof. Wiggins proceeds, "by Marconi's method, which I discovered and published in 1893, two years before Marconi began his experiments. That is, by elevated points on the same body or planet or different planets. Remove all our mountains but the highest peak. Upon this place an electrical instrument and it will affect a similar one on Mars, especially if the sun, earth and Mars are in conjunction. I am almost certain that, with a proper instrument on the summit of Mount St. Elias we could even now telegraph to the planet Mars. The nick in the edge of that planet, seen by Lowell and Javelle, July 19, 1894, was no doubt an enormous pinnacle, erected to communicate with the planets Jupiter and Saturn."

Speaking upon the question of his claim that Marconi founded his system on the published theory of Prof. Wiggins, and the latter's purpose to demand his right in the honor and emoluments accruing from the new discovery, the professor says: "Surely the philosopher, who by years of study evolves a theory, should be equally rewarded with the man who puts it to the practical test, by having a legal right in all patents. If Marconi does not give me a share of the proceeds from his French patents, I will appeal to Her Majesty, through Sir Wilfrid Laurier and His Excellency, the Governor-General of Canada, as a British subject, and ask for equal right in his patents for the British dominions. I will make the same representations to the President of the United States. My appeal to the latter will be based on the fact that my essay for the Hodgkin's prize of $10,000 was submitted by the Smithsonian Institute at Washington to the French scientists for examination in 1894, and it was from this essay Marconi first learned that the earth's electric energy collects in hills, mountains—in fact, all elevations on her surface. Marconi immediately began to erect towers, and, placing instruments upon their summits, they answered each other.

"But I am now even with him, for I have discovered that the telephone acts on the same wireless principle, and I will ask patents from Canada, Britain and even from France, and my telephone will thus supplant his telegraphy. Then, railway companies will take down their wires, for conversation can be conducted between stations, and even running trains; generals can talk with each other while the battle is raging by merely sticking their swords into the ground; ships will also speak with each other miles away, while we can converse, stretching our limbs upon the grassy lawn here, with the weary traveler trudging his icy way to the northern pole."

Prof. Wiggins further states that volcanoes, like Vesuvius and Ætna, owe their heat entirely to the electric energy that they collect from the adjacent seas, mountains and country. He predicts that before the close of the twentieth century, towers of great height will be built all over the continents and on the sea; and these, burning by the earth's electric energy, will give eternal light to the surface of our planet. With small towers with wire coils, the summits of the Rockies could now, at little expense, become a row of glowing torches from Cape Horn to the Arctic Circle.

LETTER TO THE EDITORS.

Wireless Telegraphy Over Frozen Ground.

To the Editors of Electrical World and Engineer:

Sirs:—I should like to make a correction in your columns of a statement made by me in the discussion on Wireless Telegraphy at the Am. I. E. E. meeting of last year. I there stated that according to my experiments frozen ground made little difference in the transmission of signals, the waves apparently going down to the moisture under the frozen surface.

Whilst this statement was correct for the case tested, it does not hold always. The experiments on which I based this conclusion were made on a gravelly soil, with cinders overlying a clay bottom. Consequently, the frozen moisture was probably highly charged with salts, and was a fair conductor.

I have, within the past few months, had an opportunity of testing the effect over a stretch of land of a different nature. Two stations between which I have been working—one at Cob Point, Md., the other at Arlington, Va.—are 47 miles apart, the line between them passing entirely over open land, with the exception of half a mile of water, and through the City of Alexandria, a few miles from Arlington. The land is practically all well wooded, and the trees of considerable height.

Several sets of measurements were made in fine weather, and fairly accurate results obtained. A severe frost then set in, and the ground was frozen to a depth of several inches. It was found that under these conditions the signals received had only one-seventh the power of those received in warm weather; that is, for equally good transmission, we had to use seven times the power that we used in warm weather. It is evident therefore that in some places, possibly in most places, frost will form a very serious obstacle. I may say that the ratio will not always be one-seventh, but will be still larger for longer distances.

In this connection I would point out that the usual formulæ for

the capacity of a vertical wire or cylinder are not correct, being from 500 to 1000 per cent out. After considerable labor, I have succeeded in getting approximately correct formulæ, which I will give later. The usually given formula for the self-inductance is also incorrect, but the correction has been given by Heaviside. As an example of the approximate accuracy of the new formulæ, the calculated wave length was 254 ft. and the actual length as measured was 250 ft.

The design of stations for wireless telegraphy is now on exactly the same footing as the design of telegraph lines, and the laws are now fully understood. It is perhaps unnecessary to add that the various wild hypotheses of equipotential surfaces in the air or in the ground, of "wobbling" earth charges, etc., have been definitely disproven, the matter being a plain, simple case of ordinary electrodynamics.

With regard to the so-called Martian signals, these external disturbances have long been known, and only the crassest ignorance could attribute any such origin. They formed at one time a serious obstacle to multiplex systems, but are now eliminated. The different kinds are easily distinguishable, i. e., those due to lightning flashes anywhere within 100 miles or more, those due to street cars, etc., and those due to the gradual electrification of the vertical conductor by the air currents. This last gives, unless eliminated, signals at regular intervals, and by those ignorant of the subject, might be mistaken for intelligent signals.

Some work was done with the coherer, for the purpose of making comparative tests. Lodge's theory was confirmed. After long use the particles are found strung together in groups by thin ligaments of metal. Decohering can be obtained with all metals yet tried. The action observed is as follows: With small discharges the microscopic points of contact are fused off and the circuit opened. This gives decoherence. With greater discharges, the points are fused, but the fusion extends over a greater extent, and the electrostatic attraction draws out a thin tongue of melted metal till the gap is bridged. This gives coherence. Arsenic and other metals which do not fuse (except under great pressure) do not cohere, except when oxidized slightly on the surface. Then a discharge sufficient to reduce the oxide causes coherence, but a larger current burns away the contact points and causes decoherence; and as the metal does not fuse, larger currents do not cause coherence. The action of such materials as silver bromide is due to the fact that, after reduction and coherence, the now active bromide combines again with the silver. I gave a description of a coherer worked on this principle about a year and a half ago, in a review I wrote on Lodge's book, for this journal. All of Bose's experiments are therefore quite in accordance with Lodge's theory.

The amount of senseless and sensational stuff which has been written about wireless telegraphy suggests that the little knowledge, which the poet assures us is a dangerous thing, may have a certain function. That is, a very small amount of knowledge gone bad, of no particular use even to the owner, may yet, when spread in a thin film over the columns of the newspaper, give rise, by its very superficialty and tenuity, to a pleasing and striking iridescence. But, after all, it is only scum, and an evidence of the drink underneath. The fount of truth has another appearance.

WASHINGTON, D. C. R. A. FESSENDEN.

DIGEST
OF
CURRENT ELECTRICAL LITERATURE

Electro-Physics and Magnetism.

Point Discharge from a Tesla Pole.—Knoblauch.—An investigation of the following phenomenon: The discharge from a Tesla pole charges an insulated metallic plate positively at a certain distance and negatively at a greater distance. This is due to the greater speed and penetrative power of the negative ions. He has studied the distribution of the ions by means of perforated plates, and found that the positive charges are due to visible brush-discharges. When these brush discharges are prevented from impinging upon the plate by cutting out a central portion, no positive charge is obtained. The positive ions are strongest in the axial portion of the discharge.—*Phys. Zeit.*, Dec. 15; abstracted in Lond. *Elec.*, Jan. 4.

SCIENCE AND INVENTION.

AN ALLEGED MESSAGE FROM MARS.

IT is claimed by Nikola Tesla, if we are to believe interviews published in the daily papers, that while he was experimenting recently with long-distance space-signaling, his instruments persistently recorded a signal that could not have originated on the earth and must have come from some point outside. He believes that it may have been an attempt on the part of intelligent beings in Mars to communicate with us. In an interview printed in the New York *Herald*, Mr. Tesla is made to speak as follows:

"In my investigations, disturbing atmospheric influences were almost wholly excluded. It would have been impossible for other experimenters to note the effects which I have discovered, for with the Hertzian devices only a very narrow region can be explored, whereas I was able to observe the electrical condition of a large portion of the globe, a stretch of land 2,200 miles in width and breadth. That these actions are due to causes heretofore unknown I am convinced.

"I feel that I have not been led away by my imagination, but that my sight was true as ever before, and I am confident that future investigation will confirm my statement.

"Nor have I the slightest doubt, judging from my experiments and measurements, that with a properly constructed electrical oscillator an amount of energy can be transmitted to a planet, as Venus or Mars, even at their greatest distance, sufficient to bring into action a sensitive instrument, such as I have been using in my own observations.

"Furthermore, it is an error to believe that a great expenditure of power is necessary for interplanetary communication. What is needed is an effect specifically great—an enormous rate of energy delivery, but lasting each time only a fraction of a second, so that the total power used up is small. Now, with my oscillator I can make this rate equal to five million horse-power and more, if necessary, and my calculations show that a small fraction of this rate is amply sufficient for conveying a message to Mars.

"Heretofore light was the only known agent for communicating with a planet. It is easy to show that by its means such a result is virtually impossible, owing to the rapid diminution of energy, with the distance and the impossibility of concentrating in an instrument the energy falling upon a large area. By the method and machinery I have devised we are enabled to convey an immeasurably greater amount of energy to the planet, and the observer there, instead of utilizing in his instrument only an infinitesimal amount of the entire energy conveyed, can avail himself of a large portion of the same.

"A practical solution has thus been found both for transmitting and receiving messages, and we can only hope that there are beings as far advanced, and possibly further than we are ourselves. I see no harm in holding fast to this possibility. This thought can not but make us better and give us a fresh interest in life."

Scientific journals have not commented upon these claims, and other scientific men, when interviewed by reporters of the daily press, have expressed incredulity. Some have been outspoken in ridicule. An interview is printed in *The Sun* (January 8), purporting to have been held with Sir Norman Lockyer. Sir Norman is reported in a later issue to have denied the substance of this interview, and to profess admiration and respect for Mr. Tesla's work. What Sir Norman is represented to have said does, however, fairly well represent the general attitude of the scientific world, and we reproduce it here. He is reported as saying:

"I attach no importance whatever to them [electrical disturbances reported by Tesla]. The earth is always in a state of vibration. When these vibrations are on a large scale they are called earthquakes. When they are infinitesimal, they are not noticed, except by the most delicate magnetic instruments. If Mr. Tesla received a message from Mars, the electric transmitory influence must have been general, not local.

"Why should electric energy transmitted from Mars have made its presence manifest solely in Colorado? All the magnetic observatories in the world would have been aware of it simultaneously. Paris, Peking, Berlin, and Moscow would have recorded it as soon as Colorado. Any solar magnetic disturbance affects the whole earth, and the same law governs planetary disturbances. Thus the whole of our planet would be conscious of a message from Mars at the same moment.

"Regarding the immense accumulation of electrical energy which Mr. Tesla says is necessary for the delivery of his interplanetary signals, it is quite possible for him to concentrate the enormous electrical power he speaks of. He can also launch it into space, but whether it would reach Mars is more than I should like to assert."

The editorial comments of the lay press are various. The Philadelphia *Inquirer* believes that "one man's opinion is as good as another's" on such a subject, but is disinclined to credit Mr. Tesla. The Boston *Journal* is inclined to doubt the accuracy of the interviews with Tesla, and concludes that the true scientist is content with demonstrating facts. "Beyond that kind of demonstration," it says, "the wise man will not venture." The Providence *Journal* publishes half a column about what would be true if Tesla's assertions are to be credited; but it ventures no opinion as to the facts in the case. Mr. Garrett P. Serviss writes in the Atlanta *News* on methods by which it might be possible to communicate with the inhabitants of a planet, and on devices that they might be expected to use to attract our attention; but he, too, fails to state either belief or disbelief in Mr. Tesla's reputed claims. There can be no doubt, however, that the scientific world believes him to be either trying to make a new sensation out of nothing, or to be the victim of self-deceit. As the Boston *Herald* puts it:

"The readers of Mr. Tesla's periodical announcements have borne patiently with his flights of fancy. At the same time it seems pertinent to remind him that in performance he has fallen several long laps behind promise. The world has yet to witness the realization of revolutionizing discoveries for which he claimed credit. . . . There is not an electrical advance of note which has failed to elicit from him a definite and specific asseveration that he would presently bring it to a wonderful state of perfection.

"During the earlier stages of his career Mr. Tesla did accomplish some practical results; but the clear-headed technologist who deals in concrete facts seems to have been merged in the dreamer, who beguiles his hours with fantastic visions and lives in a realm of unreality."

TESLA'S WIRELESS LIGHT,

MAKES SCARCELY ANY HEAT, AND CLOSELY RESEMBLES SUNLIGHT.

Based Upon an Entirely New Principle, and the Inventor Says It Will Purify the Atmosphere and Kill Disease Germs—Also Exercises Soothing Effect Upon the Nerves.

Nikola Tesla gave to THE SUN yesterday an authorized statement in reference to his new light, described the lamp which diffuses the light and then, darkening the windows of his laboratory in East Houston street, turned on an electric current, and in a moment the rooms were flooded with what Tesla calls "artificial sunshine." The light was diffused through a spiral of glass about eight inches high and six inches wide. The spiral is of glass tubing, about one-quarter of an inch in diameter, the ends being blown to about double the size of the tybe and closely resembling wax candles. The general effect of the lamp is that of a small box made of glass tubing with two candles lying on their sides along the top. The ends of the spiral which resemble candles are covered with a thin coating of metal and painted white. The lamp illuminates whether it is connected by wires with an electric current or not. Mr. Tesla operates it with and without wires. The wonderful thing about the wireless lamp is that it may be carried about from one part of a room to another, picked up and set down at will, just as one would carry a kerosene lamp around, and all the time there is not so much as a flicker of the light.

But more than all this, Mr. Tesla asserts that in discovering this process of illumination he has discovered a light which will be of incalcuable value in the sick room and in the hospital ward. The tube of the lamp before being closed at one end is partly filled with certain gases, the properties of which Mr. Tesla is not quite ready to disclose, but which, he says, will purify the air of a sick room when it might endanger the life of the patient to have the windows opened, so that the room's atmosphere will be as pure as if the room had been flooded with outer air. The inventor asserts that so perfect is his invention that the "ozonizing" of a room, as he calls it, may be continued as long as desired and stopped at will. Tesla says that his artificial sunshine, or his "sanitary light," is intended to be his first gift to the new century, the practical result of years of experiment in the old. Here is Mr. Tesla's statement:

"This light is the result of continuous efforts since my early experimental demonstrations before scientific societies here and abroad. In order to make it suitable for commercial use, I had to overcome great difficulties. One of these was to produce from ordinary currents of supply electrical oscillations of enormous rapidity in a simple and economical manner. This, I am glad to say, I have now accomplished and the results show that with this new form of light a higher economy is practicable than with the present illuminants. The light offers, besides, many specific advantages, not the least of which is found in its hygienic properties. It is, I believe, the closest approach to daylight which has yet been reached from any artificial source.

"The lamps are glass tubes which may be bent in any ornamental way. I most generally use a rectangular spiral, containing about twenty to twenty-five feet of tubing making some twelve to fourteen convolutions. The total illuminating surface of a lamp is from 300 to 400 square inches. The ends of the spiral tube are covered with a metallic coating and provided with hooks for hanging the lamp on the terminals of the source of oscillations. The tube contains gases rarefied to a certain degree, determined in the course of long experimentation as being conductive to the best results.

"The process of light production is, according to my views, as follows: The street current is passed through a machine which is an electrical oscillator of peculiar construction and transforms the supply current, be it direct or alternating, into electrical oscillations of a very high frequency. These oscillations, coming to the metallically coated ends of the glass tube, produce in the interior corresponding electrical oscillations, which set the molecules and atoms of the inclosed rarefied gases into violent commotion, causing them to vibrate at enormous rates and emit those radiations which we know as light. The gases are not rendered incandescent in the ordinary sense, for if it were so, they would be hot, like an incandescent filament. As a matter of fact, there is very little heat noticeable, which speaks well for the economy of the light, since all heat would be loss.

"This high economy results chiefly from three causes: First from the high rate of the electrical oscillations; second, from the fact that the entire light-giving body, being a highly attenuated gas, is exposed and can throw out its radiations unimpeded, and third, because of the smallness of the particles composing the light-giving body, in consequence of which they can be quickly thrown into a high rate of vibration, so that comparatively little energy is lost in the lower or heat vibrations. An important practical advantage is that the lamps need not be renewed like the ordinary ones, as there is nothing in them to consume. Some of these lamps I have had for years, and they are now in just as good a condition as they ever were. The illuminating power of each of these lamps is, measured by the photometric method, about fifty candle power, but I can make them of any power desired, up to that of several arc lights. It is a remarkable feature of the light that during the day it can scarcely be seen, whereas at night the whole room is brilliantly illuminated. When the eye becomes used to the light of these tubes, an ordinary incandescent lamp or gas burner produces a violent pain in the eye when it is turned on, showing in a striking manner, to what a degree these concentrated sources of light which we now use are detrimental to the eye.

"I have found that in almost all its actions the light produces the same effects as sunlight, and this makes me hopeful that its introduction into dwellings will have the effect of improving, in a measure now impossible to estimate, the hygienic conditions. Since sunlight is a very powerful curative agent, and since this light makes it possible to have sunlight, so to speak, of any desired intensity, day and night in our homes, it stands to reason that the development of germs will be checked and many diseases, as consumption for instance, successfully combatted by continually exposing the patients to the rays of these lamps. I have ascertained unmistakably, that the light produces a soothing action on the nerves, which I attribute to the effect which it has upon the retina of the eye. It also improves vision, just exactly as the sunlight, and it ozonizes slightly the atmosphere. These effects can be regulated at will. For instance, in hospitals, where such a light is of paramount importance, lamps may be designed which will produce just that quantity of ozone which the physician may desire for the purification of the atmosphere, or if necessary the ozone production can be stopped altogether.

"The lamps are very cheap to manufacture, and by the fact that they need not be exchanged like ordinary lamps or burners they are rendered still less expensive. The chief consideration is, of course, in commercial introduction, the energy consumption. While I am not yet prepared to give exact figures, I can say that, given a certain quantity of electrical energy from the mains, I can produce more light than can be produced by the ordinary methods. In introducing this system of lighting my transformer, or oscillator, will be usually located at some convenient place in the basement, and from there the transformed currents will be led as usual through the building. The lamps can be run with one wire alone, as I have shown in my early demonstrations, and in some cases I can dispense entirely with the wires. I hope that ultimately we shall get to this ideal form of illumination, and that we shall have in our rooms lamps which will be set aglow no matter where they are placed, just as an object is heated by heat rays emanating from a stove. The lamps will then be handled like kerosene lamps, with this difference, however, that the energy will be conveyed through space. The ultimate perfection of apparatus for the production of electrical oscillations will probably bring us to this great realization, and then we shall finally have the light without heat or 'cold' light. I have no difficulty now to illuminate the room with such wireless lamps, but a number of improvements must be made yet before it can be generally introduced."

The New York Tribune January 27, 1901

TESLA'S VACUUM TUBE LIGHT.

THE INVENTOR ENCOURAGED BY THE PROGRESS OF HIS WORK.

Mr. Tesla, who has been striving for years to produce an electric light without heat, feels that he is making perceptible headway in that work. As The Tribune has indicated before his general plan is to employ an alternating current of almost inconceivably great frequency, and a lamp consisting of a vacuum tube. The alternations are secured by an instrument of his own invention, known as the oscillator.

But after Mr. Tesla entered upon his interesting line of experiment he encountered various unforeseen difficulties. While he was able to obtain a beautiful light almost at the outset, it was at the expense of more energy than was desirable. In other words, he did not have his invention on a thoroughly satisfactory basis. By degrees he has improved the efficiency of his apparatus, so that his light is now more economical than it was, and he regards it as superior to both the incandescent and arc lights in this respect. At present, however, he is unwilling to indicate precisely the nature and degree of the technical advances made, or to use figures in comparing its economy with that of its rivals. One reason for reticence on the latter point may be a recognition of the possibility of further improvement. Mr. Tesla frankly declares that his lamp is not yet perfect. It does not make as good a return in light for the electrical energy invested as he would like. All that he insists upon is that it is now so efficient that he can conscientiously recommend it to those who may wish to put it on the market.

In some of his earlier experiments Mr. Tesla used a straight vacuum tube fully an inch and a half in diameter and six or eight feet long. Latterly he has employed a much more slender one, and by putting it into a rather compact coil saves a great deal of space. A score of lamps of this sort, each with a porcelain reflector over it, might be suspended from the ceilings of rooms on the tenth floor of an office building, while the special apparatus which modified the current for their use would be down in the basement. The street mains would supply an ordinary alternating current, and other wires would lead from the oscillator up to the lamps. For some purposes two wires to each lamp would be preferable but for others one would suffice. Less copper would be required for inside wiring, and the risks from escaping current would be diminished, rather than increased. The present style of insulation would be more than sufficient

TESLA'S NEW DISCOVERY.

CAPACITY OF ELECTRICAL CONDUCTORS IS VARIABLE

Not Constant, and Formulas Will Have to Be Rewritten—Capacity Varies With Absolute Height Above Sea Level, Relative Height From Earth and Distance From the Sun.

Nikola Tesla announced yesterday another new discovery in electricity. This time it is a new law and by reason of it, Mr. Tesla asserts, a large part of technical literature will have to be rewritten. Ever since anything has been known about electricity scientific men have taken for granted that the capacity of an electrical conductor is constant. When Tesla was experimenting in Colorado he found out that this capacity is not constant, but variable. Then he determined to find out the law governing this phenomenon. He did so, and all this he explained to THE SUN yesterday. Here is what he said:

"Since many years scientific men engaged in the study of physics and electrical research have taken it for granted that certain quantities, entering continuously in their estimates and calculations, are fixed and unalterable. The exact determination of these quantities being of particular importance in electrical vibrations, which are engrossing more and more the attention of experimenters all over the world, it seems to me important to acquaint others with some of my observations, which have finally led me to the results now attracting universal attention. These observations, with which I have long been familiar, show that some of the quantities referred to are variable and that, owing to this, a large portion of the technical literature is defective. I shall endeavor to convey the knowledge of the facts I have discovered in plain language, devoid as much as possible of technicalities.

"It is well known that an electric circuit comports itself like a spring with a weight attached to it. Such a spring vibrates at a definite rate, which is determined by two quantities, the pliability of the spring and the mass of the weight. Similarly an electric circuit vibrates, and its vibration, too, is dependent on two quantities, designated as electrostatic capacity and inductance. The capacity of the electric circuit corresponds to the pliability of the spring and the inductance to the mass of the weight.

"Exactly as mechanics and engineers have taken it for granted that the pliability of the spring remains the same, no matter how it be placed or used, so electricians and physicists have assumed that the electrostatic capacity of a conducting body, say of a metallic sphere which is frequently used in experiments, remains a fixed and unalterable quantity, and many scientific results of the greatest importance are dependent on this assumption. Now, I have discovered that this capacity is not fixed and unalterable at all. On the contrary, it is susceptible to great changes, so that under certain conditions it may amount to many times its theoretical value, or may eventually be smaller. Inasmuch as every electrical conductor, besides possessing an inductance, has also a certain amount of capacity, owing to the variations of the latter, the inductance, too, is seemingly modified by the same causes that tend to modify the capacity. These facts I discovered some time before I gave a technical description of my system of energy transmission and telegraphy without wires, which, I believe, became first known through my Belgian and British patents.

"In this system, I then explained, that, in estimating the wave-length of the electrical vibration in the transmitting and receiving circuits, due regard must be had to the velocity with which the vibration is propagated through each of the circuits; this velocity being given by the product of the wave-length and the number of vibrations per second. The rate of vibration being, however, as before stated, dependent on the capacity and inductance in each case, I obtained discordant values. Continuing the investigation of this astonishing phenomenon I observed that the capacity varied with the elevation of the conducting surface above the ground, and I soon ascertained the law of this variation. The capacity increased as the conducting surface was elevated, in open space, from one-half to three-quarters of 1 per cent. per each foot of elevation. In buildings, however, or near large structures, this increase often amounted to 50 per cent. per foot of elevation, and this alone will show to what an extent many of the scientific experiments recorded in technical literature are erroneous. In determining the length of the coils or conductors, such as I employ in my system of wireless telegraphy, for instance, the rule which I have given is, in view of the above, important to observe.

"Far more interesting, however, for men of science is the fact I discovered later, that the capacity undergoes an annual variation with a maximum in summer and a minimum in winter. In Colorado, where I continued with improved methods the investigations begun in New York and where I found the rate of increase slightly greater, I furthermore observed that there was a diurnal variation with a maximum during the day and a minimum during the night. Further, I found that sunlight causes a slight increase in the capacity. The moon also produces an effect, but I do not attribute it to its light.

"The importance of these observations will be better appreciated when it is stated that owing to these changes of a quantity supposed to be constant an electric circuit does not vibrate at a uniform rate, but its rate is modified in accordance with the modifications of the capacity. Thus a circuit vibrates a little slower at an elevation than when at a lower level. An oscillating system, as used in telegraphy without wires, vibrates a little quicker when the ship gets into the harbor than when on open sea. Such a circuit oscillates quicker in the winter than in the summer, though it be at the same temperature, and a trifle quicker at night than in daytime, particularly if the sun is shining.

"Taking together the results of my investigations I find that this variation of the capacity and consequently of the vibration period is evidently dependent, first, on the absolute height above sea level, though in a small degree; second, on the relative height of the conducting surface or capacity with respect to the bodies surrounding it; third, on the distance of the earth from the sun, and fourth, on the relative change of the circuit with respect to the sun caused by the diurnal rotation of the earth. These facts may be of particular interest to meteorologists and astronomers, inasmuch as practical methods of inquiry may result from these observations, which may be useful in their respective fields. It is probable that we shall perfect instruments for indicating the altitude of a place by means of a circuit properly constructed and arranged, and I have thought of a number of other uses to which this principle may be put.

"It was in the course of investigations of this kind in Colorado that I first noted certain variations in electrical systems arranged in peculiar ways. These variations I first discovered by calculating over the results I had previously noted, and it was only subsequently that I actually perceived them. It will thus be clear that some who have ventured to attribute the phenomena I have observed to ordinary atmospheric disturbances have made a hasty conclusion."

ter to the *Sun* the following details are given: "The lamps are glass tubes which may be bent in any ornamental way. I most generally use a rectangular spiral, containing about twenty or twenty-five feet of tubing making some twelve to fourteen convolutions. The total illuminating surface of a lamp is from 300 to 400 sq. ins. The ends of the spiral tube are covered with a metallic coating and provided with hooks for hanging the lamp on the terminals of the source of oscillations. The tube contains gases rarefied to a certain degree, determined in the course of long experimentation as being conducive to the best results." In this instance also Mr. Tesla has been very fortunate in departing from his custom by giving details, for the "gift to the New Century" appears to be merely the vacuum tube light, known now for almost two centuries. The description does not indicate any advance in principle over Hawksbee's work of 1709, nor any advance otherwise over the work of Geissler fifty years ago, or that of D. McFarlan Moore in recent years.

Tesla's Latest.

The New Century has already been enriched by two Tesla "discoveries," one of which he announces as his "first gift to the New Century." Several weeks ago he announced through the newspapers that certain electrical disturbances that had come under his observation were, he felt convinced, of planetary origin, which statement was followed up a few days later with another that he had discovered a means which rendered communication with Mars or any other planet not only possible, but easily practicable. Unfortunately for the credence of his claim, he added in a letter to the New York *Sun* some details which contradict all established ideas concerning the transmission of electric radiant energy, though the proposed means of communication with another planet purports to be based upon these same ideas.

The second and more recent announcement is that as the result of continuous effort since his first experimental demonstrations of years ago, he has at last perfected a means of producing "artificial sunshine," the new light being more economical and vastly superior to present forms of artificial illumination. In a letter to the *Sun* the following details are given: "The lamps are glass tubes which may be bent in any ornamental way. I most generally use a rectangular spiral, containing about twenty or twenty-five feet of tubing making some twelve to fourteen convolutions. The total illuminating surface of a lamp is from 300 to 400 sq. ins. The ends of the spiral tube are covered with a metallic coating and provided with hooks for hanging the lamp on the terminals of the source of oscillations. The tube contains gases rarefied to a certain degree, determined in the course of long experimentation as being conducive to the best results." In this instance also Mr. Tesla has been very fortunate in departing from his custom by giving details, for the "gift to the New Century" appears to be merely the vacuum tube light, known now for almost two centuries. The description does not indicate any advance in principle over Hawksbee's work of 1709, nor any advance otherwise over the work of Geissler fifty years ago, or that of D. McFarlan Moore in recent years.

At one time the frequent announcements by Tesla of revolutionary discoveries were a real source of harm to the electrical industry through giving rise to fears in the minds of investors that the current status of the electrical industry is insecure. The lay public appears, however, to have finally become surfeited with promises followed by no fulfillment, and the more recent announcements of Tesla have been received by the newspaper press with few exceptions—mostly of the "yellow" variety—in a changed spirit. Instead of serious consideration being given to his claims, he is rapidly becoming a subject for the irreverent mirth of the newspaper paragrapher, one of whom comments as follows: "Mr. Tesla is thus on the very eve of a discovery even more remarkable than the many others on whose eve he has been so often and so long. It may be asserted confidently that if any one on earth can understand Mars it is Tesla; and conversely, that if any one can understand Tesla, it must be an inhabitant of Mars." To quote sorrowfully an English electrical contemporary: "It is pitiable to see the engineer who invented the polyphase system of power transmission and who has done such valuable original work for other departments of electrical engineering, so fond of the cheap notoriety to be gained by sensational paragraphs in daily papers."

MR. TESLA'S SCIENCE.

To the Editor: In the *New York Sun* for January 3, Mr. Nikola Tesla has an article that deserves a word. The word is one of warning to all sober-minded readers to remind them that Mr. Tesla's recently published utterances have discredited him in the eyes of competent judges. In the *Century Magazine* for June, 1900, Mr. Tesla printed a long article, superbly illustrated with cuts that had little or nothing to do with his subjects, which dealt with a few electrical matters, and also with philosophic and social problems upon which he freely expressed a jumble of trivial, ignorant, pretentious and erroneous opinions. This article was freely reviewed in the POPULAR SCIENCE MONTHLY for July, 1900, and in *Science* for September 21. These reviews were doubtless seen by Mr. Tesla, but no word of reply has been made public by him. Indeed, he says in the *Sun* that from adverse criticisms on his work he experiences 'a feeling of satisfaction.' Any one who desires a standing among men of science is called upon to defend his public utterances when they have been seriously questioned in reputable scientific journals. Until an adequate rejoinder is received Mr. Tesla has no standing among professed men of science. He will have none among intelligent readers from the moment that the case is understood by them. It is not profitable to again go over the ground covered by the articles just mentioned, but readers are referred to them in passing.

The article in the *Sun* of January 3 bears the marks of authenticity. Much of it is printed in quotation marks. It gives an account of Mr. Tesla's work in Colorado during a part of the year 1899. This work had, he says, three objects: first, to transmit power without wires, and second, to develop apparatus for submarine telegraphy. These two problems have a direct commercial value. When they are solved, by Mr. Tesla or another, we shall hear of them through the Patent Office. As we have not so heard of them it is permissible to wait for results. We wish Mr. Tesla every success in these investigations. He is entitled to all the time he needs—a lifetime if necessary. If his experiments forward our present knowledge in any material degree he will be entitled to the gratitude of all mankind, and he will receive it. Until they do pronunciamentos from him and comments from us are not required.

The third problem upon which Mr. Tesla was engaged 'involves,' he says, 'a still greater mastery of electrical forces.' He will 'make it known in due course.' In the meanwhile, however, he states that he has noted "certain feeble electrical disturbances . . . . which by their character unmistakably showed that they were neither of solar origin nor produced by any causes known to me on the globe." These he supposes may have been signals from intelligent beings on Mars or some other of the 'twenty or twenty-five planets of the solar system.' Mr. Tesla obviously wants to figure in the newspapers. Every one would be greatly interested if it were true that signals are being sent from Mars. Unfortunately for Mr. Tesla's scientific standing, he has not adduced a scrap of evidence to prove it. It is of a piece with the 'twenty or twenty-five planets' he ascribes to the solar system. It would be interesting if there were so many. There is no evidence of it save Mr. Tesla's assertion, and assertions—Mr. Tesla's or another's—do not count in science. There is no further space for a notice of Mr. Tesla's latest extravagant vagary. For men of science no notice at all is needed. Any intelligent reader who will consult the reviews already mentioned and compare them with Mr. Tesla's own words will see that his vivid writings must be read with extreme caution. His electrical experiments being directed towards commercial uses must be judged by proved commercial success. His speculations on science are so reckless as to lose an interest. His philosophizing is so ignorant as to be worthless.

X.

CURRENT NEWS AND NOTES.

VACUUM TUBE LIGHTING.—According to newspaper reports Mr. Tesla is again working upon vacuum tubes. In an authoritative statement in the New York *Sun* he says: "The lamps are glass tubes which may be bent in any ornamental way. I most generally use a rectangular spiral, containing about 20 ft. to 25 ft. of tubing, making some twelve to fourteen convolutions. The total illuminating surface of a lamp is from 300 to 400 square inches. The ends of the spiral tube are covered with a metallic coating and provided with hooks for hanging the lamp on the terminals of the source of oscillations. The tube contains gases rarefied to a certain degree, determined in the course of long experimentation as being conducive to the best results." After discussing the subject in general terms, he adds: "I have no difficulty now to illuminate the room with such wireless lamps, but a number of improvements must be made yet before it can be generally introduced." Wherein this system differs from that of Geissler, Moore and the several earlier ones of Tesla, is not stated.

ANOTHER TESLA DISCOVERY.—Through the daily newspapers of Wednesday of this week Tesla announced another new discovery in electricity, which he says will require a large part of technical literature to be rewritten. The discovery is that capacity is not fixed and unalterable. In the announcement Tesla says he has found that capacity increases as the conducting surface is elevated in open space, from one-half to three-fourths of one per cent per each foot of elevation, though in buildings or near large structures this increase often amounted to 50 per cent per foot of elevation. Moreover, he says he has observed that there is a diurnal variation of the capacity, with a maximum during the day and a minimum during the night; and the astonishing statement is made that while both the sun and moon cause a slight increase in capacity, in the former case it is due to sunlight, but in the latter case not due to moonlight. Summing up, he says he finds that the variation of capacity is dependent upon the absolute height above sea level, though in a small degree; on the relative height of the conducting surface or capacity with respect to the bodies surrounding it; on the relative change of the circuit with respect to the sun, caused by diurnal rotation of the earth; and—on the distance of the earth from the sun! He considers it probable that instruments will be perfected for indicating the altitude of a place by means of a circuit properly constructed and arranged, and adds that he has thought of a number of uses to which this principle may be put. It is also said that inductance is seemingly modified by the same causes that tend to modify the capacity. Although no reference is made to the Pupin theory concerning the use of inductance in overcoming the disturbing effects of the capacity of telephone lines, the "discovery" appears to invalidate that theory.

MEN AND WOMEN OF INTEREST

NICOLA TESLA, the well-known electrician, has attracted the attention of the civilized world by his recent announcement that he had discovered a means by which it was possible to communicate



GUGLIELMO MARCONI.
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with the inhabitants of Mars. A system of wireless telegraphy, differing, however, from the Marconi system, is the power used in his experimental machine, which, he claims, has one twenty-fifth of the requisite force.

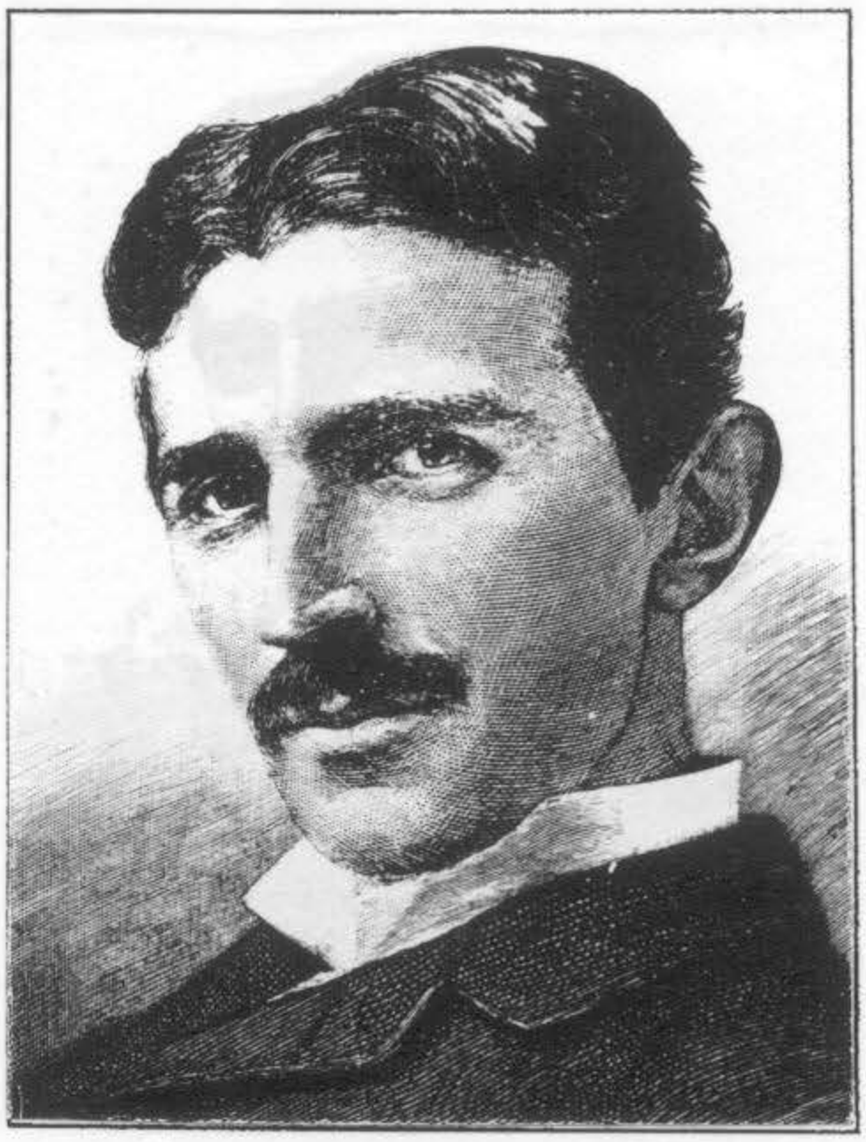
Mr. Tesla is an earnest worker along original lines. He was born forty-three years ago in the little village of Smiljam, Lika, an insignificant part of Servia. He is proud of his Slav blood. He is also proud of his three sisters, the youngest of whom was formerly considered the genius of the family. That was before her brother became the rival of Edison as an electrical wonder.

When a student at the University of Bologna, Marconi astonished his instructors by his novel ideas and original experiments. Although now only twenty-eight years old, he has astonished the world, not by ideas or experiments, but by one of the most wonderful inventions of the last century. As the inventor of wireless telegraphy his fame encircles the globe.

His mother was English, his father Italian, and Bologna was his birth-place. Meeting with neither recognition nor encouragement in his native land, in 1898 he went to England. Before leaving Italy he had clearly demonstrated the possibility of signalling without wires by means of Hertzian waves. In '99 he sent the first message across the English Channel.

Last year he came to the United States to make a test of his system before the Naval Board. Experiments were made on board the cruiser *New York* and the battle-ship *Massachusetts*, and messages were successfully sent across thirty-six miles of ocean.

The present state of the Czarina's health is of vital moment to all Russia. If the babe whose arrival is expected in May is not a boy, bitter will be the disappointment in the royal household and throughout the realm of the Czar. Already three daughters have been born to the Czar and Czarina. In case the Czar dies without male issue, the throne



NICOLA TESLA.



MISS MARY CONDIT-SMITH.

passes to his younger brother, the Grand-Duke Michael.

If all reports are true, the life of the Czarina has not been a very happy one. The people look upon her as an alien, foreign in her tastes and sympathies. The edict she caused to be issued forbidding the ladies of the court to smoke cigarettes did much to increase the animosity towards her.

She is a devoted wife and mother, and during the recent illness of the Czar she never left his bedside. It was at this time that the Czarina gave orders that no bulletins or information regarding the Czar's health should be sent out until they were first submitted to her. Baron Fredericks, Minister of Court, disobeyed this command by writing a personal letter to the Dowager Czarina. For this he was summarily dismissed by the determined young wife of Nicholas II.

The Grand-Duke Michael, who, in the event of the present Czar dying without male issue, would succeed to his brother's throne, is now in his twenty-third year. He has been a constant companion of his mother, the Dowager Czarina, making his home with her in Russia, and accompanying her in all her travels abroad. She is said to have thoroughly imbued him with the reactionary ideas and principles of his father, Alexander III.

It has been an accepted fact that the marriages of royal personages were not made in heaven, but in counsellors' chambers. But twentieth-century women, even though they be queens and princesses, will not bow to this time-honored custom. So "wilful Wilhelmina," as Holland's spirited young Queen is called by some who know her well, has chosen a husband for herself. He is a cadet of the ducal house of Mecklenburg-Schwerin, the little grand-duchy on the northeast coast of the German Empire. He is a good-looking young fellow, four years older than Wilhelmina, and the possessor of a vast amount of common-sense. There is nothing extraordinary about Duke Henry, even if he did please the fancy of a most fastidious Queen. He is the youngest child by his father's third marriage, and is closely attached to the German court, holding the commission of a lieutenant in the chasseur battalion of the Prussian Guard stationed at Potsdam. Whether skating, witnessing the manœuvres of her troops, leading her staff on horseback, opening provincial and agricultural shows, or tending her tulip-garden, Wilhelmina is the idol of her people.

The little Queen of Holland is one of the wealthiest European sovereigns, her yearly income from the civil lists being $15,000,000. In addition to this she has a large private fortune, inherited from her father.

Another independent young woman, when it comes to matrimonial matters, is the Princess Victoria, the second daughter of the



ALFRED GWYNNE VANDERBILT.



THE CZAR AND CZARINA OF RUSSIA.

Prince of Wales. She, too, has at last succumbed to Cupid's darts. Prince George of Greece is said to be the fortunate man. The Princess has long since been considered eccentric on account of her original ideas. It was said that she was the victim of two unfortunate love-affairs, and that it was her disappointment in failing to win recognition for either of her lovers that caused her to withdraw as much as possible from all gayety. At one time her queer, plain costumes, and her sad, distrait air, caused much comment and sympathy for a Princess who wanted first to be a woman.

As a second son, Prince George started life without any especially brilliant prospects. He was assigned to the navy. As commander of the Greek fleet he gave so good an account of himself during the Græco-Turkish war that the Powers in '98 appointed him Commissioner-General of Crete for three years.

In '91 Prince George visited the United States. He is tall, standing six feet three, with light complexion, kindly eyes, and an amiable expression. He took an active part in the Olympian games at Athens, and is the strongest man in the Greek navy.

The most interesting marriage of the season on this side of the water was that of Alfred Gwynne Vanderbilt, second son of Cornelius Vanderbilt, and Miss Elsie French, the daughter of the late Francis Ormond French. The young people had known each other from childhood and had been sweethearts for many years. In taste they were exceedingly congenial. Mrs. Vanderbilt is vivacious, chic, graceful, and pretty in a fresh, girlish way. She is not a beauty, however. She is fond of travel, adventure, and society, as is her husband. Mr. Vanderbilt is particularly devoted to automobiling and horse-back riding, and for less exciting diversion enjoys the theatres. Miss French was rich in her own right, her marriage dot being $3,700,000. Mr. Vanderbilt's inheritance from his father is estimated at $40,000,000.

The marriage of Miss Mary Condit-Smith, of Washington, and Lieutenant Richard S. Hooker, United States Marine Corps, now stationed at the Brooklyn Navy-yard, will occur at the national capital February 11, and will be one of the most brilliant social events of an unusually gay winter. The wedding will take place at high noon in the Epiphany Episcopal Church, with which the bride's



PRINCE GEORGE OF GREECE.

family is connected, and from which each of her three elder sisters has been married. It will be that most spectacular of all nuptials—a military wedding.

Miss Condit-Smith has been an undisputed belle in what is termed the court circle of Washington for several seasons. She comes from a family of more than ordinary distinction. She is the niece of the late Chief-Justice Field through her mother,



QUEEN WILHELMINA AND DUKE HEINRICH.

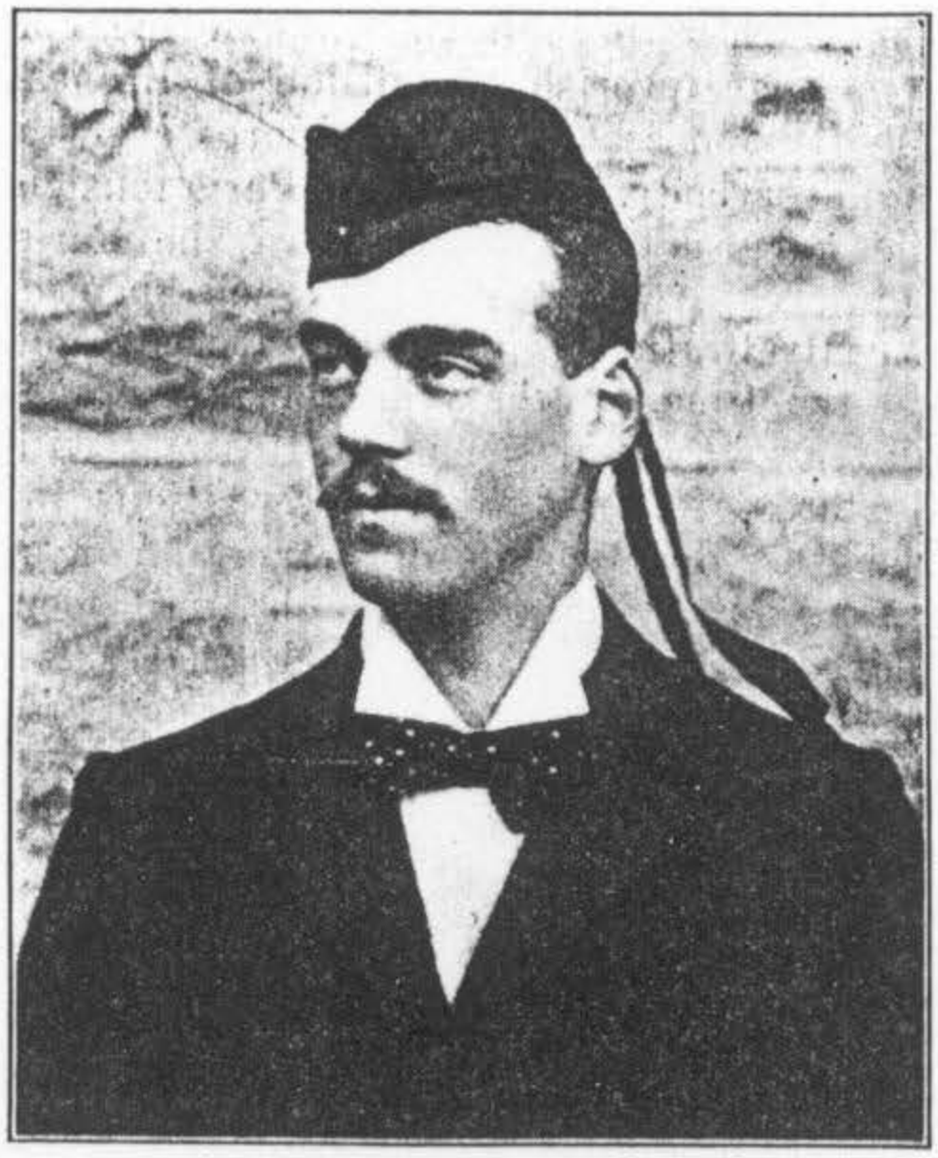
who is the sister of Mrs. Field. She has travelled extensively. A year ago she went to Japan to visit her sister, Mrs. Albert Key, wife of the military attaché of the American legation at Tokio. It was while making this visit that she accepted the invitation of Minister and Mrs. Conger to spend some time with them in the legation at Peking, and it was in this way that she came to be there during the recent Boxer outrages. Mrs. Condit-Smith has three daughters besides Miss Mary, all of whom are married and occupying high social positions. The eldest is Mrs. Cyrus Field Judson, of New York; the second is the wife of General Wood, military governor of Cuba; and the third is Mrs. Key. They are all handsome women, but Miss Mary, who is a tall, queenly girl of the blond



PRINCESS VICTORIA OF WALES.

type, and whose neck and shoulders are superb, is considered the greatest beauty.

The groom, Lieutenant Hooker, is the son of Mrs. Bessie Stewart, of Washington and New York, and the grandson of Senator W. M. Stewart, of Nevada. He met his bride while they were children in California.



GRAND DUKE MICHAEL OF RUSSIA.

TESLA'S WIRELESS LIGHT.

Nikola Tesla has given to The New York Sun an authorized statement concerning his new experiments on the production of light without the aid of wires. Mr. Tesla says:

"This light is the result of continuous efforts since my early experimental demonstrations before scientific societies here and abroad. In order to make it suitable for commercial use, I had to overcome great difficulties. One of these was to produce from ordinary currents of supply electrical oscillations of enormous rapidity in a simple and economical manner. This, I am glad to say, I have now accomplished, and the results show that with this new form of light a higher economy is practicable than with the present illuminants. The light offers, besides, many specific advantages, not the least of which is found in its hygienic properties. It is, I believe, the closest approach to daylight which has yet been reached from any artificial source.

"The lamps are glass tubes which may be bent in any ornamental way. I most generally use a rectangular spiral, containing about twenty to twenty-five feet of tubing making some twelve to fourteen convolutions. The total illuminating surface of a lamp is from 300 to 400 square inches. The ends of the spiral tube are covered with a metallic coating, and provided with hooks for hanging the lamp on the terminals of the source of oscillations. The tube contains gases rarefied to a certain degree, determined in the course of long experimentation as being conductive to the best results.

"The process of light production is, according to my views, as follows: The street current is passed through a machine which is an electrical oscillator of peculiar construction and transforms the supply current, be it direct or alternating, into electrical oscillations of a very high frequency. These oscillations, coming to the metallically-coated ends of the glass tube, produce in the interior corresponding electrical oscillations, which set the molecules and atoms of the inclosed rarefied gases into violent commotion, causing them to vibrate at enormous rates and emit those radiations which we know as light. The gases are not rendered incandescent in the ordinary sense, for if it were so, they would be hot, like an incandescent filament. As a matter of fact, there is very little heat noticeable, which speaks well for the economy of the light, since all heat would be loss.

"This high economy results chiefly from three causes: First, from the high rate of the electrical oscillations; second, from the fact that the entire light-giving body, being a highly attenuated gas, is exposed and can throw out its radiations unimpeded, and, third, because of the smallness of the particles composing the light-giving body, in consequence of which they can be quickly thrown into a high rate of vibration, so that comparatively little energy is lost in the lower or heat vibrations. An important practical advantage is that the lamps need not be renewed like the ordinary ones, as there is nothing in them to consume. Some of these lamps I have had for years, and they are now in just as good a condition as they ever were. The illuminating power of each of these lamps is, measured by the photometric method, about fifty candle power, but I can make them of any power desired, up to that of several arc lights. It is a remarkable feature of the light that during the day it can scarcely be seen, whereas at night the whole room is brilliantly illuminated. When the eye becomes used to the light of these tubes, an ordinary incandescent lamp or gas burner produces a violent pain in the eye when it is turned on, showing in a striking manner to what a degree these concentrated sources of light which we now use are detrimental to the eye.

"I have found that in almost all its actions the light produces the same effects as sunlight, and this makes me hopeful that its introduction into dwellings will have the effect of improving, in a measure now impossible to estimate, the hygienic conditions. Since sunlight is a very powerful curative agent, and since this light makes it possible to have sunlight, so to speak, of any desired intensity, day and night in our homes, it stands to reason that the development of germs will be checked and many diseases, as consumption, for instance, successfully combated by continually exposing the patients to the rays of these lamps. I have ascertained unmistakably that the light produces a soothing action on the nerves, which I attribute to the effect which it has upon the retina of the eye. It also improves vision, just exactly as the sunlight, and it ozonizes slightly the atmosphere. These effects can be regulated at will. For instance, in hospitals, where such a light is of paramount importance, lamps may be designed which will produce just that quantity of ozone which the physician may desire for the purification of the atmosphere, or if necessary, the ozone production can be stopped altogether.

"The lamps are very cheap to manufacture, and by the fact that they need not be exchanged like ordinary lamps or burners they are rendered still less expensive. The chief consideration is, of course, in commercial introduction, the energy consumption. While I am not yet prepared to give exact figures, I can say that, given a certain quantity of electrical energy from the mains, I can produce more light than can be produced by the ordinary methods. In introducing this system of lighting my transformer, or oscillator, will be usually located at some convenient place in the basement, and from there the transformed currents will be led as usual through the building. The lamps can be run with one wire alone, as I have shown in my early demonstrations, and in some cases I can dispense entirely with the wires. I hope that ultimately we shall get to this ideal form of illumination, and that we shall have in our rooms lamps which will be set aglow no matter where they are placed, just as an object is heated by heat rays emanating from a stove. The lamps will then be handled like kerosene lamps, with this difference, however, that the energy will be conveyed through space. The ultimate perfection of apparatus for the production of electrical oscillations will probably bring us to this great realization, and then we shall finally have the light without heat or 'cold' light. I have no difficulty now to illuminate the room with such wireless lamps, but a number of improvements must be made yet before it can be generally introduced."

Tesla's Vacuum-tube Lighting.

As is well known, Mr. Tesla has been engaged on experiments in vacuum-tube lighting for the last decade. According to the daily press, he has recently made a considerable advance in this direction. From one account the following statements are taken:

New York, January 26.—Nikola Tesla, who has been striving for years to produce an electric light without heat, feels that he is making perceptible headway in that undertaking. His general plan is to use an alternating current of almost inconceivably great frequency and a lamp consisting of a vacuum tube. The alternations are secured by an instrument of his own invention, known as the oscillator. But after Mr. Tesla entered upon his interesting line of experimenting he encountered various unforeseen difficulties. While he was able to obtain a beautiful light almost at the outset, it was at the expense of more energy than was desirable. In other words, he did not have his invention on a thoroughly satisfactory basis.

By degrees he has improved the efficiency of his apparatus so that his light is now more economical than it was, and he regards it as superior to both the incandescent and arc lights in this respect. At present, however, he is unwilling to indicate precisely the nature and degree of the technical advances made or to use figures in comparing its economy with that of its rivals. One reason for reticence on the latter point may be a recognition of the possibility of further improvement. Mr. Tesla frankly declares that his lamp is not yet perfect. It does not make as good a return in light for the electrical energy invested as he would like. All that he insists upon is that it is now so efficient that he can conscientiously recommend it to those who may wish to put it on the market.

In some of his earlier experiments Mr. Tesla used a straight vacuum tube fully an inch and a half in diameter and six or eight feet long. Latterly, he has employed a more slender one, and by arranging this tube in the shape of a rather compact coil he saves a great deal of space.

A score of lamps of this sort, each with a porcelain reflector over it, may be suspended from the ceilings of rooms on the tenth floor of an office building, while the special apparatus which modifies the current for their use would be down in the basement. The street mains would supply an ordinary alternating current and other wires would lead from the oscillator up to the lamps. For some purposes two wires to each lamp would be preferable, but for others one would suffice. Less copper would be required for inside wiring, and the risks from escaping currents would be diminished rather than increased. The present style of insulation would be more than sufficient.

NIKOLA TESLA Duplicates the LIGHT of DAY.



DESIGN FOR READING LAMP

MR. TESLA EXHIBITING HIS NEW LIGHT IN HIS LABRATORY

DIFFERENT STYLES OF LAMPS IN MR TESLA'S LABRATORY

WITHOUT WICK, WIRE OR CARBON FILAMENT THE INVENTOR'S NEW ELECTRIC LAMP SHEDS THE RADIANCE OF MORNING—IS THE PRODUCT OF TESLA'S FAMOUS OSCILLATOR—A SOFT, WHITE, COLORLESS LIGHT WITHOUT HEAT—THE LAMP A BABY SUN—WONDROUS SANITARY QUALITIES ATTRIBUTED TO THE NEW ILLUMINATOR. . . . . .

WITH the new century come new discoveries. Remarkable interest is now awakened by Tesla's new light. "Artificial sunlight," he calls it, "the result of ten years of thought and experiment."

Under a full head of electricity the lamp presents a magic spectacle. Without wick, wire or carbon filament it floods an apartment with the light of day. It is soothing to the eye and wonderfully diffused—almost shadowless. In its soft radiance one may read and write in any corner of the room as if it were day.

And how is this light produced?

By electrical vibrations of tremendous speed. For years the public has heard of Tesla's oscillator—that wonderful machine roaring out lightning in zigzag leaping tongues of flame, which Tesla claimed was to produce wonders, such as sending currents around the world without wires and burning the nitrogen of the air.

A thousand times it was asked, "Of what practical use is such a machine?"

One of the answers to this question is this daylight illumination.

His oscillator, the inventor says, is the key to solving the most important problems of the age. By its vibrations this new radiance is produced, as from the sun, its pulsations amounting to millions per second.

The electrical vibrations of the oscillator cause the atoms of the gases in Tesla's lamp to become little comets, shooting through the space at enormous speed, leaving trains of light filling the lamp with the brightness of noon.

It is a miracle, seemingly. The sudden starting and stopping of the electrical current at inconceivable velocity produce a continuous glow, neither of the incandescent nor arc light character, but pure solar light, the light of day.

THE OSCILLATOR EXPLAINED.

How does the oscillator accomplish this wonder? Simply by storing and discharging alternately, electricity. An instrument called a "condenser" is used for this purpose. According to Tesla, it is the most marvellous appliance ever invented.

"It can discharge," he says, "or explode its stored energy in an inconceivably short time. Owing to this it is unequalled in explosive violence. The explosion of dynamite is only the breath of a consumptive compared with its discharge. It is the means of producing the strongest current, the highest electrical pressure, the greatest commotion in the medium. Another of its properties equally valuable is that its discharge may vibrate at any rate desired up to many millions per second.

"I arranged such an instrument so as to be charged and discharged alternately in rapid succession through a coil with a few turns of stout wire, forming the primary of a transformer or induction coil. Each time the condenser was discharged the current would quiver in the primary wire and induce corresponding oscillations in the secondary. Thus a transformer or induction coil on new principles was evolved, which I have called the electrical oscillator, partaking of those unique qualities which characterize the condenser and enabling results to be attained impossible by other means."

Such is the much discussed machine of Tesla's, which, he claims, will accomplish many more wonders in light, telegraphy, telephony and the transmission of power, and set up vibrations and electric wave currents pervading the universe of matter, and perhaps entering a new world hitherto penetrated only by the imagination.

HOW THE LIGHT IS MADE

Regarding his new system of illumination, Tesla says:—"The light is the result of continuous efforts since my early experimental demonstrations before scientific societies here and abroad. In order to make it suitable for commercial use, I had to overcome great difficulties. One of these was to produce from ordinary currents of supply electrical oscillations of enormous rapidity in a simple and economical manner. This, I am glad to say, I have now accomplished, and the results show that with this new form of light a higher economy is practicable than with the present illuminants. The light offers, besides, many specific advantages, not the least of which is found in its hygienic properties. It is, I believe, the closest approach to daylight which has yet been reached from any artificial source."

Tesla's lamps are tubes of glass of the size of one's finger. They may be bent in any ornamental fashion—in spirals, expanding circles, rectangular clusters and the like. He says:—

"I generally use a rectangular spiral, containg about twenty to twenty-five feet of tubing, making some twelve to fourteen convolutions. The total illuminating surface of a lamp is from three hundred to four hundred square inches. The ends of the spiral tubes are covered with metallic coating and provided with hooks for hanging the lamp on the terminals of the source of oscillations. The tube contains gases rarefied to a certain degree, determined in the course of long experimentation as being conducive to the best results."

ILLUMINATION WITHOUT HEAT.

Here is a technical but plain description in Tesla's own words of how the light is produced:—

"The street current is passed through a machine which is an electrical oscillator of peculiar construction, and transforms the supply current, be it direct or alternating, into electrical oscillations of a very high frequency.

"These oscillations, coming to the metallically coated ends of the glass tube, produce in the interior corresponding electrical oscillations, which set the molecules and atoms of the enclosed rarefied gases into violent commotion, causing them to vibrate at enormous rates and emit those radiations which we know as light.

"The gases are not rendered incandescent in the ordinary sense, for were it so, they would be hot, like an incandescent filament. As a matter of fact, there is very little heat noticeable, which speaks well for the economy of the light, since all heat would be loss.

"This high economy results chiefly from three causes:—First from the high rate of the electrical oscillations; second, from the fact that the entire light-giving body, being a highly attenuated gas, is exposed and can throw out its radiations unimpeded, and, third, because of the smallness of the particles composing the light-giving body, in consequence of which they can be quickly thrown into a high rate of vibration, so that comparatively little energy is lost in the lower or heat vibrations."

NO WIRES OR CARBONS.

One great disadvantage in using electrical lamps has been breakage. The carbon filaments are sometimes defective, often short lived and more or less of a nuisance. Tesla has no filaments to become incandescent, neither carbons nor wires. Thus an important point is gained. He says:—

"The lamps need not be renewed like the ordinary ones, as there is nothing in them to consume. Some of these lamps I have had for years, and they are now in just as good a condition as they ever were.

"The illuminating power of each of these lamps is, measured by the photometric method, about fifty candle power, but I can make them of any power desired up to that of several arc lights. It is a remarkable feature of the light that during the day it can scarcely be seen, whereas at night the whole room is brilliantly illuminated.

"When the eye becomes used to the light of these tubes, an ordinary incandescent lamp or gas burner produces a violent pain in the eye when it is turned on, showing in a striking manner to what degree these concentrated sources of light which we now use are detrimental to the eye."

"A SANITARY LIGHT."

Regarding the sanitary features of the light, Tesla says:—

"I have found that in almost all its actions the light produces the same effects as sunlight, and this makes me hopeful that its introduction into dwellings will have the effect of improving, in a measure now impossible to estimate, the hygienic conditions.

"Since sunlight is such a very powerful curative agent, and since this light makes it possible to have sunlight, so to speak, of any desired intensity, day and night in our homes, it stands to reason that the development of germs will be checked and many diseases, as consumption, for instance, successfully combated by continually exposing the patients to the rays of these lamps.

"I have ascertained unmistakably that the light produces a soothing action on the nerves, which I attribute to the effect which it has upon the retina of the eye. It also improves vision, just exactly as the sunlight, and it ozonizes slightly the atmosphere.

"These effects can be regulated at will. For instance, in hospitals, where such a light is of paramount importance, lamps may be designed which will produce just that quantity of ozone which the physician may desire for the purification of the atmosphere, or if necessary, the ozone production can be stopped altogether."

As to the cost of these lamps, Tesla says:—

"The lamps are very cheap to manufacture, and by the fact that they need not be exchanged like ordinary lamps or burners they are rendered still less expensive. The chief consideration is, of course, in commercial introduction, the energy consumption. While I am not yet prepared to give exact figures, I can say that, given a certain quantity of electrical energy from the mains, I can produce more light than can be produced by the ordinary methods.

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"I hope that ultimately we shall get to this ideal form of illumination, and that we shall have in our rooms lamps which will be set aglow, no matter where they are placed, just as an object is heated by heat rays emanating from a stove. The lamps will then be handled like kerosene lamps, with this difference, however, that the energy will be conveyed through space.

"The ultimate perfection of apparatus for the production of electrical oscillations will probably bring us to this great realization, and then we shall finally have the light without heat, of 'cold' light. I have no difficulty now in illuminating the room with such wireless lamps, but a number of improvements must be made yet before it can be generally introduced."

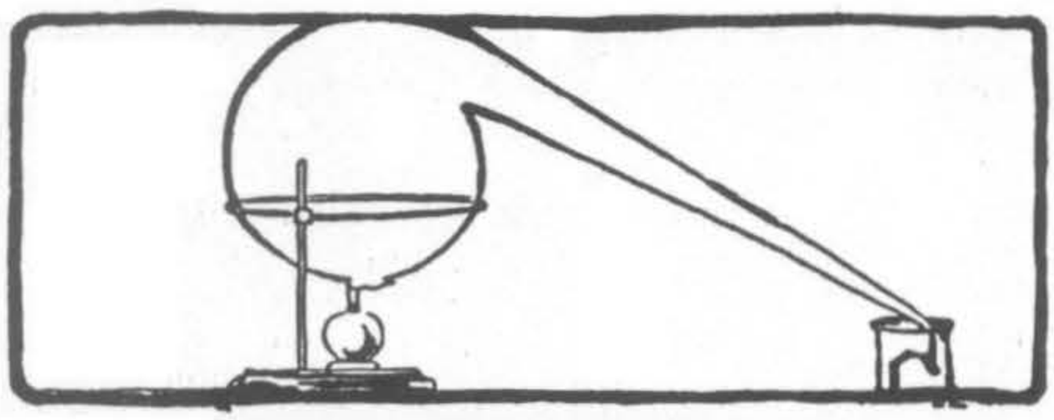
BABY SUNS AND DAYLIGHT.

In conclusion one may say of this strange all pervading crystal radiance of Tesla's that each lamp is a little baby sun filling the room with the flaming magic of life and health, the same that floods the solar system, making animal and vegetable existence possible on our earth.

As the lamps are lighted at evening you see dawn stealing over the room. It is like early morning. So perfect is the illusion that the change does not come instantly, but gradually, every corner growing brighter. Dark nooks fade out. Books, pictures and figures on walls and carpets, appear—their colors in natural shades, as at noonday.

Because of this wonderful artificial sunlight you now think the lamps may be extinguished. Day has indeed come—each moment it grows lighter. So out go the lamps.

Alas! your room is in darkness, and you see the streets dusky in the yellow glare of the city's night. But if you light the lamps again the dawn reappears, and again morning has come.



SCIENTIFIC

Tesla's "Artificial Sunshine"

Nikola Tesla gave to the New York *Sun*, last week, an authorized statement in reference to his new light, described the lamp which diffuses the light, and then, darkening the windows of his laboratory in East Houston street, turned on an electric current, and in a moment the rooms were flooded with what Tesla calls "artificial sunshine." The light was diffused through a spiral of glass about eight inches high and six inches wide. The spiral is of glass tubing, about one-quarter of an inch in diameter, the ends being blown to about double the size of the tube and closely resembling wax candles. The general effect of the lamp is that of a small box made of glass tubing with two candles lying on their sides along the top. The ends of the spiral, which resemble candles, are covered with a thin coating of metal and painted white. The lamp illuminates whether it is connected by wires with an electric current or not. Mr. Tesla operates it with and without wires. The wonderful thing about the wireless lamp is that it may be carried about from one part of a room to another, picked up and set down at will, just as one would carry a kerosene lamp around, and all the time there is not so much as a flicker.

But more than all this, Mr. Tesla asserts that in discovering this process of illumination he has discovered a light which will be of incalculable value in the sick room and in the hospital ward. The tube of the lamp, before being closed at one end, is partly filled with certain gases, the properties of which Mr. Tesla is not quite ready to disclose, but which, he says, will purify the air of a sick room when it might endanger the life of the patient to have the windows opened, so that the room's atmosphere will be as pure as if the room had been flooded with outer air. The inventor asserts that so perfect is his invention that the "ozonizing" of a room, as he calls it, may be continued as long as desired and stopped at will. Tesla says that his artificial sunshine, or his "sanitary light," is intended to be his first gift to the new century, the practical result of years of experiment in the old.

"The lamps," Mr. Tesla said, "are glass tubes which may be bent in any ornamental way. I most generally use a rectangular spiral, containing about twenty to twenty-five feet of tubing, making some twelve to fourteen convolutions. The total illuminating surface of a lamp is from 300 to 400 square inches. The ends of the spiral tube are covered with a metallic coating and provided with hooks for hanging the lamp on the terminals of the source of oscillations. The tube contains gases rarified to a certain degree, determined in the course of long experimentation as being conducive to the best results.

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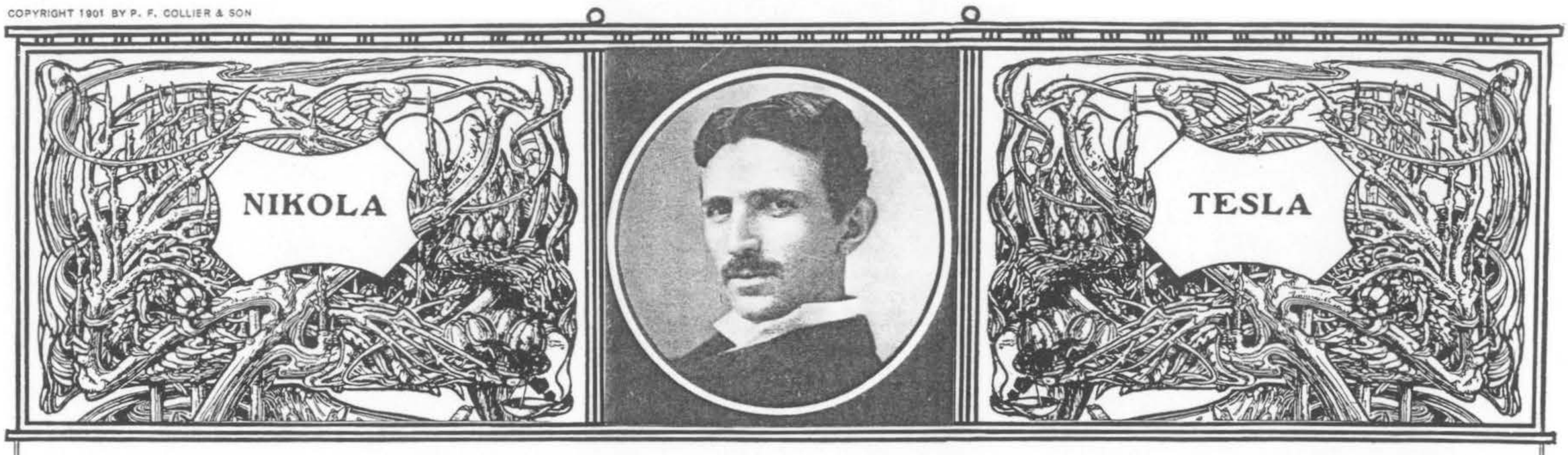


TALKING WITH THE PLANETS

By NIKOLA TESLA

EDITOR'S NOTE.—*Mr. Nikola Tesla has accomplished some marvellous results in electrical discoveries. Now, with the dawn of the new century, he announces an achievement which will amaze the entire universe, and which eclipses the wildest dream of the most visionary scientist. He has received communication, he asserts, from out the great void of space; a call from the inhabitants of Mars, or Venus, or some other sister planet! And, furthermore, noted scientists like Sir Norman Lockyer are disposed to agree with Mr. Tesla in his startling deductions.*

Mr. Tesla has not only discovered many important principles, but most of his inventions are in practical use; notably in the harnessing of the Titanic forces of Niagara Falls, and the discovery of a new light by means of a vacuum tube. He has, he declares, solved the problem of telegraphing without wires or artificial conductors of any sort, using the earth as his medium. By means of this principle he expects to be able to send messages under the ocean, and to any distance on the earth's surface. Interplanetary communication has interested him for years, and he sees no reason why we should not soon be within talking distance of Mars or of all worlds in the solar system that may be tenanted by intelligent beings.

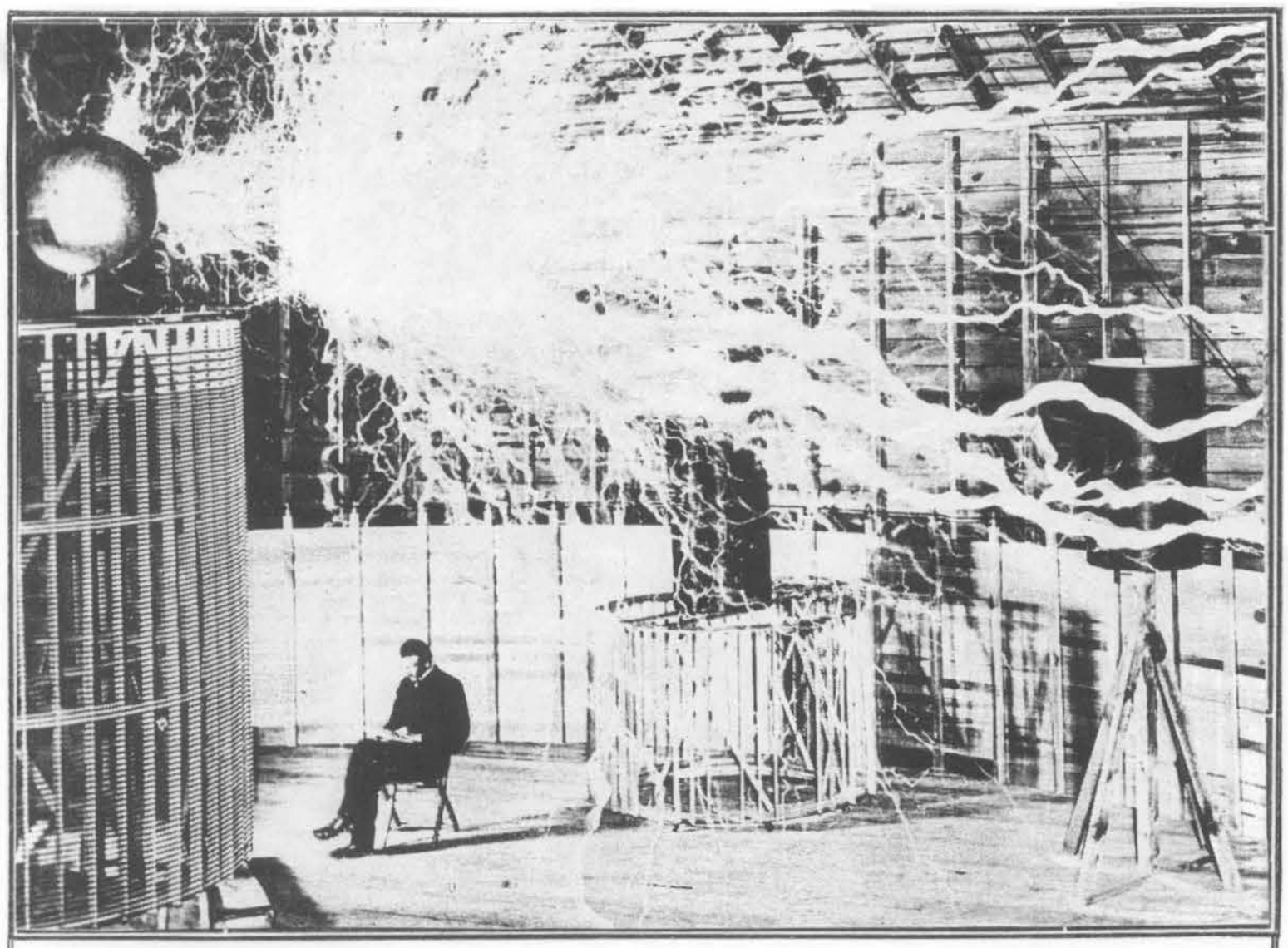
At the request of COLLIER'S WEEKLY *Mr. Tesla presents herewith a frank statement of what he expects to accomplish and how he hopes to establish communication with the planets.*

THE IDEA of communicating with the inhabitants of other worlds is an old one. But for ages it has been regarded merely as a poet's dream, forever unrealizable. And yet, with the invention and perfection of the telescope and the ever-widening knowledge of the heavens, its hold upon our imaginations has been increased, and the scientific achievements during the latter part of the nineteenth century, together with the development of the tendency toward the nature ideal of Goethe, have intensified it to such a degree that it seems as if it were destined to become the dominating idea of the century that has just begun. The desire to know something of our neighbors in the immense depths of space does not spring from idle curiosity nor from thirst for knowledge, but from a deeper cause, and it is a feeling firmly rooted in the heart of every human being capable of thinking at all.

Whence, then, does it come? Who knows? Who can assign limits to the subtlety of nature's influences? Perhaps if we could clearly perceive all the intricate mechanism of the glorious spectacle that is continually unfolding before us, and could, also, trace this desire to its distant origin, we might find it in the sorrowful vibrations of the earth which began when it parted from its celestial parent.

But in this age of reason it is not astonishing to find persons who scoff at the very thought of effecting communication with a planet. First of all, the argument is made that there is only a small probability of other planets being inhabited at all. This argument has never appealed to me. In the solar system, there seem to be only two planets—Venus and Mars—capable of sustaining life such as ours; but this does not mean that there might not be on all of them some other forms of life. Chemical processes may be maintained without the aid of oxygen, and it is still a question whether chemical processes are absolutely necessary for the sustenance of organized beings. My idea is that the development of life must lead to forms of existence that will be possible without nourishment and which will not be shackled by consequent limitations. Why should a living being not be able to obtain all the energy it needs for the performance of its life-functions from the environment, instead of through consumption of food, and transforming, by a complicated process, the energy of chemical combinations into life-sustaining energy?

If there were such beings on one of the planets we should know next to nothing about them. Nor is it necessary to go so far in our assumptions, for we can readily conceive that, in the same degree as the atmosphere diminishes in density, moisture disappears and the planet freezes up, organic life might also undergo corresponding modifications, leading finally to forms which, according to our present ideas of life, are impossible. I will readily admit, of course, that if there should be a sudden catastrophe of any kind all life processes might be arrested; but if the changes, no matter how great, should be gradual, and occupied ages, so that the ultimate results could be intelligently foreseen, I cannot but think that reasoning beings would still find means of existence. They would adapt themselves to their constantly changing environment. So I think it quite possible that in a frozen planet, such as our moon is supposed to be, intelligent beings may still dwell, in its interior, if not on its surface.



MR. TESLA'S EXPERIMENT TO ILLUSTRATE THE CAPACITY OF HIS OSCILLATOR FOR PRODUCING ELECTRICAL EXPLOSIONS OF GREAT POWER

SIGNALLING AT 100,000,000 MILES!

Then it is contended that it is beyond human power and ingenuity to convey signals to the almost inconceivable distances of fifty million or one hundred million miles. This might have been a valid argument formerly. It is not so now. Most of those who are enthusiastic upon the subject of interplanetary communication have reposed their faith in the light-ray as the best possible medium of such communication. True, waves of light, owing to their immense rapidity of succession, can penetrate space more readily than waves less rapid, but a simple consideration will show that by their means an exchange of signals between this earth and its companions in the solar system is, at least now, impossible. By way of illustration, let us suppose that a square mile of the earth's surface—the smallest area that might possibly be within reach of the best telescopic vision of other worlds—were covered with incandescent lamps, packed closely together so as to form, when illuminated, a continuous sheet of light. It would require not less than one hundred million horse-power to light this area of lamps, and this is many times the amount of motive power now in the service of man throughout the world.

But with the novel means, proposed by myself, I can readily demonstrate that, with an expenditure not exceeding two thousand horse-power, signals can be transmitted to a planet such as Mars with as much exactness and certitude as we now send messages by wire from New York to Philadelphia. These means are the result of long-continued experiment and gradual improvement.

Some ten years ago, I recognized the fact that to convey electric currents to a distance it was not at all necessary to employ a return wire, but that any amount of energy might be transmitted by using a single wire. I illustrated this principle by numerous experiments, which, at that time, excited considerable attention among scientific men.

This being practically demonstrated, my next step was to use the earth itself as the medium for conducting the currents, thus dispensing with wires and all other artificial conductors. So I was led to the development of a system of energy transmission and of telegraphy without the use of wires, which I described in 1893. The difficulties I encountered at first in the transmission of currents through the earth were very great. At that time I had at hand only ordinary apparatus, which I found to be ineffective, and I concentrated my attention immediately upon perfecting machines for this special purpose. This work consumed a number of years, but I finally vanquished all difficulties and succeeded in producing a machine which, to explain its operation in plain language, resembled a pump in its action, drawing electricity from the earth and driving it back into the same at an enormous rate, thus creating ripples or disturbances which, spreading through the earth as through a wire, could be detected at great distances by carefully attuned receiving circuits. In this manner I was able to transmit to a distance, not only feeble effects for purposes of signalling, but considerable amounts of energy, and later discoveries I made convinced me that I shall ultimately succeed in conveying power without wires, for industrial purposes, with high economy, and to any distance, however great.

EXPERIMENTS IN COLORADO

To develop these inventions further, I went to Colorado in 1899, where I continued my investigations along these and other lines, one of which in particular I now consider of even greater importance than the transmission of power without wires. I constructed a laboratory in the neighborhood of Pike's Peak. The conditions in the pure air of the Colorado Mountains proved extremely favorable for my experiments, and the results were most gratifying to me. I found that I could not only accomplish more work, physically and mentally, than I could in New York, but that electrical effects and changes were more readily and distinctly perceived. A few years ago it was virtually impossible to produce electrical sparks twenty or thirty feet long; but I produced some more than one hundred feet in length, and this without difficulty. The rates of electrical movement involved in strong induction

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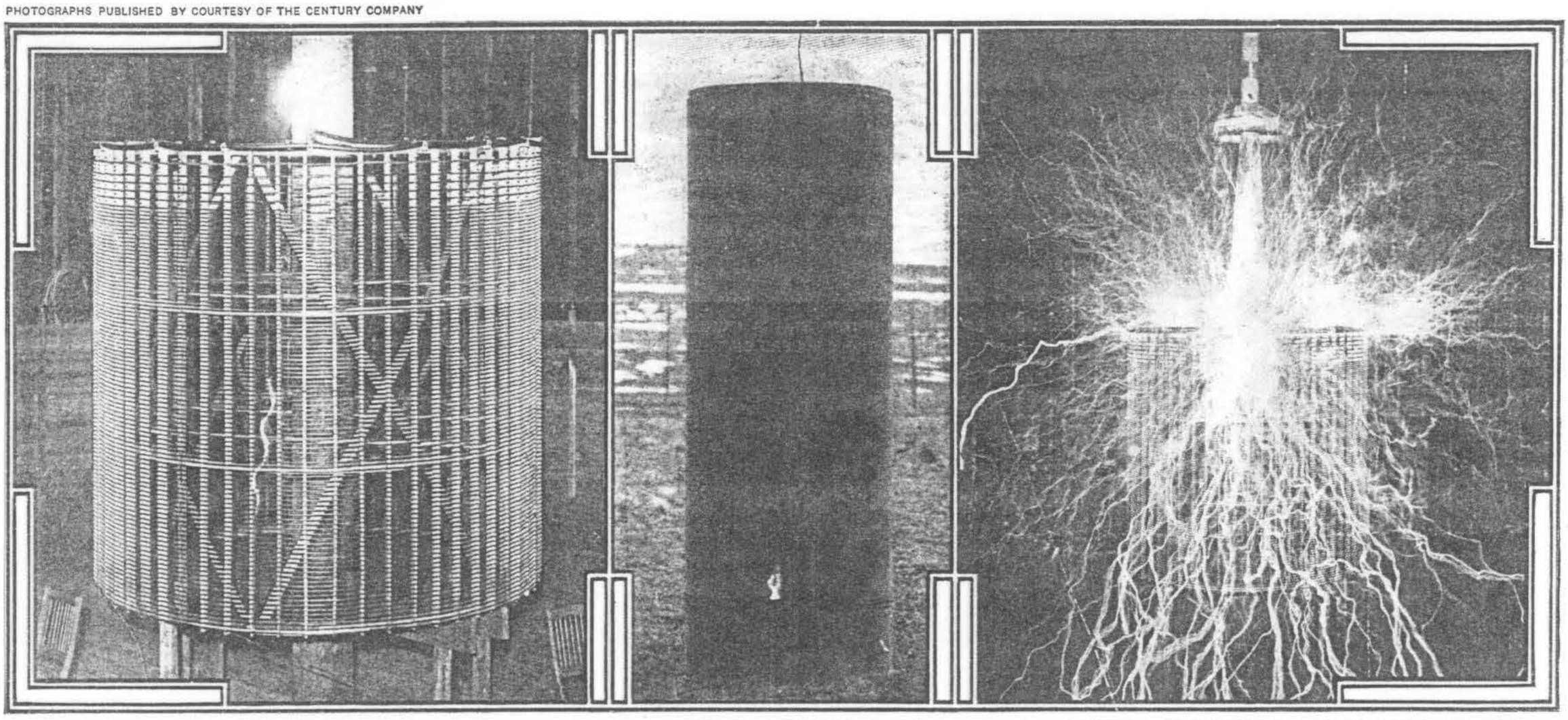


SUPPLYING ELECTRICAL ENERGY THROUGH A SINGLE WIRE WITHOUT RETURN

TRANSMITTING ELECTRICAL ENERGY THROUGH THE EARTH WITHOUT WIRE

AN ELECTRICAL OSCILLATOR DELIVERING ENERGY AT A RATE OF 75,000 HORSE-POWER

apparatus had measured but a few hundred horse-power, and I produced electrical movements of rates of one hundred and ten thousand horse-power. Prior to this, only insignificant electrical pressures were obtained, while I have reached fifty million volts.

The accompanying illustrations, with their descriptive titles, taken from an article I wrote for the "Century Magazine," may serve to convey an idea of the results I obtained in the directions indicated.

Many persons in my own profession have wondered at them and have asked what I am trying to do. But the time is not far away now when the practical results of my labors will be placed before the world and their influence felt everywhere. One of the immediate consequences will be the transmission of messages without wires, over sea or land, to an immense distance. I have already demonstrated, by crucial tests, the practicability of signalling by my system from one to any other point of the globe, no matter how remote, and I shall soon convert the disbelievers.

I have every reason for congratulating myself that throughout these experiments, many of which were exceedingly delicate and hazardous, neither myself nor any of my assistants received an injury. When working with these powerful electrical oscillations the most extraordinary phenomena take place at times. Owing to some interference of the oscillations, veritable balls of fire are apt to leap out to a great distance, and if any one were within or near their paths, he would be instantly destroyed. A machine such as I have used could easily kill, in an instant, three hundred thousand persons. I observed that the strain upon my assistants was telling, and some of them could not endure the extreme tension of the nerves. But these perils are now entirely overcome, and the operation of such apparatus, however powerful, involves no risk whatever.

As I was improving my machines for the production of intense electrical actions, I was also perfecting the means for observing feeble effects. One of the most interesting results, and also one of great practical importance, was the development of certain contrivances for indicating at a distance of many hundred miles an approaching storm, its direction, speed and distance travelled. These appliances are likely to be valuable in future meteorological observations and surveying, and will lend themselves particularly to many naval uses.

It was in carrying on this work that for the first time I discovered those mysterious effects which have elicited such unusual interest. I had perfected the apparatus referred to so far that from my laboratory in the Colorado mountains I could feel the pulse of the globe, as it were, noting every electrical change that occurred within a radius of eleven hundred miles.

TERRIFIED BY SUCCESS

I can never forget the first sensations I experienced when it dawned upon me that I had observed something possibly of incalculable consequences to mankind. I felt as though I were present at the birth of a new knowledge or the revelation of a great truth. Even now, at times, I can vividly recall the incident, and see my apparatus as though it were actually before me. My first observations positively terrified me, as there was present in them something mysterious, not to say supernatural, and I was alone in my laboratory at night; but at that time the idea of these disturbances being intelligently controlled signals did not yet present itself to me.

The changes I noted were taking place periodically, and with such a clear suggestion of number and order that they were not traceable to any cause then known to me. I was familiar, of course, with such electrical disturbances as are produced by the sun, Aurora Borealis and earth currents, and I was as sure as I could be of any fact that these variations were due to none of these causes. The nature of my experiments precluded the possibility of the changes being produced by atmospheric disturbances, as has been rashly asserted by some. It was some time afterward when the thought flashed upon my mind that the disturbances I had observed might be due to an intelligent control. Although I could not decipher their meaning, it was impossible for me to think of them as having been entirely accidental. The feeling is constantly growing on me that I had been the first to hear the greeting of one planet to another. A purpose was behind these electrical signals; and it was with this conviction that I announced to the Red Cross Society, when it asked me to indicate one of the great possible achievements of the next hundred years, that it would probably be the confirmation and interpretation of this planetary challenge to us.

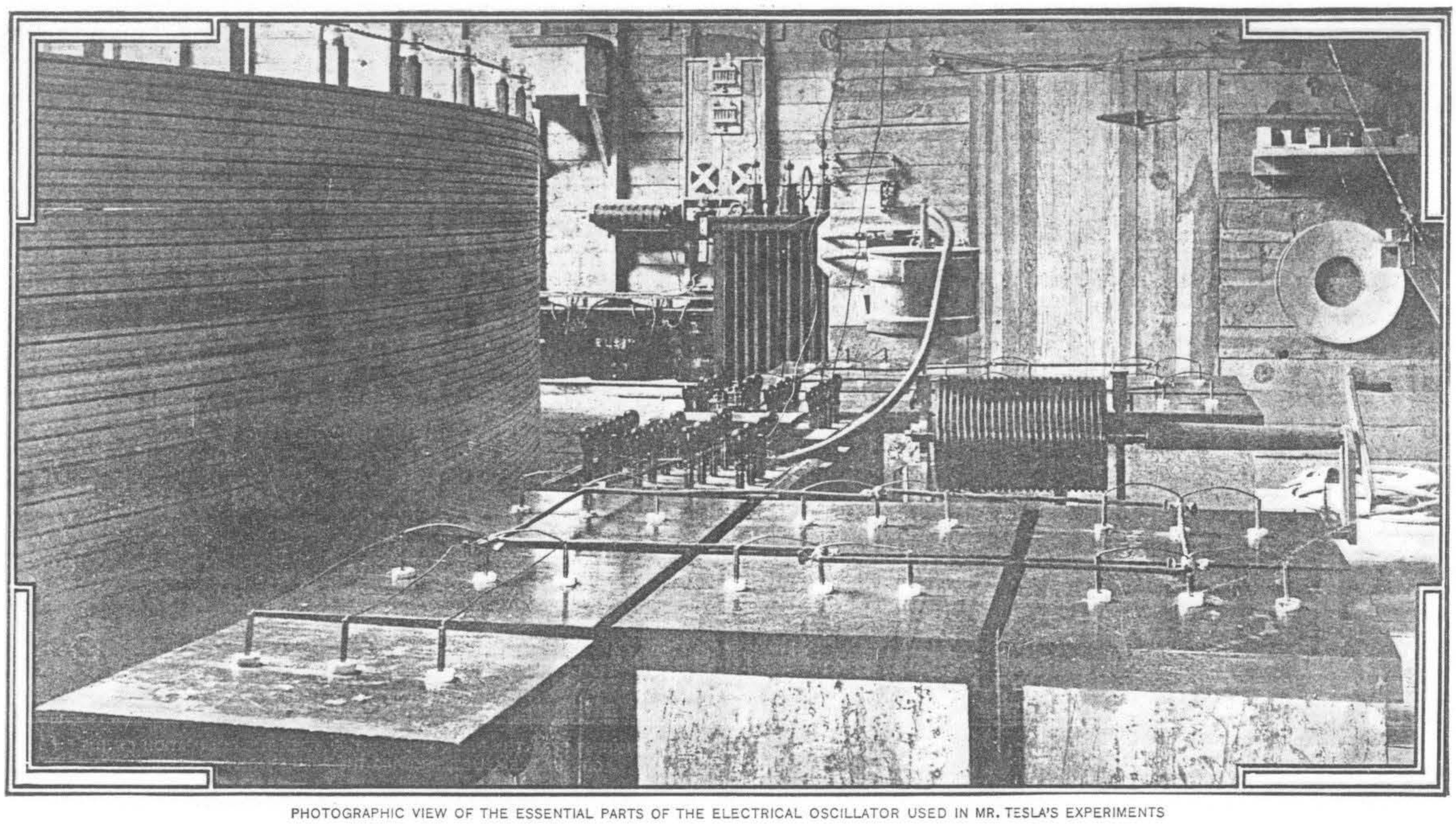
Since my return to New York more urgent work has consumed all my attention; but I have never ceased to think of those experiences and of the observations made in Colorado. I am constantly endeavoring to improve and perfect my apparatus, and just as soon as practicable I shall again take up the thread of my investigations at the point where I have been forced to lay it down for a time.

COMMUNICATING WITH THE MARTIANS

At the present stage of progress, there would be no insurmountable obstacle in constructing a machine capable of conveying a message to Mars, nor would there be any great difficulty in recording signals transmitted to us by the inhabitants of that planet, if they be skilled electricians. Communication once established, even in the simplest way, as by a mere interchange of numbers, the progress toward more intelligible communication would be rapid. Absolute certitude as to the receipt and interchange of messages would be reached as soon as we could respond with the number "four," say, in reply to the signal "one, two, three." The Martians, or the inhabitants of whatever planet had signalled to us, would understand at once that we had caught their message across the gulf of space and had sent back a response. To convey a knowledge of form by such means is, while very difficult, not impossible, and I have already found a way of doing it.

What a tremendous stir this would make in the world! How soon will it come? For that it will some time be accomplished must be clear to every thoughtful being.

Something, at least, science has gained. But I hope that it will also be demonstrated soon that in my experiments in the West I was not merely beholding a vision, but had caught sight of a great and profound truth.



PHOTOGRAPHIC VIEW OF THE ESSENTIAL PARTS OF THE ELECTRICAL OSCILLATOR USED IN MR. TESLA'S EXPERIMENTS

Syntonic and Multiple Wireless Telegraphy.

In the Digest of last week a concise account was given of the Slaby system of tuned and multiple wireless telegraphy, which system has recently been the subject of some successful experiments in Germany. As will be seen, the selective or syntonic feature consists first, in corresponding stations working with the same wave length, and in the employment at the receiving station of a vertical wire equal in length to a sub-multiple of the wave length agreed upon. By this means the receiving instrument will not respond to wave signals sent from the same or other stations where this condition is not complied with. Moreover, by a certain disposition of the aerial conductor it is made possible to receive simultaneously at a station messages of different wave length—this part of the system thus corresponding to multiplex wire telegraphy. Another part of the system consists in an "intensifier" arrangement corresponding to the local battery circuit of an ordinary telegraphic system, by means of which the potential of the received wave is increased, resulting in an increased effect on the coherer. The work of Prof. Slaby forms the most important contribution recently made to wireless telegraphy, and the system also appears to be a practical one. In tests made some weeks ago before the German Emperor, simultaneous messages were successfully received from two stations, one eight and the other two and one-half miles distant from the receiving point. The waves from the more distant station had to pass across the city of Berlin and were naturally attenuated by the high buildings and chimneys in its path, which effect, however, was counteracted by the application of the "intensifier" principle.

The work of Dr. Slaby above referred to received considerable prominence in cable newspaper dispatches, and—not unexpectedly—Mr. Nikola Tesla now comes forward with a claim of priority. In a letter to the New York *Sun*, Mr. Tesla says he has read with "deep astonishment" the statements made in his lecture before the Emperor by the Charlottenberg professor, who, moreover, had acknowledged that he—Tesla—is the "father of wireless telegraphy." Mr. Tesla also expresses disappointment that Dr. Slaby does not give him credit "for a beautiful invention which he [Dr. Slaby] calls the 'multiplier.'" "Have I not first described this device," he says, "and given rules for its construction and attunement? Was I not the first to apply it to wireless transmission?" For obvious reasons we have not been able to keep pace with all the numerous newspaper ascriptions to Mr. Tesla of revolutionary discoveries in electrical science, which probably explains our ignorance of the claim that he is the "father of wireless telegraphy," or indeed that the art of wireless telegraphy has in any manner benefited from his labors.

If Mr. Tesla would do what may fairly be asked of a man of his prominence—prepare a paper for the American Physical Society or the American Institute of Electrical Engineers covering the work he has accomplished in this branch—we shall be able to repair our own seeming neglect in not laying before our readers hitherto the record which would entitle him to be called "the father of wireless telegraphy."

Capacity of Electric Conductors.

In our issue of last week we quoted from a letter over the signature of Mr. Nikola Tesla in the New York *Sun* of Jan. 30, in which it is stated that the capacity of a fixed insulator conductor is not a fixed quantity, but varies with the hour of the day, with the season of the year, that it is influenced by moonlight, etc. It is also intimated that in consequence of this newly discovered fact a large part of technical literature will have to be rewritten. May we venture to express our doubts upon these propositions, with all due deference to Mr. Tesla. So far as text books are concerned, they are only stepping stones, and not keystones, in the structure of our

faith. The sooner they have to be cancelled, amended and rewritten, the healthier and more sturdy the growth of the science to which they relate, but the evolution of text books and of the knowledge they disclose must be like all other evolution, in a definite and orderly manner, in obedience to certain rules.

We have every reason to believe that the capacity of the condensers in our laboratories is within certain small limits a definite and constant quantity. The capacity of aerial wires insulated on poles and supported many feet from the ground seems to be a substantially constant quantity from day to day and year to year, provided that the surface of the earth is uniformly conducting. It has long been known—though not, it would seem, by Mr. Tesla—that when the surface of the earth is dry and ill-conducting, the apparent capacity of single wires supported above it is less than when the earth is wet and well-conducting. If, therefore, Mr. Tesla refers to variations of capacity between a fixed aerial conductor and the ground due to variation in the conductivity of the surface soil, he is virtually repeating a known proposition.

Concerning the variation in capacity of a conductor relatively to the earth with elevation above the earth, it is not a discovery that there must be a change of some sort in capacity. The experimental knowledge we possess concerning the capacity of very elevated conductors, is, however, so limited that there is room for valuable technical results to be observed in this direction, and if Mr. Tesla has made reliable observations of this character the science would owe him so much the more for their announcement. We hope that Mr. Tesla will publish any results which he may have obtained, in such form as may be available to electrotechnical workers.

It is quite clear that not only is no substantial technical information imparted to electrical engineers by articles of the nature which Mr. Tesla communicates so frequently to the daily press, but also that it is impossible for an electrical engineer to judge from such articles of the validity of the conclusions which are therein reached. It is quite possible that the apparent capacity of very elevated conductors might vary in a manner not generally appreciated or understood, and yet that the capacity of the ordinary conductors in the neighborhood of good conducting ground should be as fixed and constant a quantity as has always been supposed.

SLABY ON TESLA.—A special cable dispatch of Jan. 30 from Berlin says: "Prof. Slaby, of the Technische Hochschule, said in an interview to-day that he expected to revolutionize telegraphy if he was successful in applying his etheric system, which he calls spark telegraphy, to the present system of transmission by wire. He added that thousands of telegrams could then be transmitted simultaneously by the same wire. He characterized Nikola Tesla's expectations of an enormous reduction in the cost of electric currents as those of a fanatic, and said that the immediate future does not promise an improvement in the cost of conduction."

TESLA'S NEW TELEGRAPH.

AROUND THE WORLD WITH NO WIRE WITHIN EIGHT MONTHS OR SO.

Plants to Be Erected Will Be Not Experimental, but for Commercial Use, the Inventor Says Emphatically, and He Has the Necessary Financial Backing—The Instruments and the Mode of Operation.

Shortly after the New Year Nikola Tesla announced that having spent many of the later years of the nineteenth century in electrical experiments and investigations he purposed, giving to the world in the early years of the twentieth century some of the results in practical and commercial form of these experiments and investigations. Two weeks ago he brought out his "sanitary light," as he calls it. Yesterday he announced through THE SUN that the wireless telegraph --his system of the wireless telegraph—would be at the world's service in about eight months. By this system messages are to be transmitted to any distance on the earth's surface. Some of the machinery is now being constructed, and for the rest of it contracts will soon be awarded.

The chief essentials of Tesla's system are a transmitter and a receiver, with the earth, rather than wires, as the connecting medium. Both transmitter and receiver are rather simple machines or, at any rate, look so on his patents. The transmitter, which is set up at one point, receives the electrical energy from the source of power, intensifies it and sends it through a wire into the earth, through which it passes away in all directions. At a distant point from the transmitter, say in London, for instance, a receiver is set up. This is adjusted so that its vibrations are in unison with the vibrations of the transmitter. Being "in tune," as Tesla calls it, the receiver catches up from the earth the currents from the particular transmitter on the opposite side of the Atlantic, magnifying them many thousand times.

The cost of telegraphing by the wireless system will, Tesla says, be much less than by the cable system and messages may be sent much more quickly. Through the use of certain artifices it will be made impossible for a receiver in Calcutta, for instance, to take up the currents carrying a message from New York to London; and in time of war, one belligerent will not be able to interfere with, or take advantage of, the messages of the other belligerent.

Just where the first wireless telegraph office will be opened in New York Tesla does not care to tell at present. As for the financial end of the enterprise that has been privately arranged, and the inventor was most enthusiastic yesterday in his veiled references to the financial assistance he has received. In telling of the satisfactory outcome of his work on his wireless telegraph system and of his future plans in regard to putting it to commercial use, Mr. Tesla made the following statement to a SUN man:

"I am quite surprised at the lively interest manifested in my announcement to THE SUN that I am about to begin the construction of my plants for telegraphy without wires across the Atlantic. I have been steadily at work on the problem for seven years, and from time to time the advances I have made in the perfection of my apparatus have been noted. Three years ago I had so far progressed as to undertake the transmission with confidence, and had I been myself a wealthy man, I would have certainly attempted it. But I had to depend on financial help from others, and before I could conscientiously approach any one, I had to settle all doubt in my own mind as to the outcome of the experiment. This was one of the reasons for my going to Colorado, where, after eight months of investigation and perfection of my transmitters and receivers, I satisfied myself that, with my system, I could not only transmit messages across the Atlantic, but also across the Pacific Ocean.

"Three distinct experimental evidences of the practicability of my plan were obtained, each of which would have been sufficient to inspire me with confidence of success. One of these evidences was my discovery of the stationary electrical waves in the earth, which I have already published, and which demonstrates in a positive manner that vibratory currents can be transmitted through the terrestrial globe just as through a wire to the greatest distances. Another evidence I obtained by ascertaining the law of variation of the intensity of the effects produced by my transmitter at a distance, which enables me to design the transmitting apparatus for the required performance, just as I can construct a dynamo or steam engine for a given output. The third evidence I obtained by actual measurements of the intensity of the effects through varying distances of from 650 to 700 miles, and this was what may be considered the proof of the pudding.

"The greatest difficulties were encountered in the development of the transmitting apparatus, for not only was it necessary to produce impulses of enormous intensities, but they had to have certain characteristics to make them best suitable for the purpose. Another great trouble was to perfect methods for securing complete privacy and non-interference of messages, for only after this was assured could I hope to make a wireless transmission to great distance a practical success. It is quite easy to tune a circuit, but ordinary artifices were not adequate to giving that degree of safety against extraneous disturbance which was necessary, and a number of new expedients had to be resorted to. These have now been so far perfected that the same privacy is practicable as in transmission over a private wire.

"Another feature of great importance in the commercial exploitation of the system was the simultaneous transmission of a number of messages by the same apparatus, and in this direction I was fortunate enough to find a happy solution, enabling results to be attained which had been heretofore impossible."

"What is meant by tuning of circuits?" Mr Tesla was asked.

"Expressed in popular terms, tuning is the process of adjusting the vibrations of one circuit to those of another. The vibration is chiefly dependent on two quantities, which are designated as capacity and inductance, and in the coarse adjustment either one of these or both may be varied to give to the vibration the pitch required. But finer touches are necessary to insure the best success, and one might say that there is just as much difference between ordinary tuning, according to book instructions, and artistic tuning, as there is between a bar room picture and a painting by Sargent."

"What must a company operating with your system have, in order to transmit messages, for instance, from New York to London?" asked THE SUN man.

"The stations at either side will have to have transmitting and receiving apparatus, which, in substance, will be as I have described in my patents on energy transmission without wires. The essential part of the transmitter is a circuit, which is connected to the ground at one of its ends and to a conducting surface at the other end, and which is carefully adjusted so as to respond freely to the vibrations of the primary source of currents. Under these conditions currents of enormous intensities are produced in the circuit, which pass away through the ground in all directions. The circuit acts just like a pump in an ocean, drawing out and pumping in water rhythmically, creating ripples, which spread in ever widening circles, over the surface of the sea. Suppose the transmitter in New York is controlled by the key of the operator. Each time he depresses the key these ripples spread over the globe and reach London, where a receiving circuit arranged and connected similarly may be located. This receiving circuit is tuned with the greatest care to the vibrations of the transmitter, and just as a heavy pendulum is set swaying by weak impulses properly timed, so the receiving circuit is excited, the received impulses being thus magnified many thousand times. By this process impulses which would be in themselves inadequate to affect the receiving instrument, are rendered perceptible."

"You say that the currents from the transmitter pass through the earth in all directions. If that be true, then at any point on the earth's surface where a receiver is set up, those currents may be caught and messages received. Is that correct?"

"That, generally speaking, is true, but no message can be caught or read except by those receivers which are designed for the purpose. As I have stated before, I have perfected this part of my system to such a degree, that to read a message at some other place than that for which it is intended will be well nigh impossible. Obviously, any number of receiving stations may be provided, which will respond to definite signals or notes of the transmitter, as, for instance, in the transmission of time to the astronomical observatories, in weather reports, or the like, for which purposes I have devised a special apparatus.

"In time of war, could the telegrams sent by one belligerent to a distant point be caught up by receivers stationed in the possessions of the other belligerent, or in any way interfered or tampered with?"

"In such case still more rigorous measures would be adopted to exclude the possibility of the messages being read by others, and I have evolved some plans which would make the privacy absolute. The best the enemy could do would be to set up a powerful transmitter at the most effective place and try to muddle up the messages, but in such case, again, his manœuvre would be without avail, if certain provisions be adopted."

"How about the length of time consumed in transmitting messages by your system as compared with that through the cables?"

"The transmission will be much quicker than through the cables, because the latter are handicapped by what is known as electrostatic capacity. A number of schemes have been proposed to overcome this drawback, but all that I have so far examined are entirely inoperative."

"In the actual transmission of messages may the same apparatus in the way of keys and receivers be used as is employed in telegraphing over cables, and may the Morse code be used?"

"In the beginning I propose to resort to the instruments now used, but I have some plans in this regard which I hope will enable me greatly to increase the speed. The Morse code may, of course, be used."

"Are these plants to be simply experimental or are they to be commercially used? If for commercial use, when do you expect them to be in operation?"

"Most emphatically they are intended for commercial use. I have finished my experiments. I estimate that the work will consume about eight months, but I am prepared to encounter some delays and drawbacks, which always turn up somehow. You know, of course, that this is an engineering undertaking which requires special machinery and a variety of appliances, most of which are novel."

"Where are your first plants to be located?"

"I have determined the site on this side; the other is still under consideration. I prefer not to dwell on these details at present."

"What will be the cost of transmitting messages by your wireless system as compared with the cost of sending messages by the present cables?"

"Of course, it will be much cheaper; first, because of the relatively small cost of the apparatus, and secondly because of the greater speed of tranamission. The greater the distance the greater will be the advantage of the wireless transmission over the cables."

Mr. Tesla was asked whether the new system was to be exploited commercially by a company, by himself alone or by himself and a few friends. He said in reply that this will be wholly left to the judgment of those who furnish the capital. He did not believe in the inventor being his own business manager.

The New York Tribune February 15, 1901

MR. TESLA'S WIRELESS TELEGRAPHY.

HE HOPES TO SEND MESSAGES THROUGH THE EARTH ERE LONG.

Marconi, in England, Slaby, in Berlin, and other foreign electrical experts are attracting a good deal of attention just now by their achievements in wireless telegraphy. But Mr. Tesla is quite willing to have the public remember that he has been studying this subject for several years and as long ago as 1893 outlined a plan from which he hopes to secure great results before the new century is a year old.

There are two apparent points of difference between the Marconi and Tesla systems. The young Italian relies upon the ether to convey his messages, while Mr. Tesla employs the earth as a conduotor. To be sure, Marconi discovered that his apparatus worked better after he connected both transmitter and receiver with the ground, and it is not altogether clear that his first theory concerning the medium which conveys his messages is correct. Then, secondly, the particular form of energy employed by Marconi and Slaby is believed by them to be the so-called Hertz waves, which are not electricity, though produced by electrical apparatus. Mr. Tesla, on the other hand, utilizes true electric waves, of great power and frequency, such as can be generated by his much talked about "oscillator."

The advances which Mr. Tesla says he has made within the last year or two consist of the improvement of the power of his generating devices, and in the perfecting of his receivers, which are so designed as to respond only to messages intended for them. While the latter phrase would seem to describe other men's instruments as well, Mr. Tesla insists that he has developed the "tuning" system far beyond the possibilities reached by any one else, and he hopes to carry it still further. He doubts, for instance, whether Marconi could permit more than six or eight receivers in the range of a transmitter without more than a single instrument picking up a message. But Mr. Tesla believes that out of several hundred of his receivers only the right one will respond to a transmitter.

While on Pike's Peak Mr. Tesla made tests which satisfy him that he can, when the proper plant has been erected, establish communication between this country and Europe with the utmost ease. This conclusion rests largely upon electrical measurements and mathematical computation. There was no actual transmission of a message to a person on the other side of the globe, and hence no reply. But Mr. Tesla hopes to have his apparatus ready within the next eight months to furnish the latter kind of demonstration, and thus revolutionize transatlantic telegraphy.

The New York Herald February 16, 1901

PUTS NO LIMIT ON WIRELESS SYSTEM

Mr. Tesla Asserts His Ability to Send Messages for Thousands of Miles.

DEPENDS UPON VOLTAGE

Inventor Proposes to Connect Balloons at High Altitudes with Stations on the Ground.

CAN TRANSMIT POWER ALSO

HERALD BUREAU,
CORNER FIFTEENTH AND G STREETS, N. W.,
WASHINGTON, D. C., Friday.

Nikola Tesla, who has announced that he will be able to work his system of wireless telegraphy on a commercial scale in about eight months, was granted a patent early last May for his "system of transmitting electrical energy" through the higher strata of air without the use of wires.

Mr. Tesla's application sets forth at length the principles of his invention. In securing electricity for his wireless system he uses the electric "oscillator" previously patented by him. He asserts that the electric power produced in this manner has characteristics all its own. When radiated through the air at a pressure of millions of volts it transforms the atmosphere into a conductor of electricity, and if the voltage be high enough the electricity will be carried through the air for thousands of miles.

SENDING THROUGH HIGH STRATA.

A peculiarity of this phenomenon, Mr. Tesla says, is that by increasing the electrical pressure only slightly the distance that the electrical power will travel through the air is increased very greatly. He asserts that by increasing the electric power only fifty per cent the distance the electricity was carried through the air was increased sixfold. The electric energy is conducted most readily through the highly rarefied strata existing, say, at an altitude of five or six miles above the earth.

Mr. Tesla purposes, therefore, to send up a stationary balloon at the point from which he will send his power, and another at the point where it will be received. From each balloon he would hang a "terminal," consisting of a large disk. These disks would be connected by wire with stations on the ground.

In the transmission of power by this system Mr. Tesla would generate his electricity at a high pressure in his "oscillator," and would then pass it through a transforming apparatus, consisting of a primary and a secondary coil. From there the power, at a pressure of millions of volts, would be carried by a wire to the terminal suspended from the balloon. The electricity, radiating from it, would be conducted through the atmosphere to the second terminal, suspended from a balloon. The distance between these two could be indefinite, says Mr. Tesla. If the voltage be high enough, it would be possible to conduct the power through the air for thousands of miles.

FOR POWER PURPOSES ALSO.

From the receiving terminal, the power, which would be collected through the medium of the suspended disk, would be brought down to the receiving station by means of a wire. There it would be transformed by means of double coils. Telegraphic messages would then be rendered intelligible by ordinary methods.

In his claim Mr. Tesla says that not only messages can be sent in this manner, but that it is possible to transmit electricity for power purposes as well.

The New York Sun February 16, 1901

A TESLA WIRELESS DEVICE.

THE SYSTEM OF TELEGRAPHY PATENTED BY HIM ON MAY 1, 1900.

He Describes It as a System for Transmitting Electrical Energy Through the Higher Strata of the Air—Balloons to Be Used at the Sending and Receiving Stations.

WASHINGTON, Feb. 15.—The files of the Patent Office show that a patent was granted Nikola Tesla on May 1, 1900, for his system of transmitting electrical energy through the higher strata of air without the use of wires. His application sets forth at length the principles of his invention. In securing electricity for his wireless system he uses the electric oscillator, patented previously by him. He asserts that the electric power produced in this manner has characteristics all its own. When radiated through the air at a pressure of millions of volts, it transforms the atmosphere into a conductor of electricity, and if the voltage be high enough the electricity will be carried through the air for thousands of miles. A peculiarity of this phenomenon, he says, is that by increasing the electrical pressure only slightly the distance that the electrical power will travel through the air is increased very greatly. He asserts that by increasing his electric power only 50 per cent. the distance that the electricity is carried through the air is increased six fold. His electric energy is conducted much more readily through the more highly rarefied strata, existing say at an altitude of five or six miles above the earth.

He proposes, therefore, to send up a stationary balloon at the point from which he will send his power and another at the point where it will be received. From each balloon he will hang a "terminal," consisting of a large disc. These discs would each be connected by wires with the stations on the ground.

In the transmission of power by this system he would generate his electricity at a high pressure in his "oscillator" and would then pass it through a transforming apparatus, consisting of a primary and a secondary coil. From there the power, at a pressure of millions of volts, would be carried by a wire to the terminal suspended far up in the sky from the balloon. The electricity radiating from it would be conducted through the atmosphere to the second terminal suspended from a balloon. The distance between these two could be indefinite, says Tesla. If the voltage be high enough it would be possible to conduct the power through the air for thousands of miles. From the receiving terminal, the power which would be collected through the medium of the suspended disc would be brought down to the receiving station by means of a wire. There it would be transformed by means of double coils. Telegraphic messages would then be rendered intelligible by ordinary methods. In his claim Tesla says that not only messages can be sent in this manner, but that it is possible to transmit electricity for power purposes as well.

The New York Sun February 17, 1901

ARE THEY TESLA'S AGENTS?

Boston Has a New Theory to Account for the Men Camping Out in a Tent There.

BOSTON, Feb. 16.—It is now believed that the two men who have lived in a tent on Huntington avenue the last two weeks, and whose mysterious actions have caused much comment, are agents of Tesla. When a tall pole, sixty feet high, was put up a week ago and a number of wires were attached to a glass bottle, which was fastened to the top, it was believed that the men would endeavor to coax electricity from the clouds to heat the tent. To-day more wires were fastened to the pole and the men were working on something on the inside, which appears to be a huge battery.

This gives rise to the theory that it will be one of Tesla's relaying stations for his wireless telegraphy. One of the men who occupies the tent was asked to-night if he was an agent of Tesla, but he refused to commit himself, saying, "I may be and I may not be."

The New York Journal And Advertiser February 22 1901

TESLA READY TO TRY TRANSATLANTIC TALK.

His Assistant Starts from London for Portugal, and Tells How He Will Set Up Apparatus for Wireless Messages to America.

(Special Cable to the New York Journal and Advertiser.)

London, Feb. 21.—James Galbraith, a New York electrician from Tesla's Works, left London to-night for Lisbon with electrical apparatus for use in connection with a test of transatlantic wireless telegraphy. Galbraith said to the Journal correspondent:

"I am establishing a receiving station on or about the fortieth parallel. Tesla, at a point exactly opposite on the New England Coast, will try to set up communication.

"Tesla has not yet seen fit to disclose his system or the details of the transmitting and receiving apparatus, but the system is simple, like all great discoveries.

"Briefly, Tesla is satisfied that the ether is the conductor of all force in space, but is not a conductor unless set in agitation in the direction to be travelled. He discovered that the ether can be set vibrating in a straight line in any distance in an area unrestricted to length but circumscribed in circumference. Suppose a shell to be fired from Philadelphia to Lisbon, the path of the shell, if filled with vibrating ether, would represent Tesla's conductor.

"He proposes to establish with one set of apparatus a slender bridge of ether all aquiver with vibrations across the Atlantic. Here is the conductor. Over it he will transmit as over a cable or wire electrical currents, whose vibrations being infinitely slower than those of ether will pass over it as over a road. That is the essence of Tesla's theory.

"I am permitted to say nothing of the marvellous apparatus which will perform this scientific miracle. If, at my station, I find myself communicating with Tesla over the ether conductor, then, at that moment, space will be no longer untraversable; the very heavens may be opened up, for it is thus he purposes to bridge the gulf to Mars."

Tesla and Wireless Telegraphy.

THROUGH the New York *Sun,* Tesla announced last week that he is about to begin the construction of a plant for telegraphing without wires across the Atlantic Ocean, and that he estimated the work of preparation will consume eight months, adding, however, "but I am prepared to encounter some delays and drawbacks which always turn up somehow." From a statement in the same journal, it appears that the system to be employed was the subject of a patent issued to Tesla in May of last year. In looking over our files we find that two patents on "apparatus for transmission of energy" were issued to Tesla last spring, one dated March 20, and the other May 15; the latter is the one referred to by the *Sun.* We reproduce the following analyses of the patents from our issues of March 31 and May 26, 1900, respectively:

The patent dated March 20 (application filed Sept. 2, 1897), relates to the production at one point of an electrical pressure of such character and magnitude as to cause thereby a current to traverse elevated strata of the air between the point of generation and a distant point at which the energy is to be received and utilized. As illustrated, the apparatus consists of a generator supplying current to the primary of a transformer; the secondary consists of a coil of many turns and is connected at one side to the earth and at the other side to a terminal of large surface, maintained at a high elevation by such means as a balloon. The receiver duplicates this apparatus, except that instead of a generator being in one circuit of the transformer, receiving devices such as lamps and motors take its place.

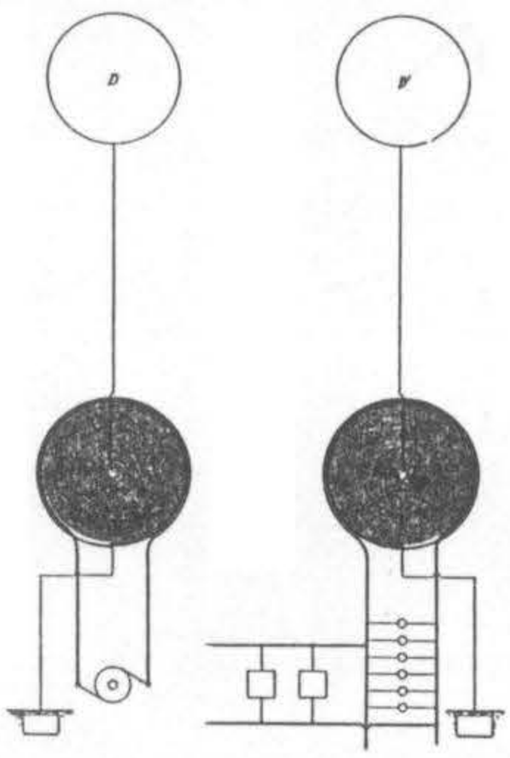


DIAGRAM OF TESLA APPARATUS.

The transformer consists of a coil of very large diameter wound in spiral form, either with or without a magnetic core. The inventor claims that this furnishes a practical method or system of transmission of energy through natural media without the use of wires.

The patent of May 15 (application filed Feb. 19, 1900), is on "apparatus for transmission of electrical energy." Referring to the accompanying illustration, which is a duplicate of that appearing in the patent of March 20, *DD'* are terminals of large surface maintained by such means as a balloon at a high elevation, the elevation depending upon the amount and quality of the work to be performed, the condition of the atmosphere, and also by the character of the surrounding country. The aerial conductors to these terminals are connected to the secondary of a spiral coil, the other end of the coil being connected to earth.

It is stated that the length of the thin wire in each of these coils should be approximately one-quarter of the wave length of the electric disturbance in the circuit, this estimate being based on the velocity of the propagation of the disturbance through the coil itself and the circuit with which it is to be used. For example, if the rate at which the current traverses the circuit including the coil be 185,000 miles per second, then the frequency of 925 miles per second would maintain 925 "stationary moves" in a circuit of 185 miles long, and each wave would be 200 miles in length. For such a low frequency, a secondary 50 miles in length would be used.

As will be noted from the illustration, the primary of the transmitting coil is supplied with a current by a dynamo, and the large coil of the receiver is connected with a circuit including lamps and motors. It is stated that the phenomenon involved in the apparatus is one of true conduction, and not to be confounded with the phenomena of electrical radiation which have heretofore been observed, and which from the very nature and mode of propagation will render practically impossible the transmission of any appreciable amount of energy to such distances as are of practical importance. The specification states that if the potential is sufficiently high and the terminals of the coil be maintained at the proper elevation where the atmosphere is rarefied, the stratum of air will serve as a conducting medium for the current produced, and the latter will be transmitted through the air "with, it may be, even less resistance than through an ordinary conductor."

SCIENCE BREVITIES.

"UNLESS, we are entirely wrong in our premises," says *The Electrical World and Engineer*, "we think Mr. Tesla is mistaken in his ideas of the mechanism of transmitting electric radiant energy from one planet to another. We hope that Mr. Tesla will publish a precise description of the phenomena which he observed, and which led him to suppose that ultra-terrean causes were at work. From his well-known experimental skill, a description of his observations before some scientific body would doubtless be extremely interesting. Our readers can not but agree to some extent with the editorial article in the New York *Tribune*, which, speaking for the lay public, ventures to say: 'It is to be regretted that the first news of the incident was not given to a scientific society of standing, rather than to a philanthropic organization or an ordinary newspaper.'"

Scientific American.

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NEW YORK, SATURDAY, FEBRUARY 23, 1901.

The Editor is always glad to receive for examination illustrated articles on subjects of timely interest. If the photographs are *sharp*, the articles *short*, and the facts *authentic*, the contributions will receive special attention. Accepted articles will be paid for at regular space rates.

TESLA'S WIRELESS TELEGRAPHY.

Long distance wireless telegraphy, if we may believe the current story of its latest developments, is about to take an enormous stride both in its reach and its rapidity, for we are shortly to be in possession of a means of wireless telegraphic communication across the Atlantic, by which we can send messages at considerably greater speed than is possible by the present cable. The feat is to be accomplished by the assistance of that "oscillator" with which the name of Nicola Tesla is so well identified. We are, all of us, fairly well familiar with the Marconi system in which Hertzian waves are utilized, the transmission of currents being aerial, or to speak more correctly ethereal. Mr. Tesla, however, manipulates his recently discovered "stationary electrical waves in the earth" by setting up "vibratory currents which can be transmitted through the terrestrial globe, just as through a wire, to the greatest distances."

According to public reports, Mr. Tesla during the past year or so has been devoting his time chiefly to the improvement of his generator and receiver. He claims to have so far perfected the system that by means of proper "tuning" he can direct his messages infallibly to any particular receiver. It seems that the primary purpose of his recent Pike's Peak experiments was a series of elaborate tests, the result of which satisfied Mr. Tesla that when a suitable plant is built, he can establish wireless electrical communication between the old and the new world. The system, as described in interviews with the author, involves the production of electrical vibrations of enormous frequency, a transmitter which receives the current, intensifies it, and sends it to the earth, through which it flows in every direction. A receiver which is adjusted so that its vibrations are in tune with those of the transmitter is set up, say in London, Paris or Berlin, picks up the vibrations, and intensifies them so that they become decipherable at the receiving station. These electrical vibrations are recoverable at any spot on the surface of the globe, provided that the Tesla receiver be at hand to pick them up, and intensify them to a point at which they may be read.

Talking With the Planets*

By Nikola Tesla

The idea of communicating with the inhabitants of other worlds is an old one. But for ages it has been regarded merely as a poet's dream, forever unrealizable. And yet, with the invention and perfection of the telescope and the ever-widening knowledge of the heavens, its hold upon our imaginations has been increased, and the scientific achievements during the latter part of the nineteenth century, together with the development of the tendency toward the nature ideal of Goethe, have intensified it to such a degree that it seems as if it were destined to become the dominating idea of the century that has just begun. But in this age of reason it is not astonishing to find persons who scoff at the very thought of effecting communication with a planet. First of all, the argument is made that there is only a small probability of other planets being inhabited at all. This argument has never appealed to me. In the solar system, there seem to be only two planets—Venus and Mars—capable of sustaining life such as ours; but this does not mean that there might not be on all of them some other forms of life. Chemical processes may be maintained without the aid of oxygen, and it is still a question whether chemical processes are absolutely necessary for the sustenance of organized beings. My idea is that the development of life must lead to forms of existence that will be possible without nourishment and which will not be shackled by consequent limitations. Why should a living being not be able to obtain all the energy it needs for the performance of its life-functions from the environment, instead of through consumption of food, and transforming, by a complicated process, the energy of chemical combinations into life-sustaining energy?

Some ten years ago, I recognized the fact that to convey electric currents to a distance it was not at all necessary to employ a return wire, but that any amount of energy might be transmitted by using a single wire. I illustrated this principle by numerous experiments, which, at that time, excited considerable attention among scientific men.

This being practically demonstrated, my next step was to use the earth itself as the medium for conducting the currents, thus dispensing with wire and all other artificial conductors. So I was led to the development of a system of energy transmission and of telegraphy without the use of wires, which I described in 1893. The difficulties I encountered at first in the transmission of currents through the earth were very great. At that time I had at hand only ordinary apparatus, which I found to be ineffective, and I concentrated my attention immediately upon perfecting machines for this special purpose. This work consumed a number of years, but I finally vanquished all difficulties and succeeded in producing a machine which, to explain its operation in plain language, resembled a pump in its action, drawing electricity from the earth and driving it back into the same at an enormous rate, thus creating ripples or disturbances which, spreading through the earth as through a wire, could be detected at great distances by carefully attuned receiving circuits. In this manner I was able to transmit to a distance, not only feeble effects for purposes of signalling, but considerable amounts of energy, and later discoveries I made convinced me that I shall ultimately succeed in conveying power without wires, for industrial purposes, with high economy, and to any distance, however great.

To develop these inventions further, I went to Colorado in 1899, where I continued my investigations along these and other lines, one of which in particular I now consider of even greater importance than the transmission of power without wires. I constructed a laboratory in the neighborhood of Pike's Peak. The conditions in the pure air of the Colorado Mountains proved extremely favorable for my experiments, and the results were most gratifying to me. I found that I could not only accomplish more work, physically and mentally, than I could in New York, but that electrical effects and changes were more readily and distinctly perceived. A few years ago it was virtually impossible to produce electrical sparks twenty or thirty feet long; but I produced some more than one hundred feet in length, and this without difficulty. The rates of electrical movement involved in strong induction apparatus had measured but a few hundred horsepower, and I produced electrical movements of rates of one hundred and ten thousand horsepower. Prior to this, only insignificant electrical pressures were obtained, while I had reached fifty million volts. But the time is not far away now when the practical results of my labors will be placed before the world and their influence felt everywhere. One of the immediate consequences

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*Collier's Weekly.

will be the transmission of messages without wires, over sea or land, to an immense distance. I have already demonstrated, by crucial tests, the practicability of signalling by my system from one to any other point of the globe, no matter how remote, and I shall soon convert the disbelievers.

I have every reason for congratulating myself that throughout these experiments, many of which were exceedingly delicate and hazardous, neither myself nor any of my assistants received an injury. When working with these powerful electrical oscillations the most extraordinary phenomena take place at times. Owing to some interference of the oscillations, veritable balls of fire are apt to leap out to a great distance, and if any one were within or near their paths, he would be instantly destroyed. A machine such as I have used could easily kill, in an instant, three hundred thousand persons. I observed that the strain upon my assistants was telling, and some of them could not endure the extreme tension of the nerves. But these perils are now entirely overcome, and the operation of such apparatus, however powerful, involves no risk whatever.

As I was improving my machines for the production of intense electrical actions, I was also perfecting the means for observing feeble efforts. One of the most interesting results, and also one of great practical importance, was the development of certain contrivances for indicating at a distance of many hundred miles an approaching storm, its direction, speed and distance traveled. These appliances are likely to be valuable in future meteorological observations and surveying, and will lend themselves particularly to many naval uses.

It was in carrying on this work that for the first time I discovered those mysterious effects which have elicited such unusual interest. I had perfected the apparatus referred to so far that from my laboratory in the Colorado mountains I could feel the pulse of the globe, as it were, noting every electrical change that occurred within a radius of eleven hundred miles.

I can never forget the first sensations I experienced when it dawned upon me that I had observed something possibly of incalculable consequences to mankind. I felt as though I were present at the birth of a new knowledge or the revelation of a great truth. Even now, at times, I can vividly recall the incident, and see my apparatus as though it were actually before me. My first observations positively terrified me, as there was present in them something mysterious, not to say supernatural, and I was alone in my laboratory at night; but at that time the idea of these disturbances being intelligently controlled signals did not yet present itself to me. The changes I noted were taking place periodically, and with such a clear suggestion of number and order that they were not traceable to any cause then known to me. I was familiar, of course, with such electrical disturbances as are produced by the sun, Aurora Borealis and earth currents, and I was as sure as I could be of any fact that these variations were due to none of these causes. The nature of my experiments precluded the possibility of the changes being produced by atmospheric disturbances, as has been rashly asserted by some. It was some time afterward when the thought flashed upon my mind that the disturbances I had observed might be due to an intelligent control. Although I could not decipher their meaning, it was impossible for me to think of them as having been entirely accidental. The feeling is constantly growing on me that I had been the first to hear the greeting of one planet to another. A purpose was behind these electrical signals; and it was with this conviction that I announced to the Red Cross Society, when it asked me to indicate one of the great possible achievements of the next hundred years, that it would probably be the confirmation and interpretation of this planetary challenge to us.

Since my return to New York more urgent work has consumed all my attention; but I have never ceased to think of those experiences and of the observations made in Colorado. I am constantly endeavoring to improve and perfect my apparatus, and just as soon as practicable I shall again take up the thread of my investigations at the point where I have been forced to lay it down for a time.

At the present stage of progress, there would be no insurmountable obstacle in constructing a machine capable of conveying a message to Mars, nor would there be any great difficulty in recording signals transmitted to us by the inhabitants of that planet, if they be skilled electricians. Communication once established, even in the simplest way, as by a mere interchange of numbers, the progress toward more intelligible communication would be rapid. Absolute certitude as to the receipt and interchange of messages would be reached as soon as we could respond with the number "four," say, in reply to the signal "one, two, three." The Martians, or the inhabitants of whatever planet had signalled to us, would understand at once that we had caught their message across a gulf of space and had sent back a response. To convey a knowledge of form by such means is, while very difficult, not impossible, and I have already found a way of doing it.

163 MILES AN HOUR ON ELECTRIC ROAD

Germany Hopes To Be First in Field with Ideal Railway of Future.

FROM BERLIN TO ZOSSEN

Cars Now Building and Will Be Running Before the End of the Year.

KAISER WILHELM INTERESTED

Experts Here Say They See No Difficulties in the Way of Attaining Such a Speed.

That Germany is making big strides in the direction of the development of electrical railways is shown in a report which has just reached this country.

During the present year a railroad, with electricity as the motive power, will be in construction, the report says, from Berlin to Zossen, on the military line, and it is hoped that trains will develop a speed of 155 miles an hour.

This news was contained in a report sent to Washington by Richard Guenther, the United States Consul General in Frankfort. Under date of January 16 he wrote:—

> It is reported from Berlin, under date of January 14, 1901, that the railway of the future was the subject of discussion at an audience which Privy Councillor Rathenau, superintendent of the works of the General Electricity Company, has recently had with the Emperor. The Emperor expressed himself as being in favor of a complete change of the entire railway service.
>
> Mr. Rathenau gave the Emperor detailed information, emphasizing the necessity of constructing electrical railways for direct and rapid connection between Berlin and the principal cities of the German empire. For the purpose of furthering this project a number of prominent industrial and banking firms formed some time ago a society for investigation. The deliberations of this society will probably result in the opening for traffic during the current year of an electric railway the Secretary of War has placed at the disposal of the society—namely, the military line from Berlin to Zossen.
>
> It is hoped that a speed of from 125 to 155 miles per hour can be attained with cars of which one will be built by the General Electricity Company and one by the firm of Siemens & Halske. By raising the speed, which now averages thirty-seven miles per hour for fast trains, to 155 miles per hour, and by despatching the cars singly, the ideal railway of the future will have been reached.

EXPERTS ARE IMPRESSED.

Electricians in this country, and especially those who are concerned in the construction of railways, were much interested in this report yesterday. Nikola Tesla, who has not given much thought to the practical operation of railroads, said:—

> While I am not acquainted with the details of the project, I heartily commend the use of electricity for the propulsion of passenger trains. There are two ways in which it may be made available for this purpose without considering the storage battery. Either electricity is supplied to the cars, as by the third rail system, or it is generated on the train itself. The latter plan has been tried in France by Heilmann, and I consider it a rational departure.
>
> It can be readily shown that by adopting a proper steam engine and dynamo a train can be propelled with greater speed by the electricity generated than by the direct application of steam. The same considerations also apply to the ocean liners, and the adoption of mutiphase motors driven by steam turbines would materially increase the economy of propulsion of ocean liners and also the speed. The first departure of this kind will be a signal success, and I believe that at a time not distant the idea will be carried out.
>
> I conjecture, however, that the plan contemplated in Germany involves the supply of electricity in some way to the trains from central stations. In this manner, unquestionably, the greatest speed is attainable, as the amount of energy is not limited by the weight of the cars.

BEGINNING ALREADY MADE.

A. M. Young, of No. 100 Broadway, is an expert in electrical railway construction. He is a leading spirit in the Albany and Hudson Railroad and Power Company, which operates a third rail road extending from Hudson to Albany, a distance of thirty-five miles. On this line passenger and freight trains are run at an average speed of thirty-five or forty miles an hour, while a speed of sixty miles has been attained. Mr. Young said:

> It would not surprise me in the least to see a speed of 155 miles an hour attained on an electric railway. It all depends on the construction, of course. In this country I expect to see electric trains running at a speed of 100 miles an hour regularly, and that before long, too.

Charles W. Price, the editor of the Electrical Review, said:—

> I see no reason why 150 miles an hour should not be covered by an electric train. It is entirely feasible, and, indeed, speaking with experts some time ago on this very subject, they said 200 miles an hour would not be impossible.

Other men in positions to speak authoritatively spoke well of the project, and asserted that electricity was the motive power of the future.

Tesla and Wireless Telegraphy.—Announcement has been made in the daily papers, apparently by Mr. Tesla's request, or at any rate with his sanction, that he is prepared to telegraph across the Atlantic without wires. Assertions regarding remarkable discoveries by Mr. Tesla have been so numerous of late and so lacking in material confirmation that the scientific press has come to allow them to pass unnoticed, save by a word, here and there, of sarcastic comment. The daily papers treat the various pronunciamentos each after its kind, the yellow journals with weird pictures and big headlines, the more serious ones with skeptical paragraphs. Exactly what the inventor believes that he is prepared to do may be learned from the following, which *The Sun* (New York) publishes as a leading editorial (February 14):

"*The Sun* is authorized to state that the plans for the machinery of wireless telegraphy to signal across the ocean have been completed and a site for the plant selected by Nikola Tesla, and that the project will at once be actively begun. It is estimated that the time required to perfect the apparatus will be about eight months. We have received inquiries of late as to Mr. Tesla's place among inventors, and as to his credentials to fame. We don't know fully about those things, but we do know that it is Tesla who has given the world what is perhaps the most precious invention of the time, the electrical transmission of power, and we have seen the letter in which Professor Slaby, of Berlin, calls him the 'father of wireless telegraphy.' Will his gorgeous vision, described above, be realized? We don't know. So we must let doubt and incredulity gnaw upon the bare statement."

The attitude of the technical press is generally that of the electrical paper which recently remarked editorially that scientific men must be excused from giving opinions regarding announcements made through the medium of the daily press, and that when Mr. Tesla reads a paper on his alleged discoveries before some scientific body, it will be time enough to consider them seriously.

The daily newspaper reader of the last two months must have been impressed with the numerous and varied announcements of electrical experiments and developments of electrical phenomena credited to Nikola Tesla. It will be interesting to consider these announcements en bloc.

Mr. Tesla began the new year with his twentieth-century greeting to the National Red Cross society, in which he asserted that his delicate instruments at his mountain laboratory in Colorado had been unquestionably affected by electrical influences of planetary origin. Mr. Tesla believes that communication may possibly be carried on between the earth and Venus or Mars by using an enormous delivery of electrical energy, but lasting each time only a fraction of a second. He has been led to this conclusion, he says, by his ability to confine electrical currents of a pressure of 50,000,000 volts and to produce electrical movements up to 110,000 horsepower, and by other experimental results and investigations.

Together with the development of machinery for the production of powerful effects, Mr. Tesla has also perfected novel methods for detecting feeble electrical actions, which, he feels confident, will be important in a number of lines of scientific research.

Of special scientific interest is the announcement that the inventor has found electrical capacity, heretofore generally regarded as a constant, to be variable. He reached this conclusion after a series of experiments at different altitudes in Colorado, from which he was led to conclude that capacity varies with the height above sea level, with the relative height of the capacity with respect to the bodies surrounding it, with the distance of the earth from the sun, and with the relative change of the circuit with respect to the sun, caused by the diurnal rotation of the earth.

Next came the announcement by Mr. Tesla of great improvements in his system of tube lighting, which is said to give the nearest approach to daylight of any artificial illumination yet invented. The lamp is composed of a rectangular spiral of glass tubing containing rarefied gases which emit the radiations when submitted to an extremely high-frequency current.

While waiting for "a number of improvements that must be made before the new light can be generally introduced," scarcely a fortnight had passed before still another startling announcement was made. This time it was to the effect that "the plans for the machinery of wireless telegraphy to signal across the ocean have been completed and a site for a plant selected by Nikola Tesla, and that the project will at once be actively begun." Eight months is said to be the time required to perfect the apparatus, and pertinent to the announcement came a later report from London, stating that an agent of Mr. Tesla was en route to Lisbon to establish a receiving station on the Portuguese coast, which is to be placed in communication with a transmitter located on the New Jersey coast. Accounts differ as to the system to be used for this long-distance, wireless telegraphy. According to one, Mr. Tesla proposes to utilize electrical waves in the earth, by the use of which, with proper apparatus, he believes a wireless transmission of signals to any point on the globe is practicable. This system has been said by some to be the one that will be used in communicating under the ocean. Other accounts refer to a patent granted to Nikola Tesla about a year ago for a system of transmitting electrical energy through the higher strata of air without the use of wires.

An interesting factor that figures in all the Tesla experiments and investigations is the use of an "oscillator." This instrument, which has been evolved after considerable study and years of experiment is at the basis of all the recent developments of Mr. Tesla, and will, so the inventor asserts, accomplish many more wonders in the production of light, in telegraphy and telephony, and in the transmission of power.

Mr. Tesla has been criticized by more prosaic electrical men for raising expectations in the mind of the public which cannot be realized—for talking much and accomplishing little, in other words. His projects are certainly bold in conception and vast in extent. If any of the schemes originating in his fertile brain, and which have been "sprung" with such bewildering rapidity in the last few weeks, should actually, in practice, measure up to the claims made for it, it will be an achievement that will equal or surpass, perhaps, Mr. Tesla's work in the electrical power-transmission field a dozen years ago. In the meantime the electrical journals and all other observers must simply await developments with fair and unbiased minds.

MARVELLOUS RAY IS PRODUCED FROM A NEW ELEMENT.

Renders All Transparent Substances Luminous in the Dark—May Create a Greater Stir Than the X-Ray.

Will Prove a Sure Test for Diamonds and Promises to Be of Great Value to Wireless Telegraphy.

Washington, March 7.—A wonderful discovery has been made in Berlin which will create as much of a stir in the scientific world as did the Roentgen ray.

An element has been discovered by which all transparent substances, by the use of a certain ray, can be made to shine in the dark. By these rays it is possible to distinguish between genuine and artificial diamonds in the dark.

The discovery may also revolutionize the science of wireless telegraphy. The mysterious light by which these wonders can be performed is an element of the Becquerel rays, so called after the French chemist who discovered them.

News from Our Consul at Frankfort.

The news of this discovery came to the State Department from Richard Guenther, the United States Consul at Frankfort, and is published in the consular reports of this date.

Mr. Guenther, writing on January 31, says:

"A new technical journal, Kirchhoff's Technische Blaetter, to be issued within a few days, will contain an interesting article concerning the latest rays.

"In 1895 a French chemist discovered rays emanating from the element uranium which possessed properties similar to the Roentgen rays. They were called Becquerel rays, after their discoverer. But while the discovery of Roentgen aroused great interest in the whole civilized world and led to radical changes in medical diagnosis, the Becquerel rays were employed only in a minor way in physical laboratories, and an assertion by the French scientist Demarcays that they were not emitted from uranium, but from a new element, made no impression.

Important Experiments in Berlin.

"Recent experiments by the Berlin High School of Technology have proven this assertion—that a new element is responsible for the Becquerel rays—and the interesting fact has been observed that these rays render almost every transparent substance luminous in the darkness.

"These rays make it possible to tell genuine diamonds from artificial ones in the dark. This will prove of great practical importance in testing. The experiments have also resulted in obtaining, for the first time, larger quantities of the new element, which has demonstrated that rays emanating from a larger quantity make the air such a conductor of electricity that it is hoped this property can be utilized in wireless telegraphy.

"Experiments for this purpose are being made in the Berlin institution, but the deepest secrecy is maintained concerning them. It is stated that the results will soon be laid before the Emperor, which seems to indicate that the discovery is regarded as one of great importance."

Tesla's Views on the Discovery.

"All this is interesting, if true," was the opening remark of Professor Nikola Tesla, last night, as he proceeded to comment on the above dispatch.

"I am aware of the Becquerel results," he said, "and also of the discoveries of Currie with respect to the properties of uranium and polonium. These discoverers in presenting their results at that time conjectured that some other element might be responsible for the phenomenon observed.

"I do not believe that this discovery will be useful in wireless telegraphy. As a matter of fact, I think that telegraphy with rays in general is of little practical value. The Hertzian telegraphy will soon be abandoned, as experiments have shown it to be limited to short distances, and that, for other reasons, it is incapable of any valuable application for practical commercia use.

"In my papers on the Lennard and Roentgen rays, which were published in the Electrical Review two years ago, I advanced a theory which is now beginning to be appreciated by scientific men. I contended that all sources of radiant energy, including the sun and bodies at an appreciably high temperature, throw off minute particles of matter. I explained that this matter—as was evident from my experiments—was of some primal form, being split up in particles much smaller than ordinary atoms."

TESLA OR HOLDEN.

COLORADO SPRINGS people feel rather kindly toward Nicola Tesla because his greatest discovery or invention eventuated in this city.

If there are people in Mars, they certainly showed most excellent taste in choosing Colorado Springs as the particular point on the earth's surface with which to open communications. In fact, we may feel assured that if the mystical "One—two—three," which Tesla says may have been impulsed from Mars, could be translated from the planetary code, it would read "How is the weather in Colorado Springs?" or something equally localized.

Unfortunately other cities and other scientists do not feel this same consideration towards Mr. Tesla. Professor Holden, for instance, formerly director of the Lick observatory, in a current magazine, says:

"Mr. Nicola Tesla has announced that he is 'almost confident' that certain disturbances of his apparatus arise from electric signals received from some source beyond the earth. They do not come from the sun, he says; hence they must be of planetary origin, he thinks; probably from Mars, he guesses. It is a rule of sound philosophizing to examine all probable causes for an unexplained phenomenon before invoking improbable ones. Every experimenter will say that it is 'almost' certain that Mr. Tesla has made an error and that the disturbances in question come from currents in our air or in the earth. How can any one possibly know that unexplained currents do not come from the sun? The physics of the sun is all but unknown as yet. At any rate, why call the currents 'planetary' if one is not quite certain? Why fasten the disturbances of Mr. Tesla's instrument on Mars? Are there no comets that will serve the purpose? May not the instruments have been disturbed by the Great Bear—or the Milky Way—or the Zodiacal light?

"There is always a possibility that great discoveries, in Mars and elsewhere, are at hand. The triumphs of the science of the past century are striking proof. But there is always a strong probability that new phenomena are explicable by old laws. Until Mr. Tesla has shown his apparatus to other experimenters and convinced them as well as himself, it may safely be taken for granted that his signals do not come from Mars."

As a scientific guesser Professor Holden is not up to the Tesla Colorado Springs altitude. Mr. Holden believes in little or no water in Mars, a temperature far below the freezing point, little or no air, polar caps composed of frozen carbon dioxide, and "canals" that are in reality long cracks or crevasses in the planet's outer crust.

Frankly, we prefer the Tesla guess to that of Holden. It is a good rule in inventional science, "When you're going to tell one, tell a good one," and men have become great by observing the rule.

The man in the moon is gone and even H. G. Wells cannot bring him back, but we refuse to give up Mars. If the selection of Colorado Springs, as a point of superior knowledge where Martian signals would be most likely to be noticed and understood, is not a sign of superior intelligence, what more could be expected?

For the present, we stand by Tesla, and we have no doubt that ere long he will not only catch the repetition of his one-two-three message, but that he will be able to announce to the Martians the quotations and sales of the Colorado Springs mining stock exchange.

"FLIPPANT DISPARAGEMENT" OF MR. TESLA.

A NEW YORK daily—*The Sun*—complains that other papers utter "flippant remarks of disparagement" regarding Mr. Nikola Tesla's recent inventions. In commenting on this, *The Electrical World and Engineer* observes that the reason for this disparagement lies in the nature of things. It says that modern electrical inventors are generally diffuse in their efforts from the fact that opportunities to win new triumphs present themselves so abundantly in every direction that the most enduring energy and the highest genius are in danger of dissipation without net results. And this is the reason why the public once in a while gets impatient with the inventor and says rude things. *The Electric World and Engineer* continues:

"The tide of this flippant disparagement has been rising high of late, possibly because Mr. Tesla, with the onrushing enthusiasm of a man who sees things ahead to be done and is fertile in expedients for doing them, inclines to discuss them as tho they were already disposed of. With men of this stamp of intellect it will be so to the end, and it would be a prosaic world of mediocre achievement if it were otherwise. Just at present Mr. Tesla and his brilliant fellow countryman, Dr. Pupin, have their names associated in the public mind with new means of communicating across the ocean, and the newspapers, as the popular sources of scientific information, are full of the subject—a thing we heartily prefer to seeing the same columns filled with murder cases. But it is certain, in advance, that before they get through both Messrs. Pupin and Tesla will encounter a good deal more of 'flippant disparagement.' What is now being heralded as a novelty in each instance has been known to the electrical community for some time past, as we show in reproducing our articles of nearly a year ago; and probably before the goal is reached there will be several successive outbursts of sensational writing, followed by more of the 'flippant disparagement.'"

Obviously, the writer goes on to say, the tasks of telegraphing to Europe without wires or telephoning to Europe with a "loaded" cable are serious problems, but the impatient public does not realize that such things may linger unaccomplished many years to come, without any fault on the part of those who are striving to bring them to pass. He adds:

"In Mr. Tesla's case the injury done him by the jokes and jibes one finds in almost every paper picked up is the more severe because so much is promised in his name without his direct personal sanction. There seems no way to stop this abuse of confidence, from which Mr. Edison has also suffered to such an extent that a shotgun is his preferred reception for the average reporter. But just now Mr. Tesla holds the center of the sensational stage, and the talk about him is all the looser for the reason that it has so little that is tangible behind it as food. He has read no scientific papers before the societies for years, and, since his monumental series of patents on polyphase work, has taken out extremely few patents. We can recall only one or two in recent years. Hence the gossip that always besets a great genius has little to feed upon save the wild and absurd stories to which few of the authors hesitate even at signing Mr. Tesla's own name. In this way, as all such men discover, the lot of the genius trying to crack the nuts of modern civilization is not much better than that of his predecessors treated as lunatics or witches. And this 'flippant disparagement' falls hardest upon those who are not drawing-room inventors with drawing-board inventions."

The New York Herald March 22, 1901

MR. TESLA IS CONFIDENT.

Says His Wireless Telegraphy Invention Will Be Practically Tested Within Six Months.

PITTSBURG, Pa., Thursday.—Nikola Tesla is in Pittsburg placing a contract with the Westinghouse Electric Company for the manufacture of certain mechanical devices to be used in his experiments in wireless telegraphy across the Atlantic Ocean. Mr. Tesla says the success of his enterprise is more assured now than ever and that within the next six months his invention will be given a practical test. He hopes to establish the proof that it is not beyond the range of possibility to establish communication across the ocean without the aid of wires.

The New York Tribune March 22, 1901

WIRELESS TELEGRAPHY ACROSS OCEAN.

Pittsburg, March 21.—Nikola Tesla, the inventor, is in Pittsburg placing a contract with the Westinghouse Electric Company for the manufacture of certain mechanical devices to be used in his experiment on wireless telegraphy across the Atlantic Ocean. Mr. Tesla states that the success of his latest enterprise is more assured now than ever before, and within the next six months his invention will have a practical test. He hopes to prove that it is not beyond the range of possibility to establish communication across the ocean without the aid of wires.

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CORRESPONDENCE relating to electricity or any of its practical applications is cordially invited, and the co-operation of all electrical thinkers and workers earnestly desired. Clear, concise, well written articles are especially welcome; and communications, views, news items, local newspaper clippings, or any information likely to interest electricians, will be thankfully received and cheerfully acknowledged.

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Astronomers do not seem to take kindly to Mr. Tesla's hypothesis that the inhabitants of Mars may be transmitting electrical signals to Earth. Edward S. Holden, formerly director of Lick Observatory, in a recent article in McClure's Magazine, is disposed to be sarcastic: "Mr. Nikola Tesla has announced that he is 'almost confident' that certain disturbances of his apparatus arise from electric signals received from some source beyond the earth. They do not come from the sun, he says; hence they must be of planetary origin, he thinks; probably from Mars, he guesses. It is a rule of sound philosophizing to examine all probable causes for an unexplained phenomenon before invoking improbable ones. Why fasten the disturbances of Mr. Tesla's instruments on Mars? Are there no comets that will serve the purpose? May not the instruments have been disturbed by the Great Bear—or the Milky Way—or the Zodiacal Light? Until Mr. Tesla has shown his apparatus to other experimenters and convinced them as well as himself, it may safely be taken for granted that his signals do not come from Mars." Mr. Holden is perhaps unnecessarily severe on Mr. Tesla; but, unfortunately, the electrical inventor has invited criticism of this sort by the vague, mystical way in which he chose to make public announcement of the disturbances on which his assumption is based.

ELECTRICAL MAGIC BY GREAT WIZARDS

"Miracles" Shown in Matter of Fact Way by American Institute of Electrical Engineers.

BARRELS OF TALK ON TAP FROM PIANO WIRE

Nikola Tesla and His Audience Cheer Thomas A. Edison, Who Gives Encouragement to His Successor in the Field of Invention, Who Makes the Deaf Hear.

Ray! Ray! Ray!
C—O—L—U—M—B—I—A.
Edison.

With such hearty welcome was "the Wizard of Menlo Park" received when he entered the lecture room of Havemeyer Hall, at Columbia University last night.

Nikola Tesla was giving experimental demonstrations with an electric oscillator when he saw Mr. Edison entering. His own greeting had been generous and hearty. When he saw the greatest of all American inventors Mr. Tesla stopped his work and grasped Mr. Edison's hand, which he shook as he led him to a seat. The great audience appreciated the courtesy of the younger man and responded with cheers for both.

The American Institute of Electrical Engineers held what it was pleased to call a "conversazione" at Columbia University last night. In reality it was an electrical exposition, and the most complete ever known in America. Fully two thousand guests had been invited, and few of those that received invitations failed to attend. The Engineering Building and Havemeyer Hall were given over to the electrical engineers and their guests, and every room in the two great buildings was used.

Matter of Fact "Miracles."

While there was nothing exhibited that was absolutely new, there were on exhibition inventions of which the public has only barely heard. "Miracles" were performed in a matter of fact way that left the beholders too dazed to do more than exclaim. Many of the wonders in operation are of too technical a nature to appeal powerfully to the layman in electric matters. Others are so practical that their value is easily understood.

Professor Waldemar Poulsen's telephonograph was exhibited in the Engineering Building, by Messrs. Lemvig Fog and Emil S. Hagemann, of Copenhagen, Denmark, and Mr. William A. Rosenbaum, of New York. This exhibition attracted the enthusiastic attention of all who saw it, and none was louder in praise than Mr. Edison, who gave great credit to the inventor for his work.

It was Jules Verne who told of conversation being frozen into the air to be heard when the weather moderated. While the Frenchman's dream has not yet been realized, Professor Poulsen has succeeded in packing into an electrically charged piano wire a conversation that may be drawn out much as one draws wine from a cask.

The apparatus, as exhibited last night, consists of a brass drum, eleven by five inches, upon which is wound piano wire. Resting upon the wire is a tiny electro magnet, which is connected to a carbon telephone transmitter, two cells of battery and preferably an induction coil.

Speech Put on Tap.

When the transmitter is spoken into, it acts as a tap on the battery, causing currents of varying strength, in proportion to the strength of the sound waves, to pass through the electro magnet. The current causes the magnet transversely to magnetize the steel wire as the drum resolves, and the magnetic lines of force are permanently recorded therein.

After the steel spiral is filled—which operation takes about 39 seconds, and permits the recording of 100 to 120 words—the tiny magnet is placed in its original position and connected with a Bell receiving telephone. The cylinder is again revolved, and as the magnetized steel wire passes before the poles of the electro-magnet it forms a species of magneto-electric generator, giving out currents of electricity of a strength and direction corresponding to the magnetization of the steel wire, which correspondingly affect a Bell telephone held to the ear, and reproduce the sounds and words originally spoken with absolute fidelity.

In addition, there was shown the band form of telephonograph and a dictation machine for office use. The band form gives the machine a practical value, as it makes it possible to extend the dictation almost indefinitely. The record is wiped out at the will of the operator, or retained permanently. There is no waste of material. The telephonograph is not yet considered perfect by its inventor, who is constantly at work upon it. The reproduction is similar to the sound of the telephone, the buzzing of the phonograph being obviated.

Aerodrome Pictured in Flight.

In the same room with the telephonograph was exhibited a remarkable collection of aeronautical pictures, comprising photographs shown for the first time, of Professor S. P. Langley's aerodrome in actual flight. Dr. Alexander Graham Bell took a photograph which shows the aerodrome in the air at least one hundred feet from the earth. At the time the picture was taken the machine made a successful flight of more than three thousand feet. The velocity attained was twenty-five miles an hour in a course that was constantly taking the aerodrome "up hill."

Peter Cooper Hewitt in another room of the Engineering Building exhibited high candle power lighted the room, using ordinary 115-or vapor. One large tube lamp of 1,000 candle power lighted the room, using ordiary 115-volt direct current. The room was perfectly lighted, remarkable color effects being produced at the will of the exhibitor. At times an effect so ghastly as to affect the nerves of many was produced. By the use of another apparatus Mr. Hewitt showed the relation of voltage to the length and the diameter of the tubes used.

Where the Deaf Heard.

On the third floor of the Engineering Building Mr. K. Hutchison exhibited the akouphone and the akoulallon, the microtelephonic instruments of his invention, by means of which he makes the deaf hear.

A class from the New York Institution for the Instruction of the Deaf and Dumb were present to illustrate the value of the akouphone. They were selected because of the fact that they are the most hopelessly deaf of all in the institution. Among them was Orris Benson, who has been deaf and blind since birth.

Benson has had five hours of training with the akouphone and is now somewhat accustomed to it. He listened to music from a phonograph, and when the sensation of sound first penetrated his brain he threw up his "talking hand" and told his teacher, who was with him, that the music sounded sweeter to him than it ever had before. Later he held a short conversation with Mr. Hutchison.

"Hello!" said the young inventor.

"Hello!" responded the boy whose life had so long been mute. His voice was hollow and metallic, but his enunciation was not bad.

"Can you say 'mamma' and 'papa'?"

"Mamma, papa," came back from Benson, who divided the words into syiables, as does a talking doll.

"Are you a bad boy?"

Benson shook his head. For a moment he studied, then replied:—

"Bad boy—no."

Other members of the class were eager to test the akouphone. When they heard music or words their faces changed in expression, losing that set condition of features that marks those whose ears are deaf.

For hours the room in which Mr. Hutchison exhibited his invention was crowded. Mr. Edison and Mr. Tesla were there, and complimented the young inventor for producing the instrument.

Telegraph Picture Machine.

Mr. H. R. Palmer exhibited a fac-simile picture telegraph in operation. This system is similar to that which has been successfully used in transmitting pictures and sketches over long distances, employing ordinary telegraph circuits.

Dr. Michael I. Pupin exhibited his original apparatus used in developing the recent invention by which he made it possible to telephone long distances under the ocean. Dr. Pupin's system consists in the location of inductance coils in the line at distances which are small fractions of a current wave length.

Wireless telegraphy, as worked out for the use of the United States government, was exhibited and explained in connection with a field telephone and telegraph kit used in the Philippine campaigns.

Professor Elihu Thomson exhibited a new rotary electrical apparatus consisting of an iron sphere heavily electroplated with copper and mounted so that it may revolve on any axis or in any plane. Surrounding this sphere are three coils in planes at right angles to each other. By suitably energizing these coils with polyphase current the sphere may be made to revolve on any axis or in any direction, or it may be said to illustrate a three dimension polyphase system.

These are only a few of the many things that were exhibited and explained. In the lecture room Mr. Tesla gave demonstrations at nine o'clock and at ten o'clock. Each time he had large audiences that marvelled at the wonders he performed, though few of them were new. With the room darkened Mr. Tesla walked about brandishing long glass tubes which flashed in a manner resembling phosphorescence that was not entirely canny.

In one hand he carried what seemed like an ordinary glass globe, fifteen inches in diameter. Suddenly a flash of electricity appeared many feet from the demonstrator, and the globe glowed as though it were filled with living fire. Again the room was darkened, and from what appeared to be an ordinary insulated wire sparks shot in every direction, filling the atmosphere for yards around with fire that drove away curious persons who had crowded too close to the demonstrator.

Mr. Tesla apologized for the failure of many of his experiments, as being due to flaws in his apparatus developed after it had been installed.

THE latest great application of natural force to a useful purpose, in which it is announced that Nikola Tesla is especially interested, is an electrical process for purifying water, says the Baltimore "Herald." The system contemplates, it must be understood, not the shaking of a few millions of unhealthy microbes out of a few gallons of water. Mr. Tesla deals in no such small schemes as that. The plan, when made to work, will be expected to purify the inflow of the open rivers that contribute to the supply of large cities. Instead of swallowing with every glassful of the murky beverage which flows from the faucet a large percentage of odorous protoplastic germs, the electrified water of Mr. Tesla may be expected to possess the sparkle and sweetness of the aqueous fluid that flows from the mountain rocks. He could confer no greater boon upon humanity. Let us hope this time for practical results.

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The Institute Conversazione.

In the dictionary a conversazione is defined as an assembly for conversation, "particularly on literary or scientific subjects." But the gathering at Columbia University, New York, on the evening of April 12th was that and more, being also an exhibition of one evening's duration of the latest advances in the science and art of electricity. It was held by the American Institute of Electrical Engineers, with the co-operation of the university authorities, and was a brilliant success. The effort to present electrical features of real novelty was satisfactorily carried out, and the attendance was worthy of the exhibits and demonstrations, including such men as Edison, Tesla, Elihu Thomson, Sprague, Bell and Pupin. The affair was held in the Engineering building and Havemeyer Hall, the latter being devoted exclusively to Tesla's demonstrations. In all there were 32 special exhibits. A collation was served on the third floor of the Engineering building. The committee of arrangements consisted of W. S. Barstow, chairman, and Edward Caldwell, W. J. Hammer, R. T. E. Lozier, F. B. Crocker, T. C. Martin, C. W. Rice and George F. Sever. The reception committee embraced a long list of well-known names, with Carl Hering as chairman and R. W. Pope as secretary. Following are brief accounts of exhibits.

Pupin's Improvement in Long-distance Telephony.

Professor M. I. Pupin of Columbia University was in attendance and explained to visitors the original apparatus used in developing his recent invention for the improvement of long-distance land and ocean telephony, consisting in the location of inductance coils in the line at distances which are definite small fractions of a current-wave length. This apparatus was shown in the basement of the Engineering building.

Tesla's Experiments.

In Havemeyer Hall, Nikola Tesla performed startling and suggestive experiments with his oscillator—experiments remarkable to see, yet impossible adequately to describe. An interesting feature of the Tesla demonstration was the high tribute paid Tesla by Edison's presence at his demonstration, for Mr. Edison's reluctance to attend functions of all sorts is well known. The entrance of Edison was the signal for tremendous cheering on the part of those present, and Tesla's smiling and evident appreciation of the high compliment paid him by the older inventor was by no means the least interesting feature of the evening.

As is often the case where highly scientific demonstrations of an impromptu nature are essayed, and with a short time for preparation or test of apparatus after transportation, Mr. Tesla had to suffer his disappointments. In the midst of his most remarkable experiments, and at a point where he had hoped forcibly to illustrate certain remarkable phenomena relative to the transmission of energy without wires, well known to himself, but it is safe to say, new to the majority of those present, the transformer on the city electric-lighting system, that had been tapped or temporarily installed by the college authorities to furnish Mr. Tesla his main supply of current gave out. The manly and patient manner in which Mr. Tesla endured what must have been a most trying ordeal won him the sympathy of every practical scientific man present. The fact, too, that he had worked throughout the entire preceding night and had brought to Havemeyer Hall an astonishing amount of heavy yet delicate and intricate apparatus, earned him the thanks of everyone present for his effort, as he smilingly put it, "not to instruct, but to amuse." Fortunately for Mr. Tesla, however, he was enabled to make an exhibition of high-frequency induction effects and of high-tension discharges of a highly interesting character. Edison's entrance and later that of Tesla were greeted with cheers by the Columbia students. Tesla explained that he was going to use an electric oscillator to produce wave vibrations which were to be discharged in various parts of the room by means of a large transmitting cable. The brilliancy of the electric light from a large coil was made to decrease and diminish by Tesla rubbing his hands along the sides of the coil.

Geissler tubes were made fluorescent, and a beautiful effect was produced by waving vacuum tubes charged with the electric current.

The later experiments partook of the nature of the results obtained by induction currents. A glass moon was lighted from a huge wire coil, the current passing through the air as in wireless telegraphy. Tinfoil was heated from the center of the coil. When the coil was short-circuited, the foil heated so quickly that the demonstrator dropped it with smothered exclamations. By far the most spectacular performance was the last. A huge, flat coil, 10 feet high, was constructed in the front of the room and the current turned on in full force. Sparks leaped six feet in all directions from the end of the wire, and the heat was so intense that the insulation began to burn. The audience felt uncomfortable and Tesla smothered the flames, remarking that "It's just nothing."



FIG. 1. THE INSTITUTE CONVERSAZIONE.—PICTURE-TELEGRAPH MACHINE AT CHICAGO END OF CIRCUIT.

Palmer and Mills' Picture Telegraph.

H. R. Palmer's and Thomas Mills' "facsimile picture telegraph" was one of the exhibits. This instrument is worked on a system whereby half-tone pictures, sketches, handwriting and the like can be transmitted over long distances by employing ordinary electrical circuits.

An attempt was made to send and receive pictures to and from Chicago, the instrument on exhibition having been connected with long-distance telephone wires, but the experiment failed this time, although the efficacy of the appliance has previously been demonstrated over long distances. The explanation for the failure was that the induction in the underground cables in New York caused the trouble.

It is not claimed that this apparatus is entirely perfected for commercial use nor that it involves any new principle in picture transmission, the idea being to utilize synchronously revolving cylinders, the one at the transmitting end having the picture on a prepared zinc plate treated with an insulating compound to break the circuit of a metallic stylus in contact with it. At the receiving end is a duplicate machine, in which, however, a pen takes the place of the stylus and produces, on a sheet of paper on the receiving cylinder, the outlines or dots transmitted by the electrical impulses of the transmitting cylinder. Automatic synchronizing apparatus is provided. In the experiment arranged for the Institute Mr. Palmer was at the New York end and Mr. Mills in Chicago. The accompanying picture (Fig. 1) shows the instrument set up in a room at the Quadrangle Club of the University of Chicago and was taken on the evening of April 12th, at the time of the test. Mr. Mills, one of the inventors, is in the chair in the foreground, with an assistant at his left. The machines will be exhibited at the Pan-American Exposition by the International Electrograph company of Cleveland, of which Mr. Palmer is president.

Poulsen's Telephoncgraph.

Poulsen's telephonograph was exhibited by Lemvig Fog and Emil S. Hagemann of Copenhagen, Denmark, and Mr. William A. Rosenbaum of New York. This exhibition attracted the enthusiastic attention of all who saw it, and none was louder in praise than Mr. Edison, who gave great credit to the inventor for his work. The apparatus, as exhibited, consists of a brass drum, 11 by five inches, upon which is wound piano wire. Resting upon the wire is a tiny electromagnet, which is connected to a carbon telephone transmitter, two cells of battery and preferably an induction coil. When the transmitter is spoken into, it acts as a tap on the battery, causing currents of varying strength, in proportion to the strength of the sound waves, to pass through the electromagnet. The current causes the magnet transversely to magnetize the steel wire as the drum revolves, and the magnetic lines of force are permanently recorded therein. After the steel spiral is filled—which operation takes about 39 seconds, and permits the recording of 100 to 120 words—the tiny magnet is placed in its original position and connected with a Bell receiving telephone. The cylinder is again revolved, and as the magnetized steel wire passes before the poles of the electromagnet it forms a species of magneto-electric generator, giving out currents of electricity of a strength and direction corresponding to the magnetization of the steel wire, which correspondingly affect a Bell telephone held to the ear and reproduce the sounds and words originally spoken with absolute fidelity. In addition, there was shown the band form of telephonograph and a dictation machine for office use. The band form gives the machine a practical value, as it makes it possible to extend the dictation almost indefinitely. The record is wiped out at the will of the operator, or retained permanently. There is no waste of material. The telephonograph is not yet considered perfect by its inventor, who is constantly at work upon it. The reproduction is similar to the sound of the telephone, the buzzing of the phonograph being obviated.

Hewitt's Mercury-vapor Lamp.

One of the most remarkable exhibits, due largely to its importance as bearing upon the future of the incandescent electric light was that of Mr. Peter Cooper Hewitt. With a knowledge of the present efficiency of ordinary types of arc and incandescent lamps and also that of such lamps as the Nernst, Mr. Hewitt's record with his mercury-vapor lamp, operating at 74 volts with three amperes, consuming a total of 222 watts and giving 700 candlepower, or, in other words, giving light at the rate of 0.32 watt per candle, measured horizontally at right angles to the tube—such a result as this means something to the electric-lamp industry. Mr. Hewitt was naturally very solicitous that those present should use the ammeters and voltmeters for themselves, and many verified the tests. This mercury-vapor lamp operates on ordinary 115-volt, constant-potential circuits and gives a most peculiar light, which will doubtless subject it to some criticism. In this lamp, it was explained, a gas is used as the illuminating medium, instead of a filament or a carbon pencil,

as in other electric lamps. Mr. Hewitt's gas is mercury vapor. The lights are long and cylindrical in shape. At the bottom of each lamp is some mercury, from which, when the current of electricity has been run through it, there issues the vapor referred to. The current is transmitted to the mercury direct. The most peculiar colored light is emitted from the tubes. It is half purple, half green. This, according to the explanation of the exhibitor, is a disadvantage, but it can be obviated by the use of counteracting colored shades. The reason the crowd seemed to be especially interested in the long tubes was the fact that everybody who came into the room had his or her features so distorted that the skin of the face appeared to be covered all over with ghastly, violet-colored eruptions. The lips that came under the light seemed purplish gray, the pupils of the eye lost their natural hue, whatever it had been, and assumed a greenish tinge.

Ryan and Phelon's Radiographing of Alternating-current Waves.

Professor Harris J. Ryan of Cornell University and Professor J. O. Phelon exhibited a most valuable application of a Braun tube in radiographing of alternating-current waves. This is a method for securing stationary and continuous diagrams or cards of alternating-current values, which are conveniently recorded by means of a simple form of pantagraph, that is run over the luminous diagram and operates a lead-pencil.

Hutchison's Akouphone.

M. R. Hutchison exhibited two instruments known as the akouphone and akoulalion, and which are intended to make the deaf hear. W. H. Van Tassel of the New York Institute for the Deaf and Dumb brought eight of the deafest boys in the institution for experimental purposes. One lad was born deaf, dumb and blind. He was led to the apparatus and the earpieces fixed over his head.

The operator spoke into the akouphone, which is described as a microtelephonic instrument, so constructed as to reproduce and largely intensify sounds and still preserve their quality. The boy jumped when words were spoken, showing the novelty of all sound to him. When the word "hello" was repeated many times he made an effort to repeat the sound, with only partial success. A phonograph was attached to the receiver and band music was played. A faint smile appeared on the boy's face and he spelled out the word music with his fingers to his preceptor. He began to keep time with his hands and his face was soon wreathed with smiles. He resisted when the cap was removed from his head. Mr. Van Tassel said experiments with the akouphone on another inmate of the asylum had resulted in great success.

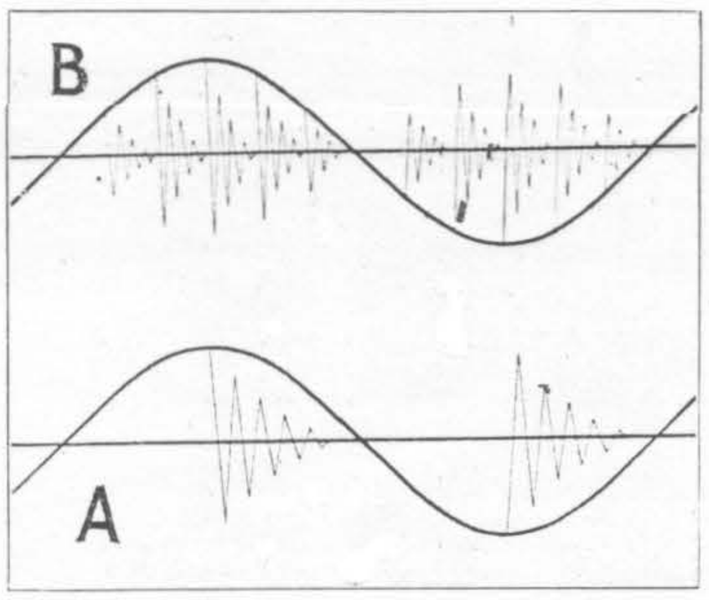


FIG. 3. THE INSTITUTE CONVERSAZIONE.—ANDREWS' SPARK EXPERIMENTS.

Elihu Thomson's Apparatus.

Professor Thomson showed a dynamo static machine, containing a small direct-current motor, the windings of which are tapped and connected to two rings, giving a primary alternating current for the operation of a step-up transformer, which gives a secondary current of about 20,000 volts, being capable, however, of regulation through a wide range. The tops of the alternating-current waves of high potential obtained from this secondary transformer are used to charge a number of glass-plate condensers in parallel. The rotating frame synchronously driven with the motor makes the connection to the condensers periodically and in synchronism with the alternating current. The connection by the rotating frame is alternately in parallel and in series, condenser plates being charged to 15,000 volts and with 10 in parallel, giving 150,000 volts when connected in series. The machine therefore furnishes from low-pressure direct current, high-potential discharges of definite polarity at the discharged terminals.

A new rotary electrical apparatus, consisting of an iron sphere heavily electroplated with copper and mounted so that it may revolve on any axis or in any plane, was also exhibited by Professor Thomson. Surrounding this sphere are three coils in planes, at right angles to each other. By suitably energizing these coils with polyphase current, the sphere may be made to revolve on any axis or in any direction, or it may be said to illustrate a three-dimension polyphase system. This apparatus illustrates the principles of the gyroscope and Bohnenberger sphere.

A third device was an illuminated disk mounted on a shaft free to rotate and having applied to it in special ways alternating-current magnetic fields, the rotations of the disk involving interesting paradoxes.

Andrews' Spark Experiments.

The following experiments were made by Mr. W. S. Andrews to determine some features of a high-frequency spark, the apparatus being energized from an alternating-current lighting circuit of 118 volts and 58 cycles. For convenience of observation.

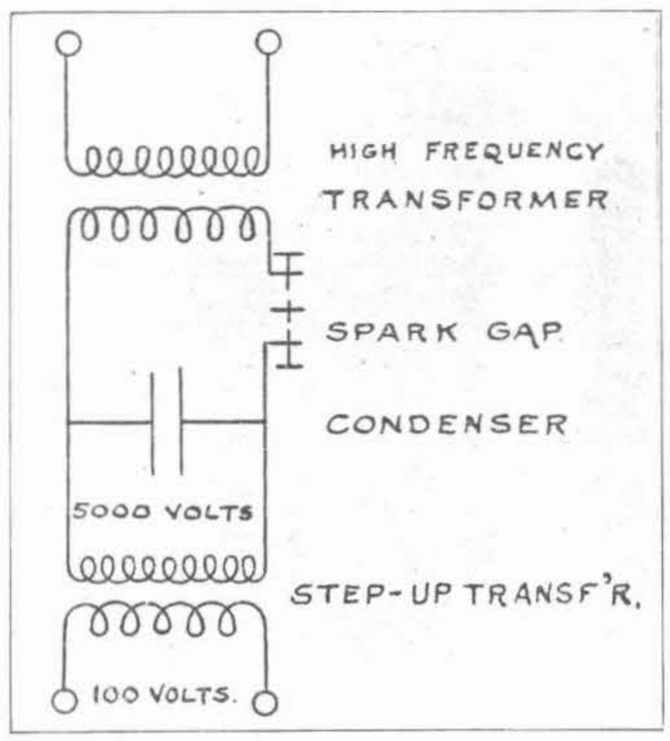


FIG. 2. THE INSTITUTE CONVERSAZIONE.—ANDREWS' SPARK EXPERIMENTS.

the spark was passed through a glass tube having a bore of about 0.25 millimeter. The current was conducted into the tube by wires inserted in the ends, leaving an air gap about five inches long inside the tube, the ends of which were not sealed. The tube was revolved while illumined by the discharge, the optical effect being a circle of bright radial lines. Under these conditions, the number of primary radii is obviously determined by the ratio between the alternations and the speed of rotation, but the characteristics of the primary radii may be changed by manipulation of the apparatus.

Referring to the theoretical diagram of high-frequency apparatus shown in Fig. 2, when the spark gap is set at a certain length and the potential of the transformers adjusted, so that the condenser discharge will only just arc across it, the radii will appear as single lines, indicating that the condenser discharges only once during a half wave. See (A), Fig. 3. If the primary potential is now increased, or if the spark gap is shortened, the single radii will be seen to open out like a fan into two or more lines, thus indicating a corresponding number of condenser discharges during each half wave. See (B), Fig. 3.

To obtain permanent records of the different effects, photographs were taken. Fig. 4 shows a snap exposure of the high-frequency sparks during two half waves. Fig. 5 shows a star produced when the tube was revolved at 430 revolutions per minute. During each half revolution eight compound radii were formed in each half of the circle, corresponding to eight half waves in a 58-cycle current.

"It would be difficult, if not impossible," says Mr. Andrews, "to record any purely high-frequency oscillations by the present method, as a sufficiently high speed of rotation could not be attained. The results described, however, appear to present a clear proof that each half wave may be the source

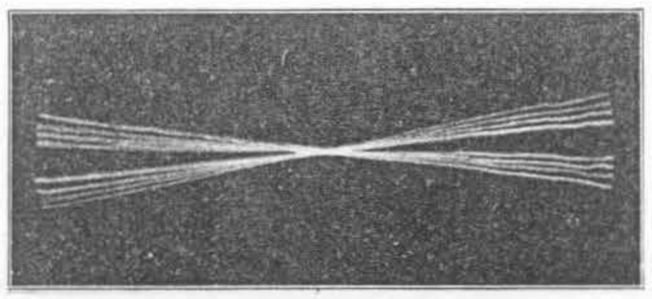


FIG. 4. THE INSTITUTE CONVERSAZIONE.—ANDREWS' SPARK EXPERIMENTS.

of a number of groups of high-frequency oscillations. It therefore follows that an arc across a high-potential circuit containing inductance and capacity ruptures itself instantly, so that, if the voltage is high enough, it can occur repeatedly during each half wave."

Nernst Lamps.

Mr. William J. Hammer exhibited European "Nernst" and other electric lamps. These lamps were shown in operation during the evening. Mr. Hammer also showed his personal collection of photographs from Hiram Maxim of his flying machine and also of his own trip in a balloon from Paris, while he was, some years ago, Mr. Edison's representative at the Paris Exposition.

Storage Batteries.

Mr. Herbert Lloyd exhibited Chloride accumulators. Cells of a special form, designed for traction purposes, as used on the Thirty-fourth street cross-town line, New York city, were shown; also oxide cells for vehicle purposes and specimen plates.

Frank Perret, J. A. Barrett and W. H. Meadowcroft exhibited a storage battery made on a unit system, whereby cells of different sizes are built up of universal units of definite capacity. Purely Planté formation is used. No oxidizing agents are employed and nothing but pure lead, sulphuric acid and water are made use of for the process of construction.

Mr. A. S. Hubbard showed the Gould storage battery as follows: (1) Positive and negative plates, having a small amount of active material, which have gone through a series of charges and discharges at half-hour and twenty-minute rates; (2) an automobile battery cell with a "spinning," giving 450 square inches of surface per pound of lead; (3) a positive and negative plate of automobile type of cell; (4) an unformed plate with delicate "spinning," giving 144 square inches per cubic inch of lead. The feature of the battery is the increase of superficial area of the plate obtained by spinning or grooving with rotary knives, which force the lead up between them, forming ribs and grooves of any desired dimensions. Each rib is made independent by tying the ends with the main cross-bars, and not depending on any center conductor or support, thus giving a low internal resistance.

Mr. Elmer A. Sperry displayed types of storage battery for automobile work, with diagrams of discharge curves.

Clarke Synchronism and Phase Indicator.

A synchronism and phase indicator for indicating when two alternating-current machines are in synchronism and the phase relations of their electromotive forces was the exhibit of Mr. Charles L. Clarke. It is also applicable for showing the lag of a current behind the electromotive force, either in the same or another circuit, provided they have equal frequencies, and also for showing the phase relations of currents of the same frequency. The instrument, as exhibited, which is intended for use in lighting and power stations, consists of two synchronous alternating-current motors, which respectively drive two stroboscopic disks, the stroboscopic image formed opposite a scale indicating when the generators respectively supplying current to the motors are in synchronism, or nearly so, and, in the latter case, which of the generators is running at the greater polar speed. When the generators are in synchronism, the stroboscopic image is stationary, and its position relative to the scale indicates the degree to which the electromotive force of one generator leads or lags behind the electromotive force of the other.

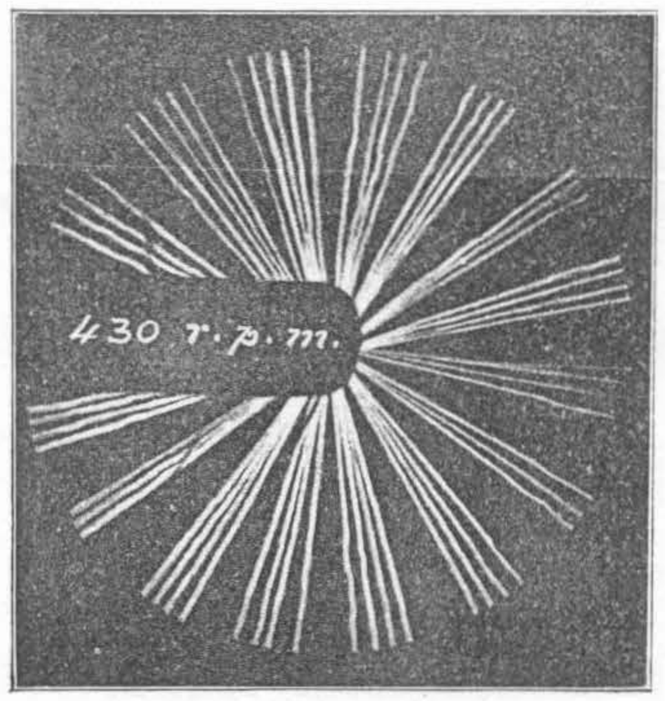


FIG. 5. THE INSTITUTE CONVERSAZIONE.—ANDREWS' SPARK EXPERIMENTS.

Miscellaneous Exhibits.

Mr. Otto T. Louis showed an electric furnace consisting of several terracotta cylinders, about two inches in diameter and one-half inch thick, around which is wound platinum wire of 22 B. & S. gauge. The wire is put on in four circuits, so that, as the resistance increases with the heat, the circuits may be thrown from series to parallel. The cylinders have longitudinal and vertical motions, and are held in position by clamps. Mr. Louis also had an ohmmeter for making direct measurements from 10,000 to 10,000,000 ohms and a 55-centimeter Wimshurst influence machine.

Other exhibits may be mentioned as follows:

Mr. E. V. Baillard.—Faradmeter and bridge for measuring low resistances.

Professor George F. Barker and Professor Arthur W. Goodspeed.—Radiographs.

Mr. A. F. Clift.—Telpherage system for the transportation of freight in small bulk, express matter, mail, etc., by means of an electric motor traveling

upon an overhead cable obtaining current by rolling contact with a lighter wire above.

Dr. Francis B. Crocker.—Magnetic liquids, with apparatus in operation for showing the magnetic properties of liquids and for measuring their permeability.

Mr. H. P. Davis.—Two switchboard panels, showing principally a phase-shifting transformer, a power-factor indicator, a synchronizer, an alternation meter and various new indicating and integrating instruments.

Professor W. S. Franklin.—Magnesia arc lamp (an electrolytic lamp on the Nernst principle, operating on 1,000 volts).

Dr. William E. Geyer.—Incandescent-lamp experiments. (Experiments employing incandescent lamps on circuits containing self-induction and capacity).

Mr. Caryl D. Haskins.—Power-factor indicator, showing relation between real and apparent energy in an alternating-current circuit, and single-coil astatic instruments, which, instead of using four coils, employ only one.

Professor Frank A. Laws.—Radiographs of alternating-current wave forms and oscillatory discharges, made by the use of cathode-ray tubes of the Braun pattern.

Colonel Samuel Reber, U. S. A.—Wireless telegraphy in operation, employing methods and improvements as worked out for the use of the United States government; also field telephone and telegraph kit used in the Cuban and Philippine campaigns.

Mr. Martin P. Rice.—New X-ray apparatus, employing a modified form of Wehnelt interrupter.

Mr. L. T. Robinson.—Wave-form indicator, consisting of a small synchronous motor in connection with suitable commutating devices, and used for determining the wave shapes of alternating current.

Mr. H. F. Sanville.—Copper-splicing machine, consisting of a portable and self-contained splicing press, with independent pump and flexible hose, used for making a solderless splice in wires and cables, forming a cold weld. This machine has an ability to give a pressure of 20 tons per square inch in the weld.

Mr. E. T. Schoonmaker.—Floating magnetic field.

Mr. Fitzhugh Townsend. — Alternating-current wave tracer. (In this device the contact is made during one-half of the period in contradistinction to the instantaneous-contact method ordinarily employed.)

A FRENCH OPINION OF TWO AMERICAN INVENTORS.

IT has recently been announced by Thomas A. Edison that by means of his magnetic ore-separator he has been able to separate hematite from magnetite, thus making it profitable to work enormous European ore deposits that do not pay with present methods and potentially blasting America's supremacy in the manufacture of steel. A representative of *The World* (New York) recently interviewed Eugene Schneider, head of the Creusot Iron Works, the most important rail, locomotive, and gun factory in France, on this subject, and reports to his paper that Mr. Schneider and his chief mining engineer expressed themselves skeptically regarding the new discovery. Mr. Schneider said:

"What is the use of discussing Edison's advertising dreams? He has no special knowledge of metallurgy, and the problems he claims to have solved have engrossed scientists all over the world.

"Let Edison occasionally do what he claims he can do and then we will be willing to give him attention. But Edison's tactics, like Tesla's, consist of finding what difficulty puzzles scientists and announcing that their own genius is about to solve it. But when the time comes neither realizes his glowing promises.

"Let it be said once and for all that real scientists all over the world consider Edison and Tesla a pair of humbugs.

"What has Edison discovered except the phonograph, which was a chance discovery and not the result of scientific perspicacity? Not electrical incandescence, for that was really invented in Germany; nor the biograph, which was discovered here by Lumiere, nor anything of real importance.

"On the other hand, has Tesla destroyed the Spanish fleet, as promised, or telephoned across the ocean, or lighted houses without wires, or entered into communication with the planet Mars?

"It is a perfect wonder that the American public, with its quick sense of humor, has not long ago shamed these two cheeky pretenders into silence."

The American technical weekly, *Electricity*, which quotes the above interview, has the following to say regarding it:

"Assuming that the above is a correct report of the interview, we think the head of the Creusot Iron Works has committed a grievous error in referring in the way he did to two such men as Edison and Tesla.

"That Edison is not a scientist every one will agree, but, on the other hand, he has given to the world invention after invention of untold value, the Frenchman's statement to the contrary notwithstanding. He did more toward perfecting incandescent electric lighting than any other investigator, invented the phonograph and gave to the world the quadruplex system of telegraphy, to say nothing of the three-wire system, the low-resistance dynamo, and innumerable other devices which have benefited the world to a greater or less extent.

"As regards Nikola Tesla, the gentleman quoted states that he is no scientist. In this we beg to differ with him, for altho it must be acknowledged that Tesla has only given the world one important invention, he is such a deep scientist and looks so far into the future that he is a century before his time. In other words, some of Tesla's ideas, which are considered by the general public as visionary dreams, will be actual facts a hundred years hence. When, therefore, a foreigner undertakes to belittle in the language quoted above two such well-known investigators and inventors as Edison and Tesla, it may safely be attributed to a feeling of envy on his part."

SYNTONIC WIRELESS TELEGRAPHY.*

BY GUGLIELMO MARCONI.

The very rapid advances which have been made in the art of telegraphy through space continue to attract much attention to this fascinating subject. What was stated yesterday to be impossible has now become possible, and what we regard as almost insurmountable difficulties may be removed in the immediate future. The number of experimenters working in this field has increased, as, many workers, who, some time ago, had little or no faith in the practical utility of wireless telegraphy, have now changed their minds and are taking up the subject. I believe it to be necessary, before I proceed to deal with the subject, to state that in my opinion a large amount of inaccurate and misleading information is being from time to time published upon it in the daily and even in the scientific press. I shall endeavour to correct some of the mis-statements which have been made.

As the title of my Paper implies, it is my intention first to describe fully the efforts I have made in order to tune or syntonise the wireless system, efforts which I am glad to say have been crowned with complete success. I also wish to mention something of the difficulties encountered in promptly publishing the results (whether successful or otherwise) obtained in the course of my experiments. A commercial concern, such as the one with which I am working, does not exist solely for the advancement of science, but especially for the purpose of securing a pecuniary return to those who have braved risks and undertaken sacrifices in assisting and forwarding the necessary experimental work. It is often considered possible that certain new methods and results may, if prematurely published before being fully patented, be utilised by persons whom I might call business rivals, thus preventing those who have borne the initial cost of the first tests from benefiting in a fair measure. I am, therefore, frequently prevented from promptly publishing the methods by which I have obtained interesting results. By quoting the dates of the British patent specifications and other publications, I hope to be able to establish, to a certain extent, the dates at which the various systems or methods were worked out. It may probably surprise some of you when I mention how comparatively long ago some of the patents which I shall discuss to-night were applied for and perfected.

Last winter I had the honour of describing before the Royal Institution of Great Britain most of the success obtained up to that date in communicating by means of my system from one place to another. It is my desire in this Paper to give a description of the further progress made, with special reference to the results obtained by tuning or syntonising the installations. So long as it was possible to work only two installations within what I may call their sphere of influence, a very important limit to the practical utilisation of the system was imposed. With simple vertical wires, as shown in Fig. 1A and Fig. 2, connected directly to the coherer and spark gap at the receiver and transmitter, as used by myself before 1898, no really satisfactory tuning was possible. It was, however, possible to obtain a certain selection of signals if various stations in the vicinity used vertical wires differing very considerably in length. Thus two stations communicating over a distance of, say, 5 miles and using wires 100ft. long, would not interfere with the signals transmitted by the other two stations, say 2 miles from the first, which were using aerials only 20ft. long, and communicating over a distance of about 1 mile. The new methods of connection which I adopted in 1898, *i.e.* (see Fig. 8), connecting the receiving aerial directly to earth instead of to the coherer, and by the introduction of a proper form of oscillation transformer in conjunction with a condenser so as to form a resonator tuned to respond best to waves given out by a given length of aerial wire, were important steps in the right direction. I referred extensively to this improvement in the discourse delivered before the Royal Institution on Feb. 2, 1900, and my first British patent specification referring thereto was applied for on June 1, 1898, No. 12,326, and published in due course. This mode of connection was also discussed by the technical press.*

It is remarkable that eminent scientists and engineers, such as Prof Slaby and G. Kapp, who have been good enough to discuss my work on wireless telegraphy, should be so badly informed on the subject in general as not to know that this method and many other improvements on my original system have been in use by myself and my assistants for several years. I wish to give you an illustration of what I mean. In a Paper on "Tuned or Multiple Wireless Telegraphy," by Prof. Slaby, of Charlottenburg, read on Dec. 22, 1900, and published in a special number of the *Elektrotechnische Zeitschrift*, he stated: "Up to the present the following method has been followed without exception:—The receiving wire was *suspended insulated and attached at the lower end to the coherer*, the other pole of which was connected to earth."

Again, G. Kapp, in an editorial review in the same publication, states:—"According to the Slaby d'Arco system and *in opposition to the Marconi system the receiving wire is earthed.*" The inaccuracy of these statements is very apparent if we compare them with the description given by myself nearly three years previously in the British patent applied for, as I have remarked, on June 1, 1898, published in July, 1899, and openly discussed by the scientific press of this and other countries a long time previous to the date of Slaby's Paper. At line 7, page 1, of my description, will be found the following passage: "According to this invention the conductor (aerial) *is no longer insulated, but is connected to earth* through the primary of an induction coil, whilst the ends of the imperfect contact (or coherer) are connected to the ends of the secondary one of the connections passing through a condenser." As you will notice, nothing is said in this patent of the necessity of insulating the vertical wire of the receiver. If the system described here had not been used by me I very much doubt whether we should have succeeded in maintaining communication with the East Goodwin lightship during 1899, in maintaining communication across the English Channel that same year during the meeting of the British Association at Dover, and in supplying the Admiralty in the course of the year 1900 with 32 installations, all of which passed an official 100 kilometre test (most of the distance being over land) at the rate of about three installations per week.

Leaving this subject for the present, I shall endeavour to describe the various steps made in the development of my syntonic system. I realised a long time ago that one great difficulty in achieving the desired effect was caused by the action of the transmitting wire. A simple straight rod in which electrical oscillations are set up forms, as is well known, a very good radiator of electrical waves. If this was in the beginning an advantage, by allowing signals to be received with a small amount of energy over considerable distances, it proved later to be one of the chief obstacles in the way of obtaining good resonance in the receiver. Now, as Dr. Fleming points out so clearly in his Cantor lectures on "Electrical Oscillations and Electric Waves," delivered before this Society in November and December of last year, there is in connection with this part of the subject one point of great interest. "Both theoretical and experimental research show that in the case of conductors of a certain form the electric oscillations die away with great rapidity." In all what we call good radiators, electrical oscillations set up by the ordinary spark discharge method cease, or are damped out very rapidly, not necessarily by resistance, but by electrical radiation removing the energy in the form of electric waves. Many mechanical analogies can be quoted which will point out the necessity of designing a persistent oscillator, in order that syntony may become apparent in properly tuned resonators. Acoustics furnish us with numerous examples of this fact, such as the resonance effects produced by the well-known tuning-fork experiment. Other illustrations of this principle may be given, *e.g.*, if we have to set in motion a heavy pendulum by means of small thrusts or impulses, these must be timed to the period of oscillation of the pendulum, since otherwise its oscillations will not acquire any perceptible amplitude. An illustration of this fact occurred to me some time ago while I was watching the ringing of

* Paper read before the Society of Arts, May 15.

* See *The Electrician*, Vol. XLIII., p. 48; also Vol. XLIV., pp. 555–556.

great bells in an Italian cathedral. As most of you probably know, the bells in many churches in Italy, as elsewhere, are rung from the bottom of the tower by means of ropes attached to the bells. The largest bells weigh several tons, and it usually requires two men to work for perhaps two minutes on the ropes before the combined effect of their pulls is sufficient to get the bell to attain an amplitude large enough to cause the hammers to strike. I observed on the occasion to which I allude that it required for each bell a number of well-timed pulls on the ropes in order to get them to swing, the larger bells requiring impulses further apart, *i.e.*, of a lower frequency, than the smaller ones. It is perfectly obvious that if the pulls on the ropes had been wrongly timed it would have been impossible with the same amount of power to ring the bells. The same kind of effect happens in a very small fraction of a second (instead of several minutes) when we try to induce electrical oscillations in a good resonator. If the form of this resonator be such as to cause it to be a persistent vibrator, *i.e.*, one in which the electrical oscillations are not rapidly damped by resistance or radiation of waves, then it is necessary for us to employ a number of properly timed electrical oscillations radiated from a persistent oscillator tuned to the period of the resonator we desire to affect.

As I pointed out before, a transmitter consisting of a vertical conductor as shown in Fig. 1 is not a very persistent oscillator.. Its electrical capacity is comparatively so small and its capability of radiating waves so great, that the oscillations which take place in it must be considerably damped. In this case receivers or resonators of a considerably different period or pitch will respond and be affected by it. From the results obtained it would seem as if the transmitter were sending out a great variety of electric waves, resembling therefore a source of white light, and that each resonator picks out and responds to its own particular wave length. This view, however, is incorrect ; the fact that, given certain conditions,

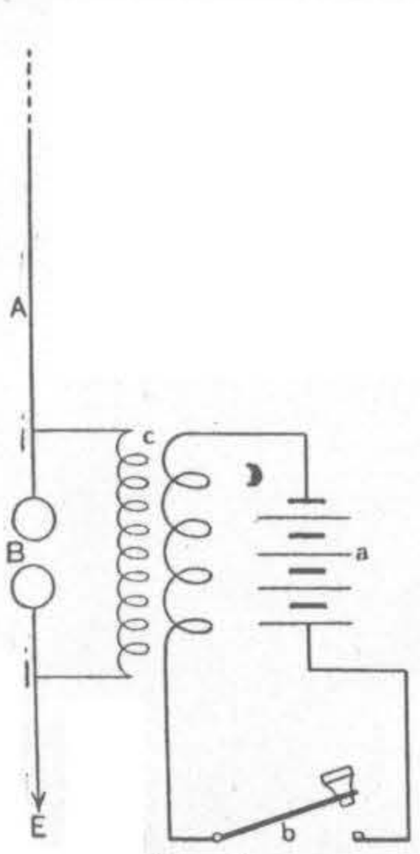


FIG. 1.

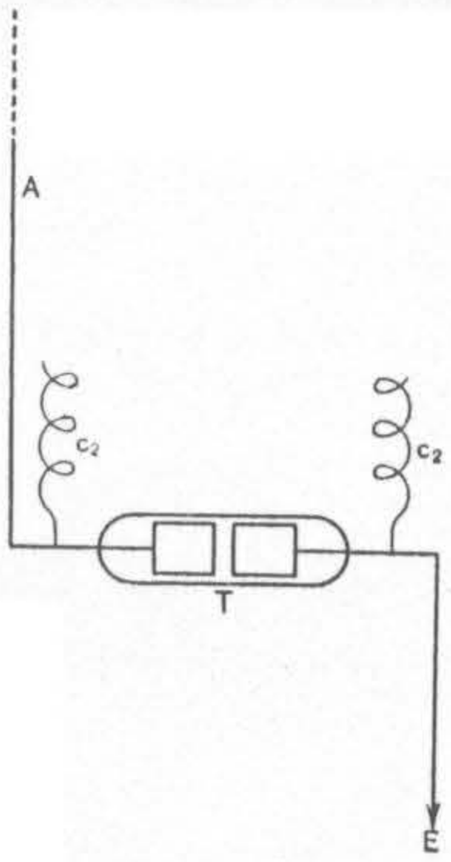


FIG. 2.

various resonators will respond, even if their period be different from the natural period of oscillation of a transmitter, is to be accounted for by the consideration that all the energy of the transmitter is radiated in only one or two swings, with the result that oscillations may be induced in resonators of different periods, whilst, if the same amount of energy be distributed in a great number of individual feeble impulses, their combined effect can only be utilised or detected by a resonator tuned so as to respond to their particular frequency. The tuned resonator will not then respond to the first two or three oscillations but only to a longer succession of properly timed impulses, so that only after an accumulation of several swings does the E.M.F. becomes sufficient to break down the insulation of the coherer, and cause a signal to be recorded.

Notwithstanding the disadvantages for obtaining electrical tuning, attributed to the form of transmitter shown in Fig. 1, selection of messages is possible when using, say, two or three transmitters having wires of considerably different lengths, and the induction coil or oscillation transformers on the receivers wound with varying lengths of wire in their secondary circuits, in order to cause them to be in tune or resonance with the length of wave of the transmitted oscillations, as pointed out in my British patent, No. 12,326, dated June 1, 1898. At page 1, line 19, this reads : "It is desirable that the induction coil should be in tune or syntony with the electrical oscillations transmitted, the most appropriate number of turns and most appropriate thickness of wire varying with the length of wave transmitted." The following experiment, which has been successfully tried, proves this point. At St. Catherine's, Isle of Wight, we had a transmitting station having a vertical wire 45 metres long, and at sea, 10 miles from our receiving station at Poole, a ship with transmitting wire of 27 metres. It is, therefore, obvious that the wave length of the electric oscillations radiated from St. Catherine's differed considerably from that radiated from the ship. Now, if at the receiving station at Poole we connected to a vertical wire two receivers, one having an induction coil with secondary in tune with the length of wave emitted by St. Catherine's and the other with that emitted by the 27-metre feet wire on the ship, if St. Catherine's and the ship transmit simultaneously two different messages, these will be picked up at Poole, and each message will be reproduced distinctly on its receiver. I pointed out in a patent specification dated Dec. 19, 1899, No. 25,185, page 2, that the best results are obtained when the length of wire of the secondary of the induction coils is equal to the length of the vertical wire used at the transmitting station, therefore the length of the secondary of the receiving induction coils was made equal to that of the transmitting wire. (Something of the same kind has been lately noticed by Prof. Slaby in what he calls an extension wire.)

These results, although in a way satisfactory, did not appear to my mind a complete solution of the problem. I found it impossible to obtain the two messages at the receiving station if the two transmitting stations were placed at equal distances from it. The following considerations may perhaps explain this failure. If the 27-metre transmitting wire was placed at the same distance from Poole as the 45-metre one, *i.e.*, 31 miles, the waves emitted by the 27-metre wire would be too weak when they reached Poole to affect the receiver. On the other hand, if the 45-metre transmitter was placed at 10 miles from the receiver, then the waves radiated by it would be so strong as to affect the receiver, tuned to respond to the 27-metre transmitter, and blur its signals.

It thus became apparent that some different form of less damped radiator was necessary in order to obtain more practical and more useful results. I carried out a great number of experiments by adding

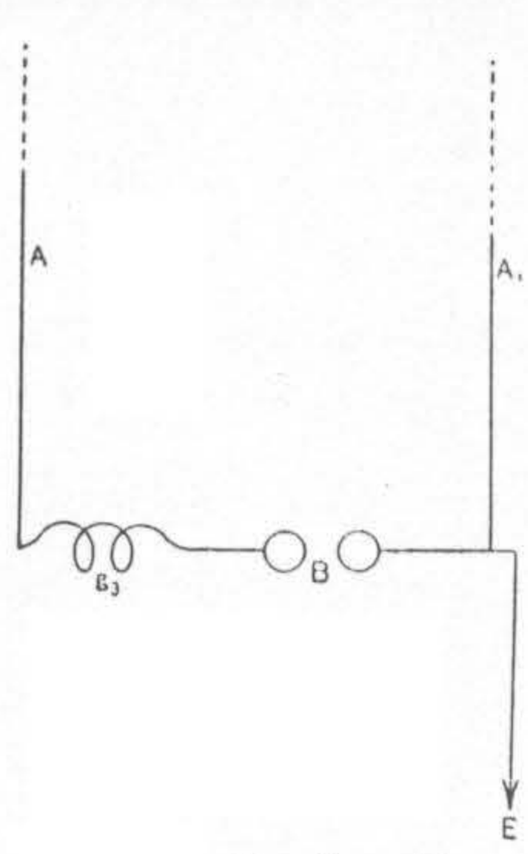


FIG. 3.

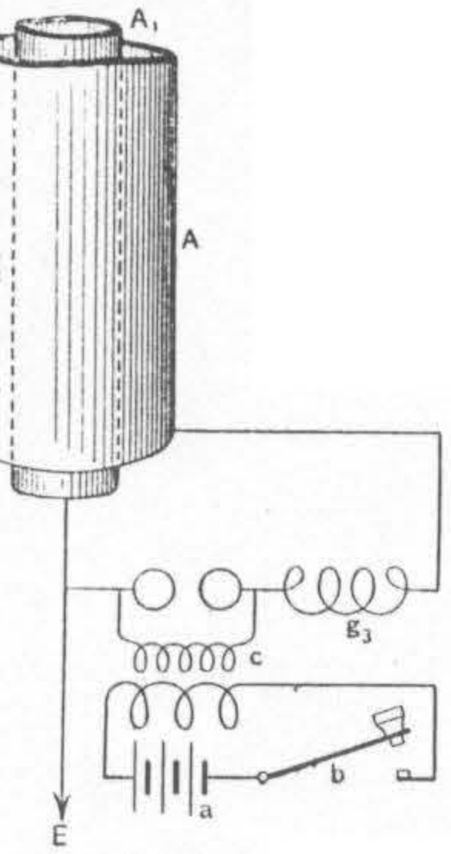


FIG. 4.

to the radiating and receiving wires inductance coils, on a principle similar to that suggested by Lodge in his 1898 patent (No. 29,069), but without obtaining any satisfactory results. The failure was probably due to the fact that the electrical capacity of the exposed conductors became too small in proportion to their inductance. I then tried various methods for increasing the capacity of the radiating system. The first and obvious mode of effecting this is by an augmentation in the size of the exposed conductor, but this method is not entirely satisfactory, in consequence of the circumstance that an increased surface means increased facility for radiating the energy during the first oscillations, and also because large plates or large exposed areas are impracticable on board ship, and are always difficult to suspend and maintain in good position during windy weather. The way out of the difficulty was discovered by adopting the arrangement shown in Fig. 3. Here we have an ordinary vertical radiator placed near an earthed conductor, the effect of the adjacent conductor being obviously to increase the capacity of the electrical radiating wire without in any way increasing its radiative power, and, as I had expected, syntonic results were not difficult to obtain with such an arrangement. Mention of this method has been made by Capt. Ferrie, one of the members of the French Commission which was present at the tests carried out across the English Channel in 1899, in a Paper on wireless telegraphy. See Paper "Etat Actuel et Progrès de la Telegraphie Sans Fil," read before the Congrès International d'Electricité, Paris, 1900.* Satisfactory results were obtained, and I was encouraged to continue my researches in order to improve the system. Early in 1900 I obtained very good

* See *The Electrician*, Oct. 26. 1900, p. 22 ("Electrician" Publishing Co.).

results with the arrangement shown in Fig. 4. This arrangement is fully described in a British patent application applied for by myself on March 21, 1900, No. 5,387. In it the radiating and resonating conductors take the form of a cylinder, the earthed conductor being placed inside. This form of radiating and receiving areas is much more efficient than the one I have previously described. One necessary condition of this system is that the inductance of the two conductors should be unequal, it being preferable that the large inductance should be joined to the non-earthed conductor. I presume that, in order to radiate the necessary amount of energy, it is essential that there should be a difference in phase of the oscillations in the two conductors, as otherwise their mutual effect would be to neutralise that of each other. In the first experiments mentioned by Capt. Ferrie this was obtained by simply using an earthed conductor shorter than the radiating or resonating one. When I used an inductance between the spark-gap or oscillation producer and the radiating conductor, I found it possible to cause the electrical period of oscillation of the receiving cylinder to correspond to that of one out of several transmitting stations, from which one alone it would receive signals. The results obtained by this system have been remarkable. By using cylinders of zinc only 7 metres high and 1·5 metres in diameter, good signals could easily be obtained between St. Catherine's, Isle of Wight, and Poole (distance 31 miles), these signals not being interfered with or read by other wireless telegraph installations worked by my assistants or by the Admiralty in the immediate vicinity. The closely adjacent plates and large capacity of the receiver cause it to be a resonator possessing a very decided period of its own, *i.e.*, it becomes no longer apt to respond to frequencies which differ from its own particular period of electrical oscillation, nor to be interfered with by stray ether waves, which are sometimes probably caused by atmospheric disturbances, and which occasionally prove troublesome during the summer. It seemed very remarkable to me during my first

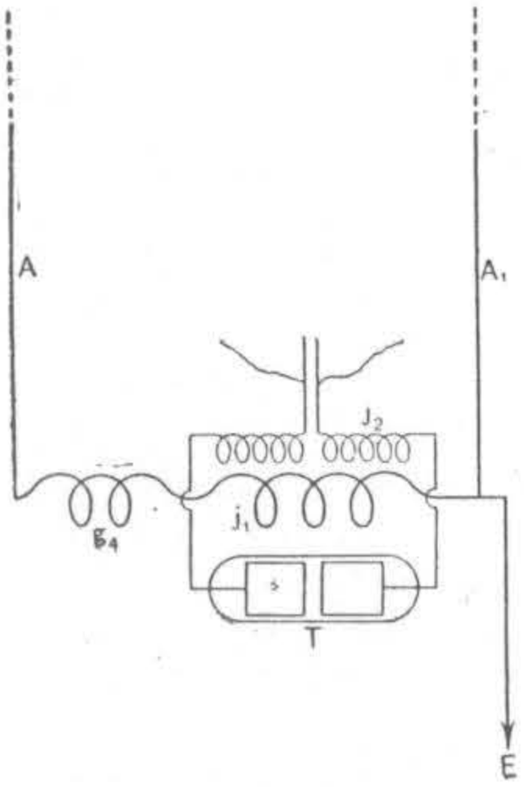


FIG. 5.

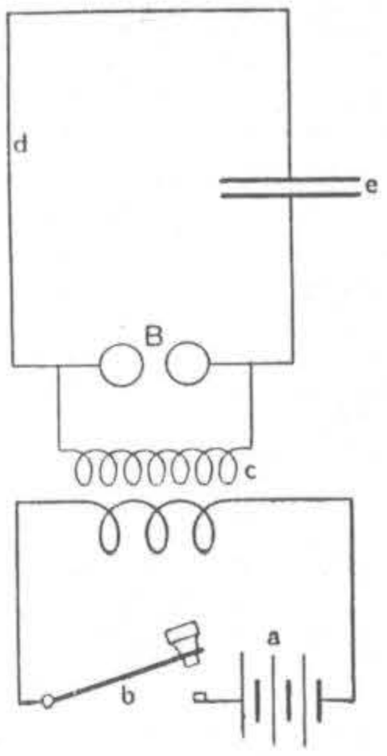


FIG. 6.

test that an arrangement similar to that shown in Fig. 4 should prove to be a good radiator and should enable such a considerable distance to be achieved with cylinders of so moderate a height. It is probable that the great majority of the electrostatic lines of force pass directly from one cylinder to the other, but it must be also true that a certain number leave the outer part of the external cylinder, exactly as in the case of an ordinary radiator. The receiver is not shown in the sketch, but consists of similar cylinders to those used for transmitting the receiving induction coil or oscillation transformer, being placed where the spark-gap is shown in Fig. 4. The capacity of the radiator due to the internal conductor is, however, comparatively so large that the energy set in motion by the spark discharge cannot all radiate in one or two oscillations, but forms a train of slowly damped oscillations, which is just what is required. A simple vertical wire, as shown in Fig. 1, may be compared with a hollow sphere of thin metal which, when heated, would cool very rapidly, and the concentric cylinder system with a solid metal sphere, which would take a very much longer time to cool. Mr. W. G. Brown suggested, in a patent specification dated July 13, 1899, No. 14,449, the use of two conductors of equal length joined to each side of the spark-gap, but he did not describe the inductance in series between them and the spark-gap, which, according to my experience, is absolutely essential for long-distance work. Another very successful syntonised transmitter and receiver system was the outcome of a series of experiments carried out with the discharge of Leyden jar circuits. Taking for granted that the chief difficulty with the old system, as shown in Fig. 1, lies in the fact, as already stated, that the oscillations are very dead beat, I tried by means of associating with the radiator wire a condenser circuit, which was known to be a persistent oscillator, to set up a series of persistent oscillations in the transmitting vertical wire.

An arrangement as shown in Fig. 6, which consists in a circuit containing a condenser and a spark-gap, constitutes a very persistent oscillator. Prof. Lodge has shown us how, by placing it near another similar circuit, it is possible to demonstrate interesting effects of resonance by the experiment usually referred to as that of Lodge's syntonic jars. But, as Lodge points out,* "A closed circuit such as this, is a feeble radiator and a feeble absorber, so that it is not adopted for action at a distance." I very much doubt if it would be possible to affect an ordinary receiver at even a few hundred yards. It is very interesting to notice how easy it is to cause the energy contained in the circuits of this arrangement to radiate into space. It is sufficient to place near one of its sides a straight metal rod or good electrical radiator. The only other condition necessary for long-distance transmission is that the period of oscillation of the wire or rod should be equal to that of the nearly closed circuit.

Stronger effects of radiation are obtained if the radiating conductor is partly bent round the circuit, including the condenser (so as to resemble the circuits of a transformer). I first constructed an arrangement as shown in Fig. 14, which consists of a Leyden jar or condenser circuit, in which is included the primary of what may be called a Tesla coil, the secondary of which is connected to the earth or aerial conductor. The idea of using a Tesla coil to produce the oscillations is not new. It was tried by the Post Office officials when experimenting with my system in 1898, and also suggested in a patent specification by Dr. Lodge, dated May 10, 1897, No. 11,575, and by Prof. Braun in the specification of a patent dated Jan. 26, 1899, No. 1,862. My idea was to associate with this compound radiator a receiver tuned to the frequency of the oscillations set up in the vertical wire by the condenser circuit. My first trials were not successful, in consequence of the fact that I had not recognised the necessity of attempting to tune to the same period of

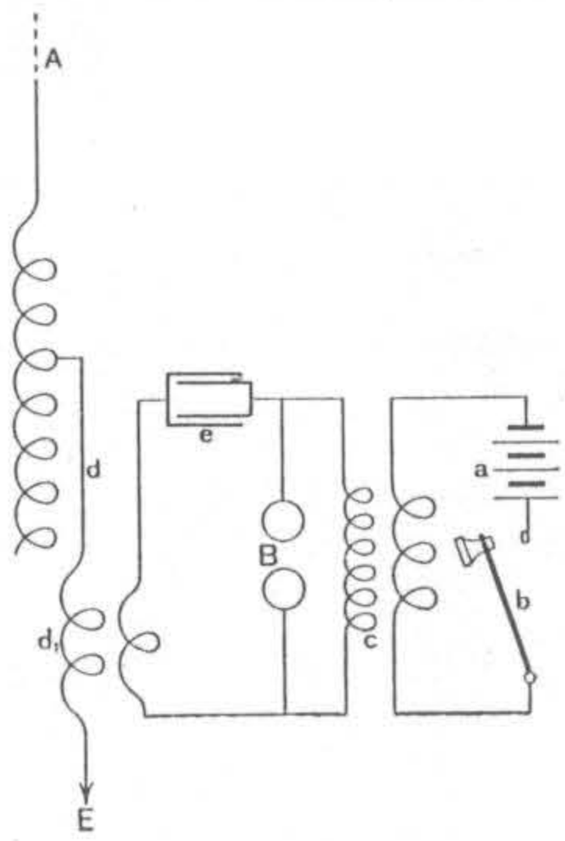


FIG. 7.

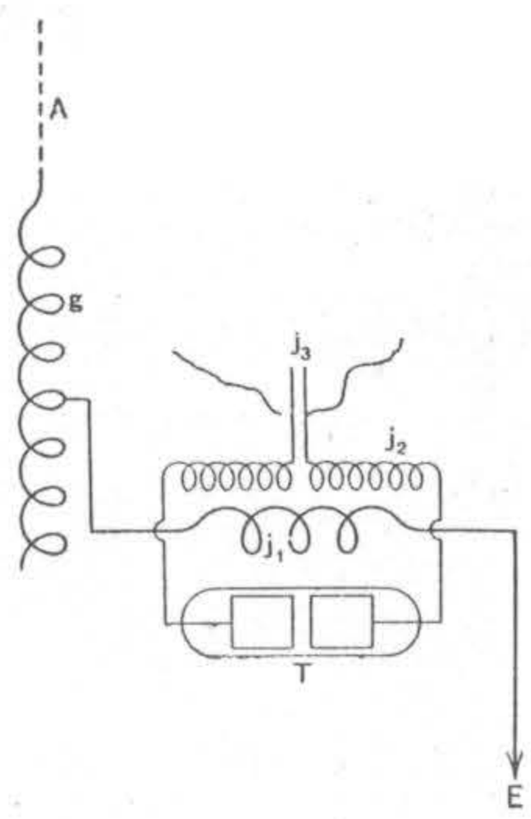


FIG. 8.

oscillation (or octaves) the two electrical circuits of the transmitting arrangement (these circuits being the circuit consisting of the condenser and primary of the Tesla coil or transformer, and the aerial conductor and secondary of the transformer). Unless this condition is fulfilled, the different periods of the two conductors create oscillations of a different frequency and phase in each circuit, with the result that the effects obtained are feeble and unsatisfactory on a tuned receiver. The syntonised transmitter is shown in Fig. 7. The period of oscillation of the vertical conductor A can be increased by introducing turns, or decreased by diminishing their number, or by introducing a condenser in the series with it. The condenser C in the primary circuit is constructed in such a manner as to render it possible to vary its electrical capacity. The receiving station arrangements are shown in Figs. 8 and 9. Here we have a vertical conductor connected to earth through the primary of a transformer, the secondary circuit of which is joined to the coherer or detector. In order to make the tuning more marked, I place an adjustable condenser across the coherer in Fig. 9. Now, in order to obtain the best results, it is necessary that the free period of electrical oscillations of the vertical wire primary of transformer and earth connection should be in electrical resonance with the second circuit of the transformer, which includes the condenser. I stated that, in order to make the tuning more marked, I placed a condenser across the coherer. This condenser increases the capacity of the secondary resonating circuit of the transformer, and in the case of a large series of comparatively feeble but properly timed electrical oscillations being received, the effect of the same is summed up until the E.M.F

* "The Work of Hertz," by O. J. Lodge, page 7.

at the terminals of the coherer is sufficient to break down its insulation and cause a signal to be recorded.

In order that the two systems, transmitter and receiver, should be in tune, it is necessary (if we assume the resistance to be very small or negligible) that the product of the capacity and inductance in all four circuits should be equal. A more complete and detailed description of this system is given in a British patent granted to me, dated April 26, 1900, No. 7,777. I have recently found that Prof.

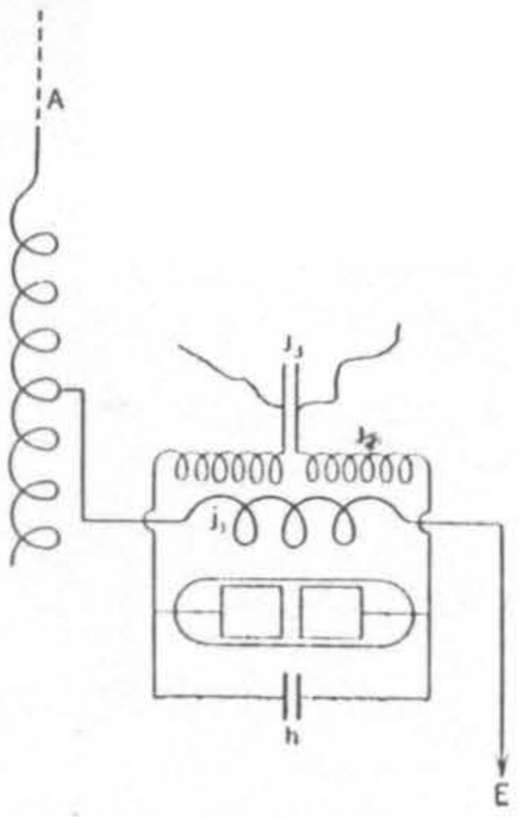


FIG. 9.

Braun has recognised the necessity of tuning the circuits of the transmitter and receiver when using a Tesla coil in order to obtain syntonic effects, but I am not aware that such a proposal was published prior to the description given in the above-mentioned patent.

Although little difficulty has been encountered in measuring the capacity used in the various circuits, the measurement or calculation of the value of the inductance is not so easy. I have found it impracticable by any of the methods with which I am acquainted

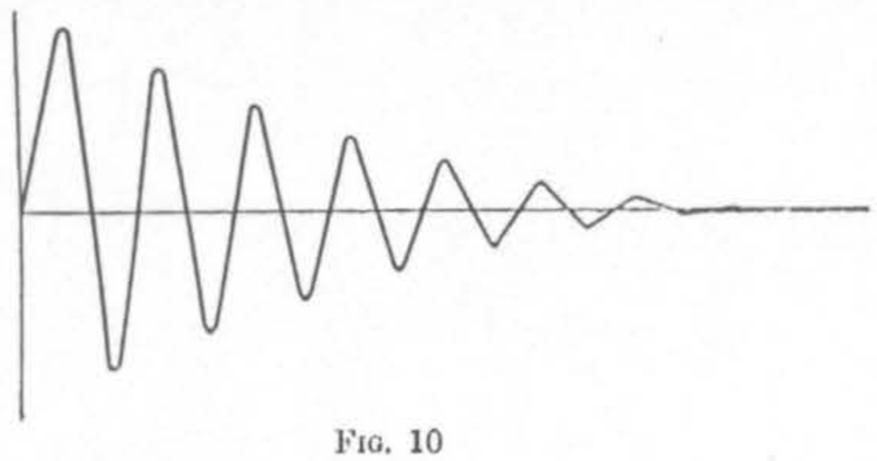


FIG. 10

directly to measure the inductance of, say, two or three small turns of wire. As for calculating the inductance of the secondary of small transformers, the mutual effect of the vicinity of the other circuits and the effects due to mutual induction greatly complicate the problem.

Experiments have confirmed the fact that the receiving induction coils having the secondary wound in one layer and at a certain distance, say 2mm. (to cause the capacity to be so small as to be negligible), have a time period approximately equal to that of a vertical conductor of equal length

FIG. 11.

(see patent granted to G. Marconi, dated Dec. 19, 1899, No. 25,186). If, therefore, we are using an induction coil having a secondary 40 metres long on the receiver, I should use a vertical wire 40 metres long at both transmitting and receiving stations. By so doing I have the two circuits at the receiving station in tune with each other, and I only have to adjust the capacity of the condenser at the transmitter, which can easily be done, either by means of a condenser having movable plates that can be slid, more or less, over each other, or by adding or removing Leyden jars.

If we start with a very small capacity which we gradually increase, a value of the capacity will be reached which will cause signals to be recorded on the receiver. Supposing the receiving system to be within the sphere of action of the transmitter, then the signals will be strongest when the capacity of the condenser is of a

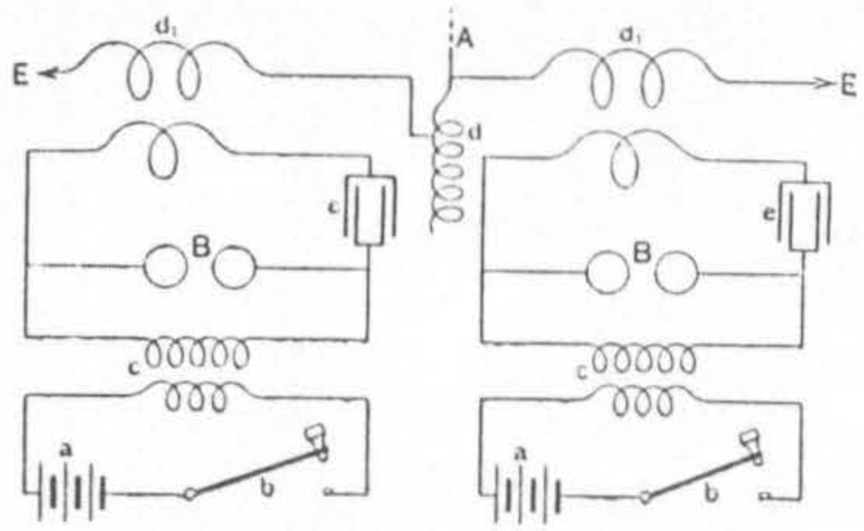


FIG. 12.

certain value. If we still increase the capacity, the signals will gradually die away, whilst if we go on increasing the capacity, and, at the same time, add inductance to the aerial, to keep it in tune with the condenser jar circuit, we are still radiating waves, but these do not affect the receiver. If, however, at the receiving station we

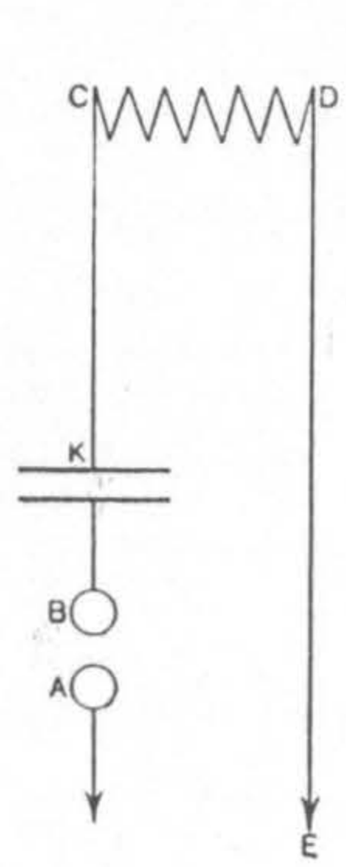


FIG. 13.

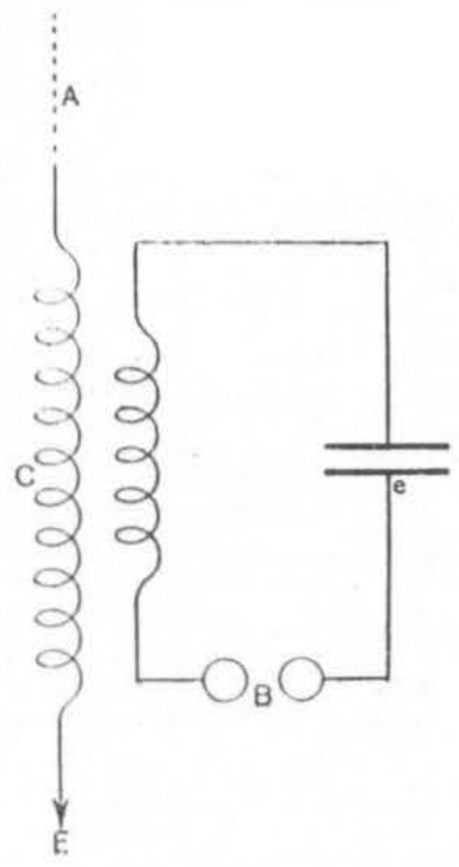


FIG. 14.

add inductance or capacity to the wire A, Fig. 9, and also to the ends of the secondary of J 2, we find ourselves able to receive messages from the transmitter although we are utilising waves of a different frequency.

(To be concluded.)

SYNTONIC WIRELESS TELEGRAPHY.*

BY GUGLIELMO MARCONI.

(*Concluded from page 175.*)

It is easy to understand that if we have several receiving stations, each tuned to a different period of electrical vibration, and of which the corresponding inductance and capacity at the transmitting station are known, it will not be difficult to transmit to any one of them without danger of the message being picked up by the other stations for which it is not intended. But, better than this, we can connect to the same vertical sending wire, through connections of different inductance, several differently tuned transmitters, and to the receiving vertical wire a number of corresponding receivers. Different messages can be sent by each transmitter connected to the same radiating wire simultaneously, and received equally simultaneously by the vertical wire connected to differently tuned receivers. This result, which I believe to be quite novel, I showed to several friends of mine, including Dr. Fleming, F.R.S., in the summer of last year, and to an Admiralty Commission. Dr. Fleming has made mention of the results I showed him, in a letter to *The Times*, dated Oct. 4, 1900, and in his Cantor lectures delivered before the Society of Arts in November and December, 1900. A further improvement has been obtained by the combination of the two systems. In this case the cylinders are connected to the secondary of the transmitting transformer, and the receiver to a properly tuned induction coil, and all circuits must be tuned to the same period as already described. (See Fig. 16.)

The tuning of the receiver to respond to the period of the transmitter, as used in the old form of transmitter shown in Fig. 1, or in the new one shown in Fig. 7, has enabled results to be obtained over considerable distances with moderate heights. As already published by Dr. Fleming in the letter above referred to, signalling has been successfully carried out over a distance of 50km. with a cylinder only 1·25 metres high, 40in. in diameter. This has led to the possibility of constructing portable apparatus for army purposes which should be of great service in the field. I have succeeded in constructing a complete installation on a steam motor car. On the roof of the car there is placed a cylinder which can be lowered when travelling, its height being only 6 or 7 metres, and by this means communication has been easily carried out with a syntonised station over a distance of 31 miles. A 25cm. spark induction coil worked by accumulators and taking about 100 watts is used for transmitting, and the accumulators can be re-charged by a small dynamo worked by the car motor. I believe such an appliance might have been of use to the besieged garrisons in South Africa and China. A strip of wire netting laid on the ground is sufficient for earth connection, and by dragging it along communication can be established even when the car is travelling. I have recently obtained as good results by not using any "connection" to earth, but only utilising in lieu of earth the electrical capacity of the boiler of the motor car. I also find that signals can be transmitted a considerable distance with the cylinder in a horizontal position.

Last spring I recognised the desirability of carrying out tests between stations situated at much greater distances apart than had been attempted heretofore.† A station was established at the Lizard, Cornwall, and on the first attempt communication was effected with St. Catherine's, Isle of Wight, over a distance of 186 miles, which, I believe, is the record distance over which signals have been sent through space without wires. It is interesting to observe that signals were obtained over this distance with the transmitting apparatus as shown in Fig. 1, or with the arrangement shown in Fig. 7, provided always that a suitable resonating induction coil was employed at the receiving station. The amount of energy used for signalling over this distance is not more than 150 watts, but experiments with a larger amount of energy will shortly be carried out. In the case of the 186 miles transmission, the aerial conductor consisted of four parallel vertical wires 1·50 metres apart, 48 metres long, or in a strip of wire netting of same length. It is interesting to note that in order to communicate between my stations at Poole and St. Catherine's (distance 31 miles) with the same amount of energy and the same kind of aerial wire this must be 20 metres high to obtain signals of about the same strength as those obtained between the 186-mile stations with the 48-metre aerials. This goes to confirm many other results previously obtained, which indicate that with a parity of other conditions the distance varies with the square of the height of the vertical conductors at the two stations. I have always found this law fulfilled, if the height of the conductors at the two stations is approximately equal, although an attempt has been made recently to throw doubt upon its correctness.

You will admit that the progress achieved in syntonic space telegraphy must have enormously increased its field of application and usefulness, since a very great number of non-interfering stations can now be worked in the immediate vicinity of each other. It will probably be of interest if I give you a few examples of the progress made in the practical utilisation of my system. An eminent electrician recently expressed a doubt whether there was at present a single circuit worked commercially on a practical system of wireless telegraphy.* If earning a revenue from working installations can be termed a commercial working, even such an incomplete list of these as time will now permit me to give you, and which are now all in permanent working order, may be sufficient proof that a beginning at least has been made in the commercial utilisation of the system.

In March, 1900, there were in use in the Royal Navy in South African waters, five installations of my system. The Admiralty was apparently well satisfied with its working, since in May of last year they decided to extend its adoption to 32 more ships and land stations. The conditions of the contract were that each apparatus before being accepted should be satisfactorily worked by naval signalmen between two ships anchored at Portsmouth and Portland, over a distance of 62 miles, a considerable portion of which—*i.e.*, 18 miles—lies over land, with intervening hills, and the height of aerial wire was specified not to exceed on each ship 49 metres. The apparatus was delivered in a comparatively short time, no sets having been found unsatisfactory. The apparatus supplied to the Admiralty is, so far, all of the old pattern—*i.e.*, the non-syntonised system; and I have been informed that messages have been transmitted and received by naval signalmen between ships more than 160km. apart. It sometimes occurs that the unfamiliarity of the operators with the particular kind of apparatus used caused unsatisfactory results to be obtained, but I believe this trouble will soon disappear. I am glad to be able to state that arrangements are being made to instal my new syntonic apparatus upon several of His Majesty's ships. I believe that in no other navy in the world is wireless telegraphy being worked regularly over such considerable distances. My system is also used for communication between the Borkum riff and Borkum lightship in Germany, where an ordinary commercial charge is made for messages received from ships, and it is employed, further, on the Nord Deutscher Lloyd's mail steamer "Kaiser Wilhelm der Grosse."

According to an official report of the imperial postal authorities of Oldenburg, the total number of commercial wireless telegrams transmitted from and to the lightship between May 15 and the end of October amounted to 565, and of these 518 came from ships at sea, whilst 47 were transmitted to ships. Of the 518 telegrams, 35·7 per cent. were addressed to the North German Lloyd and 64·3 per cent. to other shipping firms. The installations are worked by ordinary operators in a most satisfactory manner, and on one occasion, assistance was obtained for a man who was taken suddenly ill on the Borkum riff, and it was thus made possible to hand him over promptly for medical treatment on shore.

The system has been in operation at La Panne, near Ostend, and on the Belgian mail steamer, "Princess Clémentine," which plies to Dover. With a height of only 22 metres on the ship it has been found practicable to communicate from Dover Harbour to La Panne, 43 miles away, and this installation has proved of value in saving life and property. Thus, recently, a barque was wrecked on the Rattel bank. The "Princess Clémentine," which happened to pass near, at once sent a message to Ostend, and, before leaving, was able to tell the shipwrecked sailors that assistance was on the way. The men were all saved.† On another day, coming within sighting distance of the Ruytingen lightship, situated about 15½ miles from Dunkirk, the captain of the "Princess Clémentine"

* Paper read before the Society of Arts, May 15.

† See *The Electrician*, Feb. 15, 1901, p. 609.

* See *The Electrician*, Nov. 30, 1900, page 211, and editorial article, page 205.

† See *The Electrician*, March 15, 1901, p. 267.

observed that he was being signalled. It appears that the lighting apparatus of the Ruytingen had got out of order. The captain of the mail packet immediately despatched a message, which was received by the installation at La Panne, and repeated to the lighthouse department at Dunkirk. A crew immediately set out for the lightship and effected the necessary repairs, and the great inconvenience and danger of the lightship not being able to have the lights in order was averted.

Another instance of the usefulness of the wireless telegraphy in an emergency was furnished when the "Princess Clémentine" herself went ashore on the Belgian coast during a fog. Within a few minutes of the accident news of it was telegraphed from the stranded ship to Ostend, with the result that a tug was at once despatched to her assistance, and she got off at the next high tide. So successful has the installation of wireless telegraphy been on the

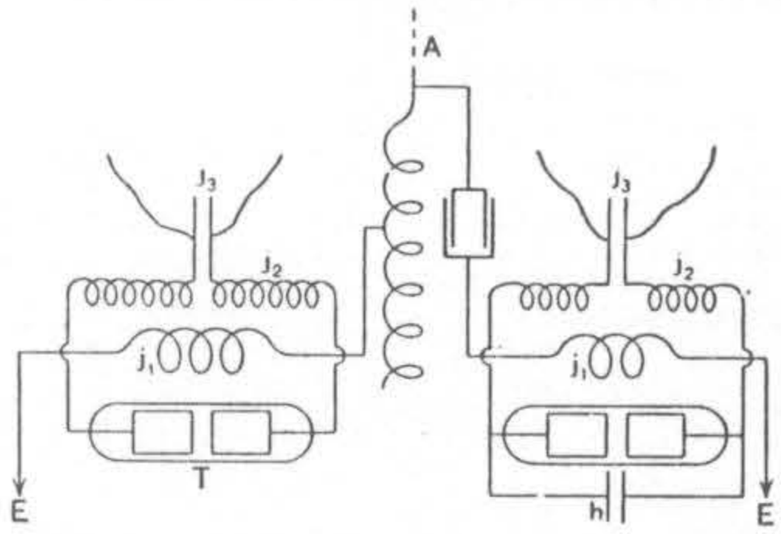


FIG. 15.

mail steamer "Princess Clémentine," between Dover and Ostend, that similar apparatus is to be fitted on the other vessels of the same fleet.

The system has been in use, furthermore, since March 1 last for ordinary commercial telegraphy between the Sandwich Islands, where a regular charge is made for the same. An installation has also been successfully carried out by my assistants for the French Government between Antibes, in France, and Corsica, a distance of 124 miles.

As has already been published in the daily papers, much use has been made of my system in the Navy during the voyage of the Duke and Duchess of Cornwall and York to Australia.

I have tried lately to ascertain how near a tuned transmitter which is radiating waves of a certain frequency must be to a receiver

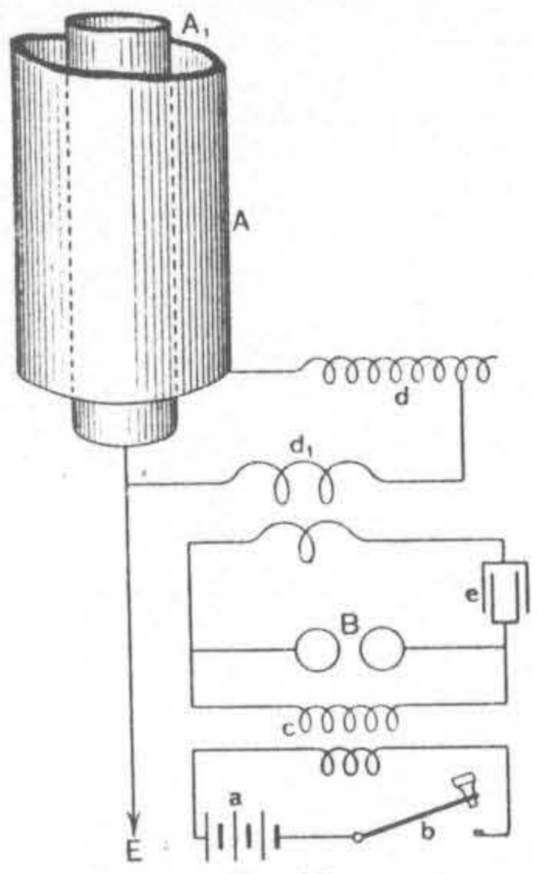


FIG. 16.

tuned to a different frequency in order that the said receiver shall be affected. I find that if we are working with oscillations which differ very considerably in period, a transmitter capable of sending signals 31 miles to a tuned receiver will not affect a non-tuned one at 50 metres. If the periods of oscillation of the two tunes are more similar to each other, then the non-tuned receiver may be affected even at several kilometres.

Considerable use is still made of the non-tuned system at my experimental stations, in order to be able to communicate with ships fitted with what I call the old system, and also in order to be able to communicate with the naval station at Portsmouth.

Before concluding, I wish to say a few words on a method proposed by Prof. Slaby, and with which I have also carried out some experiments. As transmitter, Slaby uses an arrangement as shown in Fig. 13, which consists of a vertical conductor, in which is interposed a condenser K and a spark-gap B. The top of the wire is not free, but is connected to earth through an inductance CD and a wire E. At the receiving station the arrangement shown in Fig. 17 is employed. It consists in a vertical conductor DC, connected to earth at C, which should be the nodal point of the waves induced in the wire DC, where there is joined another wire, termed an extension wire, of equal length. In this case Slaby places an apparatus which he calls a "multiplicator," connected to the coherer between the end of the extension wire and the earth, or by another arrangement (Fig. 17); he uses a loop wire FGHDCE, the multiplicator being placed between E and F in series with the extension wire J. By means of this arrangement, Slaby, on Dec. 22 of last year, showed the reception of two different messages sent from two transmitting stations situated at unequal distances from the receiving station to be possible, one station being at 4km. and the other at 14km., thus obtaining a result which may be considered similar to that obtained by me some months previously over larger distances (see Prof. Fleming's letter in *The Times* of Oct. 4, 1900). The information given in Slaby's Paper, as published in the *Elektrotechnische Zeitschrift*, is exceedingly incomplete. We are not told what was the amount of energy used for the transmission nor the height of the vertical conductor at the receiving station or at the transmitting station at the Aberspree Kablewurks. We are told that the transmission wire was suspended between the chimney shafts. Very little information is given as to the appliance which Dr. Slaby calls a multiplicator. G. Kapp, who is probably acquainted with the details of Slaby's work, commenting on this Paper of his, calls the instrument in question "an especially wound induction coil ('induction-spule') the function of which is to increase the E.M.F. of the oscillations at the ends of the coherer." Upon reading this for the first time, I assumed that the multiplicator was an oscillation transformer performing the function of those described in my patent dated June 1, 1898, and also described in my Royal Institution lecture of Feb. 2, 1901. As I subsequently, however, discovered, Prof. Slaby, referring to the multiplicator, states :—"This apparatus in its most simple form consists of a wire coil of a determined shape and form of winding,

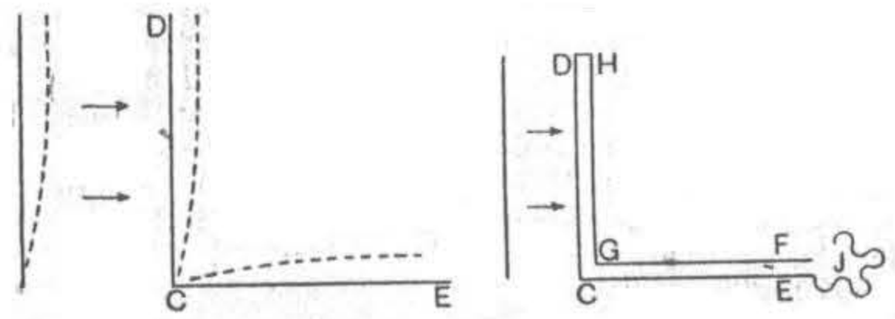


FIG. 17.

which depends upon the length of the wave. . . . I might call this apparatus, unknown to my knowledge up to the present, a multiplicator. It is not to be confounded with a transformer, as it has no secondary winding."

This statement appears to me very ambiguous, as I always have understood that what we call transformers need not have a distinct secondary winding. An appliance called an auto-transformer was used by the Westinghouse Company for regulating the E.M.F. supplied to house lighting installations, which consisted in a single winding, a certain number of turns acting inductively on the adjacent ones. (See "The Alternate-Current Transformer," by J. A. Fleming, Vol. II, pp. 187, 188.) One of the first transformers ever made is shown in the work above referred to, Vol. II., pp. 6 and 7. At page 6 we read :—"Page really made the first experiment in auto-induction and showed that different parts of the same conductor might act as primary and secondary circuits to each other, if in contiguity."

I installed the apparatus described by Slaby at Niton, Isle of Wight, and at Poole, using wires 35 metres high, but with the receiving wire earthed at C (Fig. 17) of the loop I could receive nothing although I tried various frequencies of oscillation. It is, however, probable that I might have received, had I been working over much shorter distances than 50km., as Slaby did in his demonstration, or had I used a greater height of wire. By using, however, my method of connection—*i.e.*, introducing between the vertical wire and earth an oscillation transformer having its circuits tuned to the frequency given by an ordinary vertical radiating conductor of length equal to the Slaby wire AC. I succeeded by means of extremely sensitive coherers in obtaining communication. I then tried the following experiment :—I took down the earth wire ED, and the inductance DC, and used only the conductor AC insulated, with the condenser in circuit for transmitting. An enormous strengthening of the signals at the receiver was immediately obtained, which obviously means a greater ease of working, and the possibility of obtaining signals over greater distances. The reasons which demonstrate that a closed circuit, such as is employed by Slaby, must be a poor radiator, are obvious to those who have studied and read the classical works published since the time of Hertz's experiments.

Dr. Slaby, however, states that the inductance at the top of his loop confines the oscillations to the vertical part AC. If this be the case, the frequency of these local oscillations cannot be equal to that of the whole circuit ACDE, which it has been stated was so easy to calculate, if the translations of Slaby's Paper I am relying on are correct. I believe that, notwithstanding the inductance CD, a considerable amount of energy must pass to earth through the earth wire, which acts as a leak uselessly dissipating energy which should be radiated into space in the form of ether waves. If these conclusions are correct, I am not at all clear as to what necessity there is for employing the earthed conductor ED and the inductance. It is not necessary for obtaining syntonic effects from transmitting stations placed at unequal distances from the receiver, as this can be obtained when using the primitive form of transmitter shown in Fig. 1; and Slaby has not yet described how to obtain different messages from transmitters situated at equal distances from the receivers, which is much more difficult in my experience; nor does it appear possible, with the method he describes, to transmit various messages at the same time from one sending wire as can be done with the system I have just explained. The distance obtained with the closed transmitting arrangement must be comparatively small.

As I have already stated, communication over a distance of 300km. is now being maintained with my system, but I am not aware of anything approaching even 100km. being achieved with the loop transmitter. It may be said that long distances of transmission are not necessarily an advantage, but I notice that the Navy wants long-distance apparatus supplied to it. I have also tried connections similar to Slaby's extension wire in the receiver, but I find that the real sifting out of waves is done in the oscillation transformer, although sometimes it may be desirable to increase the period of oscillation of the aerial conductor by adding inductance to it, or at other times to decrease its period by placing a suitable condenser in series with it. I trust it will not be thought that I wish in any way to minimise the importance of Slaby's work. I only wish to get at the facts and to draw a discussion on a very interesting subject.

Time does not permit me to refer to a great number of experiments upon which I am now engaged, or which have been carried out by others, but I hope on a future occasion to describe better results. I have come to the conclusion that the days of the non-tuned system are numbered. The ether about the English Channel has become, in consequence of great wireless activity, exceedingly lively, and a non-tuned receiver keeps picking up messages or parts of messages from various sources which very often render unreadable the message one is trying to receive. I am glad to say, however, that I am now prepared with syntonic apparatus suitable for commercial purposes. And, as my final word on the general subject for the present, let me say that those who are responsible for the recent development of wireless telegraphy into a practical science cannot fail to find great satisfaction in the reflection that, as already life has been saved that without this discovery would have been lost, so, in the future, apart from its manifold commercial possibilities, valuable as these are, humanity is likely to have before very long to recognise in telegraphy through space without connecting wires the most potent safeguard that has yet been devised to reduce the perils of the world's sea-going population.

DISCUSSION.

Dr. FLEMING, F.R.S., said that as he had been permitted to be a little behind the scenes, and had seen some of the apparatus before it was made public, he was able to entirely confirm Mr. Marconi's statements with regard to his experiments. A very great stride forward had been made in syntonic telegraphy. The subject was not a new one—in fact, a large number of patents had been taken out in connection with it, most of which, however, embodied more hope than experience. In spite of the fact that there were so many claims of priority in the matter, he had the strongest possible conviction that Mr. Marconi was the first person to actually achieve a true syntonic telegraphy with electric waves. He had done that in virtue of having followed out to their logical issue the fundamental scientific principles of the subject which he had so clearly grasped, one of which was the essential distinction between the radiative and the non-radiative circuit. Many inventors and patentees had professed to have obtained syntonic telegraphy with a simple open aerial insulated radiator of the Marconi type. Although it was possible to produce a kind of bastard syntonic telegraphy by that means, it was not possible to produce true syntonic telegraphy, because the aerial simply produced a sort of etheric impulse or explosion, and not a true train of waves. It was just as possible to produce true syntonic telegraphy by those means as it would be to cause one whip to crack by cracking another near to it. When a closed circuit was taken, which was a powerful absorber of electric energy and associated with a radiative circuit, a means was obtained for producing a true train of waves. If those two circuits were tuned together a great improvement was effected on anything previously accomplished. Mr. Marconi had not only constructed a receiver capable of receiving trains of waves, but also capable of not receiving those not adapted to it. No train of waves would act upon his syntonic receiver except those which had a particular period. An analogy might be found in a cork floating on water, which would be bobbed up and down by any wave, long or short, which went over it; but a heavy log of wood floating on the water and tethered to the bottom of the sea by a spiral spring would only be caused to bob up and down by waves having one particular period. The former corresponded to a simple coherer, and the latter to a syntonic receiver of the kind described in the Paper. He quite agreed with Mr. Marconi that the days of the non-syntonic telegraphy were numbered, because no one would chose a receiver capable of being affected by every vagrant wave when such an instrument as Mr. Marconi's latest form of receiver was available. Among the possibilities which lay in front of the invention was that it would be immediately possible to provide the Admiralty and the Post Office with instruments having an Admiralty or Post Office frequency, and to register frequency just as a telegraphic address was registered, so that no one else could use that particular frequency. He had had the privilege of riding on the motor car described by the reader of the Paper, and, when many miles from home, they were able to communicate with their hotel and order their lunches. In conclusion, he offered his warmest congratulations to Mr. Marconi on the immense strides he had made in the improvement of his initial invention.

Capt. KENNEDY, R.E., said he wished to explain, in common justice to Mr. Marconi, some of the points connected with the operation of the system in South Africa. A scheme was suddenly conceived and hastily executed of sending apparatus and assistants to instal the system at Durban. But instead of setting it up at that port, it was sent to the Front. No poles were available, and the attempts to substitute kites and balloons were unsuccessful. For want of labour and proper materials progress was slow, and eventually the work was stopped. On arriving in Natal, on the first opportunity, he handed the whole system over to Captain Percy Scott, who worked it most satisfactorily on board the ships at Durban up to the time he left South Africa. The operations in Cape Colony were entirely experimental, and would have succeeded had they been given a fair chance.

The CHAIRMAN (Prof. Ayrton) in proposing a vote of thanks to Mr. Marconi for his admirable Paper, said that, after listening to what wireless telegraphy had already done in saving life and ships, they realised why the reader of the Paper, although so young, had acquired fame; why he had won that more substantial reward which sometimes went with fame, but often did not, and also grasped why he had earned what should be dearer to him than fame or wealth—the gratitude of all peoples for having so courageously developed a new sense for the world. Although still far away, he thought they were gradually coming within thinkable distance of the realisation of a prophecy he ventured to make four years ago, of a time when, if a person wanted to call to a friend he knew not where, he would call in a loud, electro-magnetic voice, heard by him who had the electro-magnetic ear, silent to him who had it not. "Where are you?" he would say. A small reply would come, "I am at the bottom of a coal mine, or crossing the Andes, or in the middle of the Pacific." Or, perhaps, in spite of all the calling, no reply would come, and the person would then know his friend was dead. Let them think of what that meant, of the calling which went on every day from room to room of a house, and then think of that calling extending from pole to pole—not a noisy babble, but a call audible to him who wanted to hear and absolutely silent to him who did not; it was almost like dreamland and ghostland—not the ghostland of the heated imagination cultivated by the Psychical Society, but a real communication from a distance based on true physical laws. On seeing the young faces of so many present he was filled with green envy that they, and not he, might very likely live to see the fulfilment of his prophecy.

Mr. MARCONI, in reply, thanked Dr. Fleming for his kind remarks. To him he was also indebted for valuable advice on many subjects he did not understand, and in which Dr. Fleming's theoretical knowledge was of great value. In reference to Captain Kennedy's remarks, he wished to give an explanation. When the war broke out in South Africa he was asked whether he could send his apparatus out there. His associates, in reply, made two proposals: (1) To send apparatus for work at the Front, and (2) between shore stations and the transports at Durban. The proposal of using the apparatus at the Front was not accepted by the War Office at the time. The apparatus was sent out without poles because he was informed they would be found at Durban. On the arrival of his assistants in South Africa they pluckily volunteered to go to the Front, thinking the system might be worked with advantage to the English army; but, on reaching the front, poles could not be obtained by which to raise the wires. At that time, according to his old-fashioned system, this was absolutely necessary. Captain Baden-Powell came to the rescue with some well-designed kites, and signals were transmitted about 18 miles. Although the system was never used during operations in South Africa, it was not the fault of the system.

Review Of Reviews June 1901

THE LATEST TRIUMPHS OF ELECTRICAL INVENTION.

THE WORK OF MARCONI, TESLA, AND PUPIN.

BY PROFESSOR JOSEPH S. AMES.
(Of the Johns Hopkins University.)



WILLIAM MARCONI.

(This eminent electrical engineer was born in Italy in 1875; his father was an Italian and his mother an Englishwoman. Young Marconi studied at Leghorn under Professor Rosa, and at Bologna under Professor Righi. He experimented successfully with wireless telegraphy as early as 1896.)

PERHAPS the most important problem in science, with reference to daily life, is that of the rapid and accurate transmission of intelligence. Certainly, there is no question which at the present time is attracting so much attention from inventors and investigators; and at the Paris Exhibition of 1900 the most novel and suggestive scientific devices and methods shown were in this field. The daily press gives publicity to experiments, observations, and, unfortunately, vain prophecies on the subject, showing how much the world at large is interested in the matter. Within the past year, however, three names have been most prominent in the newspapers as having said something, or done something, which had important bearing on the question referred to. These are those of Marconi, Tesla, and Pupin; and each deserves serious consideration, although for different reasons. Marconi has made possible the practical application of wireless telegraphy; Tesla informs us that he is on the point of making great discoveries; Pupin has made a most wonderful improvement in long-distance telephony.

MARCONI AND WIRELESS TELEGRAPHY.

One of the most interesting chapters in the history of physical science is the story of what is nowadays called wireless telegraphy. By this name is meant the direct transmission of signals, without the help of connecting wires, between distant points, making use of disturbances which are produced in the luminiferous ether by electric oscillations, and which are detected by suitable means. The fact that there is in the universe a medium so subtle as to permeate the air, water, glass, and, in fact, all bodies, so that it may be regarded as a universal medium in which all the minute particles of ordinary matter are immersed, is familiar to every one at the present time. The existence of this ether was proved, at the beginning of the nineteenth century, through the labors of Thomas Young and Augustin Fresnel, who established the fact that all the phenomena of light are due to extremely short waves in a medium essentially different from air or any matter. Michael Faraday, about the middle of the century, was led by his experiments in electricity and magnetism to conclude that there must also be a medium, distinct from all forms of ordinary matter, by means of which electric and magnetic forces are felt. He conjectured that this electrical medium might be identical with the luminiferous ether of Fresnel; but it was reserved for Clerk Maxwell, the great professor of Cambridge, to prove this fact incontestably. He did so by showing, from mathematical considerations, that if the electric charges on any conductor could be made to oscillate, waves would be produced in the surrounding medium, which would spread outward

with the velocity of 186,000 miles per second, or, more exactly, 300,000 kilometers per second,—which is identically the same as the velocity of the waves in the luminiferous ether that produce the sensation of light, and are therefore ordinarily called light-waves. Maxwell showed, too, how it would be possible to calculate the wave-lengths of these waves produced by electric oscillations. But whereas those ether-waves which produce light when they reach the eye are extremely small, being on the average about one fifty-thousandth of an inch in length, those due to electric disturbances are much longer, varying from one-tenth of an inch to many miles.

No one, however, for many years devised any instrument for the detection of these long waves, or, in fact, elaborated any method for their regular production and observation. This was finally done, in 1887, by the talented young physicist, Heinrich Hertz, professor of physics at Carlsruhe, one of Helmholtz' greatest pupils. Hertz produced his electric oscillations by means of an induction-coil, charging with opposite kinds of electricity two conducting metal plates which had two projecting knobs coming close together. The action is as follows: When the charges become sufficiently great, a spark passes between the knobs; and while the spark lasts—a very minute fraction of a second—there are surgings of the electric charges backward and forward from one plate to the other through the spark. Then the plates become charged again, are discharged, and again there are those electrical surgings to and fro. As a result of these oscillations *on the conductors*, disturbances are produced in the surrounding ether, which spread outward in all directions, just as, when a stone is dropped into a pond of water, waves are seen advancing outward in ever-widening circles. It may be noted here, once for all, that the disturbances in the ether do not come from the spark, which is so conspicuous to our senses of sight and hearing, but are due to the surgings on the conductors. For this reason, it is self-evident that the length of the waves must vary with the size of the conductors; the longer the conductor, the longer the waves. It is obvious, also, that long waves are less affected by obstacles than are short ones,—they can pass around them; and it may be shown that the longer the waves are, the farther they will go before fading away and becoming too weak to be observed.

Hertz discovered that a simple means of detecting these waves was to bend a wire into the form of a circle, so that the two ends nearly, but not quite, met; for, if this "receiver" is suitably turned, there will be minute sparks across the gap as the waves pass. Using the oscillator and receiver just described, Hertz showed that the waves produced by the electric oscillations traveled with the velocity predicted by Maxwell, and that they obeyed all the ordinary laws of reflection and refraction which are associated with the phenomena of light. Hertz showed how these disturbances in the ether could be noticed at considerable distances,—many yards; and other investigators, like Lodge, Trouton, and Rutherford, who repeated and extended Hertz' experiments, proved that these effects could be observed at a distance of several miles, through intervening walls and buildings. One of the first to be interested in Hertz' work was Professor Righi, of the University of Bologna; and one of his pupils, Marconi, saw in these new discoveries the possibility of using the methods for the transmission of messages. In the meantime, too, a much more sensitive receiving instrument had been perfected by professors Onesti and Branly independently—the "coherer." This consists of a glass tube containing minute loose metallic filings, into each end of which enters a metal wire joined to a source of electric current, such as a voltaic cell. The filings do not in a normal state make electric contact, and so no current flows; but if long waves in the ether pass by, they produce electric oscillations in the conductors projecting out of the tube; and, as a consequence, the filings in the tube cohere and make connection, so that an electric current is now produced, and can be detected by any suitable means. A slight tap on the tube will cause the filings to decohere. Marconi studied the conditions under which a coherer was most sensitive, and those under which an oscillator would send out the most intense waves, and the ones best adapted for practical use over the surface of the earth. He then devised a simple method for using a "dot-and-dash" system of signals, depending upon having a short or a long series of electric discharges. Marconi deserves a great deal of credit for his perseverance in interesting the governments of Europe and this country in his enterprise, and for overcoming the practical troubles which arose when it was attempted to transmit the signals in the ether to such great distances as fifty or a hundred miles.

It is not possible, however, to increase the intensity of the electric oscillations indefinitely, and the limits of sensitiveness of the coherer have probably been reached. It must be borne in mind, too, that the waves in the ether produced by the electrical surgings travel outward in straight lines, except as modified by reflection; and this last has little effect when the oscillator is a vertical conductor, as it is in all commercial sets of apparatus. The presence of ordinary mat-

ter, such as a building or a hill, affects the progress of these waves only slightly, provided it is not a good conductor for electricity. If such is the case, however, the energy of the waves will be seriously reduced, if the body is of sufficient size. Thus, when an attempt is made to send ether-waves from one point to another distant one hidden from it by a mass of salt water owing to the curvature of the earth, there is not the least reason for believing that it will succeed. Messages are easily sent across short distances on the ocean; but this is due to the fact that the ether-waves used are so long that, unless the sending and receiving points are very far apart, portions of the waves, although passing in straight lines, do not traverse the water itself, but go above it.

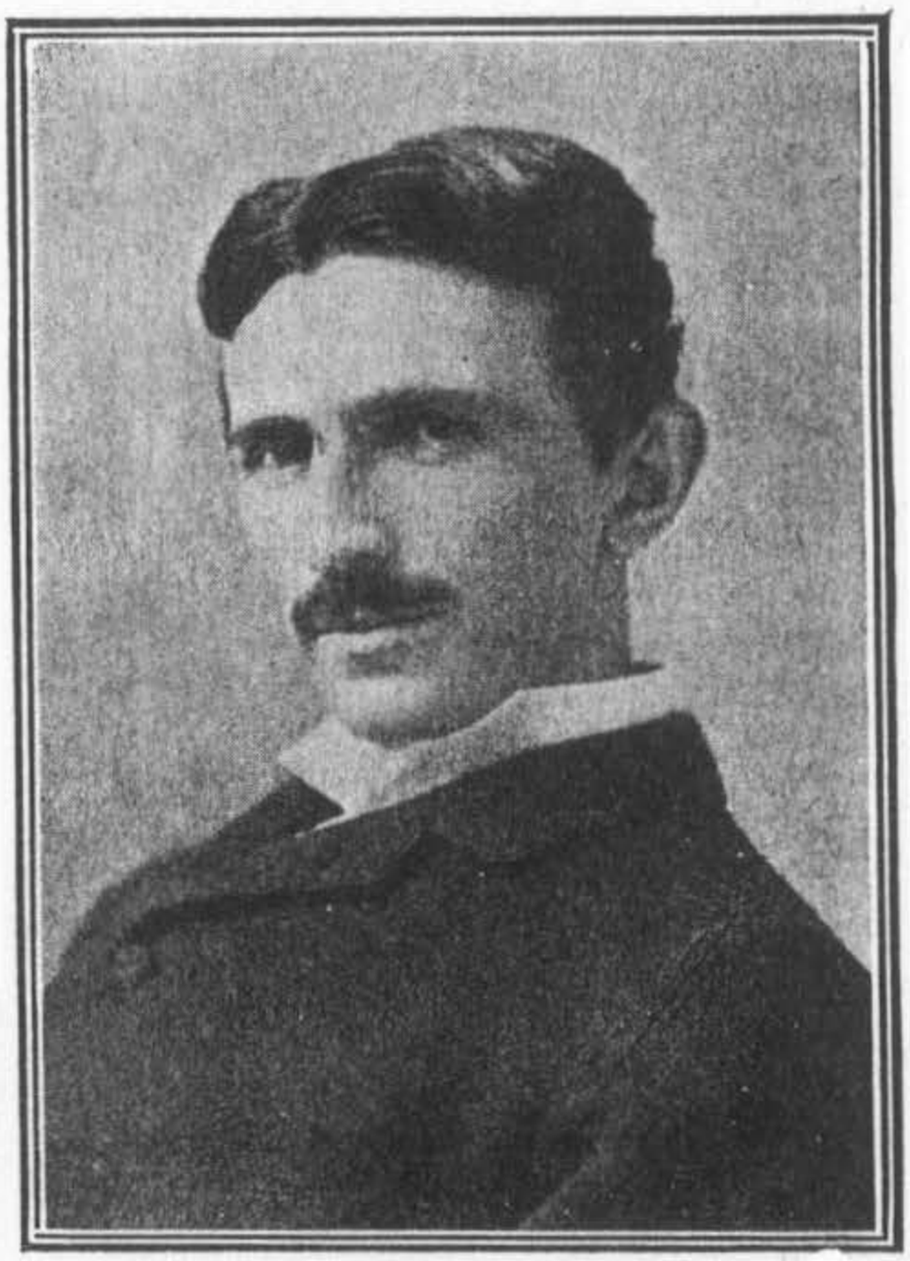
There have been, up to the present, two difficulties which have stood in the way of the more universal application of "wireless telegraphy;" one was the impossibility of locating accurately the direction from which a message came, the other was the fact that if several messages were being sent at one time their effects would overlap, and the signals received at any station would be a confused mixture. This first difficulty can be obviated to a certain extent by using suitable mirrors, provided the ether-waves are not too long; and the second has been almost completely removed by the recent work of Professor Slaby, of Berlin, using a method of resonance long since proposed by Professor Pupin, of Columbia College, New York. Slaby has perfected his apparatus to such a degree that he can make an oscillator which will produce waves in the ether of a definite period of vibration, and a receiver which will respond to waves of a definite period, but to no others; so that however many waves, of whatever periods, are passing over a receiver, it will pay no heed to them unless they are of the proper period. It thus becomes possible to transmit messages free from the disturbing influence of other ether-waves produced by vibrations.

Naturally, the field of usefulness of wireless telegraphy is limited. It can never compete with the long-distance telephone or the rapid telegraph systems; but for maintaining communication between moving vessels, vessels and the land, and across channels, where cables are not safe, it offers by far the most satisfactory solution of the obvious difficulties. It should be noted that some of the most important and successful modifications in wireless telegraphy methods have been made in this country under the direction of the officers of the United States Signal Service.

The history of wireless telegraphy would not be complete without some mention of Joseph Henry, America's greatest scientist, for it was he who first, in 1842, discovered the oscillatory character of certain electric discharges, and who showed that these oscillations produced disturbances which could by suitable receivers be detected at distances of many rods and through intervening buildings. He even arranged an apparatus on this principle to respond to the lightning discharges of distant storms. The great genius of Henry was never more apparent than in his investigation of electrical discharges and their oscillatory nature. It is a lasting testimony to the ignorance among Americans of their own great men that the name of Joseph Henry is not included in the fifty selected for the "Hall of Fame" of the nation.

TESLA.

It is extremely difficult to take Mr. Nicola Tesla seriously, and still more so to understand the credulity of the people to whom the daily paper is an organ of science. Mr. Tesla has done so much good scientific work, and has been so skillful in the preparation of theatrical lecture-



NIKOLA TESLA.

(Although of Servian birth and education, Nikola Tesla has lived for many years in the United States and is well known as an electrician, especially in connection with the problem of power transmission at Niagara Falls.)

experiments, that it is greatly to be wondered at that he does not again make a definite invention or perfect some apparatus or method. The Tesla motor, so called, and the electrical machines which

are modifications of it, are known to the world, and so is the "Tesla coil," which is a simple improvement of one of Henry's instruments; but as yet no discovery bears his name, and all the wonderful experiments with which he delights audiences at home and abroad are extensions of familiar ones, shown on many lecture-tables by the ordinary teacher of physics. With such knowledge and such skill, it is incomprehensible why the articles bearing his name should appear in magazines and daily papers. It may be that Mr. Tesla has a knowledge of experiments not known to the world; but if he has, he owes it to the world and to himself to publish the *facts*,—what he knows, not what he thinks will make interesting reading for those who are ignorant of physical science but are looking to science and scientists for extension of man's knowledge of the truth hidden in nature.

PROFESSOR PUPIN'S INVENTION.

In the recent invention by Professor Pupin, of Columbia University, of a new principle in the transmission of electrical waves along metallic wires there is much more of interest than at first sight appears. Professor Pupin is a trained physicist and mathematician, and has been interested for some time in the study of the propagation of electrical waves along conducting wires, using both theoretical and practical means to help him in his work. He investigated the subject mathematically, and saw from his equations that if he were to modify the conducting wire in an entirely new but perfectly simple manner, many of the difficulties in the way of the transmission of the waves would be removed. He therefore constructed in his laboratory the modified "line," so as to represent an improved telegraph or telephone wire, tested its action, and found that it was exactly as he had known from the start it would be. So important to practical commercial companies was the invention, that Professor Pupin has been able to dispose of his patent-rights for a sum which to the ordinary college professor seems beyond the dreams of avarice. The most striking feature in this invention, as in so many recent ones, is the fact that it could never, under any imaginable conditions, have been made by a so-called "practical man." It required, first of all, the genius of an inventor; and next, and to a no less important degree, the training in mathematics and physics which only the greatest universities in the world can give. The demand in modern technical schools should be, not for less theoretical instruction in abstract subjects, but for more. Failing this, the engineer of any kind, civil, mechanical, or electrical, is hopelessly limited in his power for invention or for the improvement of existing conditions.

It may be easier to understand the difficulties in the application of electrical waves which are overcome by Professor Pupin's invention, and the vast changes which it makes possible, if one consider for a moment a more familiar illustration of waves. If a long, thin cord, or rope, lies along a floor, one end being fastened and the other held in the hand, mechanical waves may be sent along the rope by moving the hand rapidly and regularly up and down. The more rapid the vibrations of the hand, the shorter will be the wave-length—that is, the distance from "crest" to crest. It is seen at once that the waves do not advance very far; they "die down," or become "attenuated," owing to the fact that the energy due to the work done by the hand in moving the end to and fro is all lost in the rope. It may be seen, too, by trying the experiment, that long waves are less affected than short ones, and so are propagated along the rope to a greater distance than are the short ones, before they die away entirely. It is thus easily understood that if the hand is moved up and down in a most irregular manner, yet repeating



Photo by Park.

PROF. MICHAEL I. PUPIN.

(Dr. Pupin was born in Austria in 1858. He came to America at the age of sixteen, and was graduated from Columbia in 1883. Further facts in Dr. Pupin's career are given on page 344 of the REVIEW for March, 1901.)

its motion at regular intervals, there will be waves of different lengths sent along the rope; but that as the shortest waves die down, leaving the longer ones, the character of the disturbance seen moving along the rope will change. This is called "distortion."

The attenuation of the waves is greatly diminished, and is made nearly the same for both long and short waves, if a heavier cord is taken; for instance, if the first one is like the cotton rope used to hang window-weights and the other is a flexible metal cable. (It is true that in this change the actual magnitude of the disturbance decreases; but the work done at one end of the rope will now be manifest farther along toward the other end.) Both attenuation and distortion are thus decreased. If it be not desired to use a heavy cord, the first one may be so modified as to have all the advantages of the former. This is done by attaching small, heavy pieces of lead or other metal to the rope at regular intervals apart; and the "weighted" rope will now behave like a heavy one for waves of all wave-lengths much greater than the distance from one load to another. Professor Pupin showed that the proper arrangement was to have not less than fifteen or sixteen "loads" in the distance of one wave-length. Thus, a heavy rope with its weight distributed in beads keeps all its essential properties unaltered.

For any one feature of the propagation of mechanical waves along a rope there is an exact analogy in the phenomena of electricity. Electrical waves in a conducting wire are produced in many ways,—each time one speaks into a telephone, waves are produced along the wire; whenever a telegraph-key is depressed, there is a wave. There are the same difficulties to overcome in the application of electrical waves as those just described in the illustrations of mechanical ones,—attenuation and distortion. For instance, in order to secure the transmission of a signal over a long submarine cable, it is necessary to have very long waves, and this requires a slow rate of sending messages; more rapid vibrations would die away before reaching the farther end. Again, when one speaks into a telephone, there are produced waves of many lengths, depending upon the varying notes of the voice; these waves die down at different rates, and the sound heard at the hearing instrument is essentially different from that spoken. Low sounds carry farther than high ones, and every one knows from experience how difficult it is to hear certain shrill sounds in a telephone. In "long-distance" lines, the only remedy in the past has been to use larger copper wires, and to avoid as far as possible all disturbing influences. Thus, as a rule, long-distance wires avoid towns or cities where local electric circuits might produce waves of their own. Pupin has proposed absolutely different modifications. When the rope in the mechanical experiment was made heavier, its "inertia"—its opposition to the disturbing action of the waves—was increased; now what corresponds to this with the electrical waves along a wire is to wind it in the form of a coil or helix! This was one of Joseph Henry's great discoveries, also. If a wire is wound like thread on a spool, it offers opposition to the production of an electrical wave exactly analogous to that offered by the heavy rope to the mechanical wave. Similarly, if the wire runs straight for a short distance, is then coiled up, then goes straight, is again coiled up, etc., it corresponds perfectly to the loaded rope. Electrical waves can be sent along it to great distances with comparatively no attenuation and distortion. Pupin's project is, then, in short, to modify a telephone-wire by cutting it at definite points—every few posts—and by joining the cut ends with those of a small coil of wire wound on a spool. He has worked out carefully the exact size of the coils to be used under different conditions, and the proper distance apart to insert them. For telephone purposes, the coils occupy a space of a cube scarcely five inches on an edge, and are about one mile apart; while for ocean cables, the coils are so small that they can be included in the sheath, lying close to the cable-wire itself, but they must be as near together as one-sixth of a mile.

The advantages of this system of Pupin's are enormous, especially from a commercial standpoint. The rate of signaling over submarine cables will be increased so as to rival that of land lines; and there is no reason to doubt but what telephonic communication will be possible over them. This statement should not be regarded as a prophecy, but as an interpretation in the language of commercial life of experiments in the laboratory.

On land, the saving of copper in the construction of long-distance lines will be most important. Communication can be maintained over much greater distances than is now possible. All disturbances from local induction and from lightning are absolutely avoided. The rapidity of the oscillations in a lightning-flash are so great that if a wire is struck the waves produced will be so short that when they reach one of the coils they will not be able to pass it, but will be reflected, and will thus be frittered away by being reflected to and fro along a small section of the wire. In every way, therefore, the invention of Pupin is one of the most noteworthy events in the modern application of science.

Nitrogen and Tesla Currents.—KAUFFMANN and HELL.—An account of an experiment in which nitrogen was exposed to the influence of Tesla currents. The nitrogen is contained in a wide glass tube, in which there is a narrow tube filled with mercury connected to one pole of a Tesla coil, while the other pole is connected to an external tin coating on the wider glass tube. On working the Tesla coil, a blue fluted light appears in the wide tube, accompanied by a green fluorescence of the glass walls. The green fluorescence appears to be generated wherever the blue rays impinge upon the glass, just as if these were cathode rays.—*Phys. Zeit.,* May 11; abstracted in Lond. *Elec.,* May 24.

The New York Tribune August 7, 1901

TESLA READY FOR BUSINESS.

HE HAS BOUGHT THE LAND FOR HIS WIRELESS TELEGRAPHY STATION AND LET THE CONTRACTS FOR THE BUILDINGS.

Nikola Tesla's plans for a transatlantic wireless telegraphic system are now so well in hand that he has bought a site for the station on the Long Island shore, and has agents looking for a suitable place for a station on the British coast. The station in this country will be at Wardenclyffe, on the Sound, nine miles east of Port Jefferson. Mr. Tesla has purchased two hundred acres of land in that vicinity, and closed contracts yesterday for the necessary buildings.

Five or six buildings will be erected on different parts of the tract, the largest of which is to be one hundred feet square and several stories high. It will contain, Mr. Tesla says, one of the most complete electrical plants that can be purchased. Three hundred and fifty horsepower will be developed, and the total cost will be nearly $150,000. The other buildings will be used for the electrical experiments with which Mr. Tesla is now engaged, including a system of lighting by diffused light. He will probably give up his present laboratory, at No. 46 East Houston-st., and make his headquarters at Wardenclyffe.

Mr. Tesla has been working for several years with his system of wireless telegraphy, and believes that he has advanced far enough to warrant a change from the experimental to the commercial stage. He says it will not be long before he will be transmitting commercial messages between Wardenclyffe and Europe without the use of wires or cables.

When seen at the Waldorf-Astoria Hotel last night Mr. Tesla said:

"I would have been sending messages across the ocean without the use of wires by this time if the public were not so hard to convince that it could be done. It takes time to assure people of the truth of new discoveries. It was six or eight years before people believed in my system of transmitting electric power. Now it is used everywhere. I cannot tell you just how far I have advanced in the perfection of my system of telegraphy, but I hope soon to be able to show most convincing results."

Important if True.

Press dispatches state that Nikola Tesla has received word that the apparatus he has devised for the transmission of electric energy is completed. Three stations have been arranged for on the other side of the Atlantic, it is said—one in Portugal, one in France and one in Germany. Mr. Tesla expects that by the end of September all the mechanism for the transatlantic service will be in position.

In our issue of January 18th we described Prof. Slaby's "tuned" system of wireless telegraphy, indicating the theoretical principles on which it is based. More recently Prof. Slaby has delivered another lecture on his method, and we publish an extract of this in another column, with diagrams of the connections employed—and employed with complete success. The conclusion of his article, with its allusion to the present work of Mr. Tesla, comes as a considerable surprise. No one will deny that Mr. Tesla possesses genius—his valuable work in connection with polyphase methods alone demonstrates this. But from the soil of his genius have sprung up two varieties of dangerous weeds—a craving for notoriety and dreams of ultimate possibilities, and these have grown so thickly that it requires a skilful gardener indeed to discover the fruit. If Prof. Slaby has patience enough to do this it redounds to his credit; for otherwise if the illustration in the professor's lecture is a true picture of the condition of Mr. Tesla's laboratory, it seems probable that the ultimate result of the séances held by the wizard of the Rocky Mountains may be merely another wildly imaginative article such as that written by Mr. Tesla in the *Century Magazine* a year ago, or a description of an elaborate attempt to inspire an appreciative personal notice in the sensational press of the Martians.

THE LATEST PROGRESS IN SPARK TELEGRAPHY.*

BY PROF. A. SLABY.

The latest form of connections of the wireless telegraph apparatus made by the Allgemeine Elektricitäts Gesellschaft are as follows. The transmitter (Fig. 1) consists of wire fastened to the flagstaff of

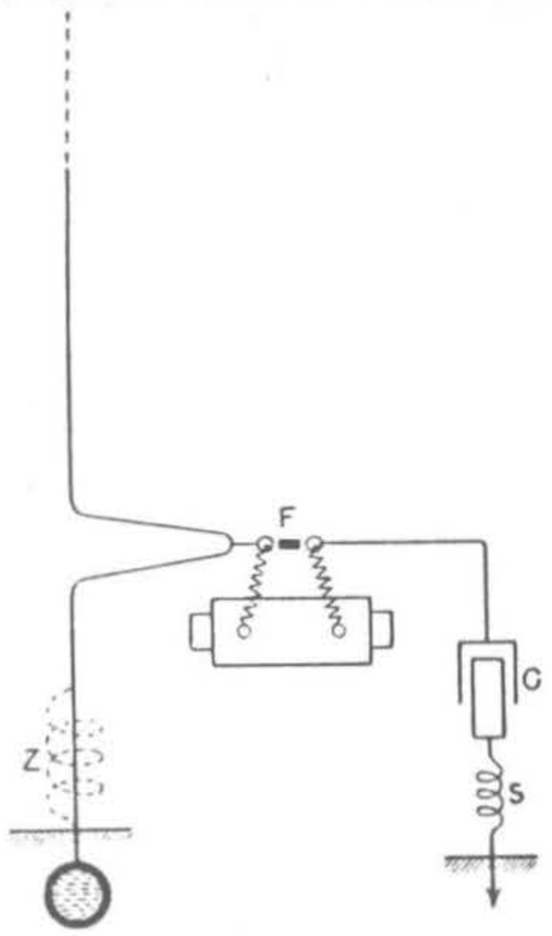


FIG. 1.

the building, which is led to earth and connected with the water main. A loop in this wire is led through the window into the room, and is connected to an induction coil, F, the other pole of whose secondary winding is connected to earth through a tuned condenser, C. If we wish to telegraph with a greater wave-length, it is only necessary to connect an additional coil, Z, in the earth wire, as shown by the dotted line. It corresponds to a certain equivalent length of wire by which we increase the quarter wave-length, and a whole set of such coils can be employed. In each case, however, it is necessary to tune the oscillation produced in the circuit closed by the earth connection to the oscillation of the wire, in order to obtain the greatest effect. This is done in the simplest manner by adjusting an adjustable self-induction, S, or the condenser C, which bear particular marks for this purpose.

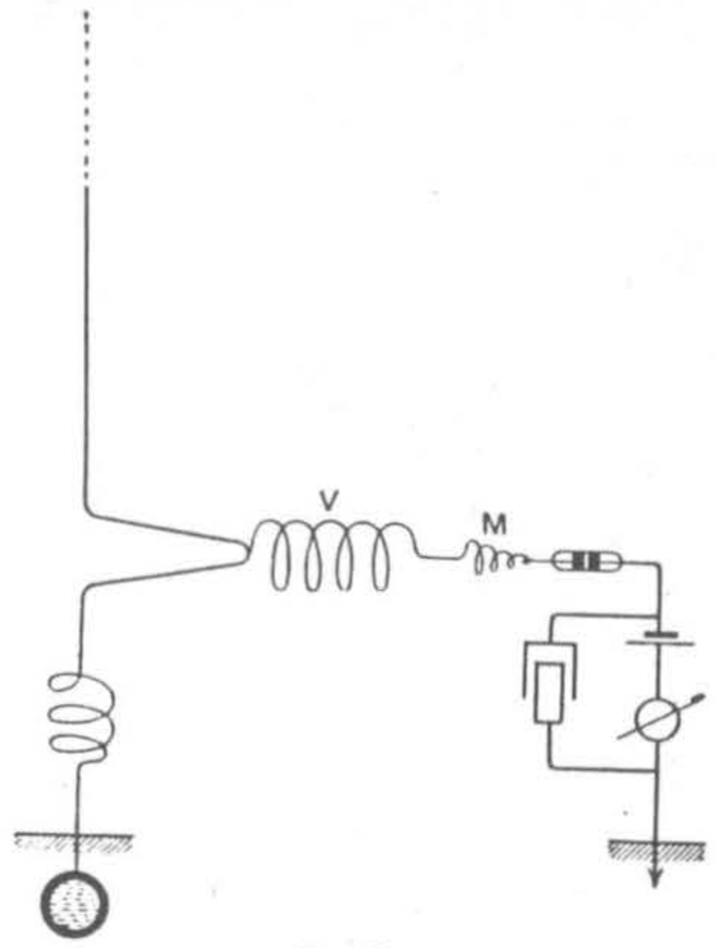


FIG. 2.

A similar wire serves as the receiver (Fig. 2), to which, also, an extension wire in the form of an equivalent coil, V, is connected by means of the loop. The pressure is at its maximum at the end of the latter, and is strengthened by a tuned intensifying coil M, which

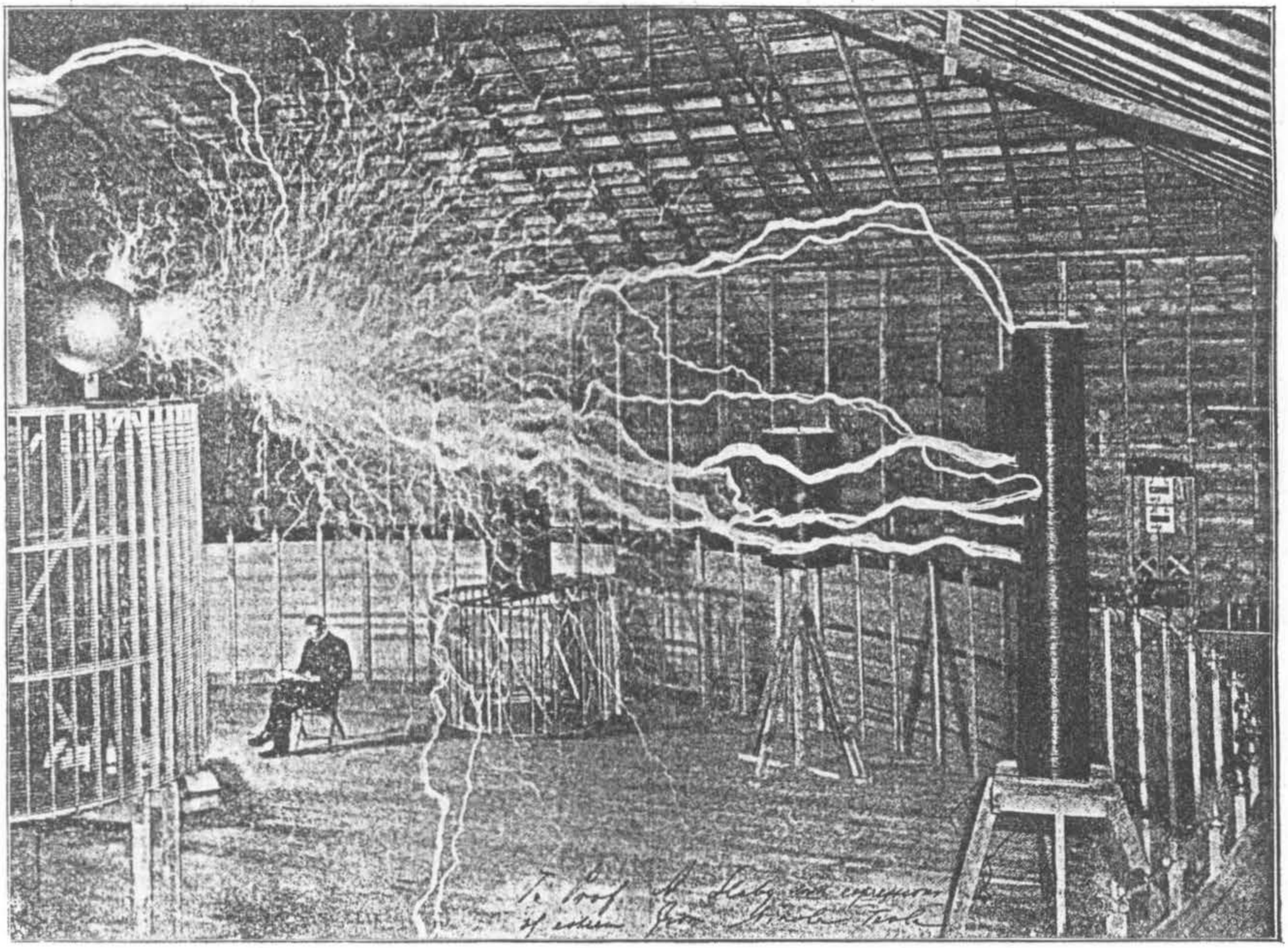


FIG. 3.

* Extract from a lecture delivered at the forty-second general meeting of the Verein Deutscher Ingénieure, at Kiel.

is connected directly to the coherer. It is also possible to replace the action of the two coils by a single coil with corresponding winding. The earth connection of the coherer contains the dry cell and the relay, which are bridged by a condenser in order not to disturb the oscillations. The Allgemeine Elektrictäts Gesellschaft guarantees with this arrangement a tuning to the required wave-length within certain limits, and a clear deciphering of signals at distances of 100km. on the sea with masts 50 metres high.

Spark telegraphy has now left the condition of tentative experiment and has developed into actual engineering to accomplish a definite object, and the active forces of the industry will soon do what is needful to extend its sphere of applicability. It will, in the first instance, become an indispensable means of communication on the coast and on the open sea, where the life and property of mankind is most endangered, and I do not think it will be long before every large ship will be equipped with this simple and useful apparatus. But spark telegraphy will also, in the future, replace cable in many cases for submarine communication, although in this respect we must not place our hopes too high. We can almost now see the limits, putting aside extravagant plans, as, for instance, elevating a wire 1,000 metres by means of balloons, which may be possible in an individual experiment, but is worthless in practice for reliable continuous working. We can scarcely expect a transmission of signals of more than a few hundred kilometres even with more perfect development of the means at present at hand.

The way open for further progress is also clear. The distance of transmission depends essentially on three things, the length of the parallel wires, the frequency of the pulsations, and the mean value of the current employed. The first two can hardly be increased, and also extending the length of the wire requires longer wave-lengths and consequently slower frequency; and, therefore, quite a new means would have to be found to make the wave-length independent of the length of wire employed. An increase of the induced current only remains therefore. This depends on two quantities, the capacity or receptive power of the wire, and the actual pressure of the spark. The higher we take the wire the smaller will be the capacity of the parts distant from the earth, and the longer it is the harder it will be to secure it in stormy weather. Thus I hope to have shown that the future of spark telegraphy lies exclusively in the direction of producing higher electrical pressures. What we have used in this direction hitherto is very modest if we compare it with what has been shown to only a few of the initiated, far from here on the other side of the ocean, on the high Rocky Mountains at the sources of the Colorado River, by an investigator who has shut himself off from the world—Nikola Tesla. I cannot report on it as an eye witness, but can only form my opinion from some photographs which he has most kindly sent me a few days ago. Here (Fig. 3) one sees him in his lonely house surrounded by artificially-produced spark discharges, which throw into the shade all that our most daring fancy has dreamt of. May his theoretical knowledge and his eminent technical ability soon be placed at the practical service of spark telegraphy.

Tesla Patents.

As noted in our issue of last week, two decisions have lately been handed down sustaining the Tesla patents, one from the United States Circuit Court of the Southern District of New York, and another from the United States Circuit Court of Appeals for the Second Circuit.

The first-mentioned decision was by Judge Lacombe. The defendant's device is an alternating-current wattmeter, and it was contended by the complainant that the circuit to which the meter is connected is divided so that part passes through a fine wire coil and another part through a coarse wire coil, and that as a consequence there is a difference in phase between such circuits. The complainant contended that this arrangement is an infringement of two Tesla split-phase patents, both bearing date of Dec. 26, 1893.

The defendant contended that the device does not constitute an infringement for two reasons, that the patents at issue cover motors only, while the device in suit is a meter. In the opinion of the court, this is a mere verbal distinction without apparent merit. The patents contemplate the production of power, though they are wholly silent as to the amount of power. The meter exerts power, its disk rotates against the action of a permanent magnet and turns a spindle which operates the registering devices. Second, the defendant contended that the meter does not operate by virtue of the so-called "Tesla rotating field" of the polyphase patents. The court considers that the preponderance of evidence indicates that in the motor in suit there are independent energizing circuits; that alternating-current from a supply circuit is passed through both, and that by a variation or modification of the relative resistance or self-induction of these energizing circuits they are put into different phase; and that the revolvable disk becomes effectively operative because such arrangement exerts its influence through the development of a rotating field, which is characteristic of Tesla methods.

The conclusion of the court is that the motor involved an infringement of the claims of both the Tesla patents above mentioned.

The second decision is by Judge Shipman, and was on an appeal from the Circuit Court of the District of Connecticut in the suit of the Westinghouse Electric Manufacturing Company against the New England Granite Company. The Circuit Court opinion of Judge Townsend was printed in our issue of Sept. 8, 1900.

The opinion of Judge Shipman is lengthy, and quotes largely from that of Judge Townsend, which it sustains. Taking up the main points of the defense, it is noted that Bailey said that the object of his experiments was to cause a disk to rotate by an intermittent rotation of the field, effected by electromagnets, and this statement is sufficient to show that he neither thought of nor unconsciously aided in solving the problem of transmission of power by electric currents of any kind. Bailey, in his experiments with reversed currents did not attempt to produce, as Tesla did, a continuously rotating field. Reverse currents and alternating currents, though they may be equivalents for some purposes, are not equivalents for transmission of power over a distance. Reverse currents cannot practically be used for that purpose.

Taking up the Bradley defense, it is stated that Bradley's alleged invention was a dynamo "which would generate an alternating or a continuous current as desired." He described two currents obtained from the same machine, and says that they can be employed for any purpose for which alternating currents are applicable, and they may be used separately, one being employed to feed one circuit and the other to feed another circuit, but he apparently did not in his application understand any benefit resulting from the transmission of two currents of different phase.

Judge Townsend is quoted to the effect that Bradley's application is limited in scope, ambiguous and indefinite. It fails to show that he had any conception of the Tesla idea of "the utilization of the motor for the purpose of progressively shifting the magnetic poles of a plurality of alternating-currents by circuits which preserve the independence and differing time relation of the other phases." Even if the idea had been first conceived by Bradley it was not sufficiently described to disclose a principle or method of operation. Bradley does not anticipate or limit this principle, Tesla being the first to reduce it to practice.

As to the Marcel Deprez defense, what Deprez did was to mathematically demonstrate that the polar line of an annular magnet may be shifted the entire circumference of the ring by two magnetizing forces properly related; he showed how a resultant magnetic field could be produced, but he did not describe or suggest apparatus for power. His currents were not the alternating currents of Tesla. Giving the Deprez theorem all the value to which it is entitled, its application by Tesla to the production of a new, original and most beneficial practical result by new and described means and the use of polyphase alternating currents; in brief, by the polyphase system —the apparatus of Tesla nevertheless was an invention of a very high order.

Referring to the Siemens patent of August, 1878, it is stated that the drawings showed direct-current machines and those capable of being both direct and alternating. The part of the specifications upon which the defendants lay stress is as follows: "It is to be understood as stated above that with suitable modifications these apparatus are generally applicable also as rotary transmitting machines, the rotary parts being caused to revolve and give out mechanical power when electricity is applied to them, and thus one of these machines may be driven by any suitable motive power so as to generate electricity, and this electricity may be conducted to a similar machine at a distance, causing it to work and to give out a portion of the power applied in the first instance." The opinion states that no modifications are described, and there is no suggestion that the patentee thought of such connections between the generator and motor, each of two phases, as to preserve the phases of the two and the difference of phase, and that currents should act independently and regularly succeed each other and thereby keep the armature constantly rotated. The hints in the patent respecting the modifications by which the apparatus could be made to give out mechanical power were valueless, as no modifications are described, the kind of apparatus to be modified is uncertain and independence of phase was not in contemplation by the patentee.

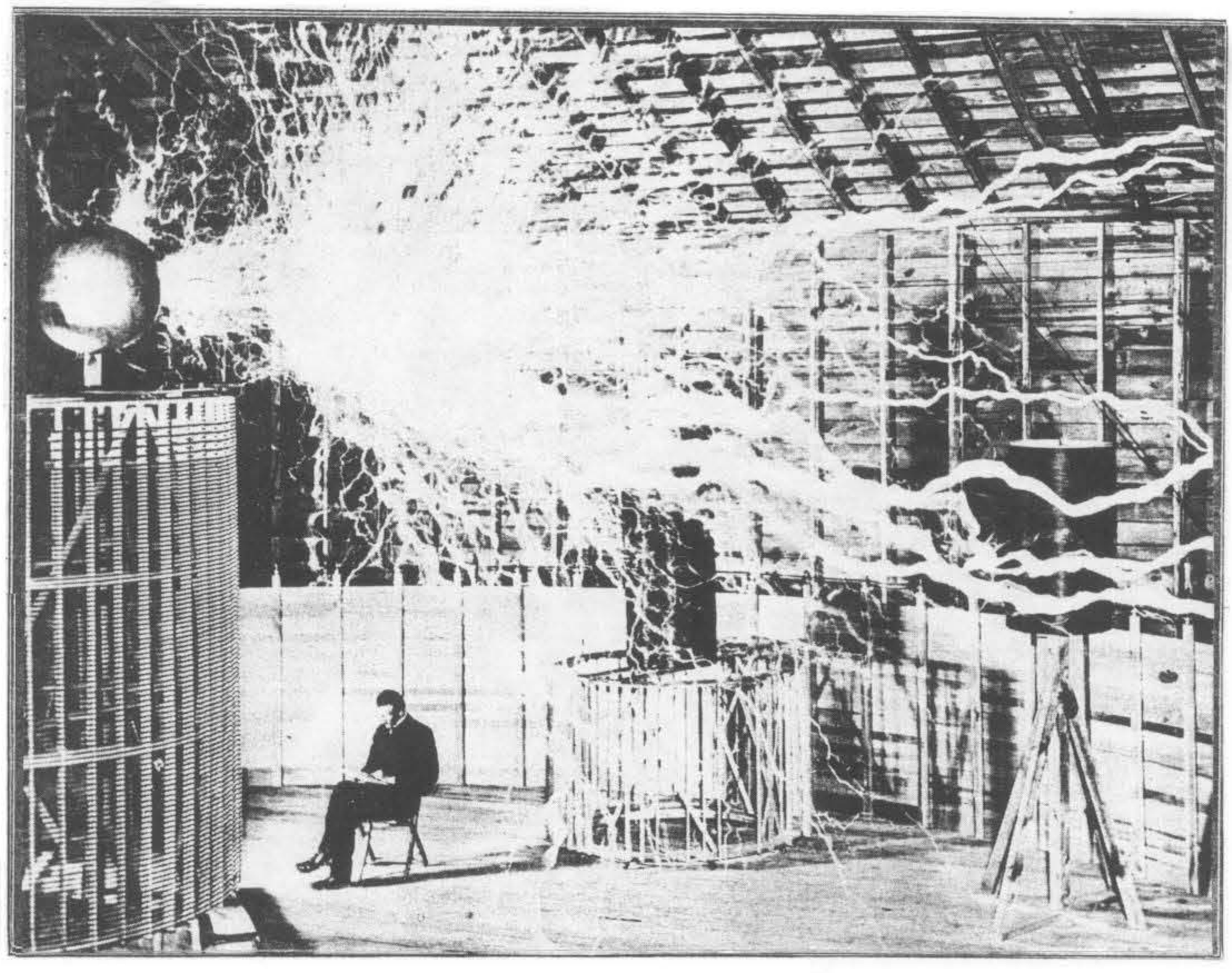
As to the claim that the reversibility of the Siemens or Bradley apparatus followed from a principle universally recognized as to the reversibility of electric machines, it is stated that the reversible principle, while true in regard to direct-current machines, was only a matter of theory and not of practice in regard to alternating-current motors for power purposes. Declarations that such machines could be so reversed so as to furnish power were merely theoretical and gave no information to the inventor of the method by which reversibility was to be made useful to accomplish any result.

As to the point that infringement of the patents in suit is limited to synchronous motors and thereby not infringed by the defendant's induction motor, the opinion says that assuming the patents did describe synchronous motors only, their claims did not make and did not intend to make synchronism a part of either patent, but were for the broadly described invention of "a novel system of electric distribution and transmission of power by means of alternating currents."

Tesla's High-potential Work.

Professor A. Slaby recently delivered a lecture on "The Latest Progress in Spark Telegraphy" before the general meeting of the Verein Deutscher Ingenieure at Kiel, Germany. He spoke of the latest systems of wireless-telegraph apparatus made by the Allegemeine Elektricitäts Gesellschaft and of the possibilities to be expected from space telegraphy in a practical way. At the conclusion of his lecture Professor Slaby showed that the future of spark telegraphy rests essentially in the possibility of producing high electrical pressures.

"What we employ at present for the purpose," said the lecturer, "is a very modest result, if we compare it with what Nikola Tesla, an investigator who lives at present [the lecture was delivered recently, but was evidently prepared some time ago] as a hermit, has shown on the peaks of the Rocky Mountains to very few intimates. Not having been an eye witness, I can only judge from a few photographs which Mr. Tesla sent me a few days ago as a token of friendly consideration. You can see him here for your self [in the accompanying illustration] in his lonely cabin surrounded by artificially produced spark discharges which overshadow everything our most daring imagination might dream of. It is to be hoped that he will put his theoretical knowledge and eminent technical power at the disposal of the practical service of spark telegraphy. We could then expect an immense advancement, which could be placed at the side of the first perception of Marconi.



TESLA'S HIGH-POTENTIAL WORK.

"It has been said that Tesla has not derived any practical results from his experiments, and many have doubted his ability to produce results on account of the poetic and fantastic remarks which he circulated in the daily press. But in the face of the wonderful demonstrations which nature has revealed to us in the mysterious play of the electric spark one involuntarily turns poet. Even such a serious savant as Professor Ayrton cannot restrain himself from day dream, as follows:

"'The day will come, when we are forgotten, when copper wires, gutta-percha coverings and iron armoring will be found only in museums. Then will man, when he desires to speak to his friend and knows not where he is, call with electric voice, which only his friend, who possesses the correspondingly tuned electric ear, can hear. He will ask: "Where art thou?" And the answer will ring into his ear: "I am in the deeps of the mine," or "on the peaks of the Andes" or "on the boundless ocean." Or perhaps no voice will respond, and he knows then that his friend is dead.'

"But science lives eternal, and with the power of youth (so may we add), and draws, for century after century, new treasures from the inexhaustible horn-of-plenty of nature."

Mr. Tesla at Wardenclyffe, L. I.

Note was made recently of the intention of Mr. Nikola Tesla to install a wireless telegraph station for ocean work, at Wardenclyffe, on the north shore of Long Island, and it would now appear that this move on his part may be the beginning of a new industrial center. A circular has just been issued by the Wardenclyffe Building Company, from which some interesting details are gleaned. The place is about 65 miles from New York, or about 1½ hours by fast train on the Long Island Railroad. The company has purchased over 200 lots, and is offering its stock for sale at $100 per share, expecting to pay 15 per cent dividends. As to Mr. Tesla's part in the matter, the circular says: "This property was purchased from the North Shore Industrial Company, which owns an estate of something more than 1600 acres adjoining, under an agreement that the Wardenclyffe Building Company shall have the first right and privilege to do all building and make all constructional improvements of said North

Shore Industrial Company, and shall have the first right of purchase of any additional land offered by it for sale, by and under which *contractual rights large profits will be realized in the future.* In addition to this exceptional advantage, Mr. Nikola Tesla, the foremost electrician of the age, whose achievements in electrical science eclipse in practical importance all other discoveries of the century, has just closed a contract to expend at Wardenclyffe a very large sum of money in constructing electrical laboratories and the main station for his wireless telegraphy system of communication with Europe and Australasia. This development will require a large number of houses for the accommodation of the several hundreds of people whom Mr. Tesla will employ."

Mr. James S. Warden is authority for the statement that the Tesla factory will be 100 ft. square, supplemented by a "wireless" tower 350 ft. high. The walls are already being rapidly run up. Mr. Tesla in addition to the 200 acres on which his factory stands has preempted another 400 acres. The factory will be devoted to the manufacture of electrical instruments invented by Mr. Tesla, of extreme delicacy and complexity. Some 50 hands are to be at work shortly, but, according to Mr. Warden, the ultimate number spoken of is 2000 to 2500. Mr. Tesla is expected to occupy a cottage opposite the Wardenclyffe Inn, which is now being prepared for him. It is said that Mr. Charles R. Flint, the well-known merchant, etc., is back of the real estate enterprise.

The Junior Mumsey November 1901

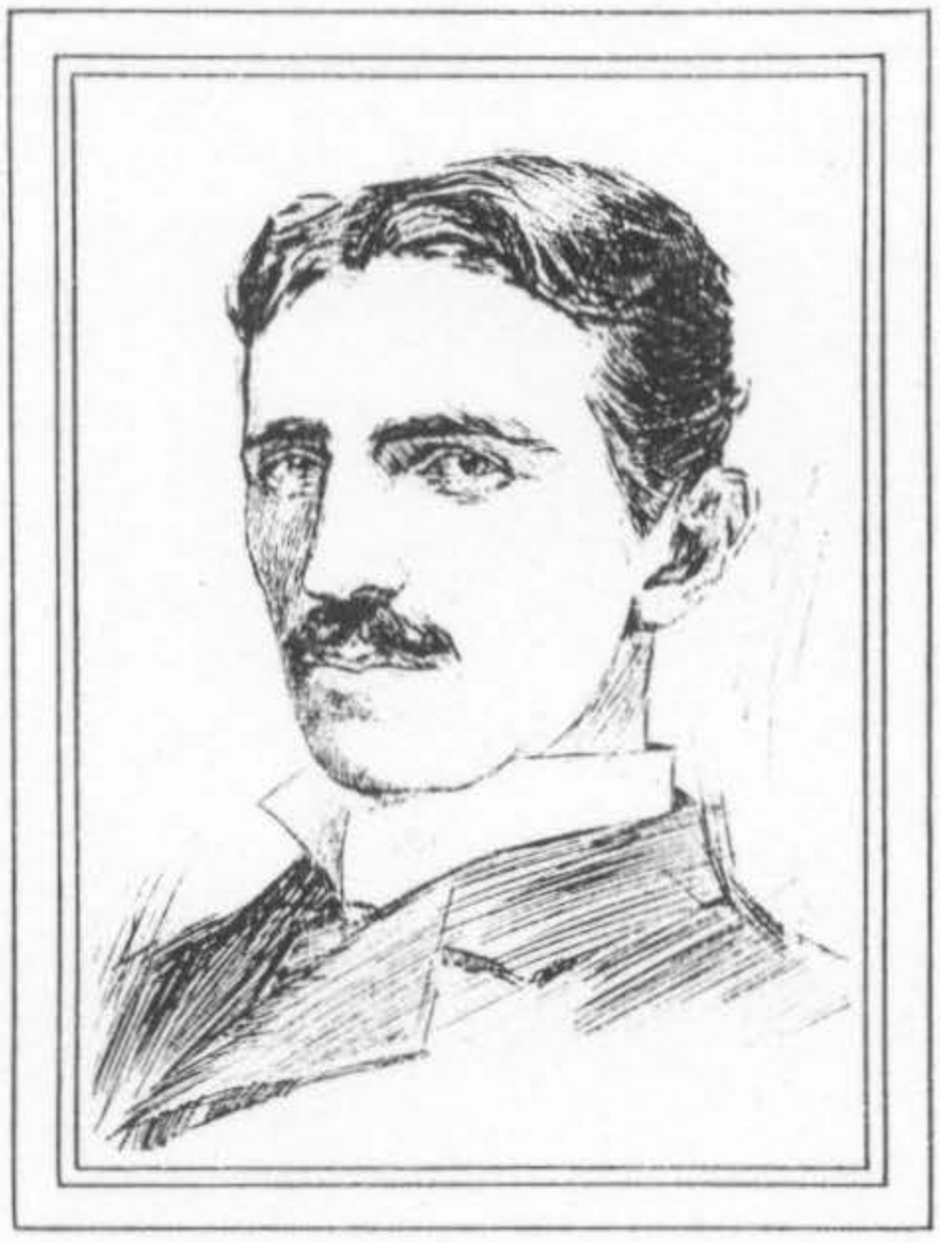
NICOLA TESLA.

BY ELIOT LORD.

A CHARACTER SKETCH OF A STRANGE GENIUS WHO LIVES IN A STRANGE WORLD—HIS CAREFUL SCIENTIFIC TRAINING, SOME OF THE WONDERS HE HAS WROUGHT, AND HIS DREAMS OF THE FUTURE.

NICOLA TESLA and his associates are now building great signal and receiving stations on the Atlantic coast, in this country and Europe, with the declared purpose of sending commercial wireless messages across the ocean before the end of the present year. This is only the preface, in Tesla's view, to the despatch of like messages to any point on the face of the globe, and the possible opening of communication with the nearer planets, like Venus or Mars.

Many ordinary persons and some staid men of science are disposed to class Tesla with Phaethon, who tried to drive the chariot of the sun, or with Icarus, who was so proud of his wings that he flew up into the sky until the wax melted, and he dropped like a spent rocket into the sea. If the Servian genius should fall short, at the outset, in the execution of his design of sending electric signals across the Atlantic without the use of cables or transmitting wires, there will be a shaking of sage heads and testifying "We told you so." Then many will venture to say that the vaulting Tesla is intoxicated with the exuberance of his own conceits, or that he is actually disturbed in brain by the electric atmosphere in which he has enveloped himself, or by the stupendous bolts which he has so boldly shot through his body.



NICOLA TESLA, THE YOUNG SERVIAN WHOSE INVENTIONS AND EXPERIMENTS IN ELECTRICITY HAVE MADE HIM FAMOUS.

Tesla knows this very well, but the thought of what people may say of him or his ventures has never been jarring to his nerves. He is not without sensitiveness. On the contrary, he is deeply touched by cordial appreciation; but he holds that what most people call impossibilities are largely bugbears born of ignorance. When he is once convinced of the feasibility of what he has in hand, no battery of doubts would make him desist from carrying it into effect. This does not mean that he is obstinate against reason. But he is so persistent and resourceful that he has often overcome seemingly insuperable obstacles. In his present undertaking, he has already a practical demonstration of success in sending a wireless message over a stretch of six hundred miles. After this determination of the correctness of the principles in the construction of his signaling system, the extension of distance is with him a matter of detail — the perfecting of the correspondence and sen-

sitiveness of recording instruments. Personally, he has absolutely no fear of failure.

Whatever the issue of his present venture may be, he is entitled to a suspension of judgment until success or failure is proven. No living man has shown any deeper insight into the unfathomed nature and adaptabilities of electricity. No man of his years, probably, has devoted so many hours to the study of electricity as a science in all its varied applications, and few can rival his quickness of apprehension. If he is cocksure of any conclusion in this field, he has certainly an array of reason and evidence in support of his judgment. Moreover, he is not given to vain pretense. No investigator is more modest in his bearing, and no one has been more frank and honest in acknowledging his indebtedness to comrades in the same field or in defining the limits of his attainments. He has never knowingly sought credit for what he has not done.

Undoubtedly he has suffered in reputation from his own offhand speaking and writing. He has not always troubled himself to define precisely what he means in his ready flow of words. Time with him is an infinite stretch, and his anticipation of what men may do is not a prediction of what they will do tomorrow, or next year, or even in the next century. In writing of the probable development of the use of aluminum, for example, he used the word "soon" in a sense so differing from the ordinary that his statement was ridiculed by a leading technical journal. Tesla didn't care enough about the matter to explain his real meaning in any answer. He never denies anything, no matter how absurd, that is written about him. Some irresponsible writers have taken advantage of this, and placed in his mouth outrageously absurd statements which he never uttered; and the alleged interviews that appear constantly in newspapers have done more harm to his standing before the lay world than anything else. They have led many people to look upon Tesla as a *poseur*—a seeker after notoriety. Nothing could be farther from the truth. He does not know of one tenth that is written about him outside of the technical journals.

He has little apparent sensitiveness to attack or ridicule—largely, perhaps, because of his strong vein of humor, as well as the observant sense which led Dr. Johnson to remark that "no man was ever written down except by himself." His temper is naturally buoyant, and, though he can assume marked reserve and dignity when he chooses, he is always quite simple and unaffected in manner.

For a better understanding of what he is now proposing to do and what other aims he has, it is essential to recall who he is and how he has worked.

TESLA'S INHERITANCE OF GENIUS.

Nicola Tesla was born in Smiljan, a town of Lika, a district of southern Austria, near Fiume. He likes to mark the provincial distinction. "I am a Likan by birth," he says. "A Servian? Yes, roundly speaking, as Montenegrins are Servians. Our type is marked like those mountaineers, tall, lean, sinewy, strong—the transmission of the old Slavic physique."

Of this type he might stand as a model. His face is oval, his forehead high and full, and his features generally shapely, though his prominent cheek bones and hollow cheeks are racial. His eyes are dark hazel, not large, but brilliant, and somewhat deeply set. He speaks with animation when he is interested, and his face is then very expressive; but when he is bored all expression vanishes, and while his eyes are open, their sense seems to be shut. The flashing change from immobility to life is peculiar.

For generations the Teslas have been men of mark in their province. Nicola's grandfather fought under Napoleon. His son, Milutin, father of Nicola, was a popular poet before entering the church, in which he rose to the foremost distinction. His varied learning and his proficiency as a linguist were a marvel even to the Likans, who think little of speaking and writing three or four languages. As a Greek scholar, he was second only to Abraham Santa Clara, the most famous preacher of Hungary. His memory was extraordinary. "My father," says Tesla, "knew all our national poetry by heart."

Nicola may trace to his father's impress his own poetic expression and facile mastery of languages, but it is his mother whom he more nearly resembles. Her maiden name was Georgina Mandic. Her family is of the oldest in Hungary, and was long of mark in the church, in which her brother was a bishop. Her father also was a priest, of high standing and of remarkably advanced ideas—a scientific student and inventor, strongly bent on improving the habits of life of his poorer parishioners. He taught them the value of sanitation, and risked his life fearlessly in fighting the spread of disease.

His daughter was no less ardent in sympathy and service. She was only seventeen when the black plague ravaged the country, but she was already an expert and fearless nurse. When a neighbor's family was prostrated by the epidemic, and all the servants fled, she went into the house alone, soothed the last hours of the dying, and when father, mother, and children died, she prepared them for burial. Like her father, she was fond of scientific inquiry, and naturally inventive. Her talent had a practical bent, and she designed a weaving machine for use in her own house. Her eye was so keen and her hands so deft that almost any kind of mechanical work was easy for her. She did in sport feats that would baffle most jugglers. When she was sixty five years old, her son says, she would pluck out an eyelash and tie three knots in it. No woman, he thinks, was ever more surely a helpmate to a husband, and no mother was more devoted to her children.

THE BOYHOOD OF NICOLA TESLA.

Nicola was the second son, one of eight children, of whom six were girls. His elder brother was a lad of extraordinary promise. When he had finished his course in the lyceum, the rector and the full staff of professors accompanied him home, as a mark of the highest honor in their power to show. But a brilliant career was cut short, when he was barely eighteen, by a fall from his horse. Nicola was only a boy of four at the time, but he remembers the scene with the utmost vividness—the dash of the frightened horse and its return, and his mother running over the field and bearing home his brother, mortally hurt.

In the years that followed, the father and mother saw the younger son fulfilling the promise of the older, but every-*thing of note the child did brought tears* to their eyes in recalling his dead brother.

From babyhood Nicola Tesla has been abnormally sensitive to impressions. His earliest recollection is of some one shaking keys before his eyes, while, at the same time, a bell was ringing. To this day whenever there is a rattle of keys near him, he hears the sound of a bell. Up to his twentieth year the sight of anything round and polished was nauseating, and he is still unpleasantly affected by the sight of smooth, round objects. If he takes a goblet of water, he prefers cut glass to molded or blown glass.

He was further troubled by a strange affection of the eye, causing the rising of images so persistent that they marred the vision of real objects, and disturbed his mind. Whenever an object was named to him, its image would appear, at once, so vividly before his eyes that he often believed it real. This illusion caused him such discomfort that he tried his best to break it, but did not succeed until he was twelve years old. Then, for a time, he was able to banish the images, but they have since returned, though less persistently. His later observations have convinced him that these images are really the recalling of former visual impressions, consciously or unconsciously received.

He learned to count almost as soon as he could walk, and has been strangely impelled to keep count of his steps; so the stretches covered in his rambles come up in his mind as chains of steps. His measure of the Brooklyn Bridge is twenty seven hundred steps. He will count, too, any other repeated motion that he makes. He even numbers his bites in eating, and whatever he counts he is impelled to divide by three, or the square or cube of three, if possible. Whatever meets his eye, a house, a ship, a cloud, a mountain, impels him to a mental calculation of its cubic contents.

He constructs in his mind whatever he designs, even to the minutest detail,

but his hand is not ready in committing his designs to paper. He has an ideal, and is impatient of any deviation from it, even if it is merely the slope of a letter. So he may begin to write and tear up fifty sheets of note paper, if the slope of a line is vexing.

Going to school when he was five, he was quick to learn in any study attractive to him. In the schools of Austria Hungary, the first place is given to mathematics, supplemented in the more advanced schools by physics. Languages, history, bookkeeping, and drawing are the other leading features of the school course. Mathematics was of absorbing interest to Nicola, and he applied himself with energy to all other branches of study except drawing, which he disliked. When he was graduated from the lyceum at Carlstadt, the head master told him that he would have broken the record if he had been a good draftsman.

AT THE GRATZ POLYTECHNIC SCHOOL.

Just as he was leaving school there was an epidemic of cholera, and he was taken sick as he went up the steps to his home. Dropsy developed from this attack. The attending physician would give his parents no hope, but, in the intervals of his fainting from weakness, the boy told his father that he would get well if he could have the hope of going to the Polytechnic School at Gratz instead of preparing to enter the service of the church—the career designed for him. When this promise was made, he began to recover, to the surprise of every one except himself, and, before long, he was able to enter the school of his choice, one of the oldest technical schools in Europe.

Here, in lines of study appealing to his taste, there was no check to his application. He rose at three o'clock in the morning to begin his work, and did not go to bed till nearly midnight. In one year he ran through the courses of five years. No student before him had ever gone so fast. His professors admired his spirit, but tried to hold it in check. When the certificates of his progress were sent to his father, accompanying letters announced that the lad was killing himself by overwork. So his father never expressed any satisfaction with his son's progress, but wrote to him discouragingly, and insisted on his remaining in school for the full five years of the course. The first year's work left so little to be mastered in the regular course of study that for the next three years Tesla was delving in the libraries and undertaking special lines of research.

THE BEGINNING OF TESLA'S CAREER.

The study of electricity attracted him greatly, and he availed himself eagerly of the instruction of Professor Poeschl and other leading physicists. From Gratz he went to Prague to continue his studies for two years longer. "I was eighteen years at school," he says. The patient perseverance shown in laying such a foundation for his practical undertakings is characteristic. So, too, was his first occupation after leaving school.

The first opening offered him was that of a draftsman in the government railway service at Budapest. "This seemed to me," he says, "the irony of fate, a chance to put my worse foot forward; but I wanted work whether I liked it or not." After showing his proficiency in varied telegraphic work, his first signal opportunity came in the call to install one of the largest telephone stations in Europe at Budapest. Then the range of his proficiency was further shown in his engagement to put an electric lighting plant and stations in Strasburg, one of the most elaborate in the world at that time. Shortly after this successful installation he went to Paris, and made such important improvements in dynamos for the Edison Company that he was engaged to continue his work in this country, and crossed the Atlantic in 1884.

Outside of his accomplishments in the advance of electric lighting, he was particularly devoted to the investigation of the problem of the transmission of power by electric agencies. This had been pressing on his mind from the day when the working of the Gramme machine was first demonstrated to him by Professor Poeschl at Gratz. When he saw the production of a magnetic pole by the revolving of a cumbrous, wire wound

wheel or ring, the thought came to him: "Why should it not be possible to produce a magnetic whirl instead of an inert, static thing?" Would it not be far better, in other words, if one could make the magnetic force go round instead of the ponderous ring? Surely, but how? It is much simpler to conceive a grand transformation than to effect one. But Tesla was not deterred by the perplexities of the task. Year by year he advanced nearer to its attainment, and in 1883 he constructed the first working model of his perfected design, technically known as the Tesla rotating field.

One of the most amusing sights in his laboratory today is the demonstration of this conversion. Older children than *Toddy* would be puzzled to find out what makes the things go round when Tesla sets spindles and tops and balls revolving and circling about within the invisible ring of his rotating magnetism. "See my parody of the earth and the planets," says Tesla, dropping globes of various sizes into the ring. "Now you may see the spinning reversed;" and he sets spindles outside the ring that begin to revolve in the opposite direction. "Columbus, you know, made an egg stand on end by breaking the shell. Now, I can make eggs stand on end without breaking shells, as you see this one spinning off on its point." So he juggles in boyish spirit with his discovery, but it is none the less one of the prime factors in the present successful conversion and transmission of energy. More than any other invention, it rendered practicable the harnessing of the falls of Niagara, and the utilization of their power in electric service many miles away.

THE PURPOSES OF TESLA'S WORK.

In the perfecting of this device and other adaptations for the electric transmission of power, Tesla was largely engrossed until 1887, when his patents were purchased by the Westinghouse Company. His contribution to the perfecting of electric converters and transmitters was soon universally recognized to be of the foremost importance. If his bent had been towards money making, he might have piled up a fortune; but, while he was not indifferent to the winning of money, he had higher ambitions, and money is never likely to be more to him than the means that must be used to reach the ends that he aims at.

"I have no time to make money," said Agassiz with noble sincerity. It cannot be justly doubted that Tesla, without any pretense of unselfishness, has been possessed by a like spirit. To work is with him an impulse of conscience. In his view, the betterment of the conditions of living, and the advance of humanity, depend on the increase of human energy. "Persistent effort, useful and accumulative, with periods of rest and recuperation aiming at higher effiecieney," is the way he sums up his rule of living, but the periods of rest are very short and very few.

Broadly speaking, there are three main requisites, in his mind, for the increase of energy—food, peace, work. It has been his constant study to promote these essentials. From his point of view, the slaughter of animals is commonly wanton and cruel, for the use of meat is economically wasteful, if its nutriment is compared with some plant foods. He thinks that oatmeal is superior to meat, weight for weight, in flesh, bone, and brain building, while it has the obvious advantage in cheapness. So he is an ardent advocate of vegetarianism, and goes so far as to attribute animal instincts and appetites, which are drag weights upon mental and moral progress, to the consumption of animal food. Thus one of his prescriptions for human progress is a radical reform in the character of food.

THE CHEAP PRODUCTION OF NITROGEN.

He thinks that with this economic and helpful change there would be a material advance; but the advance may be immensely extended by increasing the productivity of the soil. While recognizing the high importance of irrigation, the preservation of forests, and other aids to this end, the prime requisite, in his judgment, is artificial fertilization, especially by the cheap production of the compounds of nitrogen. He looks to the atmosphere as the chief available source of nitrogen in practically inexhaustible amounts. How to

extract and fix the nitrogen is a problem, therefore, which he has long labored to solve.

There is great difficulty in it, for this element is so extraordinarily inert that it will not combine even with oxygen under normal conditions. But Tesla has demonstrated that electricity is so stimulating to dormant affinities that nitrogen electrically excited will burn. In 1891 he showed the feasibility of the oxidation of nitrogen in a small way by the production of a novel form of electric flame, named "St. Elmo's hot fire." The electric discharge of flame produced was only three or four inches in length, and the combustion was comparatively trivial and wasteful. It was necessary to extend it greatly to make the utilization of nitrogen of any practical service.

This extension Tesla has succeeded in effecting, greatly stimulating the chemical activity of the electric brush discharge by using electric currents of extremely high frequency or rate of vibration. Without following the technical steps of his advance, it is sufficient to note that he has succeeded in developing the insignificant brush discharge, a few inches long, into "a marvelous electrical phenomenon—a roaring blaze, devouring the nitrogen of the atmosphere and spanning a distance of seventy feet."

He has now made it practicable, as he says, to oxidize the atmospheric nitrogen in practically unlimited quantities by the use of cheap mechanical power and simple electrical apparatus. In this way many compounds of nitrogen may be manufactured all over the world, and by means of these compounds the soil may be fertilized and its productiveness indefinitely increased, assuring an abundance of cheap and helpful food. If future developments sustain his claim, this service alone should bring to him imperishable honor.

OTHER IRONS IN TESLA'S FIRE.

His undertaking for the promotion of peace may be no less notable. It was his idea to produce an arm for attack, adaptable to submarine and aërial warfare, so formidable that its development will ultimately make war a mere contest of machines—a condition that must be reached, to his mind, before permanent peace can be secured. He has been constructing automatic machines in the form of a torpedo to be completely controlled by the impress of electric vibrations. The possible variations and stretch of this design, in Tesla's view, are so far reaching that all fighting on sea and land may be carried on by these electrified automata. To the ordinary reader all this seems more incredible than any conceit of the romancers, but who dares say that it may not again be demonstrated that truth is stranger than fiction?

In the extension of wireless telegraphy there is to be a demonstration of the novel force which Tesla has been adapting to the production of nitrogen compounds and automatic engines of war. Twelve years ago he began the experiments which have led to his present undertaking, by studying the possibilities offered by extremely rapid electrical oscillation, and undertaking the construction of special machines for this investigation. One of his first observations was the effect of rapid electric oscillations on the human body. In his own person he demonstrated repeatedly that powerful electrical discharges of several hundred thousand volts, which were then considered absolutely deadly, could be passed through a man's body without any injury. He has produced oscillations of such intensity that while circulating through his arms and chest they have melted wires that joined his hands. Now he says that he would not hesitate to transmit through his body with such very rapidly vibrating electric currents the entire electrical energy of the dynamos now working at Niagara. The results of this application are now utilized in medical service, and promise to be of much importance.

The production of light by means of these electric oscillations was another signal advance which promises to lead to an ideal system of electric illumination by vacuum tubes, dispensing with the renewal of lamps or incandescent filaments. Already, as Tesla says, he has succeeded in lighting in this manner from four to five hundred lamps at once, and could light as many more. The efficiency of the light increases in propor-

tion to the rate of the oscillations, and its commercial success is therefore dependent on the economical production of high electrical vibrations. This production Tesla is confident of effecting.

A NEW FORM OF WIRELESS TELEGRAPHY.

In line with these advances was the adaptation of electric oscillation to wireless telegraphy. In its basic principle the system devised by Tesla is very simple. Imagine two tuning forks set up on opposite sides of a large room. To the lower prong of each of these forks a piston is attached, fitting in a cylinder. Both cylinders communicate with a reservoir with elastic walls—closed at the top and filled with a light and incompressible fluid. If a prong of one of these tuning forks is struck repeatedly, the small connected piston will be vibrated and the vibrations transmitted through the fluid in the reservoir to the opposite fork, which is "tuned" precisely alike. This vibration can readily be utilized to make an electric record of a message.

Now suppose, in place of common tuning forks with piston attachments, that vertical wires are substituted. Let the earth take the place of the closed reservoir with elastic walls, and let electricity be the light and incompressible fluid. Then, instead of striking the forks, if electrical oscillations are produced in one vertical wire, used as a transmitter, they will spread through the ground and reach the distant vertical receiving wire, setting a sensitive device in action to record messages. By a simple provision, each of the two wires can be used in turn to send and receive the messages. By employing relay stations with "tuned" circuits, it will be practicable, as Tesla holds, to transmit signals to any point of the globe.

For practical service it was necessary to design and complete an efficient apparatus for the production of very powerful electrical oscillations. This was effected by a novel combination of an electric condenser with a transformer or induction coil. The electrical oscillator thus made is of tremendous power and still greater possibilities. By its means an electric discharge or flash more than one hundred feet long has been made, and Tesla anticipates the production of flashes one hundred times as great. With its aid he has produced electrical movement at the rate of one hundred thousand horse power, and he says that rates of ten million horse power are easily practicable. By this agency not only can telegraphic messages be transmitted across the ocean without cables, as he claims and proposes to demonstrate, but the transmission of thousands of horse power of electric energy may be made through the atmosphere over hundreds and even thousands of miles.

It is certain that the world will watch intently the first public trials of this marvelous system for developing wireless telegraphy.

Tesla's Method of Increasing the Intensity of Electrical Oscillations.

Nikola Tesla still continues his interesting experiments with electrical vibrations, upon which he has been engaged for the last 10 years. Among the patents issued from the United States Patent Office on October 22d was one granted to him for "Means for Increasing the Intensity of Electrical Oscillations." The patent is numbered 685,012, and the application for it was filed March 21, 1900, and renewed July 3, 1901. Mr. Tesla describes his invention in the following language:

"In many scientific and practical uses of electrical impulses or oscillations—as, for example, in systems of transmitting intelligence to distant points—it is of great importance to intensify as much as possible the current impulses or vibrations which are produced in the circuits of the transmitting and receiving instruments, particularly of the latter.

"It is well known that when electrical impulses are impressed upon a circuit adapted to oscillate freely the intensity of the oscillations developed in the same is dependent on the magnitude of its physical constants and the relation of the periods of the impressed and of the free oscillations. For the attainment of the best result it is necessary that the periods of the impressed should be the same as that of the free oscillations, under which conditions the intensity of the latter is greatest and chiefly dependent on the inductance and resistance of the circuit, being directly proportionate to the former and inversely to the latter. In order, therefore, to intensify the impulses or oscillations excited in the circuit—in other words, to produce the greatest rise of current or electrical pressure in the same—it is desirable to make its inductance as large and its resistance as small as practicable. Having this end in view, I have devised and used conductors of special forms and of relatively very large cross-section; but I have found that limitations exist in regard to the increase of the inductance as well as to the diminution of the resistance. This will be understood when it is borne in mind that the resonant rise of current or pressure in a freely oscillating circuit is proportionate to the frequency of the impulses, and that a large inductance in general involves a slow vibration. On the other hand, an increase of the section of the conductor with the object of reducing its resistance is, beyond a certain limit, of little or no value, principally because electrical oscillations, particularly those of high frequency, pass mainly through the superficial conducting layers, and, while it is true that this drawback may be overcome in a measure by the employment of thin ribbons, tubes, or standard cables, yet, in practice, other disadvantages arise, which often more than offset the gain.

"It is a well-established fact that as the temperature of a metallic conductor rises its electrical resistance increases, and, in recognition of this, constructors of commercial electrical apparatus have heretofore resorted to many expedients for preventing the coils and other parts of the same from becoming heated when in use, but merely with a view to economizing energy and reducing the cost of construction and operation of the apparatus.

"Now I have discovered that when a circuit adapted to vibrate freely is maintained at a low temperature the oscillations excited in the same are to an extraordinary degree magnified and prolonged, and I am thus enabled to produce many valuable results which have heretofore been wholly impracticable.

"Briefly stated, then, my invention consists in producing a great increase in the intensity and duration of the oscillations excited in a freely vibrating or resonating circuit by maintaining the same at a low temperature.

"Ordinarily, in commercial apparatus, such provision is made only with the object of preventing wasteful heating, and in any event its influence upon the intensity of the oscillations is very slight and practically negligible, for, as a rule, impulses of arbitrary frequency are impressed upon a circuit, irrespective of its own free vibrations, and a resonant rise is expressly avoided.

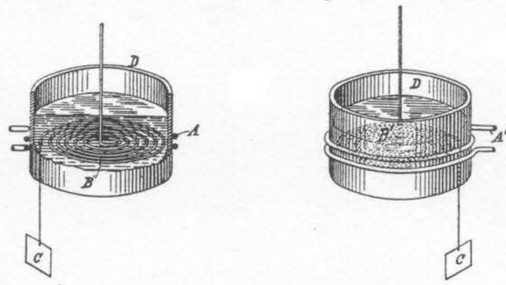
"My invention, it will be understood, does not primarily contemplate the saving of energy, but aims at the attainment of a distinctly novel and valuable result—that is, the increase to the greatest practicable degree of the intensity and duration of free oscillations. It may be usefully applied in all cases when this special object is sought, but offers exceptional advantages in those instances in which the freely oscillating discharges of a condenser are utilized.

"The best and most convenient manner of carrying out the invention of which I am now aware is to surround the freely vibrating circuit or conductor, which is to be maintained at a low temperature, with a suitable cooling medium, which may be any kind of freezing mixture or agent, such as liquid air, and in order to derive the fullest benefit from the improvement the circuit should be primarily constructed so as to have the greatest possible self-induction and the smallest practicable resistance, and other rules of construction which are now recognized should be observed. For example, when in a system of transmission of energy for any purpose through the natural media the transmitting and receiving conductors are connected to earth and to an insulated terminal, respectively, the lengths of these conductors should be one-quarter of the wave length of the disturbance propagated through them.

"In the accompanying drawing I have shown graphically a disposition of apparatus which may be used in applying practically my invention.

"The drawing illustrates in perspective two devices, either of which may be the transmitter, while the other is the receiver. In each there is a coil of few turns and low resistance, designated in one by (A) and in the other by (A′). The former coil, supposed to be forming part of the transmitter, is to be connected with a suitable source of current, while the latter is to be included in circuit with a receiving device. In inductive relation to said coils in each instrument is a flat, spirally wound coil (B) or (B′), one terminal of which is shown as connected to a ground plate (C), while the other, leading from the center, is adapted to be connected to an insulated terminal, which is generally maintained at an elevation in the air. The coils (B B′) are placed in insulating receptacles (D), which contain the freezing agent, and around which the coils (A) and (A′) are wound.

"Coils in the form of a flat spiral, such as those



TESLA'S METHOD OF INCREASING THE INTENSITY OF ELECTRICAL OSCILLATIONS.

described, are eminently suited for the production of free oscillations; but obviously conductors or circuits of any other form may be used, if desired.

"From the foregoing the operation of the apparatus will now be readily understood. Assume, first, as the simplest case that upon the coil (A) of the transmitter impulses or oscillations of an arbitrary frequency and irrespective of its own free vibrations are impressed. Corresponding oscillations will then be induced in the circuit (B), which, being constructed and adjusted, as before indicated, so as to vibrate at the same rate, will greatly magnify them, the increase being directly proportionate to the product of the frequency of the oscillations and the inductance of circuit (B) and inversely to the resistance of the latter. Other conditions remaining the same, the intensity of the oscillations in the resonating circuit (B) will be increased in the same proportion as its resistance is reduced. Very often, however, the conditions may be such that the gain sought is not realized directly by diminishing the resistance of the circuit. In such cases the skilled expert who applies the invention will turn to advantage the reduction of resistance by using a correspondingly longer conductor, thus securing a much greater self-induction, and under all circumstances he will determine the dimensions of the circuit, so as to get the greatest value of the ratio of its inductance as to its resistance, which determines the intensity of the free oscillations. The vibrations of coil (B), greatly strengthened, spread to a distance, and on reaching the tuned receiving conductor (B′) excite corresponding oscillations in the same, which, for similar reasons, are intensified, with the result of inducing correspondingly stronger currents or oscillations in circuit (A′), including the receiving device. When, as may be the case in the transmission of intelligible signals, the circuit (A) is periodically closed and opened, the effect upon the receiver is heightened in the manner above described, not only because the impulses in the coils (B) and (B′) are strengthened, but also on account of their persistence through a longer interval of time. The advantages offered by the invention are still more fully realized when the circuit (A) of the transmitter instead of having impulses of an arbitrary frequency impressed upon it is itself permitted to vibrate at its own rate, and more particularly so if it be energized by the freely oscillating high-frequency discharges of a condenser. In such a case the cooling of the conductor (A), which may be effected in any suitable manner, results in an extraordinary magnification of the oscillation in the resonating circuit (B), which I attribute to the increased intensity as well as greater number of the high-frequency oscillations obtained in the circuit (A). The receiving coil (B′) is energized stronger in proportion and induces currents of greater intensity in the circuit (A′). It is evident from the above that the greater the number of the freely vibrating circuits which alternately receive and transmit energy from one to another the greater, relatively, will be the gain secured by applying my invention."

MR. TESLA'S method of utilizing electrical effects transmitted through earth or air is described in this issue, the description being based on a careful examination of six United States patents issued last week and being largely in the language of the inventor himself. Mr. Tesla has devised a novel method of "effecting during any desired time interval a storage of energy derived from such [long-distance electrical] impulses and utilizing the potential energy so obtained for operating a receiving device." The "storage device" which Mr. Tesla prefers to use is a condenser, which allows the energy of the succeeding impulses to be accumulated for a sufficient length of time and then discharged instantaneously in a manner said to be highly effective. The inventor says that by the use of his invention results hitherto unattainable in utilizing disturbances or effects transmitted very great distances through natural media may be readily attained. Perhaps this means that wireless transmission across the Atlantic is really in contemplation. At any rate, the patents are of great interest and contain within themselves their best interpretation.

Tesla's Utilization of Electrical Effects and Radiant Energy.

Following close upon the patent for "Means for Increasing the Intensity of Electrical Oscillations" that was granted to Nikola Tesla on October 22d (illustrated description of which was given in the Western Electrician of November 2d) comes a series of six patents relating to the utilization of radiant energy and effects transmitted through natural media, such as the air and earth, that, seemingly, are of much greater importance. These patents, numbered consecutively from 685,953 to 685,958, were issued by the United States Patent Office on November 5th. From their evident basic nature the patents may have an important bearing upon the project for the transmission of messages long distances through space, which Mr. Tesla is known to have been working upon for some time.

In his introductory remarks Mr. Tesla recognizes that in wireless telegraphy, as commonly known, the electrical impulses reach a very distant receiving station in an extremely feeble and attenuated condition. So extremely feeble are these impulses that it is easy to discern the limitations of wireless telegraphy as to-day practiced.

Generally expressed, Mr. Tesla seeks to achieve results hitherto unobtainable in utilizing the feeble electrical effects transmitted through the air or the earth, by accumulating in a "storage device" the energy of succeeding impulses for a sufficient interval of time to render the sudden liberation of the accumulated charge highly effective in operating a receiver. He uses as a "storage device" a condenser. This he deems the most efficient electrical storage device known to him for this purpose.

A crude illustration of the method underlying the patents may be taken by considering a small waterwheel and a tiny stream of water—so tiny that one could hardly see or feel it—a stream that comes really not in a steady stream but in impulses, so to speak, one little spurt of water at a time. The question of having this tiny stream of impulses, each impulse having but very little energy, move and drive a comparatively bulky waterwheel is somewhat analogous to the problem Mr. Tesla has undertaken to solve—that of utilizing the feeble electrical effects transmitted through a considerable distance. In the hydraulic analogy a solution would be to collect the water of the tiny stream in a reservoir, and, when enough has accumulated to produce the desired movement, to turn it upon the wheel. Mr. Tesla's solution of the electrical problem is to employ a "storage device"—preferably a condenser.

The six patents to be described may be considered in three sets of two each. In patent No. 685,954, the application for which was filed on August 1, 1899, and renewed on May 29, 1901, the inventor describes a "Method of Utilizing Effects Transmitted Through Natural Media." In describing his invention Mr. Tesla writes as follows:

"My invention is particularly useful in connection with methods and apparatus for operating distant receiving devices by means of electrical disturbances produced by proper transmitters and conveyed to such receiving devices through the natural media; but it obviously has a wider range of applicability and may be employed, for example, in the investigation or utilization of terrestrial, solar, or other disturbances produced by natural causes.

"Several ways or methods of transmitting electrical disturbances through the natural media and utilizing them to operate distant receivers are now known and have been applied with more or less success for accomplishing a variety of useful results.

"One of these ways consists in producing, by a suitable apparatus, rays or radiations—that is, disturbances—which are propagated in straight lines through space, directing them upon a receiving or recording apparatus at a distance, and thereby bringing the latter into action. This method is the oldest and best known and has been brought particularly into prominence in recent years through the investigations of Heinrich Hertz.

"Another method consists in passing a current through a circuit, preferably one enclosing a very large area, inducing thereby in a similar circuit situated at a distance another current and affecting by the same in any convenient way a receiving device.

"Still another way, which has also been known for many years, is to pass in any suitable manner a current through a portion of the ground, as by connecting to two points of the same, preferably at a considerable distance from each other, the two terminals of a generator and to energize by a part of the current diffused through the earth a distant circuit, which is similarly arranged and grounded at two points widely apart and which is made to act upon a sensitive receiver.

"These various methods have their limitations, one especially, which is common to all, being that the receiving circuit or instrument must be maintained in a definite position with respect to the transmitting apparatus, which often imposes great disadvantages upon the use of the apparatus.

"In several applications filed by me and patents granted to me I have disclosed other methods of accomplishing results of this nature, which may be briefly described as follows: In one system the potential of a point or region of the earth is varied by imparting to it intermittent or alternating electrifications through one of the terminals of a suitable source of electrical disturbances, which, to heighten the effect, has its other terminal connected to an insulated body, preferably of large surface and at an elevation. The electrifications communicated to the earth spread in all directions through the same, reaching a distant circuit, which generally has its terminals arranged and connected similarly to those of the transmitting source and operates upon a highly sensitive receiver.

"Another method is based upon the fact that the atmospheric air, which behaves as an excellent insulator to currents generated by ordinary apparatus, becomes a conductor under the influence of currents or impulses of enormously high electromotive force which I have devised means for generating. By such means air strata, which are easily accessible, are rendered available for the production of many desired effects at distances however great. This method, furthermore, allowed advantage to be taken of many of those improvements which are practicable in the ordinary systems of transmission involving the use of a metallic conductor.

"Obviously, whatever method be employed, it is desirable that the disturbances produced by the transmitting apparatus should be as powerful as possible, and by the use of certain forms of high-frequency apparatus which I have devised and which are now well known, important practical advantages are in this respect secured.

"Furthermore, since in most cases the amount of energy conveyed to the distant circuit is but a minute fraction of the total energy emanating from the source, it is necessary, for the attainment of the best results, that whatever the character of the receiver and the nature of the disturbances as much as possible of the energy conveyed should be made available for the operation of the receiver, and, with this object in view, I have, heretofore, among other means, employed a receiving circuit of high self-induction and very small resistance and of a period such as to vibrate in synchronism with the disturbances, whereby a number of separate impulses from

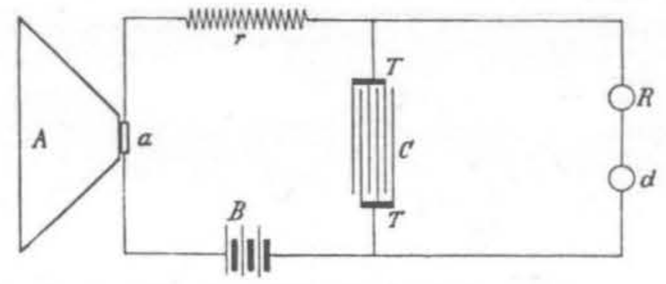


FIG. 1. TESLA'S UTILIZATION OF ELECTRICAL EFFECTS AND RADIANT ENERGY.—ARRANGEMENT OF RECEIVING APPARATUS.

the source were made to co-operate, thus magnifying the effect exerted upon and insuring the action of the receiving device. By these means decided advantages have been secured in many instances; but very often the improvement is either not applicable at all, or, if so, the gain is very slight.

"Evidently, when the source is one producing a continuous pressure or delivering impulses of long duration, it is impracticable to magnify the effects in this manner, and when, on the other hand, it is one furnishing short impulses of extreme rapidity of succession, the advantage obtained in this way is insignificant, owing to the radiation and the unavoidable frictional waste in the receiving circuit. These losses reduce greatly both the intensity and the number of the co-operative impulses, and, since the initial intensity of each of these is necessarily limited only an insignificant amount of energy is thus made available for a single operation of the receiver. As this amount is consequently dependent on the energy conveyed to the receiver by one single impulse, it is evidently necessary to employ either a very large and costly, and therefore objectionable transmitter or else to resort to the equally objectionable use of a receiving device too delicate and too easily deranged. Furthermore, the energy obtained through the co-operation of the impulses is in the form of extremely rapid vibrations, and, because of this, unsuitable for the operation of ordinary receivers, the more so as this form of energy imposes narrow restrictions in regard to the mode and time of its application to such devices.

"To overcome these and other limitations and disadvantages that have heretofore existed in such systems of transmission of signals or intelligence and to render possible an investigation of impulses or disturbances propagated through the natural media from any kind of source and their practical utilization for any purpose to which they are applicable, I have devised a novel method, which, broadly stated, consists in effecting during any desired time interval a storage of energy derived from such impulses and utilizing the potential energy so obtained for operating a receiving device.

"The best way of carrying out my invention which I at present know is to store electrical energy obtained from a suitable electrical generator in a condenser and to control the storage or the application of this energy by means of a sensitive device acted upon by the effects or disturbances, and thereby cause the operation of the receiver.

"The general principle underlying my invention and the operation of the various devices used will be clearly understood by a reference to the accompanying drawing (Fig. 1), which is a diagram illustrating a typical arrangement of apparatus which may be used in carrying my method into practice.

"In Fig. 1 (C) is a condenser, to the terminals (T) and (T) of which is connected a charging circuit including a battery (B), a sensitive device (a), and a resistance (r), all connected in series, as illustrated. The battery should be preferably of very constant electromotive force and of an intensity carefully determined to secure the best results. The resistance (r), which may be a frictional or an inductive one, is not absolutely necessary; but it is of advantage to use it in order to facilitate adjustment, and for this purpose it may be made variable in any convenient and preferably continuous manner.

"Assuming that the disturbances which are to be investigated or utilized for some practical end are rays identical with or resembling those of ordinary light, the sensitive device (a) may be a selenium cell properly prepared, so as to be highly susceptible to the influence of the rays, the action of which should be intensified by the use of a reflector (A), shown in the drawing. It is well known that when cells of this kind are exposed to such rays of greatly varying intensity they undergo corresponding modifications of their electrical resistance; but in the ways they have been heretofore used they have been of very limited utility.

"In addition to the circuit including the sensitive device or cell (a), another circuit is provided, which is likewise connected to the terminals (T) (T) of the condenser. This circuit, which may be called the 'receiving circuit,' includes the receiver (R), and in series with it a device (d) before referred to, which performs the duty of periodically discharging the condenser through the receiver.

"From the foregoing the operation of the apparatus as illustrated in Fig. 1 will be at once understood. Normally—that is, when it is not influenced by the rays at all or very slightly—the cell (a) being of a comparatively high resistance, permits only a relatively feeble current to pass from the battery into the condenser, and hence the latter is charged at too slow a rate to accumulate during the time interval between two succeeding operations of the device (d), sufficient energy to operate the receiver, or, generally speaking, to produce the required change in the receiving circuit.

"This condition is readily secured by a proper selection and adjustment of the various devices described, so that the receiver will remain unresponsive to the feeble discharges of the condenser, which may take place when the cell (a) is acted upon but slightly or not at all by the rays or disturbances; but if now new rays are permitted to fall upon the cell or if the intensity of those already acting upon it be increased by any cause, then its resistance will be diminished and the condenser will be charged by the battery at a more rapid rate, enabling sufficient potential energy to be stored in the condenser during the period of inaction of the device (d) to operate the receiver or to bring about any desired change in the receiving circuit when the device (d) acts.

"If the rays acting upon the cell or sensitive device (a) are varied or intermitted in any arbitrary manner, as when transmitting intelligence in the usual way from a distant station by means of short and long signals, the apparatus may readily be made to record or to enable an operator to read the message, since the receiver, supposing it to be an ordinary magnetic relay, for example, will be operated by each signal from the sending station a certain number of times having some relation to the duration of each signal. It will be readily seen, however, that if the rays are varied in any other way, as by impressing upon them changes in intensity, the succeeding condenser discharges will undergo corresponding changes in intensity, which may be indicated or recorded by a suitable receiver and distinguished irrespectively of duration.

"It will be observed that the condenser is an important element in the combination. I have shown that, by reason of its unique properties, it greatly adds to the efficacy of this method. It allows the energy accumulated in it to be discharged instantaneously, and therefore in a highly effective manner. It magnifies in a large degree the current supplied from the battery, and, owing to these features, it permits energy to be stored and discharged at practically any rate desired, and thereby makes it possible to receive in the retaining circuit very great changes of the current strength by impressing upon the battery current very small variations. Other means of storage possessing these characteristics to a useful degree may be employed without departing from the broad spirit of my invention; but I prefer to use a condenser, since, in these respects, it excels any other storage device of which I have knowledge.

"By carefully observing well-known rules of scientific design and adjustment of the instruments the apparatus may be made extremely sensitive and capable of responding to the feeblest influences, thus making it possible to utilize impulses or disturbances transmitted from very great distances and too feeble to be detected or utilized in any of the ways heretofore known, and, on this account, the method here described lends itself to many scientific and practical uses of great value."

Patent No. 685,956, the application for which is a division of the original application which included

[*Continued on page 326*]

Tesla's Utilization of Electrical Effects and Radiant Energy.

[*Continued from page 323.*]

the preceding patent, covers the "Apparatus for Utilizing Effects Transmitted Through Natural Media" and is essentially the same as the "method" patent just described.

To intensify the feeble and attenuated electrical effects referred to in the first patent, Mr. Tesla employs a method, the apparatus for which is diagramatically illustrated in Fig. 2. This method is patented under No. 685,953, while the apparatus therefor is covered by patent No. 685,955, its application being a division of the original "method" application, which was filed on June 24, 1899, and renewed on May 29, 1901.

This apparatus consists of a cylinder (A) of insulating material, which is moved at a uniform rate

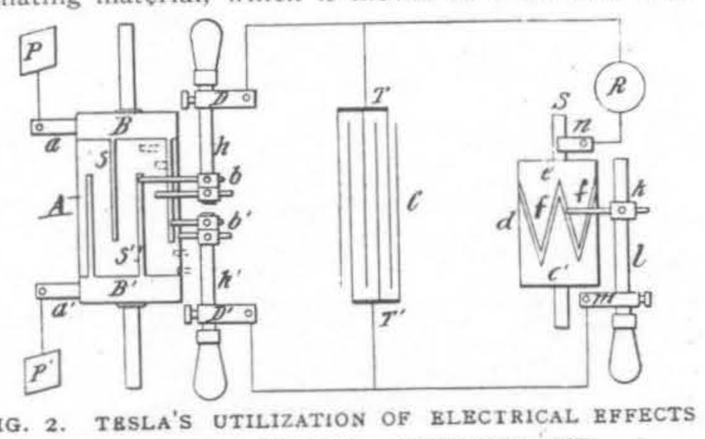


FIG. 2. TESLA'S UTILIZATION OF ELECTRICAL EFFECTS AND RADIANT ENERGY.—APPARATUS FOR INTENSIFYING EFFECTS.

of speed by clockwork or other suitable motive power, and is provided with two metal rings (B) (B'), upon which bear brushes (a) and (a'), which are connected, respectively, to the terminal plates (P) and (P'). From the rings (B) (B') extend narrow metallic segments (s) and (s'), which, by the rotation of the cylinder (A) are brought alternately into contact with double brushes (b) and (b'), carried by and in contact with conducting holders (h) and (h'), which are adjustable longitudinally in the metallic supports (D) and (D'). The latter are connected to the terminals (T) and (T') of a condenser (C), and are capable of angular displacement, as ordinary brush supports. The object of using two brushes, as (b) and (b'), in each of the holders (h) and (h'), is to vary at will the duration of the electric contact of the plates (P) and (P') with the terminals (T) and (T'), to which is connected a receiving circuit, including a receiver (R) and a device (d), which performs the duty of closing the receiving circuit at predetermined intervals of time and discharging the stored energy through the receiver.

In the present case this device consists of a cylinder (d), made partly of conducting and partly of insulating material (e) and (e'), respectively, which is rotated at the desired rate of speed by any suitable means. The conducting part (e) is in good electrical connection with the shaft (S), and is provided with tapering segments (f) (f), upon which slides a brush (k), supported on a conducting rod (l), capable of longitudinal adjustment in a metallic support (m). Another brush (n) is arranged to bear upon the shaft (S), and it will be seen that whenever one of the segments (f) comes in contact with the brush (k) the circuit, including the receiver (R), is completed and the condenser discharged through the same.

By an adjustment of the speed of rotation of the cylinder (d) and a displacement of the brush (k) along the cylinder the circuit may be made to open and close in as rapid succession and remain open or closed during such intervals of time as may be desired. The plates (P) and (P'), through which the electrifications are conveyed to the brushes (a) and (a'), may be at a considerable distance from each other and both in the ground or both in the air, or one in the ground and the other in the air, preferably at some height, or they may be connected to conductors extending to some distance or to the terminals of any kind of apparatus supplying electrical energy which is obtained from the energy of the impulses or disturbances transmitted from a distance through the natural media.

It is the function of the cylinder (A) with its brushes and connections to render the electrical impulses coming from the plates (P) and (P') suitable for charging the condenser by rectifying them when they are originally alternating in direction or by selecting such parts of them as are suitable when all are not.

When the apparatus is used in connection with the transmission of signals or intelligence, "it will, of course, be understood," says Mr. Tesla, "that the transmitter is operated in such a way as to produce disturbances or effects which are varied or intermitted in some arbitrary manner—for example, to produce longer and shorter successions of impulses, corresponding to the dashes and dots of the Morse alphabet—and the receiving device will respond to and indicate these variations or intermittences, since the storage device will be charged and discharged a number of times corresponding to the duration of the successions of impulses received."

Referring to the importance of this invention, Mr. Tesla says: "It will be seen that by the use of my invention results hitherto unattainable in utilizing disturbances or effects transmitted through natural media may be readily attained, since however great the disturbance of such transmission and however feeble or attenuated the impulses received enough energy may be accumulated from them by storing up the energy of succeeding impulses for a sufficient interval of time to render the sudden liberation of it highly effective in operating a receiver. In this way receivers of a variety of forms may be made to respond effectively to impulses too feeble to be detected or to be made to produce any sensible effect in any other way of which I am aware—a result of great value in scientific research, as well as in various applications to practical use."

The third set of Mr. Tesla's patents, Nos. 685,957 and 685,958, cover, respectively, the apparatus and the method of utilizing radiant energy. Applications for both were filed on March 21, 1901. The invention described bears a close connection to those described in the preceding patents and is exceedingly interesting and novel. In his description he says:

"It is well known that certain radiations—such as those of ultra-violet light, cathodic, Roentgen rays, or the like—possess the property of charging and discharging conductors of electricity, the discharge being particularly noticeable when the conductor upon which the rays impinge is negatively electrified. These radiations are generally considered to be ether vibrations of extremely small wave lengths, and in explanation of the phenomena noted it has been assumed by some authorities that they ionize or render conducting the atmosphere through which they are propagated. My own experiments and observations, however, lead me to conclusions more in accord with the theory heretofore advanced by me that sources of such radiant energy throw off with great velocity minute particles of matter which are strongly electrified, and therefore capable of charging an electrical conductor, or, even if not so, may at any rate discharge an electrified conductor, either by carrying off bodily its charge or otherwise.

"My present application is based upon a discovery which I have made that when rays or radiations of the above kind are permitted to fall upon an insulated conducting body connected to one of the terminals of a condenser, while the other terminal of the same is made by independent means to receive or to carry away electricity, a current flows into the condenser so long as the insulated body is exposed to the rays, and under the conditions hereinafter specified an indefinite accumulation of electrical energy in the condenser takes place. This energy, after a suitable time interval, during which the rays are allowed to act, may manifest itself in a powerful discharge, which may be utilized for the operation or control of mechanical or electrical devices or rendered useful in many other ways.

"In applying my discovery I provide a condenser, preferably of considerable electrostatic capacity, and connect one of its terminals to an insulated metal plate or other conducting body exposed to the rays or streams of radiant matter. It is very important, particularly in view of the fact that electrical energy is generally supplied at a very slow rate to the condenser, to construct the same with the greatest care. I use by preference the best quality of mica as dielectric, taking every possible precaution in insulating the armatures, so that the instrument may withstand great electrical pressures without leaking, and may leave no perceptible electrification

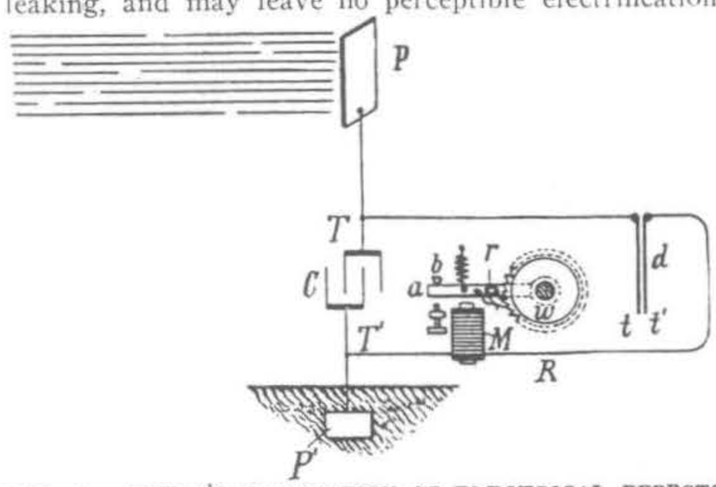


FIG. 3. TESLA'S UTILIZATION OF ELECTRICAL EFFECTS AND RADIANT ENERGY.—RECEIVING DEVICE FOR RADIANT ENERGY.

when discharging instantaneously. In practice I have found that the best results are obtained with condensers treated in the manner described in a patent granted to me February 23, 1897, No. 577,671.

"The rays or radiations which are to be utilized for the operation of the apparatus may be derived from a natural source, as the sun, or may be artificially produced by such means, for example, as an arc lamp, a Roentgen tube, and the like, and they may be employed for a great variety of useful purposes.

"My discovery will be more fully understood from the following detailed description and annexed drawing, to which reference is now made.

"Fig. 3 is a diagram showing typical forms of the devices or elements as arranged and connected in applying the method for the operation of a mechanical contrivance or instrument solely by the energy stored. (C) is the condenser, (P) the insulated plate or conducting body, which is exposed to the rays, and (P') another plate or conductor, all being joined in series, as shown. The terminals (T) (T') of the condenser are also connected to a circuit including a receiver (R) which is to be operated and a circuit-controlling device (d), which, in this case, is composed of two very thin conducting plates (t) (t'), placed in close proximity and very mobile, either by reason of extreme flexibility or owing to the character of their support. To improve their action, they should be enclosed in a receptacle from which the air may be exhausted. The receiver (R) is shown as consisting of an electromagnet (M), a movable armature (a), a retractile spring (b), and a ratchet wheel (w), provided with a spring pawl (r), which is pivoted to armature (a). The apparatus being arranged as shown, it will be found that when the radiations of the sun or of any other source capable of producing the effects before described, fall upon the plate (P) an accumulation of electrical energy in the condenser (C) will result. This phenomenon, I believe, is best explained as follows: The sun, as well as other sources of radiant energy, throw off minute particles of matter positively electrified, which, impinging upon the plate (P), communicate an electrical charge to the same. The opposite terminal of the condenser being connected to the ground, which may be considered as a vast reservoir of negative electricity, a feeble current flows continuously into the condenser, and, inasmuch as these supposed particles are of inconceivably small radius or curvature, and consequently charged to a relatively very high potential, this charging of the condenser may continue, as I have found in practice, almost indefinitely, even to the point of rupturing the dielectric. Obviously, whatever circuit controller be employed, it should operate to close the circuit in which it is included when the potential in the condenser has reached the desired magnitude."

The New York Tribune November 19, 1901

MR. TESLA'S LATEST PATENTS.

MEANS DEVISED TO INCREASE THE SENSITIVENESS OF RECEIVING APPARATUS IN WIRELESS TELEGRAPHY.

Several patents taken out by Nikola Tesla within the last few days are described by "The Electrical World and Engineer" and "The Western Electrician." They all represent methods and devices to be employed in wireless telegraphy, and relate exclusively to receiving apparatus, regardless of the transmitter or of the medium by which the impulses are conveyed.

Those who have studied Marconi's system know that at the receiving station a short circuit of wire is made to inclose a small "local" battery, an instrument called a "sounder" which ticks off the messages as in the Morse system, and a device invented by Branly and known as a "coherer." Under ordinary circumstances, the current from the battery is not strong enough to force its way around the circuit and to actuate the sounder. But when Hertz waves from some distant point reach the coherer they lessen its resistance and allow the sounder to respond. Now, when these waves come from too great a distance they are too weak to influence the coherer. The special object of Mr. Tesla's recent researches, therefore, has been to increase the effect of feeble impulses.

The most important expedient resorted to by him is to put into the receiving circuit a familiar bit of apparatus, a condenser. This acts like a storage battery, and intensifies the action of the incoming waves upon the sounder. Incidentally, there are one or two other attachments, of a purely mechanical and technical character, which need not be described here. They are designed to enable the condenser to do its work more effectively. One other idea, covered by a recent patent, deserves mention, however. It is intended for service only when the incoming signals are given by light, or radiance closely akin thereto. It is a well known property of selenium that when light falls upon it its electrical conductivity is increased. By putting a bit of this metal in his receiving circuit at the right point, Mr. Tesla makes it serve the same purpose that the coherer does in Marconi's system. It permits the local battery to act on the sounder.

TESLA AND TELEGRAPHY

TRANSMUNDANE MESSAGES FROM WARDENCLIFFE.

PROGRESS OF PREPARATIONS—POWER-HOUSE, TOWER AND MACHINERY

Since Mr. Tesla's purchase of land at Wardencliffe, Long Island, for a wireless telegraph station last summer, much progress has been made with his preparations. It is his intention not only to send messages from that point, but also to have a suitable laboratory for experimental work and a factory for the manufacture of instruments. After the system is once in operation, of course, it will be desirable to supply the requisite apparatus for equipping other stations. This, in the main, will be made at Mr. Tesla's own shops.

In designing the plant, therefore, both the needs of the future factory and laboratory, as well as the operation of the Wardencliffe telegraph station, have been kept in view. The principal building, in which power will be developed, has now been practically completed, and steam boilers and engines are on the spot, being installed as fast as possible. Owing to a variety of unforeseen causes, vexatious delays have been experienced. These have greatly tried Mr. Tesla's patience, although he takes such annoyances philosophically. For the operation of the instruments at the station he estimates that a hundred horsepower will be sufficient. To a novice this amount may seem excessive, but it must be remembered that Mr. Tesla expects to make his impulses felt at a distance of thousands of miles. Hence to his own mind this appears like a modest provision, though it has been adopted after elaborate calculation and experiment. It should be added that in order to admit of occasional change from one boiler and engine to another, this part of the plant will be duplicated at the outset.

The electrical machinery which is to be set up at Wardencliffe has not yet arrived, but will be put in place as soon as delivered. The dynamo can be made by outsiders. One very important instrument, known as a Tesla coil, or transformer, will be built in part by the inventor himself, and this will embody a number of recent improvements. All of the apparatus here mentioned will be installed at the surface of the earth.

Another feature of the Wardencliffe equipment will be a tower 150 feet high. At the present time the foundations are being laid. In the mean time the tower is being constructed in separate sections, away from the site on which it is eventually to rise. It is hoped that within three or four weeks the erection of that structure may be begun. It should then go ahead rapidly, although another month may possibly elapse before its completion. In view of the many delays already encountered, Mr. Tesla is exceedingly cautious about making predictions, even to himself. He also prefers not to go into details about the tower, although to some extent its function is indicated in his patents. There is a certain mathematical relation between the length of an upright conductor connected with the apparatus for developing Hertz waves and the length of the waves themselves. Then, too, some of the electricians who have engaged in this class of work have utilized an upright conductor for obtaining a storage of energy, or "capacity."

Mr. Tesla yesterday described the operation of telegraphy itself in something like these terms: "The current which I will use will be of the familiar alternating type. The energy which is generated in that form will be stored in a condenser, but after its discharge therefrom the intensity of the vibrations will be magnified ten thousand times. These vibrations will be of the kind best calculated for transmission through the earth, which is my real conductor. The energy thus developed will diffuse itself in all directions, but will tend to spread over the earth's surface, penetrating to a depth of four or five feet. At the receiving station I will provide means for magnifying the force of the incoming, but much weakened, vibrations a quarter of a million times."

When asked about his arrangements for having his first few messages received at some other place, Mr. Tesla preferred not to go into particulars, although he says that he has practically perfected his plans. The suggestion having been made to him that perhaps the Eiffel Tower might serve his purpose, he laughed and shook his head. He intimated that there were much better places. Although a tower is used at his transmitting station, the apparatus is really at the surface of the earth. In like manner the vibrations, after a long journey through the crust of the globe, would probably be more perceptible at sea level than at an elevation.

Wardencliffe is on the north shore of Long Island, eight or nine miles beyond Port Jefferson, and sixty-five or sixty-six from Brooklyn. A branch of the Long Island Railway extends through it to Wading River. There is a station at Wardencliffe.



Tesla's Recent Patents.

Nikola Tesla has received several patents for a "Method of Intensifying and Utilizing Effects Transmitted Through Natural Media." In one of his systems Tesla varies the potential point or region of the earth by imparting to it intermittent or alternating electrifications through one of the terminals of a suitable source of electrical disturbances which to heighten the effect, has its other terminal connected with an insulated body, preferably of large surface and at an elevation. Electrifications communicated to the earth spread in all directions, reaching a circuit which generally has its terminals arranged and connected similarly to those of the transmitting source, and which operates upon a highly sensitive receiver. Another of Tesla's methods is based upon the fact that the atmospheric air, which behaves as an excellent insulator to currents generated by ordinary apparatus, becomes a conductor under the influence of currents or impulses of enormously high electromotive force. By such means air strata, which are easily accessible, are rendered available for the production of many desired effects at distances. Although either method may be employed, it is obviously desirable that the disturbance should be as powerful as possible and should be transmitted with a minimum loss. The loss reduces greatly both the intensity and the number of the co-operative impulses, and since the initial intensity of each of these is necessarily limited, only an insignificant amount of energy is thus available for a single operation of the receiver. Furthermore the energy obtained through the co-operation of the impulses is in the form of an extremely rapid vibration and unsuitable for the operation of ordinary receivers. To overcome these limitations of the two methods mentioned, Tesla reproduces arbitrarily varied or intermittent disturbances or effects; transmits these disturbances through the air to a distant receiving station; utilizes the energy derived from such disturbances at the receiving station to charge a condenser; and uses the accumulated potential so obtained to operate a receiving device.

The apparatus which is employed at the receiving station consists in the combination of a storage d vice included in a circuit; connection points at a d tance from the source of the disturbances and tween which a difference of potential is created such disturbances; a receiving circuit connected wi the storage device; a receiver included in the receiv circuit, and a mechanism for closing the receiv circuit at any desired moment, thereby causi the receiver to be operated by the energy with whic the storage device has been charged.

In another method the energy stored is not, as in the preceding instance, obtained from the energy of the disturbance effect transmitted from a distance, but from an independent source. The method in general consists in charging a storage device with energy from an independent source, controlling the charge of the device by the action of the effects or disturbances transmitted through the natural media, and coincidently using the stored energy for operating a receiver. A condenser is used as the storag means.

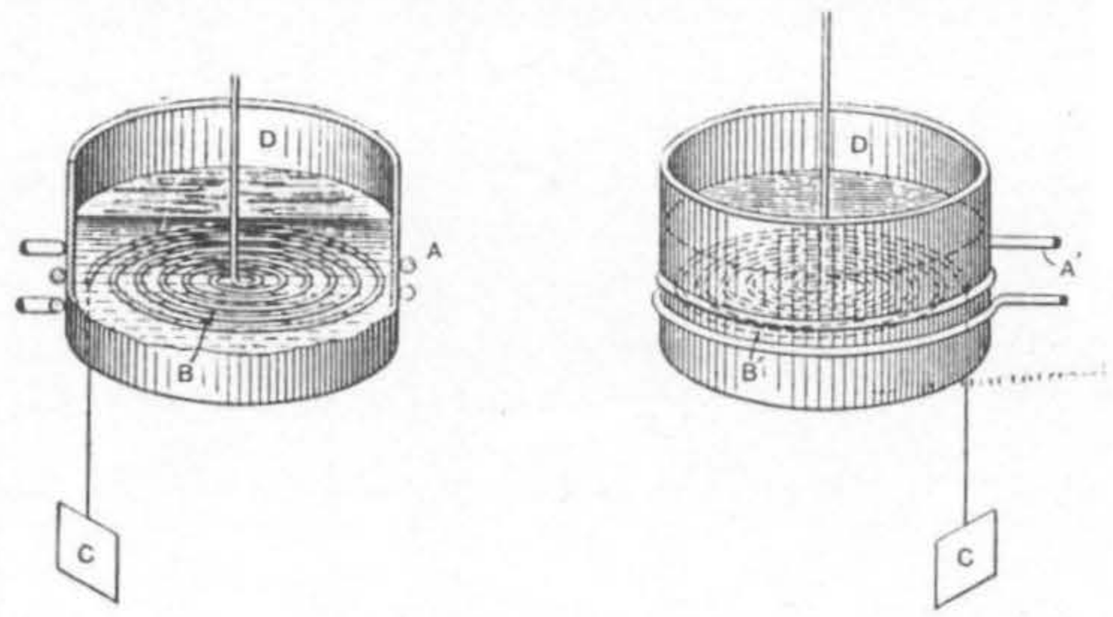
The invisible radiations of the spectrum and of vacuum tubes are generally considered to be vibrations of extremely small wave length. These radiations possess the property of charging and discharging conductors of electricity, the discharge being particularly noticeable when the conductor upon which the rays impinge is negatively electrified. is usually held that these radiations ionize or render conducting the atmosphere through which they are propagated. Tesla's own experiments lead him, however, to conclusions more in accord with the theory he has already advanced, in which he holds that sources of such radiant energy throw off with great velocity minute particles of matter which are strongly electrified, and therefore capable of charging an electrical conductor, or, even if not so, of discharging an electrified conductor either by carrying off bodily its charge or otherwise. Tesla has taken out a patent based upon a discovery which he has made, that when rays or radiations of this kind are permitted to fall upon an insulated conducting body connected with one of the terminals of a condenser, while the other terminal is made by independent means to receive or carry away electricity, a current flows into the condenser so long as the insulated body is exposed to the rays. Under certain conditions an indefinite ac-

cumulation of electrical energy takes place. This energy after a suitable time interval, during which the rays are allowed to act, may manifest itself in a powerful discharge, which can be utilized for the operation or control of mechanical or electrical devices or rendered useful in many other ways. The radiant energy is directed upon an elevated conductor, connected with one of the armatures of the condenser, positively electrified by the invisible radiations. The electricity is carried off from the other armature by connecting it with the ground. The accumulated energy is discharged through a suitable receiver.

TESLA'S METHOD OF INCREASING THE INTENSITY OF ELECTRICAL OSCILLATIONS.†

Nikola Tesla still continues his interesting experiments with electrical vibrations, upon which he has been engaged for the last 10 years. Among the patents issued from the United States Patent Office on October 22nd was one granted to him for "Means for Increasing the Intensity of Electrical Oscillations." The patent is numbered 685,012, and the application for it was filed March 21, 1900, and renewed July 3, 1901. Mr. Tesla describes his invention in the following language:—In many scientific and practical uses of electrical impulses or oscillations—as, for example, in systems of transmitting intelligence to distant points—it is of great importance to intensify as much as possible the current impulses or vibrations which are produced in the circuits of the transmitting and receiving instruments, particularly of the latter. It is well known that when electrical impulses are impressed upon a circuit adapted to oscillate freely the intensity of the oscillations developed in the same is dependent on the magnitude of its physical constants and the relation of the periods of the impressed and of the free oscillations. For the attainment of the best result it is necessary that the periods of the impressed should be the same as that of the free oscillations, under which conditions the intensity of the latter is greatest and chiefly dependent on the inductance and resistance of the circuit, being directly proportionate to the former and inversely to the latter. In order, therefore, to intensify the impulses or oscillations excited in the circuit—in other words, to produce the greatest rise of current or electrical pressure in the same—it is desirable to make its inductance as large and its resistance as small as practicable. Having this end in view I have devised and used conductors of special forms and of relatively very large cross-section; but I have fouud that limitations exist in regard to the increase of the inductance as well as to the diminution of the resistance. This will be understood when it is borne in mind that the resonant rise of current or pressure in a freely oscillating circuit is proportionate to the frequency of the impulses, and that a large inductance in general involves a slow vibration. On the other hand, an increase of the section of the conductor with the object of reducing its resistance is, beyond a certain limit, of little or no value, principally because electrical oscillations, particularly those of high frequency, pass mainly through the superficial conducting layers, and, while it is true that this drawback may be overcome in a measure by the employment of thin ribbons, tubes, or standard cables, yet in practice other disadvantages arise which often more than offset the gain. It is a well-established fact that as the temperature of a metallic conductor rises its electrical resistance increases, and, in recognition of this, constructors of commercial electrical apparatus have heretofore resorted to many expedients for preventing the coils and other parts of the same from becoming heated when in use, but merely with a view to economising energy and reducing the cost of construction and operation of the apparatus.

Now, I have discovered that when a circuit adapted to vibrate freely is maintained at a low temperature the oscillations excited in the same are to an extraordinary degree magnified and prolonged, and I am thus enabled to produce many valuable results which have heretofore been wholly impracticable. Briefly stated, then, my invention consists in producing a great increase in the intensity and duration of the oscillations excited in a freely vibrating or resonating circuit by maintaining the same at a low temperature. Ordinarily, in commercial apparatus such provision is made only with the object of preventing wasteful heating, and in any event its influence upon the intensity of the oscillations is very slight and practically negligible, for, as a rule, impulses of arbitrary frequency are impressed upon a circuit, irrespective of its own free vibrations, and a resonant rise is expressly avoided. My invention, it will be understood, does not primarily contemplate the saving of energy, but aims at the attainment of a distinctly novel and valuable result—that is, the increase to the greatest practicable degree of the intensity and duration of free oscillations. It may be usefully applied in all cases when this special object is sought, but offers exceptional advantages in those instances in which the freely oscillating discharges of a condenser are utilised. The best and most convenient manner of carrying out the invention of which I am now aware is to surround the freely vibrating circuit or conductor, which is to be maintained at a low temperature, with a suitable cooling medium, which may be any kind of freezing mixture or agent, such as liquid air, and, in order to derive the fullest benefit from the improvement, the circuit should be primarily constructed so as to have the greatest possible self-induction and the smallest practicable resistance, and other rules of construction which are now recognised should be observed. For example, when in a system of transmission of energy for any purpose through the natural media the transmitting and receiving conductors are connected to earth and to an insulated terminal respectively, the lengths of these conductors should be one-quarter of the wave length of the disturbance propagated through them.



In the accompanying drawing I have shown graphically a disposition of apparatus which may be used in applying practically my invention.

The drawing illustrates in perspective two devices, either of which may be the transmitter, while the other is the receiver. In each there is a coil of few turns and low resistance, designated in one by A and in the other by A'. The former coil, supposed to be forming part of the transmitter, is to be connected with a suitable source of current, while the latter is to be included in circuit with a receiving device.

* Whenever oil is used as a filling for transformer cases the greatest care must be taken to see that it is perfectly free from traces of water; moreover, an oil must be selected whose "critical temperature" is over 80°C., and at the same time the maximum temperature rise of the transformer should be kept well within the above-mentioned limit of 45°C.

† From the *Western Electrician*.

In inductive relation to said coils in each instrument is a flat, spirally-wound coil, B or B′, one terminal of which is shown as connected to a ground plate, C, while the other, leading from the centre, is adapted to be connected to an insulated terminal, which is generally maintained at an elevation in the air. The coils BB′ are placed in insulating receptacles, D, which contain the freezing agent, and around which the coils A and A′ are wound.

Coils in the form of a flat spiral, such as those described, are eminently suited for the production of free oscillations, but obviously conductors or circuits of any other form may be used if desired.

From the foregoing the operation of the apparatus will now be readily understood. Assume, first, as the simplest case, that upon the coil A of the transmitter impulses or oscillations of an arbitrary frequency, and irrespective of its own free vibrations, are impressed. Corresponding oscillations will then be induced in the circuit B, which, being constructed and adjusted, as before indicated, so as to vibrate at the same rate, will greatly magnify them, the increase being directly proportionate to the product of the frequency of the oscillations and the inductance of circuit, B, and inversely to the resistance of the latter. Other conditions remaining the same, the intensity of the oscillations in the resonating circuit B will be increased in the same proportion as its resistance is reduced. Very often, however, the conditions may be such that the gain sought is not realised directly by diminishing the resistance of the circuit. In such cases the skilled expert who applies the invention will turn to advantage the reduction of resistance by using a correspondingly longer conductor, thus securing a much greater self-induction, and under all circumstances he will determine the dimensions of the circuit, so as to get the greatest value of the ratio of its inductance as to its resistance, which determines the intensity of the free oscillations. The vibrations of coil B, greatly strengthened, spread to a distance, and on reaching the tuned receiving conductor B′ excite corresponding oscillations in the same, which, for similar reasons, are intensified, with the result of inducing correspondingly stronger currents or oscillations in circuit A′, including the receiving device. When, as may be the case in the transmission of intelligible signals, the circuit A is periodically closed and opened, the effect upon the receiver is heightened in the manner above described, not only because the impulses in the coils B and B′ are strengthened, but also on account of their persistence through a longer interval of time. The advantages offered by the invention are still more fully realised when the circuit A of the transmitter, instead of having impulses of an arbitrary frequency impressed upon it, is itself permitted to vibrate at its own rate, and more particularly so if it be energised by the freely oscillating high-frequency discharges of a condenser. In such a case the cooling of the conductor A, which may be effected in any suitable manner, results in an extraordinary magnification of the oscillation in the resonating circuit B, which I attribute to the increased intensity as well as greater number of the high-frequency oscillations obtained in the circuit A. The receiving coil B′ is energised stronger in proportion, and induces currents of greater intensity in the circuit A′. It is evident from the above that the greater the number of the freely vibrating circuits which alternately receive and transmit energy from one to another the greater, relatively, will be the gain secured by applying my invention.

TESLA'S WIRELESS TELEGRAPH.

Absolutely Private. Absolutely Original. Working to Great Distances.

Nikola Tesla was asked in his laboratory yesterday afternoon about a report touching his immediate intentions as to the transmission of wireless messages, which the inventor pronounced to be a mistake. Mr. Tesla said that his plans were made up long ago, but that he was not in a position to speak of them as yet. He was asked about the progress of his work and he replied:

"Since THE SUN made the first announcement of my undertaking, the work has been steadily progressing. Some delays have of course occurred, but they have been only for the better. And I am more confident than ever that when it is completed I shall give to the world as the first result of my labors in the transmission of power without wires to great distances, a system of telegraphy capable of infinite expansion, and securing the absolute privacy of the messages. I shall shortly make known a novel principle which will to a large degree remove the popular belief that it is impossible to attain that degree of secrecy which is practicable with cables."

When Mr. Tesla was asked whether there was any similarity between his own and other systems he smiled:

"I respect rigorously the rights of others," he said, "and when I give my system to the world I shall ask the entire technical profession to point to any feature of my system—the transmitter, the receiver, the means and methods of recording, the means and methods of producing the requisite electrical energy, and the means and methods of securing absolute privacy and non-interference—which is not of my own creation. I admire skill and enterprise, and my best wishes for success accompany those who sell ready made shoes; but I myself prefer not to use them. They are cheap, but they raise corns and bunions."

The Tesla patents in connection with instruments and principles involved in the transmission of wireless messages, or wireless electrical energy, date from 1896 and 1897.

The New York Sun January 23, 1902

TESLA CURE FOR CONSUMPTION.

High Frequency Currents Used at the Brompton Hospital.

Special Cable Despatch to THE SUN.

LONDON, Jan. 22.—Dr. Symes-Thomson, consulting physician at the Hospital for Consumption, Brompton, in a lecture delivered here, spoke hopefully of the experiments which are being carried on at the hospital in the treatment of phthisis by means of Tesla's high frequency currents and the injection into the veins of a chemical substance that is fatal to the bacilli.

He quoted statistics showing that the deaths from tubercular maladies in London had decreased 55 per cent. in forty years, and predicted that such diseases would be extinct within a century.

The Brooklyn Eagle February 7, 1902

INVENTOR TESLA'S PLANT NEARING COMPLETION.

Buildings at Wardencliff to Be Used in Developing His Electrical Discoveries.

SINKING A VERY DEEP WELL.

A Big Tower 100 Feet in Diameter and Over 200 Feet High—Power House and Dynamos.

(Special to the Eagle.)

Wardenclyffe, L. I., February 8—Work on the buildings to be used by Electrician Tesla in the development of his electrical discoveries, is progressing rapidly. The power house is completed and the foundations of the big tower have been laid, though the cold weather somewhat retarded the masonry work.

The working room, or tower, which will be the foundation for Mr. Tesla's across-the-world flashes, will be octagonal in shape and will be 210 feet high, 100 feet in diameter at the base, narrowing down to 80 feet in diameter at the top. It will be constructed chiefly of wood, though the builders say that fifty tons of iron and steel and 50,000 bolts of various sizes are used in its construction.

Inside the big tower a well 120 feet deep has been sunk, the well being 12 feet square, cased its entire depth with 8 inch timbers, which will be finished off with brick and cement. A staircase, which will lead down into the well, is nearly completed.

Transversely across the bottom of the well will be a series of four tunnels, each to be 100 feet long, and a force of workmen has begun work on these subterranean passages.

The power house is constructed of pressed brick, and is 100 feet square. In it are a boiler room, engine and dynamo room, machine shop and laboratory. The Westinghouse Company furnished the electrical equipment, boilers, engines and dynamos Only the finishing touches are needed on the electrical equipment to make it available and Mr. Tesla promises to begin active operations very soon.

The New York Herald March 25, 1902

NICOLA TESLA REPLIES TO PROFESSOR SLABY

Wireless Transmission of Energy Across the Ocean Will Be of Commercial Value, He Delares.

Mr. Nicola Tesla was asked yesterday for his views regarding the HERALD'S despatch from Professor Slaby on wiresless telegraphy, and he said:—

"I have read Professor Slaby's statement with interest, and I may add that I have kept in touch with his efforts in Hertzian, or 'spark,' telegraphy, as he calls it, for some time past. He has undoubtedly made most valuable contributions to the literature of the subject. He is also an appreciative worker, acknowledging freely the merit of every one, as a purely scientific man always should do.

"While I do not believe that wireless messages over the sea will be as cheap as some enterprising people have asserted of late, still I cannot quite share Professor Slaby's opinion in regard to wireless transmission of energy across the Atlantic. I began nearly two years ago the design and instalment of power plants for commercial use, with the fullest confidence of success, basing my assurance on exact tests and measurements, which admit of no doubt.

"This work was commenced only after I had completely mastered the problem of insuring the absolute privacy of mesages, and inasmuch as I have received in this undertaking the most generous help, I would be unfortunate indeed if my expectations were not to be fully realized. I hope, however, that the transmission of messages without wires is only the first and comparatively insignificant phase of a great revolution which will be wrought by the transmission of vast quantities of energy for industrial purposes to the most distant points on the globe without wires."

TESLA'S WORK AND MARCONI'S

THE FORMER IS THE "FATHER OF WIRELESS TELEGRAPHY."

Lecture in Which Tesla in 1893 Described the Idea Which Marconi Subsequently Demonstrated Practically — Tesla's Theories Followed by Marconi.

Prof. A. Slaby, inventor of the process of wireless telegraphy which the German Emperor has lately ordered to be used by all German warships, which is known as the Slaby-Arco system, and, in an interview in Berlin, given to Nikola Tesla the credit for making possible all the systems of wireless telegraphy now known.

Prof. Slaby refers to Mr. Tesla as the "father of wireless telegraphy," according to the published reports of his interview, and says that Tesla first explained and worked out in his book "Inventions and Researches," published in 1894, the theory which thereafter Marconi was the first to demonstrate practically. While he gives Marconi the credit for the demonstration Prof. Slaby ascribes the origin of wireless telegraphy to the New York inventor.

Probably few people outside of those interested in technical studies have read this first announcement of the theory and of the outline of a process for carrying it out that gave to the world the system of communication now in daily use on the seas. Indeed few know that Tesla promulgated it years before the first wireless message was sent.

The book referred to by Prof. Slaby as published in 1894 was really a republication of the facts and speculations put forth by Mr. Tesla in a lecture delivered before the National Electric Light Association at St. Louis at its sixteenth convention which was in session from Feb. 28 to March 3, 1893.

The lecture was given at a special evening session of the convention, and was entitled "Light and Other High Frequency Phenomena." It was published in the same year in the proceedings of the convention by order of the Executive Committee of the association.

Mr. Tesla had spoken at length upon phenomena produced by electrostatic force, and after devoting some attention to electrical resonance he said:

"In connection with resonance effects and the problems of transmission of energy over a single conductor, which was previously considered, I would say a few words on a subject which constantly fills my thoughts, and which concerns the welfare of all.

"I mean the transmission of intelligible signals, or, perhaps, even power, to any distance without the use of wires.

"I am becoming daily more convinced of the practicability of the scheme; and though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realized, yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thoughtful and experiment in this direction.

"My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day.

"The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb, by means of powerful machines, the electro-static condition of the earth, and thus transmit intelligible signals, and, perhaps, power.

"In fact, what is there against the carrying out of such a scheme? We now know that electrical vibration may be transmitted through a single conductor. Why, then, not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance.

"To the weary wanderer counting the mile posts, the earth may appear very large; but to that happiest of all men, the astronomer, who gazes at the heavens, and by their standard judges the magnitude of our globe, it appears very small.

"And so I think it must seem to the electrician; for when he considers the speed with which an electric disturbance is propagated through the earth all his ideas of distance must completely vanish.

"A point of great importance would be first to know what is the capacity of the earth, and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation.

"If it be a charged body insulated in space, its capacity should be extremely small—less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case, it is of the greatest importance to get an idea of what quantity of electricity the earth contains.

"It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race.

"I propose to seek for the period by means of an electric oscillator, or a source of alternating electric currents. One of the terminals of the source would be connected to earth, as, for instance, to the city water mains; the other, to an insulated body of large surface.

"It is possible that the outer conducting body of large surface.

"It is possible that the outer conducting air strata of free space contain an opposite charge, and that, together with the earth, they may form a condenser of very large capacity. In such case the period of vibration may be very low, and an alternating dynamo machine might serve for the purpose of the experiment.

"I would then transform the current to a potential as high as it would be found possible, and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents, and carefully observing the potential of the insulated body, and watching for the disturbance at various neighboring points of the earth's surface, resonance might be detected.

"Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do, and a proper electrical oscillator would have to be produced, and perhaps it might not be possible to obtain such rapid vibrations.

"But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface."

Mr. Tesla accompanied his lecture with a diagram illustrating his ideas of the wireless telegraphy instrument, which is here reproduced. He said, referring to it:

"Assume that a source of alternating currents, S, be connected, as in the figure, with one of its terminals to earth (convenient to the water mains), and with the other to a body of large surface, P. When the electric oscillation is set up, there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to or diverging from the point C, where the ground connection is made.

"In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion."

Just here it is interesting to note that Mr. Marconi in an interview with a reporter for THE SUN a few weeks ago said regarding his experiments between Poldhu and Newfoundland that the electric waves produced by his plant at Poldhu "diminished with the increase of distance," but that they "came," that being the important thing. He said also that with greater power he would have better results.

Continuing his lecture Mr. Tesla said, with further reference to the diagram:

"Since the body P is insulated, in order to displace a considerable quantity, the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source, S, will set up the same electrical movement as though its circuit were closed.

"Thus it is certainly practicable to impress an electric vibration, at least of a certain low period, upon the earth by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured.

"I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at the surface could be but extremely small, considering the size of the earth, the air would not act as a very disturbing factor, and there would be not much energy lost through the action of the air, which would be the case if the density were great.

"Theoretically, then, it could not require a great amount of energy to produce a disturbance perceptible at a great distance, or even all over the surface of the globe.

"Now, it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source, S2, similar to S, or any number of such sources, can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S1, if the same be of opposite phase to the soure S.

"I think that, beyond doubt, it is possible to operate electrical devices in a city, through the ground or pipe system, by resonance from an electrical oscillator located at a central point.

"But the practical solution of this problem would be of incomparably smaller benefit to man than the realization of the scheme of transmitting intelligence, or, perhaps, power, to any distance through the earth or environing medium. If this is at all possible distance does not mean anything.

"Proper apparatus must first be produced, by means of which the problem can be attacked, and I have devoted much thought to this subject. I am firmly convinced that it can be done, and hope that we shall live to see it done."

In March and May, 1900, Mr. Tesla secured patents additional to those which he took out in the years immediately following the first announcement of his theory, these later ones covering developments of his system for the transmission of electrical energy, carrying it far beyond what he had at first suggested, but along the same general lines.

In the specification which forms part of the letters patent dated March 20, 1900, Tesla says, in the formal notice to the public as to what it is that the patent covers:

"I have been led to the discovery of certain highly important and useful facts which have hitherto been unknown. * * * In illustration of these facts a few observations which I have made with apparatus devised for the purposes here contemplated, may be cited.

"For example, a conductor or terminal, to which impulses such as those here considered are supplied, but which is otherwise insulated in space and is remote from any conducting bodies, is surrounded by a luminous flame-like brush or discharge, often covering many hundreds or even as much as several thousands of square feet of surface, this striking phenomenon clearly attesting the high degree of conductivity which the atmosphere attains under the influence of the immense electrical stresses to which it is subjected.

"This influence is, however, not confined to that portion of the atmosphere which is discernible by the eye as luminous and which, as has been the case in some instances actually observed, may fill the space within the spherical or cylindrical envelope of a diameter of sixty feet or more, but reaches out to far remote regions, the insulating qualities of the air being, as I have ascertained, still sensibly impaired at a distance many hundred times that through which the luminous discharge projects from the terminal and in all probability much further.

"The distance extends with the increase of the electro-motive force of the impulses, with the diminution of the density of the atmosphere, with the elevation of the active terminal above the ground, and also, apparently, in a slight measure, with the degree of moisture contained in the air. * * *

"It is, furthermore, a fact that such discharges of extreme tensions, approximating those of lightning, manifest a marked tendency to pass upward away from the ground, which may be due to electrostatic repulsion, or possibly to slight heating and consequent rising of the electrified or ionized air.

"These latter observations make it appear probable that a discharge of this character allowed to escape into the atmosphere from a terminal maintained at a great height will gradually leak through and establish a good conducting path to more elevated and better conducting air strata, a process which possibly takes place in silent lightning discharges frequently witnessed on hot and sultry days.

"It will be apparent to what an extent the conductivity imparted to the air is enhanced by the increase of the electromotive force of the impulses when it is stated that in some instances the area covered by the flame discharge mentioned was enlarged more than sixfold by an augmentation of the electrical pressure amounting scarcely to more than 50 per cent."

It may be noted here that Mr. Marconi, when he went back to Cornwall after his first Newfoundland experiments,' saying that he would increase the power of his plant at Poldhu, made the statement that he had found that an increase of power showed itself multiplied many fold in the greater proportional distance to which his electric waves would carry.

Mr. Tesla's specification in his patent continues:

"By the discovery of these facts and the perfection of means for producing in a safe, economical and thoroughly practicable manner current impulses of the character described it becomes possible to transmit through easily accessible and only moderately rarefied strata of the atmosphere electrical energy not merely in insignificant quantities, such as are suitable for the operation of delicate instruments and like purposes, but also in quantities suitable for industrial uses on a large scale, up to practically any amount, and, according to all the experimental evidence I have obtained, to any terrestrial distance.

"Expressed briefly, my present invention, based upon these discoveries, consists, then, in producing at one point an electrical pressure of such character and magnitude as to cause thereby a current to traverse elevated strata of the air between the point of generation and a distant point at which the energy is to be received and utilized."

After describing his apparatus Mr. Tesla goes on to say:

"While the description here given contemplates chiefly a method and system of energy transmission to a distance through the natural media for industrial purposes, the principles which I have herein disclosed and the apparatus which I have shown will obviously have many other valuable uses—as, for instance, when it is desired to transmit intelligible messages to great distances, or to illuminate upper strata of the air, or to produce, designedly, any useful changes in the condition of the atmosphere, or to manufacture from the gases of the same products, as nitric acid, fertilizing compounds, or the like, by the action of such current impulses, for all of which and for many other valuable purposes they are eminently suitable, and I do not wish to limit myself in this respect."

In his specification in connection with the patent granted May 15, 1900, Tesla says:

"This application is a division of an application filed by me on Sept. 2, 1897, serial number 650,343, entitled 'Systems of Transmission of Electrical Energy,' and is based upon new and useful features and combinations of apparatus shown and described in said application for carrying out the method therein disclosed and claimed.

"The invention which forms the subject of my present application comprises a transmitting coil or conductor, in which electrical currents or oscillations are produced, and which is arranged to cause such currents or oscillations to be propagated by conduction through the natural medium from one point to another remote therefrom and a receiving coil or conductor at such distant point adapted to be excited by the oscillations or currents propagated from the transmitter."

ELECTRICAL ENERGY DIRECT FROM COAL

By J. Wright

THE successful solution of the problem of how to obtain electrical energy direct from coal would go a long way towards revolutionising existing methods in the engineering and scientific world generally, in that a more or less immediate application of enormous resources of power, without the intervention of the present cumbersome boiler, engine, and dynamo, would thus be rendered possible, and solve many of the existing problems which are on the eve of solution, such, for instance, as aerial navigation.

With existing methods for the production of electrical energy on a commercial scale, by means of high-grade boilers and high-efficiency steam engines and dynamos, only about 6 per cent. of the latent energy stored in coal is available at the terminals of the generator. Any system, therefore, which would tend to render this enormous store of energy immediately available, even to the extent of 50 to 60 per cent., would be exceedingly welcome to the engineer and the scientist, and it is with the object of summarising what has already been done in this connection, and in what direction such minor successes point for a final solution, that the following paragraphs have been penned.

One of the earliest discoveries in connection with this problem was that made by an engine-driver named Seghill in 1840, which culminated in the construction of Sir William G. Armstrong's hydro-electric machine. Seghill elicited the fact that steam, issuing, under pressure, from the safety-valve of a boiler, becomes electrified. Armstrong and Pattinson investigated the phenomenon, and found that it was due to the friction of the minute particles of water, or condensed steam, against the walls of the passage providing the exit, and on this fact was based the construction of the historical machine which consisted of a boiler and furnace mounted on four strong glass insulating pillars and provided with the usual gauges and steam dome, from which latter the outlet pipes were led into a species of iron chamber for the purpose of partially condensing the steam prior to its liberation, it being essential to the success of the device that the escaping steam should carry as much moisture as possible. With a similar object in view, and also to increase the frictional resistance offered to its passage, Armstrong constructed a series of wooden nozzles, in passing through which the steam was caused to impinge upon a disc and pass around the edge of the latter. In front of the nozzles was placed a series of metal points forming a collecting comb, against which the particles of condensed vapour were projected. This comb was carried by a second insulating pillar, which served as the positive terminal of the apparatus, whilst the boiler constituted the negative terminal.

With this machine Sir William Armstrong succeeded in producing large quantities of static electricity, which, in discharging from pole to pole, developed sparks from 5 to 6 feet long. The hydro-electric machine proved, however, to be impracticable and inefficient for the production of electrical energy from coal on a commercial scale, and, as a natural consequence, the discovery has never overstepped the boundary imposed by the term "interesting scientific experiment."

A still earlier method of generating an electric current from the heat of combustion of coal is by what are known as thermopiles. As far back as 1822 Seebeck discovered that a current is pro-

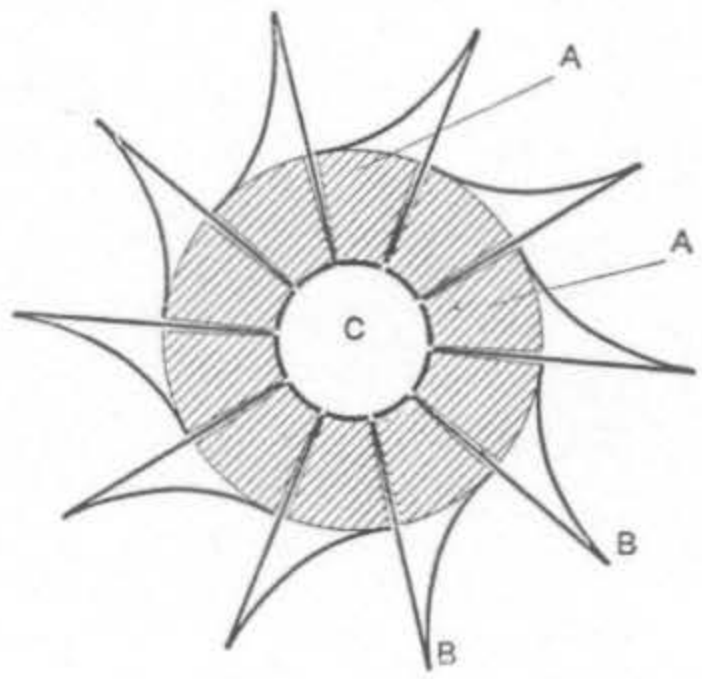


FIG. 1.—CLAMOND'S THERMOPILE

duced in a closed electric circuit by heating the point of contact of two dissimilar metals forming part of that circuit. The electromotive force of the current produced in each couple is very small, and depends upon the two metals selected to form the thermo-electric couple. As the result of his experiments, Seebeck compiled the following table of metals, arranged in their thermo-electric order, each metal being electro-positive to those which follow it in the list:—

(+)	Bismuth	Copper	Silver
	Nickel	Lead	Zinc
	Cobalt	Tin	Iron
	Platinum	Gold	Arsenic
			Antimony (—)

If any two metals be selected from this list, and a good electro-mechanical junction be effected between them, the heating of this junction will produce a flow of current from the electro-positive metal to the electro-negative through the heated junction. Alloys also are available for the production of thermo-electric currents, and Seebeck compiled a second list of metals and their combinations, in thermo-electric order. as follows:—

(+)	Bismuth	3 Bismuth, 1 Lead
	Lead	1 Antimony, 1 Copper
	Tin	1 Antimony, 3 Copper
	1 Bismuth, 3 Tin	1 Antimony, 3 Lead
	1 Bismuth, 3 Lead	1 Antimony, 3 Tin
	Platinum	Steel (cast)
	1 Bismuth, 1 Lead	Steel (rod)
	Gold	3 Bismuth, 1 Tin
	Silver	1 Bismuth, 3 Antimony
	1 Bismuth, 1 Tin	Antimony
	Zinc	1 Antimony, 1 Tin
		3 Antimony, 1 Zinc (—)

Seebeck's discovery led to a number of praiseworthy attempts to apply the thermo-electric principle to the practical generation of electrical energy on a commercial scale. The resulting devices are known as thermopiles, and consist, in the main, of a number of thermo-electric couples, connected together electrically in order to combine their resulting electromotive forces, and constructed physically in such a manner as to facilitate the simultaneous heating of all the junctions from a central source.

One of the earliest thermopiles was that of Markus, constructed in 1864-65, which gained a prize from the Vienna Society for the Promotion of Science. The positive metal was an alloy, consisting of twelve parts of antimony, five parts of zinc, and one part of bismuth, and each electrode consisted of three strips fastened together by screws. The negative electrode, on the other hand, was an alloy consisting of ten parts of copper and six parts of zinc and nickel, and was made in the shape of a rectangular bar. A number of these elements were connected together after the manner of lattice-work, and placed in two rows, sloping together at their apices, and forming a structure not unlike the roof of a house. The ridge of the

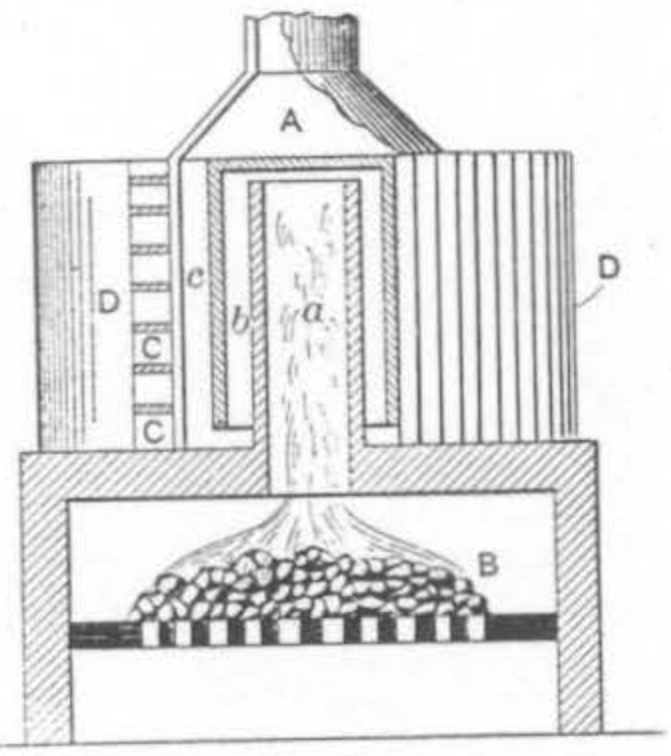


FIG. 2.—AN IMPROVED CLAMOND PILE

"roof" was constituted by an iron bar, to which the junctions were severally attached by means of screws passing through the bar; mica plates and bushings were interposed between the couples

and the bar in order to insulate them, and heat was applied to the junctions through the medium of the iron bar itself, which was supplied with heat from a convenient source. The junctions between neighbouring couples were effected at the lower edges of the slopes and immersed in cold water, in order to make the difference in temperature between the two sets of junctions more marked. The electromotive force of each of these couples was equivalent to one-twentieth of that of a Daniell cell.

Clamond's original thermopile was constructed in cylindrical form, the principle of construction being represented in Fig. 1, which shows a transverse section through one set of couples. *A A* are sector-shaped blocks of an alloy of zinc and antimony, arranged in a circle, and to their inner and outer surfaces are attached the sheet-iron plates, *B B*, these latter being extended, as shown, beyond the normal periphery of the circle, in order to provide an increased surface for the radiation of heat, thereby keeping the outer junctions cool. Several sets of electrodes thus constituted were placed one above the other, and separated by insulating pieces. The central tube or chimney, *C*, thus formed was lined with asbestos cement, and an earthenware tube, pierced with a number of holes to serve as a multiple-jet gas burner, was introduced, and supplied with gas from a convenient source.

In 1879 an improved form of Clamond pile was described by Th. Du Moncel, which was capable of being energised by the heat from a specially constructed coke furnace. It is represented in sectional elevation in Fig. 2, and consists of a zigzag flue *a b c*, made up of three concentric cylinders, communicating with one another at the top and bottom, as shown. The last of these cylinders, *c*, leads into a chimney, *A*, whilst the first receives the hot gases resulting from the combustion of coke in the furnace *B;* the heated gases of combustion are thus compelled to pass three times over the inner surfaces of the cylinders before finding an exit. *C C* are sheet-iron elements arranged immediately outside the cylinder *c*, whilst *D D* are vertical copper plates arranged radially, in order to secure a large surface for cooling the outer junctions by radiation. Cazin records that two such thermopiles, 98 inches high and 39 inches in diameter, each comprising thirty sets of one hundred couples each, were capable of generating current at an electromotive force of 109 volts, and offered an internal resistance of 15.5 ohms. The consumption of coke to achieve this result is stated to have been twenty-two pounds per hour.

Nöe and Hauck also constructed thermopiles on a circular plan; in fact, Clamond's original pile seems to have

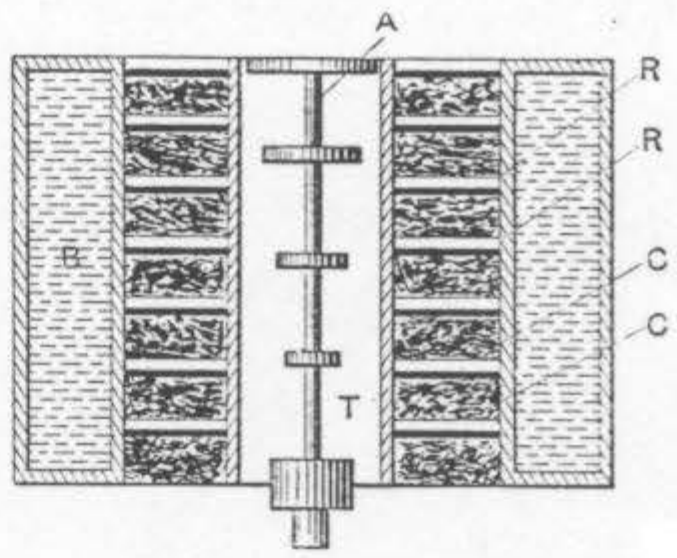


FIG. 3.—COX'S THERMOPILE

set the fashion in this respect, and a very convenient form for heating is thereby procured.

Cox's thermopile is one of the most modern productions in this field, and was, until a short time ago, obtainable in Great Britain, but it is understood that its manufacture has been discontinued. A diagrammatic view of its internal construction is represented in Fig. 3, where *R R* are the thermo-couples, arranged in annular form, and separated from one another by insulating pieces, *C C*. The central tube, *T*, is lined with fireclay and heated by a Bunsen burner, the flame from which is spread outwards against the walls of the tube by a special device, *A*. *B* is a water-jacket, provided with inlet and outlet pipes, and so arranged, immediately outside the outer junctions, as to keep them cool by the circulation of cold water whilst the pile is active. The stock patterns of this pile had electromotive forces of 3, 3.5, 4.5, 5, and 8.5

volts, and were capable of generating 4, 4·5, 3·5, 3·2, and 2.5 ampères, respectively.

There are several other types of thermopile, all of which, however, are similar in principle to the three already described, and which will serve as examples of their kind.

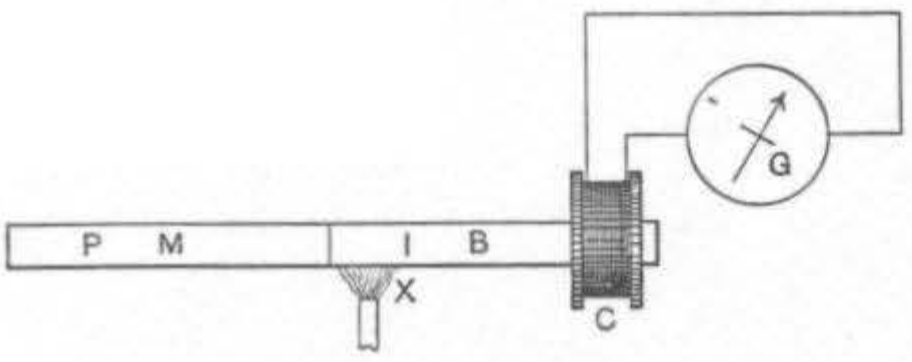


FIG. 4.—THE PRINCIPLE OF TESLA'S PYRO-MAGNETIC GENERATOR

To sum up, the thermopile is an extremely inefficient device for the production of electrical energy from heat, and possesses also several inherent defects, which render it unsuitable for any but a few special requirements. Chief among the drawbacks of this type of generator are, firstly, its necessarily high internal resistance, owing to the fact that the hot and cool junctions must be separated by an appreciable expanse of metal; secondly, the difficulty of preserving, for any length of time, good electrical conductivity at the junction, owing to oxidation and other causes; and thirdly, the extremely rapid depreciation of the pile, owing to the sudden extremes of temperature to which its parts are subjected, and which give rise to consequent expansion and contraction of the metal, tending to loosen all joints, and, in time, prove the destruction of the whole pile.

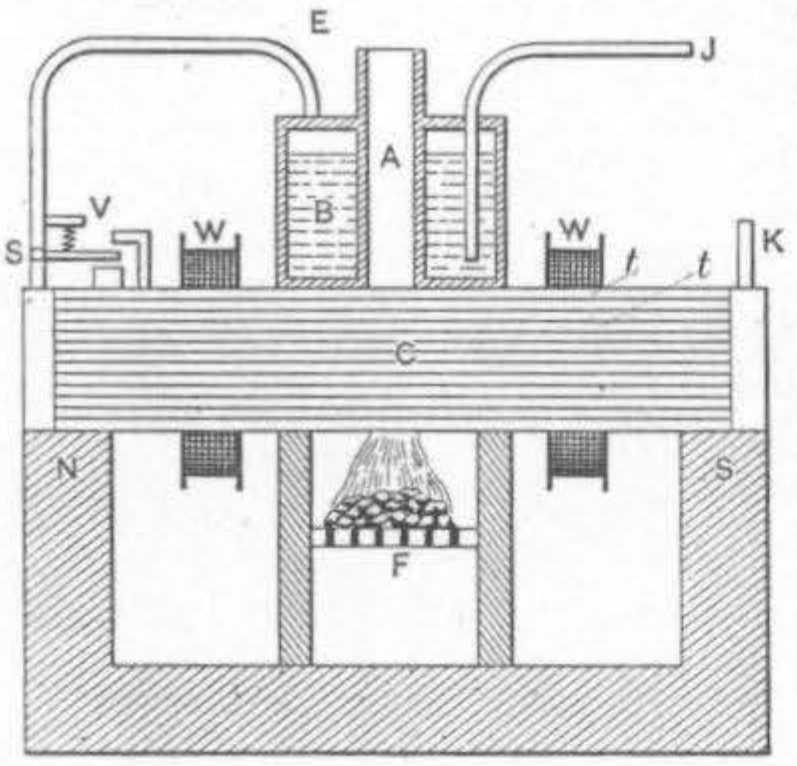


FIG. 5.—TESLA'S GENERATOR

Having thus briefly considered the subject of thermopiles, let us next proceed to discuss what are known as pyro-magnetic generators of electrical energy. At the beginning of the seventeenth century Dr. William Gilbert elicited the fact that natural magnet (loadstone) or a magnetised iron bar, if subjected to a red heat, loses its magnetic properties. On this discovery one or two devices for the generation of electrical energy have been based, and I will first proceed to deal with the work of Nikola Tesla in this direction. Tesla based the design of his pyro-magnetic generator on the above fundamental principle, and also on a second law, which is to the effect that if any conducting body (electrically considered) be subjected to a varying magnetic influence, electrical energy will be developed in that body. These two first principles may be ably demonstrated by a simple experiment, suggested, I believe, by Tesla himself. Referring to Fig. 4, if a permanent bar magnet, *P M*, be placed end on to, and in contact with, an iron bar, *I B*, in such manner as to magnetise the latter by contact, and a coil, *C*, be wound round the outer extremity of *I B*, and connected in circuit with a galvanometer, *G*, as shown, then on heating *I B* at the point *X*, by means of a suitable flame, until it becomes a bright orange-red, indicating a temperature of about 600 degrees C., the magnetism in *I B*

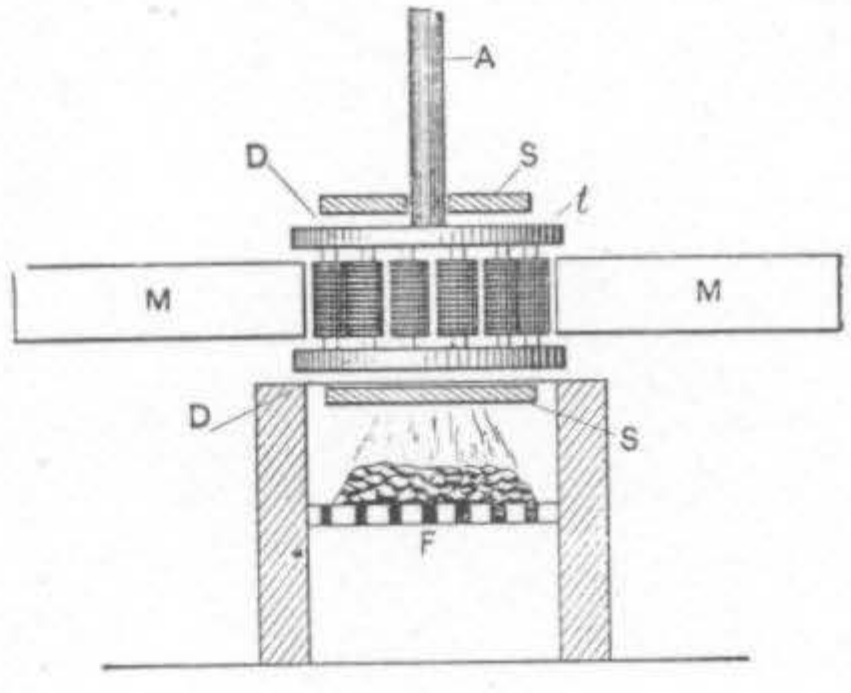


FIG. 6.—EDISON'S GENERATOR

will disappear, and, in its passage, give rise to a current of electricity in the coil, *C*, which will be duly recorded by a deflection of the galvanometer needle. On removing the source of heat and allowing *I B* to cool, its magnetic properties will again return, with the production of a second current in *C*, which, however, will be flowing in an opposite direction to the first, as indicated by the galvanometer needle, which will swing over in the opposite direction.

Tesla's suggestion for the application of this principle in practice is shown in Fig. 5, where *N S* represents a powerful magnet, the poles of which are bridged by a rectangular iron casing *C*, containing a number of iron tubes *t t*, the whole forming an armature or "keeper" to the magnet *N S*. Around the casing are wound coils of insulated wire *W W*, in which the resultant electrical energy is to be generated. The armature passes through the centre of a specially constructed furnace *F*, provided with a chimney *A*, and surmounted by a boiler *B*. A water inlet pipe, *J*, and steam outlet, *E*, are fitted to the boiler the steam outlet being led round to the common entrance of all the tubes, *t*, as shown. An exhaust pipe, *K*, is provided at the opposite extremity of the armature. *V* is a steam valve, actuated by a spring-controlled lever, *S*, which, when the armature is magnetically active, is attracted downwards, and closes the valve. On the centre of the armature becoming heated by the furnace, it loses its magnetism, with a consequent production of electrical energy in the coils *W*, and the release of the lever *S*, which is drawn up by its spring, opening the steam valve, and allowing steam to enter the armature. The steam exercises a cooling effect on the latter, with the result that its magnetism returns, a current is again produced in *W W*, and the steam is automatically cut off, as before, and so the cycle of operations goes on. The main drawback to this and other types of pyro-magnetic generator is their necessarily sluggish action, a perceptible interval being necessary to allow the active portion of the magnetic circuit to assume its extremes of temperature. In 1887 Edison turned his attention to this type of generator, and succeeded in producing a machine of 1500 pounds weight which was capable of developing electrical energy to the extent of 3 H. P. The principle of Edison's generator is represented in Fig. 6, where *M M* are a number of horizontal magnets, arranged radially with their inner poles towards a centre vertical shaft, *A*. On the latter, and so mounted as to revolve with it, is fixed an armature, consisting of a number of vertical iron tubes, *t*, one two-hundredths of an inch in thickness, and mounted, top and bottom, in thick iron discs *D D*. Each of the armature tubes is wound with an insulated wire coil, the ends of which are led to a commutating device (not shown) by which the resulting currents may be rendered unidirectional. *S S* are refractory earthenware or fire-clay screens, arranged, one above, and the other below, a segmental portion of the tubes *t*, so as to screen some of them from the heating effects of the coal furnace *F*. On rotating the armature, those tubes which are open to the furnace lose the magnetism which they receive by induction from the magnets *M*, and a current is generated in the coils surrounding them; on passing over to a position in which they are screened by the segments *S S*, they become cool, with the result that their magnetism returns, and a second current is generated in the coils.

Edison's device possesses several defects; firstly, it is heavy, compared with the output of energy; secondly, its iron tube armature, owing to the fragile construction necessitated, speedily disintegrates; and, thirdly, it can be run only at a slow speed, about 120 revolutions per minute. A generator on a similar principle to the foregoing has also been designed by M. Menges, of Holland, the necessary heat energy being supplied by a number of gas jets.

All the devices so far described for the production of electrical energy from coal have depended on a primary conversion of that latent energy into heat by direct combustion in a furnace. This,

in itself, implies considerable waste, in that many of the elementary bodies contained in the coal are either consumed or pass off in the form of vapour or gas without yielding a proportionate return as heat energy. We must look, therefore, for a more direct conversion than that represented by direct combustion pure and simple.

Volta's valuable discovery at the close of the eighteenth century which resulted in the evolution of the ubiquitous primary battery opened up a wide field for scientific research in connection with the production of electrical energy by chemical action. The element mainly concerned in the production of electrical energy by voltaic action is zinc, and this metal is, unfortunately for the success of the problem, far less plentiful than coal, so that, to contrast the two substances from the point of view of commercial economy in the production of current by known methods, shows a decided balance in favour of coal and the steam engine. With the object of overcoming this drawback many attempts have been made to substitute carbon, the predominant partner in the composition of coal, as the element to undergo combustion in a voltaic cell.

Here we are met by difficulties of a grave nature. Coal *per se* is a poor

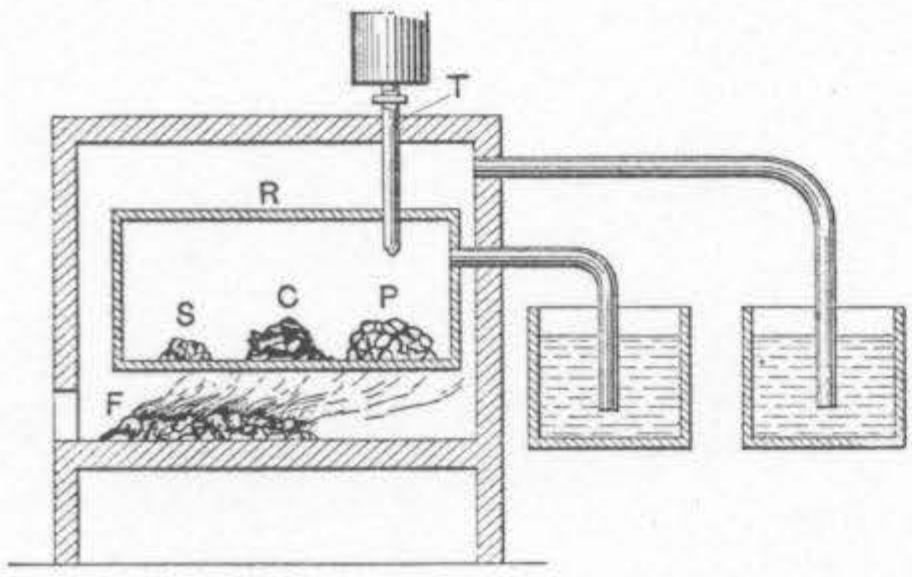


FIG. 7.—REED'S PROCESS

conductor of electricity, but is readily converted into a good one in the shape of coke, which is almost all carbon, and, moreover, gives up valuable by-products in the process of conversion. Then, again, it is essential to the success of a voltaic cell that the positive, or consumed electrode, should be strongly electro-positive, and this, in point of fact, carbon is not, being rather the reverse, and electro-negative to all but a few elements, thus rendering the available range for the selection of a suitable negative very limited in character. To crown all, carbon is insoluble in all ordinary solutions, thus introducing another difficulty,—the selection of an electrolyte.

Despite these various drawbacks, many attempts have been made to employ carbon as a positive electrode in a battery for the generation of electrical energy by voltaic action, and the writer will proceed to deal with one or two of the most noteworthy methods.

C. J. Reed's process, which was first published in 1896, is represented in Fig. 7, where *R* is a retort, mounted upon a suitable furnace, *F*, and containing the separate ingredients *S* and *C*, consisting of sulphur and carbon, respectively. *P* is a small mass of pebbles, over which water is allowed to trickle from a supply tube, *T*. The furnace *F* is fed with sulphur, which, by its combustion, is converted into sulphur dioxide gas; this passes out at the exit flue, and is collected by solution in water, forming sulphurous acid. The heat thus generated causes the sulphur *S* to vapourise, and the vapour, in passing over the mass of heated carbon *C* is converted into bisulphide of carbon. Simultaneously, the heat of the furnace *F* produces steam at the point *P*, and this steam, mingling with the carbon bisulphide vapour, forms sulphuretted hydrogen and carbon dioxide gases. These two mixed gases also pass over into water, which readily dissolves the sulphuretted hydrogen, but the carbon dioxide sparingly,—in such small quantity as to render it negligible. Sulphurous acid and sulphuretted hydrogen solution, thus formed, are placed in a two-compartment vessel, separated by a porous partition which permits diffusion. As electrodes, a carbon plate is placed in each liquid, and the resulting voltaic action produces water and sulphur, giving rise to an electromotive force of about 0.36 volt. Unfortunately, the diffusion, and consequent combination of the two liquids, goes on all the while,

whether the external circuit be open or closed; there is thus considerable waste, and the electromotive force being very low, this arrangement has not proved itself commercially practicable.

Another device, the introduction of which at about the same time created quite a furore in scientific circles, is that of Jacques, and is known as the Jacques cell. It is represented in diagrammatic section by Fig. 8, and consists of a furnace, *F*, over which is mounted an iron retort, *R*, which constitutes the negative electrode of the battery. Placed axially in this retort, but insulated from it by the lid *L*, is the carbon, or positive electrode, *C*, immersed in a mass of fused caustic soda, *S*, contained in the retort *R*, and maintained in a state of fusion by *F*. *P* is an inlet pipe for atmospheric air, under pressure, from a pump, the stream of air being distributed under the lower extremity of the carbon electrode by a perforated head, *H*, similar to the rose of a watering-pot.

The action claimed for this type of generator is as follows:—The oxygen of the air, in the presence of the fused caustic soda, unites with the carbon to form carbon dioxide, which passes off from the retort in the shape of gas, whilst the electrolyte remains unchanged, and can, in consequence, be used indefinitely. An electromotive force of one volt is produced at the terminals of the cell. Theoretically, this action looks very pretty, but the actual reaction which goes on is still, to a certain extent, shrouded in mystery. Suffice it to say that, in practice, carbonate of soda is formed in no inconsiderable quantity, and this, together with other impurities emanating from the carbon, tends to destroy the utility of the caustic soda in course of time. Moreover, an extraneous source of heat, the furnace *F*, is required to work the cell, and also an auxiliary pump for the air supply, both of which items considerably detract from the economical working of the apparatus.

Blumenberg's cell is very similar to the foregoing in its construction and the principle on which it depends for the generation of an electric current. The carbon and containing retort of iron or copper are arranged as in the previous apparatus, whilst the caustic soda is mixed with lime and cryolite. The air-pump of Jacques' cell is rendered unnecessary by the addition of an annular boiler which surrounds the retort and is heated by the same furnace. The steam generated is led into the electrolyte, and, by its decomposition into its constituent elements, hydrogen and oxygen, supplies the place of the air in the former device.

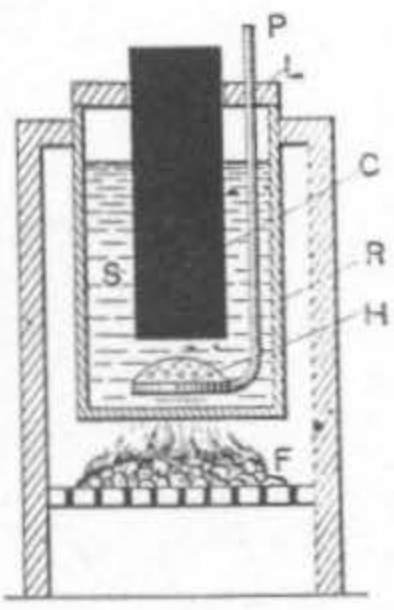


FIG. 8.—THE JACQUES CELL

Whilst on the subject of voltaic action, we must not forget the valuable services rendered by Sir William Grove in his discovery, in 1839, of the "gas battery," and his subsequent indefatigable research in connection with the subject.

As the result of his investigations the following list was compiled, in which each element or gas is electro-positive to all those which follow:—

(+) Metals which decompose water
Hydrogen
Carbonic oxide
Phosphorus
Sulphur
Alcohol
Ether
Olefiant gas
Ethereal oils
Camphor
Metals which do not decompose water
Nitrogen
Carbonic acid
Nitric acid
Oxygen
Peroxides
Iodine
Bromine
Chlorine

The principle of the gas battery consists in substituting gases for the solid electrodes in a voltaic cell, the said gases, by their reaction one upon another and the electrolyte, having the effect of generating a current, available at the terminals of the cell, which latter usually take the form of metallic or carbon plates, immersed partly in the gas and partly in the electrolyte.

One of the most recent attempts to apply the principle of the gas battery to the solution of the problem indicated in

the title of this article was that of Dr. W. Borcher's. His cell at first consisted of an outer glass or stoneware containing vessel, divided into two compartments communicating with each other at the bottom. In this vessel was placed an ammoniacal or acid solution of cuprous chloride; air was supplied to one compartment and carbonic oxide to the other. The electrodes were both of carbon, and yielded only a very weak current when connected.

An improvement on this form was shortly afterwards effected by substituting a copper electrode for the carbon in the carbonic oxide compartment. Coal gas also took the place of carbonic oxide, whilst acid solutions were found to give better results than those of an alkaline nature. By using the last-described form of apparatus, the external compartments being filled with copper turnings, a maximum electromotive force of 0.56 volt was obtained, and, on short circuit, the cell was found to give 0.64 ampère. In a later form of this battery the outer containing vessel was constructed of copper and formed one of the electrodes. The inner cell was of perforated earthenware.

It was estimated that with Dr. Borcher's gas battery at least 27 per cent. of the fuel consumed is converted into electrical energy. Unfortunately, however, recent investigations tend to show that the evolution of a current from this type of cell is due rather to the solution of the valuable copper electrode than the desired carbon or coke, thereby discounting its apparent value in this connection.

The great difficulty met with in the practical application of the gas battery principle consists in the fact that the current-producing capacity of the cell depends on the rate of occlusion of the gases by the electrodes employed. This occlusion, for all practical purposes, requires electrodes of an impracticable area, though it is possible that the preliminary storage of the gases under pressure might effect a saving in this direction. Researches in this field should, therefore, tend to the discovery of an electrode material which is capable of absorbing large volumes of gas, and, at the same time, giving up such gas when required for reaction in a gas battery. The discovery of such a material would greatly extend the scope of the gas battery problem.

Summing up the various data so far available, it is fairly obvious that the final solution of the interesting problem of producing electrical energy directly from coal does not lie with the first three methods, which, as already noted, involve the preliminary generation of heat energy on a wasteful plan. The matter, therefore, lies, so far, with the voltaic cell in which carbon is the consumed electrode and the gas battery, and it is just possible, though hardly probable in the immediate future, and under present known scientific conditions, that either of these methods, or a successful combination of the two, may provide us with a scientific solution. On the other hand, it must be remembered that the apparatus will probably prove cumbersome and costly, so that although the theoretical efficiency might be as high as 70 or even 80 per cent., the great interest on capital outlay would probably be a prohibition to its commercial adoption.

AMERICAN "CAPTAINS OF INDUSTRY."

A RAPID REVIEW OF THE GREAT INDUSTRIAL LEADERS INVITED TO MEET PRINCE HENRY OF PRUSSIA.

BY CARL SNYDER.

WHEN a prince of one of the reigning houses of our continental forebears came to explore somewhat in the Strenuous Land, it was not so much the politicians at Washington, or the Authors' Club, or the National Academy of Sciences, or the leaders of the "New Thought," as it was the captains of industry whom he most desired to meet.

The men of this type who foregathered at the luncheon given to the German visitor, made up an altogether remarkable body. It was probably as representative of American achievement to date as could well have been brought together. It was not exhaustive,—rather by the conspicuous absence of many well-known names did it suggest how imposing our army of achievement has become.

THE CHIEFS.

In the rapid *résumés*, necessarily of exceeding brevity, which follow, more especial attention has been drawn to the list of the invited "captains," comprising, as they do in large part, men not widely known to the public; but their hosts were,—it need hardly be said, a most noteworthy group of men,—the central figures of American finance.

Naturally the name of Mr. J. P. Morgan leads all the rest. He is the unquestioned chief. According to common report, he actually controls more than three billion dollars of capital, and it would not be surprising if these figures were far beneath reality. In a monetary sense he must exert a greater influence than any living man; for to an apparently unlimited amount of capital he unites an energy, an imagination, and an irresistible tenacity of purpose that would mark him in any walk of life. Enterprises, consolidations, reorganizations of a magnitude hitherto unknown in human affairs, seem almost his daily meat and drink. The colossal seems to attract rather than repel him.

The men who served with Mr. Morgan as hosts were chiefly his associates and friends. Mr. Vanderbilt represented what in former times was the largest single interest in the country, the railway holdings of his own family. Morris K. Jesup, railway president and benefactor of science, represented the best type of the American millionaire, those who have endeavored not solely to amass wealth, but to make their riches useful and creditable to their own time. Former Vice-President Morton has had a distinguished career alike as a banker, a diplomat, and as an occupant of important administrative positions. Geo. F. Baker, the veteran president of the First National Bank, stood for the conservative forces of Wall Street. James Stillman might be taken as the banker type *par excellence*, a man whose whole genius seems centered in the successful management of the great institution he directs. Edward D. Adams personated large electric interests, notably the wonderful power development at Niagara Falls, which grows more and more to the proportions of one of the greatest of American enterprises. William Rockefeller came



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J. PIERPONT MORGAN. W. K. VANDERBILT. MORRIS K. JESUP. GEORGE F. BAKER. JAMES STILLMAN.

THE AMERICAN INVENTOR.

If the development of its transportation systems has been, perhaps, the most notable fact in American life, the next most noteworthy has certainly been the perfection and utilizing of mechanical devices for the saving of human labor. Excellent examples are to be found in the inventions of Westinghouse, Brown, Church, and a crowd of others.

It was Westinghouse's device of an air brake which made modern railroading possible. Long trains and high speeds without them would be out of question. The Westinghouse brake is now in use all over the world. From the air brake, Mr. Westinghouse turned to electricity, and it is largely to his persevering efforts that the alternating current has come into general use. The lighting of the World's Fair at Chicago was one of his triumphs.



D. H. CHURCH.

Duane H. Church is the great American tool-maker. His business is to build watches. Comparatively few of his eighty million countrymen had ever heard of him until Henry of Prussia came over here, but by his associates he is regarded as a man of almost miraculous powers. His especial achievement has not been so much making fine watches as fine machinery that makes watches. The things he builds perform such a variety of ingenious and accurate functions that they seem almost human in their complicated movements. A single one of his machines will complete a work which before required passing through twenty different hands.

What Duane Church has done to make machines that will do very fine work Alexander Brown, of Cleveland, has done to make machines to do big work. He is one of the men whose inventions in hoisting and ore and iron handling machinery have brought it about that although the rate of wages is the highest, the cost of labor per ton of coal, iron, or steel product in the United States is the lowest in the world.

The inventions and improvements of Edwin Reynolds have been a vital part of the machine practice of this country. He belongs now with the Allis-Chalmers Company, of Milwaukee; but he made his mark with the Corliss Company, of Providence. A great number of inventions in various branches of mechanics testify to his activity, but the Reynolds-Corliss engine is his best-known achievement.

In an old industry it is possible only to improve, but once in a while comes to a man the opportunity to create a wholly new industry. That is what Edward G. Acheson did with carborundum. It was while he was an assistant to Edison in Menlo Park that, partly by accident, he was led to the idea of an artificial abrasive. After a lapse of ten years, systematically he set about the making of the extremely hard compound of carbon and silicon, which he called carborundum. It is some eight times as efficient as emery for grinding, and is now in use in all lines of industry.

Charles M. Hall, whose factory, like Mr. Acheson's, is at Niagara Falls, is the creator of cheap aluminium. The Pittsburg Reduction Company, which owns Mr. Hall's patents, turns out now more than a million dollars' worth of aluminium a year, and it will probably not be long before it will come into very general use. Even now, bulk for bulk, it is as cheap as copper, and improvements in the process cheapen it steadily year by year.

THE ELECTRICIANS.

In the field of electricity, the United States has been easily first. Edison, Bell, Tesla, Brush, Thomson,—these are names known in Europe



CHARLES M. HALL. ALEXANDER E. BROWN. EDWARD G. ACHESON. EDWIN REYNOLDS.



MICHAEL I. PUPIN. EDWARD WESTON. ALEXANDER G. BELL. GEORGE GRAY WARD.

hardly less than in America. All of these came to greet the German Prince, and others not less entitled to honorable mention.

In the public mind, at least, the wizard of Menlo Park is almost synonymous with electricity itself. In the multiplicity of his inventions it is hard to distinguish what was the most important. Probably his incandescent lamp should be named, but there is scarcely any department of practical electricity which he has not invaded.

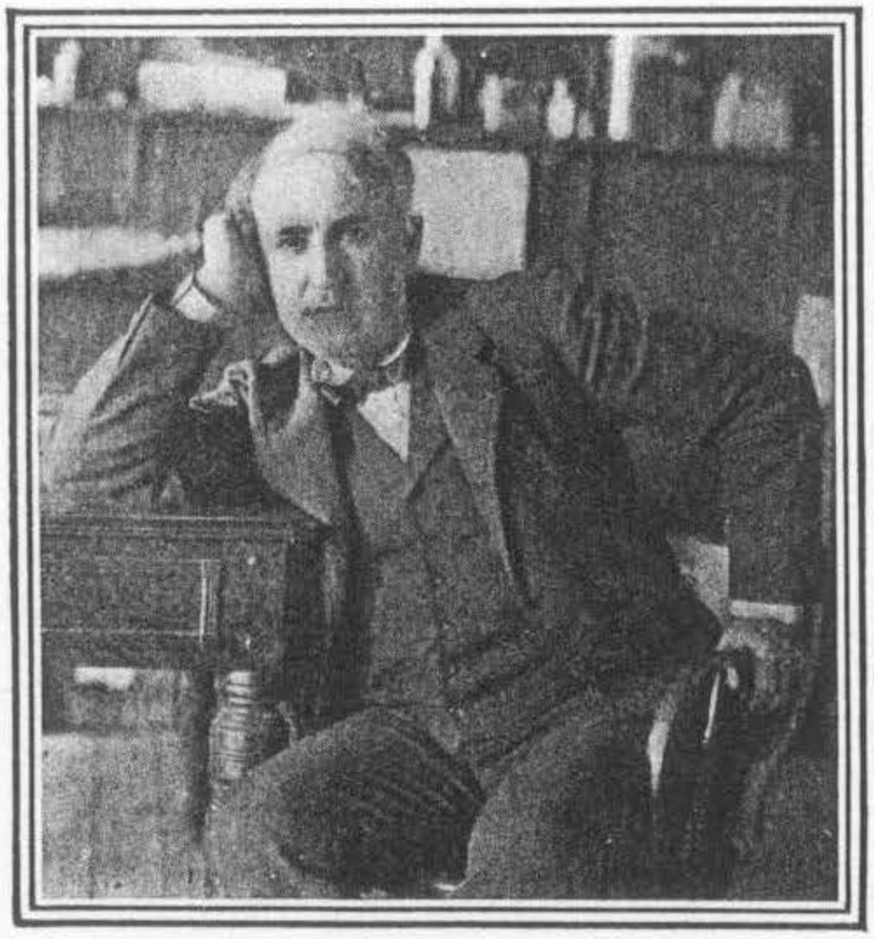
The filing of patents for the telephone on the same day of 1876, by Professor Bell and the late Elisha Gray, will ever remain one of the most remarkable incidents in the history of invention. That two men should have hit upon identically the same principle, destined to be of such immense importance to mankind at the same time, and have completed their work and claimed protection for it at almost the same hour, is one of the most memorable of coincidences.

Nikola Tesla belongs to us only by adoption, but all his notable work was done here. His invention of the induction motor, and his work in the development of long-distance transmission, have had the greatest commercial results, but it is his astonishing achievements with the high-frequency current that have given him so high a standing with scientific men. As yet this work has not found the practical applications Mr. Tesla had hoped for; yet there remain boundless possibilities. Let us hope their creator will live to realize some of them before he gets through.

The work of Elihu Thomson has been far less popular; but it has been solid, aye, and immense. Six hundred inventions in electrical applications stand to his credit. Mr. Thomson's most notable work has been the invention of electrical welding and metal working. The Thomson meter has long been a standard, and hundreds of thousands are made each year. Nearly every electric car utilizes some one or more of his devices; and in addition to all this, he has contributed much to the advance of electrical science.

Charles F. Brush is known best as the father of arc lighting; and the Brush light, in its original form, is still in general use throughout all civilized lands. Like Professor Thomson, he has been decorated by the French Government, and also been the recipient of the Rumford medal. Another pioneer in the electrical field was Edward Weston. English by birth, it was in this country that his improvements in electroplating, deposition, arc and incandescent lighting, dynamos, etc., were done. Since 1886, he has devoted his energies chiefly to the invention and designing of electrical measuring instruments of the highest precision.

The electrical railway owes its beginning and a large part of its development in America to Frank J. Sprague. The first electrically equipped street railway of importance was that which he installed at Richmond, Va. The work was attended with the most discouraging circumstances and experts declared it would never run; but it did, and it marked an epoch in street-railway service. The movable trolley, and most of the other features of electrical traction, are due to his initiative. The equipment of the South



THOMAS A. EDISON.

Side Elevated Railroad of Chicago, with what Mr. Sprague calls the "multiple unit" system, was another notable achievement. He likewise built the first large electric locomotive in this country, and has done so many other good things that he might well serve as the type of the aggressive, go-ahead American engineer.

Professor Pupin, of Columbia, is known best for discoveries which may make it possible to telephone around the world. This wonderfully original work is a good example of the practical end which sometimes comes to the most abstract research. It was a splendid work, and its possibilities are immense. Professor Pupin's associate at Columbia, Prof. Francis B. Crocker, has done valuable work in the standardization of electrical apparatus, and it is the uniformity, interchangeability, and other advantages thus secured that have been among the chief factors in placing American electrical manufacture ahead of foreign competitors.

The especial work of Professor Steinmetz, of Schenectady, has been of a technical and theoretical nature. He is the president of the American Institute of Electrical Engineers, and the engineer of the General Electric Company, the largest producers of electrical apparatus in America. His various treatises and papers upon electrical science have given him a high rank among scientific workers. He is now supervising the construction of the new 10,000-horse-power electrical generators for Niagara, by far the largest machines of the kind ever built.

George Gray Ward, the present managing director of the Postal Telegraph and Cable Line, comprising 27,000 miles of land line and 20,000 miles of Atlantic submarine cables, has seen service in many lands. When he began it was considered a great feat to get an answer from a cablegram to London inside half an hour. Now it is frequently done in five minutes. Upon the completion of the direct cable between the United States and Germany a year ago, the German Emperor conferred on Mr. Ward the order of the Royal Prussian Crown.

THE MACHINE MAKERS.

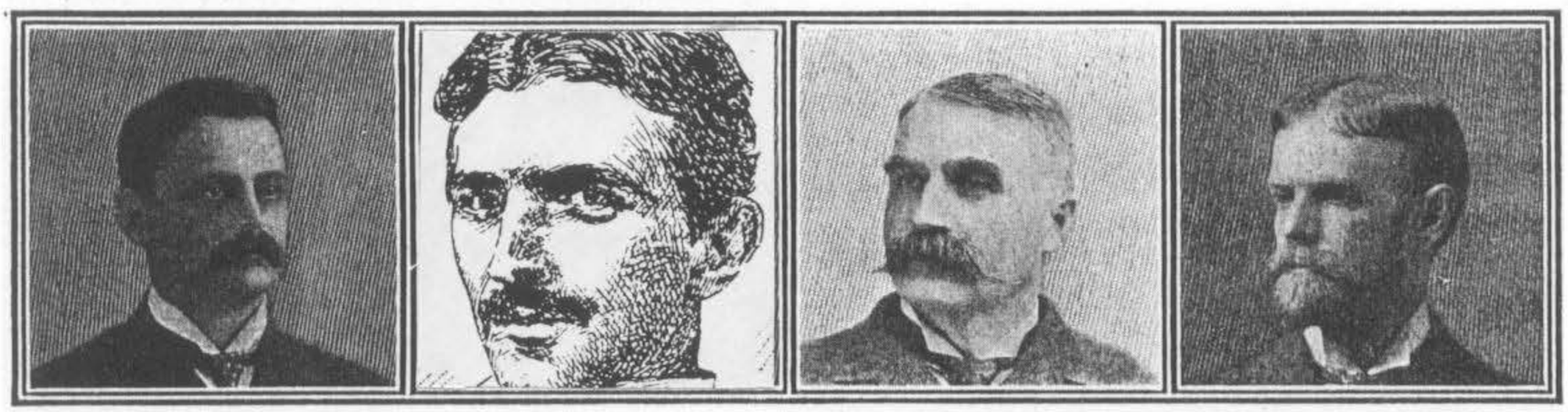
Another group of industrial captains are the great builders of mechanical hands and eyes, and draft horses, and all the other substitutes for human and animal labor which make possible this $13,000,000,000 of manufactured product of the United States each year.



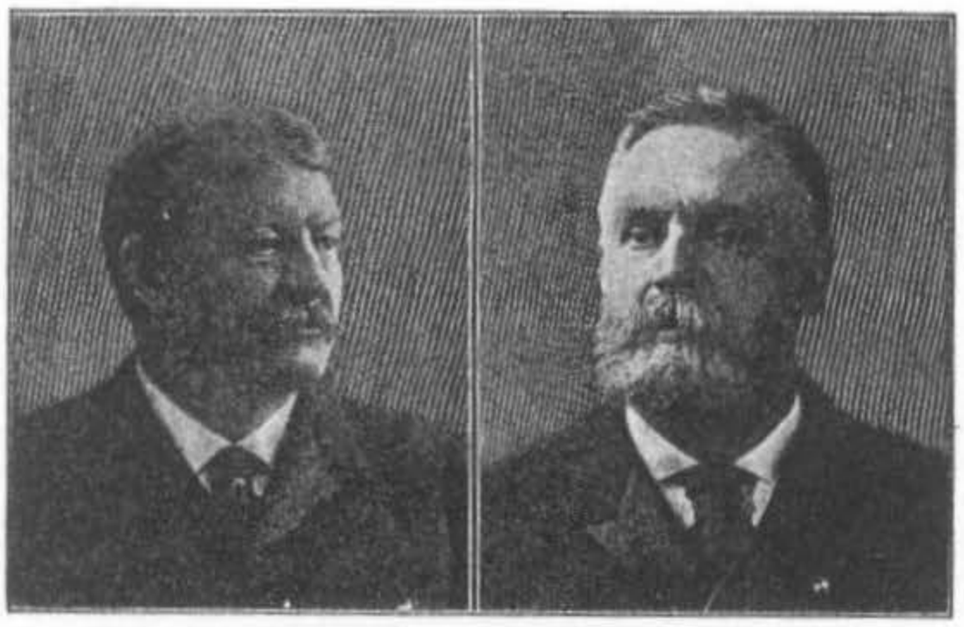
FRANK J. SPRAGUE.

The famous Baldwin locomotive works, founded three quarters of a century ago by Mathias Baldwin, in Philadelphia, was represented by John H. Converse. Its founder would hardly recognize his creation now, so vastly has it grown. When Baldwin died the capacity of the works was a little over one hundred locomotives a year. Now it turns out over a thousand. The Baldwin locomotive of to-day, compared with its prototype of forty years ago, is as a packet steamer f that time to the *Deutschland*. Yet, so perfe is the organization of the works that a locomotive has been ordered, the materials purchased, and the completed work put upon the rails in working order within a space of eight days.

Charles Deering represented the grain-harvesting machines. It is odd to think that mankind should have gone on, in all probability, reaping his fields by hand for thousands of years, and that the methods which were old when the most ancient kings of the Nile lived and ruled should have persisted down to a time within the memory of men yet living, then in half a century have been so profoundly changed. The McCormicks and Deerings have left a deeper impress in the



ELIHU THOMSON. NIKOLA TESLA. CHARLES F. BRUSH. FRANCIS B. CROCKER.



ELIPHALET W. BLISS. ALBERT A. POPE.

life of the world than any Cæsar or Napoleon ; the most distant parts of the earth have felt the effect of their innovations, and the vast wheat fields of the West are in great part their handiwork.

But the typical machine maker of the company was Col. E. W. Bliss, of Brooklyn. His first employment was making gun machinery for the Government. Then he turned his hand to making printing presses. From working paper through a press, he took to the making of all sorts of presses, dies, and special machinery for working sheet metals. He is also president of the United States Projectile Company which makes common shells, shrapnel and armor-piercing projectiles for the United States Government.

Frederick G. Bourne came as the president of the Singer Manufacturing Company. This organization now has 8 factories, making over 800 varieties of sewing machines, with the incredible annual output of 1,200,000 machines and 100,000,000 needles. The company has 75,000 employees under direct control in all parts of the world.

Colonel Pope was the pioneer in the manufacture of the bicycle in this country, and it is largely due to his efforts that American bicycles are sold all over Europe. He deserves well, of his fellow-men, on other accounts, too, for he has been an untiring worker for the betterment of American roads.

Next to the making of machines, their distribution is of prime importance, and Mr. C. A. Moore, of New York, as the representative of the largest manufacturers of machine tools in this country, stood for this especial industry. Nothing can be more gratifying to such of our people as take pride in work well done than to know that American tools, and, more especially, American tool-making machinery, are now conceded to be the best anywhere.

THE IRON AND COAL INTERESTS.

For the easy-going historian, it might suffice to accredit the fact of America's speedily reached supremacy in the production of coal and iron to the existence of an abundantly producing area, comparatively easy of access. One gets a better idea of the fact when one reads of such an undertaking as that of John Markle's construction of the famous Yeddo tunnel in Pennsylvania. That was a tunnel nearly five miles in length, draining drowned-out mines and a huge basin of coal as well. It was an excellent example of American enterprise and the growing tendency in this country to take up difficulties in a large bold way.



JOHN MARKLE.

The nestor of the iron trade is John Fritz. He began life as a blacksmith back in '38, and in his long career has been identified with almost every important thing in the process of making iron and steel which has resulted in an increase of the American product from a quarter of a million tons in 1838 to 16,000,000 tons in 1901. The crowning effort of his life was the conception, the designing, and erection of the great forge and armor plate plant of the Bethlehem Steel Company.



JOHN FRITZ.

George F. Baer, the president of the Reading Railroad, came rather as the representative of the Consolidated Anthracite Coal interests than of his railroad. He is a lawyer, and was for years the confidential legal adviser of Mr. Morgan in Pennsylvania.

Edwin J. Berwind stands for the bituminous coal interests. He has been a pioneer in its export—that is to say, among those who have been shippers of coal to Newcastle.

ELECTRICITY.

XXII. NEW YORK, APRIL 2, 1902. NO. 13.

EDITORIAL NOTES.

A Wireless Telegraphy Wrangle.

At present it looks very much as though there would be a wireless telegraphy war. Prof. Slaby of Berlin, Germany, one of the inventors of the Slaby-Arco system of wireless telegraphy, claims that the Marconi people are doing all in their power to hurt his system in a commercial way. To a representative of the "Herald's" European edition, Prof. Slaby is reported as saying:

"I would like to appeal in behalf of humanity against any undue commercialism in the employment of wireless, or rather the spark, telegraphic system. I am not interested in the commercial exploitation of the Slaby-Arco system now, but purely in its scientific aspect.

"When the Deutschland, with Prince Henry on board, was near land and tried to make connections with its Slaby-Arco system with the Nantucket Station, which is provided with Marconi apparatus, it was impolitely cut off when it was learned at the station that the Deutschland was signaling. Had the steamer been in distress, or if it had been any other ship in distress equipped with a system which the operators of the Marconi Station were not allowed to recognize, such a ship might go to the bottom with all on board, just on account of commercial rivalry, which steps over dead bodies.

"There should be an international congress, and all Governments should oblige stations to receive messages from any ship.

"I do not claim that my system is superior to Mr. Marconi's, but that I arrive at the same results by different construction. Some time ago the Marconi system was offered to the German Government for 2,500,000 marks ($500,000). The Government rejected the offer, and it was this prohibitive price which necessitated the commercial exploitation of the Slaby-Arco system, which is employed not only by the German navy, but by the navies of Sweden and Norway, Denmark and Russia, and is also used in Austria, Belgium, Portugal and Mexico."

Speaking of wireless telegraphy as a rival of the submarine cable Prof. Slaby said:

"Wireless telegraphy will in no event interfere with the cables. It is ridiculous for the shareholders of cable stock to become frightened. When the electric light was introduced holders of gas stock were frightened, but what is the result? Gas is used in overwhelmingly larger quantities than when electricity was introduced.

"The objection to transatlantic telegraphy by ether waves is that such strong currents as Mr. Marconi, for instance, could send from Poldhu interrupt communication over the entire ocean. When two boards are tuned to receive or send messages and a heavy current comes along it destroys communication."

It will be seen that as regards the supplanting of submarine cables by wireless telegraphy Prof. Slaby's opinion agrees with that expressed in these columns some time ago. On the other hand, Nikola Tesla still adheres to his idea of some day sending electric power to all parts of the world without wires, for commenting on Prof. Slaby's statement he says:

"While I do not believe that wireless messages over the sea will be as cheap as some enterprising people have asserted of late, still I cannot quite share Prof. Slaby's opinion in regard to wireless transmission of energy across the Atlantic. I began nearly two years ago the design and installment of power plants for commercial use, with the fullest confidence of success, basing my assurance on exact tests and measurements, which admit of no doubt.

"This work was commenced only after I had completely mastered the problem of insuring the absolute privacy of messages, and inasmuch as I have received in this undertaking the most generous help, I would be unfortunate indeed if my expectations were not to be fully realized. I hope, however, that the transmission of messages without wires is only the first and comparatively insignificant phase of a great revolution which will be wrought by the transmission of vast quantities of energy for industrial purposes to the most distant points on the globe without wires."

The Marconi people on their part say that they are not trying to interfere with Prof. Slaby in any way and deny that the Deutschland was cut off when it tried to communicate with Nantucket by wireless telegraphy.

The following communication on the subject has been given out by the Marconi Company:

"It is contrary to the policy of the Marconi Company to exchange messages with ships equipped with any apparatus but Mr. Marconi and the terms of the agreement under which the New York 'Herald' is using the

Marconi's apparatus at Nantucket prohibit the paper from an exchange of messages with the Slaby-Arco or any other instruments than those of Mr. Marconi.

"Judging, however, from the statements in the 'Herald,' this clause of the agreement was not adhered to. Messages were sent out from Nantucket by the 'Herald's' operators to the Deutschland. These messages were not received, nor, apparently, according to the 'Herald' were any of the Deutschland's messages received at Nantucket."

In the meantime, Rear Admiral Bradford, chief of the Bureau of Equipment, is investigating through his agents abroad all the systems of wireless telegraphy of any merit, with a view of ultimate adoption of one of them for the use of the navy. Thus it is to be presumed that the ships of war of the United States will have the best system, whether that of Marconi or Prof. Slaby.

* * *

THE INVENTOR OF WIRELESS TELEGRAPHY.

ALTHOUGH Signor Marconi is not the inventor, but the skilled exploiter, of telegraphy without wires, everyone must admire the splendid success of his achievement in sending intelligible signals over fifteen hundred miles across the Atlantic. Of ultimate success in establishing regular wireless communication between the two continents there can be no question. The original inventor of the wireless telegraph, Professor Oliver Lodge, had supposed its limits of operation to be a few hundred yards. Signor Marconi two years later gave us reason to think that the range might be extended to a few miles. He pushed his methods till he attained distances of twenty, thirty, even ninety miles. Suddenly he astonishes us with messages to Newfoundland consisting of but a single repeated letter: and lastly he receives from England intelligible records upon a ship that is nearing the American coast.

To the uninitiated this sudden extension of range seemed so remarkable that the news from Newfoundland was received with much incredulity. Those however were not taken by surprise who knew Signor Marconi and were aware of the extensive preparations made at the station at Poldhu, of the powerful engine employed to drive the alternator, of the array of twenty masts over two hundred feet high erected to constitute a transmitting battery for the electric waves. The success was the outcome of a determined plan of campaign. This brilliant result marks however a change in the instrumental methods adopted by Signor Marconi. It may be worth while to attempt in untechnical language to explain wherein the difference lies. The two methods may be distinguished by the names of their respective originators as the method of Lodge and the variety due to Tesla.

In the method of Lodge, the Hertzian waves (or electric waves) generated by a snapping spark between the polished balls of a so-called "oscillator" are received at the distant station upon a receiving apparatus consisting of an extended arm or conductor in combination with a "coherer", a sensitive tube containing minute metal filings, by means of which a local battery is relayed on to a suitable telegraphic instrument, usually a Morse sounder or recorder. The coherer is kept in its sensitive state by receiving gentle vibrations from an automatic "tapper". Every time that a spark is caused to pass in the oscillator a flight of ethereal waves is sent out; and each such flight of waves acting through the coherer at the receiving end delivers a signal in the telegraphic instrument. By careful experimenting and unstinting expenditure on instruments Signor Marconi gradually increased the range of working from the two hundred yards of Lodge's earlier successes up to ninety miles and more. He elongated the extended arm or aerial conductor: he used finer powders in the coherer: he used more sensitive telegraphic receivers; and he perfected under the meaningless name of "jigger" the induction-coils in prior use.

In the apparatus of Tesla torrents of high-frequency sparks are poured out from a secondary induction-coil at a place in the circuit where the discharge is blown aside by a magnetic field or—as in Elihu Thomson's variant—by a blast of air. Every one of such recurring sparks starts its own wave, with effects that are cumulative and therefore capable of being detected at much greater distances. The particular disposition of machinery at Poldhu is understood to be due to Professor Fleming. The precise nature of the detecting instrument used by Signor Marconi in Newfoundland has not been made public: but in the successful communications made in mid-Atlantic a coherer relayed upon a recording telegraph instrument was employed.

When Signor Marconi came to this country five years ago, and conducted experiments under the ægis of the Post Office officials across the Bristol Channel, he was still employing the Righi "oscillator," and the method of Lodge, with a coherer to relay the signals to a telegraph instrument, and an automatic tapper. From the patent which he took out about that time—a document in which he apparently puts himself forward as the inventor of oscillator, coherer, tapper and all—it would appear that the only real point of novelty that he could embody in his claims was that of connecting one end of his coherer to the earth while the other was connected to an elevated and insulated conductor. All else is simply detail or surplusage. It is a very thin claim and has this inherently weak point, that it is quite easy to make a coherer work in some other way—as in fact Lodge did at an earlier, and Professor Slaby at a later date. The man, however, who in 1897 wants to get valid patents must avoid actually claiming the things made public in England in 1894. So it was probably wise of Signor Marconi to avoid making any broad claims to the coherer, the automatic tapper, or any of the features of wireless telegraphy already invented by Lodge. He does not claim them, though audaciously describing them as novelties. Nor do Professor Slaby and Count Arco make any such broad claims in the system of wireless telegraphs which they have independently perfected, and which has been adopted in the German Navy. Both Signor Marconi and Professor Slaby must be content to patent details only—each his own—since neither of them can put himself in the position where Oliver Lodge stands as the original inventor.

Now comes the amusing turn of the whole business. Flushed with his trans-Atlantic success, Signor Marconi, though he has never once dared to contradict the prior claims of Professor Lodge, sends, through some of his underlings, communications to the news agencies whining about the doings of Professor Slaby and Count Arco. His grumbles are duly cabled over from New York and find credence in the English press. But the Slaby-Arco system is as much a lineal descendant of Lodge's earlier work as is Signor Marconi's. Both of them employ Lodge's methods, in that both of them use a coherer to relay Herzian waves upon a telegraphic receiver; and both of them employ an automatic tapper. Eliminate these features, due to Lodge, of coherer-relay and tapper, and both Marconi and Slaby collapse. So Marconi, who uses—without acknowledgment—these devices of Lodge, mouths out denunciations of Slaby, who dares to use the same devices for the same purpose! It is a pretty quarrel. If Signor Marconi imagines that his thin patent claims entitle him to a monopoly of the æther for the purpose of transmitting signals he is much mistaken. His dog-in-the-manger policy toward Professor Slaby is simply silly, and the more so because neither of them can either transmit or receive a single "wireless" message in the United States without infringing the patents of Professor Oliver Lodge. It seems like the irony of fate that Professor Lodge, the well-known Principal of the University of Birmingham, after expounding the principles of wireless telegraphy in London and at Oxford in 1894, should find himself pushed aside, first by the Italian, who by dint of advertisement gains the public ear, and then by the German professor, and yet should actually stand master of the trans-Atlantic situation because he holds the master-patents in the United States. It is said that Lloyds has made an agreement with Signor Marconi for fourteen years. Perhaps Lloyds was not aware of the question as to where the patent rights lie. Signor Marconi may whine as he pleases about other men snatching the rewards from a scientific investigator; that is precisely what he himself has been trying to do for these last four or five years, his victim being the Englishman who was first in the field, and who, if he but knew it, is to-day master of the situation.

SILVANUS P. THOMPSON.

The New York Sun April 7, 1902

TESLA ON LODGE'S PRIORITY.

Less Disputable Than the Importance of His Devices in Wireless Telegraphy.

Nikola Tesla returned yesterday to New York from his plant on Long Island and was seen by a SUN reporter in reference to Prof. Silvanus Thompson's statement that both Marconi and Slaby are indebted to Lodge for his discoveries in wireless telegraphy, rather than to anything that they have originated.

"It is to be regretted that so many eminent men should engage in battle over this matter," Mr. Tesla said, "especially when there is no necessity for it. All the facts in the case may easily be ascertained by going over the records.

"In reference to Hertzian telegraphy, I have been a disinterested onlooker, as I devoted myself to my own system. But I know in a general way that Lodge gave first descriptions of certain devices known as the coherer and the tapper, subsequently used by others. Lodge is a pioneer of great force, and I have myself frequently acknowledged my indebtedness to him in other lines of work.

"Nevertheless, I consider that the published writings of Prof. Slaby on Hertzian apparatus are deserving of the greatest credit, which every one should unhesitatingly accord to him, as he has never failed to acknowledge duly the work of others.

"I disagree with Prof. Thompson on the importance he assigns to the coherer and tapper, as I have exhaustively tested these devices and proved them inadequate for carrying on practically quick telegraphy.

"The coherer is an instrument of wonderful sensitiveness, but there are other devices better suited to use in connection with tuned circuits in all cases in which reliability of action is an important factor.

"Quite apart from that, however, the Hertzian circuits separated from the ground by spark gaps and choking coils, as used by Lodge and others, are for all purposes inoperative, as they permit neither the transmission of effects at considerable distances nor tunings."

TESLA'S WORK AND MARCONI'S.

(From the New York Sun.)

Prof. A. Slaby, inventor of the process of wireless telegraphy which the German Emperor has lately ordered to be used by all German warships, which is known as the Slaby-Arco system, has, in an interview in Berlin, given to Nikola Tesla the credit for making possible all the systems of wireless telegraphy now known.

Prof. Slaby refers to Mr. Tesla as the "father of wireless telegraphy," according to the published reports of his interview, and says that Tesla first explained and worked out in his book "Inventions and Researches," published in 1894, the theory which thereafter Marconi was the first to demonstrate practically. While he gives Marconi the credit for the demonstration, Prof. Slaby ascribes the origin of wireless telegraphy to the New York inventor.

Probably few people outside of those interested in technical studies have read this first announcement of the theory and of the outline of a process for carrying it out that gave to the world the system of communication now in daily use on the seas. Indeed few know that Tesla promulgated it years before the first wireless message was sent.

The book referred to by Prof. Slaby as published in 1894 was really a republication of the facts and speculations put forth by Mr. Tesla in a lecture delivered before the National Electric Light Association at St. Louis at its sixteenth convention which was in session from February 28 to March 3, 1893.

The lecture was given at a special evening session of the convention, and was entitled "Light and Other High Frequency Phenomena." It was published in the same year in the proceedings of the convention by order of the executive committee of the association.

Mr. Tesla had spoken at length upon phenomena produced by electrostatic force, and after devoting some attention to electrical resonance, he said:

"In connection with resonance effects and the problems of transmission of energy over a single conductor, which was previously considered, I would say a few words on a subject which constantly fills my thoughts, and which concerns the welfare of all.

"I mean the transmission of intelligible signals, or perhaps, even power, to any distance without the use of wires.

"I am becoming daily more convinced of the practicability of the scheme, and, though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realized, yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thoughtful experiment in this direction.

"My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day.

"The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe

that it is practicable to disturb, by means of powerful machines, the electro-static condition of the earth, and thus transmit intelligible signals, and perhaps power.

"In fact, what is there against the carrying out of such a scheme? We now know that electrical vibration may be transmitted through a single conductor. Why, then, not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance.

"To the weary wanderer counting the mile posts, the earth may appear very large, but to that happiest of all men, the astronomer, who gazes at the heavens, and by their standard judges the magnitude of our globe, it appears very small.

"And so I think it must seem to the electrician; for when he considers the speed with which an electric disturbance is propagated through the earth all his ideas of distance must completely vanish.

"A point of great importance would be first to know what is the capacity of the earth, and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for, by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation.

"If it be a charged body insulated in space, its capacity should be extremely small—less than one thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case, it is of the greatest importance to get an idea of what quantity of electricity the earth contains.

"It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race.

"I propose to seek for the period by means of an electric oscillator, or a source of alternating electric currents. One of the terminals of the source would be connected to earth, as, for instance, to the city water mains; the other to an insulated body of large surface.

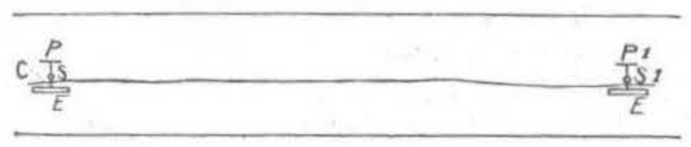
"It is possible that the outer conducting air strata of free space contain an opposite charge, and that, together with the earth, they may form a condenser of very large capacity. In such case the period of vibration may be very low, and an alternating dynamo machine might serve for the purpose of the experiment.

"I would then transform the current to a potential as high as it would be found possible, and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents, and carefully observing the potential of the insulated body, and watching for the disturbance at various neighboring points of the earth's surface, resonance might be detected.

"Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do, and a proper electrical oscillator would have to be produced, and perhaps it might not be possible to obtain such rapid vibrations.

"But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface."

Mr. Tesla accompanied his lecture with a diagram illustrating his idea of the wireless telegraphy instrument, which is here reproduced. He said, referring to it:



"Assume that a source of alternating currents, S, be connected, as in the figure, with one of its terminals to earth (convenient to the water mains), and with the other to a body of large surface, P. When the electric oscillation is set up, there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to or diverging from the point C, where the ground connection is made.

"In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will be perceptible will depend on the quantity of electricity set in motion."

Just here it is interesting to note that Mr. Marconi in an interview with a reporter for the "Sun" a few weeks ago said regarding his experiments between Poldhu and Newfoundland that the electric waves produced by his plant at Poldhu "diminished with the increase of distance," but that they "came," that being the important thing. He said also that with greater power he would have better results.

Continuing his lecture Mr. Tesla said, with further reference to the diagram:

"Since the body P is insulated, in order to displace a considerable quantity, the potential of the source must be excessive, since there would be limitations as to the service of P. The conditions might be adjusted so that the generator or source, S, will set up the same electrical movement as though its circuit were closed.

"Thus it is certainly practicable to impress an electric vibration, at least of a certain low period, upon the earth by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured.

"I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at the surface could be but extremely small, considering the size of the earth, the air would not act as a very disturbing factor, and there would be not much energy lost through the action of the air, which would be the case if the density were great.

"Theoretically, then, it could not require a great amount of energy to produce a disturbance perceptible at a great distance, or even all over the surface of the globe.

"Now, it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source, S2, similar to S, or any number of such sources, can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S1, if the same be on opposite phase to the source S.

"I think that, beyond doubt, it is possible to operate electrical devices in a city, through the ground or pipe system, by resonance from an electrical oscillator located at a central point.

"But the practical solution of this problem would be of incomparably smaller benefit to man than the realization of the scheme of transmitting intelligence, or perhaps, power, to any distance through the earth or environing medium. If this is at all possible distance does not mean anything.

"Proper apparatus must first be produced by means of which the problem can be attacked, and I have devoted much thought to this subject. I am firmly convinced that it can be done, and hope that we shall live to see it done."

In March and May, 1900, Mr. Tesla secured patents additional to those which he took out in the years immediately following the first announcement of his theory, these later ones covering developments of his system for the transmission of electrical energy, carrying it far beyond what he had at first suggested, but along the same general lines.

In the specification which forms part of the letters patent dated March 20, 1900, Tesla says, in the formal notice to the public as to what it is that the patent covers:

"I have been led to the discovery of certain highly important and useful facts which have hitherto been unknown. . . . In illustration of these facts a few observations which I have made with apparatus devised for the purposes here contemplated, may be cited.

"For example, a conductor or terminal, to which impulses such as those here considered are supplied, but which is otherwise insulated in space, and is remote from any conducting bodies, is surrounded by a luminous flame-like brush or discharge, often covering many hundreds or even as much as several thousands of square feet of surface, this striking phenomenon clearly attesting the high degree of conductivity which the atmosphere attains under the influence of the immense electrical stresses to which it is subjected.

"This influence is, however, not confined to that portion of the atmosphere which is discernible by the eye as luminous and which, as has been the case in some instances actually observed, may fill the space within the spherical or cylindrical envelope of a diameter of sixty feet or more, but reaches out to far remote regions, the insulating qualities of the air being, as I have ascertained, still sensibly impaired at a distance many hundred times that through which the luminous discharge projects from the terminal and in all probability much further.

"It is, furthermore, a fact that such discharges of extreme tensions, approximating those of lightning, manifest a marked tendency to pass upwards away from the ground, which may be due to electrostatic repulsion, or possibly to slight heating and consequent rising of the electrified or ionized air."

It may be noted here that Mr. Marconi,

when he went back to Cornwall after his first Newfoundland experiments, saying that he would increase the power of his plant at Poldhu, made the statement that he had found that an increase of power showed itself multiplied many fold in the greater proportional distance to which his electric waves would carry.

Mr. Tesla's specification in his patent continues:

"By the discovery of these facts and the perfection of means for producing in a safe, economical and thoroughly practicable manner current impulses of the character described it becomes possible to transmit through easily accessible and only moderately rarified strata of the atmosphere electrical energy not merely in insignificant quantities, such as are suitable for the operation of delicate instruments and like purposes, but also in quantities suitable for industrial uses on a large scale, up to practically any amount, and, according to all the experimental evidence I have obtained, to any terrestrial distance.

"Expressed briefly, my present invention, based upon these discoveries, consists, then, in producing at one point an electrical pressure of such character and magnitude as to cause thereby a current to traverse elevated strata of the air between the point of generation and a distant point at which the energy is to be received and utilized."

After describing his apparatus Mr. Tesla goes on to say:

"While the description here given contemplates chiefly a method and system of energy transmission to a distance through the natural media for industrial purposes, the principles which I have herein disclosed, and the apparatus which I have shown, will obviously have many other valuable uses—as, for instance, when it is desired to transmit intelligible messages to great distances, or to illuminate upper strata of the air, or to produce, designedly, any useful changes in the condition of the atmosphere, or to manufacture from the gases of the same products, as nitric acid, fertilizing compounds, or the like, by the action of such current impulses, for all of which and for many other valuable purposes, they are eminently suitable, and I do not wish to limit myself in this respect."

In his specification in connection with the patent granted May 15, 1900, Tesla says:

"This application is a division of an application filed by me on September 2, 1897, serial number 650,343, entitled 'Systems of Transmission of Electrical Energy,' and is based upon new and useful features and combinations of apparatus shown and described in said application for carrying out the method therein disclosed and claimed.

"The invention which forms the subject of my present application comprises a transmitting coil or conductor, in which electrical currents or oscillations are produced, and which is arranged to cause such currents or oscillations to be propagated by conduction through the natural medium from one point to another remote therefrom and a receiving coil or conductor at such distant point adapted to be excited by the oscillations or currents propagated from the transmitter."

TESLA SPLIT-PHASE PATENTS.—The United States Circuit Court of Appeals of the Sixth Ohio District has rendered a decision sustaining the Tesla split-phase patents of Dec. 26, 1893. The decision was on an appeal from the lower circuit court in a suit for the infringement of the above patents as applied to a fan motor. The defence in both cases was that the invention of the above-mentioned patents had been the subject of an earlier patent issued to the same inventor Dec. 3, 1889, on an application filed May 20, 1889. The applications for the first mentioned patents were filed Dec. 8, 1888. The court held that the earlier patent relates to the construction of motors and circuits capable of utilizing the properties of self-induction and the resistance in the circuit, to effect the delivery of alternating currents such as to induce a sustained rotation of the motor. The claims are for special means or apparatus designed to be employed in carrying out the inventor's method of operating his motor as described in the later patents. Since the invention of the specific means covered by these claims, and the generic invention of the later patents were for independent inventions, and neither had been given to the public, the court held that it was competent for the inventor to take out a patent for each; and that in such case it is not material that the taking out of one patent was prior to that of the other. The subject matter of the later patents—that is, the invention covered by them—was not a component part of the former invention, but was an independent invention not necessary to the composition of the first, or included in it.

Tesla Patents Decision.

The United States Circuit Court of the District of Rhode Island handed down an opinion, May 12, sustaining the Tesla patents, in a suit of the Westinghouse Electric Manufacturing Company against the Royal Weaving Company, of Pawtucket, R. I. The suit was on a preliminary injunction against the infringement of certain patents which the court states were the same as those sustained in a suit against the New England Granite Company, the opinion in which suit was reprinted in our columns at the time. The opinion states that the defendant relied principally on a French patent issued to Dumesnil, Aug. 8, 1884, and on a French patent issued to Cabanellas, April 9, 1885. The contention was that these patents disclosed what was not before the courts in the Granite case, namely, that two single-phase synchronous motors could be coupled together, as for example, by having their armatures mounted on the same shaft; and that these two motors might be run each by its own circuit of alternating currents, which might be supplied either by two single-phase generators so mounted on the same shaft as to give currents out of phase with each other; or that a single generator, such as is known in the prior art, and which furnished alternating currents differing in phase, might have been used as the source of supply. The court considers that the above-mentioned patents, if produced in the Granite State case would not have affected the decisions as to the nature and novelty of the Tesla invention and as to the validity of the patents in suit. Referring to the Dumesnil patent, the court considered that to couple two single-phase synchronous motors upon one shaft, displacing the poles of one armature angularly with respect to the other so that one motor expends its maximum effort while the other expends its minimum effort, does not seem to exhibit the Tesla invention as described and claimed in the Tesla patent. Referring to the Cabanellas patent, the court said that this patent, upon many readings, seems to it to be fairly characterized by the complainant's counsel as "expressed in such obscure and indefinite terms as to be hopelessly unintelligible except in a few unimportant particulars," and as requiring an exceptional exercise of the imaginative powers in translating its phrases into electrical diagrams. The opinion further states that the Dumesnil and Cabanellas patents at best were based upon the use of two motors of an old type having the characteristic defects of such motors, and lacking the characteristics of the Tesla motors. Even if two of these motors can assist each other, by so timing their mechanical efforts that one exerts its maximum effect while the other exerts its minimum effect, the court does not find in such a combination of the two machines the invention of Tesla, nor the rotary field which was apparently conceded by the defendant in prior suits to be proper subject matter of controversy in determining the validity of the Tesla patent. The court decides that the question of infringement seems to be substantially determined by the prior decisions. The questions as to whether the defendant may be permitted to continue temporarily the use of the motors now installed, and if so, upon what terms, were reserved by the court.

Philadelphia North American May 18, 1902

TESLA THINKS WIND POWER SHOULD BE USED MORE NOW

By Nikola Tesla



The power of the wind has been overlooked. Some day it will be forcibly brought to the position it deserves through the need of a substitute for the present method of generating power. Given a good breeze, I have estimated that there is as much as half a horse-power to every square fooot of area exposed. Imagine what energy is left unused with all this force at hand.

The contrivance that has been at the disposal of mankind from all time, the windmill, is now seen in the rural districts only. The popular mind cannot grasp the power there is in the wind. Many a deluded inventor has spent years of his life in endeavoring to harness the tides, and some have even proposed to compress air by tide or wave power for supplying energy, never understanding the signs of the old windmill on the hill as it sorrowfully waves its arms about and bids them stop.

The fact is that the wave or tide motor would have but small chance of competing commercially with the windmill.
which is by far the better machine, allowing a much greater amount of energy to be obtained in a simpler way.

Wind power has been in all times of inestimable value to man, if for nothing else than for enabling him to cross the seas, and it is even now a very important factor in transportation. But there are limitations in this simple method of utilizing the sun's energy. The machines are large for a given output and the power is intermittent, thus necessitating a storage of energy and increasing the cost of the plant. But there is no question as to its usefulness as a substitute for the energy derived from fuel, and the fact that this power is literally as free as air makes it a wonderful factor in the future of the world of industry.

Apart from the views expressed by Lord Kelvin regarding the future, when the coal supply shall have been exhausted, there is need of more attention being paid to it in the present day.

The man who cannot afford to have a furnace in his house may have a windmill on the roof. In this labor-saving age it is astonishing that farmers are the only citizens who call the wind their friend. Dwellers in cities toil up and down stairs hauling and carrying, while above them is a good-natured giant who can do all this work for them if they will but force him into service. Why wait for the coal supply of the earth to be exhausted before enlisting the aid of this vast aerial force?

The power to run elevators, pump water to roof tanks, cool houses in the summer and heat them in the winter is above us, at any one's beck and call.

A little ingenuity will enable any householder to harness the wind and leave it to do the work that he has considered part of the curse of Adam.

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An Important Polyphase Motor Decision.

In the Circuit Court of the United States for the District of Rhode Island, Mr. Justice Brown has just rendered a decision and opinion in the suit of the Westinghouse Electric and Manufacturing Company *versus* the Royal Weaving Company for infringement of the Tesla patents for polyphase motors. The opinion grants an injunction against the Weaving company, although it reserves decision as to whether the defendant may be permitted temporarily to use the motors which it now has installed.

The opinion of the court in full is as follows:

This is a petition for a preliminary injunction against infringement of patents No. 381,968, No. 382,279 and No. 382,280, granted May 1, 1888, to Nicola Tesla. These patents have been sustained, after full consideration, by the Circuit Court of the United States for the District of Connecticut in a suit against the New England Granite Company *et al*, 103 F. R., 951; and by the Circuit Court of Appeals for the Second Circuit, in the same case, 110 F. R. 753.

The defendant cites the language of the Supreme Court of the United States in Mast, Foos & Co. *vs.* Stover Mfg. Co., 177 U. S., 485:

"Comity, however, has no application to questions not considered by the prior court, or, in patent cases, to alleged anticipating devices which were not laid before that court.

"As to such, the action of the court is purely original, though the fact that such anticipating devices were not called to the attention of the prior court is likely to open them to suspicion."

The defendant contends that this Court should not be governed by the prior decisions, for the reason that it has before it new issues and new evidence.

The defendant relies principally on the French patent to Dumesnil, No. 161,564, dated August 8, 1884; and upon the French patent to Cabanellas, No. 168,172, dated April 9, 1885. It is said that the Dumesnil and Cabanellas patents disclose what was not before the courts of the Second Circuit, namely, that two single-phase synchronous motors could be coupled together, as by having their armatures mounted on the same shaft; and that these two motors might be run each by its own circuit of alternating currents, which might be supplied either by two single-phase alternating-current generators mounted on the same shaft, but so as to give currents out of phase with each other, or that a single generator such as was known in the prior art and which furnished the alternating currents of differing phase, might have been used as the source of supply.

While some of the general expressions of the opinions might have been modified, had the Dumesnil and Cabanellas patents been presented to the courts of the Second Circuit, a somewhat careful and laborious examination of these patents, and of the interpretations of them by experts, leads to the conclusion that these patents, if produced to the courts of the Second Circuit, would not have affected their decisions as to the nature and novelty of Tesla's invention, and as to the validity of the patents in suit. Neither does it seem to me that these patents would have affected the conclusion that the invention of Tesla was one of great novelty and merit.

The question whether Tesla was anticipated in the production of a rotary magnetic field for power purposes, by the use of alternating currents of different phase, was fully and elaborately argued in these cases, and fully and closely considered by the courts. By the decisions, it was found that:

"Tesla's invention, considered in its essence, was the production of a continuously rotating or whirling field of magnetic forces for power purposes by generating two or more displaced or differing phases of the alternating current, transmitting such phases, with their independence preserved, to the motor, and utilizing the displaced phases as such in the motor."

Also that he was the first to produce, by alternating currents, for power purposes, the shifting of the polar lines of the annular magnet through the entire circumference of the ring by the action of the magnetizing forces properly related.

A magnetic field wherein, by the cooperative action of two alternating currents, a resultant polar line progresses continuously towards the strengthening current, thus producing an effect as if a permanent magnet has been carried bodily around a rotable armature, I am unable to discover in the patents of Dumesnil or Cabanellas.

It is immaterial, therefore, to consider whether Tesla was the first to disclose the use of two alternating currents of different phase to rotate a shaft, or the criticism of those expressions in the opinions which may attribute to Tesla priority in the disclosure of the use of alternating currents of different phase for power purposes.

The decisions upheld the Tesla patents, and these patents well describe and claim the rotary magnetic field.

The sphere within which the defendant must show anticipation is narrower than that of the use of alternating currents of different phase, with an ultimate object of rotating a shaft. This renders much of the matter in the defendant's affidavits irrelevant to the question whether the prior decisions are controlling upon this petition for a preliminary injunction.

Narrowing the question, then, whether the defendant has disclosed any anticipation of the rotary magnetic field for which Tesla's patents were upheld, we will consider the contention based upon the Dumesnil and Cabanellas patents.

While the fact that these patents, though pleaded in previous litigation, were not put in evidence or brought before the courts, tends to awaken the suspicion that they have heretofore been considered too remote from the real questions presented by the Tesla patents, the defendant is still entitled to a consideration of the argument which it bases upon these patents.

Considering first the Dumesnil patent, and the drawings which are offered to show the "double crank action" of the alternating currents could, by their combined use, produce such magnetic effects as would be sufficient in themselves to rotate an armature; much less a suggestion that, by the combined use of two currents, a continuous rotary effect could be produced like that of a magnet carried bodily around the armature.

To couple two single-phase synchronous motors upon one shaft, displacing the poles of one armature angularly with respect to the other, so that one motor expends its maximum effort while the other expends its minimum effort, does not seem to me to exhibit the Tesla invention as described and claimed in the Tesla patents. In the opinion of Judge Shipman, it is stated that "Tesla must have a continuously rotating field."

The combination of two single-phase machines may have a "resultant" as distinguished from a summative effect upon the shaft; but the "resultant" of the operation of two machines is a different thing from the magnetic resultant of two currents upon a common element, as a Tesla ring or an armature within that ring.

If two single-phase machines are capable of rotating a shaft better than one machine, it is because the mechanical action of each single-phase machine is communicated through a shaft to assist the other machine. The armature of one machine would then be subjected, first, to a magnetic effort from its own field magnet, then to a mechanical effort from the shaft, which would bring it in position for the next magnetic impulse. The whole operation of the two single-pnase machines in combination would be from intermittent magnetic and mechanical efforts—neither magnetic field would be a rotary.

To show Dumesnil's combination of two single-phase machines, however, it is necessary to add another factor: The action of the magnetic poles of his armatures. Dumesnil nowhere suggests that continuous rotary action or tendency will result without the opposition of the magnetism of the armature to the magnetism of the field poles, or that by induction the field poles will properly magnetize the armature. Dumesnil, therefore, does not anticipate, since he fails to show that two alternating currents can, merely by combination of their magnetic effects, produce a continuous rotary effort, or that the action of two different magnetic forces upon a common element will give a resultant magnetic pole which exerts its force at positions intermediate of the field poles.

If we concede that Fig. 9 of the Hering affidavit might be considered as a mere mechanical consolidation of Figs. 7 and 8, we can not accept the statement that Dumesnil shows beyond question the arrangement of Figs. 7 and 8, as adequate to produce a constant rotary effect upon a shaft. Dumesnil nowhere discloses or suggests the idea

that such an electrical device as is shown in Figs. 7 and 8 can produce a rotary effect upon a shaft. The magnetic poles of the armature are described by him as features essential to rotary motion. His patent must be considered as a mere publication, giving a description and plan of operation. To make figures of the Hering affidavit illustrate both Dumesnil and Tesla, it is necessary to ignore what Dumesnil proposes as an essential feature.

Dumesnil, in my opinion, does not show a magnetic polar line, which is the resultant of two alternating currents of different phase; neither does he show any plan for producing a rotary effect merely by the unaided action of two alternating currents.

THE PATENT TO CABANELLAS.

This patent, upon many readings, seems to me to be fairly characterized by the complainant's counsel as "expressed in such obscure and indefinite terms as to be hopelessly unintelligible, except in a few unimportant particulars," and as requiring an exceptional exercise of the imaginative powers in translating its phrases into electrical diagrams.

It is contended that Cabanellas, like Dumesnil, contemplated arranging two single-phase machines side by side with the elements displaced so as to displace the phases of the currents, and thus get a continuous rotary effort from two currents. But, like Dumesnil, Cabanellas fails to show a magnetic pole which is the resultant of two alternating currents. When, therefore, the defendant's experts say that the armatures of Dumesnil and Cabanellas are caused to rotate "by the rotation of resultant magnetic attractions set up the joint action of two or more alternating currents of different phases," and that "these features of the prior Dumesnil and Cabanellas patent cover the ground of the Tesla patents in suit, and in substantially the same manner when the said patents are given a broad interpretation in accordance with the decisions of the court;" their testimony must be regarded as based upon a misinterpretation of the decisions of those courts, and upon a failure to recognize that it was expressly found that Tesla must have as a resultant of the currents a continually rotating field of magnetic forces. The "resultant" of the decisions is that which is produced by combining upon a common element the magnetism created by two alternating currents. This magnetic resultant, applied to power purposes, I understand to be the Tesla invention. The defendant's "resultant" is not a magnetic resultant, but merely the rotation of the armature.

Conceding that Dumesnil, Cabanellas, and Tesla all rotate an armature, the point for comparison is as to the way in which this rotation is accomplished. Conceding, further, for the purposes of this petition, that all employ alternating currents of different phase, Tesla alone discloses means whereby two alternating currents may so magnetize a common element as to produce a force with a constant rotary effect. Dumesnil and Cabanellas at best show the combined use of two motors of an old type having the characteristic defects of such motors, and lacking the characteristics of the Tesla motors. Even if two of these motors can assist each other by so timing their mechanical efforts that one exerts its maximum effect while the other exerts its minimum effect, I do not find in such a combination of two machines the invention of Tesla, nor the "rotary field" which was apparently conceded by the defendant in the prior suits to be the proper subject-matter of controversy in determining the validity of the Tesla patent.

This defendant seeks to show anticipation by an interpretation of the prior decisions which is too broad; and does not, in my opinion, show anticipation of what was decided to be the Tesla invention, and the subject-matter of his patents.

The question of infringement seems to be substantially determined by the prior decisions.

The question of laches and estoppel do not require extended discussion. These matters were ably and carefully presented at the hearing, and the opinion formed by me at that time was adverse to these contentions. Upon an examination of the entire record relating to these points, my opinion is confirmed that this defendant decided the question of adopting its motors as a mere business proposition; that it contemplated, as a part of this proposition, the risk of infringing the complainant's patents, and took the risk with its eyes open, relying upon protection from its vendors or from others; consequently, upon this hearing, it must stand by its business proposition. I fail to see that the defendant has in any way been inequitably treated by the complainant.

It is implied by the argument that if a patentee does not see fit to shape his business to suit the wishes of persons who desire to use his invention, this in some way creates an equity which entitles such persons to use the invention in such specific form as they prefer, without the consent of the patentee. I see no ground for thus abridging the rights of the patentee.

The objection to granting a full preliminary injunction is the hardship which would result to the defendant and its employés from preventing the use of the motors now installed in the defendant's factory. This objection, however, is insufficient to deprive the complainant of all right to a preliminary injunction, but goes rather to the question of the extent of the decree. The record upon this petition is voluminous; and we must recognize the possibility of error upon a subject of considerable complication and difficulty and should seek to avoid so far as possible mischief which might arise before such error can be corrected. It is also due to the complainant that we should recognize that it has established the validity of the patents after meeting and overcoming a most skillful and elaborate defence; and that its rights, thus established, should not be evaded or rendered worthless by unnecessary delay in their enforcement. While there are objections to determining questions like those raised upon this petition, save upon final hearing, the court must also consider that it is objectionable to refuse an injunction merely because of voluminous or complicated matters of defence.

This defendant, to avoid the effect of the former decisions, should show, not only that new matters and new issues are presented but that the new matter might require a different decision as to the character of Tesla's invention and as to the validity of his patents. Though the argument for the defendant has been presented forcibly and with ability, I am of the opinion that the defence to this petition is insufficient, since it does not seem to me to meet the points actually decided by the Courts of the Second Circuit.

Upon the complainant's brief, it is suggested that the order for a preliminary injunction can be granted upon terms which will impose no hardship or unnecessary damage upon the defendant, its employés, or the public. To such an injunction, with special terms as to the motors actually installed and in use in the defendant's factory, I am of the opinion that the complainant is entitled. Under all the circumstances, it would seem hardly necessary to make an immediate order permitting or requiring the gradual substitution of licensed for unlicensed motors. The complainant probably can be sufficiently protected as to these motors by a suitable bond, and by terms as to the speedy prosecution of the case to a final decision. The questions whether the defendant may be permitted to continue temporarily the use of the motors now installed and if so upon what terms, are reserved.

UNDER THE SEARCHLIGHT.

Notes and Comments on Various Topics.

MR. NIKOLA TESLA requests us to state that his office and laboratory have been removed to Wardenclyffe, Long Island, N. Y., and that all correspondence should be addressed there.

CURRENT NEWS AND NOTES.

TESLA PATENT LITIGATION.—Judge Lacombe, in the United States Circuit Court, New York City, on June 4, denied the application of the Westinghouse Electric and Manufacturing Company for an injunction to prevent the Stanley Electric Company from manufacturing apparatus claimed to come under certain Tesla patents. The refusal was made on the ground that the Stanley company manufactured the appliances in Pittsfield, Mass., and that, therefore, the matter was not within Judge Lacombe's jurisdiction. The question of the alleged infringement of the patents was not considered. The case was argued last week, the defendants being represented by ex-Speaker T. B. Reed, ex-Patent Commissioner Mitchell, and Mr. W. H. Kenyon.

The New York Herald June 9, 1902

USES ELECTRICITY WITHOUT A MEDIUM

Scientist Declares He Can Apply Atmospheric Current Without Motive Force.

WAS SIMPLE DISCOVERY

Senor Clemente Figueras, Engineer, of Canary Isles, Inventor of the Method.

[SPECIAL CABLE TO THE HERALD.]

The HERALD'S European edition publishes the following from its correspondent:—

LONDON, Monday. — A most remarkable claim, the genuineness of which it is as yet impossible to test, says a cable despatch published by the Daily Mail from its Las Palmas correspondent, has been made by Señor Clemente Figueras, Engineer of Woods and Forests in the Canary Islands, for many years professor of physics at St. Augustine's College at Las Palmas.

It seems that for many years he has been working silently at a method of directly utilizing atmospheric electricity—that is to say, without chemicals or dynamos—and making a practical application of it without the need of employing any motive force.

A true revelation might rob him of his reward, and even now, while he claims to have succeeded, he is silent concerning the exact principles of his discovery.

He asserts, however, he has invented a generator by which he can collect electric fluid so as to be able to store it and apply it for infinite purposes—for instance, in connection with shops, railways and manufactures.

He says he expects its effect will be a tremendous economic and industrial revolution. He will not give the key to the invention, but declares that the only extraordinary point about it is that it has taken so long to discover a simple scientific fact.

He intends shortly going to Madrid and Berlin to patent his inventions.

In addition to the discovery, the Daily Mail says that, according to letters received in London from his friends in Teneriffe, Señor Figueras has constructed a rough apparatus by which, in spite of its small size and defects, he obtains a current of 350 volts, which he utilizes in his own house for lighting purposes and driving a motor of twenty horse power.

His inventions comprise a generator, a motor and a sort of governor or regulator, the whole apparatus being so simple that a child could work it.

ELECTRICIANS IN CONVENTION

NOTABLE GATHERING IN GREAT BARRINGTON TO-MORROW.

One Feature Will Be a Test of Overland Wireless Telegraphy Over the Greatest Distance Yet Attempted—Many Learned Papers and Social Fetes.

One of the features of the nineteenth annual convention of American Electrical Engineers to be held in Great Barrington, Mass., to-morrow and the rest of the week, will be a test of long-distance, overland wireless telegraphy at the summer home of William Stanley, president of the Pittsfield Electrical Works.

Mr. Stanley has had constructed a station on the grounds, and has had a similar one at Watch Hill. From these two private messages will be sent and received, and if they are successful they will be the longest overland wireless communications that have yet been attempted.

Many distinguished scientists will attend the convention, including Mr. Edison, Prof. Thomson, Prof. Pupin, Dr. Kennedy, Mr. Tesla, Prof. Williams, Dr. Perrine, Dr. Kelley, Stephen Field and many others from all parts of the country.

These annual conventions have previously been held in some of the large cities of the country, but this season the institute decided to break away from time-honored precedents. They argued that a certain amount of pleasure could be combined with the business to be transacted, and that in the up-to-date summer resort the former coould be found.

GREAT PREPARATIONS.

In return for the honor done its town the prominent citizens of Great Barrington are making most elaborate preparations to receive their distinguished visitors, and for five days the town will be practically turned over to them. As this village is in close proximity to Lenox, Stockbridge and Pittsfield, they also propose to do their share in the way of entertaining. Local committees have been formed who are arranging the details, and these committees contain the names of men who are well known in the business and social world of New York, and who have their summer homes in the Berkshire Hills.

The visitors are expected to arrive from New York by a special train to-morrow afternoon, and in the evening a large reception will be given to them at the Berkshire Inn. There will be addresses of welcome and a banquet, followed by a dance.

PAPERS TO BE READ.

The convention proper will have one morning session each day. The first will be devoted to the steam turbine, with papers by Prof. Francis Hodgkinson on the Parsons turbine, and by R. R. Bowker on the De Laral turbine.

Another session will be given up to electric railroading, the education of electrical engineers, and to technical papers. Some of those who are to speak, and their subjects, are:

"A New Photometer for Incandescent Lights, and Similar Sources," Prof. C. P. Matthews, of Lafayette, Ind.; "The New Generating Plants of the Niagara Falls Power Co.," Harold W. Buck, of Niagara Falls, N. Y.; "A New Type of Current Tracing Instrument," Prof. R. B. Owens, of Montreal; "Notes on Railway Speed-time Curves.," by C. O. Mailloux, of New York;" Commutation, by David B. Rushmore, and many others that will be of interest even to outsiders.

During the afternoons the learned visitors and any members of their families who may accompany them will take drives through the picturesque parts of the country about Lenox, Stockbridge and Sheffield and visit the many places of historic interest.

MANY FETES PLANNED.

Probably the most brilliant entertainment of any that has been planned will be a lawn party that Mr. and Mrs. Stanley will give at their residence, Brookside, on the second day of the convention. This place is one of the most beautiful among the many splendid homes found in this part of the country.

Thursday will be strictly Great Barrington day, for in the afternoon the golf club will give an open-air concert, there will be May-pole dances by children of the village at the fair grounds, and in the evening a real country dance will be given.

The particular feature of Friday will be a visit to the Stanley Electrical Works at Pittsfield. After an inspection of the works Prof. and Mrs. Perrine will give a lawn party in honor of the guests at their charming place just out of Pittsfield.

In addition to these public affairs, several private dinners and other entertainments will be given. On Saturday, June 21, the distinguished party will say good-by, and will be conveyed by special train to New York.

This same wonder of wireless work is possibly destined to further feats in the great future of scientific civilization. Not merely in the way of beautiful laboratory phenomena, but rather in the domain of human wants and practical industry. Along Tesla's lines, why can not large quantities of electrical energy be transmitted as well as the pigmy potentials now successful? Should it be any more difficult than the development of the giant steam hammer used on armor-plate from the little tack-driver Artemus Ward used to fatten his thumb?

A New Tesla Laboratory on Long Island.

The public is always very much interested in whatever Mr. Tesla may say or do, and we are very glad, therefore, to have the opportunity of presenting herewith two views which have been forwarded us by a correspondent on Long Island, showing his new laboratory at Wardenclyffe, L. I., and the interesting tower that is associated with it. It will be remembered that after the unfortunate destruction by fire some years ago of his laboratory, near Bleecker Street, New

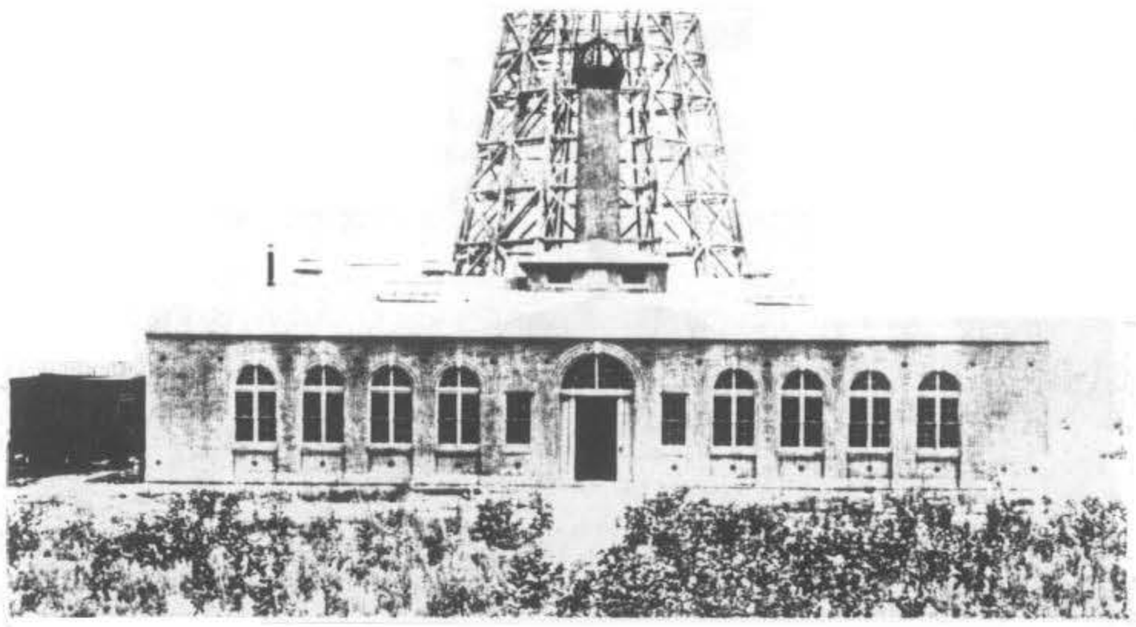

FIG. I.—TESLA LABORATORY AT WARDENCLYFFE, L. I.

York City, Mr. Tesla established himself in East Houston Street, where a great deal of interesting work and many new inventions have resulted from the indefatigable labors of this well-known inventor. It would appear, however, that Mr. Tesla has needed more seclusion and quiet than could be obtained in the city, where his laboratory is not only the rendezvous of inquisitive reporters, but is the center of pilgrimages from all parts of the world of those who have heard of his work and desire to meet him, either from sheer curiosity or for legitimate purposes of scientific inquiry or industrial development. Hence Mr. Tesla has now, like Mr. Edison, established himself out of town, yet within easy reach of the metropolis.

The new Tesla laboratory at Wardenclyffe is about 65 miles from New York, or 1½ hours by fast train on the Long Island Railroad. According to the statement, quoted in our columns last year, from a circular as to Wardenclyffe, "This property was purchased from the North Shore Industrial Company, which owns an estate of something more than 1,600 acres adjoining, under an agreement that the Wardenclyffe Building Company shall have the first right and privilege to do all building and make all constructional improvements of said North Shore Industrial Company, and shall have the first right of purchase of any additional land offered by it for sale, and under which contractual rights large profits will be realized in the future. In addition to this exceptional advantage, Mr. Nikola Tesla, the foremost electrician of the age, whose achievements in electrical science eclipse in practical importance all other discoveries of the century, has just closed a contract to expend at Wardenclyffe a very large sum of money in constructing electrical laboratories and the main station for his wireless telegraphy system of communication with Europe and Australasia. This development will require

a large number of houses for the accommodation of the several hundred of people whom Mr. Tesla will employ." It was further stated that the real estate enterprise is backed by Mr. Chas. R. Flint, the well-known merchant, and that Mr. Tesla is to occupy a cottage in the vicinity of the Wardenclyffe Inn.

We are not able to give any details as to the equipment of the work, other than that some little while ago Mr. Tesla placed a con-



FIG. 2.—TESLA TOWER AT WARDENCLYFFE, L. I.

tract with Westinghouse, Church, Kerr & Company for a power plant equipment. As might be expected, and in keeping with Mr. Tesla's custom in such matters, great privacy and secrecy are observed in regard to the laboratory, and the visitor who can secure entrance is indeed a lucky man, while at the same time he is likely to be an ignorant one, unable even to conjecture the meaning of what he may see going on around him. It has been stated that the large tower, shown in one of our cuts, is intended for wireless telegraphy and wireless power transmission experiments, and that underneath it is an excavation as deep as the tower is high, possibly for the purpose of perfect ground connection. A subway with conduits leads from the laboratory or factory proper to the tower.

The New York Herald October 8, 1902

NIKOLA TESLA FINED $100.

For failing to appear in answer to a summons for jury duty, Nikola Tesla, the electrician, was fined $100 by Judge Foster yesterday. He will have to explain or pay or go to Ludlow Street Jail.

The New York Sun October 8, 1902

NIKOLA TESLA FINED $100.

Fails to Show Up for Jury Duty in General Sessions—Is Sorry Now.

Nikola Tesla, the electrician, was fined $100 by Judge Foster in Part I., General Sessions yesterday, for failing to appear as a talesman on the jury panel of that court for the October term.

Mr. Tesla said last night that he had overlooked the summons, because he had been absorbed in very important work, and, besides, had been away on Long Island for three days

"I got the notice too late," explained Mr. Tesla, "but, nevertheless, I will apologize to the Court. When I become absorbed in my work I forget everything else."

The New York Tribune October 8, 1902

NIKOLA TESLA FINED $100.

HE FAILED TO OBEY A SUMMONS FOR JURY DUTY

For failing to appear in answer to a summons for jury duty Nikola Tesla, the inventor, was fined $100 by Judge Foster, in Part II, General Sessions, yesterday. Unless he can give a good reason for his failure to appear in court he will have to pay the fine, the alternative being imprisonment in Ludlow Street Jail.

The New York Herald October 9, 1902

CITY JOTTINGS.

Nicola Tesla, inventor, explained to Judge Foster, of the Court of General Sessions, yesterday that because of absent mindedness he did not answer a summons for jury duty. The fine of $100 was remitted.

The New York Tribune October 9, 1902

NICOLA TESLA'S FINE REMITTED.

Nicola Tesla, the electrical inventor, on whom a fine of $100 was imposed on Tuesday by Judge Foster, in the Court of General Sessions, for failing to answer a summons for jury duty, appeared in court yesterday and explained to Judge Foster that he was very busy at the present time and had overlooked the summons. He said that he meant no disrespect to the court, and that it was merely a case of absentmindedness. The fine was remitted, and Mr. Tesla was excused until October 15 on account of his business.

The New York Times October 16, 1902

COURT EXCUSES TESLA.

Inventor, Summoned in Murder Case, Termed the Death Penalty Barbarous, Inhuman, and Unnecessary.

Nikola Tesla, the electrical inventor, was excused from jury duty in a murder case yesterday on account of his views on capital punishment. Mr. Tesla stated emphatically that he thought the infliction of the death penalty not only barbarous and inhuman, but unnecessary as a factor in the scheme of modern civilization.

The inventor was called as talesman in the case of Michaele La Mendola, an Italian, who is being tried on a charge of murder in the first degree before Judge Warren W. Foster in General Sessions. La Mendola is accused of having killed Micapro Alangi, another Italian, in an altercation over $6 last January.

Only a week ago Mr. Tesla was fined $100 by Judge Foster for failing to obey a summons to jury duty, also in a capital case. The fine was later remitted, when Mr. Tesla explained that he had been very busy and overlooked the summons.

The New York Tribune October 16, 1902

TESLA AGAINST DEATH PENALTY.

SO THE ELECTRICIAN IS EXCUSED FROM JURY DUTY IN LA MENDOLA MURDER TRIAL.

Nikola Tesla, the electrician, was excused from jury duty yesterday in the trial of Michael La Mendola, for murder in the first degree, because he said emphatically that he did not believe in capital punishment. A few days ago Mr. Tesla was fined $100 because he failed to obey a summons for jury duty. When he appeared and said that he was so absorbed in his work that he overlooked the summons the fine was remitted, and he was excused until yesterday.

La Mendola is accused of having been a party to the killing of Micapio Alangi, in January last. La Mendola and his son Samuel got into a fight with Alangi, during which Samuel La Mendola shot and killed Alangi. The fight was over the ownership of $6. The defence is that Alangi tried to kill Samuel's father, and that Samuel prevented it by shooting. Samuel pleaded guilty to murder in the second degree on March 16, and is now serving a life sentence.

When Mr. Tesla was called he was asked by Assistant District Attorney Ely if he believed in capital punishment, when the death penalty was warranted by the finding of a jury.

"I do not," replied Mr. Tesla. "I think it is barbarous."

"Well, Mr. Tesla," interposed the judge, "you would uphold the laws of the State which are on the statute books, would you not?"—

"I would within my power and reason," was the reply, 'but I do not believe that capital punishment is proper. I do not see how one person can condemn another to death. I could not.'

Mr. Tesla was excused for the term because of his views. After a jury had been obtained the trial was adjourned for the day

Tesla's New Laboratory.—In a recent issue of the *Electrical World* illustrations are given of the new Tesla laboratory at Wardenclyff, and of the large tower erected near by for experiments in wireless telegraphy and the transmission of power. The reasons which have induced Mr. Tesla to erect his new laboratory 65 miles away from New York are given in a short article. Amongst these is the isolation of this expert from the reporters of the daily papers. If this can only be accomplished we think that the move will be a most valuable one, but we are afraid that Mr. Tesla will not be free from the effects of the encouragement which he has given to these gentlemen in the past. With respect to the tower, we regret that no dimensions are given. It consists of a vertical cone of iron girder work, on the top of which there appears from the illustration to be a large disc. It is said that the tower stands on a hollow base excavated in the ground and of practically equal dimensions There is only one small building near the tower, and from the character of this we infer that the height of the tower is considerably over 150ft. It will be interesting to see whether the announcements concerning the object and use of this tower will be communicated first to a scientific society, or to the reporter of one of the New York newspapers.

Tesla Motor Patents in Litigation.

In the infringement suit which the Westinghouse Electric and Manufacturing Company brought against the Catskill Illuminating and Power Company some interesting facts appear concerning the Tesla motor. The case was decided in favor of the Westinghouse company by the United States Circuit Court of the Southern District of New York, but has been carried up to the United States Circuit Court of Appeals by the Catskill company. The appealed case was called for Monday, November 10th, but was postponed until last Monday, at which time it came up for a rehearing. In the brief for the appellant, prepared by Charles A. Brown of Chicago, many interesting historical facts are presented.

The patents on which it is claimed the Catskill company is infringing were applied for by Nikola Tesla on December 8, 1888. These patents were granted as improvements to prior patents granted to the same inventor, and relate to the rotating-field motor. The infringement proceedings involve the working principles of the Scheefer meter.

An idea of the slight knowledge of the action of the electric current in dynamo-electric machines some 14 years ago may be obtained from the following, which is an extract from a paper read before the American Institute of Electrical Engineers by Mr. Tesla in May, 1888: "In our dynamo machines, it is well known, we generate alternate currents which we direct by means of a commutator, a complicated device, and, it may be justly said, the source of most of the troubles experienced in the operation of the machines. Now, the currents so directed cannot be utilized in the motor, but they must—again by means of a similar unreliable device—be reconverted into their original state of alternate currents. The function of the commutator is entirely external, and in no way does it affect the internal working of the machines. In reality, therefore, all machines are alternate-current machines, the currents appearing as continuous only in the external circuit during their transit from generator to motor. In view simply of this fact, alternate currents would commend themselves as a mere direct application of electrical energy, and the employment of continuous currents would only be justified if we had dynamos which would primarily generate, and motors which would be directly actuated by, such currents.

"But the operation of the commutator on a motor is twofold; first, it reverses the currents through the motor; and, secondly, it effects, automatically, a progressive shifting of the poles of one of its magnetic constituents. Assuming, therefore, that both of the useless operations in the systems, that is to say, the directing of the alternate currents on the generator and reversing the direct currents on the motor, be eliminated, it would still be necessary, in order to cause a rotation of the motor, to produce a progressive shifting of the poles of one of its elements, and the question presented itself—How to perform this operation by the direct action of alternate currents?" From the above one easily understands what rapid strides have been made in the applications of electricity since that time. It seems scarcely possible to realize how short a time it has taken to develop a science which, 15 years ago, was just becoming known to the inventor.

Another instance of the work being done on the alternating current is shown in a paper written by G. Ferraris in April, 1888. He conceived the idea of the rotating-field principle or mode of operation of a motor obtained by the direct action of two out-of-phase alternating currents in fixed energizing coils of the motor, and he embodied it in illustrative apparatus and lectured at the Turin Institution on the subject, a full disclosure of his work having been published on April 22, 1888. The important thing in the mind of Ferraris was the motor and its rotating-field mode of operation, and that the method of producing the required out-of-phase alternating currents was of no consequence. Records show that for four or five years he had been working on inductive and other split-phase methods, measuring the difference of phase obtained under different conditions and generally determining the laws of transformers, the differences in phases of currents, the retardation of induction, etc.

Mr. Ferraris treated the obtaining of the necessary out-of-phase relationship of the currents as a manifest thing. Either two independent and originally out-of-phase currents of the same period or rapidity of alternation could be employed, or the two could be obtained from a single alternating current. And he describes three ways of obtaining them from a single alternating current, and describes it as manifest and well-known matter in the following: "The effects above described may be produced (the rotating magnetic field) by means of a single alternating current. It is, in fact, always possible in various ways to obtain the two currents necessary to produce the component magnetic forces from a single alternating current, and to vary the difference of phase between them within certain limits. One way of doing this is by letting the current pass through the primary coil of a transformer. Then the original current and the induced current are at our disposal.

"Another method of obtaining the same result consists in producing the two component fields from the two secondary currents produced in two transformers, or in two portions of the same transformer traversed by the primary current. Finally, to produce the forces, two derived currents can be used. If in one of the circuits resistances free from self-induction are introduced, and in the other circuit a coil of small resistance and high self-induction, it may be brought about that, while the mean intensities of the two curents are equal, or have a predetermined ratio, the phases of the currents themselves differ considerably." Ferraris, from his knowledge of the electrical laws governing split-phasing predicted the failure of such a source of out-of-phase currents for power-transmission purposes, but suggested the utility for meter purposes, a prediction which has been fulfilled by the present developments of the art.

Again, Shallenberger, in the spring of 1888, developed a meter having a rotating-field motive device run by out-of-phase currents, obtained by split-phase apparatus from a single source. The device was gotten up as a meter for single-phase alternating-current systems, just then coming into use.

Borel and Paccaud devised a motor apparatus operated by split-phase currents some time in 1887, the publication and patents occurring in the summer of 1888.

Meylan, in La Lumiere Electrique, July 14, 1888, describing the Borel meters for alternating currents, says, in the course of a description of the work of Ferraris, and after setting out the rotating idea: "How is it possible now to attain the two alternating currents which we need? Nothing is simpler, and there are many means offered us for that; in the first place by the use of a transformer; one of the coils is inserted in the primary circuit and the other in the secondary circuit. . . . Another arrangement that allows of obtaining currents with a difference of phase consists in putting the two circuits in multiple arc and in inserting in one of the branches a large self-induction." Thus the idea of using split-phase currents and split-phase apparatus for producing the necessary out-of-phase currents seems to have come naturally to all to whom the rotating-field motor idea became known, and the fact that such a motor required two or more out-of-phase alternating currents.

What all the technical men of that day seem to have been seeking for, was the modern economical multiphase system of transmitting power. The Tesla motor required double circuits, and these the inventors were trying to do away with by some means which would still retain the full and undiminished power-carrying capacity of the currents.

The Tesla invention of the May 1, 1888, patents solved the problem of the utilization in a motor of double-phase alternating currents for power-transmission purposes, and did this by a peculiar construction of motor, to wit, with two or more independent energizing circuits and such a connection of those circuits with the source or sources of the double-phase currents (an alternating-current dynamo) that that out-of-step characteristic of the currents was preserved in the energizing coils of the motor, and a rotating or whirling magnetic field was thereby produced, which caused the armature to start up and rotate.

The invention of the patents in suit, granted December 8, 1888, is not addressed to the utilization of two-phase currents in a motor, but to a way of producing the necessary two out-of-phase currents. Whereas, in the patents of May 1, 1888, the two-phase currents were produced separately in fact and in point of time by the separate coils of the ordinary polyphase alternating-current generator, in the patents in suit the two out-of-phase currents employed are produced from a single-phase alternating current, one being delayed or made to lag more than the other by the inductive or the derivative method. The original unitary current is divided into two currents, and the two are then artificially thrown out of step

with relation to each other, and in that condition they enter and operate the motor.

For a better idea of the relation of the two sets of Tesla patents to each other, the three diagrams, shown in Fig. 1 are given. The first is typical of the earlier Tesla patents and the second and third of the patents now in suit. In these diagrams are shown in dotted lines those parts of the apparatus that make use of the out-of-phase alternating currents after they are produced, and in full lines those parts of the apparatus which are involved in the production of the out-of-phase alternating currents prior to their utilization. (G) is the generator; (L), the line wires; (M), the motor; (a) and (b), the two independent energizing circuits of the motor; (I), an induction coil or transformer; (S), a self-induction coil; (R), a resistance coil. The line (x) (x) separates the current-producing parts of the systems from the current-utilizing parts.

The Scheefer meter, which, as has been said, is involved in the infringement suit, is shown in Fig. 6. Figs. 2, 3, 4 and 5 are diagrams of development stages. Fig. 2 represents a disk which is operated by means of a single energizing circuit, wound upon a field core similar to that of the Scheefer meter. This is wound upon one leg of the core and causes a rotation by means of a difference in the strength of the magnetic poles. It makes no difference whether this winding upon one leg of the core be a series or a shunt winding. In either case the meter will rotate and will be in one case a meter which will measure volts (that is, when it has a pressure winding), and which will in the other case measure current or amperes (when it has a current winding). The trouble with a meter like this is that it will not measure watts unless both windings are superposed, but when both windings are superposed upon the same leg of the core, as in Fig. 3, a rotation is obtained, which is in proportion to the volts times the amperes, or the watts, because both the pressure and the series windings are delivering their magnetic fluxes into the circuit and causing rotation of the disk.

The trouble with this meter, however, is that, because it is under the influence of the shunt winding at all times, even when there is no load connected in circuit, a rotation will ensue and the meter will register when there are no lights in the circuit. To obviate this difficulty, Mr. Scheefer put upon both legs of the core a shunt winding, and thereby secured two opposing balanced tendencies to rotation (Fig. 4), which exactly balanced each other. There would be no rotation, therefore, in the disk with this arrangement under no load. Now if to the shunt windings which thus balance each other in their effect upon the disk are added two series windings which assist the shunt winding on one leg and oppose the effect of the shunt winding upon the other leg, a rotation will ensue which is in proportion to the watts, and a wattmeter will be the result. This arrangement is shown in Fig. 5.

This is a meter which will operate to secure the same result as the Scheefer meter. The Scheefer meter, however, takes the series winding, and for convenience in arrangement, places it between the two legs of the magnet, and causes it to operate by its magnetic flux to strengthen one pole and weaken the other. It is by this last step that infringement is claimed.

While considering either one of the two devices (Figs. 5 and 6) it will be readily understood that the magnetic flux produced by the shunt winding upon the two legs of the magnetic cores creates a north pole at one end and a south pole at the other end. The series winding, whether placed upon each leg of the core or placed in the center between the two legs, operates by its magnetic flux to strengthen one pole and weaken the other. There results from this condition of unbalanced poles the following action: Each pole sets up in the disk eddy currents, which produce magnetic effects opposed to that of the core There will be repulsion, therefore, between the magnetic poles created in the disk and the magnetic poles of the field. The stronger pole, however, having a predominating effect, will drive away the polar region created in proximity to it upon the disk, and will thus overcome the opposing tendency of the other pole. In addition to this repulsion effect, there will be likewise an attraction between the strong pole and the polar regions of the opposite sign in the disk, which will tend to assist the rotation of the disk. The meter may have a difference of phase in the circuits of its two windings, but this depends wholly upon the character of the translating devices connected in circuit therewith. It continues to operate whether there is a difference of phase or not, and it operates according to the same principle of operation, whether there is a difference of phase between the currents of its energizing circuits or not.

The essential feature of the patents in suit is the rotating or whirling field of force. This rotating or whirling field of force, as defined in the Tesla patents, is produced by the blending of the fluxes due to the independent energizing circuits of the motor. As expressed by Mr. Ferarris in his disclosure of the inventions of the patents, "the magnetic fields produced by two electric currents are superposed" in order to produce the rotating field. The Tesla rotating or whirling field of force requires the superposition of the magnetic fluxes in one and the same space. Otherwise they do not lose themselves in a resultant. This superposition of the magnetic fields does not occur, and the operation of thereby securing a resultant in accordance with the law of the parallelogram of forces does not proceed in the Scheefer apparatus.

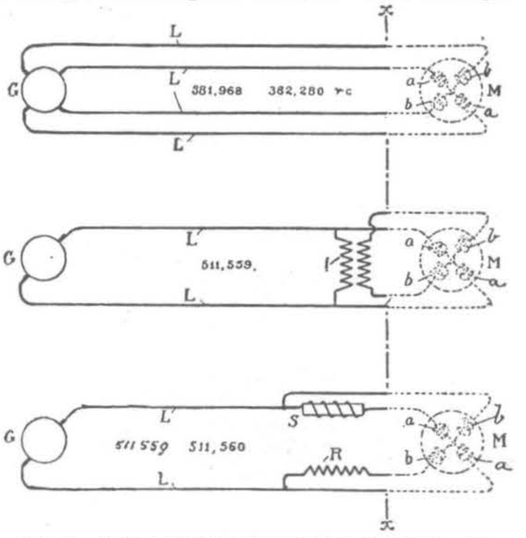

FIG. 1. TESLA MOTOR PATENTS IN LITIGATION. — DIAGRAMS OF TESLA PATENTS.

On the contrary, the arrangement of the parts necessary to bring about that operation is practically reversed. The fluxes or lines of force or operating magnetic fields of the two out-of-phase currents do not traverse the same space or cross each other at an angle in that space. As a consequence, there is no parallelogram of forces brought into play. Again, the fluxes due to the separate currents are exerted in lines that are parallel to each other and independent of each other and far apart, and they maintain their independence throughout. There is no resultant in the sense of the Tesla patents. The individual fluxes do not lose themselves in a resultant. There is no motion of a resultant which is essential to the rotation of the armature. In the Scheefer meter the currents coact, not on the principle of the parallelogram of forces, nor through the action of a resultant magnetizing force, the whirling of which whirls the armature, but on a different principle.

It does not operate by a difference of phase, but by a principle of attraction and repulsion, distinct from that of the Tesla patents. The defendant asserts, moreover, that the patents in suit are completely anticipated and void on that account.

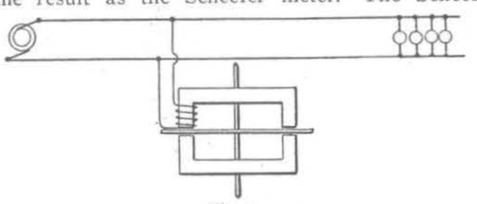

Fig. 2.

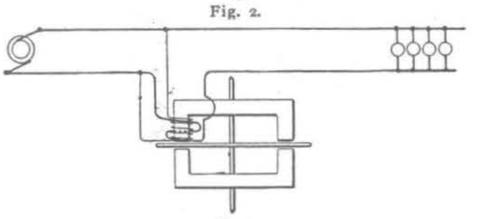

Fig. 3.

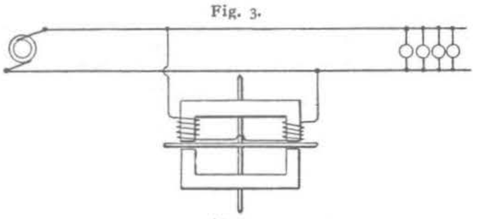

Fig. 4.

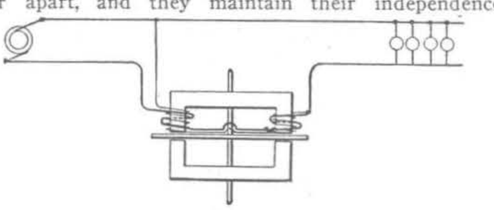

Fig. 5.

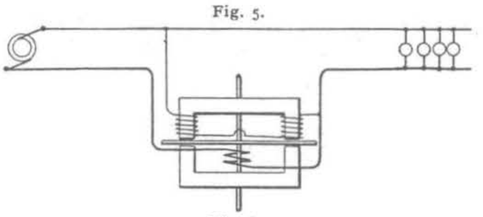

Fig. 6.

TESLA MOTOR PATENTS IN LITIGATION. — DIAGRAMS OF SCHEEFER METER.

The Penalty of Fame.

The subjoined, from the *New York Journal,* is extraordinary, anyhow, and shows how the "people" note what is taking place: Since Judge Warren W. Foster imposed a fine of $100 on Nikola Tesla, the electrical inventor, for failing to obey a jury notice, the Judge has received a number of eccentric letters from Mrs. Annie Thierstein, of No. 239 East Fifty-fourth Street. One, which he received recently, was registered to insure its reaching the Judge. It reads as follows: "I must remind again you, Mr. Judge, as to Nikola Tesla, the electrician. He used me as a living telephone for his revolving motion, already since four years, causing ruin to my existence and good reputation. I lose all the parties for whom I do laundry work because the fine people of the West Side complain of the nuisance deriving from the telephonograph. Tesla knows all about the damage done by him for four years. He must give compensation for it, and cannot deny charge as I have witnesses. I desire, Mr. Judge, you would call us both officially as soon as possible. I already sent you three times to assist me. I am not bound to take my own life for want of work and means. Tesla drives me to despair. He is an unscrupulous fellow. He, unconcerned, looks on at his living telephone as it wastes away in misery. I trust, Judge, you won't forget calling Tesla to task." Judge Foster says he does not know exactly what he will do with this "human telephone," but declared his secretary would probably attend to the matter.

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Nikola Tesla, His Work and Unfulfilled Promises

By LAURENCE A. HAWKINS, E. E.

THAT commendation on the part of the public which we call fame is a prize struggled for throughout the world. It is as distinctly valuable as a mine, a 20-story building or any other property, and, in the estimation of many, great fame is of more value to its possessor than would be any section of mines or 20-story buildings. It is wise, then, on the part of society to see that this valuable thing, fame, is distributed justly.

Ten years ago, if public opinion in this country had been required to name the electrician of greatest promise, the answer without doubt would have been "Nikola Tesla." To-day his name provokes at best a regret that so great a promise should have been unfulfilled. In ten years the attitude of the scientific press has passed from admiring expectancy to good natured banter and at last to charitable silence. In 1892 a leading electrical periodical of this country contained the following ("Electrical World," Vol. 19, p. 20):

"During the past six months Mr. Nikola Tesla has been steadily at work developing the beautiful principles that he enunciated in his striking lecture before the American Institute of Electrical Engineers. In his skilful hands the experiments have extended far beyond their merely theoretical importance in the direction of important practical applications. The revolutionary character of his methods will make any extensive application of them of unique interest." In 1898, the same journal, speaking of Tesla's latest patented scheme, says ("Electrical World," Vol. 32, p 466): "Mr. Tesla, if correctly re-

ported, previously proposed to wobble the earth's charge for man's ignoble uses, but he now, if these things can be taken seriously, has designs on the universe. The price of copper remains in the neighborhood of 11 cents, however." In 1900, a description of a Tesla patent which if practicable would revolutionize the electrical industry, is printed without one word of editorial comment. ("Electrical World," Vol. 35, p. 792.)

Tesla's career, since the time he first stepped into prominence by his lecture before the A. I. E. E. in 1888, naturally divides itself into three periods, which may be designated as the rotary field or patent period, the high voltage and high frequency or lecture period, and the present or newspaper period. It will be well to consider these separately in an endeavor to arrive at a just estimation of the man's work and of the value of his contributions to the engineering or scientific world.

Prior to 1884, the alternating current system of distribution, though older than the direct current system, was in little use. Gramme had taught the world how to build a satisfactory direct current commutator. Direct current seemed to have all the advantages of alternating current and would perform many services for which the latter was not suitable, notably electrolytic work. But in '83 and '84 Gaulard showed that the well known Ruhmkoff coil could be used to transform alternating current from high to low voltage, permitting of great economy in line wire, and he built and operated his transformer for lighting.

In 1885 Zipernowski & Deri produced a transformer of high commercial efficiency, and showed how to obtain excellent regulation, impossible with Gaulard's series system, by proper connection of the primaries in parallel. From this time alternating current began to be more used for electric lighting. One of the objections to the system was that there were no small self-starting motors that would operate efficiently on it. Accordingly, when Tesla announced, in May, 1888, that he had solved this motor problem, he at once became one of the most prominent figures in the engineering world. His solution was a theory of the combination of two or more alternating currents of different phase to produce a resultant rotating magnetic field. This same theory had been published in Italy a few weeks prior to Tesla by Ferraris. ("L'Elettricita," April 22, 1888.) Ferraris, however, contented himself with publication of the theory, while Tesla patented it, and followed up his first patents with a mass of other patents describing every conceivable construction and mode of operation that could in any way be imagined to embody his rotating magnetic field. It is for this reason that the rotating field theory is associated in this country with the name of Tesla rather than with that of Ferraris, although the contrary is the fact in every other country.

The idea of a rotating magnetic field as the resultant of two currents was not novel. It had been produced by Bailey ("Phil. Magazine," October, 1879) in 1879 with commutated direct currents, and by Deprez ("La Lumiere Electrique," December 8, 1883) in 1883 with alternating currents. It is scarcely conceivable that the application of these experiments would have escaped the eyes of the engineering world when the greater efficiency of polyphase alternators over single-phase alternators forced the former into general use. But that time had not come in 1888, and the motors described by Tesla, even if they had been commercially efficient struc-

tures, could not be operated on the circuits then existing.

Like Edison's three-wire system, the rotating field must have been obvious when changed conditions called for its application, but in 1888 it was not what was wanted. As Swinbourne said at the time ("Electrician," Vol. 21, p. 342): "The low efficiency is not at all the chief objection to the scheme. The whole arrangement is impracticable, as it demands special alternate-current generators and leads. Until Mr. Tesla can produce a motor which will work on alternate-current circuits as they are, and do that efficiently even with varying loads and without difficulty in starting, he can hardly be said to have solved the problem." The achievement of the Tesla and Ferraris publications was not the solution of a problem presented by existing conditions. They assumed non-existent and, at that time, impracticable conditions, and then applied the obvious principle of the rotating field of Bailey and Deprez. Had not experience subsequently proved the polyphase generator more efficient than the single phase, the rotary field of Tesla and Ferraris, like that of Bailey and Deprez, would never have become of more than academic interest.

In time the polyphase generator did prove its superiority per se, and brought polyphase motors of different types with it into commercial use. But engineering to-day owes Tesla no more than it owes Ferraris, Deprez or Bailey, for Tesla never produced a commercially successful motor. As the demand for polyphase motors gradually came into existence he worked hard to produce a commercial motor, but it did not appear in the market. The motors of the so-called fundamental patents failed absolutely to meet commercial conditions. Though the later Tesla patents describe multitudinous modifications, Tesla himself, with practically unlimited means at his disposal, seems to have failed to produce a commercial self-starting motor for power purposes. Undoubtedly Tesla's theory of magnetic laws, as shown in some of his patents depending on so-called magnetic screening and on reducing iron losses by removing the iron, was an important factor in his failure. But other engineers equally failed to reduce those patents to practice, although on one occasion, according to the sworn testimony of a prominent engineer, $100,000 was offered if he would make the Tesla motor operate successfully.

Two widely different classes of alternating-current motors are in general commercial use to-day. They are known as synchronous motors and induction motors. The two differ radically in principle of design, in theory of operation, in method of manipulation, in the necessary accessory apparatus and in adaptability to different kinds of work.

The synchronous motor is simply an alternating-current generator with its function reversed. The same machine, with no change whatever, runs equally well as generator or motor. This is true of either single phase or polyphase. The polyphase generator is two or more single-phase machines wound on the same frame, and the same is true of the polyphase motor. When the electrical world had polyphase machines given it, and was told that alternating-current generators, like direct-current generators, were reversible, it knew all that was necessary for the successful operation of polyphase synchronous motors. And it had the machines (United States patent, No. 218,520, Gramme; "Electrician," October 28, 1882, p. 565; Gordon's dynamo electric machine) and it

had the knowledge ("Jour. Soc. Tel. Eng." and "Electricity," Vol. 13, p. 496 and p. 515; "Electrician," November 15, 1884, p. 11; "Electric Illumination," by Dredge, London, 1882, Vol. 1, p. 69; "L'Electricien," August 1, 1884, p. 131; United States patent, No. 390,439) years before Tesla and Ferraris published the rotating field principle in 1888.

The synchronous motor, however, finds its applications in conditions of large power and continuous running. Those conditions are furnished by the great long-distance systems of power transmission of to-day, and it is only in such systems that the synchronous motor is or ever has been used. No such systems existed in 1888, and it was for this reason that though the reversibility of the alternating-current generator was known, it had never been utilized. The machine was there, but the conditions for its use were lacking. What was wanted then, and is wanted now, for general distribution and subdivision of power, was a small self-starting motor. This requirement is met by the "rotary field" or "induction" motor of to-day.

The man, in my opinion, to whom the induction motor is chiefly due is Dobrowolski. He was the first clearly to perceive the theory of its operation and the requirements in its design. To produce the maximum action of the alternating currents on the other member he perceived the necessity of a minimum magnetic air gap He gained the desired result, among other things, by imbedding the conductors in the iron, and his motor was a success. The first commercially successful induction motor of any size was the one built by him and exhibited at Frankfort in 1891. His designs were successfully copied in this country, and the induction motor of to-day became a fact.

After Tesla's apparent failure in motor production he turned to more promising fields. In 1891 he burst upon the electrical world with the first of a series of the most remarkable lectures ever delivered before a scientific audience. The experiments shown were fairly startling. Lamps and motors were operated on open circuit with a single-line wire. Lamps were made to burn brightly when short-circuited by a heavy copper bar, while exhausted tubes were brought to incandescence without any wire near them. Tubes were lighted by merely approaching them with the hand. Beautiful flames of varied appearance were made to leap from many objects, even from the hand of the lecturer himself.

Before the eyes of the startled spectators Tesla touched both terminals of a 200,000-volt transformer, with no more serious result than the production of the flames aforesaid. And throughout the lecture vague hints were offered of the tremendous possibilities exposed by the experiments—possibilities of obtaining unlimited light and power anywhere on the earth's surface, not by means of expensive wires from costly central stations, but by taking the energy directly from the earth itself or from the circumambient ether.

The public was astounded. Popular opinion, ever ready to ascribe the most impossible attributes to that vaguely understood force, electricity, hailed the lectures as disclosing a new era of wonders and Tesla as the last and greatest of electrical wizards. Even the eye of science was dazzled by Tesla's brilliant flames, and the most extravagant tributes were poured upon him. As stated in the London "Electrical Engineer": "No man in our age has achieved such a universal scientific reputation in a single stride as this gifted young electrical engineer."

It was asserted that similar effects to those shown by Tesla had previously been produced by Crookes, Hertz, Rayleigh, Spottiswood, Lodge, De La Rue, Kennedy and Thomson, some of those effects having been patented nine years before the first Tesla lecture (British patent, No. 4,752, Rankin Kennedy, 1882). But Tesla had made his experiments more spectacular by the use of higher voltages and higher frequencies, and the difference in degree passed for novelty in kind. It is true that the lectures abounded in fallacies and absurdities, as, for instance, Tesla's favorite theory of magnetic screening ("Inventions, Researches and Writings of Nikola Tesla," p. 185), his misconception of harmonics (Id., 187), his inexplicable statement regarding Arago's experiment (Id., 233), and even a gross misunderstanding of the fundamental law of physical science—the conservation of energy (Id., 147)—but all were overlooked or forgiven. Few, if any, measurements are recorded in the lectures; nor is there more than the feeblest attempt at even orderly sequence in the experiments, but spectacular sensationalism was accepted as a substitute for scientific methods. No attempt at any commercial adaptation of the experiments is described, but, instead, Tesla's vague hints at possibilities won him the reputation of prophet of the new era.

To-day, as we look back on those lectures of ten years ago and the developments since then, it is hard to understand the scientific enthusiasm Tesla aroused. Have any useful results ever come from those famous experiments? Instead of Tesla's high frequencies, the tendency has been steadily to lower frequencies. Instead of using static effects for power transmission, the chief problem on modern long-distance lines is to diminish those very effects. The electrostatic light is still a laboratory toy, while two wires and a filament are still used in commerce. Central stations still produce their power and distribute it through their mains. The prophecies of those lectures and articles are still unfulfilled, and their suggestions forgotten or disregarded. But ten years ago those who could see beyond the glamour of the Tesla tubes were few. Even then, however, there were some who regarded the lectures in the less spectacular light of science. The London "Electrical Review," in an editorial expressive of some bewilderment at the chaotic mass of experiments and of an inclination to suspend judgment until Tesla should have opportunity for further explanation through the press, calls attention to the fact that Tesla's work was not in a wholly unexplored field. (London "Electrical Review," Vol. 30, p. 184.) "The Electrician" at first called attention to the fact that the experiments were not new, but consisted "in repetitions of well-known effects on a large scale" ("Electrician," Vol. 28, p. 395), and later expressed itself conservatively as follows ("Electrician," Vol. 31, p. 139): "If a few quantitative determinations of current, voltage, or even of frequency, had been given in the lecture it would have had a definite scientific value. To reduce even one out of the 50 experiments to a complete reasearch would be worth all the other 49 brilliant and suggestive demonstrations." And "Industries" said (London "Electrical Review," Vol. 29, p. 193): "We have no desire to pick out weak points in such an interesting lecture, but we think that any one who read Mr. Tesla's articles must have had great difficulty in understanding his repeated idiomatic statements. Is it asking Mr. Tesla too much, holding the prominent position he does in the American electrical world,

when we say we think if he omitted some of the confusing passages his lecture would be much better understood, and if he would keep ideas anent electro-magnetic theory of light, also Hertz and Dr. Lodge from his work, his experiments would be clearer, as well as more interesting. We hope Mr. Tesla is correct when he surmises that the future light may be produced by vacuum tubes, but we believe the subject has been thoroughly searched out ere this by many inventors without a result which has been very promising." In this connection, it might be mentioned that small acknowledgment of the work of Hertz or Lodge occurs in the lectures. The ambiguity referred to in the above quotation, and certainly existing in the lectures, has been passed over in this paper, as in Tesla's case a certain lack of facility in handling English may account for what in another would seem an attempt at mystification.

Had Tesla's labors ended with these lectures perhaps he would have received less criticism in these later days. They seemed to teem with brilliant possibilities. But the applause they had evoked seems to have resolved him to keep himself before the public at all hazards. In the succeeding years each new idea or fad in the electrical world was eagerly seized upon by him and made the pretext for rushing into print, at first in the technical papers, and later, as the engineering press began to regard his effusions askance, in the non-technical daily papers, the adoption of the latter medium being accompanied with increase in sensationalism. When X rays were holding the popular attention, he dabbled in them and published his results. ("Electrical World," Vol. 27, p. 343.) When the Wehnelt interrupter attracted the interest of scientists, Tesla immediately leaped into notice. As the London "Electrical Review" says (Vol. 44, p. 653): "Tesla lets himself out on the Wehnelt interruption in the 'Electrical Review' (New York), March 15th. He invented this device two or three years ago. This belated publication in our contemporary would not, according to the generally accepted code, secure to Tesla the credit of being the inventor; but Tesla evidently does not regret this, since he considers there is not merit in the invention." And again (at p. 733): "Tesla has expressed a somewhat ungenerous contempt for the Wehnelt break, which has recently given such remarkable results in the hands of experimenters here and abroad. Its inferiority to Tesla's break appears to be known as yet only to Tesla; in simplicity, at least, it is certainly superior."

When the efforts of Marconi, Lodge and Slaby brought their first achievements in wireless telegraphy before the world Tesla had nothing but pity for their puerile efforts. When Marconi was ready to send a signal a few hundred miles, Tesla was ready (in the papers) to transmit thousands of horsepower the same distance. ("Century Magazine," June, 1900.) When Marconi was attempting to signal across the Atlantic, Tesla had already (in the papers) received a signal from Mars. (New York "Sun," Jan. 3, 1901). Before the enthusiasm over the Spanish War had had time to cool, Tesla had published a description of his torpedoes, which would revolutionize warfare. (New York "Sun," November 21, 1898.) The "Electrical Engineer" quotes the following from Tesla's signed article (at p. 514 of vol. 26): "We shall be able, availing ourselves of this advance, to send a projectile, at a much greater distance; it will not be limited in any way by weight or amount of explosive charge; we shall be able to submerge

it at command, to arrest it in its flight and call it back, and to send it out again and explode it at will; and, more than this, it will never make a miss." The editorial comment follows: "When we are expected, wide awake and in our sober senses, to accept in silence such an utterance as that quoted above, or that which describes as 'a possibility' the operation of a distant torpedo boat by the mere exercise of the will, we refuse point blank, and we are willing to face the consequences." The significance of this comment lies in the fact that this paper had always been so ardent a supporter of Mr. Tesla that it had been said to have made him and his reputation, and from the pen of its editor-in-chief had come only four years previous the greatest tribute Tesla ever received. "Inventions, Researches and Writings of Nikola Tesla," by T. C. Martin.

It was of this torpedo boat invention that Tesla said ("Criterion," November 19, 1898): "Had I nothing else to show for a life-work, this would put the laurels of everlasting fame on my head." It was of this same invention that Prof. Brackett, of Princeton, said ("Electrical Engineer," Vol. 26, p. 491): "The shortest, most correct and most complete criticism which I can make in reference to this bold boast is that, what is new about it is useless, while that which is useful had all been discovered by other scientists long before Tesla made this startling announcement." It was of this invention that Prof. Dolbear, of Tufts College, said ("Electrical Engineer," Vol. 26, p. 491): "This last so-called invention of Nikola Tesla's is a very pretentious affair, and it is so incredible that the story is not to be believed until the work is actually done. The announcement is most amazing, and, coming as it does from Tesla, scientists are all the more chary about accepting it. During the last six years he has made so many startling announcements and has performed so few of his promises that he is getting to be like the man who called 'Wolf! wolf!' until no one listened to him. Mr. Tesla has failed so often before that there is no call to believe these things until he really does them."

Lack of time and space forbids more than a passing reference to the Tesla engine which was to revolutionize steam engineering; the "discovery" of the variation of capacity with elevation, which was to necessitate the rewriting of all electrical literature ("Electrical World," Vol. 37, p. 201); the torpedo boat, which was to be manipulated at the Paris Exposition from Tesla's laboratory at New York, but which failed to appear; the Tesla oscillator, which was to enable central stations to dispense with wires ("Century Magazine," June, 1900); the method of insulation by refrigeration, which was to give the highest efficiency to transmission with wires ("Western Electrician," Vol. 27, p. 122); and even the message actually received from Mars (New York "Sun," January 3, 1901) must be passed by with merely the comment made by Prof. Fessenden ("Electrical World," Vol. 37, p. 165) that "only the crassest ignorance could attribute any such origin" to the so-called signals.

From the mass of imaginative literature that has recently issued from Tesla's ever-ready pen a single one is here selected for comment. It is chosen both because it includes a large number of Tesla's vagaries, and also because its publication in a magazine of some standing drew more attention to it than was bestowed on others appearing in the more sensational daily press.

"In the 'Century Magazine' for

June, 1900, Mr. Tesla printed a long article, superbly illustrated with cuts that had little or nothing to do with his subject, which dealt with a few electrical matters and also with philosophies and social problems, upon which he freely expressed a jumble of trivial, ignorant, pretentious and erroneous opinions." ("Popular Science Monthly," Vol. 58, p. 437.) This article attracted widespread attention, and if Tesla in truth experiences a feeling of satisfaction at adverse criticism, as he once stated in the New York "Sun," he must have enjoyed keen ecstacies on reading the comments it evoked, as the above quotation would indicate. Nor did the "Century" itself escape criticism. In publishing such pseudo-scientific productions such magazines "descend to a footing with the Sunday newspaper. They evidently do not know science from rubbish, and apparently seldom make any effort to find out the difference." ("Popular Science Monthly," July, 1900.) A brief review of the article will assist to an appreciation of the justice of the criticisms, and, perhaps, to a truer estimate of Tesla's character and the value to be put upon his work than could otherwise be obtained.

The problem treated is that of humanity as a mass acted on by forces, one tending to acceleration, the other to retardation. The three methods of increasing the energy are the increase of the mass, the diminution of the retarding force, and the increase of the force making for progress. The treatment of the first method need not be considered here. It consists merely in the assertion of well-known sociological principles. It is the second method that introduces the first novel element in this remarkable paper. War is justly considered an important factor in the retarding force, and the means of its elimination are unique. Battles will no longer be waged by human beings, but, instead, by machines, by Tesla's "telautomatons."

Rival fleets of these beneficent Frankensteins will clash in mid-ocean for the determination of maritime supremacy, their maneuvers being controlled from physicists' laboratories on shore. These long-distance weapons, the harbingers of universal peace, are already perfected. Another more wonderful type is on its way. (Quoting from the "Century" article): "An automaton may be contrived which will have its 'own mind,' and by this I mean that it will be able, independent of any operator, left entirely to itself, to perform, in response to external influences affecting its sensitive organs, a great variety of acts and operations as if it had intelligence. It will be able to follow a course laid out or to obey orders given far in advance. It will be capable of distinguishing between what it ought and what it ought not to do, and of making experiences, or, otherwise stated, of recording impressions which will definitely affect its subsequent actions. In fact, I have already conceived such a plan." Truly, Tesla's science is stranger than fiction. This noble scheme for universal peace must be passed by with a single quoted comment ("Popular Science Monthly," July, 1900): "Inasmuch as the interest in this telautomatic warfare is to be purely aesthetic, it would seem as if international bull fights or kite flying, or spelling matches, or potato races, might do as well, and have the added advantage of leaving Mr. Tesla's expectations free to wander among the following prospective discoveries."

The methods of increasing the accelerating force comprise the third and largest division of the "Century" article This section is introduced by the

wise but trite statement that all energy is derived from the sun. Three ways of manipulating this energy efficiently are suggested—the cold coal battery, direct utilization of the energy of the ether, and transmission of power through the ether. The first method is introduced by a digression on the value of iron and the wastefulness of its present production, with incidental reference to a new method of manufacture perfected by Tesla in which water is the fuel, having previously been decomposed electrolytically. This method of reduction is stated to be "cheaper than by any of the adopted methods." The digression is continued by a reference to aluminum and its prospective value to mankind. Then electric transmission is considered and the following remarkable statement appears: "Steamers and trains are still being propelled by the direct application of steam power to shafts or axles. A much greater percentage of the heat energy of the fuel could be transformed in motive energy by using, in place of the adopted marine engines and locomotives, dynamos driven by specially designed high-pressure steam or gas engines and by utilizing the electricity generated for the propulsion. A gain of 50 to 100 per cent. in the effective energy derived from the coal could be secured in this manner. It is difficult to understand why a fact so plain and obvious is not receiving more attention from engineers. In ocean steamers such an improvement would be particularly desirable, as it would do away with noise and increase materially the speed and the carrying capacity of the liners." This difficulty of Tesla's must have been cleared away by a paper of Prof. Durand's ("Marine Engineering," July, 1900), who points out that in the case of a liner of 25,000 horse power, Tesla's scheme would result in loss of about one-third of carrying capacity, besides a loss of about 2,500 horse power due to two transformations of energy, hence a loss in speed of one-half to three-quarters of a knot. As Prof. Durand remarks, "The increase of carrying capacity referred to at the close of the quotation would be, therefore, of a character not likely to commend itself to the stockholders or board of directors."

The cold coal battery itself receives scant notice. Apparently it is one of the few things Tesla has not yet perfected.

The treatment of the method of deriving energy direct from the ether contains numerous suggestions. Brief reference is made to the windmill and the solar engine. Then two perpetual motion possibilities are described. The first is a disc kept in motion by a gravity screen. A critic regrets ("Popular Science Mo.," July, 1900) that "Into further particulars concerning the nature of such a screen Mr. Tesla does not enter, though it would seem a matter well fitted to engage his peculiar gifts." The second is a perpetual heat engine, regarding which the critic just quoted says: "We should thus employ 'an ideal way of obtaining motor power' and incidentally rebuke the narrow minded physics of Carnot and Lord Kelvin." This section ends with a mention of the Tesla mechanical oscillator and a reference to liquid air.

The third and last method, that of utilizing the ether as a bus bar, is stated to find greatest favor in the author's eyes. Mention is made of his experiments with one wire and with none, with wobbling the earth's charge and with electrifying the upper strata of the atmosphere. The secret of tuning for wireless transmission is revealed and the errors of the experiments of Hertz pointed out. The possibility of signaling to Mars is asserted, and the facts of

power transmission are stated as follows: "The experiments have shown conclusively that, with two terminals maintained at an elevation of not more than 30,000 to 35,000 feet above the sea level, and with an electric pressure of 15,000,000 to 20,000,000 volts, the energy of thousands of horse power can be transmitted over distances which may be hundreds and, if necessary, thousands of miles." No data as to methods of ballooning or of supporting wires at this elevation are given. Instead, the article closes with a quotation from Goethe. This quotation, with its reference to fulfilment, furnishes a most strikingly complete and sarcastic, though evidently unconscious, comment on the whole ludicrous production.

A perusal of the article forces one to coincide with the verdict of "Marine Engineering," whose editor describes it ("Marine Engineering," July, 1900) as the "handiwork of a cerebrose individual —a bombastical genius who has illumined unknown fields of imaginative science with his intellectual searchlight, and is willing to permit the gaping world of ignorance or complaisance to peep in and wonder, the credulous editor drawing the curtain. This dazzling contribution to modern unscientific research reads like nothing so much as an essay on Christian Science, so profound is it in the ambiguous nothingness whereby it leads through the intricacies of incoherency into the climax of absolute assininity."

Enough has been given to indicate the reason for the standing that is Tesla's today in the scientific world. Not even the brilliancy of suggestion and experiment contained in his early work, not even the persistent efforts of powerful friends, moved by their commercial interests to magnify and exalt the value of his patented inventions, could avert the discredit to his reputation as a scientist brought upon himself by his wild struggles for notoriety He has been condemned by his own extravagant boasts, never followed by the realization of their claims and often revealing a total misunderstanding of the very elements of physical laws.

Tesla is still a young man, and those whose sympathetic expectation was aroused by his early work still hope that he will turn from the gaudy notoriety of the Sunday newspaper, and by conscientious work give at last one complete useful invention that may be honestly set to his credit, and that may make its influence felt on the progress of engineering science.

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NOTES.

THE second Paper deals with Prof. BRAUN'S apparatus for military signalling. Here, in a remarkably portable form, is arranged powerful apparatus capable of operating without the earthing of the air-wire across a distance of 50 miles on land. A 5 H.P. benzine engine drives a dynamo whose current is transformed to yield a 16in. spark. This spark occurs between balls in the primary circuit of a Tesla coil. The air-wire, suspended by balloon, is in series with the secondary of the Tesla transformer; but, instead of being earthed, it is connected to a large insulated plate. The generating plant is virtually a Poldhu in miniature. Evidently, BRAUN, like MARCONI, has been converted to the high potential methods introduced by TESLA. BRAUN has freed himself from the earth, however, and has thus produced a system endowed to the fullest with that mobility so urgently demanded in modern warfare.

WIRELESS TELEGRAPHY FOR MILITARY PURPOSES.*

BY ARTHUR WILKE.

The first experiments in the use of wireless telegraphy for military purposes were in the Boer war, but these met with little success, and it is possible that for this reason interest in wireless telegraphy for such purpose has somewhat abated. By means of the Braun system, however, the German army authorities, in conjunction with the Braun and Siemens and Halske Wireless Telegraph Co., have succeeded in developing a useful system of wireless telegraphy for the German army, and have constructed portable stations which can communicate with one another with certainty over distances up to 100km.

Owing to topographical considerations the transmission of Hertzian waves over land is extremely difficult unless an extremely high air-wire is employed. This requisite for a successful system has been provided for by the balloon section of the German army, under which the wireless telegraph department was placed. The air-wire, which is a fine steel wire, is elevated by a small balloon held captive by the wire itself, or, if the conditions are favourable, by a kite. I will first shortly sketch the Braun wireless principle and the form it takes for field wireless telegraphy in the German army. First, the difference between an open and closed oscillating circuit must be explained, and this explanation will be a technical one and differs to some extent in this form from the theoretical one which Prof. Braun has given.

Let us consider a positive quantity of electricity on one-half, *oa*, Fig. 1, of a wire so collected that the pressure grows towards one end of the wire, and in the same manner an equal quantity of negative electricity on the other half of the wire *ob*. Let the curve above and below the wire represent the pressure at each point. This distribution represents that of a stationary electric wave at one moment of the oscillation. It is now evident that the action which the one

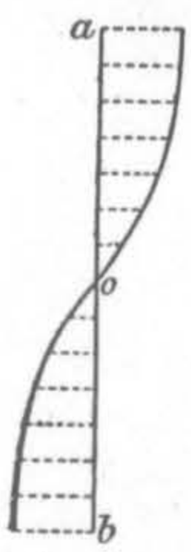


FIG. 1.

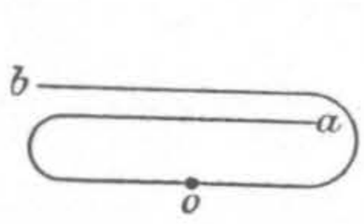


FIG. 2.

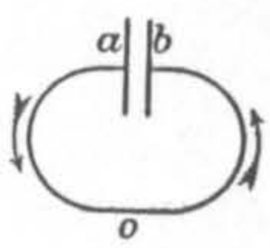


FIG. 3.

quantity of electricity exerts upon the other will be a minimum in this arrangement. In the same way the capacity possible for a good conductor will also be a minimum. Such a conductor thus absorbs the relatively smallest amount of energy. Further, the two quantities of electricity in such a conductor will annul themselves in relatively the quickest time, and the highest discharge currents will be developed. Now, let us consider further the straight form of conductor. If the conductor discharges itself with the distribution of electricity shown in Fig. 1, a current flows from *a* to *b*. Thus waves will be emitted radially in all directions from the whole length of the wires. It is thus clear that the emitting capacity of such an oscillating conductor will be the maximum. With this kind of oscillating conductor in which the charges are subject to the smallest mutual effect on one another—viz., in an open oscillating circuit, as we will now call it, we have the maximum absorption of energy and the maximum emitting capacity. Now, if we have the wire *aob* and bend it in the form shown in Fig. 2, the discharges on both ends of the wire will influence one another. Thus the oscillating circuit assumes another character whose properties will be clearer to us, if we bring the charges of the two ends of the wire to two plates which are placed opposite one another, and are connected by a wire as shown in Fig. 3. By this arrangement the capacity of the conductor will be considerably increased. The relative amount of energy is a maximum to this closed oscillating circuit. Now, the conductor *aob* will likewise omit waves, but considered geometrically the direction of the current in *ao* is opposed to that in *ob*, so the effects of the two halves cancel out, either entirely or to a certain extent. The closed oscillating circuit is, therefore, of no use for transmitting. Its emitting capacity can, in addition, be diminished at will, for the connecting wire *aob* can be shortened down to the very smallest length. Thus it happens that the closed oscillating circuit can absorb a great quantity of electrical energy, and can maintain a condition of oscillation for a comparatively very long time, as the losses by radiation and by resistance can be diminished by shortening the conductor *aob* considerably. The closed oscillating circuit is thus the form for the excitation of strong oscillations and successions of waves. As it further admits of a very accurate tuning, the generation of pure and accurately tuned oscillations are possible. The open oscillating circuit is without all these advantages, but in place of them, as has already been said, it possesses what is absent in the closed oscillating circuit—viz., a high degree of emitting capacity.

Thus Braun's conclusions are as follows:—If one wishes to obtain a powerful transmitting action, the waves should be generated in a closed oscillating circuit, and then conveyed to an open oscillating circuit for transmitting. Then we are in a position to send out long, persistent and pure successions of waves, and thus increase the

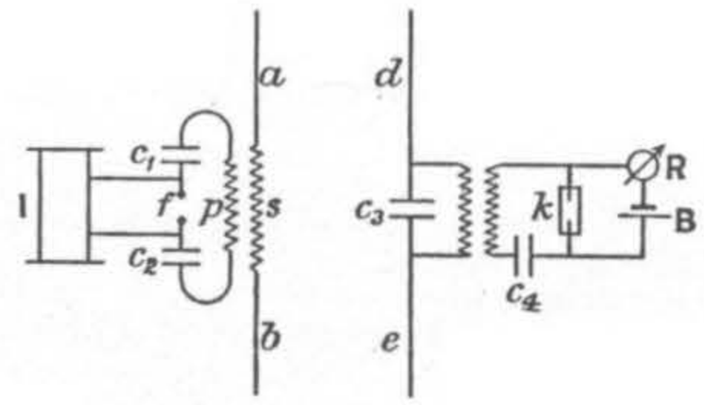


FIG. 4.

amount of energy sent out, and tune the apparatus to a given wave-length. Here it must also be observed that the powerful closed oscillating circuit can force its oscillations upon the open oscillating circuit connected to it, even if the latter has another period of its own. The open oscillating circuit must oscillate in tune with the closed one, and its own period is only the effect of a slight superposition or light ripple on the main wave. What has here been said about the transmission applies to the same extent to the receiving apparatus. The open form of oscillating circuit is the one provided to receive the energy from the incoming waves. If used alone, however, it would quickly be saturated. By connecting it with the large reservoir which the closed oscillating circuit affords, it can lead the received energy directly to the latter, and is thus ready to receive more. Thus, by a combination of the open and closed oscillating

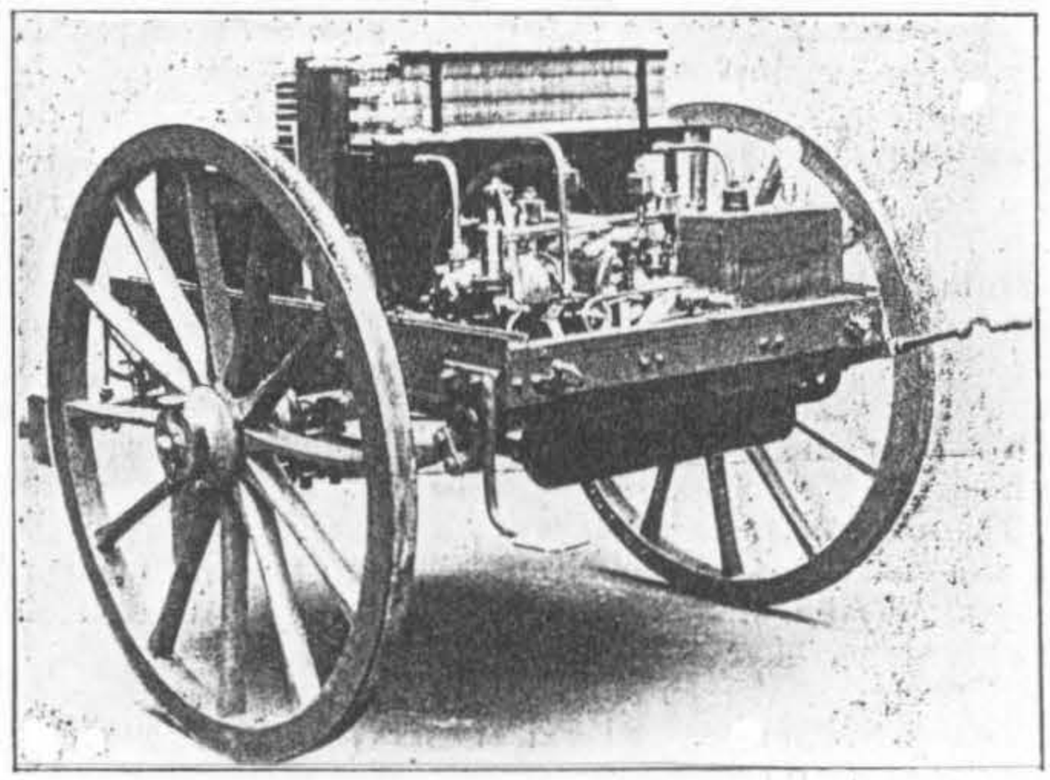


FIG. 5.—BENZINE MOTOR ON THE REAR CARRIAGE.

circuits, the receiving station can receive the maximum of energy from the waves. For good transmission over long distances it is also of governing importance that the coherer shall have as much energy as possible led to it, so that an increase in the quantity of energy received means an increase in the distance over which it can be transmitted.

It may be remarked that in the application of this system to field wireless telegraphy, owing, on the one hand, to the length of the wire attached to the kite, or, on the other hand, to the fact that this wire must be very thin, to save weight, the good, but also the bad, properties of the open oscillating circuit are evidenced to a much greater extent than with the air-wire arrangements with ordinary

* Abstract of an article in the *Elektrotechnische Zeitschrift* for January 15, 1903.

fixed stations, and, therefore, in this case, the use of a closed circuit as an auxiliary is particularly important.

Fig. 4 shows diagramatically the connections employed. I is the induction coil, whose secondary coil is connected to the spark-gap *f* The spark-gap is also connected into the oscillating circuit which is formed by the condenser c_1, the connecting wire, and the condenser c_2. In this circuit the primary winding *p* of a transformer is also included. It may be observed that connecting two condensers in the oscillating circuit in place of the single one shown in Fig. 3, implies no alteration in the principle. The rapidly oscillating alternating currents produced in the closed oscillating circuit act inductively on the secondary winding *s* of the transformer to which the straight wires *a* and *b* are connected. These wires have such dimensions that each is a quarter wave-length in length, corresponding to the period of oscillation obtained in the closed oscillating circuit. On *a* and *b*, therefore, stationary waves of opposite nature will be formed whose maxima will be at the ends of *a* and *b*. The electrical condition in the open oscillating circuit *asb* is thus balanced. At any moment there will be equal and opposite quantities of electricity on the two halves *as* and *sb*. The open oscillating circuit of the Braun arrangement, therefore, needs no earth connection, and it will at once be recognised what an advantage this is for portable stations. The inductive transmission of the oscillations of the closed circuit to the open circuit can be replaced by direct conduction, and Braun speaks of a direct and indirect (inductive) connection which are, however, the same in principle. Now, one could extend the two halves of the open oscillating circuit above one another in the air, as in Fig. 4; but it is at once evident that the transformer would then have to be placed in the middle of the air-wire. It is possible, however, to keep the transformer below at the station, and employ the half *sb* in another form to serve as a balancing conductor. This half of the conductor can be replaced by an insulated metal plate.

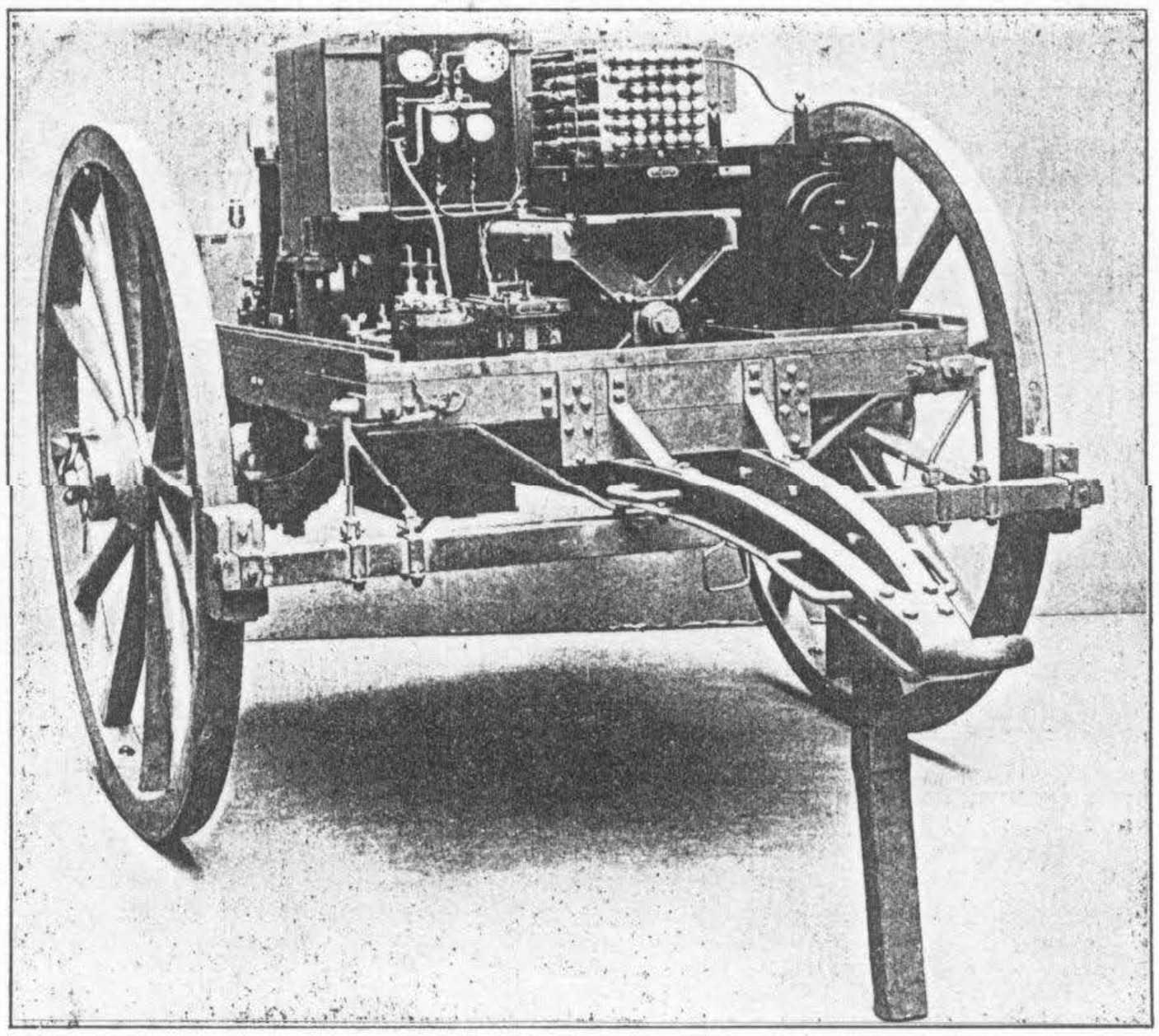


FIG. 6.—DYNAMO AND TRANSMITTER.

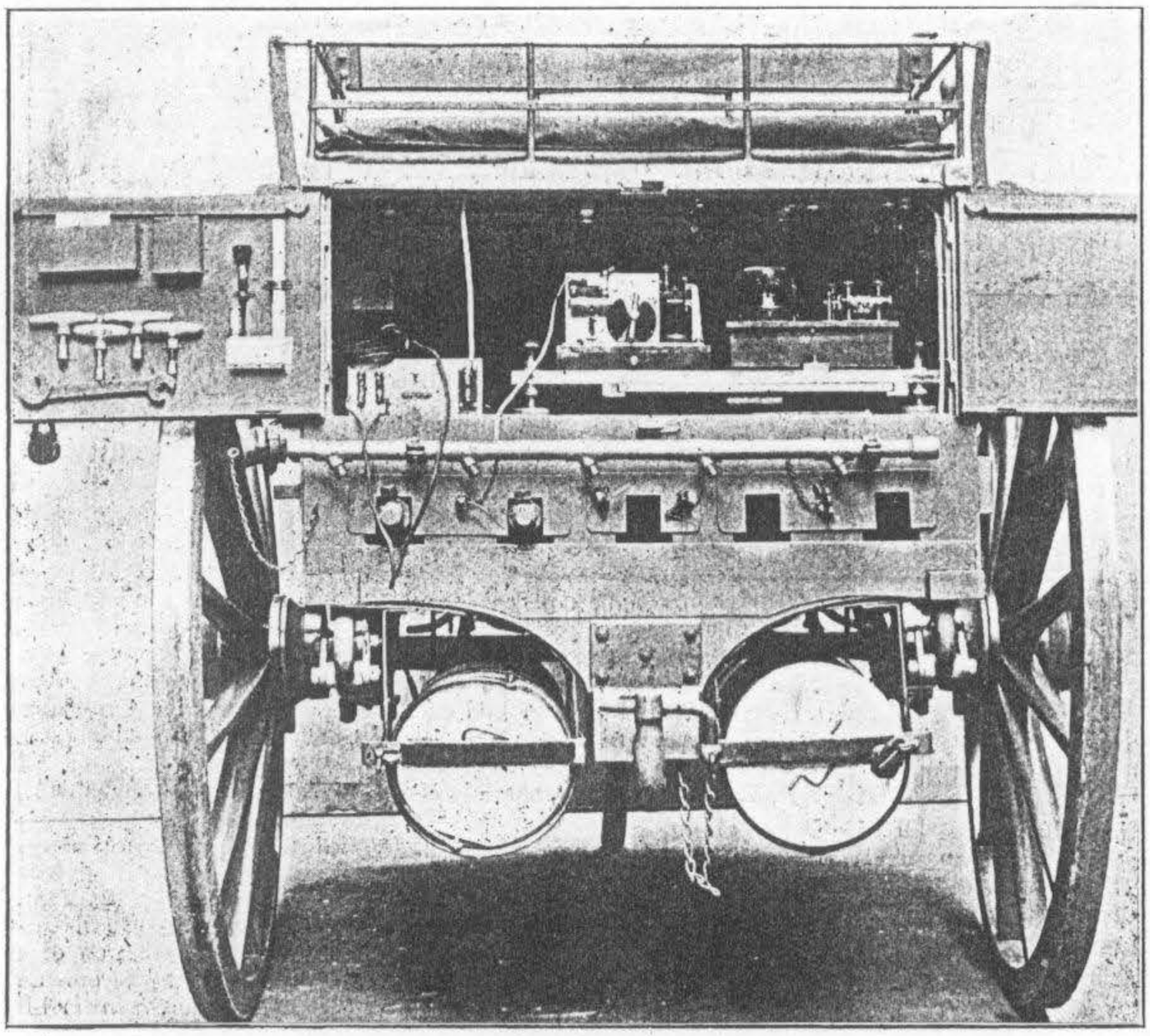


FIG. 7.—FRONT CARRIAGE WITH RECEIVER.

The actual apparatus as used in field wireless telegraphy is divided into two halves: one for the production of current and the oscillations, and thus for transmission; the other for receiving. Each half is carried on a two-wheeled cart, and the two carts are coupled together, as seen in Fig. 8. Fig. 9 shows the two carts disconnected and in actual work. As in these illustrations only the external appearance of the carts is seen, Figs. 5, 6 and 7 are added, showing the disposition of the apparatus in the carts. In Figs. 5 and 6 the transmitting plant is seen. This consists of a 5 H P. benzine motor driving a dynamo at 800 revs. per min. The benzine motor is seen in Fig. 5, and the dynamo can be distinguished in Fig. 6. This generates 2·5kw. at a pressure of 120 volts. This method of generating current is the only one that could be applied, as for military reasons the employment of dry batteries or accumulators would not be possible. To the right of the dynamo in Fig. 6 is the series resistance, which is contained in a wooden box. In the pipe leading to the cooler of the benzine motor, a small pump is connected, whch is driven by the motor shaft and circulates the cooling water. To the left of the dynamo in Fig. 6 is the induction coil, which is designed for a sparking distance of 40cm., and on the dividing wall between the front and back of the cart and to the back of the cooler is a small switchboard with an ammeter and voltmeter. Between the switchboard and the induction coil over the dynamo the Leyden jar circuit is fixed. This circuit is the part of the apparatus which we call the condensers, c_1 and c_2, in Fig. 4. It consists of 40 Leyden jars, each 30cm. long, with an external diameter of 2·5cm. The two batteries formed in this manner are then connected in the closed oscillating circuit, as shown diagrammatically in Fig. 4. The capacity of the double battery is 0·01 microfarad, and this is not altered. Such an oscillating circuit produces many hundred—up to 1,000—single waves for each spark, while the sequence of waves of the open oscillating circuit may be as little as one or a few dozen oscillations. There is little to say about the front carriage, shown open in Fig. 7. Each carries a receiving apparatus. To the right is the coherer, with its relay, and next to these the Morse ink-writer. For the relay circuit, as well as for the Morse ink-writer circuit, Hellessen dry cells are used. Particular attention has been paid to ensure high insulation

both for the receiver and transmitter, and tests have shown that absolute certainty of working may be obtained in the worst weather. The containers for the hydrogen gas used for filling the balloon are placed under the body of the front cart. In addition to this, the balloons themselves, kites, and the various material necessary for military purposes are carried on the carts. Each pair of carts is accompanied by one officer, one non-commissioned officer and five men in addition to the driver. The apparatus was used with success during the German manœuvres last year, and was employed to transmit the most important news. Various distances of transmission were successfully overcome. In general, the distance was from 40km. to 50km., but in some cases it was over 60km. and up to 80km. It is evident that these distances are not the ultimate limits of wireless telegraphy over land.

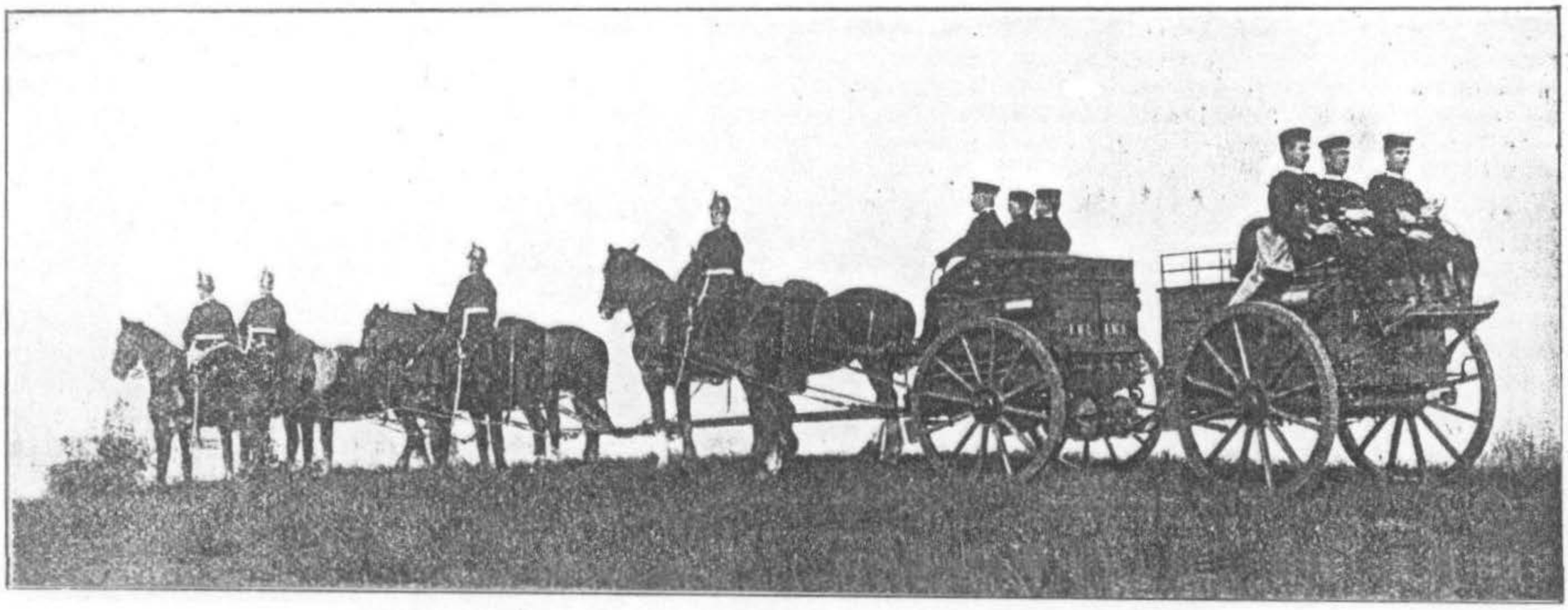


FIG. 8.—FIELD WIRELESS TELEGRAPH APPARATUS READY TO TAKE THE FIELD.



FIG. 9.—APPARATUS READY FOR OPERATION.

Tesla Split-phase Patents Not Infringed.

Meter manufacturers and electrical men generally are greatly interested in the litigation based on the Tesla split-phase patents. On February 26th, by a decision handed down in New York city, the United States Circuit Court of Appeals for the Second Circuit reversed the decision of the court below and declared that invention by Tesla prior to April 22, 1888, had not been proved, thus deciding against the patents and in favor of the defendant. The case was that of the Westinghouse Electric and Manufacturing Company, appellee and owner of the patents, against the Catskill (N. Y.) Illuminating and Power Company, appellant, which was a user of the well-known Scheeffer meter, the device complained of as infringing the patents. The manufacturer of this meter, the Diamond Meter Company of Peoria, was the real defendant, and is receiving congratulations on the strong and successful defense made on its behalf.

The opinion of the court in this important case was written by Judge Townsend, Judges Wallace and Coxe concurring. It is as follows:

Appeal by defendant in the court below from its decree on bill alleging infringement of complainant's patents, Nos. 511,559 and 511,560, granted to Nikola Tesla on December 26, 1893. The court below sustained both patents and found infringement of both claims of patent No. 511,559 and of the first claim of patent No. 511,560.

Inasmuch as we have reached a conclusion adverse to the complainant upon the question of priority of invention, the other issues will not be discussed.

The claims of patent No. 511,559 are as follows:

"1. The method of operating motors having independent energizing circuits, as herein set forth, which consists in passing alternating currents through both of the said circuits and retarding the phases of the current in one circuit to a greater or less extent than in the other.

"2. The method of operating motors having independent energizing circuits, as herein set forth, which consists in directing an alternating current from a single source through both circuits of the motor and varying or modifying the relative resistance or self-induction of the motor circuits and thereby producing in the currents differences of phase, as set forth."

The first claim of No. 511,560 is as follows:

"1. The combination with a source of alternating currents, and a circuit from the same, of a motor having independent energizing circuits connected with the said circuit, and means for rendering the magnetic effects due to said energizing circuits of different phase, and an armature within the influence of said energizing circuits."

The claims of the former patent cover a certain method, and of the latter certain means of operating electrical motors by means of alternating currents from a single original source. This system is known as the "split-phase" system.

Nikola Tesla, the patentee herein, was the inventor of what is known as the polyphase system of transmission of power, and had covered by his earlier patents, Nos. 381,968, 382,279 and 382,280, said system when operated by means of currents of varying phase from independent lines or circuits. The applications for these earlier patents were filed during the fall and winter of 1887, and the winter and spring of 1888, the final fees were mailed on April 8, 1888, and said patents issued May 1, 1888.

Up to April 8th Tesla had not intimated to his solicitor that his broad invention of the rotary-field motor could be practiced by any means which did not involve the use of two independent circuits from the generator to the motor.

The applications for the patents in suit were filed December 8, 1888. By the method and means therein described Tesla dispensed with one of the line circuits and was able to run the motor by means of alternating currents from a single original source. This was accomplished, as appears from the foregoing claims, by means which so retarded the phases of the current in all circuits or so varied the relative resistance of the motor circuits as to maintain the necessary difference of phase in the currents. Such utilization of a single original source by thus splitting a single current into two currents, was an improvement of great practical value.

But on April 22, 1888, there had been published at Milan, in an Italian journal, a report of a lecture by Professor Galileo Ferraris, in which the system covered by the patents in suit was fully described. This printed publication is such a disclosure of the subject-matter of the patents in suit that if prior thereto would constitute an anticipation.

To support the burden thus cast upon it of proving to the satisfaction of the court that the supposed inventions in suit were made prior to April 22, 1888, complainant has introduced a photograph and the evidence of two witnesses, Messrs. Brown and Page. One of said witnesses has testified that said photograph represented a motor which was in Tesla's shop in the fall of 1887, and in which the difference in phase was secured by the introduction in one of the circuits of a coil having self-induction. There is nothing in the photograph, however, to indicate the means by which said motor was operated, nor whether it was adapted to receive a single or double current from the generator. Its construction is at least as suggestive of use in connection with the earlier polyphase as with the latter split-phase patents. We are, therefore, confined to a consideration of the testimony of said two witnesses.

Mr. Brown furnished capital to Tesla to make his experiments at the date here in question, and afterward sold his interest in the Tesla inventions to this complainant. On May 25, 1900, he testified that in 1887 Tesla disclosed to him certain inventions made by him relating to split-phase alternating-current motors and showed him such motors in operation in his shop in Liberty Street (in 1887), and that the shop was afterward moved and destroyed by fire, and he thought all the motors were destroyed in said fire. He further stated that he had had no experience with alternating currents beyond that which he had had through his connection with Tesla. He failed to identify the date of the disclosure or to account for the loss of said motors further than as hereinbefore shown, and complicated his vague general description of said apparatus by contradictory statements as to the specific means used in their operation. But, apart from all this, he failed to so describe the said apparatus that this court can determine whether they did, in fact, embody in structure and practical operation the specific form of apparatus used by the defendant. Such evidence, under the familiar rule, called either for corroboration or for some explanation why corroboration was impossible.

The complainant failed to comply with said rule. It failed to show that Tesla alone constructed said motors, or to produce anyone employed in said shop in 1887 who might have seen said motors or taken part in their construction, or to account for their absence. It failed to put Tesla himself, a resident of New York, on the stand to show to the court the precise nature of the inventions disclosed and practiced by him in 1887.

Farther than this, other uncontradicted testimony strongly tends to show that the witness must have been mistaken as to the date of this disclosure and of the operation of said motors. It appears that in 1888 Tesla spent nearly two weeks at the factory of the Mather Electric Company, explaining his new alternating-current motor inventions, with a view to interesting said company in their development and manufacture; that one of the objections made to their operation was the fact that they required a special generator and extra wires, but that Mr. Tesla did not then claim that he had made any invention whereby two currents of different phase could be derived from a single source. Again, complainant's other witness to the date of invention, Page, who was Tesla's attorney, and who, during 1887 and 1888, prepared the Tesla applications for the polyphase and other patents, including those here in suit, testified that up to a few days after April 8, 1888, "Mr. Tesla had never intimated in any way to me that his invention of the rotary-field motor could be practiced by any means which did not involve the use of two independent circuits from the generator to the motor."

We are forced to the conclusion that Brown, testifying at this distance of 13 years, must have had in mind the year 1888, during which year also, as he testifies, he saw said motors in said shop.

We are brought, then, to a consideration of the testimony of said Page, the witness chiefly relied on to carry the date of invention back of April 22, 1888. The material parts of his testimony are as follows, namely, that having been employed as aforesaid, Tesla "explained that he had other ideas about the operation of these motors, and thereupon disclosed to me his scheme for operating the motors by connecting them with single circuits; that when he first described the scheme of patent 555,190 (application filed May 15, 1888), Mr. Tesla also described to me the plan of operating these motors which involves the splitting of a circuit, * * * upon which patent 511,560, which is one of the patents in suit, is based; and that I understood fully from his description, not only the principal and essential features of the inventions involved in the patents in suit, but also another plan which he had at that time developed for effecting the same result by making the poles of a motor of different magnetic susceptibility, * * * the subject of an application filed October 20, 1888, and which became patent No. 524,426."

It further appeared on the hearing in this court that Mr. Page filed three other Tesla applications on April 23, 24, and 25, 1888, respectively, and which issued in October, 1888, as patents Nos. 390,414, 390,820 and 390,721, respectively. Neither these patents nor Nos. 555,190 and 524,426 are in suit herein. Some of the patents cover modifications of the polyphase, others of the split-phase invention. The applications which resulted in the patents in suit were not filed until December 8, 1888. As to the character and date of said disclosures, the witness further testified as follows:

"I cannot say, from present recollection, how many of the specific arrangements for producing artificially the necessary differences of phase which are described in the two patents in suit Mr. Tesla described to me in the early part of April, 1888, but my recollection is clear to the fact that between April 8, and April 18, 1888, on which latter date I entered a charge in my diary for services in this particular matter."

The diary was not produced. The witness stated: "I had occasion several years ago to look up the facts in connection with the matter about which I have just testified, and at that time I had this book in my possession;" that he then used it in giving certain testimony; that he had since searched for it, but had been unable to find it; and that his present testimony was based upon his recollection of the matter and upon the records of previous testimony given on this point.

This evidence is clear, direct and persuasive as to a disclosure by Tesla of various schemes for operating motors on the split-phase principle. But it falls far short of the requirement in such a case.

"The burden which rested upon the defendant in the first instance has been transferred to the complainant, and it must furnish the court with convincing proof that the anticipation has been anticipated." (The Westinghouse Electric and Manufacturing Company v. Saranac Lake Electric Light Company, 108 Fed., 221, 222; Clark Thread Company v. Willimantic Linen Company, 140 U. S., 481.)

It is to be noted that this testimony relates to events which occurred 12 years before; that the only means which the witness had for refreshing his recollection is the lost diary. The witness could not be expected to have any independent recollection as to what was covered by the charge, entered four days before the date of the anticipating publication, for "services in this particular matter," nor whether the date and character of said charge was correctly entered. The evidence fails to show the specific character of said disclosure, whether it covered the constructions herein held to be infringed or some of the other constructions embraced in the patents in suit or in said other patents not in suit on which the witness was then engaged. Nor does it appear with satisfactory definiteness that the disclosure was a sufficiently full and complete disclosure of the particular claims involved herein, or, if so, which were thus disclosed. The witness does not state what Tesla said to him. Apparently, all that he learned from Tesla was the "principal and essential features of the inventions involved in the patents in suit."

The fact that the applications for the patents in suit were not filed until December 8, 1888, while said applications for other specific phases of said invention were filed on May 15th and October 20th, tends to support the claim that the "particular services" were rendered in regard to said earlier specific inventions and that Tesla did not perfect and complete the inventions in suit until a later date.

In these circumstances it was incumbent upon complainant to furnish additional evidence in order to remove these uncertainties or to account for its failure so to do. No attempt was made, however, to further fix the date or character of Page's services, either by the books of his firm, the bills rendered, the testimony of his partners or of his Washington associates, with both of whom he consulted, or by the date of the trip taken to Washington in regard to the matter, or by the testimony of Tesla himself. Complainant has failed to comply with the fundamental rule that the best evidence of which the case is, in itself, susceptible, must be produced.

In these circumstances we are constrained to hold that invention by Tesla prior to April 22, 1888, has not been proved.

The decree is reversed with costs and with instructions to the court below to dismiss the bill with costs.

Charles A. Brown, the well-known patent lawyer of Chicago, in commenting on the decision for the benefit of the readers of the Western Electrician, expressed himself as follows:

"The patents involved in this suit are known as the Tesla split-phase patents. The claims which are quoted in the opinion of the court show that the patents are very broad in their apparent scope—so broad, in fact, that unless limited to the particular mode of operation of the so-called Tesla rotating field, they are anticipated by many devices of the prior art.

"The anticipating reference on which the Tesla patents were found to be invalid by the Circuit Court of Appeals was the well-known Ferraris publication. Ferraris' lecture, which fully described the construction and mode of operation set forth in the Tesla patents, was delivered in Turin on the 16th of March, 1888. Publication of this lecture occurred in the Italian journal l'Eletricitta, April 22, 1888, and other technical journals in Europe and America published the lecture soon afterward. Shallenberger and others also made the improvements set forth in the patents independently of Tesla, and before December 8, 1888, the date of filing the applications for the patents under consideration.

"As the court's opinion shows, it was necessary for complainant to establish a date for Tesla's invention earlier than April 22, 1888, and to do this clearly. The failure to do this was fatal to complainant's case and to the patents.

"Tesla's claim was based solely upon a legal technicality. He was not in any case the one who gave the split-phase motor to the world. Ferraris did that. Not only was the Ferraris publication earlier, but he undoubtedly made the improvement actually long before Tesla thought of it. Tesla could get no patents in Europe on account of Ferraris' work. But in this country, under our laws, the use of an improvement in a foreign country does not anticipate an invention. It is the publication that counts as an anticipation in such a case. It was upon this legal technicality that the Tesla patents were based. The Westinghouse company bought the Ferraris rights in this country.

"An interesting fact in connection with this matter is not referred to in the opinion of the court. In

the latter part of February, 1888, Tesla went to Manchester, Conn., to show his rotating-field motors (it was Ferraris, by the way, and not Tesla, who gave the name 'rotating field' to these motors) to Professor Anthony, with a view of getting a report from him. When Professor Anthony saw and understood the polyphase motor, he promptly thought of operating the motor on a split-phase circuit, and he wrote to his friend, Dugald C. Jackson, now professor of electrical engineering in the University of Wisconsin, explaining both the polyphase and split-phase modes of operation. Professor Jackson replied, giving descriptions of other ways of operating the rotating-field motor. It was some nine months later that Tesla applied for patents showing precisely the plans and methods of operation set forth in this correspondence between Professor Anthony and Professor Jackson. The patents thus applied for are those which have just been declared invalid by the Circuit Court of Appeals.

"The point upon which the decision turns lies at the threshold of the defense in this case. That other and serious defenses were presented may be appreciated from the fact that the record comprises between 2,300 and 2,400 printed pages."

What Mr. Tesla Is Said to Have Said.

In a floating newspaper paragraph Nikola Tesla is thus reported: "The wireless telegraphy plants you may have seen are but networks of flimsy wire. We are not doing anything of that sort here at Wardenclyffe. We are building for the future. It will be some time before our preparations are complete, but when we are ready we will be able to accomplish what we desire. We shall not be handling a plaything. It will be something for business. I do not believe that messages can be transmitted without wires for more than 50 or 60 miles without the use of the principles which I have patented throughout the civilized countries of the world. By the use of my system you will be able to put an instrument in your house and talk to anyone who has a similar apparatus anywhere in the country without any metallic or artificial connection."

The New York Sun March 15, 1903

DIFFER OVER TESLA METERS.

U. S. Court in One Circuit Upholds His Patents, in Another Does Not.

Judge Cult, in the United States Circuit Court for the First Judicial district, which includes Maine, Vermont and Massachusetts, handed down a decision Thursday in the case of the Westinghouse Electric Manufacturing Company against the Stanley Instrument Company of Great Barrington, Mass. The suit was brought to restrain the Stanley company in its principal business, manufacturing electric meters, which, it was alleged, Nicola Tesla had invented and the patents on which the Westinghouse Company owns.

The decision was in favor of the Stanley Company, the court holding that the plaintiffs had not satisfactorily established Tesla's priority of invention over that of an Italian of the name of Galileo Ferraris Tesla asserted that he had, in April, 1887 taken out letters patent on a meter of the particular "phase" of the one in litigation The Stanley company asserted that he had simply patented in this country the device of the Italian inventor.

Several years ago Tesla's labratory took fire and all the records of earlier inventions were destroyed. Therefore direct proof of the plaintiff's contention was wanting. On the proof which was adduced before Judge Cult, however, the Westinghouse company won a similiar suit in a Western circuit, and a similiar suit is now pending in Pennsylvania.

The decision has no bearing whatever on the transmission-of-power invention, the greatest of all Tesla's inventions and one of the greatest of any age, all claims against which have been decided in Tesla's favor.

Stanley Instruments Held not to Infringe Tesla Split-phase Patents.

Judge Colt of the United States Circuit Court, District of Massachusetts, has handed down a decision in the suit brought by the Westinghouse Electric and Manufacturing Company against the Stanley Instrument Company of Great Barrington, Mass., for alleged infringements of certain Tesla patents, holding that the complainant failed to establish the conception by Tesla of the inventions in suit prior to April 22, 1888, the date of the Ferraris publication. The patents in suit are what are commonly known as the Tesla split-phase patents, and they were held to be non-infringed by the Circuit Court of Appeals in a similar suit by the Westinghouse company against the Catskill Illuminating and Power Company, as stated in the Western Electrician of March 7th. The same evidence was produced by the complainant in both cases, so that Judge Colt considers an opinion unnecessary, as it would be only a repetition of the decision of the Appellate Court. The bill is accordingly dismissed with costs.

Tesla Double-circuit Selective Space-telegraph System.

Nikola Tesla has found that, notwithstanding all constructive advantages and experimental resources, the method of selective signaling in space telegraphy, as commonly practiced, is in many cases inadequate. Thus, while he has succeeded in so operating selectively under certain favorable conditions more than 100 receivers, in most cases it is practicable to work successfully but a few, the number rapidly diminishing as, either owing to great distance or other causes, the energy available in the tuned circuits becomes smaller and the receivers necessarily more delicate. Evidently, a circuit however well constructed and adjusted to respond exclusively to vibrations of one period is apt to be affected by higher harmonics, and still more so by lower ones. When the oscillations are of a very high frequency, the number of the effective harmonics may be large and the receiver consequently easily disturbed by extraneous influences to such an extent that when very short waves, such as those produced by Hertzian spark apparatus, are used little advantage in this respect is to be derived from tuning the circuits.

"It being an imperative requirement in most practical applications of such systems of signaling or intelligence transmission," says Mr. Tesla, "that the signals or messages should be exclusive or private, it is highly desirable to do away with the above limitations, especially in view of the fact which I have observed, that the influence of powerful electrical disturbances upon sensitive receivers extends even

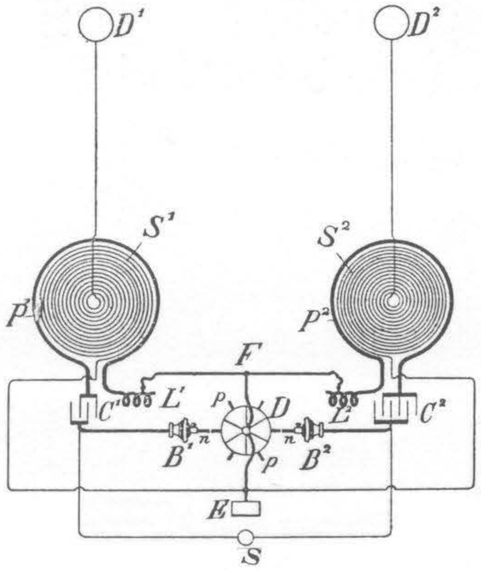


FIG. 1. TESLA DOUBLE-CIRCUIT SELECTIVE SPACE-TELEGRAPH SYSTEM.—SENDING STATION.

on land to distances of many hundreds of miles, and consequently, in accordance with theory, still farther on sea." To overcome these drawbacks and to enable a great number of transmitting and receiving stations to be operated selectively and exclusively and without any danger of the signals or messages being disturbed, intercepted, or interfered with in any way is the object of an invention recently patented by Mr. Tesla.

Broadly stated, this invention consists in generating two or more kinds or classes of disturbances or impulses of distinctive character with respect to their effect upon a receiving circuit and operating thereby a distant receiver which comprises two or more circuits, each of which is tuned to respond exclusively to the disturbances or impulses of one kind or class and so arranged that the operation of the receiver is dependent upon their conjoint or resultant action.

By employing only two kinds of disturbances or series of impulses instead of one, as has heretofore been done, to operate a receiver of this kind, he has found that safety against the disturbing influences of other sources is increased to such an extent that he believes this number to be amply sufficient in most cases for rendering the exchange of signals or messages reliable and exclusive; but in exceptional instances a greater number may be used and a degree of safety against mutual and extraneous interference attained, such as is comparable to that afforded by a combination lock. The liability of a receiver being affected by disturbances emanating from other sources, as well as that of the signals or messages being received by instruments for which they are not intended, may, however, be reduced not only by an increased number of the co-operative disturbances or series of impulses, but also by judicious choice of the same and order in which they are made to act upon the receiver.

Figs. 1 and 2 represent diagrammatically an apparatus and circuit connections employed at the sending and receiving stations, respectively, for the practice of Mr. Tesla's invention.

In Fig. 1, (S') (S²) are two spirally wound coils or conductors connected with their inner ends, to preferably elevated terminals (D') and (D²), respectively, and with their outer ends to an earth plate (E). These two coils, conductors, or systems, (D') (S') (E) and (D²) (S²) (E) have different and suitably chosen periods of vibration, and, as pointed out in other patents relating to his system of energy and intelligence transmission, their lengths should be such that the points of maximum pressure developed therein coincide with the elevated terminals (D') (D²). The two systems may have electrical oscillations impressed upon them in any desired manner conveniently by energizing them through primaries (P') and (P²), placed in proximity to them. Adjustable inductances (L') and (L²) are preferably included in the primary circuits chiefly for the purpose of regulating the rates of the primary oscillations. In the drawings these primaries (P') and (P²) surround the coils (S') (S²), and are joined in series through the inductances (L') (L²), conductor (F), condensers (C') and (C²), brush-holders (B') and (B²), and a toothed disk (D), which is connected to the conductor (F), and, if desired, also to the ground-plate (E), as shown, two independent primary circuits being thus formed.

The condensers (C') and (C²) are of such capacity and the inductances (L') (L²) are so adjusted that each primary is in close resonance with its secondary system, as explained in other Tesla patents. The brush-holders (B') and (B²) are capable independently of angular and, if necessary, also of lateral adjustment, so that any desired order of succession or any difference of time interval between the discharges occurring in the two primary circuits may be obtained. The condensers being energized from a suitable source (S), preferably of high potential, and the disk (D) being rotated, its projections or teeth (p p) coming at periodically recurring intervals in very close proximity to or, as the case may be, in contact with conducting rods or brushes (n n), cause the condensers to be discharged in rapid succession through their respective circuits. In this manner the two secondary systems (D') (S') (E) and (D²) (S²) (E) are set in vibration and oscillate freely, each at its proper rate for a certain period of time at every discharge. The two vibrations are impressed upon the ground through

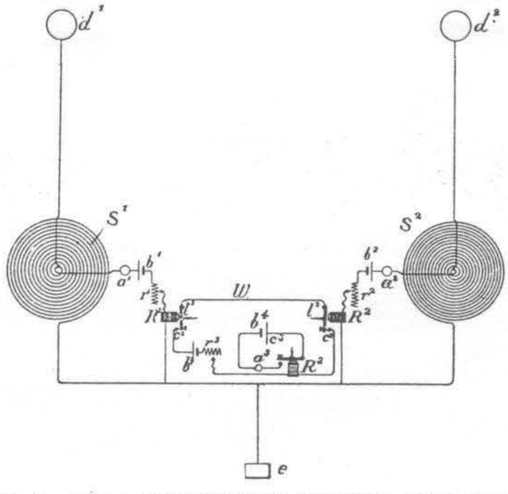


FIG. 2. TESLA DOUBLE-CIRCUIT SELECTIVE SPACE-TELEGRAPH SYSTEM.—RECEIVING STATION.

the plate (E) and spread to a distance reaching the receiving station, which has two similar circuits or systems (e) (s') (d') and (e) (s²) (d²), arranged and connected in the same manner and tuned to the systems at the sending station, so that each responds exclusively to one of the two vibrations produced by the transmitting apparatus.

The same rules of adjustment are observed with respect to the receiving circuits, care being furthermore taken that the tuning is effected when all the apparatus is connected to the circuits and placed in position, as any change may more or less modify the vibration. Each of the receiving coils (s') and (s²) is shunted by a local circuit containing, respectively, sensitive devices (a') (a²), batteries (b') (b²), adjustable resistances (r') (r²), and sensitive relays (R') (R²), all joined in series, as shown. The relays (R') (R²) have armatures (l') (l²), which are connected by a wire (w), and when attracted establish electrical contacts at (c') and (c²), thus closing a circuit containing a battery (b³) and adjustable resistance (r³) and a relay (R³). From the above description it will be readily seen that the

relay (R^3) will be operated only when both contacts (c') and (c^2) are closed.

The apparatus at the sending station may be controlled in any suitable manner—as, for instance, by momentarily closing the circuit of the source (S), two different electrical vibrations being emitted simultaneously or in rapid succession, as may be desired, at each closure of the circuit. The two receiving circuits at the distant station, each tuned to respond to the vibrations produced by one of the elements of the transmitter, affect the sensitive devices (a') and (a^2) and cause the relays (R') and (R^2) to be operated and contacts (c') and (c^2) to be closed, thus actuating the receiver or relay (R^3), which in turn establishes a contact (c^3) and brings into action a device (a^3), by means of a battery (d^4), included in a local circuit, as shown. But evidently if through any extraneous disturbance only one of the circuits at the receiving station is affected the relay (R^3) will fail to respond. In this way a communication may be carried on with greatly increased safety against interference, and privacy of the messages may be secured.

The receiving station shown in Fig. 2 is supposed to be one requiring no return message; but if the use of the system is such that this is necessary, then the two stations will be similarly equipped, and any well-known means may be resorted to for enabling the apparatus at each station to be used in turn as transmitter and receiver. In like manner the operation of a receiver, as (R^3), may be made dependent, instead of upon two, upon more than two such transmitting systems or circuits, and thus any desired degree of exclusiveness or privacy and safety against extraneous disturbances may be attained. The apparatus, as illustrated in Figs. 1 and 2, permits, however, special results to be secured by the adjustment of the order of succession of the discharges of the primary circuits (P') and (P^2), or of the time intervals between such discharges.

"Whatever the nature of the specific devices employed," says Mr. Tesla, "it will be seen that the fundamental idea in my invention is the operation of a receiver by the conjoint or resultant effect of two or more circuits, each attuned to respond exclusively to waves, impulses, or vibrations of a certain kind or class, produced either simultaneously or successively, by a suitable transmitter."

April 1903

THE JOURNAL OF ELECTRICITY, POWER AND GAS. [Vol. XIII—No. 4

THE TESLA SPLIT-PHASE PATENTS.

JUDGE COLT, of the United States Circuit, District of Massachusetts, on March 11th, handed down a decision covering the Tesla split-phase patents, the parties to the suit being the Westinghouse Electric and Manufacturing Company and the Stanley Instrument Company. The opinion, which is very brief, refers to the recent decision of Judge Townsend in a suit on appeal in which the same patents were involved.

The opinion states that upon careful consideration of the evidence, the court has reached the conclusion that the complainant has failed to establish, by sufficient proofs, the conception by Tesla of the inventions in suit prior to April 22, 1888, the date of the Ferraris publication. In a complainant's supplemental brief no reasons were found stated or authorities cited which should lead the court to any different conclusion. Since the hearing in case at bar, the Circuit Court of Appeals for the Second Circuit, in a suit invoking the same patents brought by the complainant against the Catskill Illuminating and Power Company, upon the same evidence which was before the present court, has held that the proofs were insufficient to establish invention by Tesla prior to April 22, 1888. Judge Colt considers that this decision, which was passed down February 26, 1903, renders unnecessary an extended opinion by him, since it would be only repetition of the views so clearly expressed by Judge Townsend in the opinion of the court in the Catskill case. A decree is to be entered dismissing the bill, with costs.

Loaded Lines in Telephonic Transmission.—CAMPBELL.—A mathematical investigation of the effect of inserting self-induction coils on long telephone lines as in Pupin's system, and an account of some experiments. He worked with a cable circuit 46 miles in length, partly artificial, containing 100 equally-spaced inductance coils. The initial loss due to the loading was found to be equivalent to the introduction of 9 miles of standard cable, but on account of the greatly reduced attenuation, the loaded line is better than the unloaded line for all distances greater than 15 miles. In the author's arrangement, the distance over which transmission could be obtained was nearly trebled by the loading, and the quality was improved in addi-

tion. At the transmitting end a person talked in a steady, monotonous manner, and at the receiving end a person could switch instantly from the loaded line to the artificial cable standard, to compare the clearness of transmission over the two. The comparison gave the equivalents of the two circuits for commercial service. The author admits that much further experimental work remains to be done.—*Phil. Mag.*, March; abstracted in Lond. *Elec.* March 13.

MISCELLANEOUS.

REFERENCE.

Biographical.—HAWKINS.—An article on "Nikola Tesla, his work and unfulfilled promises."—*Elec. Age.*, February.

WIRELESS TELEGRAPHY IN THE UNITED STATES.

By E. GUARINI.

The first experiments in wireless telegraphy, and the first patents taken out in connection with this branch of telegraphy in the United States, date from long ago. Without going back to the attempts of Morse in 1842, we must begin as far back as 1891. In that year, in his patent No. 465,971, dated December 29th, taken out for his system of transmission of electric signals, Thomas Alva Edison expressed as follows his first claim:—"A method of transmitting signals between stations separated from one another, consisting of an elevated condensing surface at each station, of a transmitter connected with one of these condensing surfaces in order to modify its electric tension according to the signal to be transmitted, and thus varying in a corresponding manner the tension of the other condensing surface, and of a receiver connected with the other condensing surface in substance as described."

Few people have a clear or adequate idea of the importance of this patent of Edison's in the history of wireless telegraphy. The greater number of the component parts of the present systems of wireless telegraphy are found in it; the antennæ, the coil, the connections to earth. The receiver of the future will probably be Edison's, *i.e.*, a receiver in which the energy of the wave works directly the apparatus that operates the signals.

A complete Edison station was constituted as follows (fig. 1):—A source of current, either variable in itself or

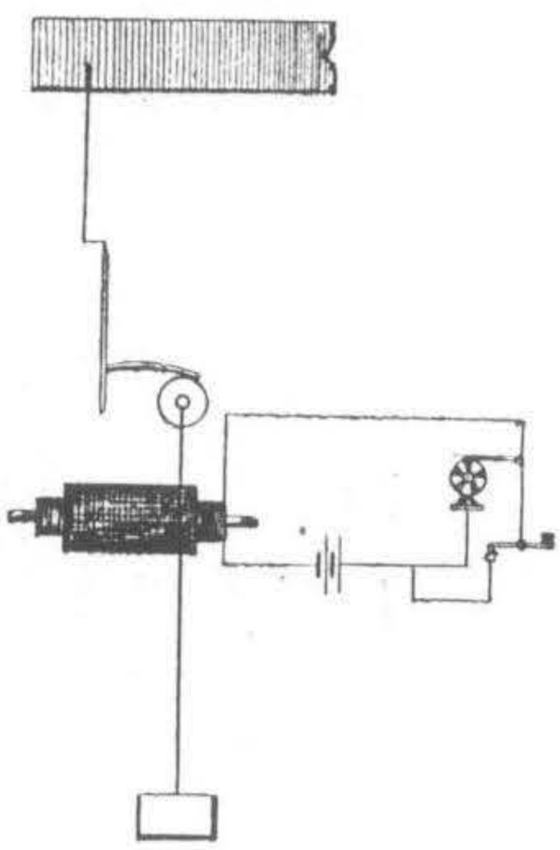


Fig. 1.

rendered so by an interrupter, fed the primary of an induction coil, the secondary of which was, at one end, connected to earth; and at the other through a telephone by a vertical wire to a capacity, *e.g.*, a plate, placed at a certain height.

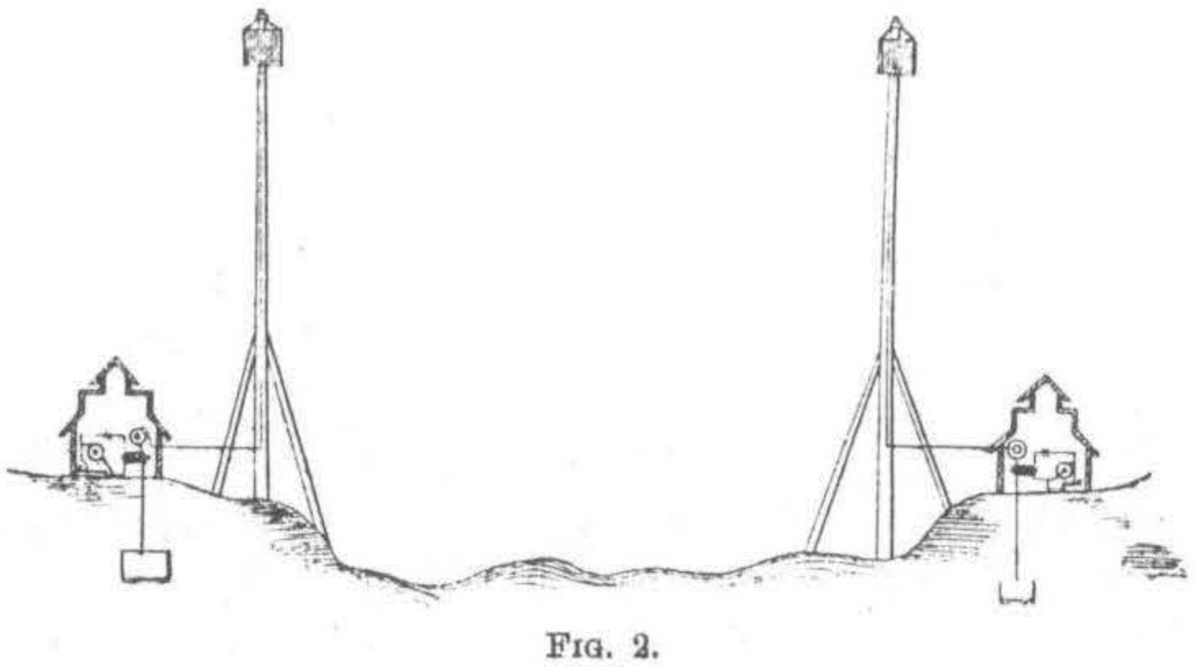


Fig. 2.

Communication was established between two stations by providing each of them with a similar apparatus (fig. 2). On working the coil the high pressure current of the secondary charged the antenna and the capacity. An induced current

was produced in the capacity and in the antenna of the other station. This current proceeded towards earth through the winding of the telephone. A sound was heard in the telephone, and its duration was in proportion to that of the primary current.

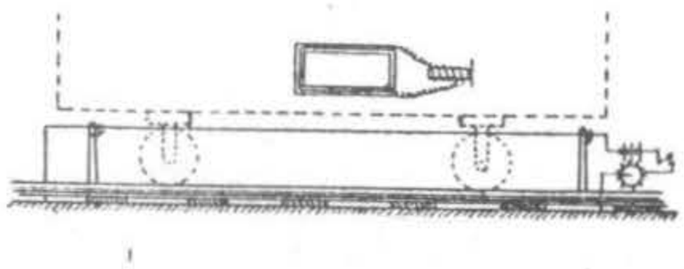
The writer may remark in passing that it was with the aid of the Edison transmitter, and by the substitution of a coherer for the telephone in the receiver, that he was able to effect the overland experiments over a distance of 44 km. between Brussels, Mechlin and Antwerp (Electrical Review, May 24th, June 7th and 28th, and July 12th, 1901), and by means of which he is able to dispense with the Hertzian waves, which are generally thought indispensable, in realising long-distance wireless telegraphy. This is in no way surprising: the current which an antenna on open circuit can send out is the product of the frequency and the capacity. Thus two methods of radiating great energy present themselves:—(1) To use a high frequency (Hertzian waves) and antennæ of small capacity. This is the method employed by Marconi, Braun, Slaby, &c. (2) To employ a current of low frequency and antennæ of great capacity. This is the method used by Edison and by the writer.

In concluding these remarks upon the Edison system, we will here quote a passage from his patent, which will remain one of the most noteworthy pages in the still early history of wireless telegraphy:—"I have discovered," says Edison, "that if we get an elevation sufficient to clear the curvature of the earth, and to reduce to a minimum the absorption of the earth, electric telegraphy, or the interchange of signals between far distant points, can be worked by induction without the use of wires connecting these points. This discovery is specially applicable to telegraphy across masses of water, so as to avoid the use of submarine cables, or to communication between vessels at sea or between vessels at sea and stations on land; but it is also applicable to electric communication between distant points on land, although on land (except in the case of open prairies) there is always the necessity of increasing the elevation in order to reduce to a minimum the absorbing effect of houses, trees, and elevations of the ground itself. At sea, with an elevation of 100 ft., I can send electric communications to a great distance, and as this height can be attained by using the masts of ships, signals can be transmitted and received between vessels separated by a considerable distance, and if these signals are repeated to other vessels, communication can be established for any distance, even across the largest seas and oceans. Collisions during fogs can be prevented by this system of signals, which might also be used to warn a vessel approaching a dangerous coast during foggy weather. For communications between points on land, poles of great height may be used, or captive balloons."

Edison, as we see, proposed captive balloons, antennæ, repeaters—in fact, all that is now being used, and all that is at present likely to be used, at any rate on land.

After Edison's apparatus, those designed by Mr. Phelps, with a view to effecting communication between trains in

Fig. 3.



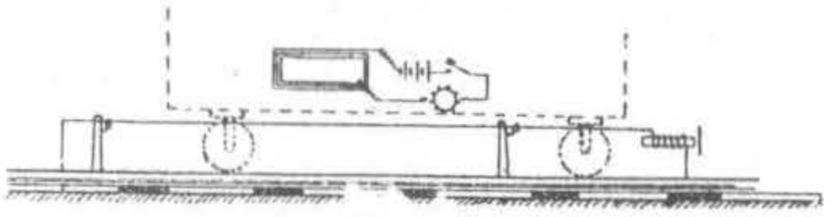


Fig. 4.

motion, are worthy of attention, though they are not strictly wireless (figs. 3 and 4). The system comprises:—

1. Between the rails a line, the extremities of which are connected to earth.

2. A rectangular coil placed vertically on the train, as near as possible to the line.

The transmitting system comprises a variable source of current, *e.g.*, a toothed wheel interrupting the current of a battery; the receiving system, a simple telephone. Fig. 3 shows the arrangement required for sending signals to the train; fig. 4, that which is required at a station for the reception of signals sent by a train.

In order to allow of communications in both directions, each station consists of a transmitter and a receiver, placed in circuit in succession.

An application having the same object was designed by Gilliland with a modification of the Edison system. In the Edison-Gilliland system, as applied to railways, a line goes along the track; the metal roofing of the carriage constitutes the capacity of the Edison system; the wheels form the connection to earth. In the line, as on the train, the Morse key serves to switch on the antenna.

Another most interesting patent was taken out in 1897; this time by Mr. Nicola Tesla, who has become famous through his Martian communications and his towers, which in 1899 were constructed for wireless telegraphy. He took out the patent in question for "improvements in the system for the transmission of electrical energy, and in the apparatus used for this transmission." The title is most modest, but when we penetrate into the details we soon perceive that we have before us a Pindaric flight of the fertile imagination of the child of Montenegro.

In principle the Tesla method consists in establishing a circuit in which the rarefied air of the upper strata of the atmosphere serves as the outgoing and the earth as the return conductor.

As in the Edison system, the transmitter consists of an induction coil, but an induction coil of special construction, the high pressure circuit of which is connected at one end to earth and at the other to a disc supported by a balloon in the rarefied air of the upper strata of the atmosphere. The arrangements made for the reception are similar to those used for the transmission. The fine wire winding of the transformer is connected at one extremity to earth and at the other to the aerial disc. The thick wire circuit of the transformer comprises lamps, motors, &c., which it is designed to feed.

Without doubt electricity owes some important discoveries to Tesla. But in this case we fear that his so-called invention, or discovery, will remain a dead letter and never be carried out in a practical way.

Tesla compares his system to a Geissler tube fed by the secondary of an induction coil, and draws from this comparison conclusions too long to reproduce here. But is the comparison justified? Can the Tesla system really be compared to the Geissler tube? That is the question. Admitting that a sufficiently high pressure can be produced to overcome the resistance of the earth and of the rarefied air, why should the current go towards the Tesla receiver, and not in all directions? Would not the conduction of the air and the earth constitute a serious difficulty? We can limit the area of *radiation*, but how can we limit the *conduction* of the earth and the atmosphere to certain sectors? Moreover, if the whole of the surrounding earth and atmosphere be involved, has Mr. Tesla thought what a small quantity of energy would arrive at his receiver, if, indeed, any arrived?

Mr. Tesla, however, has not given up his idea, and does not own himself beaten. Moreover, the New York *Electrical World and Engineer* recently published an engraving and a short description of a tower constructed by Tesla at Wardencliff with a view to experiments in wireless telegraphy, and in the transmission of energy without conductors to Europe and Australia, where corresponding stations are to be established. *Qui vivra verra!* In the meantime, let us glance at some other systems.

(*To be continued.*)

THE ROYAL SOCIETY SOIRÉE.

THIS year, for the first time within our recollection, the annual soirée of the Royal Society was held on Friday night instead of Wednesday night. The change, no doubt, is due to the altered rules under which Parliament works. Formerly Wednesday night was an off evening in the House, and members were at liberty to attend the conversazione of the Royal Society; under the present rules they are all occupied on Wednesday, and Friday is the only evening which they have at leisure. The meeting last Friday, the 15th inst., was a highly successful one, and was attended by the Prince of Wales and by a very large gathering of men of science and others. The collection of exhibits for the instruction and amusement of the visitors was rather smaller than the average, and excepting Sir William Crookes's display of the emanations of radium, it can scarcely be said that there was much that was either new or important. There was, however, a good level of excellence all round, and the visitors found plenty to attract them.

The Rev. F. J. Jervis-Smith, F.R.S., showed his high-pressure spark-gap for Tesla inductors. The spark-gap consists of two brass balls, platinum faced, fixed at an adjustable distance in a glass sphere, which can be charged with compressed air. The gap and the inner coatings of two Leyden jars were joined in the secondary circuit of a Tesla inductor, the outer coatings to the primary. The brush discharge in air is changed into a torrent of thick sparks when the air pressure in the sphere is raised to 40 lb. per square inch, and a glass plate nearly $\frac{1}{2}$ in. in thickness, placed between two point terminals in an oil-trough, is at once perforated. Yet that discharge is physiologically harmless, and only pricks the finger a little when approached to one of the terminals. Another peculiarity is that if a spark strikes a vacuum glass tube without electrodes, a greenish glow appears on the inner coating opposite—not on the coating nearest to the point struck—and at any point earthed outside through the hand in which the tube is held; this glow emits Röntgen rays, and gives good skiagraphs. The sparks also produce Hertzian waves, a property which has been utilised in wireless telegraphy. For this reason Mr. Jervis-Smith has probably resumed these interesting experiments, which date back to 1892 and 1896.

Mr. Tesla and His Oscillator.

The New York Sun, which is supposed to have excellent sources of information in matters relating to the work of Nikola Tesla, published this short but interesting editorial in its issue of May 31st:

"It is now a little more than two years since the Sun gave to the world Mr. Tesla's announcement that, some time within the eight months following, he would send a wireless telegram across the Atlantic Ocean.

"With the failure of that prediction the public is familiar, although not with the immediate cause. As we understand it, progress toward fulfillment revealed possibilities so much greater that it was determined to aim at a higher mark, and we are now authorized to say, in Mr. Tesla's behalf, that some time within the present year he will send wireless telegrams to the other side of the world. The Tesla oscillator is to deliver to the earth the shock that will be felt and recorded on its uttermost confines.

"As before, we have to wait and see, doubtful because of the miraculous character of the task, but hopeful on the strength of the wonders that science has already done."

Tesla Patent Litigation.—An important decision was lately given by the United States Circuit Court of Massachusetts in the case of the Westinghouse Electric and Manufacturing Company against the Stanley Instrument Company for alleged infringement of certain patents of Nikola Tesla. A similar suit was brought against the Catskill Illuminating and Power Company, and resulted in the Circuit Court of Appeals giving judgment, as in the first-mentioned case, in favour of the defendants. The point involved was as to the priority of invention. The claims of the first patent which came up for consideration cover a certain method, and of the second certain means of operating electrical motors by means of alternating currents from a single original source. This system is known as the "split-phase" system. Nikola Tesla was the inventor of what is known as the polyphase system of transmission of power, and had covered by his earlier patents the said system when operated by means of currents of varying phase from independent lines or circuits. By the methods and means therein described Tesla dispensed with one of the line circuits, and was able to run the motor by means of alternating currents from a single original source. This was accomplished by means which so retarded the phases of the current in certain circuits, or so varied the relative resistance of the motor circuits, as to maintain the necessary difference of phase in the circuits. Such utilisation of a single original source by thus splitting a single current into two currents was an improvement of great practical value. But on April 22, 1888, there had been published at Milan, in an Italian journal, a report of a lecture by Prof. Galileo Ferraris, in which the system covered by the patents in suit was fully described. This printed publication is such a disclosure of the subject matter of the patents that if prior thereto it would constitute an anticipation. After reviewing the evidence the court found that the claims of Telsa had been anticipated, and that there was therefore no infringement of his patents

CONTEMPORARY ELECTRICAL SCIENCE.

[Compiled by E. E. FOURNIER D'ALBE.]

Energy of Transmission in Wireless Telegraphy.—The energy available for wireless telegraphy with a Tesla transformer depends upon the capacities which can be introduced into the exciting circuit and upon their discharge potential, and hence the antennæ should have a large surface so as to facilitate their being tuned to an exciting circuit containing high capacities. But when induction coils are used, a certain value of these capacities cannot be exceeded without interfering with the proper working of the coils, and the antenna can, therefore, not go beyond certain dimensions. On the other hand, since the discharge potential is nearly inversely as the capacity, the available energy is sensibly constant, and it is usual to tune the antenna to two or three turns only of the Tesla secondary. Marconi has solved the difficulty by first devoting all the available energy to produce oscillations of any period in a primary circuit of the highest possible capacity. These oscillations are then brought to a high potential by means of a first Tesla coil, which charges another capacity, so that its period of discharge can be adjusted to the antenna by means of a second Tesla coil. G. Ferrié proposes an alternative scheme. He divides all the capacities which the transformer can charge into two or more groups placed in different oscillating circuits, but mounted on the same oscillator. All these circuits, adjusted to equal periods, act upon the antenna through as many Tesla coils whose secondaries are mounted in series or in parallel on the antenna. Adjustment is made by trial with a thermal ammeter, which must show the maximum reading.

[G. FERRIÉ, *Comptes Rendus*, June 2, 1903.]

The New York Sun July 17, 1903

TESLA'S FLASHES STARTLING.

But He Won't Tell What He Is Trying For at Wardenclifte.

WARDENCLIFFE, L. I., July 16.—Natives hereabouts are intensely interested in the nightly electrical display shown from the tall tower and poles in the grounds where Nicola Tesla is conducting his experiments in wireless telegraphy and telephony. All sorts of lightning were flashed from the tall tower and poles last night. For a time the air was filled with blinding streaks of electricity which seemed to shoot off into the darkness on some mysterious errand. The display was continued until after midnight.

This morning workmen about the plant declined to say anything. It is understood that Tesla has a well more than 200 feet deep driven beneath the tower and that the electrical waves are sent both underground and through the air.

Mr. Tesla said last evening that the evidences of experiments which have been seen by the people of Wardenclifte, near which his laboratory is located, have been going on for some time there, but that he had no announcement to make at this time as to their character or the success that had been achieved.

"It is true," said Mr. Tesla, "that some of them have had to do with wireless telegraphy and that in addition to the tower and poles there is a hole dug in the ground. This is 150 feet deep and is used in these experiments. The people about there, had they been awake instead of asleep, at other times would have seen even stranger things. Some day, but not at this time, I shall make an annnouncement of something that I never once dreamed of."

The New York Tribune July 19, 1903

STRANGE LIGHT AT TESLA'S TOWER.

Manager, However, Refuses to Explain Its Significance—Inventor's Reserve.

From the top of Mr. Tesla's lattice work tower, on the north shore of Long Island, there was a vivid display of light several nights last week. This phenomenon provoked the curiosity of the few people who live near by, but the proprietor of the Wardencliffe plant declined to explain the spectacle when inquiries were addressed to him.

For several years Mr. Tesla has been talking about wireless telegraphy and the transmission of electricity for commercial purposes through the upper air. So numerous were the postponements of any actual consummation that the public began to fear that nothing would ever come of the prophecies attributed to this inventor. The outlook was more encouraging when he bought land at Wardencliffe two years ago, and began putting up a tower there and building workshops and a laboratory. The latter having been completed, they have taken the place of those long used by him in Houston-st. The tower was 150 or 200 feet high, and had a well underneath.

In a conversation reported by The Tribune on November 27, 1901, Mr. Tesla said that he would probably install an engine of 100 horsepower to drive his dynamo. In connection with this he intended to use that combination of the condenser and induction coil with which he has for several years been able to produce high pressures. This resembles the outfit at Marconi's Glace Bay and Cape Cod stations. In some experiments in his laboratory and in public lectures Mr. Tesla has often produced a brilliant light at one end of a wire, and has taken photographs therewith.

From what Mr. Tesla has himself said on several occasions it might have been inferred that he had abandoned wireless telegraphy altogether, and was planning only a transient power. So long as he continues to maintain his usual mysterious reserve the public can adopt any one of half a dozen explanations of his conduct. Though sensitive to criticism, he sometimes appears to be oblivious to some of the uncomplimentary interpretations which are put upon his delays.

Action of Tesla Coil on Radiometer.

THE following phenomena, observed while experimenting with a small Tesla coil, will, I believe, interest some of your readers. Not having access to the necessary literature, I am not in a position to find out whether they are new or already known.

The knobs of the Tesla coil were placed in contact with, or just close to, the bulb of a Crookes's radiometer, and the coil set at work. When the brush discharge fell upon the bulb, the blackened surfaces of the vanes first retreated, as they do under the influence of radiant heat, but soon the direction of rotation changed, and the blackened surfaces moved forward, the motion continuing as long as the brush discharge fell upon the bulb.

At the same time, inside the bulb, were seen diverging from the glass sides close to the knobs two cones of pale blue light, which, falling on the opposite sides of the bulb, caused a yellowish-green fluorescence. On the fluorescent parts the shadows of the rotating cones were clearly visible, the shadow on one side being always more intense than on the other side. When the direction of the current in the charging Ruhmkorff was reversed, the shadows exchanged places, but no change in the direction of rotation of the vanes was noticed.

On examining the fluorescent parts with a screen of potassium platinocyanide, the same effects were noticed as with the X-ray tubes.

Similar effects were obtained on repeating the experiments with two incandescent lamps in the laboratory. The larger of these, an old Swan lamp, fluoresced green, and the smaller new one, supplied with the Tesla coil by the manufacturer, fluoresced blue. But in both cases, though somewhat feeble, the same X-ray effects were observed.

To study further the cause of the motion of the vanes of the radiometer, the experiment was repeated with a Crookes's tube containing a freely suspended wheel with transparent mica waves. In this case it was found possible to alter the direction of rotation of the wheel by adjusting the positions of the knobs of the Tesla coil relatively to the sides of the tube and the wheel inside it.

P. L. NARASU.

Christian College, Madras, June 18.

Tesla's Doings.

According to the newspapers, strange things are happening at Wardencliffe, L. I., where Tesla has his laboratory.

Ever since Mr. Tesla retired from the public gaze and hid himself in Long Island, he has been credited with performing strange feats. These rumors are at last confirmed. For some time, residents about the laboratory have been startled by vivid flashes of light emanating from a tall tower erected by the inventor. Just what this tall tower, and the gleams and flashes which come and go, may mean, no one knows; but it is to be inferred that Mr. Tesla is bent upon improving the present methods of telegraphing by the Hertzian waves.

The New York Tribune August 3, 1903

TESLA'S TUNING PLAN.

IT ASSURES SECRECY.

An Advance in Wireless Telegraphy —Meddling Impossible.

Any one who has ever tried to persuade Mr. Tesla to talk for publication about his experiments and projects knows how firm and courteous are his refusals. Nevertheless, one source of information about his inventions is open to the public. His patents are matters of record. Any one may obtain copies by proceeding in the right manner, though familiarity with legal phraseology and electricity is necessary fully to understand them. Two patents, almost identical in tenor, were recently issued to Mr. Tesla. The invention which they cover seems to constitute a distinct improvement in wireless telegraphy, and its character and purpose are perfectly intelligible.

Almost from the first it has been apparent that that system of communication would have a limited application unless secrecy could be insured. Hence, several of the most conspicuous workers in this field have been studying how to attain such a result. While their methods differ in detail, they all agree that the problem is to be solved by "tuning." By that phrase electricians mean a regulation or adjustment of the transmitter which makes it send out waves of a certain frequency—say 500,000 a second—and a treatment of the receiving apparatus which renders the latter more susceptible to that number than to any other. It has been assumed, rashly perhaps, that unless a piratically disposed outsider either knew what frequency was being used, or hit upon it by accident, he could not adjust his instruments so that he could steal a message where "tuning" had been employed. Of course, where no attempt was made to insure such agreement, wireless communications would not be private. In some kinds of service, indeed—as between steamships meeting at sea—no harm would result from overhearing.

In his patent specification Mr. Tesla points out a difficulty which is experienced in the operation just described, and which he has sought to evade. A phenomenon is observed in the generation of electric waves which parallels one in music. If a given tone is produced by a violin string, several others, less audible, will also be emitted. If that tone be the one which is caused by one hundred vibrations a second, the additional but fainter sounds will be those resulting from 200, 300 and other frequencies. Such extra tones, or "harmonics," represent exact multiples of the number of vibrations requisite to the lowest, or fundamental, one, and there are usually six of them. When a Hertz wave generator is put in operation, that, too, produces "harmonics." Besides the one principal frequency which the operator aims to employ, his apparatus will also give out multiples. Mr. Tesla declares that a receiver which has been regulated to respond to one frequency is likely to pick up waves which are given off anywhere from exactly twice to exactly seven times as often. Hence it might receive messages not intended for that station. That system of tuning, therefore, seems less secure than is desirable.

Mr. Tesla's plan certainly appears distinctly superior to this. What he proposes to do is to generate two or more sets of waves at once, and employ them all simultaneously in sending. These might have frequencies proportioned to each other in some such fashion as 13 and 17, or 37 and 43, or 73, 80 and 101. Only a receiver which had been tuned to respond to two or three selected rates of vibration, when all were in use, would be able to pick up a message thus sent. It will be seen at a glance that this scheme differs from the other very much as the many notched Yale key differs from an ordinary latch key. Though Mr. Tesla thinks that only two frequencies would usually be enough, the system admits of considerable multiplicates. Moreover, it may be taken for granted that the mechanism used would admit of a quick alteration of the selected frequencies, like that of the numbers of a combination for a bank safe lock.

Another advantage may result from this invention besides that of secrecy. It may avert mischievous interference. Some years ago, when preparations had been made for reporting the international yacht races off Sandy Hook, the following incident occurred: A press boat went down the Bay, a day or two in advance, to test its apparatus, and began sending messages to land. Persons on another boat, with similar apparatus, sent out signals at the same moment. In consequence, there was a confusing jumble of letters at the receiving station. One message overlapped the other. A few weeks ago, while Dr. Fleming was giving a lecture in London to prove how beautifully the Marconi "tuning" system worked, Nevil Maskelyne sent in "Rats!" and other inappropriate remarks from a point outside, and the speaker's instruments recorded them, much to his embarrassment.

Only last week Dr. Slaby, the author of one of the German systems of wireless telegraphy, openly avowed his belief in the propriety of interfering with the receipt of Marconi messages in England by sending out a continuous stream of signals with a powerful transmitter on the German coast. Finally, it is interesting to speculate for about ten seconds as to what would happen at Cape Cod if, while Marconi was trying to send thither from Poldhu, Mr. Tesla were to start up his generators at Wardencliffe. The South Wellfleet receiving operator's hair would probably turn gray with perplexity in the effort to decipher the communications that actuated his instruments.

Quite aside from the morality of such conduct (which might depend on circumstances not known to the public), it seems to be entirely feasible. Apparently, too, a receiver which has been adjusted to respond to Mr. Tesla's combination would be immune against any amount of outside interference. Time only can tell the full value of his latest patents, but an unprejudiced judge can easily see immense possibilities in the idea.

[29.]—**Tesla Coil.**—You will find full directions for making these in my book "Electrical Instrument Making for Amateurs." I know of no book treating of the experiments that can be made with the Tesla, and, in fact, nearly everything that requires high tension can be performed by its aid.

S. BOTTONE.

[29.]—**Tesla Coil.**—Rather a large order for limited space. Experiments can be found in a few up-to-date electrical handbooks, and in a great many of the illustrated science papers.

ELECTROMETER.

Wire for Small Tesla Coil.

To the Editor of *The Model Engineer*.

Dear Sir,—With reference to my former query *re* rubber-covered wire (Reply No. 9,320) for Tesla coil, mentioned at page 515 of The Model Engineer, dated May 28th, I am pleased to say Mr. Pike (the writer of the article) has written to me direct explaining that the primary is built of No. 22 gutta-percha covered wire, and not as stated in the article, and that this can now be obtained from Whitney's.

Mr. Pike was kind enough to send me sufficient of the wire for the coil I am making, and I had sat down to write and thank him for it, when I discovered that he had not sent his address. May I ask, therefore, that you will be good enough to convey to Mr. Pike, in your next issue, if possible, my thanks for his courtesy in writing and sending me the wire. I have no doubt this will also interest your readers, as Whitney's informed me they had several enquiries regarding the same.—Yours faithfully,

Southsea. W. Hack.

The New York Herald September 12, 1903

VICTORY FOR TESLA IN COURT DECISION

He Is Credited with First Obtaining Idea of Utilizing Split-Phase Currents.

IN USE ON SMALL MOTORS

Opinion Given Is in Suit of the Westinghouse Against the Sangamo Electric Company.

Judge Archibald, of the United States Circuit Court of the Eastern District of Pennsylvania, has given an important decision in favor of the Westinghouse Electric and Manufacturing Company in a suit against the Sangamo Electric Company. The decision declares that Nicola Tesla invented the split-phase alternating currents prior to the discovery of the same thing by an Italian electrician named Farraris.

The ownership of the split-phase patents is regarded by electricians as very important. The most successful small motors now use this current. Nearly all fan motors are run by it.

The decision covers about fifty pages of typewritten matter and shows that from the evidence produced Tesla announced his discovery in the latter part of 1887, while Farraris did not make known the result of his investigations until April 22, 1888.

Counsel for the Westinghouse Company said yesterday that the Tesla patents had been recognized generally up to the present and that probably no infringement suits would follow.

The Tesla effect, so called, is the production of a whirling or rotating magnetic force by means of two alternating currents out of phase with each other.

In his fundamental patents Tesla produced these out of phase currents at the generator and transmitted them over three wires to the motor, where they were used to produce the rotating or "Tesla field."

In the split-phase patents he generated a single phase current and transmitted it as a single phase current, and then at or near the motor derived from it the second or out of phase current, which, in conjunction with the transmitted current, is used for producing the same class of rotating field in the motor.

Farraris' invention was along similar lines.

Important Decision on Tesla Split-Phase Patents.

Judge Archbold, in the United States Circuit Court, Eastern District of Pennsylvania, has just handed down a decision in the suit of the Westinghouse Electric and Manufacturing Company *vs.* H. C. Roberts and the Sangamo Electric Company, which has an important bearing on alternating-current meters and fan motors. The suit was under the so-called Tesla split-phase patents. The defendants' device against which suit was brought was the Sangamo electric meter. The Court, after a careful review of the testimony, decided that the complainant had proved satisfactorily that Tesla's date of invention preceded that of Ferraris's and others, and that the device in question was an infringement.

The importance of these patents is great, as some of the most successful alternating-current meters and motors of small size are tributary to them.

The following is an abstract of Judge Archbold's review of the testimony:

The patents in suit and those on which they are based, or which are kindred to them, have been so fully considered in previous cases which until recently have also been uniformly in their favor, that little is left to be brought forward with regard to them.

The deriyitive patents in suit, numbers 511,559 and 511,560, were first considered in the Dayton fan and motor case, 106 Fed. 724; affirmed in 118 Fed. 562, and a decision rendered in substantial accord with those which had preceded it. One defence there, as here attempted to be made, was that it involved no inventive skill when once the practicable use of alternating currents of different phase was established, to substitute the dephased split current which was a well recognized equivalent; but it was not so held, nor can it be here.

The patents in suit were also before Judge Lacombe in the Westinghouse Electric and Manufacturing Company *vs.* the Catskill Illuminating and Power Company, 110 Fed. 377. In addition to the attack made upon them in other cases, it was further urged that, in a paper read by Professor Ferraris before the Royal Academy of Sciences, of Turin, Italy, March 18, 1888, a portion of which was published on April 22 following, at Milan, in *L'Elettricita,* not only was there a full disclosure of the transmission of electric power by means of alternating currents of different phase, but also the use for the same purpose of a dephased split current derived from a single source, the same as in the patents in suit. Upon a due consideration of the opposing proofs the invention of Tesla was held to be carried back of this publication; but on appeal, the decision was reversed, the evidence brought forward by the complainants not being considered sufficient for that purpose; 121 Fed. 831; a conclusion which was followed by Judge Colt in a case by the same plaintiffs against the Stanley Instrument Company, in the first circuit, not yet in print. This, and the matter of infringement, are the overshadowing questions in the present case.

The Ferraris publication, as we have seen, was April 22, 1888, and the patents in suits were not applied for until December 8 following. To relieve from this apparent priority the invention has, therefore, to be carried back of the earlier date by competent and convincing evidence. That Tesla, early in May, 1888, had a complete grasp of the split-phase idea is established by his application of May 15 for patents, Nos. 511,915 and 555,190, which embody it, the same that were before Judge McPherson in the Scott & Janney case 97 Fed. 582, already alluded to. This is important evidence which can not be contradicted and I, therefore, start with it. Not only is the invention beyond question carried back by it to the date named, which is within twenty-three days of the Ferraris publication, but from the known order of events, a patent not being able to be worked out in a day, ground is thus persuasively laid for an earlier date if there is any fair evidence to warrant it. In the face of it, I hardly see how we can doubt the accuracy of Mr. Page's statement that Tesla disclosed to him the principles of the invention somewhere in the first part of April of that year. His testimony on this point is specific and convincing. In the fall of 1887 and spring of 1888, as he says, he was engaged in developing in the Patent Office a number of Tesla's inventions, and among them the polyphase motors and transformers which were patented May 1, 1888. These were prosecuted to an allowance in the early part of April, the final fees, as shown by the books of the firm of which he was a member, having been forwarded to Washington on April 6. After having secured the allowance of this group and made arrangements for similar applications in a number of foreign countries for patent to issue simultaneously therewith, Tesla gave him the material for application one feature of which was the inducing of one current from another in the operation or construction of a motor, and in this connection disclosed to him his plan for operating his polyphase motors by means of a single split-phase circuit. Startled by this revelation and questioning whether the claims which he had drawn in the pending cases would protect this new improvement he had a long conference with Tesla, getting from him all that he could as to the different ways he proposed to operate this two-wire system. It seems to me convincingly established that prior to April 22 the date of the Ferraris publication, Tesla had disclosed to Mr. Page, his solicitor, the principle of his split-phase adaptation.

But the testimony of Mr. Page is by no means all there is upon this subject. Mr. A. S. Brown formerly connected with the Western Union Telegraph Company, became interested in the summer or fall of 1887 in bringing out the original Tesla motor; and he testifies that once when it was first brought to his notice it occurred to him as a great objection that it required two separate currents; not long after which Tesla showed him how it could be operated on a single main line from the generator.

So far as I have considered only the proofs, about which no question can be raised, and basing my decision solely upon them, I am satisfied that the patents should be sustained.

The question of infringement still remains. At the time suit was brought, the defendant, Roberts, was engaged at Philadelphia in the sale of Gutmann recording wattmeters, as agent for the Sangamo Electric Company, of Springfield, Ill., by whom they were made.

It is contended that a meter is not a motor, and that on this ground of itself no infringement can be charged. No doubt the strict object of a meter of this class is to measure and record the element which passes through or actuates it, gas, water, the electric current, or whatever it may be; but where, as here, it is, in mechanical construction, nothing more than an adopted motor with meter attachments, it can not escape infringement on that plea.

The Tesla motor as an invention, was first in its own peculiar field, and is entitled in consequence to a liberal application of the doctrine of equivalents, and of the substantial equivalency of the defendants' device I am fully convinced. The significant thing in each is the conjoint or resultant action of the two opposite sets of poles, the magnetic influence, whether of attraction or repulsion, waxing and waning, and shifting progressively about the armature, of the existence of which there can be little doubt. It is persuasive of the equivalency of operation which is so contended for, although by no means conclusive of it, in a patent applied for by Tesla May 20, and granted December 3, 1889, this equivalency is assumed without explanation as being within the terms of the invention. Other confirmations of the equivalency of the two arrangements with that of a Tesla motor, as well as with each other, could be drawn from this record, but these must suffice. They establish to my satisfaction the general infringing character of the defendants' meter as is charged.

Finding therefore that the patents in suit are valid and have been infringed, a decree is directed in favor of the complainants in the usual form, with costs.

Tesla Split-Phase Patent Sustained.

Judge Archbold, of the United States Circuit Court for the Eastern District of Pennsylvania, has handed down a decision in a case involving the Gutmann wattmeter, which sustains the fundamental Tesla split-phase patent. The principal defense was a publication by Ferraris in 1888 on the rotary field and of the means for obtaining polyphase from single-phase currents. These disclosures were made in a paper read by Prof. Ferraris before the Royal Academy of Sciences of Turin, Italy, in March, 1888, a portion of which was published on April 22 following, in *L'Elettricita.* The Tesla patents in suit were not applied for until December 8 following, but the court held that the testimony in the case showed conclusively that Tesla had, early in May, 1888, a complete grasp of the split-phase idea; and not only is the invention beyond question carried back by it to that period, but the patent not being able to be worked out in a day, ground is thus laid for an earlier date if there is fair evidence to warrant it. The court holds there is such evidence, testimony showing that Tesla disclosed the principles of his invention at a date prior to April 22 to his patent solicitor, the date being somewhere between the 8th and the 18th of April. This evidence is supported also by the testimony of a former business associate of Mr. Tesla, who states that Tesla spoke to him of the idea in the summer or fall of 1887. The date claimed by Tesla of his discovery was September, 1887.

After reviewing at great length the testimony as to priority between Ferraris and Tesla, and deciding in favor of the latter, the court considered at equal length the question of infringement of the Tesla split-phase patent by the Gutmann meter. Its conclusion is that the construction of the meter is in effect a motor in which the armature is operated upon by two independent interconnecting circuits produced by passing through them a divided and dephased alternating current derived from a single source, this apparently realizing the patents in suit. After further consideration of the principles of the meter in suit, the court decided that the meter infringed the Tesla patent. The finding is that the patents in suit are valid and have been infringed.

An interesting portion of Judge Archbold's opinion is that in which he gives a history to date of the opinions rendered in suits involving the Tesla split-phase patents. Judge Townsend, in reviewing the fundamental patents, discussed the alleged disclosures of Siemens, 1878; Bailey, 1879; Deprez, 1889, 1884, and Bradley, 1887, and the claims advanced for them as anticipations, which he held to be unfounded, and these conclusions were affirmed on appeal. The essence of the invention was declared by Judge Townsend to be "the production of a continuously-rotating or whirling field of magnetic forces for power purposes by generating two or more displaced or differing phases of the alternating current, transmitting such phases with their independence preserved to the motor, and utilizing the displaced phases as such therein."

The same patents came up before Justice Brown and a similar result was reached. The Dumesnil (1884) and the Cabanellas (1885), two French patents, which had not been brought forward before, were particularly relied on as anticipations, but were distinguished from those in suit in a carefully-expressed and convincing opinion. These French patents, however, according to Judge Brown, established that Tesla was not the first to employ alternating currents out of phase with each other for power purposes, so that the expressions in previous cases which attributed this to him would have, as he thought, to be qualified if not recalled. But it was at the same time pointed out that in neither the Dumesnil nor the Cabanellas was there a resultant magnetic force, the distinctive feature of the Tesla invention; each of the others named providing for the independent action of separate alternating currents operating on different ends of the motor armature without any play of the magnetic and electric forces in between. "As it stands, the Cabanellas patent is unintelligible to me, but taking it as it is explained by the defendant's experts and illustrated by the exhibit in evidence (of the correctness of which, however, I have much doubt), there is nothing more at the best than a mechanical combination of the two operative devices like the opposite cranks on the same axis of a locomotive driving wheel. There is no conjoint operation as in a Tesla motor of the two energizing circuits by means of a combined magnetic influence to produce a common result. It is important, however, to observe that while in no sense anticipations, the Dumesnil and Cabanellas serve to limit the invention of Tesla—if not, indeed, so limited in his patents themselves—to a device in which a magnetic resultant of dephased alternating currents exist, the mere use of alternating currents out of phase with each other made otherwise effective being something aside and different."

The derivative patents in suit were first considered in the Dayton Fan & Motor case and affirmed, and a decision rendered in substantial accord with those which had preceded it. One defense there, as in the present suit, attempted to be made, was that it involved no inventive skill when once the practicable use of alternating currents of different phase was established, to substitute the dephased split current which was a well recognized equivalent; but it was not so held, nor could it be in the present case. This question was practically put at rest in this court by the decision of Judge McPherson in a case where two of the earliest Tesla split-phase patents were sustained. But aside from that, and upon an entirely independent consideration of it, Judge Archbold says the same conclusion must be reached.

The patents in suit were also before Judge Lacombe, and in addition to the attack made upon them in other cases, it was further urged that, in the paper read by Prof. Ferraris before the Royal Academy of Sciences, of Turin, Italy, March 18, 1888, a portion of which was published on April 22 following, at Milan, in *L'Elettricita,* a journal devoted to electrical subjects, not only was there a full disclosure of the transmission of electric power by means of alternating currents of different phase, but also the use for the same purpose of a dephased split current derived from a single source, the same as in the patents in suit. Upon a due consideration of the opposing proofs, the invention of Tesla was held to be carried back of this publication; but on appeal the decision was reversed, the evidence brought forward by the complainants not being considered sufficient for that purpose; a conclusion which was followed by Judge Colt in a case by the same plaintiffs against the Stanley Instrument Company, in the First Circuit, not yet in print. This, said Judge Archbold, in concluding his review, and the matter of infringement, are the overshadowing questions in the present case.

Discussing the contention that a meter is not a motor, and that on this ground of itself no infringement can be charged, Judge Archbold said that, as pointed out by Judge Lacombe in the Catskill case, while the Tesla patents contemplate the production of power, they are silent as to the amount of it; and as a meter armature rotates against the action of a permanent magnet and turns a spindle which operates the registering devices, the production of some power is necessarily involved. It is somewhat aside from the question, but still it is a circumstance that Gutmann himself, in accordance with whose patents the meters in question are constructed, recognizes and claims therein that this device may be used for power purposes also. No doubt the strict object of a meter of this class is to measure and record the element which passes through or actuates it, gas, water, the electric current, or whatever it may be; but where, as here, it is, in mechanical construction, nothing more than an adapted motor with meter attachments, it cannot escape infringement on the plea. Judge Archbold holds that there is nothing in conflict with this, when rightly considered, in what is said in an opinion cited relating to a water meter. The attempt there made was to defeat a special safety appliance of a water meter by references drawn from the general motor art, and it was in that connection that it was held that the two were not the same.

Tesla Split-phase Patents Upheld.

Judge Archbald of the United States Circuit Court for the Eastern District of Pennsylvania has just handed down a decision in the suit of the Westinghouse Electric and Manufacturing Company against H. C. Roberts and the Sangamo Electric Company, which may have an important bearing upon alternating-current meters and fan motors. The suit was under the so-called Tesla split-phase patents. The defendants' device against which suit was brought was a meter formerly made by the Sangamo Electric Company, but the manufacture of which was discontinued about two years ago. The court, after a careful review of the testimony, decided that the complainant had satisfactorily proved that Tesla's date of invention preceded that of Farraris' and others, and that the device in question was an infringement. Evidence was adduced by the Westinghouse Electric and Manufacturing Company showing that Tesla's date of invention was several months prior to the Farraris' publication.

On the part of the Westinghouse company it is declared that "the importance of these patents can scarcely be over-estimated as the most successful alternating-current meters and motors of small size are tributary to them."

For the defendants an appeal will be taken from Judge Archbald's decision to the United States Circuit Court of Appeals for the Third Circuit.

The New York Herald October 9, 1903

MR. TESLA PRAISES PROFESSOR LANGLEY

To the Editor of the Herald:—

I cannot refrain from protesting against the most ungenerous comments in this morning's papers on Professor Langley's efforts. Professor Manly's tests, in view of the great difficulties attending them, should have received more appreciation.

The atmosphere is a capricious medium, and as regards air navigation we are still in a barbarous state of ignorance. Professor Langley undertook many years ago task which has baffled human ingenuity and skill for centuries. He had nothing to go by—not even a theory, let alone practical data.

After long and patient labor, requiring the exercise of the rarest faculties, he finally perceived a great truth, which he announced—the secret of the bird's sailing flight. He recognized that a machine heavier than air could be made to fly provided its mechanism be controlled intelligently and that advantage be taken of the energy of the air currents. Had he accomplished nothing else, this would be enough.

But Professor Langley did not stop at this. He concentrated his efforts toward embodying these principles in a mechanical model. Years were naturally consumed in these endeavors. Experiments are expensive. We are told that he has expended $50,000 in these trials. This is what the public is made to believe.

But those who have had experience know that he not only has spent this sum, but has in all probability exhausted all his own resources.

The reflections made in the papers regarding the expenditure of this paltry sum contributed by the government are not only not justified, but ridiculous in the extreme.

Professor Langley has grasped more thoroughly the problam of aerial navigation than any other man on this globe. There are many skilled mechanics who are lacking in scientific knowledge, there are many scientific men who do not possess sufficient mechanical skill; Professor Langley has both.

His success does not depend on chance. Such a man should be provided with the necessary means to complete his work immediately. Great honor attaches to this achievement, also great practical utility, which this country can ill afford to lose.

New York, Oct. 8, 1903. N. TESLA.

The Colorado Springs Gazette October 30, 1903

TESLA PLANNING TO COME HERE

WATER COMMISSIONER RECEIVES INFORMATION THAT SCIENTIST WILL SOON ARRIVE IN COLORADO SPRINGS.

Water Commissioner E. W. Davis has received information to the effect that Nicola Tesla, the celebrated electrical experimentist and inventor will be in Colorado Springs within a few weeks.

The experiment station erected by Mr. Tesla on Knob hill about two years ago, is still in as good condition as it was when he left it, and if he comes here no may decide to conduct further experiments. The station here has been in charge of two watchmen ever since Mr. Tesla returned to the east and everything has been kept in perfect trim ready for his return.

The station here was used by Mr. Tesla in his wireless telegraphy experiments.

The New York Times Novermber 24, 1903

HOLDS TESLA'S PATENTS GOOD.

Validity of Devices Passed on by an Ohio Judge.

Special to The New York Times.

CINCINNATI, Nov. 23.—The validity of two patents granted to Nicola Tesla, the famous electrical inventor, was under consideration before Judge Thompson of the United States District Court to-day. He held that both patents were good, and are the property of the Westinghouse Electrical and Manufacturing Company of Pittsburg.

One is for the electrical transmission of power, and the second is a method of operating motors.

The Westinghouse Company in 1901 brought suit against the Dayton (Ohio) Fan and Motor Company, asking that it be restrained from manufacturing these appliances, and that damages be granted the Westinghouse people for the injury sustained by the manufacture of these devices by the Dayton Company.

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GEORGE WESTINGHOUSE

Response to a Toast at the Dinner in Connection with the Annual Meeting of the District Managers of the Westinghouse Electric and Manufacturing Company at the Duquesne Club, Pittsburg, December 3, 1903.

By Frank H. Taylor, Vice-President

GEORGE WESTINGHOUSE:

Mechanic; Friend of Labor;
Inventor; Tireless Organizer;
Financier; Founder of Enduring Industries.

What all the world knows needs only to be mentioned to you who are his associates in business:

The revolution in railroading wrought by the developed air brake;

The foresight that recognized the importance of the discovery of natural gas in the Pittsburg district and controlled its development;

The resourcefulness and ingenuity which won the great victory at the World's Fair in Chicago;

The courage that triumphed over the difficulties of a financial crisis;

The power that has led the unparalleled increase in the Westinghouse industries which, started but a few years ago, are now appalling in their size and extent;

The executive ability that has been the controlling factor in these interests, so numerous that no one here in an hour's time could write out a complete list of them.

These interests have grown so large and the number of responsible officers has become so great that Mr. Westinghouse is not as intimately known to you as I should desire, and as I am sure he himself would desire, if it were possible.

Some of the peculiarities which have aided him to acquire his present position may be illustrated. For example, it is unusual for an inventive genius to be so perfectly open-minded to the inventions of others. I sometimes think he is as happy over the discoveries of other minds as though they were his own. He has found a means for the development of new inventions all his life. Great intellects have worked for him, been encouraged and protected by him. I names at random: Shallenberger, Tesla, Scott, Parsons, Nernst, Ruud, Cooper Hewitt, Thomas, Davis, Bremer, Lamme, Wurts, Lange.

His mind is constantly reaching out into the future, and after one has been much with him it becomes practically impossible to live altogether in the present, because there is brought to view at every turn possibilities of new things yet undeveloped which are to serve future generations at a time when the world has advanced far beyond its present stage. The imagination is constantly stimulated and interest kept alive by the new principle that is struggling on towards definite shape.

There is always present the evidence of good will toward every one; a quick appreciation of the good points of other people. In the course of his life he has been forsaken by friends who lacked courage to follow him, and in its main crisis he was greatly hampered by heart-breaking incidents of this kind. Yet no one has ever heard him say an unkind word of these men. His foresight is phenomenal. The industries in this country have grown up even faster than seemed wise to a great many who were associated with him. They did not see the value of what he was doing as clearly as he saw it, and time alone has justified the thoroughness with which plans have been laid, buildings designed and executed. Energy and expense have not been spared upon any of his works. They have been developed in such a way that they can be extended forever.

No sooner had provision been made for this country than many of his closest friends were startled by a move upon Europe and the markets of the world. Some men have charged this move to a mere ambition to plant his name in Europe. They wondered that he should tax his resources and take upon himself the tremendous strain which has finally resulted in the great organizations and plants in England, France, Russia and Germany.

The associates who questioned his wisdom did not have his foresight and did not see that these things were necessary for the

protection of the initial developments in the United States. I give no importance to my own judgment in this matter, but Mr. Westinghouse knew that the foundations here would have been insecure had not the foreign field been entered during his period of maximum activity. We shall live to see all the effort justified, and the Westinghouse interests the world over fitting together and helping one another.

After all, what is the ultimate aim of it? Men work for wealth, for social position, for the esteem of professional associates, for the applause of the world. These things may be nominated ambition and of that all men must plead guilty.

In the case of Mr. Westinghouse the aim is not immediate wealth. He has done his work too thoroughly to have that as his goal. From my closer observation of him I should determine that he meant to leave a monument upon the earth that shall be strong enough to stand alone without consolidation with other interests, and that shall bear his name for a hundred years. Napoleon's words to his brother when he was made ruler of Spain were: "My one word of advice to you—be master," and I anticipate that the Westinghouse interests will be master of anything they associate with during the next century. By that time the appreciation of what Mr. Westinghouse has done for the world will be clearer and more just than it is to-day.

Great men cannot be compared one with another. They are moulded by circumstances and no two are alike any more than two great trees are alike, yet no man is great who lacks certain essential qualities: First, he must at all times be just, and in the case before us this quality has prevailed. A great nature shows itself by being kind and considerate. The underlying sweetness of his spirit is illustrated by the watchword that he uses among all his interests—a constant repetition of a plea for harmonious action. Other virtues are shown by the cleanness of his life. You who have, at times, worked for other kinds of men must know the power that comes to those who work for a clean man, and one who demands soundness of thought and expression. He is never satisfied with surface appearances, but seems to look right through to the heart. His mind is so quick that he sees the essential point in a complicated situation even before the story can be fully told to him. Once determined upon his course, he is not to be laughed out of it, frightened out of it, nor bought off.

The boundless hospitality of his home has been often mentioned, but when one has had the opportunity repeatedly of seeing him there, he is impressed with the uniform cheerfulness of the man and of his sustained interest in every detail of household life. I saw somewhere a letter from a wife written upon the birthday of her middle-aged husband. In the letter this sentence appeared: "To me, you will always be my young lover." This one sentence defines Mr. Westinghouse in his home.

To one associated with him in business, it has often seemed that to be loved of the man is an aim worthy of a life of devotion to his interests.

I have referred to the fact that all men have their ambitions. Every one here is anxious for a broader field, and I am sure will attain to it. Yet every one of us has arrived at an age when we can make a fairly good estimate of our probable attainments. This is our annual dinner and it is a good time to take account of stock. My judgment is that there is in our organization an opportunity for every man to be satisfied. For myself, first of all, I want a conscience void of offense. Next, I want to leave some record in the world for my family. I should like to be remembered as one who has accomplished something. I, too, want to leave a monument. My ambition is not for popularity, nor for fortune. I am satisfied if I leave my children the inheritance that their father had been able to catch something of the spirit of a great leader, and that he had been somehow useful in perfecting that leader's work and in developing his plans. For me it shall be enough that I served under George Westinghouse; that I was accounted one of his efficient lieutenants.

The Annual Dinner of the American Institute of Electrical Engineers.

The annual dinner of the American Institute of Electrical Engineers will be held in the main ball room of the Waldorf-Astoria, New York City, Thursday, February 11, 1904, at 7 P.M., precisely. The guest of honor will be Mr. Thomas Alva Edison, and it is expected that an opportunity will be given to meet Mr. Edison at an informal reception, at half-past 6. This dinner will commemorate the twenty-fifth anniversary of the introduction of the incandescent lamp, and will also celebrate Mr. Edison's birthday. Upon this occasion will also be presented the deed of gift of the Edison Medal Association, which has raised a fund of several thousand dollars.

The following guests have accepted invitations: Mr. Ambrose Swasey, president American Society of Mechanical Engineers; Dr. A. R. Ledoux, president American Institute of Mining Engineers; Col. Robert Clowry, president Western Union Telegraph Company; Mr. George G. Ward, vice-president and manager Commercial Cable Company; Mr. W. H. Baker, vice-president Postal Telegraph Cable Company; Mr. John Fritz, founder Bethlehem Steel & Iron Works; Mr. W. H. Fletcher, president Engineers' Club; Mr. A. B. Chandler, president Postal Telegraph-Cable Company.

Autographed souvenir menus have been prepared containing a colored photogravure of Mr. Edison and two original poems prepared by Mr. R. R. Bowker. The exercises will be as follows: Salutatory address by President B. J. Arnold; presentation of the medal fund and deed of gift by Mr. Samuel Insull, chairman of the Edison Medal Association; acceptance of same on behalf of the Institute by Dr. A. E. Kennelly, of Harvard University, past president; address on behalf of the colleges and universities by Prof. Cyrus F. Brackett, of Princeton University; address on behalf of the Association of Edison Illuminating Companies by President J. B. McCall; address on behalf of the National Electric Light Association by President Charles L. Edgar.

Mr. Edison has flatly declined to speak, but in response to the toast in his honor has agreed to send from the table a telegraphic acknowledgment. It is a great many years since he used the key. He will use one of the original quad sets built by him for, and loaned by the Western Union Telegraph Company. The message will be received in the banquet hall on a Postal quad of latest date by President A. B. Chandler, of the Postal Telegraph Cable Company, and will then be read to the audience. These arrangements are in the hands of Mr. C. P. Bruch, assistant general manager of the Postal system, and Mr. J. C. Barclay, chief engineer of the Western Union system. A number of special cable messages and telegrams will also be received at the same time.

The seating arrangements provide for the accommodation of eight persons at each table. Orders for seats should be sent in at once and should be accompanied by cash or check, payable to Mr. Ralph W. Pope, secretary. Price of tickets, without wine: Gentlemen, $7; ladies, $5; admission to galleries, $1. In order to secure accommodation, responses should reach Mr. Pope not later than February 9, 1904, 95 Liberty Street, New York. Mr. Arthur Williams, chairman of the committee on decorations, has made elaborate preparations for ornamenting and illuminating the ball room, and the effect will be very pretty and appropriate.

A Striking Tesla Manifesto.

We reproduce herewith in slightly reduced fac-simile the first page of a four-page circular which has been issued this week by Mr. Nikola Tesla in a large square envelope bearing a large red wax seal with the initials, "N. T." At the back of the page which we reproduce is given a list of 93 patents issued in this country to Mr. Tesla. The fourth page is blank. The third page has a little vignette of Niagara Falls and is devoted to quotations from various utterances of Mr. Tesla. The first of these is from his lecture delivered in 1893 before the Franklin Institute and the National Electric Light Association, as to transmission of intelligible signals and power to any distance without the use of wires. The second quotation is from his article on the problem of increasing human energy, which appeared in the *Century Magazine* in June, 1900, dealing with virtually the same subject. The third item quotes from his patents, Nos. 645,576 and 649,621, dealing with the transmission of electrical energy in any quantity to any distance, with transmitting and receiving apparatus movable as in ships or balloons. The circular is an extremely interesting one. It is most sumptuously got up on vellum paper and altogether constitutes a manifesto worthy of the original genius issuing it. It is to be gathered from the circular that Mr. Tesla proposes to enter the field of consulting engineership, in which he already has enjoyed an extensive connection here and abroad.

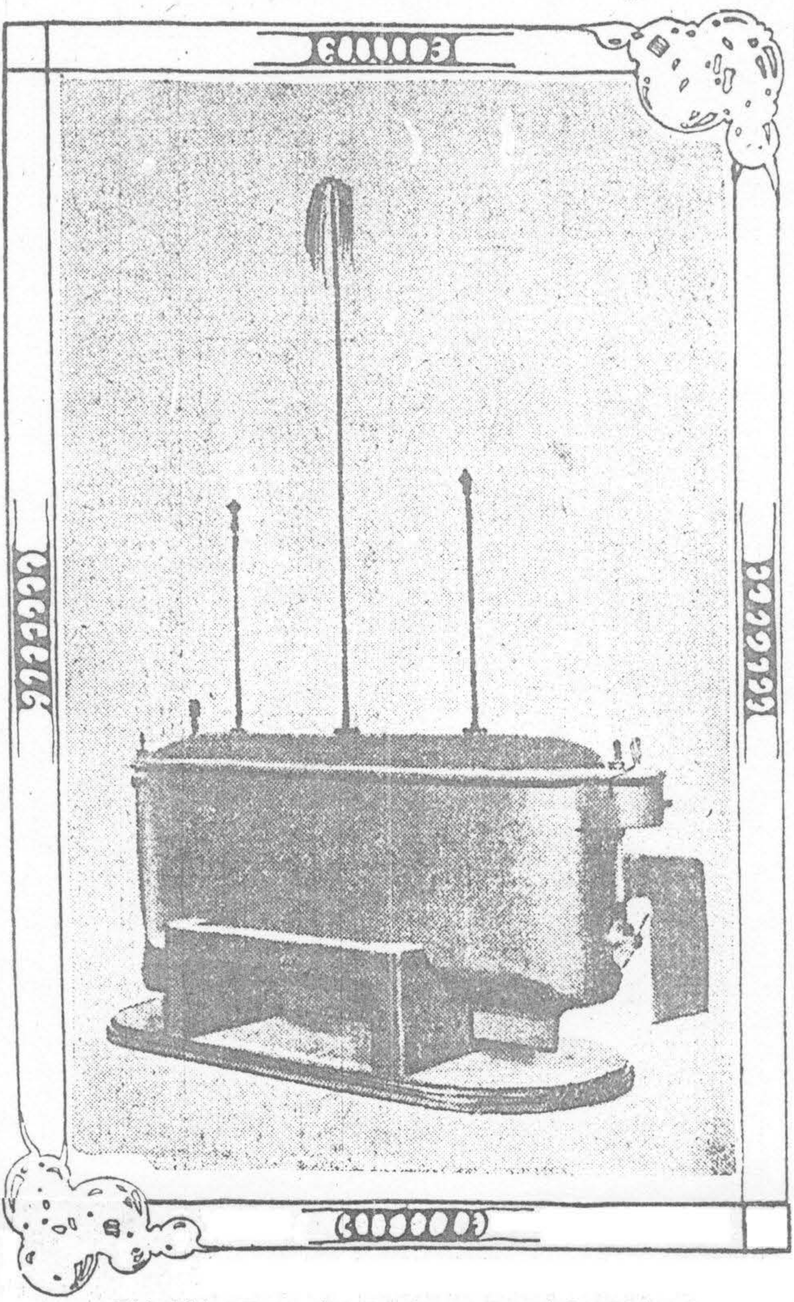


PAGE FROM CIRCULAR SHOWING TESLA TOWER, WARDENCLIFFE, LONG ISLAND.

The New York Journal And American February 13, 1904

DID JAPANESE USE WIRELESS TORPEDO?

Tesla Says He Gave the Details of His Invention to the Mikado's Men Three Years Ago.



Did This Torpedo Destroy Russia's Ships?

Photograph of a torpedo invented by Nicola Tesla in accordance with a principle discovered by him. It contains automatic propelling machinery and can be set free under the water and directed by wireless electrical waves in any direction and to any distance.

Reports of Japanese victories have hinted at the use against Russian battleships of a mysterious, wireless, dirigible torpedo. Such a craft was invented four years ago by Nicola Tesla, of this city, the principle of it being his own discovery. Mr. Tesla and Lewis Nixon are now perfecting the machine. Mr. Tesla was asked yesterday by an "AMERICAN" reporter whether it could be that Japan had destroyed the Russian ships with his torpedo. He answered that while he had no information on the point, it was quite likely.

"I took out no patents in Japan," said he. "Of course, the Japanese are extremely skillful people, and the fact is that several officials of their Government and a number of scientific men visited me three years ago, and to these I gave the most complete information on all the patents. I gave to one of their men copies of my patents also.

"It would not surprise me if by this time they had succeeded in producing models of my automaton. Naturally, they would be more or less crude, but even if so they would be sufficient to accomplish their purpose.

Mr. Tesla's machine is not a mere engine of war, nor need it be used in the water exclusively. He can, with his apparatus, send an automobile overland on missions of war or peace, for pleasure or business. His idea in putting forward the machine as an implement of war is to make war bloodless by making its possibilities so terrible that all battles will be between mere automatic machines.

After a battle is fought between these machines, the nation deprived of its automatons will be forced to surrender because it will be so absolutely defenceless. It would be madness for it to attempt further resistance.

"I attained the result aimed at," says Mr. Tesla, "by means of an electric circuit placed within the boat, and adjusted, or 'tuned,' exactly to electrical vibrations of the proper kind transmitted to it from a distant 'electrical oscillator.' This circuit, in responding, however feebly, to the transmitted vibrations, affected magnets and other contrivances, through which were controlled the movements of the propeller and rudder, and also the operations of numerous other appliances.

"By the simple means described, the knowledge, experience and judgment—the mind, so to speak—of the distant operator were embodied in that machine, which was thus enabled to perform all its operations with reason and intelligence. It behaved just like a blindfolded person obeying directions received through the ear."

Mr. Tesla and Mr. Nixon are waiting with intense impatience to hear certain news that the Tesla torpedo is being used by the Japanese. No other nation has the machine, and if it prove that Japan has perfected the terrible engine it practically makes her master of the sea, for no navy, however powerful in units or numbers, could hope to escape complete destruction with these submarine monsters directed against it.

Injunction on Tesla Patents Denied.

Judge Seaman of Milwaukee has decided the motion for injunction made under Tesla patents Nos. 381,968, 381,969, 382,280 and 382,281, which are the Tesla polyphase patents. The suit was brought against the National Electric Company of Milwaukee, and the device involved was that company's polyphase-synchronous motor. Judge Seaman found that the complainant has not made out such a case of infringement as is required in a matter of this kind. The case was argued on January 6th and 7th by Thomas B. Kerr and Parker W. Page for the Westinghouse Electric and Manufacturing Company, complainant, and E. H. Bottum and Charles A. Brown for the defendant. This is the first adverse decision that has been rendered upon the broad Tesla patents involved in this suit.

Tesla Patent Decision.

Judge Seaman of the United States Circuit Court of the Eastern District of Wisconsin, has handed down a decision on a motion for a preliminary injunction against the National Electric Company, applied for on the grounds that a polyphase synchronous motor manufactured by that company infringed four Tesla patents granted May 1, 1888, two of these being fundamental patents and two on specific means. The injunction was denied on the grounds that previous decisions sustaining Tesla patents did not pass upon the question whether they also covered polyphase synchronous motors.

Judge Seaman discussed the several opinions sustaining Tesla patents, beginning with that of the New England Granite Company case, and concluded that the terms of these only apply to polyphase non-synchronous motors. The sweeping opinion in the New England Granite Company case he considers must be treated as modified by subsequent opinions, and he quotes Judge Brown to the effect that Tesla discovery was not broadly the use of alternating currents of different phase with an ultimate object of rotating any shaft. No case involving the use of a motor operated in synchronism has been brought to final hearing, though such use constantly appeared, while litigation was vigorously prosecuted against non-synchronous infringements—one instance being that of the continuous manufacture of synchronous motors by a defendant, who was under injunction against infringement by a non-synchronous motor in suit and this without interference until lately. The question of infringement in the present case under the fundamental facts depends upon the scope of the invention and involves a broader construction than was involved in any other prior cases, and consequently the court denied the motion for preliminary injunction.

Tesla Patents.

Judge Seaman of Milwaukee, in his decision adverse to the Westinghouse Electric and Manufacturing Company in its case against the National Electric Company asking for a preliminary injunction under a bill alleging an infringement of the Tesla patents for electrical transmission of power and for specific motors, gives the first adverse ruling on the Tesla patents. The patents in the suit are Nos. 381,968 and 382,280 for the fundamental invention, and Nos. 381,969 and 382,281 for specific means. A report of the ruling in this case was published in the Western Electrician of February 13th, but the following abstract of Judge Seaman's opinion will be of interest:

"The fundamental patents (so called) have been upheld and the scope of invention therein passed upon in several cases. They were directly involved in the New England Granite Company case in the Second Circuit, and the decree on final hearing (103 Fed., 951) was affirmed (110 Fed., 753) on appeal; both opinions are instructive, and in respect of the validity of the patents at least are deemed controlling for the purposes of this motion. Upon application for a preliminary injunction in Royal Weaving Company case, in the Rhode Island district (115 Fed., 733), the French patents of Dumesnil and Cabanellas (which were not before the courts in the first-mentioned case) were introduced, and are well considered and distinguished from the invention in suit in the opinion of Judge Brown granting an injunction. In the case against H. C. Roberts and Sangamo Electric Company, in the Eastern District of Pennsylvania, subordinate patents were involved, but Judge Archibald reviews the question of fundamental invention in an excellent opinion upon final hearing.

"The present application is governed by the settled rule in this circuit, which entitles the complainant to the benefit of these adjudications by way of presumptive right to an injunction against other infringers of the patents so upheld when the infringement is undoubted. Such rule, however, excludes the specific patents (Nos. 381,969 and 382,281) from consideration in so far as the issue of infringement rests upon the devices there shown, for the reason that neither adjudication of their validity, no public acquiescence therein, as demanded by the rule, appears in evidence. The presentation of these derivative patents in the bill does not aid the motion for preliminary injunction under the rule referred to, whatever may prove to be their bearing upon the issue of infringement at final hearing, but infringement for the purposes of the motion must be tested alone by the patents which have been adjudicated and in the light of their construction as there given, with the modifications imposed by the production of the Dumesnil and Cabanallas patents. Whether the inquiry is materially simplified by such exclusion I am not prepared to say.

"The great advance in the art which was made by Tesla's discovery is not fairly questionable, but difficulty arises, nevertheless, in ascertaining the essence of the invention when the contentions and opinions in the prior cases are read in connection with the record and arguments in the case at bar. * * *

"The defendant's machine, which is alleged to be an infringement of the patents, is used as a generator and then as a motor alternately. It is claimed that it was constructed for the purposes of a generator, but subsequently utilized to serve as a motor; that it 'always operates as a generator during the period of starting;' that 'at one instant it will be generating currents and at the succeeding instant it will be running as a motor;' that 'in both cases identically the same principles of operation are employed, and they are principles of operation which were well known in the prior art;' that as a motor it is distinctively synchronous and not self-starting, and thus neither within the adjudication cited nor within the contentions on which they were predicated. In other words, the contention is that the Tesla rotating field is not employed in the operation of the motor in the way or for the purposes of the Tesla invention. It is undisputed that the infringing motors in each of the prior adjudications were nonsynchronous; that no case involving the use of a motor operated in synchronism has been brought to final hearing, though such use constantly appeared, while litigation was vigorously prosecuted against nonsynchronous infringers, one instance appearing of continuous manufacture of synchronous motors by a defendant who was under injunction against infringement by a nonsynchronous motor in suit, and this without interference until recently. Explanations of the fact that no such case of alleged infringement has reached hearing is made on the part of the complainant, and while the explanation is not unreasonable the fact remains and must enter into consideration upon this motion.

"The question of infringement in the present case under the fundamental patents depends upon the scope of invention and involves a broader construction than was involved in either of the prior cases. I am not sure that the contentions on behalf of the complainant in the prior cases are consistent with the construction now sought to reach the alleged infringement. In this view I am not prepared to conclude that infringement appears beyond question or unreasonable. Recognizing the protection due to the owner of the patents on the strength of the decree upholding their validity and scope—of special importance under the circumstances disclosed here—I have carefully examined to that end much of the expert testimony, and while I am impressed with the force of the contention urged on behalf of the complainant as to the true advance in the art made by the Tesla discovery and the scope of invention therein, the issues now raised require hearing upon complete proofs. So considered, discussion of the merits of the present controversy is unnecessary and inadvisable, and the motion for preliminary injunction must be denied."

The Development of Alternating-Current Work in America.

By Charles Appleton Terry.

Your request for reminiscences concerning the development of the commercial alternating-current system carries one's thoughts back to the early eighties when, though the direct-current system was in fairly extensive use, the alternating current had yet to receive the serious consideration of our engineers. Looking back over this period, the names of a few individuals stand out with peculiar prominence.

It is needless to say that the personality of Mr. Westinghouse is most conspicuously interwoven with the entire development of this system. When the work of Gaulard & Gibbs was first brought to his attention, he engaged the services of one of the most prominent of the electrical engineers of that time, Franklin L. Pope, a man whose quiet, forceful work aided greatly in the successful introduction of the alternating system to a skeptical public. Mr. Pope possessed an extraordinarily resourceful mind and a retentive memory, stored with useful facts and apt information. His rare sense of humor and genial kindness of manner were combined with a persistence of will and untiring studiousness which had rendered him a recognized authority upon all electrical subjects; and to-day his publications upon telegraphy and kindred subjects are valuable works of reference. His railway signalling inventions had brought him into close association with Mr. Westinghouse, and it thus came about that in February, 1886, as a direct result of experiments made with the Gaulard & Gibbs system at Pittsburg in 1885, Mr. Pope went to England commissioned by Mr. Westinghouse to secure the American rights to the Gaulard & Gibbs system. Throughout the formative period of the system, Mr. Pope was closely identified with the patent and scientific matters involved.

The rapid march from the experimental plant of 1885, to the commercial plant installed at Buffalo in November, 1886, was largely to the credit of the engineering ability of Shallenberger, Stanley and Belfield. Within a year thereafter sixty-five plants were sold, representing a total generating capacity of 125,000 incandescent lamps. Almost immediately a strong opposition to the alternating system was developed by the partisans of the direct-current system, an opposition which though gradually lessened did not cease until the commercial advent of the rotary transformer or converter which wedded the two systems.

In the earlier days the alternating system was at first seriously handicapped by the lack of a meter and a power motor. In April, 1888, Shallenberger, while experimenting with an arc lamp, noted a peculiar action of a small coiled spring which accidentally lodged on the brass flange of the magnet spool; the spring slowly turned about its longitudinal axis. From this accidental circumstance Shallenberger within a month developed his alternating-current meter, which for nearly ten years was the principal recording meter for this system, the only other commercial one being that devised by Prof. Elihu Thomson, who also made important inventions in the alternating-current field.

The requirement of a motor was met by Tesla's discoveries, the public announcement of which was nearly coincident with the independent discovery of Shallenberger and the publication of Ferrari's work along similar lines. Tesla's discoveries, however, included the polyphase system, which lent itself more perfectly to the distribution of large power units.

There still remained the requirement of a power motor adapted to railway service, and this is now being met by the assured single-phase motors of Lamme and Steinmetz.

It would seem that as a result of this perseverance of those interested in the alternating-current system, the perfection of the detail apparatus and the growing appreciation of its possibilities, the handicap now rests upon the shoulders of the direct-current system rather than upon that using the current which Shallenberger once described as "the electric current as God gave it to us."

The Transmission of Electric Energy Without Wires.

By NIKOLA TESLA.

IT is impossible to resist your courteous request extended on an occasion of such moment in the life of your journal. Your letter has vivified the memory of our beginning friendship, of the first imperfect attempts and undeserved successes, of kindnesses and misunderstandings. It has brought painfully to my mind the greatness of early expectations, the quick flight of time, and, alas! the smallness of realizations. The following lines which, but for your initiative, might not have been given to the world for a long time yet, are an offering in the friendly spirit of old, and my best wishes for your future success accompany them.

Towards the close of 1898 a systematic research, carried on for a number of years with the object of perfecting a method of transmission of electrical energy through the natural medium, led me to recognize three important necessities: First, to develop a transmitter of great power; second, to perfect means for individualizing and isolating the energy transmitted; and, third, to ascertain the laws of propagation of currents through the earth and the atmosphere. Various reasons, not the least of which was the help proferred by my friend Leonard E. Curtis and the Colorado Springs Electric Company, determined me to select for my experimental investigations the large plateau, two thousand meters above sea level, in the vicinity of that delightful resort, which I reached late in May, 1899. I had not been there but a few days when I congratulated myself on the happy choice and I began the task, for which I had long trained myself, with a grateful sense and full of inspiring hope. The perfect purity of the air, the unequaled beauty of the sky, the imposing sight of a high mountain range, the quiet and restfulness of the place—all around contributed to make the conditions for scientific observation ideal. To this was added the exhilarating influence of a glorious climate and a singular sharpening of the senses. In those regions the organs undergo perceptible physical changes. The eyes assume an extraordinary limpidity, improving vision; the ears dry out and become more susceptible to sound. Objects can be clearly distinguished there at distances such that I prefer to have them told by someone else, and I have heard—this I can venture to vouch for—the claps of thunder seven and eight hundred kilometers away. I might have done better still, had it not been tedious to wait for the sounds to arrive, in definite intervals, as heralded precisely by an electrical indicating apparatus—nearly an hour before.

In the middle of June, while preparations for other work were going on, I arranged one of my receiving transformers with the view of determining in a novel manner, experimentally, the electric potential of the globe and studying its periodic and casual fluctuations. This formed part of a plan carefully mapped out in advance. A highly sensitive, self-restorative device, controlling a recording instrument, was included in the secondary circuit, while the primary was connected to the ground and an elevated terminal of adjustable capacity. The variations of potential gave rise to electric surgings in the primary; these generated secondary currents, which in turn affected the sensitive device and recorder in proportion to their intensity. The earth was found to be, literally, alive with electrical vibrations, and soon I was deeply absorbed in this interesting investigation. No better opportunities for such observations as I intended to make could be found anywhere. Colorado is a country famous for the natural displays of electric force. In that dry and rarefied atmosphere the sun's rays beat the objects with fierce intensity. I raised steam, to a dangerous pressure, in barrels filled with concentrated salt solution, and the tinfoil coatings of some of my elevated terminals shriveled up in the fiery blaze. An experimental high-tension transformer, carelessly exposed to the rays of the setting sun, had most of its insulating compound melted out and was rendered useless. Aided by the dryness and rarefaction of the air, the water evaporates as in a boiler, and static electricity is developed in abundance. Lightning discharges are, accordingly, very frequent and sometimes of inconceivable violence. On one occasion approximately twelve thousand discharges occurred in two hours, and all in a radius of certainly less than fifty kilometers from the laboratory. Many of them resembled gigantic trees of fire with the trunks up or down. I never saw fire balls, but as a compensation for my disappointment I succeeded later in determining the mode of their formation and producing them artificially.

In the latter part of the same month I noticed several times that my instruments were affected stronger by discharges taking place at great distances than by those near by. This puzzled me very much. What was the cause? A number of observations proved that it could not be due to the differences in the intensity of the individual discharges, and I readily ascertained that the phenomenon was not the result of a varying relation between the periods of my receiving circuits and those of the terrestrial disturbances. One night, as I was walking home with an assistant, meditating over these experiences, I was suddenly staggered by a thought. Years ago, when I wrote a chapter of my lecture before the Franklin Institute and the National Electric Light Association, it had presented itself to me, but I had dismissed it as absurd and impossible. I banished it again. Nevertheless, my instinct was aroused and somehow I felt that I was nearing a great revelation.

It was on the third of July—the date I shall never forget—when I obtained the first decisive experimental evidence of a truth of overwhelming importance for the advancement of humanity. A dense mass of strongly charged clouds gathered in the west and towards the evening a violent storm broke loose which, after spending much of its fury in the mountains, was driven away with great velocity

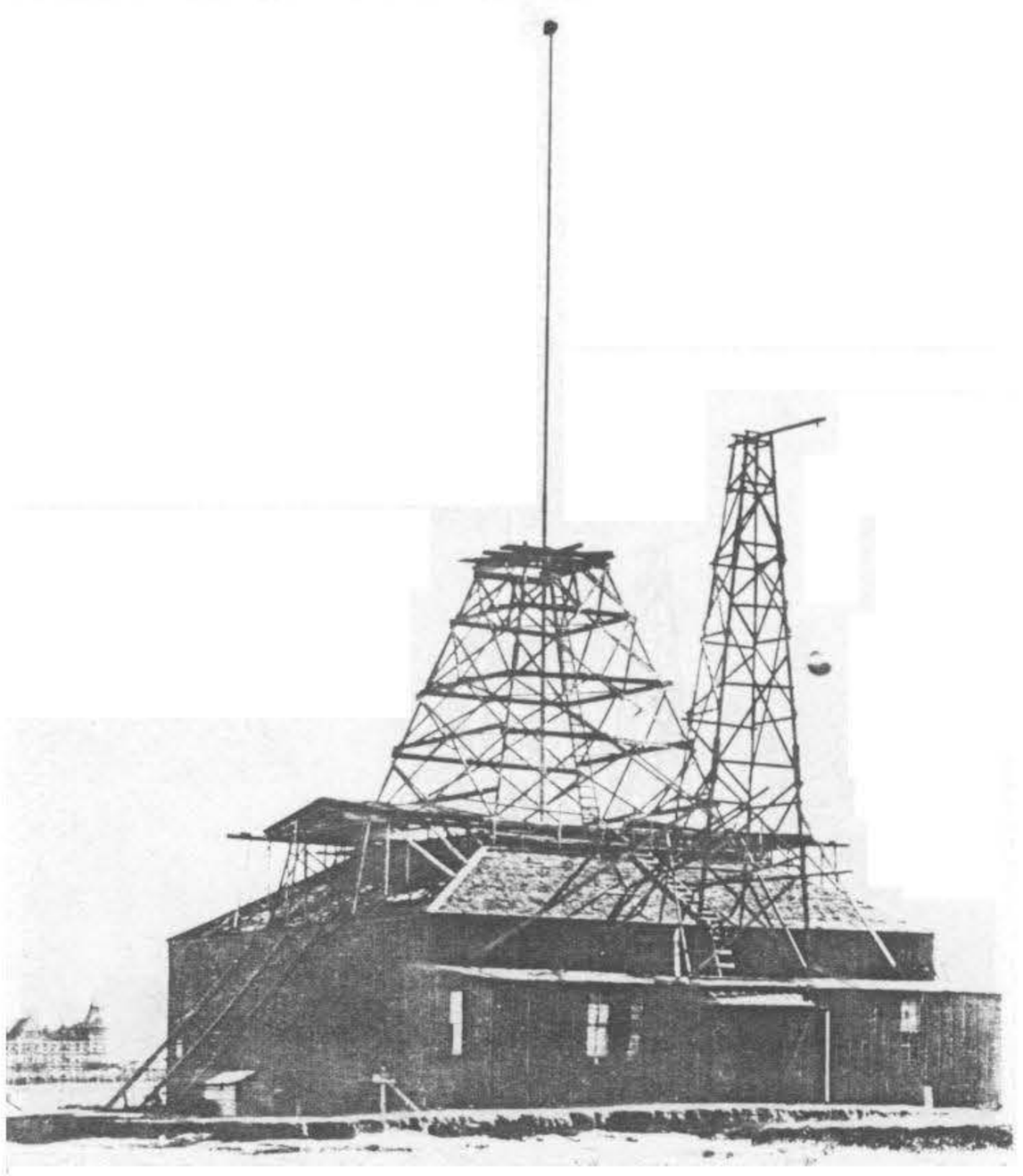


FIG. I.—TESLA EXPERIMENTAL LABORATORY, COLORADO, ERECTED SUMMER OF 1899.

(Discovery by Mr. Tesla of the Stationary Waves in the Earth was Here Made.)

over the plains. Heavy and long persisting arcs formed almost in regular time intervals. My observations were now greatly facilitated and rendered more accurate by the experiences already gained. I was able to handle my instruments quickly and I was prepared. The recording apparatus being properly adjusted, its indications became fainter and fainter with the increasing distance of the storm, until they ceased altogether. I was watching in eager expectation. Surely enough, in a little while the indications again began, grew stronger and stronger and, after passing through a maximum, gradually decreased and ceased once more. Many times, in regularly recurring intervals, the same actions were repeated until the storm which, as evident from simple computations, was moving with nearly constant speed, had retreated to a distance of about three hundred kilometers. Nor did these strange actions stop then, but continued to manifest themselves with undiminished force. Subsequently, similar observations were also made by my assistant, Mr. Fritz Lowenstein, and shortly afterward several admirable opportunities presented themselves which brought out, still more forcibly, and unmistakably, the true nature of the wonderful phenomenon. No doubt whatever remained: I was observing stationary waves.

As the source of disturbances moved away the receiving circuit came successively upon their nodes and loops. Impossible as it seemed, this planet, despite its vast extent, behaved like a conductor of limited dimensions. The tremendous significance of this fact in

the transmission of energy by my system had already become quite clear to me. Not only was it practicable to send telegraphic messages to any distance without wires, as I recognized long ago, but also to impress upon the entire globe the faint modulations of the human voice, far more still, to transmit power, in unlimited amounts, to any terrestrial distance and almost without any loss.

With these stupendous possibilities in sight, with the experimental evidence before me that their realization was henceforth merely a question of expert knowledge, patience and skill, I attacked vigorously the development of my magnifying transmitter, now, however, not so much with the original intention of producing one of great power, as with the object of learning how to construct the best one. This is, essentially, a circuit of very high self-induction and small resistance which in its arrangement, mode of excitation and action, may be said to be the diametrically opposite of a transmitting circuit typical of telegraphy by Hertzian or electromagnetic radiations. It is difficult to form an adequate idea of the marvelous

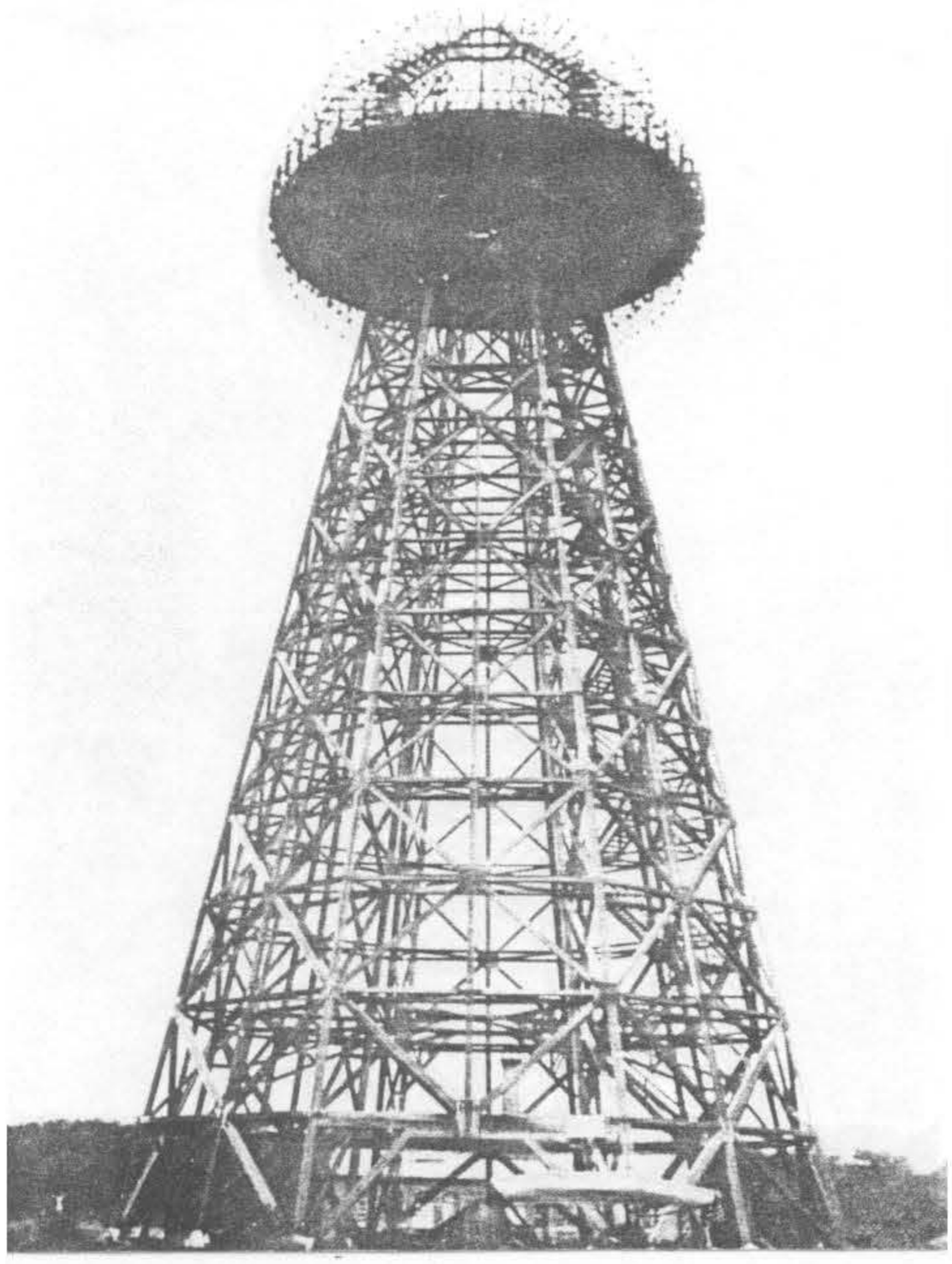


FIG. 2.—TESLA CENTRAL POWER PLANT AND TRANSMITTING TOWER FOR WORLD TELEGRAPHY, WARDENCLYFFE, LONG ISLAND, N. Y.

(Tower is a pyramid having eight sides; smallest dimensions across base, 29 meters; height, 47 meters; total height from ground to top, 57 meters; cupola on top, 20 meters diameter.)

power of this unique appliance, by the aid of which the globe will be transformed. The electromagnetic radiations being reduced to an insignificant quantity, and proper conditions of resonance maintained, the circuit acts like an immense pendulum, storing indefinitely the energy of the primary exciting impulses and impressing upon the earth and its conducting atmosphere uniform harmonic oscillations of intensities which, as actual tests have shown, may be pushed so far as to surpass those attained in the natural displays of static electricity.

Simultaneously with these endeavors, the means of individualization and isolation were gradually improved. Great importance was attached to this, for it was found that simple tuning was not sufficient to meet the vigorous practical requirements. The fundamental idea of employing a number of distinctive elements, co-operatively associated, for the purpose of isolating energy transmitted, I trace directly to my perusal of Spencer's clear and suggestive exposition of the human nerve mechanism. The influence of this principle on the transmission of intelligence, and electrical energy in general, cannot as yet be estimated, for the art is still in the embryonic stage; but many thousands of simultaneous telegraphic and telephonic messages, through one single conducting channel, natural or artificial, and without serious mutual interference, are certainly practicable, while millions are possible. On the other hand, any desired degree of individualization may be secured by the use of a great number of co-operative elements and arbitrary variation of their distinctive features and order of succession. For obvious reasons, the principle will also be valuable in the extension of the distance of transmission.

Progress though of necessity slow was steady and sure, for the objects aimed at were in a direction of my constant study and exercise. It is, therefore, not astonishing that before the end of 1899 I completed the task undertaken and reached the results which I have announced in my article in the *Century Magazine* of June, 1900, every word of which was carefully weighed.

Much has already been done towards making my system commercially available, in the transmission of energy in small amounts for specific purposes, as well as on an industrial scale. The results attained by me have made my scheme of intelligence transmission, for which the name of "World Telegraphy" has been suggested, easily realizable. It constitutes, I believe, in its principle of operation, means employed and capacities of application, a radical and fruitful departure from what has been done heretofore. I have no doubt that it will prove very efficient in enlightening the masses, particularly in still uncivilized countries and less accessible regions, and that it will add materially to general safety, comfort and convenience, and maintenance of peaceful relations. It involves the employment of a number of plants, all of which are capable of transmitting individualized signals to the uttermost confines of the earth. Each of them will be preferably located near some important center of civilization and the news it receives through any channel will be flashed to all points of the globe. A cheap and simple device, which might be carried in one's pocket may then be set up somewhere on sea or land, and it will record the world's news or such special messages as may be intended for it. Thus the entire earth will be converted into a huge brain, as it were, capable of response in every one of its parts. Since a single plant of but one hundred horse-power can operate hundreds of millions of instruments, the system will have a virtually infinite working capacity, and it must needs immensely facilitate and cheapen the transmission of intelligence.

The first of these central plants would have been already completed had it not been for unforeseen delays which, fortunately, have nothing to do with its purely technical features. But this loss of time, while vexatious, may, after all, prove to be a blessing in disguise. The best design of which I knew has been adopted, and the transmitter will emit a wave complex of a total maximum activity of ten million horse-power, one per cent. of which is amply sufficient to "girdle the globe." This enormous rate of energy delivery, approximately twice that of the combined falls of Niagara, is obtainable only by the use of certain artifices, which I shall make known in due course.

For a large part of the work which I have done so far I am indebted to the noble generosity of Mr. J. Pierpont Morgan, which was all the more welcome and stimulating, as it was extended at a time when those, who have since promised most, were the greatest of doubters. I have also to thank my friend, Stanford White, for much unselfish and valuable assistance. This work is now far advanced, and though the results may be tardy, they are sure to come.

Meanwhile, the transmission of energy on an industrial scale is not being neglected. The Canadian Niagara Power Company have offered me a splendid inducement, and next to achieving success for the sake of the art, it will give me the greatest satisfaction to make their concession financially profitable to them. In this first power plant, which I have been designing since a long time, I propose to distribute ten thousand horse-power under a tension of one hundred million volts, which I am now able to produce and handle with safety.

This energy will be collected all over the globe preferably in small amounts, ranging from a fraction of one to a few horse-power. One of its chief uses will be the illumination of isolated homes. It takes very little power to light a dwelling with vacuum tubes operated by high-frequency currents and in each instance a terminal a little above the roof will be sufficient. Another valuable application will be the driving of clocks and other such apparatus. These clocks will be exceedingly simple, will require absolutely no attention and

will indicate rigorously correct time. The idea of impressing upon the earth American time is fascinating and very likely to become popular. There are innumerable devices of all kinds which are either now employed or can be supplied, and by operating them in this manner I may be able to offer a great convenience to the whole world with a plant of no more than ten thousand horse-power. The introduction of this system will give opportunities for invention and manufacture such as have never presented themselves before.

Knowing the far-reaching importance of this first attempt and its effect upon future development, I shall proceed slowly and carefully. Experience has taught me not to assign a term to enterprises the consummation of which is not wholly dependent on my own abilities and exertions. But I am hopeful that these great realizations are not far off, and I know that when this first work is completed they will follow with mathematical certitude.

When the great truth accidentally revealed and experimentally confirmed is fully recognized, that this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball and that by virtue of this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment; when the first plant is inaugurated and it is shown that a telegraphic message, almost as secret and non-interferable as a thought, can be transmitted to any terrestrial distance, the sound of the human voice, with all its intonations and inflections faithfully and instantly reproduced at any other point of the globe, the energy of a waterfall made available for supplying light, heat or motive power, anywhere—on sea, or land, or high in the air—humanity will be like an antheap stirred up with a stick: See the excitement coming!

The New York American March 9, 1904

TESLA HAS PLAN TO DO AWAY WITH NEWSPAPERS.

With Wireless Waves of Communication, Plans to Girdle the World with Story of Happenings Far and Near

BUILDING BIG TOWER OUT ON LONG ISLAND

By means of the gigantic transmitting tower he is erecting at Wardencliff, L. I., Nikola Tesla hopes to put every newspaper in the world out of existence and to transmit telegraphic messages to the uttermost parts of the globe.

In an aritcle in the Electrical World and Engineer Mr. Tesla explains the system, and adds that "the noble generosity of J. Pierpont Morgan," who furnished the money when others did nothing but doubt, enables him to put the system in operation.

If the new system works a man may stand in the middle of the Sahara and by means of an inexpensive instrument so small that it may be carried in a vest pocket receive news of events in New York.

Mr. Tesla says he will magnify the stationary electric waves in the earth to such a degree of power that the globe easily can be girdled.

Earth Hears Our Whispers.

Discoveries made in Colorado, he says, showed him that the earth is a conductor of limited dimensions, and that it is possible to impress upon the whole globe the faint modulations of the human voice. Having determined these basic facts Mr. Tesla says he set himself to work to develop a magnifying transmitter which should make the modulations louder and stronger.

The tower which Mr. Tesla is building at Wardencliff is almost two hundred feet tall and is surmounted by a big cupola. The tower is in the shape of an eight-sided pyramid from the top of which will be sent the messages that are to circle the globe.

"See the Excitement Coming!"

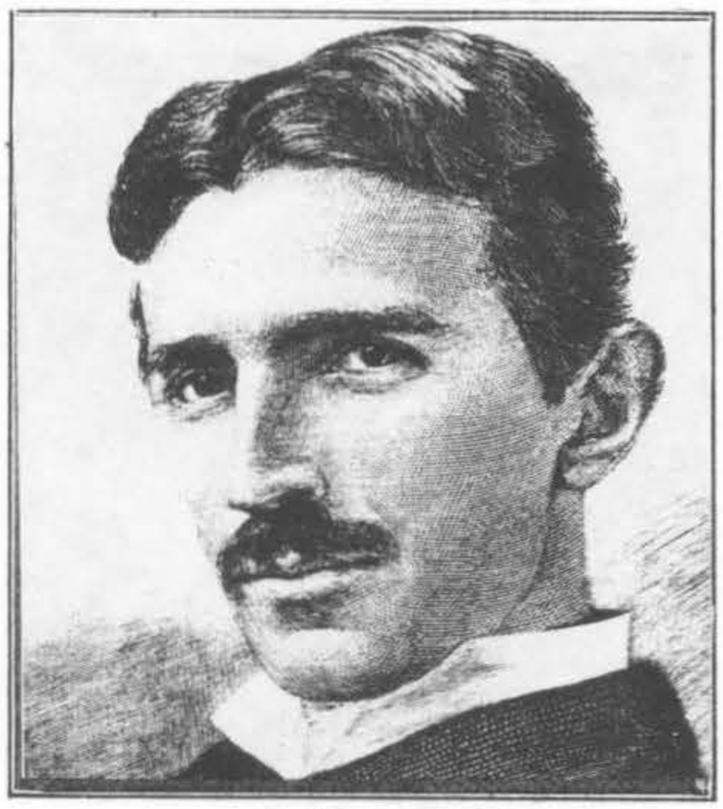
That Mr. Tesla believes there are great possibilities in the system he is perfecting is shown by the conclusion of his article:

"When the great truth accidentally revealed and experimentally confirmed is fully recognized, that this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball and that by virtue of this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment; when the first plant is inaugurated and it is shown that a telegraphic message, almost as secret and non-interferable as a thought, can be transmitted to any terrestrial distance, the sound of the human voice, with all its intonations and inflections faithfully and instantly reproduced at any other point of the globe, the energy of a waterfall made available for supplying light, heat, or motive power, anywhere—on sea, or land, or high in the air—humanity will be like an antheap stirred up with a stick: See the excitement coming!"

WIRELESS POWER TRANSMISSION

NIKOLA TESLA'S LATER EXPERIMENTS IN THIS FIELD—HOW THE INVENTOR EXPECTS TO REVOLUTIONIZE THE WORLD

SINCE his article in the *Century Magazine* for June, 1900, little or nothing has been heard from Mr. Tesla as to the progress of his experiments in the transmission of electrical energy without wires. It has been understood, however, that the inventor was still at work along the lines he suggested in the article referred to, and now we have in the *Electrical World and Engineer* another statement from him, showing that the inventor is just as firmly convinced as ever that the system he has devised, if not perfected, will in a short time revolutionize the world. With a realization of the stupendous possibilities in sight, Mr. Tesla says that he has been working upon the development of his "magnifying transmitter" with the sole idea of producing the best type of such an instrument:



NIKOLA TESLA

This is, essentially, a circuit of very high self-induction and small resistance which in its arrangement, mode of excitation and action, may be said to be the diametrical opposite of a transmitting circuit typical of telegraphy by Hertzian or electromagnetic radiations. It is difficult to form an adequate idea of the marvelous power of this unique appliance, by the aid of which the globe will be transformed. The electromagnetic radiations being reduced to an insignificant quantity, and proper conditions of resonance maintained, the circuit acts like an immense pendulum, storing indefinitely the energy of the primary exciting impulses and impressing upon the earth and its conducting atmosphere uniform harmonic oscillations of intensities which, as actual tests have shown, may be pushed so far as to surpass those attained in the natural displays of static electricity.

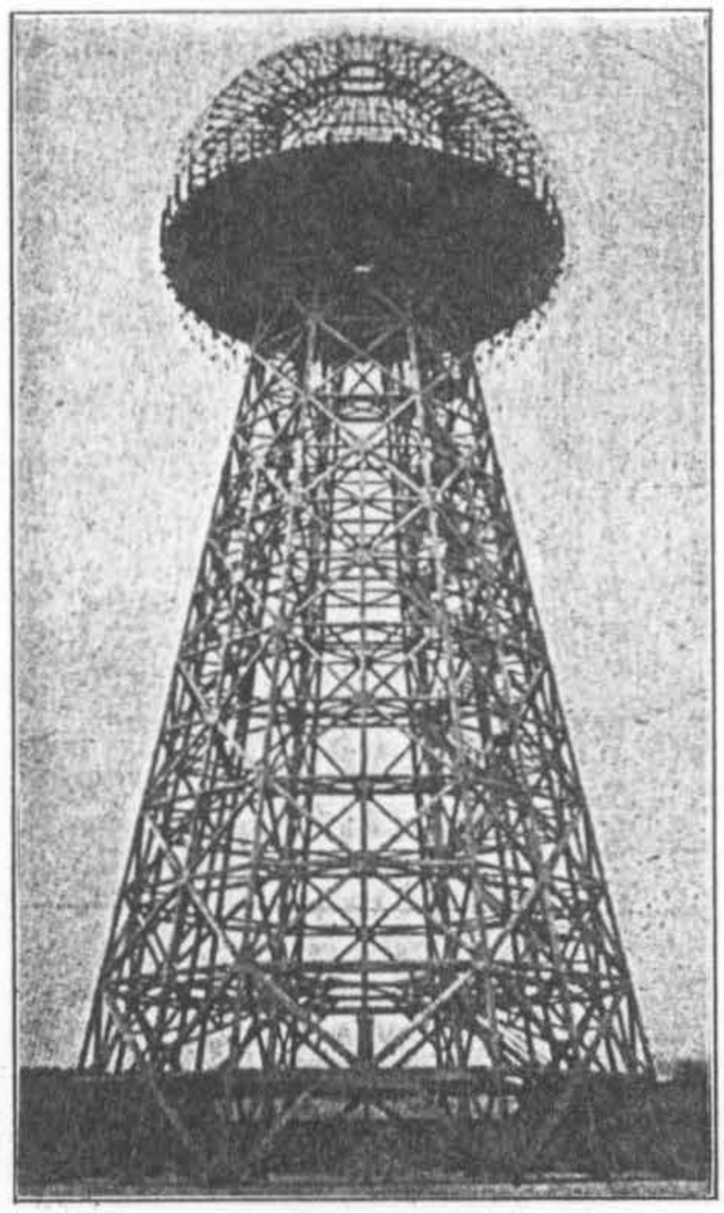
Much, Mr. Tesla adds, has been done toward making his system commercially available for the transmission of energy in small or large amounts:

The results attained by me have made my scheme of intelligence transmission, for which the name of "World Telegraphy" has been suggested, easily realizable. It constitutes, I believe, in its principle of operation, means employed and capacities of application, a radical and fruitful departure from what has been done heretofore. I have no doubt that it will prove very efficient in enlightening the masses, particularly in still uncivilized countries and less accessible regions, and that it will add materially to general safety, comfort, and convenience, and maintenance of peaceful relations. It involves the employment of a number of plants, all of which are capable of transmitting individualized signals to the uttermost confines of the earth. Each of them will be preferably located near some important center of civilization, and the news it receives through any channel will be flashed to all points of the globe. A cheap and simple device, which might be carried in one's pocket may then be set up somewhere on sea or land, and it will record the world's news or such special messages as may be intended for it. Thus the entire earth will be converted into a huge brain, as it were, capable of response in every one of its parts. Since a single plant of but one hundred horse-power can operate hundreds of millions of instruments, the system will have a virtually infinite working capacity, and it must needs immensely facilitate and cheapen the transmission of intelligence.

The Transmitter

The transmitter Mr. Tesla has completed will, we understand, emit a wave of a total maximum activity of ten million horse-power. But the "artifices" by which this result is obtained, the inventor is not ready to explain. In the power plant which Mr. Tesla is designing now he proposes to distribute ten thousand horse-power under a tension of one hundred million volts, which, he states, he "is able to produce and handle with safety":

This energy will be collected all over the globe, preferably in small amounts, ranging from a fraction of one to a few horse-power. One of its chief uses will be the illumination of isolated homes. It takes very little power to light a dwelling with vacuum tubes operated by high-frequency currents and in each instance a terminal a little above the roof will be sufficient. Another valuable application will be the driving of clocks and other such apparatus. These clocks will be exceedingly simple, will require absolutely no attention, and will indicate rigorously correct time. The idea of impressing upon the earth American time is fascinating and very likely to become popular. There are innumerable devices of all kinds which are either now employed or can be supplied, and by operating them in this manner I may be able to offer a great convenience to the whole world with a plant of no more than ten thousand horse-power. The introduction of this system will give opportunities for invention and manufacture such as have never presented themselves before.



THE TESLA TRANSMITTING TOWER AT WARDENCLYFFE, L. I., HEIGHT, 175 FEET

It was in Colorado that Mr. Tesla first became impressed with the possibilities of experimentation along the lines he has lately pursued, but the perfection of his apparatus has been carried on at a plant established on Long Island, the picture on this page showing the transmitting tower erected at this plant. No detailed description of it is given in the article from which we are quoting. Mr. Tesla states that he has been greatly assisted by Mr. J. Pierpont Morgan. The inventor continues:

Knowing the far-reaching importance of this first attempt and its effect upon future development, I shall proceed slowly and carefully. Experience has taught me not to assign a term to enterprises the consummation of which is not wholly dependent on my own abilities and exertions. But I am hopeful that these great realizations are not far off, and I know that when this first work is completed they will follow with mathematical certitude.

When the great truth accidentally revealed and experimentally confirmed is fully recognized, that this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball and that by virtue of this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment; when the first plant is inaugurated and it is shown that a telegraphic message, almost as secret and non-transferable as a thought, can be transmitted to any terrestrial distance, the sound of the human voice, with all its intonations and inflections faithfully and instantly reproduced at any other point of the globe, the energy of a waterfall made available for supplying light, heat, or motive power, anywhere—on sea, or land, or high in the air—humanity will be like an ant-heap stirred up with a stick.

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SUGGESTIONS FOR PRODUCING HIGH-FREQUENCY CURRENTS AND SOME OF THEIR PHENOMENA.

BY EDWIN F. NORTHRUP AND ELLIOTT WOODS.

Inclination and circumstances have led the writers of this article to construct and play, rather than experiment in a logical and scientific manner, with apparatus of various forms for producing high-frequency currents. As the work has always been fascinating, and often instructive, even if not commercially valuable, it is thought a sort of narrative description of what we have done with high-frequency apparatus and how we constructed it and the phenomena we observed, would not be without interest to electricians interested in the laws and manifestations of electric forces.

The most difficult thing to realize by any artificial means is a strictly constant condition; be it a constant temperature, a constant illumination, a constant tone, a constant current or a constant motion. Nature left to herself tends ever to change, mutations being in general rhythmical. The most striking illustration of this tendency of Nature to a periodic variation which has been recently observed is seen in the action of a Wehnelt interrupter.

When one observes how a violin bow drawn smoothly over the string starts it into vibrations, or how a wet cork rubbed upon a window pane produces a shrill note, or a rotating wheel slightly out of balance sets up violent vibrations, and many other similar phenomena, the action of a Wehnelt interrupter, which acts upon the constantly applied electromotive force to throw the current into rapid pulsations, could certainly have been expected and might have been prophesied.

The movements of electricity in Nature as seen in lightning, in earth currents and in Northern Lights, are fluctuating or oscillating motions. It has been by the exercise of special ingenuity that, through artificial means, direct and constant electric currents have been obtained.

When an electric current flows with perfect uniformity in a circuit the concomitant phenomena are few indeed compared with the phenomena which arise when the current becomes a changing current, varying in magnitude or alternating in direction. A constant direct current is uniformly distributed over the cross-section of the wire, its external inductive effects are nil, and special contrivances must be employed to make evident its very existence. Alternate the current, the more rapidly the more striking the phenomena, and numerous effects external to the circuit are observed. The current is no longer evenly distributed over the cross-section of the wire, but crowds toward its surface until, when the variations are rapid enough, a tube having a thin wall will convey as much energy as if it were a solid rod. With the direct constant current the flow of the current can be calculated by Ohm's law. When the current alternates slowly the calculation can still be made by substituting impedance for resistance, but when the alternations reach a frequency that obtains when the electricity swings freely to and fro in the circuit, exact calculations can no longer be made, as the energy is escaping from the circuit by heat, by radiation and by other paths.

The reason that the study of high-frequency or oscillating currents is so fascinating and instructive lies in the fact

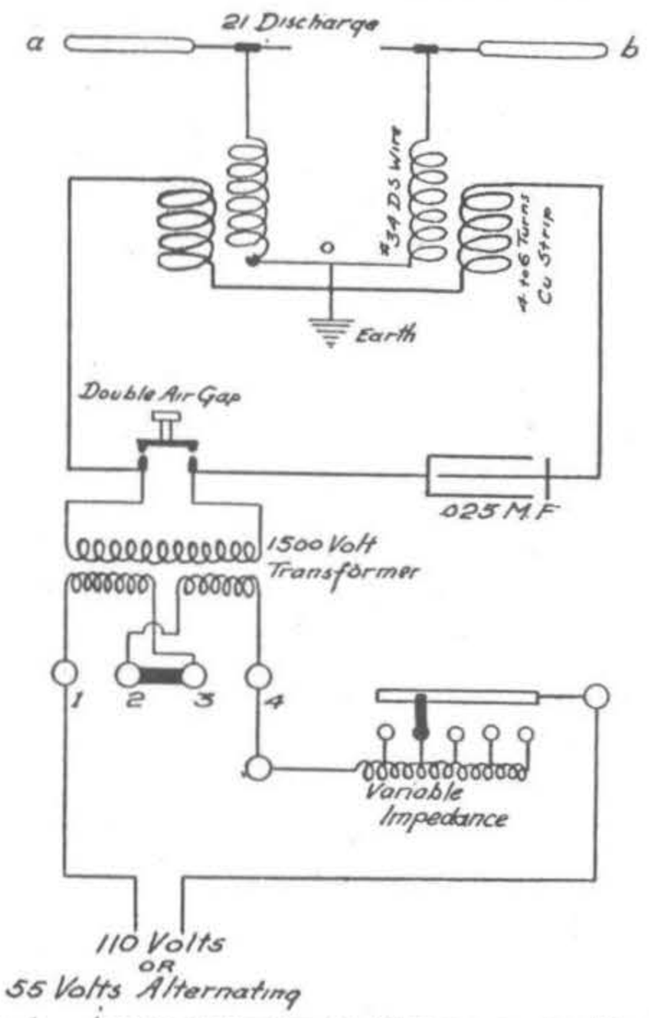


FIG. 1.—ARRANGEMENT OF CIRCUITS FOR HIGH-FREQUENCY MACHINES.

that the complexity of the phenomena which are observed forbids and makes impossible prophecies of what will happen by the aid of calculations. As we change the apparatus and vary the conditions under which we work, pleasant surprises are in store and the electrician, if he will make progress, must drop his calculus and become the observant experimenter. The writers have tried a large number of forms of apparatus and different arrangements of circuits for obtaining currents of high frequency of both low and high potential. In this article we shall confine ourselves to describing only one or two forms of apparatus and arrangements of circuits which gave best results.

The experiments of the writers have been confined to the obtaining of oscillating currents by means of the sudden disruptions of an air-gap, though there are other methods by which the equilibrium of the electricity can be disturbed and strong oscillations be obtained. In describing how the writers recently constructed a high-frequency high-potential apparatus, giving a discharge of great volume and over twenty inches in length, the essential features of design and the precautions which must be observed to obtain the best results will be brought out. It should be stated that equally good results might possibly be obtained in a number of other ways, and that the particular method adopted is only that which appeared best to the writers from theoretical considerations and many trials of different forms of apparatus.

It should be stated at the outset, and emphasized, that for obtaining the most powerful and continuous oscillations it is never necessary to resort to any device, such as a magnetic blowout, a blast of air or a mechanical contrivance for making and breaking the circuit, for disrupting the arc which, with improper arrangements, tends to form in the air-gap, weakening or destroying the oscillations. Though there are several methods by which fairly good results may be obtained, by using a source of direct electromotive force, a source of alternating electromotive force of 55 or 110 volts and of about 7,200 alternations is much to be preferred, and for the most powerful effects is necessary. There are five essential parts of a high-frequency apparatus of high potential. First, a variable impedance having as little ohmic resistance as possible and capable of carrying twenty-five or thirty amperes. This is best made by winding No. 8 wire on a core of soft iron wires. This core may be twelve inches long and two to three inches in diameter. The impedance can be made variable by bringing out any number of tapoff points, so that more or less of the turns of the winding may be used. Second, a transformer which will raise 110 volts to about 10,000 or 15,000 volts. This transformer should have a closed magnetic circuit and should be able to deliver at least two-tenths of an ampere from its high-tension winding. Third, a condenser of sufficient capacity and of dielectric strength sufficient to withstand the strain put upon it when a discharge is passing across a parallel discharge-gap of three-quarters to one inch in length. Fourth, a properly constructed double parallel discharge-gap. Fifth, a high-frequency induction coil. The last three of these pieces of apparatus will be more particularly described. Next

to the proper proportioning of the apparatus, the most essential and difficult requirement to fulfil is, that all the parts be properly insulated.

The arrangement of the circuits that the writers finally adopted in obtaining the best results with the high-frequency machine that gave over a twenty-inch discharge is given in Fig. 1. The variable impedance that is shown connected in series with a 15,000-volt transformer performs a very important function. It can not be replaced successfully by an ohmic resistance. Its action may be described as follows: when the potential has risen to a point where the double air-gap breaks down, the secondary of the transformer becomes short-circuited through the low-resistance path now formed in the double air-gap by the hot gases evolved, and if it were not for the variable impedance a rush of current would flow into the primary of the transformer and a yellow flaming arc would form in the air-gap, still further decreasing the resistance of this air-gap, and prevent the condenser from again becoming charged to a high potential. The impedance prevents this formation of the arc by holding back the sudden rush of current to the primary of the transformer. The disrupted air-gap mends and the potential of the secondary of the transformer again comes upon the condenser, charging it to its full capacity. Curiously enough, varying the amount of the impedance does not appreciably affect the length of the double air-gap that will disrupt. Increasing, however, the impedance beyond a certain point, which is fairly definite, will cause the disruptions of the air-gap, when opened a fixed distance, to quite suddenly cease. When the impedance is thrown entirely out, arcing will generally take place in the air-gap, especially if the capacity of the condenser is small and the transformer a large one, and the oscillations will become very poor or cease altogether. The variation of the impedance through wide limits produces, in a marked manner, a variation of the number of disruptions in the air-gap that take place at each alternation of the electromotive force of the source, this result being made plainly manifest in the varying thickness or volume of the high-tension discharge, as well as in the amount of current which the primary of the transformer will draw.

It will be noted that the primary and secondary of the high-frequency coils of the transformer are divided into two sections, and that the middle points of the primary and secondary are joined together and connected to the ground. The separation of the primary and secondary windings into halves is made chiefly for convenience in mechanical construction and to economize space. Connecting the lower terminals of the two sets of windings together and joining the points united to the ground, is done to protect from the high-tension discharge the insulation between the primary and secondary of the 15,000-volt transformer. If the above precaution be not taken and one side of the secondary of the high-frequency transformer be connected to ground, as is often done in certain experiments with the apparatus, one-half of the potential of the secondary of the high-frequency coil is thrown upon the insulation between the two windings of the 15,000-volt transformer.

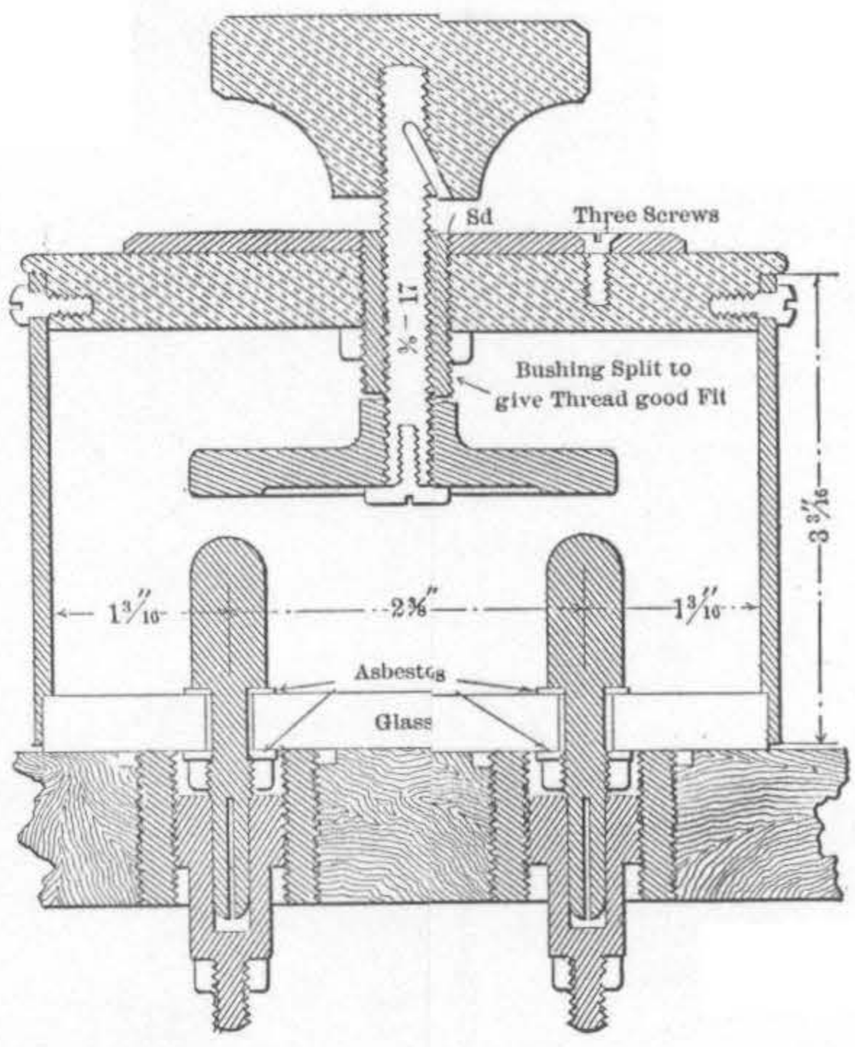


FIG. 2.—CONVENIENT METHOD OF CONSTRUCTING SPARK BOX.

Suppose the terminal *a* were connected to earth and the ground connection omitted, and the primary circuit of the 15,000-volt transformer is separated from ground by a weak insulation, then the current from the secondary of the high-frequency coil would tend to take the following course: from *a* to ground, from ground to the primary of the 15,000-volt transformer, across the insulation between the primary and secondary of this transformer to the secondary, then through the left-hand winding of the primary of the high-frequency coil to the point *o*, where the primary and secondary of the high-frequency coils are joined, through the left-hand winding of the secondary and back to *a*. Thus if the coil gives twenty inches, the insulation between the primary and the secondary of the 15,000-volt transformer may have to withstand a strain equal to a ten-inch discharge of the high-frequency coil. If the ground connection is made at *o*, it is readily seen that this strain does not come upon the insulation of the transformer.

If the primary of the transformer be made with two windings brought out to terminals 1, 2, 3, 4, the two coils of the primary may be connected in series or in parallel, thus adapting it to a 110 or 55-volt circuit. It is not convenient, however, to construct a variable impedance so as to be equally adapted to different voltages. It is not difficult to construct a high-tension transformer for this work, but it would hardly pay one to make this piece of apparatus, since it can be easily obtained in the market. The spark box, and a convenient manner of constructing it, are illustrated in detail in Fig. 2.

In this form of construction the double air-gap is easily controlled and varied in length by turning the insulated handle, which raises and lowers the circular metal disc; this can be done while the coil is in operation without danger of obtaining a shock. If the discharge-gaps are enclosed in a box, as shown in Fig. 2, the noise of the discharge will be lessened. The coil will be generally found to work better after the terminals of the gap and the air on the inside of the box have become heated from operating the coil.

The condenser is most conveniently made as follows: choose plates of the best quality of window glass, fourteen by ten

inches, and one-eighth of an inch thick. Tin-foil might answer for the metal sheet of the condenser, but a thin brass or metal sheet is much to be preferred because of its greater mechanical strength and the greater ease with which terminals may be soldered to it. The metal sheet when laid on the glass plate should reach to within one inch on the side margins of the sheet, but be kept two inches from the end opposite to which the terminal is fastened. Thus the effective area of two opposing sheets would be eight by ten inches. The condenser should be laid up in the following order: glass, a sheet of heavy paper, brass sheet, another sheet of heavy paper, glass plate, paper, brass, paper, glass, etc. Half of the brass sheets should have their ends projecting a quarter of an inch from one end of the condenser, and the other half of the brass

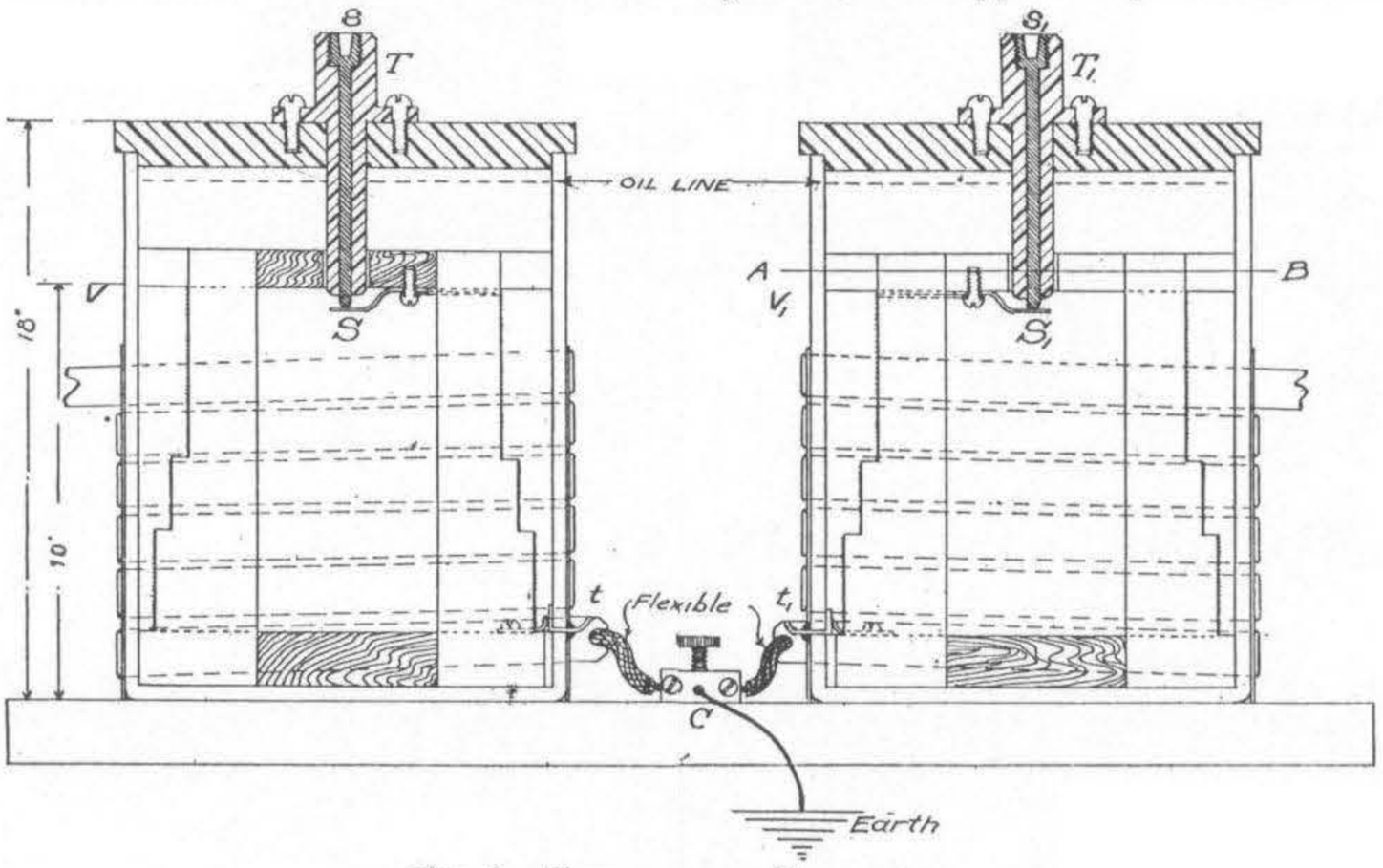


FIG. 3.—ELEVATION OF CONDENSER.

sheets, alternately placed with the first half, should project in a similar manner from the other end of the condenser. The terminals are, of course, soldered to the projecting ends of the sheets, which are bent down to lie flat and slightly overlap at each end of the condenser. To make this condenser so that it will not break down, it should be laid up under oil, care being taken that no air bubbles get in between the plates. The plates may be held in position by means of a wooden frame, and if the condenser be lifted quickly out of the oil in which it was stacked and placed in its permanent box, and the space between the condenser and its box be filled with melted paraffin, a very strong and dry condenser will be obtained, which will not break down with a one-inch discharge across a parallel gap. The capacity of such a condenser, made of forty plates of glass, is about 0.025 microfarad and is very well adapted for the production of very heavy high-frequency discharges. The writers believe that the particular form given to their high-frequency coil is the most efficient that can be built and that it is somewhat novel, and so we will describe its construction with more detail.

Fig. 3 gives in section and elevation the general form of the design adopted. Fig. 4 is a section on the line AB, of one of the halves of the coil, the two halves being identical. V and V_1 of Fig. 3 are two vessels having the relative dimensions indicated in the figure. These vessels may be of glass, hard rubber or compressed paper. The vessels employed by the writers were made of glass. The primary of the high-frequency coil should preferably consist of about four turns of insulated copper strip wound upon each of the two vessels, the two windings being joined together by a flexible connector C. A convenient way of holding the windings in place is to wind them upon a cardboard cylinder which will just fit over the glass cylinder, the copper straps of which the windings are made being fastened to the cardboard cylinders by being sewed to the cardboard with a strong thread. If the copper strap is insulated with tape or ribbon, the turns can come quite close together; if not insulated they must be kept about one-eighth of an inch apart. By adopting the arrangement shown, the highest possible insulation can be secured for the high-tension secondary winding by filling each of the two vessels nearly to the top with thin paraffin oil. The thinner and better the quality of the oil, the better the insulation secured. If the apparatus is located in a place where there is no fear of fire, the highest possible insulation is secured by the use of kerosene oil. The construction of the secondary coil requires considerable care to obtain the highest efficiency and perfectly secure insulation. The dimensions of the secondary should be proportioned about as shown in Fig. 3. The best way to form a framework on which to wind the wire of the secondary coil is to take two circular boards of hard wood which will just fit on the inside of the glass vessels and make in these boards a dozen or more radial slots one-quarter of an inch wide as indicated in Fig. 4. Hard rubber pieces should then be cut out, having the shape shown in Fig. 3, and these be inserted tightly in the radial slots of the two circular boards. By this means a tapered polygon is formed, upon which the secondary winding may be wound. This winding may be made of double silk-covered No. 34 copper wire, the turns should be laid on evenly and close together, great care being exercised that no single turn shall cross over its neighbors. After the winding is completed, it should be ended off with terminals of heavier wire and the whole be given a thick coating of shellac. This must be allowed to become thoroughly dry before the coil is used. A small hole may be drilled in the bottom of each of the glass vessels t and t_1, through which one end of each of the terminals may be passed and then be fastened to the middle point between the two primaries. The holes can be stopped up with cement so the vessels will not leak oil. Heavy terminals mounted in hard rubber can be fastened in circular

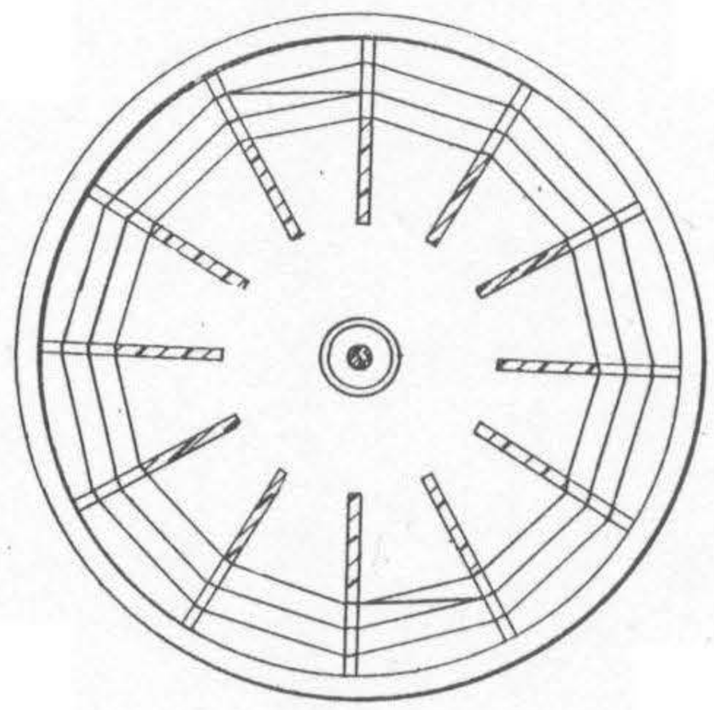


FIG. 4.—SECTION OF CONDENSER.

covers that rest on the tops of the two vessels and make automatic connections with the two terminals of the secondary by means of spring contacts as at S and S_1. One suitable form of construction is plainly shown in Fig. 3. One must be cautioned to make the circular covers of the two vessels of some perfectly insulating material, as hard rubber, otherwise brush discharges and streamers will continually pass up the outside surface of the glass vessels, the discharge attempting to take place between the primary and the terminal in the centre of the cover.

The terminals between which the high-frequency discharge is to pass may consist of balls or points which can be attached to the tops of the permanent terminals passing up through the centres of the covers. As the two halves of the high-frequency coil are independent of each other, being merely joined together by a flexible connector, the halves of the coil can be moved closer together or farther apart, according to the length of discharge which one wishes to obtain.

(To be concluded.)

SUGGESTIONS FOR PRODUCING HIGH-FREQUENCY CURRENTS AND SOME OF THEIR PHENOMENA.

(*Concluded.*)

BY EDWIN F. NORTHRUP AND ELLIOTT WOODS.

Two views, reproduced from photographs, of two coils constructed on the general lines described above are illustrated in Figs. 5 and 6. The coil shown in Fig. 5 gave a very good twenty-inch discharge. The terminals in the picture, Fig. 5, are shown twenty and one-quarter inches apart, from which standard of reference the reader can determine the other dimensions of the apparatus. The coils shown in Figs. 5 and 6 had their secondaries wound on glass jars which set on the inside of larger glass jars around which the primary coils are wound. The construction as indicated in Fig. 3 would, however, if followed, have been somewhat more efficient. The primary turns, as indicated above, should preferably be made of copper strip, as the high-frequency currents in the primary coils are chiefly confined to the surface of the conductor and by using copper ribbon instead of round wire as actually used, it is possible to surround a larger portion of the secondary windings without increasing the number of primary turns.

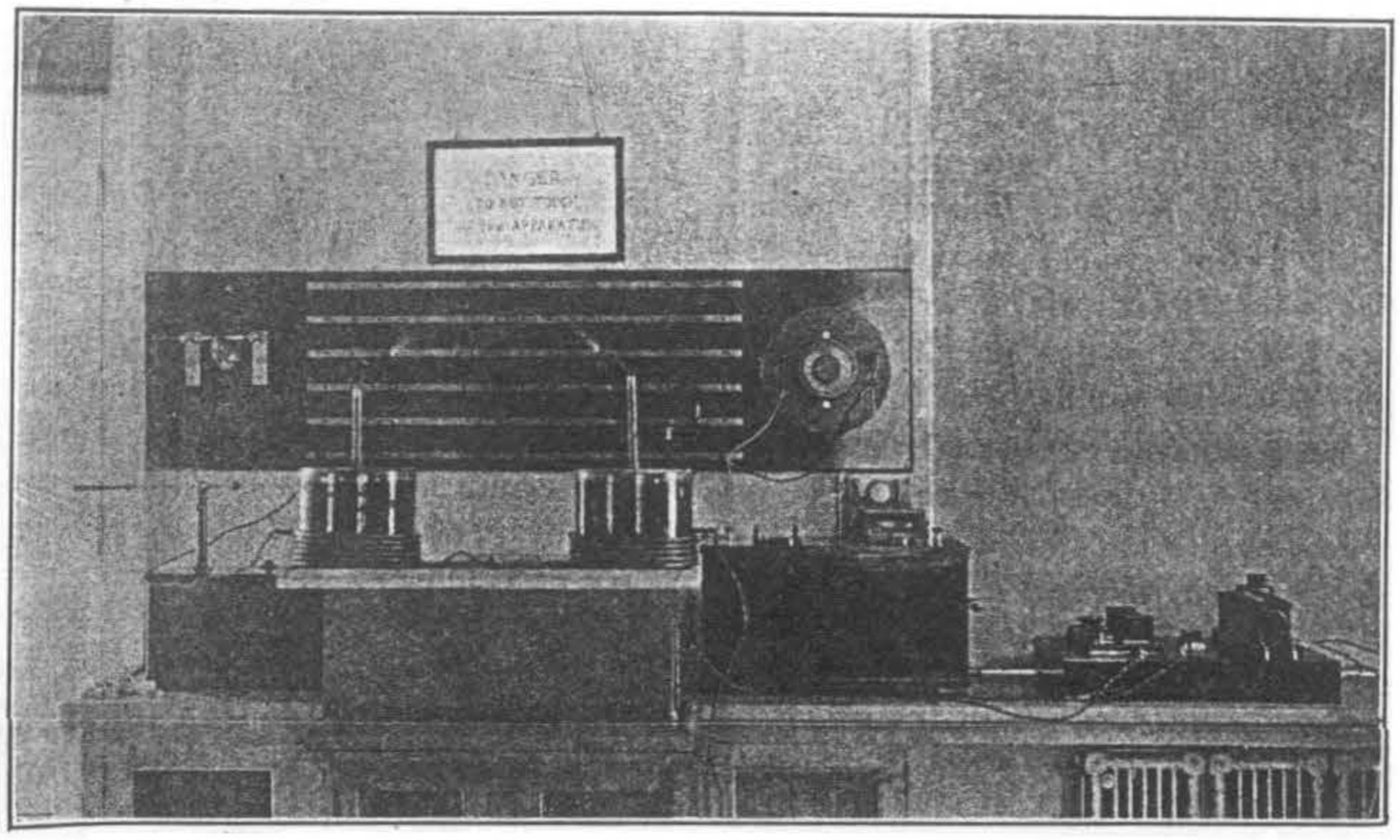


FIG. 5.—COIL FOR TWENTY-INCH SPARK—SUGGESTIONS FOR PRODUCING HIGH-FREQUENCY CURRENTS.

Experiments with the coils illustrated in Figs. 5 and 6 showed that for obtaining the maximum length of discharge a certain number of primary turns were required. For the coil shown in Fig. 6 four turns on each half seemed to give the best result. The efficiency of the high-frequency coil in regard to length and volume of discharge is greatly increased when the leads to the primary windings, or, in other words, the connecting wires in the circuit in which the electricity oscillates, are kept as short as possible. The discharge from a high-frequency coil will vary in volume, as well as in length, very greatly, according to the form of construction of the apparatus and the power which is put into it. A coil such as has been described above, when the transformer is taking about twenty amperes at 110 volts and 7,200 alternations per minute, should give a discharge of sufficient volume to bring the filament of a 110-volt sixteen-candle-power lamp to a bright red when passed through it. We have seen as many as ten incandescent lamps brought nearly to candle-power when joined in series and the discharge from a high-frequency coil, capable of giving eight inches, passed through all of them. Observations taken on a wattmeter which measured the true power put into the apparatus apparently showed that the apparatus was taking less power than would be required with ordinary currents to light ten lamps to two-thirds candle-power, as they actually were lighted from the high-frequency discharge which was passed through them. To all appearances the filaments were brought to incandescence by true conduction currents. As far as the indications went, a considerably larger number than ten lamps could have been lighted in the same way and to the same brilliancy; as one lamp, when the current was passed through it alone, was lighted no more brilliantly than when passed through ten in series, and an air-gap, in series with the lamps over which the discharge passed, very slightly, if at all, diminished their glow. The explanation of this apparent paradox, that more energy was displayed in the lamps than was actually put into the apparatus, as measured by a wattmeter measuring true watts, can not be satisfactorily given by the writers. No opportunity has been presented to investigate the matter experimentally so as to reach a certain conclusion. We consider any explanation based upon theory as of little value and a study of the interesting phenomenon above described is suggested as being well worth the trouble. Any high-frequency

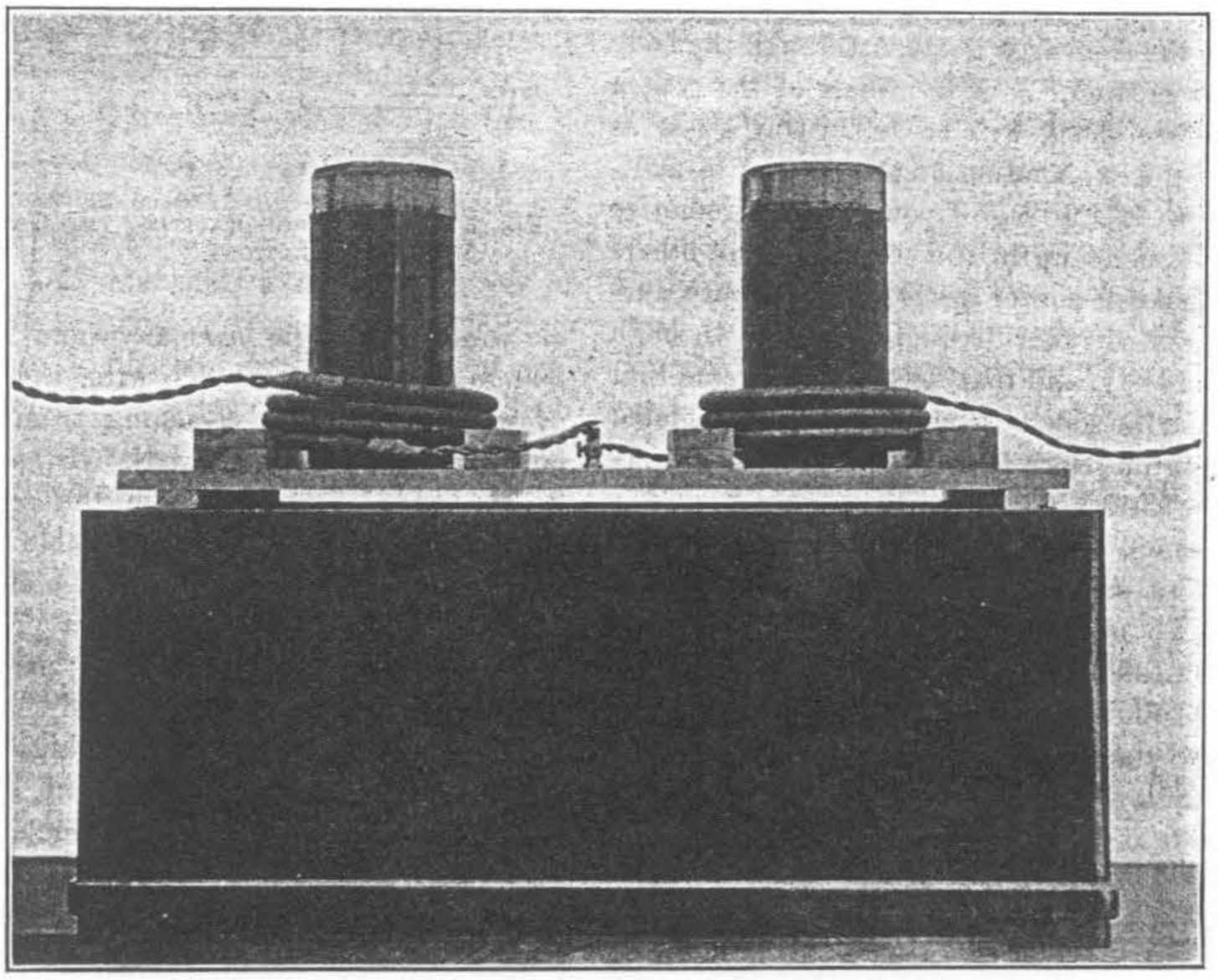


FIG. 6.—NO. 2 COIL—SUGGESTIONS FOR PRODUCING HIGH-FREQUENCY CURRENTS.

discharge which is not of sufficient volume to light up lamps, when passed directly through their filaments, may be considered poor as to what may easily be obtained by proper construction.

Many experiments were tried by the writers with the high-frequency apparatus shown in Figs. 5 and 6. None of the experiments was strictly new, having been described by Tesla and other writers, and only a brief mention will be made of some experiments which indicate strikingly the properties of high-frequency currents, which show phenomena totally unlike direct currents and those of moderate frequency. Thus, presenting a piece of metal held in the hand to one terminal of the high-frequency coil draws a discharge from the terminal into the body, even though the body be insulated by a stool with glass legs. Simple and common as is this observation to those familiar with high-frequency currents, it would be inexplicable to one who does not appreciate that electricity always flows in a closed circuit, and that the circuit, according to Maxwell's theory, is, for high-frequency currents, as perfectly closed through the dielectric medium as it is through a wire for ordinary currents. The experiment as described can be performed without any disagreeable sensations, but, contrary to the common notion, if the discharge is taken through the body by grasping both terminals of the coil, a severe shock will be felt. Our guess as to the explanation of this is that in addition to the high-frequency electromotive forces set up in the coil, there are others of much slower period which cause currents of lower frequency to pass through the body, and that it is these currents that give the shock. When the body is insulated and one terminal is touched, it is only the currents which have a very high frequency that can pass into the body and these produce little or no sensation.

To obtain from a high-frequency coil a most brilliant display of light, proceed as follows: take a large piece of plate glass and fasten a piece of tin-foil about as big as a dollar on each side of the glass near its centre. Connect to each piece of tin-foil a terminal of the coil. When the coil is in operation, even if it is a very large one, the discharge will not puncture the glass, but will spread out in fiery streamers on each side of the glass like the roots of a tree, covering a wide area and producing a most beautiful effect, especially when seen in the dark.

All kinds of vacuum tubes, including electric light bulbs, can be made to glow brightly by being held in the hand and approached to one terminal of the coil. Vacuum tubes will generally glow if suspended between two metal sheets which are connected to the terminals of the coil. Many other experiments along the same line, which attracted such lively attention when first exhibited in a striking manner by Tesla, can be performed with a coil constructed like those described above.

A very beautiful display of light and a high-frequency discharge of considerable length can very easily and inexpensively be obtained by constructing an air-insulated coil made as follows: Describe on the top of an old wooden table two concentric circles, the inner one about three feet in diameter and the outer one about four and one-half feet in diameter. On the circumference of each circle bore fifteen or twenty evenly spaced holes. In each hole insert a rod about three feet long, of hard, dry wood, glass or fibre. Around the upright rods of the inside circle wind in a single layer anywhere from 500 to 1,000 turns of fine wire, the coil of wire thus formed reaching from the bottom to the top of the rods. Bring the bottom terminal up through the centre of the coil, fastening it to a suitable support above the coil. Wind around the outside circle of upright rods, eight or ten turns of heavier wire, say No. 12; making the outside turns the primary and the inside turns the secondary of a high-frequency coil, the other parts of the high-frequency apparatus being the same as we have described above, a high-frequency discharge of a foot or more in length may be obtained. If the terminals of the secondary are separated, so that the discharge can not pass, the wire coils formed as above will appear, when viewed in a darkened room, like a huge, brilliantly glowing cylinder of purplish light. One of the writers once entertained a small audience of ladies and gentlemen for an hour and a half with a display of a large

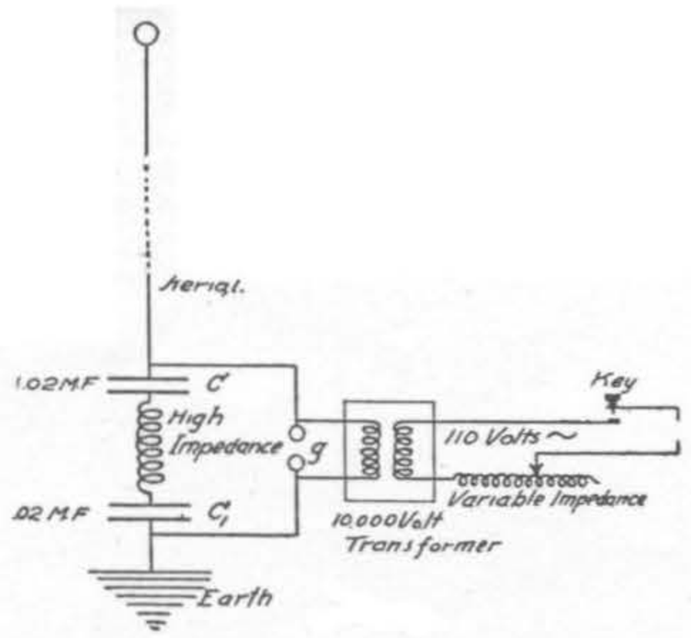


FIG. 7.—METHOD FOR EXCITING THE OSCILLATIONS.

variety of light effects obtained with a high-frequency apparatus, and we know of no more pleasing entertainment than can be furnished with properly selected experiments performed with a high-frequency apparatus of large power.

The high-frequency currents of low potential which pass through the primary circuit only may be made to yield in a simple manner many striking effects of induction and impedance. Thus an impressive but simple experiment is performed as follows: a single turn of heavy wire is made to complete the condenser circuit. Another single turn of heavy wire is connected near its ends by a suitable mounting upon which a small lamp socket is placed, containing a lamp of about six candle-power. The mounting of the lamp is so arranged that it can be used as a handle. When the condenser current is flowing through a single turn of wire and this is approached with the turn holding the small lamp, the latter will light up when the turns are at some little distance and can readily be made to give its full candle-power. One of Tesla's experiments is easily performed with great success as follows: a one-quarter-inch brass rod ten feet long is bent at its centre so as to form a narrow arch, the vertical sides of which are about ten inches apart. Suitable slides are made to work on these rods and upon these slides electric lamp sockets are placed. As we performed the experiment, a sixteen-candle-power lamp was placed in one socket near the bottom of the arch. Near the centre of the arch a ten-candle-power lamp was placed. Near the top an eight-candle-power lamp. When the current is taken from the condenser and passed through the arch, the phenomena of impedance are strikingly shown by these lamps. The lower lamp lights up nearly to full candle-power. The middle one remains dark, and the upper one, if care is not taken, will quickly burn out.

These simple experiments, and a great many others which space will not permit us to describe, can be performed by any one and the appliances for them can generally be made with very little trouble.

So many of these experiments come to the mind of one working with high-frequency currents, and go to show in a most convincing manner how influential are the effects of capacity, impedance and molecular bombardment, that it seems to us that the physical laboratory of any school or college is not complete unless supplied with apparatus for the production of high-frequency phenomena.

As the spectacular features of high-

frequency currents increase with the length and volume of the discharge which is obtained, it is of interest to many persons to strive to obtain the most powerful apparatus which can be built. The largest apparatus, for which the writers have specifications, gives a discharge of thirty-two inches.

It is probable, however, that an apparatus could be constructed which would give a discharge of considerably greater length and volume sufficient to bring sixteen-candle-power lamps to incandescence. The experience of the writers would indicate that the form of construction shown in diagrams 1 and 3 is that which is best adapted to obtaining the longest possible discharge lengths with greatest safety in insulation, and with apparatus constructed in the smallest compass. Whatever the length of discharge one wishes to obtain, the apparatus should be proportioned as above described. Roughly speaking, the length and diameter of each half of the secondary coil should be the same. For each inch of secondary winding of one-half of the secondary coil, two inches of discharge can be obtained. A good oil to use for the insulation is a clear thin paraffin oil, and its dielectric strength can be reckoned as at least ten times that of air for high-frequency potentials. As shown in a previous article by one of the writers, the dielectric strength of oil is greater for high-frequency potentials than for low-frequency potentials. If the above considerations hold beyond the range over which the writers have experimented, one ought to be able to obtain a discharge five feet in length with a coil, each half of which has a secondary winding about thirty inches high and about thirty inches in diameter at its base, and about twenty-two to twenty-four inches at its top. Of course, the greater the discharge length with a discharge having a given thickness, which one wishes to obtain, the greater must be the capacity of the transformer which charges the condenser. Our experiments indicated that the primary of the transformer required about one ampere at 110 volts pressure for each inch of high-frequency discharge, which had sufficient volume to light an incandescent lamp of sixteen candle-power. If great discharge lengths are sought, the condenser should be arranged to withstand a potential that will disrupt a parallel gap of at least one and one-half to two inches. The most feasible way to obtain a condenser of this strength and of sufficient capacity is to construct four condensers like the one described above, and join two pairs in series. It may here be remarked that to double the dielectric strength of a condenser and maintain its capacity unchanged, its volume must be increased four times. It is better to make several condensers and join them together in the combinations required for the capacity and dielectric strength sought, than to make one large condenser. In the former case, various capacities can be obtained for experimental purposes, and breakdowns are much more easily repaired.

The commercial uses of a powerful high-frequency coil are not very obvious at the present time. A coil, however, giving a six-inch discharge is very useful for the production of X-rays, chiefly where these are to be used for therapeutic purposes and where sharpness of definition is not essential. A coil of moderate power will excite a large tube to its fullest capacity, which will very brilliantly light fluorescent screens. It is possible that the physiological effects produced by charging the body of an insulated person from one terminal of a powerful coil may have certain beneficial effects.

Unquestionably, the best method of charging the aerial wire in wireless telegraphy experiments is by means of an oscillating discharge made with condensers and a transformer. One of the writers in April, 1902, made several experiments on the application of a transformer and condensers to exciting oscillations in the aerial of a wireless telegraph station. We can not enter into a full description of this much discussed subject, but for reference a diagram is here given of one method for exciting the oscillations, which was tried with great success. Consult Fig. 7, which is self-explanatory to those familiar with wireless telegraphy. The method shown in the diagram is only one of several that were successfully tried. The large impedance, which consisted of the secondary of a small induction coil, permitted the two condensers C and C to become charged from the transformer, but when the air-gap broke down a powerful surge of electricity was produced up and down the aerial and through the air-gap *g*, the resistance of which is greatly reduced by the heavy flow of current from the condensers and transformer. This was proved by the action on the coherer, the blowing of the fuses in the electric light circuits of a near-by building, as well as by the fact that sparks of considerable length could be drawn from the aerial a third way up its length into an insulated conductor, such as the blade of a shovel, which was held near it. In these experiments, the discharge across the gap would answer instantly to the most rapid tapping of the key, and the energy available was vastly in excess of what might be obtained from an induction coil.

In conclusion, we have to say that the phenomena of oscillating currents and high-frequency discharges are so complex, and the observations made so unexpected, that one must rely almost entirely upon experiment to learn what will happen each time that the conditions are slightly varied.

Tesla's Split Phase Motor Patent Decision.

Judge Hazel, of the United States Circuit Court of the Western District of New York, has handed down an opinion sustaining the two Tesla fundamental patents (Nos. 511,559 and 511,569), covering the split-phase motor. The suit was instituted by the owners of the patents against the manufacturer of a wattmeter, and the court held that the wattmeter infringed the patents for the reason that it depended for its action on two currents differing in phase, derived from a single supply circuit.

The patents involved were the same that figured in the Catskill case, in which suit they were sustained by the Circuit Court, but declared invalid upon appeal. This reversal was on the grounds that the publication of a magazine article on April 22, 1888, by Prof. Galileo Ferraris fully described and disclosed the system covered by the patents. This publication was held to be prior to the date of the invention in suit and constituted an anticipation.

Judge Hazel, in his opinion, disagrees very materially with Judge Townsend, who wrote the opinion on appeal, declaring the patents invalid. The conflict arises from the different weight which the two judges gave to the testimony of the several leading witnesses, this testimony being held by Judge Townsend to be inconclusive, and by Judge Hazel to establish clearly that Tesla conceived the invention prior to the publication of the Ferraris article. Judge Hazel considers that, according to the testimony, Tesla conceived his split-phase invention in his laboratory at 89 Liberty Street, New York, and completed the same in the month of September, 1887; and that he made the disclosure thereof to others during the fall of 1887, especially to Mr. Brown and Mr. Nellis, and subsequently in the month of April prior to the Ferraris publication to his solicitor, Mr. Page.

PATENT LITIGATION.

Tesla Split-phase Motor.

The suit of the Westinghouse Electric and Manufacturing Company against the Mutual Life Insurance Company of New York and H. C. Mandeville, brought to recover for alleged infringement by the defendants of Tesla patents, Nos. 511,559 and 511,560, has been decided in favor of the complainant. The infringement complained of was brought about by the use by the defendants of an alternating split-phase motor in a recording wattmeter, the infringing apparatus used being the Gutman meter. Judge Hazel, in his opinion, filed in the United States Circuit Court for the Western District of New York, on final hearing, says that the defense is "want of patentability, non-infringement and anticipation."

The first claim of patent No. 511,559 relates broadly to the method and extent of retardation of the phase of the current. The second claim refers specifically to the method of accomplishing in the electric currents a difference of phase. The claims of patent No. 511,560 refer particularly to the apparatus for effecting the object of the process of patent 511,559, and specify the devices constituting the split-phase motor with a single circuit. The construction adopted by the court is as follows:

"By the method and means therein described Tesla dispensed with one of the line circuits, and was able to run the motor by means of alternating currents from a single original source. This was accomplished by means which retarded the phases of the current in all circuits, or so varied the relative resistance of the motor circuits as to maintain the necessary difference in phase in the currents. Such utilization of a single original source by thus splitting a single current into two currents was an improvement of great practical value."

Of the contention that the patents were invalid because anticipated by the admitted publications of Prof. Galileo Ferraris on April 22, 1888, in Turin, Italy, Judge Hazel says: "Upon careful consideration of the proofs I have arrived at the conclusion that the actual date of the Tesla inventions is prior to this publication and that the patents were not void for anticipation. According to the evidence, Tesla conceived his invention in his laboratory, No. 89 Liberty Street, New York city, and completed the same in the month of September, 1887. He made disclosure thereof to others during the fall of 1887."

Judge Hazel concludes with the statement that the defendant has failed to establish any of the grounds upon which complainant's right to sue for infringement depends, and the complainant is therefore entitled to a decree in the usual form, with costs and disbursements.

The New York Times March 27, 1904

CLOUDBORN ELECTRIC WAVELETS TO ENCIRCLE THE GLOBE

This is Nicola Tesla's Latest Dream, and the Long Island Hamlet of Wardenclyffe Marvels Thereat.

TO gather in the latent electricity from the clouds and with the globe itself as a medium of transmission to convey telegraphic messages, power for commercial purposes, or even the sound of the human voice to the utmost confines of the earth is the latest dream of Nikola Tesla.

In an article which appeared recently in The Electrical World Mr. Tesla explains the theories on which the world telegraphy system is founded and what he expects to accomplish by it. His plans involve the establishment of stations for the transmission of messages and power, "preferably near important centres of civilization." Oddly enough, what Mr. Tesla proudly designates as the first of his commercial "world telegraphy" stations has been established at Wardenclyffe, L. I., which is not in any sense an important "centre of civilization," but a place described by train hands of the Long Island Railroad as a way station where "a passenger alights occasionally."

The transmitting station is an octagonal tower, pyramidal in shape, and some 180 feet in height. It consists of huge wooden stilts, heavily braced and reinforced, and surmounted by a cupola of interlaced steel wires, bent so as to form an arc. In the cupola there is a wooden platform occupying its entire width.

Mr. Tesla began work on his transmitting station about eighteen months ago. When he first came there, and it was understood that J. Pierpont Morgan had become interested in his odd enterprise and furnished him with financial assistance, a thrill of vague expectancy ran through the little settlement. The Wardenclyffe Land Company, which owns practically all the available ground in the vicinity, gave the inventor a free grant of some 175 acres of fine land, and then settled down to wait for the day when Wardenclyffe would become the centre of the universe.

Some of the farmers who come to Wardenclyffe to send their products to this city look at Mr. Tesla's tower, which is situated directly opposite the railroad station, and shake their heads sadly. They are inclined to take a skeptical view regarding the feasibility of the wireless "world telegraphy" idea, but yet Tesla's transmitting tower as it stands in lonely grandeur and boldly silhouetted against the sky on a wide clearing on the concession is a source of great satisfaction and of some mystification to them all.

"It is a mighty fine tower, said one good farmer to a visitor last week. "The breeze up there is something grand of a Summer evening, and you can see the Sound and all the steamers that go by. We are tired, though, trying to figure out why he put it here instead of at Coney Island."

While the tower itself is very "stagey" and picturesque, it is the wonders that are supposed to be hidden in the earth underneath it that excite the curiosity of the population in the little settlement. In the centre of the wide concrete platform which serves as a base for the structure there is a wooden affair very much like the companionway on an ocean steamer. The tower and the inclosure in which it has been built are being carefully guarded these days, and no one except Mr. Tesla's own men is allowed to approach it. Only they have been allowed as much as the briefest peep down the companionway.

Mr. Scherff, the private secretary of the inventor, told an inquirer that the companionway led to a small drainage passage built for the purpose of keeping the ground about the tower dry. But such of the villagers as saw the tower constructed tell a different story

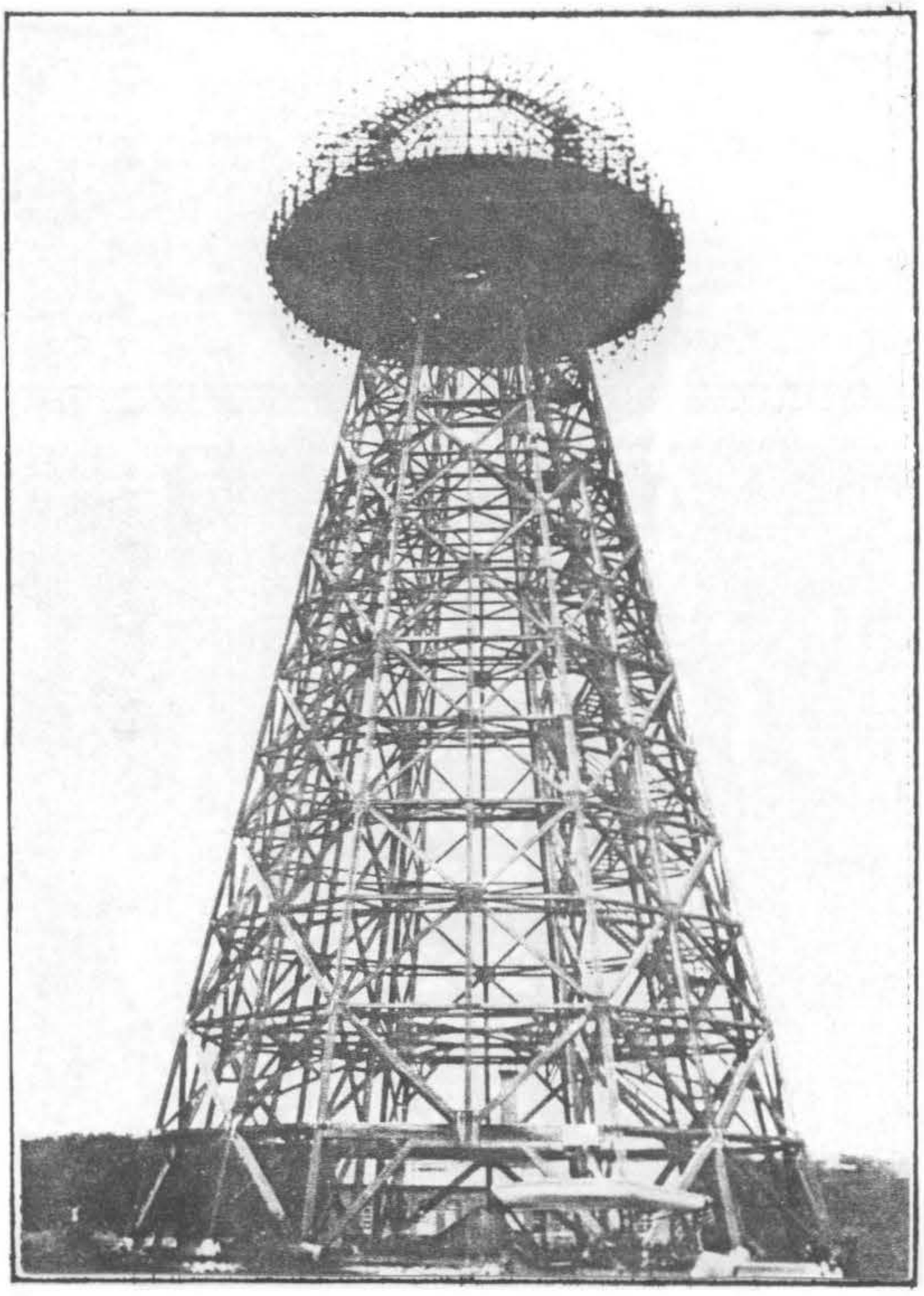
They declare that it leads to a well-like excavation as deep as the tower is high, with walls of masonwork and a circular stairway leading to the bottom. From there, they say, tunnels have been built in all directions, until the entire ground below the little plain on which the tower is raised has been honeycombed with subterranean passages.

They tell with awe how Mr. Tesla, on his weekly visits to Wardenclyffe, spends as much time in the underground passages as he does on the tower or in the handsome laboratory and workshop erected beside it, and where the power plant for the world telegraph has been installed.

No instruments have been installed as yet in the transmitter, nor has Mr. Tesla vouchsafed any description of what they will be like. But in his article he announces that he will transmit from the tower an electric wave of a total maximum activity of ten million horse power. This, he says, will be possible with a plant of but 100 horse power by the use of a magnifying transmitter of his own invention and certain artifices which he promises to make known in due course.

What he expects to accomplish is summed up in the closing paragraph as follows:

"When the great truth, accidentally revealed and experimentally confirmed, is fully recognized, that this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball and that by virtue of this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment; when the first plant is inaugurated and it is shown that a telegraphic message, almost as secret and non-interferable as a thought, can be transmitted to any terrestrial distance, the sound of the human voice, with all its intonations and inflections faithfully and instantly reproduced at any other point of the globe, the energy of a waterfall made available for supplying light, heat, or motive power, anywhere—on sea, or land, or high in the air—humanity will be like an antheap stirred up with a stick. See the excitement coming!"



TESLA'S MYSTERIOUS TOWER

With the aid of this structure the inventor proposes to operate a system of wireless telegraphy covering all the earth.

[409.]—**Tesla Oil Transformer.**—To Mr. Bottone.—I have made several of these, but none with the primary *outside* the secondary. But I do not think that the reverse position you propose would greatly influence the result, except perhaps as it may necessitate a rather longer length of primary wire. The gauge of your primary is very large, so I presume you propose using a very heavy current, say, 30 or 40 amps., as a minimum. I have never tried *bare* wire for the primary, but with oil insulation, provided the spirals can be kept accurately spaced, I see no reason why it should not do as well as covered wire. The secondary *must* be most heavily insulated (guttapercha, about $\frac{3}{32}$in. diameter, seems to give the best results). For the mode of construction see "Electrical Transmitters for Amateurs," p. 109, 7th edition. The difference in the spark, provided the *length* of secondary be the same, would be that the stouter wire would give a rather fatter spark. Not much; because, compared with the enormous voltage in the secondary, the difference of resistance would be but very trifling.

S. Bottone.

Tesla Split-Phase Motor Patent Decision.

Judge Kohlsaat on Saturday of last week handed down a d in a case involving the Tesla split-phase motor patent brought before the U. S. Circuit Court for the Northern District of Illinois, which decision upholds the Tesla patent and grants an injunction against the use of the split-phase principle in a wattmeter made by the defendants in the action. The opinion cites the opinions of Judges Archbold, Hazel, Townsend and Lacombe sustaining the patent, and the opinion of the Court of Appeals reversing the Lacombe decision, which latter ruling was followed by Judge Colt in another case. All of the above cases have been reported in these columns.

Judge Kohlsaat says that the decision of Judge Lacombe was reversed largely upon the ground that it did not appear from the record that Tesla's invention was not anticipated or described in a paper read by the late Prof. Ferraris before the Royal Acadmy of Sciences, of Turin, Italy, on March 18, 1888, and published, in part, in an electrical journal issued at Milan on April 22, 1888. He holds, however, that in the later cases—those decided by Judges Archbold and Hazel—the records, together with certain original proofs offered in the present case, establish that Tesla's invention in suit antedated the Ferraris article, was original with Tesla, and that his patents are valid.

The Colorado Springs Gazette April 6, 1904

TESLA IS SUED

Is Asked to Pay for Electricity Furnished Experimental Station He Abandoned.

Nicola Tesla, the famous electrical expert, whose experiment station on Knob hill has furnished material for queries on the part of visitors here during the past few years, is the defendant in a suit instituted in the county court yesterday by the Colorado Springs Electric company. The suit is brought to secure judgment for $180, said to be due for electrical energy furnished Tesla from June 1, 1903 to March 31, 1904. Tesla himself has not been in Colorado Springs for three years and the sheriff's office is trying to locate him for the service of the papers.

Tesla erected his experiment station for the purpose of perfecting his apparatus for the transmission of telegraphic messages without wires. Recently Tesla was sent a bill by the city for water furnished the station. In his novel reply he said that inasmuch as he had graced this city with his presence and had erected an experimental station here, he considered that the city should donate all the water used at the station.

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Wednesday Tesla's experiment station on Knob Hill was attached and will be sold under the hammer in five days if the $180 due the Electric company is not forthcoming.

Tesla Split-phase Patents.

In the action brought by the Westinghouse Electric and Manufacturing Company against the Electric Appliance Company of Chicago to restrain that company from selling or manufacturing the Gutmann wattmeter, Judge Kohlsaat of the United States Circuit Court in Chicago handed down the following decision on March 26th, sustaining the Tesla patents Nos. 511,559 and 511,560, on the rotating-field split-phase system, and granting the injunction asked for:

"This case comes now on to be heard upon complainant's motion for an injunction pendente lite restraining defendant from infringing letters patent Nos. 511,559 and 511,560. The inventions relate to the operation of rotating-field motors upon a single alternating-current circuit, under what is known as the Tesla split-phase system, applied in the present case to the operation of electric motors. The former patent covers the method of operating the motors, while the latter covers the means for so doing. The inventions may be said to consist in splitting the current, at the motor, into two or more branches, constituting the independent circuits of the motor, and producing by artificial means the difference of phase necessary to operate the motor. The drawings of the patents seem to call for an armature in the form of a cylinder.

"The defendant's armature consists of a disk. The specification and claims, however, of the patents in suit are not limited to details of form, but call broadly for 'an armature within the influence' of the energizing circuits. I am of the opinion that defendant's device is fairly embraced within the terms of the patents in suit. Both are operated under the principles of Tesla's patent of May 1, 1888, the invention of which was the production, by means of a series of stationary magnet poles, energized by alternating currents of different phase, of an effect upon an armature, mounted within the influence of such poles, similar to that which would be produced upon the same armature by rotating around it bodily the pole or poles of a physical magnet. The equivalency of the two is shown in Gutmann patent No. 614,225, under which defendant's device is manufactured. The difference in the location and application of the magnetic influence is equalized and compensated by a corresponding difference in the angles of the slots in the cylinder or disk. The principle of the rotary impulse and progression is the same. The question is satisfactorily settled for the purpose of this motion by the respective decisions in the suits brought by complainant herein v. Roberts, decided by Judge Archbald of the Eastern District of Pennsylvania, September 10, 1903, and same v. Mutual Life Insurance Company et al., decided by Judge Hazel of the Western District of New York, February 4, 1904.

"I deem the question of infringement duly established. From the record it appears that the validity of the patents in suit is assailed principally upon the Bailey and Ferraris publication set out. The former was practically eliminated from this case by the decision of Judge Townsend of the Second Circuit in the original suit upon Tesla's fundamental patents Nos. 381,968, 382,279 and 382,280, entitled Westinghouse Electric and Manufacturing Company v. New England Granite Company, 103 Fed. Rep., 95, which ruling was affirmed on appeal 110 Fed. Rep., 753, and again by Judge Archbald in the Roberts case (supra.). In the case of this complainant v. the Catskill Illuminating and Power Company, 121 Fed. Rep., 631, the Court of Appeals for the Second Circuit reversed the decision of Judge Lacombe, 110 Fed. Rep., 377, largely upon the ground that it did not appear from the record that Tesla's said inventions were not anticipated or described in the paper read by Professor Ferraris before the Royal Academy of Sciences, of Turin, Italy, on March 18, 1888, and published, in part, in an electrical journal issued at Milan on April 22, 1888. This ruling was followed by Judge Colt of the First Circuit in the case of complainants herein v. Stanley Instrument Company, not yet published. In the cases of Roberts and Mutual Life Insurance Company of New York (supra.), as herein, this difficulty was overcome. The records in those cases, together with certain original proofs herein, corroborative thereof, are now before the court, from which I am satisfied that Tesla's inventions in suit antedated the Ferraris article, and were original with him, and that the said patents are valid.

"It therefore becomes unnecessary to pass upon the other questions raised by complainant.

"The patents being found valid for the purposes of this motion, and also infringed, it follows that the preliminary injunction should be granted. Complainant's counsel may prepare an order in compliance herewith."

OUR GREAT PATENT OFFICE.

Nikola Tesla Discusses Its Workings and Calls for More Liberal Appropriations.

TO THE EDITOR OF THE SUN—*Sir:* It is to be regretted that statements discrediting the Patent Office should be given publicity, all the more as there is scarcely another institution reflecting such honor on the United States. Considering the vast amount and exquisite character of their work, the performance of the officials is really remarkable. In long personal experience I have found the examinations to be far more satisfactory than I would have ever thought possible. Many times I have noted with astonishment the thorough grasp of ideas, the keenness of the criticisms and the exhaustiveness of the search for anticipations, and invariably I have obtained valuable knowledge through the references cited and suggestions made.

The Patent Office is so vital to the interests of this country that any expressions capable of creating a doubt in the minds of people as to the faithful performance of duties and competency of its organs must be deemed unfortunate. Almost all the technical arts, industries and undertakings are more or less founded on patent protection, and if the belief should gain ground that the men called upon to render important decisions are incapable, and that the Commissioner in charge is a Khan, or Mogul, or Pooh Bah, running the office to suit his whims, public confidence in the value of these properties might be destroyed.

As a matter of fact, while it is true that examiners can never keep quite abreast with inventors, they are men well educated and trained, recruited from colleges. In addition to acquiring the indispensable special knowledge, they must pass an examination in physics, chemistry, quantitative and qualitative analysis, mathematics, including calculus, mechanical drawing and foreign languages. Surely such men should be able to understand an idea and to pass intelligently on the general merits of the documentary evidences submitted. Serious dissatisfaction, then, is not likely to arise from an examiner's deficient knowledge or lack of comprehension. Nor is it apt to come from an inherent defect of adopted procedures, although some of these might be omitted to advantage. For example, the suggestion of claims by the examiner in a case of conflicting applications is, in my opinion, always in favor of the inventor possessed of better knowledge and stronger imagination. The introduction of greater rigidity in the withdrawal and amendment of specifications might also be helpful. But, after all, what difference does it make how the original documents are modified? The successive changes are all recorded and can be examined at any time. If new matter is injected in an amended application it will not be permitted to remain, and, ultimately, the testimony in the interference will bring out the exact facts which will settle the question of priority. The advantages which might be secured by such or similar changes would be slight. But great improvements can be made in another direction.

Of late years the demand on certain departments has been increasing so fast that more expeditious methods had to be adopted; and this has naturally detracted from the quality of the work. The remedy, however, is simple and should be at once applied. What the Patent Office needs is a liberal appropriation.

One of the greatest problems confronting the world is to devise methods and means for protecting intellectual property. As we develop, this need asserts itself more and more. The ultimate aim should be to arrive at laws and regulations at least as precise as those which define the ownership of tangible things. A new principle is still to be discovered which will make this possible. Perhaps in the distant future, photographic records of the retina of the eye may furnish a foundation for a new and more perfect system of protection and just valuation of the creations of the mind. As far as I am able to understand the working of the human mechanism, such records offer the only chance of doing away with the present imperfect ideas of possession and use of crude equivalents. But let us bear in mind that for the time being the United States Patent Office is the farthest advance toward that ultimate aim. Taking this broader view of the institution we shall better appreciate its immense influence on the welfare and morals of the country.

So important an establishment should be provided for with the greatest liberality. This is by no means the case at present. All the departments are cramped to the utmost, and the salaries of the officials are ignominiously small. An examiner starts with $1,200 a year as fourth assistant, and may manage to get up to $1,800 as first assistant. The examiner-in-chief, whose decisions are so far-reaching, draws the noble salary of $2,500 a year. By the time he has attained this exalted position he realizes that he can earn four times as much elsewhere and he sends in his resignation. From the official replies I notice that in Division 16 no less than four chief examiners—Bissing, Rice, Winter and Dean—have left their posts in less than six years. That was a great loss to the Patent Office. Nothing but generous provision will do away with this evil. I should say that the salaries of the examiners should be at least doubled and their number increased, so as to induce able men to remain in office and permit the employment of specialists. A monumental building should be erected affording ample space, well lighted and ventilated, and provided with the most perfect facilities for the making of records and experimental demonstration of ideas.

For such purposes no expenditure could be too large. In a time when millions are allowed by our Government for what in but a few years must inevitably be turned into scrap iron and lost to the world, one of the greatest institutions in existence, of which even now the United States has every reason to be proud, should not be forgotten.

NEW YORK, May 18. NIKOLA TESLA.

Tesla on the Patent Office.

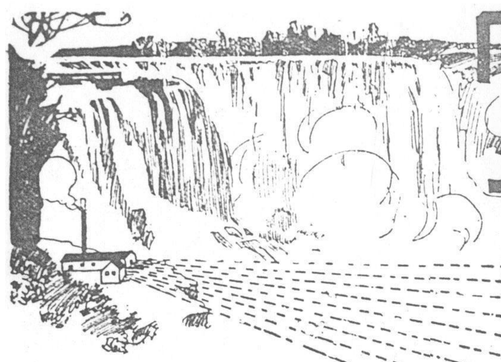
The New York *Sun* of Wednesday contained a letter from Mr. Nikola Tesla in which, referring apparently to recent publications concerning difficulties between Edison and the Patent Office, he takes up the cudgels for the office and is particularly complimentary in references to its technical staff. In a long personal experience he said he has found the examiners to be far more satisfactory than he had thought possible, and many times he has noted with astonishment the thorough grasp of ideas, the keenness of the criticisms and the exhaustiveness of the search for anticipations, while invariably he has obtained valuable information through the references cited and the suggestions made. He considers any criticism capable of creating a doubt in the minds of people as to the faithful performance of duties and competency of its staff must be deemed unfortunate, since such doubt may destroy confidence in the value of patent property. Mr. Tesla advocates more liberal appropriations and more suitable quarters for the Patent Office, and refers to the fact that owing to low salaries difficulty is found in retaining the services of competent men.

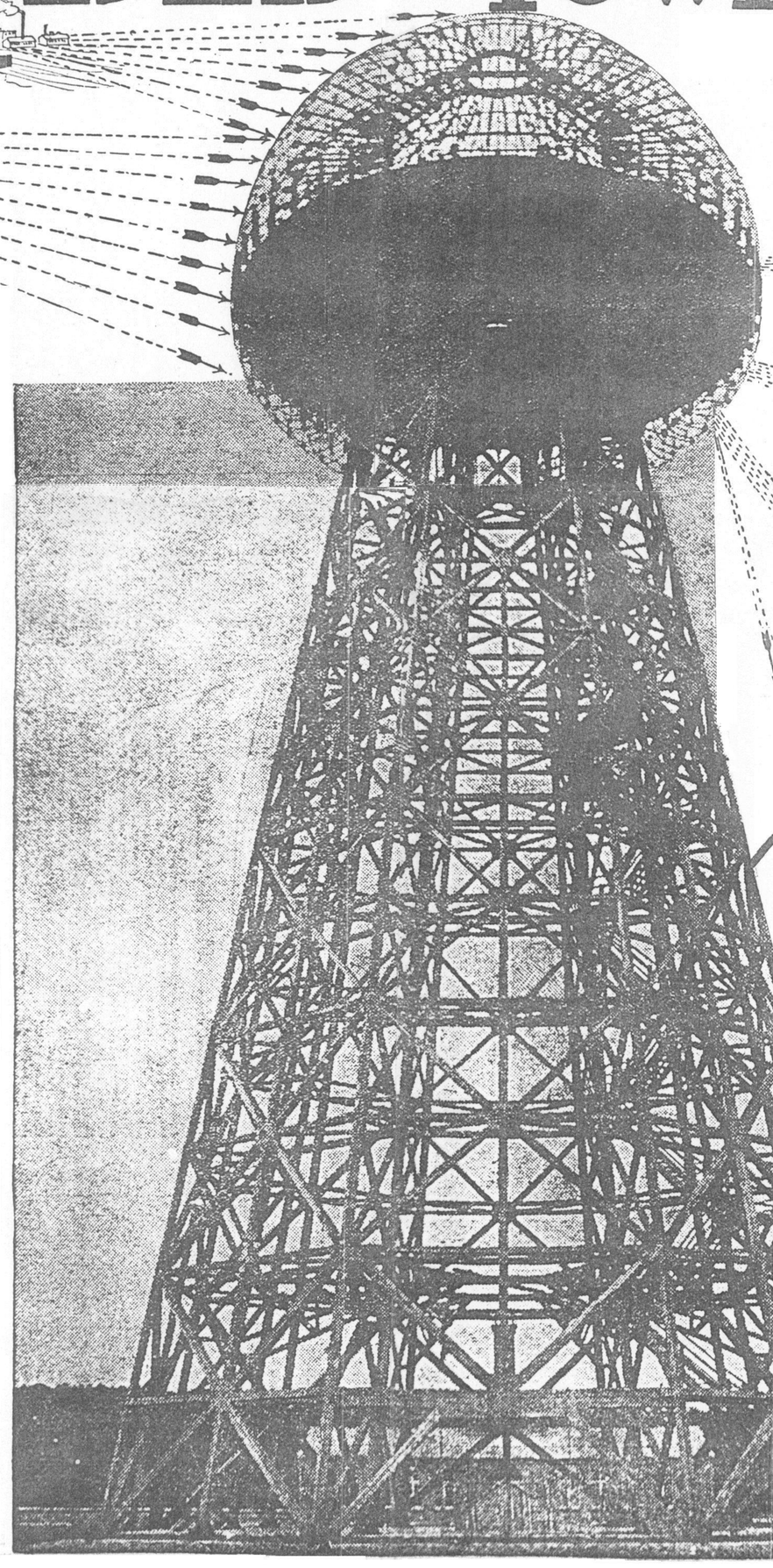
While examiners, he says, can never keep quite abreast with inventors, they are men well educated and trained, recruited from colleges, and to obtain appointment have to pass a severe examination covering the several branches of applied and cognate sciences. Serious dissatisfaction then is not likely to arise from the examiners' insufficient knowledge or lack of comprehension, nor is it apt to come from an inherent defect of adopted procedures, although some of these might be omitted to advantage. For example, the suggestion of claims by the examiner in a case of conflicting applications is, in my opinion, always in favor of the inventor possessed of better knowledge and stronger imagination. The introduction of greater rigidity in the withdrawal and amendment of specifications might also be helpful. But, after all, what difference does it make how the original documents are modified? The successive changes are all recorded and can be examined at any time. If new matter is injected in an amended application it will not be permitted to remain, and, ultimately, the testimony in the interference will bring out the exact facts which will settle the question of priority. The advantages which might be secured by such or similar changes would be slight. Of late years the demand on certain departments has been increasing so fast that more expeditious methods had to be adopted; and this has naturally detracted from the quality of the work. The remedy for this is a liberal appropriation.

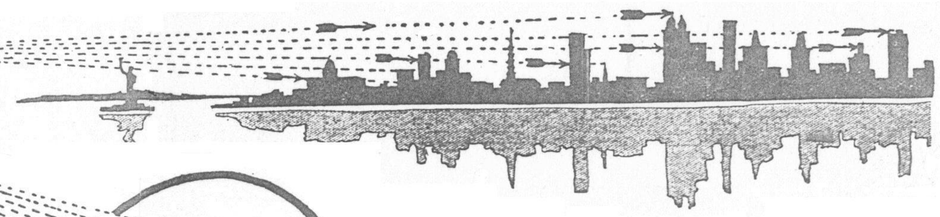
Mr. Tesla considers that one of the greatest problems confronting the world is to devise methods and means for protecting intellectual property. "As we develop, this need asserts itself more and more. The ultimate aim should be to arrive at laws and regulations at least as precise as those which define the ownership of tangible things. A new principle is still to be discovered which will make this possible. Perhaps in the distant future photographic records of the retina of the eye may furnish a foundation for a new and more perfect system of protection and just valuation of the creations of the mind. As far as I am able to understand the working of the human mechanism, such records offer the only chance of doing away with the present imperfect ideas of possession and use of crude equivalents. But let us bear in mind that for the time being the United States Patent Office is the farthest advance toward that ultimate aim. Taking this broader view of the institution we shall better appreciate its immense influence on the welfare and morals of the country."

TESLA'S TOWER

Amazing Scheme of the Great Inventor to Draw Millions of Volts of Electricity Through the Air From Niagara Falls and Then Feed It Out to Cities, Factories and Private Houses from the Tops of the Towers WITHOUT WIRES.









(Photo from the Electrical World and Engineer.)

Tesla's Wireless Transmitting Tower, 185 feet high, at Wardenclyffe, N. Y., from which the city of New York will be fed with electricity and by means of which the camperout, the yachtsman and Summer resort visitor will be able to communicate instantly with friends at home.

AN enormous mushroom-shaped tower, a photograph of which is reproduced on this page, has just been completed at Wardenclyffe, Long Island, N. Y., by Nikola Tesla, the distinguished electric inventor. From this tower Mr. Tesla is now preparing to put into operation the most daring and amazing scheme ever conceived in the development of wireless telegraphy.

For over four years Mr. Tesla has been hard at work almost day and night experimenting and endeavoring to make his marvellous theory practicable. From time to time during that period he has intimated vaguely at the immensity of his plan, and the equally tremendous results that would follow its introduction, and now, at last, he has announced his preparedness to put his theories to their first practical test.

Briefly explained, Mr. Tesla's assurances of what we may surely expect within the next year or so are as follows:

A perfect system of world-wide wireless telegraphy through which widely separated friends will be able to converse instantaneously and without the slightest danger that their wireless conversations will be overheard by a third person.

Little instruments about the size and shape of a watch, to be carried in the vest pocket and which will record market quotations, races and important news features in very much the same manner as the familiar "stock ticker" does at present. These vest pocket newsgatherers will enable the wearer to tell at a glance the condition of the stock market, etc.; even though he be thirty miles out at sea or as far distant inland from the nearest newspaper, "ticker," telephone or telegraph office.

Another little watch-like instrument, with a dial face by means of which the wearer can transmit and receive wireless messages to and from friends many miles away, watches of both sender and receiver being keyed to a certain pitch to prevent their communications from going astray or falling into the watches of disinterested third persons.

Wireless Trains and Trolleys.

A ceaseless day and night service of millions upon millions of volts of electricity from the Canadian Niagara Power Company's electric power plants at Niagara Falls to the Wardenclyffe tower, the electric power being forwarded from there by Tesla's wireless system to New York City for the purpose of illuminating the entire metropolis, running elevated and subway trains and street cars, operating elevators, automobiles, trucks and ferryboats, furnishing heat and even winding up clocks and making them keep perfect time by a system of half-hourly regulation.

The erection of Tesla towers similar to the one now at Wardenclyffe, at convenient places everywhere for the purpose of distributing wireless telegraphy to be used for illumination, power and heat. Only such towers as are erected within a given distance from Niagara Falls will be supplied from the power plants there with electricity. Each other tower will derive its own power from a generating plant erected alongside or between the main uprights, and each will distribute about ten thousand horse-power of wireless electricity under a tension of one hundred million volts. Mr. Tesla declares that he is able to produce and handle that much with perfect safety from one tower. Each tower will be capable of transmitting heat, power and light to cities, factories and private houses within a radius of thirty miles or more. Eventually Mr. Tesla proposes the extension of this tower system until practically the whole North American continent is dotted over with them, spaced about sixty miles apart, so that practically every inch of ground is covered by the new wireless service.

The woodsman, yachtsman or Summer resort visitor, wherever he or she may be can be communicated with instantly through the medium of one of the little watch tickers. The point of a parasol held aloft a mast or short pole as the case may be, will ensure the complete "picking up" of the wireless message after the watch has ticked off the first signal in the pocket.

In short, as Mr. Tesla has frankly admitted the possibilities of his amazing engine are simply boundless. He has not been able to realise to what extent it may be developed in the future.

The Wardenclyffe tower is 185 feet high from the ground to the top of the cupola. The smallest dimension across the base of uprights is 97 feet. The height to ledge of cupola is 153 feet, while the cupola itself is 65 feet in diameter. The tower has eight sides, with a staircase and lift for reaching the cupola platform. It is there that the wireless vibrations are received and shot out again in the voltage desired to given points scattered over a very wide radius.

Newspaper Printed in Vest Pocket.

"Much has already been done toward making my system commercially available in the transmission of energy in small amounts for specific purposes as well as on an industrial scale," said Mr. Tesla. "The results attained by me have made my scheme of intelligence transmission easily realizable. It constitutes I believe, in its principle of operation, means employed and capacities of application, a radical and fruitful departure from what has been done heretofore. I have no doubt that it will prove very efficient in enlightening the masses, particularly in still uncivilized countries and less accessible regions, and that it will add materially to general safety, comfort and convenience, and maintenance of peaceful relations. It involves the employment of a number of plants, all of which are capable of transmitting individualized signals to the uttermost confines of the earth. Each of them will be preferably located near some important centre of civilization, and the news it receives through any channel will be flashed to all points of the globe. A cheap and simple device, which might be carried in one's pocket, will accurately record the world's news or such special messages as may be intended for it. Thus the entire earth will be converted into a huge brain as it were, capable of response in every one of its parts. Since a single plant of but one hundred horse-power can operate hundreds of millions of instruments the system will have a virtually infinite working capacity, and it must needs immensely facilitate and cheapen transmission of intelligence.

"The first of these central plants is already completed. The best design of which I knew has been adopted, and the transmitter will emit a wave complex of a total maximum activity of 10,000,000 horse power, one per cent of which is amply sufficient to 'girdle the globe.' This enormous rate of energy delivery, approximately twice that of the combined falls of Niagara, is obtainable only by the use of certain artifices.

"For a large part of the work which I have done so far I am indebted to the noble generosity of Mr. J. Pierpont Morgan, which was all the more welcome and stimulating as it was extended at a time when those who have since promised most were the greatest of doubters.

Wireless Clocks and Light.

"Meanwhile, the transmission of energy on an industrial scale is not being neglected. The Canadian Niagara Power Company has offered me a splendid inducement. In this first power plant, which I have erected at Wardenclyffe, I propose to distribute 10,000 horse-power under a tension of 100,000,000 volts, which I am now able to produce and handle with safety.

"One of the chief uses will be the illumination of residences. It takes very little power to light a dwelling with vacuum tubes operated by high-frequency currents, and in each instance a terminal a little above the roof will be sufficient. Another valuable application will be the driving of clocks and other such apparatus. These clocks will be exceedingly simple, will require absolutely no attention and will indicate rigorously correct time. There are innumerable devices of all kinds which are either now employed or can be supplied, and by operating them in this manner I may be able to offer a great convenience to the whole world with a plant of no more than 10,000 horse power. The introduction of this system will give opportunities for invention and manufacture such as have never presented themselves before.

"Knowing the far-reaching importance of this first attempt and its effect upon future development, I shall proceed slowly and carefully. Experience has taught me not to assign a term to enterprises the consummation of which is not wholly dependent on my own abilities and exertions. But I am hopeful that these great realizations are not far off, and I know that when this first work is completed they will follow with mathematical certitude.

"Toward the close of 1898 a systematic research, carried on for a number of years with the object of perfecting a method of transmission of electrical energy through the natural medium, led me to recognize three important necessities: First, to develop a transmitter of great power; second, to perfect means for individualizing and isolating the energy transmitted; and, third, to ascertain the laws of propagation of currents through the earth and the atmosphere. Various reasons determined me to select for my experimental investigations the large plateau at Colorado Springs, two thousand metres above sea level, which I reached late in May, 1899.

Tesla's First Important Discovery.

"I found the earth was literally alive with electrical vibrations, and soon I was deeply absorbed in this interesting investigation. No better opportunities for such observations as I intended to make could be found anywhere. Colorado is a country famous for the natural displays of electric force. In that dry and rarefied atmosphere the sun's rays beat the objects with fierce intensity. I raised steam, to a dangerous pressure, in barrels filled with concentrated salt solution, and the tinfoil coatings of some of my elevated terminals shrivelled up in the fiery blaze. An experimental high-tension transformer, carelessly exposed to the rays of the setting sun, had most of its insulating compound melted out and was rendered useless. Aided by the dryness and rarefaction of the air, the water evaporates as in a boiler, and static electricity is developed in abundance. Lightning discharges are, accordingly, very frequent and sometimes of inconceivable violence. On one occasion approximately twelve thousand discharges occurred in two hours, and all in a radius of certainly less than fifty kilometres from the laboratory. Many of them resembled gigantic trees of fire with the trunks up or down.

"In the latter part of the same month I noticed several times that my instruments were affected stronger by discharges taking place at great distances than by those near by. This puzzled me very much. What was the cause? A number of observations proved that it could not be due to the differences in the intensity of the individual discharges, and I really ascertained that the phenomenon was not the result of a varying relation between the periods of my receiving circuits and those of the terrestrial disturbances. One night, as I was walking home with an assistant, meditating over these experiences, I was suddenly staggered by a thought.

"Once before it had presented itself to me, but I had dismissed it as absurd and impossible. Now I banished it again. Nevertheless, my instinct was aroused and somehow I felt that I was nearing a great revelation.

Experimenting with Stationary Waves.

"It was on the third of July—the date I shall never forget—when I obtained the first decisive experimental evidence of a truth of overwhelming importance for the advancement of humanity. A dense mass of strongly charged clouds gathered in the west, and toward the evening a violent storm broke loose which, after spending much of its fury in the mountains, was driven away with great velocity over the plains. Heavy and long persisting arcs formed almost in regular time intervals. My observations were now greatly facilitated and rendered more accurate by the experiences already gained. I was able to handle my instruments quickly and I was prepared. The recording apparatus being properly adjusted, its indications became fainter and fainter with the increasing distance of the storm, until they ceased altogether. I was watching in eager expectation. Surely enough, in a little while the indications again began, grew stronger and stronger and, after passing through a maximum, gradually decreased and ceased once more. Many times, in regularly recurring intervals, the same actions were repeated until the storm, which, as evident from simple computations, was moving with nearly constant speed, had retreated to a distance of about three hundred kilometres. Nor did these strange actions stop then, but continued to manifest themselves with undiminished force. Subsequently, similar observations were also made by my assistant, Mr. Fritz Lowenstein, and shortly afterward several admirable opportunities presented themselves which brought out still more forcibly and unmistakably the true nature of the wonderful phenomenon. No doubt whatever remained: I was observing stationary waves.

Confidential Chats Across Oceans.

"With these stupendous possibilities in sight, with the experimental evidence before me that their realization was henceforth merely a question of expert knowledge, patience and skill, I attacked vigorously the development of my magnifying transmitter, now, however, not so much with the original intention of producing one of great power as with the object of learning how to construct the best one. This is, essentially, a circuit of very high self-induction and small resistance which in its arrangement, mode of excitation and action, may be said to be the diametrically opposite of a transmitting circuit typical of telegraphy by Hertzian or electromagnetic radiations. It is difficult to form an adequate idea of the marvellous power of this unique appliance, by the aid of which the globe will be transformed. The electromagnetic radiations being reduced to an insignificant quantity, and proper conditions of resonance maintained, the circuit acts like an immense pendulum, storing indefinitely the energy of the primary exciting impulses and impressing upon the earth and its conducting atmosphere uniform harmonic oscillations of intensities which, as actual tests have shown, may be pushed so far as to surpass those attained in the natural displays of static electricity.

"When the great truth accidentally revealed and experimentally confirmed is fully recognised it will be seen that this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball, and that by virtue of this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment. When the first plant is inaugurated it will be shown that a telegraphic message, almost as secret and non-interferable as a thought, can be transmitted to any terrestrial distance, the sound of the human voice, with all its intonations and inflections faithfully and instantly reproduced at any other point of the globe and the energy of a waterfall made available for supplying light, heat or motive power anywhere—on sea, or land, or high in the air."

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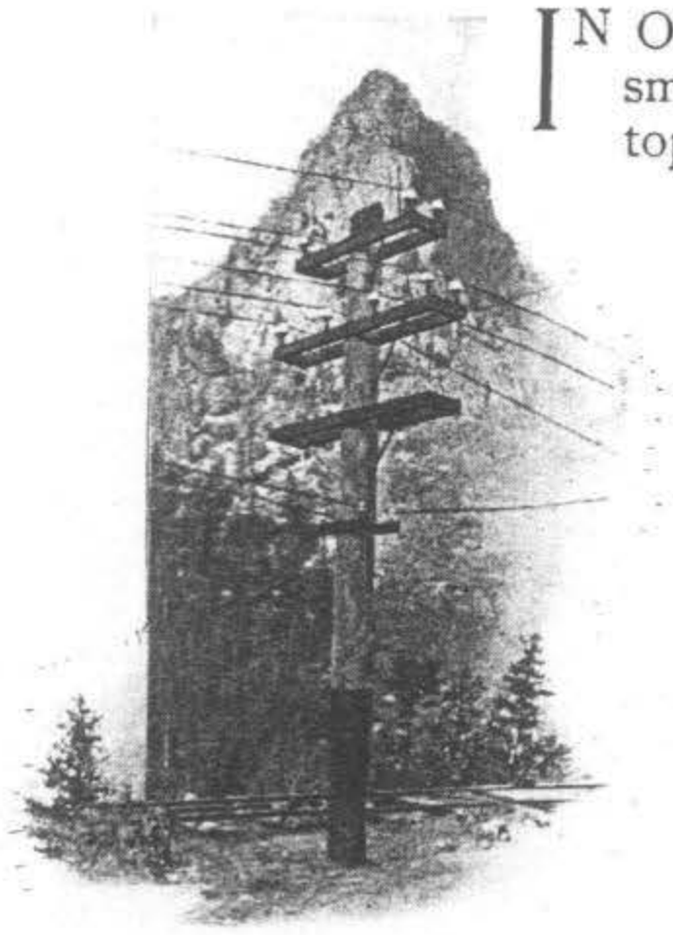
CASSIER'S MAGAZINE

VOL. XXVI JUNE, 1904 No. 2

THE DEVELOPMENT OF ELECTRIC POWER TRANSMISSION

By Lewis Buckley Stillwell



IN October, 1886, in a small room on the top floor of an old house in Pittsburgh, Pa., three hundred incandescent lamps were lighted continuously for a period of about two weeks by alternating current, transmitted a distance slightly exceeding two miles, over a single-phase circuit, comprising two copper wires of No. 4 B. & S. gauge. The potential used was 1000 volts, the frequency about 130 cycles per second, and the lamps were connected in parallel to the secondary circuits of half a dozen transformers. The ratio of transformation was 1000 to 50.

This was the first instance, in America at least, in which alternating current was used in transmitting electric energy beyond laboratory distances for the supply of translating devices connected in multiple arc. The alternator used to supply the power was driven by belt from a line shaft, to which a high-speed automatic engine was connected, and this generating plant was located in a shop of the Westinghouse Electric & Manufacturing Company on the banks of the Allegheny River within a mile of the site of old Fort Duquesne.

It was the writer's fortune to be detailed to watch those lamps during twelve hours out of every twenty-four during the test,—his first practical experience in applied electricity,—and he vividly recalls the keen interest with which everybody who had anything to do with the work observed the results. In the history of American industrial progress the Lawrenceville test, as it has been called, was an event of no little importance. To Stanley and Shallenberger, for the technical skill and for the patient work which produced the apparatus, and to George Westinghouse, whose far-sighted enterprise realised possibilities at that time scouted by others, all those who now are deriving benefit from the wonderfully extended use of alternating currents are under an obligation which they should be glad to recognise.

Prior to the Lawrenceville test, distribution of electric energy to lamps or motors had been accomplished by continuous-current systems operating at potentials of 110 to 220 volts. The

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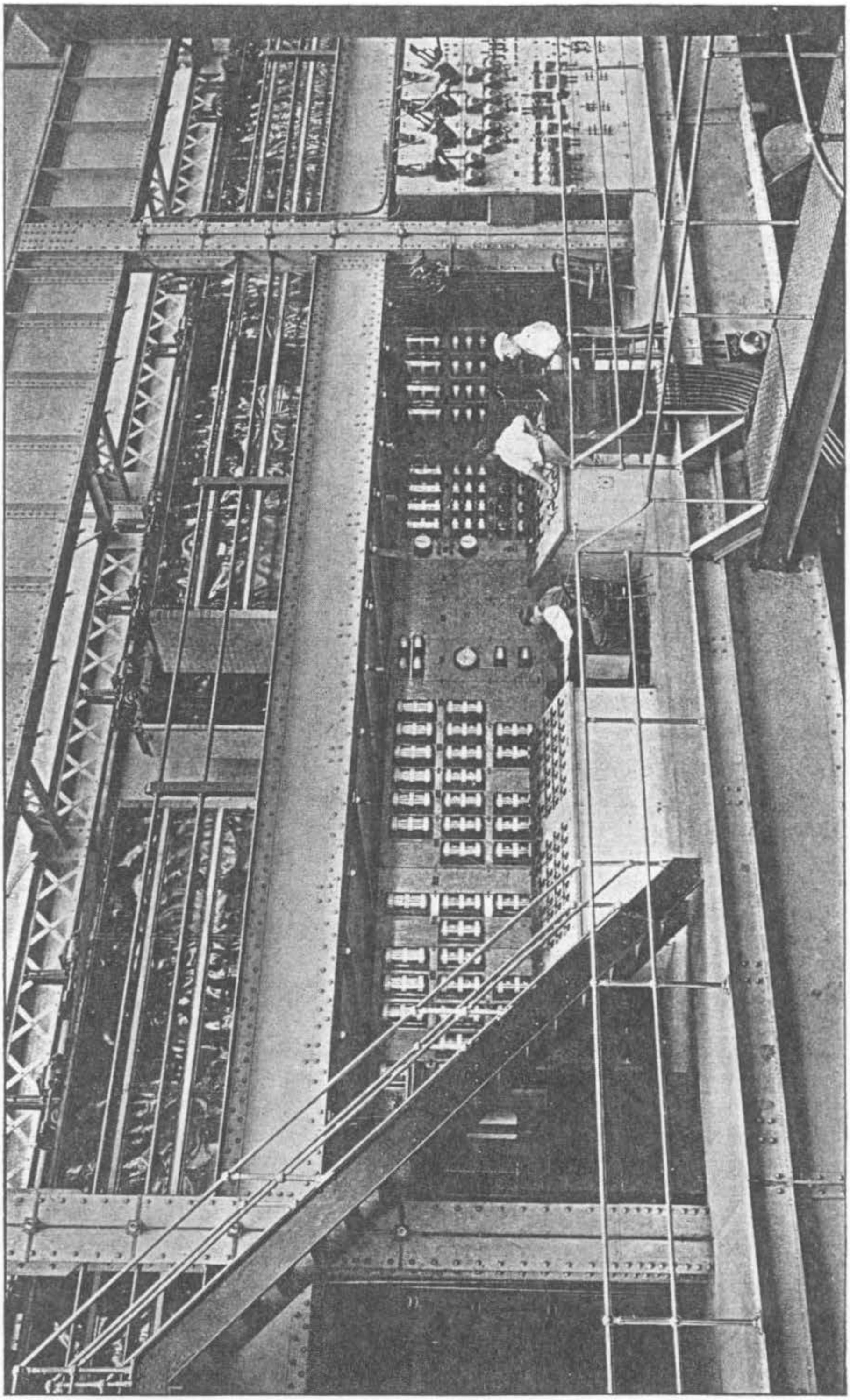


OPERATING AND INSTRUMENT BOARD OF THE MANHATTAN RAILWAY COMPANY, NEW YORK

TABLE I.—AMERICAN CENTRAL ELECTRIC STATIONS IN 1902

Items	Total	Private Stations	Municipal Stations
Number of stations	3,620	2,805	815
Cost of construction and equipment	$504,740,352	$482,719,879	$22.020,473
Earnings from operation	84,186,605	77,349,749	*6,836,856
Income from all other sources	1,514,000	1,385,751	128,249
Gross income	85,700,605	78,735,500	6,965,105
Total expenses	68,081,375	62,835,388	5,245,987
Salaried officials and clerks—			
Average number	6,996	6,046	950
Salaries	$5,663 580	$5,206,199	$457,381
Wage-earners—			
Average number	23,330	20,863	2,467
Wages	$14 983.112	$13,560,771	$1,422,341
Power plant equipment—			
Steam engines—			
Number	5.930	4,870	1,060
Horse-power	1,379,941	1,232.923	147,018
Water-wheels—			
Number	1,390	1,308	82
Horse-power	438.472	427,254	11,218
Generating plant equipment—			
Dynamos—			
Direct current, constant voltage—			
Number	3,823	3.405	418
Horse-power	442,446	418,913	23,533
Direct current, constant amperage—			
Number	3.539	2 957	582
Horse-power	195,531	157.768	37,763
Alternating and polyphase current—			
Number	5,122	4,300	822
Horse-power	987,003	896,315	90,688
Output of stations—			
Kilowatt hours, total for year	2,453,502,652	2,257,598,213	195,906,439
Total number of arc lamps	385,698	334,903	50,795
Total number of incandescent lamps	18,194,044	16,616,593	1,577,451

* Includes estimated income from public service.

three-wire system invented by Edison, permitting the use of a potential of 220 volts, was coming into use for general purposes in the larger cities, and was regarded as the highest potential available for such work. The general significance of the results of the Lawrenceville test was keenly realised; but the difficulties encountered in attempting to develop single-phase, alternating-current motors, capable of operation at the high frequency then used, practically prevented for a number of years the use of alternating current for power purposes. It was, however, rapidly developed and extensively applied in the field of incandescent lighting.

Tesla patented the polyphase alternating-current motor in 1888, but this also was slow in development, owing largely to the fact that for a long time in America efforts were principally directed toward the development of a motor adapted to the high frequency of 130 cycles per second. In 1890 the Westinghouse Company adopted as standards two lower frequencies,—60 cycles per second and 30 cycles per second. The step facilitated greatly the development of satisfactory polyphase motors, and not long afterward they began to come into commercial use.

The commercial significance of the Lawrenceville test is strikingly illustrated—although the impression conveyed by the illustration is a somewhat exaggerated one—by the story of the manager of a gold mine in Colorado, who, in 1896, was able to operate a stamp mill located at a distance of about three miles from his water-power by alternating current transmitted to the motor over a circuit consisting of iron telephone wire of ordinary size. This was accomplished by using a high-potential single-phase alternating current. The cost of the telephone wire was about sixty dollars. It is stated that an estimate for a continuous-current plant to do the same work had been submitted by a manufacturer of continuous-current machinery, and that these plans called for the installation of copper circuits costing more than sixty thousand dollars.

United States Census Bulletin No. 5, recently issued, places us for the first time in possession of many important and extremely interesting statistical facts relating to the use of electricity for light

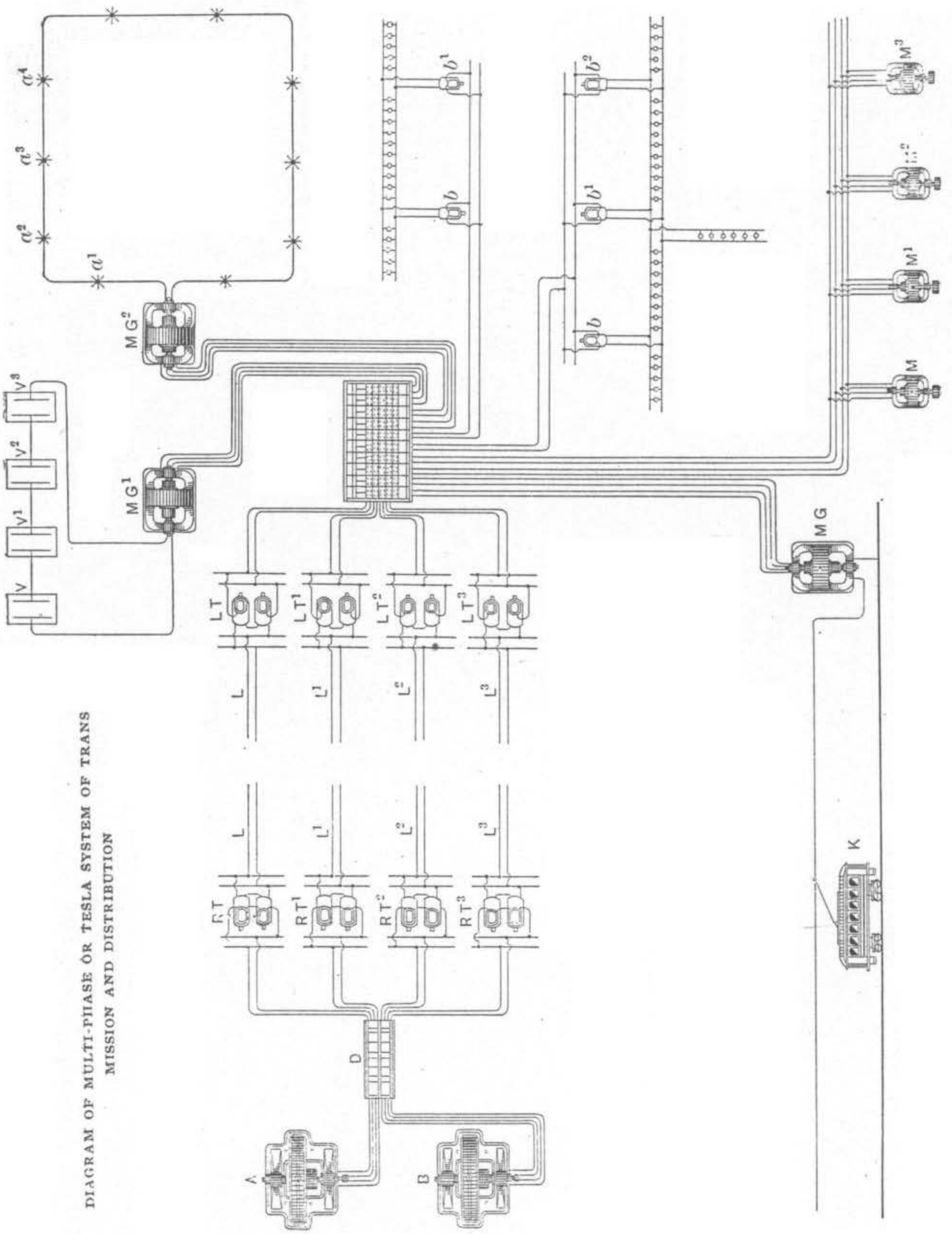


DIAGRAM OF MULTI-PHASE OR TESLA SYSTEM OF TRANS MISSION AND DISTRIBUTION

and power purposes in the United States exclusive of its use for traction purposes. Table I. of this bulletin cannot be improved by further condensation, and is, therefore, here reproduced.

It will be noted that of the aggregate output of dynamos installed in central stations which supply power exclusively for lighting and power purposes, which aggregate amounts to 1,624,480 horse-power, the rated output of alternating-current dynamos constitutes more than 60 per cent. A considerable number of electric power plants, installed primarily for the purpose of operating street and electric railways, also supply current for lighting and power purposes, and if these be added to those which furnish power for lighting and power purposes only, the grand aggregate of central stations becomes 3738, the number of arc lamps 419,561, the number of incandescent lamps 19,636,729, and the total income from the sale of current $90,458,420.

The relative commercial importance of the central electric station industry and gas industry is shown in Table II., which also is reproduced from Census Bulletin No. 5.

The peculiar value of alternating-current development resulting from the reduction in cost of distribution which is effected by this class of apparatus is illustrated by the fact that 75 per cent. of the central electric stations are in towns of less than 5000 inhabitants, as compared with 22.8 per cent. of the gas plants.

As regards stationary motors, the aggregate number installed is 101,064, and their aggregate horse-power amounts to 624,686. The total rated horse-power of steam engines and water-wheels used to drive dynamos is 1,772,813, of which total 77.8 per cent. are the indicated capacity of steam engines and 22.2 per cent. the stated capacity of water-wheels.

TABLE III.—PERCENTAGES THAT THE NUMBER AND HORSE-POWER OF THE DIFFERENT VARIETIES OF DYNAMOS ARE OF THE TOTAL STATIONS IN 1902

Kind of Dynamo	Total
Total—	
Number	100.0
Horse-power	100.0
Direct-current, constant voltage—	
Number	30.6
Horse-power	27.2
Direct-current, constant amperage—	
Number	28.3
Horse-power	12.0
Alternating and polyphase current—	
Number	41.0
Horse-power	60.8

The relative number of dynamos and relative aggregate horse-power of alternators, as compared with direct-current, constant voltage machines and direct-current, constant ampèrage machines, are shown in Table III.

It will be noted that the average alternator is a much larger machine than the average direct-current machine of either of the two direct-current classes.

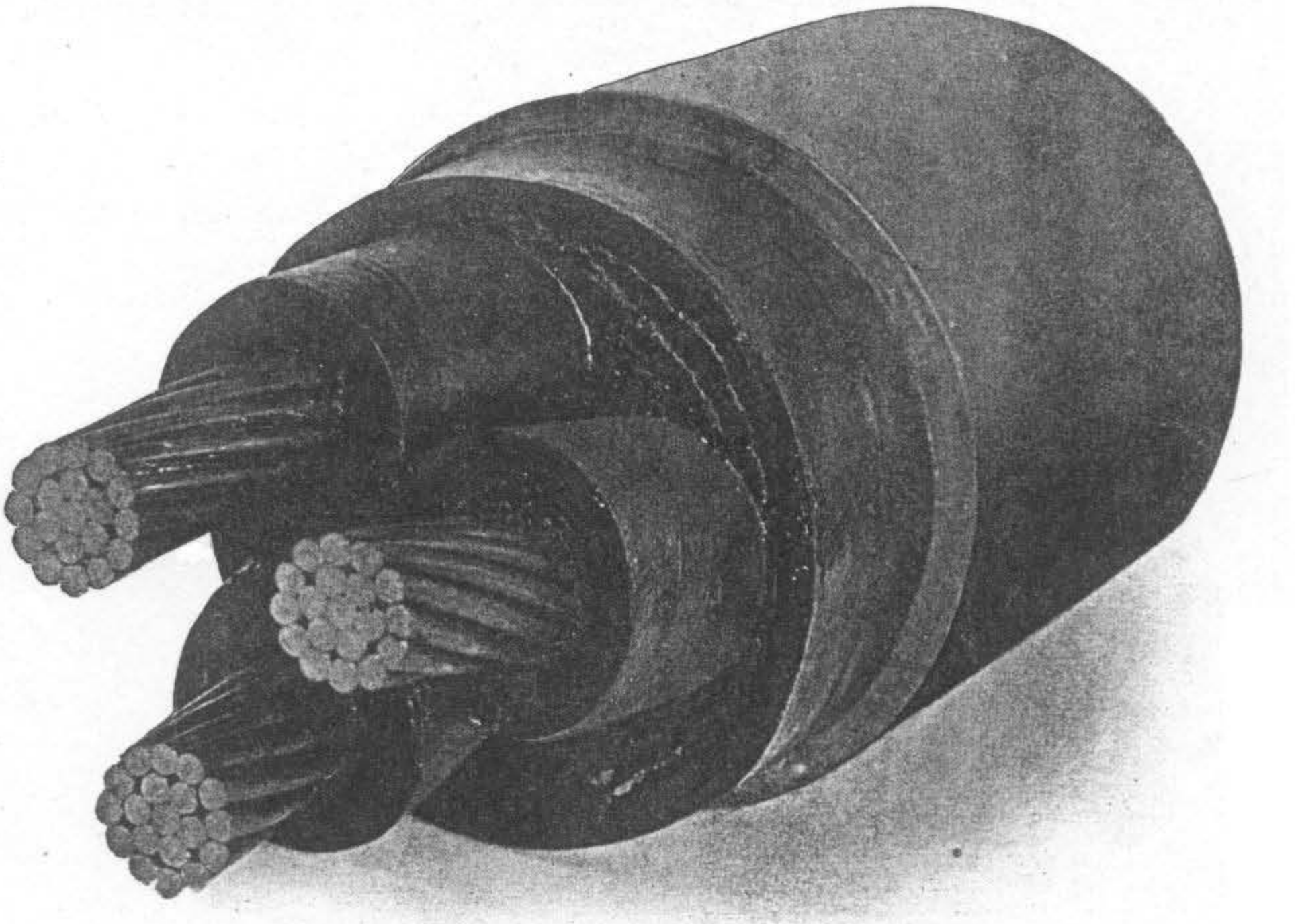
It is impracticable within the limits of this article to attempt anything like a comprehensive review of the development of alternating-current apparatus for transmission and distribution of power which shall refer even briefly to the many small steps which, in the aggregate, have contributed so much to the march of progress; but in brief retrospect reference to a few of the more important steps may serve to emphasise the remarkable rapidity which has characterised the evolution of this comparatively young, but very vigorous, addition to present industrial assets.

TABLE II.—COMPARATIVE SUMMARY OF AMERICAN CENTRAL ELECTRIC STATIONS AND GAS PLANTS

Items	Central Electric Stations, 1902	Gas Plants, 1,900
Number of establishments	3,620	877
Cost of construction and equipment	$504,740 352	*$567,000,506
Cost of supplies, material and fuel	22 915,932	$20,605,356
Salaried officials and clerks—		
Average number	6,996	5,904
Salaries	$5,663,580	$5,273,500
Wage-earners—		
Average number	23,330	22,459
Wages	$14 983,112	$12,436.296
Income	85,700,605	†75,716,693

* Capital. † Value of products.

In 1890 the celebrated Frankfort-Lauffen transmission illustrated and emphasised the possibilities of high-potential alternating current in bridging



A FULL-SIZE SECTION OF THREE-CONDUCTOR, PAPER-INSULATED CABLE FOR 11,000 VOLT THREE-PHASE TRANSMISSION USED BY THE INTERBOROUGH RAPID TRANSIT CO., NEW YORK

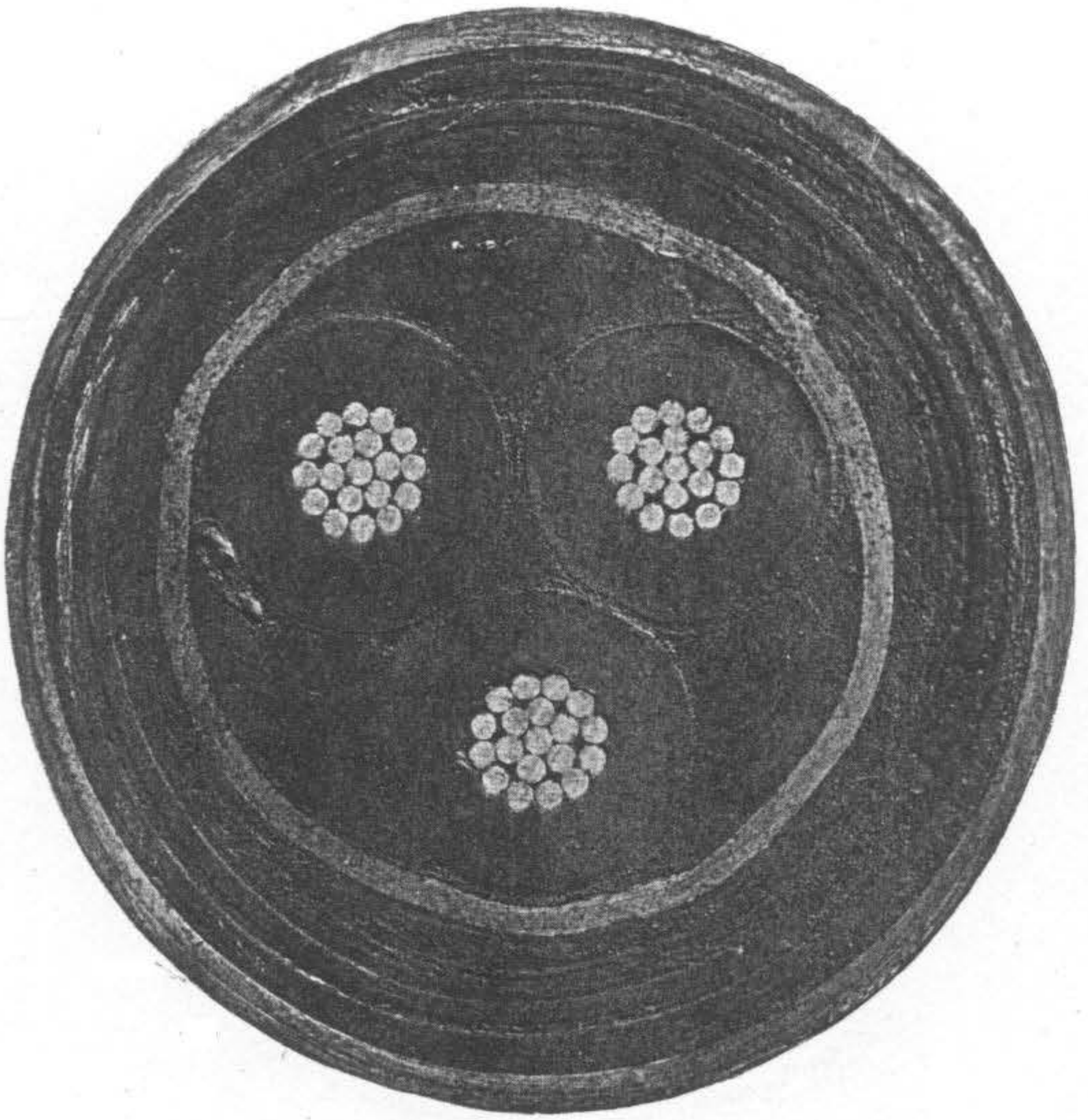
great distances. The potential used during the test was at times 14,000 volts, and at other times 28,000 volts; the distance was 110 miles; the amount of power was small,—about 200 H. P. The transmission was in no sense a commercial success, nor, indeed, was it expected to be. It served its purpose, however, of demonstrating, upon a scale sufficiently large, the possibility of insulating a long circuit effectively for potentials very high as compared with anything previously attempted, and it also served the purpose of concentrating attention in many quarters upon the subject of electric power transmission, and so contributed in a striking and effective manner to the commercial development of a relatively new art.

In America the first important attempt at transmitting power for commercial purposes at a potential materially exceeding the 3000 volts used at Telluride, Colorado, in 1890, was the installation of the plant at San Bernardino and Pomona, in Southern California. The potential used was 10,000 volts; the distance from the water-power to San Bernardino was twenty-nine miles.

On May 2, 1893, Mr. George H. Winslow, engineer in charge of the plant, connected the Pomona circuit in series with that to San Bernardino and transmitted about 100 E. H. P. to San Bernardino, a distance of forty-two and one-half miles, this being by far the greatest distance attained in America up to that time.

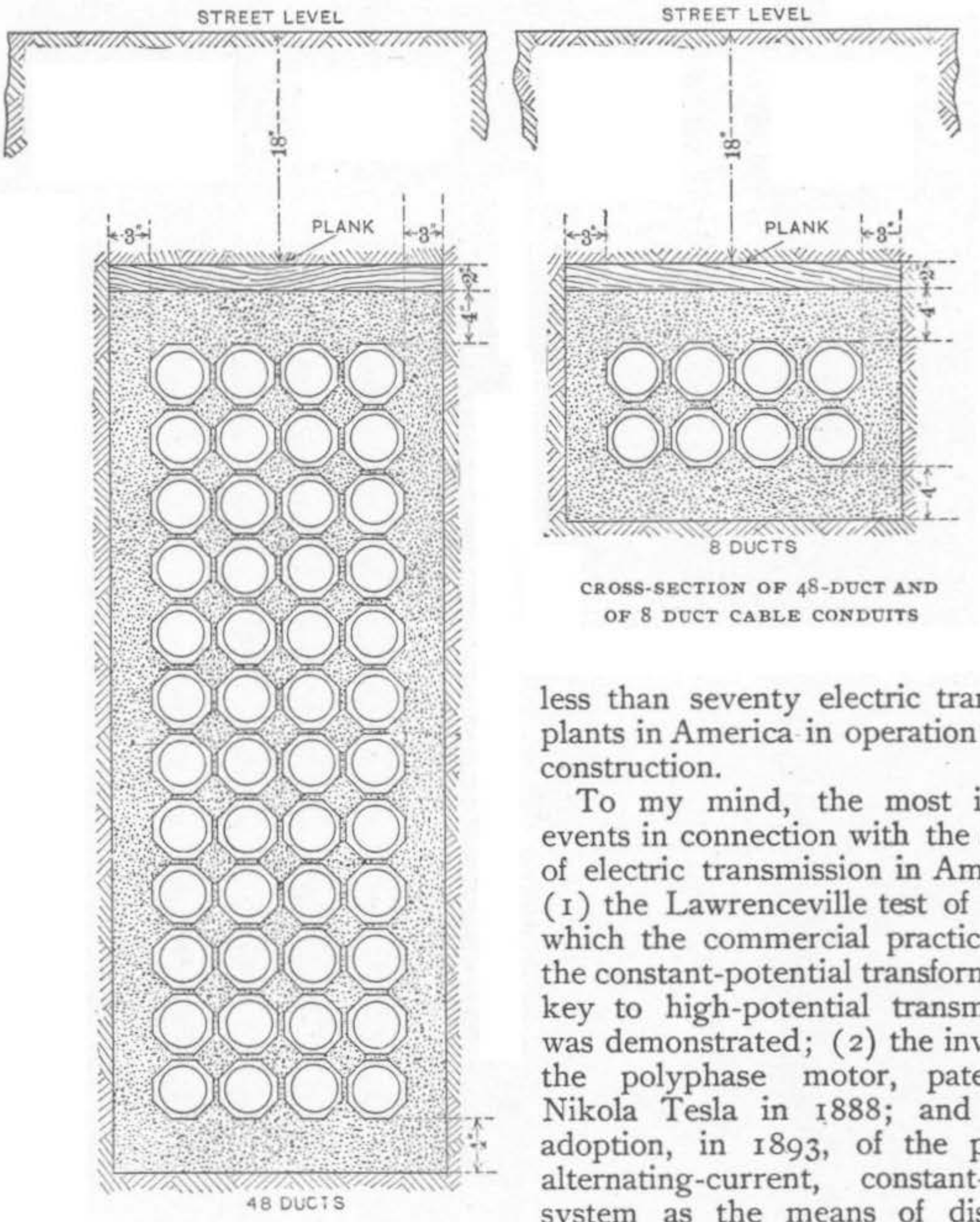
About that time, in various shops and laboratories of America and Europe, the polyphase motor was fast taking commercial form, and at the Chicago Exposition of 1893 some striking and important exhibits of polyphase apparatus were shown in operation. Among these was a complete power transmission

plant, comprising a 375-KW, two-phase alternator, an outfit of step-up and step-down transformers connected by a high-potential circuit, a 375-KW rotary converter delivering continuous current at 550 volts, a 60 H. P. synchronous motor, and a number of induction motors, ranging from 1 H. P. to 15 H. P. The system was two-phase, the frequency 30 cycles per second, and the potential of the transmission circuit 10,000 volts. At the receiving end of the line incandescent lamps were supplied through transformers, and arc lamps were fed by continuous current from the rotary converter. Continuous current from the rotary converter was also used to operate direct-current motors. The diagram on page 100, which is reproduced from a descriptive circular published at the time, shows that this plant embodied all essential features of the latest transmission plants, except that two-phase circuits were employed instead of the three-phase plan now generally preferred. The Germans were first to perceive clearly the advantages of the three-phase system, as compared with the two-phase system, and to push the development of three-phase apparatus. Dobrovolski showed me, in Berlin, in 1890,—possibly as early as 1889,—a three-phase motor probably capable of developing a quarter of a horse-power. In America, Bell, of the General Electric Company, installed the first three-phase plant at Redlands, in California, in 1893.



FULL SIZE RUBBER-INSULATED, STEEL-ARMOURED, THREE-CONDUCTOR CABLE FOR SUBMARINE WORK, USED BY THE INTERBOROUGH RAPID TRANSIT COMPANY OF NEW YORK, UNDERNEATH HARLEM RIVER

From the autumn of 1892, to October, 1893, the officers and engineers of the Cataract Construction Company were systematically working toward a



CROSS-SECTION OF 48-DUCT AND OF 8 DUCT CABLE CONDUITS

decision of the great engineering question of the best method of utilising the power of Niagara, and in the month last mentioned they executed a contract for polyphase alternating-current machinery to be installed in a central station and utilised in generating electricity to be distributed for power and lighting purposes. The decision of the Cataract Company, which had studied the subject exhaustively, both in Europe and America, had a notably stimulating effect, and less than two years later, in the Niagara power number of CASSIER'S MAGAZINE, issued in July, 1895, the late S. Dana Greene, in a very interesting article upon "Distribution of Niagara Energy," was able to list not less than seventy electric transmission plants in America in operation or under construction.

To my mind, the most important events in connection with the evolution of electric transmission in America are (1) the Lawrenceville test of 1886, by which the commercial practicability of the constant-potential transformer,—the key to high-potential transmission,—was demonstrated; (2) the invention of the polyphase motor, patented by Nikola Tesla in 1888; and (3) the adoption, in 1893, of the polyphase alternating-current, constant-potential system as the means of distributing power from Niagara Falls.

The Lawrenceville test demonstrated the possibilities of the transformer in reducing the cost of transmitting circuits; the invention of the polyphase motor furnished the means of utilising the transmitted power for power purposes, and the adoption of polyphase alternating currents by the Cataract Construction Company for the great work at Niagara Falls sealed the commercial success of the system. An excellent meter for alternating currents had been invented and perfected by Shallenberger as early as 1888, and Elihu Thomson also had produced an effective meter for the same kind of service.

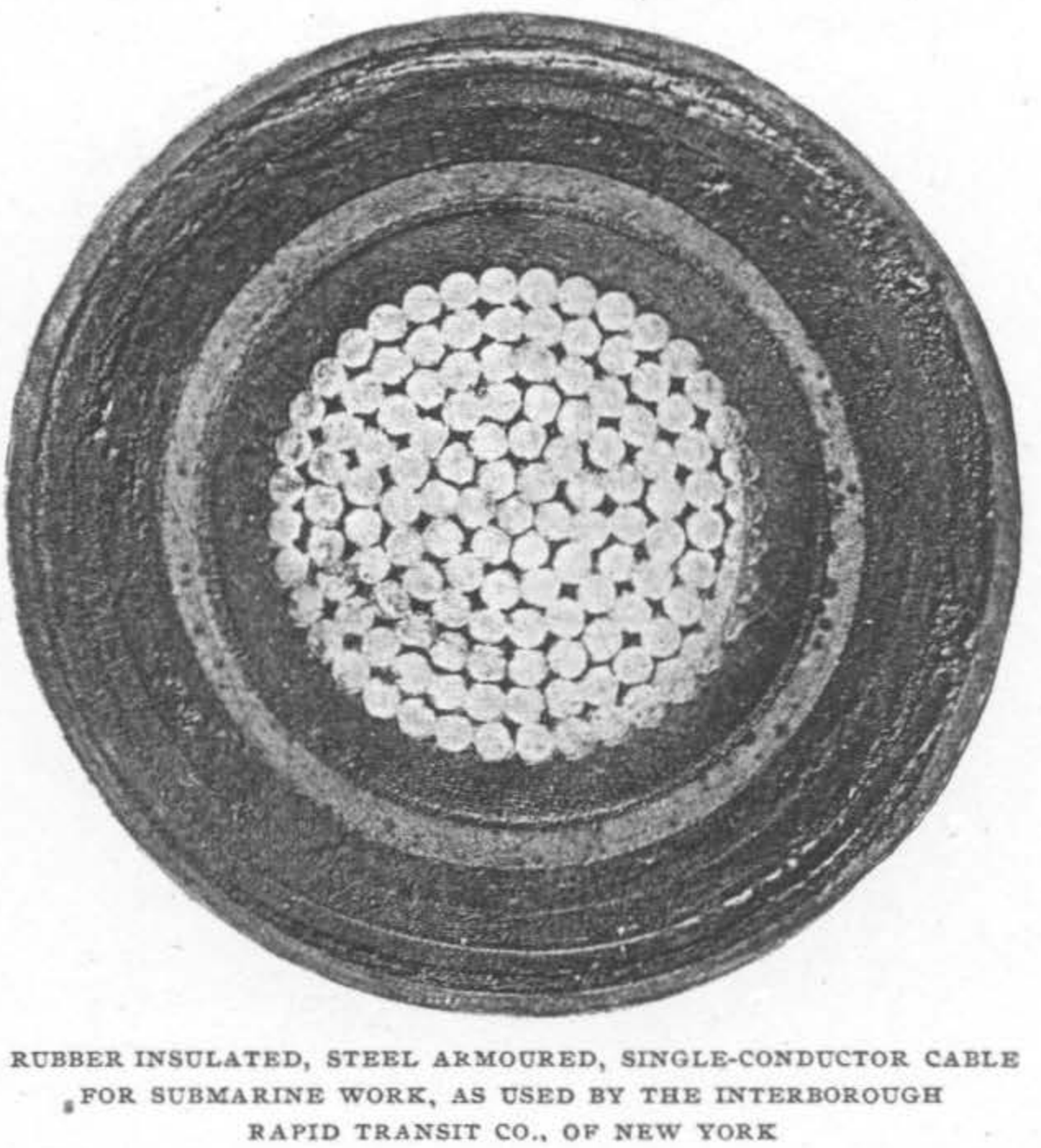
But the invention of the transformer,

the motor, and the meter left still to be developed much apparatus of prime importance in the construction of the complete and effective plant for transmission and distribution of power by electricity. Switches, operated automatically or otherwise, and adapted to high-potential circuits; insulators for overhead lines and insulation for underground cables; devices for protecting apparatus against the effects of lightning,—all these and other adjuncts, now deemed essential, were still in the future in 1893 so far as heavy power circuits carrying high potentials were concerned, and still in the future also was the question how best to aggregate the complicated apparatus of a transmission system,—one of the great questions of engineering practice which still receives answers varying in respect to important details, but varying far less than they did ten years ago. There remained also the training of men and the development of effective organisations for operation,—a work in itself requiring time, thought, and painstaking effort.

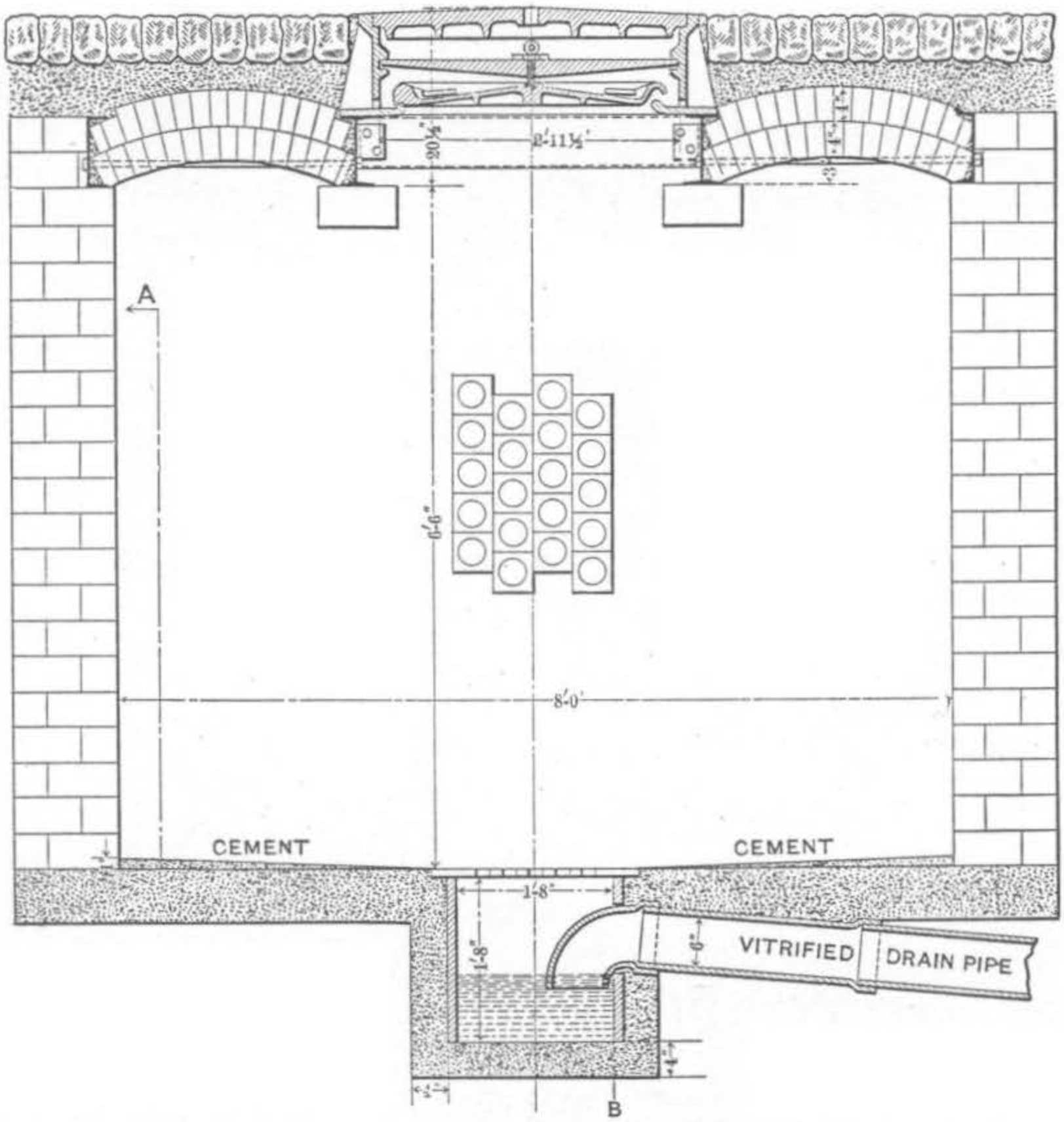
Thanks to Hopkinson, Kapp, Schmid, Brown and others, the art of dynamo design had been developed to a point where it became possible to predetermine the constants of a dynamo, and to design and build in full confidence that the results attained under test would coincide with expectation based upon calculations. The transformer, the motor and the meter placed us in possession of means for delivering and measuring power at a distance; but, as has been indicated, much remained to be done in the development of a reliable system.

It should be noted also that the development of apparatus for electric transmission thus far has been effected necessarily not with reference to fixed ultimate conditions, but with reference to conditions which are constantly changing by reason of the demand for higher and still higher potentials, and by reason of the increased complexity of circuits which results from the growth of existing plants. As the possibility of bringing greater distances becomes apparent, the demand for increased potentials makes itself felt, and every important increase of potential implies corresponding increase in insulation of circuits, including transformers, switches and all devices connected therewith.

Again, as a given power company extends the sale of its product, every additional user of power implies additional apparatus connected to the circuits and increased risk of interruption of the general supply of power to customers of the company. Increase of potential must be met by improvement in insulation, and interruptions due to aggregate length and complexity of an interconnected system of conductors must be met by improvement in automatic circuit-breaking devices, arranged with reference to the location of interruptions of service due to failure of insulation or



RUBBER INSULATED, STEEL ARMOURED, SINGLE-CONDUCTOR CABLE FOR SUBMARINE WORK, AS USED BY THE INTERBOROUGH RAPID TRANSIT CO., OF NEW YORK



CROSS SECTION OF A CABLE MANHOLE OF THE MANHATTAN DIVISION OF THE INTER-BOROUGH RAPID TRANSIT COMPANY, OF NEW YORK

other causes. The fact that during the past ten years the rate of interest upon capital has been decreasing in America has, doubtless, tended to lessen in some degree the force of the argument in favour of a rapid increase in potentials adopted for new plants; but the reasoning which is brought to bear upon such questions as the selection of potential too often has little connection, or at least little conscious connection, with such matters as a progressive fall in rates of interest.

A subject that has received less attention than it deserves is the difficulty of maintaining an uninterrupted supply of power to the motors, lamps, and other translating devices used by customers which results from increased lengths of conductors and increased numbers of translating devices connected to a single source of supply. Electrical engineers are not accustomed to enlarge upon the subject of interruptions of service, but the first step in the correction of defects is recognition of their existence, and reference to this phase of the general subject may be useful.

Obviously, interruptions of service may have their origin in the power plant, in the transmitting circuits, or in apparatus located upon the premises of the user. Other things being equal, those due to line troubles will vary with the length of the line, as has been clearly recognised since the earliest days of transmission. Equally obvious, but apparently less clearly recognised, is the fact that a plant delivering power to a dozen users over a line of equal length faces an increased risk of interruption of service by reason of the addi-

tion of a number of branch circuits at the receiving end of the line, and connection to the system of a dozen outfits of apparatus in users' premises in place of one. Where it happens necessarily, as at Buffalo, at Milan, and at a few other places, that a very considerable number of users are supplied through cables placed underground, which cables, in turn, receive through transforming stations their supply from overhead transmitting circuits extending across country from the water-power, the difficulties in the way of maintaining an uninterrupted supply of power become very serious.

Imagine, if you please, that in a given city a score of separate steam engines are used to drive line shafts in twenty factories and mills. Each of these engines is liable to a certain number of accidental interruptions of service, averaging, perhaps, one per annum. If, for the twenty steam plants, twenty electric motors, supplied through an inter-connected system of conductors, be substituted, it is evident that effective means must be adopted to prevent an accident to one motor, resulting in interruption of service in the twenty factories and mills; otherwise if accidents causing interruption average the same with motors as with steam plants, each user will suffer from twenty interruptions per annum instead of from one.

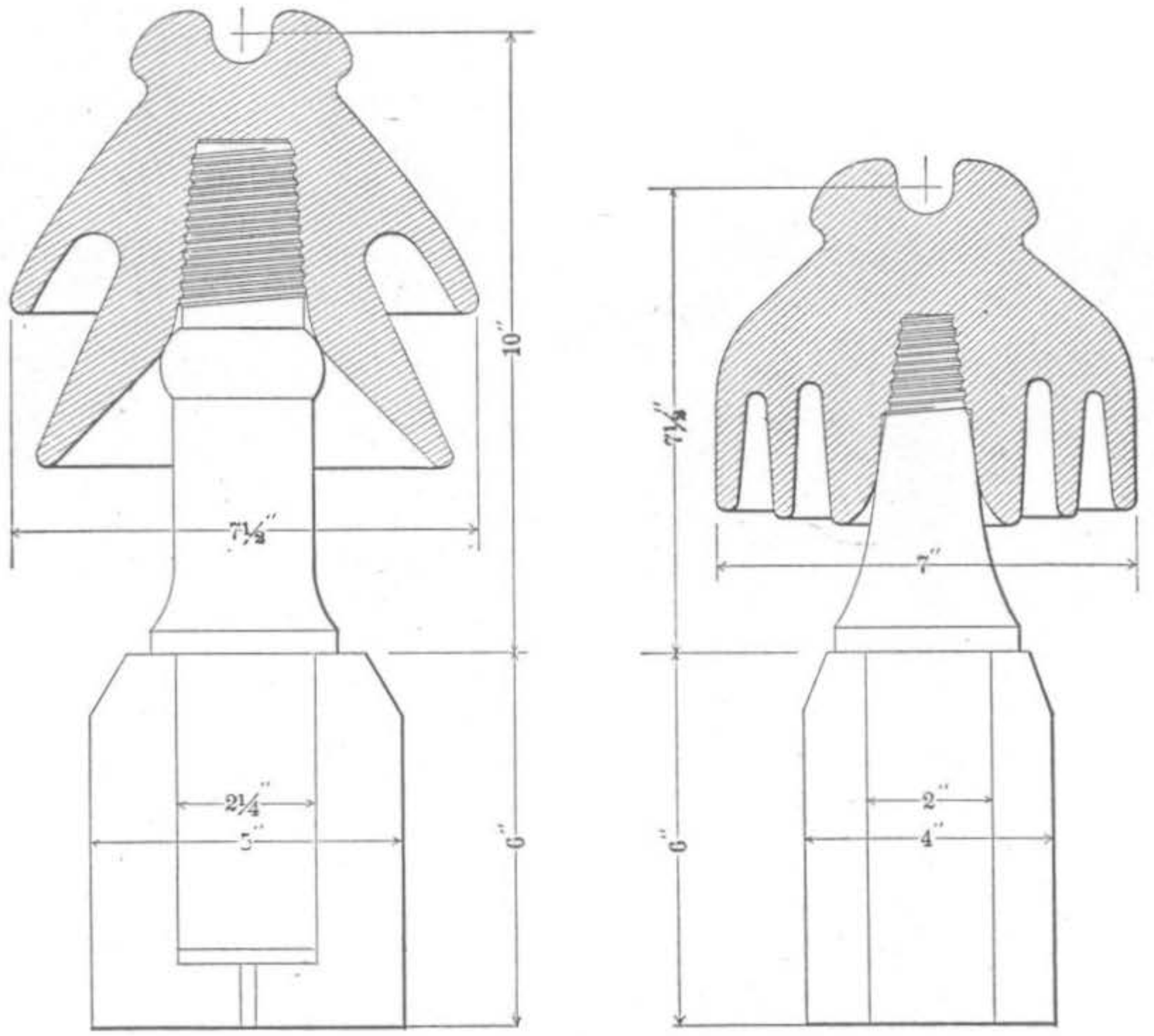
It may be noted still further that the user who philosophically bears with an interruption caused by apparatus owned by himself is usually far from philosophical when inconvenienced by interruptions of service due primarily to failure of other people's machinery. The reasons for adopting effective means for preventing interruptions of service, therefore, increase in a ratio greater than the increase in number of users.

Unfortunately, the complete solution of the problem cannot be found in the adoption of the fuse or safety-link, which is generally and satisfactorily used in dealing with the similar problem which arises in supplying lamps and motors connected to the great direct-current networks in the large cities, since in such cases as that of Buffalo the distances involved in the local distribution are so great as to make the use of high-potential circuits to more than one transforming station imperative, and with circuits conveying alternating currents at 10,000 volts or even at 2000 volts ordinary fuse strips are altogether inapplicable, while nine-tenths of the special devices which have been proposed to take their place are equally useless.

The problem is made still more difficult by the phenomena of resonance and so-called electric surging, the latter of which always follows a sudden disturbance of potential of the system, while the former, under certain conditions of capacity, inductance, and frequency, is liable to develop potentials capable of breaking down the most perfect insulation available at the present time. Obviously here is a fine opportunity for the exercise of skill, sound judgment, and perhaps even inventive ability upon the part of the engineer who lays out a system of high-potential alternating-current distribution destined to supply power at some future time, if not at the outstart, to a large number of users distributed over territory too extensive to be reached by direct current.

The first thing to be done is, of course, to secure throughout the system the most perfect insulation that is practicable. Could the insulation be maintained perfect in all parts, nothing more would be needed. This, unfortunately, is not the case, and it becomes necessary, therefore, to lay out such a system of distribution with the greatest possible care, adopting effective means for localising the interruption which can result from a failure of insulation in any part of the system.

Much has been done since 1893 to overcome the difficulties faced by the companies which first ventured into the field of polyphase transmission and distribution, but there is still room for material improvement. The insulation of cables has made wonderful progress, as have also glass and porcelain insulators for overhead lines, although the quality of American porcelain is not yet equal



TYPE C AND TYPE E INSULATORS USED BY THE NIAGARA FALLS POWER COMPANY

to that of European porcelain used for the same purpose.

The time-limit circuit-breaker, intelligently applied, is of great value in lessening the evil consequence of failure of insulation by localising the resultant interruption of service; but the reversed current circuit-breaker, first used by Andrews, at Hastings, England, which should be an equally valuable adjunct to a transmission plant, is not yet available in thoroughly satisfactory form. The extraordinary development of the oil switch in recent years in America, following, but quickly surpassing, European practice, has furnished an effective solution to many of the vexing questions of switchboard practice which caused so much trouble a few years ago. The insulation of dynamos to-day is such that the generation of currents at 11,000 volts is effected with a factor of safety equal to what was possible ten years ago with generated potentials of 2200 volts, and the advance in construction of transformers is almost equally striking.

In large plants the general adoption of the method of operating switches in the power circuits at a distance from the operator by means of compressed air or electricity, insuring safety of the operator, has resulted in great gain in certainty of operation. To this end also have contributed a number of valuable auxiliary devices, such as the ingenious and effective synchronism indicator invented by Mr. Paul M. Lincoln, the diagrammatic arrangement of control switches, which places under the eye of the operator at all times an accurate diagram of connections existing throughout the system, various improvements in regulating and governing mechanism of engines, and more particularly of hydraulic turbines, and, most important of all, perhaps, the development of devices for the protection of electric apparatus against the effects of atmospheric electricity.

It may be interesting to refer briefly to some of the more important of these improvements of the last decade. As

regards means available for transmission, the most striking development is the rapid evolution of cables insulated by paper, treated with resinous oils.

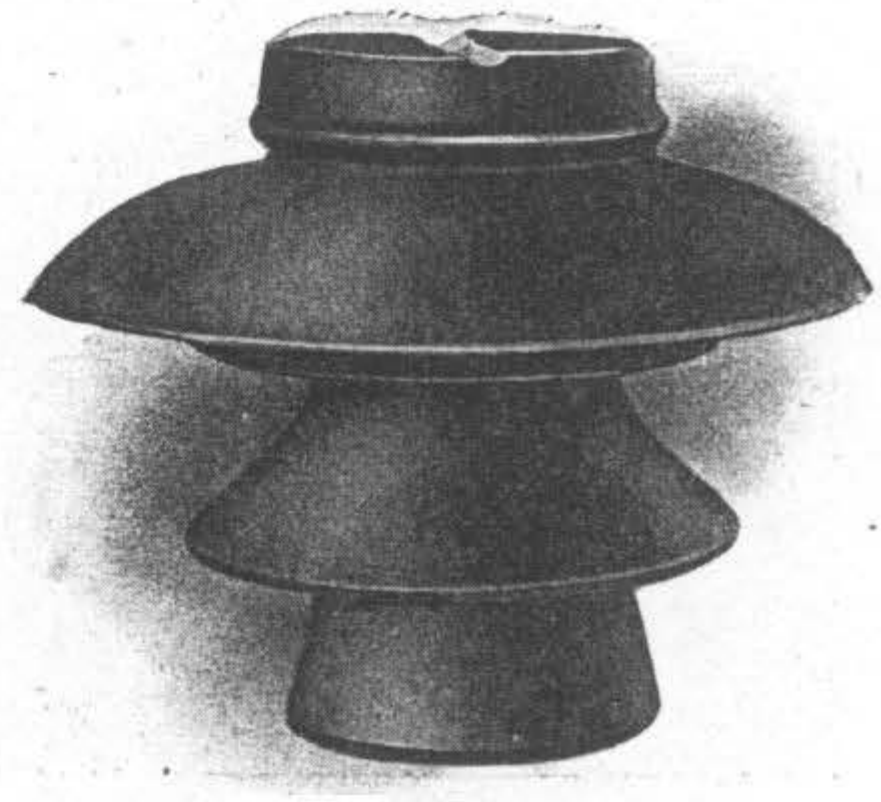


They are necessarily lead-sheathed to protect the insulation against moisture, and if the sheath be preserved and the cables be not operated at temperatures exceeding 80 C. degrees, there appears to be no reason to doubt their durability. In the city of New York, the Manhattan division of the Interborough Rapid Transit Company now has in use upwards of 120 miles of cable of this character, operating at a potential of 10,500 volts, and during the last nine months there have been only two failures of cable insulation, one of which, however, did not cause any interruption of service.

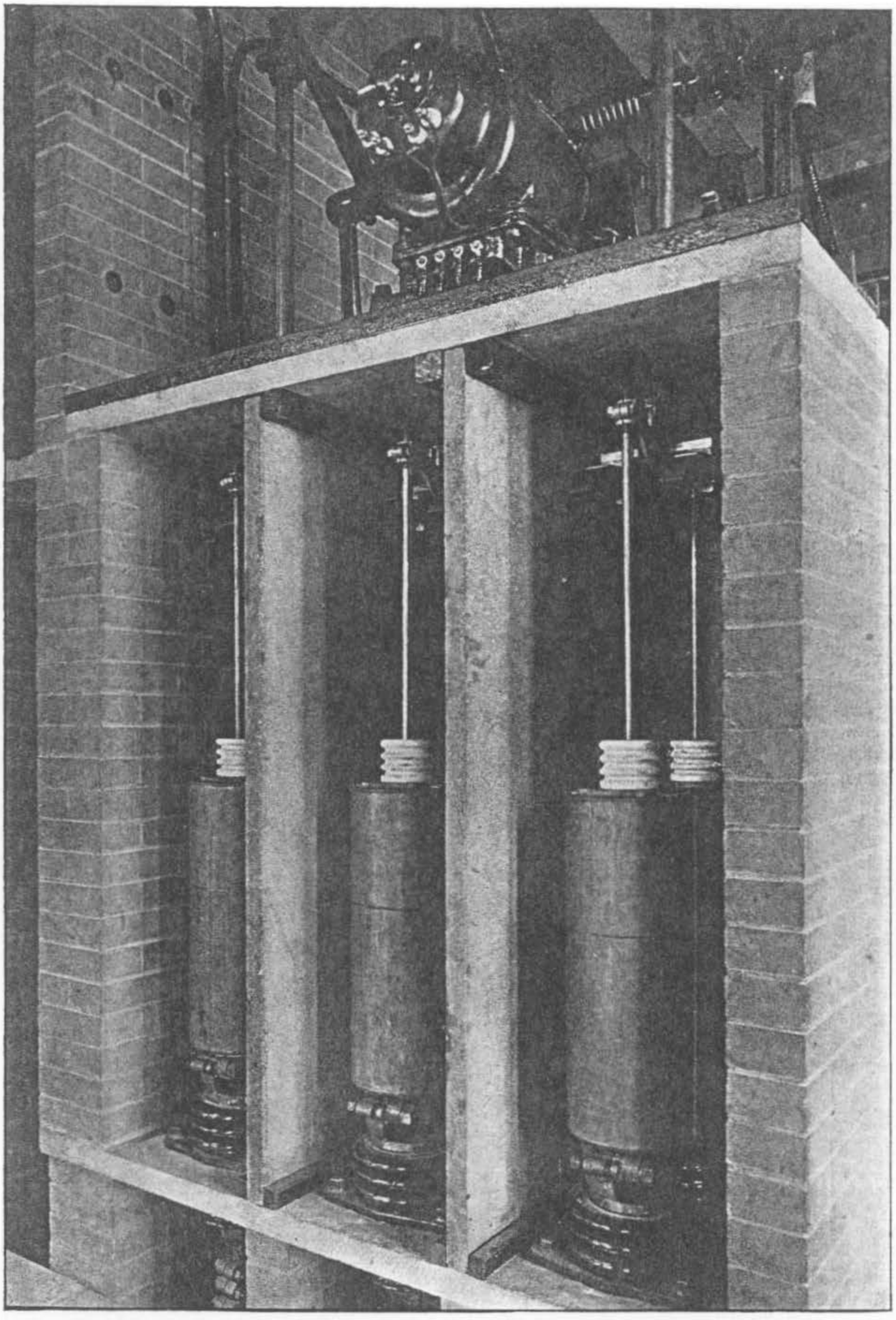
At St. Paul, Minnesota, the gas light company has, for the past four years, successfully operated cable of this kind under a potential exceeding 20,000 volts, and recently in developing plans for an important transmission project I have received from two reliable manufacturing companies quotations upon paper-insulated cables guaranteed for service under a potential of 33,000 volts, alternating. There is no reason to doubt that cable of this type, constructed under proper specifications and with sufficient care may now be considered thoroughly reliable for commercial service under such potentials as these, provided proper precautions are observed in the arrangement of circuits and in the installation of protective devices to prevent such cables being subjected for any appreciable length of time to potentials materially exceeding the working potentials for which they are intended. The illustration on page 102 shows the construction of three-conductor cable as used by the Interborough Rapid Transit Company for 11,000-volt, three-phase distribution in ducts.

The illustrations on pages 103 and 105 show, respectively, cross sections of three-conductor, rubber-insulated, steel armoured cable and single-conductor, rubber-insulated, steel-armoured cable, as used by the same company in submarine work.

Methods of laying cables also have greatly im-



PORCELAIN INSULATORS FOR HIGH-POTENTIAL CIRCUITS



A MOTOR-OPERATED OIL SWITCH FOR 11,000-VOLT THREE-PHASE CIRCUITS, MADE BY THE GENERAL ELECTRIC COMPANY, SCHENECTADY, NEW YORK

proved. In the United States they are now usually laid in tile ducts, set in concrete. Much of this duct work is still badly done, particularly with reference to the dissipation of heat, due to currents traversing the cables; but general practice in this respect has improved greatly within the last two or three years. The illustrations on pages 104 and 106 show, respectively, a cross-section of a cable conduit and a cross-section of a manhole as used by the Manhattan division of the Interborough Rapid Transit Company.

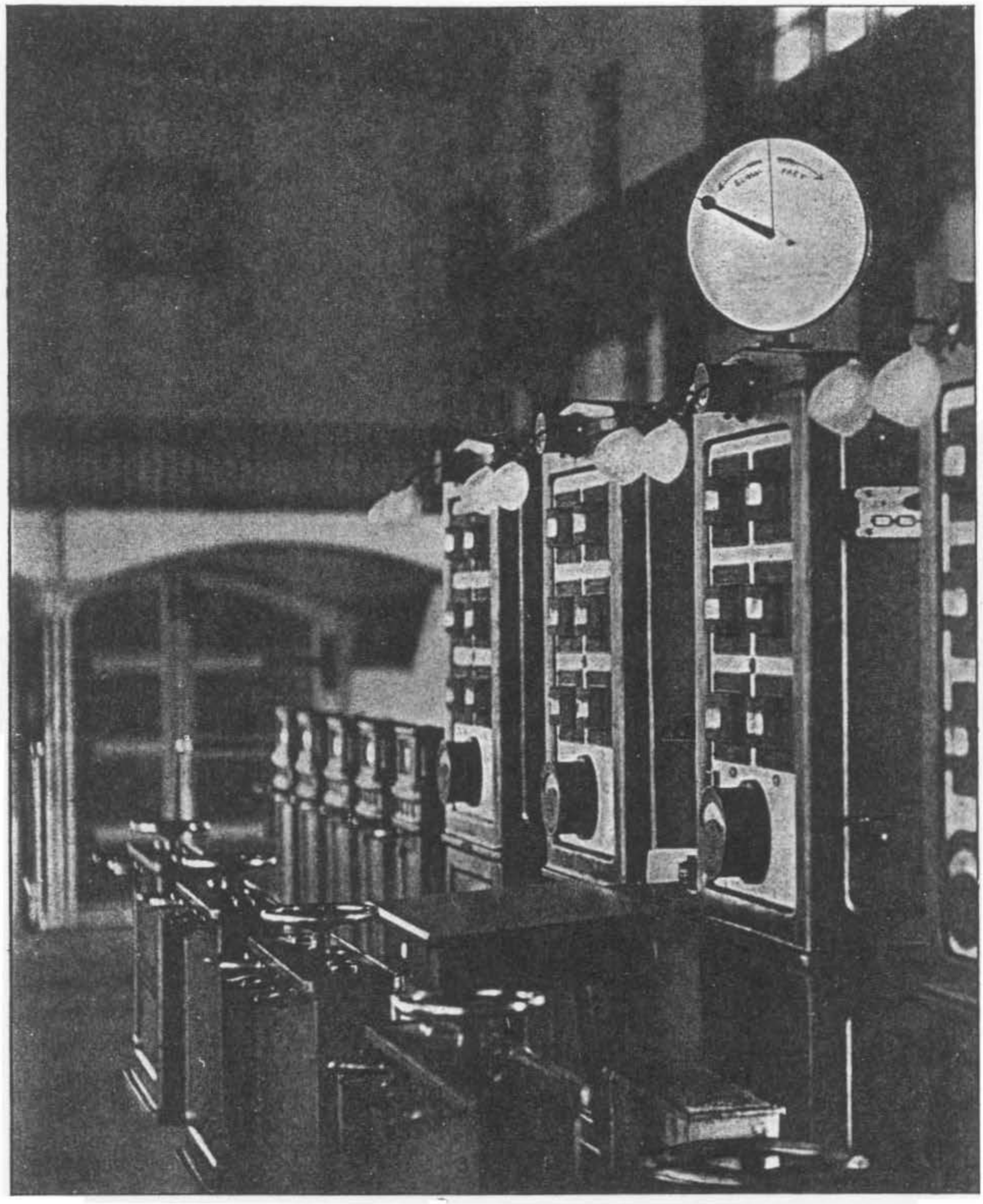
Insulators for overhead lines have been very radically improved since 1893. The insulator used in the Frankfort-Lauffen transmission employed an oil cup to decrease surface leakage. Dust and other material, accumulating upon the surface of the oil, destroy its insulating value, and this type of insulator is, therefore, not now used commercially. The 10,000-volt plant at Pomona and San Bernardino, California, installed in 1890 and still in successful operation, uses a double-petticoat glass insulator designed by Morris, of the Westinghouse Company, and the writer, and in 1895 this insulator was successfully used by Mershon during the high-potential tests which he conducted at Telluride, Colorado, under a potential of 45,000 volts.

The so-called "Type C" insulator, as used by the Niagara Falls Power Company upon the first pole line, erected between the Falls and Buffalo, and the "Type E" insulator, as used upon the second pole line, erected in 1900, are shown in section on page 108. The former was particularly defective in respect to its mechanical attachment to the pin, which was but ⅞ inch in diameter at the top, while the number of screw threads engaging pin with insulator was but six. The pin used with the "Type E" insulator is 1½ inches in diameter at the top, and nine threads secure the insulator to the pin. The Niagara Falls Power Company increased the line potential between Niagara and Buffalo from 11,000 volts to 22,000 volts in the spring of 1901, and since that time has been replacing gradually the "Type C" insulators on the old line by insulators of the newer type, which have been very successful.

On page 109 are shown illustrations of three insulators. The smallest is "Type E," as now used at Niagara, while the largest is an insulator made by the Locke Insulator Manufacturing Company, of Victor, New York, for very high voltage. This insulator has been selected for the 101-mile transmission plant of the Guanajuato Power & Electric Company, in Mexico, which company is now using successfully a potential of 60,000 volts. The insulator of intermediate size is one which the writer designed several years ago for line potentials of from 40,000 to 50,000 volts. It is the largest porcelain insulator made in a single piece, the Locke insulator being made in several concentric materials or cups which are cemented together. Many other insulators effective for line potentials up to 50,000 volts are now available, and some of the more recent of these are designed for pins of adequate size.

Probably the most valuable single addition to apparatus developed since 1893 for high-potential transmission is the electrically-operated oil switch. The illustration on page 110 gives an excellent idea of its construction, as built by the General Electric Company, of Schenectady, New York, for 11,000 volt, three-phase circuits.

Two breaks are provided for each of the three sides of the circuit, and in opening the circuit the break is made under oil contained in large metal cylinders. Each cylinder contains a fixed terminal. When the switch is closed, current passes from one terminal of each pair to the other through two vertical rods of copper connected at their upper ends. The switch parts belonging to each of the three sides of the circuit are separated from all other parts of the switch and its mechanism by being enclosed in a brick compartment with vertical partitions of soapstone, as shown in the illustration. The moving parts of the switch are operated by mechanism located upon the top of the brick compartment, this mechanism being, in turn, actuated by an



LINCOLN SYNCHRONISM INDICATOR AS USED BY THE NIAGARA FALLS POWER COMPANY

electric motor which is controlled by circuits extending from the control board, or pilot board as it is sometimes called. At the control board the operator has before him a small switch, sometimes two, corresponding to each of the large three-phase switches, and the movements of the latter are controlled by opening and closing the former.

The plan of opening and closing switches located at a distance from the operator by compressed air or electricity was first adopted, I believe, by the Westinghouse Company in connection with the switch gear installed in the first power house of the Niagara Falls Power Company. In that plant the plan demonstrated its value, and it is now generally and in fact almost necessarily

adopted in the case of all large modern plants. The sense of security enjoyed by the operator while controlling these great switches at a distance results in confidence which goes far to ensure that precision which is so absolutely essential.

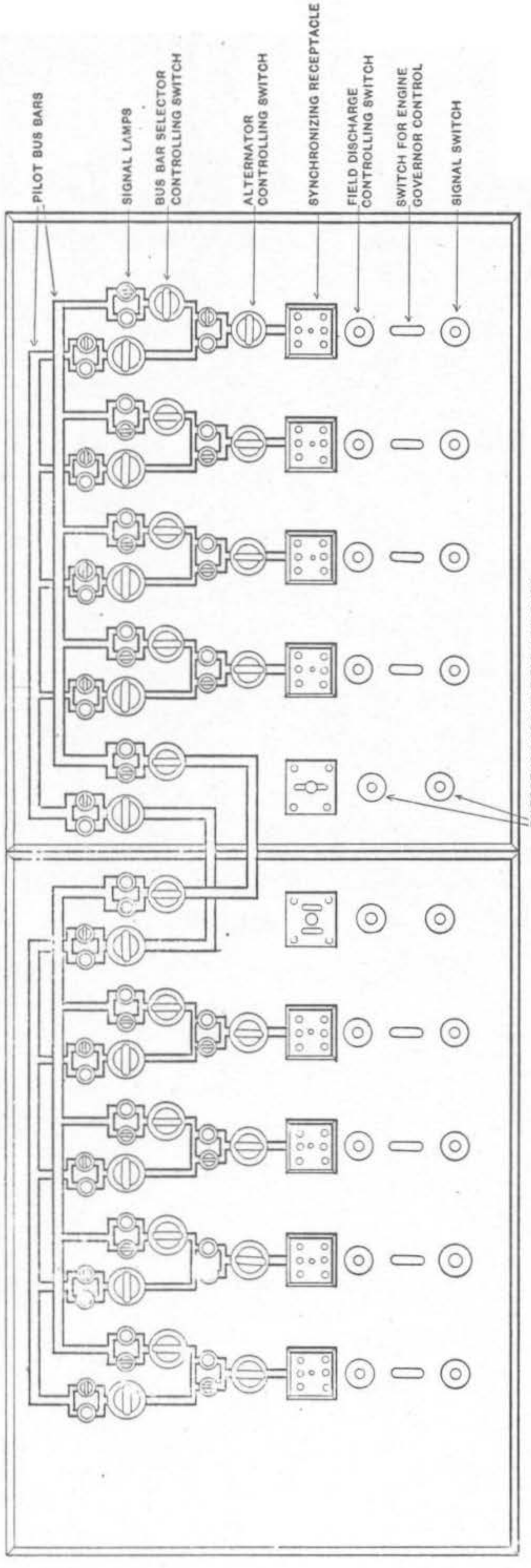
At the Manhattan Railway power plant in New York City sixty-six switches of this type are installed, and, on the average, have been in use about eighteen months. During that time not one of these switches has failed to operate as and when expected, and while some of them have been called upon to open automatically circuits in which extremely heavy short-circuited currents were flowing, they have done this without damage other than some spilling of oil from the oil cups.

The illustration on page 112 shows a synchronism indicator as installed upon Switchboard No. 1 in Power House No. 1 at Niagara Falls. This synchronism indicator, invented by Mr. Paul M. Lincoln, is an ingenious and most useful adjunct to a power plant using alternators. When an alternator is to be connected in parallel to bus bars supplied by one or more alternators the synchronism indicator is connected to the circuits through suitable transformers and becomes a perfect guide to the operator. The index arm of the indicator revolves at a speed proportional to the difference in speed between the alternator to be synchronised and the alternators supplying the bus bars, and it shows also which of the two is running at the higher speed. As used at Niagara, it is of very large size, and is mounted upon a vertical shaft which makes it possible to turn the face of the instrument so that it becomes visible not only to the operator upon the switchboard who throws the switches, but also to the governor attendant upon the floor who is adjusting the speed of the alternator preliminary to the operation of synchronising.

Still another comparatively recent auxiliary of value in the operation of large plants is the diagrammatic pilot board illustrated on pages 114 and 115. In this arrangement of the operating switches which control the power switches at a distance, dummy bus bars and other apparent (but not real) connections are provided and assembled in connection with the operating switches in such a way as to place before the operator at all times a diagram of the existing connections of the power circuits. Every time he changes the position of the pilot or control switches he alters the diagram to conform to the resulting connections of the power circuits, the diagram as indicated to the eye by handles of the pilot switches being corroborated by red and green signal lamps, one or the other of which is lighted when the corresponding power switch reaches the end of its travel in the movement incident to opening or closing the circuit. The illustrations on pages 114 and 115 show the diagrammatic pilot board and the instrument board as used for controlling the operation of eight 5000-KW alternators at the Manhattan power plant.

The development of the oil switch, which is capable not only of reliably making and breaking circuits in ordinary operation of the plant, but also of opening circuits traversed by short-circuiting currents as a result of failure of insulation, opens the way to the effective use of the time-limit relay attachment and of the reverse current relay attachment for such switches used as automatic circuit-breakers. The respective functions of these two relay attachments can be described best by reference to the diagram on page 116.

This diagram shows the essential connections of power circuits in a power plant comprising five alternators and transmitting power to a sub-station through two cables or overhead circuits. To simplify the diagram, the arrangement shown is that required for a single-phase apparatus, and but one set of bus bars is shown in the power house and also in the sub-station. From the sub-station four circuits serve to distribute power at low potential. If no time-limit circuit-breakers be used, a heavy short-circuit upon one of the distributing circuits from the sub-station may result in opening not only the circuit-breaker or fuse located in the sub-station to cut off

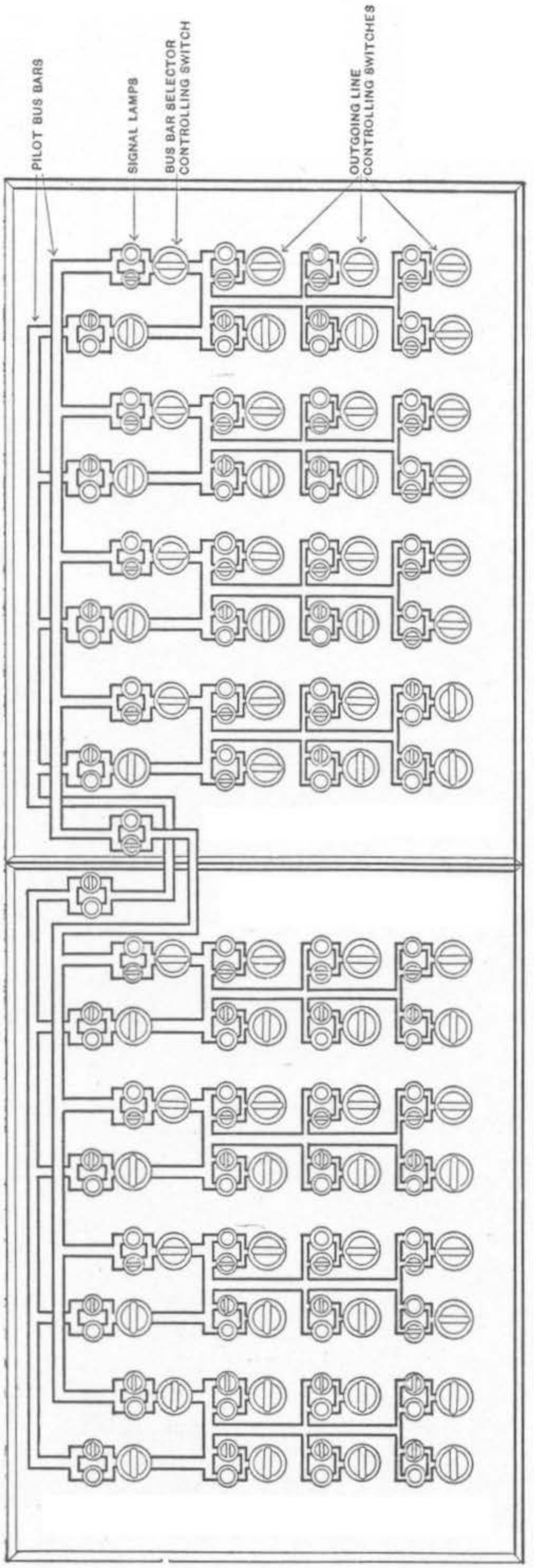


ALTERNATOR CONTROLLING BENCH BOARD USED BY THE MANHATTAN RAILWAY COMPANY, NEW YORK

the particular circuit affected, but also the circuit-breakers or other devices located at the power house and intended to cut off one or the other of the transmission circuits in case of a heavy short-circuit between power house and sub-station.

Instances have been known where even the automatic circuit-opening devices between dynamos and bus-bars have been opened as a result of a short-circuit beyond the transformers in the sub-station. If the time-limit relay be used in connection with the circuit-breakers, and if it be set, say, for three seconds in the case of circuit-breakers between dynamos and bus-bars, one second in the case of circuit-breakers in the transmission circuits at the power house end of the line and for instantaneous operation in distributing circuits from sub-station, the circuit-breaker in the distributing circuits at the sub-station may be relied upon to open before those in the transmission circuit at the power house, and, of course, also before those in the dynamo circuits at the power house can open. The interruption of service, therefore, which results from failure of insulation in one of the distributing circuits from the sub-station will be limited to the supply of power through the particular distributing circuit affected.

The reversed current circuit-breaker, which should be an equally valuable adjunct to a transmission plant, unfortunately, as has been said, is not yet available in thoroughly satisfactory form. Andrews used it between alternators and bus-bars for the purpose of cutting out an alternator which might become short-circuited. It is equally applicable, of course, to alternating-current circuits between a power house and sub-station, provided the circuits are connected in multiple with each other at both ends of the line.



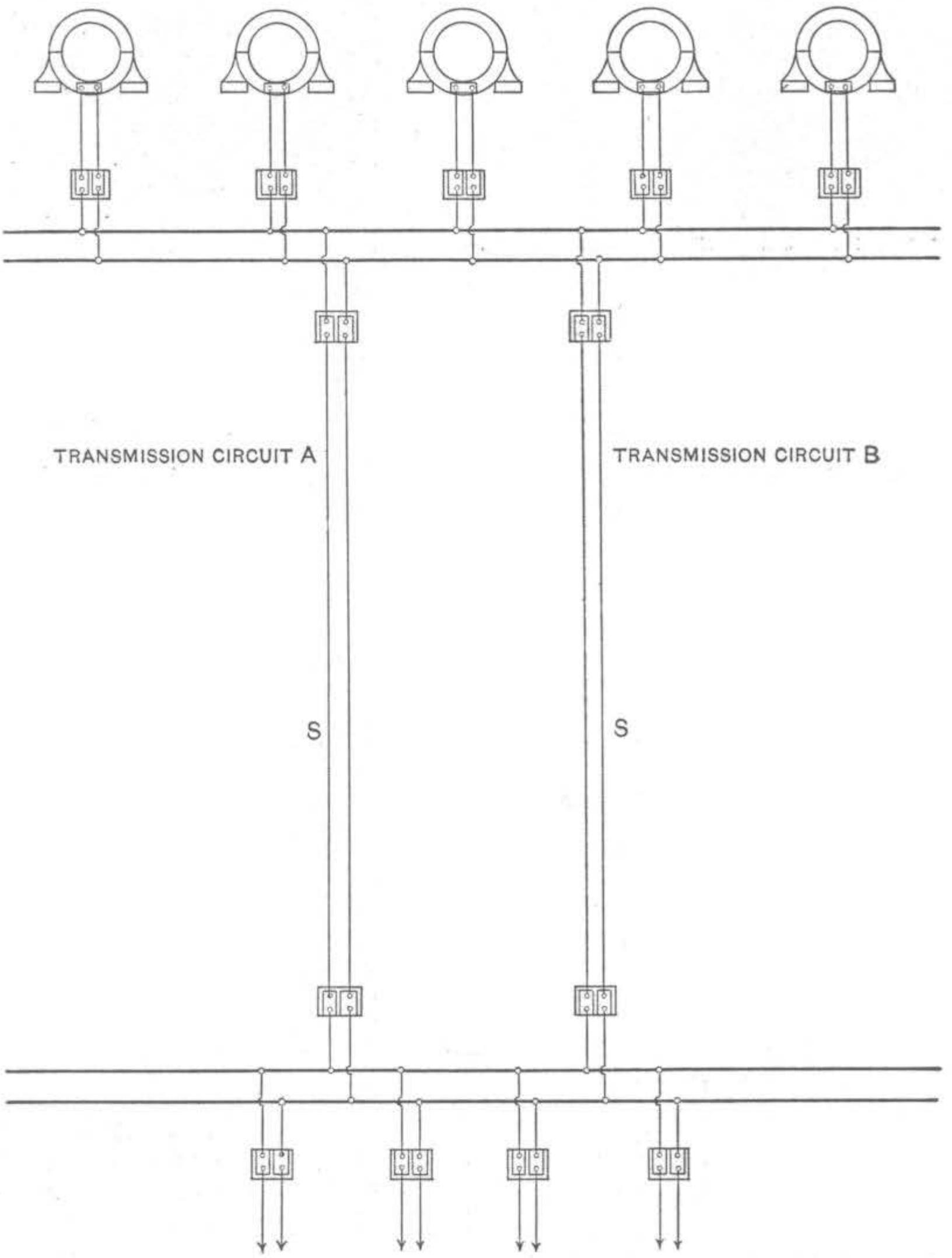
ALTERNATING CURRENT FEEDER CONTROLLING BENCH BOARD USED BY THE MANHATTAN RAILWAY COMPANY, NEW YORK

Referring again to the diagram on page 116, we may imagine that a short-circuit occurs on a transmission circuit, designated *A*, at the instant of maximum flow of current in one direction, which, for convenience, we may call positive. It is evident that the instant the insulation between conductors of circuit *A* is broken down, *e. g.*, at point designated *S*, current will flow from the bus-bars at the power house and also from bus-bars at the sub-station toward the point *S*. This implies a reversal in the direction of flow of current between the bus-bars at the sub-station and the point *S*, as compared with its direction at the given instant had no short-circuit occurred. This reversal may be utilised to open the circuit-breaker by actuating a relay device.

Practically all of the reversed current relays thus far tried in the United States have proved unsatisfactory by reason of the fact that they require a potential in phase with bus-bars at sub-stations, and in case of very heavy short-circuits this potential usually drops below the limit effective for operation. The required potential might be obtained from a small alternator, normally operated in synchronism with the power supply and equipped with a fly-wheel of sufficient size to keep the alternator going at synchronous speed for the necessary fraction of a second after the occurrence of the short-circuit, or perhaps better means might be devised for accomplishing the same purpose.

Where three or more circuits between power house and sub-station are available, reversed current relays can be operated by difference in current flowing through the short-circuited line and the other lines, and relays of this type are now upon the market.

Without entering further into discussion of details, it will be



TYPICAL DIAGRAM ILLUSTRATING USE OF TIME LIMIT AND REVERSED CURRENT CIRCUIT BREAKERS

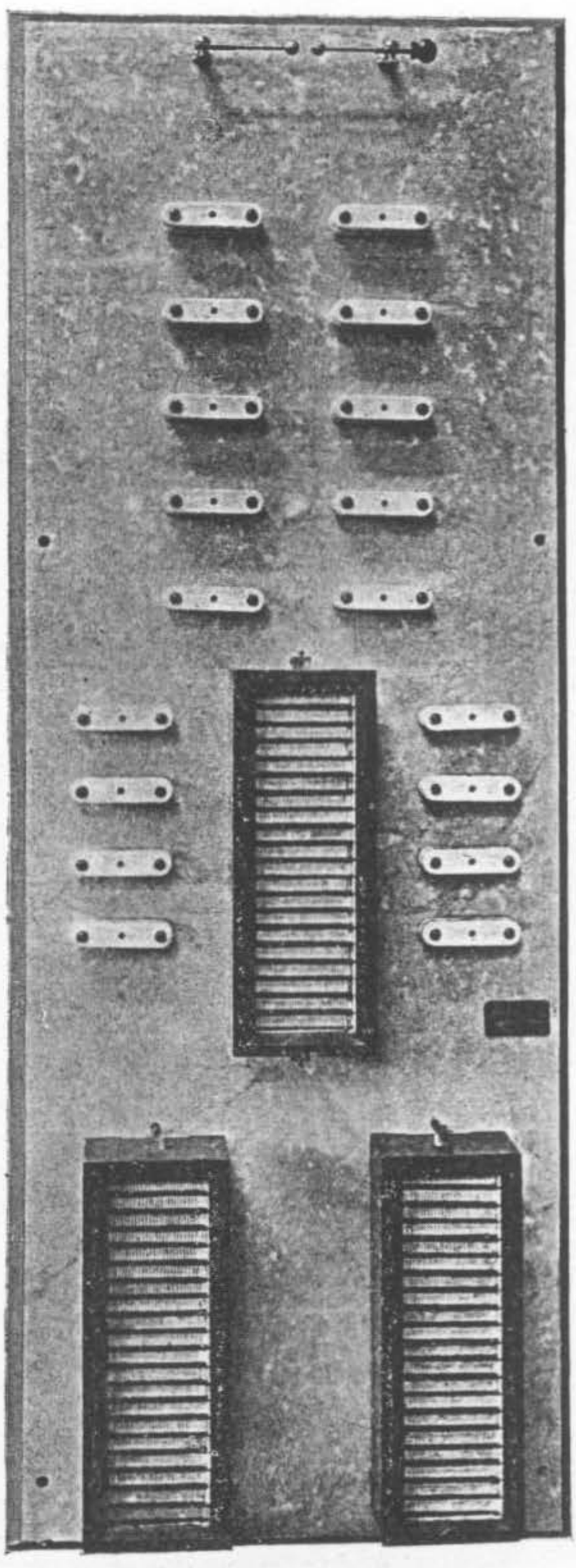
evident that proper use of the time-limit relay and of the reversed current relay, in combination with the oil switches now available, afford means for effectively localising the troubles resulting from any short-circuit in an interconnected alternating-current system of distribution which is carefully laid out with a view to such localisation.

Perhaps no adjunct of a successful transmission plant employing overhead circuits is more important than the lightning arrester, and in the development of none has more remarkable progress been made since the days immediately following the Lawrenceville test. For this progress we are indebted chiefly to Alexander J. Wurts. The first alternating-current plants in America used the brass "saw tooth" arrester which was then in general use by the telegraph companies. Bitter experience soon demonstrated the futility of this device when applied to 1100-volt, constant-potential circuits, supplied by dynamos having low internal resistance, and it was soon displaced by a flood of ingenious and more or less effective

arresters, which, in turn, were effectively superseded by the so-called non-arcing metal arrester discovered by Wurts in 1892. The problem was to provide an easy path from conductor to earth for static electricity due to lightning and to prevent the dynamic current following in the path of the static discharge and short-circuiting the system. This, for potentials up to about 25,000 volts, has been effectively accomplished by means of the non-arcing metal cylinders. For higher potentials, the performance of lightning arresters is not yet altogether reliable. The illustration on this page shows a modern lightning arrester outfit for a 25,000-volt circuit. Detail descriptions have been printed in various technical journals and in advertising publications of manufacturing companies.

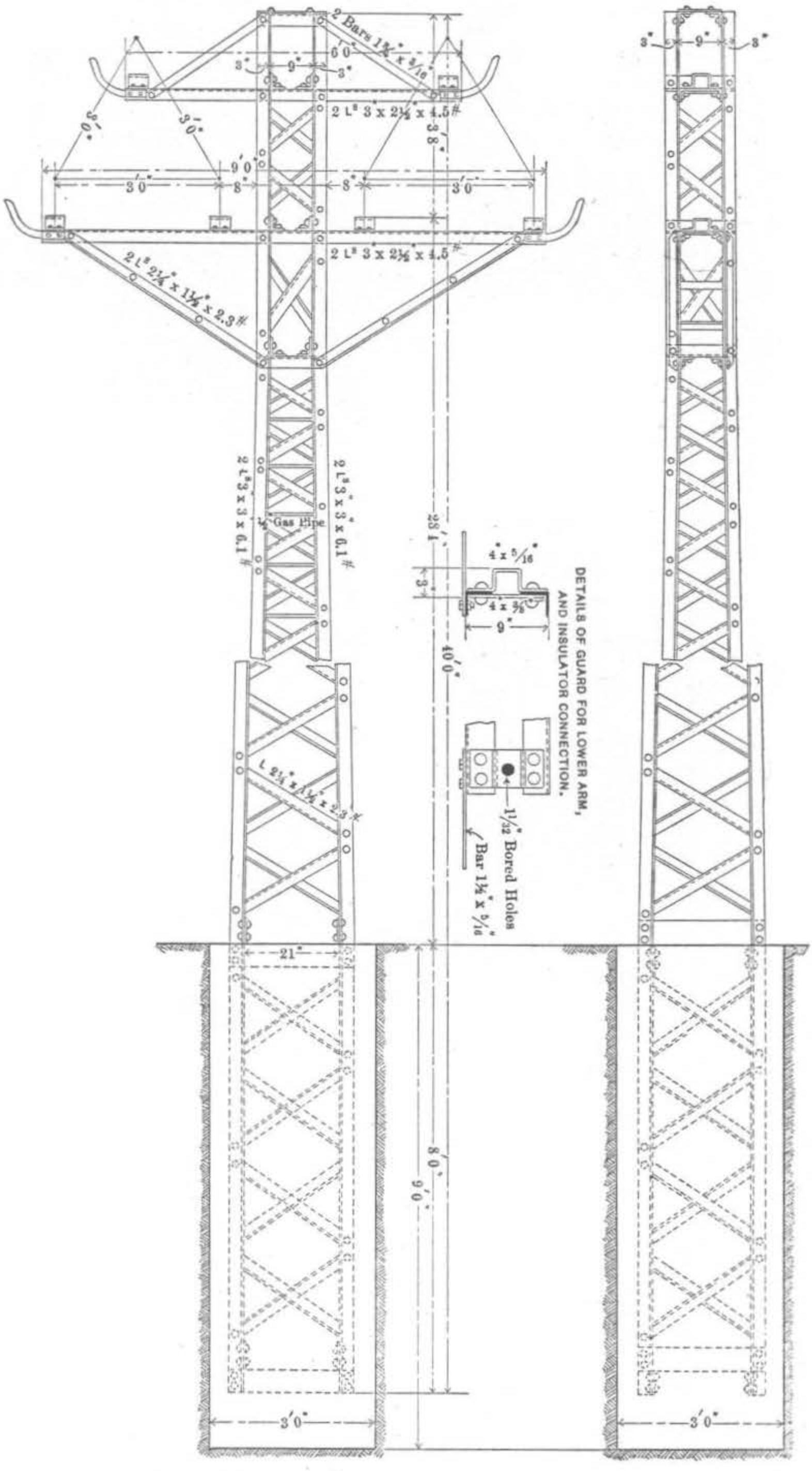
As regards line construction, it is to be regretted that few plants in the United States up to the present time have erected transmission circuits which, from the standpoint of permanence, compare favourably with approved European practice as illustrated, for example, in the illustration on page 120, showing the steel pole line used between Paderno and Milan. For this illustration I am indebted to Mr. Guido Semenza, the very able engineer of this important and interesting plant. Nearly all pole lines in America are of wood, and, so far as insulation is concerned, there is much to be said in favour of this material. In my opinion, however, the lines of the future will use steel poles or towers, widely spaced, and will rely for insulation exclusively upon the insulators to which the conductors are attached. The idea of using steel poles is not new in America.*

The illustration on page 118 shows a design for a steel pole carrying two transmission circuits, as designed under the writer's direction in 1894 by the Pittsburgh Bridge Company and submitted to the Cataract Construction Company with reference to the then proposed transmission from Niagara to Buffalo. It will be noted that the three conductors of each circuit are triangled,



A LIGHTNING ARRESTER FOR 25,000-VOLT ALTERNATING CURRENT CIRCUITS

* Since this article was written, the writer has been furnished, through the courtesy of Mr. Henry Hine, president of the Guanajuato Power & Electric Co., Mexico, with a description of the steel tower construction adopted by that company, which marks a most interesting and important advance in the art of electric power transmission in America, not only by reason of the substitution of steel towers for the usual wooden poles, but also because of the long spans used. Further reference to this remarkable example of modern line con-construction will be made in a future article.

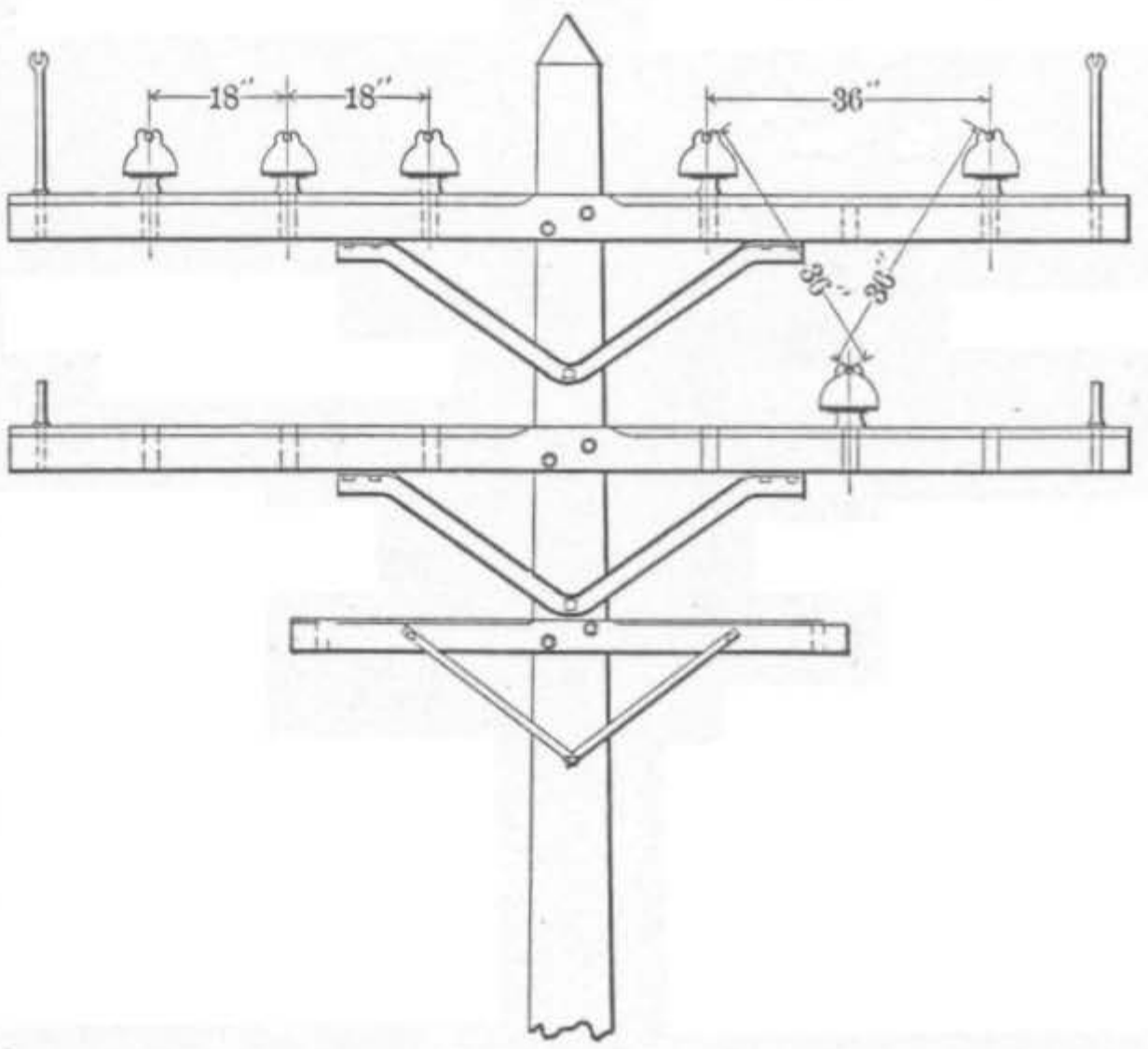


A 40 FOOT STEEL POLE DESIGNED BY THE PITTSBURGH BRIDGE COMPANY

the sides of the equilateral triangle measuring 36 inches.

Unfortunately, this plan was rejected, and the first pole line carrying two circuits was erected between Niagara Falls and Buffalo in line with the plan illustrated on this page, both circuits originally being carried upon the upper cross-arm, the three wires constituting each circuit being spaced at intervals of 18 inches and carried at the same level as shown at the left.

This arrangement was a great temptation to mischievous boys, who threw wires and sticks across the line wire. Owing to the position of the conductors they inevitably came in contact with at least two sides of the circuit, causing tremendous short-circuits, which blazed along the line until the power was cut off. The light of these short-circuits in some cases was seen at a distance of a mile, and unless the power was cut off at the power house they inevitably resulted in burning off and dropping the conductors of the transmission circuit. The triangular arrangement of conductors illustrated on the right hand side of the drawing on this page shows the location of the conductors of the first two circuits as subsequently located. In this position they have given little trouble.

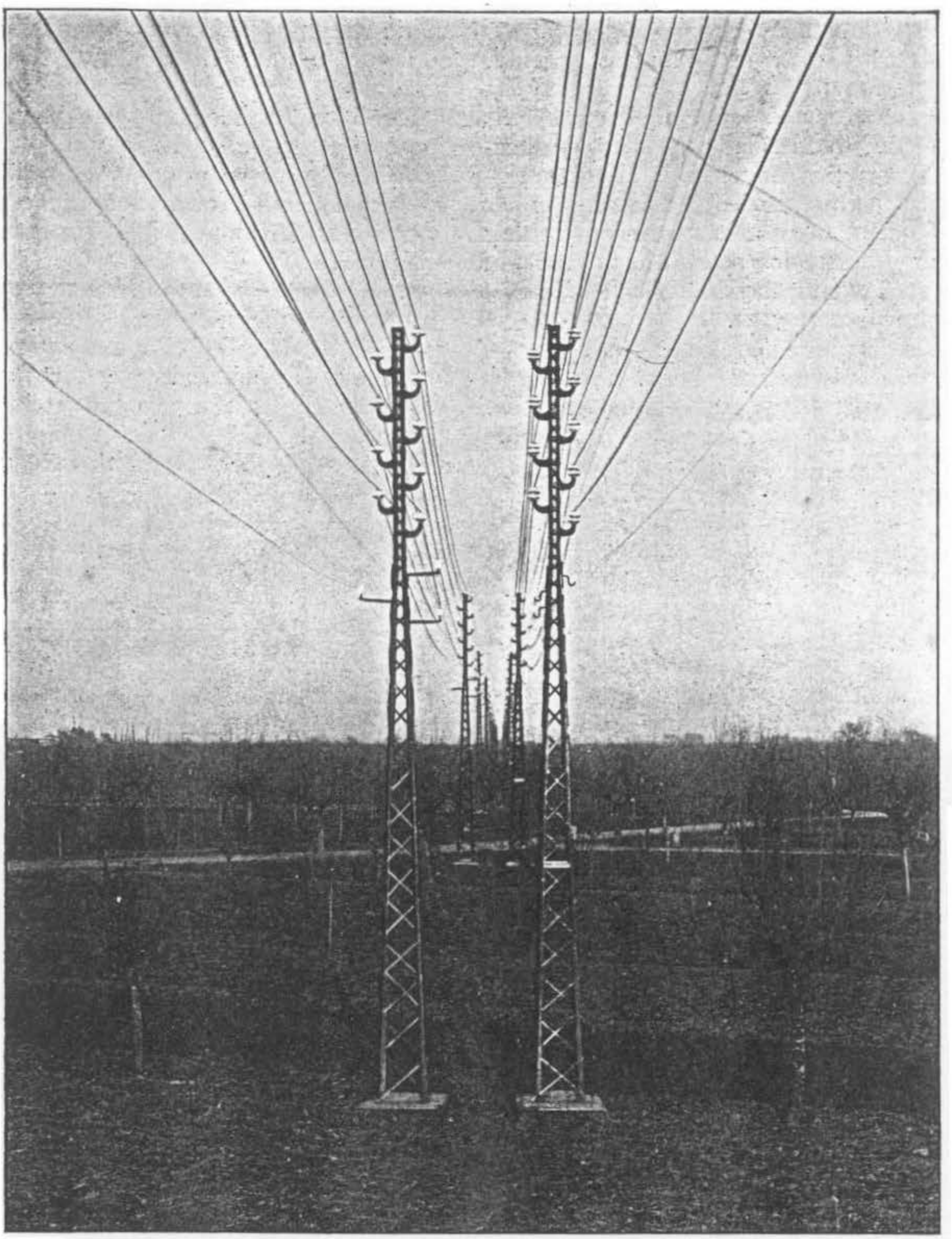


POSITION OF INSULATORS ON THE FIRST NIAGARA-BUFFALO POLE LINE

Enough has been said to show that engineers who to-day are designing electric power plants have available for use much highly important, if not absolutely essential, apparatus which did not exist ten years ago. Efficiency of dynamo, transformer, and motor has improved since then, but it has gained little as compared with the development of such auxiliary apparatus as has been referred to here. The latest dynamo installed at Niagara is not materially more efficient than the first one which was put into commercial operation there in 1895; but line insulators, cable insulation, switches, and relay devices for automatic circuit-breakers are incomparably superior to any that existed at that time.

Doubtless further improvement in respect to details of construction is to be expected, but the apparatus available to-day is such that transmission at 60,000 volts should be more reliable than transmission at 6000 volts was ten years ago. Accurate and extensive knowledge and sound judgment the engineer who designs and installs such a plant must have, but the materials are now available if he knows where to find and how to use them.

Considering the probabilities of future development of electric transmission, it is reasonable to expect that the utilisation of water-powers will continue until practically all of any considerable magnitude are put to work. The ability to employ higher potentials means ability to span greater distances, and thus markets will be found for water-powers which hitherto have been deemed too remote from industrial markets for profitable utilisation. Improved reliability and gradually lessening cost of apparatus will co-operate influentially toward this result, as will also the decrease in rates



STEEL POLE LINE AND CIRCUITS ON THE MILAN-PADERNO TRANSMISSION, ITALY

of interest upon capital which has been so marked in recent years.

It is to be expected also that power plants using steam or gas engines to drive dynamos and distribute power electrically over large districts will be constructed. Recently in Great Britain a number of corporations have been chartered with this object in view. Some of these plants are now under construction, and the commercial results of their operation will be of great interest. So far as I am aware, nothing of this kind on a large scale has been attempted up to the present time in America; but there are undoubtedly districts where such enterprises should be profitable.

The opportunity for profit rests chiefly upon three facts:—(1) that power can

be produced more economically by a very large steam plant than by a small one; (2) that the aggregate power which a central station plant, supplying a certain district, is called upon to develop at any given time is very much less than the sum of the maximum outputs of the small plants required to do the same work; and (3) that an electric motor occupies much less space and requires less attention than a steam plant. A 50,000 horse-power steam plant, supplying electric power for general purposes to a district having a radius of fifty miles, will burn about 3 lbs. of coal per average kilowatt-hour delivered throughout the district, while the average consumption of coal by the steam plants which such a central power plant would displace is usually not less than 10 lbs. per kilowatt-hour.

As regards ratio of the maximum output of the central station to the sum of the maximum outputs of the displaced small plants, definite generalisation is impossible, because everything will depend upon the kind of work done by the small plants. I think it safe, however, to say that this ratio will rarely, if ever, be higher than 2 to 3, and in some instances which have come under my observation it is as low as 1 to 3. In other words, a 50,000 horse-power central station plant will rarely, if ever, fail to do the work of small plants aggregating 75,000 horse-power, and in some instances will be capable of doing the work of small plants aggregating 150,000 horse-power.

Transmission of power from coal fields to large cities works out much less favourably, since in this case it must compete with the alternative plan of transporting the coal to the city or to a point near it and there generating electric power in a steam plant equally economical and equally deriving the benefit which results from the fact that a single large plant can displace a large number of small plants whose aggregate output considerably exceeds its own. In this case, the plant located at a distance from the city must be larger by an amount equivalent to the maximum losses in transmission, and the fuel burned for a given delivery of power in the city will exceed the amount which would be burned if the plant were located in or near the city by an amount proportioned to the average square of the power transmitted.

Generally speaking, the difference in the cost of coal delivered to a plant in the city and the cost of coal delivered to a similar plant located in the coal fields at a distance of 250 miles from the city will not represent as much as 10 per cent. upon the difference in annual cost of the two plants thus respectively located, and when we take into account the possibilities of interruption of service in the case of the plant located at a distance, it appears evident that in the present state of the art of transmission, the better plan is to locate the central station near the city and pay the cost of transporting the coal to the point.

But what may prove to be the greatest of all fields for alternating-current transmission now confronts us in the application of electricity to the operation of railways. The successful substitution of electricity for steam by Ganz & Co., of Buda-Pesth, upon the Valtelina line, in Italy, by which a great economy has been effected in cost of operation of a railway more than sixty miles long, is an object lesson of great significance. Freight as well as passenger traffic is handled successfully under very severe conditions of grade, curvature, and climate, and the economy resulting from the substitution of electricity for steam challenges the attention of railway managers and engineers.

The recent high-speed trials at Zossen, Germany, in which a fifteen-ton car, operated electrically, attained a speed exceeding 131 miles an hour, invite attention in the same direction, and the development of two single-phase, alternating-current motors in America and of two similar motors in Europe, each of which is stated to meet effectively the requirements of railway service, mark by far the most interesting and important practical step of this new century in the use of electricity for power purposes.

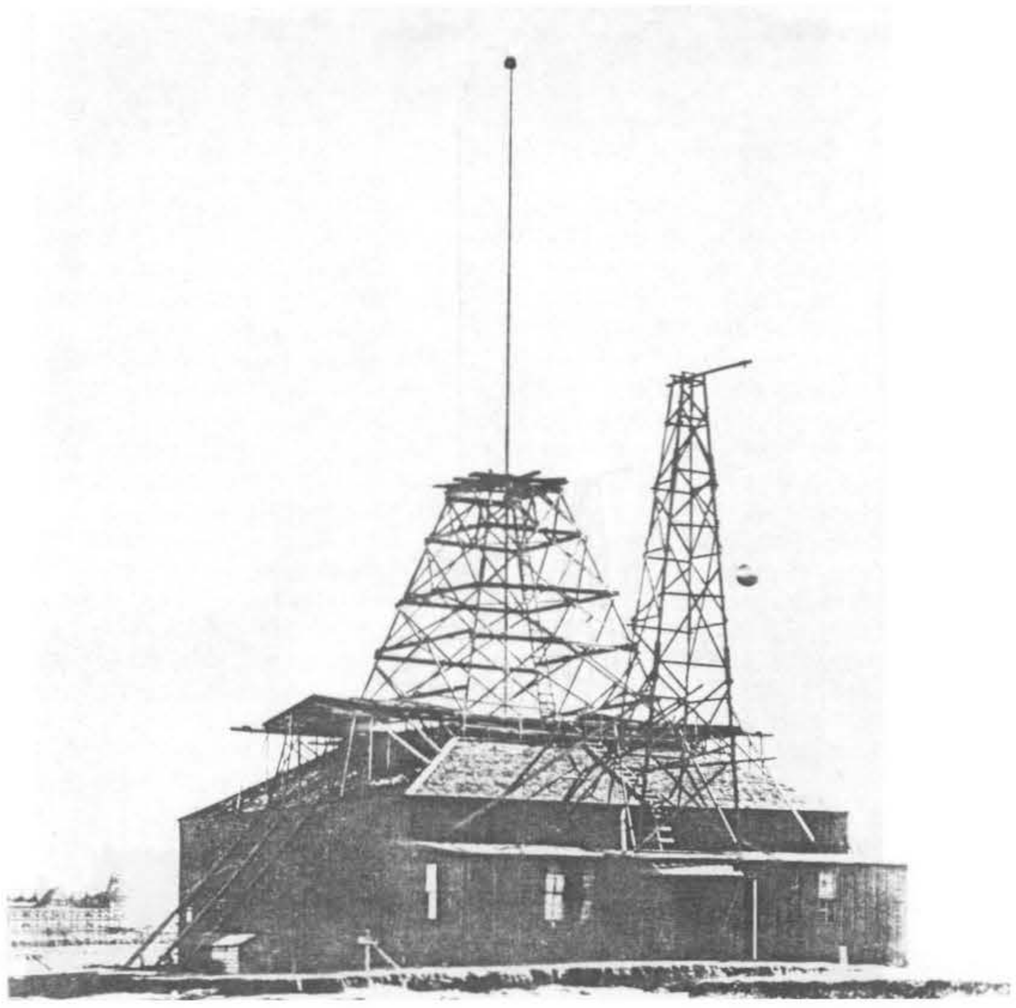


FIG. 1.—TESLA EXPERIMENTAL LABORATORY IN COLORADO, ERECTED DURING THE SUMMER OF 1899.

(The discovery by Mr. Tesla of the stationary waves in the earth was made here.)

THE TRANSMISSION OF ELECTRIC ENERGY WITHOUT WIRES.*

By NIKOLA TESLA.

TOWARD the close of 1898 a systematic research, carried on for a number of years with the object of perfecting a method of transmission of electrical energy through the natural medium, led me to recognize three important necessities: First, to develop a transmitter of great power; second, to perfect means for individualizing and isolating the energy transmitted; and, third, to ascertain the laws of propagation of currents through the earth and the atmosphere. Various reasons, not the least of which was the help proffered by my friend Leonard E. Curtis and the Colorado Springs Electric Company, determined me to select for my experimental investigations the large plateau, two thousand meters above sea level, in the vicinity of that delightful resort, which I reached late in May, 1899. I had been there but a few days when I congratulated myself on the happy choice, and I began the task for which I had long trained myself, with a grateful sense and full of inspiring hope. The perfect purity of the air, the unequaled beauty of the sky, the imposing sight of a high mountain range, the quiet and restfulness of the place—all around contributed to make the conditions for scientific observation ideal. To this was added the exhilarating influence of a glorious climate and a singular sharpening of the senses. In those regions the organs undergo perceptible physical changes. The eyes assume an extraordinary limpidity, improving vision; the ears dry out and become more susceptible to sound. Objects can be clearly distinguished there at distances such that I prefer to have them told by someone else, and I have heard—this I can venture to vouch for—the claps of thunder seven and eight hundred kilometers away. I might have done better still, had it not been tedious to wait for the sounds to arrive, in definite intervals, as heralded precisely by an electrical indicating apparatus—nearly an hour before.

In the middle of June, while preparations for other work were going on, I arranged one of my receiving transformers with the view of determining in a novel manner, experimentally, the electric potential of the globe and studying its periodic and casual fluctuations. This formed part of a plan carefully mapped out in advance. A highly sensitive, self-restorative device, controlling a recording instrument, was included in the secondary circuit, while the primary was connected to the ground and an elevated terminal of adjustable capacity. The variations of potential gave rise to electric surgings in the primary; these generated secondary currents, which in turn affected the sensitive device and recorder in proportion to their intensity. The earth was found to be, literally, alive with electrical vibrations, and soon I was deeply absorbed in this interesting investigation. No better opportunities for such observations as I intended to make could be found anywhere. Colorado is a country famous for the natural displays of electric force. In that dry and rarefied atmosphere the sun's rays beat the objects with fierce intensity. I raised steam, to a dangerous pressure, in barrels filled with concentrated salt solution, and the tinfoil coatings of some of my elevated terminals shriveled up in the fiery blaze. An experimental high-tension transformer, carelessly exposed to the rays of the setting sun, had most of its insulating compound melted out and was rendered useless. Aided by the dryness and rarefaction of the air, the water evaporates as in a boiler, and static electricity is developed in abundance. Lightning discharges are, accordingly, very frequent and sometimes of inconceivable violence. On one occasion approximately twelve thousand discharges occurred in two hours, and all in a radius of certainly less than fifty kilometers from the laboratory. Many of them resembled gigantic trees of fire with the trunks up or down. I never saw fire balls, but as a compensation for my disappointment I succeeded later in determining the mode of their formation and producing them artificially.

In the latter part of the same month I noticed several times that my instruments were affected stronger by discharges taking place at great distances than by those near by. This puzzled me very much. What was the cause? A number of observations proved that it could not be due to the differences in the intensity of the individual discharges, and I readily ascertained that the phenomenon was not the result of a varying relation between the periods of my receiving circuits and those of the terrestrial disturbances. One night, as I was walking home with my assistant, meditating over these experiences, I was suddenly staggered by a thought. Years ago, when I wrote a chapter of my lecture before the Franklin Institute and the National Electric Light Association, it had presented itself to me, but I had dismissed it as absurd and impossible. I banished it again. Nevertheless, my instinct was aroused and somehow I felt that I was nearing a great revelation.

It was on the third of July—the date I shall never forget—when I obtained the first decisive experimental evidence of a truth of overwhelming importance for the advancement of humanity. A dense mass of strongly charged clouds gathered in the west and toward the evening a violent storm broke loose which, after spending much of its fury in the mountains, was driven away with great velocity over the plains. Heavy and long persisting arcs formed almost in regular time intervals. My observations were now greatly facilitated and rendered more accurate by the experiences already gained. I was able to handle my instruments quickly and I was prepared. The recording apparatus being properly adjusted, its indications became fainter and fainter with the increasing distance of the storm, until they ceased altogether. I was watching in eager expectation. Surely enough, in a little while the indications again began, grew stronger and stronger and, after passing through a maximum, gradually decreased and ceased once more. Many times, in regularly recurring intervals, the same actions were repeated, until the storm which, as evident from simple computations, was moving with nearly constant speed, had retreated to a distance of about three hundred kilometers (186 miles). Nor did these strange actions stop then, but continued to manifest themselves with undiminished force. Subsequently, similar observations were also made by my assistant, Mr. Fritz Lowenstein, and shortly afterward several admirable opportunities presented themselves which brought out, still more forcibly, and unmistakably, the true nature of the wonderful phenomenon. No doubt whatever remained—I was observing stationary waves.

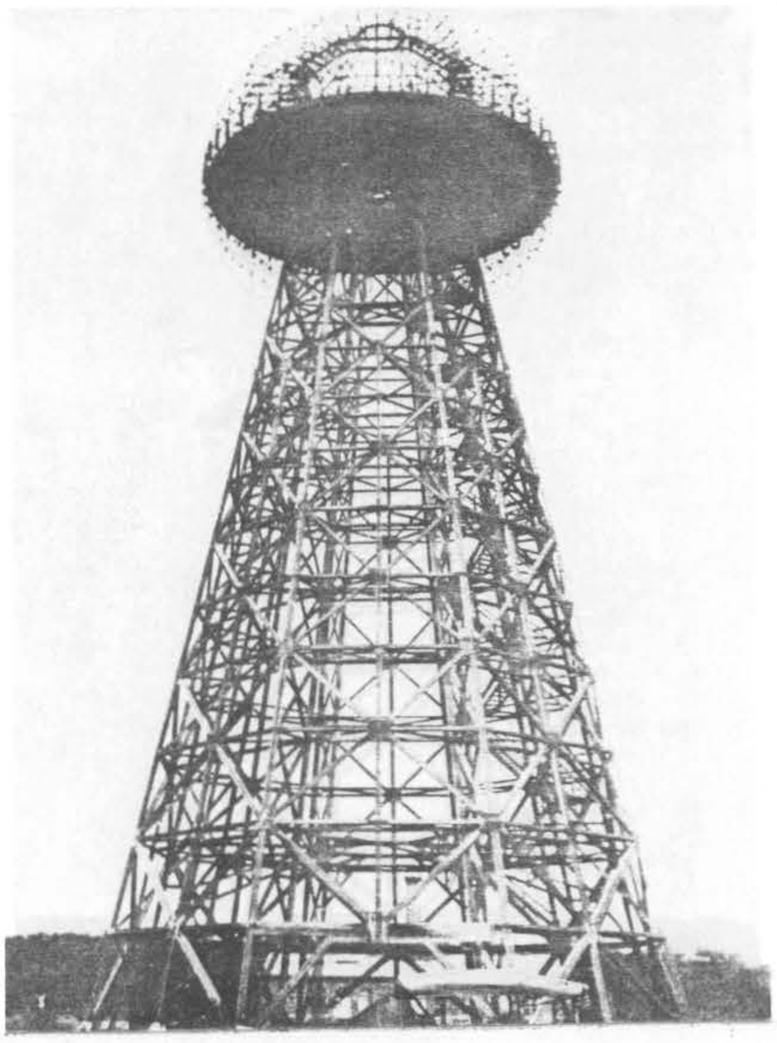


FIG. 2.—TESLA CENTRAL POWER PLANT AND TRANSMITTING TOWER FOR WORLD TELEGRAPHY, AT WARDENCLYFFE, LONG ISLAND, N. Y.

(The tower is a pyramid having eight sides; smallest dimensions across base, 95 feet; height, 154 feet; total height from ground to top, 187 feet; cupola on top, 65.62 feet in diameter.)

* Electrical World and Engineer.

As the source of disturbances moved away, the receiving circuit came successively upon their nodes and loops. Impossible as it seemed, this planet, despite its vast extent, behaved like a conductor of limited dimensions. The tremendous significance of this fact in the transmission of energy by my system had already become quite clear to me. Not only was it practicable to send telegraphic messages to any distance without wires, as I recognized long ago, but also to impress upon the entire globe the faint modulations of the human voice, far more still, to transmit power, in unlimited amounts, to any terrestrial distance and almost without any loss.

With these stupendous possibilities in sight, with the experimental evidence before me that their realization was henceforth merely a question of expert knowledge, patience, and skill, I attacked vigorously the development of my magnifying transmitter, now, however, not so much with the original intention of producing one of great power, as with the object of learning how to construct the best one. This is, essentially, a circuit of very high self-induction and small resistance which, in its arrangement, mode of excitation, and action, may be said to be the diametrically opposite of a transmitting circuit typical of telegraphy by Hertzian or electromagnetic radiations. It is difficult to form an adequate idea of the marvelous power of this unique appliance, by the aid of which the globe will be transformed. The electromagnetic radiations being reduced to an insignificant quantity, and proper conditions of resonance maintained, the circuit acts like an immense pendulum, storing indefinitely the energy of the primary exciting impulses and impressing upon the earth and its conducting atmosphere uniform harmonic oscillations of intensities which, as actual tests have shown, may be pushed so far as to surpass those attained in the natural displays of static electricity.

Simultaneously with these endeavors, the means of individualization and isolation were gradually improved. Great importance was attached to this, for it was found that simple tuning was not sufficient to meet the vigorous practical requirements. The fundamental idea of employing a number of distinctive elements, co-operatively associated, for the purpose of isolating energy transmitted, I trace directly to my perusal of Spencer's clear and suggestive exposition of the human nerve mechanism. The influence of this principle on the transmission of intelligence, and electrical energy in general, cannot as yet be estimated, for the art is still in the embryonic stage; but many thousands of simultaneous telegraphic and telephonic messages, through one single conducting channel, natural or artificial, and without serious mutual interference, are certainly practicable, while millions are possible. On the other hand, any desired degree of individualization may be secured by the use of a great number of co-operative elements and arbitrary variation of their distinctive features and order of succession. For obvious reasons, the principle will also be valuable in the extension of the distance of transmission.

Progress, though of necessity slow, was steady and sure, for the objects aimed at were in a direction of my constant study and exercise. It is, therefore, not astonishing that before the end of 1899 I completed the task undertaken and reached the results which I have announced in my article in the Century Magazine of June, 1900, every word of which was carefully weighed.

Much has already been done toward making my system commercially available, in the transmission of energy in small amounts for specific purposes, as well as on an industrial scale. The results attained by me have made my scheme of intelligence transmission, for which the name of "world telegraphy" has been suggested, easily realizable. It constitutes, I believe, in its principle of operation, means employed, and capacities of application, a radical and fruitful departure from what has been done heretofore. I have no doubt that it will prove very efficient in enlightening the masses, particularly in still uncivilized countries and less accessible regions, and that it will add materially to general safety, comfort, and convenience, and maintenance of peaceful relations. It involves the employment of a number of plants, all of which are capable of transmitting individualized signals to the uttermost confines of the earth. Each of them will be preferably located near some important center of civilization and the news it receives through any channel will be flashed to all points of the globe. A cheap and simple device, which might be carried in one's pocket, may then be set up somewhere on sea or land, and it will record the world's news or such special messages as may be intended for it. Thus the entire earth will be converted into a huge brain, as it were, capable of response in every one of its parts. Since a single plant of but one hundred horse-power can operate hundreds of millions of instruments, the system will have a virtually infinite working capacity, and it must needs immensely facilitate and cheapen the transmission of intelligence.

The first of these central plants would have been already completed had it not been for unforeseen delays which, fortunately, have nothing to do with its purely technical features. But this loss of time, while vexatious, may after all prove to be a blessing in disguise. The best design of which I knew has been adopted, and the transmitter will emit a wave complex of a total maximum activity of ten million horse-power, one per cent of which is amply sufficient to "girdle the globe." This enormous rate of energy delivery, approximately twice that of the combined falls of Niagara, is obtainable only by the use of certain artifices, which I shall make known in due course.

For a large part of the work which I have done so far I am indebted to the noble generosity of Mr. J. P. Morgan, which was all the more welcome and stimulating, as it was extended at a time when those who have since promised most were the greatest of doubters. I have also to thank my friend, Stanford White, for much unselfish and valuable assistance. This work is now far advanced, and though the results may be tardy, they are sure to come.

Meanwhile, the transmission of energy on an industrial scale is not being neglected. The Canadian Niagara Power Company have offered me a splendid inducement, and next to achieving success for the sake of the art, it will give me the greatest satisfaction to make their concession financially profitable to them. In this first power plant, which I have been designing for a long time, I propose to distribute ten thousand horse-power under a tension of one hundred million volts, which I am now able to produce and handle with safety.

The energy will be collected all over the globe, preferably in small amounts, ranging from a fraction of one to a few horse-power. One of its chief uses will be the illumination of isolated homes. It takes very little power to light a dwelling with vacuum tubes operated by high-frequency currents, and in each instance a terminal a little above the roof will be sufficient. Another valuable application will be the driving of clocks and other such apparatus. These clocks will be exceedingly simple, will require absolutely no attention, and will indicate rigorously correct time. The idea of impressing upon the earth American time is fascinating and very likely to become popular. There are innumerable devices of all kinds which are either now employed or can be supplied, and by operating them in this manner I may be able to offer a great convenience to the whole world with a plant of no more than ten thousand horse-power. The introduction of this system will give opportunities for invention and manufacture such as have never presented themselves before.

Knowing the far-reaching importance of this first attempt and its effect upon future development, I shall proceed slowly and carefully. Experience has taught me not to assign a term to enterprises the consummation of which is not wholly dependent on my own abilities and exertions. But I am hopeful that these great realizations are not far off, and I know that when this first work is completed they will follow with mathematical certitude.

When the great truth accidentally revealed and experimentally confirmed is fully recognized, and this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball, and that by virtue of this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment; when the first plant is inaugurated and it is shown that a telegraphic message, almost as secret and non-interferable as a thought, can be transmitted to any terrestrial distance, the sound of the human voice, with all its intonations and inflections faithfully and instantly reproduced at any other point of the globe, the energy of a waterfall made available for supplying light, heat or motive power, anywhere—on sea, or land, or high in the air—humanity will be like an antheap stirred up with a stick. See the excitement coming!

NOTES.

Tesla in the "Daily Mail."—Marvels beyond belief—*our* belief, at any rate—are to be accomplished by Mr. Nikola Tesla by-and-by, according, of course, to the *D. M.*:—

"An enormous mushroom-shaped tower has just been completed at Wardenclyffe, Long Island, by Mr. Nikola Tesla, the distinguished electrical inventor. From this tower Mr. Tesla is now preparing to put into operation the most daring and amazing scheme ever conceived in the development of wireless telegraphy.

"For over four years Mr. Tesla has been hard at work almost day and night experimenting and endeavouring to make his marvellous theory practicable. From time to time during that period he had intimated vaguely the immensity of his plan, and the equally tremendous results that would follow its introduction, and now, at last, he has announced his preparedness to put his theories to their first practical test.

"For a large part of the work already done Mr. Tesla is indebted to the generosity of Mr. J. Pierpont Morgan, who is extremely interested in the scheme."

Poor Mr. J. P. M.

"Briefly explained, Mr. Tesla's assurances of what we may expect in the next few years are as follows:—

"A ceaseless day and night service of millions upon millions of volts of electricity from the Canadian Niagara Power Co.'s electric power plants at Niagara Falls to the Wardenclyffe tower, the electric power being forwarded from there by Tesla's wireless system to New York City for the purpose of illuminating the entire metropolis, running elevated and underground trains and tramway cars, operating lifts, motor-cars, trucks, and ferry-boats, furnishing heat, and even winding up clocks and making them keep perfect time by a system of half-hourly regulation.

"Each will distribute about 10,000 H.P. of wireless electricity under a tension of one hundred million volts. Mr. Tesla declares that he is able to produce and handle that much with perfect safety from one tower.

"Among his other schemes Mr. Tesla proposes a perfect system of world-wide wireless telegraphy through which widely separated friends will be able to converse instantaneously and without the slightest danger that their wireless conversations will be overheard by a third person.

"Little instruments about the size and shape of a watch will be carried in the vest pocket and will record market quotations, races, and important news features.

"Another little watch-like instrument is one with a dial face by means of which the wearer can transmit and receive wireless messages to and from friends many miles away. Watches of both sender and receiver will be keyed to a certain pitch to prevent their communications from going astray or falling into the watches of disinterested third persons."

We envy the *D. M.'s* good luck in coming into possession of these wonderful items of news; but we fear they are *bad* news.

The Colorado Springs Gazette July 2, 1904

TESLA'S ELECTRICAL STATION IS SOLD FOR VALUE OF LUMBER

The Nicola Tesla experimental electrical station, near the Deaf and Blind school east of the city, has been abandoned. The building still stands there but even that trace of the visit of the great electrician is soon to disappear, for the station has been sold.

Five years ago last May, Tesla decided to construct this station and did so. He stated that he intended to carry on wireless telegraphy experiments from the summit of Pike's Peak to this station. So far as can be learned he never really carried on any important experiments here. He left this city shortly after erecting his station and has not returned since. He was recently sued for an electricity bill, for power furnished by the Colorado Springs Electrical company. He failed to answer the summons either personally or by an attorney and his property was advertised for sale. He later sent the sheriff enough money to cancel the bill and the station again became his property.

Supposedly on his order the property has been sold; that is, all but the apparatus. This has been stored and will probably be shipped to Tesla in the near future.

The building has been sold to C. E. Maddocks, who is erecting a new house in Ivywild and will use the lumber in its construction or for some other purpose about his property, it is understood. The piping has been sold to St. John Bros.

The New York Herald July 4, 1904

TESLA "WIRELESS" STATION ABANDONED

Plumber Has Bought Pipes and Some One Else Lumber of Colorado Experiment House.

[SPECIAL DESPATCH TO THE HERALD.]

COLORADO SPRINGS, Col., Sunday.—Nikola Tesla has abandoned his wireless telegraph station which he established here in 1898, and the lumber has been sold to a party who will utilize it in the construction of a residence.

A plumber has bought the pipes connecting the station with the city water system and with the Colorado Springs Electric Company's batteries. The instruments will be shipped to New York. The station stood at an altitude of seven thousand feet, facing Pike's Peak.

[1133.]—Tesla Coils.—I know of no book treating solely on this subject. In my "Electrical Instrument Making for Amateurs" you will find directions for making two forms, along with good constructive drawings. If there is anything I can assist you in as regards other portions of the high frequency apparatus, such as resonators, &c., I shall be only too pleased to do so, if you will only let me know in these pages what you require.

S. BOTTONE.

The New York Herald September 10, 1904

UPHOLDS TESLA PATENTS.

United States Circuit Court of Appeals Reverses Judgment of Lower Body.

[SPECIAL DESPATCH TO THE HERALD.]

BOSTON, Mass., Friday.—The United States Circuit Court of Appeals to-day handed down a decision in the case of the Westinghouse Electric and Manufacturing Company vs. the Stanley Instrument Company, reversing the judgment of the Circuit Court, which dismissed a bill brought with a view to prevent infringement of patents issued to Nikola Tesla relating to the conversion of alternating currents of electricity into a continuous current.

The defendant had contended that the invention was not addressed to the utilization of two-phased currents in a motor, but to a new way of producing the necessary two out-of-phase currents, and that this specific way of producing two out-of-phase currents was old and well known in the art.

Tesla Patents Upheld.

The U. S. Circuit Court of Appeals at Boston has reversed the decision of the lower court and decided in favor of the Westinghouse Electric Manufacturing Company against the Stanley Instrument Company, upholding the Tesla patents, relating to the conversion of alternating currents of electricity into a continuous current.

Sustaining Tesla Patent on Appeal.

The United States Circuit Court of Appeals at Boston on September 9 handed down a decision in the case of Westinghouse Electric & Manufacturing Company vs. Stanley Instrument Company, reversing the judgment of the Circuit Court, which dismissed a bill brought with a view to prevent alleged infringement of patents issued to Nikola Tesla relating to conversion of alternating currents of electricity into a continuous current. The lower court dismissed the bill on the ground that complainant had failed to establish by sufficient proofs a conception of the invention by Tesla prior to April 22, 1888, the date of a certain publication in Italy known as the Ferraris publication. Complainant appealed, and the Appellate Court sustains the appeal, remanding the case to the Circuit Court with a direction to enter a decree for plaintiff for an injunction against defendant restraining the latter from infringing the patents, numbered respectively 511,559 and 511,560, and for an accounting.

Defendant had contended that the alleged invention was not addressed to the utilization of two-phased currents in a motor, but to a new way of producing the necessary two out-of-phase currents; that this specific way of producing two out-of-phase currents was old and well known in the art, and was old and well known as an equivalent of the method in a prior patent; that all the methods of producing two or more out-of-phase alternating currents set out in the Tesla patents were, in and of themselves, old and well known in the art as means and methods of producing such out-of-phase currents; and that their laws and limitations had been known and set out in a way not even approximated in accuracy or fulness in any of the Tesla patents. Respondent further maintained that Dr. Kenney had explained the fact that the invention in the patents involved merely the substitution of one means of obtaining two-phase currents for another means; and that he showed that these two means were old and well known equivalents.

The Court says in regard to the contention: "Of course all this was with the purpose of maintaining that there was no invention in any view of the patents now in issue. It unavoidably concedes, however, that, if there were invention, it was fundamental. When under special circumstances a particular practical application of a known principle proves to be of advantage in the arts, and yet the thought of making it had not occurred to those expert therein, such application, at times, involves invention. The corollary of this proposition, which we will apply later, is that, in cases of this character, where the originator has boldly struck out into a practical application, and stated it, though only in general terms, he has, for the most part, made his conception clear, even though the mechanical details have not been expressed or thought out. Therefore Professor Main was right in testifying that, if Tesla made clear his conception in a general way, he made clear his invention, leaving the artisan skilled in electrical science to work out the practical details required in applying what was previously within the bounds of philosophical knowledge.

"With reference to the apparent lack of supporting proof on the part of complainant which has been very much pressed against it, it must be conceded, as is apparent from the general tone of the record and from the way in which the case has been developed before us, that the patent was long acquiesced in. It is also certain that an interference was declared between Ferraris and Tesla and decided in favor of the latter. The difficulty which pressed itself upon us on the question of infringement grows out of the fact that the amount of power used by respondent is very minute. Nevertheless it is power developed, as set out by Blathy's claims, by 'a metallic rotating body,' and transmitted to a 'suitable counting apparatus, operated by the same rotating body.' If the device stopped with 'a metallic rotating body' and some method other than a counting machine operated by it was used for determining the number of its revolutions, we might not be able to charge respondent with infringing. We might then well apply the proposition of respondent that a mere meter is in a different art from a motor, but as it does not stop there we must look further. The Tesla invention, in issue, as already explained by us, derives its right to recognition from the fact that it was applied to the production of power. The ingenuity of Tesla was displayed in the conception of an adaptation to a particular use."

EDITORIAL COMMENT

The Tesla Motor and the Polyphase System

The types of alternating-current apparatus which are in use to-day have resulted from a process of evolution which has been going on for many years and in which the polyphase induction motor has been the fundamental element. The announcement of the polyphase induction motor and of the polyphase system were made by Mr. Tesla in 1888. The motor excited much interest and expectation. The polyphase system received little consideration. The motor, however, was helpless without a supply of suitable current. The alternators of that day were single-phase, they gave 120 to 133 cycles; alternators and transformers were ill adapted for supplying out-of-phase current. Persistent work, not only in the design and development of the motor but in that of the system as well was required before commercial success could be secured. In reaching this point it was not only necessary to overcome preconceived ideas of the public, but the electrical workers themselves had to unlearn, or at least readjust much of the information which they had acquired in connection with direct-current and single-phase alternating current apparatus and practice. In point of fact the Tesla invention was not merely a motor, but a system. Commercial men and engineers who did not understand the problems involved were naturally impatient and critical because the Tesla motor was not immediately supplied for operation upon existing circuits and in connection with the then prevalent types of generators. As a matter of history it is the Tesla principle and the Tesla system which have been the directing factors in modern electrical engineering practice. Alternators are now polyphase; they are of low frequency, they have close inherent regulation. All of the long distance systems for power transmission involving hundreds of installations, hundreds of thousands of horse-power and many millions of dollars of capital use the polyphase system. Nearly all of the great central stations for city railway and lighting service, even when the consumption circuits are supplied with direct current employ low frequency polyphase alternators. There is scarcely an important city or town in the country that has not a polyphase

plant and polyphase apparatus is largely used for power distribution in industrial establishments.

This evolution has involved far more than the mere perfection of the motor. In fact polyphase motors as made prior to 1890 if operated in connection with modern generators would probably be more successful than the motors of to-day if operated in connection with polyphase alternators of the types first employed. The early polyphase alternators were small, they were of high frequency, they were of poor regulating qualities. Changes have been made in alternators and in transformers. Parallel operation of alternators has become a necessity, imposing exacting problems in the design and operation of steam engines. The extent to which everything in modern electrical power work has been affected by Tesla inventions makes it apparent that the polyphase motor which he proposed was no simple and isolated thing, but it was the central factor in a great and comprehensive system. The whole trend and evolution for the past sixteen years has been in the development of the polyphase system primarily that it may operate the polyphase induction motor. The realization of the Tesla invention was looked for simply in a motor to be forthcoming in a few months; it has come in an evolution of engineering practice which has been the work of years.

CHAS. F. SCOTT.

Tesla Patents Upheld in Stanley Instrument Case.

An opinion was handed down September 9th by the Circuit Court of Appeals for the first circuit in the case of the Westinghouse Electric and Manufacturing Company, complainant and appellant, against the Stanley Instrument Company, defendant and appellee, known as the "Stanley instrument case," the case having been appealed from the United States Circuit Court for the District of Massachusetts. The Court of Appeals reversed the decree of the lower court, which was in favor of the defendant. The opening and closing paragraphs of the opinion of the court, written by Judge Putnam, are of interest, and are here given:

There is so much judicial literature bearing on this case that only a brief preliminary statement is required. The bill alleges an infringement of the two claims of letters patent for an invention, No. 511,559, issued to Nikola Tesla on December 26, 1893, on an application filed on December 8, 1888, and of the first claim of No. 511,560, issued to Tesla on the same December 26th, on an application filed on the same December 8th. No. 511,559 is captioned "Electrical Transmission of Power," and opens with the statement that Tesla had invented "certain new and useful improvements in electrical transmission of power." No. 511,560 is captioned "Systems of Electrical Power Transmission," and opens with the claim that Tesla had invented "certain new and useful improvements in systems of electrical power transmission." The claims of No. 511,559 are as follows:

"1. The method of operating motors having independent energizing circuits, as herein set forth which consists in passing alternating currents through both of the said circuits and retarding the phases of the current in one circuit to a greater or less extent than in the other.

"2. The method of operating motors having independent energizing circuits, as herein set forth, which consists in directing an alternating current from a single source through both circuits of the motor and varying or modifying the relative resistance or self-induction of the motor circuits and thereby producing in the currents differences of phase, as set forth."

The claim of 511,560 in issue is as follows:

"1. The combination with a source of alternating currents, and a circuit from the same, of a motor having independent energizing circuits connected with the said circuit, and means for rendering the magnetic effects due to said energizing circuits of different phase and an armature within the influence of said energizing circuits."

The bill was dismissed by the Circuit Court by an opinion passed down on March 11, 1903, 129 Fed. Rep., 140. The only reason for dismissal given was that the complainant had failed to establish by sufficient proofs a conception of the invention by Tesla prior to April 22, 1888, the date of a certain publication in Italy known as the Ferraris publication. The opinion refers to one of the Circuit Court of Appeals for the second circuit, Westinghouse Company vs. Catskill company, 121 Fed. Rep., 831, passed down on February 25, 1903, wherein it was held that the proofs were insufficient to establish invention by Tesla prior to April 22d, as rendering unnecessary an extended statement by himself. Thereupon, the complainant appealed to us.

The patents in suit relate to the conversion of alternating currents of electricity into a continuous current. The latest condition of the prior art is shown by patents issued to Tesla under date of May 1, 1888, referred to over and over again in the judicial literature on this topic. These describe a system "of electrical power transmission in which the motor contains two or more independent energizing circuits through which were caused to pass alternating currents," "conveyed directly from the generators to the corresponding motor coils by independent lines or circuits." The improvement of the patents in suit dispenses with one of the lines, or circuits.

* * * * * * *

It is not necessary for us to discuss whether what Tesla applied his inventive ability to was a "great engineering problem," as described by plaintiff; but it was a problem practically unsolved in the then state of the art, and of such a character that its solution was certainly a useful one. Therefore, the invention, according to settled rules, is to be protected to its fullest extent unless something of a positive character, either in the patent itself or elsewhere, prevents. It is true that Tesla's specification indicates strongly that he probably had not in mind the application of his invention to any motors except his own. Possibly he valued no other two-phased alternating-current motors, or he conceived that there were no others; so that naturally the practical application which he had in mind was limited accordingly. Nevertheless, he is entitled to the advantage of the well-settled rule by virtue of which an inventor who has patented his invention, is entitled to all the uses to which it may be applied, of the class to which he himself practically applied it. Therefore, we do not perceive how, on any rule relating to the fundamental nature of inventive conceptions, or to the construction and effect to be given to the specifications and claims in patents for invention, it can be held that the respondent can escape, for any reason we are now discussing, the charge of infringement.

Our observations so far have been more particularly with reference to the phraseology of the only claim of patent No. 511,560 in issue. The claims of patent No. 511,559, so far as the topic we are discussing is concerned, are as broad as the single claim of patent No. 511,560. It is true they contain the words "as herein set forth," which are not found in the other patent; but these words connect directly with the words "independent energizing circuits," and they do not necessarily relate, either grammatically or by any reasonable demands of the rules of construction, to any particular description of motors. Therefore, within the rules stated in Reece Button-Hole Company vs. Globe Button-Hole Company, ubi supra, by virtue of which all expressions in specifications or claims are to be held to sustain the actual invention so far as they can reasonably be so construed, this one does not stand in the way of our giving, so far as the topic we are discussing is concerned, as broad a construction to patent No. 511,559 as to the claim of patent No. 511,560 in issue.

The difficulty which presses itself upon us on the question of infringement, grows out of the fact that the amount of power used by the respondent is approximately what is described by it as negligible; that is very minute. Nevertheless, it is power developed, as set out by Blathy's claims, by "a metallic rotating body," and transmitted to a "suitable counting apparatus, operated" by the same rotating body. If the device stopped with "a metallic rotating body," and some method other than a counting machine operated by it was used for determining the number of its revolutions, we might not be able to charge the respondent with infringing. We might then well apply the proposition of the respondent that a mere meter is in a different art from a motor: but, as it does not stop there, we must look further.

The Tesla invention in issue, as already explained by us, derives its right to recognition from the fact that it was applied to the production of power. In that respect, it falls within the limited class referred to or described by us in Davey Company vs. Isaac Prouty & Co., 107 Fed. Rep. 505, 509, 510, 511. The adaptation of the tortional spring which laid the basis of Western Electric Company vs. Larue, 130 U. S. 601, was a marked instance of this class of cases. The ingenuity of Tesla was displayed in the conception of an adaptation to a particular use; and any adaptation which did not involve that conception could hardly infringe. Therefore, as it may well be that, if the counting mechanism was of a kind not operated by the "metallic rotating body" we should not be compelled to find infringement, we hesitate in view of the minute amount of energy exerted. But Blathy did not merely reproduce the academic experiments which must have preceded Tesla. While Tesla uses the word power, he makes no maximum nor minimum: and it is entirely conceivable that, for certain fine work, or work of a peculiar character, the minimum may be of the utmost value. Therefore, we are unable to make any distinction on this account.

Probably we ought to refer to what is spoken of by the parties as Baily and Deprez. We apprehend that Deprez is disclosed by what is known as "Deprez French Patent of 1870," and that Baily is represented by the article in the Philosophical Magazine of October, 1870. These are each relied on by the respondent. Baily was seeking simply a revolving disk, and not looking beyond that. He did not attempt to transmit that electrical power which, as we have shown, was the soul of Tesla's invention, and which we have also shown is involved in the infringing device, although, perhaps, to a minimum. It is apparent, also, that Baily did not concern himself about alternating currents as such; and it is not at all clear that he proposed to make use of them at all. Deprez, on the other hand, made commutators necessary elements in his device, which essentially distinguishes him from both the complainant and respondent, and lays him out of the case without the necessity of further discussion.

Possibly, relating to some other infringers than those at bar, we might be compelled to determine more positively than we have the construction of some of the claims which are put in issue here, pertaining to the two patents in suits. For the present case, however, any further investigation or discussion relating to them would be purely academic and of no practical importance. The infringement by the respondent relates entirely to the method by derivation, or self-induction, which for present purposes, are the same; and, so far as that is concerned, it can make no possible difference as to practical results whether the injunction and accounting relate to all the claims in issue or only to one or two of them. Therefore, in view of the construction which we are now inclined to give the claims, as already stated, we hold that the relief granted should relate to all.

We wish to call attention to the fact that, at various points, the respondent has referred to the affidavits filed in connection with the motion to the

Circuit Court to reopen the case, as though they were adverse to the complainant, and, especially, as though contradicting, in one important particular, the testimony of Mr. Page. On the other hand, at some points, the complainant has undertaken to strengthen its case by reference to the same affidavits. We reject all these, and open the record only so far as it is properly before us. To do otherwise would be to enter on a field which has not been explored by the parties according to proper rules of procedure.

The decree of the Circuit Court is reversed; the case is remanded to that court, with instructions to enter a decree in favor of the complainant for an injunction and an accounting, and to take such further proceedings as may be required not inconsistent with this opinion; and the appellant recovers the costs of this appeal.

Wireless Telegraph Aerial Wires and Earths.*

BY A. FREDERICK COLLINS.

HISTORICAL.

IN a patent granted to Thomas A. Edison, dated December 29, 1901, means are shown for transmitting signals without wires by elevating plates of metal on poles or by balloons. The aerial wire was connected to one terminal of a secondary coil with the opposite terminal leading to the earth; while this is perhaps the earliest reference to aerial wires and earth plates, the method does not employ either a spark-gap or a wave detector for oscillatory currents. In Amos E. Dolbear's patent, issued in 1886, no reference is made to the elevation of the capacities he suggested for the equalization of the coefficients of the circuit connected with the earth. In 1895 Isadore Kitsee obtained a patent for signaling without wires and indicated how one terminal of the system was extended vertically to an elevation approximating the height of a vessel's mast. The antenna and earth utilized by Prof. Popoff in his meterological receptor in 1895 and that by Signor Marconi in his electric wave transmitter, the patent application of which was filed in England in 1896, are the earliest references to the subject of aerial wires and grounds in connection with electric wave wireless telegraphy. In Nikola Tesla's British specification, filed October 21, 1897, he describes a method of producing "a very high electrical pressure, conducting the current thereby to earth and to a terminal at an elevation." The various designs for aerial radiators and antennæ employed in different systems will be treated in sequence in the text appertaining to their application in practice.

THEORETICAL.

There are two theories relating to the probable capacity of the earth and several concerning the rôle the earth plays in the operation and propagation of electric wave signals. The true solution of the problems presented by the earth might prove the key to syntonic wireless telegraphy. In one of the two theories referred to the earth is considered as a sphere insulated in space; the second and opposition theory assumes the earth with its surrounding envelope of air to be a condenser. Koepsel[1] by a formula in electrostatics for the potential of a charged sphere insulated in space deduced a result showing the earth's capacity to have a low value and comparable with artificial capacities used in wireless telegraph practice.

The second theory treats the earth and air as if they were two concentric spherical shells, the medium between them representing its specific inductive capacity, when their capacity will be the same as in the case of two parallel plates with their surfaces brought in close proximity with each other in the form of a condenser. If, as the first theory postulates, the earth is a single spherical shell insulated in space, its capacity must necessarily be very limited, since a single coating on a glass jar would be incapable of acquiring more than the slightest charge; but if the stratum of atmosphere holds a charge opposite to that of the earth, then it may be likened to a complete Leyden jar with its inner and outer coatings, and its capacity would be enormously increased. The importance of knowing absolutely the capacity of the earth cannot be overestimated, but could such conclusions be thus positively ascertained, the density of the charge at a given point could only be taken as a theoretical standard; for, owing to the differences of atmospheric densities, the electric charge may be maximum or minimum at any point at any given instant, and even then of a different sign.

Many different views have been submitted to explain the relation of the earth to the radiating and receiving systems; among the most prominent may be mentioned the following: (*a*) that high-frequency currents are projected from the earthed terminal of the oscillator, whence they are conducted by the earth to the resonator; (*b*) that the earth acts simply as a local capacity for the aerial wires; and (*c*) that the earth, having a large value, serves to tune the oscillator and resonator, since both being grounded would represent the same capacity. As to the nature of the earth as a conducting medium for electric waves there is also a variance of opinion; by those advocating sliding waves the sea is regarded as opaque to electric waves, and it is claimed that in this it fulfills Maxwell's law in that salt water is a conductor of electricity. Others voice the opinion that the sea will transmit electric waves, since salt water does not follow the general law for conductors, in that it conducts by electrolytic action. One fact, however, is positively known, namely, that electric waves are much more easily transmitted over salt water than over fresh water or land. Whatever these conditions may be, it is well known that if a metallic conductor, as a lightning rod, be extended upward in the air and its lower terminal connected with the earth, a constant current will flow through it, equalizing in a small measure a difference of potential that is always present. If this conductor is divided and the resulting terminals form an air-gap, the potential difference may be measured by a galvanometer, or if the air-gap is microscopic in size sparks will pass; if a detector of the coherer type is inserted in the gap the filings will cohere under certain meterological conditions and the restoration of the charge will be indicated. In practice these atmospheric disturbances often produce characters on the tape of the recording instrument, and these untoward indications are called "X's," or strays. The purpose of the aerial wire, on the one hand, is to send out transverse vibrations in the ether in the form of electric waves, and on the other, to receive them; it was ascertained by Dr. Slaby and Prof. Braun that the proper length of the aerial wires should be one-fourth the length of the emitted wave, and therefore the radiator and antenna should have as nearly the same height as possible.

A law relating to the distance over which electric waves may be transmitted with a given height of aerial wire was deduced empirically by Marconi very early in the practice of the art. This law states that with a given current, instruments of standard dimensions and all other factors being equal, the distance to which signals may be transmitted increases as the square of the length of the radiating wire; or, graphically, if a wire 20 feet in height will transmit one mile, a wire 40 feet in height will send waves four

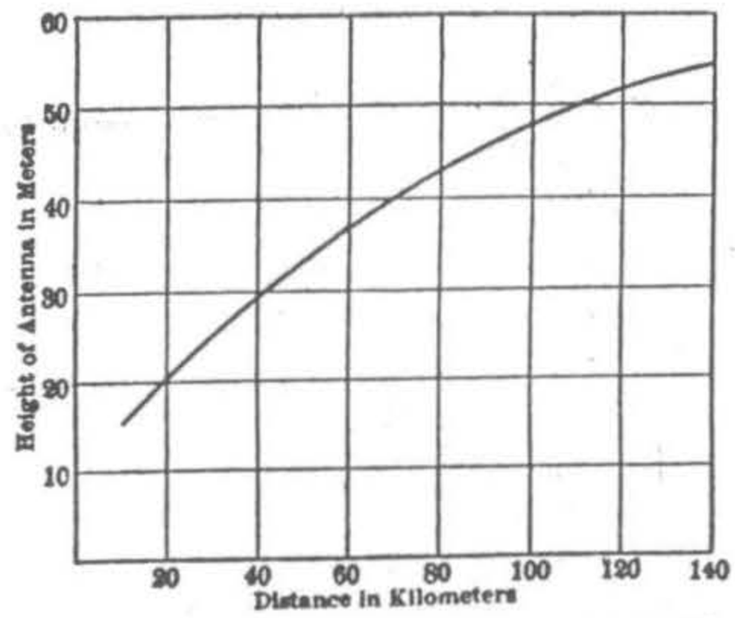


FIG. 1.—CURVE OF TRANSMISSION DISTANCES.

miles, and one 80 feet in height will transmit waves sixteen miles, *et cetera*. This general law was mathematically evolved by Prof. Ascoli, who deduced his conclusions in accordance with Neumann's formula and found the reciprocal action to be proportional to the square of the length of one of the two aerial wires if these are of equal length, and in simple inverse proportion of the distance between them.

It would seem that the empirical law of Marconi and the deductions of Ascoli are subject to modification for Captain Bonomo, of the Royal Italian Navy has determined that the distance to which signals may be transmitted is in accordance with the formula $L = O.15 \sqrt{D}$ where L represents the length of the aerial wire, D the signaling distance in meters and $O.15$ is a constant. Where a number of parallel wires are employed instead of the single vertical wire as first used by Marconi this apparent discrepancy is accounted for, not only because of the greater radiation of energy, but also in virtue of a longer wave length emitted.

The intensity of the oscillations does not diminish with the increase of distance if the length of the aerial wires is increased in proportion or as the square of the distance; therefore, by doubling the height of the aerial wires the distance of signaling may be four times as great. In a series of experiments carried out by Dr. Slaby to determine with precision the exact height of aerial wire required to transmit messages over a given distance the curve shown in Fig. 1 was plotted. Starting with an initial energy of 746 watts, the curve represents the maximum distance for transmission over bodies of salt water, with the Slaby-Arco standard station apparatus. Considerable latitude has been allowed for meterological, climatic changes and unfavorable conditions of the year, as, for instance, the heated atmosphere of the summer months. The accuracy of the

*From advance sheets of "Wireless Telegraphy; Its History, Theory and Practice" in press.

[1]Koepsel, Dingler's Polytechnisches Journal, June, 1903.

curve has been tested carefully, and while the sending and receiving instruments are calibrated in accordance with the curve, their actual working distance may be much greater, as, for instance, it was found possible to obtain messages between the *Deutschland* and the *Duhmen*, a distance of 150 kilometers, whereas the curve gives the working distance as 80 kilometers. The photo-electric effect of sunlight on aerial wires was deduced by Marconi[1] upon the conclusions reached by Hertz[2] in 1887, who found that the effect of one electric spark from an induction coil on another had a tendency to diminish the size of the latter, and that this curious result was due to the ultra-violet radiation—in which the disruptive discharge is rich—dissipating the charge of electricity stored in the second oscillatory system. Righi[3] attributed the cause to the ultra-violet radiation producing correction or the process of dispersing negative electricity, the charge being carried away by the molecules of air. Righi also determined that ultra-violet radiation charged wires, when insulated, with positive electricity, and Elster and Geitel have been able to show the dissipating influence of not only sunlight, but of diffused daylight on conductors. This phenomenon was observed at the antennæ by Marconi when he received signals a distance of 2,099 miles from Poldhu, Cornwall, England, on the steamship *Philadelphia*. During the tests made on this trip it was ascertained on one occasion that the signals were distinct and clear at night for 2,000 miles, but in daylight the signaling distance was only a fourth part as great, or 500 miles.

PRACTICAL.

In practice it is of vital importance to maintain absolute insulation of the aerial wires and earthed terminals of the radiator and resonator, for in utilizing high-frequency, high-potential currents leakage becomes excessive should any portions of the systems come in contact with masts, buildings or other physical appurtances. Where the aerial and ground wires are sustained or supported heavy glass or porcelain insulators are desirable. The wires themselves should be highly insulated, since this protects the oscillatory currents from dissipating their energy in the atmosphere and does not retard the action of the electric waves, for insulators are transparent to them.

METHOD OF SUSPENSION.—A simple and efficient method for suspending aerial wires from the yardarm of a mast is shown in Fig. 2; the mast is represented at 1, the yardarm 2, insulator 3, capacity area 4, and wire 5. The insulator is supported by a loop of tarred rope attached to the yardarm, and the capacity area, or wire if it be used direct, is inserted longitudinally in the insulator as as shown. The method illustrated in Fig. 3 was designed by Ducretet and is a superior modification of the one just described.

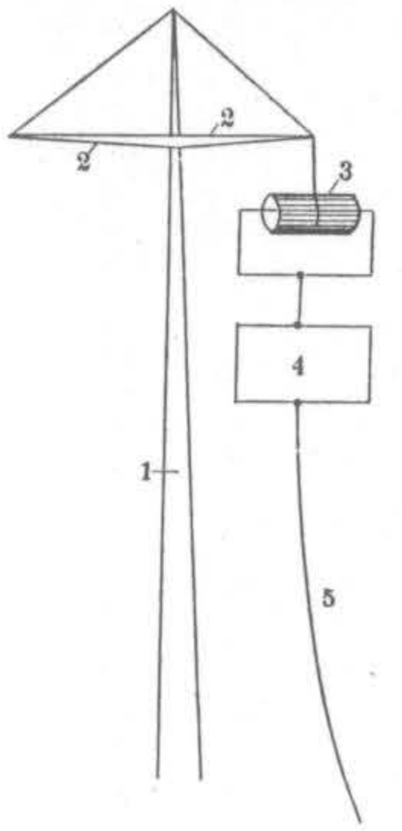


FIG. 2.—METHOD OF SUSPENSION.

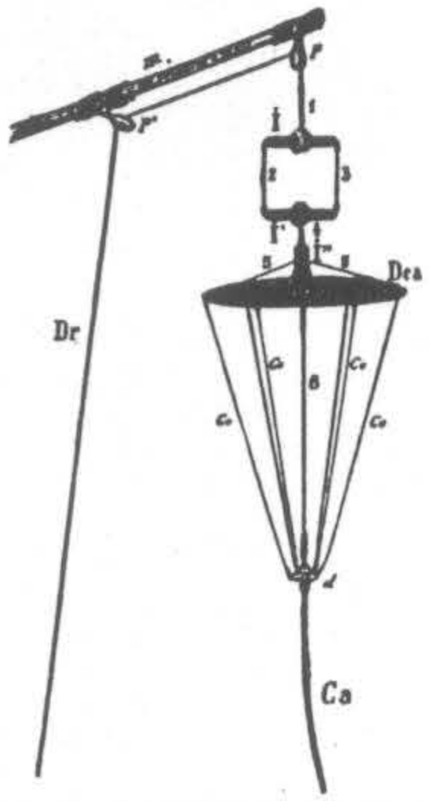


FIG. 3.—DUCRETET METHOD OF SUSPENSION.

A method to eliminate leakage where the aerial wire leads into the station to the instruments is shown in Fig. 4 and is due to Dr. Braun; it will be seen that the leading-in wire passes through a porcelain bushing inserted in an aperture cut in the window-pane.

FORMS OF ORDINARY AERIALS.—The early Popoff antenna consisted of a lightning-rod, while that employed by Marconi in his first essays comprised a single copper wire leading from the instruments and to which a large metal plate was attached to its upper free terminal. Various forms of aerial wires are shown in Fig. 5; the object of adding to the number of wires is to obtain a greater radiating and receptive surface. Referring to the figures, *a* is the ordinary single wire aerial, *b* parallel wires which are in some cases arranged in fan shape, *c* multiple quadrangular aerial, *d* multiple cylindrical aerial, and *e* inverted pyramidal aerial form for long-distance transmission. The length of aerials is from 50 to 200 feet. Fleming has pointed out that if an aerial is composed of seven strands of wire, each having a diameter of No. 22 B. S. G., and a

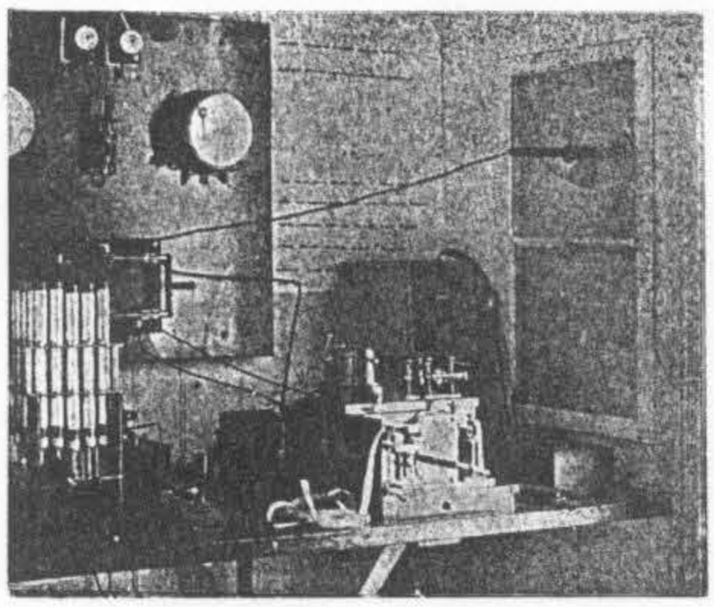


FIG. 4.—BRAUN LEADING-IN METHOD.

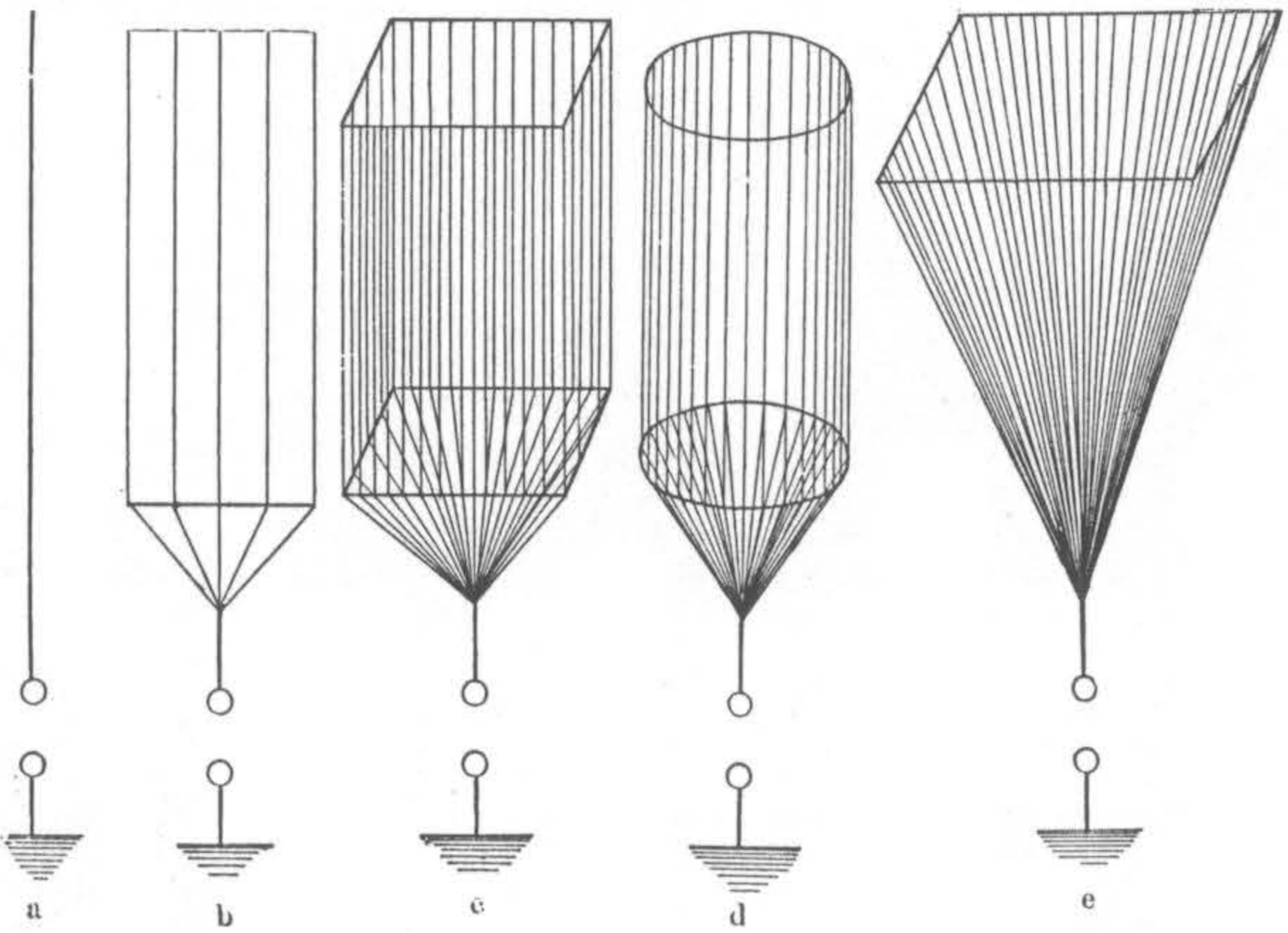


FIG. 5.—VARIOUS FORMS OF AERIAL WIRES.

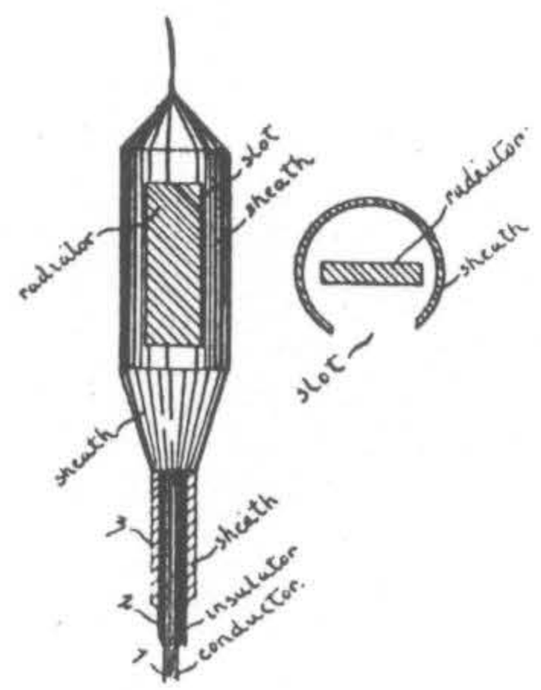


FIG. 6.—GUARINI SHEATHED AERIAL.

[1]Royal Society; Discourse by Marconi, June 12, 1902.
[2]Wiedemann's Annalen 31, p. 983.
[3]Comptes Rendus, vol. 107, p. 559.

length of 150 feet, and insulated from the earth. Its capacity, if held vertically, is 0.0003 microfarads. If a number of wires are placed very closely together, their combined capacity is not merely equal

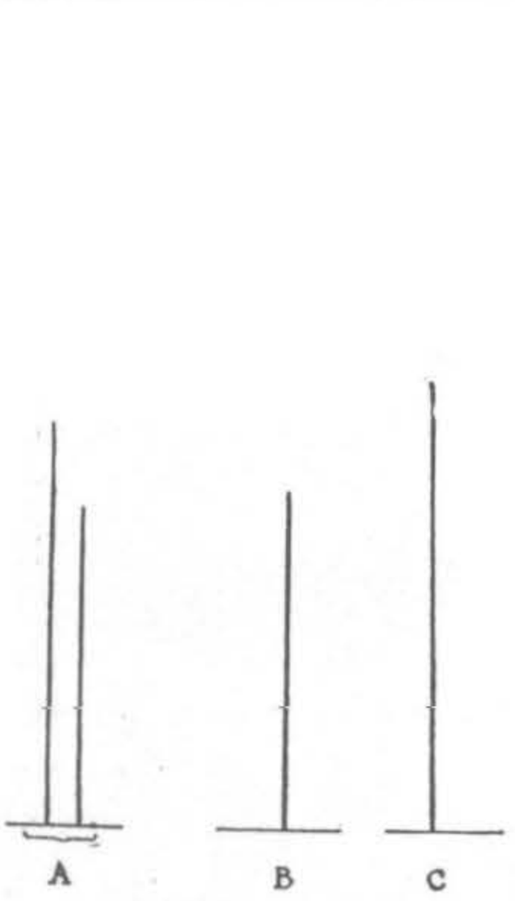


FIG. 7.—DIFFERENTIAL AERIAL SYSTEM OF JEGON.

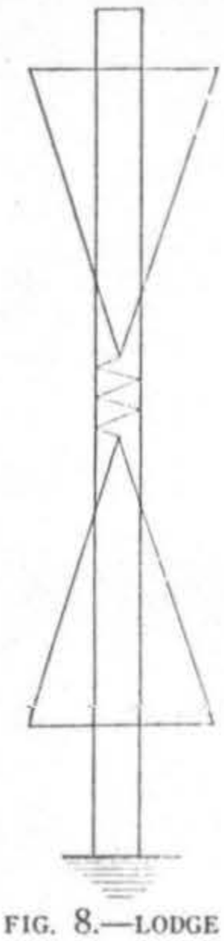


FIG. 8.—LODGE CAPACITY AERIAL

to the sum of their individual capacities[4], and therefore the wires should be placed at a considerable distance apart.

LODGE CAPACITY AERIAL.—The earliest form of aerial, if such it may be termed, for the purpose of selective signaling, is due to Lodge; it is shown in diagram Fig. 8. Two cones of large dimensions, made of metal and insulated from themselves and the earth, served to increase the capacity of the system as well as to indicate and receive the electric wires. The capacity areas were of a definite value, but were connected with an inductance coil so that this factor could be changed.

TOMMASSI JEGON DIFFERENTIAL WIRE AERIAL.—The differential aerial system introduced by Tommassi Jegon some years ago was intended to receive various wave lengths simultaneously by employ-

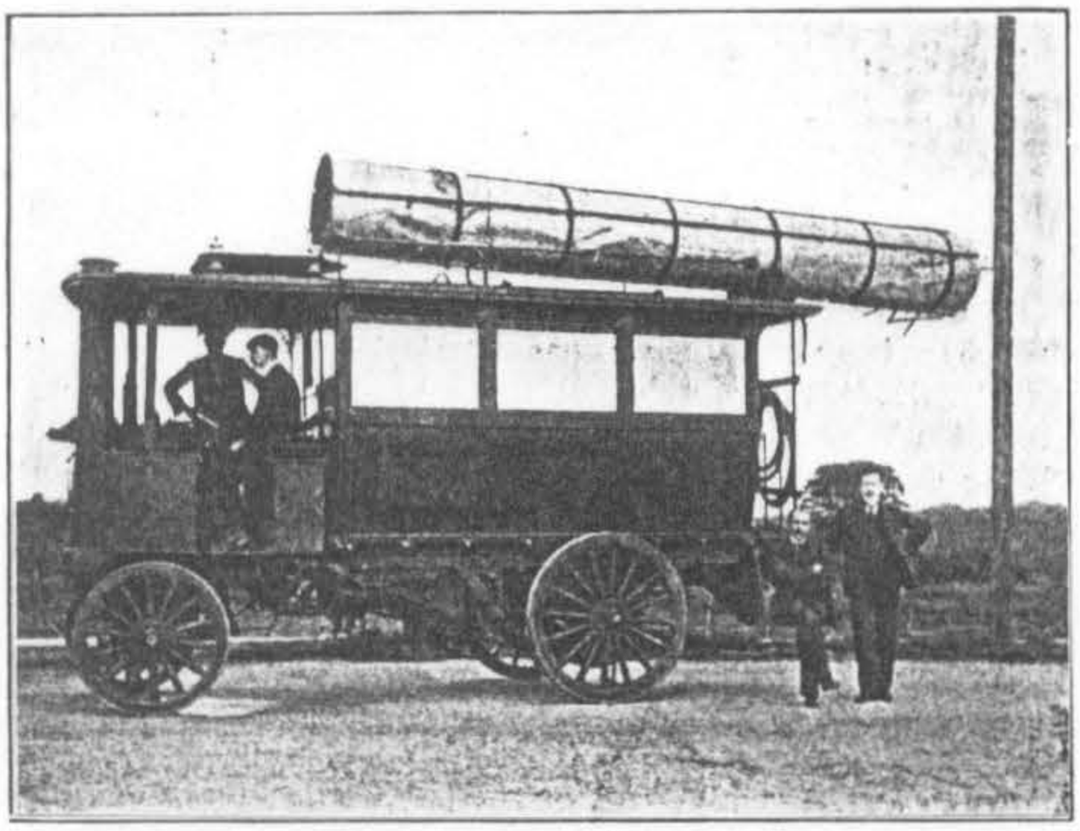


FIG. 9.—MARCONI WIRELESS TELEGRAPH AUTOMOBILE.

ing two or more wires at the transmitting station, as at *A*, Fig. 7; these radiating wires were of different lengths at the receiving station, *B*; 5 km. distant the antenna was equal in length to the shorter one at *A*, while at station *C*, 10 km. distant, the antenna was equal to the longest wire at *A*. By a proper adjustment the indications will not respond except when the shortest wire at *A* is sending to *B* or the longest one at *A* to *C*, except where a definite value of the distance produces a neutral effect on both receivers.

GUARINI SHEATHED AERIAL.—The fact that electric waves are intercepted, reflected and absorbed by metals led Guarini to devise the sheathed aerial shown in Fig. 6; the aerial wires emitting and receiving the waves were insulated and then encased in a metallic sheath diverging at the top, forming a cylinder of large diameter in which a slot was cut; the purpose of this arrangement was to reflect the emitted waves in a given direction or to receive them from a

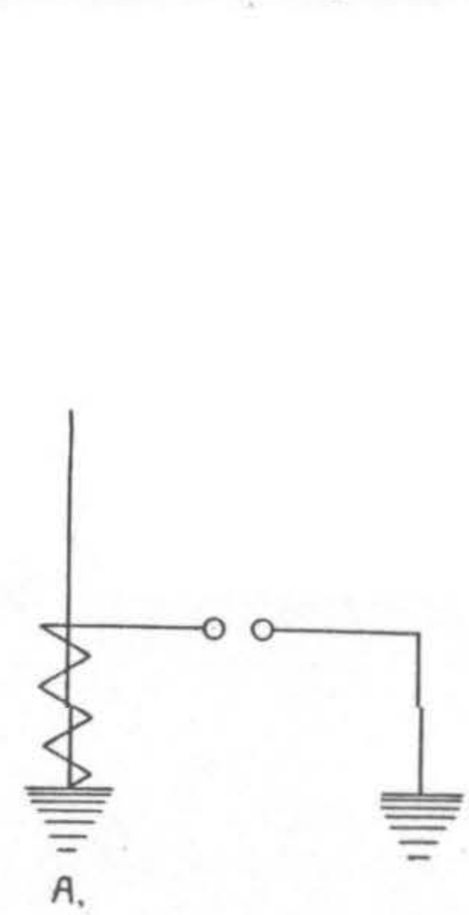


FIG. 10.—SLABY-ARCO DIRECT-EARTHED AERIAL.

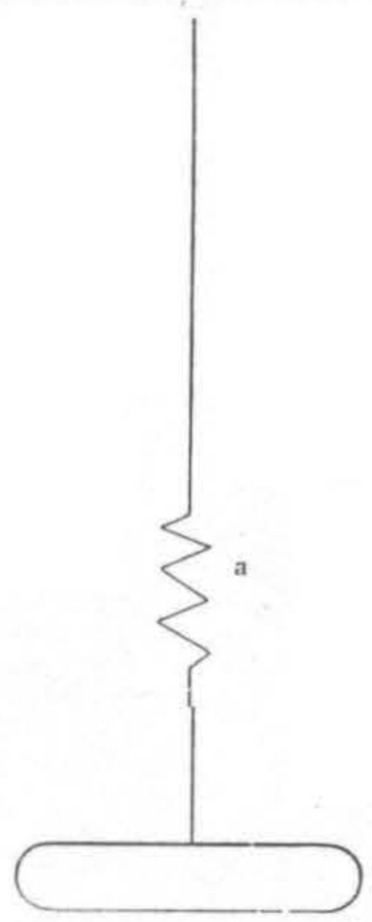
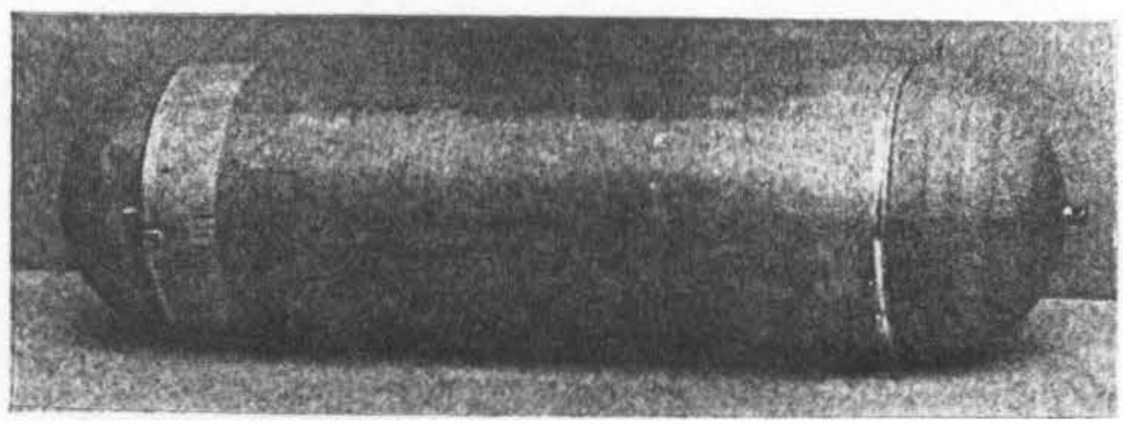


FIG. 11.—BRAUN ARTIFICIAL EARTH.

given point of the compass. There is a very great loss of energy in this method of transmission, but in specific cases it might be useful.



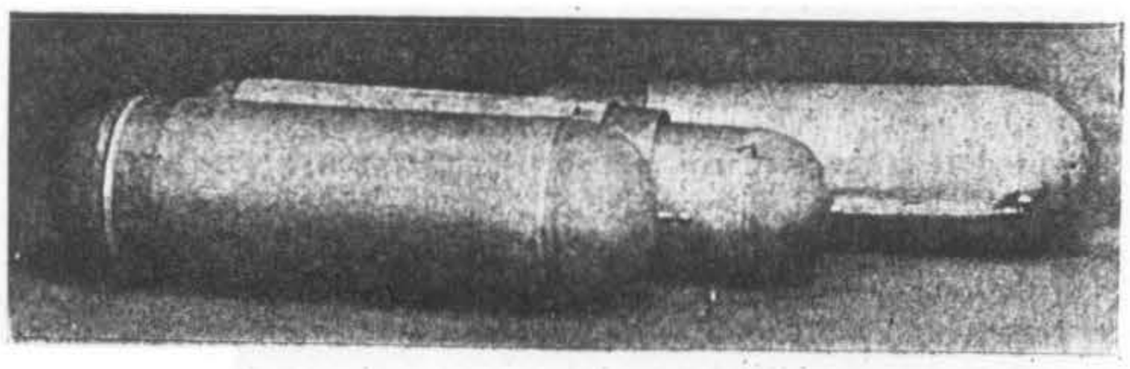


FIG. 12.—BRAUN ARTIFICIAL EARTH.

When receiving all extraneous electric waves are either reflected from the steath surrounding the aerial wire or transformed into oscillations which are conducted to the earth.

MARCONI AERIAL (SECOND FORM).—The aerials employed by Marconi in his first syntonic system, composed of inner and outer metal cylinders, mark the first attempt to eliminate the high vertical wire as a factor in wireless telegraphy. Marconi has used single cylin-

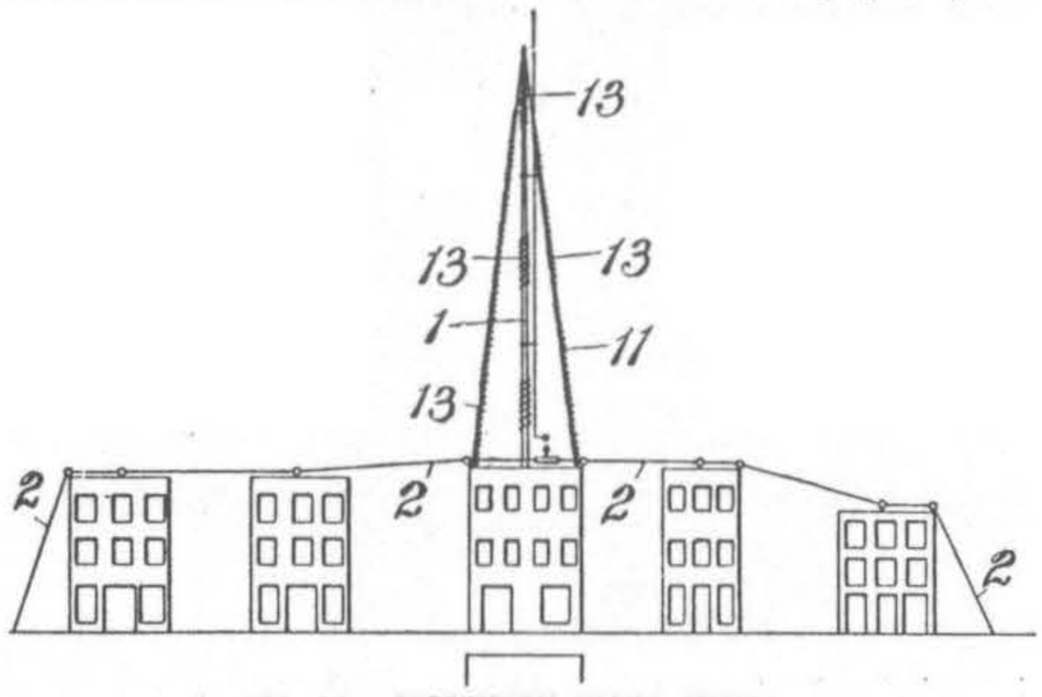


FIG. 13.—FESSENDEN WAVE CHUTE.

[4]Cantor Lectures, Society of Arts, London, March, 1903.

ders of four or five meters in height in some of his experiments, and it is stated that messages have been sent and received a distance of twenty miles with their aid. A wireless telegraph automobile designed by this inventor for military purposes is equipped with an adjustable cylinder arranged to fold back on top of the vehicle when not in active service. It is illustrated in Fig. 9.

SLABY-ARCO DIRECT EARTHED AERIAL.—To Dr. Slaby and Count Arco is due the credit of having employed the sending and receiving aerials directly connected with the earth. Before the researches which led to this method it was the common practice to connect the lower free end of the aerial wire with one side of the spark-gap or coherer and the earth to the complementary side, but it was subsequently found that if the oscillators and wave detectors were connected to the aerial wire at a point where it found contact with the earth, as in Fig. 10, the potential of the oscillators was equally effec-

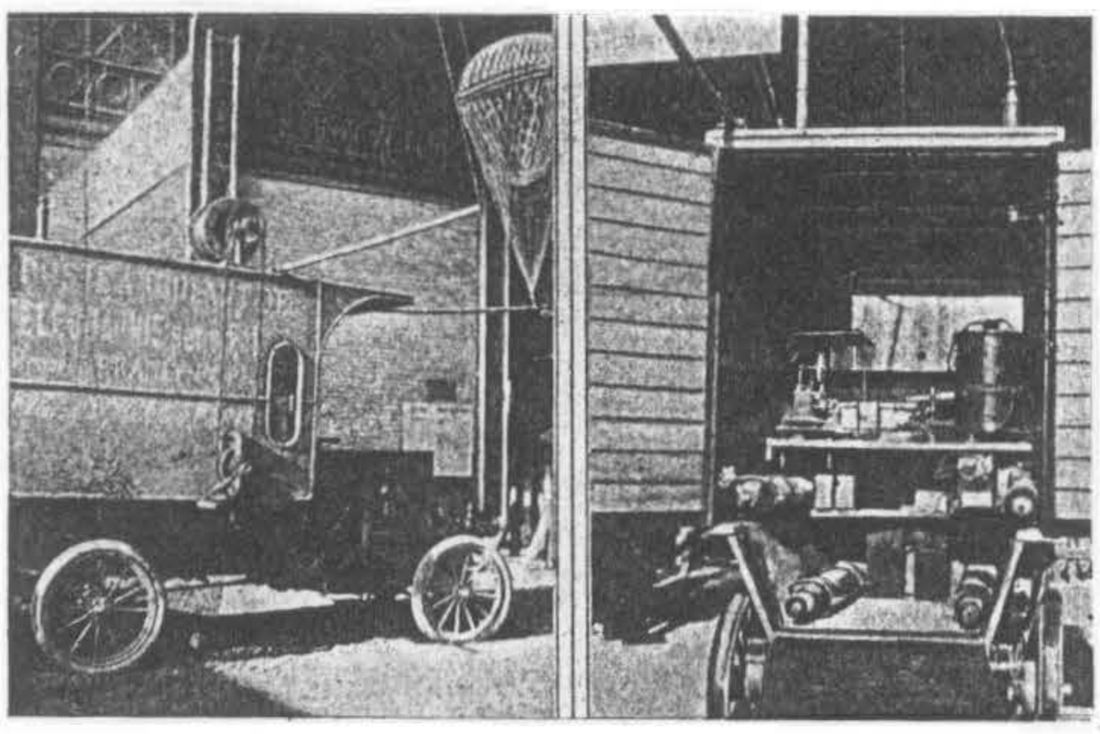


FIG. 14.—BRANLY-POPP WIRELESS TELEGRAPH AUTOMOBILE.

tive, while the discharge of atmospheric through the detector would be dissipated in the earth at *A*. In accordance also with the theory evolved, all waves received by the aerial which were not of a predetermined length will pass into the earth, since the nodal point is at *A;* the aerial wire should be in this case one-fourth the length of the wave it is desired to receive.

BRAUN NON-EARTHED AERIAL.—In Braun's system the radiator, Fig. 11, *A,* is connected with the primary of a transformer coil, *a,* whose opposite terminal is not earth, but is attached to a cylinder of copper or zinc, called an artificial earth, illustrated in the photograph, Fig. 12. This is one of the striking features of the Braun system and an original departure in commercial wireless telegraphy. It is claimed that this method effectually eliminates the disturbances due to atmospheric electricity.

DE FOREST MAST AND AERIAL.—One of the stations of the De Forest system is located at Steeplechase Park, Coney Island. It is equipped with a mast 210 feet in height; it is constructed of four

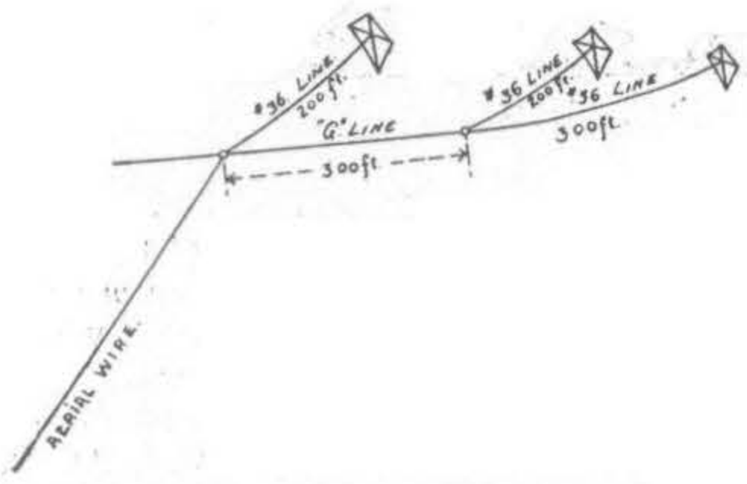


FIG. 15.—AERIAL ATTACHED TO KITES.

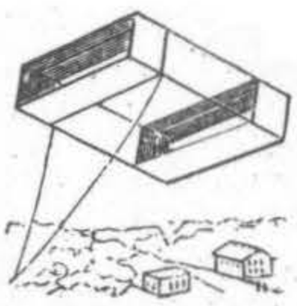


FIG. 16.—BLUE HILL BOX KITE.

poles set in crosstrees and supported by square bars of iron with a shoulder at one end to sustain the topmast over the head of the lower mast. These are termed fids; the mast is guyed to braces sunk into the sand sixteen feet deep. The guys are of wire rope with hemp rope terminals spliced to about 100 feet from the ground; the object of this combination is to maintain the insulation of the aerial cables, of which there are two supported by a yardarm near the top, and to prevent them from coming in contact with the guys.

FESSENDEN WAVE CHUTE.—In a recent patent granted to Prof. Fessenden additional data are given relating to aerials and grounds. This physicist has found it desirable to have a highly conducting surface over which the waves are propagated in the neighborhood of the point where they are generated, and that this highly conducting surface should extend to a distance from the point of their production at least one-fourth of the length of the wave in air and in the direction toward the station to which it is desired to send the

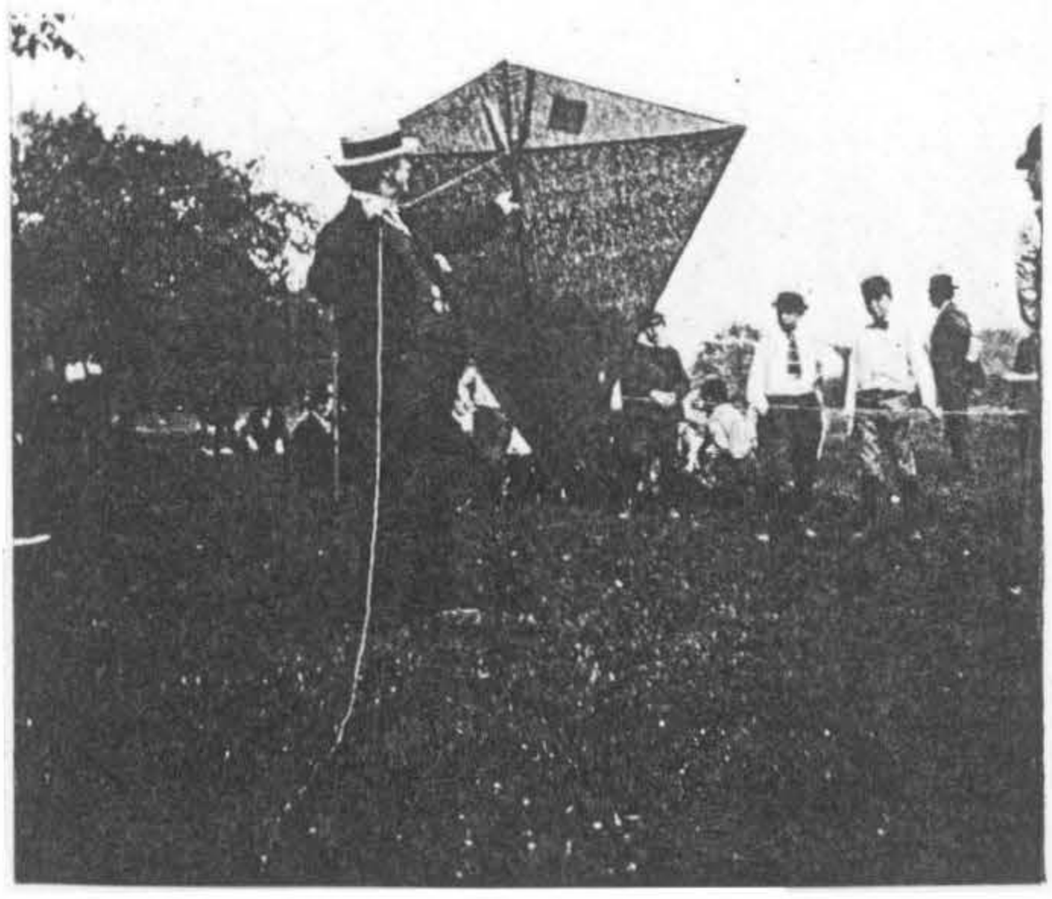


FIG. 17.—MALAY OR EDDY KITE.

message. The diagram, Fig. 13, illustrates the method for producing the desired results and is termed by Fessenden *a wave chute;* in the figure, 1 is the sending conductor, and 2, 2′, 2″ is the grounded conductor leading across building and other obstacles to a $\frac{\gamma}{4}$ beyond the limit of obstructions where the terminals are earthed as shown. The coils 3 and 4, forming guys from the mast, have a period of oscillation different from that of the antenna, and this with the grounded conductor or wave chute eliminates the interference of extraneous waves and serves to dissipate atmospheric potentials which occur in ordinary aerial wire systems. In practice Fessenden employs a sending wire having a large capacity and low inductance. The former is regulated by increasing the area of the

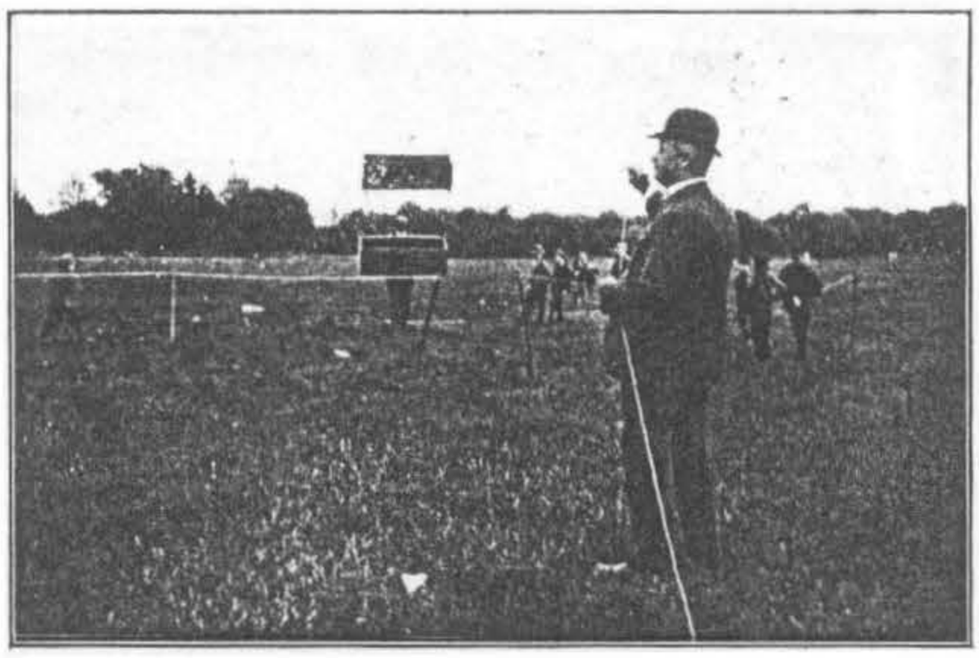


FIG. 18.—BLUE HILL BOX KITE IN FLIGHT.

aerial wire and the latter by adding to the number of turns of wire connecting the vertical wire with oscillator.

KITE-SUSTAINED AERIALS.—With the advent of the auto-coherer and current-actuated detectors came portable transmitters and receptors and the kite-sustained aerial wires. Heretofore one of the greatest obstacles to the successful transmission of wireless messages in military operations was the heavy accoutrements entailed by the use of masts, as these are much too cumbersome to be transported with the facility necessary in such all-important operations, and instruments without 80- or 100-foot aerials are useless. The kite and the balloon offer the solution. Kites are preferable, except in cases when there is no wind, and then small hydrogen gas-bags are useful. In the Branly-Popp wireless telegraph automobile ambulances and balloons are employed. The exterior and interior of these ambulances are reproduced in Fig. 14. Various forms of kites

especially adapted to the velocity of the wind may be obtained for elevating and sustaining the aerial wires. The aerial is attached to the kite as illustrated in Fig. 15. Aluminum wire, in virtue of its extreme lightness, makes a desirable vertical wire for this purpose. The transmitter and receptor utilizes the same vertical wire for radiating and receiving the waves, the change being made by means of an ordinary switch.



FIG. 19.—PORTABLE ARMY EQUIPMENT.

In very light winds the Malay, or, as its improved form is known,



FIG. 20.—INSTRUMENTS IN OPERATION.

the Eddy kite, is largely employed; it is shown in Fig. 17. These kites are fitted with a "bridle," which is already adjusted. To the ring or loop at the center of this bridle the end of the ball of kite-

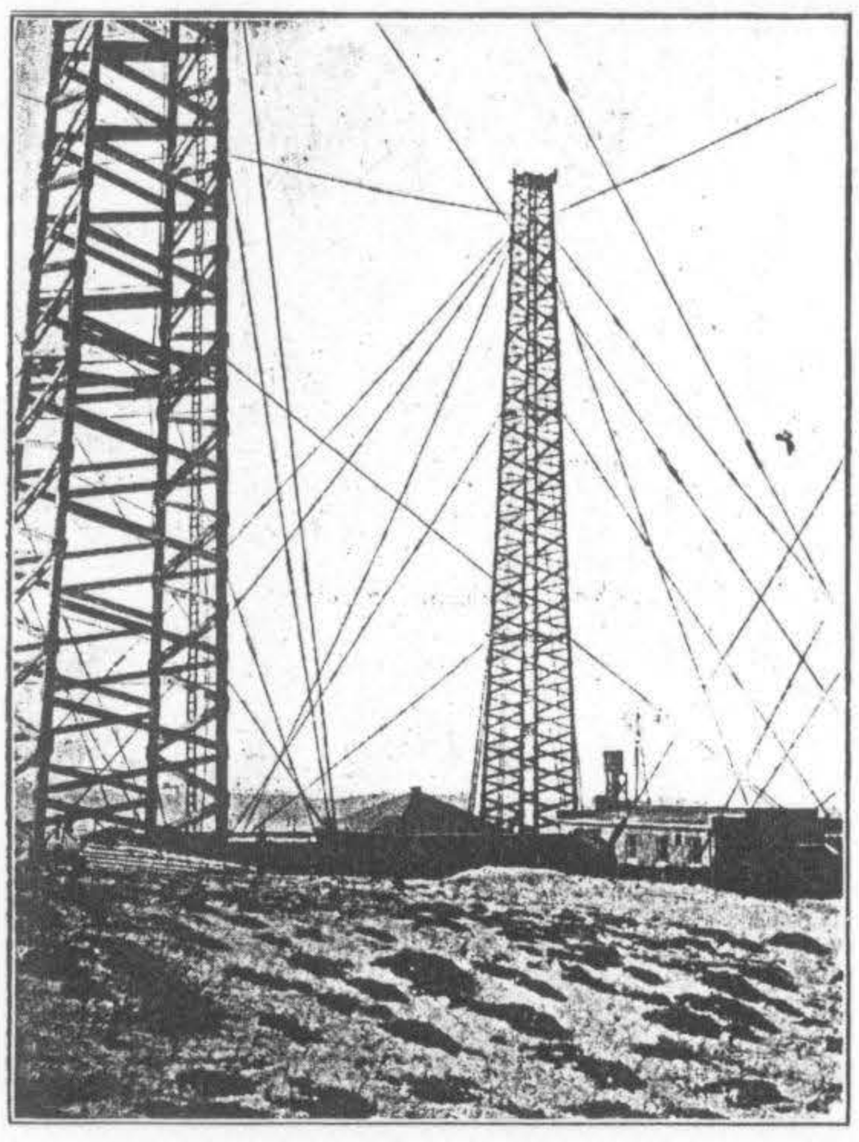


FIG. 21.—MARCONI SOUTH WELLFLEET STATION IN COURSE OF CONSTRUCTION.

cord is secured so that the knot is a firm one. These kites are tailless, may be flown in a very light breeze, and a number of the kites may be connected in tandem and their sustaining properties increased. In winds having a higher velocity the cellular or the American modification of it, known as the Blue Hill box kite, shown in Fig. 17 in outline, and a photographic reproduction in Fig. 18. It has a large sustaining surface and may be used in winds of ordinary velocities; in winds having a velocity of thirty or forty miles per hour a box kite having a very small sustaining surface is especially serviceable, since it possesses marvelous stability. Fig. 19 is a complete portable army equipment constructed by the Braun-Siemens and Halske Company for the German Government; it was placed in charge of the Royal Military Aerostat Battalion; Fig. 20 shows the aerial wire suspended from a kite and the instruments in operation. The transmitting apparatus includes a dynamo direct connected to a gasolene engine and is arranged on one while the receiver is placed on a second gun-carriage.

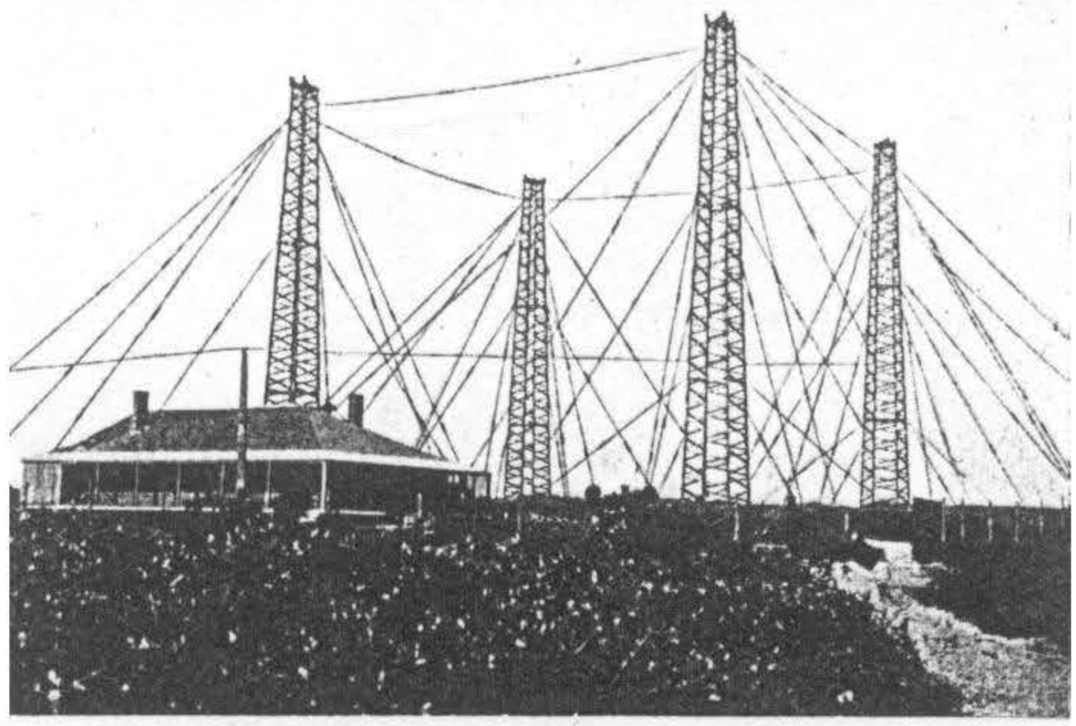


FIG. 22.—SOUTH WELLFLEET STATION IN COURSE OF CONSTRUCTION.

MARCONI CABLELESS STATION AERIAL.—The first transatlantic signals transmitted from the cableless station at Poldhu, England, on December 12, 1901, were received by a single aerial wire suspended from a kite at an elevation of 400 feet at St. Johns, Newfoundland. The kites employed during these aerial tests were constructed on the same general lines as those designed by Major Baden-Powell, consisting of a bamboo frame nine feet in height

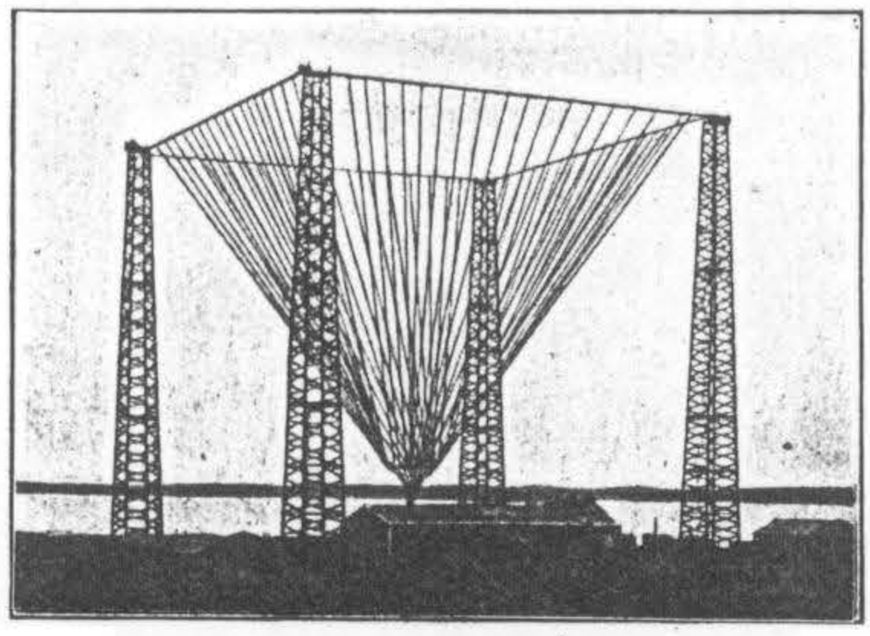


FIG. 23.—WELLFLEET STATION COMPLETED.

covered with silk and having a hexagonal form. The aerial wire passed through a window and was attached to a pole, and from this it led to the kite. The wire leading to earth forming the opposite arm of the resonator was suspended over the cliff from the station at Signal Hill and was connected to heavy plates of copper anchored in the sea. The aerial wires of the transmitting station at Poldhu, England, consisted of 15 vertical wires suspended from masts 210 feet in height and arranged in a circle. The construction of the multiplex aerials at Glace Bay, Nova Scotia, and South Wellfleet, Mass., cableless stations are designed especially for emitting long and powerful electric waves. Figs. 21 and 22 are photographs of the South Wellfleet station in the course of construction; four wooden standards 210 feet in height are arranged in a quadrangle and are sustained by guy wires, appearing as in Fig. 23 when completed; the aerial is composed of 400 wires forming an inverted pyramid; the upper terminals are insulated and the lower ends terminate in a single conductor of large dimensions. The opposite arm of the system is connected with several large metal plates deeply imbedded in the earth to make good contact.

Tesla Currents.

In a paper read before the Bunsen Society at Bonn, Prof. Nernst discusses the fact that it is possible to pass through the body without the least discomfort Tesla currents of a strength which at a much lower frequency would certainly cause death. The explanation hitherto offered has been that the current passed by the surface of the body only. According to Prof. Nernst, however, the explanation is to be found elsewhere; and he maintains that the solution of the problem lies in the fact that the current never lasts sufficiently long in one direction to alter the concentration of the contents of the cell. He finds that changes in concentration vary directly with the strength of the current, and inversely as the square root of the frequency. He has confirmed this hypothesis by an experiment on a frog submitted to a current, the frequency of which could be varied between 100 and 200 cycles per second.

The New York Sun November 1, 1904

THE NEW SUBWAY.

Its Electrical Equipment and System Criticised Severely by Mr. Tesla.

TO THE EDITOR OF THE SUN—*Sir:* I would not disturb the hymn sung by the press in praise of the subway had it not occurred to me that just these few fugitive moments of ecstasy offer the best opportunity for pointing out the necessity of its speedy reequipment. My idea is by no means as odd as it must at first appear to your readers. Permit me to explain.

Electrical power transmission has been my specialty for many years. After the general adoption of my alternating system of distribution, popularly known as the "two, three, multi, or poly phase," I turned my attention exclusively to currents of high tension and devised a scheme of artificial insulation by power, permitting an indefinite extension of the distance of transmission and doing away altogether with the loss in the mains. Finally, through a series of improvements, I arrived at my high potential system, dispensing with wires, in which I have carried the arc of electrical energy transmission well toward its highest technical perfection and capacity of application. These inventions, abolishing all barriers to electrical development, will soon sweep the world with irresistible force.

Naturally enough, I have been intensely interested in this great project, in the city of my home, from its very inception, and have devoted much thought to the best means to employ. The tunnel itself I have never seen and do not know its location. It must be a fine piece of engineering. I am compelled to confess to the same ignorance as regards the power house. The Rapid Transit company has never asked me for any expert advice or suggestion and I have never been invited to examine any part of the work. It is true that my "three phase" system with my "rotary converters" has been adopted, but it is precisely because of this that a change will be necessary in the near future. This combination of alternating and direct current should not have been employed. It represents the state of the art of more than ten years ago. In the power house three phase dynamos are installed. The electro-motive force of the currents is raised by "static transformers." The high tension currents operate in each of the sections of the road a "rotating transformer," in this case one of my three phase synchronous motors having its field excited by and generating direct currents, which in turn, actuate the motors on the cars.

Now, this plan, while operative, is for a great many reasons objectionable, more so in this particular instance. The subway problem was peculiar. The length of the circuits was insignificant. The facilities for placing and insulating the mains were great. Financial limitations, which usually hamper an electrical enterprise, did not exist. There was money to burn. The quickness of travel, the safety of the public and of the adjacent property were the dominating requirements. These have not been properly met. A mistake was made in not asking the electric companies to furnish the best instead of the cheapest equipment.

But it is better to mend late than never. Ignoring the improvements which might be made in the power house, the mains should be insulated artificially by refrigeration. This would save the energy which is now lost in the mains and money besides. More than this, it would insure complete safety against any breakdown of the insulation, which, however, would be self-restorative. The "rotating transformers," introducing many elements of incertitude and danger, should be done away with and "static transformers," if necessary, installed in the sub-stations. Direct currents, which are a constant menace to life and property, despite subdivision, should be most certainly avoided. Motors of this kind, with their brushes and commutators, sparks, copper dust, nitric acid and what not, are not suitable for so important a thoroughfare, and should be replaced by my "induction motors" without brushes and commutators, and perfectly free from the innumerable troubles these devices entail. It would be advisable also to employ a greater number of correspondingly smaller motors on each car. This would be, in my opinion, an entirely safe, economical, and in the long run the cheapest apparatus, which could be taxed, without the slightest risk, in the hours of rush, to its utmost capacity, and which, if properly constructed, should last a century.

To conclude, as I examine the equipment of the subway, I find that about all to be preserved would be Mr. Belmont's beautiful car, this as a *corpus delicti*. The changes suggested will have to be made sooner or later, and I am quite earnest in recommending an immediate appropriation and commencement of this work of reconstruction without delay, else Philadelphia will have an underground railway several decades ahead of ours.

NEW YORK, Oct. 30. N. TESLA.

BOOK TABLE.

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY. By Nikola Tesla. New York: McGraw Publishing Company. 1904. Pp. (five by seven inches), ix., 162, with a new portrait of the author and 40 illustrations in the text. Price, $1.

Tesla's is a name to conjure by, and this little book will not lack for readers, although it is but a reprint of a lecture delivered several years ago before the Institution of Electrical Engineers in London and of an article on "The Transmission of Electric Energy Without Wires," published in the Electrical World and Engineer last spring. There is a fascination about the personality and work of Tesla, due partly to his fame as an inventor, but largely to his daring conceptions and prodigal predictions. An example of the latter and of the writer's fervid style is the very last paragraph of the book:

"When the great truth, accidentally revealed and experimentally confirmed, is fully recognized, that this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball and that by this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment; when the first plant is inaugurated and it is shown that a telegraphic message, almost as secret and non-interferable as a thought, can be transmitted to any terrestrial distance, the sound of the human voice, with all its intonations and inflections faithfully and instantly reproduced at any other point of the globe, the energy of a waterfall made available for supplying light, heat or motive power anywhere—on sea or land, or high in the air—humanity will be like an ant heap stirred up with a stick. See the excitement coming!"

An interesting biographical sketch forms the introduction to the lecture. In this it is said that Mr. Tesla is "tall and spare, with a clean-cut, thin, refined face and eyes that recall all the stories one has read of keenness of vision and phenomenal ability to see through things."

UNDER THE SEARCHLIGHT.

Notes and Comments on Various Topics.

Mr. Nicola Tesla, in a communication to a daily paper, criticized the equipment of the New York Subway very unfavorably, which drew forth the following reply from Mr. L. B. Stillwell, the electrical director of the Interborough Company: "My recollection of what Mr. Tesla has done for electrical progress in the past is so vivid that I am disinclined to comment upon his technical suggestions, which perhaps appear more plausible to the average reader than to the engineer. I would suggest to Mr. Tesla, however, that a paper from him containing specific and definite criticism of the electrical equipment of the Subway might be presented before the American Institute of Electrical Engineers, and that if he will present such a paper I shall be glad to meet him upon such an occasion for the purpose of a full and frank discussion."

SUBWAY ELECTRIC TRACTION.

The Views of Mr. Tesla on the Subject Presented and Defended.

TO THE EDITOR OF THE SUN—Sir: My attention has been called to numerous comments on my letter, published in your issue of Nov. 1, and relating to the electrical equipment of the newly opened catacomb in this city. Some of them are based on erroneous assumptions, which it is necessary for me to correct.

When I stated that my system was adopted, I did not mean that I originated every electrical appliance in the subway. For instance, the one which that ill fated electrician was repairing when he was killed, two days after the catacomb was ready for public use, was not invented by me. Nor was that other device on the sidetracked car, which, as will be remembered, caused the burning of two men. I also must deny any connection with that switch or contrivance which was responsible for the premature death of a man immediately afterward, as well as with that other, which cut short the life of his unfortunate successor. None of these funeral devices, I emphatically state, or any of the others which brought on collisions, delays and various troubles and were instrumental in the loss of arms and legs of several victims, are of my invention, nor do they form, in my opinion, necessary appurtenances of an intelligently planned scheme for the propulsion of cars. Referring to these contrivances, it is significant to read in some journals of the 8th inst. that a small firm failed because their bid was too low. This is indicative of keen competition and sharp cutting of prices, and does not seem in keeping with the munificence claimed for the Interborough company.

I merely intended to say in my letter that my system of power transmission with three-phase generators and synchronous motor converters was adopted in the subway, the same as on the elevated road. I devised it many years ago for the express purpose of meeting the varied wants of a general electrical distribution of light and power. It has been extensively introduced all over the world because of its great flexibility, and under such conditions of use has been found of great value. But the idea of employing in this great city's main artery in a case presenting such rigid requirements, this flexible system, offering innumerable chances for breakdowns, accidents and injuries to life and property, is altogether too absurd to dignify it with any serious comment. Here only my multiphase system, with induction motors and closed coil armatures—apparatus unfailing in its operation and minimizing the dangers of travel should have been installed. Nothing, not even ignorance, will prevent its ultimate adoption; and the sooner the change is made the better it will be for all concerned. Personally I have no financial or other interest in the matter, except that as a long resident of this city I would have been glad to see my inventions properly used to the advantage of the community. Under the circumstances I must forego this gratification.

The consequences of the unpardonable mistake of the Interborough company are not confined to this first subway or even to this city. We are driven to travel underground. The elevated road is the eighth world wonder, as colossal and imposing in the feature of public forbearance as the Pyramid of Cheops in its dimensions. Sooner or later all interurban railways must be transformed into subterranean. This will call for immense investments of capital, and if defective electrical apparatus is generally adopted the damage to life and property will be incalculable, not to speak of inconvenience to the public.

It seems proper for me to acknowledge on this occasion the painstaking suggestions of some friends of mine, mostly unknown to me, both in the large domain of electrical achievement and in the small sphere of my friendship, to again address the American Institute. It is customary with scientific men to present an original subject only once. I have done so and do not desire to depart from this established precedent. A lecture on the defects of the subway offers great opportunities, but would not be original. In view of certain insinuations I may cite a recently published statement of Mr. C. F. Scott, formerly president of the American Institute: "As a matter of history it is the Tesla principle and the Tesla system which have been the directing factors in modern electrical engineering practice." There are but a few men whose acknowledgment of my own work I would quote. Mr. Scott is one of them, as the man whose cooperation was most efficient in bringing about the great industrial revolution through these inventions. But the suggestions of my good friends have fallen on fruitful ground, and should it be possible for me to spare time and energy I may ask the city authorities for power to investigate the subway and make a sworn report to them on all the defects and deficiencies I may discover, in the interest of public welfare.

A few more words in relation to the signs. With all due respect to general opinion, I entertain quite a different view on that subject. Advertising is a useful art, which is being lifted continually to a higher plane and will soon be quite respectable. It should not be hampered, but rather encouraged. I would give the Interborough company every facility for exploiting it, restricting it only in so far as the artistic execution is concerned. A commission of capable men, comprising a painter, a sculptor, an architect, a literary man, an engineer and an executive business man, might be appointed, to pass upon the merits of the signs submitted for acceptance. I do not see why the public should object to them if they were regulated in this manner. They will further business, make travel less tedious and help many skilful artisans. The subways are bound to become municipal property, and the city will then derive a revenue from them. What is most important for the safety of life and property, quickness and security of travel, should be first considered. All this depends on the electrical equipment. The engineers have built a good tunnel, and proper apparatus should be installed to match it.

NEW YORK, Nov. 26. NIKOLA TESLA.

TESLA'S CAUSTIC LETTER.

The following communication from Mr. Nikola Tesla appeared in the New York *Sun* November 27:

"My attention has been called to numerous comments on my letter, published in your issue of November 1, and relating to the electrical equipment of the newly opened catacomb in this city. Some of them are based on erroneous assumptions, which it is necessary for me to correct.

"When I stated that my system was adopted, I did not mean that I originated every electrical appliance in the subway. For instance, the one which that ill-fated electrician was repairing when he was killed, two days after the catacomb was ready for public use, was not invented by me. Nor was that other device on the sidetracked car, which, as will be remembered, caused the burning of two men. I also must deny any connection with that switch or contrivance which was responsible for the premature death of a man immediately afterward, as well as with that other, which cut short the life of his unfortunate successor. None of these funeral devices, I emphatically state, or any of the others which brought on collisions, delays and various troubles and were instrumental in the loss of arms and legs of several victims, are of my invention, nor do they form, in my opinion, necessary appurtenances of an intelligently planned scheme for the propulsion of cars. Referring to these contrivances, it is significant to read in some journals of the 8th inst. that a small firm failed because their bid was too low. This is indicative of keen competition and sharp cutting of prices, and does not seem in keeping with the munificence claimed for the Interborough Company.

"I merely intended to say in my letter that my system of power transmission with three-phase generators and synchronous motor converters was adopted in the subway, the same as on the elevated road. I devised it many years ago for the express purpose of meeting the varied wants of a general electrical distribution of light and power. It has been extensively introduced all over the world because of its great flexibility, and under such conditions of use has been found of great value. But the idea of employing in this great city's main artery, in a case presenting such rigid requirements, this flexible system, offering innumerable chances for breakdowns, accidents and injuries to life and property, is altogether too absurd to dignify it with any serious comment. Here only my multiphase system, with induction motors and closed coil armatures—apparatus unfailing in its operation and minimizing the dangers of travel—should have been installed. Nothing, not even ignorance, will prevent its ultimate adoption; and the sooner the change is made the better it will be for all concerned. Personally, I have no financial or other interest in the matter, except that as a long resident of this city I would have been glad to see my inventions properly used to the advantage of the community. Under the circumstances I must forego this gratification.

"The consequences of the unpardonable mistake of the Interborough Company are not confined to this first subway or even to this city. We are driven to travel underground. The elevated road is the eighth world wonder, as colossal and imposing in the feature of public forbearance as the Pyramid of Cheops in its dimensions Sooner or later all interurban railways must be transformed into subterranean. This will call for immense investments of capital, and if defective electrical apparatus is generally adopted the damage to life and property will be incalculable, not to speak of inconvenience to the public.

"It seems proper for me to acknowledge on this occasion the painstaking suggestions of some friends of mine, mostly unknown to me, both in the large domain of electrical achievement and in the small sphere of my friendship, to again address the American Institute. It is customary with scientific men to present an original subject only once. I have done so and do not desire to depart from this established precedent. A lecture on the defects of the subway offers great opportunities, but would not be original. In view of certain insinuations I may cite a recently published statement of Mr. C. F. Scott, formerly president of the American Institute: 'As a matter of history it is the Tesla principle and the Tesla system which have been the directing factors in modern electrical engineering practice.' There are but a few men whose acknowledgment of my own work I would quote. Mr. Scott is one of them, as the man whose co-operation was most efficient in bringing about the great industrial revolution through these inventions. But the suggestions of my good friends have fallen on fruitful ground, and should it be possible for me to spare time and energy I may ask the city authorities for power to investigate the subway, and make a sworn report to them on all the defects and deficiencies I may discover, in the interest of public welfare.

"A few more words in relation to the signs. With all due respect to general opinion, I entertain quite a different view on that subject. Advertising is a useful art, which is being lifted continually to a higher plane, and will soon be quite respectable. It should not be hampered, but rather encouraged. I would give the Interborough Company every facility for exploiting it, restricting it only in so far as the artistic execution is concerned. A commision of capable men, comprising a painter, a sculptor, an architect, a literary man, an engineer and an executive business man might be appointed, to pass upon the merits of the signs submitted for acceptance. I do not see why the public should object to them if they were regulated in this manner. They will further business, make travel less tedious, and help many skillful artisans. The subways are bound to become

municipal property, and the city will then derive a revenue from them. What is most important for the safety of life and property, quickness and security of travel, should be first considered. All this depends on the electrical equipment. The engineers have built a good tunnel, and proper apparatus should be installed to match it. NIKOLA TESLA.

"New York. Nov. 26."

Design for an Edison Medal.

A meeting of the jury in the matter of a competition for the selection of a design for an Edison medal commemorating the invention of the incandescent lamp, under the auspices of the National Sculpture Society, was held recently at the studio of Mr. J. Q. A. Ward, New York City.

Those present were J. Q. A. Ward, chairman, Daniel C. French, Augustus Saint Gaudens, for the National Sculpture Society; Edward D. Adams and T. C. Martin, for the Edison Medal Association and on behalf of the American Institute of Electrical Engineers.

After a further examination of the 29 designs submitted in competition, the committee by unanimous action, awarded the first prize of $1,000 for the successful design, including its execution in such shape and detail as will permit direct reduction to medal size, to Mr. James Earl Fraser. The second prise of $100 to Mr. Adolph A. Weinman, and the third prize of $50 to Miss Evelyn B. Longman. The successful competitor, Mr. Fraser, has been requested to develop his design for final consideration by the committee.

Supreme Court Action on Tesla Split-Phase Patents.

On Monday, November 28, the United States Supreme Court denied a petition for a writ of certiorari directing the United States Court of Appeals for the First Circuit to certify a case tried by that court for review by the Supreme Court. The petitioner was the Stanley Instrument Company and the respondent the Westinghouse Electric & Manufacturing Company.

The patents in suit were the Tesla patents, Nos. 511,559 and 511,560, granted December 26, 1893, and commonly known as the Tesla split-phase patents. The first stage of the litigation ended March 11, 1903, when Judge Colt, of the Massachusetts Circuit Court, declared the patents invalid owing to a publication in an Italian journal dated April 22, 1888, of a lecture by Ferraris. The case was then carried to the Circuit Court of Appeals and on September 9, 1904, that court decided that sufficient proof had been presented to show that Tesla had made the invention involved prior to the date of the Ferraris publication.

The principal contention for a review of the case by the Supreme Court was that the Circuit Court of Appeals for the Second Circuit had decided in an opinion dated February 25, 1903, that the said patents were invalid on the grounds of the Ferraris anticipation, and that the decisions of the Courts of Appeal of the First and Second Districts were at variance and conflict with each other, and that the error of one or the other could only be authoritatively corrected by the Supreme Court. The respondents in answer to this contention held that the alleged divergence between the courts relates only to the sufficiency of the Tesla proofs as contained in the two records, on a question of fact; that the two courts had before them substantially different records, and therefore there was no "conflict" and the case consequently was not appropriate for certiorari.

Advertising Almost Respectable.

In a recent letter to the New York Sun Mr. Tesla spoke, among other features of the New York subway, of the advertising signs that have been criticized. He made this curiously worded statement: "A few more words in relation to the signs. With all due respect to general opinion, I entertain quite a different view on that subject. Advertising is a useful art, which is being lifted continually to a higher plane, and will soon be quite respectable. It should not be hampered, but rather encouraged. I would give the Interborough company every facility for exploiting it, restricting it only in so far as the artistic execution is concerned."

Wonderful Discoveries in Electricity

ELECTRICAL FORCE WITHOUT WIRES

Nikola Tesla Talks of His Wonderful Discoveries in Transmitting Energy.

THE INVENTOR'S QUEER MIND

Expects to Send Force and Intelligence Around the World Sans Cable.

By FRANK G. CARPENTER.

[*Special Letter to The Dispatch.*]

NEW YORK, Dec. 17.—I give you today the substance of two remarkable talks with Nikola Tesla. The first I had in his laboratory on East Houston street nine years ago last September. The second was held in the Waldorf to-night.

The first interview was most interesting, giving a wonderful insight into Tesla the inventor and Tesla the man, but it was never published, for Mr. Tesla, at its close, on the ground of business reasons, begged that I say nothing about him for months to come. I wrote out the notes, however, and laid them away, and when I met Mr. Tesla to-night I told him I now intended to use them. At the same time we had the extraordinary conversation about his recent discoveries and inventions as to the transmission of force, which I reproduce in the latter part of this article.

Tesla the Man.

First take a glance at Tesla the man. He looked more like an Italian savant than a hard-working inventor when I saw him in the Waldorf to-night. He was in evening dress and was the most striking figure of the score of public men who stood about the lobby. Mr. Tesla is now 47 years of age and is in his physical and intellectual prime. He is tall and slender, his head is long, thin and intellectual, with a forehead high and full. He was born in Hungary and educated there, but he speaks English perfectly and is one of the most charming conversationalists I have ever met.

During my chat of some years ago he talked of his boyhood. His father was a clergyman of the Greek Church, and Nikola was intended for the priesthood. He had a brother older than himself, whom the rest of the family considered much brighter. That brother died young, and this so crazed his father and mother that it took them long to realize the genius of Nikola. If he stood well in his studies his father's eyes would fill as he thought how much better, perhaps, the other son might have done, and whatever Nikola did was always compared with the possible work of the boy who had passed away. His first education was in the public schools of Gospich, and after that he went to the Real Schule at Karlstadt. As he went on with his studies he liked mathematics so much that he intended to fit himself to be a professor of mathematics and physics, and with that view studied at the Polytechnic School at Gratz. He changed to the engineering course, and later on studied philosophy and languages in the colleges at Prague and Budapest. He has since been made a doctor of laws by Yale and Columbia.

Shortly after completing his studies Mr. Tesla was associated with the Government of Austria-Hungary in the telegraph engineering department, where he invented several improvements. From there he went to Paris to be eingineer of a large lighting company, and thence to the United States, where he was employed by Thomas Edison in his laboratory. His next position was that of electrician to the Tesla Electric Light Company, and at the same time he established the Tesla laboratory here, from which his great inventions have come.

Tesla the Inventor.

During my chat with Mr. Tesla I asked him when he first realized that he had the inventive faculty and he told me he had always been inventing something or other. When he was quite a small boy he made toy guns, which would shoot birds, and as he was the only one who could make them he supplied the boys of his neighborhood. He made clocks at 8 or 9 years and began to dabble in electricity before he was in his teens. His first determination to devote his life to invention came shortly after he went to London to deliver a lecture before a scientific society there. At this lecture he met Lord Rayleigh, the great physicist, and showed him some of his experiments. Rayleigh said that he had undoubtedly the faculty of discovery and that he would succeed as an inventor.

"Shortly after this my mother died," said Mr. Tesla, "and I concluded to exert this faculty. Lord Rayleigh had said I possessed it and upon examining myself I believed him correct. I did not want to waste my powers on small things and I decided to strive toward something that would benefit humanity. I am working on an invention for the transmission of force. This invention will, I believe, revolutionize the world of labor. I am also working on electricity and I cannot remember when I was not working more or less in the direction of a successful flying machine. My idea as to that is along different lines than any yet proposed and I expect to see it realized. Indeed, we shall eventually have flying machines that will be large enough to carry crowds through the air. They must be large in order to succeed."



TESLA IN HIS WORKSHOP.

These words were uttered by Mr. Tesla nine years ago. To-day he says he has completed his force transmission invention, as will be seen by my Waldorf conversation, which follows. He has also done other things which he proposed in that interview. Remember it was before the time of the wireless telegraph, but he then said to me the following:

"I tell you, we are on the threshold of a new era. We have only begun to master the great forces of nature, and the inventions of the next few decades will be far superior to any of the past. What would you think of standing on the shore and telephoning to your friends in midocean? What of being in the center of a room and making your whole body blaze with light? What of sending power to and fro over the earth at will and making it do its work anywhere and almost anyhow?"

How Tesla Works.

As to Mr. Tesla himself, there is no harder worker known. He told me that he seldom slept more than four hours of a night, and during some periods not more than three. When in the thick of a new invention it is hard to sleep. His work is always with him and he says that his mind sometimes works in his sleep. He awakens in the morning to find that the problem which had worried him when he went to bed has been practically sloved over night. He has always been a light sleeper. His mother died at 70 and she never took more than four hours' sleep. His father was a light sleeper.

Tesla is a peculiar worker. Failures do not trouble him. After he undertakes a thing and decides that it should come out a certain way he keeps on experimenting and experimenting, believing in his success. He says that if he doubted his ability it would make him crazy. He seems to have a dual mind. He told me that he often found himself carrying on two trains of thought at the same time, and said that while he was talking to me he could see the figures of some of his calculations behind me and could carry them on at the same time. He is always figuring. His scrap basket is filled with the calculations which he has torn up and thrown away. He keeps a record of his experiments, and when his laboratory burned some years ago he lost the work of years in ideas and suggestions which had been thus recorded.

Tesla's New Inventions.

And now to Mr. Tesla's latest discoveries. If he has what he thinks he has he will revolutionize labor and give man greater benefits than have come from any inventor since the world began. Indeed, the statements made me to-night in the mouth of any other man would be a fair test of insanity. But many of Tesla's wild statements of the past have been verified by great working inventions. He said he could harness Niagara, and through his experiments in the rotary magnetic fields Niagara is now furnishing a power equal to that of tens of thousands of horses, and electrical works are being run by the same principle all over the globe. The New York subway, for instance, is founded upon it. Tesla demonstrated that wireless telegraphy could be done in 1893, and it is a question whether his inventions in that field are not prior to those of Marconi or De Forrest.

To-night he told me that he had almost completed inventions by which he could send electrical power to any distance without wires, and that in any quantity, small or great. Said he:

"I have proved that power can be thus transmitted. Let us suppose I have my plant at Niagara and you are running a sugar factory in Australia; by my discoveries it will be possible to send you 100, 500 or 1,000 horse-power for your factory, and to supply the same regularity by the force furnished from Niagara Falls. Suppose you are traveling in the wilds of the Andes and make your camp on the shores of Lake Titicaca. By the outcome of this principle you may have telegraphed to you there instantaneous reports of the news of the world as it happens from time to time. You may cook your dinner over an electric fire thus transmitted, and you may have the same at will on any part of the globe. We shall be able to send power from place to place at will, and that at such a small cost that it will be industrially profitable."

The Transmission Energy

"How did you discover that this might be done, Mr. Tesla?" I asked.

"I have for years been working on the transmission of electrical energy, and in 1898 established a laboratory on the edge of the Rock mountains near Colorado Springs. My laboratory there was over 6,000 feet high, higher than the top of Mount Washington, and I had extraordinary conditions for my experiments. Colorado is famous for its natural displays of electrical force. The earth at times is alive with electrical vibrations and the air is full of electricity. I have seen 12,000 lightning discharges within two hours and all within a radius of 30 miles of my laboratory. These discharges were of great violence, some of them looking like trees of fire on the heavens. It was among such discharges that I had my electrical transmission through the earth and air. One day while watching the lightning I noticed that the discharges afar off often affected the instruments in my laboratory more than those near by. Upon examination I found that this could not be caused by the difference of intensity in the individual discharges.

"What could it be?

"Through instruments made for the purpose I tested the matter from time to time and finally came to the conclusion that the vibrations caused by the lightning moved around the world and that there were stationary waves. I could gauge the discharges near the laboratory and see them fade away and after a certain fixed period find them returning with almost no loss of power. In short, this planet, as big as it is, was acting as a conductor, and I became convinced that upon it not only telegraphic messages, but also the modulations of the human voice and electrical power in unlimited amounts could be carried around the entire globe and sent to any part of it with hardly any perceptible loss. With my transmitter I actually sent electrical vibrations around the world and received them again, and I then went on to develop my machinery. I had, as I have told you, been studying and inventing along the lines of electrical transmission and was ready to take advantage of my discovery. I have since so improved the means of individualization and isolation that such energy may be sent in any amount to any fixed place without danger of its going elsewhere or affecting others, and I believe the individualization can be carried out to almost any degree."

Niagara for the World.

"Will this enable the power of Niagara to be sent anywhere over the world?"

"Yes. I have been experimenting at my laboratory on Long Island. I have machinery and buildings there which have cost in the neighborhood of $350,000, and the results show me that a plant could be erected at Niagara which can transmit its force to any place desired. I am designing such a plant now at my laboratory, and would have had it completed had it not been for unforeseen delays, which have nothing to do with its technical features. The design which I have adopted will have a transmitter which will emit a wave complex of a total maximum activity of 10,000,000-horse power, 1 per cent of which is enough to girdle the globe. This enormous rate of energy delivery—it is twice as much as the force of Niagara Falls—is obtainable only by the use of certain artifices which I shall make known some time in the future.

"We have been offered 10,000-horse power from the Canadian Power Company. What I want to do is to build machinery there and transmit this power to different parts of the globe. The value of that amount of horse power would be about $200,000 per year, and a plant erected to take advantage of it will pay large dividends."

"How much would the plant cost?"

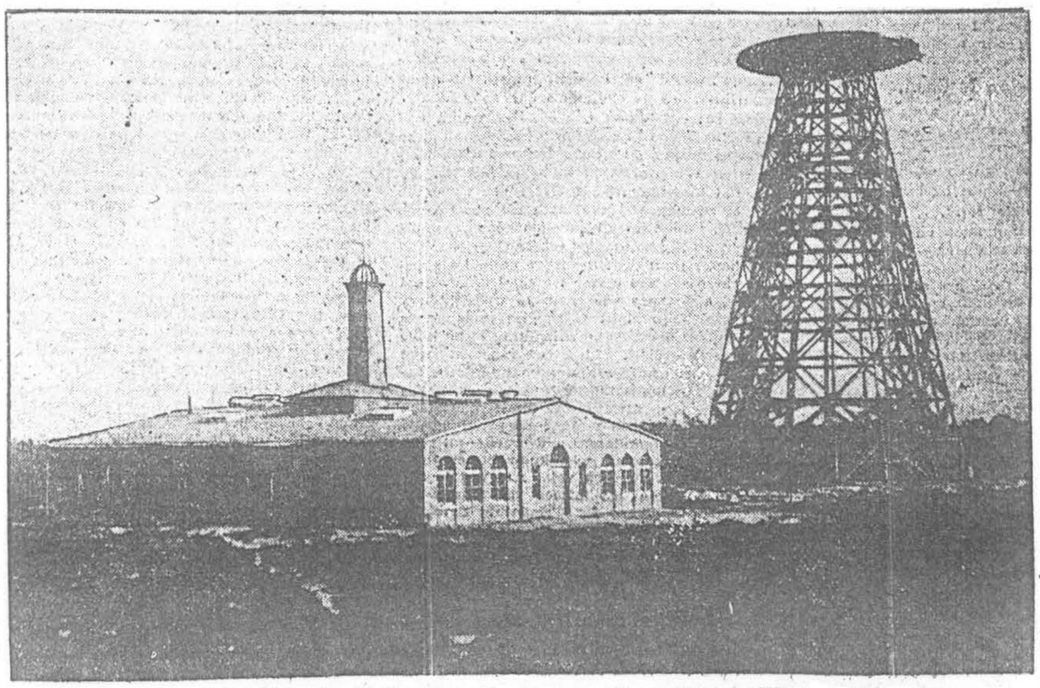
"It might cost in the neighborhood of $2,000,000, but its value would be enormous, and its success would revolutionize the working forces of the globe. It would result in other plants being erected otherwheres and in the utilization of all the great waterfalls for the work of man."

"By this invention every live part of Mother Earth's body would be brought into action. Energy will be collected all over the globe in amounts small or large, as it may exist, ranging from a fraction of one to a few horse power or more. Every water fall can be utilized, every coal field made to produce energy to be transmitted to vast distances, and every place on earth can have power at small cost. One of the minor uses might be the illumination of isolated homes. We could light houses all over the country by means of vacuum tubes operated by high frequency currents. We could keep the clocks of the United States going and give every one exact time; we could turn factories, machine shops and mills, small or large, anywhere, and I believe could also navigate the air.

The Transmission of Intelligence.

"One of the most important features of this invention," said Mr. Tesla, "will be the transmission of intelligence. It will convert the entire earth into a huge brain, capable of responding in every one of its parts. By the employment of a number of plants, each of which can transmit signals to all parts of the world, the news of the globe will be flashed to all points. A cheap and simple receiving device, which might be carried in one's pocket, can be set up anywhere on sea or land, and it will record the world's news as it occurs, or take such special messages as are intended for it. If you are in the heart of Sahara your wife can telegraph to you from Washington, and if the instrument is properly made you alone will get the message. A single plant of a few horse power could operate hundreds of such instruments, so that the invention has an infinite working capacity and will cheapen the transmission of all kinds of intelligence."

[Copyright, 1904, by Frank G. Carpenter.]



THE TESLA POWER PLANT FOR TRANSMITTING FORCE WITHOUT WIRES.

A TALK WITH NIKOLA TESLA

Written for The State.

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New York, Dec. 17.—I give you today the substance of two remarkable talks with Nikola Tesla. The first I had in his laboratory on east Houston street nine years ago last September. The second was held in the Waldorf tonight.

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HOW IT FEELS TO INVENT.

Mr. Tesla told me that his greatest pleasure was in his work, and that he could conceive no moment so exciting and rapturous as that connected with the discovery of a new principle which, when put into use, would revolutionize the work of the world. Take, for instance, the invention which brought forth the apparatus used in the transmission of power at Niagara Falls. Said he, as he took me to a great coil of wire wound about a stationary magnet, which was connected with the dynamo, and held above it a little glass globe in which was a steel wheel moving on a pivot: "I had been working upon that experiment for a long time, and this was the test. I knew that if I were correct that the wheel in this globe would revolve as soon as I turned on the electricity. It did revolve, and I knew I had discovered what would revolutionize the labor of the world. You can run all sorts of power by that principle. You can take power from Niagara and bring it to New York. The cars can be pulled by it, factories run, houses heated and dinners cooked. I cannot describe my sensation when I saw the wheel revolve. I thought I should go crazy, and I went to my laboratory and took some bromide of potassium to quiet me.

"It has been the same in some of my experiments with electric lights and other things. No; the greatest rapture one can have is to discover a new force or series of forces, which will reduce man's working necessities to the minimum. I do not believe in laziness, and I should like to see the loafer wiped from the face of the earth; but I want that those who are willing to work should accomplish their results with the least labor and in the best way."

HOW TESLA WORKS.

As to Mr. Tesla himself, there is no harder worker known. He told me that he seldom slept more than four hours of a night, and during some periods not more than three. When in the thick of a new invention it is hard to sleep. His work is always with him and he says that his mind sometimes works in his sleep. He awakes in the morning to find that the problem which had worried him when he went to bed has been practically solved over night. He has always been a light sleeper. His mother died at seventy and she never took more than four hours' sleep. His father was a light sleeper.

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TRANSMISSION OF ELECTRICAL ENERGY WITHOUT WIRES.

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NIAGARA FOR THE WORLD.

"Will this enable the power of Niagara to be sent anywhere over the world?"

"Yes. I have been experimenting at my laboratory on Long Island. I have machinery and buildings there which have cost in the neighborhood of $350,000, and the results show me that a plant could be erected at Niagara which can transmit its force to any place desired. I am designing such a plant now at my laboratory, and would have had it completed had it not been for unforeseen delays, which have nothing to do with its technical features. The design which I have adopted will have a transmitter which will emit a wave complex of a total maximum activity of 10,000,000 horse power, 1 per cent. of which is enough to girdle the globe. This enormous rate of energy delivery—it is twice as much as the force of Niagara Falls—is obtainable only by the use of certain artifices which I shall make known some time in the future.

"We have been offered 10,000 horse power from the Canadian Power company. What I want to do is to build machinery there and transmit this power to different parts of the globe. The value of that amount of horse power would be about $200,000 per year, and a plant erected to take advantage of it will pay large dividends."

"How much would the plant cost?"

"It might cost in the neighborhood of $2,000,000, but its value would be enormous, and its success would revolutionize the working forces of the globe. It would result in other plants being erected otherwheres and in the utilization of all the great water falls for the work of man."

MOTHER EARTH PUT TO WORK.

"By this invention every live part of Mother Earth's body would be brought into action. Energy will be collected all over the globe in amounts small or large, as it may exist, ranging from a fraction of one to a few horse power or more. Every water fall can be utilized, every coal field made to produce energy to be transmitted to vast distances, and every place on earth can have power at small cost. One of the minor uses might be the illumination of isolated homes. We could light houses all over the country by means of vacuum tubes operated by high frequency currents. We could keep the clocks of the United States going and give every one exact time; we could turn factories, machine shops and mills, small or large, anywhere, and I believe could also navigate the air.

THE TRANSMISSION OF INTELLIGENCE.

"One of the most important features of this invention," said Mr. Tesla, "will be the transmission of intelligence. It will convert the entire earth into a huge brain, capable of responding in every one of its parts. By the employment of a number of plants, each of which can transmit signals to all parts of the world, the news of the globe will be flashed to all points. A cheap and simple receiving device, which might be carried in one's pocket, can be set up anywhere on sea or land, and it will record the world's news as it occurs, or take such special messages as are intended for it. If you are in the heart of the Sahara, your wife can telegraph to you from Washington, and if the instrument is properly made you alone will get the message. A single plant of a few horse power could operate hundreds of such instruments, so that the invention has an infinite working capacity and will cheapen the transmission of all kinds of intelligence."

Frank G. Carpenter.

ELECTRIC AUTOS.

Nicola Tesla's View of the Future in Motive Power.

[Special Cor. Manufacturers' Record.]
New York, December 27.

In view of the great interest which is being taken in the articles published by the Manufacturers' Record and some of the magazines on the development of new power-producers, through the internal-combusion engine, for use for transportation purposes both by land and sea, the following signed statement, made by Mr. Nicola Tesla after a discussion of a new type of auto-bus designed by Mr. Charles A. Lieb, mechanical engineer of the Manhattan Transit Co., will doubtless be read with much general interest:

"New York, December 17.

"*Mr. Albert Phenis, Special Correspondent Manufacturers' Record, New York*:

"Dear Sir—Replying to your inquiry of yesterday, the application of electricity to the propulsion of automobiles is certainly a rational idea. I am glad to know that Mr. Lieb has undertaken to put it into practice. His long experience with the General Electric Co. and other concerns must have excellently fitted him for the task.

"There is no doubt that a highly-successful machine can be produced on these lines. The field is inexhaustible, and this new type of automobile, introducing electricity between the prime mover and the wheels, has, in my opinion, a great future.

"I have myself for many years advocated this principle. You will find in numerous technical publications statements made by me to this effect. In my article in the Century, June, 1900, I said, in dealing with the subject: 'Steamers and trains are still being propelled by the direct application of steam power to shafts or axles. A much greater percentage of the heat energy of the fuel could be transformed in motive energy by using, in place of the adopted marine engines and locomotives, dynamos driven by specially-designed high-pressure steam or gas engines, by utilizing the electricity generated for the propulsion. A gain of 50 to 100 per cent. in the effective energy derived from the fuel could be secured in this manner. It is difficult to understand why a fact so plain and obvious is not receiving more attention from engineers.'

"At first glance it may appear that to generate electricity by an engine and then apply the current to turn a wheel, instead of turning it by means of some mechanical connection with the engine, is a complicated and more or less wasteful process. But it is not so; on the contrary, the use of electricity in this manner secures great practical advantages. It is but a question of time when this idea will be extensively applied to railways and also to ocean liners, though in the latter case the conditions are not quite so favorable. How the railroad companies can persist in using the ordinary locomotive is a mystery. By providing an engine generating electricity and operating with the current motors under the cars a train can be propelled with greater speed and more economically. In France this has already been done by Heilman, and although his machinery was not the best, the results he obtained were creditable and encouraging. I have calculated that a notable gain in speed and economy can also be secured in ocean liners, on which the improvement is particularly desirable for many reasons. It is very likely that in the near future oil will be adopted as fuel, and that will make the new method of propulsion all the more commendable. The electric manufacturing companies will scarcely be able to meet this new demand for generators and motors.

"In automobiles practically nothing has been done in this direction, and yet it would seem they offer the greatest opportunities for application of this principle. The question, however, is which motor to employ—the direct-current or my induction motor. The former has certain preferences as regards the starting and regulation, but the commutators and brushes are very objectionable on an automobile. In view of this I would advocate the use of the induction motor as an ideally simple machine which can never get out of order. The conditions are excellent, inasmuch as a very low frequency is practicable and more than three phases can be used. The regulation should offer little difficulty, and once an automobile on this novel plan is produced its advantages will be readily appreciated.

"Yours very truly, N. TESLA."

The Transmission of Electrical Energy Without Wires As a Means for Furthering Peace.

By NIKOLA TESLA.

UNIVERSAL PEACE, assuming it to be in the fullest sense realizable, might not require eons for its accomplishment, however probable this may appear, judging from the imperceptibly slow growth of all great reformatory ideas of the past. Man, as a mass in movement, is inseparable from sluggishness and persistence in his life manifestations, but it does not follow from this that any passing phase, or any permanent state of his existence, must necessarily be attained through a *stataclitic* process of development.

Our accepted estimates of the duration of natural metamorphoses, or changes in general, have been thrown in doubt of late. The very foundations of science have been shaken. We can no longer believe in the Maxwellian hypothesis of transversal ether-undulations and the literal truth of its corollaries. The practical utilization of electrical vibrations, this most important field of human endeavor, particularly in the advancement of philanthropy and peace, was in no small measure retarded by that fascinating illusion, which I since long hoped to dispel. I have noted with satisfaction the first signs of a change of scientific opinion. The brilliant discovery of the exceptionally "radio-active" substances, radium and polonium, by Mrs. Sklodowska Curie, has likewise afforded me much personal gratification, being an eclatant confirmation of my early experimental demonstrations, of electrified radiant streams of primary matter or corpuscular emanations (*Electrical Review*, New York, 1896-1897), which were then received with incredulity. They have awakened us from the poetical dream of an intangible conveyor of energy, weightless, structureless ether, to the plain, palpable reality of a ponderous medium of coarse particles, or bodily carriers of force. They have led us to a radically new interpretation of the changes and transformations we perceive. Enlightened by this recognition, we cannot say the sun is hot, the moon is cold, the star is bright, for all these might be purely electrical phenomena. If this be the case, then even our conceptions of time and space may have to be modified.

So, too, as regards the organic world, a similar revolution of thought is distinctly observable. In biological and zoological research the bold ideas of Haensel have found support in recent discoveries. A heretic belief in such possibilities as the artificial production of simple living material aggregates, the spontaneous natural creation of complex organisms and willful sex control, is gaining ground. We still brush it aside, but not with pedantic disdain as before. The fact is—our faith in the orthodox theory of slow evolution is being destroyed!

Thus a state of human life vaguely defined by the term "Universal Peace," while a result of cumulative effort through centuries past, might come into existence *quickly*, not unlike a crystal suddenly forms in a solution which has been slowly prepared. But just as no effect can precede its cause, so this state can never be *brought on* by any pact between nations, however solemn. Experience is made before the law is formulated, both are related like cause and effect. So long as we are clearly conscious of the expectation, that peace is to result from such a parliamentary decision, so long have we a conclusive evidence that we are not fit for peace. Only then when we shall feel that such international meetings are mere formal procedures, unnecessary except in so far as they might serve to give definite expression to a common desire, will peace be assured.

To judge from current events we must be, as yet, very distant from that blissful goal. It is true that we are proceeding towards it rapidly. There are abundant signs of this progress everywhere. The race enmities and prejudices are decidedly waning. A recent act of His Excellency, the President of the United States, is significant in this respect. We begin to think cosmically. Our sympathetic feelers reach out into the dim distance. The bacteria of the "Weltschmerz," are upon us. So far, however, universal harmony has been attained only in a single sphere of international relationship. That is the postal service. Its mechanism is working satisfactorily, but—how remote are we still from that scrupulous respect of the sanctity of the mail bag! And how much farther again is the next milestone on the road to peace—an international judicial service equally reliable as the postal!

The coming meeting at the Hague, now indefinitely postponed, can only consider temporary expedients. General disarmament being for the present entirely out of question, a proportionate reduction might be recommended. The safety of any country and of the world's commerce depending not on the absolute, but relative amount of war material, this would be evidently the first reasonable step to take towards universal economy and peace. But it would be a hopeless task to establish an equitable basis of adjustment. Population, naval strength, force of army, commercial importance, water-power, or any other natural resource, actual or prospective, are equally unsatisfactory standards to consider.

In view of this difficulty a measure suggested by Carnegie might be adopted by a few strong countries to scare all the weaker ones into peace. But while for the time being such a course may seem advisable, the beneficial effects of this homœopathic treatment of the martial disease could hardly be lasting. In the first place, a coalition of the leading powers could not fail to create an organized opposition, which might result in a disaster all the greater as it was long deferred. The ultimate falling out of the virtuous, peace-dictating nations, as *certain* as the law of gravitation, should be all the more reckoned with, as it would be extremely demoralizing. Again, it is by no means demonstrated that any combination of a few powers would have sufficient authority.

To conquer by sheer force is becoming harder and harder every day. Defensive is getting continuously the advantage of offensive, as we progress in the satanic science of destruction. The new art of controlling electrically the movements and operations of individualized automata at a distance without wires, will soon enable any country to render its coasts impregnable against all naval attacks. It is to be regretted, in this connection, that my proposal to the United States Navy four years ago, to introduce this invention, did not receive the least encouragement. Also that my offer to Secretary Long to establish telegraphic communication across the Pacific Ocean by my wireless system was thrown in the naval waste basket in Washington, quite *sans façon*. At that time I had already announced in the *Century Magazine* of June, 1900, my successful "girdling" of the globe with electrical impulses (stationary waves), and my "telautomata" had been publicly exhibited. But that was not the fault of the naval officials, for then these inventions of mine were decried as bald, visionary schemes, loudest indeed by those who have since become Crœsuses of Promise—in "light" storage batteries, "Ocean" telephony and "transatlantic" wireless telegraphy, yet remained to this day—Sisyphuses of Attainment. Had only a few "telautomatic" torpedoes been constructed and adopted by our navy, the mere moral influence of this would have been powerfully and most beneficially felt in the present Eastern complication. Not to speak of the advantages which might have been secured through the direct and instantaneous transmission of messages to our distant colonies and scenes of the present barbarous conflicts. Since advancing that principle, I have invented a number of improvements, making it possible to direct such a torpedo, submersible at will, from a distance much greater than the range of the largest gun, with *unerring* precision, upon the object to be destroyed. What is still more surprising, the operator will not need to see the infernal engine or even know its location, and the enemy will be unable to interfere, in the slightest, with its movements by any electrical means. One of these devil-telautomata will soon be constructed, and I shall bring it to the attention of governments. The development of this art must unavoidably arrest the construction of expensive battleships as well as land fortifications, and revolutionize the means and methods of warfare. The distance at which it can strike, and the destructive power of such a *quasi-intelligent* machine being for all practical purposes unlimited, the gun, the armor of the battleship and the wall of the fortress, lose their import and significance. One can prophesy with a Daniel's confidence that skilled electricians will settle the battles of the near future. But this is the least. In its effect upon war and peace, electricity offers still much greater and more wonderful possibilities. To stop war by the perfection of engines of destruction alone, might consume centuries and centuries. Other means must be employed to hasten the end. What are these to be? Let us consider.

Fights between individuals, as well as governments and nations, invariably result from misunderstandings in the broadest interpretation of this term. Misunderstandings are always caused by the inability of appreciating one another's point of view. This again is due to the ignorance of those concerned, not so much in their *own*, as in their *mutual* fields. The peril of a clash is aggravated by a more or less predominant sense of combativeness, possessed by every human being. To resist this inherent fighting tendency the

best way is to dispel ignorance of the doings of others by a systematic spread of general knowledge. With this object in view, it is most important to aid exchange of thought and intercourse.

Mutual understanding would be immensely facilitated by the use of one universal tongue. But which shall it be, is the great question. At present it looks as if the English might be adopted as such, though it must be admitted that it is not the most suitable. Each language, of course, excels in some feature. The English lends itself to a terse, forceful expression of facts. The French is precise and finely distinctive. The Italian is probably the most melodious and easiest to learn. The Slavic tongues are very rich in sound but extremely difficult to master. The German is unequaled in the facility it offers for coining and combining words. A practical answer to that momentous question must perforce be found in times to come, for it is manifest that by adopting one common language the onward march of man would be prodigiously quickened. I do not believe that an artificial concoction, like Volapuk, will ever find universal acceptance, however time-saving it might be. That would be contrary to human nature. Languages have grown into our hearts. I rather look to the possibility of a reversion to the old Latin or Greek mother tongues, basing myself in this conclusion on the Spencerian law of rhythm. It seems unfortunate that the English-speaking nations, who are now fittest to rule the world, while endowed with extraordinary energy and practical intelligence, are singularly wanting in linguistic talent.

Next to speech we must consider permanent records of all kinds as a means for disseminating general information, or that knowledge of *mutual* endeavor which is chiefly conducive to harmony. Here the newspapers play by far the most important part. They are undoubtedly more effective than institutions of learning, libraries, museums and individual correspondence, all combined. The knowledge they convey is, on the whole, superficial anl sometimes defective, but it is poured out in a mighty stream that reaches far and wide. Disregarding the force of electrical invention, that of journalism is the greatest in urging us to peace. Our schools are instrumental, mainly, in the furtherance of special thorough knowledge in our *own* fields, which is destructive of concordance. A world composed of crass specialists only would be perpetually at war. The diffusion of general knowledge through libraries and similar sources of information is very slow. As to individual correspondence, it is principally useful as an indispensable ingredient of the cement of commercial interest, that most powerful binding material between heterogeneous masses of humanity. It would be hard to overestimate the beneficial influence of the marvelous and precise art of photography, nor can that of other arts or means of recording be ignored. But a simple reflection will show that the peace-making force of all permanent, printed or other records, resides not in themselves. It must be sought elsewhere. This is also true of speech.

Our senses enable us to perceive only a minute portion of the outside world. Our touch, taste and smell, require actual contact. Our hearing extends to a small distance. Our sight is impeded by intervening bodies and shadows. To know each other we must reach beyond the sphere of our sense perceptions. We must transmit our intelligence, travel, transport the materials and transfer the energies necessary for our existence. Following this thought we now realize, forcibly enough to dispense with argument, that of all other conquests of man, without exception, that which is most desirable, which would be most helpful in the establishment of universal peaceful relations is—the complete *ANNIHILATION OF DISTANCE.*

To achieve this wonder, electricity is the one and only means. Inestimable good has already been done by the use of this all-powerful agent, the nature of which is still a mystery. Our astonishment at what has been accomplished would be uncontrollable were it not held in check by the expectation of greater miracles to come. That one, the greatest of all, can be viewed in three aspects: *Dissemination of intelligence, transportation, and transmission of power.*

Referring to the first, the present systems of telegraphic and telephonic communication are very limited in scope. The conducting channels are costly and of small working capacity. There is serious inductive disturbance, and storms render the service unsafe which, moreover, is too expensive. A vast improvement will be effected by placing the wires underground and insulating them artificially, by refrigeration. Their working capacity also could be indefinitely augmented by resorting to the new principle of "individualization," which I have more recently announced, permitting the simultaneous transmission of thousands of telegraphic and telephonic messages, without interference, over a single wire. The public would be already profiting from these great advances were it not for the stolid indifference of the leading companies engaged in the transmission of intelligence. But new concerns are springing into existence and the near future will witness a great transformation along these two lines of invention. The submarine cables are subject to still greater limitations. Some obstacles to rapid signaling, through them, seem insuperable. The attempts to overcome these have been numerous, but so far all have proved futile. The celebrated mathematician, O. Heaviside, and several able electricians following in his footsteps, have fallen into the singular error that rapid telegraphy and even telephony through ocean cables would be made practicable by the use of induction coils. Inductances might be to some extent helpful on comparatively short lines with thick paper insulation; on long lines insulated with rubber or gutta-percha they would be positively detrimental. Improvements will, undoubtedly, be made, but great electrostatic capacity and unavoidable loss of energy in the insulation and surrounding conductors will always restrict the usefulness of these delicate and precious nerves of commerce. Apart from all this, the transmission through artificial conductors is necessarily confined to a small number of stations.

It is therefore evident that the abolishment of all these drawbacks by the conveyance of signals or messages without wires, as I have undertaken in my "world" telegraphy and telephony, will be of the greatest moment in the furtherance of peace. The unifying influence of this advance will be felt all the more, as it will not only completely annihilate distance, but also make it possible to operate from a single "world" telegraphy plant, an unlimited number of receiving stations distributed all over the globe, and with equal facility, irrespective of location. Within a few years a simple and inexpensive device, readily carried about, will enable one to receive on land or sea the principal news, to hear a speech, a lecture, a song or play of a musical instrument, conveyed from any other region of the globe. The invention will also meet the crying need for cheap transmission to great distances, more especially over the oceans. The small working capacity of the cables and the excessive cost of messages are now fatal impediments in the dissemination of intelligence which can only be removed by transmission without wires.

The deficiencies of Hertzian telegraphy have created in the public mind the impression that exclusive or private messages without the use of artificial channels are impracticable. As a matter of fact, nothing could be more erroneous. Ever since its first appearance in 1891, I have denied the commercial possibilities of the system of signaling by Hertzian or electromagnetic waves, and my forecasts have been fully confirmed. It lends itself little to tuning, still less to the higher artifices of "individualization," and transmission to considerable distances is wholly out of the question. Portentous claims for this method of communication were made three years ago, but they have been unable to stand the hard, cruel test of time. Moreover, I have recently learned through the leading British electrical journal (*Electrician,* London, February 27, 1903), that some experimenters have abandoned all their own and have been "converted" to my methods and appliances, without my approval and officiation. I was both astonished and pained—astonished at the nonchalance and lack of appreciation of these men, pained at the inability exhibited in the construction and use of my apparatus. My high hopes raised by that excellent journal, however, are still to be realized, for I have ascertained that His Majesty the King of England, His Excellency the President of the United States, and other persons of exalted positions have, after all, not conferred upon me the imperishable honor of graciously condescending to the use of my coils, transformers and high-potential methods of transmission, but have exchanged their august greetings through the medium of a cable in the old-fashioned way. What has been actually achieved by Hertzian telegraphy can only be conjectured.

Quite different conditions exist in my system in which the electromagnetic waves or radiations are designedly minimized, the connection of one of the terminals of the transmitting circuit to the ground having, itself, the effect of reducing the energy of these radiations to about one-half. Under observance of proper rules and artifices the distance is of little or no consequence, and by skillful application of the principle of "individualization," repeatedly referred to, the messages may be rendered both non-interfering and non-interfer-

able. This invention, which I have described in technical publications, attempts to imitate, in a very crude way, the nervous system in the human body. It was the outcome of long-continued tests demonstrating the impossibility of satisfying rigorous commercial requirements by my earlier system, based on simple tuning, in which the selective quality is dependent on a single characteristic feature. In this later improvement the exclusiveness and non-interferability of impulses transmitted through a common channel result from cooperative association of a *number* of distinctive elements, and can be pushed as far as desired. In actual practice it is found that by combining only two vibrations or tones, a degree of privacy sufficient for most purposes is attained. When three vibrations are combined, it is extremely difficult, even for a skilled expert, to read or to disturb signals not intended for him, with four it is a vain undertaking. The probability of his getting the secret combinations at the right moments and in proper order, is much smaller than that of drawing an ambo, terno or quaterno, respectively, in a lottery. From experimental facts, I conclude that the invention will permit the simultaneous transmission of several millions of separately distinguishable messages through the earth, which, strangely enough, is in this respect much superior to an artificial conductor. This number ought to be sufficient to meet all the pressing necessities of intelligence transmission for at least one century to come. It is important to observe that but one "world" telegraphy plant, such as I am now completing, will have a greater working capacity than *all the ocean cables combined.* Once these facts are recognized this new art, which I am inaugurating, will sweep the world with the force of a uragan.

In transportation a great change is now going on. The trolley lines are being extended, the steam locomotive is making place for the electric motor. The ocean liners are adopting the turbine. Land travel is being improved by the automobile. The waterfalls are being harnessed and the energy used in the propulsion of cars. The advantages of first generating electricity by a prime mover, and then applying the current to produce mechanical motion, are being more and more appreciated. To the majority, this may appear a roundabout way of doing, but in reality it is as direct as the driving of a pulley from another by a belt. The idea is already being applied to railroads, and automobiles of this new type are making their appearance. The ocean vessels are bound to follow. An immense and virgin field will be thus opened up to the manufacturers of electric machinery. Effort towards saving time and money is characteristic of all modern methods of transportation. In many of these new developments, the artificial insulation of the high-tension mains by refrigeration will be very useful. However paradoxical, it is true, that by the use of this invention, power for all industrial purposes can be transmitted to distances of many hundreds of miles, not only without any loss, but with appreciable *gain* of energy. This is due to the fact that the conductor is much colder than the surrounding medium. The operativeness of this method is restricted to the use of a gaseous refrigerant, no known liquid permitting the attainment of a sufficiently low temperature of the transmission line. Hydrogen is by far the best cooling agent to employ. By its use electric railways can be extended to any desired distance. Owing to the smallness of ohmic loss, the objections to the multiphase system disappear and induction motors with closed coil armatures can be adopted. I find that even transmission through a submarine cable, as from Sweden to England, of great amounts of power is perfectly practicable. But the ideal solution of the problem of transportation will be arrived at only when the complete annihilation of distance in the transmission of power in large amounts shall have become a commercial reality. That day we shall invade the domain of the bird. When the vexing problem of aerial navigation, which has defied his attempts for ages, is solved, man will advance with giant strides.

That electrical energy can be economically transmitted without wires to any terrestrial distance, I have unmistakably established in numerous observations, experiments and measurements, qualitative and quantitative. These have demonstrated that it is practicable to distribute power from a central plant in unlimited amounts, with a loss not exceeding *a small fraction of one per cent.* in the transmission, even to the greatest distance, twelve thousand miles—to the opposite end of the globe. This seemingly impossible feat can now be readily performed by any electrician familiar with the design and construction of my "high-potential magnifying transmitter," the most marvelous electrical apparatus of which I have knowledge, enabling the production of effects of unlimited intensities in the earth and its ambiant atmosphere. It is, essentially, a freely vibrating secondary circuit of definite length, very high self-induction and small resistance, which has one of its terminals in intimate direct or inductive connection with the ground and the other with an elevated conductor, and upon which the electrical oscillations of a primary or exciting circuit are impressed under conditions of resonance. To give an idea of the capabilities of this wonderful appliance, I may state that I have obtained, by its means, spark discharges extending through more than one hundred feet and carrying currents of one thousand amperes, electromotive forces approximating twenty million volts, chemically active streamers covering areas of several thousand square feet, and electrical disturbances in the natural media *surpassing* those caused by lightning, in itensity.

Whatever the future may bring, the universal application of these great principles is fully assured, though it may be long in coming. With the opening of the first power plant, incredulity will give way to wonderment, and this to ingratitude, as ever before. The time is not distant when the energy of falling water will be man's life energy. So far only about three million horse-power have been harnessed by my system of alternating-current transmission. This is little, but corresponds, nevertheless, to the adding of sixty million indefatigable laborers, working virtually without food and pay, to the world's population. The projects which have come to my own attention, however, contemplate the exploitation of water-powers aggregating something like one hundred and fifty million horse-power. Should they be carried out in a quarter of a century, as seems probable from present indications, there will be, on the average two such untiring laborers for every individual. Long before this consummation, coal and oil must cease to be important factors in the sustenance of human life on this planet. It should be borne in mind that electrical energy obtained by harnessing a waterfall is probably fifty times more effective than fuel energy. Since this is the most perfect way of rendering the sun's energy available, the direction of the future material development of man is clearly indicated. He will live on "white coal." Like a babe to the mother's breast will he cling to his waterfall. "Give us our daily waterfall," will be the prayer of the coming generations. *Deus futurus est deus aquae deiectus!*

But the fact that stationary waves are producible in the earth is of special and, in many ways, still greater significance in the intellectual development of humanity. Popularly explained, such a wave is a phenomenon generically akin to an echo—a result of reflection. It affords a positive and uncontrovertible experimental evidence that the electric current, after passing into the earth travels to the diametrically opposite region of the same and rebounding from there, returns to its point of departure with virtually undiminished force. The outgoing and returning currents clash and form nodes and loops similar to those observable on a vibrating cord. To traverse the entire distance of about twenty-five thousand miles, equal to the circumference of the globe, the current requires a certain time interval, which I have approximately ascertained. In yielding this knowledge, nature has revealed one of its most precious secrets, of inestimable consequence to man. So astounding are the facts in this connection, that it would seem as though the Creator, himself, had electrically designed this planet just for the purpose of enabling us to achieve wonders which, before my discovery, could not have been conceived by the wildest imagination. A full account of my discoveries and improvements will be given to the world in a special work which I am preparing. In so far, however, as they relate to industrial and commercial uses, they will be disclosed in patent specifications most carefully drawn.

As stated in a recent article (ELECTRICAL WORLD AND ENGINEER, March 5, 1904), I have been since some time at work on designs of a power plant which is to transmit ten thousand horse-power without wires. The energy is to be collected all over the earth at many places and in varying amounts. It should not be understood that the practical realization of this undertaking is *necessarily* far off. The plans could be easily finished this winter, and if some preliminary work on the foundations could be done in the meantime the plant might be ready for operation before the close of next fall. We would then have at our disposal a unique and invaluable machine. Just this *one* oscillator would advance the world a century. Its civilizing influence would be felt even by the humblest dweller in the wilderness. Millions of instruments of all kinds, for all imaginable purposes, could be operated from that one machine. Universal time could be distributed by simple inexpensive clocks requiring no attention and running with nearly mathematical

precision. Stock-tickers, synchronous movements and innumerable devices of this character could be worked in unison all over the earth. Instruments might be provided for indicating the course of a vessel at sea, the distance traversed, the speed, the hour at any particular place, the latitude and longitude. Incalculable commercial advantages could be thus secured and countless accidents and disasters avoided. Here and there a house might be lighted or some other work requiring a few horse-power performed. What is far more important than this, flying machines might be driven in any part of the world. They could be made to travel swiftly because of their small weight and great motive power. My intention would be to utilize this first plant rather as means of enlightenment, to collect its power in very small amounts, and at as many places as possible. The knowedge that there is throbbing through the earth energy readily available everywhere, would exert a strong stimulus on students, mechanics and inventors of all countries. This would be productive of infinite good. Manufacture would receive a fresh and powerful incentive. Conditions, such as never existed before in commerce, would be brought about. Supply would be ever inadequate to demand. The industries of iron, copper, aluminum, insulated wire and many others, could not fail to derive great and lasting benefits from this development.

The economic transmission of power without wires is of all-surpassing importance to man. By its means he will gain complete mastery of the air, the sea and the desert. It will enable him to dispense with the necessity of mining, pumping, transporting and burning fuel, and so do away with innumerable causes of sinful waste. By its means, he will obtain at any place and in any desired amount, the energy of remote waterfalls—to drive his machinery, to construct his canals, tunnels and highways, to manufacture the materials of his want, his clothing and food, to heat and light his home—year in, year out, ever and ever, by day and by night. It will make the living glorious sun his obedient, toiling slave. It will bring peace and harmony on earth.

Over five years have elapsed since that providential lightning storm on the 3d of July, 1899, of which I told in the article before mentioned, and through which I discovered the terrestrial stationary waves; nearly five years since I performed the great experiment which, on that unforgettable day, the dark God of Thunder mercifully showed me in his vast, awe-sounding laboratory. I thought then that it would take a year to establish commercially my wireless girdle around the world. Alas! my first "world telegraphy" plant is not yet completed, its construction has progressed but slowly during the past two years. And this machine I am *building* is but a plaything, an oscillator of a maximum activity of only ten million horse-power, just enough to throw this planet into feeble tremors, by sign and word—to telegraph and to telephone. *When* shall I see completed that first power plant, that big oscillator which I am *designing?* From which a current stronger than that of a welding machine, under a tension of one hundred million volts, is to rush through the earth! Which will deliver energy at the rate of one thousand million horse-power—one hundred Falls of Niagara combined in one, striking the universe with blows—blows that will wake from their slumber the sleepiest electricians, if there be any, on Venus or Mars! . . . It is not a dream, it is a *simple feat of scientific electrical engineering,* only expensive—blind, faint-hearted, doubting world! . . . Humanity is not yet sufficiently advanced to be willingly led by the discoverer's keen searching sense. But who knows? Perhaps it is better in this present world of ours that a revolutionary idea or invention instead of being helped and patted, be hampered and ill-treated in its adolescence—by want of means, by selfish interest, pedantery, stupidity and ignorance; that it be attacked and stifled; that it pass through bitter trials and tribulations, through the heartless strife of commercial exisence. *So* do we get our light. So all that was great in the past was ridiculed, condemned, combatted, suppressed—only to emerge all the more powerfully, all the more triumphantly from the struggle.

Practical Letters from our Readers.

[*The Editor invites readers to make use of this column for the full discussion of matters of practical and mutual interest. Letters may be signed with a* nom-de-plume *if desired, but the full name and address of the sender* MUST *invariably be attached, though not necessarily intended for publication.*]

The Use of Tesla Coils for *X*-ray Work.

TO THE EDITOR OF *The Model Engineer*.

DEAR SIR,—Mr. Howgrave-Graham's criticism of my article of November 17th loses much of its point by reason of the fact that he omitted to first read up my previous article of May 28th, 1903. Indeed, I, or anyone fully acquainted with the facts of the case, might be excused if on reading in "*X*-rays Simply Explained" a reference to the article just referred to, I came to the conclusion that even then Mr. Graham had not read it, and consequently had not seen the photographic illustration which accompanied it. The criticism thus becomes purely academic. I quite agree with Mr. Howgrave Graham on one point—viz., that an *iron core* would be worse than useless in such a coil. Mr. Graham refers to the matter in one of his articles dated June 4th, 1903, MODEL ENGINEER, page 533, and for my part I should find it difficult to say who first suggested the use of an *iron* core for high frequency transformer or self-induction coils. Certainly, unless I am greatly mistaken, Tesla makes no reference to it in his article of April, 1892, *Journal of the Institute of Electrical Engineers*.

Early in the history of Röntgen ray work a more or less simple form of Tesla coil was introduced for the purpose of supplementing or augmenting the power of existing induction coils in the production of the *X*-rays. More than one list of "*X*-ray apparatus and accessories" contains estimate for this; £6 10s. appears to have been the usual figure, and, presumably, making every and liberal allowance for profits, there was a nicely made and more or less efficient piece of apparatus for the money. The only objection raised to the method was, so far as my memory serves, that the life of the tube was considerably shortened from the fact probably that the apparatus and tube were used frequently without sufficient discrimination.

That a simple form of Tesla (and I refer to apparatus on a small scale) was used, and *found efficient*, is indisputable. Personally, I never purchased such a coil, but simple forms were described from time to time in *Electricity* and, I believe, the *English Mechanic*. My first was made several years ago, and was used by me mainly for demonstration purposes, as I found that for a long continued run, or when it was desired to show the *X*-rays through a cryptoscope, there was much less risk of damage to one's *coil* (less current being required), while the deterioration of the *tube* was thought to be somewhat exaggerated. At all events, I was more disposed to risk a focus-tube than my coil!

Theoretically, I suppose, the Tesla discharges being oscillatory, by this arrangement *X*-ray should *not be so completely harnessed* for purposes of visual examination by means of a screen, as they undoubtedly are. Photographically, also, starting from similar premises, the absence of absolute sharpness—and this might be disputed—over a wider area is balanced by their greater power of *penetration*, and the consequent increase in the number of subjects available for purposes of delineation.

An inspection of the tube while working shows

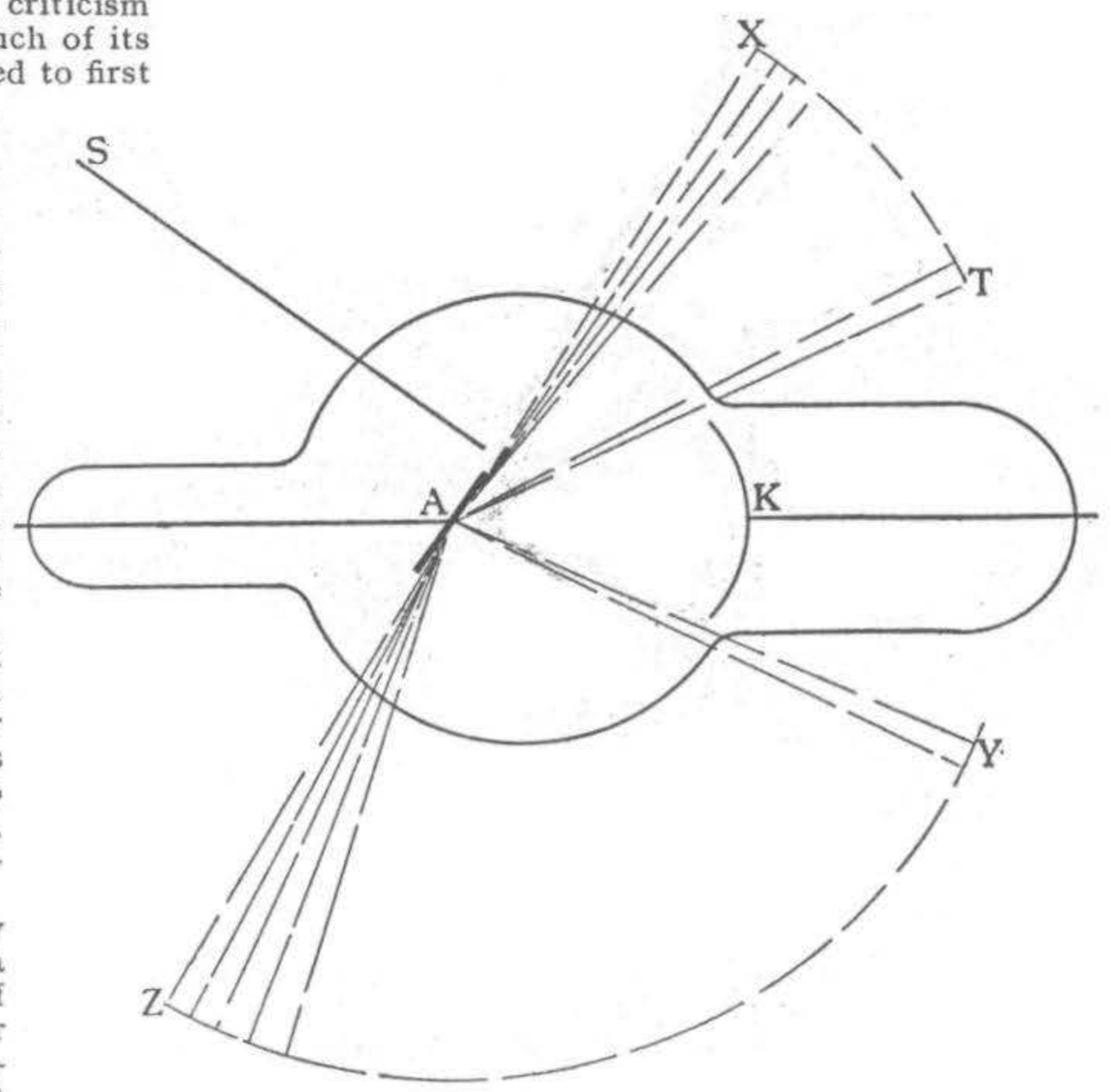

FIG. 1.

that (referring to Fig. 1) there is the usual line of demarcation from Z to X, not perhaps so strongly marked as when using induction coil only, but still perfectly definite; between S and X there is also fluorescence, and in greater volume than between X and T. Examining the tube also per cryptoscope, slowly revolving same, faint glimmers of rays are visible here and there, but nothing in comparison with the volume of *X*-rays which illumine the screen from Z to Y; and the conclusion arrived at must be that although A and K are constantly alternating, it is always to the advantage of the illuminated space between Y and Z. It would

appear that every other half-wave or reversal *does not decrease the efficiency of working*, but results photographically, in not a loss of definition exactly, but rather a *diffusion of focus*, which is not unpleasing.

The accompanying radiograph, which was taken for the purpose of this letter, is one more proof of

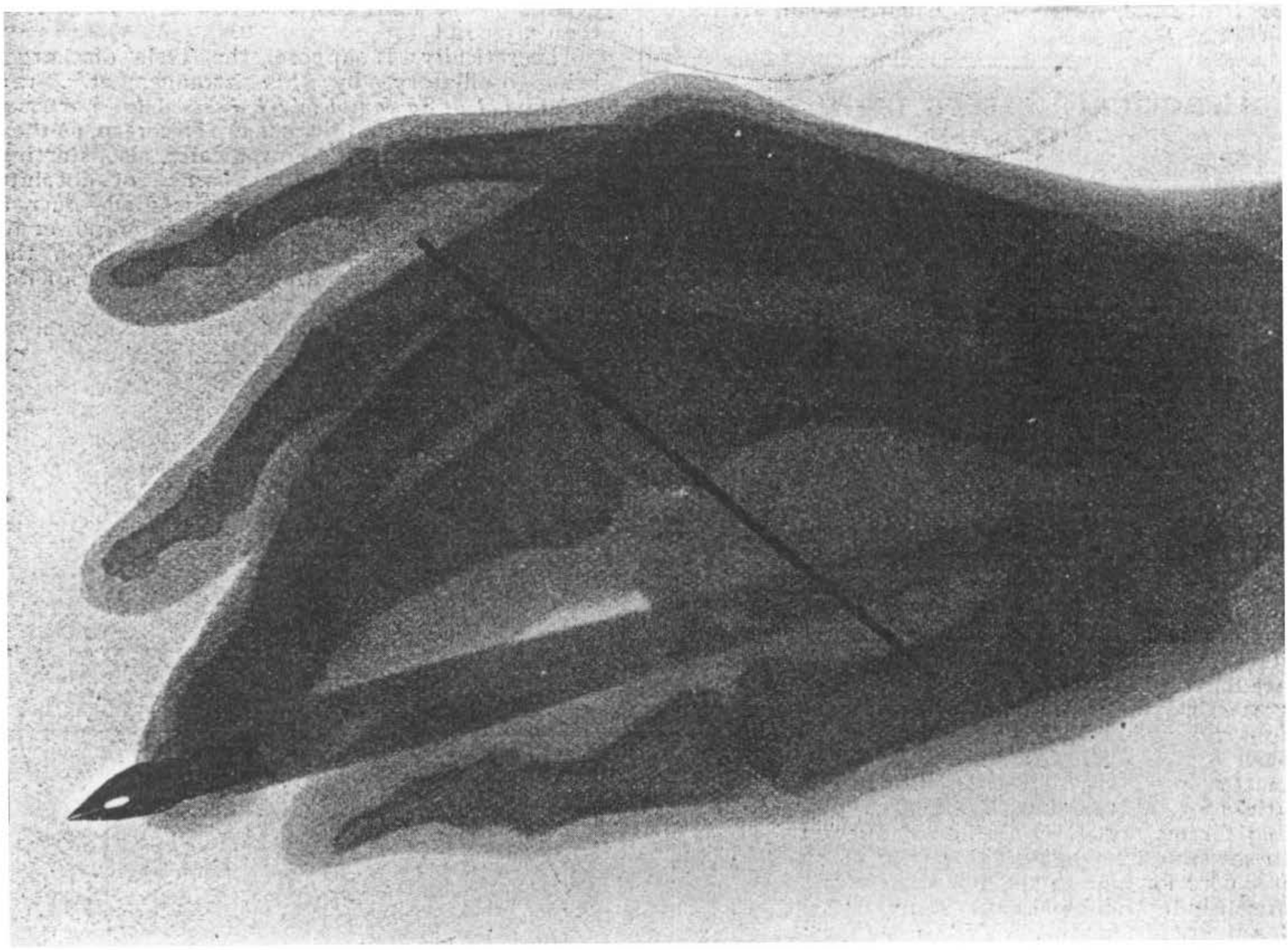

FIG. 2.

the efficiency of the apparatus. Here the hand is arched, the apex of the figure being 3 ins. above the base—a distinct handicap from the photographic point of view, as, for uniform sharpness in the usual way, the bones should be co-planar. The radiograph may, I think, be left to tell its own tale.

—Yours truly,
J. PIKE.

Nottingham.

An Important Decision Sustaining the Tesla Patents.

On February 20 Judge Seaman, in the United States Circuit Court for the Eastern District of Wisconsin, handed down a decision sustaining the Tesla patents owned by the Westinghouse Electric and Manufacturing Company. The defendant was the National Electric Company, and infringement was claimed of the broad rights covered in Tesla patents Nos. 381,968, 381,969, 382,280 and 382,281. Judge Seaman, in Milwaukee, on February 24 enjoined the defendant company from the further sale of synchronous motors. The decision in the suit is the first that has been obtained in the litigation begun some time ago by the Westinghouse company to prevent the sale of synchronous motors and rotary converters by American manufacturers not enjoying a license under the Tesla polyphase motor patents. A decision is pending in the United States Circuit Court for the Southern District of Ohio in the suit brought by the Westinghouse company against the Bullock Electric Manufacturing Company, alleging infringement of the same patent rights. The final hearing in the latter suit was conducted before Judge Thompson, in Cincinnati, on February 7 and 8.

The Tesla patents involved in these suits have been the subject of considerable litigation in the past few years. The action instituted by the Westinghouse company a number of years ago against the Thomson-Houston Company, for alleged infringement of the Tesla patents, was discontinued upon the execution of a patent agreement under which the General Electric Company has for several years manufactured and sold induction and synchronous motors and rotary converters. A number of manufacturers have been enjoined from manufacturing induction motors, but the decision by the Wisconsin court is the first court ruling that the synchronous motor is within the generic Tesla invention. Judge Seaman's decision, covering the main points, is as follows:

"With the excellent and thorough review of the earlier patents and prior art, and the well considered concurrent view of the novelty and scope of the Tesla invention covered by the patents (thus appearing in several of these opinions) I am relieved of any need to attempt an analysis of the general showing in the present case, which departs from the prior cases only in respect of the application of the invention of the synchronous-motor type. Although the enquiry thus presented is not free from difficulty—involving abstruse discussion and distinctions in the electrical art which are perplexing to the non-expert understanding, and are not clarified by the many pages of conflicting expert testimony—the arguments at the bar were clear and well directed, and I am convinced that the issue as now presented is within narrow compass and governed by tests for its solution which are not complicated.

"The defendant's contentions are, in substance, that the Tesla invention, embodied in each of the patents, is the rotating field mode of operation, which is 'the production of the conjoint effect of out-of-phase currents of a progressive shifting by the polarity,' and thus 'identical in its effect with that of a rotating physical magnet;' that it is limited to a self-starting motor so operated and both by the terms of the patents and the state of the art, the defendant's synchronous motor with direct-current excitation is not within the invention; that the defendant's synchronous motor is simply a reversed 'two-phase alternating-current dynamo of the prior art used as a generator,' adapted to alternating use; and that the claims of patents 381,969 and 382,281, which bring in 'direct-current excitation producing synchronous operation,' must be limited to such use 'after the motor is started by the Tesla means and method and brought up to speed.' If the invention is so limited by the prior art it is plain that the defendant escapes infringement. On the other hand, if not so restricted, it is equally clear that the patents are broad enough to reach the defendant's means and methods of operation.

"The Tesla discovery for which these patents were granted revolutionized the art of electrical power transmission, as well demonstrated in the record from both judicial and scientific standpoints. Judge Townsend's definition in reference to the generic patents in the New England Granite case, repeatedly approved by other courts, is adopted for this consideration, namely, 'Tesla's invention, considered in its essence, was the production of a continuously rotating or whirling field of magnetic forces for power purposes by generating two or more displaced or different phases of the alternating current, transmitting such phases, with their independence preserved, to the motor, and utilizing the displaced phases as such in the motor.' So viewed the patent monopoly was rightly granted for its brief term to the use of the means and methods thus discovered. While it could not exclude the known uses of the prior art, it is surely entitled to be protected against like motor structure and mode of operation, not clearly disclosed in the prior art, and the patent claims to that end must be fairly construed in conformity with the rule applicable to such inventions. I am of the opinion, therefore, that the several contentions for the defendant are either without force or untenable for the following reasons:

"Whether the effect of the Tesla invention in its production of the 'whirling field of magnetic force' is identical with that of a rotating physical magnet, as argued by experts and counsel, does not impress me as material to this issue. Nor does it seem material that in the one form of motor 'the rotation is produced by the unaided effect of alternating out-of-phase currents,' as described by counsel, and that so applied a self-starting motor is obtained. The discovery was of means and method in the polyphase rotating field motor to produce the whirling field of force, and employment thereof was patentable with or without direct-current excitation of the armature or secondary element. So the fact that its use produced a self-starting motor without the aid of such excitation can not alone serve to limit the invention to that effect, and I find no such limitation in the terms of the patent. The quotations from the arguments of counsel and experts for the complainant in prior cases, urging the distinction of this self-starting effect in reference to the application of the generic patents to non-synchronous motors, are without force in the present controversy, and it is unnecessary to ascertain their consistency or inconsistency with the interpretation sought on this hearing. Unless limitation to self-starting motors arises out of the prior art none can be imposed upon the claims in suit.

"The further propositions urged by way of defence—aside from the defence founded upon prior inventions of the synchronous type to be considered—are these (1) that the synchronous motor of the defendant is the old generator of the art, simply reversed; and (2) that the Tesla invention is not present therein, because (as asserted) 'the prepondering magnetization of the' direct current displaced and obliterates the 'shifting alternating-current magnetization,' or Tesla 'whirling field of force.' However specious both propositions appear on their face and in the argument, neither of them impresses me as controlling.

"I believe that no proposition in the able and extended arguments on the part of the defence have been overlooked in my consideration of this case, although it has not seemed needful to discuss all of them for the purposes of this opinion. My conclusions are that the defendant's synchronous motor structure and operation are within the generic invention as patented, and expressly covered by the claims of Nos. 381,969 and 382,281; that the invention is utilized in the defendant's motor operation, notwithstanding the introduction of direct-current excitation to make it synchronous, in lieu of the full realization of the revolving field effect for self-starting; that such supplemental aid does not escape infringement, with or without advantage in such associations; and that, in any view the combination patents referred to are not limited to after-effect of the direct-current excitation, but apply to the defendant's combination. Decree will be entered accordingly as prayed in the bill."

Tesla Polyphase Patents held to Cover Polyphase Synchronous Motors.

On February 20 Judge Seaman, of the Circuit Court of the United States of the Eastern District of Wisconsin, handed down an opinion holding that the fundamental Tesla patents, issued May 1, 1888, cover the rotary converter and synchronous motor operated by polyphase currents. The defendants to the suit contended that Tesla's invention is the rotating field mode of operation and this is limited to a self-starting motor so operated; that the defendants' synchronous motor with direct-current excitation is not within the invention, being simply a reversed two-phase alternating-current dynamo of the prior art used as a generator; and that the claims in the Tesla patents which introduced "direct-current excitation producing synchronous operation" must be limited to such use after the motor is started by the Tesla means and method and brought up to speed. The court held that if the invention is to be so limited the defendant escapes infringement; on the other hand, if not so restricted, it is equally clear that the claims of the patents are broad enough to reach the defendants' means and method of operation.

The court stated that the Tesla discovery was of means and methods in the polyphase rotating field motor to produce the "whirling field of force," and employment thereof was obtainable, with or without direct-current excitation of the armature or secondary element. The fact that its use produced a self-starting motor without the aid of such excitation cannot alone serve to limit the invention to that effect. The theory advanced of the obliteration of the alternating-current magnetization by that of the direct current of the secondary element of the motor, the court held, was not material, as it is unquestionable that the Tesla invention is brought into the operation of the motor and the structure is within the patent description.

As to the Bradley patent, upon which stress was laid in the argument as showing a polyphase machine stated to be adapted for use "as a motor when fed or actuated by alternating currents," this is subsequent in date of patent issue to the Tesla patents, though the original application bears date prior to that of Tesla. The testimony of Mr. Bradley and his attorney cannot affect the interpretation which must be given the disclosure of the invention in the original application, and if such application can be treated as a disclosure of the prior art, it fails to reach the Tesla conception. Its deficiencies in that regard were pointed out in previous suits involving the Tesla patents.

The conclusions of the court are that the defendants' synchronous motor structure and operation are within the generic invention covered by the claims of two of the fundamental Tesla patents; that the invention is utilized in the defendants' motor operation, notwithstanding the introduction of direct-current excitation to make it synchronous in lieu of the full realization of the revolving field effect for self-starting; that such supplemental aid does not escape infringement with or without advantage in such association; and that, in any view the combination patents referred to are not limited to after effect of direct-current excitation, but apply to the defendants' combination.

The parties of the suit were the Westinghouse Electric & Manufacturing Company and the National Electric Company.

Tesla Synchronous Motor Patents Upheld.

In pursuance of a decision handed down by him on February 20th, in the United States Circuit Court for the Eastern District of Wisconsin, sustaining the contention of the Westinghouse Electric and Manufacturing Company that synchronous motors made by the National Electric Company were an infringement of the broad rights covered in Tesla patents Nos. 381,969 and 382,281, Judge Seaman, in Milwaukee, on February 24th, enjoined the National company from the sale of such motors. The decision in the suit is the first that has been obtained in the litigation begun some time ago by the Westinghouse company to prevent the sale of synchronous motors and rotary converters by American manufacturers not enjoying a license under the Tesla polyphase-motor patents. The hearing in the suit against the National Electric Company was conducted before Judge Seaman on February 6th and 7th, Thomas B. Kerr and Parker W. Page appearing for the Westinghouse company.

The Tesla patents involved in suit have been the subject of considerable litigation in the last few years. Other manufacturers have been enjoined from manufacturing induction motors, but the decision in the suit against the National company is the first court ruling that the synchronous motor is within the generic Tesla invention. Extracts from Judge Seaman's decision are as follows:

"The defendant's contentions are, in substance, that the Tesla invention, embodied in each of the patents, is the rotating-field mode of operation, which is 'the production of the conjoint effect of out-of-phase currents of a progressive shifting by the polarity,' and thus 'identical in its effect with that of a rotating physical magnet' that it is limited to a self-starting motor so operated, and both by the terms of the patents and the state of the art, the defendant's synchronous motor with direct-current excitation is not within the invention; that the defendant's synchronous motor is simply a reversed 'two-phase alternating-current dynamo of the prior art used as a generator,' adapted to alternative use; and that the claims of patents 381,969 and 382,281, which bring in 'direct-current excitation producing synchronous operation,' must be limited to such use 'after the motor is started by the Tesla means and method and brought up to speed.' If the invention is so limited by the prior art it is plain that the defendant escapes infringement. On the other hand, if not so restricted, it is equally clear that the claims of the patents are broad enough to reach the defendant's means and method of operation."

"The Tesla discovery for which these patents were granted revolutionized the art of electrical power transmission, as well demonstrated in the record from both judicial and scientific standpoints. Judge Townsend's definition, in reference to the generic patents in the New England Granite case, repeatedly approved by other courts, is adopted for this consideration, namely, 'Tesla's invention, considered in its essence, was the production of a continually rotating or whirling field of magnetic forces for power purposes by generating two or more displaced or different phases of the alternating current, transmitting such phases, with their independence preserved, to the motor, and utilizing the displaced phases as such in the motor.' So viewed, the patent monopoly was rightly granted for its brief term to the use of the means and methods thus discovered. While it could not exclude the known uses of the prior art, it is surely entitled to be protected against like motor structure and mode of operation, not clearly disclosed in the prior art, and the patent claims to that end must be fairly construed in conformity with the rule applicable to such inventions. I am of the opinion, therefore, that the several contentions for the defendant are either without force or untenable."

"Whether the effect of the Tesla invention in its production of the 'whirling field of magnetic force' is identical with that of a rotating physical magnet, as argued by experts and counsel, does not impress me as material to this issue. Nor does it seem material that in the one form of motor 'the rotation is produced by the unaided effect of alternating out-of-phase currents,' as described by counsel, and that so applied a self-starting motor is obtained. The discovery was of means and method in the polyphase rotating-field motor to produce the whirling field of force, and employment thereof was patentable with or without direct-current excitation of the armature or secondary element. So the fact that its use produced a self-starting motor without the aid of such excitation cannot alone serve to limit the invention to that effect, and I find no such limitation in the terms of the patent. The quotations from the arguments of counsel and experts for the complainant in prior cases, urging the distinction of this self-starting effect in reference to the application of the generic patents to non-synchronous motors, are without force in the present controversy, and it is unnecessary to ascertain their consistency or inconsistency with the interpretation sought on this hearing. Unless limitation to self-starting motors arises out of the prior art none can be imposed upon the claims in suit."

"The further propositions urged by way of defense—aside from the defense founded upon prior inventions of the synchronous type to be considered—are these—(1) that the synchronous motor of the defendant is the old generator of the art, simply reversed, and (2) that the Tesla invention is not present therein, because (as asserted) 'the preponderating magnetization of the direct current displaced and obliterates the 'shifting alternating-current magnetization,' or Tesla's 'whirling field of force.' However specious both propositions appear on their face and in the argument, neither of them impresses me as controlling."

"I believe that no proposition in the able and extended arguments on the part of the defense have been overlooked in my consideration of this case, although it has not seemed needful to discuss all of them for the purposes of this opinion. My conclusions are that the defendant's synchronous-motor structure and operation are within the generic invention as patented, and expressly covered by the claims of Nos. 381,969 and 382,281; that the invention is utilized in the defendant's motor operation, notwithstanding the introduction of direct-current excitation to make it synchronous, in lieu of the full realization of the revolving-field effect for self-starting; that such supplemental aid does not escape infringement, with or without advantage in such associations; and that, in any view, the combination patents referred to are not limited to after-effect of the direct-current excitation, but apply to the defendant's combination. Decree will be entered accordingly as prayed in the bill."

The National Electric Company has given notice of appeal from the injunction. On its behalf, it is also declared that the patents expire in May of this year in any event.

A WIDE APPLICATION OF THE TESLA POLYPHASE patents was made by Judge Seaman in the Federal Circuit Court at Milwaukee, Wis., in the decision in a suit brought by the Westinghouse Electric & Mfg. Co., of Pittsburg, Pa., against the National Electric Co., of Milwaukee, Wis. The complainants, owners of the Tesla polyphase patents, sought to enjoin the defendant from the further sale of synchronous motors (reversed alternating-current generators). Their contention was that the claim of Tesla for producing a rotating field by means of currents differing in phase applies to synchronous polyphase motors and rotary converters as well as to induction motors. This contention was upheld by the court. The material portion of the decision delivered Feb 24, 1905, is reproduced in the "Electrical Review" of March 4, from which we quote the following:

Whether the effect of the Tesla invention in its production of the "whirling field of magnetic force" is identical with that of a rotating physical magnet, as argued by experts and counsel, does not impress me as material to this issue. Nor does it seem material that in the one form of motor "the rotation is produced by the unaided effect of alternating out-of-phase currents," as described by counsel, and that so applied a self-starting motor is obtained. The discovery was of means and method in the polyphase rotating field motor to produce the whirling field of force, and employment thereof was patentable with or without direct-current excitation of the armature or secondary element. So the fact that its use produced a self-starting motor without the aid of such excitation cannot alone serve to limit the invention to that effect, and I find no such limitation in the terms of the patent. The quotations from the arguments of counsel and experts for the complainant in prior cases, urging the distinction of this self-starting effect in reference to the application of the generic patents to non-synchronous motors, are without force in the present controversy, and it is unnecessary to ascertain their consistency or inconsistency with the interpretation sought on this hearing. Unless limitation to self-starting motors arises out of the prior art none can be imposed upon the claims in suit.

The further propositions urged by way of defence—aside from the defence founded upon prior inventions of the synchronous type to be considered—are these (1) that the synchronous motor of the defendant is the old generator of the art, simply reversed; and (2) that the Tesla invention is not present therein, because (as asserted) "the prepondering magnetization of the" direct current displaces and obliterates the "shifting alternating-current magnetization." or Tesla "whirling field of force." However specious both propositions appear on their face and in the argument, neither of them impresses me as controlling.

I believe that no proposition in the able and extended arguments on the part of the defence have been overlooked in my consideration of this case, although it has not seemed needful to discuss all of them for the purpose of this opinion. My conclusions are that the defendant's synchronous motor structure and operation are within the generic invention as patented, and expressly covered by the claims of Nos. 381,969 and 382,281; that the invention is utilized in the defendant's motor operation, notwithstanding the introduction of direct-current excitation to make it synchronous, in lieu of the full realization of the revolving field effect for self-starting; that such supplemental aid does not escape in ngement, with or without advantage in such associations; and that, in any view the combination patents referred to are not limited to after-effect of the direct-current excitation, but apply to the defendant's combination. Decree will be entered accordingly as prayed in the bill.

Another Tesla Patent.—We have received a copy of the judgment delivered in the United States Circuit Court in the case of the Westinghouse Company against the National Electrical Company, which had reference to the patents of May 1, 1888, for the Telsa polyphase system The plaintiffs contended that these patents were infringed by the defendants' synchronous motor and alternating-current polyphase generator. The defendants contended that Tesla's invention was the rotating field mode of operation, and that this was limited to a self-starting motor so operated; that their own synchronous motor with direct-current excitation was not covered by the Tesla patents, being simply a reversed two-phase alternating-current dynamo of a prior type used as a generator; and that the claims in the Tesla patents which introduced "direct-current excitation producing synchronous operation" must be limited to such use after the motor is started by the Tesla means and method and brought up to speed. The Court held that if the invention could be so limited the defendants escaped infringement; on the other hand, if it could not, the claims of the patents were broad enough to reach the defendant's method of operation. Reviewing the Tesla discovery, the Court defined it as a method to produce in the polyphase rotating field motor, the "whirling field of force,' and employment thereof was obtainable with or without direct-current excitation of the armature or secondary element. The fact that its use produced a self-starting motor without the aid of such excitation could not alone serve to limit the invention to that effect. The theory advanced of the obliteration of the alternating-current magnetisation by that of the direct current of the secondary element of the motor was not material, as the Tesla invention was unquestionably introduced in the operation of the defendants' motor, and the structure was within the patent description. The Court, therefore, held that "the defendants' synchronous motor structure and operation are within the generic invention covered by the claims of two of the fundamental Tesla patents; that the invention is utilised in the defendants' motor operation, notwithstanding the introduction of direct-current excitation to make it synchronous in lieu of the full realisation of the revolving field effect for self-starting; that such supplemental aid does not escape infringement with or without advantage in such association; and that in any view the combination patents referred to are not limited to after-effect of direct-current excitation, but apply to the defendants' combination. Judgment was therefore entered for the plaintiffs, the decree restraining the defendants from infringing the Tesla patents.

The New York Herald April 19, 1905

Companies Incorporated.

Stock companies incorporated at Albany yesterday include the following:—

Just Reduction Company, of Syracuse; capital $1,000,000. Directors—J. A. Just, of Pulaski; R. F. Pettigrew, of Sioux Falls, S. D., and W. W. Robacher, of Rochester,

Tesla Machine Company, of New York: capital $300,000. Directors—Nikola Tesla and Langdon Greenwood, of New York. and William Andrews, of Brooklyn.

CURRENT NEWS AND NOTES.

TESLA PATENT.—A patent was issued to Mr. Nikola Tesla April 18 on the "Art of Transmitting Electrical Energy Through the Natural Mediums." A full account of the patent will be given next week. The claims are on an improvement in the art of transmitting electrical energy to a distance which consists in the establishment of stationary electrical waves in the earth or natural conducting media and operating therefrom one or more receiving devices remote from the source of energy. Electrical oscillations are impressed on the earth or other media to produce the stationary waves, the length of which may be varied and controlled, and their neutral and nodal regions shifted.

Tesla Patent on Wireless Transmission of Electrical Signals.

A patent issued April 18 to Mr. Nikola Tesla was briefly noticed in these columns last week, the subject being "The Art of Transmitting Electrical Energy Through the Natural Mediums." Below is given a fuller account of the patent.

In the preamble it is stated that experiments and observations have tended to confirm the opinion held by the majority of scientific men, that the earth, owing to its immense extent, does not behave in the manner of a conductor of limited dimensions with respect to electrical disturbances, but much like a vast reservoir or ocean, which, while it may be locally disturbed by commotion of some kind, remains unresponsive and quiescent in a large part or as a whole. The inventor states he has discovered that notwithstanding its vast dimensions and contrary to all observations heretofore made, the terrestrial globe may in a large part or as a whole behave toward disturbances impressed upon it in the same manner as a conductor of limited size.

In the course of certain investigations he noted unsuspected behavior of sensitive instruments, which he discovered to be due to the character of electrical waves produced in the earth by lightning discharges, and which had nodal regions following at definite distances the shifting source of the disturbances. From data obtained in a large number of observations on a maxima and minima of these waves, their length was found to vary approximately from 25 to 70 meters, and these results and certain theoretical deductions led to the conclusion that waves of this kind may be propagated in all directions over the globe, and that they may be of still more widely differing lengths, the extreme limit being imposed by the physical dimensions and properties of the earth. By means of gradual improvements in the generation of electrical oscillations, electrical movements were finally reached not only approximating, but, as shown in many comparative tests and measurements, actually surpassing those of lightning discharges; and by means of this apparatus it was found possible to reproduce whenever desired phenomena in the earth the same or similar to those due to such discharges.

For example, by the use of such a generator of stationary waves and receiving apparatus properly placed and adjusted in any other locality, however remote, it is practicable to transmit intelligible signals or to control or actuate at will any one or all of such apparatus for many other important and valuable purposes, as for indicating wherever desired the correct time of an observatory, or for ascertaining the relative position of a body or distance of the same with reference to a given point, or for determining the course of a moving object, such as a vessel at sea, the distance traversed by the same or its speed, or for producing many other useful effects at a distance dependent on the intensity, wave length, direction or velocity of movement, or other feature or property of disturbances of this character.

In the accompanying figure is represented diagrammatically the generator which produces stationary waves in the earth, and an apparatus situated in a remote locality for recording the effects of these waves. The generator consists of a primary coil forming part of a transformer and consisting generally of a few turns of a stout cable of inappreciable resistance, the ends of which are connected to the terminals of a source of powerful electrical oscillations, this generally being a condenser charged to a high potential and discharged in rapid succession through the primary. *C* is a spiral-wound secondary coil within the primary, one end being connected

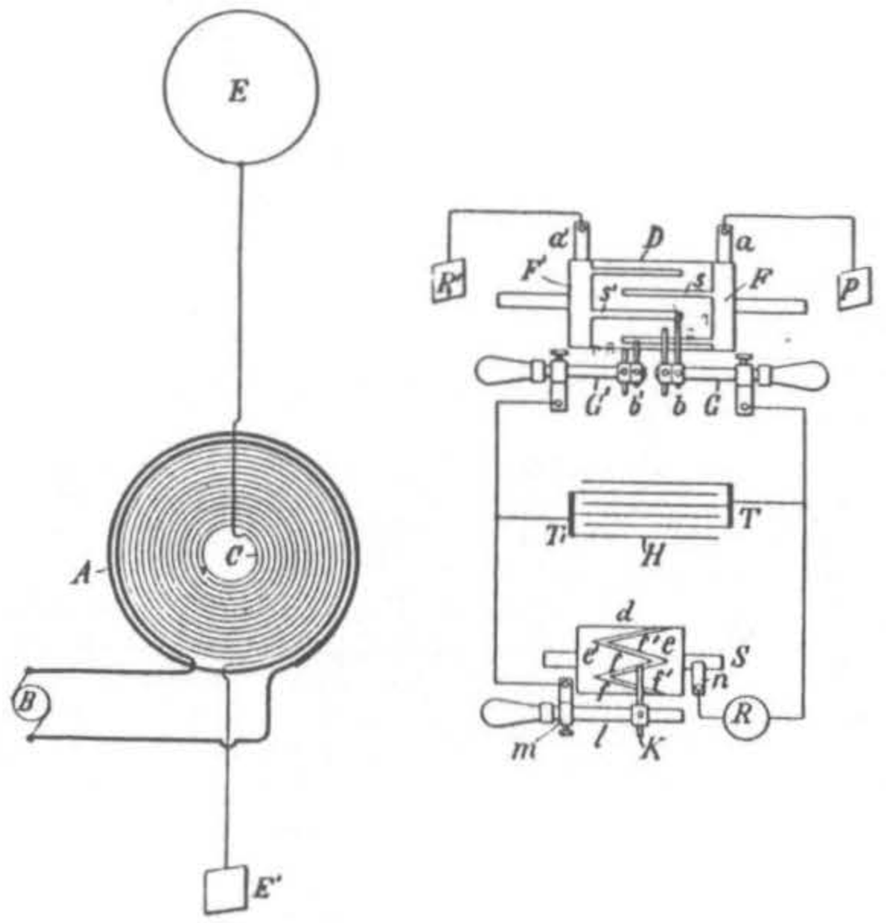

DIAGRAM OF TESLA WIRELESS SIGNAL APPARATUS.

to ground and the other to an elevated terminal, *E*. The resistance of the secondary system should be as small as practicable, its self induction as large as possible and the ground should be made with great care. The total length of the conductor from the ground plate to the elevator terminal *E*, should be equal to ¼ of the wave length of the electrical disturbance or to that length multiplied by an odd number. This relation being observed, the terminal *E* will be made to coincide with the points of maxima pressure in the secondary or excited circuit and the greatest flow of electricity will take place in the same to permit free oscillation. The inductive connection between the primary and secondary should not be very intimate as in ordinary transformers, and this is accomplished by the spiral form given to coil *C*. With this arrangement it has been possible to produce an electrical movement thousands of times greater than the initial, and activity of rates of flow have been produced measured by many tens of thousands of horse power. The powerful electrical oscillations being communicated to the ground cause corresponding vibrations to be propagated to distant parts of the globe, whence they are reflected and by interference with the outgoing vibrations produce stationary waves, the crests and hollows of which lie in parallel circles, relative to which the ground plate may be considered to be the pole. That is to say, the terrestrial conductor is tuned into resonance with the oscillations impressed upon it, just like a wire. A number of facts ascertained clearly show that the movements of electricity through the system follow certain laws with merely mathematical rigor. For the present it is sufficient to state that the planet behaves like a perfectly smooth or polished conductor of inappreciable resistance, with capacity and self-induction uniformly distributed along the axis of symmetry of wave propagation and transmitting slow electrical oscillations without sensible distortion and attenuation.

Three additional requirements seem to be essential to the establishment of the resonant condition as follows: First, the earth's diameter passing through the pole should be an odd multiple

of the quarter wave length—that is, of the ratio between the velocity of light and four times the frequency of the currents; second, the frequency should be smaller than 20,000 per second. The lowest frequency would appear to be 6 per second, in which case there will be but one load at or near the ground plate, and, paradoxical as it may seem, the effect will increase with the distance and will be greatest in a region diametrically opposite the transmitter. With oscillations still slower, the earth, strictly speaking, will not resonate, but simply acts as a capacity, and the variations of potential will be more or less uniform over its entire surface; third, the main essential requirement is that, irrespective of frequency, the wave train will continue for a certain interval of time, which is estimated at not less than 1-12 or 0.08484 of a second, and which is taken in passing to and returning from the region diametrically opposite the pole over the earth's surface with a mean velocity of about 471,240 kilo meters per second.

Fig. 2 shows a device for detecting the presence of the waves. It consists of a cylinder *D* of insulating material, which is moved at a uniform rate of speed by clock-work or other suitable motor power, and is provided with two metal rings, *F F'* upon which bear brushes *A A'* connected to terminal plates. From the rings *F F'* extend narrow metallic segments *S S'*, which by rotation of the cylinder *D* are brought alternately into contact with double brushes *b b'* carried by and in contact with conducting holders, *H H'*, supported in the metal bearings, *G G'*. The latter are connected to the terminals *T T'* of a condenser *H*, and are capable of angular displacement as ordinary brush supports. The object of two brushes in the holder is to vary at will the duration of the electrical contact with the terminal plates and the condenser. To the latter is connected a receiver *R* and a device *d* performing the duty of closing the receiving circuit at predetermined intervals of time and charging the stored energy through the receiver.

The receiver consists of a cylinder made partly of conducting and partly of insulating material which is rotated at a desired rate of speed by any suitable means. The conducting part *e* is in electrical connection with the shaft *S*, upon which slides a brush *K* capable of longitudinal adjustment in the metallic support *m*. Another brush *n* is arranged to bear upon a shaft *S*. It will be seen that whenever one of the segments *F'* comes in contact with the brush *K*, the circuit including the receiver *R* is completed and the condenser discharged through the same. By suitable adjustment the circuit may be made to open and close in rapid succession and remain open or closed during such intervals of time as may be necessary.

The terminal plates *P P'*, through which the electrical energy is conveyed to the brushes *A A'*, may be at a considerable distance from each other in the ground or one in the ground and the other in the air, preferably at some height. In the latter case the location of the apparatus must be determined with reference to the position of the stationary waves. If both plates be connected to earth, the points of connection must be selected with reference to the differences of potential which it is desired to secure. In receiving, the speed of rotation of the cylinder *D* is varied until it is in synchronism with the alternate impulses of the distant generator; the brushes being properly adjusted electrical charges of the same sign will be conveyed to each of the terminals of the condenser and with each fresh impulse it will be charged to a higher potential. In this manner the energy of any number of separate impulses may be accumulated and discharged through the receiver *R*. Thus a relatively great amount of energy may be accumulated and the receiver need not be very sensitive. It being possible to shift the nodal and ventral regions of the waves at will from the sending station, the regions of maximum and minimum effect may be made to coincide with any receiving station or stations.

By impressing upon the earth two or more oscillations of different wave length, a resonant stationary wave may be made to travel slowly over the globe. If the nodal and ventral regions are maintained in a fixed position, the speed of a vessel carrying receiving apparatus may be exactly computed from observations of the maximum and minimum regions successively traversed. In any region at the surface the wave length can be ascertained from certain rules of geometry and conversely, knowing the wave length, the distance from the source can be readily calculated. Thus the distance of one point from another, the altitude and longitude, the hour, etc., may be obtained from the observation of such stationary waves. With several generators, preferably generating different wave lengths, installed in selected localities, the entire globe could be sub-divided in different zones of electrical activity and important data could be at once obtained by similar calculations or readings from suitably graduated instruments.

New York.

New York, April 22.—The state committee charged Nikola Tesla, who is now living at the Waldorf-Astoria, is one of the directors of the newly incorporated Tesla Machine Company, which has a capital of $300,000. The company will manufacture air compressors.

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EXPIRATION OF THE TESLA FUNDAMENTAL POLYPHASE PATENTS.

The expiration this week of the three Tesla patents covering fundamentally the rotary-field type of electric motor marks the close of the first stage of one of the several epochal developments of the modern electrical era. It would be interesting to review the great rôle that the invention covered by these patents has played in electrical engineering and in industrial electrical progress, but what is probably at present uppermost in the minds of all interested directly in this branch, is the effect of the expiration of the 1888 Tesla patents toward opening up to the world at large a department of the industry which, for seventeen years, has been a monopoly under the Federal constitutional provision that so wisely grants this privilege as a reward for the labors of the inventor, and to encourage others through invention to add to the wealth and to the well-being of the country. As in the case of the termination of other close patent monopolies, there is unfortunately no clear understanding at the present moment as to the actual situation developed by the expiration of the 1888 Tesla patents. The litigation of the past has had relation only to two sets of polyphase patents—those just expired and the 1893 Tesla split-phase group—and little or no specific information is obtainable in regard to the situation now presented, even from those who have taken an active part in this litigation. To complicate the matter still further, it is announced by the owners of the patents just expired that more than a score of other patents relating to polyphase motors and polyphase operation are yet active, the inference being that it is by no means conceded that the polyphase

art is opened wide by the expiration this week of the three 1888 Tesla patents.

Of the three patents which have just expired, the first has been defined by the courts as covering the apparatus by which the polyphase system is put in practice; the second as covering the electrical transmission of power by the method of operation described in the first patent, which patent also covers a different construction of motor; and the third as covering a specific construction of motor embodying the invention of the other two patents. In considering these three patents, the courts in various decisions have held them, broadly, to cover the system of producing power from an electric motor by means of a rotary field. It is, therefore, reasonable to assume that the expiration of these three patents releases to the world the principle of the rotary field. As to the split-phase patents, the consideration of their validity was so bound up with the rotary-field principle that their affirmation by the courts is now subject to challenge, which doubtless will be offered. While the rotary-field principle was invariably sustained in all litigation, the invention by Tesla of the split-field principle was denied by two courts of first instance, one of which was sustained on appeal and the other reversed.

Naturally, during the seventeen years' life of the patents just terminated, many subsidiary patents have been issued, which latter, owing to the coutrolling issue of the rotary field, have not figured in litigation or, at least have not been subject to interpretation by courts. To what extent this line of patents may narrow the effect of the termination of the life of the fundamental patents is a matter for judgment by those intimately interested, or for determination ultimately by the courts. If litigation with respect to these subsidiary and detail patents should ensue, it is to be hoped that during its course some principle may be established making a clear distinction between invention proper and improvement merely incident to the normal development of a basic invention. The criterion which the courts have in the past so freely applied—that lack of prior conception is a presumption in favor of real invention—is certainly of doubtful value when applied to an art closed to the world during its period of development.

Tesla and the Polyphase Patents.

By B. A. Behrend.

In May, 1888, were granted to Nikola Tesla, from Smiljan Lika, border country of Austria-Hungary, a series of patents, which are commonly known as the fundamental Tesla patents. These patents expired on the 4th of May, 1905.

The genius of Tesla has been instrumental in stimulating, if not in creating, a wonderful industry—wonderful in magnitude, and wonderful in the ingenuity of the apparatus used in the accomplishing of the transmission of power over long distances.

Great ideas are rarely the exclusive property of individual men. The history of the evolution of thought shows distinctly that novel ideas arise in certain generations simultaneously in the minds of some of the most talented men whose personalities, as it were, thus represent the ideas and lend them their names; and so it has undoubtedly been with the ideas and inventions that form the basis of the polyphase system. The official sanction of the Patent Office, depending as it does as much upon the technicalities observed in wording the claims as upon the character and ingenuity of the invention itself, can hardly be taken as a criterion of the originality of the inventor. The function of the Patent Office is rather to be compared with the function assumed by the courts in recording deeds of property than as a scientific court passing upon the inventor's work. The paramount importance of the Patent Office lies in the fact that, as no property can be rightfully owned without a deed therefor, no man can use his ideas and inventions without obtaining a deed, which deed we call a letters patent. You may use your ideas without such letters patent only to find that some one else, by applying for and securing such patent after you have put out your invention, has secured the deed from the Patent Office.

But we are not concerned here with the philosophy of patent law and the existing conditions—we want to pay a tribute to Nikola Tesla, the ingenious inventor who, by a "sort of glorified common sense and unfailing intuition, picked his way through puzzling mazes of complicated phenomena, and protected himself from the pitfalls and the alluring by paths ensnaring smaller intellects." With Nikola Tesla, in this country and in Europe, worked a host of capable and ingenious engineers, and their work, vivified by the ingenuity of Tesla's inventions, has become one of the greatest monuments of engineering achievement crowning the work of the nineteenth century. Let us turn our attention for a moment to Tesla's remarkable paper, entitled "A New System of Alternate-Current Motors and Transformers," read at the meeting of the American Institute of Electrical Engineers, in New York, on May 16, 1888. This paper, even when considered in the light of subsequent discoveries and knowledge, is one of the most brilliant pieces of engineering thought, teeming with suggestions and ideas, animated with an intuition of the highest order, and giving an exposition of the working of the induction motor in a manner which resembles the methods pursued in the "Experimental Researches on Electricity," of the great master, Michael Faraday.

For seventeen years, the Tesla patents have formed the nucleus of the electrical industry. Through plenty of litigation and decisions they have survived, as all things survive the struggles of this world, only to expire, and it must be said that the expiration of these patents is looked upon in general as a very happy event. We do not wish to say that the monopoly which these patents created has been abused; we do not wish to say that the progress in this field has not been as vigorous as it would have been had the patents not been quite so sweeping; the field is so wide and the desire for vigorous competition so strong, that the expiration of these patents will give the electrical industry a new stimulus, and it must be borne in mind that, after all, these patents do not represent the only valuable ideas on the subject of polyphase alternating-current systems. Many are the inventions and ideas which have been originated by others, and which have made the polyphase system practicable. We all know how great is the difference between mere ideas, which are as plentiful as blackberries, and the working out of these ideas into practical form, which often requires the expenditure of as much genius as was required for the evolution of the idea itself. Ideas appear to me to be somewhat like what Darwin called "variations," from which, by a process of selection, *those* ideas are singled out which can hold their own, and are developed into practical form, while the greater number of ideas are cast aside, unfit, condemned to be destroyed in the struggle for existence.

Nikola Tesla and his patents have had their day; the art of electrical engineering, the capital invested therein, the users of polyphase electrical machinery, all are grateful to Nikola Tesla and to those who have developed his ideas.

The Expiration of the Tesla Patents.

By William Stanley.

In 1885 Prof. Galileo Ferraris, of Turin, discovered the electromagnetic rotating field, and applied his invention to the operation of a rotating field motor. On May 1, 1888, Mr. Nikola Tesla received United States patents covering the broad application of the Ferraris discovery of alternating-current motors. In 1888 Mr. George Westinghouse purchased the Tesla patents and contracted with Prof. Ferraris to exploit his inventions in this country, paying to the great Italian savant the munificent sum of 5,000 lire—$1.000—for such right. The Ferraris applications for United States patents were then entrusted to the Westinghouse (Tesla) attorneys, and having promptly died in the patent office, were followed by new applications drawn in the name of Mr. Tesla. These later applications exactly described the original (1885) discovery of Ferraris, the United States rights to which had been purchased by Mr. Westinghouse, as stated above. As a result of these various moves we have the original (1885) Ferraris split-phase motor patented by Tesla in 1890, and still in force, and the subsequent 1888 patents by Tesla, now expired.

The advent of the rotary field motor patents in 1888 was of great importance to the art, for while these patents did not disclose means for constructing commercial alternating-current motors, yet they threw a strong light on the art, illuminating its future. The expiring Tesla patents were usefully drawn and were sufficiently comprehensive to protect the subject they disclosed, yet it is doubtful if they would have been maintained and their validity established in the courts had they not fallen into the hands of the "Patent Pool Trust." The owners of the Tesla patents, realizing the great weight of public opinion and its effect upon the courts before which the patents would surely be brought for adjudication, early began a systematic campaign of personal publicity, in which the wonderful achievements of Mr. Tesla were set forth with the coloring of a gold mine prospectus; and their efforts to fasten attention upon the inventor and his work were ably supplemented by numerous startling statements, promises and disclosures that he himself constantly poured forth. Surely, at this time his oracular activity was remarkable.

When, therefore, the Tesla patents were brought into court and the picturesque wizardship of the patentee was frequently contrasted with the simple and modest researches of prior investigators, the courts quite innocently swallowed the bait prepared for them and rendered verdicts for the "Patent Pool Trust." To-day the Tesla (1888) patents have ceased to exist, the "Patent Pool" campaign is over, the object for which the patents were created has been accomplished and all pecuniary interest in the maintaining of patents have vanished. There is now, it seems to me, no valid reason why all engineers in this country may not unite in the future "to render unto Cæsar the things that are Cæsar's," and may further find expression for the sentiment by prefixing the name of Ferraris to devices containing the principles he first discovered.

Polyphase Patents.

The Westinghouse Electric & Manufacturing Company has announced in connection with the expiration this week of the three fundamental Tesla patents, that it holds numerous other patents relating to polyphase synchronous motors and subsidiary apparatus. Seven of these patents were granted to Nikola Tesla on dates between September 3, 1889, and January 2, 1894, the subjects being as follows: Induction motors; the use of the induction motor as a starting device for the synchronous motor; relation between the number of poles on generator and motor, and four patents on the split-phase method of operating motors. Three of the list of patents were granted to Hutin and Leblanc, the subjects being damping devices for alternating-current motors, variable-speed induction motors, and alternating-current transformation. Nine patents were granted to Mr. B. G. Lamme, the subjects being induction motors, starting arrangements for induction motors, and alternating-current motor. Of the

remaining patents, two were granted to Mr. William Stanley for an alternating-current motor with compensated field and a self-regulating transformer (1892), another to Nolan for armature core construction and two others to Dusinberre for induction motors.

Tesla's Method of Transmitting Electrical Energy Through Space.

Nikola Tesla of New York city, who, as is well known, has done much work of an original nature in the direction of the transmission of electrical energy through space, has recently been granted a patent (No. 787,412, April 18, 1905) upon such a method for the propagation of energy. The title of the patent is "Art of Transmitting Electrical Energy Through the Natural Mediums." Application for it was made May 16, 1900, and renewed June 17, 1902.

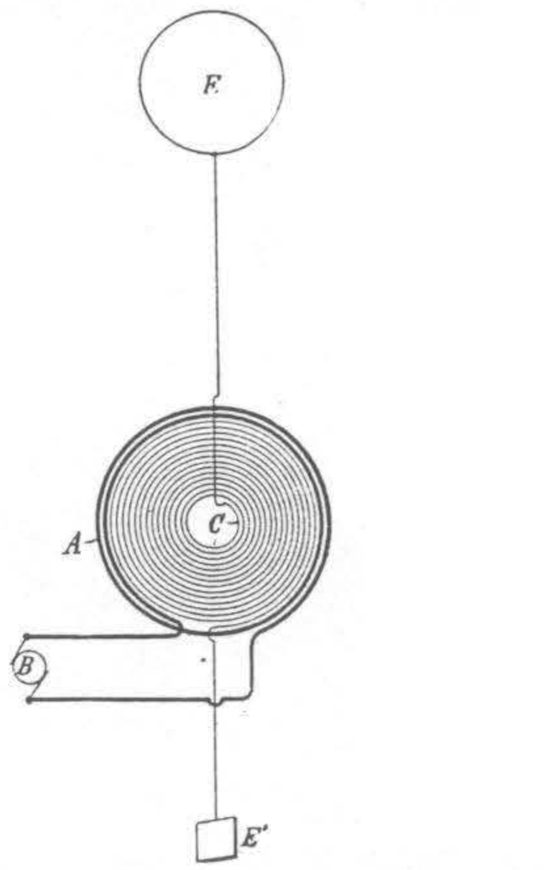
A fact now of common knowledge is that when electrical waves or oscillations are impressed upon such a conducting path as a metallic wire, reflection takes place, under certain conditions, from the ends of the wire, and in consequence of the interference of the impressed and reflected oscillations the phenomenon of "stationary waves" with maxima and minima in definite fixed positions is produced. The existence of these waves indicates that some of the outgoing waves have reached the boundaries of the conducting path and have been reflected therefrom. Mr. Tesla has been led to believe from his observations that notwithstanding its vast dimensions the terrestrial globe may in a large part or as a whole behave toward disturbances impressed upon it in the same manner as a conductor of limited size.

In the course of certain investigations which he carried on for the purpose of studying the effects of lightning discharges upon the electrical condition of the earth it was observed that sensitive receiving instruments arranged so as to be capable of responding to electrical disturbances created by the discharges at times failed to respond when they should have done so, and upon inquiring into the causes of this unexpected behavior it was discovered to be due to the character of the electrical waves which were produced in the earth by the lightning discharges and which had nodal regions following at definite distances the shifting source of the disturbances. From data obtained in a large number of observations of the maxima and minima of these waves their length has been found to vary approximately from 25 to 75 kilometers, and these results and certain theoretical deductions led Mr. Tesla to the conclusion that waves of this kind may be propagated in all directions over the globe and that they may be of still more widely differing lengths, the extreme limits being imposed by the physical dimensions and properties of the earth.

Recognizing in the existence of these waves an unmistakable evidence that the disturbances created had been conducted from their origin to the most remote portions of the globe and had been thence reflected, the idea was conceived of producing such waves in the earth by artificial means with the object of utilizing them for many useful purposes for which they are or might be found applicable. This problem was rendered extremely difficult, owing to the immense dimensions of the planet, and consequently enormous movement of electricity or rate at which electrical energy had to be delivered in order to approximate, even in a remote degree, movements or rates which are manifestly attained in the displays of electrical forces in nature and which seemed at first unrealizable by any human agencies. But by gradual and continuous improvements of a generator of electrical oscillations, for which Mr. Tesla had previously obtained a patent, he finally succeeded in reaching electrical movements or rates of delivery of electrical energy which he believed not only approximated, but, as shown in many comparative tests and measurements, actually surpassed those of lightning discharges, and by means of this apparatus he found it possible to reproduce, whenever desired, phenomena in the earth the same as or similar to those due to such discharges.

In the figure, (A) designates a primary coil forming part of a transformer and consisting generally of a few turns of a stout cable of inappreciable resistance, the ends of which are connected to the terminals of a source of powerful electrical oscillations, diagrammatically represented by (B). This source is usually a condenser charged to a high potential and discharged in rapid succession through the primary. But when it is desired to produce stationary waves of great lengths an alternating dynamo of suitable construction may be used to energize the primary. A spirally wound secondary coil (C) within the primary has the end nearer to the latter connected to the ground (E') and the other end to an elevated terminal (E). The physical constants of coil (C), determining its period of vibration, are so chosen and adjusted that the secondary system (E' C E) is in the closest possible resonance with the oscillations impressed upon it by the primary. It is, moreover, of the greatest importance in order to still further enhance the rise of pressure and to increase the electrical movement in the secondary system that its resistance be as small as practicable and its self-induction as large as possible under the conditions imposed. The ground should be made with great care, with the object of reducing its resistance. Instead of being directly grounded, as indicated, the coil (C) may be joined in series or otherwise to the primary (A), in which case the latter will be connected to the plate (E'). The total length of the conductor from the ground-plate (E') to the elevated terminal (E) should be equal to one-quarter of the wave length of the electrical disturbance in the system (E' C E), or else equal to that length multiplied by an odd number. This relation being observed, the terminal (E) will be made to coincide with the points of maximum pressure in the secondary or excited circuit, and the greatest flow of electricity will take place.

In order to magnify the electrical movement in the secondary as much as possible, it is essential that its inductive connection with the primary (A) should not be very intimate, as in ordinary transformers, but loose, so as to permit free oscillation—that is to say, their mutual induction should be small. The spiral form of coil (C) secures this advantage, while the turns near the primary (A) are subjected to a strong inductive action and develop a high initial electromotive force. These adjustments and relations being carefully completed and other constructive features indicated rigorously observed, the electrical movement produced in the secondary system by the inductive action of the primary (A), will be enormously magnified, the increase being directly proportionate to the inductance and frequency and inversely to the resistance of the secondary system. It is practicable to produce in this manner an electrical movement thousands of times greater than the initial—that is, the one impressed upon the secondary by the primary (A), and the inventor claims to have thus reached activities or rates of flow of electrical energy in the system (E' C E) measured by many tens of thousands of horsepower. Such immense movements of electricity give rise to a variety of novel and striking phenomena, among which are those already described. The powerful electrical oscillations in the system (E' C E) being communicated to the ground cause corresponding vibrations to be propagated to distant parts of the globe, whence they are rflected, and by interference with the outgoing vibrations produce stationary waves, the crests and hollows of which lie in parallel circles relatively to which the ground-plate (E') may be considered to be the pole. Stated otherwise, the terrestrial conductor is thrown into resonance with the oscillations impressed upon it just like a wire. More than this, the movement of electricity through it follows certain laws with nearly mathematical precision. It will be, however, sufficient to state that the planet behaves like a perfectly smooth or polished conductor of inappreciable resistance with capacity and self-induction uniformly distributed along the axis of symmetry of wave propagation and transmitting slow electrical oscillations without sensible distortion and attenuation.



TESLA'S METHOD OF TRANSMITTING ELECTRICAL ENERGY THROUGH SPACE.

Besides the above, three requirements seem to be essential to the establishment of the resonating condition.

First—The earth's diameter passing through the pole should be an odd multiple of the quarter-wave length—that is, of the ratio between the velocity of light and four times the frequency of the currents.

Second—It is necessary to employ oscillations in which the rate of radiation of energy into space in the form of hertzian or electromagnetic waves is very small. To give an idea it may be said that the frequency should be smaller than 20,000 per second, though shorter waves might be practicable. The lowest frequency would appear to be six per second, in which case there will be but one node, at or near the ground-plate, and, paradoxical as it may seem, the effect will increase with the distance and will be greatest in a region diametrically opposite the transmitter. With oscillations still slower the earth, strictly speaking, will not resonate, but simply act as a capacity, and the variation of potential will be more or less uniform over its entire surface.

Third—The most essential requirement is, however, that irrespective of frequency the wave or wave train should continue for a certain interval of time, which estimated to be not less than one-twelth or probably 0.08484 of a second and which is taken in passing to and returning from the region diametrically opposite the pole over the earth's surface with a mean velocity of about 471,240 kilometers per second.

The presence of the stationary waves may be detected in many ways. For instance, a circuit may be connected directly or inductively to the ground and to an elevated terminal and tuned to respond more effectively to the oscillations. Another way is to connect a tuned circuit to the ground at two points lying more or less in a meridian passing through the pole (E'), or, generally stated, to any two points of a different potential.

The Brooklyn Eagle May 9, 1905

VERDICT AGAINST TESLA.

Wireless Telegraph Inventor, Defeated in Civil Suit Tried at Riverhead, Will Appeal.

(Special to the Eagle.)

Riverhead, L. I., May 9—At the opening of the county court here yesterday afternoon, Judge Jaycox presiding, the action against Nikola Tesla, the well known electrician and wireless telegrapher expert, to recovr on a land deal, was the first case tried and Judge Jaycox directed verdict for the plaintiff, Dr. James S. Warden, for $610.97. The defendant put in no testimony, but at the conclusion of plaintiff's case the defendant moved to dismiss the complaint. Judge Jaycox refused, however, and upon plaintiff's motion judgment was directed for him.

From the testimony it was revealed that Mr. Tesla agreed to purchase a tract of land for $25 an acre containing "410 acres more or less." It was shown that Tesla agreed to take an option for two years by paying 4 per cent. on the total purchase price. After he had failed to pay for six months suit was commenced.

The case was tried once before, and at that time, also, a judgment was directed for plaintiff without going to the jury. An appeal was taken to the Appellate Division and the case sent back for a retrial. Upon the first hearing and also upon the one yesterday, defendant contended that the tract by measurement did not contain 410 acres, and even though it did, it was not so stated in his agreement, and he, therefore, could not pay money on a piece of property not knowing definitely how much property there was and consequently, how much money was due on a "more or less" tract.

The piece of property that Tesla wanted to buy is located near his big experimental tower and buildings ot Wardenclyffe, L. I.

The case will be again appealed.

TESLA PATENT ON WIRELESS TRANSMISSION OF ELECTRICAL SIGNALS.

An U.S.A. patent was issued on April 18 to Mr. Nikola Tesla for "The Art of Transmitting Electrical Energy through the Natural Mediums." We are indebted to the *Electrical World* for the abstract of this patent given below:

In the preamble it is stated that experiments and observations have tended to confirm the opinion held by the majority of scientific men, that the earth, owing to its immense extent, does not behave in the manner of a conductor of limited dimensions with respect to electrical disturbances, but much like a vast reservoir or ocean, which, while it may be locally disturbed by commotion of some kind, remains unresponsive and quiescent in a large part or as a whole. The inventor states he has discovered that notwithstanding its vast dimensions and contrary to all observations heretofore made, the terrestrial globe may in a large part or as a whole behave toward disturbances impressed upon it in the same manner as a conductor of limited size.

In the course of certain investigations he noted unsuspected behaviour of sensitive instruments, which he discovered to be due to the character of electrical waves produced in the earth by lightning discharges, and which had nodal regions following at definite distances the shifting source of the disturbances. From data obtained in a large number of observations on a maxima and minima of these waves, their length was found to vary approximately from 25m. to 70m., and these results and certain theoretical deductions led to the conclusion that waves of this kind may be propagated in all directions over the globe, and that they may be of still more widely differing lengths, the extreme limit being imposed by the physical dimensions and properties of the earth. By means of gradual improvements in the generation of electrical oscillations, electrical movements were finally reached not only approximating, but, as shown in many comparative tests and measurements, actually surpassing those of lightning discharges; and by means of this apparatus it was found possible to reproduce whenever desired phenomena in the earth the same or similar to those due to such discharges.

For example, by the use of such a generator of stationary waves and receiving apparatus properly placed and adjusted in any other locality, however remote, it is practicable to transmit intelligible signals or to control or actuate at will any one or all of such apparatus for many other important and valuable purposes, as for indicating wherever desired the correct time of an observatory, or for ascertaining the relative position of a body or distance of the same with reference to a given point, or for determining the course of a moving object, such as a vessel at sea, the distance traversed by the same or its speed, or for producing many other useful effects at a distance dependent on the intensity, wave-length, direction or velocity of movement, or other feature or property of disturbances of this character.

In the accompanying figure is represented diagrammatically the generator which produces stationary waves in the earth, and an apparatus situated in a remote locality for recording the effects of these waves. The generator consists of a primary coil forming part of a transformer and consisting generally of a few turns of a stout cable of inappreciable resistance, the ends of which are connected to the terminals of a source of powerful electrical oscillations, this generally being a condenser charged to a high potential and discharged in rapid succession through the primary. *C* is a spiral-wound secondary coil within the primary, one end being connected to ground and the other

to an elevated terminal, E. The resistance of the secondary system should be as small as practicable, its self-induction as large as possible, and the ground should be made with great care. The total length of the conductor from the ground-plate to the elevator terminal, E, should be equal to one-fourth of the wave-length of the electrical disturbance or to that length multiplied by an odd number. The relation being observed, the terminal, E, will be made to coincide with the points of maxima pressure in the secondary or excited circuit, and the greatest flow of electricity will take place in the same to permit free oscillation. The inductive connection between the primary and scondary should not be very intimate as in ordinary transformers, and this is accomplished by the spiral form given to coil C. With this arrangement it has been possible to produce an electrical movement thousands of times greater than the initial, and activity of rates of flow have been produced measured by many tens of thousands of horse-power. The powerful electrical oscillations being communicated to the ground cause corresponding vibrations to be propagated to distant parts of the globe, whence they are reflected, and by interference with the outgoing vibrations produce stationary waves, the crests and hollows of which lie in parallel circles, relative to which the ground-plate may be considered to be the pole—that is to say, the terrestrial conductor is tuned into resonance with the oscillations impressed upon it, just like a wire. A number of facts ascertained clearly show that the movements of electricity through the system follow certain laws

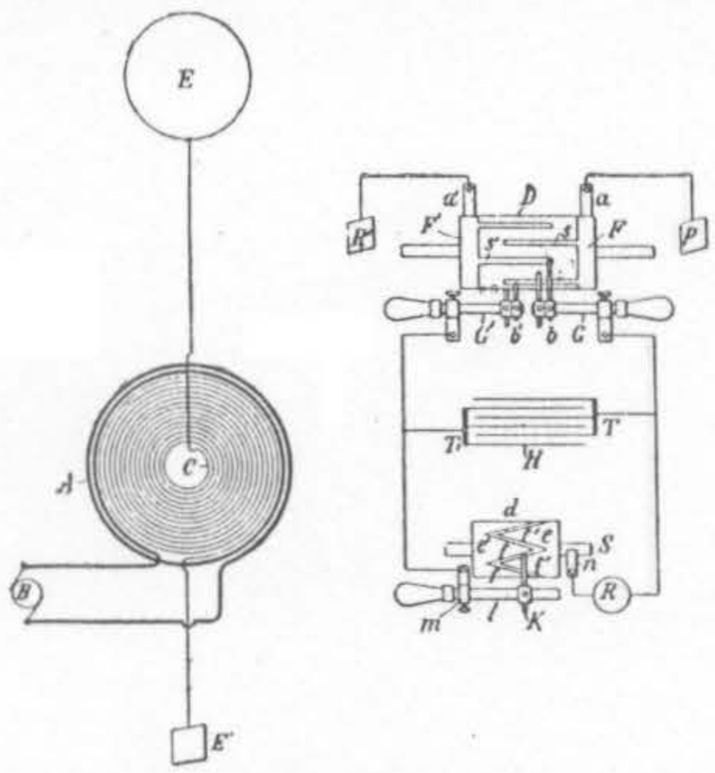


Diagram of Tesla Wireless Signal Apparatus.

with merely mathematical rigour. For the present it is sufficient to state that the planet behaves like a perfectly smooth or polished conductor of inappreciable resistance, with capacity and self-induction uniformly distributed along the axis of symmetry of wave propagation, and transmitting slow electrical oscillations without sensible distortion and attenuation.

Three additional requirements seem to be essential to the establishment of the resonant condition, as follows: First, the earth's diameter passing through the pole should be an odd multiple of the quarter wave-length—that is, of the ratio between the velocity of light and four times the frequency of the currents. Second, the frequency should be smaller than 20,000 per second. The lowest frequency would appear to be six per second, in which case there will be but one load at or near the ground-plate, and paradoxical as it may seem, the effect will increase with the distance, and will be greatest in a region diametrically opposite the transmitter. With oscillations still slower, the earth, strictly speaking, will not resonate, but simply acts as a capacity, and the variations of potential will be more or less uniform over its entire surface. Third, the main essential requirement is that, irrespective of frequency, the wave train will continue for a certain interval of time, which is estimated at not less than one-twelfth, or 0 08484 of a second, and which is taken in passing to and returning from the region diametrically opposite the pole over the earth's surface with a mean velocity of about 471,240 km. per second.

Fig. 2 shows a device for detecting the presence of the waves. It consists of a cylinder, D, of insulating material, which is moved at a uniform rate of speed by clockwork and other suitable motor power, and is provided with two metal rings, $F\,F'$, upon which bear brushes, $A\,A'$, connected to terminal plates. From the rings, $F\,F'$, extend narrow metallic segments, SS', which by rotation of the cylinder, D, are brought alternately into contact with double brushes, $b\,b'$, carried by and in contact with conducting holders, HH', supported in the metal bearings, $G\,G'$. The latter are connected to the terminals, $T\,T'$, of a condenser, H, and are capable of angular displacement as ordinary brush supports. The object of two brushes in the holder is to vary at will the duration of the electrical contact with the terminal plates and the condenser. To the latter is connected a receiver, R, and a device, d, performing the duty of closing the receiving circuit at predetermined intervals of time, and charging the restored energy through the receiver.

The receiver consists of a cylinder made partly of conducting and partly of insulating material, which is rotated at a desired rate of speed by any suitable means. The conducting part, e, is in electrical connection with the shaft, S, upon which slides a brush, K, capable of longitudinal adjustment in the metallic support, m. Another brush, n, is arranged to bear upon a shaft, S. It will be seen that whenever one of the segments, F, comes in contact with the brush, K, the circuit, including the receiver, R, is completed, and the condenser discharged through the same. By suitable adjustment the circuit may be made to open and close in rapid succession and remain open or closed during such intervals of time as may be necessary.

The terminal plates, $P\,P'$, through which the electrical energy is conveyed to the brushes, $A\,A'$, may be at a considerable distance from each other in the ground or one in the ground and the other in the air, preferably at some height. In the latter case the location of the apparatus must be determined with reference to the position of the stationary waves. If both plates be connected to earth, the points of connection must be selected with reference to the differences of potential which it is desired to secure. In receiving the speed of rotation of the cylinder, D, is varied until it is in synchronism with the alternate impulses of the distant generator; the brushes being properly adjusted, electrical charges of the same sign will be conveyed to each of the terminals of the condenser, and with each fresh impulse it will be charged to a higher potential. In this manner the energy of any number of separate impulses may be accumulated and discharged through the receiver, R. Thus a relatively great amount of energy may be accumulated and the receiver need not be very sensitive. It being possible to shift the nodal and ventral regions of the waves at will from the sending station, the regions of maximum and minimum effect may be made to coincide with any receiving station or stations.

By impressing upon the earth two or more oscillations of different wave-length, a resonant stationary wave may be made to travel slowly over the globe. If the nodal and ventral regions are maintained in a fixed position, the speed of a vessel carrying receiving apparatus may be exactly computed from observations of the maximum and minimum regions successively traversed. In any region at the surface the wave-length can be ascertained from certain rules of geometry, and, conversely, knowing the wave-length, the distance from the source can be readily calculated. Thus the distance of one point from another, the altitude and longitude, the hour, etc., may be obtained from the observation of such stationary waves. With several generators, preferably generating different wave-lengths, installed in selected localities, the entire globe could be sub-divided in different zones of electrical activity, and important data could be at once obtained by similar calculations or readings from suitably graduated instruments.

The Polyphase Patent Situation.

Last week we referred to a list of patents issued by the owners of the recently expired Tesla fundamental rotary field patents. A notice accompanying the list stated that certain manufacturers are offering to supply polyphase induction and synchronous motors and apparatus for use therewith because certain of the Tesla patents have expired, and intending purchasers of polyphase apparatus are notified that numerous other patents relating to these subjects are still in force. Below is given an analysis of the various patents named in the list, together with a brief account of the litigation in which some of the patents have figured. In addition to the patents in the list above referred to are several others which in a minor way have also figured in this same litigation.

TESLA PATENTS.

Of the Tesla patents the most important are the two fundamental patents on the split-phase system. These are Nos. 511,559 and 511,560, issued December 26, 1893, on applications filed December 8, 1888. Both of these patents have been in litigation for some years.

Judge Thompson, of the Southern District of Ohio, filed an opinion February 6, 1901, sustaining the patents in a suit brought against the Dayton Fan & Motor Company. The courts held that the first-mentioned patent covered the case of an alternating current passing through one energizing circuit and inducing a second current in the other energizing circuit; and also the case of two motor energizing circuits connected in derivation or multiple arc with the main circuit from the source. The second patent was held to cover apparatus for carrying out the method by derivation. It was also held that the retardation of phase by artificial means and its conversion from an element of disadvantage to one of usefulness in the transmission of electric power, must be regarded as evidence of invention. The court also pronounced against the defense that the inventions of the two patents in suit are covered by a prior patent issued to the same inventor, No. 416,193, issued December 3, 1889, on an application filed May 30, 1889. The claims of this patent are for an alternating-current motor having two or more energizing circuits, the coils of one circuit being composed of conductors of large size or low resistance and those of the other of fewer turns of wire of smaller size or higher resistance; also the combination with long and short field cores of energizing coils, including in independent circuits, the coils on the longer cores containing an excess of copper or conductor over that in the others; also, a field magnet composed of magnetic plates having an open center, and pole pieces or cores of different length, coils surrounding the cores and included in independent circuits, the coils on the longer cores containing an excess of copper, the longer cores being set in recesses in the iron core formed by the plates. It was held that in this latter patent there is claimed only a specific form of construction and not the method or process by which all motors of its class are operated. This decision was sustained on appeal in an opinion filed November 5, 1902. Judge Severen, who wrote the opinion, defined patent No. 511,559 as relating to a method or methods of transmitting alternating currents proceeding from one original source to both of the energizing circuits of a motor, and at the same time retarding the phases of the current in one circuit to a greater or less extent than in the other. The second patent was defined as relating to means employed in the transmission of electrical power to a motor through divided currents derived from a single current proceeding from the generator; the said divided currents being so regulated with reference to each other as to arrive at their destination in the motor-alternator.

In an opinion filed August 22, 1901, in a case in which the Catskill Illuminating & Power Company was defendant, and in which the Sheeffer meter figured as the alleged infringing device, Judge Lacombe held that two claims of the first patent were infringed and the first claim of the second patent. The second claim of the latter patent was stated to be restricted to apparatus in which the energizing currents are connected in derivation of multiple arc with the supply circuit, and this claim was declared not to be infringed. The Catskill suit was appealed and in an opinion written by Judge Townsend and filed February 25, 1903, the court below was reversed. It was held that the two patents were invalid on the ground that the system covered by the patents in suit was fully described in an article by Prof. Ferraris printed in an Italian journal April 22, 1888, which date was prior to the invention by Tesla.

The same two patents figured in litigation in the Massachusetts Circuit Court. On March 11, 1903, Judge Colt dismissed a bill alleging infringement of the patents by the Stanley Instrument Company on the ground that it had been shown by Judge Townsend that the Tesla patents were anticipated by the Ferraris publication. Upon appeal, in an opinion written by Judge Putnam, filed September 9, 1904, Judge Colt's decision was reversed, it being held that the testimony of a witness, Mr. Page, had established that Tesla had conceived the invention prior to the date of the Ferraris publication. Owing to the conflict in the two decisions on appeal, the case came before the United States Supreme Court on petition for a writ of certiorari. This was denied on the grounds that the two courts had before them substantially different records and therefore there was no conflict. The two patents were sustained in the United States Circuit Court for the Eastern District of Pennsylvania in a suit involving the Guttmann wattmeter. The opinion was rendered by Judge Archbald, who dismissed the defenses based upon patents issued to Dumesnil and Cabanellas and on the Ferraris publication, declaring the two patents to be valid. In another case before the United States Circuit Court for the Western District of New York, decided February 9, 1904, involving also the Guttmann meter, Judge Hazel held the two above patents to be valid, the defense being the Ferraris publication.

In still another case involving the Sheefer meter, Judge Kohlsaat, in an opinion filed March 26, 1904, sustained the patents, basing his decision upon previous decisions in their favor. Judge Buffington, in the United States Circuit Court for the Western District of Pennsylvania, on March 28, also sustained the patents in a case involving the Sheefer meter, basing his decision upon prior decisions sustaining the patents.

No. 416,194.—*Electric motor, December* 3, 1889. *Application filed May* 20, 1889. An induction motor with field and armature of equal strength when energized by a given current; the combination with field and armature coils of equal mass, of energizing coils containing equal amounts of copper. The specification states that such a motor will give the maximum output for the material used.

No. 445,207.—*Electromagnetic motor, January* 27, 1891. *Application filed May* 20, 1889. The motor is of the split-phase induction type, and is a self-starting, single-phase machine. There are on the motor two energizing circuits, one of which is connected directly to the source of supply of current, while the second circuit is placed in inductive relation to the first, the two circuits being constructed with different time constants. In the operation of this motor the current impulses in the first, or primary, coils produce currents in the secondary coils, and by the conjoint action of the two an unsymmetrical revolving field is obtained. There are three claims. In the Scott and Janney case it was held that this patent did not conflict with the patents there in suit, as it carried a distinct invention.

No. 459,772.—*Electromagnetic motor, September* 22, 1891. *Application filed April* 6, 1889. The seven claims relate to the combina-

tion of an induction motor used as a starting device for a synchronous motor. The induction motor is mounted on the same shaft with the synchronous motor, the number of poles of each being so chosen as to give to the former motor a speed greater than that of the latter. The use of a self-starting, split-phase induction motor is disclosed in the drawings, but not referred to specifically in the claims.

No. 487,796.—*System of electrical transmission of power, December* 13, 1892. *Application filed May* 15, 1888. The four claims cover a multipolar generator with independent armature circuits used in combination with a motor having independent energizing circuits, the type of neither the generator nor the motor being specified. The drawings show two-phase generators and motors, all of which are of the synchronous type. The claims dwell upon the use of a number of motor poles greater or less than the number of generator armature circuits.

No. 511,915.—*Electrical transmission of power, January* 2, 1894. *Application filed May* 15, 1888. *No.* 555,190.—*Alternating motor, February* 25, 1896. *Application filed May* 15, 1888. These two patents figured as a single issue in a suit against the Scott & Janney Co., decided September 27, 1899, in the United States Circuit Court of the Eastern District of Pennsylvania. Judge McPherson, in his opinion, held that the invention of the patents was for a specific method of obtaining difference of phase, namely, by induction instead of self-induction, and therefore they did not conflict with the fundamental rotary field and the fundamental split-phase patents. The motor has two independent energizing circuits through only one of which current from the source is passed. In the second circuit the current is produced by the inductive effect of the current in the first circuit.

STANLEY PATENTS.

No. 469,809.—*System of Electrical Distribution, March* 1, 1892. This is known as the Stanley transformer patent, issued on an application by William Stanley, Jr., filed August 15, 1888, and has been subject to litigation. On April 26, 1901, Judge Coxe handed down a decision in two suits of the Westinghouse Co. against the Saranac Lake Electric Light Company, alleging infringement of two patents on transformers, one issued to Rankin Kennedy, the other being the present patent. An abstract of the decision in this case was given in our columns in the issue of May 4, 1901. Judge Coxe held the Kennedy patent to be void, and upheld the Stanley patent on the ground that in this patent Stanley first described how to make a regulating transformer. He discovered that he could remedy existing faults by regulating the length of the wire on the primary coil of the transformer and laid down the following rule: "He determines the correct length of the primary coil by winding on wire after the transformer, in circuit, is connected with the dynamo until the loss of voltage represented by the formula C^2R equals the predetermined loss of energy to be suffered in the system." The patent came up on appeal from this decision, and Judge Lacombe, on January 14, 1902, wrote an opinion sustaining the lower court. Judge Lacombe stated the Stanley rule as follows: "It says you may determine the proper length of the primary coil by connecting the transformer in circuit with the dynamo with which it is to be used, and then wind on the wire until the loss indicated by the formula C^2R within the secondary can equal a certain loss of degree." He also held that this rule is part of the invention disclosed and claimed in the patent. The same patent is now in course of litigation, the defendants being the Montgomery Electric Light & Power Company. On June 18, 1904, Judge Coxe handed down an opinion in this suit again sustaining the patent, holding, first, that Stanley made a valuable invention; second, that the invention is described in the patent with sufficient clearness to enable skilled electricians to practice it without difficulty; and third, that the defendant had appropriated the invention, though its transformers were not designed in the manner pointed out by Stanley. An abstract of this opinion appeared in our issue of July 23, 1904. An injunction was granted but, as noted in our columns last week, the order for the injunction has been reversed on appeal on the grounds that in view of the large importance of the controversy the rights of the party should be reserved for decision until the final hearing of the case, which will come up in due course. In this case the alleged infringing device was a Wagner transformer.

No. 508,188.—*Alternate-current electric motor, Nov.* 7, 1893. *Application filed Oct.* 23, 1888. The motor is of the single-phase commutator type, and is similar to a repulsion motor in that the stator field winding constitutes the primary circuit. The secondary (rotor) circuit, however, is not closed upon itself directly, but is connected to a supplemental coil, which surrounds the armature, and through which there flows current, produced by induction from the primary

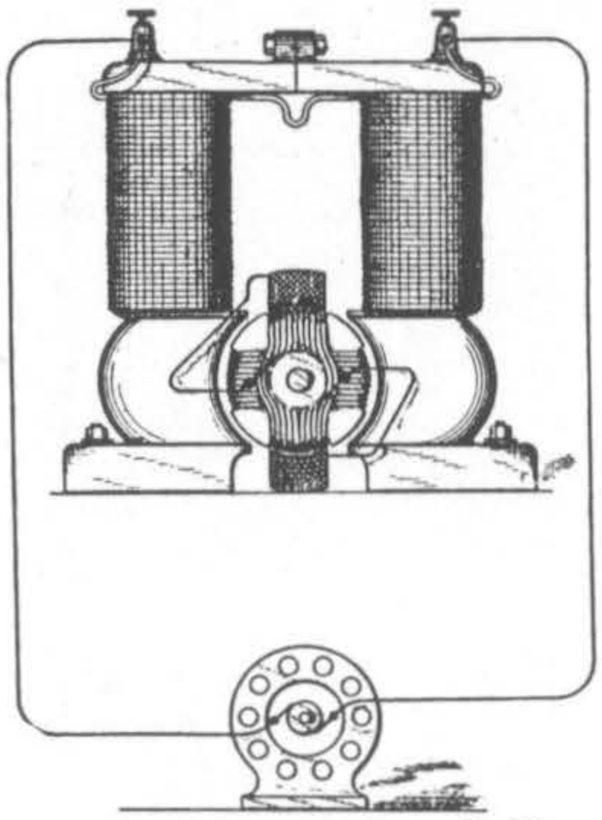


FIG. 1.—STANLEY, NO. 508,188.

circuit, in a direction to assist the polarizing effect of the current in the armature coils. There are four claims covering the combination shown in the accompanying illustration.

LAMME PATENTS.

No. 519,862.—*Method of and means for starting synchronous motors, May* 15, 1904. *Application filed April* 5, 1893. The invention contemplates the applying to the armature of the motor a starting current of low potential and large volume, thereby causing the armature to excite the field magnets by induction, and then gradually increasing the potential of the starting current to that of the supply circuit. The 9 claims, in addition to the general method of operation, cover the means for obtaining the variable potential. This patent is now in litigation, with the Indianapolis, Shelbyville & Southeastern Traction Company as defendant.

No. 582,132.—*Alternating-current motor, May* 4, 1897. *Application filed October* 30, 1895. The motor is of the induction type, having a revolving primary and stationary secondary. The invention relates to the construction of the stationary member. A starting resistance of proper value is included in the secondary circuit, and means provided in order to short-circuit the resistance when the motor reaches normal speed. The 15 claims cover the construction of the stator of the Westinghouse Type B motor.

No. 599,940.—*Non-synchronous electric motor, March* 1, 1898. *Application filed April* 30, 1894. The invention deals with the shape and size of the primary coils of an induction motor. Each coil of the distributed primary winding embraces an arc which is either greater or less than that resulting from dividing the entire circumference by the product of the number of poles and the number of phases. The object is to produce a sinusoidal distribution of field magnetism. There are four claims.

No. 609,990.—*Means for controlling non-synchronous alternating-current motors, August* 30, 1898. *Application filed March* 11, 1896. This patent relates to the use of a variable primary impressed e.m.f. for varying the speed of the motor. The four claims are for the combination with a primary member of a secondary member pro-

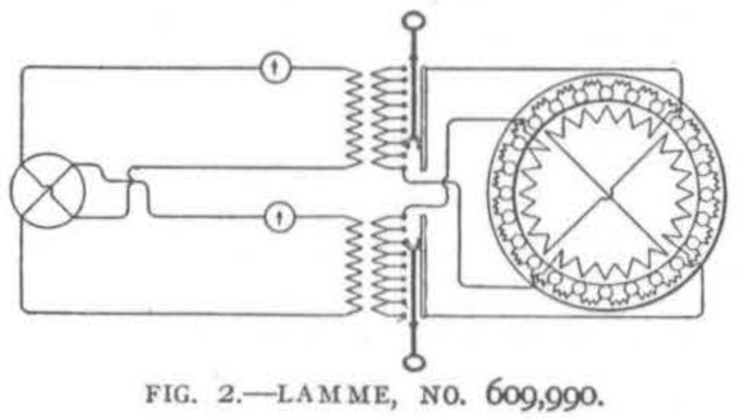


FIG. 2.—LAMME, NO. 609,990.

vided with a comparatively high-resistance winding directly short-circuited on itself, and means for varying the e.m.f. applied to the primary whereby the speed of the motor is varied; a small degree

of magnetic leakage between the primary and secondary; means for varying the speed of the motor consisting of a transformer for supplying current to the primary and means for varying the relation between the primary and secondary, thereby varying the e.m.f. supplied by the secondary; and means for varying the active lengths of the transformer secondary, whereby the e.m.f. applied to the primary of the motor is varied.

No. 609,991.—*Method of and means for securing constant torque in polyphase motors, August* 30, 1898. *Application filed February* 10, 1898. The motor is of the induction type, and has a comparatively high resistance in the secondary winding and a low degree of magnetic leakage, so that normally its torque increases continually with decrease of speed, and becomes maximum at standstill. In each of the supply circuits is placed a reactive coil, the core of which becomes saturated by a predetermined amount of current, the result being that the torque remains practically constant (at a reduced value) from standstill to that speed at which the current

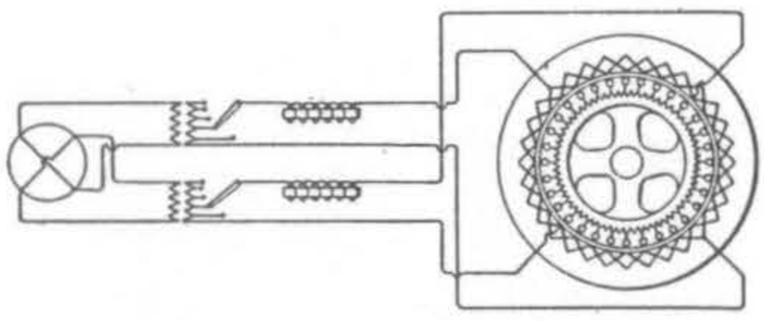


FIG. 3.—LAMME, NO. 609,991.

flows, causing the saturation of the cores of the choke coils. There are four claims, the first of which reads as follows: The combination with an induction alternating-current motor having a comparatively high resistance, secondary winding and a low degree of magnetic leakage, of a reactive coil in each of the supply circuits the core of which becomes saturated by a predetermined amount of current whereby a substantially constant torque is secured.

No. 610,067.—*Induction motor, August* 30, 1898. *Application filed July* 22, 1897. This patent relates to the construction of squirrel-cage secondary windings for the rotor of an induction motor, and the four claims refer to the use of ventilating blades on the resistance rings.

No. 633,856.—*Distributed winding for electrical machines, September* 26, 1899. *Application filed February* 6, 1899. The patent relates to mechanical details of the end connectors for the windings, which are covered by 8 claims. J. P. Mallet is a co-patentee. As usually constructed the portions of the armature conductors located in the slots of the core are in the form of bars, the ends of these bars being properly connected outside the core by means of end-connectors of suitable form, which are riveted and soldered or bolted to the ends of the bars.

No. 644,865.—*System of electrical distribution, March* 6, 1900. *Application filed June* 14, 1899. The invention refers to the method of obtaining e.m.f's lower than the normal voltages of a two-phase

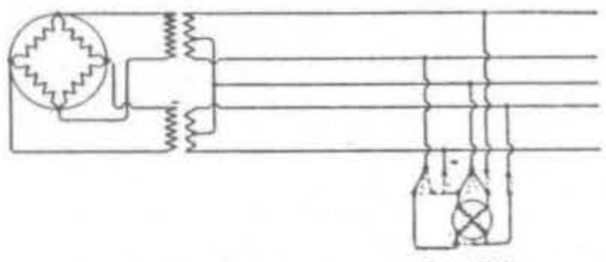


FIG. 4.—LAMME, NO. 644,865.

system by connecting the coils of the receiver between adjacent leads, or between adjacent single leads and a joint intermediate lead of the supply system. There are eight claims covering the various combinations of e.m.f's in quadrature obtainable from symmetrically and unsymmetrically disposed two-phase circuits. The cut shows the method by which can be obtained a voltage seven-tenths of normal value, at which e.m.f. the exciting volt-amperes for an induction motor, when lightly loaded, will be approximately one-half of the normal.

No. 759,183.—*Method of utilizing single-phase, alternating-current energy, May* 3, 1904. *Application filed December* 26, 1901. The invention refers to the use of the commutator type of single-phase motor, which was described fully in our issue of February 13 of last year. There are 8 claims relating to the proper proportioning of the field and armature windings.

HUTIN AND LEBLANC PATENTS.

No. 592,272.—*Alternating-current electrodynamic machine, November* 13, 1904. *Application filed August* 20, 1892. The invention relates to damping devices for preventing oscillations in the speed of synchronous motors and generators. There are six claims which cover the use of paths of low electrical resistance located within the path of the magnetic flux of the machine, at the margin of the interpolar space. This patent is now in litigation, the Bullock Electric Manufacturing Company being defendant.

No. 553,469.—*Alternating-current motor, January* 21, 1896. *Application filed November* 17, 1892. According to the patent, the secondary resistance of an induction motor is to be decreased in direct ratio with the frequency of the secondary circuit, so as to maintain the rotor torque at a constant maximum whatever may be the speed of rotation. Although the resistance is to be varied mechanically and the five claims cover means for producing the variation, the specification discloses no means other than the manual operation of a rheostat.

No. 12,223 (*reissue*).—*Alternating-current transformation, May* 24, 1904. *Original, No.* 754,371, *March* 8, 1904. There are two separate transformers in which the individual magnetic fluxes are in time quadrature. Two-phase e.m.f's may be obtained (or supplied) by winding similar coils on the cores of the two transformers, while three-phase e.m.f's may be supplied (or obtained) by passing around one of the magnetic cores for one of the three phases a number of turns proportionate to the sine of a certain arbitrarily chosen angle, and around the other core a number of turns proportionate to the cosine of the same angle; and for the other two phases using numbers proportionate to the sine and cosine of the same angle plus $2\pi/3$, or minus $2\pi/3$, respectively. The six claims cover the method in general without reference to specific apparatus.

DUSINBERRE PATENTS.

No. 763,379.—*Alternating-current induction motor, June* 28, 1904. *Application filed February* 27, 1904. The starting resistance of the revolving secondary is mounted in the form of a helix concentric with the shaft of the rotor, and variation in the effective length is accomplished by means of a contact device movable longitudinally upon the shaft. There are 12 claims covering the constructive details.

No. 763,547.—*Alternating-current induction motor, June* 28, 1904. *Application filed February* 27, 1904. The invention relates to means for automatically decreasing the resistance of the secondary circuit as the speed increases. The auxiliary resistance is assembled in spiral form and mounted so as to rotate with the motor shaft, which shaft also carries a contact device operated by centrifugal force whereby the amount of resistance included in the secondary circuit is decreased with increase of speed. The four claims cover the constructive features.

NOLAN PATENT.

No. 582,481.—*Fastening means for core plates of electrical machines, May* 11, 1897. *Application filed January* 20, 1897. In a circumferential groove in the core spider there is placed a spring metal ring which extends outside the groove and against a shoulder

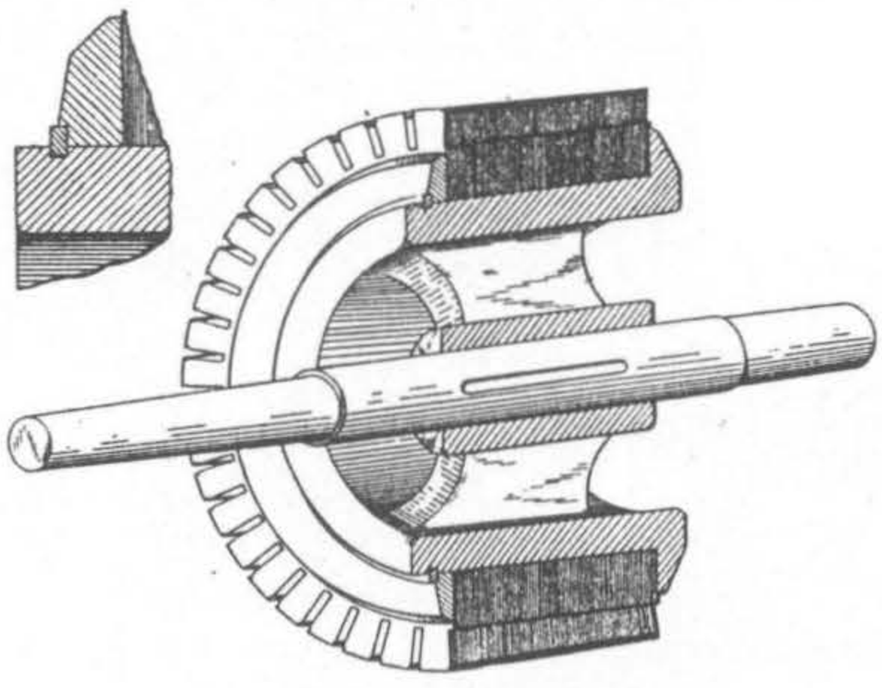


FIG. 5.—NOLAN, NO. 582,481.

on an annular plate between which and a flange on the core the laminæ are clamped. The construction is illustrated in Fig. 5 and is covered by four claims. This patent is now in litigation, the Bullock Electric Manufacturing Company being defendant.

The New York World May 15, 1905

TESLA'S VALUABLE PATENTS EXPIRE.

"Wizard" Inventor Has Drawn Princely Income on Electrical Monopoly.

A great stir has been created among electricians everywhere by the announcement that the famous patents of Nicola Thesla covering the alternating current dynamo, have just expired. They have been widely known for years as the "three fundamental patents." Their expiration is an event in the world of electricity, not second in importance to the dying out of the Bell telephone patents. The alternating motor has been a monopoly.

Tesla has been drawing princely royalties on these patents, much of which the picturesque inventor is said to have applied to his experiments in wireless telegraphy. His mysterious tower at Wardencliffe, Long Island, is said to have been built in part by money subscribed by J. Pierpont Morgan, and in part out of the royalties from the motor patents.

In 1885 Prof. Galileo Ferraris, of Turin, Italy, discovered the electromagnetic rotating field, and applied his invention ,according to William Stanley, to a rotating field motor. In 1888 Tesla received United States patents covering the broad application of the Ferraris discovery. George Westinghouse bought the Tesla patents and also the rights of Ferraris.

The fundamental Tesla patents have been for years in the possession of what is called the "Patent Pool Trust." They have been attacked many times in the courts, but without success. It is now generally believed by electricians that the expiration of the patents releases to the world at large the immensely important principle of the rotary field. There will be a grand scramble everywhere to make the Tesla motor now invariably used without paying any more royalty to Tesla. The Westinghouses announce they have a number of subsidiary patents, and will fight.

The Tesla Patents.—The series of American patents generally known as the fundamental Tesla patents, which have played such a conspicuous part in the electrical industry during the two last decades, expired on the 4th of this month. Mr. B. A. Behrend takes the opportunity of paying a tribute to Tesla's work in an article contributed to the *Electrical World* of New York. The genius of Tesla has been instrumental in stimulating, if not in creating, a wonderful industry—wonderful in magnitude, and wonderful in the ingenuity of the apparatus used in the accomplishing of the transmission of power over long distances. After discussing the evolution of scientific principles and the patent system, the author deals with the personal achievements of Tesla, the ingenious inventor who, by a "sort of glorified common sense and unfailing intuition, picked his way through puzzling mazes of complicated phenomena, and protected himself from the pitfalls and the alluring by-paths ensnaring smaller intellects." With Tesla, in America and in Europe, worked a host of capable and ingenious engineers, and their work, vivified by the ingenuity of Tesla's inventions, has become one of the greatest monuments of engineering achievement crowning the work of the nineteenth century. Turning to Tesla's remarkable paper, entitled "A New System of Alternate-Current Motors and Transformers," read at the meeting of the American Institute of Electrical Engineers in New York on May 16, 1888, the author remarks that this paper, even when considered in the light of previous discoveries and knowledge, is one of the most brilliant pieces of engineering thought, teeming with suggestions and ideas, animated with an intuition of the highest order, and giving an exposition of the working of the induction motor in a manner which resembles the methods pursued in the "Experimental Researches on Electricity" of the great master, Michael Faraday. While stating, however, that for 17 years the Tesla patents have formed the nucleus of the electrical industry, Mr. Behrend points out that these patents do not represent the only valuable ideas on the subject of polyphase alternating-current systems. He predicts that the expiry of the patents, aided by vigorous competition, will give the electrical industry a new stimulus.

Expiry of Tesla Patents.—The American patents in connection with rotating magnetic fields as applied to electric motors, granted to Mr. Nikola Tesla in 1888, expired on May 5th.

News of Tesla. — From the *Globe* of May 19th we cull the following, for which we take no responsibility:—"At last, Mr. Nikola Tesla, after a long isolation in his experimental tower of Wardenclyffe, Long Island, has broken silence in a United States patent recently granted to him. It appears from the specifications that he has been sending electrical oscillations through the ground by means of a powerful transformer having one end of the secondary coil to earth and the other to an elevated metal disk, probably the colossal griddle on the summit of his tower. He was led to do so by observing that lightning discharges produce electric waves or oscillations in the ground, varying in length from about 25 to 70 metres. His apparatus produces waves of similar kind, which travel to great distances, and they not only transmit messages, but control or actuate apparatus for other purposes—such as indicating the time of an observatory, determining the position and distance of bodies, and the course or speed of a ship at sea.

"According to his patent, the electric waves from the earthplate travel to distant parts of the earth, and are there reflected back on themselves, producing by interference with the outgoing waves a series of stationary waves having crests and hollows lying in parallel circles round the earthplate as a pole. By impressing on the earth two or more oscillations of different wave length, a resonant stationary wave can be made to travel slowly over the globe. A delicate receiving apparatus has been invented for detecting these resonant waves. It consists essentially of a condenser charged from the ground and discharged through an indicating or a recording instrument. In any part of the globe, the wave-length of a resonant stationary wave can be found by mathematics, and the distance of the place from the source of waves calculated. A ship can thus find its latitude or longitude, time, &c. With several generators in chosen localities, the entire globe could be sub-divided into different zones of electrical activity, and important data obtained from observation of the waves."

The New York Sun June 15, 1905

SUBWAY DANGERS.

Mr. Tesla's Views of Possibilities and Proper Equipment.

To the Editor of The Sun—Sir: The flooding of the subway is a calamity apt to repeat itself. As your readers will remember, it did not occur for the first time last Sunday. Water, like fire, will break loose occasionally in spite of precautions. It will never be possible to guard against a casual bursting of a main; for while the conduits can be safely relied upon under normal working conditions, any accidental obstruction to the flow may cause a pressure which no pipe or joint can withstand.

In fact, if we are to place faith in the gloomy forecasts of Commissioner Oakley, who ought to know, such floods may be expected to happen frequently in the future. In view of this it seems timely to call to public attention a danger inherent to the electrical equipment which has been thrust upon the Interborough company by incompetent advisers.

The subway is bound to be successful, and would be so if the cars were drawn by mules, for it is the ideal means of transportation in crowded cities. But the full measure of success of which it is capable will be attained only when the financiers shall say to the electric companies: "Give us the best, regardless of expense."

It is to be regretted that this important pioneering enterprise, in other respects ably managed and engineered, should have been treated with such gross neglect in its most vital feature. No opportunity was given to myself, the inventor and patentee of the system adopted in the subway and the elevated roads, for offering some useful suggestion, nor was a single electrician or engineer of the General Electric and Westinghouse companies consulted, the very men who should have been thought of first of all.

Once large sums of money are invested in a defective scheme it is difficult to make a change, however desirable it may be. The movement of new capital is largely determined by previous investment. Even the new roads now planned are likely to be equipped with the same claptrap devices, and so the evil will grow. "Das eben ist der Fluch der boesen That, dass sie fortzeugend Boeses muss gebaeren."

The danger to which I refer lies in the possibility of generating an explosive mixture by electrolytic decomposition and thermic dissociation of the water through the direct currents used in the operation of the cars. Such a process might go on for hours and days without being noticed; and with currents of this kind it is scarcely practicable to avoid it altogether.

It will be recalled that an expert found the percentage of free oxygen in the subway appreciably above that which might reasonably have been expected in such a more or less stagnated channel. I have never doubted the correctness of that analysis and have assumed that oxygen is being continuously set free by stray currents passing through the moist ground. The total amperage of the normal working current in the tunnel is very great, and in case of flooding would be sufficient to generate not far from 100 cubic feet of hydrogen per minute. Inasmuch, however, as in railway operation the fuses must be not hard, in order to avoid frequent interruption of the service by their blowing out, in such an emergency the current would be of much greater volume and hydrogen would be more abundantly liberated.

It is a peculiar property of this gas that it is capable of exploding when mixed with a comparatively large volume of air, and any engineer can convince himself by a simple calculation that, say, 100,000 cubic feet of explosive might be formed before the danger is discovered, reported and preventive measures taken. What the effect of such an explosion might be on life and property is not pleasant to contemplate. True, such a disaster is not probable, but the present electrical equipment makes it possible, and this possibility should be, by all means, removed.

The oppressiveness of the tunnel atmosphere is in a large measure due to the heat supplied by the currents, and to the production of nitrous acid in the arcs, which is enhanced by rarefaction of the air through rapid motion. Some provision for ventilation is imperative. But ventilation will not do away with the danger I have pointed out. It can be completely avoided only by discarding the direct current.

I should say that the city authorities, for this if for no other reason, should forbid its use by a proper act of legislation. Meanwhile, the owners of adjacent property should object to its employment, and the insurance companies should refuse the grant of policies on such property except on terms which it may please them to make. N. Tesla.

New York, June 15.

Tesla Split-Phase Patent Litigation.

An opinion has been rendered by the United States Circuit Court of Appeals for the Third Circuit (Western Pennsylvania) in a suit involving the Tesla split-phase patents, in which he Jefferson Light, Heat & Power Company was alleged to have infringed these patents in having used a meter involving the split-phase principle. The case had previously come before the court on an appeal from an order granting a preliminary injunction. This order of the lower court was reversed pending a plea that the case was *res adjudicata* in view of a decision rendered in the United States Circuit Court of Appeals sitting in New York in the case of the Catskill Illuminating & Power Company, the decision of this court being that the Tesla split-phase patents were invalid through anticipation. Subsequently the present cause proceeded to a hearing, resulting in a decree overruling the bill of *res adjudicata,* declaring infringement and granting an injunction. From that decree the defendant appealed on the ground that inasmuch as the Catskill case was defended by the Diamond Meter Company, and the present case is defended by the same company, the Catskill case was *res adjudicata* of everything involved in the present case. The opinion was written by Judge Acheson, and the court held that the Diamond Meter Company did not avowedly or openly conduct the defense in the Catskill case, and having concealed its connection with the case while it was pending, it is now too late for it to set up the decree in that case as an estoppal against the complainant in the present case. The plea was overruled and the granting of a preliminary injunction by the court below affirmed.

The United States Circuit Court of Appeals for the First District in a suit involving also the Tesla split-phase patents, in which the Stanley Instrument Company was the defendant, has denied a petition of the latter to file a supplementary bill in the nature of a bill of review, or to amend the judgment on appeal. In this case the lower court decided against the split-phase patents and was reversed on appeal. Application was then made to the Supreme Court for a writ of certiorari on the grounds of conflict with the action of the Catskill case, which was denied. The petition of the present cause was based on the grounds that certain English Tesla patents on identically the same subject matter as the patents in suit expired in 1903, and that this expiration was a complete defense as against the patents in suit. The court held that since the foreign patents expired only a few days after the decree was entered in the lower court and before the appeal was heard, the question of laches on the part of the petitioner could not be wholly overlooked. The court held, however, that the merits of the case with respect to the identity of the foriegn and American patents are so clearly against the petitioner that it was not necessary to pronounce on the question of laches. In order that the term of a foreign patent may be limited by a domestic patent, it is essential that the inventions covered by the two patents should be identical. This is not true with respect to the patent cited in this suit. While it is true that one claim of the British patent neces-

sarily includes all the elements of the American patents, it also includes other elements establishing a new combination which is an essential, novel and patentable improvement on what was claimed in the patents before the court on appeal. This claim covers not only the mere improvement on either split-phase invention or polyphase invention separately, but it covers an invention by which a convertable motor is produced. This necessarily takes the case out of the field of identity with either the earlier polyphase or the later split-phase patents. The petition was denied.

Tesla on Subway Dangers.

The New York *Sun* of June 16 printed the following letter from Mr. Nikola Tesla:

The flooding of the subway is a calamity apt to repeat itself. As your readers will remember, it did not occur for the first time last Sunday. Water, like fire, will break loose occasionally in spite of precautions. It will never be possible to guard against a casual bursting of a main; for while the conduits can be safely relied upon under normal working conditions, any accidental obstruction to the flow may cause a pressure which no pipe or joint can withstand.

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The oppressiveness of the tunnel atmosphere is in a large measure due to the heat supplied by the currents, and to the production of nitrous acid in the arcs, which is enhanced by rarefaction of the air through rapid motion. Some provision for ventilation is imperative. But ventilation will not do away with the danger I have pointed out. It can be completely avoided only by discarding the direct current.

I should say that the city authorities, for this if for no other reason, should forbid its use by a proper act of legislation. Meanwhile, the owners of adjacent property should object to its employment, and the insurance companies should refuse the grant of policies on such property except on terms which it may please them to make.

The New York World June 25, 1905

Thomas A. Edison Talks of His Search for Radium and of the Future of Electricity.

Says Marconi Is Right and Tesla Wrong as to the Means of Talking from One Side of the World to the Other.

Thomas A. Edison has been devoting his days for some time past to a keen search for radium, the newly discovered metal which promises such wonderful results in healing the sick, making the blind to see and curing malignant cancers.

In an interview with a representative of The World at Menlo Park a few days ago Mr. Edison said:

"I have hunted for this new substance in a thousand places and chemically examined no end of specimens of ore from different mines and mountains, but thus far have not succeeded in finding it in any quantity. I have, however, reached some decided conclusions on the subject.

"Radium is similar to X-rays in its power to pass through substances, and its effects are apparently as injurious to investigators. This is especially true of the X-rays. My wife is unwilling to have me experiment with [illegible] any more. One of my eyes was drawn out of focus, and my stomach was more or less affected, so that I was seriously inconvenienced in my laboratory work. Besides this, my assistant died about a year ago from the effects of their baneful influence; and now his brother, another assistant, is suffering from a red discoloration of the flesh on his breast and arms, although he has not been making any X-ray experiments for a year. Strange that the injury from their influence should only manifest itself twelve months after laboratory investigations ceased!"

"What have you under way now?" inquired the World representative. "Do you believe with Tesla that we shall be able to talk around the world one of these days?"

"No," answered the Wizard, "I do not look for developments in that line. The wonderful thing that will be more and more developed is wireless telegraphy. Marconi is all right and is bound sooner or later to perfect his system. He has just been married, and is not working as hard at present as he did at first. But he will come out all right, and we shall have the oceans bridged by wireless telegraphy. That was a remarkable performance the other day when the steamship Campania was never out of communication with one side or the other of the Atlantic ocean. It shows what we are coming to.

"Cables will not be superseded. Business will only be increased for both wireless and cable companies, just as the telegraph and telephone supplement each other.

"The Japs are making splendid use of wireless telegraphy in the present war with Russia. They are a wonderful little people and are up to date in everything. They will revolutionize things in the Orient when the war is over, and will spur on China to be more like the Western nations.

"I admire the Japs because they are up to date. I don't believe in war and am a man of peace. The only kind of war that interests me is one between the great 'captains of industry,' in which the one with the biggest brain wins every time. The Japs when once peace is declared will enter upon an industrial campaign and buy all the improved labor-saving machinery they can. Then they will make things lively for us.

"The machine nations will lead the world and decide the issues between the other countries."

"What do you mean by machine nations?"

"Why," replied the Wizard, "those that use labor-saving machinery. In the last analysis the three or four great nations of the world will be those that are up-to-date in making and manufacturing goods cheaper and better than any one else and [illegible] more intelligent and wide-awake. Commerce will be the great thing after all, which nations will strive after.

"Coming back to wireless telegraphy again, cannot the messages be intercepted by outsiders?"

"There is not the least danger from that," said the Wizard in reply. "Any important message by cable or overland even now is sent by code, and that is what will be done when wireless messages are sent. When you forward a cable message from New York to London it goes through the hands of four or five operators. And the way you protect your secret is by using code words. The same thing can be done with wireless messages. The Japs certainly understand this game to perfection, for they seemed to be posted on every move of the enemy on land or sea.

"Electricity is still in its infancy, and you will find that the Japs will employ it to still greater uses. I am not in the least alarmed at the yellow peril. I wish I had a lot of Japs in my laboratory.

"Speaking of telegraphy," continued the Wizard, "the General Superintendent of the Lackawanna Railroad was here yesterday and told me a very interesting thing. At the recent Railroad Congress in Washington, out of the seventy-five officials at one of the banquets given forty-three of them (or over half) were old operators. And they were very proud of the fact that they had risen from the ranks. Not a few of the most prominent men in the United States have been 'knights of the key.' All of which goes to show that an operator may have a big future ahead of him."

I know Mr. Edison is very busy with some interesting experiments and has 14,000 cells at work in trucks and delivery wagons throughout the country. The results obtained from actual work he will finally embody in the contracted battery.

The New York World July 2, 1905

NIKOLA TESLA SAYS WE WILL SOON BE TALKING CLEAR AROUND THE WORLD.

Replies to Wizard Edison in Vigorous Fashion—Beating the Lightning Flashes—His Compliments to His Rivals.

The article to which Mr. Tesla refers in the following letter was an interview with Thomas A. Edison, in which, in reply to The World reporter's question, "Do you believe with Tesla that we shall be able to talk around the world one of these days?" Mr. Edison said: "No, I do not look for developments in that line. The wonderful thing that will be more and more developed is wireless telegraphy. Marconi is all right, and is bound sooner or later to perfect his system." Mr. Tesla's letter is as follows:

New York, June 30, 1905.

To the Editor of The World:

Sir—My attention has been called to an article in The World of last Sunday, announcing in an interview that I am wrong in my wireless propositions. Such statements, authorized or not, are apt to produce erroneous impressions regarding my work as well as the state of the art. For my protection and your readers' enightenment, I only need to quote the following passage from one of my specifications which was filed five years ago in the United States Patent Office and is descriptive of some results attained by me about that time:

"In the course of certain investigations which I carried on for the purpose of studying the effects of lightning discharges upon the electrical condition of the earth I observed that sensitive receiving instruments arranged so as to be capable of responding to electrical disturbances created by the discharges at times failed to respond when they should have done so, and upon inquiring into the causes of this unexpected behavior I discovered it to be due to the character of the electrical waves which were produced in the earth by the lightning discharges, and which had nodal regions following at definite distances the shifting source of the disturbances. From data obtained in a large number of observations of the maxima and minima of these waves I found their length to vary approximately from twenty-five to seventy kilometres, and these results and theoretical deductions led me to the conclusion that **waves of this kind may be propogated in all directions over the globe**, and that they gated in all directions over the globe, and that they may be of still more widely differing lengths, the extreme limits being imposed by the physical dimensions and properties of the earth. Recognizing in the existence of these waves an unmistakable evidence that the disturbances created had been conducted from their origin to the most remote portions of the globe and had been thence reflected,

Beat Lightning Flashes.

I conceived the idea of producing such waves in the earth by artificial means, with the object of utilizing them for many useful purposes for which they are or might be found applicable. This problem was rendered extremely difficult owing to the immense dimensions of the planet, and consequently enormous movement of electricity or rate at which electrical energy had to be delivered in order to approximate, even in a remote degree, movements or rates which are manifestly attained in the displays of electrical forces in nature, and which seemed at first unrealizable by any human agencies; but by gradual and continuous improvements of a generator of electrical oscillations, which I have described in my Patents [illegible] I finally succeeded in reaching electrical movements or rates of delivery of electrical energy not only approximately, but, as shown in comparative tests and measurements, **actually surpassing those of lightning discharges**, and by means of this apparatus I have found it possible to reproduce whenever desired phenomena in the earth the same as or similar to those due to such discharges. With the knowledge of the phenomena discovered by me and the means at command for accomplishing these results I am enabled not only to carry out many operations by the use of known instruments, but also to offer a solution for many important problems involving the operation or control of remote devices which for want of this knowledge and the absence of these means have heretofore been entirely impossible. For example, by the use of such a generator of stationary waves and receiving apparatus properly placed and adjusted in any other locality, however remote, it is practicable to transmit intelligible signals or to control or actuate at will any one or all of such apparatus for many other important and valuable purposes, as for indicating wherever desired the correct time of an observatory, or for ascertaining the relative position of a body or distance of the same with reference to a given point, or for determining the course of a moving object, such as a vessel at sea, the distance traversed by the same or its speed; or for producing many other useful effects at a distance dependent on the intensity, wave length, direction or velocity of movement, or other feature or property of disturbances of this character."

A Bit of Sarcasm.

Permit me to say on this occasion, that if there exist, to-day, no facilities for wireless telegraphic and telephonic communication between the most distant countries, it is merely because a series of misfortunes and obstacles have delayed the consummation of my labors, which might have been completed three years ago. In this connection I shall well remember the efforts of some, unwise enough to believe that they can gain an advantage by throwing sand in the eyes of people and retarding the progress of invention. Should the first messages across the seas prove calamitous to them, it will be a punishment regrettable but fully deserved.

In my article in the Century of June, 1900, and subsequent publications in a technical journal (Electrical World and Engineer), I have carefully and conscientiously prepared them for the impending revolution.

I may add that any expert, not a blacksmith or woodchopper in electrical experiments whose cheeks are covered with horn-back alligator skin, and who is thus enabled to make use of my patented [illegible] without my permission and public acknowledgment can easily enough girdle the world with [illegible] messages, and in Smardis's fashion achieve [illegible] and distinction, cheap and unprofitable. With [illegible] marvellous appliances an engineer possessed of knowledge and skill not greater than my own [illegible] throw this planet out of its orbit.

NIKOLA TESLA.

THE ELECTRICAL EQUIPMENT OF THE SUBWAY.

The fact that there are a great many people who take Mr. TESLA seriously, notwithstanding the fact that for some years past he has been more distinguished for magnificent promises than for brilliant performances, gives greater significance than it would otherwise have to his persistent effort to discredit the electrical equipment of the Rapid Transit Subway. The method of this attack is not exactly that which one would expect from a gentleman of Mr. TESLA's professional reputation. It is by the publication of letters full of vague generalities, so worded as to impress the public without inviting the specific and authoritative contradiction which would follow them if they consisted of definite statements. So far as they admit of paraphrasing into clear-cut declarations of opinion, Mr. TESLA's views respecting the electrical equipment of the Subway are that the system chosen and installed was preferred because it was cheap and not because it was good; that it is far behind the present state of the are in plan and in detail; that a serious mistake was made in not adopting the alternating system of distribution, "popularly known as the two, three, multi, or polyphase"; that the system selected was one invented by him and discarded years ago for later, riper, and more perfect devices; that in planning it no engineer of the General Electric or Westinghouse Company was consulted or permitted to give advice; that the mechanical appliances installed are cheap and inferior; that the Interborough management imposed upon its technical advisers the obligation of wasteful economy in first cost; and that in consequence of the absence of safeguards against the leakage of currents into the ground, insulating materials and ground water are decomposed and converted into highly explosive gases which at any moment may blow the whole Subway into another county and do incalculable damage to life and property.

With the strictly technical points of an impeachment of this kind the daily newspaper press does not need to concern itself. With the practical side if there be one, it may properly concern itself very intimately. As certain specific statements are likely to be of more interest to the reader than abstractions or generalities, we will confine our comments to them.

The electrical equipment of the Rapid Transit Subway is probably not perfect, but it is unquestionably the best ever installed in this or any other city. The instructions of the Interborough management to its electrical engineer were to provide the best of everything, and there was absolutely no restriction in the matter of cost imposed at any stage of the work. The alternating current and the polyphase induction motor, which Mr. TESLA believes in, were carefully studied and rejected This was not because they would have cost more than the system approved, for they would have been materially cheaper; but because they were not the best for use in the circumstances. To have adopted them would have saved perhaps a third or a quarter of the cost of installation. It is doubtful if a single induction motor of the kind referred to by Mr. TESLA was then used in the United States for traction purposes. On the other hand, the system adopted is identical in principle with that which has been tested in practice in London and Paris, in Brooklyn for the operation of the elevated lines, and by the engineers of the Pennsylvania, the New York Central, and the Long Island Railroad. In details the development has been advanced in the Subway equipment beyond any previous experience. Since trains began running it has been critically watched, and in every respect has vindicated the judgment of the experts responsible for its adoption and installation. As we said, it is not perfect, but it comes nearer to that standard than any system elsewhere in use.

That Mr. TESLA was not called in consultation as to plan or details is probably true. The work was done under the immediate direction of one of the most accomplished and discreetly conservative electrical engineers of the United States, Mr. L. B. STILLWELL, who was from the outset and still is the Electrical Director of the Interborough Company. He stands well at the head of his profession. On a comparison of experiences it would probably be found that Mr. STILLWELL has been intrusted with the expenditure of a thousand dollars in constructive work for every dollar thus intrusted to the judgment of Mr. TESLA. When the latter began his campaign of criticism, Mr. STILLWELL declined a newspaper controversy, on the reasonable ground that the points involved were such as could best be decided by a jury of experts, and offered, if Mr. TESLA would present before the American Institute of Electrical Engineers a paper containing specific and definite criticisms of the Subway equipment, to meet him in a full and frank discussion which would be equally open to every electrical engineer in the United States. The fact that Mr. TESLA declined this invitation would seem to close the incident so far as he is concerned.

THOMAS A. EDISON ON RADIUM AND THE FUTURE OF ELECTRICITY.

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"The machine nations will lead the world and decide the issues between the other countries."

"What do you mean by machine nations?"

"Why," replied the Wizard," "those that use labour-saving machinery. In the last analysis the three or four great nations of the world will be those that are up-to-date in making and manufacturing goods cheaper and better than anyone else, and that are more intelligent and wide-awake. Commerce will be the great thing, after all, which nations will strive after."

TESLA'S REPLY TO EDISON.

Says "We shall soon be Talking Round the World."

AS we said last week, Mr. Edison was reported to have said to an interviewer of the *New York World* that he did not believe with Tesla in being able to talk round the world, but that he thought Marconi would, sooner or later, perfect his system.

Nikola Tesla has replied. He says:—

In the course of certain investigations which I carried on for the purpose of studying the effects of lightning discharges upon the electrical condition of the earth I observed that sensitive receiving instruments arranged so as to be capable of responding to electrical disturbances created by the discharges at times failed to respond when they should have done so, and upon inquiring into the causes of this unexpected behaviour I discovered it to be due to the character of the electrical waves which were produced in the earth by the lightning discharges, and which had nodal regions following at definite distances the shifting source of the disturbances. From data obtained in a large number of observations of the maxima and minima of these waves I found their length to vary approximately from twenty-five to seventy kilomètres, and these results and theoretical deductions led me to the conclusion that waves of this kind may be propagated in all directions over the globe, and that they may be of still more widely differing lengths, the extreme limits being imposed by the physical dimensions and properties of the earth. Recognising in the existencs of these waves an unmistakable evidence that the disturbances created had been conducted from their origin to the most remote portions of the globe, and had been thence reflected, I conceived the idea of producing such waves in the earth by artificial means, with the object of utilising them for many useful purposes for which they are or might be found applicable.

Beat Lightning Flashes.

This problem was rendered extremely difficult owing to the immense dimensions of the planet, and consequently enormous movement of electricity or rate at which electrical energy had to be delivered in order to approximate, even in a remote degree, movements or rates which are manifestly attained in the displays of electrical forces in nature, and which seemed at first unrealisable by any human agencies; but by gradual and continuous improvements of a generator of electrical oscillations, which I have described in my Patents Nos. 645576 and 649621, I finally succeeded in reaching electrical movements or rates of delivery of electrical energy not only approximately, but, as shown in comparative rests and measurements, actually surpassing those of lightning discharges and by means of this apparatus I have found it possible to reproduce, whenever desired, phenomena in the earth the same as or similar to those due to such discharges. With the knowledge of the phenomena discovered by me, and the means at command for accomplishing these results, I am enabled, not only to carry out many operations by the use of known instruments, but also to offer a solution for many important problems involving the operation or control of remote devices which, for want of this knowledge and the absence of these means, have heretofore been entirely impossible. For example, by the use of such a generator of stationary waves and receiving apparatus properly placed and adjusted in any other locality, however remote, it is practicable to transmit intelligible signals, or to control or actuate at will any one or all of such apparatus for many other important and valuable purposes, as for indicating wherever desired the correct time of an observatory, or for ascertaining the relative position of a body or distance of the same with reference to a given point, or for determining the course of a moving object, such as a vessel at sea, the distance traversed by the same or its speed; or for producing many other useful effects at a distance dependent on the intensity, wavelength, direction or velocity of movements, or other feature or property of disturbances of this character.

A Bit of Sarcasm.

Permit me to say on this occasion that if there exist to-day no facilities for wireless telegraphic and telephonic communication between the most distant countries, it is merely because a series of misfortunes and obstacles have delayed the consummation of my labours, which might have been completed three years ago. In this connection I shall well remember the efforts of some, unwise enough to believe that they can gain an advantage by throwing sand in the eyes of people and retarding the progress of invention. Should the first messages across the seas prove calamitous to them, it will be a punishment regrettable but fully deserved.

THE TRANSFORMATIONS OF MATTER.*

SOME twenty years ago the suggestion that matter can be destroyed could be discussed on metaphysical grounds only. The indestructibility of matter, complemented by its sister doctrine of the conservation of energy, formed one of the pillars upon which the whole system of physics appeared to rest, and Herbert Spencer—whose acquaintance with physics was by no means his strong point—declared in his "First Principles" that if we could suppose matter to be destructible, both science and philosophy would be impossible. Recent discoveries have, however, changed all that, and both the indestructibility of matter and the conservation of energy find themselves exposed to a frontal attack which it seems impossible that they can long resist.

Now it is plain that these discoveries, while overthrowing our best-settled conceptions of matter and energy, yet raise a great many more puzzles than they solve. While atoms are shown to be no longer atoms, and energy is produced apparently from nowhere without the previous expenditure of work, electricity, at one time thought to be merely a form of energy, now appears as a component, and perhaps the sole component, of matter. Yet till now no one could say what electricity was, and every new discovery seemed to make its behaviour more and more mysterious. It seemed to have mass, and one of the most popular theories of English electricians was that all mass was electromagnetic in its origin. It behaved in most cases like a liquid, yet a liquid some of whose particles attracted, while others repelled, each other seemed inconceivable; and it was proved to be entirely exempt from the laws of gravitation which govern the behaviour of all other liquids. Nor did any of the new discoveries quite square with the hitherto observed laws of electrical phenomena. It has always been said that a gas cannot act as a conductor of electricity, yet the fact that the atmosphere becomes a conductor under the influence of the electrons emitted by radium proves the best test of its presence. Again, Sir William Ramsay's emanation, which eventually becomes positive and negative electricity, will remain for years on the surface of metals such as bismuth, and will then resist the efforts of liquids like concentrated sulphuric acid to remove it. Moreover, many of these effects can be imitated by reactions in which the so-called radio-active metals have nothing to do. An electric discharge of high tension and frequency, such as M. Tesla showed us how to produce, will discharge an electroscope as readily as radium. So will the rays emitted by a sheet of clean metal on which the ultra-violet rays of the sun or of an electric light fall. So will the gases emitted by the flame of a burning candle or a piece of red-hot metal; and so will the formation of acetylene by the decomposition of carbide of calcium or the dissolution of sodium amalgam in water. And above all is the crowning mystery of the evolution of helium from the radium emanation and its transformation into electricity. How can a gas consisting, like other gases, of atoms of known weight come into existence from a metallic salt into whose composition this gas does not enter? And how can a gas disappear leaving nothing behind it but a substance which presents hardly any of the properties of matter? Plainly a synthesis which can afford a reasonable explanation of these incoherent and apparently contradictory facts is required if physical science is to be saved from chaos.

Such a synthesis has now been furnished by M. Gustave Le Bon, whose just-published book on "L'Evolution de la Matière" (Paris: Flammarion) is a republication and amplification of the separate studies and articles which have appeared over his signature during the last eight years. His theory is that matter, instead of being, as it appears to us, the most stable and reposeful of all natural things, is, in fact, never at rest, but is always changing from one form to another. Once, he says, the world was a nebula, consisting apparently entirely of ether. From causes which we cannot even guess at, this ether became condensed into the atoms as known to modern chemistry, the energy thus stored up being that which is liberated when the atom is dissociated or split up as in the now familiar case of radium. But this process of dissociation, instead of being rare and occasional, is always going on with all substances, and always with the same result, which is the production of an emanation like that already made evident by Sir William Ramsay, Prof. Rutherford, and others in the case of radium and thorium. This emanation, though not itself electrified, transforms itself into what he calls the ionic fluid, which in turn gives rise first to positive and negative ions, or almost infinitely small masses of matter combined with charges of positive and negative electricity, and then to detached electrons or corpuscles of negative electricity only, having no material support. These negative electrons, in which alone, according to him, the inertia varies with the speed at which they travel, are the cause of

* From the *Athenæum*.

those Hertzian waves which are emitted whenever a discharge takes place from an electrified point, and only differ from waves of light in their far greater wave-length. Finally, the same negative electrons give rise when stopped to the Röntgen rays, which are one of the last stages by which matter sinks back into the ether from which it originally came. For this is the end towards which all material things are tending. Whether they are reborn we cannot tell, until we know something of the cause which first gave them birth; but that matter is every day taking one step the more on the road to death M. Le Bon has no doubt whatever. From matter to emanation, from emanation to electricity, from electricity to ether, are the stages of transformation which he has as yet succeeded, in his opinion, in identifying. Yet he warns us that these are probably only a few of those through which matter finally has to pass. Already he thinks he can detect a difference between the rays emitted by metals when exposed to different parts of the solar spectrum. Nor are all the negative electrons exactly alike. Their unequal deviation in a powerful magnetic field shows, according to him, that they are composed of divers elements, which, he suggests, may be arranged on the sun-and-planet system which other observers have ascribed to the atom. And at the other end of the scale there are probably many intermediate stages, of which we as yet have no knowledge. All the chemical elements are probably formed, as Prout thought, from one element, and crystals may be the intermediary form between "brute" and living matter. The theory that electrons are, in fact, centres of vortical strain in the ether he looks on with favour; but as we do not know how these vortices came first to be formed, it does not advance us much.

Further discussion of M. Le Bon's theory the *Athenæum* leaves for another article; but it may be said that full details of the experiments by which he seeks to prove it are given in his book, while the care and pains which he has bestowed upon his researches during many years make it impossible that it should be lightly regarded. And if the views now put forward by him emerge triumphant from the controversies that they will doubtless arouse, we fancy that his researches will be considered as important for the twentieth century as those of Darwin were for the nineteenth.

Tesla on the Peary North Pole Expedition.

The New York *Sun* of July 16 prints the following letter from Mr. Nikola Tesla:

Everybody must have been pleased to learn that Commodore Peary has finally obtained the financial assistance which will enable him to start without further delay on his important journey. Let us wish the bold navigator the most complete success in his perilous undertaking, in the interest of humanity as well as for his own and his companions' sake and the gratification of the generous donors who have aided him. But, while voicing these sentiments, let us hope that Peary's will be the last attempt to reach the pole in this slow, penible and hazardous way.

We have already sufficiently advanced in the knowledge of electricity and its applications to avail ourselves of better means of transportation, enabling us to reach and to explore without difficulty and in a more perfect manner not only the North, but also the South Pole, and any other still unknown regions of the earth's surface. I refer to the facilities afforded in this respect by the transmission of electrical energy without wires and aerial navigation, which has found in this novel art its ideal solution.

Many of your readers will, no doubt, be under the impression that I am speaking merely of possibilities. As a matter of fact, from the principles involved and the experiments which I have actually performed, not only is the practical success of such distribution of power reduced to a degree of mathematical certitude, but the transmission can be effected with an economy much greater than possible by the present method involving the use of wires.

It would not take long to build a plant for purposes of aerial navigation and geographical research, nor would it cost as much as might be supposed. Its location would be perfectly immaterial. It might be at the Niagara, or at the Victorian Falls in Africa, without any appreciable difference in the power collected in a flying machine or other apparatus.

A popular error, which I have often opportunity to correct, is to believe that the energy of such a plant would dissipate itself in all directions. This is not so, as I have pointed out in my technical publications. Electricity is displaced by the transmitter in all directions, equally through the earth and the air; that is true, but energy is expended only at the place where it is collected and used to perform some work. To illustrate, a plant of 10,000 hp, such as I have been planning, might be running full blast at Niagara, and there might be but one flying machine, of, say, 50 hp operating in some distant place, the location being of absolutely no consequence. In this case 50 hp would be all the power furnished by the plant to the rest of the universe. Although the electrical oscillations would manifest themselves all over the earth, at the surface as well as high in the air, virtually no power would be consumed. My experiments have shown that the entire electrical movement which keeps the whole globe a-tremble can be maintained with but a few horsepower. Apart from the transmitting and receiving apparatus, the only loss incurred is the energy radiated in the form of Hertzian or electro-magnetic waves, which can be reduced to an entirely insignificant quantity.

I appreciate the difficulty which your non-technical readers must experience in comprehending the working of this system. To gain a rough idea, let them imagine the transmitter and the earth to be two elastic bags, one very small and the other immense, both being connected by a tube and filled with some incompressible fluid. A pump is provided for forcing the fluid from one into the other, alternately and in rapid succession. Now, to produce a great movement of the fluid in a bag of such enormous size as the earth would require a pump so large that it would be a greater task to construct it than to build a thousand Egyptian pyramids. But there is a way of accomplishing this with a pump of very small dimensions. The bag connected to the earth is elastic, and when suddenly struck vibrates at a certain rate. The first artifice consists in so designing and adjusting the parts that the natural vibrations of the bag are in synchronism with the strokes of the pump. Under such conditions the bag is set into violent vibrations, and the fluid is made to rush in and out with terrific force. But the immense bag—the earth, is still comparatively undisturbed. Its size, however, does not exempt it from the laws of nature, and just as the small bag, so too the earth, responds to certain impulses. This fact I discovered in 1899.

The second artifice is to so adjust the transmitter that it will furnish these particular impulses. When all is properly done the large bag is thrown into spasms of vibration, and the effects are bewildering. But no power is yet transmitted, and all this colossal movement requires little energy to maintain. It is like an engine running without load.

Next let your readers imagine that at any place where it may be desired to deliver energy a small elastic bag, not unlike the first, is connected to the large one through a tube. The third artifice consists in so proportioning the parts that the attachment will be responsive to the impulses transmitted, this resulting in a great intensification of the vibration of the bag. Still the pump will not furnish power until these vibrations are made to do work of some kind.

To conduce to an understanding of the fourth artifice, that of "individualization," let your readers follow me a step further, and conceive that the flow of energy to any point can be controlled from the place where the pump is located at will, and with equal facility and precision, regardless of distance, and, furthermore, through a device such as the combination lock of a safe, they will then have a crude idea of the processes involved. But only when they realize that all these and many other processes not mentioned, and related to one another like the links of a chain, are completed in a fraction of a second, will your readers be able to appreciate the magical potencies of electrical vibrations and form a conception of the miracles which a skilled electrician can perform by the use of these appliances.

I earnestly hope that in the near future the conditions will be favorable for the construction of a plant such as I have proposed. As soon as this is done it will be possible to adapt electrical motors to flying machines of the type popularized by Santos Dumont. There will be no necessity of carrying a generator or store of motive energy and consequently the machine will be much lighter and smaller. Owing to this and also to the greater power available for propulsion, the speed will be considerably increased. But a few of such machines, properly equipped with photographic and other appliances, will be sufficient to give us in a short time an exact knowledge of the entire earth's surface. It should be borne in mind, however, that for the ordinary uses of a single person a very small machine of not more than one-quarter horse-power, corresponding to the work of two men, would be amply sufficient so that when the first plant of 10,000 hp is installed, the commodity of aerial flight can be offered to a great many individuals all the world over. I can conceive of no improvement which would be more efficient in the furtherance of civilization than this.

[1227.]—**Tesla Coil.**—If you will kindly refer to my book, "Electrical Instrument Making for Amateurs," at p. 109, *et seq.*, you will find description and cut of the manner of building a Tesla. Of course, unless your supply is an alternating one, you will be obliged to rig up some form of contact-breaker, either electro-magnetic, mechanical, or mercurial, and please note that unless you have had some experience in coil making, so as to be able to appreciate the nicety required in insulating the primary from the secondary, &c., you will very likely not succeed the first time. S. BOTTONE.

The Colorado Springs Gazette September 6, 1905

NIKOLA TESLA SAYS HE IS NOT INDEBTED TO DUFFNER

Nikola Tesla, the wizard of the world electric, has answered C. J. Duffner in the county court at this place.

Duffner brought suit recently for $899.22, which he claimed to be the balance due him for acting as caretaker for Nikola Tesla's house of experimentation on Nob hill.

Tesla came into the court yesterday morning accompanied by his attorney, M. L. Brown, and declares that he never employed Duffner at the time alleged for the purpose alleged or at any other time for any other purpose and that he is not indebted to the plaintiff.

In the original complaint Duffner alleges that he was employed by Tesla as caretaker of the Nob hill house January 1, 1903, at $18 a week, and that he continued in that capacity until July 2, 1904. Tesla, Duffner says, remitted $558.41 of the $1,332 due him for services and also owed him $25 for coal and building paper.

That Nikola Tesla should quarrel about money is odd, for while here he acquired the reputation of being absolutely without an idea of the value of money. For instance, one day he wanted to construct a large barrel. Being short of barrel hoops he came to the city, went to a bicycle repairing shop and ordered a wagon load of bicycle rims, which he used for hoops. He had a habit of setting his house afire by pressing electric buttons to see how general a conflagration he could start in how few seconds and he employed a private fire department to extinguish the flames after he had ignited it.

The New York Herald September 7, 1905

Nikola Tesla Sued.

[SPECIAL DESPATCH TO THE HERALD.]

COLORADO SPRINGS, Col., Wednesday.—Nikola Tesla, electrical inventor, of New York, has been made defendant in a suit here to recover $900 in wages.

MEN
WOMEN AND
AFFAIRS

OUR OWN TIMES

BOOKS
THE ARTS AND
THE DRAMA

AFTER being a wanderer for twenty-five years, William Lawson went into the Harrison Street station in Chicago the other day and asked to be restrained from following the open road. He wished, he said, to settle down, but his legs had the roaming habit. He wanted to be held—rendered stationary—rooted to some spot on mother earth. He thought of going home and "becoming a man." The newspaper that printed this interesting paragraph only opened this vista into the life of William Watson—no, no, William Lawson—and then closed it again. It is left for the speculative reader to imagine why he of the good, sound-sense name acquired the vagrant habit. One would suppose that William Lawson would keep the general store at Squirrelville, and would know all the folks, and have no passion stronger than his obstinate intention to avoid the road tax. But Lawson, it appears, has escaped all taxes. The commonplaceness of life has never been his. He had never wearied to the innermost soul of him at the aspect of his neighbor's woodshed; he knew nothing of those arranged, pestering, persistent entities—such as the coal bill, the ice bill, and the grocer's order boy with his matutinal demand upon the domestic ingenuity,—which kill the fancy and murder the joy in the most buoyant of us. For William Lawson there had been a quarter of a century of whimsical exploration. He had watched the dawn, grown familiar with the stars, sipped of the brooks—if nothing better offered—and made himself intimate with all the little brothers of the wild. He, like Jaques, had journeyed far and had seen how other men live, and to glimpse other men's lives is the most fascinating thing in all the world except to have a sense of expectancy in regard to your own. Why, then, should William Lawson, who triumphed over dull destiny and refused to play the rôle of grocer in a banal world, have deliberately foregone his enviable madness and returned to sanity and the dull paths of penitence? It is not as if Lawson's heart was dead within. That, apparently, is as young as ever it has been. The innumerable roads and byways of the world still beckon him; there are still habitations which he has not seen, forests which he has not penetrated, fields in which he has not slept. There is still, as Percy B. Shelley would have remarked, had he known William Lawson, "a spirit in his feet." In these circumstances, it seems nothing less than a waste to want to "go back home!" At home, no doubt, the rain barrel is in the same old place, the barn



WILLIAM ALLEN WHITE

Whose article, "The Kansas Conscience," appears in this issue of THE READER

door is off its hinges, the fence lies prone among the protesting hollyhocks. There are two or three women who, for a quarter of a century, have enjoyed the marvel of the mysterious disappearance, to be deprived now of their sad entertainment, and to suggest odd jobs for William Lawson to do. It seems, all things considered, a mistake for William Lawson to return. He says he has seen almost all the world, but no doubt if he were to go over it again with more care he would observe some entertaining trifles which have thus far escaped him. The wanderers have always appealed to the fancy of poets. No idea is more enchanting than that of him who in the night and the storm comes knocking at the door, sits for a moment by the hearth, gives one wild kiss to the home-keeping maiden, and flies on, driven by the Lords of Destiny, upon his endless quest. William Lawson, had his heart been as valiant as it is youthful, might have shared with this immortal figure the fame which is his right. But he has faltered. His imagination has failed him. Or perhaps he has acquired rheumatism from lying too long under the stars. At any rate, by this time he is no doubt back home, stifling in the lean-to bedroom and washing in an ugly china bowl. The days of his dreams are over. He has voluntarily come back into civilization, which shuts us all up in box stalls—some have bare stalls and some a gorge of grain—but all of us are sure of harness and of weary feet. And yet, to have been wise for a quarter of a century must mitigate the folly of a life! There will always be something about William Lawson that will cause his neighbors to regard him with curious eyes. Little children will wistfully make his acquaintance. He can, if he will, contribute to the Sunday syndicates. And to the last, he will have his memories.

SOMEHOW the famous "bread line" of New York City, which has for so many years stretched itself along Broadway to the side door of a large bakery, has become closely identified in fiction with Albert Bigelow Paine's novel of the same name. And the story contains a deal of biographical information, for it was the outcome of Mr. Paine's venture in 1897, with Irving Bachellor, Orson Lowell and Frank VerBeck, to establish a juvenile magazine, which they called *Youth and Home,* and which was short-lived. Not that Mr. Paine actually had to seek his nightly loaf, as so many poor mortals have to do, but it was a very handy and sarcastic outlet for him to point a moral and adorn a tale. Mr. Paine is a typical example of the modern writer; he began, as so many others have, with a volume of verse, "Rhymes by Two Friends," the co-author being William Allen White—a production which these two young Kansas men thought

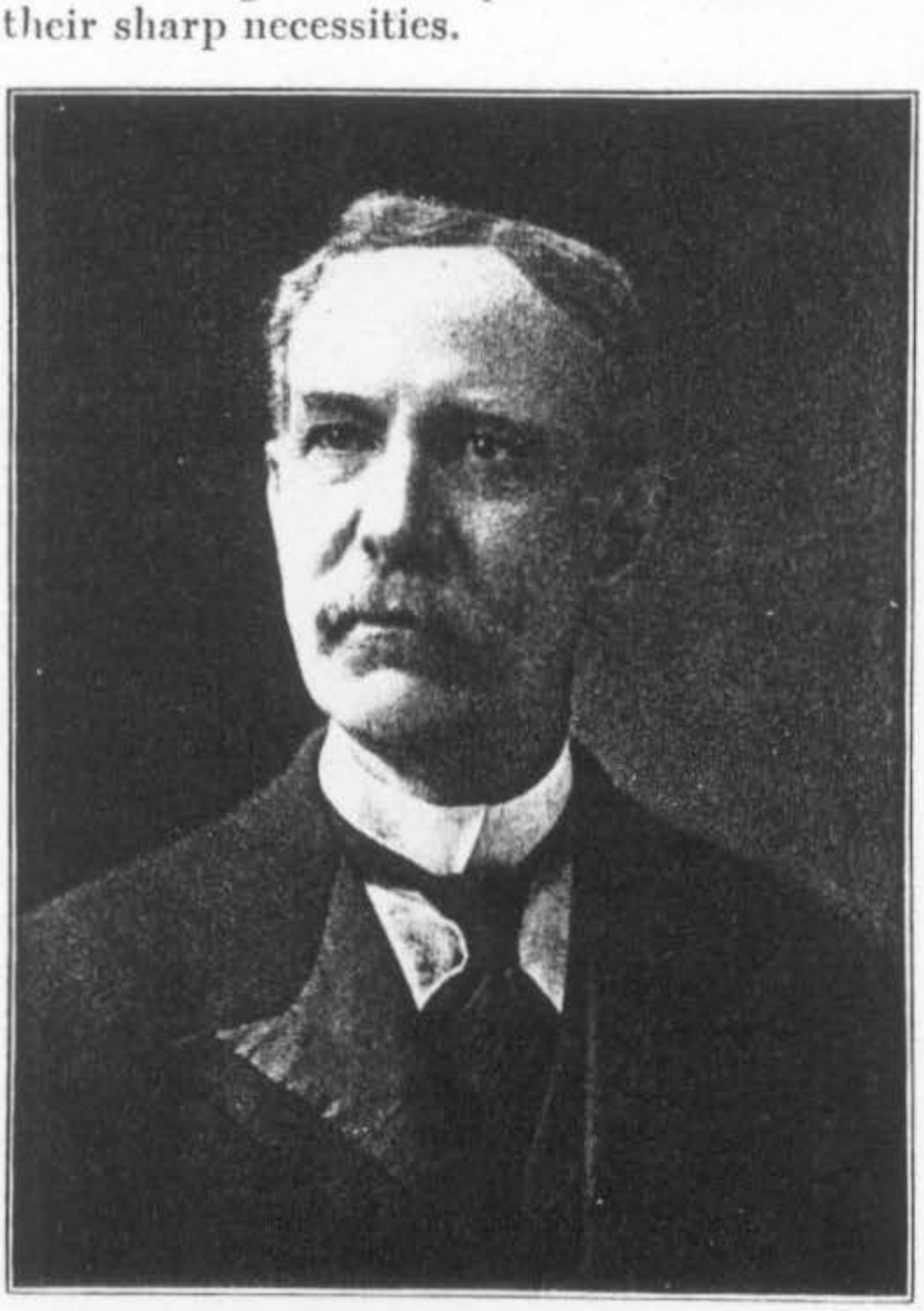


ALBERT BIGELOW PAINE

the world was waiting for. After this, in 1895, Mr. Paine came to New York, where he gained experience in syndicate writing, and invented, with Ruth McEnery Stuart, those delightful Gobolinks, which, made with pools of ink upon white paper, are the joy of children and the fear of parents. As a juvenile writer, Mr. Paine rapidly proved himself possessed of imagination and a quick comprehension of the child taste. That is why, as editor of the league department of the *St. Nicholas Magazine,* he has so successfully

called forth the efforts of young writers and artists. But the "Bread Line," published in 1900, is virtually Mr. Paine's first distinctive book. Thomas Nast, the cartoonist, read it and selected Mr. Paine as his biographer on the strength of it. He, too, had started a magazine, with the same direful results. Soon after the death of Nast, Mr. Paine gathered together his material and traced a most varied career in a work that is noteworthy and interesting. At present Mr. Paine is engaged upon a life of Capt. B. S. Osbon, Farragut's signal officer. And in the midst of his editorial duties he finds time to write extensively for the magazines.

THE family of Bret Harte has been afflicted with many misfortunes recently. The eldest son has been stricken with blindness; Miss Bret Harte, a concert singer, has been prostrated with ill health, and many minor misfortunes have been added to fill their cup of ill luck to the full. A number of the old friends of Bret Harte have been raising a subscription to minister to their sharp necessities.



ELROY MC KENDREE AVERY

Author of a new twelve-volume "History of the United States and Its People"

ARIZONA appears to be not so eager for statehood as she is for independence. The efforts of a certain faction to induce a union between her and New Mexico, and thus present to congress the aggregate of citizenship which will entitle the two territories to be admitted to the union as one state, has been repudiated with courtesy but decision by both democrats and republicans in Arizona.

"While we entertain for the people of our sister territory," says the protest forwarded to Congress by the voters of Arizona, "the most kindly feelings and sympathize with them in their efforts for admission as a state into the Union, yet we profoundly believe that the union of the two territories as one state would be inimical to the best and highest interests of both, and particularly harmful to the people of Arizona. To be compelled against our will and desire to lose our identity and be merged into the proposed state, in which we have so little voice, wounds our pride and violates our sense of justness and fairness. Therefore, as a patriotic and law-abiding people, we confidently appeal to the Congress of the United States to avert the disaster that threatens us; and, rather than force upon us this proposed union, to allow us to remain a territory indefinitely."

This is to be laid before both houses of Congress; the Governor of Arizona will make a protest on behalf of his people through the Secretary of the Interior; and the President will be asked to embody in his annual message a recommendation against joint statehood. Should these efforts fail and Arizona be forced into partnership with what may be termed our Spanish-American territory, New Mexico, the matter will be carried to the supreme court. The question would, in that event, be an interesting one. Can Congress impose statehood on a community? Can an act of union be forced upon a self-governing state that desires to remain in that condition of comparative autonomy which a state of the United States enjoys?

Senator Beveridge and other senators advocate the union of the two territories, and have gone the length of making a hasty tour of Arizona to acquaint themselves with her condition, resources, etcetera, etcetera. It is not too much to say that if they are sensitive to swift impressions they must have

been bewildered by the paradoxes, physical and sociological, that Arizona presents. At once the most ancient and the most modern, the most foreign and the most native, the most fertile and the most barren, the most stupendous and the most squalid, the most beautiful and the most disheartening of sections, in her geographical and in her social features, she amazes and fascinates. To have seen her deserts, her cañons, her remains of ancient cities, is to remember her forever as the monument to a savage and fascinating past; to witness the methods by which she overcomes her disadvantages of semi-aridity, the enterprise she shows in certain of her towns, the engineering ability and industrial activity she has achieved, is to think of her as the very modern of the moderns. The remnant of the old life still lives there side by side with the alert, energetic, ambitious young American element, which pioneers with contemporary science in electricity, hydraulics, chemistry and engineering at its command.

Arizona is one of the most strongly individualized of any territory that ever laid the foundations of an independent-minded state; and she should not be compelled to merge her individuality in that of an adjoining state uncongenial, in some ways, to her, and moved by ideas and ideals at variance with her own.

A VERY large proportion of the American literary brotherhood has essayed newspaper work before venturing upon the less ephemeral forms of pen product. Richard Harding Davis once made a list of the successful authors who had begun their careers under the tuition of a city editor, and the list was long and honorable. Burges Johnson, author of "Rhymes of Little Boys," is an instance in point. Mr. Johnson is an Amherst man, and after leaving college worked on newspapers, venturing finally into the publishing business. Essays and verse, both serious and light, have been his achievements thus far.

MR. John McCutcheon, the cartoonist, has taken a dash to Russia to enable him to work with more definiteness and understanding in cartoons relating to the various phases of the Russian question.



ARTHUR TRAIN

Assistant to District Attorney Jerome, of New York, and author of "McAllister and His Double"

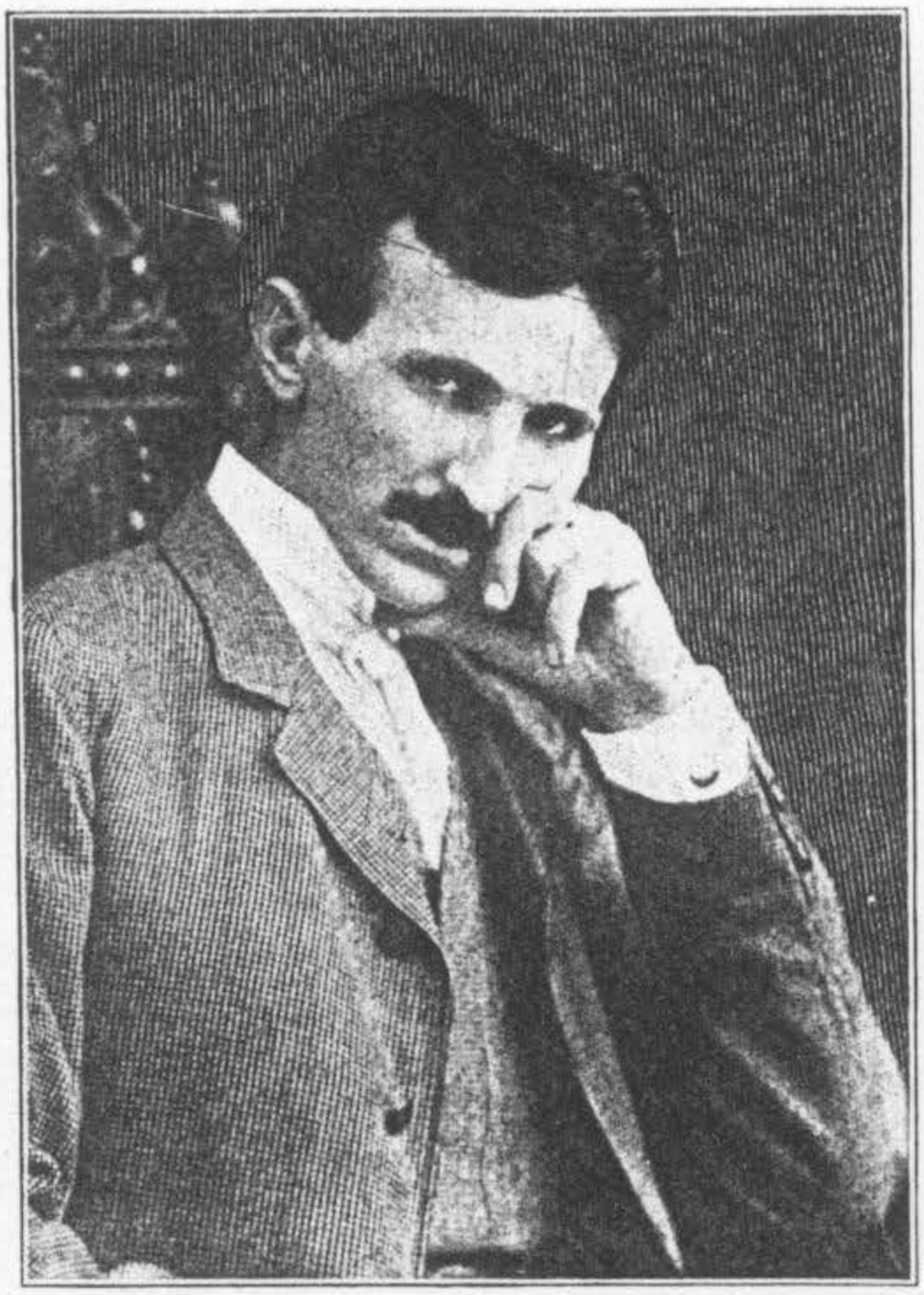
IN a recent magazine article Thomas Dixon, Jr., again solves his favorite problem, the negro and what to do with him. This time Booker T. Washington and "some dangerous aspects of his work at Tuskegee" are made the centers of attack. As usual, there is no mistaking Mr. Dixon's meaning. He knows what he wants to say and says what he thinks he knows. He writes with clearness and with vigor; his style is always energetic and often picturesque. In this latest tilt at the black windmill Mr. Dixon is more conservative, and therefore more convincing, than usual. Admit a few early premises, and Mr. Dixon can write the negroes out of the country and set them up in Liberia, a peace-keeping, God-fearing people, masters of their own destinies and the happy bosses of a free republic.

"If allowed to remain here the negro race in the United States will number sixty million at the end of the century by their present rate of increase." Mr. Dixon doubtless has the figures to prove this statement, but

figures are all things to all men. To Mr. Dixon they are simple, straightforward and free from guile. At the close of the war, forty years ago, there were four million negroes enfranchised. By the last census there were eleven million scattered over the country. Mr. Dixon doesn't say so, but no doubt with these amiable figures and a Dixon lead pencil he can turn out sixty million at the end of the century. But how does he know the present rate of increase will be maintained? He doesn't know, of course. He assumes, and the conclusion based on the assumption is made the foundation for his "irreconcilable conflict". To believe that this rate will remain unchanged is to believe that physical and social conditions will remain unchanged. It is ninety-five years to the end of the century. A long time for even the Meads and the Persians. What Mr. Dixon really knows is that the colored man's conditions are changing rapidly and that all the changes tend to a lowering of the present rate. The negro no longer draws strength from the soil. He has swapped the fresh air of the plantation for the foul air of the alley. The cabin and the corn-patch know him no more. He has become a sophisticated but unsanitary man about town. With the city comes cocaine. The corner drug store, unaided, will make Mr. Dixon's "present rate of increase" look like an overheated thermometer in a cold-storage house. Late hours, dissipation, idleness, these and other alluring dangers call to him beyond his power to resist. It is an unequal struggle, in which he withers and falls, a victim of progress, a martyr to civilization. Mr. Dixon is a modern abolitionist, deeply serious, intensely earnest. But in his enthusiasm for the "cause" he forgets some things he knows better than any one else.

THE accusation—if such it may be termed—of plagiarism brought against Mrs. Katherine C. Thurston by Mr. Lewis in an article which draws close parallels between the plot, circumstances and scenes of "The Masquerader" and Mr. Zangwill's "The Premier and the Painter," has brought forth a letter of frank and honest disavowal from Mrs. Thurston. She says that her first feeling upon reading the heading of Mr. Lewis' article was one of resentment, "but," she adds, "as I read the article itself, I confess that my anger gave place to amazement, for certainly the facts brought forward by Mr. Lewis are to me very amazing, forming, as they do, the most extraordinary case of dual suggestion that has come within my knowledge. For let me state, finally and most emphatically, that I have never seen a copy of Mr. Zangwill's 'The Premier and the Painter'; the book has never been discussed—or even mentioned—in my presence; the story, even in the most shadowy outline, has never been related to me."

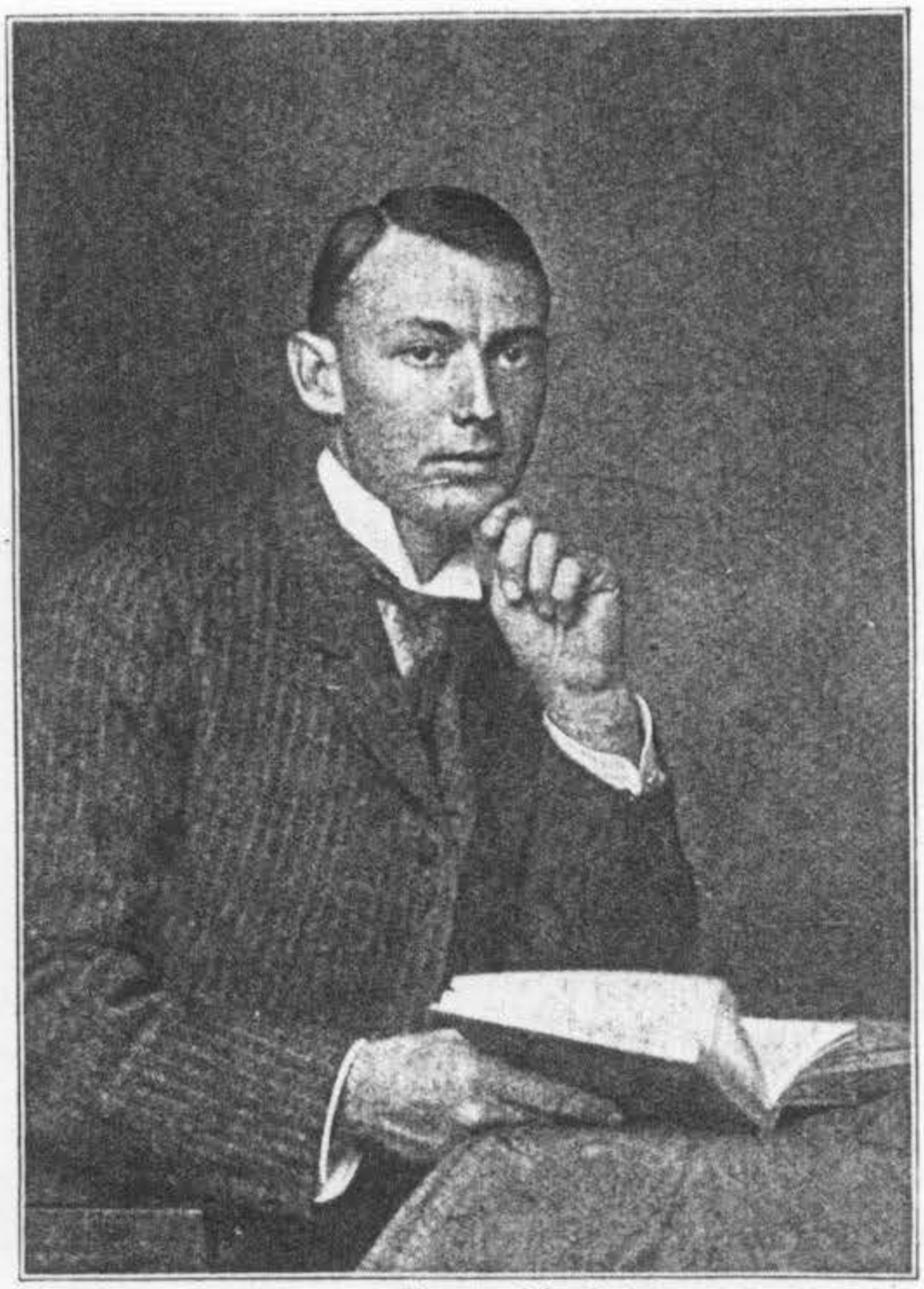
This has the utter accent of truth, and none will be so ungenerous as to doubt Mrs. Thurston's statement. Nor is the thing so marvelous after all, for fact itself has fairly taken the suggestion from Mrs. Thurston's book, as the newspaper annals of the past month bear witness. The occurrence of this case, so singularly resembling the "impossible" story of "The Masquerader," occurred in Rome. Count Adriano Beniculli, an eccentric nobleman, charged his valet with having indirectly caused the death of the Countess Beniculli. The evidence offered in court brought to light the fact that, taking advantage of an extraordinary resemblance between himself and his valet, the count employed the latter to impersonate him at various social functions at Rome and elsewhere, while he devoted himself to his hobby of collecting and repairing ancient locks. Paolo, the valet, provided with money and appropriate raiment, was received everywhere in the best society, and acquitted himself, apparently, more creditably than the count had done. Meeting the Countess Beniculli at a ball, the valet paid her assiduous attention. He was, in truth, infatuated with the charm of this great lady, who accepted his attentions with a certain gratitude. For many years she and her husband had not lived together, and she had come to think of him as a semi-madman. She found him instead, a sane, handsome and magnetic gentleman, from whom it was a compliment to receive attentions. She became reconciled, as she believed, to her husband, and a period of happiness followed to be broken in a tragic manner one day when the countess and the valet drove to Rimini, and walking toward some of the caves, were interrupted by a peasant woman, who rushed upon



Photograph by Vander Weyde

NIKOLA TESLA

The Italian Edison, from what is said to be the second photograph for which he ever sat



Photograph by the Misses Selby, New York

DR. HENRY C. ROWLAND

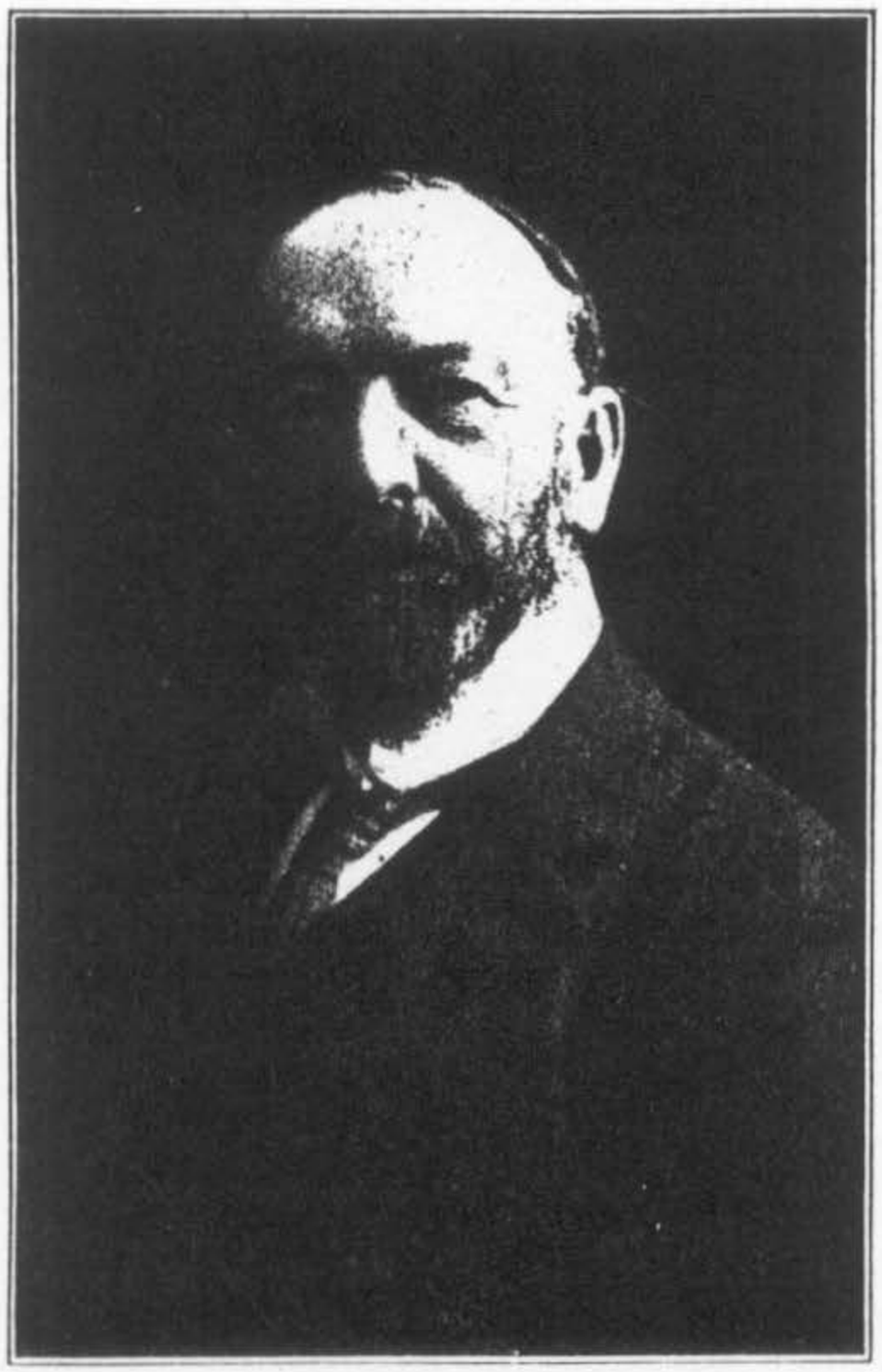
Whose new book, "The Mountain of Fears," is to appear in October

Paolo, accusing him of having deserted her. The truth came out, and the countess, who seems to have had a character in strong contrast to these men, knelt at the feet of Paolo's wife begging her pardon. She returned alone to her palace, thinking heaven knows what thoughts concerning the tricks of fate, and was that same night found dead in her room. She had poisoned herself and got safe beyond all chance of further disappointment and mockery. She left a letter explaining the facts to her husband and saying that she was unwilling to sully the records of her ancestry. A pathetic figure, worthy the art of a nobler d'Annuncio! Count Beniculli may have been moved to a belated remorse, and a realization of the dignity of his countess. At any rate he brought suit against the valet.

Whether the poor countess would, in the event of her pseudo-husband having been a man superior in character to her actual lord, have proved as complaisant and unconventional as the heroine of Mrs. Thurston's romance, may not be known. The Countess Benieulli would, perhaps, in any case, have been more solicitous about her honor than about her happiness. Mrs. Thurston's heroine could not satisfy herself with "honor" which may, in the circumstances, have seemed a fetich. She took happiness with eager hands, scandalized the subscribers to *Harper's Bazar,* and won the approval of a number of argumentative persons who thought she showed singularly good sense—for a heroine—in taking a good man in exchange for a bad one, "without benefit of clergy" or unnecessary explanation to a captious public.

THE Ben Greet Woodland Players have met with gratifying success in the West. On the college campuses and at parks they have presented "Midsummer's Night Dream," "As You Like It," "Much Ado About Nothing," "Twelfth Night," "Comedy of Errors" and "The Tempest." In the last play only they failed to attain that high

standard they have set for themselves. But the company acted both a *Ferdinand* and a *Miranda* of the adequate spiritual measure. Not the least interesting feature of these performances has been the Shakespearean songs sung to tunes of the sixteenth and seventeenth century. A number of these have been arranged by Arnold Dolmetsch, apostle of old-time tunes and instruments.



HENRY ARTHUR JONES

The dramatist, author of "The Manœuvers of Jane," "The Case of Rebellious Susan," etc.

NOTWITHSTANDING the ever increasing number of deaths and injuries caused by reckless automobilists, the criminally careless chauffeurs have almost invariably escaped punishment. As ruthless and insolent as any patrician of Rome in the days of its self-debasement, these drivers of our modern chariots leave their dead lying in the road and escape by the combined means of their speed and of their falsified numbers; for it transpires that the wanton automobilist does not lay himself liable to responsibility by carrying a recorded number, but changes the number to suit the occasion. In spite of efforts more or less earnest, the police find it impossible or impolitic to track these up-to-date murderers to their homes, if such men can be said to have homes, and the injured pay their own hospital bills, and the dead go unavenged in consequence. It is noticeable, since the occurrence of the summer accidents, that many of the finest machines are run with conspicuous care, the occupants being unwilling to be classed with that band of conscienceless marauders who are bringing automobiling into disgrace.

France is trying to meet the exigencies of the situation by building speedways on which nothing but automobiles are to be allowed. Such a speedway ninety miles in length is being constructed by Biarritz, at a cost of $1,600,000, along the coast at Arcachon. Here the speed madness may have its way, with none to hinder nor make afraid, while on other thoroughfares moderation of pace can be rigidly enforced.

SCIENTISTS will feel a keen interest in the new theory of the creation of the universe offered by Professor F. R. Moulton and Professor Thomas C. Chamberlain, of the University of Chicago. These men, three years ago, proved to their own satisfaction, that Laplace was mistaken in his ring theory of the nebular hypothesis. Professor Moulton said in class room the other day:

"To prove the nebular 'ring' theory the combined momentum of all the parts of the solar system at present ought to equal the momentum of the sun at the time when it extended to the orbit of Neptune, or in the beginning. I have worked with the problem a long time, and I am convinced that the solar system now has only one two-hundred-and-fiftieth of the momentum it had when the sun extended out to Neptune."

These two radical scientists, having satisfied themselves three years ago that calculations would not substantiate the ingenious theory of Laplace, have been at work, aided by a grant from the Carnegie Institute at Washington, formulating what they have called the spiral theory.

"Professor Chamberlain and myself be-

lieve," says Professor Moulton, "a second sun—a disturbing sun—moved down near our sun and caused on our sun enormous tides, thousands of miles high. The tides were similar to the tides of the sea. Our tide was at the point nearest the disturbing sun and the other tide was on the opposite side. The matter shot toward the disturbing sun. Ordinarily it would have been straight up, but the disturbing sun moved around in an elliptical sort of orbit. Consequently all the masses thrown off were in a spiral direction, one after another, which accounts for the orbits of the planets. The swollen masses were attracted to the large nuclei which made them into planets."

Hence the good round earth!

The results worked out are to be published presently, Professor Moulton treating the astronomical, and Professor Chamberlain the geological phase of the question. It remains to be seen what comment is made by the critical scientists of Germany, Italy and France.

MRS. H. A. M. Keays, author of that intensely interesting novel, "He that Eateth Bread with Me," is engaged upon another problem novel, the title of which is to be "The Work of Our Hands." Divorce was the matter dealt with in the first book; wealth is to be the subject of its successor. Mrs. Keays adjusts her life, so far as residence goes, to the convenience of her sons. For the past two years she has lived at Ann Arbor, where her sons were attending the University of Michigan, and has now moved to Cambridge that the young men may finish their collegiate course at Harvard.

THERE are many uses to which humor may be put, and one of these might well be to restrain the humorist from being amusing at the wrong time and in the wrong place. It is a commonplace for lovers of poetry to sigh: "Oh, that Wordsworth had possessed a sense of humor and had spared us much that was maudlin and more that was dull!" A more subtle accusation may be brought, however, against such a poet as Sidney Lanier, who lacked humor sufficient to restrain his humor. No lover of Lanier at his best can bring himself to endure the presence in his volume of the poems which the author was pleased to consider humorous, and which it seems rather too confiding of his publishers to offer to a public that is under the necessity of judging Lanier by severe standards as the result of the high position now accredited to him. A well-developed sense of humor would have shown the writer of "The Marshes of Glynn" that it was not his *metier* to be amusing, and that, indeed, he could not well be amusing without being ridiculous.



JAMES HUNEKER

Dramatic editor of the New York *Sun*, author of "The Iconoclasts," etc.

WILLIAM Vaughn Moody is industriously at work upon a volume of short poems—poems which, it is safe to say, will be greeted by the public with intense interest. Mr. Moody has expressed himself with a poetic truth and loveliness rare enough in these utilitarian days, and he has now to confirm the pleasant suspicion that he is a poet of sustained power. It is said that he has not yet entered upon the composition of the third book of his trilogy.



NELSON LLOYD

Author of "Mrs. Radigan"

AT the present time, in view of the great revival of interest in Victor Hugo, it may be of interest to recall a story concerning his relations with the late Louise Michel, the famous anarchist, who, despite the fact that she enjoyed world-wide notoriety as an anarchist, was universally respected for her boundless sympathy with all who suffered and for her heroic self-sacrifice. The incident was told by Hugo's private secretary, M. Lesclide, and published in the Parisian press at the time of his death, in 1885.

During the siege of Paris Hugo gave most liberally to the poor and necessitous. He was assisted in the distribution of his alms by his friend, Madame Paul Leurice, who was herself a most bountiful giver. One day Madame Leurice came to Victor Hugo, telling a pitiful story of a poor woman whom she had found in the most terrible state of destitution and *misère*. Hugo at once gave her a hundred francs for her needy *protégée*. Now, despite the high prices which ruled in consequence of the siege, a hundred francs could be made to go a long way in providing against starvation, so the poet was very much surprised to receive word from Madame Leurice next day that the poor woman was "as badly off as ever".

"Well, what of the hundred francs of yesterday, then?"

"Ah, the hundred francs. She has given them away to poor mothers, to little children, starving of hunger and perishing with cold."

"Good! Here is another hundred francs, but upon the express condition that she keeps them for herself."

"Is it only on that condition he gives them?" asked the poor woman when Madame Leurice gave her the poet's message.

"Exactly."

"'Then take them back! Thank Victor Hugo for his good intentions, for which I am grateful."

Madame Leurice was embarrassed. She dared not take the money back to Victor Hugo, so, after scolding the woman and calling her "Obstinate Louise," she handed her the money unconditionally.

The "Obstinate Louise" was Louise Michel, the "Red Virgin." And the money was spent as before, to relieve other hungry women and their children.

"WHY, he's the translator of Maeterlinck," is the usual exclamation when one is asked something concerning Alfred Sutro, the dramatist. The book stores will assert that he never wrote plays, and you might believe them if you did not know that several of his dramas had been presented in London last year, and that two or three were to be given here; one, "The Walls of Jericho," with James K. Hackett in the leading rôle, and another, "The Maker of Men," a curtain piece for Margaret Illington. But if English critics can be relied on, his plays are of conventional design; yet of Alfred Sutro, the translator, naught can be said but that he is excellent. The beauty of Maeterlinck in English reveals a keen sense of the Belgian's style. There seems to be a poetic sympathy existing between these two men; the most fluent English takes the stead of the most fluent French. This is a rare instance of a man winning reputation as a translator. Marcel Schwab's French

version of "Hamlet" is another example, and in German the Shakespeare of A. W. Schlegel. As for Fitzgerald, Omar became English—changed his Persian personality for an alluring dress of another land. But Maeterlinck loses naught of his full value.

It is to be deplored that we Americans miss so much of what is written about the English stage—and the foreign also. William Archer's "year books" are not as full as they should be, and in America, outside of the theatrical journals, there is no yearly record of the drama easily accessible for the library. And after a season's work are there not some criticisms worth preserving? It would take comparatively little trouble to systematize our dramatic records for future reference. Where look for something concerning Alfred Sutro? We need a dramatic guide. Apropos of this subject it is a welcome announcement that comes to us concerning George Bernard Shaw. Nowhere has he been more brilliant than in the dramatic criticisms he used to write some years ago; and nowhere were they accessible save in the files of the London *Saturday Review*. They have now been gathered together and will soon be issued in book form.

IT is a curious thing that the American issue of Swinburne's poems should not include the trilogy dealing with Mary Stuart. It is, perhaps, not too much to claim for them the high-water mark of the poet's psychological achievement. These dramas have a robustness about them too often lacking in Swinburne's work. His incomparable preciosity too frequently submerged his intellectuality, and he gave to his listeners the rhythmical clamor of poetry without its substance. But in the Mary Stuart plays, character after character appears in full stature, with enigmatic soul made lucid, and placed properly in that dark tangle of ambitions and hates and passions which gave to Scotland one of the most sinister and fascinating of her historical dramas.

WHEN Miss Cather, author of "The Troll Garden," was not quite nine years old her father moved from the Shenandoah Valley to a ranch in the southwestern part of Nebraska about ten miles north of the Kansas line. The years when she first began to notice surroundings at all were "pretty much devoted," she says, "to discovering ugliness. . . . You can't imagine anything so bleak and desolate as a Nebraska ranch of eight or nine years ago." Most of the Cathers' neighbors were Swedes and Norwegians; and she remembers being taken to a Christmas entertainment at the Norwegian church, where the Christmas tree was "a poor, little, naked box elder wrapped in green tissue paper cut in fringes to look like foliage." From 1890-1894, while she was at the state university at Lincoln, there was a steady drouth over the country which plunged the Norsemen into a grim and dreadful despair, and brought forth only suicides and broken households. Miss Cather said once that no matter how great may be its prosperity, whenever she revisits the country she sees in the background the old tragedies that she knew so intimately. She has been out there this summer working on a novel which a friend who has seen it declares to be of a rather dark cast,—shadowed, it may be, by the "old tragedies."



MARY STEWART CUTTING
Author of "Little Stories of Courtship," etc.

MR. RANDALL PARRISH is to the front with another novel—his third. "A Sword of the Old Frontier" is the characteristic title. Pontiac's conspiracy is the subject, and it is one sufficiently thrilling to suit even Mr. Parrish, that lover of excessive danger and true love gone wrong. Raoul de Coubert, sometime captain of hussars in Languedoc, is the adventurous hero, whose indomitable struggles and marvelous escapes are said to hold the reader's attention to the end. Mr. Parrish's previous novels have proved to be extraordinarily popular. It is prophesied that "A Sword of the Old Frontier" will prove to be as fascinating as its predecessors.

Another novel to be published by the same house—A. C. McClurg—is "Ben Blair," by an author new and untried, Will Lillibridge, in whom the publishers have great confidence. It is the story of a cowboy handicapped in life and love, who wins out, as a good cowboy should. The atmosphere and the incidents, the character of the hero and the nature of the victory which concludes a story of love and adventure, all recommend themselves to the judicious lover of romance, so it is said. Both of these novels are finely illustrated.

ONE result of the centralizing of the circus business and the enlarging of the shows has been the elimination of the old-time fun of the clown, who now finds the tents too large in which to make his voice carry to the thousands of auditors, and has to resort to the pantomime art of long ago. Time was when pantomime was almost as popular in this country as it was in England, France or Italy, where it was considered the basis of all stage acting, and where aspirants for dramatic honors learned it as the first step toward their goal. There are those still alive who remember with keen delight the remarkable pantomimic art of George L. Fox and his astonishingly clever imitations and caricatures of the great actors of his day. Tony Denier, one of his associates, is living yet, we believe, forgotten by the generation which enjoyed his silent comedy and unknown by that which now leans to other forms of amusement. After these men the Kiralfy brothers introduced slight touches of pantomime in their productions, and the Hanlons went a little farther, but were more acrobats than real pantomime actors. Even in England the taste for pantomime survives only in the annual productions at Christmas time. That an appreciation of pantomime still exists in America was proved by the success which attended the visit here several years ago by a French company of great ability.

IT is interesting to read the comments made upon the spiritual inheritance of Secretary of the Navy Charles J. Bonaparte. His name is one which summons swift recollection of the good little adage, "blood will tell," but our American editorial writers are jealously claiming for an American mother the honor of transmitting to Mr. Bonaparte those qualities of fearlessness, decision and civic rectitude which have caused him to be appointed to his present high place. That he is the grandson of a king seems to them, in view of certain acts of that evanescent monarch, to be a fact best honored in the forgetting. But the down-east Yankee mother of Mr. Bonaparte, a woman of sufficient strength of opinion to sustain her northern principles in spite of her alliance with a Baltimorean, is accredited—justly, no doubt,—with having passed on to her son those characteristics which have made him an aggressive reformer and a politician of impeccable honor. He knows how to go down with the right and to make a victory out of the defeat, as was shown in his long fight with the forces of corruption in the municipal politics of Baltimore. He is a man of sufficient independence to excoriate the members of his own party when he finds them running counter to the ideals which they are supposed to cherish. He has given the prestige of his name and his character to a party which, in the section from which he comes, suffers from being in a negligible minority, socially inconspicuous and pining from a merciless stigma. He has been with the under dog, and has contrived, by methods which commend themselves to all honest men, sometimes to get the under dog on top. He is an intense American in his ideals and principles, notwithstanding the ease with which he could lay claim to aristocratic advantages. "A good citizen," he declares, "needs no grandfather." This remark was

not, it must be noted, made with copybook obviousness, but was spoken spontaneously and wittily in connection with the disfranchising act for Maryland, which contains a "grandfather" clause.

AFTER a protracted period of apparent inactivity M. Rostand has appeared in Paris with the manuscript of a new play. It is called "Chanteclair," and all the characters are birds. Coquelin is to represent *Chanteclair,* and he and the other sixty personages in the play will appear dressed as birds. The play, as usual, is in the familiar couplet form of French verse, and it is satirical in character. It is to be produced at Coquelin's theater after three months of rehearsals, a provision on which M. Rostand is said to have insisted. One may reasonably expect something charming and piquant from a theme like this handled by such a master, although it is almost too whimsical to promise extended life. Talented as M. Rostand is, it is noticeable that he is prone to use ideas already exploited, although his apparent appropriations may be more or less unconscious. The controversy over the authorship, or perhaps priority of idea, of "Cyrano" is well known, and his indebtedness to previous authors for his "L'Aiglon" was still more apparent. The conceit of this new play is as old as Aristophanes, and even in America within a year we have had a comic opera in which all the characters were dressed as birds, and the stage was made to represent a huge bird-cage.

PAUL Elmer More is one of those fortunate journalists who has the happy distinction of combining a high quality of scholarship with a facile pen. There is a certain timeliness in what he writes that is journalistic; there is also a leisurely vein which suggests the easy chair. It is not incompatible that a journalist's work should have in it the element of permanence; what we mean by timeliness, however, is in contradistinction to such essays as those comprised by W. C. Brownell in his "Victorian Prose Masters," which are estimates intended for the library rather than for readers of the magazine or the newspaper. Mr. More's latest volume of "Shelburne Essays" is witness to what we mean. His "Elizabethan Sonnets" is apropos of Sidney Lees's recently compiled volumes on the subject; his "Lafcadio Hearn" appeared soon after the death of that author in 1904; his "Hazlitt" and "Lamb" were both called forth by those exhaustively personal editions of the essayists which the publishers



PAUL ELMER MORE

have been issuing within the past months, and so on through the book. Mr. More has a wide knowledge of English and classical literature, and his duties as literary editor of the New York *Evening Post* afford him ample opportunity for using it in the right direction.

MR. Hamlin Garland is off again to the mountains. He has with him the same guide who accompanied him to the Yukon, and who on this occasion will lead him over twelve hundred miles of wild mountain travel, the destination being some lofty and splendid peak of the Rockies in Montana. On such an expedition Mr. Garland himself performs the more arduous tasks, such as loading and unloading the pack train, pitching the tents, cooking the

meals, etc. For a man who has been so acutely conscious of the pain of labor, Mr. Garland seems willing to assume a disproportionate amount. But he would probably say that there is a world of difference between the toil of a man who is tied to it like Ixion to his wheel and the *insouciant* assumption of labor because of the zest it gives to life.

IT seems to be the consensus of opinion that Mr. Swinburne's novel, "Love's Cross-Currents," written in the poet's youth and exhumed by Mr. Theodore Watts-Dunton, is a "school-girlish performance." The characters are trivial gossips, the ideas are conspicuous by their absence, and the book drags its slow length along without sweetness and without light. Mr. Swinburne's luscious lyricism has won for him a high place among poets. So enchanting has been his melody that the comparative absence of ideas has been overlooked; but the puerilities of this novel of his youth throw another light upon his character, his culture and his dreams.

IS Mr. George Ade going to become a dramatist? That is the question his friends are asking with a good deal of eagerness and expectancy. At the beginning of his composition for the stage his pretensions were accepted lightly. It was taken for granted that he would do a few popular pieces, make a snug fortune, reform and live a better life. But it is not to be denied that the young man develops. "A College Widow" has proved to be an innocuous, engaging satire, amusing enough to divert even the middle aged, and full of situations and characters that delight the young. It breathes, indeed, the spirit of youth. The thought is young, the story very, very young; the joy is of the young variety, and there is no sorrow. No more charming, innocent and gay satire has ever been put on the American stage, or, one might venture to say, upon the stage anywhere. Satire is usually written for the sophisticated. Even the delightful libretti of Gilbert revealed sophistication. But Mr. Ade's plane of thought as indicated by "The College Widow," hardly goes beyond adolescence—and is all the better for it, too. Young folk adore the drama, but there is not, once in a blue moon, anything to which it is an undefiled pleasure to take the growing inmates of the household. Mr. Ade's play is an exception. It is within the realm of possibility that Mr. Ade may not consider this praise. But why should he not? So many have written dramas for the sinful, the tempted, the learned, the sophisticated, that he, at least, may be willing and proud to write for that large constituency of innocent and lighthearted persons and for that yet larger company who, knowing of the pain, the struggle and the sin of the world, are quite willing to forget it for one pleasant hour in which their youth attains a partial recrudescence.

Down at his fine farm in Indiana Mr. Ade has completed two more plays, which will be presented this winter, one to be called "The Bad Samaritan," and the other "Just Out of College."

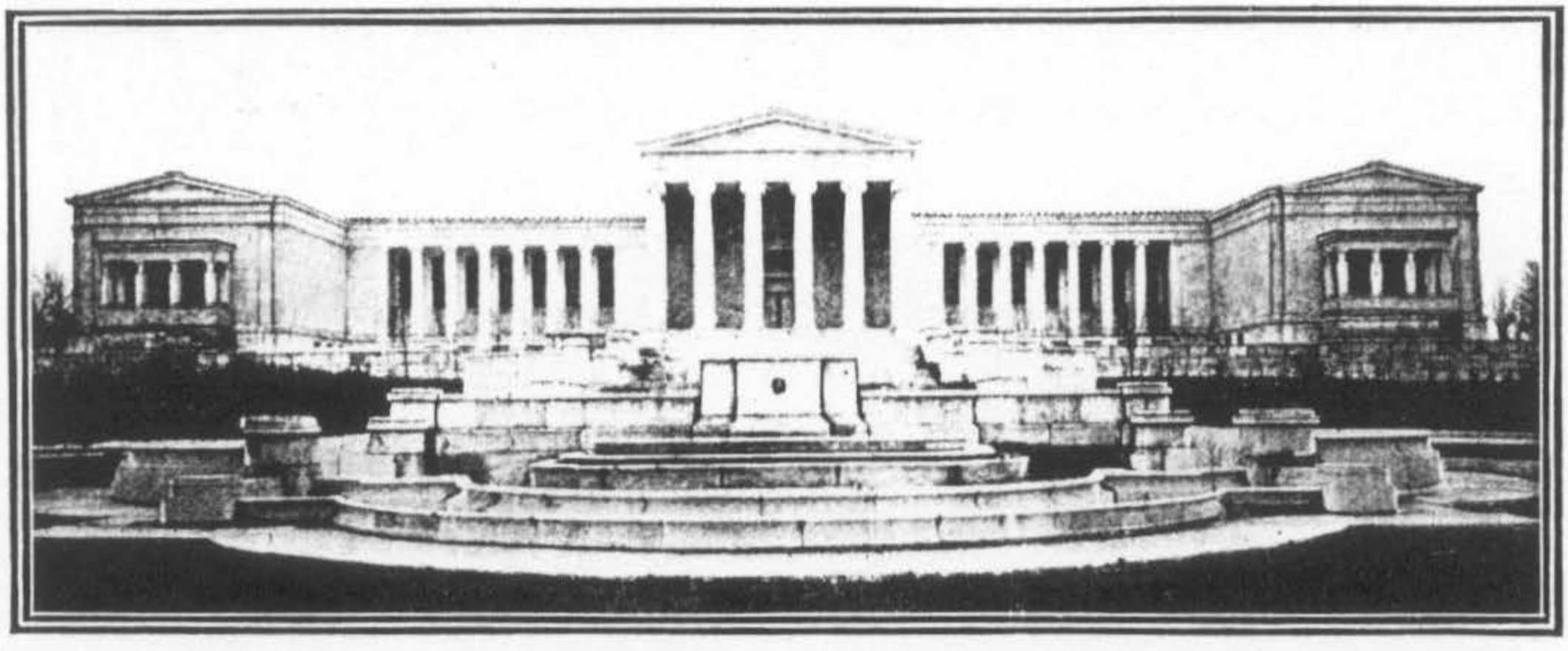
IT may not be recognized among the non-musical, but it is a fact nevertheless, that the number of musical festivals is continually increasing in the United States. Several villages, both North and South, have their spring or mid-winter festivals, their seasons of oratorio or concert-opera, and Scotch-Americans, Irish-Americans, Welsh-Americans and German-Americans, all have their respective singing societies. Among the leaders in work of this class is Tali Esen Morgan, who has organized and who trains and leads at least six fine choruses. The largest of these is at Ocean Grove, where four hundred voices are trained and supplemented by orchestral accompaniment; another is at New York, where the chorus consists of three hundred and fifty; the one at Philadelphia includes three hundred voices; that at Cumberland, Maryland, two hundred and fifty; that at Thousand Isles two hundred and fifty, and the one at Pittsburg one hundred.

All the best in oratorio, cantata and song cycle, with orchestral accompaniment, has been presented by Mr. Morgan's choruses. Mr. Morgan frankly avows himself the advocate of popular musicianship. These ideas he brought with him from the old world, to find that in America they were at a decided discount. Sight reading was an unknown art, and he can felicitate himself on having

taught at least five thousand singers the art of sight reading. It is, therefore, no formidable undertaking for him to produce a new work, and it is not too much to say that the existence of such choruses as his acts as an incentive to composers to prepare musical works for their production. Seven years ago, when Mr. Morgan began his work, there were no musical bodies outside of the Apollo clubs of the large cities capable of presenting such works as the "Messiah" and "Elijah." At Ocean Grove, this summer, Mr. Morgan's chorus has presented these oratorios, and Stainer's "Crucifixion," Dr. Adam Geibel's "The Nativity," Gaul's "Joan of Arc," and Cowen's "Rose Maiden." Mr. Morgan has, it is said, a winning personality. He is a modest man, and one that can talk about something else besides music when the occasion demands.

WHEN Clyde Fitch rests it means that he goes off somewhere and writes hard and persistently. This very quality of untiring effort on his part is perhaps his greatest weakness. Mr. Fitch has remarkable cleverness as a practical playwright; in many of his plays he has come very near permanent satire; his dialogue is usually crisp and ofttimes brilliant. His enemy is his haste; he often writes before the idea has crystallized, and this is not so with Henry Arthur Jones or Pinero. Yet Mr. Fitch rarely ever fails to interest. When he returned from abroad this year he brought with him a play of George IV's era, for Viola Allen, called "The Comedy Mask," and also a revised text of "His Grace De Grammont" for Otis Skinner, though we hope this actor has not abandoned his intention of playing Richepin's "Don Quixote." Mr. Fitch has also written "Her Great Match" for Maxine Elliott, and helped turn Alfred Henry Lewis's "Wolfville" into a play. Naturally Mr. Fitch leads in the productiveness of the American dramatist; he is closely seconded by Augustus Thomas, who generally conceals the names of his plays until the last moment; then follows George Ade, whose pieces are stamped all over with American humor, even to their titles, such, for instance, as the new ones, "Just Out of College" and "The Bad Samaritan." Ella Wheeler Wilcox has essayed a drama, which she calls "Mizpah;" and "The Letters of a Self-Made Merchant to his Son" has not escaped the stage, for "Old Gorgon Graham" is announced for early production.

ROBERT Hitchens is to follow "The Garden of Allah" with "The Black Spaniel." No doubt the worshipping admirers of the former will approach the latter with some apprehension, for they must know that only a remarkable production could interest them as vigorously as did "The Garden of Allah."



THE ALBRIGHT ART GALLERY, BUFFALO

The Colorado Springs Gazette November 19, 1905

NICOLA TESLA MUST PAY UP

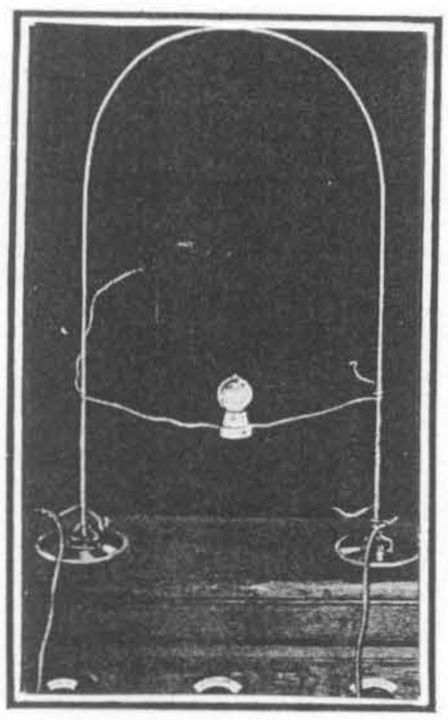
C. J. DUFFNER GETS JUDGMENT AGAINST FAMOUS INVENTOR IN THE DISTRICT COURT.

Judge Robert Kerr in the county court yesterday sustained the attachment of the plaintiff in the case of C. J. Duffner vs. Nicola Tesla, and entered judgment for the plaintiff for the sum of $789.59, together with $100.63 interest to the commencement of the action and $29.35 to the date of trial, making a total of $928.57.

HIGH-POTENTIAL DISCHARGES.

BY A. FREDERICK COLLINS.

The various manifestations of high-frequency and high-potential discharges offer a fertile field of research, especially for the amateur investigator, since it is a subject that has received comparatively little attention considering its significance as revealed in its recent applications to electrotherapy, radiography, and wireless telegraphy.



LIGHTING AN INCANDESCENT LAMP SHORT-CIRCUITED WITH HEAVY COPPER.

The current has the choice of two paths—an easy one through the copper bar and a path of higher resistance through the lamp—and it chooses the latter. Ordinary currents would take the easier path.

The term "electric discharge" is understood to include all modes of equalization of differences of potential between the terminals of a source of electrical energy on their connection by a conductor, by the removal of their charges by a stream of electrical particies of air, or by a sudden discharge that breaks down the air or other intervening dielectric. These are the three chief methods of restoring the electrical equilibrium, and are known respectively as the conductive, the connective, and the disruptive discharge.

The various forms may be further subdivided into alternating, arc, brush, brush and spray, dead-beat, flaming, glowing, lateral, oscillating, periodic, streaming, stratified, impulsive, and periodic discharges, and these may be produced by utilizing a source of direct or alternating current of low voltage, as for instance a commercial generator; a high-potential apparatus as an induction coil, or a high-potential, high-frequency arrangement, as a Tesla coil, depending upon the requirements of the various cases.

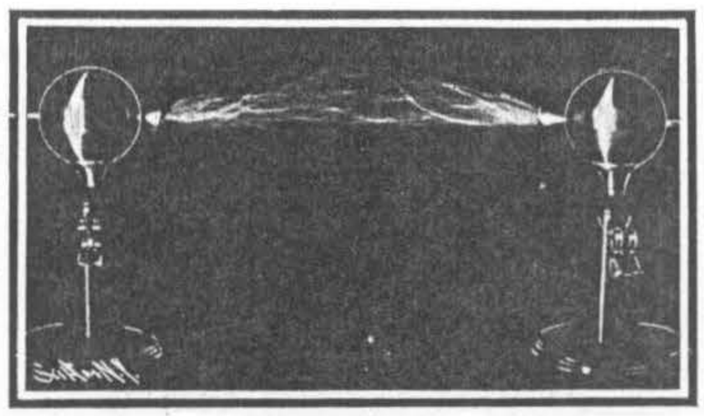
In this review we are concerned only with disruptive and connective discharges, the former in its application to wireless telegraphy and the latter in its relation to the human body. Since only potentials such as can be obtained with an ordinary induction coil are needed for disruptive discharges, these will be described first.

In the production of a discharge of this nature there are two diametrically opposite conditions involved, the first representing an oscillator and spark-gap in an unenergized and non-conductive state, and the second when it is energized and rendered highly conductive, thus completing the circuit. To bring about this result the arms of the oscillator are charged with high-potential energy impressed upon them, which is set up in the secondary of the coil in the form of currents. This kinetic energy is then converted into electrostatic energy, and when the static charge is maximum for a given resistance offered by the dielectric between the surfaces of the spark-gap electrodes heat is evolved in consequence, and when a certain critical temperature is reached the positive electrode volatilizes, and it is this effect that forms the initiative in breaking down the dielectric of the spark-gap.

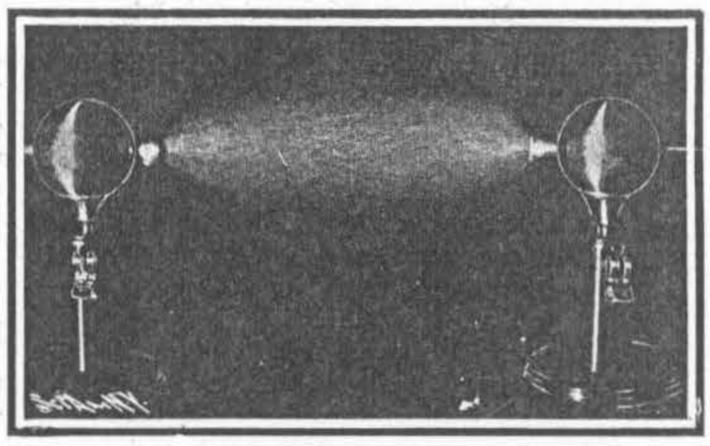
The law relating to the heat evolved states that it is proportional to the square of the charging current and to the resistance of the dielectric between the positive and negative electrodes forming the boundaries of the spark-gap. The energy that is emitted from the positive electrode is proportional to the potential difference impressed on the oscillator system and the specific inductive capacity, while it is inversely as the distance separating the spark-gap electrodes. The length of the spark that passes depends also largely on the following factors, namely, the difference of potential between them, the character of the medium that separates them, and on the density or pressure of the dielectric through which the discharge passes.

A decrease in the pressure of the medium serves to increase the distance through which a spark will pass, but a point is quickly reached wherein a further decrease has the effect of cutting down the length of the spark, and hence where a low vacuum will permit the passage of high-potential currents over longer distances than in air, a high vacuum retards them even though the potential may be considerably increased. Then again the metal of which the electrodes are made determines the sparking capacity to a certain appreciable extent since some retard and others assist the process of volatilization, and finally the size and shape of the spark-gap-electrodes also have their effect upon the discharges.

From these considerations it will be observed that when the electrodes are placed closely together the strength of the charging current is increased, and hence the heat developed causes the temperature to rise. When the sparking distance is greater than the maximum difference of potential can easily break down, a faintly luminous discharge will be seen issuing from the positive electrode, especially if it should present any sharp points. This phenomenon occurs in virtue of the fact that metallic points are more easily heated than those in the form of spheres.



HIGH-FREQUENCY ARC DISCHARGE.



HIGH-FREQUENCY STREAMING DISCHARGE.

When the charge and temperature reach a critical value a conducting microscopic thread of gaseous vapor is developed and this is attracted to the negative electrode, to which it passes by the path of the least resistance. When this filament bridges the gap its diameter is very greatly increased, the resistance that was previously enormously high becomes minimum, and the current surges forth and back until the energy of the system is damped out by the sum of the resistances.

While Tesla was not the first to produce the varied and beautiful forms of convective discharges he was probably the first to systematically investigate them. Though convective discharges may be frequently observed from a pointed positive electrode of an induction coil, they are much more intense and brilliant when the potential and frequency of the oscillations are stepped up by means of a secondary transformer.

The compact apparatus for obtaining high-frequency and high-potential discharges shown in the illustrations was designed by Prof. Ovington, who repeated many of Tesla's experiments and introduced several new ones during the recent electrical exhibition at the Madison Square Garden.

With high potentials and high frequencies the electrostatic field is collapsed more easily than when those of lower value are reached, while the oscillations increase the temperature developed by the transition of static into kinetic energy and for this reason the volume of vapor is increased and an arc discharge results.

The flaming and streaming discharges which are forms of the connective discharge are closely allied and occur when the frequency and potential is increased beyond a certain value; under these conditions the discharge assumes definite characteristics wholly different from those of the disruptive discharge. In these



BURNING PLATINUM WIRE WITH CURRENTS PASSING THROUGH THE BODY.

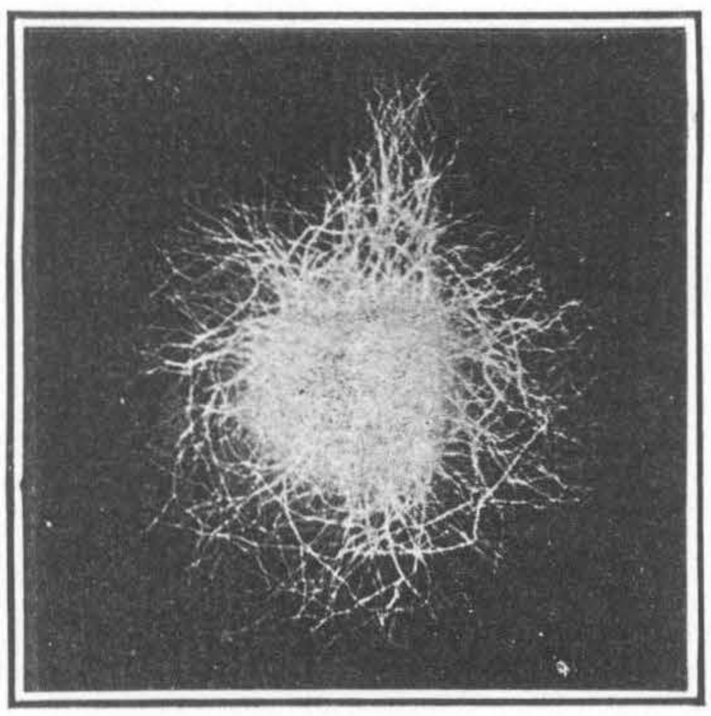
A platinum wire is held in the fingers and near one terminal of the machine. The spark jumps to the body and through the wire.

forms of discharge the energy passes between the electrodes as luminous streams. Such discharges obtained with high-frequency coils are different from those obtained with electrostatic machines, as they lack in the violet color developed by the positive static electrode as well as the bright glow of the negative electrode.

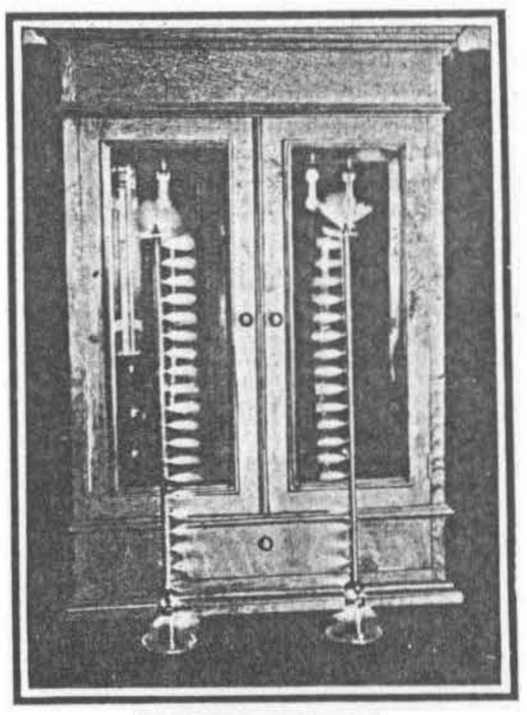
When the frequency and potential necessary to produce the flaming and streaming discharges is increased new phenomena result and a brush and spray discharge is obtained. With suitable electrodes comprising a large number of small points the emanations resemble jets from a gas-flame escaping under high pressure. According to Tesla "they not only resemble but they are veritable flames, for they are hot. Certainly they are not as hot as a flame of gas, but they would be so if the frequency and potential would be sufficiently high."

If the frequency and potential is further increased, the discharge will pass through several inches of solid glass. Ordinarily glass is an insulator of electricity, and yet in this case the streams flow through it apparently with the greatest freedom. The flow of luminous energy has a tendency to stream out and to be dissipated to such an extent that when the brush is produced at the positive electrode no disruptive discharges will occur, even though the hand or any conducting object is held within the stream, and what is even more singular, the luminous stream is not at all easily deflected from its path by the approach of a conducting body.

Under these remarkable conditions the energy loses its property of producing sensation when it comes in contact with or passes through the human body, and a person may now be connected with the source of high-potential and high-frequency currents and be completely charged, though he will feel nothing; that he is a portion of an oscillator, however, can be readily determined, for if a vacuum tube is brought near any part of his body it will glow due to the electric waves emanating from him. To illustrate how absolutely devoid the sensory nerves are to these currents, a



THE AUTOGRAPH OF AN ELECTRIC SPARK, WRITTEN ON A PHOTOGRAPHIC PLATE.



ELECTRIC TESTS.

The current issues at an enormous voltage from a large number of small points, so that it seems like jets of burning gas escaping at high pressure.

vacuum tube may be held in the mouth, and a current passed through the lamp lights it and then continues on its course, passing through the membranes of the mouth, which are perhaps the most sensitive of any in the body, yet no sensation whatever is experienced. A half-dozen incandescent lamps may be lighted with current passing through the body and no sensation is felt although instant death would result were the rate of oscillation reduced within certain limits.

To show the impedance a copper bar of large diameter offers to a high-frequency current, an incandescent lamp is short-circuited across the former and the current is thus given the choice of two paths, an apparently easy one of small ohmic resistance and high impedance through the copper rod, or a seemingly more difficult one of large ohmic resistance and low impedance through the lamp. While an ordinary current would of course choose the former, the extraordinary current traverses the latter path.

The practical application of these discharges is found in radiotherapy. Their use is being extended more and more, and by many it is considered a rational method in therapeutic practice. Heat, light, and electricity when properly applied have accomplished surprising results. With the apparatus shown not only are all the various remedial manipulations of electricity available, but current is also supplied suitable for producing the X-rays, ultra-violet light, etc.

Tesla Split-Phase Patent Litigation.

On January 19 Judge Kohlsaat rendered an opinion in a suit on final hearing involving the validity of the 1893 Tesla split-phase patents, the parties to the suit being the Westinghouse Electric & Manufacturing Company, complainant, and the Electric Appliance Company, defendant. The defenses in the suit were, first, that the claims at issue in the two 1893 patents are void for double patenting by reason of the grant to the same inventors of an earlier patent dated April 16, 1889; and second, that each of the patents in suit expired in the year 1903 by the reason of the expiration in that year of two British patents granted in 1889.

The court in its opinion stated that according to established judicial precedents, if the difference between the claims of the 1893 patents and those of the 1889 patent are only colorable, then either the former patents are void or the latter patent is void, but in fact, the later American patents were entirely unlike the earlier American patent, the latter being on means and the former a method. Assuming that Tesla had taken out the 1893 patents in advance of the 1889 patent, he would in them have disclosed all the elements of the latter patent, but being the inventor in both cases he would have had a right to proceed in this particular manner. To hold the two 1893 patents in suit to be identical with the 1889 patent would be to do violence to the facts and the rule of law; the contention of double patenting does not apply since the earlier patent covers a method for operating a motor by the means disclosed in the later patents. This being so, the 1893 patents were also in no wise affected by the expiration of the English patents, since these were nothing more than improvements upon the 1893 patents. The finding of the court was for the complainants.

The Colorado Springs Gazette March 10, 1906

TESLA'S FIXTURES IN SHERIFF'S SALE

FAMOUS INVENTOR'S PARAPHERNALIA TO BE SOLD TO SATISFY A JUDGMENT FOR $928.

The sale of a quantity of personal property belonging to Nicola Tesla, the famous electric inventor, to satisfy an execution issued out of the county court in favor of C. J. Duffner, for $928.75 and costs, was scheduled to be held yesterday but was postponed by consent until 10 o'clock on the morning of March 22. The property held by the sheriff consists of 27 cases of goods and 10 coils of copper wire, all of which was levied upon in Tesla's experimental station on Nob hill.

Marconi Says—"Ten Years From Now We May Be Talking With the Inhabitants of the Planet Mars."

By Guglielmo Marconi.

In ten years, probably much less, the world will be able to send messages to Mars directly and unhesitatingly, without a hitch or a stop or a word lost in space. If there existed any accurate knowledge in relation to the possibility of Mars being populated by intelligent beings, and if there existed a commercial necessity for communication with that planet, and if such communication could be rebuilt into profit for a commercial organization, I am certain that the attempt would be made in even less time than I have indicated. That it is possible to transmit signals to Mars I know, as surely as if I had a gun big enough or powder strong enough to shoot there—more surely, in fact, for a gun might miss the mark, while my wireless will strike the entire solar system without aiming.

Attempts to communicate with that planet in the absence of any certain information that there are inhabitants there of sufficient intelligence to recognize our signals as such, and with knowledge sufficient to enable them to translate such signals into their own language, if they possess a language, would be without any certainty of results.

Mars and our earth lie in the same great unbroken bed of ether. We know this because all signals long the beams of the sun reflected from Mars's red surface stream down the astronomer's telescope.

Wherever these rays can travel the ether exists, for light is only a vibration or wave of the ether, and the electric disturbances caused by the wireless travels in the same way. If there were a gulf in the ether we would see it, perhaps like a crack in a great block of ice, and Mars and all on the other side of the crack would be invisible.

If our nearest planetary neighbor floating off yonder 35,000,000 miles away is inhabited, it will soon be fairly pelted with messages transmitted with as much certainty and accuracy as were the messages which I recently transmitted from the company's station at Poldhu, in Cornwall, to H. M. S. Renown, while en voyage to India, bearing the Prince and Princess of Wales. These messages were received on board the Renown until she was within one hundred miles of the Port Said entrance to the Suez Canal.

In order to reach the Renown at that place it was necessary that the messages cross the English Channel, over the Islands of Jersey and Sicily, over the entire width of France, crossing the Cote-d'Or Mountains, the cities of Orleans and Auxerre, the Alps, Mt. Blanc, town of Lausanne, Switzerland; Lake Geneva, the Italian cities of Milan, Parma, Modena, Bologna and San Martino, crossing almost the entire length of the Apennine Range, the Adriatic Sea, Turkey, the Rimbus Mountains, Greece, City of Athens, Mt. St. Elias, crossing the Grecian Archipelago, the Aegean Sea, Karpathos Island and a portion of the Mediterranean.

This feat of transmitting wireless telegrams over a combined route of land and water for a distance of 2,100 miles is even more difficult than sending messages through interstellar space where no obstacles intervene.

It is not within my province to say that Mars, Jupiter or any other planets are inhabited; but if they are, and their inhabitants have our senses, they may recognize the new and unnatural disturbances that will be caused about them.

During the past few months wireless telegraphy has progressed with such tremendous and gratifying strides that one might venture almost anything for it and yet be within the bounds of possibility and even probability.

This progress is best illustrated by my recent invention, by means of which I am enabled to direct my wireless messages to a given point with as unerring accuracy as we are now enabled to focus rays of light by means of the lens upon a given point. Recently from the Poldhu station, before referred to, in a test conducted by the British Admiralty, I sent messages to one of the squadron lying at anchor in the harbor of Gibraltar. The commander of the other ships composing the squadron were instructed by the Admiralty to intercept this message if possible; to confuse it if possible, and to divert it if possible. Nevertheless, under the rigorous conditions prescribed by the Admiralty I was able to communicate with the vessel selected. Messages were uninterrupted, uninterrepted, unconfused. None of the other vessels was able to receive those messages.

Subsequently I was able to follow the course of the vessel in question in its voyage through the Strait of Gibraltar, up the coast of France, back to its home station in British waters, all the while preserving the secrecy of the messages invisible from the attempts of other wireless installations to confuse and to intercept them. This was as severe a test as ever wireless telegraphy has been compelled to undergo. Those messages were transmitted across the English Channel, across the entire length of the Spanish peninsula, over the Cantabrian Mountain, over the Sierra Candrama, the Sierra Toledo, Sierra Moreno, Sierra Nevada and also over the important cities of Valladolid and Seville.

Martian Knowledge Will Overwhelm Us.

If we are able to send signals through space over such intervening obstacles as mountains, forests, cities, liberating vast quantities of electricity, and yet safely deliver them at the point of reception undistorted and unconfused, it follows as a natural deduction that it is merely a question of commanding sufficient power to set up the necessary disturbance in the ether where there are no obstructions intervening to send signals to even so distant a point as Mars.

If Mars answers and tells us his history, then, for the first time on earth, imagination and discovery will be of little use to humanity in the face of the flood of actual information which will roll in as fast as our intelligence can apprehend it.

Had any one in his sober senses predicted a generation ago that Europe and America would today be communicating with each other without any material agency between the sending and receiving points he would have been adjudged insane or would have been ignored as a crank.

Yet today wireless telegraphy has progressed to such an extent that it is actually accomplishing that very thing. Within a very short time it will be accepted as an ordinary fact—a matter of daily commercial routine. Instruments which I have perfected, sending messages at the rate of 200 words per minute, will enable us to send as many words in twenty-four hours through the medium of these two stations—one near Sidney, N. S., and the other on the west coast of Ireland—as are now transmitted by all the cables connecting Europe and America.

Why, then, should it appear preposterous to venture that within a decade, or even half the time, wireless instruments will be so developed and perfected that it will be possible to transmit a message through 50,000,000 miles of space? It is not only possible, but very probable.

It is likely, so far as the system has been evolved, that the first agency capable of rationally reaching as far as Mars, for example, will be the heliograph. And this is only natural.

Why? Because it is an accepted scientific fact that light carries a much greater distance than sound or its equivalent. But, while the heliograph will be the pathfinder through the immensities of space, there is every reason to believe that it will simply be the utilization of wireless telegraphy as it is now being developed.

It may surprise many people that Mars may not be inhabited by intelligent creatures who could understand in every major instance, our earth before they could travel here if not in a condition to be introduced to the people of other planets.

As a look for an answer to Professor Lowell, an astronomer of note and in good standing in his profession. Quite recently he succeeded in photographing the many Martian canals.

From these photographs it is certain they are not natural builders but instead intelligent beings. Their stupendous canal construction proves that the degrees are neither very small nor likewise and strength, but infinitly skilled and trained to the use of mechanical devices of a nature that could most easily and quickly convert allowing them to visit our planet.

Should the United States ever engage in war with another nation, New York could be made absolutely impregnable for the first time. How? By means of torpedoes operated and discharged by wireless telegraphy.

A Whitehead torpedo, properly equipped, can be launched, timed, and then, while under both water and ship, can be accurately discharged by wireless. It also has been proved conclusively in the course of a series of tests by the British Admiralty that cannon can be fired and all manner of signals given at long distance by the same method.

We have more real substantial information about Mars, our nearest neighbor, than of any other of the planets. Taken altogether, we know that Mars is very much like our earth.

When the southern pole is directed toward the sun it is Summer for the southern hemisphere of Mars; and Winter for the northern. The northern pole can be seen growing bigger and whiter, while the southern shrinks and darkens.

It is in connection with the melting ice caps that the famous Martian canals appear. As Mars has little rain and much sun, the globe would be a desert of ice at the poles, and dry land between, without some stupendous system of irrigation. And this is just what appears.

A network of fine lines running from the ice caps to the equator appears clearer and clearer as the warm season advances on each hemisphere and grows fainter during the cold. A ruddy brown area shows dark and spreading about the canals until toward the Fall of the season it changes the entire color of the hemisphere. This, most astronomers agree, can be nothing else than vegetation following the flow of water from the melting ice caps.

The canals are too straight and methodically arranged for nature or accident, according to the latest astronomical belief. An object to be visible in Mars must be at least twenty miles in diameter. As these canals were observed long ago with inferior instruments they must be much more than twenty miles across.

Even the heaviest and fattest human specimen would be an acrobat on Mars. He would vault lightly into second story windows and would find no difficulty in climbing the waterspout or the lightning rod. But the chances are he would feel very insignificant in the presence of the native Martian.

Mars, being smaller and lighter, one would think of pigmy inhabitants to correspond. According to Sir Perceval Lowell, Sir William Ramsay, M. Flammarion and other great authorities the Martians are giants. Their reasons are based on force of gravity, which is about a third on Mars of what it is on earth.

Supposing the Martian to be three times as large as a man. If he were on earth he would weigh 27 times as much as a man, and would be unable to support his weight, as the cross section of his muscle would only be nine times as great. But on Mars he would weigh only nine times as much as a man, and with his nine times greater muscles he would be able to support his mighty frame with as little fatigue as a man on earth. In performing work he would be twenty-seven times as efficient as a man were it not that Mars's lightness makes physical work only one-third as hard. Therefore, the work of a laborer on Mars is variously estimated at from fifty to eighty-one days' work of a man.

Professor Gregory thinks all Martian creatures have enormous chests to adapt themselves to the rarefied Martian atmosphere. Gills like those of a fish would be necessary to give such great volumes of air a short cut to the lungs.

Sir Robert Ball has conceived a Martian with a prolonged nose, or proboscis, and long, slender arms reaching to his feet.

These arms would be strong enough on Mars to carry him up the side of a house from window to window, or up the branches of a tree, without touching the feet at all.

Perhaps the strangest of all attempts to picture the beings on the red planet are those by Professor Flournoy, of the University of Geneva, who drew his ideas from Miss Elise Muller, of Geneva, a medium, who believed herself transported to Mars during her hypnotic trances, and reported what she saw on Mars' and 's strange, unknown planet called Ultramars. Professor Flournoy put her utterance into scientific shape. She saw strange, huge insects, with feathers and long necks, flying about in the dim twilight of Ultramars. Her Martian man is very human, save for his great size.

Emanuel Swedenborg, the great Northern mystic, believed he saw a Martian. The creature was much like a man. His face had a Mark's area about the lower part which looked like a board, yet he was hairless. He had no chin.

But all this is tributary to the vaster problem of interplanetary communication. If wireless, or the heliograph, proves Professor Lowell to be correct in surmising the Martians to be such a formidable race, we may be thankful that our red neighbor is so distant. Whoever succeeds in mastering the problem will alone be able to say with the poet, "I stole the secret from the stars."

How the Inventor of Wireless Telegraphy is Planning to Find Out if Mars is Inhabited and What Sort of People They Are

"Mars is Surely Inhabited," says Prof. Camillé Flammarion.

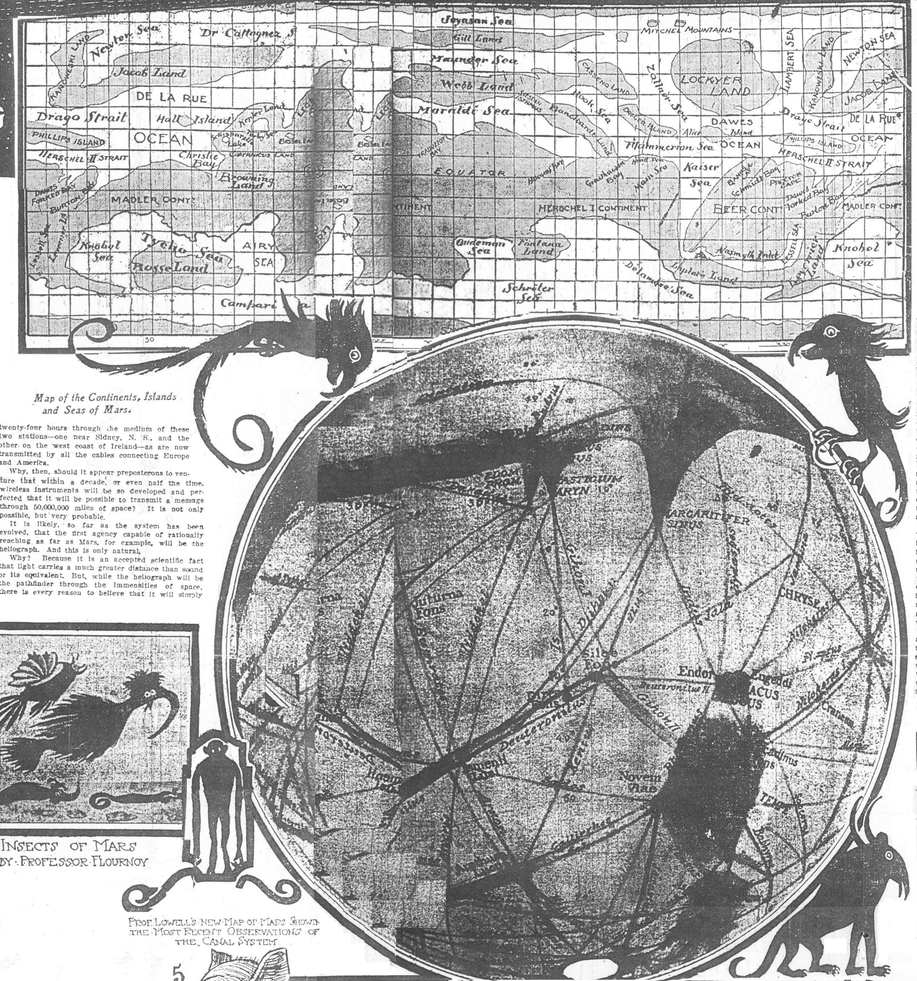
By CAMILLE FLAMMARION.

It is forty years since I began to study the possibilities of certain planets as habitations. Personally, I am certain that the planet Mars is inhabited. But how shall I prove this to you in a few words? Ah!

The question is much more serious, more vast and more complex than certain minds, even scientific ones, seem to consider it. This is largely so because the practical utility of such knowledge is small, and our present generation, brought up to consider only the worth of material interests, wishing primarily to earn money, are content to ignore unknown marvels. But there is an intellectual minority who are not satisfied to remain ignorant.

This intelligent minority know that the terrestrial manifestations of life do not set a limit to its possible forms, and that, elsewhere, our epoch is only a wave in the ocean of ages. As to what constitutes life, we usually recognize only that which exists about us. We believe that an atmosphere identical to ours is everywhere necessary to life; that there must be water composed exactly of two parts of hydrogen to one part of oxygen; a temperature neither too cold nor too hot. Such reasoning by human beings is the sort that fish may imagine in if they are capable of reasoning—unable to understand life out of the waters in which nature's resources are infinite.

In the first place, it would be difficult for any human species to be less intelligent than ours, since we do not even know how to live. Then, again, progress is an absolute law which nothing may resist. Therefore the inhabitants of Mars, older than we, may represent what our humanity will become in several millions of years. Another of their advantages is that they are better placed than we are to throw off more quickly the heaviness of matter. They weigh less, their years are twice as long as on our moving island. To conclude, their climatic conditions seem to be much more agreeable than ours.



PROF. LOWELL'S NEW MAP OF MARS FOUND THE MOST RECENT OBSERVATIONS OF THE CANAL SYSTEM



How Various Modern Scientists Have Figured



That a Dweller on the Planet Mars Would Probably Look.

1—Prof. Lowell's Idea of a Martian of immense size and great muscular power.
2—Prof. Gregory's idea that the Martians have great chests and gills like fishes.
3—The strange kind of giant Prof. Ball thinks the Martian is.
4—Another conception by Sir Robert Ball.
5—Emanuel Swedenborg's vision of a Martian.

"Only a Matter of Patience Now," Says Tesla.

By NICOLA TESLA.

With a billion horsepower drawn from Niagara I am going to signal Mars, and think for mankind.

My message will reach not only that nearby planet, but one hundred times farther, even to Neptune, which is so distant that day nor moon looks little bigger than a star.

Our generators will soon be complete, and the waters of Niagara Falls will supply me with a billion horsepower in the form of electricity. My tower at Wardenclyffe, L. I., will receive as much of this power as is needed. Only one one-hundredth part will be necessary to reach Mars.

Whether we get an answer or not depends on who is there. More than likely the first answer from our neighbor will be:

"Well—well—at last. We have been calling you the last ten thousand years."

Astounding as this prediction is—a prediction that is also a boon fully promised—it becomes even more astonishing when translated into plain terms capable of human comprehension. For it means that we are on the eve of sending communications into space for a distance of 4,800,000,000 miles. In other words, no planet within the solar universe will be outside the range of communication promised.

It will be as simple as telephoning from one part of a city to another after the preliminary attuning of instruments on the two planets and the study and interpretation of each other's codes and languages are done.

As the Martians are probably the most advanced and skilled they will take our code and language and learn it first and then teach us theirs in plain English. Difficult as this fact would seem, it in reality would not be comparable with the achievement of teaching a deaf, dumb and blind child to understand. Yet this is only a matter of patience.

Mars Would Learn English.

By using a little more power than is necessary to transmit a message to Mars, it will be possible to project a message across or through the 2,900,000,000 miles between ourselves and Jupiter. By using one-fifth of the Niagara Falls voltage, a message may be sent to Saturn floating off yonder 850,000,000 miles from the sun, or 735,000,000 miles from the earth. Even Neptune, the most distant planet in the solar system, will not be able to hide longer behind the 2,800,000,000 miles separating it from the earth.

Realizing the far-reaching importance of the stupendous riddle of universal communication, I have been proceeding slowly and carefully, but I have now reached the point where I am absolutely convinced of my ability to make the greatest dream of humanity come true.

My first step was to develop the magnifying transmitter. This met with such success that it is hard to form an adequate conception of the marvelous power of the unique appliance, by the aid of which the globe will be transformed. The electromagnetic pulsations being minimized and proper conditions of resonance maintained, the circuit acts like an immense pendulum, storing indefinitely the energy of the primary existing impulses and impressing upon the earth and its conducting atmosphere uniform harmonic oscillations of intensities which actual tests have shown to be capable of surpassing those attained in the natural displays of static electricity.

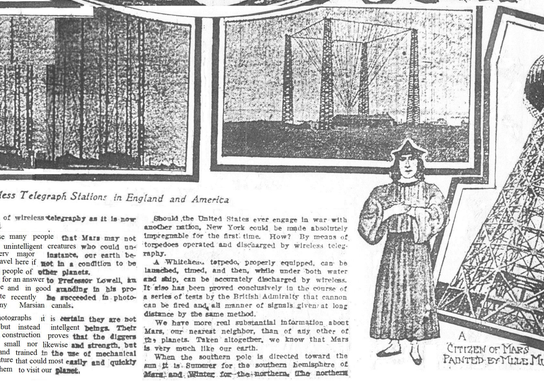
Briefly explained, my method, when fully inaugurated, will permit of a direct wireless service of thousands and millions of electric volts from the Niagara Falls plant to the great Wardenclyffe Tower, which is now practically completed, on Long Island. Wardenclyffe will be the main distributing point for sufficient wireless power, not only to illumine all of Greater New York, but to operate its elevated and subway trains and surface cars; to supply motive power to factories, automobiles, vans, ferryboats; to wind and regulate timepieces and to do nearly everything but think for mankind.

So stupendous is the capacity of the Wardenclyffe Tower, as compared with the Niagara Falls generators, that messages may be dispatched from it to Mars and millions of leagues beyond the red-named planet.

Other tributary towers are to be erected within a radius of three hundred miles of Niagara Falls, which will likewise supply them with electrical energy, each tower to distribute about ten thousand horsepower of wireless electricity under a tension of approximately one million volts or more, as occasion may demand, to cities, factories and private residences within a radius of thirty miles of each distributing station.

Eventually it is proposed to extend the system until the entire North American continent is fairly freckled with tower stations, about sixty miles apart, capable of operating the motive and stationary machinery of the United States, Canada, Mexico and Central America.

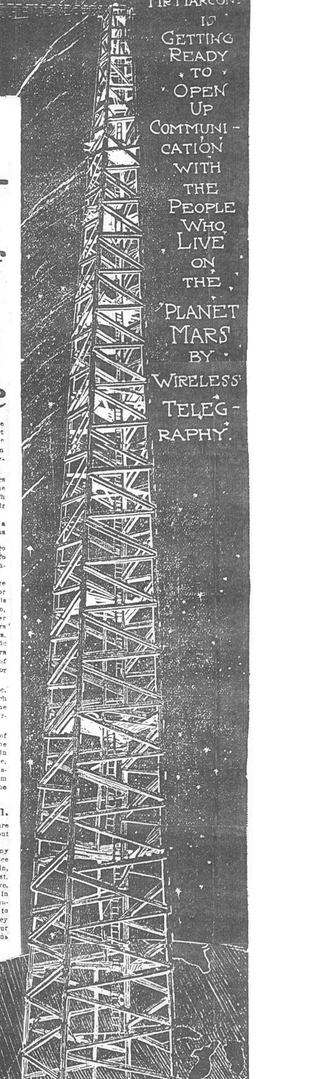
NICOLA TESLA.



Wireless Telegraph Stations in England and America

TESLA'S TOWER ON LONG ISLAND.

A CITIZEN OF MARS PAINTED BY HELENE MULLER.



The New York Herald March 11, 1906

TO SELL TESLA'S STATION.

[SPECIAL DESPATCH TO THE HERALD.]

COLORADO SPRINGS, Col., Saturday.—The experimental station which Nikola Tesla, electrical expert, established here six years ago, will be sold at auction by Sheriff Grimes on March 22, to satisfy a judgment for $928.57, in favor of C. J. Duffner, the caretaker. After a year of experiments with wireless telegraphy in high altitudes, Tesla went to New York, saying he would return in two weeks.

LEFT PROPERTY HERE; SKIPS; SHERIFF'S SALE

TESLA, FAMOUS INVENTOR, ENDS COLORADO CAREER.

EXPERIMENTS AT NOB HILL NOT SUCCESSFUL.

The beginning of the end of Nicola Tesla and his experiments in power transmission in the rarefied air of the Pike's Peak region, was witnessed by a curious crowd of electricians and the usual "sidewalk committee," at the sheriff's sale of the Nob hill station equipment, at the court house this morning.

From a business point of view, the sale cannot be chronicled as a success, for property said to be worth $4,000 failed to sell for enough to cover the judgment of approximately $1,100 standing against it. A specimen of the slaughter in values can be seen in the disposal of one of the articles, an electrical transformer, which went for about $10, or one-tenth its market value. The apparatus was bidden in by C. J. Duffner, who held the judgment on which the sale was based. The sheriff's hammer had hardly fallen, however, when the transformer was attached by an officer, under instruction from County Treasurer C. A. Pollen, who claimed $80 in taxes. This throws the taxes on the purchaser, but still leaves a good margin of profit.

The Duffner judgment was secured for services as caretaker. Tesla came in Colorado Springs in May, 1899, and remained until the following January, when he returned to New York. He expected to return to this city however, but soon after reaching New York became interested in a new station on Long Island and never came to the city. His actions would indicate that Colorado Springs and his work here dropped from his memory, for he allowed his property to go at sheriff's sale and failed to pay his bills, or even the accruing taxes.

The New York Tribune May 17, 1906

TESLA ASKS CHANGE OF VENUE.

Nikola Tesla's attorney yesterday applied to Justice Bischoff, of the Supreme Court, for a change of venue to Suffolk County in a suit brought by Frank W. Clark, a machinist, employed at one time by Tesla in his laboratory at Wardenclyffe, in that county, to recover $889 24 alleged to be balance due in wages, the suit having been brought in the City Court, Manhattan. Tesla said in an affidavit, after reciting that he had employed the plaintiff and paid him $743 76 in full, that he had never employed him for the services named in the suit, asserting that at the time of the alleged services at Wardenclyffe Clark was actually in the employ of Frederick C. Griswold at Port Jefferson. Decision was reserved.

WIRELESS AERIAL NAVIGATION.

Mr. Tesla's Experiments Antedating Those of Professor Bell.

TO THE EDITOR OF THE SUN—*Sir:* I am an assiduous reader of THE SUN, but somehow I overlooked a report contained in a recent number, which has just been forwarded to me through the courtesy of the *Electrical Review* and interests me keenly. During the last few days I have run across a number of newspaper comments and was wondering what had called them forth, until the clipping received enabled me to understand and trace to your columns of August 27 the origin of the disturbance.

I refer to an experiment supposed to have been performed by Professor Alexander Graham Bell, the inventor of the telephone, which consisted in propelling an aerial vessel by power transmitted without wire. This could have been practically accomplished only by the use of some of my inventions, and should I have been forestalled in this one of their many applications I shall have the satisfaction of knowing that it is by a man whose name is already linked with an immortal achievement. But if Professor Bell has undertaken this just to satisfy the world that an airship can be operated by power transmitted without wires he has gone to quite unnecessary trouble, for long ago I made a much better and further reaching demonstration. His experiment would only show that such can be done close to the source of electrical energy, but my experiments have established the fact that an aerial vessel or flying machine can be propelled with the same facility and efficiency either near the transmitter or at the antipodes.

The problem of aerial navigation was solved in the most satisfactory manner imaginable when, in the fall of 1899, I produced stationary terrestrial waves and passed a current equivalent to that of several hundred incandescent lamps around the globe. In a carefully prepared statement, which appeared in the *Century Magazine* of June, 1900, I have announced this advance in popular language, but clear and unmistakable. In my patents and technical articles, however, I have fully exposed my methods and appliances and given an account of my experiments; and the transmission of electrical energy without wires is no longer a secret to electricians.

NIKOLA TESLA.

NEW YORK, September 3.

The New York Herald November 26, 1906

TESLA ADMITS HE'S GREAT.

He Testifies in Court That He Is One of the Foremost Men of the Age.

PATCHOGUE, L. I., Sunday.—Nikola Tesla testified yesterday that he considers himself one of the greatest men of the age before Supreme Court Justice Jaycox, while defending himself in a suit for wages brought by a workman.

Frank N. Clark, of Port Jefferson, was employed by Tesla at his plant at Wardenclife as a machinist. Tesla said he had paid Clark all that was due him, but Clark claimed $389.24 balance due. Tesla admitted offering to settle by paying Clark $50 down and $12 a week. Clark won his case.

The New York Tribune November 26, 1906

NIKOLA TESLA'S IDEA OF HIMSELF.

Testifies in Suit That He Is One of the Greatest Men of the Age.

Patchogue, Long Island, Nov. 25.—Nikola Tesla considers himself one of the greatest men of the age, and so testified yesterday before Justice Jaycox, of the Supreme Court, in a suit brought by a former workman for wages due. Frank N. Clark, of Port Jefferson, formerly employed by Tesla at his plant at Wardencliffe as a machinist, sued the inventor for $889 25 for wages alleged to be due. Tesla admitted having offered to settle by paying Clark $50 down and $12 a week.

Clark's counsel asked Tesla if he was an inventor and promoter. Tesla said he was not a promoter and never received a fee, but that he was an inventor and could take rank among the foremost men of the age. Clark won his case.

The Patent Factory.

By George Ethelbert Walsh.

Contrary to a rather widespread impression an invention is generally a growth rather than a sudden inspiration. Moreover, it is often the product of several minds working along parallel lines, each contributing its quota of experimental knowledge. Forecasting an invention is not an impossible feat. The need of some sort of time-saving or labor-saving device is felt in an industry. Experts are called in and the ground thoroughly canvassed, impracticable methods eliminated, and the most feasible systematized and described. Then the work of developing the invention is turned over to experts, or rather to professional inventors, who can roughly forecast what they will do.

The conditions of modern industry demand the elimination of chance and uncertainty so far as possible. Inventions have upset business and manufacturing interests more than any other factor in the last ten years. The installation of expensive machinery is a costly undertaking if some inventor comes along with a patent six months later which practically makes the machinery ancient and obsolete.

"Last year," confessed a leading manufacturer of novelties, "my plant was practically knocked out by the invention of a device which makes it possible for my rivals to save $50,000 a year. I must either go out of business or invest in new machinery and pay big royalties to the inventor. This periodical revolutionizing of conditions by new inventions is one of the disturbing features of manufacturing. Is it any wonder that big concerns keep a sharp lookout for patents and even employ an army of experts to watch the applications for new patents?"

The professional inventor works better in cooperation with others interested in similar subjects, the deficiencies of one thus often being supplied by another. Associations of inventors have therefore become important organizations in this industrial age, and most of our great patents are products of one of these "patent factories" rather than of a single individual.

Edison's patent factory is not an exception to this rule, for while his personality dominates the establishment over which he presides, and credit is given to him for the inventions, he has surrounded himself with experts whose labors contribute to the general cause. Not only is the great "wizard" relieved of a great mass of detail work by his assistants, but suggestions and experiments are constantly coming to him from his associates. In his "patent factory" he employs some of the best chemists and mechanical experts in the country. Work of an experimental nature is intrusted to them which would require years of patient toil from a single inventor without the equipment of the modern plant.

Tesla is another great inventor who conducts his own "patent factory." With one of the best-equipped electrical and experimental laboratories in the world, he has surrounded himself with bright young men who have succeeded in chemistry, electrical sciences, mechanics and physics, and his labors of inventing are systematized to the point of simplicity. Most of Tesla's important discoveries in electrical science were predicted years ahead of their ultimate perfection, and the work of making good his promises has established for this inventor a unique position in the world of electricity.

Another important "patent factory," which differs from these two in some important respects, is the Ampere Electrochemical Company of Niagara Falls. Instead of a single dominating mind heading this plant, half a dozen inventors compose the company and direct its affairs. The company is not an operating concern, but purely an experimental organization or association of inventors. The object of the "patent factory" at Niagara Falls is to delve into the mysteries of electrochemistry for the purpose of discovering new processes for commercial application; but when a new patent is developed it is turned over to an operating company for exploitation. The inventors themselves have no interest in the applications of their patents.

The founders of this strange "patent factory" are men well known in the world of electrochemistry. Professor F. B. Crocker, C. A. Doremus, S. S. Wheeler and C. S. Bradley were the original organizers of the experimental plant, and later they had associated with them A. H. Buch, D. R. Lovejoy, H. E. Knight, N. Thurlow and Charles B. Jacobs. The results of this patent factory are evident in a hasty glance at some of the most important electrochemical industries which have grown up around Niagara, where a vast amount of electric current can be had at small cost.

To this "patent factory" can be traced the discovery of the present method of making artificial corundum by fusing bauxite by a patented process; the work of obtaining nitric acid from nitrogen and oxygen by electrical methods; the different processes of utilizing and producing barium sulphate and barium salts for the purification of our drinking water, and the production of artificial camphor from turpentine at Port Chester, which a few years ago failed after a short experimental test.

The large industrial and manufacturing companies have in recent years established "patent factories" of their own, where experts conduct tests and experiments along certain well-defined lines for mutual interests. These commercial "patent factories" are equipped with the best laboratories in the world, and men of genius and experience preside over them. The association of half a dozen experts in such a plant tends to make the work of discovery and invention simpler and more practical.

The General Electric Company spends tens of thousands of dollars every year in supporting its "patent factory." The presiding genius of this plant is Dr. C. P. Steinmetz, an inventor of world-wide fame. He has to his credit a long list of patents which have helped to bring the generation, transmission and application of electricity up to their present-day efficiency. With him are associated men of almost equal gift for invention and specialists in certain fields. The total output of this factory averages scores of new patents and improvements upon old ones every year. Any employe of the company who has a promising idea is encouraged to present it to the head of the patent factory, and if considered of value it is exhaustively tested and tried by experts. While the company holds all the patents developed by any of its employes, proper remuneration is made to the inventors, so that each one is stimulated to make suggestions and improvements. Frequently the development of a patent is more dependent upon the opportunities of the inventor to make exhaustive experiments with costly machinery and tools than upon the initiative impulse of the individual. Thus many valuable patents of today would never have been perfected had the inventors been forced to rely upon their individual means and work.

The Westinghouse Electric and Manufacturing Company is another representative concern which has a well-equipped "patent factory" in operation in connection with its manufacturing plant. Many valuable patents are taken out by this company, and most of them are traceable to the energy and foresight of the professional inventors employed by the company.

Another important "patent factory" is that of the Western Electric Company, which has to do largely, although not exclusively by any means, with telephone patents.

The various large concerns owning their own "patent factories" are rapidly specializing the work of inventing. The electrical manufacturers confine their attention to inventions in their industries, and the makers of special machines limit their tests and experiments to machinery in their particular line. The Ampere Electrochemical Company makes no efforts to invent dynamos and motors and equipents, but studies only the field of electrochemistry. Iron and steel mills find it more convenient and economical to confine their labors to the perfection of details of their plants and rarely branch out into other industries. In this way inventions are becoming specialized, and the professional inventor devotes his time and genius to certain departments of work.

The possibilities of inventions are probably greater in the electrical and electrochemical fields than in any other to-day. The electrochemist, in particular, has many untrodden paths ahead of him. By the aid of the electric current changes have been effected in the sugar and paint trades which make for efficiency. Electrochemists are to-day working with promise of success toward the manufacture of starch from by-products. Artificial rubber of fair value has also been produced, and the cyanides, silicides and ammonia are all promising products for the electrochemist. Synthetic electrochemistry is generally recognized as one of the greatest future businesses of the world; and that the Falls of Niagara were created for this purpose is the opinion of the workers in this field.

While the individual inventor may find his opportunities somewhat circumscribed by these changes, the gain obtained through the organization of professional inventors is great. Greater results flow therefrom, and the young man associated with a modern "patent factory" secures in time a training which makes his inventive gift of far greater value to himself and the world. In the field of discovery and invention of to-day expensive and elaborate tools and laboratory equipment are frequently essential to success, and the modern "patent factory" supplies these requirements.

"Tuned Lightning," Mysterious New Energy, to Turn Every Wheel on Earth.

FLEET ocean liners without steam or any other visible means of generating power; airships furnished with wireless energy, and telephone and telegraph stations connected by wireless ether waves only, are among the projected products of "tuned lightning," a marvellous new species of energy.

Poulsen, the Danish inventor, known as the Edison of Europe, predicts that tuned lightning will make wireless lighting, transatlantic wireless telephoning and telegraphy commercially possible very soon. Wireless ocean liners and airships will follow in due course.

At a remarkable demonstration in London lately before Prof. Silvanus Thompson, Sir William Preece and other distinguished scientists, Poulsen succeeded in lighting a series of arc lamps by means of his new and marvellous energy, which first passed through his own body. By means also of his wonderful electric waves sent into the atmosphere he fused a piece of copper suspended in midair without contact with wires or conductor of any kind.

The lighting of electric lamps without wires by energy passing through the human body opens up a wonderful vista of scientific accomplishment. By means of properly installed generating stations Poulsen will soon be able to effect electric lighting at great distances; and this absolutely without wires.

From his Danish generating station near Copenhagen he is to-day sending most powerful charges of what is practically nothing but raw tuned lightning between points separated by long distances.

Modern warfare will undergo a complete revolution when the Poulsen generating stations come into working order. If he can light a town by wireless energy conveyed through the air alone, it will be a simple matter to explode at long range an enemy's mines, or even burn up his ships and armies.

Owing to these startling possibilities the British war office through its most skilled electricians and scientists is manifesting considerable interest in Poulsen's experiments. Up to the present, however, the Poulsen power is only utilized for improvement and convenience; not for destruction. Lord Armstrong, the famous cannon manufacturer, one of the wealthiest men in England, has evinced his faith in the new energy by undertaking to finance Poulsen to an almost unlimited extent. A big company has just been formed with Lord Armstrong as chairman, and it is anticipated that it will soon be possible to send wireless messages across the Atlantic as rapidly and cheaply as ordinary telegrams.

But this is not all. Wireless trans-Atlantic telephones will be installed before very long; while wireless electric lighting has passed the experimental stage.

It will even be possible—and that perhaps before the end of two years—to build ships that will receive their motor power from shore stations. This will result in immense saving of space, for the great amount of room at present taken up by the bunkers and machinery of a modern liner will be available for passengers and freight. If Poulsen can direct his electric waves with sufficient energy to operate an electric lighting station miles away the supplying driving power to ships should be a mere question of detail. This will also apply to air ships, which so far have been failures owing to the weight of their motors. With Poulsen's tuned lightning, however, the problem will be solved.

Some of Poulsen's recent inventions have been quite Edisonian in their marvellous character. He invented the "telegraphone," an instrument somewhat on the order of the phonograph, but far more perfect. The telegraphone can be attached to any telephone and will receive messages mechanically, recording the voice on flat sheets of magnetized steel. The records are made simply by magnetism, and the steel sheet shows no indentations or markings of any kind.

A singular attribute of the telegraphone consists in the fact that one can talk upon one of the steel sheets, enclose it in an envelope and mail it for two cents, just as anyone would mail an ordinary letter. The receiver of this steel letter inserts the thin sheet into his telegraphone and the letter is spoken, with every inflection of voice of the sender.

Poulsen says it will be the only form of correspondence before very long.

In order to efface the record one has only to pass a magnet over the surface of the steel sheet, and it is ready for another message. Kelvin, Tesla, Graham Bell, Preece, Marconi and all the most noteworthy scientists of the day have attested their high appreciation of the merits of this wondrous instrument. Poulsen has many other inventions of a similar character.

Associated with Poulsen in his work is P. O. Pedersen, a mathematical genius. It is said that Pedersen thinks in figures. He can tell, without leaving his laboratory, just what is wrong with an installation, and his calculations are so marvellously accurate that they virtually amount to intuition.

It is these two men, working in harmony, who have brought wireless telegraphy to a state of final perfection.

Hitherto the sending of wireless messages has only been a scientific accomplishment. So far as the man on the street was concerned, wireless telegraphy may as well never have existed. Of course, between ships at sea under favorable weather conditions wireless has proved more or less effective.

Herr Poulsen long ago recognized the unsatisfactory nature of the spark principle. He has been working for years trying to find some wireless energy that could be made continuous and accumulative—that is, instead of using pistol shots for signalling, he has eben able to send through the air a continuous stream of energy in a given direction. This stream, by means of a receiving instrument, can be used just as an ordinary current of electricity would be. Poulsen calls it tuned lightning. Not only can he send his energy hundreds of miles in a certain direction, but his instruments are so perfect that he can utilize the same stream of energy for conveying two or more messages at the same time in opposite directions, just as is done in duplex and multiplex telegraphy to-day. Sir William Preece, speaking of the Poulsen wireless discovery, recently said that "it sounded the death knell of spark telegraphy."



WALDEMAR POULSEN The EDISON of DENMARK



The LETTER of the FUTURE. A STEEL DISK and VALVE

WIRELESS LIGHTING OF ARC LAMPS BY POULSEN'S SYSTEM

[1238.]—**Tesla Coil.**—The oils generally used for such are those of high insulating power, such as heavy petroleum (fluid vaseline) and boiled linseed oil. Resin oil is also excellent. The reason for boiling linseed oil is to drive off any moisture, which would tend to lower its insulating properties.

S. BOTTONE.

WONDERFUL PRANKS of the "NEW ELECTRICITY"



NIKOLA TESLA

NIKOLA TESLA Describes for the Sunday World a Spectacular Electrical Experiment, and Says We Will Soon be Able, Without Wires, to Talk Across the Ocean and Light a Lamp Anywhere on Earth.

THE announcement that Thomas A. Edison is tired of hard work—no American has worked harder—and that he is going to give himself more time for play, finds Mr. Edison's distinguished rival, Nikola Tesla, more than ever in the midst of strenuous labors that give no hint of cessation for many years to come.

A Sunday World representative has found Mr. Tesla deep in new experiments as well as in current construction associated with highly important electrical improvements having a world-wide significance.

The following statement by Mr. Tesla takes for its text a recent article on "Tuned Lightning" printed in the Sunday World.

BY NIKOLA TESLA.

I READ with interest an article in the Sunday World of Jan. 20 on "Tuned Lightning," described as a mysterious new energy, which is to turn every wheel on earth, and is supposed to have been recently discovered by the Danish inventors Waldemar Poulsen and P. O. Pedersen.

From other reports I have gathered that these gentlemen have so far confined themselves to the peaceful production of miniature bolts not many inches long, and I am wondering what an account of their prospective achievements would read like if they had succeeded in obtaining, like myself, electrical discharges of 100 feet, far surpassing lightning in some features of intensity and power.

In view of their limited Jovian experience, the programme outlined by the Danish engineers is rather extensive, Lord Armstrong's vast resources notwithstanding. Naturally enough, I shall look with interest to their telephoning across the Atlantic, supplying light and propelling airships without wires. *Anch'io sono pittore.* (I, too, am a painter.) In the mean time it may not be amiss to state here, incidentally, that all the essential processes of, and appliances for the generation, transmission, transformation, distribution, direction, storage, regulation, control and economic utilization of "Tuned Lightning" have been patented by me, and that I have long since undertaken and am sparing no effort to render these advances instrumental in insuring the welfare, comfort and convenience, primarily, of my fellow-citizens.

There is nothing remarkable in the demonstration reported to have been made before Sir William Preece and Prof. Sylvanus P. Thompson, nor is there any novelty in the electrical devices employed. The lighting of arc lamps through the human body, the fusing of a piece of copper in mid-air, as described, are simple experiments which by the use of my high-frequency transformers any student of electricity can readily perform. They teach nothing new and have no bearing on wireless transmission, for the actions virtually cease at a distance of a few feet from the source of vibratory energy. Years ago I gave exhibitions of similar and other much more striking experiments with the same kind of apparatus, many of which have been illustrated and explained in technical journals. The published records are open to inspection.

Regardless of all that, the Danish inventors have not as yet offered the slightest proof that their expectations are realizable, and before advancing seriously the claim that an efficient wireless distribution of light and power to great distances is possible, they should, at least, repeat those of my experiments which have furnished this evidence.

A scientific audience cannot help being impressed by a display of interesting phenomena, but the originality and significance of a demonstration such as that referred to can only be judged by an expert possessed of full knowledge and capable of drawing correct conclusions. A novel effect, spectacular and surprising, might be quite unimportant, while another, seemingly trifling, is of the greatest consequence.

To illustrate, let me mention here two widely different experiments of mine. In one the body of a person was subjected to the rapidly alternating pressure of an electrical oscillator of two and a half million volts; in the other a small incandescent lamp was lighted by means of a resonant circuit grounded on one end, all the energy being drawn through the earth electrified from a distant transmitter.

The first presents a sight marvellous and unforgettable. One sees the experimenter standing on a big sheet of fierce, blinding flame, his whole body enveloped in a mass of phosphorescent cloud. From his ears, nose and hair issue iridescent wriggling streamers like the tentacles of an octopus. Bundles of light stick out from his spine. As he stretches out the arms, thus forcing the electric fluid outwardly, roaring tongues of fire leap from his finger tips. Objects in his vicinity bristle with rays, emit musical notes, glow, grow hot. He is the centre of still more curious actions, which are invisible. At each throb of the electric force myriads of minute projectiles are shot off from him with such velocities as to pass through the adjoining walls. He is in turn being violently bombarded by the surrounding air and dust. He experiences sensations which are indescribable.

A layman, after witnessing this stupendous and incredible spectacle, will think little of the second modest exhibit. But the expert will not be deceived. He realizes at once that the second experiment is ever so much more difficult to perform and immensely more consequential. He knows that to make the little filament glow, the entire surface of the planet, two hundred million square miles, must be strongly electrified. This calls for peculiar electrical activities, hundreds of times greater than those involved in the lighting of an arc lamp through the human body. What impresses him most, however, is the knowledge that the little lamp will spring into the same brilliancy anywhere on the globe, there being no appreciable diminution of the effect with the increase of distance from the transmitter.

This is a fact of overwhelming importance, pointing with certitude to the final and lasting solution of all the great social, industrial, financial philanthropic, international and other problems confronting humanity, a solution of which will be brought about by the complete annihilation of distance in the conveyance of intelligence, transport of bodies and materials and the transmission of the energy necessary to man's existence. More light has been thrown on this scientific truth lately through Prof. Slaby's splendid and path-breaking experiment in establishing perfect wireless telephonic connection between Naum and Berlin, Germany, a distance of twenty miles. With apparatus properly organized such telephonic communication can be effected with the same facility and precision at the greatest terrestrial distance.

The discovery of the stationary terrestrial waves, showing that, despite its vast extent, the entire planet can be thrown into resonant vibration like a little tuning fork; that electrical oscillations suited to its physical properties and dimensions pass through it unimpeded, in strict obedience to a simple mathematical law, has proved beyond the shadow of a doubt that the earth, considered as a channel for conveying electrical energy, even in such delicate and complex transmissions as human speech or musical composition, is infinitely superior to a wire or cable, however well designed.

Very soon it will be possible to talk across an ocean as clearly and distinctly as across a table. The first practical success, already forecast by Slaby's convincing demonstration, will be the signal for revolutionary improvements which will take the world by storm.

However great the success of the telephone, it is just beginning its evidence of usefulness. Wireless transmission of speech will not only provide new but also enormously extend existing facilities. This will be merely the forerunner of ever so much more important development, which will proceed at a furious pace until, by the application of these same great principles, the power of waterfalls can be focussed wherever desired; until the air is conquered, the soil fructified and embellished; until, in all departments of human life, distance has lost its meaning and even the immense gulf separating us from other worlds is bridged.

Nikola Tesla

WIRELESS ACHIEVEMENTS BY TESLA

NIKOLA TESLA, the wizard of electricity, believes that he has at last found the secret of driving dirigible balloons through the air. This discovery Mr. Tesla ranks as the very climax of his active, fruitful life.

The wireless and at the same time absolutely limitless transmission of electric power has been the one problem to the solution of which Mr. Tesla has given all of his time and energy during the past few years. And now he believes that he has solved it.

Mr. Tesla has perfected a transmitter that he believes is destined to revolutionize the world. It will enable him to throw hundreds, and, if necessary, thousands, of volts of electricity, producing unlimited horse-power, to airships in any part of the world; it will enable him to drive an airship to the North Pole and back; it will enable him to drive ocean liners back and forth across the Atlantic without coal or any material conductor of electric power aside from the air; it will enable him not only to telephone to Europe without wires or cables; it will enable him to run our trolley cars, light our houses, operate our elevators and cook our meals without wires or third rails.

It is the perfecting of this transmitter that Mr. Tesla believes to be the greatest achievement of his life.

Mr. Tesla was one of the first modern inventors to devote his great mind to practically utilizing electricity. He first recognized the limitless power of Niagara Falls, and sought the means to harness it. Long before the public had become accustomed to the marvels of the trolley car, the telegraph and telephone, Mr. Tesla was seeking to do away with the primitive wires and cables used to transmit the electric power and to accomplish the same results with no other conductor than the air.

Bound, fettered and restrained by wires, Mr. Tesla felt the great value of electricity to mankind was lost. The enormous loss of power in its transmission over miles of wires, Mr. Tesla believed, made the apparent value of electricity as nothing to its actual worth. It was to save this loss that Mr. sought the wireless transmission of electric power.

And it is the solution of this problem that Mr. Tesla now offers the world.

To-day the wireless transmitter has accomplished what, ten years ago, would have been pronounced impossible. Its practicability has been thoroughly demonstrated.



This strange picture, showing the effect of Mr. Tesla's extraordinary experiment, was made by Dan Smith after a personal visit to Mr. Tesla at his laboratory.

SIGNALLING TO MARS—A PROBLEM OF ELECTRICAL ENGINEERING.

BY NIKOLA TESLA.

In the early part of 1900, still vividly impressed by certain observations I had made shortly before, and feeling that the time had come to prepare the world for an experiment which will soon be undertaken, I dwelt on the practicabilty of interplanetary signalling in an article which appeared in the June number of the *Century Magazine* of the same year. In order to correct an erroneous report

which gained wide circulation, a statement was published in *Collier's Weekly* of Feb. 9, 1901, defining my position in general terms. Ever since, my thoughts have been centred on the subject, and my original conviction has been strengthened both by reflection and suggestion.

Chief among the stimulating influences was the revelatory work of Percival Lowell, described in a volume with which the observatory, bearing his name, has honored me. No one can look at his globe of Mars without a feeling of profound astonishment, if not awe. These markings, still imperfectly discerned and incomprehensible, but evi...tly intended for a useful purpose, may they not contain a record of deep meaning left by a superior race, perhaps extinct, to tell its young brethren in other worlds of secrets discovered, of life and struggle, of their own terrible fate? What mighty pathos and love in such a gigantic drama of the universe! But let us hope that the astronomer has seen true, that Mars is not a cold grave, but the abode of happy intelligent creatures, from whom we may learn. In the light of this glorious possibility, signalling to that planet presents itself as a preëminently practical proposition which, to carry out, no human sacrifice could be too great. Can it be done? What chance is there that it will be done?

These questions will be answered definitely the moment all doubt as to the existence of highly developed beings on Mars is dispelled. The straightness of the lines on Lowell's map, their uniform width and other geometrical peculiarities, do not, themselves, appeal to me as strong proofs of artificiality. I should think that a planet large enough not to be frozen stiff in a spasm of volcanic action, like our moon, must, in the course of eons, have all its mountains leveled, the valleys filled, the rocks ground to sand, and ultimately assume the form of a smooth spheroid, with all its rivers flowing in geodetically straight lines. The uniform width of the waterways can be consistently explained, their crossings, however odd and puzzling, might be accidental. But I quite agree with Professor Morse, that this whole wonderful map produces the absolute and irresistible conviction, that these "canals" owe their existence to a guiding intelligence. Their great size is



Nikola Tesla.

not a valid argument to the contrary. It would merely imply that the Martians have harnessed the energy of waterfalls. We know of no other source of power competent to explain such tremendous feats of engineering. They could not be accomplished by capturing the sun's rays or abstracting heat imparted to the atmosphere, for this, according to our best knowledge, would require clumsy and inefficient machinery. Large falls could be obtained near the

polar caps by extensive dams. While much less effective than our own, they could well furnish several billions of horse-power. It should be borne in mind that many Martian tasks in mechanical engineering are much easier than the terrestrial, on account of the smaller mass of the planet and lesser density, which, in the superficial layers, may be considerably below the mean. To a still greater degree this is true of electrical engineering. Taking into account the space encompassed by Mars, a system of wireless transmission of energy, such as I have perfected, would be there much more advantageously applied, for, under similar conditions, a receiving circuit would collect sixteen times as much energy as on the earth.

The astonishing evidences furnished by Lowell are not only indicative of organic life, but they make it appear very probable that Mars is still populated; and furthermore, that its inhabitants are highly developed intelligent beings. Is there any other proof of such existence? I answer, emphatically, yes, prompted both by an instinct which has never yet deceived me, and observation. I refer to the strange electrical disturbances, the discovery of which I announced six years ago. At that time I was only certain that they were of planetary origin. Now, after mature thought and study, I have come to the positive conclusion that they must emanate from Mars.

Life, as a great philosopher has said, is but a continuous adjustment to the environment. Similar conditions must bring forth similar automata. We can have no idea what a Martian might be like, but he certainly has sensitive organs, much as our own, responsive to external stimuli. The indications of these instruments must be real and true. A straight line, a geometrical figure, a number, must convey to his mind a clear and definite conception. He ought to think and reason like ourselves. If he breathes, eats and drinks, he is moved by motives and desires not very different from our own. Such colossal transformation as is observable on the face of Mars could not have been wrought except by beings ages ahead of us in development. What wonder, then, if they have maps of this, our globe, as perfect as Professor Pickering's photographs of the moon? What wonder if they are signalling to us? We are sufficiently advanced in electrical science to know that their task is much easier than ours. The question is, Can we transmit electrical energy to that immense distance? This I think myself competent to answer in the affirmative.



TUNED LIGHTNING.

By NIKOLA TESLA.

I READ with interest an article in the *Sunday World* of Jan. 20 on "Tuned Lightning," described as a mysterious new energy, which is to turn every wheel on earth, and is supposed to have been recently discovered by the Danish inventors Waldemar Poulsen and P. O. Pedersen.

From other reports I have gathered that these gentlemen have so far confined themselves to the peaceful production of miniature bolts not many inches long, and I am wondering what an account of their prospective achievements would read like if they had succeeded in obtaining, like myself, electrical discharges of 100ft., far surpassing lightning in some features of intensity and power.

In view of their limited Jovian experience, the programme outlined by the Danish engineers is rather extensive, Lord Armstrong's vast resources notwithstanding. Naturally enough, I shall look with interest to their telephoning across the Atlantic, supplying light and propelling airships without wires. *Anch' io sono pittore.* (I, too, am a painter.) In the mean time it may not be amiss to state here incidentally that all the essential processes of and appliances for the generation, transmission, transformation, distribution, direction, storage, regulation, control, and economic utilisation of "tuned lightning" have been patented by me, and that I have long since undertaken, and am sparing no effort to render these advances instrumental in insuring the welfare, comfort, and convenience, primarily, of my fellow-citizens.

There is nothing remarkable in the demonstration reported to have been made before Sir William Preece and Prof. Sylvanus P. Thompson, nor is there any novelty in the electrical devices employed. The lighting of arc lamps through the human body, the fusing of a piece of copper in mid-air, as described, are simple experiments which by the use of my high-frequency transformers any student of electricity can readily perform. They teach nothing new, and have no bearing on wireless transmission, for the actions virtually cease at a distance of a few feet from the source of vibratory energy. Years ago I gave exhibitions of similar and other much more striking experiments with the same kind of apparatus, many of which have been illustrated and explained in technical journals. The published records are open to inspection.

Regardless of all that, the Danish inventors have not as yet offered the slightest proof that their expectations are realisable, and before advancing seriously the claim that an efficient wireless distribution of light and power to great distances is possible, they should, at least, repeat those of my experiments which have furnished this evidence.

A scientific audience cannot help being impressed by a display of interesting phenomena, but the originality and significance of a demonstration such as that referred to can only be judged by an expert possessed of full knowledge and capable of drawing correct conclusions. A novel effect, spectacular and surprising, might be quite unimportant, while another, seemingly trifling, is of the greatest consequence.

To illustrate, let me mention here two widely different experiments of mine. In one the body of a person was subjected to the rapidly-alternating pressure of an electrical oscillator of two and a half million volts; in the other a small incandescent lamp was lighted by means of a resonant circuit grounded on one end, all the energy being drawn through the earth electrified from a distant transmitter.

The first presents a sight marvellous and unforgettable. One sees the experimenter standing on a big sheet of fierce, blinding flame, his whole body enveloped in a mass of phosphorescent cloud. From his ears, nose, and hair issue iridescent wriggling streamers like the tentacles of an octopus. Bundles of light stick out from his spine. As he stretches out the arms, thus forcing the electric fluid outwardly, roaring tongues of fire leap from his finger-tips. Objects in his vicinity bristle with rays, emit musical notes, glow, grow hot. He is the centre of still more curious actions, which are invisible. At each throb of the electric force myriads of minute projectiles are shot off from him with such velocities as to pass through the adjoining walls. He is in turn being violently bombarded by the surrounding

air and dust. He experiences sensations which are indescribable.

A layman, after witnessing this stupendous and incredible spectacle, will think little of the second modest exhibit. But the expert will not be deceived. He realises at once that the second experiment is ever so much more difficult to perform and immensely more consequential. He knows that to make the little filament glow, the entire surface of the planet, two hundred million square miles, must be strongly electrified. This calls for peculiar electrical activities, hundreds of times greater than those involved in the lighting of an arc lamp through the human body. What impresses him most, however, is the knowledge that the little lamp will spring into the same brilliancy anywhere on the globe, there being no appreciable diminution of the effect with the increase of distance from the transmitter.

This is a fact of overwhelming importance, pointing with certitude to the final and lasting solution of all the great social, industrial, financial, philanthropic, international, and other problems confronting humanity, a solution of which will be brought about by the complete annihilation of distance in the conveyance of intelligence, transport of bodies and materials, and the transmission of the energy necessary to man's existence. More light has been thrown on this scientific truth lately through Prof. Slaby's splendid and path-breaking experiment in establishing perfect wireless telephonic connection between Naum and Berlin, Germany, a distance of twenty miles. With apparatus properly organised such telephonic communication can be effected with the same facility and precision at the greatest terrestrial distance.

The discovery of the stationary terrestrial waves, showing that, despite its vast extent, the entire planet can be thrown into resonant vibration like a little tuning-fork; that electrical oscillations suited to its physical properties and dimensions pass through it unimpeded, in strict obedience to a simple mathematical law, has proved beyond the shadow of a doubt that the earth, considered as a channel for conveying electrical energy, even in such delicate and complex transmissions as human speech or musical composition, is infinitely superior to a wire or cable, however well designed.

Very soon it will be possible to talk across an ocean as clearly and distinctly as across a table. The first practical success, already forecast by Slaby's convincing demonstration, will be the signal for revolutionary improvements which will take the world by storm.

However great the success of the telephone, it is just beginning its evidence of usefulness. Wireless transmission of speech will not only provide new but also enormously extend existing facilities. This will be merely the forerunner of ever so much more important development, which will proceed at a furious pace until, by the application of these same great principles, the power of waterfalls can be focussed whenever desired; until the air is conquered, the soil fructified and embellished; until, in all departments of human life distance has lost its meaning, and even the immense gulf separating us from other worlds is bridged.

SCIENTISTS DOUBT THE HUMAN SOUL WAS WEIGHED.

Nikola Tesla Considers the Statement Made by Five Boston Physicians Too Absurd for Discussion.

DR. I. K. FUNK, IF DYING, WOULD WELCOME TEST.

Dr. Carleton Simon Thinks Deflation of the Lungs May Have Caused Phenomenon.

A subject of widespread discussion during the past week was the statement published in The World that five Boston physicians of the highest standing have attained what they hold to be decisive results in establishing the weight of the human soul.

Dr. Isaac K. Funk was intensely interested, but he said to a World reporter:

"I cannot accept this experiment or series of experiments as decisive. I should like to see a thorough investigation made by other scientists. Mind you, I do not say that it is impossible. I only say that it is not conclusive; I have no doubt that there are other formations so fine that our grosser senses do not take cognizance of them.

"It all becomes a question of vibrations. To make myself more clear, I cannot do better than quote Sir William Crookes, who when elected President of the British Association said in his remarkable address that all of the phenomena of the universe are presumably waves and vibrations.

"I personally, if I were dying, would not in the least mind doctors making the experiment. My bed might be placed on delicately adjusted scales, and any difference after making all scientific allowances carefully noted."

Prof. John D. Quackenbos said: "I do not attach any importance to it.

"The experiment is subject to so many errors that it is not dependable. The weight of the human body varies all the time. Sometimes your clothes feel tight and at others loose, so, for that reason alone, the conclusion arrived at is erroneous.

"We must get a clearer definition of what is meant by the soul. I do not for one instant believe that the astral body has any weight.

"In my opinion if this experiment were true there would be a difference of weight when a man is asleep, for I believe that during his sleeping hours there is a temporary disconnection of the soul and the body."

No Loss of Weight, Says Tesla.

Nikola Tesla, discussing the subject said:

"That an aggregation of impressions, thoughts and feelings having no materiality, and vaguely designated as mind, or soul, should be a substance susceptible of quantitative determination is altogether too absurd for discussion.

"The change, however, which takes place in the human body during its awful transition from life to death is a great subject for scientific investigation which may possibly lead to important results. If the experiments of the Massachusetts physicians are to be at all seriously considered, it is only in this respect.

"I could not help being struck by the fact that men of a scientific calibre sufficiently large to undertake measurements requiring the greatest delicacy and skill, should not be correspondingly resourceful in divising the apparatus for the purpose. A scale responding to the weight of one-tenth of an ounce is not a fit instrument for weighing the human soul.

"It is not less astonishing that such trained observers should have overlooked a trivial cause responsible for the seeming lightening of the body. I use this term designedly, for excepting the exudations which have been taken into consideration there was no loss of substance in death.

"When rigor mortis sets in there is an increase of volume for various reasons. Just to give a rough idea I shall assume that the living body, weighing say 150 pounds, had filled a space of three cubic feet. The air in a sick room may weigh about fourteen ounces per cubic foot. Half an ounce of the air would consequently occupy a space of sixty-two cubic inches, and that would be only one per cent. of the original volume of three cubic feet. As will readily be seen, a very slight general deformation of the body, scarcely perceptible, is adequate to explain the puzzling observation. The sudden tipping of the scale demonstrates nothing except the coarseness of the instrument. Had the balance been very sensitive, owing to the resistance of the air, the platform would have ascended slowly."

Absurd, Says Dr. Simon.

Dr. Carleton Simon said: "If these experiments were performed honestly—that is to say if they were genuine, there can only be one conclusion, and that is that the loss of weight is due to the fact that the lungs are deflated.

"During life there is always a certain amount of air held in suspension in the lungs, that is, outside the air that is regularly inhaled and exhaled, and there must necessarily be a great difference in weight when this air leaves the body.

"If this difference in weight after death is seriously attributed to the loss of the soul, I can only qualify the whole conclusion as absurd."

Dr. Hereward Carrington, who is an associate of Prof. James H. Hyslop, and has been prominently identified with psychical research, on the other hand, was enthusiastic, and described the experiment as the most important addition to science the world has ever known. He, however, suggested that the experiment was not conclusive, as the subjects were ill and practically moribund, and therefore decomposition might set in the instant after death.

Scales May Have Been Influenced.

A well-known Newark scientist who does not wish his name published, said:

"The difference in weight, even of an ounce, in the several subjects' bodies immediately after death certainly appears remarkable if not attributable to some other physical influence, but such a phenomenon per se seems ill-adapted to dispel what to very many people is an article of faith, namely, the conviction that their souls, while being real and substantial, are nevertheless immaterial and therefore non-susceptible to space or scales.

"Just precisely what calculations and deductions based on physical agencies have been made by the medical experimenters, it is difficult to conjecture, but it seems safe to presume that in six at least of the seven cases mentioned, the counter action of these highly sensitive scales might be directly attributed to the cessation of the heart's beating, or in other words that the pulsation itself acted as an independent factor in influencing the balance until the moment when death intervened.

"As to the case of No. 7—termed the phlegmatic—if life had really ceased at the precise moment it is supposed to have, is it not possible that the mechanism of these highly sensitive scales may have been influenced by some physical agency apart from the subject under experiment that escaped the attention of the observers, or being phlegmatic, was the body slower to emit the gases than that of the others?

"However that may be, one cannot readily become reconciled to the rather singular theory put forward by Dr. Duncan MacDougal in regard to this latter case, viz.: that the soul remained 'suspended' in the body after death. Surely if death means pure and simple 'the separation of soul and body' the idea of this particular soul being suspended in this particular body is to the ordinary individual inconceivable."

The New York Times March 19, 1907

WIRELESS CAUSED IENA DISASTER?

French Expert Thinks Outside Current Communicated High-Tension Spark.

LOCAL SCIENTISTS' VIEWS

They Say If the Theory Is Correct It Indicates Gross Carelessness on the Vessel.

TOULON, March 18.—M. Naudin, the wireless telegraph expert, has advanced a new theory regarding the cause of the disaster to the battleship Iéna, whose afterpart was destroyed by the explosion of a magazine on March 12.

M. Naudin says that at the time of the explosion it was noted that powerful wireless currents were passing and he believes that the vessel's isolation in the dry dock here resulted in the accumulation of secondary Hertzian waves in the "B" powder magazine from the ship's wireless apparatus and that an outside current communicated a high-tension spark.

Prof. Michael I. Pupin of Columbia University, who has been deeply interested in the development of wireless telegraphy and has made many experiments with various apparatus, said last night:

"If explosives are kept in metallic cases and grounded there could be no explosion caused by wireless waves, but if explosives are not kept in metallic cases and grounded, it might happen. Failure to store explosives on a battleship in any other way would be the highest degree of carelessness, I should say. Of course, I have no information about the conditions on the Iéna at the time of the disaster."

Dr. Lee De Forest told a TIMES reporter last night that he considered the theory of M. Naudin as to the cause of the Iéna disaster improbable, but admitted ,that under certain conditions it might be correct. He said:

"The thinnest sheet of metal completely inclosing a space is an absolute barrier to electrical waves, no matter how intense. It is absurd to suppose, then, that any spark could have been caused within the magazine of the Iéna by waves sent out from some wireless transmitter outside the ship.

"It is, however, possible that high-potential, high-frequency currents could be induced in the electric light wires on board from the 'kick-back' of a powerful induction coil or transformer feeding an oscillating circuit and supplied from the same source of electric current. It is also conceivable that from such electric light wires faultily insulated from the steel walls of the magazine and not protected in iron conduits, sparks could jump."

Dr. De Forest added that it was almost inconceivable that such an explosion should occur unless the French were grossly negligent in their method of wiring the Iéna. While it was possible, he said, that a defectively insulated wire was in close contact with the powder, it was highly improbable.

He recalled the experiments of Nicola Tesla with a dirigible torpedo about the time of the Spanish-American war. Tesla then considered the problem of the use of wireless telegraphy for directing torpedoes and discharging them. It was Tesla's theory that a torpedo's movements could be controlled by means of waves of electrical energy, and he made many experiments to this end, but with no practical results.

At that time Tesla made the statement that in the same manner he could project a wave of sufficient intensity to cause a spark in a ship's magazine and explode it. That statement was ridiculed by other electrical experts.

The New York Times March 20, 1907

TESLA'S WIRELESS TORPEDO.

Inventor Says He Did Show That It Worked Perfectly.

To the Editor of The New York Times:

A report in THE TIMES of this morning says that I have attained no practical results with my dirigible wireless torpedo. This statement should be qualified. I have constructed such machines, and shown them in operation on frequent occasions. They have worked perfectly, and everybody who saw them was amazed at their performances.

It is true that my efforts to have this novel means for attack and defense adopted by our Government have been unsuccessful, but this is no discredit to my invention. I have spent years in fruitless endeavor before the world recognized the value of my rotating field discoveries which are now universally applied. The time is not yet ripe for the telautomatic art. If its possibilities were appreciated the nations would not be building large battleships. Such a floating fortress may be safe against an ordinary torpedo, but would be helpless in a battle with a machine which carries twenty tons of explosive, moves swiftly under water, and is controlled with precision by an operator beyond the range of the largest gun.

As to projecting wave-energy to any particular region of the globe, I have given a clear description of the means in technical publications. Not only can this be done by the use of my devices, but the spot at which the desired effect is to be produced can be calculated very closely, assuming the accepted terrestrial measurements to be correct. This, of course, is not the case. Up to this day we do not know a diameter of the globe within one thousand feet. My wireless plant will enable me to determine it within fifty feet or less, when it will be possible to rectify many geodetical data and make such calculations as those referred to with greater accuracy.

NIKOLA TESLA.

New York, March 19, 1907.

The New York Times March 26, 1907

WIRELESS ON RAILROADS.

Nikola Tesla Says It Is Perfectly Practical and Will Soon Be In Use.

To the Editor of The New York Times:

No argument is needed to show that the railroads offer opportunities for advantageous use of a practical wireless system. Without question, its widest field of application is the conveyance to the trains of such general information as is indispensable for keeping the traveler in touch with the world. In the near future a telegraphic printer of news, a stock ticker, a telephone, and other kindred appliances will form parts of the regular wireless equipment of a railroad train. Success in this sphere is all the more certain, as the new is not antagonistic but, on the contrary, very helpful to the old. The technical difficulties are minimized by the employment of a transmitter the effectiveness of which is unimpaired by distance.

In view of the great losses of life and property improved safety devices on the cars are urgently needed. But upon careful investigation it will be found that the outlook in this direction is not very promising for the wireless art. In the first place the railroads are rapidly changing to electric motive power, and in all such cases the lines become available for the operation of all sorts of signaling apparatus, of which the telephone is by far the most important. This valuable improvement is due to Prof. J. Puley, who introduced it in Germany eight years ago. By enabling the engineer or conductor of any train to call up any other train or station along the track and obtain full and unmistakable information, the liability of collisions and other accidents will be greatly reduced. Public opinion should compel the immediate adoption of this invention.

Those roads which do not contemplate this transformation might avail themselves of wireless transmission for similar purposes, but inasmuch as every train will require in addition to a complete outfit an expert operator, many roads may prefer to use a wire, unless a wireless telephone can be offered to them.

NIKOLA TESLA.

New York, March 25, 1907.

The New York Times March 28, 1907

A Positive If Not Expert Opinion.

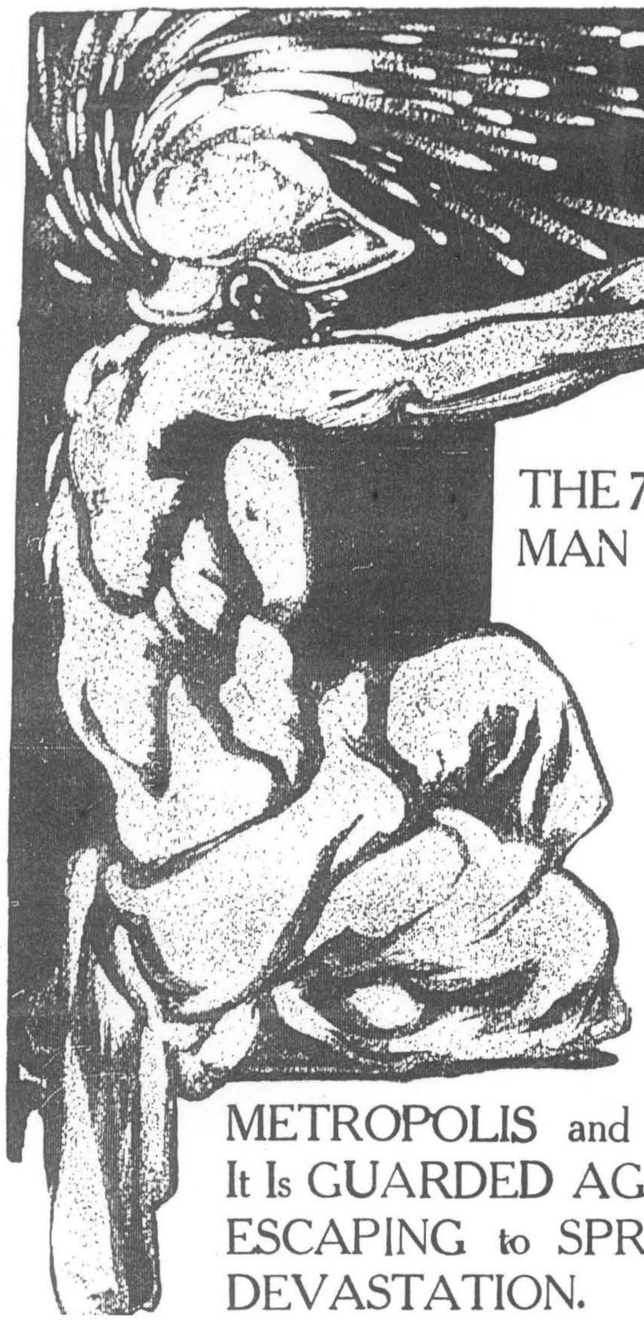
To the Editor of The New York Times:

The undersigned, not a proper electrician but only a student of applied mathematics, cannot refrain from setting the public right apropos of Mr. Tesla's letter in this morning's TIMES concerning wireless telegraphing on moving trains. If the reader will try a wireless receiver while he is shaking it violently, though moderately in the distances involved, he will understand a little of the simplicity of Mr. Tesla's suggestion. And if he will, moreover, have his room filled with fine, minute dust, of which many of the particles are magnetic and all are particularly handsomely minute, he will appreciate the delicacy of this precious discovery of Marconi, capable of all things perhaps, but certainly not within the compass of a fanning mill such as a moving train resembles.

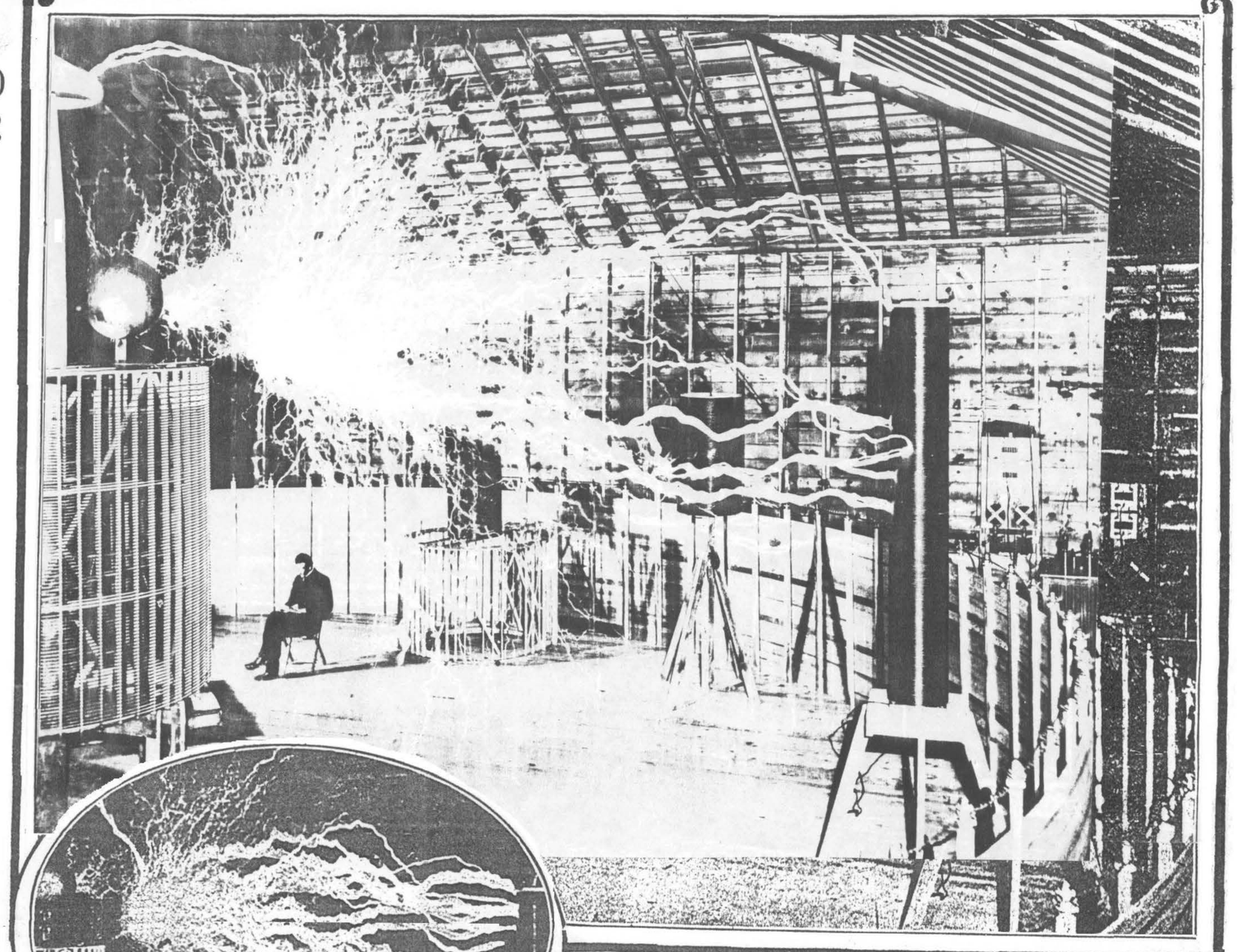
M. W. HARRINGTON.

New York, March 28, 1907.

THIS GIANT could WRECK NEW YORK



THE 7,000,000 MAN POWER ELECTRIC FORCE Running Through the Wire VEINS of the METROPOLIS and HOW It Is GUARDED AGAINST ESCAPING to SPREAD DEVASTATION.



These photographs of Nikola Tesla's magnifying transmitter were made under Mr. Tesla's supervision at his Long Island laboratory. The upper picture shows the results of a double exposure, one made to record the leaping electric flame, forty feet long, the second to impress on the plate the seated figure of Mr. Tesla himself. The potentiality of this remarkable exhibition of electrical force has been estimated at 25,000,000 horse-power—five times the power of Niagara.

WHOEVER has been upon a street car when a fuse burned out, have no doubt wondered what would happen if all the electricity in this most electric city of the world got loose.

There is an immediate exodus from the car. Often all of the car that is combustible is consumed by flame before the nearest fire engine can be brought to the spot. Between the first startling sharp report and the ignition of woodwork and the melting of insulation the period is short. But only one car is involved—or a train of cars, as one day last year in the Subway. In the event of a simultaneous breaking of bounds all over town by this marvellous agent which we hold to slavery by shackles confessedly weak, what would it do to Manhattan?

Manhattan and the Bronx has seised and harnessed and put to labor electricity to the total of 1,000,000 horse-power. The strength of a million horses! It does the equivalent of the work of 5,000,000 men—indeed, two and one-half times that number, for it sustains its power not for eight or nine hours but for twenty-four—adding to New York's industrial output nearly six times that of all the males in this tremendous city.

Here are the capacities of the power stations:

	Horse-Power.
Rapid Transit Subway	130,000
Metropolitan Railway	98,000
Manhattan Railway	180,000
New York City Railway	96,000
New York Central Railway (by July)	100,000
Edison Company	216,000
United Company	90,000
Pennsylvania Railroad	95,000
Private plants	125,000
Municipal lights	20,000
Total	1,070,000

In addition, there are the Edison light storage batteries in twenty different buildings on Manhattan, holding 75,000 horse-power for emergency. This, more than a million electric horse-power—practically all in Manhattan—is three times what there was in the entire United States seven years ago. In the Greater City two-million-man power may be added to the figures.

When Electricity Does Escape.

Electricians assert that in electrical science there is no such term as "breaking loose." Yet electricity does escape from third rails and light wires and wanders about town, eating copper roofs, corroding bridges and the steel frames of buildings.

At a recent hearing on the cost of gas, sections of iron pipe were shown in which vagrant electricity had bored immense holes. At a moment of puncture, if air were present, it is conceded that a spark would result and an explosion follow. Many a mysterious explosion has been caused by the wearing off of the insulation of wires and the instant ignition of leaked gas.

"The leakage of electricity is undeniably considerable," declared the editor of the Electrical Age the other day, "and the problem how to stop it is now the object of anxious research and experiment. In some cities electric railways are seriously troubled by the quantity that gets free. Conduits are made of fire-clay, and all known precautions are taken, but it is true that electrolysis is acting into the steel frames of modern buildings and iron structures generally — 'electrolysis' being the decomposition caused by errant electricity."

A definite impression exists that in relation to this subtle power, the nature of which we do not know, we may be dwelling in a false security.

Most of us know from photographs, at least, what electricity looks like when it leaps from one grounded pole to another. It streams across the intervening space in weird dazzling undulations. White tatters of ribbons—broken gleams, radiations, streaks—wave more erratically than strands snapping in a gale.

On this page you may see such a photograph, with a man calmly reading a newspaper a few feet beyond. Of course the man was not really there. Short time he would have lasted! By a well-known trick of photograph-making the picture of the man calmly reading was superimposed upon a picture of electricity darting from pole to pole.

Supposing all the electricity produced continuously in Manhattan were thus to disport itself? What could it do? Suppose it possible that this giant which we have set to drive wheels, make heat and supply light—which in this city we have compelled to operate the biggest artificial light system and the busiest transportation lines the world ever saw, at the same time subjecting its power to innumerable uses, even to curling a lady's hair, suppose all should escape, with its power of a million horses, what could it not do to Manhattan?

Dangers of a Short Circuit.

"Well, now," objects the practical electrician, "cables would be burned up by that escape—then the engines which drive the dynamos would stop. Engines stop on a short circuit. Remember that there are two electricities—the negative and the positive—which tend to unite, and in uniting produce the electric current. One punctured insulation makes no trouble. There's nothing doing unless there is a puncture on the other cable also. When one escapes it dashes for the other by the shortest route. Why should the engines stop? Because 10,000 horse-power becomes by such a crossing of cables equal to 100,000 horse-power, and the engine having only 10,000 capacity would be overwhelmed."

Sixty thousand volts is the present safety limit for power transmission. Anything more bursts through all insulators yet devised. At Niagara a plant with 10,000 horse-power, transmits its current under a pressure of 20,000 volts. On the Manhattan Elevated and Subway roads the pressure is 12,000 volts; on the lighting wires 240 volts.

Now, as at Sing Sing the voltage used to kill a man is only 2,000, the total voltage from Manhattan's horse-power could cause a very bad scene.

"Yes," assents the practical electrician, "it could kill everybody on the island.

"A little more than three amperes of current under pressure of 240 volts is furnished by one horse-power. If all the city used this pressure the amperage would be 3,000,000; and that would be able to fuse at a breath a steel column the thickness of 200 rails."

"Then suppose," the practical electrician was urged, "that some night all this mighty mystery threw off its man-made restraints and gathered itself into one super-Jovian thunderbolt?"

"Oh, the things it could do to Manhattan are beyond scientific estimating! They are only to be dealt with by fancy," he answered, ignoring every electric principle to suppose such an impossibility. Nothing merely earthly would be comparable with the monstrous happening. If all this New York electric power were condensed into one explosive cloud it would cause an explosion which would be heard around the world! However," he added, "electrical horse-power is not in an explosive condition. We can only put it in that state theoretically."

What Would Happen "Theoretically."

Putting it "in that state theoretically," it was fancied that this might happen.

Manhattan would be in its night pomp and splendor, "fabric of diamond and gold." The theatres would be letting out. Above, upon and below the surface the crowded cars would be hurrying people homeward. Suddenly every wheel would stop. The city's bright avenues would fall silent and black.

Then all that goes to light up the Great White Way would join the flashes leaping up from every Subway opening, and these would join the fantastic glares climbing down elevated road pillars, darting from buildings, lifting themselves from the crevice of the underground trolley; all signing-magging with enormous velocity.

Whatever was combustible would flash into flame at a touch.

Lead running like water; iron softened, and releasing the brick and stone it had upheld; glass melting, walls rushing asunder, "the noise of a thousand waters." There would be a rush from houses, apartments, tenements; a "tumult and gathering of feet." The Great White Way would be a roaring white furnace. Human beings thrillingly shocked, uttering those weird dying cries of the electrocuted, would clog the street.

"Electricity, awful sister of the air, would be walking in a kingdom of her own.

In plain sight she would exhibit a species of mad hilarity. Above the majestic copper and iron Liberty in the harbor the free atmospheric electricity would hover as always in great threatening density. Protecting the statue would be her seven pointed cap and her asbestos packing, insulating her exterior copper from interior iron. Diana, of Madison Square, being of copper gilded, would be a good conductress, and she would assist atmospheric electrons down to the ground to increase the forces. Diana's fatality would arise from the numerous illuminating wires and incandescents, which, overrunning tower and building—her underpinning—would drop her at last on a heap of bricks.

Manhattan a Gray Waste.

In this preposterous wild ritual of sacrifice and fiery strife the whole island would have glowed and smelled with luminous unbearable gaseous exhalations from burning casings, clothings, harnessings, seared flesh, exploded chemicals; until at last from the concentrated loose and reckless forces Manhattan would have suffered the ultimate dread eclipse. And the sun would rise over a sterile, gray waste of ashes.

Any feature would be recognizable except the Park Reservoir, whose storage of water might save it from the general sepulchral obliteration.

"You forget Wall Street," broke in the practical electrician lightly. "Its stock-water would preserve it from the cataclysm, no doubt."

What New York's Electricity Combined Could Do.

It would have the strength of 7,000,000 men, or 1,250,000 horses.

It could fuse at a breath a steel column the thickness of 200 rails.

It could leap in one continuous flame from shore to shore of Manhattan.

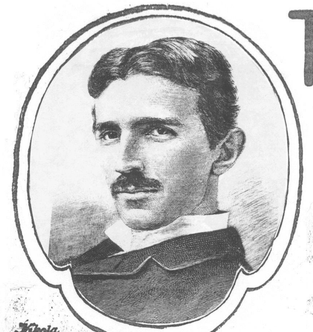
It is 625 times more powerful than the man-killing current of Sing Sing, and could kill every one in the city at a flash.

Its explosion would be felt around the world.

With one night of freedom it would leave the Metropolis a gray solitude of ashes.

Then he went on, after a moment's smiling consideration:

"As a matter of fact, you know, after this paroxysmic dream, you would wake up and learn that our million electrical horse-power could not heat to white heat one-hundredth part of the Waldorf. Also that, really, if all the electricity in Manhattan did escape, it would be no more than if you had a huge reservoir of air and it suddenly got out of its tank and mixed harmlessly with the outer atmosphere!"



TESLA'S TIDAL WAVE TO MAKE WAR IMPOSSIBLE

The New Wireless Wonder That Will Create Fleet-Destroying Convulsions in the Open Sea, Engulf the Heaviest Fighting Ships Like Toy Boats in a Tub and by Its Horrors Hasten the Day of Universal Peace.

BY NIKOLA TESLA.

TO urge peace was the dream of the Peace Conference. To compel peace is the newest dream of Science.

Representative men of many nations have been gathered in New York to plead the altruistic cause of international harmony. At this very juncture inventive Science comes forward to promise a device so terrible that, should it be perfected, and put into practice, sea battles will become impossible.

Nikola Tesla has devised a plan which will make navies as useless as the paper boats that babies float in bathtubs. Imagine a great navy approaching the coast of New York, battle-flags flying, decks cleared for action, guns shotted, lookouts peering westward in expectation of sighting the defending fleet. Then imagine a vast tidal wave suddenly rising from the ocean and swallowing up that hostile fleet, ships, guns, men and all, as Pharaoh's host was engulfed by the waters of the Red Sea. Imagine then the sea returning to its ordinary calm, with not a vestige of that vast armada left to tell the tale. Such is the unanswerable peace argument offered by Nikola Tesla.

The knowledge that any nation possessed the secret of creating such an invincible tidal wave would make that nation invulnerable. No other nation would dare attack it, at least by sea.

Wireless telegraphy is the force that Mr. Tesla will apply to the generation of such a tidal wave.

Wireless telegraphy, to-day but just out of its swaddling clothes, is destined to grow to be a giant Mr. Tesla describes below how it can be made to direct his "teleautomaton," which could be sent out against a hostile fleet, unmanned, steered from shore, its wave-crashing torpedoes discharged by electric waves impeled from shore. This invention would go far to make war too dangerous and too expensive to be undertaken by any nation; but the almost human messenger itself is a trifle in comparison with the annihilating tidal wave which Mr Tesla goes on to describe in this remarkable article written by him especially for The Sunday World.

JUST at this time, when all efforts toward peaceful arbitration notwithstanding, the nations are preparing to expend immense sums in the design and construction of monstrous battle-ships, it may be useful to bring to the attention of the general public a singular means for naval attack and defense, which the telautomatic art has made possible and which is likely to become a deciding factor in the near future.

A few remarks on this invention, of which the wireless torpedo is but a special application, are indispensable to the understanding and full appreciation of the naval principle of destruction.

The telautomatic art is the result of endeavors to produce an automaton capable of moving and acting as if possessed of intelligence and distinct individuality. Disconnected from its higher embodiment, an organism, such as a human being, is a heat—or thermodynamic engine—comprising: 1, a complete plant for receiving, transforming and supplying energy; 2, apparatus for locomotion and other mechanical performance; 3, directive organs, and, 4, sensitive instruments responsive to external influences, all these parts constituting a whole of marvellous perfection.

The ambient medium is alive with movement and energy, in a state of unceasing agitation which is beyond comprehension. Strangely enough, to most of this terrible turmoil the human machine is insensible. The automaton does not feel the weight of the atmosphere crushing him with a force of sixteen tons. He is unaffected by the shower of particles shooting through his body of cloud and the hurricane of finer substance rushing through him with the speed of light. He is unconscious that he is being whisked through space in the fearful rate of 10,000 miles an hour. But when gentle waves of light or sound strike him his eye and ear respond, his resonant nerve-fibres transmit the vibrations and his muscles contract and relax. Thus, like a float on a turbulent sea, swayed by external influences, he moves and acts. The average person is not aware of this constant dependence on his environment but a trained observer has no difficulty in locating the primary disturbance which prompts him to action, and continued exercise soon satisfies him that virtually all of his purely mechanical motions are caused by visual impressions, directly or indirectly received.

Using the Principles of Human Action.

A machine of such inconceivable complexity as the body of an organized being, capable of an infinite variety of actions, with controlling organs super-sensitive, responsive to influences almost immaterial, cannot be manufactured by man; but the mechanical principles involved in the working of the living automaton are also applicable to an inanimate engine, however crude.

An automobile boat was first employed to carry out the idea. Its storage battery and motor furnished the power; the propeller and rudder, respectively, served as locomotive and directive organs, and a very delicate electrical device, actuated by a circuit tuned to a distance transmitter, took the place of the ear. This mechanism followed perfectly the wireless signals or comments of the operator in control of the transmitter, performing every movement and action as if it had been gifted with intelligence.

The next step was to individualize the machine. The attunement of the controlling circuits gave it a special feature, but this was not sufficiently distinctive. An individuality implies a number of characteristic traits which though perhaps extant elsewhere, are unique in that particular combination. Here again the animated automaton, with its nerve-signal system, was coarsely imitated. The action of the delicate device—the ear—was made dependent on a number of sensitized receiving circuits each recognizable by its own free vibrations and all together by the character of their operative combination. Correspondingly the transmitter was designed to emit a wave-compound exactly matching the combination in the number and pitch of individual vibrations, the groupment and order of succession.

Wonders of the New Telautomaton.

That much is done, but more is to come the mechanism is being perfected which with the operator in control, left to itself, will behave as if endowed with intelligence of its own. It will be responsive to the faintest external influence and from these, unaided, determine its subsequent actions as if possessed of selective quantities, logic and reason. It will perform the duties of an intelligent slave. Many of us will live to see Bulwer's dream realized.

The reader for whom the preceding short explanation of this novel art is intended may think it simple and easy of execution, but it is far from being so. It has taken years of study and experiment to develop the necessary methods and apparatus, and five inventions, all more or less fundamental and difficult to practice must be employed to operate successfully an individualized telautomaton.

Such a novel engine of war—a vessel of any kind, submarine or aerial—carrying an agent of unlimited potency of destruction, with no soul aboard yet capable of doing all it is designed for, as if fully equipped with a fearless crew to command of its captain, must needs bring out a revolution in the present means of attack and defense.

Since ages human ingenuity has been bond upon inventing infernal machines. Of these the modern cannon has been so far the most remarkable. A twelve-inch gun charged with cordite is said to hurl a projectile of 850 pounds with the initial velocity of nearly 2,900 feet per second, imparting to it the energy of 110,000,000 foot-pounds. Were it not for the resistance of the air such a projectile would travel about fifty mile before striking the ground. It would take 3,300 horse-power more than a minute to accumulate its mechanical energy. Bear in mind, however that all this energy is imparted to the projectile while it is being urged through the gun-barrel with a mean force of 1,100 tons. If the barrel is fifty feet long and the average velocity through it 1,450 feet per second, the whole energy transferred to the moving mass in one thirty of a second, hence the rate of performance is 1,000 times the above—that is, about 6,000,000 horse-power. This seems wonderful indeed, but is nothing as compared with rates obtainable by other means. Electricity can be stored in the form of explosive energy of a violence against which the detonation of cordite is but a breath. With a magnifying transmitter, as diagrammatically illustrated, rates of 25,000,000 horse-power have already been obtained. A similiar and much improved machine, now under construction will make it possible to attain maximum explosive rates of over 800,000,000 horse-power, twenty times the performance of the Dreadnought's blindside of eight 12-inch guns simultaneously fired. some figures are so incredible that astronomers acquainted with the marvellous appliances have naturally doubted the practicability of signalling to Mars. In reality, by its means this seemingly visible project has been reduced to a rational enduring problem.

The time is not far distant when all the tremendous wastes of war will be stopped, and then, that there are battles, they will be fought with solar-power and electrical waves. That humanity is moving fast toward this realization is evident from many indications.

What is most to be regretted in the present day regime is that the effort of so many exquisite intelligences must be uneconomically applied, since it cannot be steadily directed toward a scientific truth, unalterable and of permanent usefulness, but must be entirely governed by the wavering struggle of opposing principles. This feverish applying to meet the instant demand, to create type after type, one to devour the other, to merge into one contrasting element, leads, like a nightmare, from one to another absurdity. Such a monstrosity is the latest creation of the naval constructor—the twenty-thousand-ton battleship. In theory it is condemned by competent authorities.

Everything points to the development of a small vessel with internal combustion engines, extreme speed and few weapons of great destructiveness. But the new leviathan is admirably adapted to be practical requirements of his day. In attack it could alone annihilate a nation's fleet. It is equally effective in defense. If equipped with proper acoustic and electric appliances it has little to fear from a submarine, and an ordinary torpedo will scarcely hurt it. That is why the first of these monsters, built in England, has been named Dreadnight. Now, there is a novel means for attacking a fortress of this kind, from shore or on the high seas, against which all its gun-power and prior resistance are of no avail.

This is the tidal wave.

What the Tesla Tidal Wave Will Do.

Such a wave can be produced with twenty or thirty tons of cheap explosive, carried to its destination and ignited by an inexpensive time estimation

The tidal disturbance, as here considered, is a peculiar hydrodynamic phenomenon, in many respects different from the commonly occurring, characterized by a rhythmical succession of waves. It consists generally of but a single advancing swell superceded by a hollow, the water if not otherwise excited being perfectly calm in front and very nearly so behind. The wave is produced by some hidden explosion or upheaval and is, as a rule, symmetrical for a large part of its course. Those who have encountered a tidal wave must have observed that the sea rises rather slowly, but the disturbance gains in violence as it progresses, and under the action of a varying force, great at first, but dying out quickly, while the raised mass is urged downward by the constant force of gravity. When produced by natural causes these waves are very dangerous to ordinary vessels, because the disturbance originates at a great depth. They give a very high idea of the efficacy of this novel means of destruction, particularly adapted for coast defenses, it may be assumed that thirty tons of nitro-glycerine compound, as dynamite, be employed to create the tidal disturbance. This material, weighing about twice as much as water, can be stowed in a cubical tank eight feet each way, or a spherical vessel of ten feet diameter. The reader will now understand that this charge is to be intrusted to a non-interferible telautomaton, heavily protected and partly submerged or submarine, which is under the perfect control of a skilled operator far away. At the propitious moment the signal is given, the charge sunk to the proper depth and ignited.

The water is incompressible. The hydrostatic pressure is the same in all directions. The explosion propagate through the compound with a speed of three miles a second. Owing to all this the whole mass will be converted into gas before the water can give way sensibly. Hence a spherical bubble ten feet in diameter will form. The immense pressure against the surrounding water will be twenty thousand atmospheres, or one hundred and forty tons per square inch. When the great bubble has expanded to twice its original volume it will weigh as much as the water it displaces, and from that moment on, its lower end tapering more and more into a cone, it will be driven up with a rapidly increasing force tending towards twenty thousand tons. Under this terrific impetus, it would shoot up the surface like a bullet were it not for the water resistance, which will limit its maximum speed to eighty feet per second.

Consider now the quantity and energy of the upheaval. The caloric potential energy of the compound is 2,800 heat units per pound, or, in mechanical equivalent, almost one thousand foot tons. The entire potential energy of the explosive will thus be sixty-six million foot tons. Of course, only a part of this immense store is transformable in mechanical effort. Theoretically 40 pounds of good smokeless powder would be sufficient to impart to the Dreadnought's displacement projectile the tremendous velocity mentioned above, but it actually takes a charge of 280 pounds. The tidal wave generator is a dynamic transformer much superior to the gun, its greatest possible efficiency being as high as 95 per cent. Taking, to be conservative, 25 per cent, instead, there will be of the total potential store about twenty-five million foot tons obtained in mechanical energy.

How the Enemy Would Be Engulfed.

Otherwise stated, 25,000,000 tons, that is, 800,000,000 cubic feet of water, could be raised, one foot, or a smaller quantity to a correspondingly greater elevation. The height and length of the wave will be determined by the depth at which the disturbance originated. Opening in the centre like a Volcano the great hollows will beak forth in a shower of ice. Some sixteen seconds later a valley of 800 feet depth, counted from normal ocean level, will form, surrounded by a perfectly circular swell, approximately of equal height, which will embrace in diameter at the rate of about 330 feet per second.

It is fair to consider the effect of such an eruption on a vessel situated nearby, however large. The entire navy of a great country, if massed around, would be destroyed. But it is instructive to inquire what such a wave could do to a battleship of the Dreadnought type at considerable distance from its origin. A simple calculation will show that when the outer circle has expanded to three-quarters of a mile, the swell, about 1,250 feet long, would still be more than 350 feet in height, from crest to normal sea level, and when the circle is one and one-quarter mile in diameter the vertical distance, from crest to trough will be over 180 feet.

The diagram on the right of this page shows the successive positions of the vessel in the gravity. The first impact of the water will produce pressures of three tons per square foot, which all over the submerged surfaces of, say, 20,000 square feet, may amount to 60,000 tons, eight times the force of the recoil of the broadside. That first impact may in itself be fatal. During more than one second the vessel will be entirely submerged and finally dropped into the hollow from a height of about seventy-five feet, the descent being effected, more or less like a free fall. It will then sink far below the surface, never to rise.

Nikola Tesla



The Earthquake Tidal Wave of Feb. 26, as Described by First Officer Brown, of the Steamship Planet Neptune

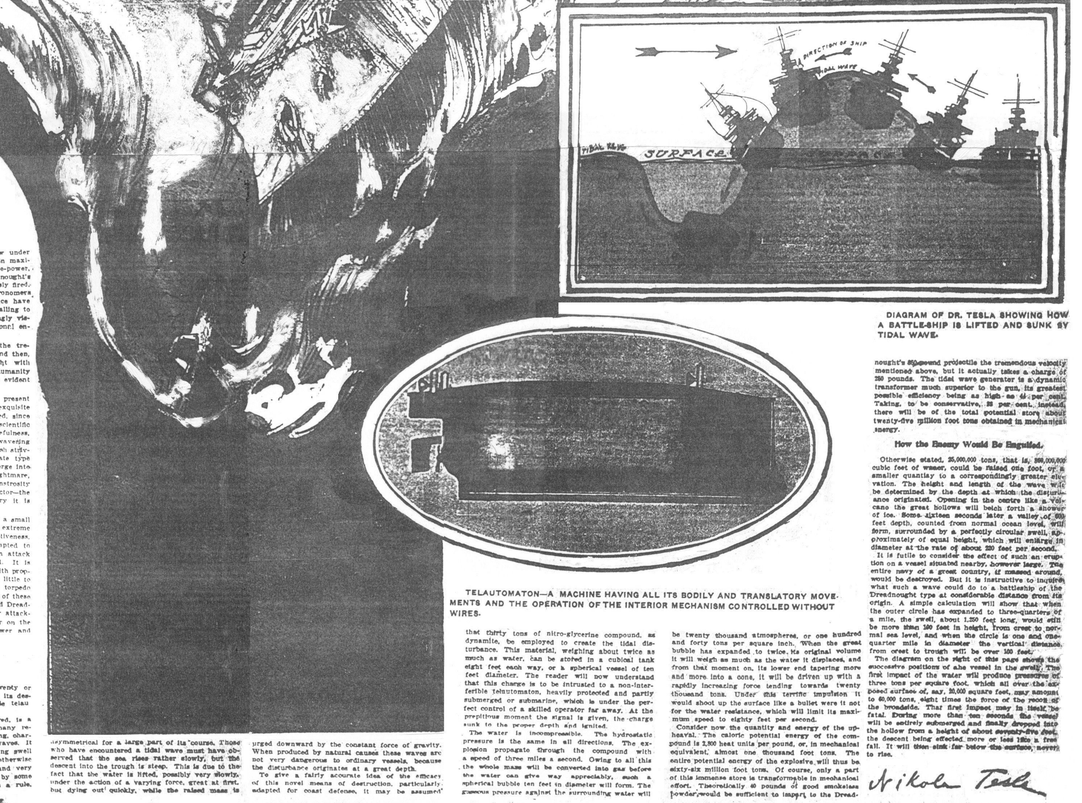


DIAGRAM OF DR. TESLA SHOWING HOW A BATTLE-SHIP IS LIFTED AND SUNK BY TIDAL WAVE.

TELAUTOMATON—A MACHINE HAVING ALL ITS BODILY AND TRANSLATORY MOVEMENTS AND THE OPERATION OF THE INTERIOR MECHANISM CONTROLLED WITHOUT WIRES.

Terrors of Tidal Wave Caused by an Earthquake at Sea.

Earthquakes on land are familiar, at least from hearsay, to everybody, but earthquakes in the depths of the sea are rarely heard of and even more rarely felt. They do take place, however, and sometimes cause tremendous tidal waves. The daily papers ten days ago contained a brief account of the experience of the steamship Planet Neptune in passing over the site of a submarine earthquake. The following account of it was written for the Sunday World by First Officer Vans Brown, who was on the bridge of that vessel when the awful thing happened.

BY VANS BROWN

First Officer, Steamship Planet Neptune.

I HOPE, as a seafaring man, that I shall never have to go through such an experience as we all had on the steamship Planet Neptune on the evening of Feb. 26. All hands thought their last hour had come.

The Planet Neptune had left Montevideo for New York a few days before. Everything went well for the first few days out. The sea was fairly calm. I was on the bridge with no thought that anything would happen. Most of the crew were below.

All of a sudden there was some mighty catclysm of the floor of the sea.

It could have been nothing less than a submarine earthquake. This is not uncommon, as a matter of fact. Several of my friends who have followed the sea have had the same experience, but none went through what we did.

There was no warning. It just seemed as if the bottom had fallen out of the sea. The big ship just dropped right down—there is no other way to describe it. It seemed as if we were going down into a bottomless pit. Actually we were falling into a great hole in the water.

It is hard to describe the sensation, for it seemed as though down, down, down we fell—I thought we should never stop, ship and all. I grabbed the flying bridge railing and held on for dear life. But we did stop. And then, to my horror, when I looked up there was a giant wave curling over us and ready to break.

A moment later it broke upon us, tons and tons of water. It seemed as if the ship had been lifted right up in the air and had fallen upon us.

Most of the loose gear on the deck was swept away. We had several coops of chickens on deck. They were carried away, of course. Two boats, all the deck gear, water butts—all were smashed and washed away. A dozen ports were smashed in, letting the water inside the ship. I thought we were all gone.

But the ship stood the shock. She shivered, her bows rose and up we popped as if she had been a toy boat in a bath tub. We were safe.

But poor Seaman Shalburg lay unconscious on the deck. He had been lookout and he was thrown against a stanchion. His leg was broken, he had concussion of the brain and internal injuries. I guess he will be a cripple for life.

The superstructure of the ship was well battered, too. But the ship proved her seaworthiness and it didn't affect our voyage north at all. Just as quickly, too, the sea calmed down again and the big wave died away in ripples.

But it was like your Niagara while it lasted. For thousands of yards round the great hole in the sea the waves were churned up into whitecaps. Yet there was no storm.

Give me a storm every time. There are no holes in the water then, and if you are a good sailor you can get out of it. But don't give me a submarine earthquake ever again.

The New York Times May 2, 1907

NICOLA TESLA OBJECTS.

Thinks He Should Receive Credit for His Own Inventions.

To the Editor of The New York Times:

I have been much surprised to read in THE TIMES of Sunday, April 21, that Admiral H. N. Manney, U. S. N., attributes a well-known invention of mine, a process for the production of continuous electrical oscillations by means of the electric arc and condenser, to Valentine Poulsen, the Danish engineer. This improvement has been embodied by me in numerous forms of apparatus identified with my name, and I have described it minutely in patents and scientific articles. To quote but one of many references, I may mention my experimental lecture on "Light and Other High-Frequency Phenomena," published under the auspices of the Franklin Institute and the National Electric Light Association, for which both of these societies have distinguished me.

I share with Admiral Manney in the gratification that we are in the lead, and particularly that wireless messages have been transmitted from Pensacola to Point Lorne. Inasmuch, however, as this feat could not have been accomplished except by the use of some of my own devices, it would have been a graceful act on his part to bring this feat to the attention of the wireless conference. My theory has always been that military men are superior to civilians in courtesy. I have not been discouraged by the refusal of our Government to adopt my wireless system six years ago, when I offered it, nor by the unpleasant prospect of my passing through the experiences described by Mark Twain in his story of the beef contract, but I see no reason why I should be deprived of a well-earned honor and satisfaction.

THE TIMES has hurt me grievously; not by accusing me of commercialism, nor by its unkind editorial comments on those letters I wrote, in condemnation of my system of power transmission in the Subway. It is another injury, perhaps unintentional, which I have felt most keenly.

The editor of THE TIMES may not have known that I am a student of applied mathematics when he permitted a fellow student of mine to insinuate in THE TIMES of March 28 that I avail myself of inventions of others. I cannot permit such ideas to gain ground in this community, and, just to illuminate the situation, I shall quote from the leading electrical paper, The London Electrician, referring to some wireless plants of Braun and Marconi: "The spark occurs between balls in the primary circuit of a Tesla coil. The air wire * * * is in series with a Tesla transformer. * * * The generating plant is virtually a Poldhu in miniature. Evidently Braun, like Marconi, has been converted to the high-potential methods introduced by Tesla." Needless to add that this substitution of the old, ineffective Hertzian appliances for my own has not been authorized by me.

My fellow-student can rest assured that I am scrupulously respecting the rights of others. If I were not prompted to do so by a sense of fairness and pride I would be by the power I have of inventing anything I please.

N. TESLA.

New York, April 30, 1907.

TESLA'S TIDAL WAVE TO MAKE WAR IMPOSSIBLE.*

By NIKOLA TESLA.

JUST at this time, when all efforts towards peaceful arbitration notwithstanding, the nations are preparing to expend immense sums in the design and construction of monstrous battleships, it may be useful to bring to the attention of the general public a singular means for naval attack and defence, which the telautomatic art has made possible, and which is likely to become a deciding factor in the near future.

A few remarks on this invention, of which the wireless torpedo is but a special application, are indispensable to the understanding and full appreciation of the naval principle of destruction.

The telautomatic art is the result of endeavours to produce an automaton capable of moving and acting as if possessed of intelligence and distinct individuality. Disconnected from its higher embodiment, an organism, such as a human being, is a heat—or thermodynamic engine—comprising:—(1) a complete plant for receiving, transforming, and supplying energy; (2) apparatus for locomotion and other mechanical performance; (3) directive organs; and (4) sensitive instruments responsive to external influences, all these parts constituting a whole of marvellous perfection.

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Using the Principles of Human Action.

A machine of such inconceivable complexity as the body of an organised being, capable of an infinite variety of actions, with controlling organs supersensitive, responsive to influences almost immaterial, cannot be manufactured by man; but the mechanical principles involved in the working of the living automaton are also applicable to an inanimate engine, however crude.

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The time is not far distant when all the tremendous wastes of war will be stopped, and then, if there are battles, they will be fought with water-power and electrical waves. That humanity is moving fast towards this realisation is evident from many indications.

What is most to be regretted in the present war *régime* is that the effort of so many exquisite intelligences must be uneconomically applied, since it cannot be steadily directed towards a scientific truth, unalterable and of permanent usefulness, but must be entirely governed by the wavering struggle of opposing principles. This feverish striving to meet the instant demand, to create type after type, one to devour the other, to merge into one contrasting element, leads, like a nightmare, from one to another absurdity. Such a monstrosity is the latest creation of the naval constructor—a 20,000 ton battleship. In theory it is condemned by competent authorities.

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What the Tesla Tidal Wave will Do.

Such a wave can be produced with twenty or thirty tons of cheap explosive, carried to its destination and ignited by a non-interferible telautomaton.

The tidal disturbance, as here considered, is a peculiar hydrodynamic phenomenon, in many respects different from the commonly occurring, characterised by a rhythmical succession of waves. It consists generally of but a single advancing swell succeeded by a hollow, the water if not otherwise agitated being perfectly calm in front and very nearly so behind. The wave is produced by some sudden explosion or upheaval, and is, as a rule, asymmetrical for a large part of its course. Those who have encountered a tidal wave must have observed that the sea rises rather slowly, but the descent into the trough is steep. This is due to the fact that the water is lifted, possibly very slowly, under the action of a varying force, great at first, but dying out quickly, while the raised mass is urged downward by the constant force of gravity. When produced by natural causes these waves are not very dangerous to ordinary vessels, because the disturbance originates at a great depth.

To give a fairly accurate idea of the efficacy of this novel means of destruction, particularly adapted for coast defence, it may be assumed that thirty tons of nitro-glycerine compound, as dynamite, be employed to create the tidal disturbance. This material, weighing about twice as much as water, can be stored in a cubical tank 8ft. each way, or a spherical vessel of 10ft. diameter. The reader will now understand that this charge is to be entrusted to a non-interferible telautomaton, heavily protected, and partly submerged or submarine, which is under the perfect control of a skilled operator far away. At the propitious moment the signal is given, the charge sunk to the proper depth and ignited.

The water is incompressible. The hydrostatic pressure is the same in all directions. The explosion propagates through the compound with a speed of three miles a second. Owing to all this, the whole mass will be converted into gas before the water can give way appreciably, and a spherical bubble 10ft. in diameter will form. The gaseous pressure against the surrounding water will be 20,000 atmospheres, or 140 tons per square inch. When the great bubble has expanded to twice its original volume it will weigh as much as the water it displaces, and from that moment on, its lower end tapering more and more into a cone, it will be driven up with a rapidly-increasing force tending towards 20,000 tons. Under this terrific impulsion it would shoot up the surface like a bullet were it not for the water resistance, which will limit its maximum speed to 80ft. per second.

Consider now the quantity and energy of the upheaval. The caloric potential energy of the compound is 2,800 heat units per pound, or, in mechanical equivalent, almost 1,000ft.-tons. The entire potential energy of the explosive will thus be 66,000,000ft.-tons. Of course, only a part of this immense store is transformable into mechanical effort. Theoretically, 40lb. of good smokeless powder would be sufficient to impart to the *Dreadnought's* 850lb. projectile the tremendous velocity mentioned above, but it actually takes a charge of 250lb. The tidal wave generator is a dynamic transformer much superior to the gun, its greatest possible efficiency being as high as 44 per cent. Taking, to be conservative, 38 per cent. instead, there will be of the total potential store about 25 million foot-tons obtained in mechanical energy.

How the Enemy would be Engulfed.

Otherwise stated, 25,000,000 tons — that is, 860,000,000c.ft. of water, could be raised 1ft., or a smaller quantity to a correspondingly greater elevation. The height and length of the wave will be determined by the depth at which the disturbance originated. Opening in the centre like a volcano, the great hollows will belch forth a shower of ice. Some sixteen seconds later a valley of 600ft. depth, counted from normal ocean level, will form, surrounded by a perfectly circular swell, approximately of equal height, which will enlarge in diameter at the rate of about 220ft. per second.

It is futile to consider the effect of such an eruption on a vessel situated near-by, however large. The entire navy of a great country, if massed around, would be destroyed. But it is instructive to inquire what such a wave could do to a battleship of the Dreadnought type at considerable distance from its origin. A simple calculation will show that when the outer circle has expanded to three-quarters of a mile, the swell, about 1,250ft. long, would still be more than 100ft. in height, from crest to normal sea level, and when the circle is one and one-quarter mile in diameter the vertical distance from crest to trough will be over 100ft.

The first impact of the water will produce pressures of three tons per square foot, which all over the exposed surface of, say, 20,000sq.ft., may amount to 60,000 tons, eight times the force of the recoil of the broadside. That first impact may in itself be fatal. During more than ten seconds the vessel will be entirely submerged and finally dropped into the hollow from a height of about 75ft., the descent being effected more or less like a free fall. It will then sink far below the surface, never to rise.

* From the *New York World*.

TESLA'S TIDAL WAVE.

[383.]—To the man in the street these "high falutin'" descriptions of the Jules Verne order may be exciting: to the practical engineer they provoke a large amount of contempt. Some years ago Mr. Tesla propounded to the newspaper men that he had invented a new means of transmitting large amounts of horse-power across the world—New York to Paris I think. There was a lot of preliminary very tall talk, and one received queries from various sources as to the truth of this new American wonder. For my part I advised large doses of sodium chloride, and finally the "wonder" collapsed, and it appeared the H.P. was to be placed on board a boat in the form of a storage-battery, a means of conveying H.P. to Paris or elsewhere which has been in use (before Tesla was born or thought of) in the form of the old-time "Geordie" collier of our own Tyne, only it carried coal instead of storage-cells.

In the case in question the cells were used to drive or steer the vessel under the control of a director ashore with a wireless telegraph. Given the invention of the transmission of H.P. in a boat whether in the form of coal in a "Geordie" or accumulators in a submarine, or compressed air in a torpedo; given also the wireless telegraph, the use of the latter to steer the former was all that was left for Tesla to talk about doing. Whether even this has come into successful being, except in the smoke of an after-dinner cigar, I do not know; but I should like to. How, for instance, can the director ashore tell where the submarine is? With a crew on board, the ordinary submarine captain finds it difficult enough to locate his position when he has been diving for some time.

On page 296 this would-be wonder appears again. Now it is not carrying accumulators to Paris, but becomes an animated submarine mine. It carries 30 tons dynamite, the explosion of which is intended to create a tidal wave, and destroy the *Dreadnought* and the Navy generally massed together in the neighbourhood. [Before letting it off, all persons living in the same hemisphere will be warned by wireless or other telegraph not to leave "the baby on the shore," or, indeed, any other property, within 500 yards of the sea, otherwise the tidal wave starter could not be held responsible for its devastations. N.B.—This warning was no doubt omitted from the *New York World*, but it is only too obviously necessary.]

Let us consider the proposed destruction of the *Dreadnought*. If she were close over the explosion, we might agree with Tesla as to the nature of the result. If, however, she were, as in the case he describes, a three-quarter mile off, she would encounter the wave of the explosion about 100ft. high, say about twice the height of the usual ocean wave storms, and 1,250ft. long, a comparatively gentle slope of water up and down, as anyone may see who draws it to scale, say 6in. long by ⅛in. high, coming at a speed of 220ft. per second. [Airy, and also Scott, give a considerably lower velocity, especially in deep water.] Tesla does not say what depth he takes, but we accept his figure. The resulting action is simply the rising of the water about the ship 100ft. in three seconds, and then sinking in the same time. The question as to whether her buoyancy would overcome her inertia so as to raise her at this rate may be left to the mathematicians. Supposing, however, she were immersed during the passage of the wave—i.e., for some fraction of six seconds, possibly three seconds, it is not necessary to suppose she will not "bob up serenely" afterwards. Ordinary vessels on ordinary tidal waves do so. An old skipper told me of a case where he and his mate on a little coaster, hearing the roar of an enormous wave approaching, sprang into the rigging. The whole hull becoming deeply immersed, the mate yelled, "She's down!" My friend replied: "Not so long as you can see the masts." And she rose trembling out of the depths.

Be that as it may, there are other consequences not considered; for instance, the after-effects of this tidal wave. Whatever fate would befall the *Dreadnought* would depend partly on the state of her preparedness, which would probably be complete when artificial tidal waves were raging around. What about merchant vessels within a few miles? Also, what about low-lying shores and their inhabitants? For we must remember that when such waves get into shallow water they rise in height and then break and sweep long distances inland in a solid rush of water. Fancy such a wave in New York Harbour, or the bore of one rushing up the Mersey or Belfast Lough, or any estuary, and the millions of innocent New Yorkers or coast dwellers anywhere that would be drowned. No, no: international law would step in, and public opinion would class tidal-wave starters with dynamitards, pirates, assassins, Guy Fawkes, and all the other vermin that have disgraced the human race.

Belfast. J. Brown.

The Brooklyn Daily Times June 12, 1907

TESLA'S BIG TOWER TO BE SOLD FOR DEBT

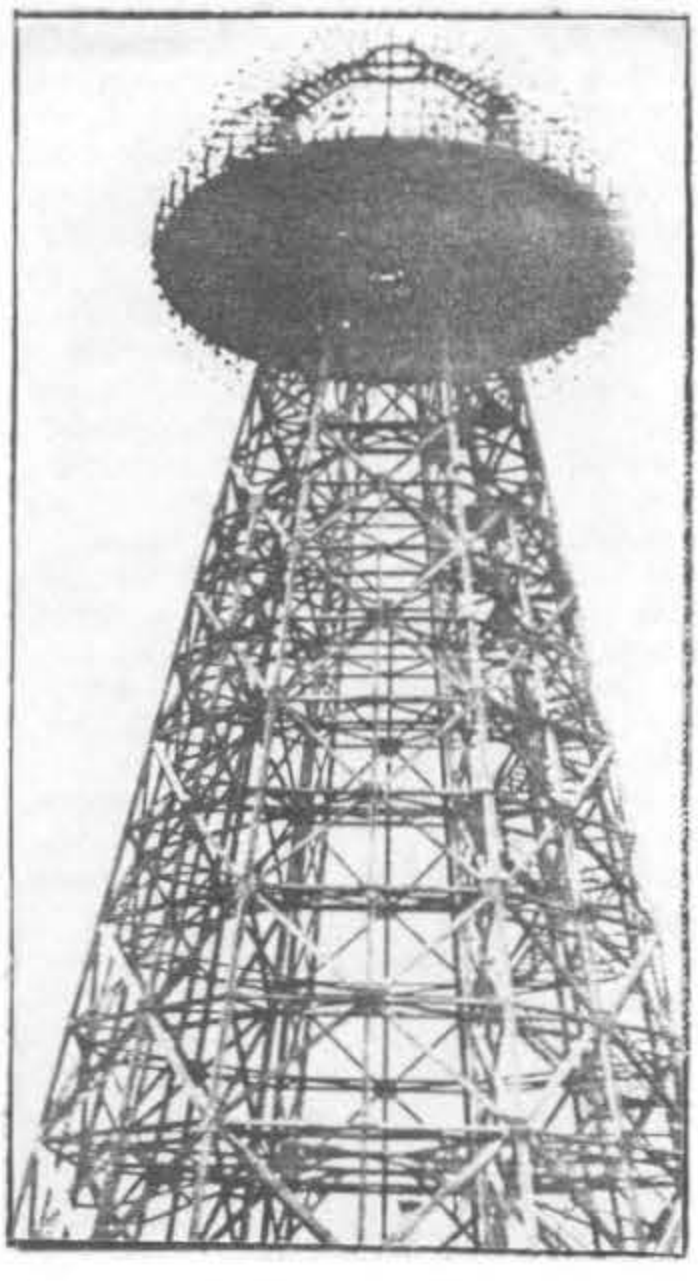
GREAT INVENTOR'S PET SCHEME SEEMS TO HAVE RECEIVED A BLOW

JUDGMENT IS FOR $1,108.20

Structure Was 150 Feet High in Air and 150 Feet Shaft in Ground— Has Been a Mystery Ever Since It Was Built— Magnificent Ideas.

(Special to the Brooklyn Times.)

Riverhead, L. I., ~~June 12.~~ ~~The Tow~~er of Wonders at Wardencliffe, where Nikola Tesla, the inventor, preserved such mystery and where it was whispered scientific experiments were to be carried on greater in scope than any ever before attempted, is for sale. The Sheriff of Suffolk County to-day advertised the entire property to be disposed of to satisfy a judgment held by Dr. James S. Warden. The Tesla property consists of 200 acres and the wonderful steel tower 150 feet high and with a shaft sunk 150 feet in the ground. Tesla has spent a fortune in rearing the huge steel mass, which ever since its building has been the theme for discussion among the puzzled laymen of the Island.



TESLA TOWER AT WARDENCLIFF.

What did Tesla intend to do? This is the question that for a long time perplexed the people living in the Wading River and Wardencliffe neighborhood. It was at first believed that he intended experimenting with a project to store solar rays and transmit their power in some merchantable form. In a scientific treatise, he had promulgated the belief that it was possible to attract solar energy and find a market for the stored power. The height of the tower and its peculiar dome-shaped top readily lent substance to the belief that Tesla did, indeed, intend to utilize the sun's rays for motive power.

However, nothing has ever been learned of the Tower of Wonders. Tesla himself is a brave fellow, not seeking notoriety, and steadfastly holding to his belief, recently endorsed by Edison, that in regard to electricity the human race knows little or nothing. Just previous to building the tower, Tesla expounded the theory that messages could be transmitted between any points on the globe, using the earth as a medium, and there were not lacking people who asserted that his huge shaft was sunk 150 feet in the ground in order that messages might be transmitted through the earth's substance.

The tower itself is a bare steel structure. Near the base is a machine house of some kind. This is filled with intricate machinery. No one, so far as it known, has ever been able to find out from Tesla or his men just what the machinery is for and what was or is to be done with it. Visitors are not welcome and they are told very politely that the property is private and trespassing is not desired.

Niles and Johnson, of Wall street, are the attorneys for the sale. The judgment is for $1,108.20, and will probably be settled.

Nikola Tesla came into prominence many years ago as an inventor. In 1884 he took out citizenship papers and since that time has lived in America. He has of late years spent nearly all of his time on his scheme of world telegraphy and telephony and in designing plans for the transmission of power without a direct medium. He is a man of the most splendid visions and may prove to be as far ahead of the scientific world as Kepler was when his astronomical theories were scoffed at as dreams.

The Brooklyn Eagle June 13, 1907

TESLA WILL PAY UP.

Inventor Will Not Let His Wardenclyffe "Wonder Tower" Go Under the Hammer.

(Special to the Eagle.)

Riverhead, L. I., June 13—Under a judgment secured some time ago against Nikola Tesla, the inventor, Sheriff Wells has advertised for sale the Tesla property at Wardenclyffe, at Wading River, on which is located the big steel tower which has been so much of a mystery ever since it was built several years ago.

The "wonder tower," as it is called, is a huge structure of steel and cement, and no one appears to know exactly what it was intended for. That it was to be used to demonstrate his long-cherished theory of communicating with the Martians is popularly believed.

The judgment, which is for $1,108.20, is held by Dr. James W. Warden. The security is the two hundred acres owned by Tesla, upon which stands the tower, which is sunk into the ground a distance of 150 feet and is 150 feet in height.

Tesla is expected to satisfy the judgment and save his "wonder tower" from going under the hammer. The entire plant at Wardenclyffe is said to be valued at $350,000.

Colorado Springs, Col., June 13—Nikolai Tesla about ten years ago erected a laboratory and tower on Nob Hill, near this city, for experiments in the transmission of power without wires. This plant was valued at approximately $30,000. Shortly after he left this city the caretaker of the plant, a man named Duffmer, sued Tesla for about $1,000 salary. Subsequently the assessors' office levied upon the property for taxes, with the result that the building and machinery were sold under the judgment obtained by Duffmer, and the taxes were paid out of the proceeds of the sale.

TESLA'S TOWER LEVIED UPON.

Inventor's Mysterious Structure in Hands of Sheriff.

The steel tower, 216 feet high, erected by Nikola Tesla, the inventor, at the eastern end of Long Island, together with his entire property there, was advertised for sale by the sheriff of Suffolk County yesterday, to satisfy a judgment for $1,080. The judgment was obtained four years ago by Dr. James S. Warden and now belongs to his heirs. Mr. Tesla's tower has been a mystery for years. The public has never known the purpose for which it was erected. The property is at Wardencliffe, and consists of about 200 acres.

COLORADO SPRINGS, Col., June 13.—Nikola Tesla about ten years ago erected a laboratory and tower on Nob Hill, near this city, for experiments in the transmission of power without wires. The plant was valued at approximately $30,000. Soon after he left this city the caretaker of the plant, a man named Duffmer, sued Tesla for about $1,000 salary. Subsequently, the assessors' office levied upon the property for taxes, with the result that the building and machinery were sold under the judgment obtained by Duffmer, and the taxes were paid out of the proceeds of the sale.

The New York Sun June 13, 1907

SHERIFF TAKES TESLA'S TOWER

And the Inventor Guesses He'll Have to Pay a $1,080 Judgment Now.

The steel tower, 216 feet high, erected by Nikola Tesla, the inventor, at the eastern end of Long Island, together with his entire property there, was advertised for sale by the Sheriff of Suffolk county yesterday, to satisfy a judgment for $1,080. The judgment was obtained four years ago by Dr. James S. Warden and now belongs to his heirs.

Mr. Tesla, when seen at the Waldorf-Astoria last night, did not seem to be at all afraid that he would lose the tower, which has been a puzzle to the people of Long Island ever since it was erected four years ago. He was afraid, however, that he would have to pay the judgment.

"This is an old case which has been dragging in the courts for years," he explained. "I took an option on 400 acres of land down there at some distance from my property on which my plant is located. I intended to use this land for an agricultural experiment in fertilizing soil by means of electricity. I thought that by the use of certain electrical principles the productivity of the soil could be increased very much. I agreed to take a certain option, but subsequently discovered that the person who entered into the agreement had no right to make such a disposition of the property. I told him the option was off and paid no further attention to the matter. A year or so later a suit was brought and has been fought with varying results. The heirs of the owner have simply pressed the claim and it is very likely that it will have to be paid. It does not in the least affect my undertakings and the work at my plant."

Mr. Tesla said that altogether his plant was worth $350,000, but he refused to dispel the mystery surrounding the tower. At the time that work on this was begun it was reported that it was to send the human voice on wireless waves around the globe.

"I have no announcement to make now," sain Mr. Tesla. "In a few months I shall begin to manufacture new devices of mine at this plant and then I may have something of interest to say."

The Tesla property is at Wardencliffe and consists of 200 acres. The tower has a great mushroom top, from which there used to be blinding flashes of electricity at night some years ago.

CAN BRIDGE THE GAP TO MARS

Nikola Tesla on His Wireless System for the Transmission of Energy.

To the Editor of The New York Times:

You have called me an "inventor of some useful pieces of electrical apparatus." It is not quite up to my aspirations, but I must resign myself to my prosaic fate. I cannot deny that you are right.

Nearly four million horse power of waterfalls are harnessed by my alternating current system of transmission, which is like saying that one hundred million men—untiring, consuming nothing, receiving no pay—are laboring to provide for our wants, incidentally saving the waste of one hundred million tons of coal annually. In this great city the elevated roads, the subways, and street railways are operated by my system, and the lamps and other electrical appliances get the current through machinery of my invention. And as in New York so all the world over where electricity is introduced. The telephone and the incandescent lamp fill specific and minor demands, electric power meets the many general and sterner necessities of life. Yes, I must admit, however reluctantly, the truth of your unflattering contention.

But the greater commercial importance of this invention of mine is not the only advantage I have over my celebrated predecessors in the realm of the useful, who have given us the telephone and the incandescent lamp. Permit me to remind you that I did not have, like Bell, such powerful help as the Reis telephone, which reproduced music and only needed a deft turn of an adjusting screw to repeat the human voice; or such vigorous assistance as Edison found in the incandescent lamps of King and Starr, which only needed to be made of high resistance. Not at all. I had to cut the path myself, and my hands are still sore. All the army of my opponents and detractors was ever able to drum up against me in a fanatic contest has simmered down to a short article by an Italian—Prof. Ferraris—dealing with an abstract and physically meaningless idea of a rotating magnetic pole and published years after my discovery, months even after my complete disclosure of the whole practically developed system in all its essential universally adopted features. It is a publication, pessimistic and discouraging, devoid of the discoverer's virility and force, devoid of results, utterly wanting in the faith and devotion of the inventor, a defective and belated record of a good but feeble man whose only response to my whole-souled brother greeting was a plaintive cry of priority—a sad contrast to the strong and equanimous Schallenberger, a true American engineer, who stoically bore the pain that killed him.

A fundamental discovery or original invention is always useful, but it is often more than that. There are physicists and philosophers to whom the marvelous manifestations of my rotating magnetic field, the suggestive phenomena of rotation without visible connection, the ideal beauty of my induction motor with its contactless armature, mean quite as much as the thousands of millions of dollars invested in enterprises of which it is the foundation.

And this is true of all my discoveries, inventions, and scientific results which I have since announced, for I have never invented what immediate necessity suggested, but what I found as most desirable to invent, irrespective of time. Let me tell you only of one—my "magnifying transmitter," a machine with which I have passed a current of one hundred amperes around the globe, with which I can make the whole earth loudly repeat a word spoken in the telephone, with which I can easily bridge the gulf which separates us from Mars. Do you mean to say that my transmitter is nothing more than a "useful piece of electrical apparatus"?

I do not wish to enlarge on this for obvious reasons. To be compelled by taciturn admirers to dwell on my own achievements is hurting my delicate sensibilities, but as I observe your heroic and unceasing efforts in praising your paper, while your distinguished confreres maintain on its merits a stolid silence, I feel that there is, at least, one man in New York able to appreciate the incongeniality of this correspondence. Allow me to ask you just one or two questions in regard to a work which I began in 1892, inspired by a high tribute from Lord Rayleigh at the Royal Institution, most difficult labor which I have carried on for years, encouraged by the sympathetic interest and approval of Helmholtz, Lord Kelvin, and my great friends, Sir William Crookes and Sir James Dewar, ridiculed by the small men whose names I have seen displayed in vulgar and deceptive advertisements. I refer to my system of wireless transmission of energy.

The principles which it involves are eternal. We are on a conducting body, insulated in space, of definite and unchangeable dimensions and properties. It will never be possible to transmit electrical energy economically through this body and its environment except by essentially the same means and methods which I have discovered, and the system is so perfect now that it admits of but little improvement. Since I have accepted as true your opinion, which I hope will not be shared by posterity, would you mind telling a reason why this advance should not stand worthily beside the discoveries of Copernicus? Will you state why it should not be ever so much more important and valuable to the progress and welfare of man?

We could still believe in the geocentric theory and yet advance virtually as we do. The work of the astronomer would suffer, for some of his deductions would rest on erroneous assumptions. But, after all, we shall never know the intimate nature of things. So long as our perceptions are accurate our logic will be true. No one can estimate to what an extent the great knowledge he conveyed has been instrumental in developing the power of our minds and furthering discovery and invention. Yet, it has left all the pressing material problems confronting us unsolved.

Now my wireless system offers practical solutions for all. The aerial navigation, which now agitates the minds, is only one of its many and obvious applications equally consequential. The waterfalls of this country alone, its greatest wealth, are adequate to satisfy the wants of humanity for thousands of years to come. Their energy can be used with the same facility to dig the Panama Canal as to operate the Siberian Railway or to irrigate and fertilize the Sahara. The Anglo-Saxon race has a great past and present, but its real greatness is in the future, when the water power it owns or controls shall supply the necessities of the entire world.

As to universal peace—if there is nothing in the order of nature which makes war indispensable to the safe and sane progress of man, if that utopian existence is at all possible, it can be only attained through this very means, for all international friction can be traced to but one cause—the immense extension of the planet. My system of wireless transmission completely annihilates distance in all departments of human activity.

If this does not appeal to you sufficiently to recognize in me a discoverer of principles, do me, at least, the justice of calling me an "inventor of some beautiful pieces of electrical apparatus."

NIKOLA TESLA.

New York, June 21, 1907.

Tesla.

The following letter from Mr. Nikola Tesla appeared in the *New York Times* of Sunday, June 23:

"You have called me an 'inventor of some useful pieces of electrical apparatus.' It is not quite up to my aspirations, but I must resign myself to my prosaic fate. I cannot deny that you are right.

"Nearly 4,000,000 horse-power of waterfalls are harnessed by my alternating-current system of transmission, which is like saying that one hundred million men—untiring, consuming nothing, receiving no pay—are laboring to provide for our wants, incidentally saving the waste of one hundred million tons of coal annually. In this great city the elevated roads, the subways, and street railways are operated by my system, and the lamps and other electrical appliances get the current through machinery of my invention. And as in New York so all the world over where electricity is introduced. The telephone and the incandescent lamp fill specific and minor demands, electric power meets the many general and sterner necessities of life. Yes, I must admit, however reluctantly, the truth of your unflattering contention.

"But the greater commercial importance of this invention of mine is not the only advantage I have over my celebrated predecessors in the realm of the useful, who have given us the telephone and the incandescent lamp. Permit me to remind you that I did not have, like Bell, such powerful help as the Reis telephone, which reproduced music and only needed a deft turn of an adjusting screw to repeat the human voice; or such vigorous assistance as Edison found in the incandescent lamps of King and Starr, which only needed to be made of high resistance. Not at all. I had to cut the path myself, and my hands are still sore. All the army of my opponents and detractors was ever able to drum up against me in a fanatic contest has simmered down to a short article by an Italian—Prof. Ferraris—dealing with an abstract and physically meaningless idea of a rotating magnetic pole and published years after my discovery, months even after my complete disclosure of the whole practically developed system in all its essential universally adopted features. It is a publication, pessimistic and discouraging, devoid of the discoverer's virility and force, devoid of results, utterly wanting in the faith and devotion of the inventor, a defective and belated record of a good but feeble man whose only response to my whole-souled brother greeting was a plaintive cry of priority—a sad contrast to the strong and equanimous Schallenberger, a true American engineer, who stoically bore the pain that killed him.

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"And this is true of all my discoveries, inventions and scientific results which I have since announced, for I have never invented what immediate necessity suggested, but what I found as most desirable to invent, irrespective of time. Let me tell you only of one—my 'magnifying transmitter,' a machine with which I have passed a current of 100 amperes around the globe, with which I can make the whole earth loudly repeat a word spoken in the telephone, with which I can easily bridge the gulf which separates us from Mars. Do you mean to say that my transmitter is nothing more than a 'useful piece of electrical apparatus'?

"I do not wish to enlarge on this for obvious reasons. To be compelled by taciturn admirers to dwell on my own achievements is hurting my delicate sensibilities, but as I observe your heroic and unceasing efforts in praising your paper, while your distinguished confreres maintain on its merits a stolid silence, I feel that there is, at least, one man in New York able to appreciate the incongeniality of this correspondence. Allow me to ask you just one or two questions in regard to a work which I began in 1892, inspired by a high tribute from Lord Rayleigh at the Royal Institution, most difficult labor which I have carried on for years, encouraged by the sympathetic interest and approval of Helmholtz, Lord Kelvin, and my great friends, Sir William Crookes and Sir James Dewar, ridiculed by the small men whose names I have seen displayed in vulgar and deceptive advertisements. I refer to my system of wireless transmission of energy.

"The principles which it involves are eternal. We are on a conducting body, insulated in space, of definite and unchangeable dimensions and properties. It will never be possible to transmit electrical energy economically through this body and its environment except by essentially the same means and methods which I have discovered, and the system is so perfect now that it admits of but little improvement. Since I have accepted as true your opinion, which I hope will not be shared by posterity, would you mind telling a reason why this advance should not stand worthily beside the discoveries of Copernicus? Will you state why it should not be ever so much more important and valuable to the progress and welfare of man?

"We could still believe in the geocentric theory and yet advance virtually as we do. The work of the astronomer would suffer, for some of his deductions would rest on erroneous assumptions. But, after all, we shall never know the ultimate nature of things. So long as our perceptions are accurate our logic will be true. No one can estimate to what an extent the great knowledge he conveyed has been instrumental in developing the power of our minds and furthering discovery and invention. Yet, it has left all the pressing material problems confronting us unsolved.

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"If this does not appeal to you sufficiently to recognize in me a discoverer of principles, do me, at least, the justice of calling me an 'inventor of some beautiful pieces of electrical apparatus.'"

LETTER TO THE EDITORS.

Wireless Transmission of Energy.

To the Editors of Electrical World:

SIRS:—The writer has read with a good deal of interest the reprint in your issue of June 29, 1907, of Mr. Nikola Tesla's recent letter to the *New York Times.*

In this letter it is to be observed that Mr. Tesla is still harping on his system for the "wireless transmission of energy" and proclaiming it as a discovery deserving to rank with that of Copernicus. It occurs to the writer, however, that we have been hearing about this system (mostly from Mr. Tesla himself) for a number of years, but apparently the "system" has never progressed beyond the *paper* stage.

At the exposition in St. Louis in 1904, a very substantial purse was offered to anyone who would succeed in transmitting even one-tenth of a horse-power a few hundred feet without

wires, but there were no successful contestants. May I enquire why Mr. Tesla did not wade in boldly and carry off the prize? And if he will enlighten us as to how *many* air ships he has *in operation,* deriving their power from water-falls, it will be greatly appreciated.

No one appreciates Mr. Tesla's achievements in the electrical field more than the writer, but it certainly seems that it is incumbent upon the inventor to show why his "system" of wireless transmission has failed to materialize, practically.

WASHINGTON, D. C. J. HANSON BOYDEN.

Nikola Tesla writes to the New York Times under date of July 2d to say that he is receiving many notices and inquiries on the subject of Martian signaling, mentioned in his letter in the Times of Sunday, June 23d. He refers those who have taken occasion to comment on this feature of the letter to his recent article in The Harvard Illustrated Magazine, which is all he cares to say now despite "tauntings and temptations." For particular reasons, he says, that he reserves his full technical report, descriptive of the apparatus and results for the records of old institutions—academies of science—of which he is an honorary member.

The Brooklyn Eagle July 26, 1907

MAY KEEP HIS TOWER.

Tesla, Wizard of Wardenclyffe, Not to Be Sold Out.

(Special to the Eagle.)

Riverhead, L. I., July 26—Having settled the judgment against him by Dr. James S. Warden, Nicola Tesla, the wizard of Wardencylffe, may retain possession of his mysterious steel tower there. It was to have been sold by the sheriff on Monday, but the sale is off. The judgment has been paid.

The New York Herald July 29, 1907

TESLA SNEERS AT GLIDING CRAFT

Declares Hydroplane Invention of Peter Cooper Hewitt Is Old and Worthless.

HIS JEALOUSY CRITICISED

In Letter in New York Times Electrical Expert Takes Petulant Fling at Achievement.

Many persons were surprised yesterday at the following letter from Nicola Tesla, published in the New York Times, and which seems to have been inspired by jealousy of Mr. Peter Cooper Hewitt's invention and achievements with a hydroplane, described in recent issues of the HERALD:—

GLIDING CRAFT.

Nicola Tesla Says the Hydroplane is Neither New Nor Practical.

To the Editor of the New York Times:—

The science of engineering has become so positive and precise that practical results are generally in close agreement with theory, and pretty nearly everything turns out as expected. Naturally, then, the exercise of this profession is more or less tedious and uninteresting. Occasionally, though, life is infused into the apathetic community by the sudden announcement of some stunning scheme or puzzling travesty of some old discovery or invention.

Two weeks ago an enterprising journal of this city created quite a ripple of excitement in engineering circles by the news that a most novel and startling advance in marine propulsion had been made. It was a gliding craft or "hydroplane," which was to make a speed of 100 miles an hour possible. The discovery was indorsed by a great engineer and a naval officer of no mean attainments, both of whom preferred to remain incognito. For a good reason, I should think. When it comes to being identified with the "hydroplane" discretion is decidedly better than valor. As a matter of fact, it is an old and worthless idea, an illusion and a snare.

The Times has done some good service in dispelling the myth of novelty in its issue of the 17th inst., but the optimistic tone of the otherwise accurate report will only tend to add to the number of those who have fallen victims of the delusion.

NICOLA TESLA.

NEW YORK, July 26, 1907.

After reading the letter Mr. Hewitt dictated the following reply:—

"My attention has been called to a letter published in the New York Times and I feel compelled in fairness to the future of the art employed by devices using planes as a means of support, such as hydroplanes and aeroplanes, to state that the old idea is not 'worthless,' but that in a short time it will find its field of utility in the world's work. The gliding craft referred to was designed to demonstrate by performance some of the most interesting theories that have been from time to time forecast by great scientists and engineers. The performance of the gliding craft was so successful and so near to theory that it impressed others as well as myself with the great possibilities of the art in the future."

Mr. Hewitt declined to make any further comment upon the motives behind Mr. Tesla's letter, but several experts who have given the invention close study asserted that it gave promise of greater importance to the world generally than anything ever accomplished by Mr. Tesla.

Both Mr. Tesla and Mr. Hewitt are men of international reputation and by friends of both Mr. Tesla's petulant fling at the achievement of a brother scientist was a matter of much surprise.

Particularly was his sneer at the "great engineer and naval officer of no mean attainments" regarded as beneath the dignity of a man of Mr. Tesla's reputation.

Both the engineer and the naval officer referred to are men whose scientific opinions overbalance those of Mr. Tesla, and their names were withheld from publication because of the request of Mr. Hewitt.

Their indorsement of the possibilities of the hydroplane, following its performances, will count for a great deal more than Mr. Tesla's jealous and prejudiced slur based entirely upon theory.

The New York Herald July 30, 1907

MR. TESLA ON GLIDING BOAT

TO THE EDITOR OF THE HERALD

The imputation in a report contained in your issue of this morning that in condemning the old and fallacious idea of the gliding boat or "hydroplane" I was prompted by jealousy, must have provoked some mirth among those who are acquainted both with my friend Cooper Hewitt and myself and our respective endeavors and accomplishments. But there is nothing to laugh about in the assertion that this worthless thing promises to be more important to the world than anything I have done. Thousands of millions of dollars are invested in enterprises based on my inventions in the transmission of power alone, and yet they are less than twenty years old. Not one cent is invested in the "hydroplane," although it has been well known and tried again and again for the last fifty years.

My opinion is not founded "merely on theory," as you seem to believe. I always try to be as thorough as possible. It is a characteristic trait of my family. Permit me to give an example. Sometime in 1899, while I was carrying on my wireless experiments in Colorado, a special despatch appeared in your columns to the effect that I was afflicted with consumption. Nothing could be further from my mind than the thought that the injury was intended. A great newspaper is a big, complicated machine difficult to control. I was simply run down by a one million horse power automobile. It was a small consolation that the chauffeur—I mean the editor—did not intend to do it. Nearly everybody in such a case would rush into print to deny. But I am a peculiar man. It occurred to me that—perhaps—if I waited eight or nine years my denial would be more convincing to the HERALD'S readers, and so it comes that I am taking advantage of this agreeable opportunity.

I have observed the same attitude as regards the "hydroplane." It so happened that long ago I hit upon a much better scheme of marine propulsion which appeared revolutionary. The errors I discovered after careful study turned out to be of the same nature as those involved in the gliding boat. Believing that I might be of service to those who were laboring under an illusion, I wrote to your distinguished confrère of the New York Times, concluding my letter as follows:

"Every ill spent effort is to be regretted. Should you think it desirable I shall be glad to expose in a popular and easily understandable manner the fallacies and deficiencies of the gliding craft on some occasion at your pleasure in the near future."

I was evidently misunderstood, but through my own fault.

You have criticised statements not intended for publication, which once more proves the truth of the proverb, "Gouvent les apparences sont trompeuses."

NIKOLA TESLA.

NEW YORK, July 29, 1907.

The New York Herald July 31, 1907

HEWITT ASKS TESLA TO SHOW "FALLACIES"

Builder of Gliding Craft Thinks Inventor Should Point to Errors He Sees.

In a letter to the HERALD, printed yesterday morning Nikola Tesla repeated the assertion made previously by him that the hydroplane, or gliding craft, recently built and demonstrated by Peter Cooper Hewitt is worthless as an invention and based upon a false and disproved theory.

When Mr. Hewitt's attention was directed to the letter yesterday he dictated the following answer:—

"I stated in the HERALD that I believed the hydroplane theory practical. My reasons, as then stated, were based on the performance of an experimental craft built by me to embody the essential features required by theory for a device of the hydroplane type. This experimental device, designed for the special purpose of testing theories, operated practically, not only once, but many times. In fact, it is a practical craft and with a few structural alterations would be a satisfactory commercial craft.

"In your issue of to-day there is the following statement by Nikola Tesla:—'Every ill spent effort is to be regretted. Should you think it desirable, I shall be glad to expose in a popular and understandable manner the fallacies and difficulties of the gliding craft on some occasion at your pleasure in the near future.'

"If I am in error concerning the gliding craft, notwithstanding the photographs and facts announced in the HERALD of July 14, and if I am misleading the public because of inherent 'fallacies and deficiencies of the gliding craft,' I regard it as his duty to the public to point out what these 'fallacies and deficiencies' are."

Engineers who have witnessed the performances of Mr. Hewitt's gliding craft said yesterday they believed it to be based upon a theory quite as substantial and profitable to the world as Mr. Tesla's latest theory of telegraphing to the planet Mars. These men insisted that they were basing their faith on what Mr. Hewitt had already done and not upon what he or Mr. Tesla or anybody else might dream to be false or substantial in theory. If the hydroplane theory had hitherto been held as an illusion, they said, it was greatly to Mr. Hewitt's credit to have proved the contrary.

SANTOS-DUMONT EXPERIMENT

TO THE EDITOR OF THE HERALD:—

The experiment which, according to a special cable in the HERALD, is to be performed by Santos-Dumont should yield very valuable and much needed engineering data. He succeeded in producing a remarkably light and powerful machine. If there is truth in certain old notions which have been strengthened by misleading experiments with gliding boats he would have no difficulty in attaining a speed of one hundred miles an hour, in view of the fact that Count Lambert reached twenty-five miles with a craft of this kind weighing sixty pounds to the horse power. It was a crude machine compared with the Dumont apparatus of 122-horse power, which, with operator and some fuel, will hardly exceed 600 pounds to the horse power. But the popular ideas in regard to the hydroplane and also the aeroplane are not in agreement with practice. It takes much more power to glide on the water or to soar than generally assumed.

There is a simple way of accomplishing this feat which Santos-Dumont has undertaken which absolutely precludes failure. Let him construct a shell resembling that of a Whitehead torpedo. The central part may contain the engine. Fuel and other necessaries may be put between the motor and the propeller. In the front part the operator should place himself in a reclining posture with the controlling levers conveniently at hand and looking out through a small glass window. Virtually the whole surface will thus be below the surface of the water. * * * The essence of this philosophy is that he cannot accomplish the feat if he attempts to glide, nor yet if he tries to soar, but he will without fail if he will change his plans and dive.

NIKOLA TESLA.

NEW YORK, Sept. 27, 1907.

Dynamo-electric Machinery and Its Evolution During the Last Twenty Years.

By B. A. Behrend,

Chief Engineer and Chief Designer, Bullock Works, Allis-Chalmers Company.

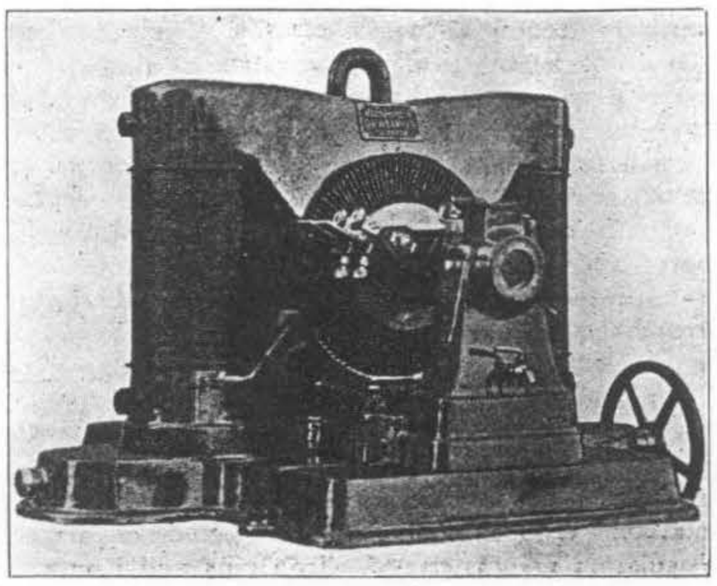
WHEN the historian-engineer writes upon the evolution of electric machinery during the last twenty years, he must needs write a story in which his own work and the work with which he has been associated form a more prominent part than is desirable in an impartial historical review. But every writer has the defects of his qualities, and the historian-engineer is prone to be either too much of a historian, or too much of an engineer, in relating the story of the growth and development of electric generating machinery and electric motors. No one who has ever carefully read history can deny that the bias of the author lends a peculiar color to his views and statements, and, in writing this article, I cannot plead guiltless of a similar bias.



BERNARD A. BEHREND.

Twenty years ago we find a number of gifted physicists and engineers, the latter mostly of the telegraph type, engaged in fathoming the mysteries of electricity for the purpose of making machines which generate electric energy. Great masters of physical science, as Faraday, William Thomson and Maxwell, understood all about electromagnetic induction, but did not care to build dynamo-electric machinery, or, perhaps, heresy though it may be to say so, could not have done it. Here the engineer stepped in, a little lame, perhaps, in the mastery of theory, but with that creative imagination and poetic vision which form an important quality in the designing engineer.

There were dynamos built by Gramme, by Deprez, by Edison, by Elihu Thomson, by Siemens, and others whose names are beginning to fade from our memory. It must be irreverently stated, however, that our college boys would laugh to scorn these attempts and deem themselves greatly superior designers to the pioneers. The weakness of these early machines was not confined to the electrical design; in point of fact, it has always struck me that these early designers were more deficient in knowledge and experience in mechanical matters than in electrical. And there was much less excuse for this, as the mechanical art was developed and could be utilized without much difficulty. To this condition is to be attributed the deplorable patent situation in the electrical field, which has led to the protection by patent of mechanical features, known for many years, applied to electrical machinery because of the profound ignorance of the mechanical arts displayed by the electrical experts.



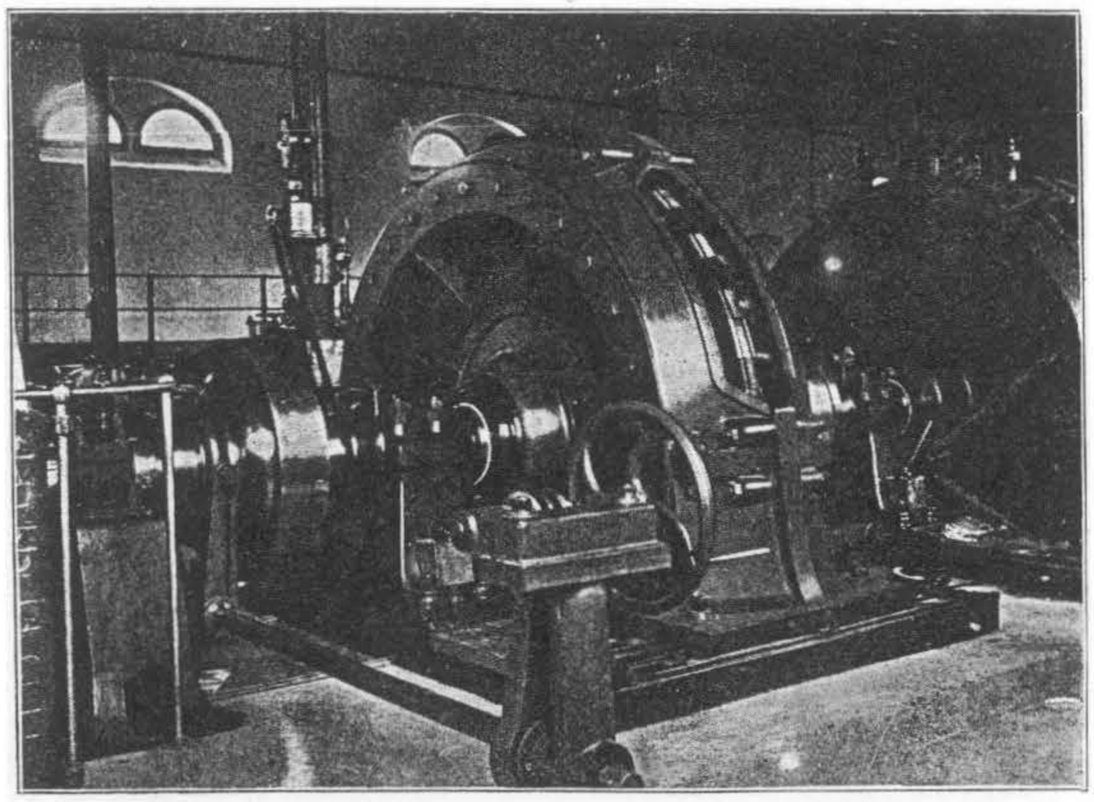
HIGH-VOLTAGE DIRECT-CURRENT DYNAMO OF 1887 (OERLIKON).

I have always contended that electrical designing is but a branch of mechanical engineering, as the design of heat engines is considered but a branch of the same field. That, of course, the electrical engineer should possess a thorough familiarity with the principles of electrical phenomena is as fundamental a requirement as that the steam engineer should know thermo-dynamics. These electrical machines which generated electricity but came to pieces in the process, burning out their bearings and being altogether nothing but toy machines turned over to a millwright, started the procession. And as any glaring faults are often made the starting point for improvements, so the dynamo-electric machine was taken out of the instrument makers' hands and placed with mechanical men in machine shops. In America I believe it was the Westinghouse & Schmidt Company, the precursor of the Westinghouse Electric and Manufacturing Company, which greatly improved the mechanical features of dynamo-electric machinery, while in Europe the Oerlikon Company made machines in which the art of mechanical engineering was utilized to the full.

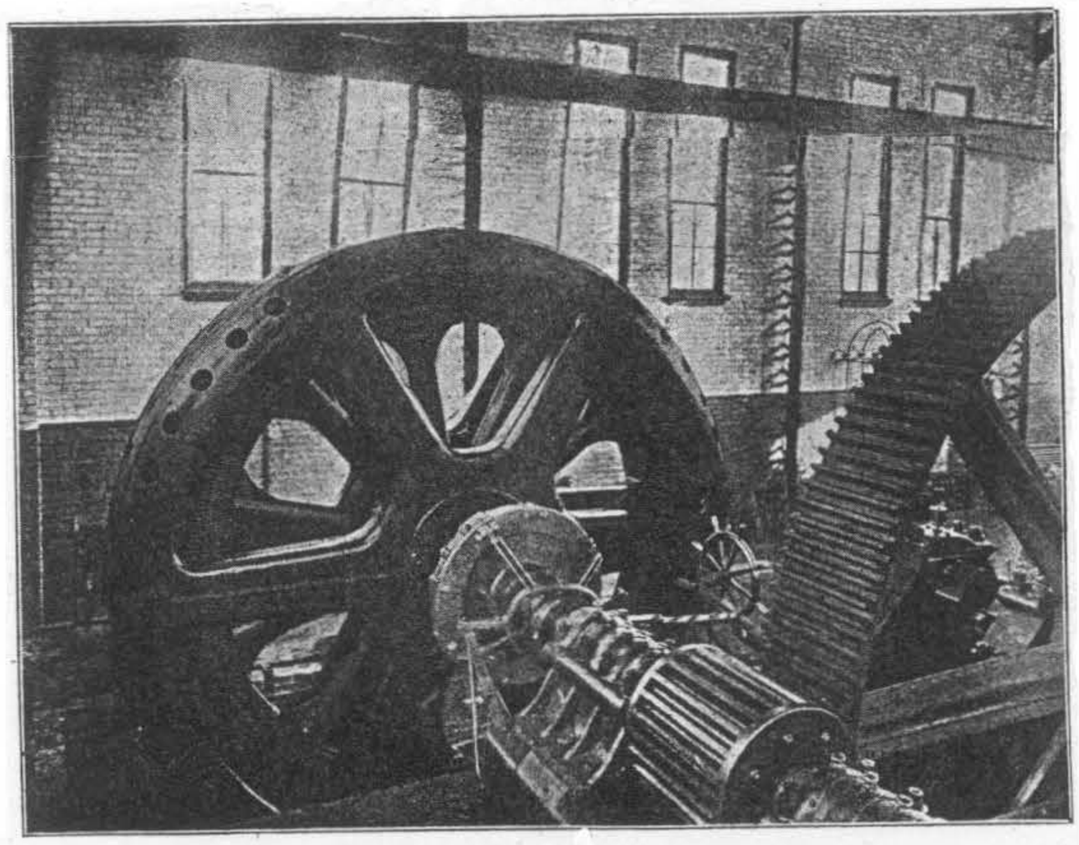
To all those who have followed the recent discussions about the relative merits of single-phase alternating currents and of high-voltage direct current for railway work it must be interesting to be reminded that the first electric generators of any account were direct-current machines of from 50 kilowatts to 150 kilowatts, generating from 1,200 volts to 3,000 volts, and being used for the transmission of power as series-wound machines. These machines were of the Manchester type, credited to Hopkinson, being bipolar and having copper brushes. Both the careful mechanical and electrical work which was put into these forerunners of modern electric machinery is testified to by the fact that a number of these plants are still in operation with commutators whose once cylindrical surfaces have been worn into bodies of revolution with fantastically curved outlines. The series winding of these machines was, of course, an essential condition; but we have in the interpole, which is over twenty years old, and which has recently been unearthed, a means of obtaining equally satisfactory results with shunt-wound generators.

While intent upon the development and improvement of the direct-current machine, there came the startling work of Nikola Tesla, which prevented any further concentration of thought on anything excepting alternating currents and their combinations into polyphase currents. The work of Tesla has never been clearly understood or appreciated according to its intrinsic value by the majority of engineers. Mr. Tesla's early papers are classical contributions to the art of engineering and rank with the best that have been written. This statement is altogether independent of the validity of his patents—a matter which is not here under discussion.

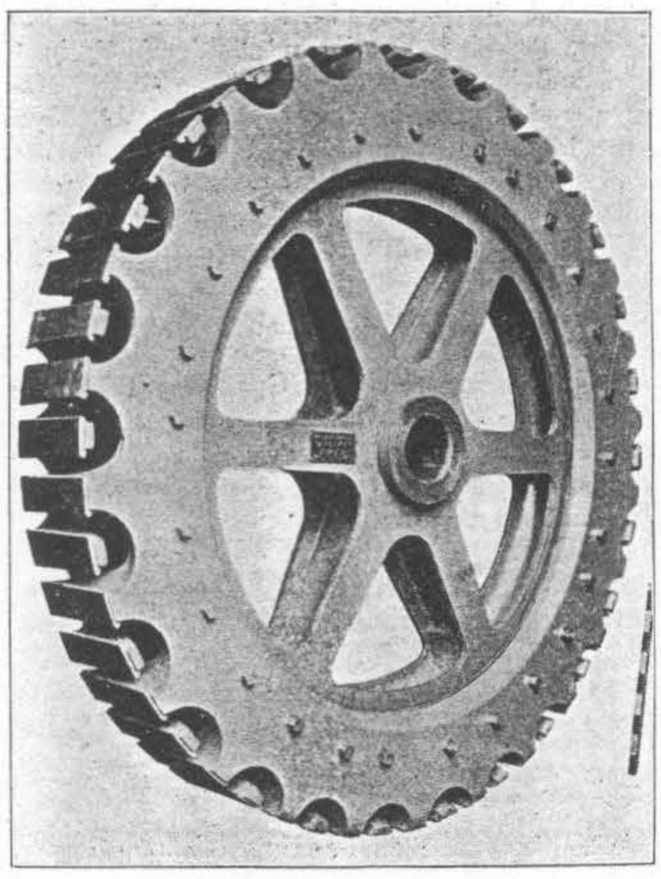
Mr. Tesla is the victim of his friends. It is a peculiar trait of ignorant men to go always from one extreme to another, and those who once were the blind admirers of Mr. Tesla, exalting him to an extent which can be likened only to the infatuated praise bestowed on victims of popular admiration, are now eagerly engaged in his derision. There is something deeply melancholy in the aspect, and I can never think of Nikola Tesla without warming up to



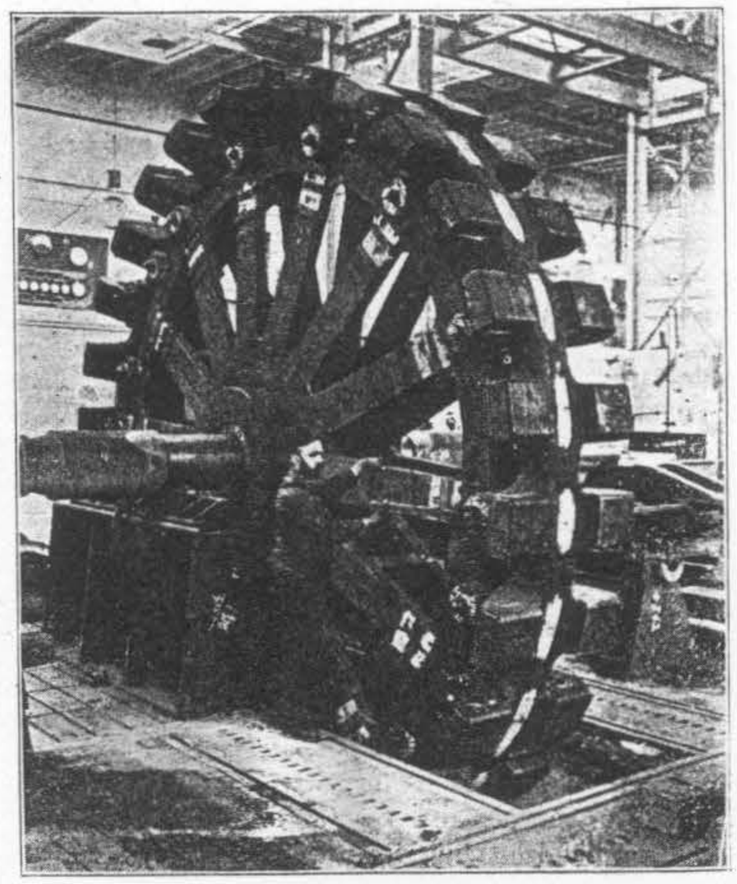
KAPP ALTERNATORS AT ZURICH, SWITZERLAND, 1890.



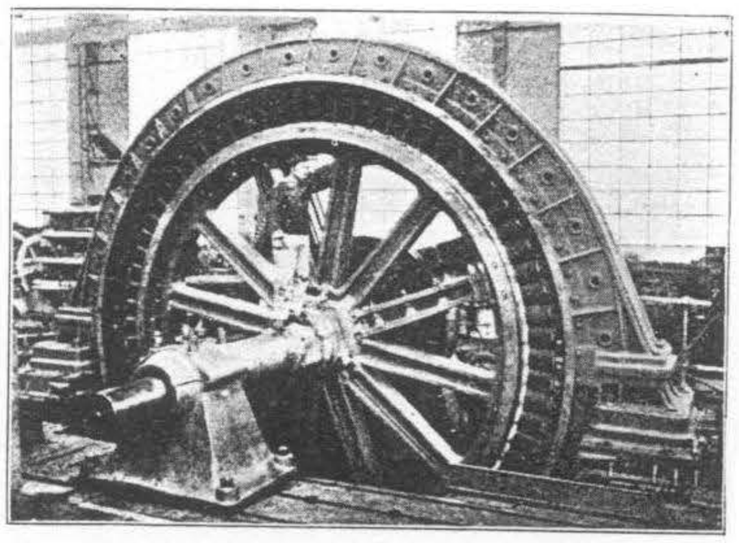
LOW-SPEED 500-HORSEPOWER INDUCTION MOTOR (BULLOCK) AT MONTREAL WATERWORKS



LAUFFEN-TYPE REVOLVING FIELD, 1893 (OERLIKON).

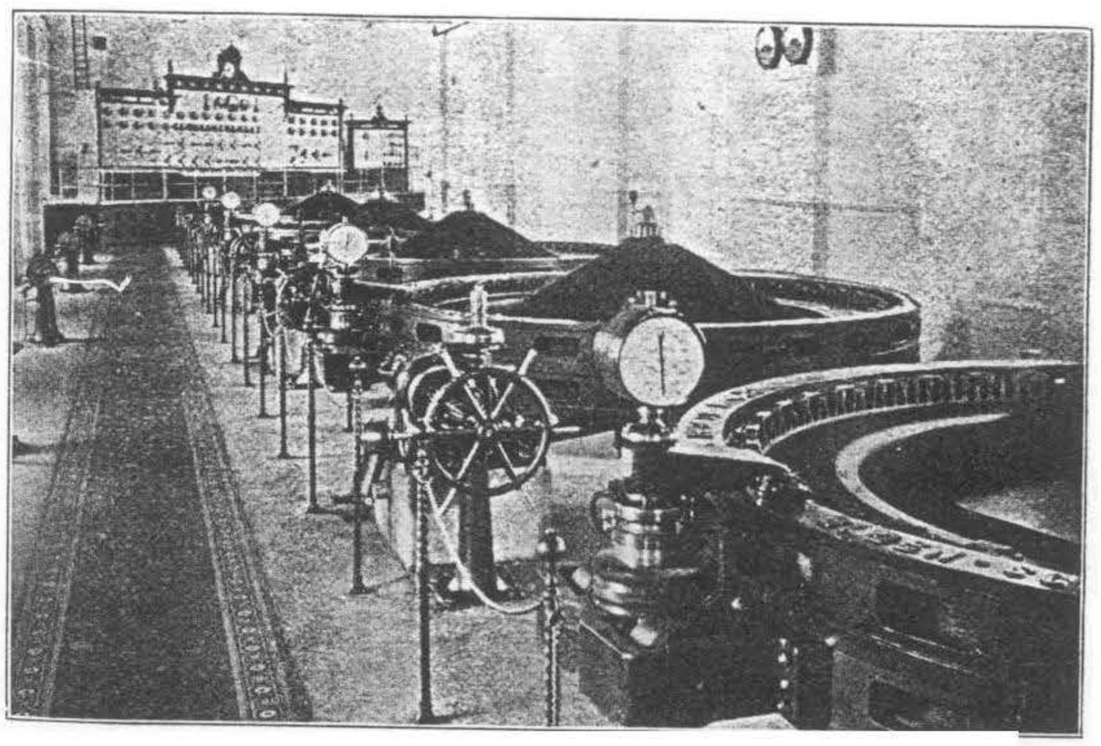


REVOLVING ELEMENT OF 1,000-KILOWATT INDUCTOR ALTERNATOR (OERLIKON), 1896.



LARGE REVOLVING-FIELD ALTERNATOR (OERLIKON, 1898.

my subject and condemning the injustice and ingratitude which he has received alike at the hands of the public and of the engineering profession. A child of genius, springing from a race not inured to the poisoning of flattery, he came to this country and did great and imperishable work. His admirers feted and celebrated him, and he took them seriously. It was only natural that his later work did not show the clearness and originality which characterized his work on polyphase machinery, and which made him famous. The engineering profession, unjustly and ungratefully ignoring his early work, labeled him a charlatan, and the public, always on the lookout for new sensations, dropped Mr. Tesla and forgot him. As my professional work for almost a score of years has had for its object the development and improvement of electrical machinery, for which Nikola Tesla has done much, I wish to take this opportunity to pay a tribute to his work done at the opening of the epoch which has culminated in the large industry of electrical engineering.

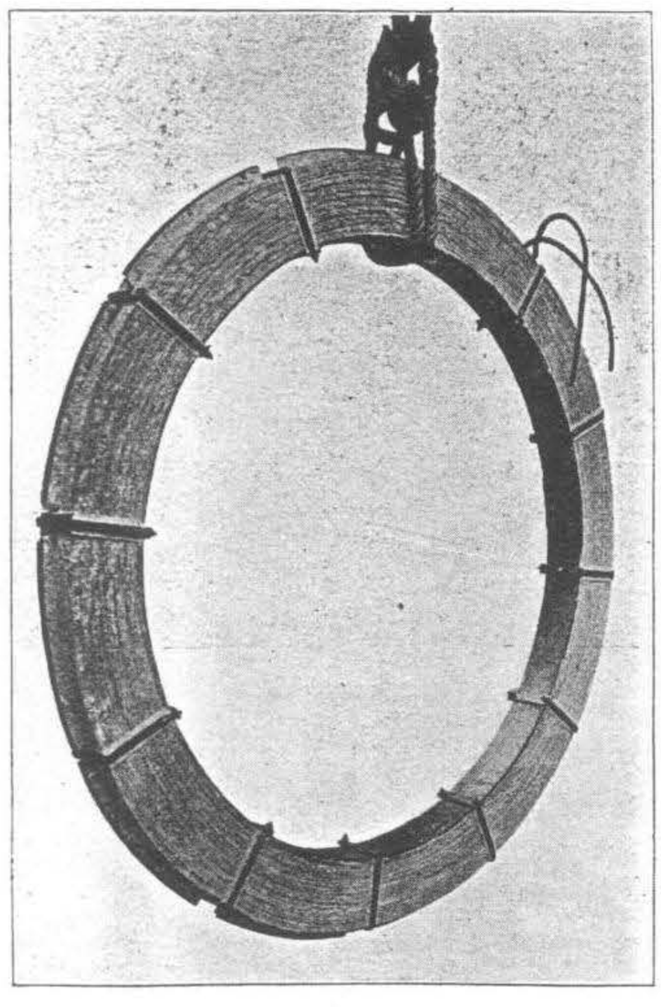


UMBRELLA-TYPE REVOLVING-FIELD ALTERNATORS (BROWN-BOVERI), 1897.

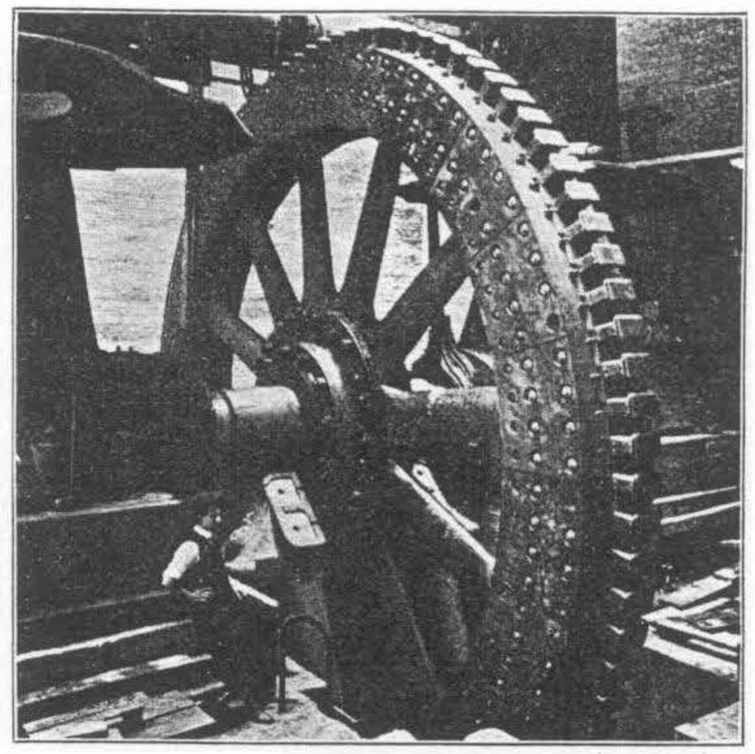
As the early direct-current machines were all wound as Gramme rings, there became established a preference for this construction in alternating-current generators. Besides the ironless types represented by Mordey, Ferranti and Siemens alternators, we notice the iron-core alternators of Kapp and of Schuckert, in which flat rings are wound with coils, in principle like the Gramme ring. The application of mechanical principles soon created reliable mechanical construction by using drum windings, and we record the next step in improvement of dynamo-electric machines when we refer to the direct-current generators built by the Westinghouse & Schmidt Company and the Thomson-Houston Company in America for railway work. Mr. Sidney H. Short, of the Walker Company, should here receive honorable mention for his pioneer work in this respect.

It has always seemed to me that the designs of electrical machinery in the early '90's lacked a clear recognition of underlying principles until the designing genius of C. E. L. Brown had done for the art what Corliss and Reynolds had been doing for the steam engine. Unity of plan enters into the field, and the present dynamo-electric machines become stereotyped. The direct-current generators have become multiple-wound multipolar units, with cross connectors in the armatures, and with commutators and brush-holders which we are all familiar with in present designs. The alternating-current generators are multipolar machines with internal revolving fields and external stationary armatures with windings arranged similar to those of drum-wound armatures. No more are we tempted from the straight path of engineering by such will-o'-the-wisps as Lauffen types, inductor types and other patent articles. The general design and construction have become established and will remain established until the introduction of entirely new principles which will relegate present dynamos to the past.

In reviewing the evolution of dynamo-electric machinery during the last twenty years, we must needs comment on the careful development of details and upon the adoption of rational processes for the manufacturing of this machinery. Fifteen years ago it was quite customary to manufacture the core plates by using circular shears and to build up the plates without slots, these being milled in the cores after the cores were built up. The manufacture of a large number of machines of the same size has made it possible to use dies and punchings for this operation, so that sectional plates completely slotted and dovetailed for fastening can be turned out with the greatest accuracy.

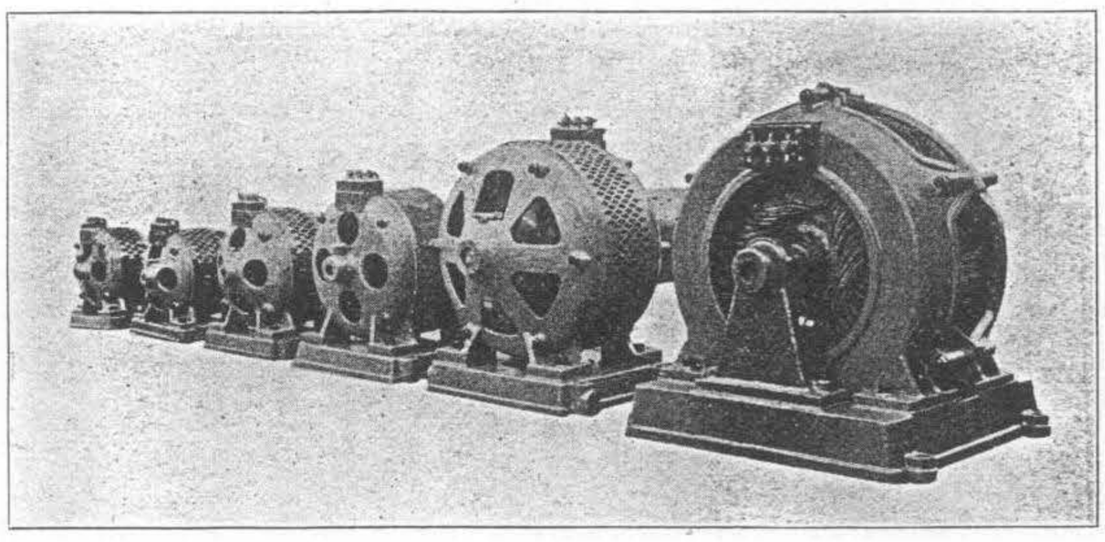


STATIONARY FIELD COIL OF INDUCTOR ALTERNATOR (OERLIKON), 1896.



REVOLVING FIELD OF 3,200-KILOWATT ALTERNATOR (BULLOCK), 1902.

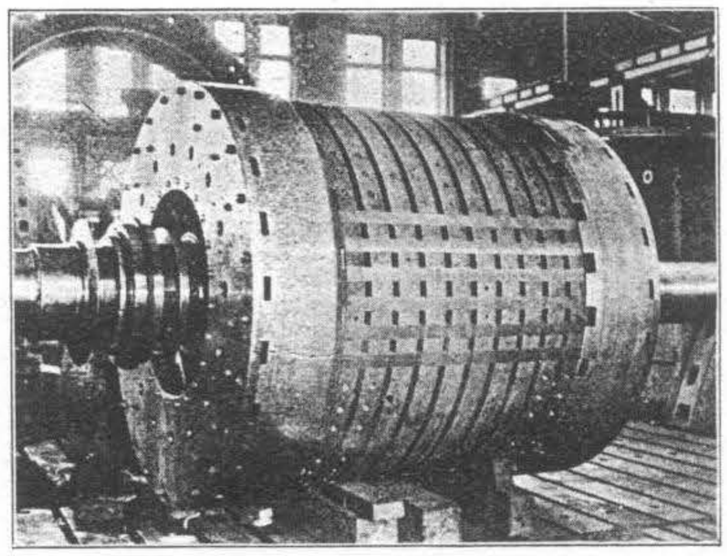
Field coils which, in the early dynamos, were made of insulated wire, are made of copper strip bent on edge, and coils thoroughly mechanical and strong have thus been evolved.



A LINE OF RING-WOUND INDUCTION MOTORS (OERLIKON), 1893.

Instead of hand-wound armatures, the winding of which required great skill and patience, form-wound armature coils were introduced, leading to mechanical construction with easy possibility of repair.

The gradual evolution from step to step which is pursued by Nature is also pursued by engineers in the development of an art. Different steps are evolved by different designers in different parts of the world in almost exactly the same way, because this evolution is the product of the human brain, which is the same the world over. It appears, therefore, most preposterous to any thoughtful man of culture and knowledge to designate these intrinsically small steps as inventions, and to bewilder the mind with claims couched in words of ambiguity and prolixity which apply to the objects they are meant to describe as well as to the process of the creation of the world as related to us in the first chapter of Genesis.



FOUR-POLE RKVOLVING FIELD OF 10,000-HORSEPOWER TURBO-GENERATOR (ALLIS-CHALMERS), 1904.

Much yet has to be done to educate the public, and the engineering public in particular, to understand the philosophy of progress and invention and to appreciate a complex situation created by a well-meaning institution like the Patent Department, but here, as elsewhere, human institutions founded

with the best of intentions have defeated their own purpose. In an art which has hastily grown and whose principles have been considered mysterious, it may be excusable if certain means for mechanically fastening pole-pieces, for example, are represented to serve certain occult purposes conducting magnetism; but it seems pitiful that experts can be found to give their support to such humbug.

Though the perfection of the present dynamo-electric machines can be traced step by step from a modest beginning, yet there is a vast gulf between the first slow-speed machines and the present 7,500-kilowatt generators operating at 750 revolutions per minute. Yet little or nothing has had to be changed in the principles underlying the design of electric machinery, and the engineers must be filled with pride who, twenty years ago, recognized in the principles of Faraday and Maxwell the leading light of their art.

The New York Herald October 17, 1907

SUBMERGED VESSEL, HE SAYS, CAN GO 65 MILES

Mr. Tesla Comments on the Idea of Resistance Under Water Advanced by Lord Kelvin.

FASTER THAN ON SURFACE

Inventor Says Aeronauts Overlook Important Law in Their Attempt to Attain High Speed.

TO THE EDITOR OF THE HERALD:—

In the European edition of the HERALD of October 1, Santos-Dumont has credited me with a theory which is not my own, namely, that a higher speed can be attained in the water than by gliding on the surface. This idea was advanced long ago by Lord Kelvin and has been since accepted in all classical works as a manifest truth. A vessel completely submerged and creating no surface disturbance has nothing but skin friction to overcome.

In attempting to reach a speed of 100 kilometres, or 62½ miles, the aeronaut evidently places faith in the demonstrations of Pictet with the hydroplane, paralleled by those of Langley with the aeroplane. But in both of these an important law has been ignored, of which, however, no hint or suggestion can be found in the entire scientific literature from Newton's principia to the most modern treatises and which profoundly affects the results in gliding and soaring.

The experiment which, as reported in the HERALD, Santos-Dumont is to make will forever dispel the popular notions of the hydroplane, according to which, were it not for air resistance, a speed of 360 miles would be attainable with his remarkable craft. In the light of the law I have discovered that this gliding boat, weighing, with operator and fuel included, five pounds per horse power, will reach only a speed of forty-eight miles. To attain 100 kilometres the motor would have to develop much more than 120 horse power. What is true of the hydroplane likewise applies, with a slight modification, to the aeroplane. But a submerged vessel of the Whitehead torpedo type could be propelled at a rate of sixty-five miles.

NIKOLA TESLA.

NEW YORK, Oct. 16, 1907.

Through the Water? Or Over It?

Nikola Tesla says that Santos-Dumont's new hydroplane will not be able to travel sixty-two miles an hour, as expected by its ingenious constructor—that it will not exceed a speed of forty-eight miles.

It is in the column of letters from HERALD readers this morning that Mr. Tesla presents his views on the subject. He insists, in short, that higher speed can be made in the water than by gliding on the surface.

M. Santos-Dumont, through the European edition of the HERALD, recently replied to the first letter of Mr. Tesla and expressed a wish on the subject that the latter would put his theories to the test.

"If he cares to build a boat on the lines indicated in his letter," said M. Santos-Dumont, "I will give him half of the 50,000 francs I stand to gain." The communication from Mr. Tesla which we print this morning is very interesting, but makes no refereuce to this "sporting" challenge of the young Brazilian aeronaut and inventor.

The New York Times October 19, 1907

SLEEP FROM ELECTRICITY.

Nikola Tesla Noted Narcotic Influences of Periodic Currents in 1898.

To the Editor of The New York Times:

I have read with interest the reports in THE TIMES of the 13th and 15th insts. referring to Prof. Leduc's discovery of causing sleep by electric means. While it is possible that he has made a distinct advance there is no novelty in the effect itself.

The narcotic influence of certain periodic currents was long ago discovered by me and has been pointed out in some of my technical publications, among which I may mention a paper on "High Frequency Oscillators for Electro Therapeutic and Other Purposes," read before the American Electro Therapeutic Association Sept. 13, 1898. I have also shown that human tissues offer little resistance to the electric flow and suggested an absolutely painless method of electrocution by passing the currents through the brain. It is very likely that Prof. Leduc has taken advantage of the same general principles though he applies the currents in a different manner.

In one respect, however, my observations are at variance with those reported. From the special dispatch in THE TIMES of the 13th inst. it would appear that sleep is induced the moment the currents are turned on, and that awakening follows as soon as the electrodes are withdrawn. It is, of course, impossible to tell how strong a current was employed, but the resistance of the head might have been, perhaps, 3,000 ohms, so that at thirty volts the current could have been only about 1/100 of an ampere. Now, I have passed a current at least 5,000 times stronger through my head and did not lose consciousness, but I invariably fell into a lethargic sleep some time after. This fact impresses me with certain arguments of Prof. Barker of Columbia University in your issue of Sept. 15.

I have always been convinced that electric anaesthesia will become practical, but the application of currents to the brain is so delicate and dangerous an operation that the new method will require long and careful experimentation before it can be used with certitude.

NIKOLA TESLA.

New York, Oct. 16, 1907.

The New York Times October 22, 1907

POSSIBILITIES OF 'WIRELESS.'

Nikola Tesla Says Distance Forms No Obstacle to Transmission of Energy.

To the Editor of The New York Times:

In your issue of the 11th inst. Edison makes statements which cannot fail to create erroneous impressions.

There is a vast difference between primitive Hertzwave signalling practicable to but a few miles, and the great art of wireless transmission of energy which enables an expert to transmit, to any distance, not only signals, but power in unlimited amounts, and of which the experiments across the Atlantic are a crude application. The plants are quite inefficient, unsuitable for finer work, and fatally doomed to an effect less than 1 per cent. of that I attained in my tests in 1899.

Edison thinks that Sir Hiram Maxim is blowing hot air. The fact is my Long Island plant will transmit almost its entire energy to the antipodes, if desired. As to Martin's communication I can only say, that I shall be able to attain a wave activity of 800,000,000 horse power and a simple calculation will show, that the inhabitants of that planet, if there be any, need not have a Lord Raleigh to detect the disturbance.

Referring to your editorial comment of even date the question of wireless interference is puzzling only becaus of its novelty. The underlying principle is old, and it has presented itself for consideration in numerous forms. Just now it appears in the novel aspects of aerial navigation and wireless transmission. Every human effort must of necessity create a disturbance. What difference is there in essence, between the commotion produced by any revolutionary idea or improvement and that of a wireless transmitter? The spectre of interference has been conjured by Hertzwave—or radiotelegraphy in which attunement is absolutely impossible, simply because the effect diminishes rapidly with distance. But in my system of energy transmission, based on the use of impulses not sensibly diminishing with distance, perfect attunement and the higher artifice of individualization are practicable. As ever, the ghost will vanish with the wireless dawn.

NIKOLA TESLA.

New York, Oct. 21, 1907.

The New York Tribune October 25, 1907

LETTERS TO THE EDITOR

TESLA ON WIRELESS.

Electrical Inventor Thinks Marconi's Plants Inefficient.

To the Editor of The Tribune.

Sir: In so far as wireless art is concerned there is a vast difference between the great inventor Thomas A. Edison and myself, integrally in my favor. Mr Edison knows little of the theory and practice of electrical vibrations; I have, in this special field, probably more experience than any of my contemporaries. That you are not as yet able to impart your wisdom by wireless telephone to some subscriber in any other part of the world, however remote, and that the presses of your valuable paper are not operated by wireless power is largely due to your own effort and those of some of your distinguished confreres of this city, and to the efficient assistance you have received from my celebrated colleagues, Thomas A. Edison and Michael I. Pupin, assistant consulting wireless engineers. But it was all welcome to me. Difficulty develops resource.

The transmission across the Atlantic was not made by any device of Mr. Marconi's, but by my system of wireless transmission of energy, and I have already given notice by cable to my friend Sir James DeWar and the royal institution of this fact. I shall also request some eminent man of science to take careful note of the whole apparatus, its mode of operation, dimensions, linear and electrical, all constants and qualitative performance, so as to make possible its exact reproduction and a repetition of the experiments. This request is entirely impersonal. I am a citizen of the United States, and I know that the time will come when my busy fellow citizens, too absorbed in commercial pursuits to think of posterity, will honor my memory. A measurement of the time interval taken in the passage of the signal necessary to the full and positive demonstration will show that the current crosses the ocean with a mean speed of 625,000 miles a second.

The Marconi plants are inefficient, and do not lend themselves to the practice of two discoveries of mine, the "art of individualization," that makes the message non-interfering and non-interferable, and the "stationary waves," which annihilate distance absolutely and make the whole earth equivalent to a conductor devoid of resistance. Were it not for this deficiency, the number of words a minute could be increased at will by "individualizing."

You have already commented upon this advance in terms which have caused me no small astonishment, in view of your normal attitude. The underlying principle is to combine a number of vibrations, preferably slightly displaced, to reduce further the danger of interference, active and passive, and to make the operation of the receiver dependent on the co-operative effect of a number of attuned elements. Just to illustrate what can be done, suppose that only four vibrations were isolated on each transmitter. Let those on one side be respectively a, b, c and d. Then the following individualized lines would be ab, ac, ad, bc, bd, cd, abc, abd, acd, bcd and abcd. The same article on the other side will give eleven similar combinations, and both together twenty-two lines, which can be simultaneously operated. To transmit one thousand words a minute, only forty-six words on each combination are necessary. If the plants were suitable, not ten years, as Edison thinks, but ten hours would be necessary to put this improvement into practice. To do this, Marconi will have to reconstruct the plants, and it will then be observed that the indefatigable Italian has departed from universal engineering customs for the fourth time.

New York, Oct. 24, 1907. NIKOLA TESLA.

The New York Herald October 26, 1907

SANTOS-DUMONT'S SPEED.

TO THE EDITOR OF THE HERALD:—

I notice from the HERALD of even date (page 8) that Santos-Dumont managed to attain a speed of 32 miles instead of 48, as I calculated. I assumed an efficiency of 6[illegible] per cent for propeller and inclined plane combined. If his motor was driven at full power the efficiency was only 43 per cent, and it is more likely to be true than the highest theoretical figure I assumed. I wish that he had made a good test and come close to 48 miles, as I calculated to give my theory a better test. But you see that the old notions of the hydroplane cannot possibly be true. * * * Santos-Dumont can still win the bet if he will follow my suggestion.

NIKOLA TESLA.

NEW YORK, Oct. 24, 1907.

The New York Times October 27, 1907

TESLA TOWER TO BE SOLD.

Property of Electrician to be Disposed of to Satisfy a Judgment for $199.31.

The tower erected by Nicola Tesla, the electrical inventor, at Wardencliffe Long Island, is advertised for sale, by Sheriff Wells of Suffolk County on Monday, Dec. 9, for a debt of $199.31. August Eisenmann, through his attorney, Ralph J. Hawkins, has obtained a judgment for this amount against the electrician.

This is the second time it has been advertised for a judgment sale within half a year. Dr. Warden, the founder of Wardencliffe, had it seized a few months ago to satisfy a small judgment. Mr. Tesla paid the judgment just before the time of sale.

The property is valuable and consists of about two hundred acres. The tower was built at great cost. It extends deep into the ground, and rises a great height in the air, and its equipment was expensive.

The New York Tribune October 27, 1907

TESLA'S TOWER FOR SALE AGAIN.

The tower erected by Nicola Tesla at Wardencliffe, Long Island, is to be sold by Sheriff Wells of Suffolk County on Monday, December 9, for a debt of $199 31. August Eisenmann is the creditor. This is the second time the tower has been advertised for sale to satisfy a judgment within half a year. The last time, Dr. Warden, founder of Wardencliffe, was the creditor. Mr. Tesla paid just before the sale. The Tesla property at Wardencliffe consists of about two hundred acres. The tower was built at great cost.

The New York World October 27, 1907

TO SELL TESLA'S TOWER.

Sheriff to Auction Costly Structure to Satisfy Small Claim.

For a debt of $199.31 the tower erected by Nikola Tesla at Wardenclitte, L. I., is to be sold by Sheriff Wells, of Suffolk County, on Monday, Dec. 9. Any one wishing to dabble in electrical oscillations preparatory to launching wireless messages to Mars will find the Tesla tower especially fitted for the purpose.

August Eisenmann, through his attorney, Ralph J. Hawkins, obtained a judgment of $199.31 against the inventor and handed it to the Sheriff to execute.

The Tesla property at Wardenclitte is valuable, consisting of about 200 acres of exceedingly desirable property. The tower was built at a cost, it is said, of many thousands of dollars.

The New York World October 29, 1907

Tesla's Wireless Patents.

To the Editor of The World:

As bearing intimately on the report in your issue of even date that my tower is to be sold for $199.31 on Dec. 9, which, to use Mark Twain's phrase, is "greatly exaggerated," your readers might be interested to know that, among others, the following patents on wireless transmission, transformation and utilization of energy have been granted to me in the United States: Nos. 568,176, 568,178, 568,179, 568,180, 577,670, 645,576, 649,621, 685,595, 685,954, 723,183, 725,605, 787,412.

These documents, most carefully drawn with the assistance of some of the ablest attorneys, set forth clearly my fundamental discoveries on which this novel art is based, and give a faithful description of my processes, apparatus and experiments, thus enabling experts not only to flash wireless telegraphic and telephonic messages to any distance, but also to transmit power in unlimited amounts and with the highest economy.

Copies of these specifications can be readily obtained by addressing a courteous request to the Honorable Commissioner of the Patent Office, Washington, D. C., inclosing $1.20 postage stamps.

NIKOLA TESLA.

New York, Oct. 27.

Narcotic Effects of Electricity.

Mr. Nikola Tesla in a recent communication to the New York *Times* says: "I have read with interest the reports referring to Prof. Leduc's discovery of causing sleep by electric means. While it is possible that he has made a distinct advance there is no novelty in the effect itself. The narcotic influence of certain periodic currents was long ago discovered by me and has been pointed out in some of my technical publications, among which I may mention a paper on 'High Frequency Oscillators for Electro Therapeutic and Other Purposes,' read before the American Electro-Therapeutic Association, Sept. 13, 1898. I have also shown that human tissues offer little resistance to the electric flow and suggested an absolutely painless method of electrocution by passing the currents through the brain. It is very likely that Prof. Leduc has taken advantage of the same general principles, though he applies the currents in a different manner.

"In one respect, however, my observations are at variance with those reported. From the special dispatch in the *Times* of the 13th inst. it would appear that sleep is induced the moment the currents are turned on, and that awakening follows as soon as the electrodes are withdrawn. It is, of course, impossible to tell how strong a current was employed, but the resistance of the head might have been, perhaps, 3000 ohms, so that at 30 volts the current could have been only about 1/100 of an ampere. Now, I have passed a current at least 5000 times stronger through my head and did not lose consciousness, but I invariably fell into a lethargic sleep some time after.

"I have always been convinced that electric anæsthesia will become practical, but the application of currents to the brain is so delicate and dangerous an operation that the new method will require long and careful experimentation before it can be used with certitude."

TO TALK TO MARS WITH NIAGARA'S VOICE

"With the Co-operation of Niagara Power Companies I Am Now Preparing to Project an 800,000,000 Horse-power Message Over the 100,000,000 Mile Gulf Between the Earth and Mars."—*Nikola Tesla*

"This Will be the Next Great Achievement of Science."—*Sir Hiram S. Maxim.*

WHEN Sir Hiram S. Maxim, the distinguished inventor and scientist, made his recent announcement to Peter Cooper Hewitt that the next great achievement of science would be the harnessing of the whole energy of Niagara and the sending of a message to Mars, he hit the nail, in the opinion of Nikola Tesla, squarely on the head.

Mr. Tesla announces to-day that with the co-operation of power-producing companies at Niagara Falls he is preparing to hail Mars with Niagara's voice. A way has been found at last for transmitting a wireless message across the gulf, varying from 40,000,000 to 100,000,000 miles, which separates this earth from Mars. Once that has been accomplished and Mars, which is considerably older and supposedly more advanced in science than us, has acknowledged the receipt of our signal and sent back flash for flash, it will remain to devise an interplanetary code through the medium of which the scientists of this world and of Mars will be able to understand what each is saying to the other.

Mr. Tesla has been quietly working for several years on a wireless power plant capable of transmitting 10,000 horse-power to any part of the world, or to any of our neighboring planets, for that matter. The mere matter of distance between despatching and receiving points is absolutely no object whatever. Wireless power, Mr. Tesla says, may be sent one million or more miles just as easily as one mile.

Several of the electric power companies with immense generating plants at Niagara Falls have agreed to co-operate with Mr. Tesla in an effort to reach Mars by wireless.

These Niagara power plants, Mr. Tesla declares, are now capable of producing electrical vibrations of such intensity that, if measured according to ordinary standards, the rate at which their energy is delivered could readily be advanced to a billion horse-power. But no such performance is necessary to produce strong electrical impulses on Mars. Mr. Tesla has estimated that a rate of a few hundred million horse-power is quite sufficient to establish wireless communication with that planet.

Mr. Tesla's wireless plant, which he has already equipped at Wardenclyffe, L. I., for the sending of long distance electric waves, will enable him to attain a rate of 800,000,000 horse-power—much more than is necessary to bridge the gulf of from 40,000,000 to 100,000,000 miles between this earth and Mars.

Now, it was explained by Mr. Tesla, if his magnifying wireless transmitter and corresponding receiver, or a somewhat similar apparatus, were installed on Mars it would be a very simple matter for the Martians to receive wireless flashes from the earth and to send us others in reply. And in sending messages to this earth the Martians would not need to use more than one-sixteenth the electrical energy needed to send flashes from the earth to Mars.

"It should be borne in mind," Mr. Tesla wrote, "that many Martian tasks in mechanical engineering are much easier than the terrestrial, on account of the smaller mass of the planet and lesser density, which, in the superficial layers, may be considerably below the mean. To a still greater degree this is true of electrical engineering. Taking into account the space encompassed by Mars, a system of wireless transmission of energy, such as I have perfected, would be there much more advantageously applied, for, under similar conditions a receiving circuit would collect sixteen times as much energy as on the earth.

"The astonishing evidences furnished by Lowell are not only indicative of organic life, but they make it appear very probable that Mars is still populated; and furthermore, its inhabitants are highly developed, intelligent beings."

"Is there any other proof of such existence?"

"I answer, emphatically, yes, prompted both by an instinct, which has never yet deceived me, and observation. I refer to the strange electrical disturbances, the discovery of which I announced six years ago. At that time I was only certain that they were of planetary origin. Now, after mature thought and study, I have come to the positive conclusion that they must have emanated from Mars.

"Such colossal transformation as is observable on the face of Mars could not have been wrought except by beings ahead of us in development.

"What wonder if they are signalling to us? We are sufficiently advanced in electrical science to know that their task is much easier than ours. The question is, can we transmit electrical energy to that immense distance? This I think myself competent to answer in the affirmative."

THE SUN MAY AID US IN SIGNALLING MARS.

By Prof. Garret P. Serviss.

IF the men of Mars—the majority of astronomers agree that the planet is probably inhabited—have telescopes comparable with ours, it is perfectly conceivable that they can see the great canals which are under construction on the vast, arid plains of the West. The so-called canals of Mars are at least sixty miles wide. Now, if we build a canal here in the western desert tapping some great lake which can readily be seen from Mars, and from this long canal there radiate many little canals for irrigation, bordering this giant waterway, there will be a long strip of bright green one hundred miles wide. Set in the gray of the desert, this could easily be seen. Then the flashing of the water in the sunshine would make it even more visible.

Very likely, too, should the Martians notice this sudden and remarkable change on the earth's surface, especially if the aspect assumed, even roughly, some geometrical shape, they would naturally suppose we were signalling to them. Then it would be not beyond the range of possibility that they might answer back.

WHY THE MARTIANS WILL ANSWER OUR SIGNALS.

By Nikola Tesla.

AS the Martians are probably more advanced and skilled than us, their first readable message to this earth will undoubtedly be, "We have been calling you for the last ten thousand years."

Once communication is established, the Martians will gradually take our code and language and learn it first and then teach us theirs in plain English. Difficult as this fact would seem, it in reality would not be comparable with the achievement of teaching a deaf, dumb and blind child to understand. To talk to Mars is only a matter of patience now.



Prof. David P. Todd of Amherst College.

New Evidence That Mars Is Inhabited.

By Prof. E. C. Slipper,
of the Flagstaff, Ariz., Observatory.

A PRELIMINARY inspection of the results of my recent observations of Mars, taken in the Andes, entirely corroborates Prof. Lowell's theory that there is intelligent life on that planet. Several new canals in addition to those already known have been discovered, and a great many double canals have been observed, indicating the employment of great intelligence and care in their construction.

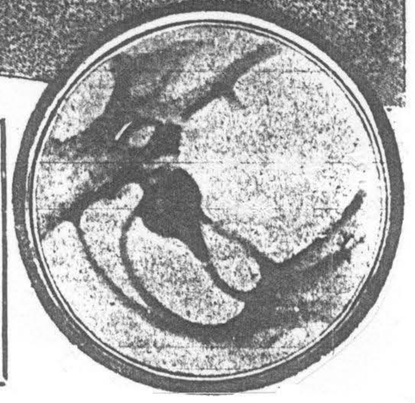
If any reasonable doubt yet exists as to the existence of life on Mars the announcement of that very conservative astronomer, Prof. David P. Todd, of Amherst, that there is something like human life on Mars, may be taken as authoritative and conclusive. During six weeks' observation this spring with a specially constructed photographic telescope set up in the Andes Mountains, in Northern Chili, Prof. Todd took more than 2,000 remarkable photographs of Mars.

These pictures constitute a complete series of surface photographs of Mars, from pole to pole, from side to side, the enlargements of which will enable a new sphere to be made. To this sphere the lines and cross lines of the planet will be attached in raised edges, so that in three months' time we shall have an entirely new and most complete globe of the planet.

"Of course, the difficulty heretofore has been to trust the observations of the naked eye through the telescope," said Prof. Todd. "Prof. Lowell has made photographs of Mars, but the aerial and atmospheric conditions at Flagstaff have not been so advantageous as to secure so thorough an examination as the one we have just made.

"During the six weeks that we observed Mars the planet exposed its spherical surface completely, and although I base my conclusions that there is something like human intelligence at work up there purely upon inferential indications, I was much impressed with the possibility.

"Among the six or seven thousand photographs, however, which I was fortunate enough to obtain there is no illusive line, no questionable dot. What the camera saw is there, and what these pictures will reveal when they have been carefully examined I am sure will add a great deal to our knowledge of Mars."



How Mars Looked to Prof. Todd When Viewed from a Distance of 43,000,000 Miles. The Thin Lines Are Now Believed to Be Strips of Vegetation Fifty Miles Wide, Irrigated from Central Canals.

What the Martians Might Say to Us in Reply

By Edward Sylvester Morse, A.M., Ph.D.

FOR every single perplexity of interpretation we encounter in our study of the surface workings of Mars the Martian would encounter a dozen perplexities in interpreting the various features on the surface of the earth. What must be the Martian interpretation of the surface features of this world? It is a perfectly fair inquiry, for by such means we may appreciate the attitude of some of our interpreters of Mars.

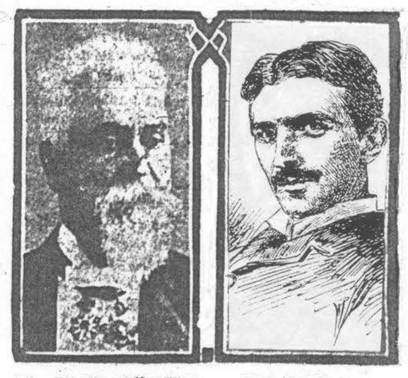
In examining the earth, then, as we have examined Mars, the Martian would find large yellow and reddish areas, extensive greenish areas, and, besides, large regions of varying shades of blue, possibly occupying three-fourths of the earth's surface. The yellow areas he would interpret as desert land; the greenish areas he might consider vegetation, but what would he make out of the larger regions of blue? This would certainly puzzle him, because, unfamiliar with oceans, he could not believe that such vast tracts could really be water. He would easily interpret the Polar snow caps and the waters at their edges, but the oceans would be impossible to solve. They form the basis for one of the first questions the Martian would ask us in seeking information about the earth.

The perennial character of the vegetation in the tropics would also be a puzzle requiring much explanation from us. Even if the Martian recognized oases in the deserts of America and Africa, the result of artesian wells or springs, he could not believe them to be vegetation, for he would detect no irrigating canals running into them. He would come to the conclusion that no creature could possibly exist on the earth, as the tremendous force of gravitation, with great atmospheric pressure, would forbid the existence of any organic forms.

The immense clouds veiling the surface of the earth must, in the probable opinion of the Martian, at times suffer condensation, and the impact of the rain drops would, from their velocity and weight, smash everything in the way of life. Life would apparently exist only in forms supported by stupendages, with legs of iron to sustain their weight and a turtle-like crust, to be impervious to rain drops; and this would be contrary to all Martian analogy.

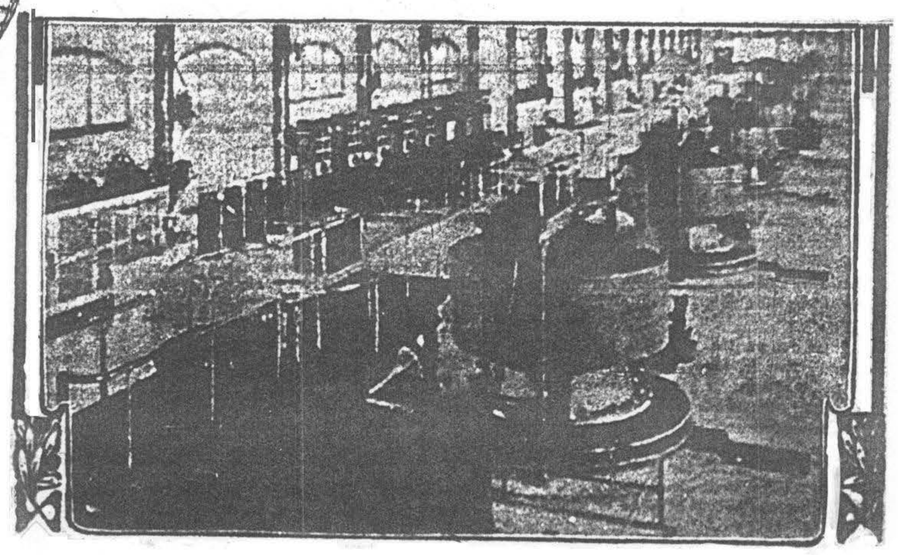
The courses of rivers, if detected, would puzzle him from their irregularity, unless he dared to suggest or we explained to him, that these long, sinuous channels, extending for thousands of miles, are identical with the little rivulets he had studied near his own pole.

If Mars is an older sphere, we trust it has outgrown the superstitions which still hamper man in his interpretation of the inexorable phenomena of nature.



Sir Hiram S. Maxim. Nikola Tesla.





Great Generators Converting the Power of Niagara Falls Into Electric Force.

The New York Herald December 3, 1907

MR. TESLA'S INVENTION

TO THE EDITOR OF THE HERALD:—

In a special despatch in your issue of to-day a well known improvement of mine is referred to as if invented by German engineers. This is all the more disappointing to me as I have been virtually ridiculed for advocating the idea. I refer to the electric driving of propellers, which I have recommended as particularly suitable for ocean liners.

A common mistake of my critics was to assume that the adoption of the system would necessitate a great increase in weight, but it is not so. The turbo-generators would weigh much less than the equivalent marine engine, and the motors designed for very high peripheral velocity would be light. Numerous auxiliary engines, the special lighting plant, belts, shafting, pulleys, supports and miles of pipe could be done away with, thus diminishing the total weight and saving power besides. Much more energy could be obtained from the prime movers and the propellers could be made to work with the highest efficiency. In making this change on the existing vessels the boiler plant could remain intact. The gain in space would be considerable.

I cannot agree with the opinion unanimously expressed by the Association of Shipbuilders and Shipbuilding Engineers that "electric power transmission affords the only solution," for, as stated in a previous letter to the HERALD, I have discovered another and better one.

NIKOLA TESLA

NEW YORK, Nov. 30, 1907.

TESLA TO TALK TO MARS.

Mr. Tesla announces that, with the co-operation of power-producing companies at Niagara Falls, he is preparing to hail Mars with Niagara's voice. A way has been found at last, it is asserted, for transmitting a wireless message across the gulf which separates this earth from Mars. Once that has been accomplished, and Mars—which is considerably older and supposedly more advanced in science than us—has acknowledged the receipt of our signal, and sent back flash for flash, it will remain to devise an interplanetary code through the medium of which the scientists of this world and of Mars will be able to understand what each is saying to the other.

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These Niagara power plants, Mr. Tesla declares, are now capable of producing electrical vibrations of such intensity that, if measured according to ordinary standards, the rate at which their energy is delivered could readily be advanced to a billion horse-power. But no such performance is necessary to produce strong electrical impulses on Mars. Mr. Tesla has estimated that a rate of a few hundred million horse-power is quite sufficient to establish wireless communication with that planet.

Mr. Tesla's wireless plant, which he has already equipped at Wardenclyffe, L.I., for the sending of long-distance electric waves is to be utilised.

Mr. Tesla seems to believe that Mars is already signalling to us:

"The astonishing evidences furnished by Lowell are not only indicative of organic life, but they make it appear very probable that Mars is still populated, and, furthermore, its inhabitants are highly-developed, intelligent beings."

"Is there any proof of such existence?"

"I answer, emphatically, yes, prompted both by an instinct, which has never yet deceived me, and observation. I refer to the strange electrical disturbances, the discovery of which I announced six years ago. At that time I was only certain that they were of planetary origin. Now, after mature thought and study, I have come to the positive conclusion that they must have emanated from Mars.

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MARCONI NOT INFORMED.

"An Achievement of Far-Reaching Importance," If Claims Are Correct.

To the Editor of The New York Times:

GLACE BAY, N. S., Dec. 19.—As I am not familiar with the details of Prof. Poulson's wireless telephone I am not in a position to give a definite opinion thereon, but should he accomplish what he claims it would be an achievement of far-reaching importance. MARCONI.

MY APPARATUS, SAYS TESLA.

Confident, However, That Wireless Telephony Is Entirely Possible.

To the Editor of The New York Times:

I have read with great interest the report in your issue of to-day that the Danish engineer, Waldemar Poulson, the inventor of the interesting device known as the "telegraphone," has succeeded in transmitting accurately wireless telephonic messages over a distance of 240 miles.

I have looked up the description of the apparatus he has employed in the experiment and find that it comprises:

(1) My grounded resonant transmitting circuit; (2) my inductive exciter; (3) the so-called "Tesla transformer"; (4) my inductive coils for raising the tension on the condenser; (5) my entire apparatus for producing undamped or continuous oscillations; (6) my concatenated tuned transforming circuits; (7) my grounded resonant receiving circuit; (8) my secondary receiving transformer. I note other improvements of mine, but those mentioned will be sufficient to show that Denmark is a land of easy invention.

The claim that transatlantic wireless telephone service will soon be established by these means is a modest one. To my system distance has absolutely no significance. My own wireless plant will transmit speech across the Pacific with the same precision and accuracy as across a table. NIKOLA TESLA.

New York, Dec. 19, 1907.

DEADLY WAVE

Naval Battles of the Future to Be Fought by Water Power.

Cynamite, Discharged Beneath the Surface of the Sea, Will Create a Tidal Wave That Could Engulf a Fleet.

By NIKOLA TESLA.

THE time is not far distant when all the tremendous wastes of naval war will be stopped, and then, if there are battles, they will be fought with water power and electric waves. That humanity is moving fast towards this realization is evident from many indications.

What is most to be regretted in the present war regime is, that the effect of so many exquisite intelligences must be uneconomically applied, since it cannot be steadily directed toward a scientific truth, unaltered and of permanent usefulness, but must be entirely governed by the wavering struggle of opposing principles. This feverish striving to meet the instant demand, to create type after type, one to devour the other, to merge into one contrasting element, leads, like a nightmare, from one to another absurdity. Such a monstrosity is the latest creation of the naval constructor—a 20,000 ton battleship. In theory, it is condemned by competent authorities.

Everything points to the development of a small vessel with internal combustion engines, extreme speed, and few weapons of great destructiveness. But the new leviathan is admirably adapted to the practical requirements of the day. In attack it can alone annihilate a nation's fleet. It is equally effective in defense. If equipped with proper acoustic and electrical appliances, it has little to fear from a submarine, and an ordinary torpedo will scarcely hurt it. That is why the first of these monsters, built in England, has been named the Dreadnought. Now, there is a novel means for attacking a fortress of this kind, from shore or on the high seas, against which all its gun power and armor resistance are of no avail. It is the tidal wave.

Such a wave can be produced with 20 or 30 tons of cheap explosive, carried to its destination and ignited by a non-interferable telautomaton.

The tidal disturbance, as here considered, is a peculiar hydrodynamic phenomenon, in many respects different from the commonly occurring characterized by a rythmical succession of waves. It consists generally of but a single advancing swell succeeded by a hollow, the water if not otherwise agitated being perfectly calm in front and very nearly so behind. The wave is produced by some sudden sxplosion or upheaval, and is, as a rule, symmetrical for a large part of its course. Those who have encountered a tidal wave must have observed that the sea rises rather slowly, but the descent into the trough is steep. This is due to the fact that the water is lifted, possibly very slowly, under the action of a varying force, great at first, but dying out quickly, while the raised mass is urged downward by the constant force of gravity. When produced by natural causes these waves are not very dangerous to ordinary vessels, because the disturbance originates at a great depth.

To give a fairly accurate idea of the efficacy of this novel means of destruction, particularly adapted for coast defense, it may be assumed that 30 tons of nitro-glycerin compound, as dynamite, be employed to create the tidal disturbance. This material, weighing about twice as much as water, can be stored in a cubical tank eight feet each way, or a spherical vessel of 10 feet diameter. The reader will now understand that this charge is to be entrusted to a non-interferable telautomaton, heavily protected, and partly submerged or submarine, which is under the control of a skilled operator far away. At the propitious moment the signal is given, the charge sunk to the proper depth, and ignited.

The water is incompressible. The hydrostatic pressure is the same in all directions. The explosion propagates through the nitro-glycerin compound with a speed of three miles a second. Owing to all this, the whole mass will be converted into gas before the water can give way appreciably, and a spherical bubble 10 feet in diameter will form. The gaseous pressure against the surrounding water will be 20,000 atmospheres, or 140 tons per square inch. When the great bubble has expanded to twice its original volume, it will weigh as much as the water it displaces, and from that moment on, its lowering and tapering more and more into a cone, it will be driven up with a rapidly-increasing force tending towards 20,000 tons. Under this terrible impulsion it would shoot up to the surface like a bullet were it not for the water resistance, which will limit its maximum speed to 80 feet per second.

Consider now the quantity and energy of the upheaval. The caloric potential energy of the compound is 2,800 heat units per pound, or, in mechanical equivalent, almost 1,000-foot tons. Of course, only a part of this immense store is transformable into mechanical effort. Theoretically, 40 pounds of good smokeless powder would be sufficient to impart to the Dreadnought's 850-pound projectile the tremendous velocity mentioned above, but it actually takes a charge of 250 pounds. The tidal wave generator is a dynamic transformer much superior to the gun, its greatest possible efficiency being as high as 44 per cent. Taking, to be conservative, 33 per cent instead, there will be of the total potential store about 25,000,000 foot-tons obtained in mechanical energy.

Otherwise stated, 25,000,000 tons—that is, 860,000,000 cubic feet of water—could be raised one foot, or a smaller quantity to a correspondingly greater elevation. The hight and length of the wave will be determined by the depth at which the disturbance originated. Opening in the center like a volcano, the great hollows will belch forth with a roar. Some 15 seconds later a valley of 600 feet depth, counted from normal ocean level, will form, surrounded by a perfectly circular swell, approximately of equal hight, which will enlarge in diameter at the rate of about 220 feet per second.

It is futile to consider the effect of such an eruption on a vessel situated near by, however large. The entire navy of a great country, if massed around would be destroyed. But it is instructive to inquire what such a wave could do to a battleship of the Dreadnought type at considerable distance from its origin. A simple calculation will show that, when the outer circle has expanded to three-quarters of a mile, the swell, about 1,250 feet long, would still be more than 100 feet in hight, and when the circle is one and one-quarter miles in diameter the vertical distance from crest to trough would be over 100 feet.

The first impact of the water will produce pressures of three tons per square foot, which all over the exposed surface of, say, 20,000 square feet, may amount to 60,000 tons, eight times the force of the recoil of the broadside. That first impact may in itself be fatal. During more than 10 seconds the vessel will be entirely submerged and finally dropped into the hollow from a hight of about 75 feet, the descent being effected more or less like a free fall. It will then sink far below the surface, never to rise.

The New York World January 5, 1908

NIKOLA TESLA'S FORECAST FOR 1908.

Aerial and Sea Navigation and Wireless Telegraphy to Make Astounding Strides.

To the Editor of The World:

A forecast—not a prophecy!

Constant and careful study of the state of things in the particular sphere enables an expert to make a forecast fairly accurate of the next step. The seemingly isolated events are to him but links of a chain. As a rule, the signs he notes are so pronounced that he can predict the changes about to take place with certitude. The performance is a mere banality as compared with the piercing view of the inspired into the distant future. This is a forecast—not a prophecy.

The coming year will be great in thought and result. It will mark the end of a number of erroneous ideas which, by their paralyzing effect on the mind, have throttled independent research and hampered progress and development in various departments of science and engineering.

The first to be dispelled is the illusion of the Hertz or electro-magnetic waves. The expert already realizes that practical wireless telegraphy and telephony are possible only by minimizing this wasteful radiation. The results recently attained in this manner with comparatively crude appliances illustrate strikingly the possibilities of the genuine art. Before the close of the year wireless transmission across the Pacific and trans-Atlantic wireless telephony may be expected with perfect confidence. The use of the wireless telephone in isolated districts will spread like fire.

The year will mark the fall of the illusionary idea that action must diminish with distance. By impressing upon the earth certain vibrations, to which it responds resonantly, the whole planet is virtually reduced to the size of a little marble, thus enabling the reproduction of any kind of effect, as human speech, music, picture or character whatever, and even the transmission of power in unlimited amounts with exactly the same facility and economy at any distance, however great.

The next twelve months will witness a similar revolution of ideas regarding radio-activity. That there is no such element as radium, polonium or tonium is becoming more and more evident. These are simply deceptive appearances of a modern phlogiston. As I have stated in my early announcement of these emanations before the discovery of Mme. Curie, they are emitted more or less by all bodies, and are all of the same kind—merely effects of shattered molecules, differentiated not by the nature of substance but by size, speed and electrification.

The coming year will dispel another error which has greatly retarded the progress of aerial navigation. The aeronaut will soon satisfy himself that an aëroplane proportioned according to data obtained by Langley is altogether too heavy to soar, and that such a machine, while it will have some uses, can never fly as fast as a dirigible balloon. Once this is fully recognized the expert will concentrate his efforts on the latter type, and before many months are passed it will be a familiar object in the sky.

There is abundant evidence that distinct improvements will be made in ship propulsion. The numerous theories are giving place to the view that what propels the vessel is a reactive jet; hence the propeller is doomed to inefficiency at high speed. A new principle will be introduced.

The World is invited to test the accuracy of this forecast at the close of the year.

NIKOLA TESLA.

The New York Times January 28, 1908

WIRELESS AROUND THE WORLD.

Nothing Novel in the Accomplishment, Says Nikola Tesla.

To the Editor of The New York Times:

I read in your issue of to-day that, according to Lieut. Col. Ginsies, Director of Military Telegraphs of France, a wireless message "should theoretically go around the world." If you will take the trouble of perusing my French patent, No. 354,791, you will find that this has long since ceased to be a theory, for that document, while bearing the date of April, 1905, describes experiments which I made in the Fall of 1899, and one of which was to pass currents of 100 amperes around the globe; a mere breath in view of its immensity, but more than necessary to affect a sensitive receiver. You will also notice that in those tests I used "undamped" oscillations, one of my earliest improvements, which you seem to find pleasure in attributing to other electricians. These facts are mentioned incidentally, merely with the desire of informing you correctly.

What I wish to bring to your attention relates to certain provisions of the last wireless conference which are now being considered by the United States Senate. Some of the rules were undoubtedly proper and applicable to "radio-telegraphy" by electro-magnetic or Hertzian rays, in view of the impossibility of preventing interference and because many different forms of apparatus were employed. But since that time the Hertz waves have been abandoned by the more advanced experts and a uniform system adopted which permits the simultaneous transmission of any desired number of wireless messages without interference and with a precision and accuracy equal to, if not greater, than that practicable with cables. If international rules are to be established, they should be in reasonable harmony with existing conditions. Their consideration might be made the subject of another wireless conference, which it would be proper to hold here, as all the essential principles, processes, and devices have been discovered and perfected in this country.

You will probably agree with me that the contemplated compulsory exchange of messages is a measure not flattering to our enlightened age. We have no law compelling a person to go to the rescue of another in peril, and yet one who would fail to do so would be guilty of a crime insignificant as compared with that of ignoring a call of a vessel in distress. So ignominious a rule should not be permitted to go on record. Besides, the scheme is entirely impracticable. Even if sealed recording and controlling instruments were installed on the vessels, they would be of little use.

The trampling of rights granted to pioneers and attendant throttling of commercial undertakings, offering infinite possibilities, can be but hurtful to progress. As I have stated in a previous letter to THE TIMES, the wireless transmission of energy will ultimately insure the supremacy of the Anglo-Saxons, who are the fittest race to govern. Their interests and the world's peace are in the free and unhampered development of the art.

NIKOLA TESLA.

New York, Jan. 26, 1908.

Mr. Tesla Makes Further Disclosures.

Nikola Tesla, who has been making some rather remarkable assertions of late in letters printed in the New York Times, publishes another communication under date of January 26th. This is a part of it:

"I read in your issue of today that, according to Lieutenant-Colonel Chales, director of military telegraphs of France, a wireless message 'should theoretically go around the world.' If you will take the trouble of perusing my French patent, No. 354,791, you will find that this has long since ceased to be a theory, for that document, while bearing the date of April, 1905, describes experiments which I made in the fall of 1899, and one of which was to pass currents of 100 amperes around the globe, a mere breadth in view of its immensity, but more than necessary to affect a sensitive receiver. You will also notice that in those tests I used 'undamped' oscillations, one of my earliest improvements, which you seem to find pleasure in attributing to other electricians. These facts are mentioned incidentally, merely with the desire of informing you correctly.

"What I wish to bring to your attention relates to certain provisions of the last wireless conference which are now being considered by the United States Senate. Some of the rules were undoubtedly proper and applicable to 'radio-telegraphy' by electromagnetic or Hertzian rays, in view of the impossibility of preventing interference and because many different forms of apparatus were employed. But since that time the Hertz waves have been abandoned by the more advanced experts and a uniform system adopted which permits the simultaneous transmission of any desired number of wireless messages without interference and with a precision and accuracy equal to, if not greater than, that practicable with cables."

[89.]—TESLA COIL.—You will get better results by using a greater number of turns on an increased length of core. Of course, if you insulate every layer carefully, you may wind on several layers, both of primary and secondary; and, in order to prevent the insulation giving way, it would be better to stand the transformer bodily in an earthen vessel containing resinous paraffin oil of such a consistency that it will flow in between the layers of wire.

Arthur E. R. Bottone.

COMMUNICATION.

Mr. Tesla's Work.

To the Editor of the Western Electrician.

I note with interest the article in the issue of the Western Electrician of February 8th, entitled "Mr. Tesla Makes Further Disclosures." I have reason to believe that Mr. Nikola Tesla has already transmitted electrical energy without conducting wires to greater distances than any other inventor of "wireless" that the world has produced. In an interview with Daniel Drawbaugh, inventor of the telephone, some time ago he said that the Hertzian ray, or radio-telegraphy, is old. Mr. Drawbaugh said that the best transmission is through the earth. I have reason to believe that he is right. It seems very clear to me that some inventors are making use of some of Mr. Tesla's apparatus in modified forms.

J. HOLMES WILSON.

Carlisle, Pa., February 11, 1908.

The New York Herald March 11, 1908

TESLA WILL DESTROY AN ARMY A MINUTE

Twenty Million Horse Power Generator to Fight the Battles of the Future.

That present methods of warfare will be displaced by the use of electric waves projected through the air with effect sufficient to destroy an entire army in the space of a few minutes was the assertion of Nikola Tesla in an address delivered before the Entertainment Club at the Waldorf-Astoria last night. A twenty million horse power energy source will develop this electric force, he continued, its generating power in turn being drawn from the waterfalls of the country.

"With the age of great economies upon which we now are entering," he said, "it will be held wasteful to construct at great cost battle ships which are fit for active service only a few years. The battles of the future will be fought through the air. Further, there will be the creation of a system of wireless telephony which will render it possible to hold communication not only with every corner of the world, but with the other planets."

Commenting upon this picture of the future, Rear Admiral Charles D. Sigsbee said:—

"Well, all the naval and army officers of the future will have to do, evidently, in the light of the developments which Mr. Tesla promises, will be to sit down and fight their battles with kid gloves."

The New York Times March 11, 1908

AERIAL WARSHIPS COMING.

Also Wireless Telephony That Will Circle the Globe, Tesla Tells Diners.

Rear Admiral Charles Sigsbee and Nikola Tesla were guests of honor at a dinner and reception given by the Entertainment Club in the Waldorf-Astoria last night. Gen. J. Fred Pierson presided. Nikola Tesla spoke on the future of warfare. He said:

"Mankind will eventually harness the waterfalls and transform this enormous pressure into energy, and this will simplify warfare. Aerial vessels of war will be used to the exclusion of ships, and with 10,000,000 tons of energy this country will be equipped to rout the civilized world.

"I consider the greatest achievement of humanity will be wireless telephony, which may be operated throughout the globe. This will solve a thousand intricate features of our civilization. It is scientifically possible, and it will gradually become an actuality."

Admiral Sigsbee related his social activities during his long career in the navy. He told of a pork and beans dinner he ate with the family of Mme. Emma Eames in Shanghai in 1866.

TECHNICAL WORLD MAGAZINE April 1908

ENGINEERING PROGRESS



HOW TESLA WOULD DESTROY A NAVY

NIKOLA TESLA bears an honored name in electrical science and has done memorable work in oscillatory currents and in connection with Hertzian waves. A few years ago, it may be remembered, he stood in the theater of the Royal Institution with oscillatory currents of unheard-of voltage playing about his unharmed head, and this taste for the sensational appears to grow with increasing years, so that now Tesla's projects nearly always have a ring of the glaringly impossible, and are seldom anything more than plausible. His latest idea is that of creating an enormous tidal wave for purposes of coast defense in order to annihilate a hostile fleet. It may be assumed, remarks Mr. Tesla, that "thirty tons of nitroglycerine compound be employed to create the tidal disturbance. This material, weighing about twice as much as water, can be stored in a cubical tank eight feet each way or in a spherical vessel of ten feet diameter. . . . At the propitious moment the signal is given, the charge sunk to the proper depth and ignited. . . . The water is incompressible. The explosion propagates through the compound at a speed of three miles a second, so that the whole mass will be converted into gas before the water can give way appreciably, and a spherical bubble ten feet in diameter will form. The gaseous pressure against the surrounding water will be 20,000 atmospheres, or 140 tons to the square inch." At this point Mr. Tesla relapses into a maze of calculations of calories and power units, where it is difficult and unnecessary to follow him. He emerges presently with the resultant statement that 25,000,000 tons of water would be raised one foot, or a smaller quantity to a correspondingly greater elevation. The height and length of the wave will be determined by the depth at which the disturbance originated. Opening in the center like a volcano, the great hollows will belch forth a shower of ice. Some sixteen seconds later a valley of 600 feet depth, counted from normal ocean level, will form, surrounded by a perfectly circular swell, approximately of equal height, which will enlarge in diameter at the rate of about 220 feet per second. It is futile, concludes Mr. Tesla, pleasantly, to consider the effect on a neighboring vessel, however large. Even a navy would be destroyed.

WAR À LA TESLA

IT is suggested by Nikola Tesla that in the event of war a hostile navy could be swamped by a huge tidal wave created by the explosion at sea of a large quantity of nitroglycerin. Says a writer in *The Technical World Magazine* (Chicago, April):

"Nikola Tesla bears an honored name in electrical science and has done memorable work in oscillatory currents and in connection with Hertzian waves. A few years ago, it may be remembered, he stood in the theater of the Royal Institution with oscillatory currents of unheard of voltage playing about his unharmed head, and this taste for the sensational appears to grow with increasing years, so that now Tesla's projects nearly always have a ring of the glaringly impossible, and are seldom anything more than plausible. His latest idea is that of creating an enormous tidal wave for purposes of coast defense in order to annihilate a hostile fleet. It may be assumed, remarks Mr. Tesla, that 'thirty tons of nitroglycerin compound be employed to create the tidal disturbance. This material, weighing about twice as much as water, can be stored in a cubical tank eight feet each way or in a spherical vessel of ten feet diameter. . . . At the propitious moment the signal is given, the charge sunk to the proper depth and ignited. . . . The water is incompressible. The explosion propagates through the compound at a speed of three miles a second, so that the whole mass will be converted into gas before the water can give way appreciably, and a spherical bubble ten feet in diameter will form. The gaseous pressure against the surrounding water will be 20,000 atmospheres, or 140 tons to the square inch. At this point Mr. Tesla relapses into a maze of calculations of calories and power units, where it is difficult and unnecessary to follow him. He emerges presently with the resultant statement that 25,000,000 tons of water would be raised one foot, or a smaller quantity to a correspondingly greater elevation. The height and length of the wave will be determined by the depth at which the disturbance originated. Opening in the center like a volcano, the great hollows will belch forth a shower of ice. Some sixteen seconds later a valley of 600 feet depth, counted from normal ocean-level, will form, surrounded by a perfectly circular swell, approximately of equal height, which will enlarge in diameter at the rate of about 220 feet per second. It is futile, concludes Mr. Tesla, pleasantly, to consider the effect on a neighboring vessel, however large. Even a navy would be destroyed."

The New York Times April 21, 1908

MR. TESLA'S VISION.

How the Electrician's Lamp of Aladdin May Construct New Worlds.

To the Editor of The New York Times:

From a report in your issue of March 11, which escaped my attention, I notice that some remarks I made on the occasion referred to have been misunderstood. Allow me to make a correction.

When I spoke of future welfare I meant that it would be conducted by direct application of electrical waves without the use of aerial engines or other implements of destruction. This means, as I pointed out, would be ideal, for not only would the energy of war require no effort for the maintenance of its potentiality, but it would be productive in times of peace. This is not a dream. Even now wireless power plants could be constructed by which any region of the globe might be rendered uninhabitable without subjecting the population of other parts to serious danger or inconvenience.

What I said in regard to the greatest achievement of the man of science, whose mind is bent upon the mastery of the physical universe, was nothing more than what I stated in one of my unpublished addresses, from which I quote: "According to an adopted theory, every ponderable atom is differentiated from a tenuous fluid, filling all space merely by spinning motion, as a whirl of water in a calm lake. By being set in movement this fluid, the ether, becomes gross matter; its movement arrested, the primary substance reverts to its normal state. It appears, then, possible for man through harnessed energy of the medium and suitable agencies for starting and stopping ether whirls to cause matter to form and disappear. At his command, almost without effort on his part, old worlds would vanish and new ones would spring into being. He could alter the size of this planet, control its seasons, adjust its distance from the sun, guide it on its eternal journey along any path he might choose, through the depths of the universe. He could make planets collide and produce his suns and stars, his heat and light; he could originate life in all its infinite forms. To cause at will the birth and death of matter would be man's grandest deed, which would give him the mastery of physical creation, make him fulfill his ultimate destiny."

Nothing could be further from my thought than to call wireless telephony around the world "the greatest achievement of humanity," as reported. This is a feat which, however stupefying, can be readily performed by any expert. I have myself constructed a plant for this very purpose. The wireless wonders are only seeming, not results of exceptional skill, as popularly believed. The truth is the electrician has been put in possession of a veritable lamp of Aladdin. All he has to do is to rub it. Now, to rub the lamp of Aladdin is no achievement.

If you are desirous of hastening the accomplishment of still greater and further-reaching wonders you can do no better than by emphatically opposing any measure tending to interfere with the free commercial exploitation of water power and the wireless art. So absolutely does human progress depend on the development of these that the smallest impediment, particularly through the legislative bodies of this country, may set back civilization and the cause of peace for centuries.

NIKOLA TESLA.

New York, April 10, 1908.

The New York Sun May 7, 1908

PATENTS IN GERMANY.

Complaints of Ill Treatment of American Inventors.

To the Editor of The Sun—*Sir:* In a special cable despatch from Berlin in The Sun of May 3 the president of the Imperial Patent Office is reported as saying that he did not recall a case in which the rights of unexploited American patents have been withdrawn. That statement reminds me painfully of at least one such case, the annulment by a special act of the Reichsgeriche of my patents on the transmission of power, which deprived me of a great fortune. My discoveries in that field are the foundation of an immense industry in Germany, but it is of no benefit to myself or to the firm which undertook their introduction in that country. This, however, is not my only disappointing experience with the Imperial Patent Office. My application for my system of wireless transmission of energy, anticipating all others, is still locked up there, while German companies are exploiting the advances in the art it disclosed.

I could say more, but it would be nothing novel, for such has been the uniform experience of American inventors. The ablest patent attorneys here now advise their clients, almost as a rule, not to bother with German rights, and for good reasons. Ask any of the great inventors of this country, Bell, Edison, Thomson, Brush, Weston and others, what pecuniary benefits they have received from Germany, and the answer will be, none.

How much we have to fear from a patent war with Germany I leave it to yourself to infer. That the United Sates should adopt some measures for the protection of home invention is a perfectly obvious conclusion, particularly in view of the recent change in the British patent law. Nikola Tesla.

New York, May 5.

LITTLE AEROPLANE PROGRESS

So Says Nikola Tesla.—But He Is Working on One of His. Own.

To the Editor of The New York Times:

It was not a little amusing to read a short time ago how the "great secret" of the aeroplane was revealed. By surrounding that old device with an atmosphere of mystery one gives life and interest to the report; but the plain fact is that all forms of aerial apparatus are well known to engineers, and can be designed for any specific duty without previous trials and with a fair degree of accuracy. The flying machine has materialized—not through leaps and bounds of invention, but by progress slow and imperceptible, not through original individual effort, but by a combination of the same forces which brought forth the automobile and the motorboat. It is due to the enterprise of the steel, oil, electrical, and other concerns, who have been instrumental in the improvement of materials of construction and in the production of high-power fuels, as well as to the untiring labors of the army of skilled but unknown mechanics, who have been for years perfecting the internal combustion engine.

There is no salient difference between the dirigible balloon of Renard & Krebs of thirty years ago and that of Santos Dumont with which the bold Brazilian performed his feats. The Langley and Maxim aerodromes, which did not soar, were in my opinion better pieces of mechanism than their very latest imitations. The powerful gasoline motor which has since come into existence is practically the only radical improvement.

So far, however, only the self-propelled machine or aerial automobile is in sight. While the dirigible balloon is rapidly nearing the commercial stage, nothing practical has as yet been achieved with the heavier-than-air machine. Without exception the apparatus is flimsy and unreliable. The motor, too light for its power, gives out after a few minutes' run, the propeller blades fly off the rudder is broken, and, after a series of such familiar mishaps, there comes the inevitable and general smash-up. In strong contrast with these unnecessarily hazardous trials are the serious and dignified efforts of Count Zeppelin, who is building a real flying machine, safe and reliable, to carry a dozen men and provisions over distances of thousands of miles, and with a speed far in excess of those obtained with aeroplanes.

The limits of improvement in the flying machine, propelled by its own power, whether light or heavy, are already clearly defined. We know very closely what we may expect from the ultimate perfection of the internal combustion engine, the resistances which are to be overcome, and the limitations of the screw propeller. The margin is not very great. For many reasons the wireless transmission of power is the only perfect and lasting solution of the problem of aerial navigation. But even then it will scarcely be possible to reach very high speeds.

In this respect many experts are mistaken. The popular belief is that because the air has only one-hundredth of the density of water, enormous velocities should be practicable. But it is not so. It should be borne in mind that the air is one hundred times more viscous than water, and because of this alone the speed of the flying machine could not be much in excess of a properly designed aqueous craft.

The aeroplane of the Langley type, such as was used by Farman and others with some success, will hardly ever prove a practical aerial machine, because no provision is made for maintaining it in the air in a downward current. This and the perfect balance independently of the navigator's control is absolutely essential to the success of the heavier-than-air machine. These two improvements I am myself endeavoring to embody in a machine of my own design. NIKOLA TESLA.

New York, June 6, 1908.

A paper presented at the 25th annual convention of the American Institute of Electrical Engineers, Atlantic City, N.J., June 29, 1908.

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WIRELESS TELEPHONY

BY R. A. FESSENDEN

Synopsis

A. Preface.
B. Brief history of the development of wireless signaling.
   1. Introduction.
   2. Period 1838–1897. Origin and development of old or damped wave-coherer method.
   3. 1898. Return to first principles and foundation, on lines antithetical to old, of new or sustained oscillation-non-microphonic receiver method.

During the course of this work, now extending over twelve years, since 1906, I have naturally incurred indebtedness on all hands. Amongst others to whom my thanks are due are: Professor Kintner for much valuable assistance in the experimental work; Mr. Brashear, for his kindness in making up a number of special pieces of optical and other apparatus for use in the work; Mr. H. W. Fisher, and to Professor Frost, for the loan of electrical apparatus. For the development of the high-frequency alternator, I have to thank Messrs. Steinmetz, Haskins, Alexanderson, Reist, Geisenhoner and Dempster, and Mr. Guy. For much valuable assistance in the construction of my transatlantic apparatus, I am obliged to Mr. Green. Especially am I indebted to the gentlemen who have acted as my assistants during the progress of the work, especially Mr. Stein and Mr. Mansbendel and Mr. Bennet, Mr. Davis, Mr. Hill, Mr. Kroeger, Mr. Boyle and Mr. Bryant, and to our shop superintendent, Mr. Williams.

In order to avoid repetition, patents covering inventions made and developed by the writer without assistance or coöperation are referred to by the patent number and date only. Where there has been co-operation on the part of an assistant the patent has been taken out and referred to under the joint names of the coöperators. All inventions made or developed by assistants are taken out and referred to by the assistant's name.

4. Fundamental differences between the old and new wireless schools.
5. Period 1898–1902.
   (a) Development and perfecting of sustained oscillation-non-microphonic receiver method.
   (b) Further development of damped wave-coherer method.
6. Period 1902–1908. General abandonment of old method and adoption of new method. Later developments.

C. Theory of wireless telephony.
D. History of development of wireless telephony.
E. Methods and apparatus.
F. Operation.
G. Possibilities.
H. How wireless development has been prevented by governmental action.
I. Considerations.
K. Appendix.

A. Preface

The discussion of the theory, practical operation, and possibilities of wireless telephony is facilitated by first briefly considering the history of the development of wireless signaling generally.

B. Brief History of the Development of Wireless Signaling

1. *Introduction.* In preparing this note it has been considered best, for the sake of accuracy, to refer to published results, such as scientific articles or theses or patent specifications. For the sake of brevity, references to work done in repetition of previously published work has as a rule been omitted. So far as possible, the expression of personal opinion has been avoided in this section of the paper, the object being to gather together in concise form the facts known in regard to the development of the art. With the exception of Munk's original paper, which could not be obtained, all references have been verified by consulting the original publications, a work of some labor, and if any omissions or mistakes have been made data for their correction will be much appreciated.

2. *Period* 1838–1897. *Origin and Development of Old or Damped Wave-coherer Method.* Joseph Henry, to whose work

the development of wire telegraphy owes so much, was the first (1838-1842) to produce high frequency electrical oscillations, and to point out and experimentally demonstrate the fact that the discharge of a condenser is under certain conditions oscillatory, or, as he puts it, consists "of a principal discharge in one direction and then several reflex actions backward and forward, each more feeble than the preceding until equilibrium is attained".[1]

This view was also later adopted by Helmholz[2] but the mathematical demonstration of the fact was first given by Lord Kelvin in his paper on "Transient Electric Currents".[3]

In 1870 Van Bezold discovered and experimentally demonstrated the fact that the advancing and reflected oscillations produced in conductors by a condenser discharge gave rise to interference phenomena.[4]

Professors Elihu Thomson and E. J. Houston in 1876 made a number of experiments and observations on high frequency oscillatory discharges.[5]

In 1883 Professor Fitzgerald suggested at a British Association meeting[6] that electromagnetic waves could be generated by the discharge of a condenser, but the suggestion was not followed up, possibly because no means was known for detecting the waves.

Hertz[7] discovered a method of detecting such waves by means of a minute spark-gap and before March 30, 1888, had concluded his remarkable series of researches in which for the first time electromagnetic waves were actually produced by a spark-gap and radiating conductor and received and detected at a distance by a tuned receiving circuit.

Hertz changed the frequency of his radiated waves by altering the inductance or capacity of his radiating conductor or antenna, and reflected and focused the electromagnetic waves, thus demonstrating the correctness of Maxwell's electromagnetic theory of light.

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1. Scientific Writings of Joseph Henry, Smithsonian Institution.
2. Helmholz "Erhaltung der Kraft", Berlin, 1847.
3. Kelvin, *Philosophical Magazine*, June, 1853.
4. Van Bezold, *Poggendorff's Annalen*, 140, p. 541.
5. *Journal Franklin Institute*, April 1876.
6. Fitzgerald "On a method of producing Electromagnetic Disturbances of comparatively short wave lengths". *Report of British Association*, 1883.
7. Hertz "Electric Waves".

Lodge later in the same year read a paper on the " Protection of Buildings from Lightning "[1], before the Society of Arts, in which he described a number of interesting experiments on oscillatory discharges.

Great interest was excited by the experiments of Hertz, primarily on account of their immense scientific importance. It was not long, however, before several eminent scientists perceived that the property possessed by the Hertz waves of passing through fog and material obstacles made them particularly suitable for use for electric signaling.

Professor Elihu Thomson in a lecture delivered at Lynn, Mass., on " Alternating Currents and Electric Waves ", in 1889, suggested this use.

Sir William Crookes in the *Fortnightly Review* for February, 1892, discussed the matter in some detail. I quote his statement in full as it shows what a clear conception he had of the possibilities and obstacles to be overcome:

> Here is unfolded to us a new and astonishing world, one which it is hard to conceive should contain no possibilities of transmitting and receiving intelligence.
>
> Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog. But the electrical vibrations of a yard or more in wave length of which I have spoken will easily pierce such medium, which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfilment. At the present time experimentalists are able to generate electrical waves of any desired wave-length from a few feet upwards, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so direct a sheaf of rays in any given direction; enormous lens-shaped masses of pitch and similar bodies have been used for this purpose. Also an experimentalist at a distance can receive some, if not all, of these rays on a properly constituted instrument, and by concerted signals messages in the Morse code can thus pass from one operator to another What, therefore, remains to be discovered is—firstly, simpler and more certain means of generating electrical rays of any desired wave-length, from the shortest, say of a few feet in length, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers, which will respond to wave-lengths between certain defined limits and be silent to all others; thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver

1. Lodge *Society* of *Arts*, 1888.

> (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space in all directions, and fading away according to the law of inverse squares.
>
> I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw or altering the length of a wire, so as to become receptive of wave-lengths of any preconcerted length. Thus, when adjusted to 50 yards, the transmitter might emit, and the receiver respond to, rays varying between 45 to 55 yards, and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for curiosity the most inveterate would surely recoil from the task of passing in review all the millions of possible wave-lengths on the remote chance of ultimately hitting on the particular wave-length employed by his friends whose correspondence he wished to tap. By " coding " the message even this remote chance of surreptitious straying could be obviated.
>
> This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. Even now, indeed, telegraphing without wires is possible within a restricted radius of a few hundred yards, and some years ago I assisted at experiments where messages were transmitted from one part of a house to another without an intervening wire by almost the identical means here described.

The statement in the last paragraph of the quotation refers to the work of Professor David E. Hughes.[1]

Professor Dolbear also suggested the same thing in an article in Donahoe's Magazine, March, 1893.

In fact the idea of using Hertzian waves for wireless telegraphy seems to have been quite widespread in the years immediately following Hertz's publications.

Fairly efficient means of generating electromagnetic waves of any desired length had been made known by Hertz. Vertical antennas connected with the ground had been previously used for sending and receiving by Dolbear in 1882 in connection with his system for telegraphing by electrostatic induction[2] and also later by Edison and others.

Hertz's receiver, the minute spark-gap, was not suited for wireless telegraphy and before any telegraphic work could be done a suitable receiver had to be found.

1. For Report of this work see *Electrician*, May 5, 1899.
2. Dolbear U. S. patent 350,299, March 24, 1882.

The fact that tubes containing conducting powders had their resistance altered by the discharge of a Leyden jar and that the original resistance could be restored by tapping the tube was first noted by Munk in 1835.[1]

In 1890 Branly showed that such a tube would respond to sparks produced at a distance from it.[2]

In 1892, at the meeting of the British Association at Edinburgh, Professor George Forbes suggested that such a tube would respond to Hertzian waves.

In 1893 Professor Minchen demonstrated experimentally that such powders would respond to electromagnetic waves generated at a distance.[3] He used a battery and galvanometer shunted around the powder to detect the effect of the waves.

Sir Oliver J. Lodge on June 1, 1894, delivered a lecture before the Royal Institution.[4] In this remarkable lecture Lodge described among other things the following:

1. The filings coherer.
2. The filings coherer in hydrogen under reduced pressure (this in a note added July, 1894).
3. The automatic tapper back for the coherer.
4. The metallic reflector for focusing the waves.
5. The connection of the coherer to a grounded conductor; *i.e.*, a gas pipe system.
6. The method of making the coherer so connected respond by setting up oscillations in a separate grounded system, *i.e.*, a hot-water pipe system, in another part of the building.
7. The method of detecting distant thunder storms by connecting the coherer to a grounded gas pipe system.

In this lecture Professor Lodge stated that in his estimate the apparatus used would respond to signals at a distance of half a mile.

Early in 1895 Professor Popoff[5] of Cronstadt, Russia, constructed a very sensitive filings coherer, one form of which was used in some surveying experiments by the Russian govern-

1. See Guthe "Coherer action" *Transactions of the International Electrical Congress*, St. Louis, 1904, page 242. *Munck. Poggendorff Ann.* 1838, *Vol.* 43, *p.* 193.
2. Branley, *Comtes Rendues*, 1890, page 785, and 1891, page 90.
3. Minchen, *Proceedings Physical Society*, London 1893, page 455.
4. Sir O. J. Lodge, "The Work of Hertz", *Proceedings Royal Institution*, June 1, 1904, Vol. 14, page 321.
5. *Journal Russian Physico-Chemical Society*, Vol.27. April 25,1895,

ment,[1] consisting of iron filings suspended by a magnet and resting upon a metallic plate or cup. Other forms consisted of filings in glass tubes with platinum electrodes. He used early in 1895, the automatic tapping back mechanism, and substituted for the galvanometer an ordinary telegraphic relay. He operated this apparatus at a distance by means of a large Hertzian radiator. One terminal of his coherer was connected to a conductor fastened to a mast about 30 ft. high on the top of the Institute building and the other terminal of the coherer was grounded.

At the conclusion of his paper, which is dated December, 1895, Popoff made the following statement "In conclusion I can express the hope that my apparatus, with further improvements of same, may be adapted to the transmission of signals at a distance by the aid of quick electric vibrations, as soon as the source of such vibrations, possessing sufficient energy, will be found."

Among other experimenters who were working on this subject at the same time may be mentioned Captain Jackson of the British Navy, and Mr. A. C. Brown.

Marconi, on June 2, 1896, filed a provisional specification[2] showing two forms of apparatus, one similar to Lodge's 1894 apparatus using ungrounded aerials for both sending and receiving and the other for use "when transmitting through the earth or water" substantially identical with Lodge's 1894 and Popoff's 1895 apparatus, with tapper back etc., and the receiving antenna only being grounded.

Soon after, in July 1896, Marconi arrived in England and made a number of experiments for the English Post Office at Salisbury Plain and elsewhere, using ungrounded aerials and parabolic reflectors and succeeded in reaching nearly two miles.

On March 2, 1897, Marconi filed the complete specification in which was included a statement that the transmitting antenna also could be grounded.

Lodge filed a provisional specification[3] showing radiating spheres but no antenna on May 10, 1897. The complete specification filed on Feb. 5, 1898, shows as one form both antennæ

1. A. S. Popoff, "Apparatus for detection and registration of electrical vibrations", *Journal Russian Physico-Chemical Society*, Vol. 28, Dec. 1895.
2. Marconi, Great Britain patent, 12,039, 1896.
3. Lodge, Great Britain, patent, 11,575, 1897.

grounded and also the use of an inductance wound in the form of a coil for the purpose of diminishing the rate of damping of the waves.

So far as is known little work was done in America during this period. The writer made some experiments in 1896 and in conjunction with two of his students, Messrs. Bennett and Bradshaw, did considerable work on receivers of various type in the fall of 1896 and spring of 1897, the results of which were incorporated in a thesis.[1]

3. 1898. *Return to First Principles and Foundation, on lines Antithetical to Old, of New or Sustained Oscillation non-microphonic Receiver Method.* Up to the year 1898, as may be seen from the above, the development of wireless telegraphy had proceeded along a single line. In that year, however, an entirely new method of wireless telegraphy was developed, characterized by a return to first principles, the abandonment of the previously used methods and by the introduction of methods in almost every respect their exact antitheses.

While the coherer is of more or less interest theoretically it is not adapted for use for telegraphic purposes. Responding as it does to voltage rises above a certain limit it does not discriminate between impulses of different characters, and is therefore peculiarly susceptible to interfering signals and atmospheric disturbances, and the operation of coherer systems cannot be guaranteed during the summer months or in the tropics. Roughly speaking a coherer acts by starting an arc and making a short-circuit on the line every time a signal is received, which short-circuit persists until it is broken by a blow from an additional mechanism, and such a method of operation is obviously far from practical. In addition it is practically impossible to obtain sharp tuning in a local circuit containing a coherer; its action is always more or less erratic, its electrostatic capacity variable, and it is insensitive.

At the sending end the energy which can be liberated by the discharge of an antenna is limited and in the form used prior to 1897 the dampening is so great that there are only a few oscillations per spark.

Lodge[2] by placing a coil of large inductance in the antenna throttled down the amount of energy radiated per oscillation and so obtained with the same limited amount of energy derived from the charged antenna, an increase in the time of damping.

1. Western University of Pennsylvania, May, 1897.
2. Lodge, Great Britian, patent 11,575, 1897.

Braun[1] patented the method of using a local oscillatory circuit connected to an antenna, the local oscillatory circuit having a much longer period than the natural period of the antenna and of a different order of magnitude. Such a system, however, does not radiate energy appreciably, and produces a damped wave.

This dampening and the limited amount of energy obtainable by charging and discharging the antenna operates to prevent sharp tuning and working over long distances.

The coherer is well adapted for working with damped waves, but the coherer-damped wave method can never be developed into a practical telegraph system. It is a question whether the invention of the coherer has not been on the whole a misfortune as tending to lead the development of the art astray into impracticable and futile lines and thereby retarding the development of a really practical system.

The fact that no coherer-damped wave system could ever be developed into a practically operative telegraph system, and the fact that it was necessary to return to first principles and initiate a new line of development along engineering rather than laboratory lines was perceived in America in 1898[2] and a new method was advised which may be called the Sustained Oscillation-non-microphonic Receiver method as opposed to the Damped Oscillation-coherer method previously used.

4. *Fundamental Differences between the Old and New Wireless Schools.* The differences between the two methods are shown in tabulated form:

	Damped Oscillation-coherer Method		Sustained Oscillation-non-microphonic Method.
A1:	Damped oscillations are produced at the sending end.	A1:	Sustained oscillations are produced at the sending end.
2:	The energy transmitted is obtained by charging the antenna and discharging it.	2:	The energy transmitted is derived from a local source and fed into the antenna.
3:	A spark gap is used for producing the oscillations.	3:	An arc or high frequency dynamo is generally used for producing the oscillations.

1. Braun, German patent 11,578, Oct. 14, 1898.
2. *Electrical World*, July 29, Aug. 12, Sept. 16, 1899 and *Proceedings American Institute of Electrical Engineers*, Nov. 1899, p. 635 and Nov. 20, 1906, p. 781.

B1:	Imperfect or microphonic contact receivers are used.	B1: Non-microphonic contact receivers are used.
2:	The action of the receiver depends upon the voltage rise and is independent of the amount of energy received.	2: The receiver response is determined by the integral amount of energy received.
3:	An open tuned circuit is used for receiving.	3: A closed tuned circuit is used for receiving.
4:	The receiving circuit is tuned to the wave frequency only.	4: The receiving circuit may be tuned to a group frequency as well as to the wave frequency.
C1:	In transmitting messages the production of the electromagnetic waves is intermittent.	C1: The waves are preferably generated continuously and the transmission accomplished by changing the character of the wave.
2:	The wave energy flux is intermittent.	2: The wave energy flux is constant.
3:	A high voltage is used.	3: A low voltage is used.
4:	Comparatively short wave lengths are used.	4: Comparatively long wave lengths are used.
5:	The signals consist of dots and dashes, whose interpretation is fixed.	5: The signals may consist of dots only, whose interpretation depends on the station sending and receiving.
D1:	Antennæ are used adapted, roughly speaking, to utilize the electrostatic component of the electromagnetic waves.	D1: The antennæ are preferably arranged so as to utilize the other component of the electromagnetic waves instead of the electrostatic component.

The history of these two antithetical lines of development will be treated of separately.

5. *Period* 1898–1902 A. *Development and Perfecting of Sustained Oscillation-non-microphonic Receiver Method* (a) *The current-operated receiver.* The first essential for the development of the system was, of course, a quantitatively responsive receiver. Several forms of this were tried including the modification of the Boys' radio-micrometer (consisting of a light thermo couple suspended in the field of a permanent magnet

and heated by radiation from a wire which in turn was heated by the current to be detected) described by the writer at the Columbus meeting of the American Association in 1897.[1] This was abandoned in favor of Professor Elihu Thomson's alternating-current galvanometer[2] suitably modified for telegraphic work.[3]

Among other forms of current-operated receiver may be mentioned the following.

The *Hot-wire Barretter*,[4] consisting of a minute platinum wire a few hundred thousandths of an inch in diameter and approximately a hundredth of an inch in length. The term " barretter " was coined for this device for the reason that it differs essentially from the bolometer of Langley in that it is arranged to be affected by external sources of radiant heat as little as possible instead of as much as possible, and, to have an extremely small specific heat, an object not sought in the case of the bolometer.

The *Liquid Barretter*[5] in which the change of resistance is effected by heating a liquid, the concentration of path being obtained by means of a fine platinum wire point. Some question has been raised as to the theory of operation of this device but I think there is no question but that the effect is due to heat, though what per cent. of the effect is due to change in ohmic conductivity by heat and what per cent. is due to depolarization by heat is still, as originally stated by the writer,[6] uncertain. The facts that the device operates practically equally well irrespective of which terminal is connected to the local battery, and that the effect varies as the square of the alternating current (as a heat operated device should do) instead of directly with the alternating current as a rectifier would do, and that depolarization is produced by the heat, have been confirmed by Dr. L. W. Austin.[7] The writer has experimentally determined the fact that though the electrical impulses may have a duration of less than a millionth part of a second the change in resistance persists for approximately the ten thousandth part of a second, which would seem to show conclusively that the action is not a *direct* effect of the waves.

1. *Electrician*, June 24, 1904.
2. Elihu Thomson, U. S. patent 363,185, Jan. 26, 1887.
3. U. S. patents 706,736 and 706,737, Dec. 15, 1899.
4. U. S. patent 706,744, June 6, 1902.
5. U. S. patent 727,331, April 9, 1903.
6. *Ibid.*
7. Austin, *Bulletin of the Bureau of Standards*, Vol. 2 No. 2.

The term electrolytic receiver has sometimes been applied to the liquid barretter. This is objectionable, as there are a number of electrolytic receivers. For example, the Neughschwender-Schaefer[1] receiver, in which a number of microscopic filaments are produced between two terminals by electrolysis, which filaments are ruptured by the wave produced oscillations, thus increasing the resistance; also the liquid coherer of Captain Ferrie, described by him as follows:[2]

> The same effect of self-decohering coherence has been determined for a contact of a metallic wire and a liquid conductor, acidulated water, contained in a glass tube of small diameter, and placed under the same conditions as the preceding. Always, the sensitiveness of this contact is very notably inferior to that obtained in the experiments disclosed above. The maximum sensitiveness was obtained when the resistance of the imperfect contact was about 2000 ohms and when the extremity of the metal wire scarcely grazed the meniscus of the liquid. The results obtained were better with a copper wire, attacked by the acidulated water, than with a platinum wire.

which probably acts through a chemical effect producing a thin film of gas and has never come into use, doubtless because, as Captain Ferrie points out, it is even less sensitive than the Marconi coherer. Also the rectifier of Pupin[3] in which the terminals are placed so closely together that practically no energy is absorbed in the receiver, in order that the rectified energy may be utilized outside in the external circuit, in opposition to the liquid barretter, where the position of the terminals is such that all the received wave energy is absorbed in the barretter for the purpose of producing a secondary effect, and so influencing the current in a shunted local circuit.

(b) *Methods of Obtaining Sustained Oscillations.* 1. *Spark-gap and Local Oscillatory or "tank" Circuit.* Professor Elihu Thomson discovered that by using a transformer without an iron core (the well known Elihu Thomson air-core transformer, later used by Tesla and others), and a spark-gap and condenser in the primary circuit and with the secondary circuit suitably tuned great resonant rises of potential could be obtained. In 1892 he constructed such a transformer giving discharges 64 inches long.[4]

The same method was later used by Tesla[5] in his experimental

1. Neughschwender German Patent 107843, Dec. 13, 1898, and Schaefer British Patent 6002, 1899.
2. Blondel, *L'Eclairage Electrique*, Sept. 29, 1900.
3. Pupin, U. S. Patent 713,044, January 4, 1898.
4. *Electrical World*, Feb. 20 and 27, 1892.
5. U. S. patent 645,516, Sept. 2, 1897.

researches and in his attempt to carry out Loomis'[1] method of transmitting a current through a hypothetical conducting stratum in the upper regions of the atmosphere.

The device, suitably modified for wireless telegraphic purposes, so as to give instead of a continuously cumulative rise of potential an initial rise of potential followed by a gradual feeding in of the energy from the local circuit to supply the energy lost from radiation, was made use of in 1898 for the purpose of producing prolonged trains of sustained waves.

Various types of connection between the antenna and the local oscillatory circuit were tested but it was found that the most efficient results were obtained by connecting the local circuit directly across the spark-gap.[2]

The results of some comparative tests are here given. The figures in the column "A" are for the local circuit connected directly to the terminals of the spark-gap, those in column "B" are for an auto-transformer, those in column "C" for a loose coupled primary and secondary.

	A	B	C
Frequency	212,000	212,000	212,000
Tank capacity	0.072 m.f.	0.072 m.f.	0.072 m.f.
Kilowatt output dynamo	30	30	30
Tank current	400 amperes	370 amperes	300 amperes
Antenna current	48.5	46.	48.

The large station at Brant Rock is operated with the local circuit directly connected across the spark-gap, partly because the efficiency is somewhat greater, but also on account of the great simplification of connections and the fact that the degree of sustainment of the wave train may be adjusted very simply, if desired, by sliding the lower terminal of the antenna along a few inches of the lead of the local oscillatory circuit.

Cooper Hewitt[3] in 1902 used a modification of his mercury lamp to obtain intermittent discharges each followed by a train of high frequency oscillations.

2. *Arc methods.* The worker with high frequency oscillatory currents will soon discover that we are indebted to the genius of Professor Elihu Thomson for practically every device of any importance in this art.

1. Loomis, U. S. patent, 129,971, July 30, 1872.
2. U. S. patents 706,735 and 706,736, Dec. 15, 1899.
3. Cooper Hewitt, U. S. patent 780,999, April 25, 1902.

The method of producing high frequency oscillations from an arc and continuous current was discovered by him in 1892.[1] Fig. 1, taken from his patent, shows the general form of his arrangement. If the directions given in the specification are followed no difficulty will be met with in obtaining frequencies as high as 50,000 per second.

Between 1900 and 1902 some experiments were carried out with the Elihu Thomson arc as a source of high frequency oscillations for wireless telegraphy and telephony.

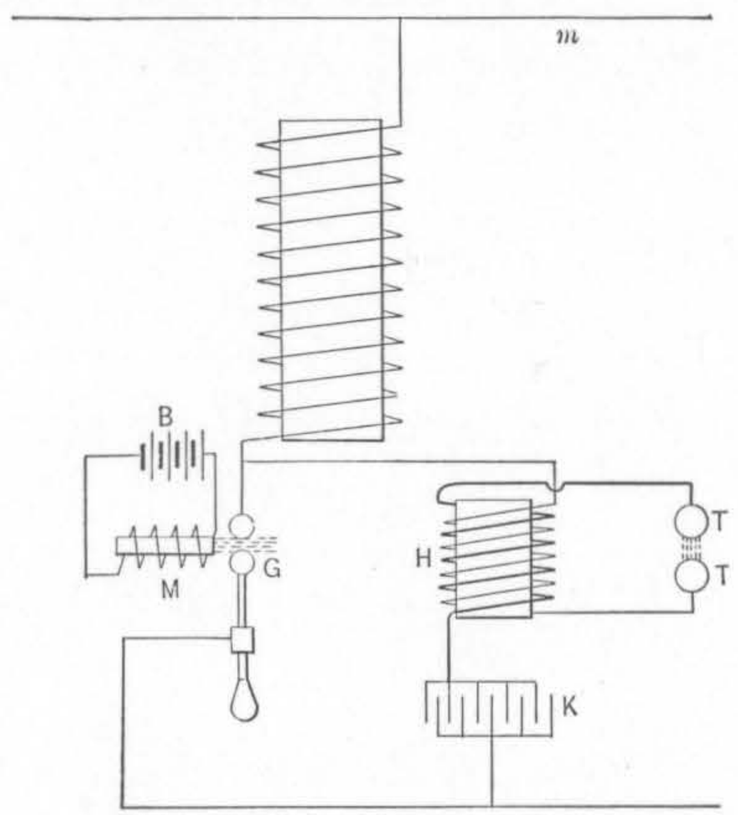


Fig.1

Some difficulties were found, for example the arc could not be started and stopped as quickly as was necessary for telegraphic purposes and the intensity of the oscillations and their frequency varied considerably. These were overcome by making some minor improvements, for example the difficulty in sending was overcome by permitting the arc to run continuously and using the key to change the electrical constants of the circuits.[2] The difficulty in keeping the intensity and frequency constant was

1. Elihu Thomson U. S. patent 500,630, July 18, 1892.

2. U. S. patents 706,742, July 6, 1902, 706,747, Sept. 28, 1901, 727,330, March 21, 1903, 730,753, April 9, 1903.

overcome by substituting resistance for a portion of the inductance, and also by using the arc under pressure.[1]

Tests made by Dr. Austin[2] show that with this method frequencies as high as 3,000,000 per second and efficiencies as high as 60% can be obtained together with an absolutely steady[3] generation of the high frequency currents and an absence of harmonic frequencies.

3. *High frequency alternator.* The first high frequency alternator was built by Professor Elihu Thomson in 1889. And it[4] was while experimenting with it in 1900 that Dr. Tatum made his very interesting discovery that high frequency currents of large amperage could be passed through the body without injury.[5]

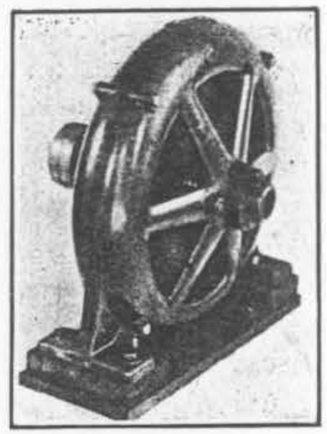


Fig. 2

From 1898 to 1900 numerous experiments were made on antennæ of large capacity and it was found that instead of using sheets of solid metal or wire netting, single wires could be placed at a considerable fraction of the wave-length apart and yet give practically the same capacity effect as if the space between them were filled with solid conductors.

From other investigations on the variation of radiation with

1. *Ibid* and U. S. patent 706,741.

2. Austin, *Bulletin of the Bureau of Standards*, Vol. 3, No. 2.

3. Austin assumed from the figure he obtained for the dampening, that the oscillations were not continuous; but the method used for determining the dampening is not applicable to this case, and a comparison of the currents and voltages with the frequencies given in Austin's experiments, shows that these oscillations must have been continuous.

4. Thomson, *Elec.Engineer*, July 30,1890 and *London Elec.*,Sept.12,1890.

5. Thomson, *Elec. Engineer*, March 11, 1891.

frequency the result was arrived at that it should be possible to construct an alternating-current dynamo of sufficiently high frequency and output to give ample radiation for wireless telegraphic purposes.[1]

In 1900 a large American electrical manufacturing company kindly consented to take up the construction of such a dynamo. As a preliminary, a dynamo of 1 kw. output and 10,000 cycles (shown in Fig. 2) was built in 1902. By the summer of 1906 many of the difficulties had been overcome and a machine giving 50,000 cycles was installed at the Brant Rock station. Various improvements were made by the writer's assistants, and in the fall of 1906 the dynamo was working regularly at 75,000 cycles, with an output of half a kilowatt and was being used for telephoning to Plymouth, a distance of approximately 11 miles. In the following year machines were constructed having a frequency of 100,000 cycles per second and outputs of 1 and 2 kilowatts.

The credit for the development of this machine is due to Messrs. Steinmetz, Haskins, Alexanderson, Dempster, and Geisenhoner and also to the writer's assistants, Messrs. Stein and Mansbendel.

(*c*) *Closed tuned circuits.* In 1898 the open tuned circuits originally used were discarded for closed tuned circuits[2] and it was discovered that valuable selective effects could be obtained by placing the condenser in shunt to the inductance instead of in series with it.[3]

(*d*) *Combination of wave and group tuning.* The fact that if selectivity is obtained solely by tuning to wave frequencies, the number of stations is limited, was appreciated at an early date. In 1900[4] a new method was developed, the stations being tuned both to the wave frequency and to an independent or group frequency, so that stations might obtain selectivity by varying either the wave or the group frequency and thus have at their disposal a virtually unlimited number of combinations and be practically free from atmospheric disturbances. Fig. 3 shows a type of group tuner.

(*b*) *Further development of damped wave-coherer method.* Marconi by 1898 had carried the development of the filings coherer to its maximum point.

1. U. S. patent 706,737, May 29, 1901.
2. U. S. patents 706,735 and 706,736, Dec. 15, 1899.
3. *Ibid.*
4. U. S. patents 727,325, June 2, 1900, and 727,330 March 21, 1903.

Lodge in 1897[1] had disclosed the open secondary circuit for receiving.

Marconi in 1898[2] greatly improved this by adjusting the length of the secondary so as to tune it, and by the aid of this improvement was enabled to telegraph a distance of 35 miles[3] in October, 1899.

Lodge in 1902[4] invented what is perhaps the most perfect form of coherer, consisting of a thin steel disc dipping in oil

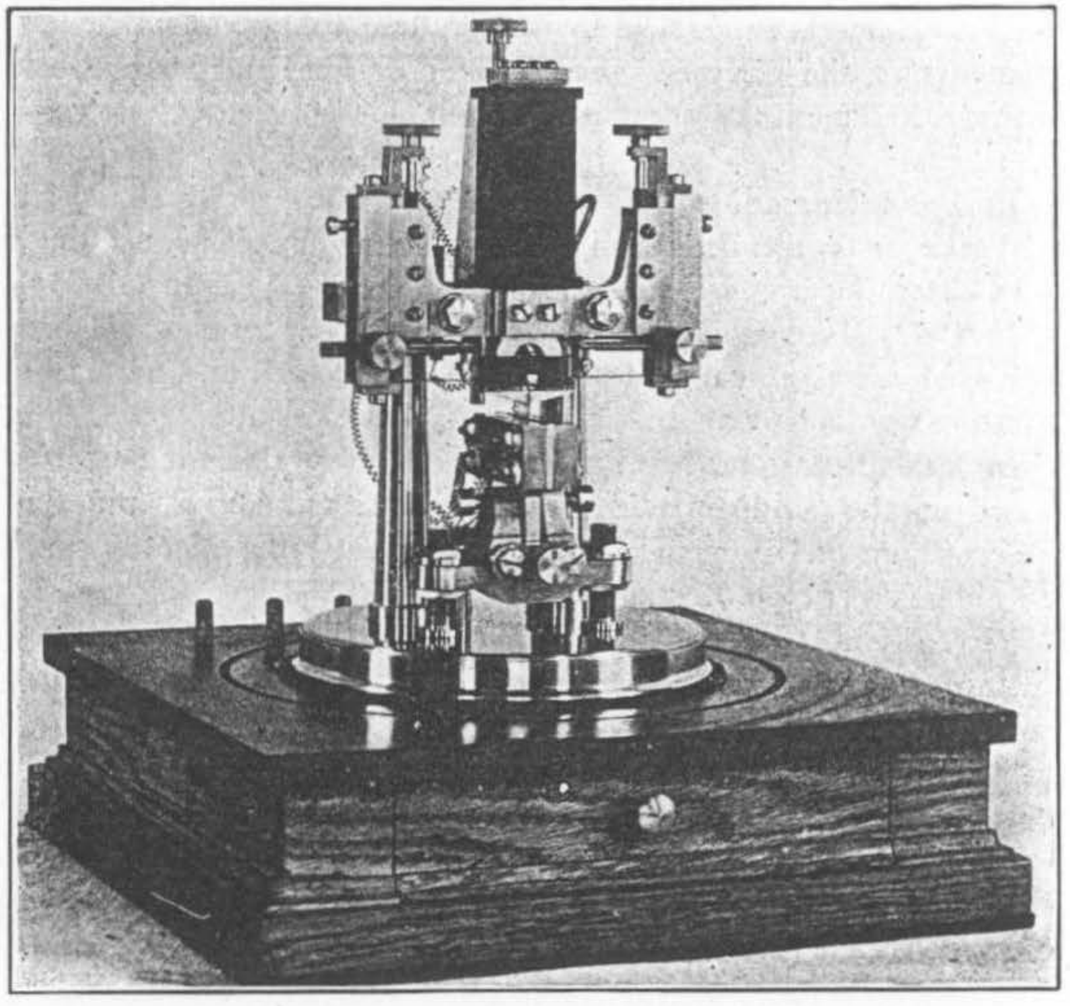


FIG. 3.

covered mercury and automatically decohered by being kept in continuous rotation.

A number of self-restoring coherers of which the Brown[5]

1. Lodge, Great Britain patent, 11,575, May 10, 1897.
2. Marconi, Great Britain patent, 12,326, June 1, 1898.
3. Official report U. S. Navy of test U. S. S. Massachusetts, Oct. 1899.
4. Lodge, Muirhead and Robinson, Great Britain patent, 13,521, June 14, 1902.
5. Brown and Neilson, Great Britain patent, 28,955, Dec. 17, 1896.

carbon coherer may be taken as a type, including the mercury carbon coherer of Solari, came into more or less extended use, and also modifications of the imperfect contact receiver of Neugschwender.[1]

The small progress made along these lines is to be explained by the fact that the damped wave-coherer system is essentially and fundamentally incapable of development into a practical system.

Period 1902-1908—*Later Developments.* Progress in Europe since 1902 has been marked by the gradual abandonment of the elements of the damped wave-coherer system and the substitution of elements of the sustained wave non-microphonic contact type.

In 1900[2] Marconi substituted for the plain aerial an aerial with the writer's tuned local circuit or tank circuit for sending, thus obtaining a considerable increase in range of transmission.

In 1902, Marconi invented a very ingenious form of current operated receiver, called the magnetic detector[3], and with this combination achieved some very remarkable results.

In 1905 Professor Fleming[4] invented a very efficient detector based on the " Edison effect " in incandescent lamps, and the observations of Elster and Geitel[5] on the rectifying effect of such an arrangement on Hertzian oscillations.

Virtually nothing was done in Europe in the way of producing sustained oscillations by the arc or high frequency method until recently, possibly because of Duddell's erroneous statement[6] to the effect that frequencies much above 10,000 could not be obtained by the Elihu Thomson arc method, and Fleming's statement[7] that an abrupt impulse was necessary and that high frequency currents, even if of sufficient frequency, could not produce radiation.

In 1903 Poulsen[8] invented an interesting modification of the Elihu Thomson arc, which consists in forming the arc in hydro-

1. A. Neugschwender, *Wied. Ann. der Physik*, 1899, vol. 67, p. 430. Schafer, British patent, 6,002, 1899.
2. Marconi, Great Britain, patent, 7,777, Apr. 26, 1900.
3. Marconi, Great Britain, patent, 10,245, 1902.
4. Fleming, *Proceedings Royal Society London*, 1905, Vol. 74.
5. Elster and Geitel, *Wied. Ann der Physic*, Vol. 52, page 433.
6. Duddell, *The Electrician*, 1903, Vol. LI, page 902.
7. Fleming, *Proceedings of the International Congress, St. Louis*, 1904, Vol. 3, page 603.
8. Poulsen U. S. patent 789,449, June 19, 1903.

gen instead of in air or compressed gas as previously done. This modification is not, however, so efficient as the older methods and gives oscillations varying in amplitude and intensity and accompanied by strong harmonics,[1] but I have considered it worth mentioning on account of the amount of interest it appears to have excited in Europe.

Some very important and interesting papers on electrical oscillations were published during these years by Oberbeck,[2] Wien,[3] Drude,[4] and Bjerknes.[5]

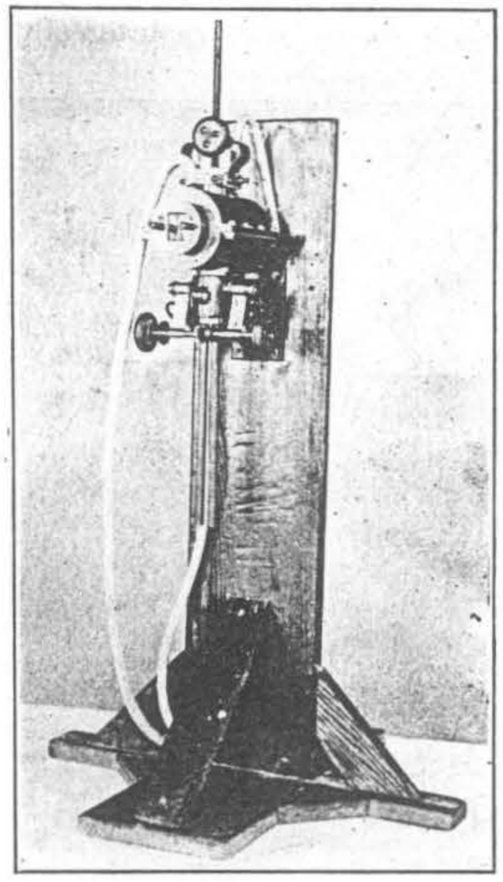


FIG. 4.

In America the development of the sustained oscillation non-microphonic system has proceeded steadily and it may now be said to have reached the stage of commercial practicability. On account of the amount of work which has been done it is impossible to refer to more than a few of the recent advances.

1. Austin, *Bulletin of the Bureau of Standards*, Vol. 3 No. 2.
2. Oberbeck Wied. *Ann. der Physik*, Vol. 55, 1895.
3. *Wied Ann. der Physik* Vol. 8, 1902.
4. Drude *Ann. der Physik*, Vol. 13, 1904.
5. Bjerknes, *Ann. der Physik*, Vol. 44, 1891, and Vol. 47, 1892.

The following are some of the later types of detectors:

The *frictional receiver*,[1] in which the waves produce a change of friction between two moving surfaces and so cause an indication.

The *heterodyne receiver*,[2] in which a local field of force actuated by a continuous source of high frequency oscillations interacts with a field produced by the received oscillations and creates beats of an audible frequency.

The so called *thermoelectric receivers* of Austin,[3] Pickard[4] and Dunwoody.[5]

The "*audion*" *of deForest*,[6] a very interesting and sensitive

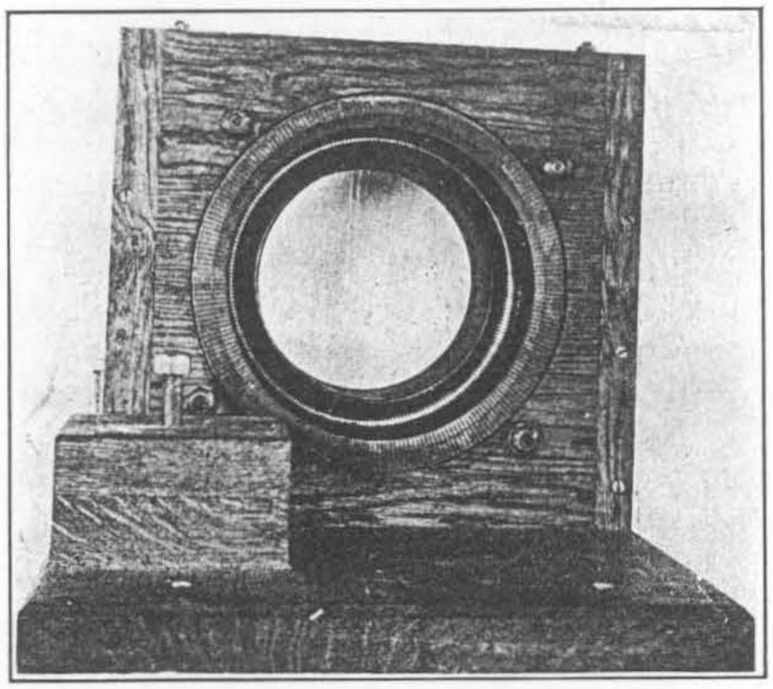


FIG. 5.

device, which though superficially resembling Professor Fleming's rectifier appears to act on an entirely different principle.

The *Cooper Hewitt mercury receiver*, about which little is kno but which appears to be very sensitive.

The following are some of the later methods of producing s tained oscillations:

1. U. S. application, 251,538, March 22, 1905.
2. U. S. application, 271,539, June 28, 1905.
3. Austin, U. S. application, 319,241, May 29, 1906.
4. Pickard, U. S. application, 342,465, Nov. 8, 1906.
5. Dunwoody, patent, 837,616, March 23, 1906.
6. deForest, U. S. patent, 836,070, Jan. 18, 1906.

The *substitution of a number of arcs in series having terminals of large heat capacity* in place of the single arc in the arc method.[1]

The *use of regulating or "fly-wheel" circuits* in connection with the arc method.[2]

The *method of producing oscillations* shown in Fig. 4 by using two arcs and throwing the discharge from one side to the other alternately at a frequency regulated by the constants of the electric circuit.[3]

The *condenser dynamo*[4] which consists of two radially slotted discs separated by a mica diaphragm, charged by a continuous current source of potential, and rotating in opposite directions.

Two-phase high frequency dynamo method.[5]

Commutator method.[6] In this method the high frequency is produced by means of a ball rotating at high speed on the interior surface of a commutator. Shown in Fig. 5.

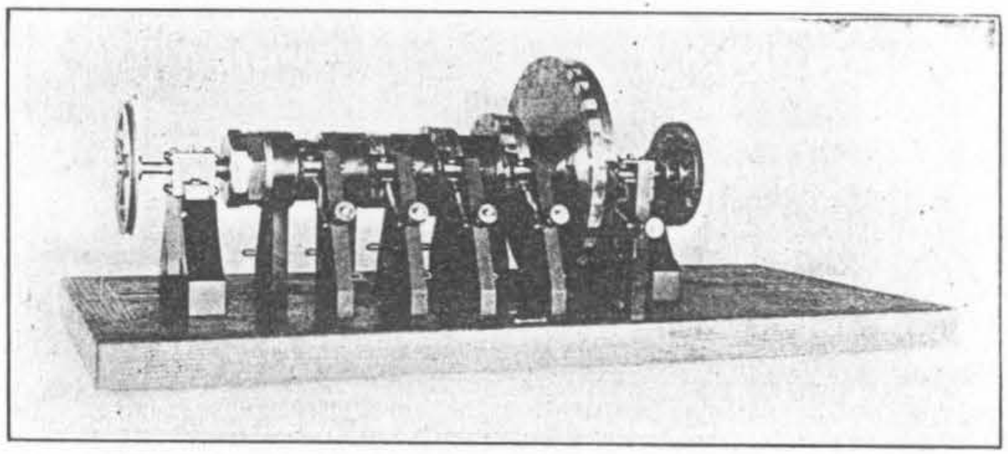


FIG. 6.

The *helium arc method*[7] in which the arc is produced in helium or argon or similar gases.

The *critical pressure method*[8] in which the electrodes extend within a certain critical distance, depending upon the pressure used, so that the discharge always passes at the same voltage irrespective of the distance between the electrodes.

1. U. S. application, 291,737, Dec. 14, 1905.
2. *Ibid.*
3. *Ibid.*
4. U. S. application, 291,739, Dec. 14, 1905.
5. U. S. patent, 793,649, March 30, 1905.
6. U. S. application, 316,521, May 12, 1906.
7. U. S. application, 351,560, Jan. 7, 1907.
8. U. S. application, 355,787, Feb. 4, 1907.

Methods of Signaling. Continuous production of waves but changing constants of sending circuit.[1]

The *inverted method* of sending and the method of signaling by sending dots, the interpretation of which is determined by similar commutators at the sending and receiving stations.

Duplex and Multiplex Methods. A considerable number of these have been worked out, mostly operating either by balance methods[2] or commutators.[3] It is impossible to discuss all the various improvements, such for example as the method of indicating the busy and free state of a station, the methods of sending and receiving in one direction, the various types of aerials used for receiving the other components of the electromagnetic waves besides the electrostatic component, etc.

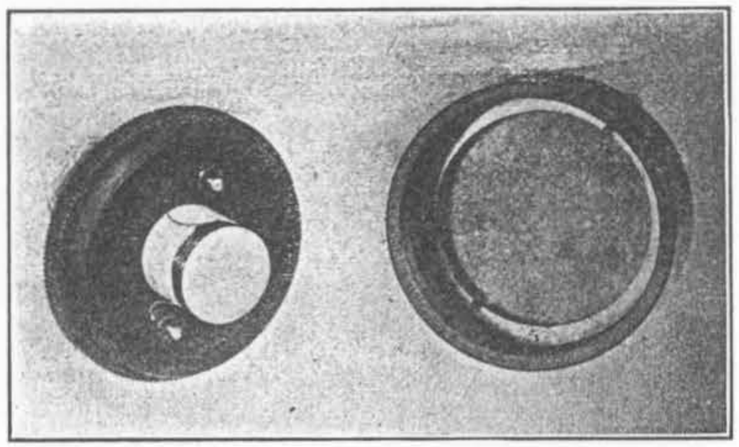


FIG. 7.

Fig. 6 shows the harmonic interrupter for determining the variation of intensity with change of note.

Fig. 7 shows a type of receiver described in U. S. Patent 706,747, in which the telephone diaphram is formed of thin copper and repelled by a fixed coil having a resistance of about 16 ohms. The principle of this receiver was discovered by Professor Elihu Thomson. It has been used for wireless telephony for a distance of 11 miles with fairly satisfactory results.

Fig. 8 shows a transformer used in the transmitting circuit. The number of primary and secondary turns can be altered continuously, and also the degree of coupling. The wire is

1. U. S. patents 706,747, Sept. 28, 1901; 706,742, June 6, 1902; 727,747, March 21, 1903.
2. U. S. application, 366,528, April 5, 1907.
3. U. S. patent, 793,652, April 6, 1905.

wound off from an insulating cylinder onto a cylinder of copper, and the cylinder of copper, forming a closed circuit secondary of the transformer, annuls the inductance of that portion of the wire wound upon the copper cylinder.

Fig. 9 shows an apparatus for determining the best shape of coil for use with the heterodyne receiver.

Fig. 10 shows a group-tuned call; that is, a vibration galvanometer which operates a selenium cell and rings a bell when a call is received.

C. THEORY OF WIRELESS TELEPHONY

For wireless telephony three things are necessary:

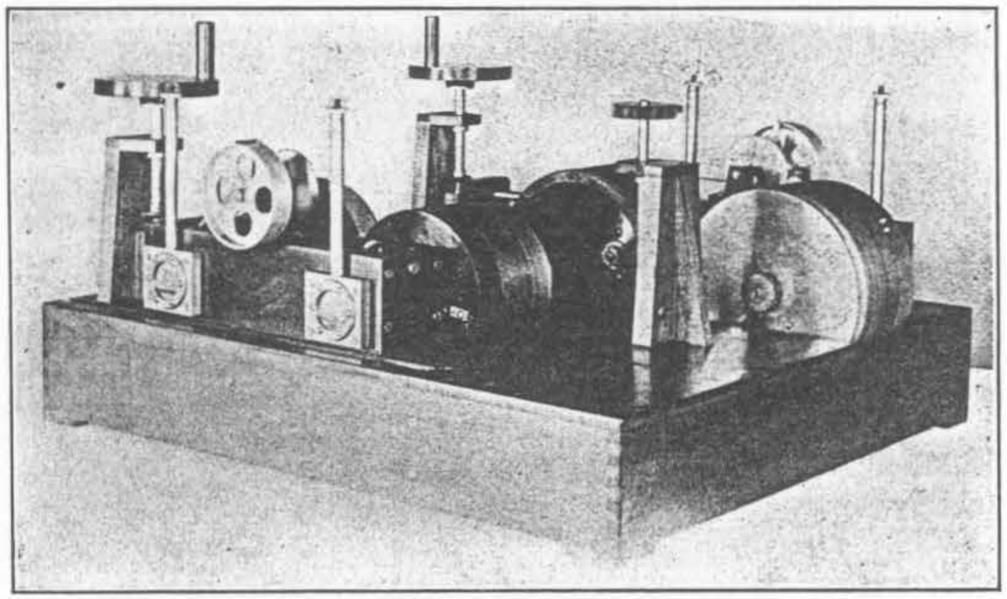


FIG. 8.

1. Means for radiating a stream of electrical waves sufficiently continuous to transmit the upper harmonics on which the quality of the talking depends.

2. Means for modulating this stream of waves in accordance with the sound waves.

3. A continuously responsive receiver giving indications proportional to the energy received, and capable of responding with sufficient rapidity to the speech harmonics.

Work on the wireless telephone was commenced before a satisfactory means was discovered for producing sustained oscillations.

To ascertain the number of sparks per second which was necessary to determine articulate speech, a phonograph cylinder

was taken and grooves were cut in it longitudinally. It was found in this way that practical transmission could be accomplished with 10,000 breaks per second. It is believed now that this number is unnecessarily high, possibly owing to the fact that it was impossible to cut the grooves on the cylinder without producing ridges. The lower limit may be fixed in another way.

Electrical circuits met with in actual working have resistance, self inductance capacity, and leakance. Heaviside gave the differential equations for the pressure and current over such circuits when alternating voltages were applied, but no method of solution being known the mathematical treatment of such

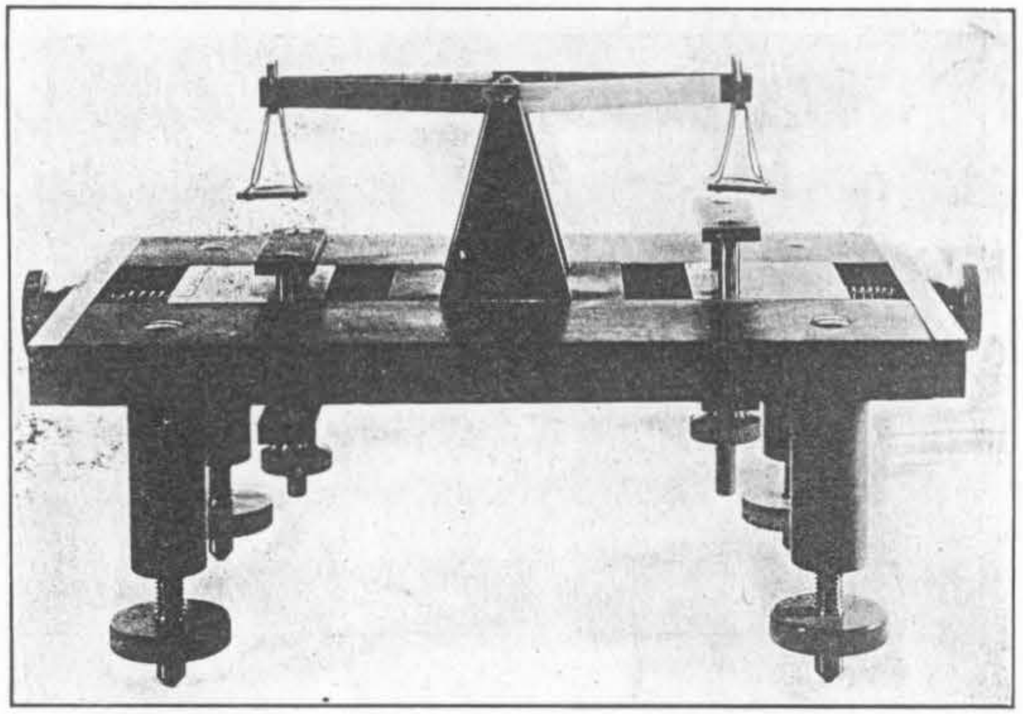


FIG. 9.

circuits was restricted to cases where one of the constants was neglected, until Dr. A. E. Kennelly in a masterly series of papers gave the complete solution.

The results were immediately found applicable to a great variety of problems, such as the transmission of signals through cables and of telephonic speech through various types of circuits.

In this way Dr. Kennelly[1] by comparing the results obtained by Dr. Hammond V. Hayes[2] in practical telephonic transmission

1. Kennelly, " Distribution of Pressure and Current over Alternating Current Circuits ", *Harvard Engineering Journal*, 1906, page 43.

2. Hayes, " Loaded Telephone Lines in Practice ", *Transactions International Electrical Congress*, St. Louis, Vol. 3.

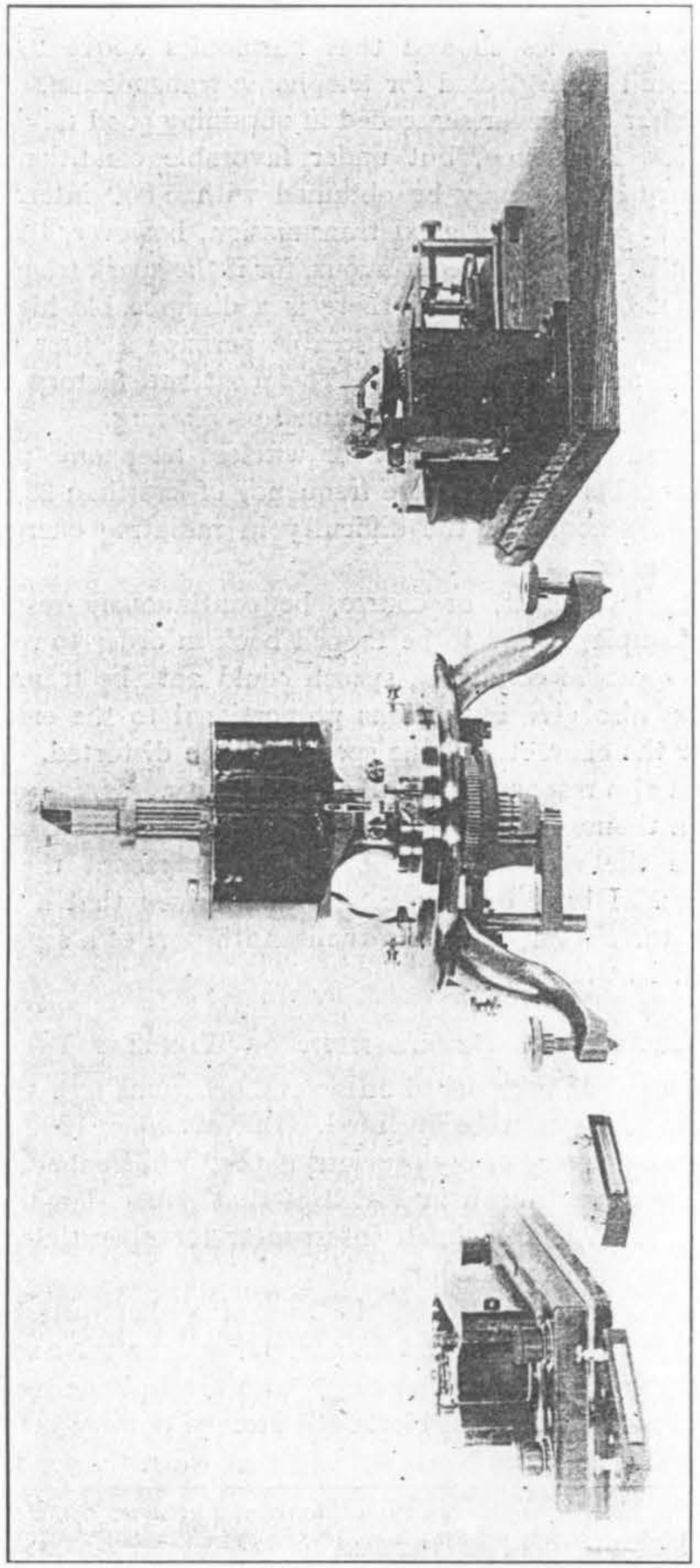


FIG. 10.

over loaded lines with the theoretical values of the current for different harmonics showed that harmonics above 2,000 per second could be neglected for telephonic transmission.

The writer has never succeeded in obtaining good talking with such a low frequency, but under favorable conditions fairly satisfactory speech may be obtained with 5,000 interruptions per second. For really good transmission, however, the radiation must be practically continuous, for if the spark frequency is less than 20,000 per second there is a disagreeable high pitch note in the telephone, not noticeable perhaps at first but apt to become annoying with use. The most satisfactory way is, of course, to use a source of sustained oscillations.

It fortunately happens that for wireless telephonic purposes it is inadvisable to use a wave frequency of less than 25,000 per second, on account of the difficulty in radiating energy with low frequencies.

The receiver must, of course, be continuously responsive. If, for example, it had to be tapped back in order to restore it to the responsive condition, speech could not be transmitted.

It must also give indications proportional to the energy received or the character of the speech will be distorted.

It must also respond with sufficient rapidity. If, for example, it takes a thousandth of a second to restore itself to its original resistance the receiver will obviously not record the higher harmonics. I have experimentally determined that a receiver which restores itself in the ten thousandth part of a second acts with sufficient rapidity.

D. History of the Development of Wireless Telephony

The writer has been asked on several occasions how the wireless telephone came to be invented. In November, 1899, shortly prior to the delivery of my previous paper,[1] while experimenting with the receiver shown in Fig. 3 of that paper, I made some experiments with a Wehnelt interrupter for operating the induction coil used for sending.

In the receiver mentioned the ring of a short-period Elihu Thomson oscillating current galvanometer rests on three supports, *i.e.*, two pivots and a carbon block, and a telephone receiver is in circuit with the carbon block. A storage battery being used in the receiver circuit[2] it was noticed that when the sending key

1. *Transactions American Institute Electrical Engineers*, Nov. 22, 1899.
2. U. S. patent, 706.736, December 15, 1899.

was kept down at the sending station for a long dash the peculiar wailing sound of the Wehnelt interrupter was reproduced with absolute fidelity in the receiving telephone. It at once suggested itself that by using a source with a frequency above audibility wireless telephony could be accomplished.

Professor Kintner, who was at that time assisting me in these experiments and to whose aid their success is very largely due, was kind enough to make the drawings for an interrupter to give 10,000 breaks per second. Mr. Brashear, the celebrated optician kindly consented to make up the apparatus and it was completed in January or February, 1900.

The experimental work was, however, delayed as the writer was at that time transferring his laboratory from Allegheny, Pa., to Rock Point, Md., and it was not until six months later that the stations at that point were completed and a suitable mast was erected for trying the apparatus.

The first experiments were made in the fall of 1900 with the above mentioned apparatus which was supposed to give 10,000 sparks per second but which probably gave less. Transmission over a distance of one mile was attained but the character of the speech was not good and it was accompanied by an extremely loud and disagreeable noise, due to the irregularity of the spark.

By the end of 1903 fairly satisfactory speech had been obtained by the arc method above referred to, but it was still accompanied by a disagreeable hissing noise. In 1904 and 1905 both the arc method and another method in which the 10,000 cycle alternator above referred to was employed, had been developed to such an extent that the apparatus could be used practically and sets were advertised and tendered to the U. S. Government.[1] The transmission was, however, still not absolutely perfect.

By the fall of 1906 the high frequency alternator had been brought to a practical shape and was used for telephoning from Brant Rock to Plymouth, a distance of 11 miles, and to a small fishing schooner,[2] this being the first instance in which wireless telephony was put in practical use. The transmission was perfect

1. Letter of July 8, 1905; see *The Electrician*, London, Feb. 22, 1907; also catalogue of 1904 and subsequent.
2. An amusing instance may be mentioned as illustrating the incredulity with which the wireless telephone was received. Some of the local papers having published an account of the experiments with the schooner above referred to the following appeared under the heading

and was admitted by telephone experts to be more distinct than that over wire lines, the sound of breathing and the slightest inflections of the voice being reproduced with the utmost fidelity.

As it was realized that the use of the wireless telephone would be seriously curtailed unless it could be operated in conjunction with wire lines, telephone relays were invented both for the receiving and transmitting ends and were found to operate satisfactorily, speech being transmitted over a wire line to the station at Brant Rock, retransmitted there wirelessly by a telephone relay, received wirelessly at Plymouth and there relayed out again on another wire line. On Dec. 11, 1906, invitations were issued to a number of scientific men to witness the operation of the wireless transmission in conjunction with the wire lines.[1] A report of these tests appeared in the American Telephone Journal of Jan. 26 and Feb. 2, 1907, the editor being one of the men present.

" Current News and Notes " in the columns of a prominent technical journal, Nov. 10, 1906.

" A New Fish Story.—It is stated from Massachusetts that the wireless telephone has successfully entered into the deep sea fishing industry. For the last week experiments have been conducted by the wireless telegraph station at Brant Rock, which is equipped with a wireless telephone, with a small vessel stationed in the fleet of the South Shore fishermen, twelve miles out in Massachusetts Bay. Recently, it is asserted, the fishermen wished to learn the prices ruling in the Boston market. The operator on the wireless fitted boat called up Brant Rock and telephoned the fishermen's request. The land operator asked Boston by wire and the answer was forwarded back to the fishermen. This is a rather fishy fish story ".

The doubt expressed was, however, only natural. I remember the astonishment displayed by one of the company's new operators some months previously on placing the receiving telephone to his head while the vessel was almost out of sight of land and hearing the operator at the land station call his name and begin to talk to him.

1. Brant Rock, Mass., Dec. 11, 1906.

American Telephone Journal, 100 William St., New York City.

Dear Sirs: A limited number of invitations have been issued to witness the operation of the National Electric Signaling Co's. wireless telephone system between Brant Rock and Plymouth, Mass., over a distance of between ten and eleven miles.

The tests will be as follows:

1. Transmission of ordinary speech, and also transmission of phonographic talking and music by wireless telephone between Brant Rock and Plymouth.

2. Transmission of speech over ordinary wire line to wireless station at Brant Rock, relaying the speech there automatically by telephone relay and automatically transmitting the speech by wireless to Plymouth,

In July 1907 the range was considerably extended and speech was successfully transmitted between Brant Rock and Jamaica, Long Island, a distance of nearly 200 miles, in daylight and mostly over land,[1] the mast at Jamaica being approximately 180 ft. high.

In 1907 several European experimenters succeeded in transmitting speech wirelessly, using some of the earlier forms of the writer's arc method, and some months ago the vessels of

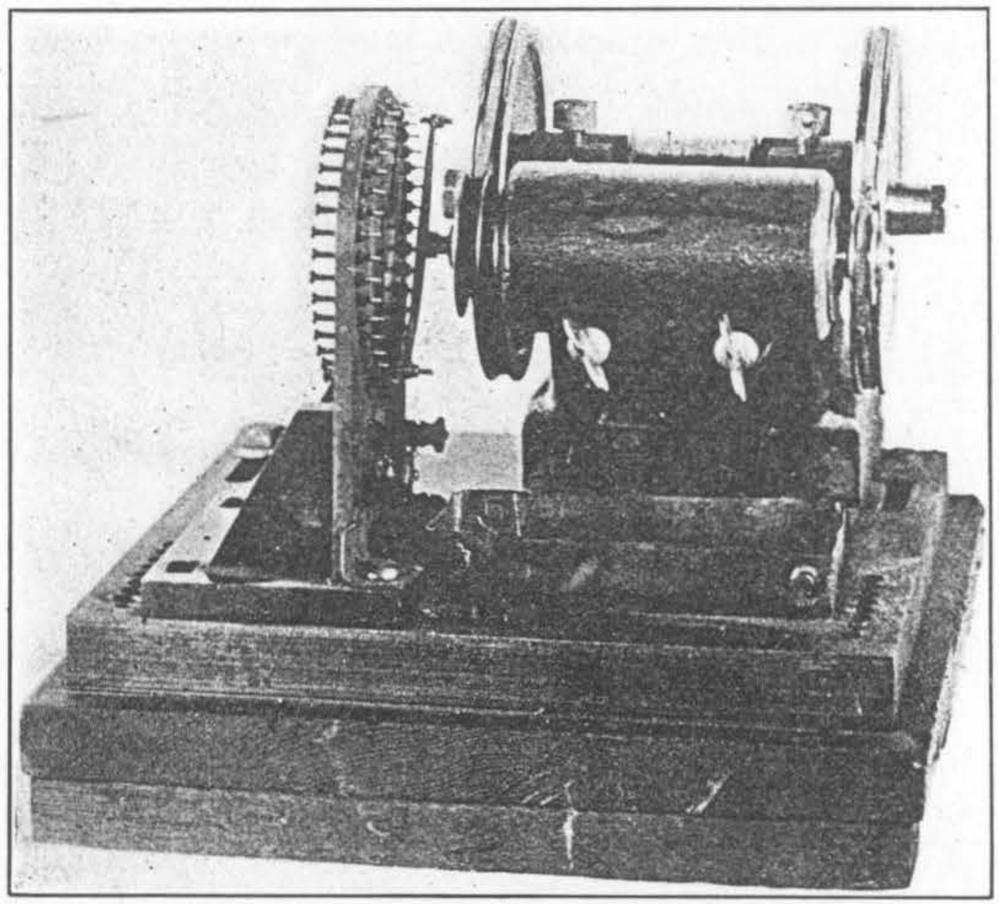


FIG. 11.

our Pacific squadron were equipped with wireless telephones, using this arc method, by another American company.

transmitting same at Plymouth automatically directly or by telephone relay over regular wire line.

Invitations have been issued to the following gentlemen, (here follows list of some of the guests, including Dr. A. E. Kennelly, Professor Elihu Thomson, etc., and a request to the company to send a representative).

Yours very truly,

National Electric Signaling Co.

1. "Long Distance Wireless Telephony," *The Electrician*, Oct. 4, 1907.

E. Methods and Apparatus

1. *Methods and apparatus for producing the electromagnetic waves.* These have been already referred to. Fig. 11 shows a rotating spark-gap giving approximately 20,000 discharges per

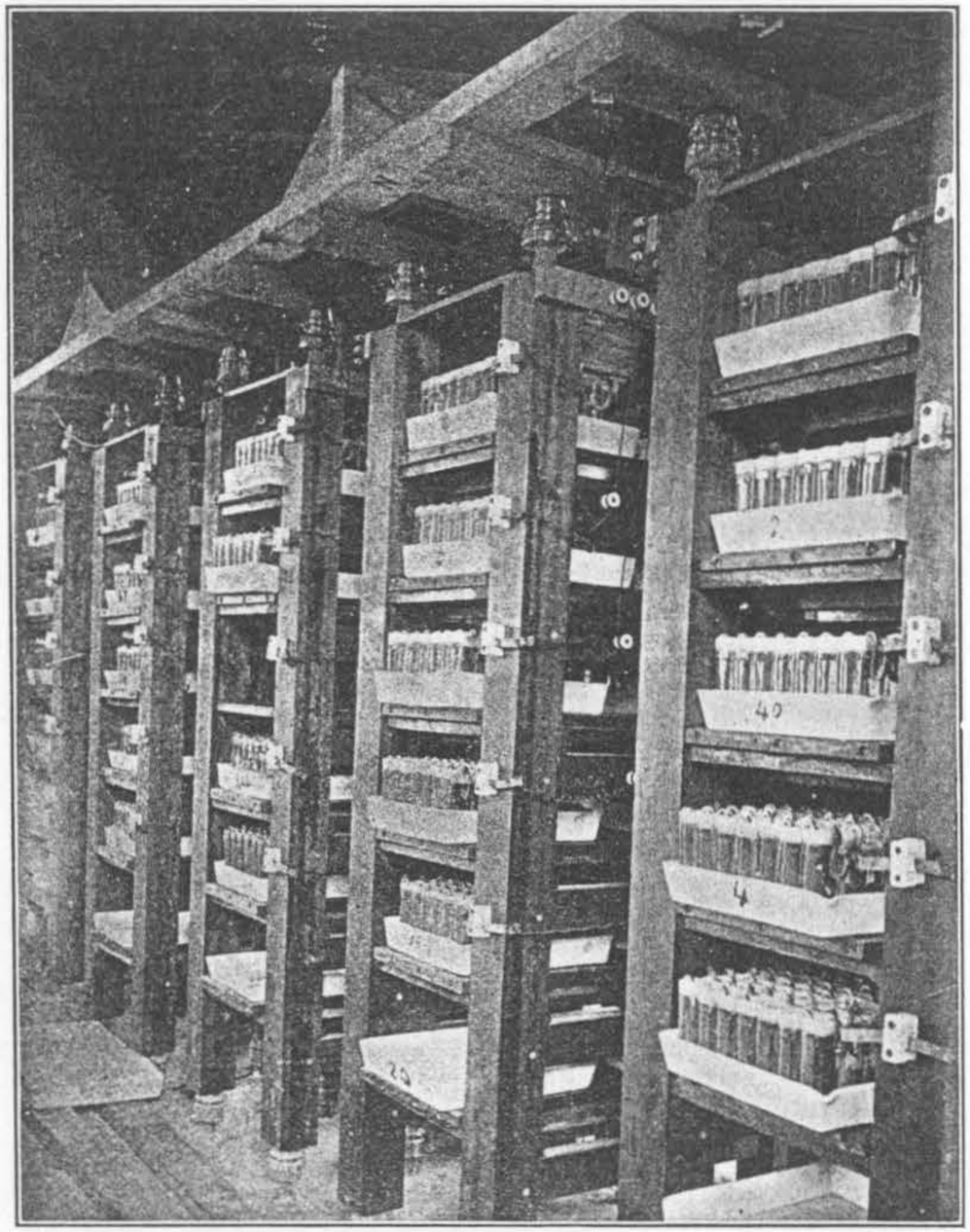


Fig. 12

second. This was connected to a 5,000-volt source of direct current. The terminals are of 40% platinum-iridium. In operation the apparatus is arranged to charge a condenser to a definite potential and discharge it.

Figs. 12 and 13 show forms of apparatus for operating the arc in a gas under pressure.

The apparatus of Fig. 13 is also used for the arc in vacuum and the critical distance arc.

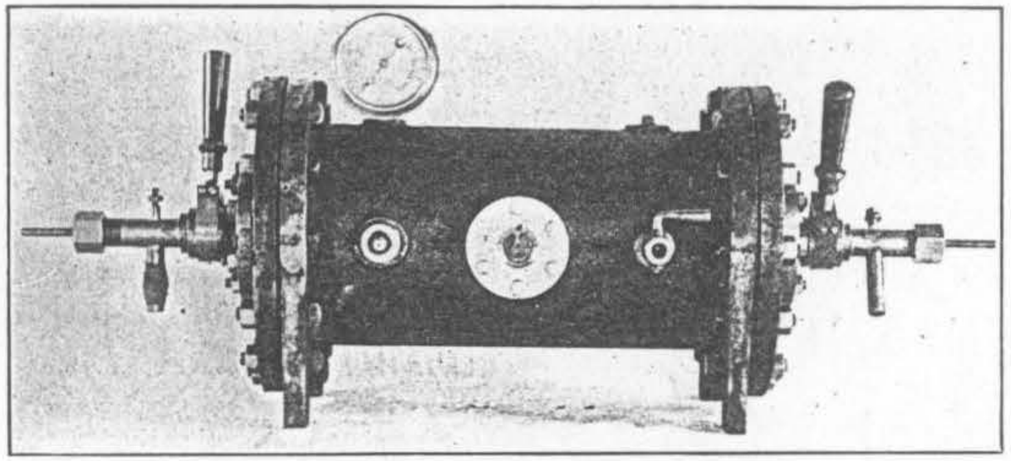


Fig. 13.

Fig. 14 shows a multiple gap with rotating electrodes, brass, amalgamated zinc and graphite being used.

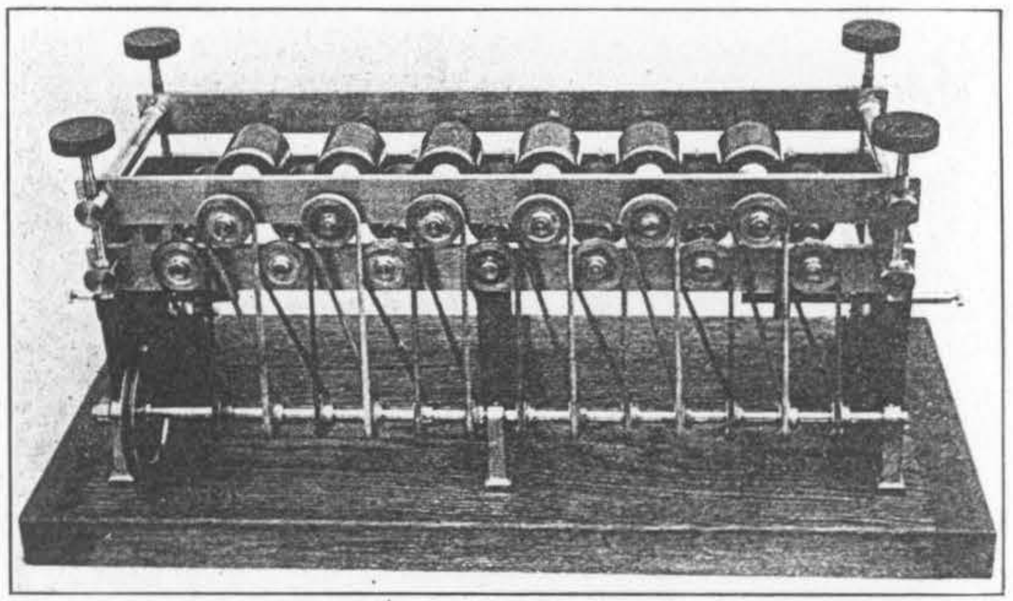


Fig. 14.

Fig. 15 shows a multiple arc gap with electrodes of different materials, the upper terminals being water cooled.

Fig. 16 shows a condenser dynamo.

Fig. 17 shows a general view of one type of high frequency alternator. It is driven by a motor and a DeLaval gear. It has been operated at 96,000 cycles per second, but is generally run at 81,700.

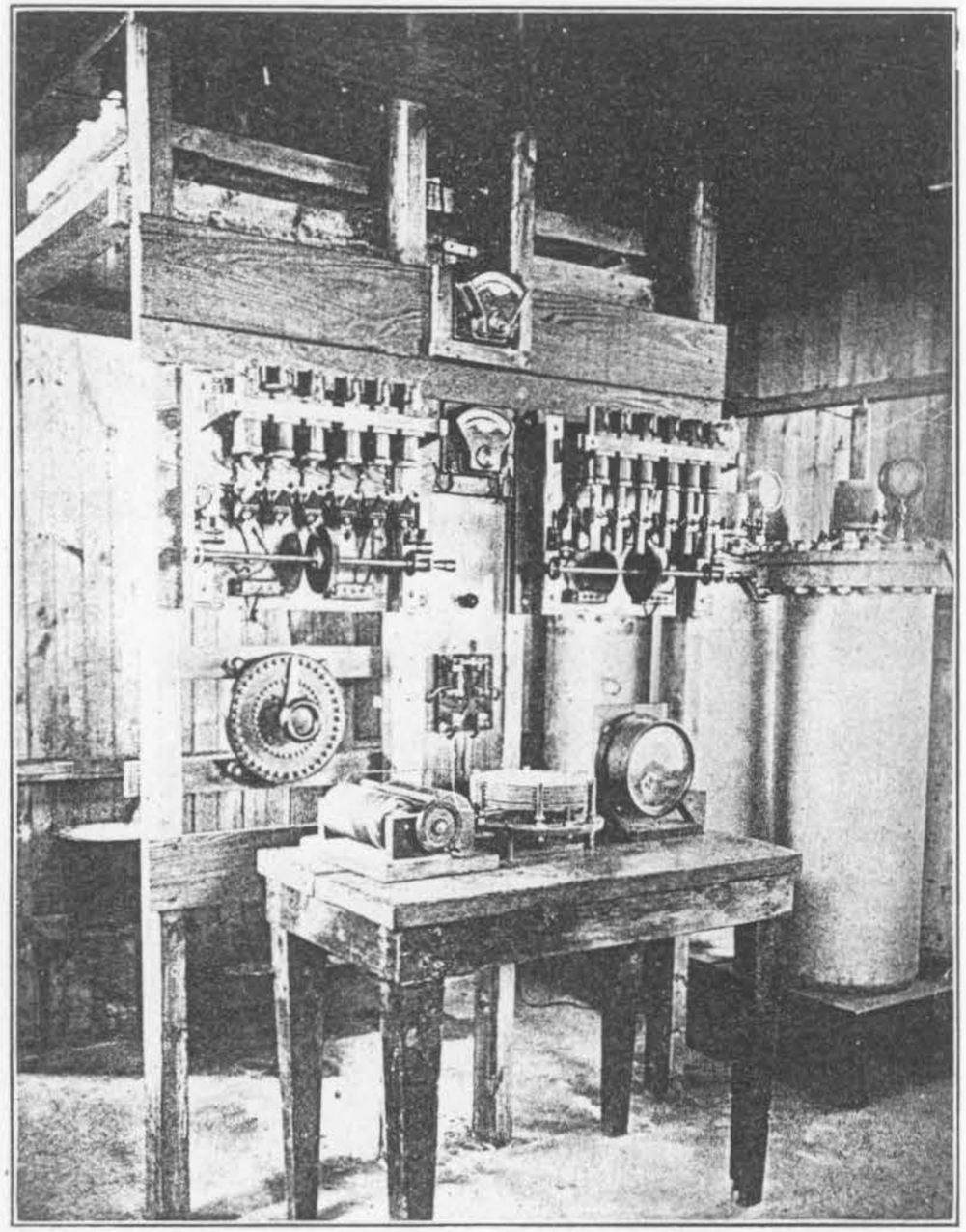


FIG. 15.

Fig. 18 shows a field disc; it is 12 inches in diameter and there are 300 slots on it.

Fig. 19 shows the armature and field coils. There are 600 armature slots each containing two turns of 13 mil wire. The

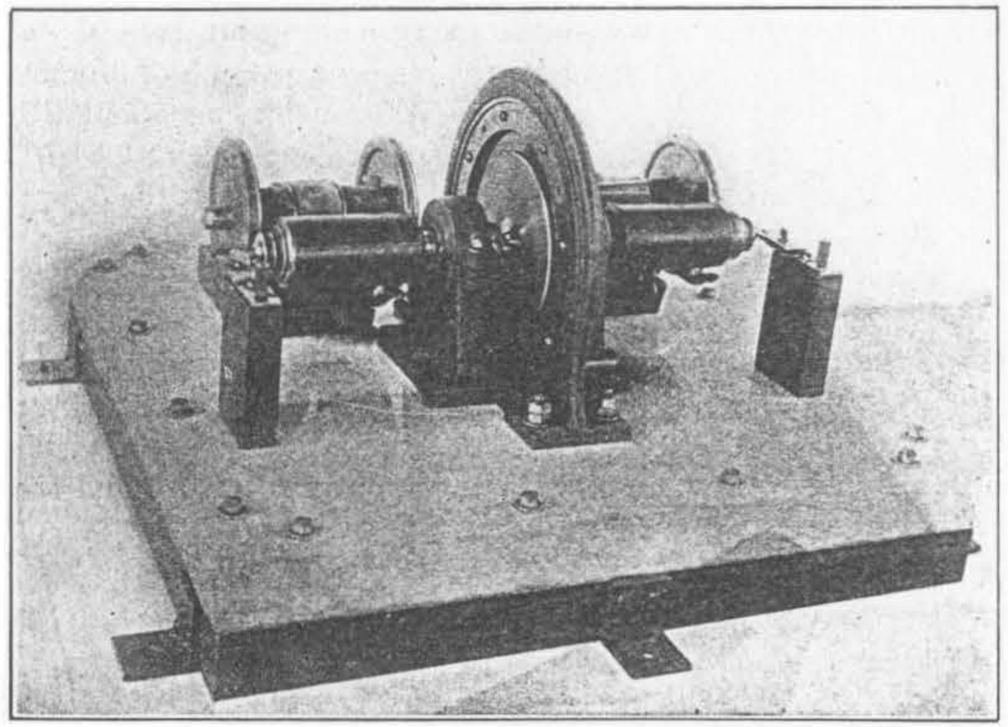


FIG. 16.

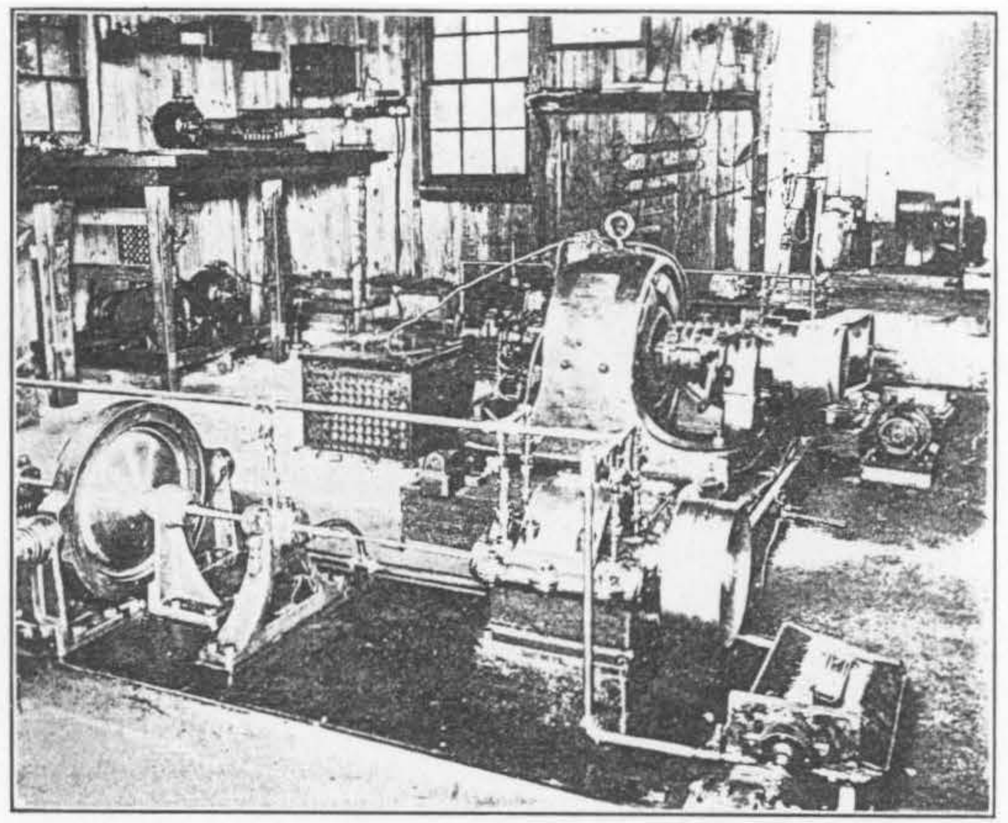


FIG. 17.

field current is 5 amperes. The resistance of the armature is 6 ohms; it gives 160 volts and about 7 or 8 amperes. Other armatures have been constructed having a resistance of 4 ohms. For some work double armatures are used giving about 270 volts. The output of the single armature machines at 81,700 cycles is approximately one kilowatt. The output of the double armature machine is approximately 2 kilowatts.

Other types of high frequency alternators are under construction. One type shown in Fig. 20 is designed for use on shipboard. The armature disc is 6 inches in diameter and two armatures are used. It is arranged to be mounted on gimbals and to be driven by a steam turbine connected to the steam pipe by flexible armored steam hose. The frequency is about 100,000 and the output about 3 kilowatts.

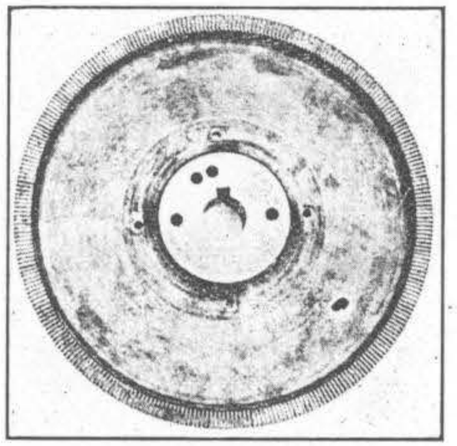


FIG. 18

Another type, which is at present being constructed by Mr. Alexanderson, to whose efforts the success of this type of generator is largely due, is designed to have an output of 10 kilowatts. Designs have been made for a generator of still larger size with a calculated output of 50 kilowatts and a frequency of 50,000. This machine is intended for transatlantic work.

For some of these machines, instead of driving by gear or steam turbine, a special two-cycle motor has been devised, to operate at a frequency of 500 cycles per second.

The high frequency alternator method is believed to possess a number of advantages over other methods, inasmuch as it is set in operation by merely opening a steam valve and has no complicated electrical apparatus or circuits of any kind. The

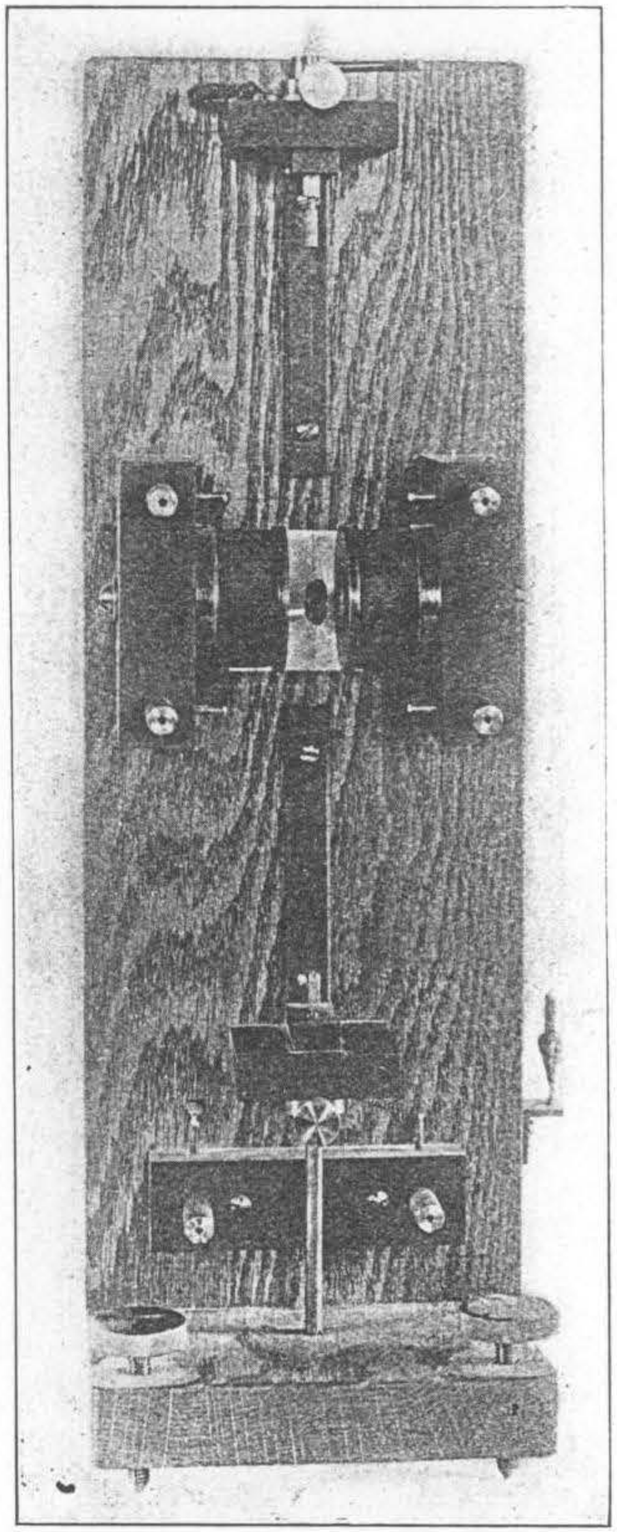


FIG. 21,

speed is regulated by the steam pressure, this being accomplished by an electrically operated reducing valve.

For measuring the frequency various speed indicators have been tried, but it has been found that the best way is to use a resonant circuit with an ammeter shown in Fig. 21 in it,[1] this being an extremely sensitive means of indicating the frequency and in addition affording a means of automatically keeping

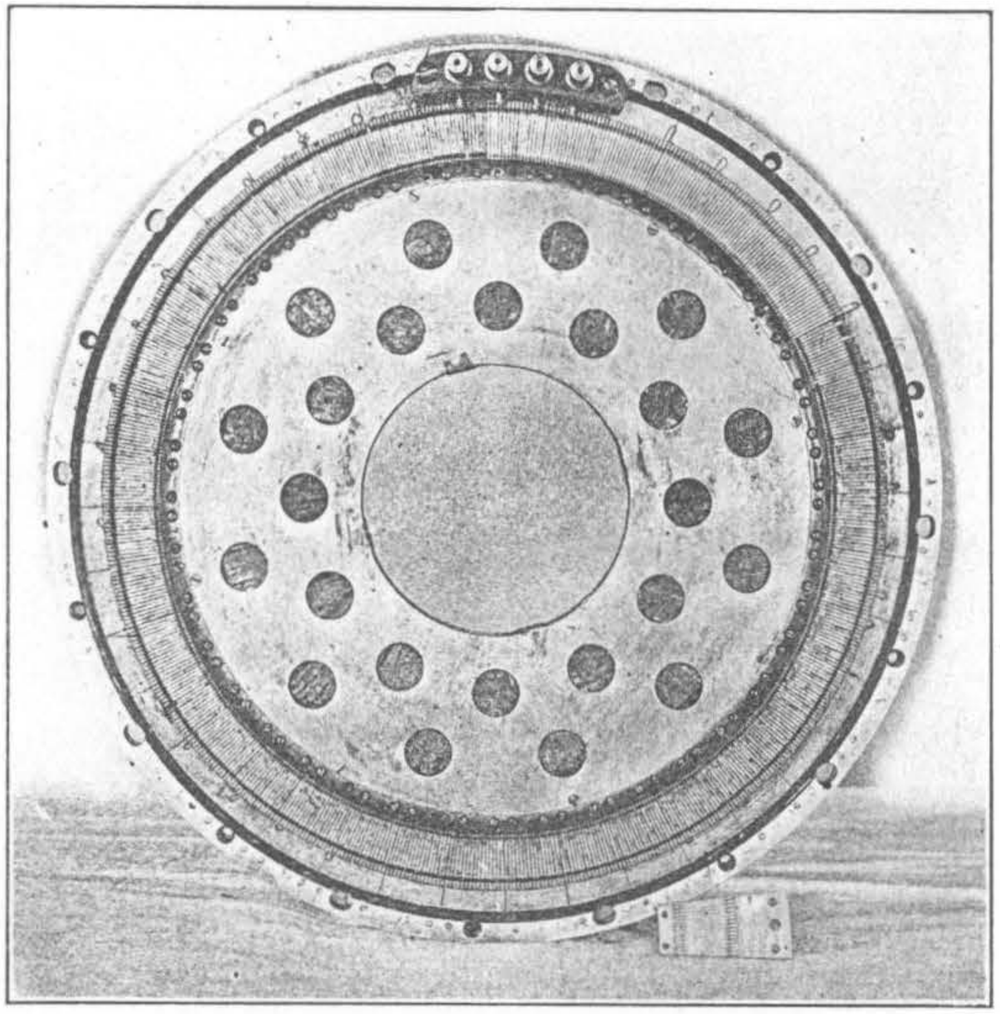


FIG. 19.

the speed constant to a small fraction of a per cent. The reducing valve is adjusted so that if left to itself the machine will run slightly above speed.[2] As soon as it reaches one-tenth of one per cent. higher than its designed speed the resonance begins to fall and a contact is opened which slightly throttles the steam. In

1. *Electrical World and Engineer*, Nov. 11, 1899.

2. Since writing the above, my attention has been called to the fact that the general method of governing by resonance was invented and patented by Kempster B. Miller, U. S. patent 559,187, Feb. 25, 1896.

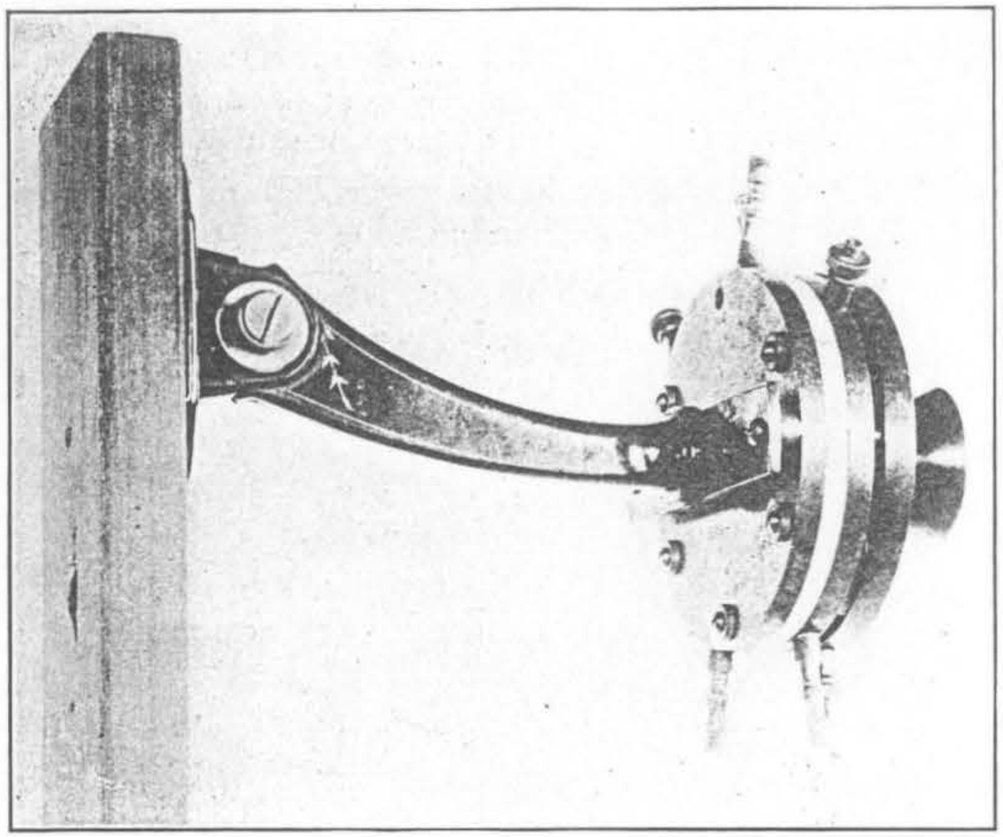


FIG. 20,

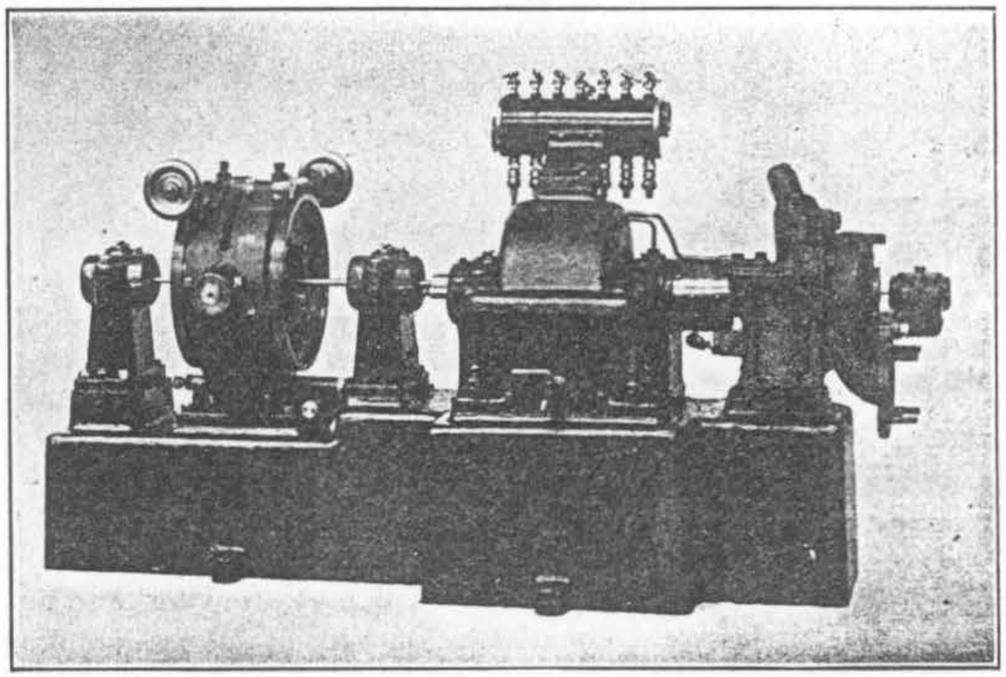


FIG. 22.

this way the frequency is kept varying between the limits of one-tenth of one per cent. above speed and one-tenth of one per cent. below speed. Where the drive is electric instead of by turbine, a storage battery is used to drive the two-phase generator and even better results may be obtained as regards regulation than with steam.

2. *Transmitters.* The types of transmitters most commonly

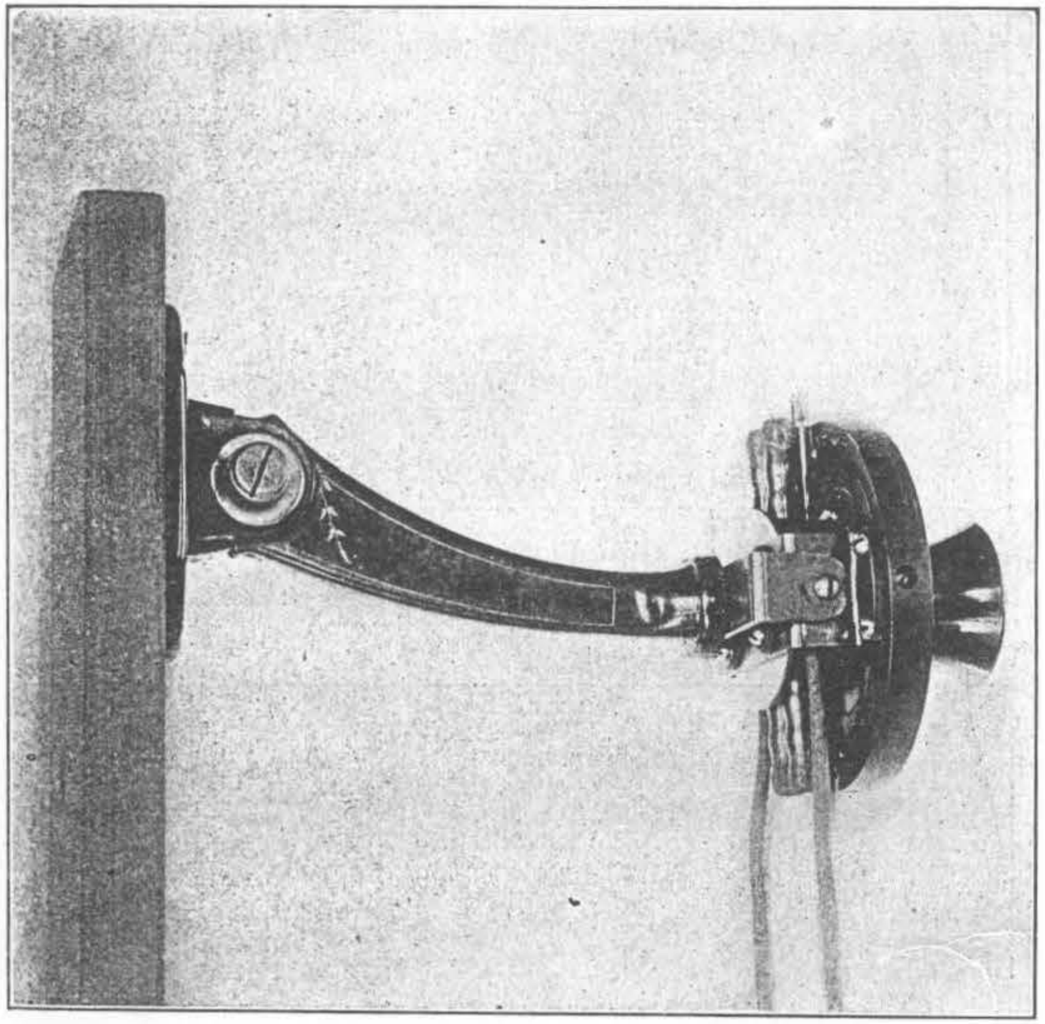


FIG. 23.

used are the carbon transmitter and static transmitter, and the carbon transmitter relay.

Fig. 22 shows the standard type of carbon transmitter.

It was found that the ordinary carbon transmitter was unsuited for wireless telephonic work on account of its inability to handle large amounts of power. A new type of transmitter was therefore designed which the writer has called the " trough "

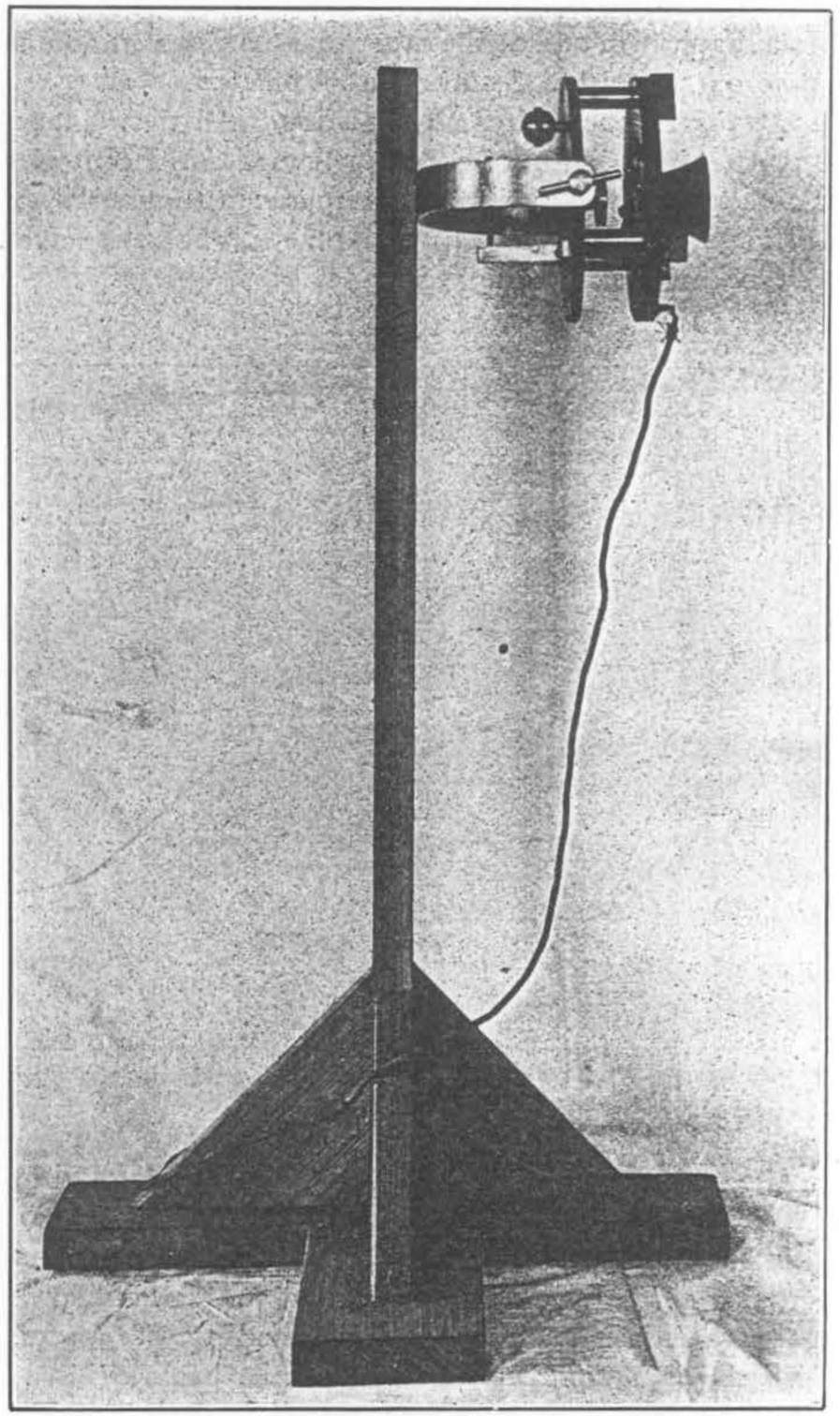


FIG. 24.

transmitter. It consists of a soapstone annulus to which are clamped two plates with platinum iridium electrodes. Through a hole in the center of one plate passes a rod, attached at one end to a diaphragm and at the other to a platinum iridium spade. The two outside electrodes are water-jacketed.

This transmitter requires no adjusting. All that is necessary is to place a teaspoonful of carbon granules in the central space. It is able to carry as much as 15 amperes continuously without the articulation falling off appreciably. It has the advantage that it never packs. The reason for this appears to be that

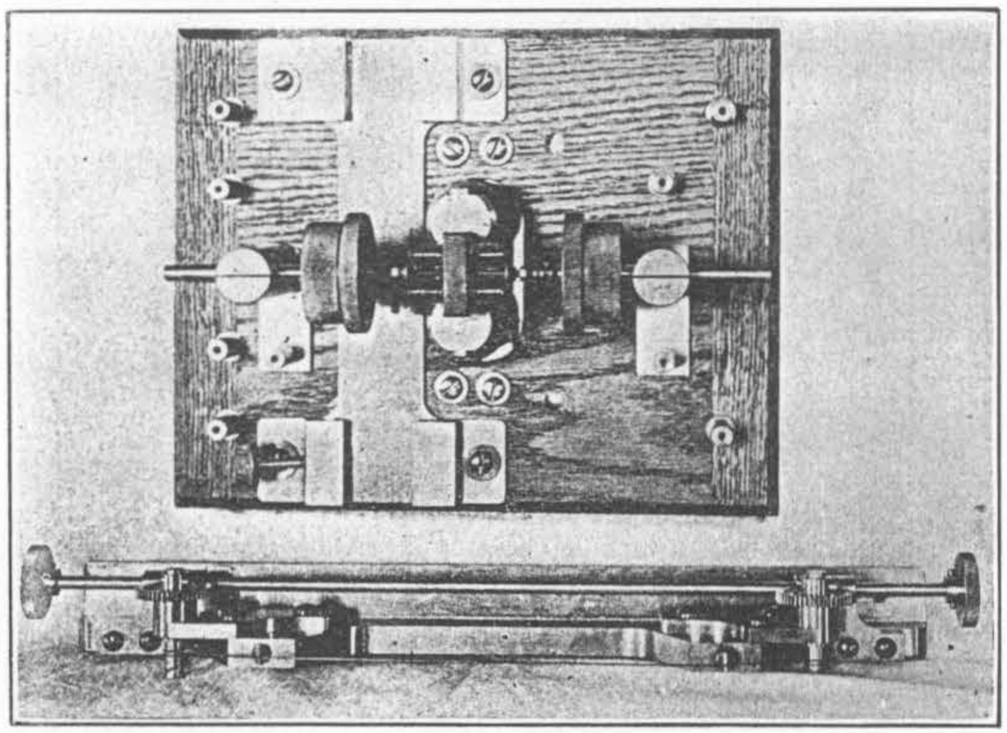


FIG. 25.

when the carbon on one side heats and expands the electrode is pushed over against the carbon on the other side. These transmitters have handled amounts of energy up to one-half horse power, and under these circumstances give remarkably clear and perfect articulation and may be left in circuit for hours at a time. Fig. 23 shows a modified form with split back.

Fig. 24 shows a type of condenser transmitter in which the vibration of the diaphragm alters the electrical capacity of the transmitter, thus throwing the circuit in and out of tune or spilling more or less energy through a leakage circuit.

Fig. 25 shows a transmitting relay for strong currents. The only thing noticeable about this is that the telephone magnet is a differential one.

Fig. 26 shows another type of transmitting relay, for amplifying very feeble currents. It will readily be understood that where a person in Albany, for example, wishes to talk to another person on board a ship off New York, the wireless station being located near New York, the volume of the transmission received at New York will not be very strong, and while it may be possible

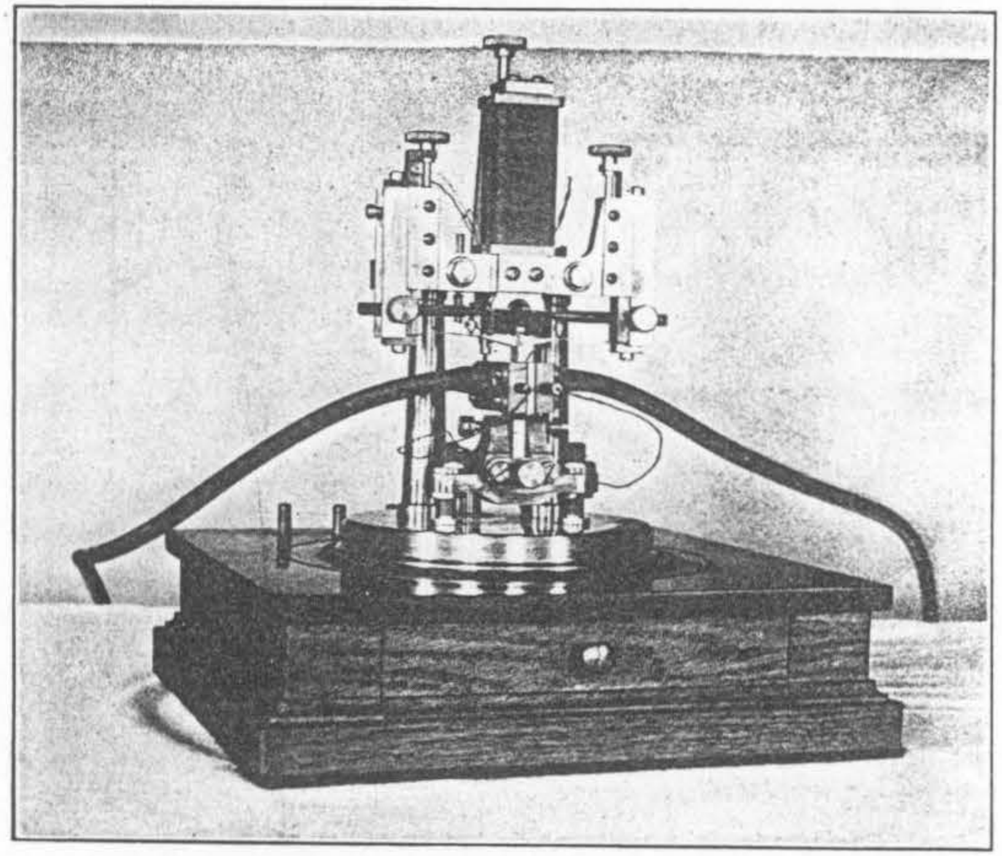


FIG. 26

to transmit it without amplification, amplification is advisable.

This receiver is a combination of the differential magnetic relay and the trough transmitter. An amplification of fifteen times can be obtained without loss of distinctness. The side electrodes of the trough are water-jacketed. The successful amplification depends upon the use of strong forces and upon keeping the moment of inertia of the moving parts as small as possible. Amplification may also be obtained by mechanical means but as a rule this method introduces scratching noises which are very objectionable even though comparatively faint.

Other types of transmitters have also been used, such as liquid jet transmitters, Fig. 27 transmitters operating by closing the air-gap in a magnetic circuit, and so changing the inductance of the oscillating circuit, etc.

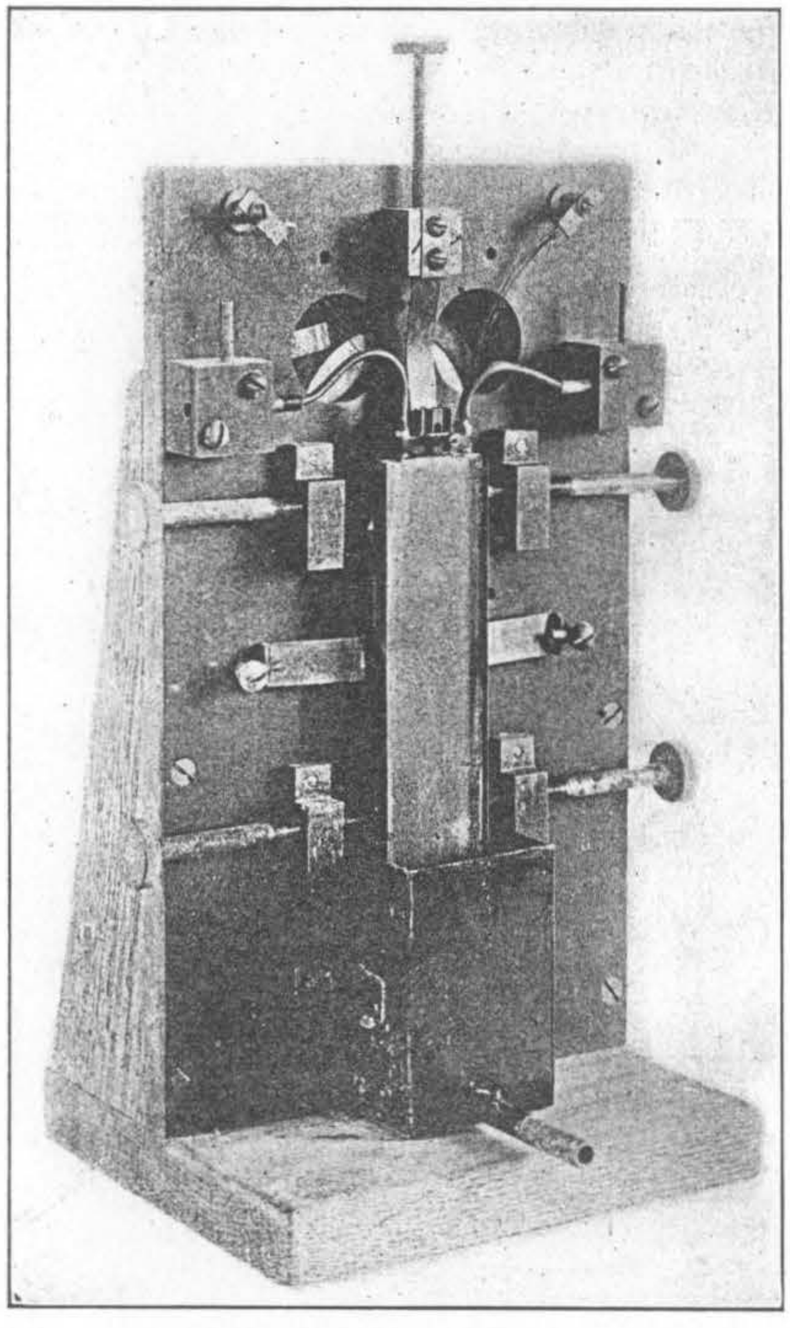


FIG. 27.

Fig. 28 shows a loud-speaking telephone receiver. A small iron disk is placed opposite a nozzle through which air at high pressure is blown. As is well known, this causes the disk to

be held close to the nozzle. The telephone magnets alter the position of the disk and thus produce very loud talking.

The transmitting relays are connected in the wire line circuit in the same way as the regular telephone relay, except that in place of being inserted in the middle of the line they are placed in the wireless station and an artificial line is used for balancing. There is no difficulty met with on the wireless side of the apparatus, but on the wire line side there are the well-known difficulties

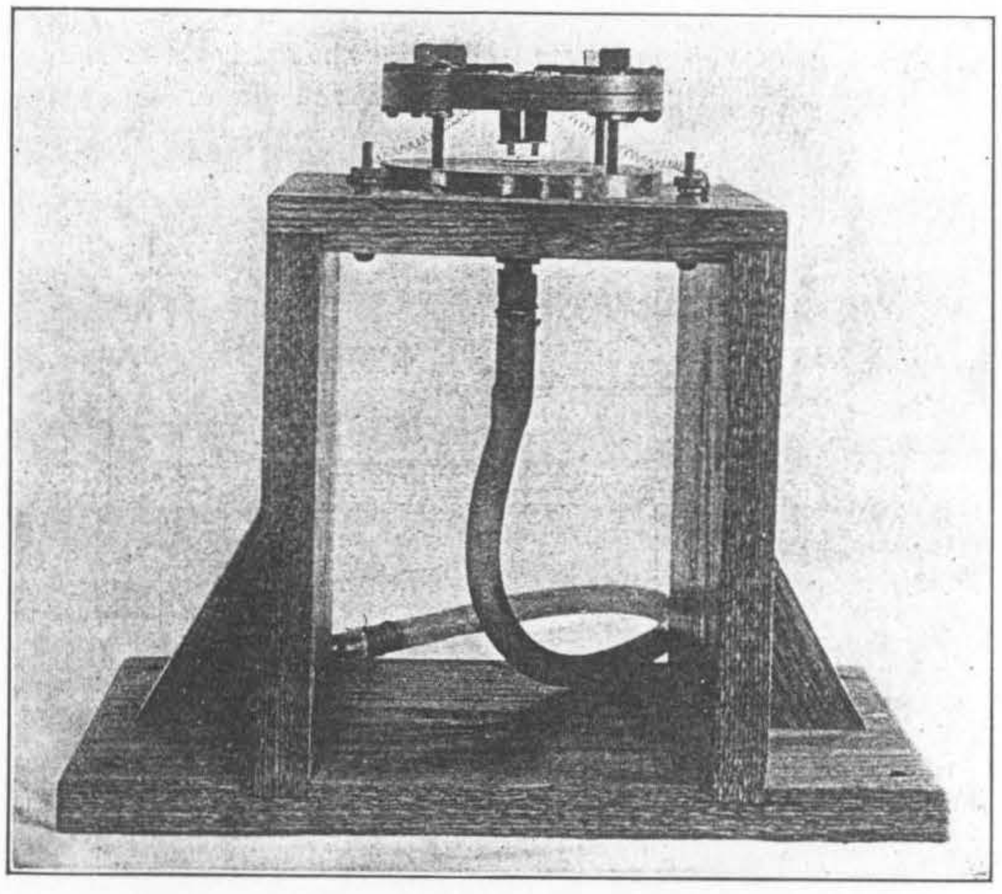


FIG. 28.

due to unbalancing which have not yet been entirely overcome. For the correction of these difficulties, therefore, we must look to the engineers of the wire telephone companies. At present the difficulties are if anything less than those met with in relaying on wire lines alone.

3. *Transmitting circuits.* Fig. 29[1] shows a type of arc circuit.

Fig. 30[2] shows a suitable type of connection for use with a high frequency alternator.

1. U. S. patents Nos. 706,742, June 6, 1902 and 730,753, April 9, 1903.
2. U. S. patent No. 706,742, June 6, 1902.

Fig. 31[1] shows a type of circuit for use with the condenser transmitter.

Fig. 32[2] shows a type of circuit in which the modulation is accomplished by changing the inductance of one of the oscillating circuits.

As a matter of fact the transmitter may be placed almost anywhere in the circuit between the arc or dynamo and the antenna, or between the arc or dynamo and ground, or in the transformer circuit, or in shunt to an inductance or capacity, the results obtained in all cases being indistinguishable. The sole criterion of success seems to be that the transmitter should be capable of handling the energy and the circuit should be

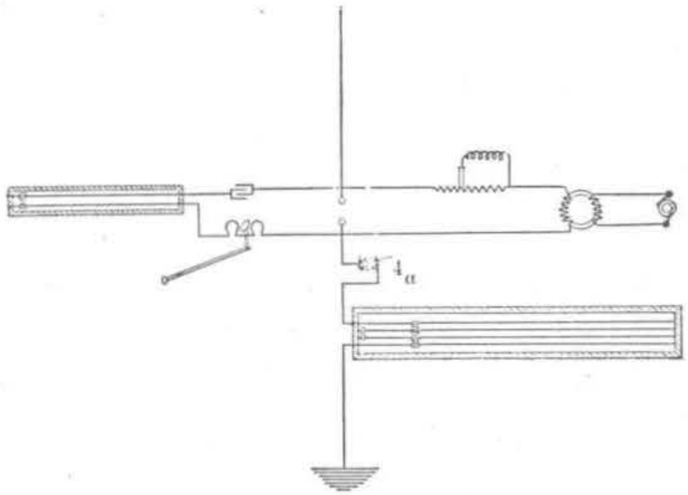


Fig. 29.



Fig. 30.

properly adjusted. Some success has also been attained by placing the transmitter in the field of the dynamo[3] but this method requires very careful designing of the field circuit.

4. *Receivers.* The receiver which the writer has found most satisfactory for general purposes is the liquid barretter. Fig. 33 and 34 shows this receiver. It consists of a fine platinum wire, about a ten thousandth of an inch in diameter immersed in nitric acid. Tests made with this receiver show that it responds without apparent loss of efficiency to notes as high as 5000 per second. Some very careful measurements recently made by my assistants, Messrs. Glaubitz and Stein, give the following results:

1. U. S. patent No. 706,747, Sept. 28, 1901.
2. U. S. patent No. 706,747, Sept. 28, 1901.
3. U. S. patent No. 793,649, March 30, 1905.

Voltage of high frequency circuit necessary to produce readable signals,	15×10^{-5} volts.
Ohmic resistance of receiver,	2,500 ohms.
Value of high frequency current necessary to produce readable signals,	6×10^{-5} amperes.
Electromagnetic wave energy required to produce audible note for period of one second,	1×10^{-4} ergs.

The telephone used for detecting the signals had a resistance of approximately 1000 ohms. Some measurements were made

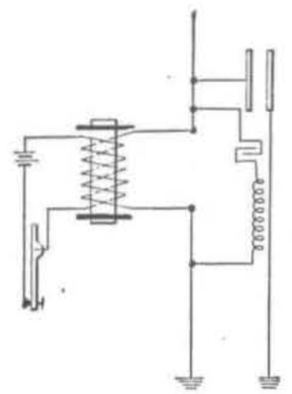


Fig. 31.

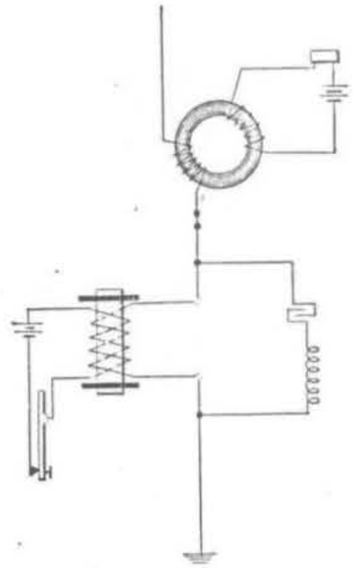


Fig. 32.

to determine the change of current in the telephone circuit by using a sensitive galvanometer in series with the telephone but the results obtained were obviously too low, possibly on account of the electrostatic capacity of the turns of the galvanometer with respect to each other. It will be noted that the amount of electromagnetic wave energy necessary to produce a signal is considerably less than that given in a previous note.[1] The difference is possibly to be attributed to improvements in adjustment and operation.

The above measurements were taken by shunting the barretter across a piece of straight resistance wire in series with a hot-wire ammeter, to determine the voltage necessary, and by intro-

1. *Electrical World and Engineer*, Oct. 31, 1905.

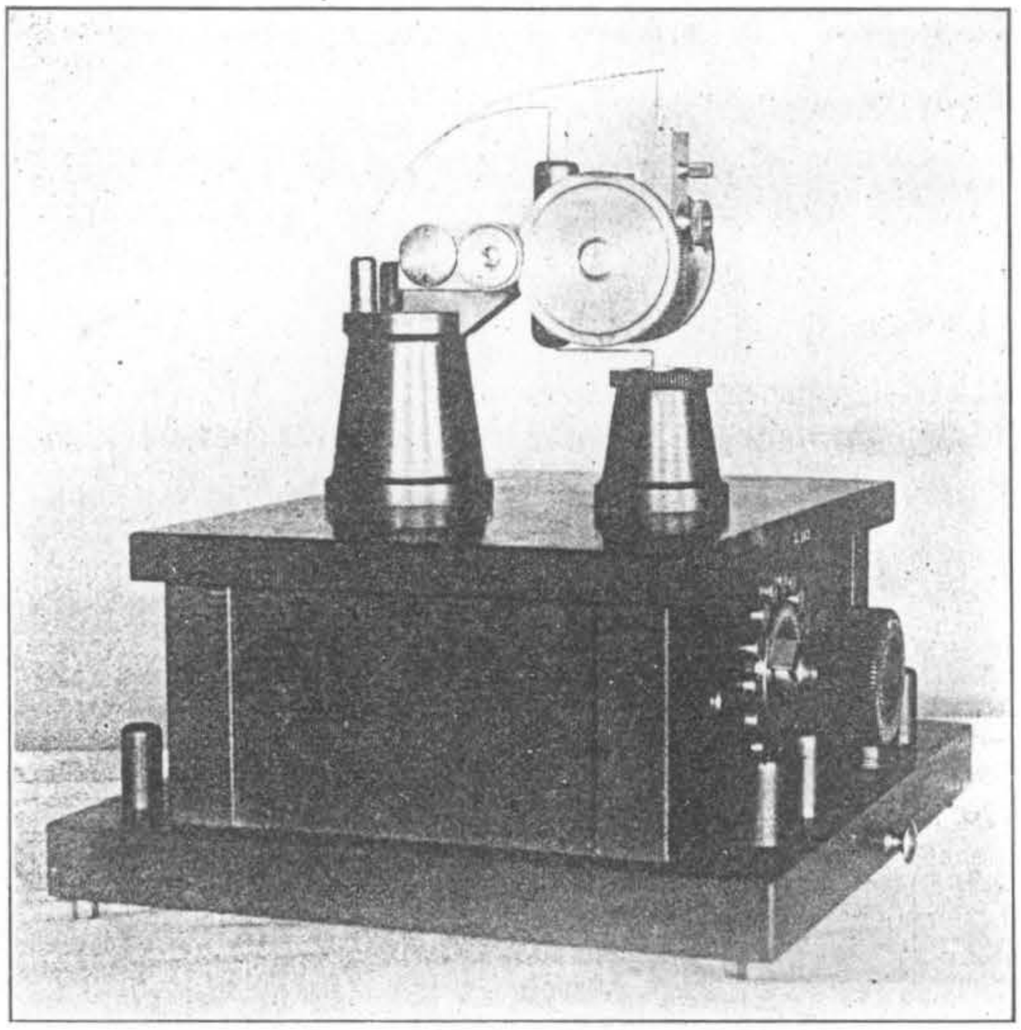


FIG. 33.

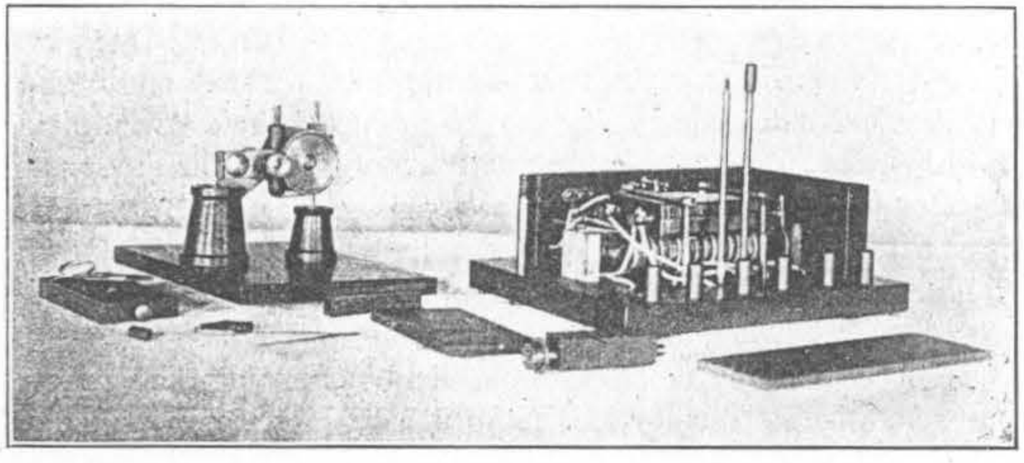


FIG. 34.

ducing resistance in series with the barretter to determine the resistance of the barretter. The figures were also checked in a number of other ways and very concordant results were obtained, so that it is believed they may be relied upon.

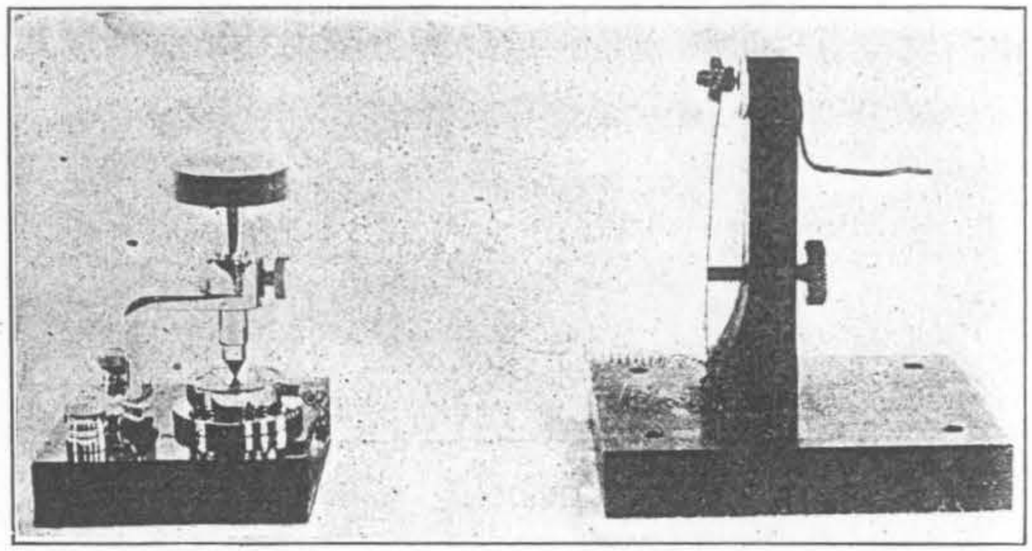


FIG. 36. FIG. 35.

The previously mentioned thermoelectric receivers or rectifiers of Dr. Austin and Mr. Pickard shown in Figs. 35 and 36 and the vacuum tube receivers of Fleming, deForest, and Cooper Hewitt also act very satisfactorily. The fact that the writer

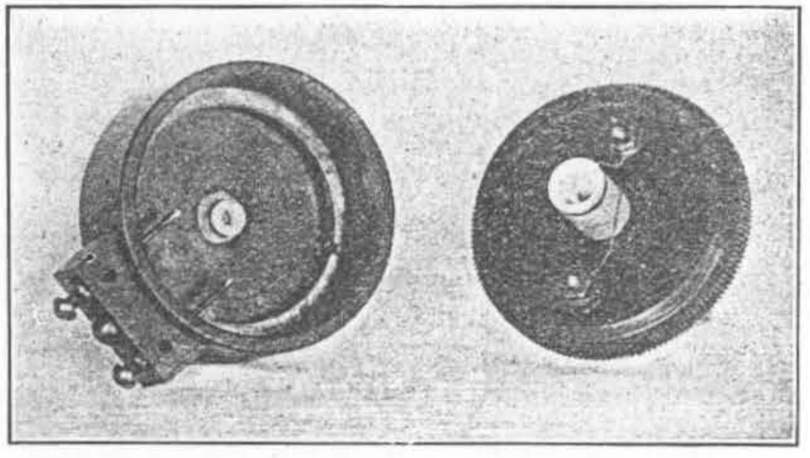


FIG. 37.

has not been able to get as good results from them may be due to greater familiarity with the liquid barretter and heterodyne receiver.

Figs. 37, 38, and 39 show forms of heterodyne receiver adapted for use for telephonic work.

5. *Receiver connections.* Where the wireless telephone is operated by first talking into the transmitter and then throwing a switch and listening, the usual wireless telegraphic connections

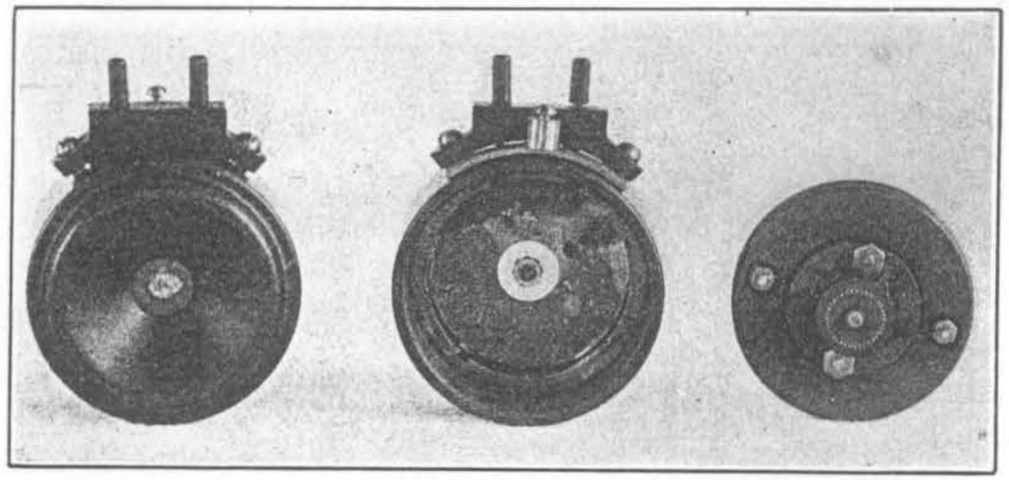


FIG. 38.

are used. This has been found in practice to be very inconvenient, however, and several methods have therefore been devised for talking and listening simultaneously, which methods

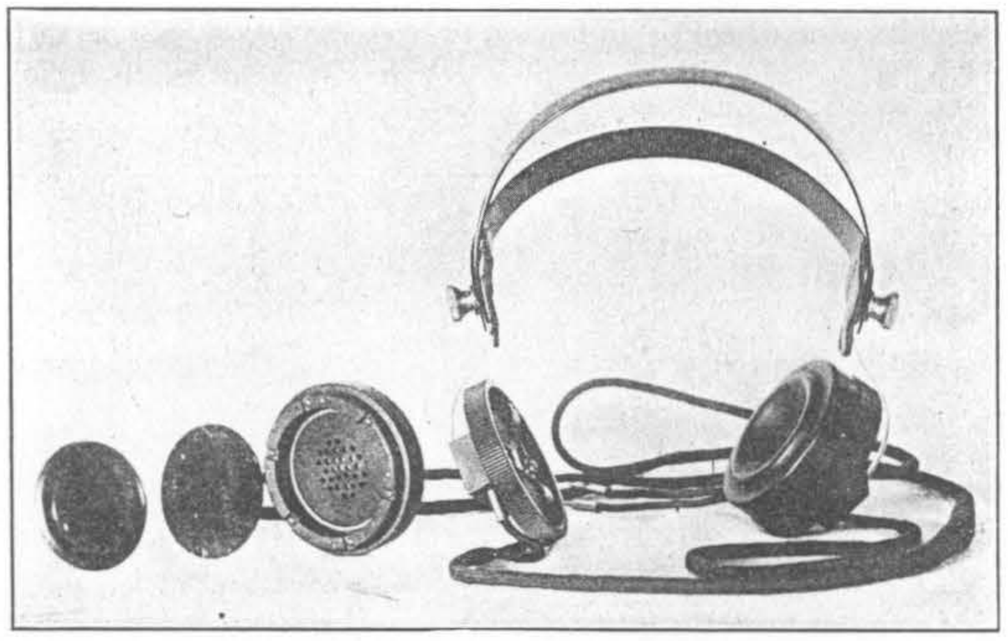


FIG. 39.

can, of course, also be applied to duplex wireless telegraphy. Among these methods may be mentioned the commutator method[1] and the balance method.[2]

1. U. S. application, 350,199, Dec. 31, 1906.
2. U. S. application, 366,528, April 5, 1907.

The former method is fairly well known and consists in rapidly connecting alternately the transmitter and receiver. The balance method consists in using a phantom aerial as shown in Fig. 40, where P is a phantom aerial, the circuit having such capacity inductance and resistance as to balance the radiating antenna. The apparatus is shown in Fig. 41.

In order entirely to cut out disturbances in the receiver while sending, an interference preventer, *I. P.*, the elements of which are shown in Figs. 42 and 43, is used in the receiving circuit.

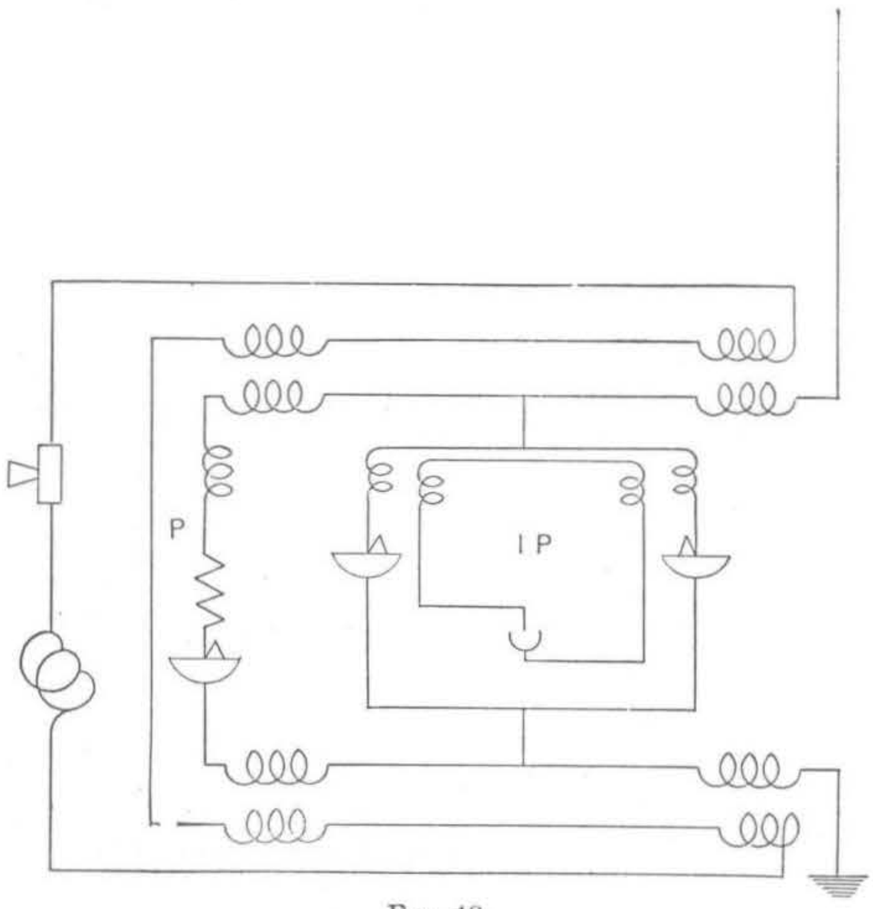


FIG. 40.

It may be here mentioned that balance methods work much better with wireless telephony and telegraphy than with line telephony and telegraphy, for the reason that the radiation resistance of an antenna is absolutely definite and is not affected by the weather, as are line circuits. Consequently, the balance can be made very sharp and once made does not need to be altered.[1] Of course, half the energy is lost but this is a matter

1. This method may, of course, be used for duplex working in wireless telegraphy. As some question has been raised in regard to the capacity of wireless telegraph lines the writer would say that he has received

of practically no importance, as the cutting down of the strength of a telephonic conversation to one-half is as a rule hardly noticeable, especially where there are no line noises or distortion of the speech through capacity effects.

6. *Receiving station relay.* The receiving station relay is similar to the transmitting relay shown in Fig. 26. The same

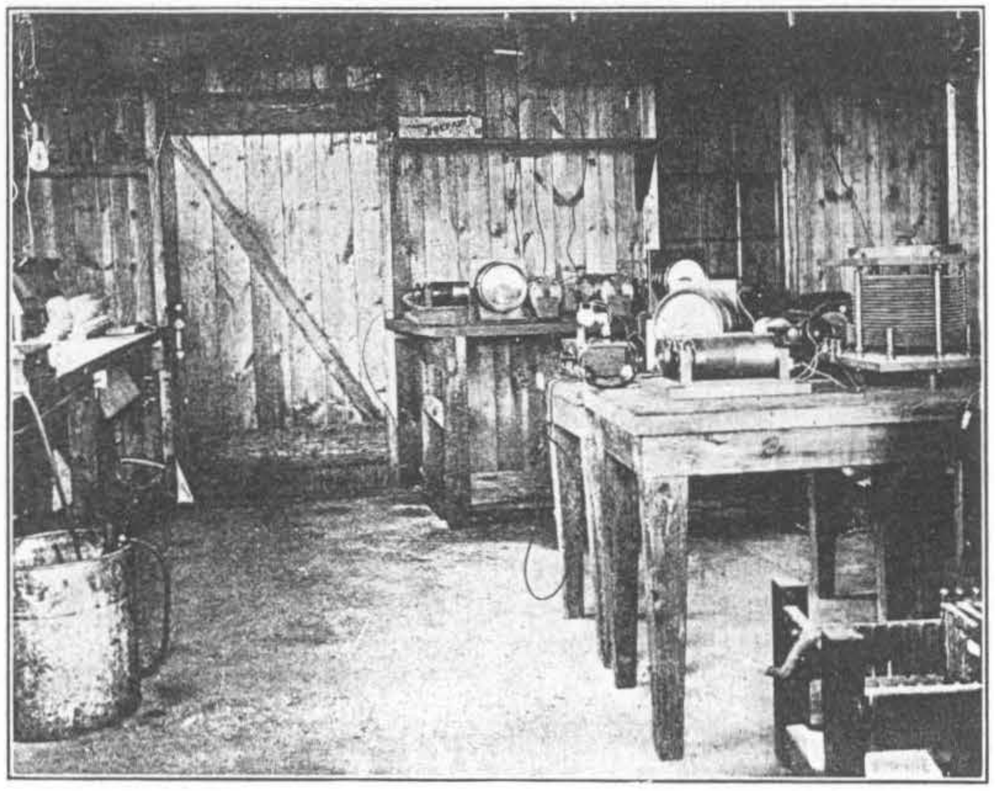


FIG. 41.

remarks apply to its use in connection with wire lines as to the transmitting relay.

messages at the rate of 250 words per minute by wireless and is now experimenting with apparatus designed to give 500 words per minute. With duplexing this gives 1,000 words per minute or 60,000 words per hour. The manager of one of the largest cable companies has stated (*London Daily Mail*, Sept. 24, 1907) that all the Trans-Atlantic cables together send 24,000 words per hour. It would appear, therefore, that if capacity alone be considered a single station on each side of the Atlantic can handle more traffic than all the present cables. It should be pointed out, however, that the mere ability to handle the messages is not sufficient and that unless the wireless telegraph companies obtain land facilities equal to those at present enjoyed by the cable companies they cannot handle the traffic as efficiency, *i.e.*, cannot deliver a message from New York to an individual in London and receive a reply in the same time. Fig. 44 shows a Wheatstone transmitter used for the test referred to.

F. OPERATION

As will be realized from the above, the operation of a wireless telephone system is very simple. The operator merely throws his switch to the position for telephoning and talks into an

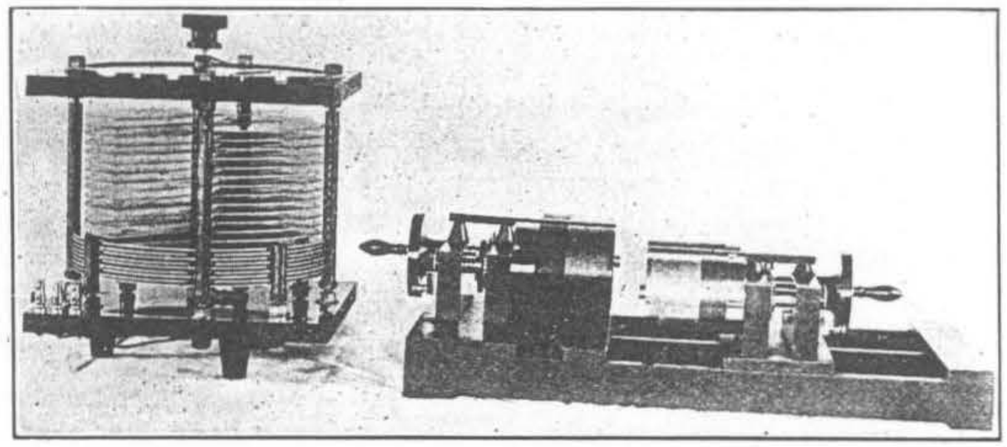


FIG. 42.

ordinary transmitter and listens in an ordinary telephone receiver. When the duplex method is used, as is always advisable, the conversation proceeds exactly as over an ordinary telephone line. Fig. 45 shows a phonograph transmitting music and speech wirelessly. Fig. 46 shows talking by relays from a local circuit.

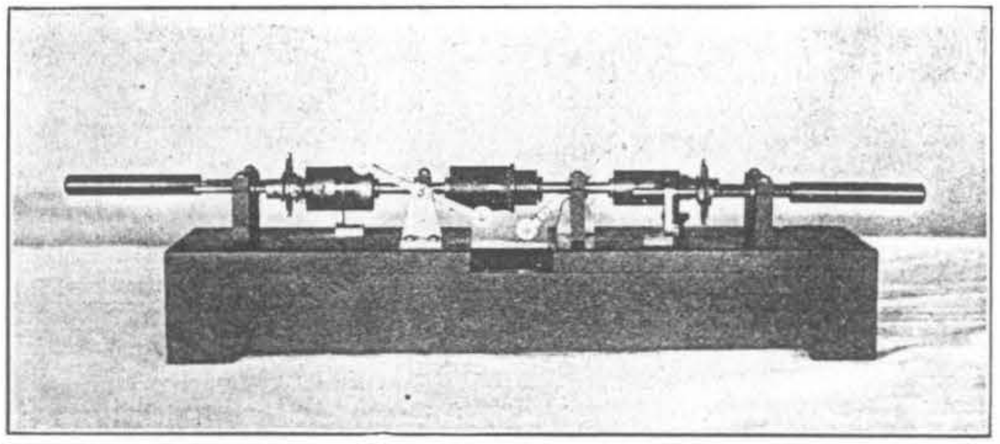


FIG. 43.

I believe I am correct in saying that the transmission by wireless telephone is considerably more distinct than by wire line and that the fine inflections of the voice are brought out much better. This, I presume, is due to the fact that there is no electrostatic capacity to distort the speech, as in the case of

wire lines, though I think the effect is also partly due to the absence of telephone induction coils with iron cores. Possibly some of the gentlemen present have witnessed the operation of the wireless telephone transmission between Brant Rock and Plymouth and between Brant Rock and Brooklyn. If so I think they will bear me out in saying that the transmission was clearer than over wire lines.

As a rule, there is absolute silence in the wireless telephone receiver except when talking is going on, though of course the usual noises may be heard if persons are walking across the room, etc. This makes listening in less of a strain than when talking over wire line. Even during severe atmospheric disturbances the talking is not interfered with to any noticeable extent, provided of course that an interference preventer is used.

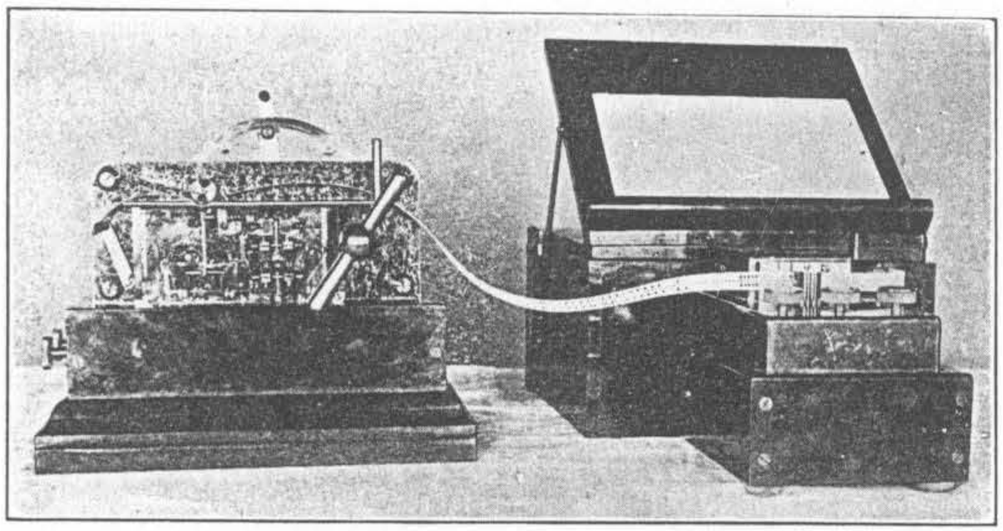


FIG. 44.

A comparative test was made with talking between Brant Rock and Brooklyn by wireless and by wire telephony. The talking over the wire line was done from a long distance station in Brooklyn. The wireless transmission was considerably the better. The fact that the wire line included in its circuits a cable from New York to Brooklyn was of course a disadvantage, but even allowing for this, practice and theory appear to be in agreement to the effect that transmission by wireless telephony over long distances is better than by wire line.

This method should be of especial value to independent telephone companies, which have their local exchanges, but no long distance lines, especially since no franchises or rights of way are necessary.

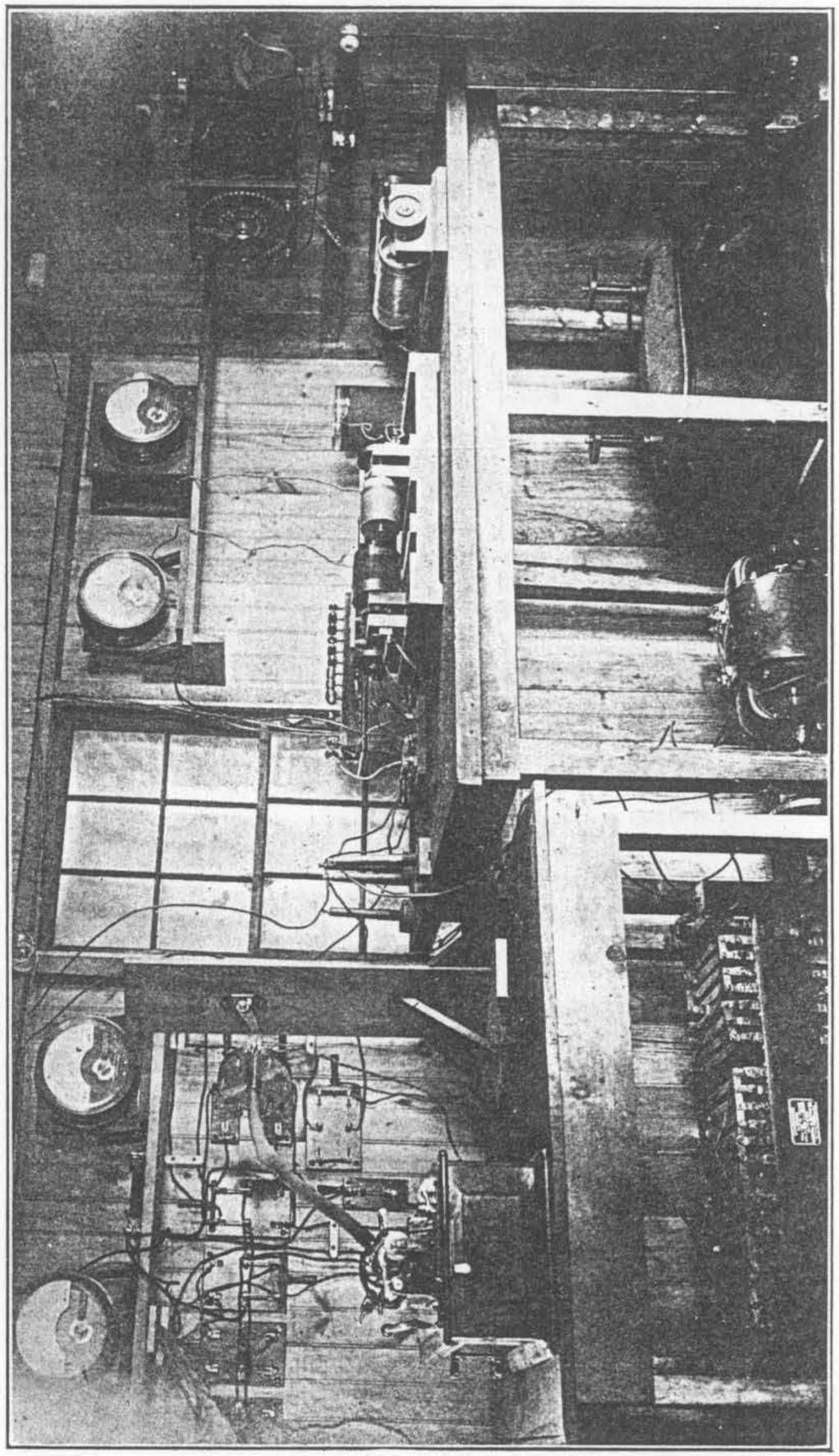


FIG. 45.

G. Possibilities

A. *Local exchanges.* There is no immediate prospect that wireless telephony will take the place of local exchanges. The difficulty in regard to the number of tunes can be overcome, but the fact remains that high frequency oscillations cannot be transmitted over wire and hence each subscriber must have his own generating station. At the present time no method is known which would be practical if placed in the hands of a subscriber. If such means should be found it would be very convenient to call up directly instead of through an exchange, but as I see it there are no immediate prospects of this.

B. *Long-distance lines.* I believe, however, that there is a

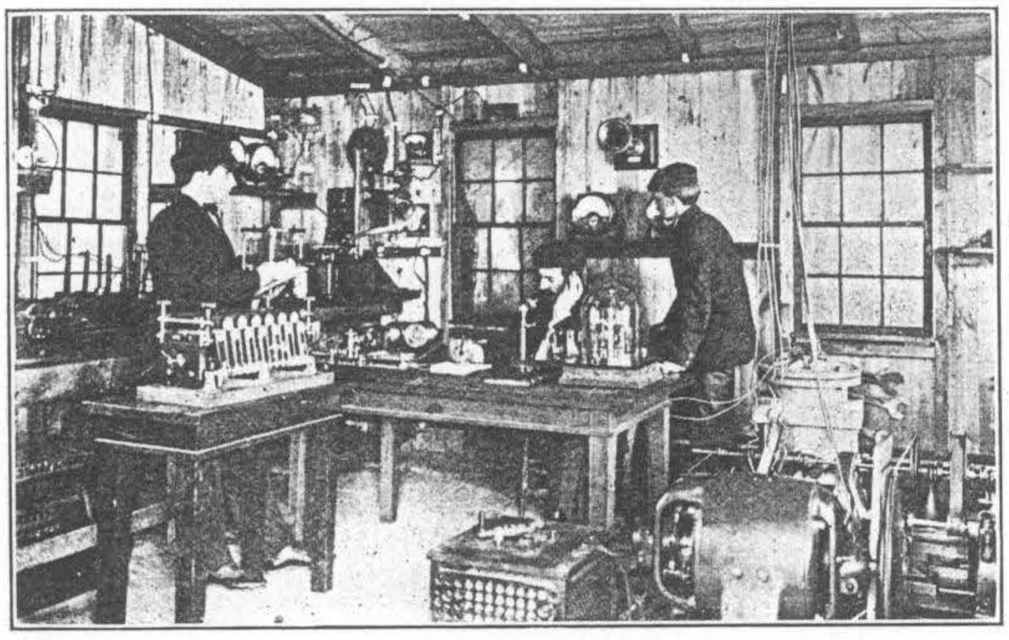


Fig. 46.

field for wireless telephony for long distance lines. The present long distance lines are very expensive to construct and to maintain, and a storm extending over any considerable section of country inflicts considerable loss on the telephone companies. Moreover, the distance of transmission is limited by the electrostatic capacity of the line, as I understand it. Wireless telephony would have the following advantages.

1. The initial cost would be very much less than that of wire lines.

2. The maintenance would be practically negligible in comparison.

3. In case of any breakdown, it would be right in the station and not at some unknown point outside on the line.

4. The depreciation would be comparatively small.

5. The number of employees required would be smaller.

6. The transmission is better, and as there is no distortion of the speech, the working distance is, it is believed, considerably greater.

7. The flexibility is greater. With wire lines a telephone company may not be able to give a Boston subscriber a line to New York, while having lines from Boston to Chicago and from Chicago to New York free. Operating wirelessly the wireless circuit normally used for operating between New York and Chicago and between Boston and Chicago could be used to operate from Boston to New York.

8. No right of way need be purchased and franchises it is believed, are not necessary.

It will be noted that I have not mentioned any disadvantages of wireless telephony for long distance work. I presume this is because I am not a telephone engineer. I hope the defects will be discussed by the experts who are familiar with telephone operation and therefore better able to point them out. Before leaving this part of the subject I would say that I think the question of interference has been worked out to such an extent that no serious difficulty need be feared in that direction.

C. *Transmarine Transmission.* Wireless telephony is peculiarly suited for this class of work. Pupin's ingenious and beautiful method has been successful at Lake Constance, Switzerland, I believe, but even assuming that deep-sea cables of this type could be laid and operated successfully, they would nevertheless be very much more expensive than wireless telephone stations. It is believed that wireless telephony will come into extended use for this purpose. Even without further development telephonic communication could be established between Norway or Denmark or Germany or Spain and Great Britain; between Sardinia and Corsica and France and Italy; between France and Algeria, between Australia and Tasmania and New Zealand; between the United States and Cuba and Porto Rico, etc, were it not that it is at present forbidden by law.

As regards telephonic communication between England and America, my measurements show that this should be possible with an expenditure of approximately ten kilowatts and suitably large towers say 600 feet high, or with some of the new forms of

antenna. Whether such a transmission would be commercially valuable or not is another matter. Personally I do not see that it would, but when I remember that at the time when the telephone was first being introduced a number of eminent business men decided that the house-to-house printing telegraph would be more of a success commercially than the telephone for the reason that no one would want to do business unless he were able to have a record of the transaction, I must admit that there is a possibility of my being mistaken in this.

D. *Wireless telephony from ship to ship.* Here, of course, wireless telephony occupies a unique position. Wireless telegraphy has the disadvantage that a telegraph operator must be carried. The additional expense is an objection in many cases. The proposition that the captain or mate should also be a telegraph operator has not met with favor. Anybody, however, can operate the wireless telephone and almost every vessel carries an engineer capable of repairing the electrical apparatus in case of accident. The final arrangement will, I believe, (if we can prevent the governments from carrying out their proposed laws, forbidding wireless telephony), be this; that passenger vessels will carry a telegraph operator and use the telephoning apparatus for ordinary work and for telegraphing where it is desired to communicate over long distances. Other vessels will use the telephone alone.

E. *Wireless telephone from ship to local exchange.* This also will, I think, have considerable value, as enabling the captain of a vessel to communicate, by relaying over the wire line, with the owner of the ship, or enabling a passenger on a vessel to communicate with friends on shore.

F. *Range of wireless telephony.* 1. *Atmospheric absorption.* The great obstacle to long distance wireless telegraphy and telephony is atmospheric absorption. For short distances up to 100 miles in the Temperate Zone there is little difference between the strength of the signals at one time of the day and another. As soon as the distance is increased much over 100 miles for the Temperate Zones and 40 or 50 miles for the Tropics the signals at night are very irregular and there is great absorption during the day time. The daylight absorption may be so great that less than a tenth of one per cent. of the energy transmitted gets through. Some nights will be as bad as day-time while on other nights there will be apparently no absorption.

Fig. 47 is a curve showing the strength of the messages transmitted between Brant Rock, Mass., and Machrihanish, Scotland, at night, during January, 1906. Nothing at all was received that month during daytime.

The change in the strength of the signals is very sudden. In working from Brant Rock to Porto Rico, a distance of 1700 miles, the strength of the signals with short wave lengths would fall off to one one-thousandth of their former value during a period of less than fifteen minutes, while the sun was rising.

Early experiments showed that the absorption was greater as the wave length was increased and the effect was at first attributed to absorption in the neighborhood of the sending

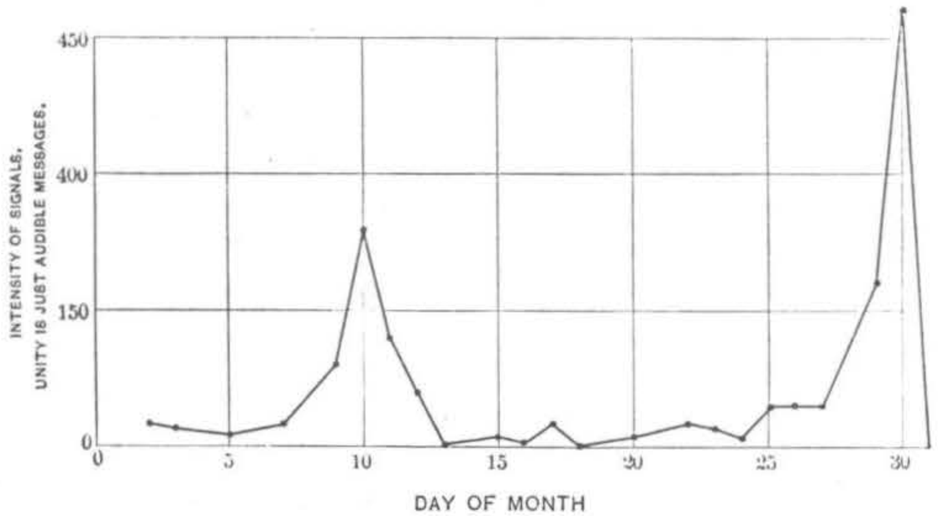


Fig. 47.—Curve showing variation of intensity of transatlantic messages for the month of January, 1906

station, and was thought to increase continuously with the wave length.[1] This fluctuating absorption at one time appeared to place a fundamental obstacle to commercial wireless telegraphy, as telegraph engineers will easily appreciate the impossibility of operating telegraph systems with circuits where the strength of the received signals may fall to one thousandth of its value

1. A mathematical explanation of this supposed fact was given by Dr. Fleming "Principles of Electric Waves Telegraphy" pages 617-618, 1906, the following conclusions being reached:

"Accordingly, the chief part of the weakening of the wave by sunlight is done in the neighborhood of the sending antenna, where the magnetic force H is greatest, and it is more sensible for long and powerful waves than for short and feeble ones. This agrees with the observations of Mr. Marconi".

or rise to a thousand times its value in the course of a few minutes.

It was therefore considered absolutely essential, in order to decide whether long distance wireless telegraphy was commercially possible or not, to investigate this phenomenon fully. As a preliminary the station at Brant Rock sent to four or five other stations at varying distances and comparative readings were taken. The following table shows the general character of the results obtained:

Station	Distance	Strength of signals received on worst nights (strength of unabsorbed signals being taken as 1000).
Company's cottage	200 yards	1000
Lynn	30 miles	1000
Schenectady	170 miles	500
Philadelphia	270 miles	300
Washington	400 miles	150
Machrihanish	3000 miles	1

These experiments proved conclusively that the absorption did not take place in the neighborhood of the sending station, because the strength of the signals received at nearby stations was the same during the day as during the night while there was great variation in the strength of signals received at stations further away.

It was also found that the absorption at a given instant was a function of the direction as well as of the distance, since on a given night the signals received by stations in one direction would be greatly weakened, while there would be less weakening of the signals received by stations lying in another direction, while a few hours or a few minutes later the reverse would be the case.

This was thought to be connected with the coming weather conditions but before this fact is proved a much larger amount of data must be collected. Through the kindness of the U. S. Weather Bureau I was enabled to obtain a chart of the magnetic variations and on comparison of these with the absorption between the Massachusetts and Scotland stations there appeared to be a quite definite relation, *i.e.*, the greater the absorption the greater the magnetic variation. Here also, however, much more data is needed before arriving at a definite conclusion. The fact that the absorption did not take place in the neighborhood of the sending station having thus been definitely settled

the next point to be investigated was whether or not there was any way of overcoming it.

The fact that variations in the absorption occurred with extreme rapidity, the absorption increasing sometimes a hundred fold in a single minute, and at night, when the effect could not be due to the sun directly, seemed to indicate that the body producing the absorption, whatever it was, was not in a state of continuity but was broken up into masses like clouds.[1] This also was in accordance with some experiments made in Brazil in 1905.

From optical theories it is known that where the absorption is produced by conducting masses of a more or less definite size the absorption is to a certain extent selective. The next point in the investigation was, therefore, to determine whether there

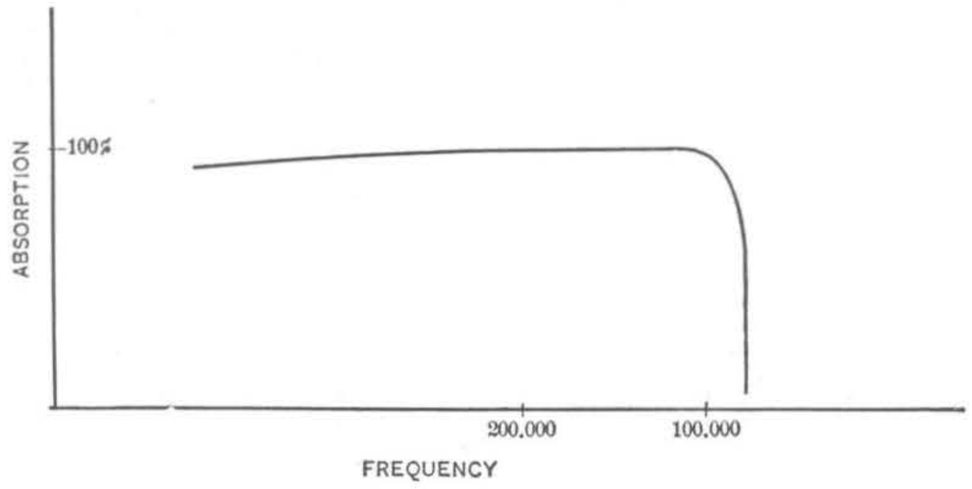


Fig. 47

was any possibility of this being the fact in the case of the absorption of wireless signals.

Comparative tests were therefore made of the absorption at night and during the day between Brant Rock and Washington, with wave lengths varying from a fraction of a mile up to four or five miles. It was found that the absorption did not increase continuously with the wave length but reached a maximum and then fell off with great suddenness.

Fig. 47 shows the general character of the curve, the ordinates referring to the amount of the absorption and the abscissas to the wave frequency.

1. *Electrical Review*, May 18, 1906.

It may be noted that the absorption is a maximum at a frequency of about 200,000 per second, nine hundred and ninety nine thousandths (0.999) of the energy being absorbed at this frequency during daylight, while for a frequency of 50,000 the absorption does not appear to be appreciable. Longer experiments, of course, might show some absorption, but in any case it is of a different order from the absorption for the shorter wave lengths.

Experiments were then made between Brant Rock and the West Indies, a distance of 1700 miles, during the spring and summer of 1907. It was found that the results were of the same character, *i.e.* that while there was greater absorption for frequencies of 200,000 there was comparatively little absorption for frequencies in the neighborhood of 80,000 and messages were successfully transmitted in daylight with this latter frequency. No messages were received in daylight with the higher frequency, though messages transmitted from the same station and with the same power and frequency were officially reported as having been received at Alexandria, Egypt, a distance of approximately 4000 miles.

The fact that these experiments were made during summer weather, and the receiving station was in the Tropics, and the fact that the distance, 1700 miles, was practically the same as that between Ireland and Newfoundland definitely settled the question as to whether long distance wireless telegraphy was a commercial possibility or not and the results were therefore published.[1]

Since the publication of the above results transmission has been accomplished by means of these long waves over still greater distances during daylight. Sig. Marconi early in October, 1907, abandoned the short-wave lengths previously used, and adopted one over two units in length, and immediately succeeded in operating between Glace Bay, Nova Scotia, and Clifden, Ireland a distance of more than 2000 miles, the frequency being approximately 70,000. The same messages were received at Brant Rock, Mass., a distance of nearly 3000 miles.

Still more recently Captain Hogg of the "Glacier" has written that during the southward passage of the Pacific fleet he received messages from the station at Brant Rock, Mass., while off Cape Ste. Roque, Brazil, S. A. The frequency used for sending was approximately 80,000, and the messages were

1. *The Electrician* (London), July 26, 1907.

received with the very interesting and sensitive silicon receiver invented by Mr. Pickard. This distance of 3000 miles is the greatest yet achieved by wireless transmission during daylight and would indicate that with the use of suitably high towers much longer distances can be reached.

2. *Range of wireless telephony and wireless telegraphy compared.* For the same power it is possible to telegraph to a further distance than to telephone. Distinct speech depends upon the presence of harmonics of a frequency as high as 1200 per second. The amplitude of these harmonics is according to some rough experiments made by the writer only about one per cent. of the fundamental frequency. Consequently, with a perfectly modulated transmitter 100 times as much energy would be necessary to telephone a given distance as to telegraph. It fortunately happens, however, that a carbon transmitter and also the circuits in which it is used, can be so constructed as not to modulate perfectly but can be arranged so as to accent the higher harmonics.

With transmitters arranged for the purpose good transmission has been obtained with thirty times the energy required to produce audible telegraphic signals. By still further modification the power required has been reduced to approximately ten times that necessary for telegraphing, curiously enough without noticeably distorting the character of the speech. There is one fact, however, which prevents the ratio from being as large practically as the instruments show, *i.e.*, speech can be satisfactorily understood with a less increase of power above a minimum audibility than telegraphic signals.

The amount of power necessary for wireless telephony may therefore be taken as approximately five to fifteen times that necessary for wireless telegraphy; *i.e.*, under the same circumstances and for the same power the wireless telegraph will carry two to four times as far. The difference in range would be very much greater also but for the curious fact that there is much less falling off with sustained oscillations than with intermittent groups of waves, even though the frequencies are identical.

This fact has been repeatedly determined by sending between Brant Rock and Brooklyn on the same frequency, using in the one case spark produced trains of waves and in the other the high frequency dynamo. The difference in the falling off for the same frequency and energy is very great but further work is necessary before anything very definite can be said about it or the reasons finally determined.

H. How Wireless Telegraphy has been Throttled by Governmental Action

The question has been asked why, if wireless telegraphy can compete with wire lines and cables, it is not put into operation. This is not an unnatural question. Ninety nine individuals out of a hundred would probably consider that if an inventor had perfected a system of wireless telegraphy or telephony so that it would operate reliably over long distances and would handle messages at a fraction of the cost of the present cables and without interfering with other stations, he would immediately pick out from an atlas half a dozen suitable points for operation, such as from France to Algiers, Italy to Egypt, Great Britain to Germany, New Zealand to Australia, Australia to Hong Kong, or Canada to Great Britain, and immediately commence commercial work, being perhaps delayed a few weeks on account of some slight formalities in connection with obtaining permits. The statement that nothing of the sort could be done would be received with incredulity, especially if it were known that the business men who would benefit by the reduced tolls were strongly desirous of having them put into operation.

This is a very important matter, not because the crushing out of a new system of telegraphy is so very important in itself, but because the prospects are that other branches of the electrical profession may have to face the same situation in the near future and it is, therefore, advisable to show in some detail just what governmental ownership means in its relation to the progress of civilization. I will, therefore, explain fully, but as briefly as possible how commercial wireless telegraphy is hindered by governmental action.

Examination of a chart of the world immediately suggests a number of points as suitable for the installation of wireless communication. For example the following:

1. United States to Cuba.
2. " " " Porto Rico.
3. " " " Jamaica and other West Indian Islands.
4. " " " Bermuda.
5. " " " Newfoundland.
6. " " " Great Britain.
7. " " " France.
8. " " " Azores.

9. Newfoundland " Great Britain.
10. Great Britain " Ireland.
11. " " " France.
12. " " " Spain.
13. " " " Germany.
14. " " " Denmark.
15. " " " Norway.
16. France " Algiers.
17. Italy " Egypt.
18. New Zealand " Australia.
19. Australia " Hong Kong.

The first fact to be noted is that these countries with the exception of Porto Rico are foreign countries and that in practically every one of these, Porto Rico is believed to be the only exception, there are stringent laws in force forbidding the erection of wireless stations without permits. The difficulty of obtaining these permits is shown by the fact that one wireless company within the writer's knowledge has been endeavoring for more than four years to obtain permits in the majority of the above mentioned foreign countries and has so far succeeded in obtaining only one permit and that for direct communication between the United States and Great Britain.

To take a specific illustration. In 1903 an American company was requested to install communication between Bermuda and the United States. The principal industry of Bermuda is the growing of produce of various kinds, which is exported almost entirely to the United States. The only present means of communicating is through Nova Scotia, and in winter especially, owing to the delays on the land lines, the service is often quite insufficient. Permission was asked of the Home Government by the Bermudian incorporators, but without success.

A petition was then signed by virtually every prominent business man in the islands and forwarded to the Home Government. The members of the New York Produce Exchange drew up a petition and forwarded it to the Secretary of State requesting him to use his influence in the matter. The Colonial Office stated in reply that it was favorable to the project but that the matter must be referred to other branches.

The Bermudian business men also sent several representatives to Great Britain to urge personally the granting of the permit. After a lapse of several years a definite reply was received to

the effect that the permit would not be granted. The Bermudians then took up the matter through a Canadian company which sent several representatives to interview the authorities in Great Britain but without success. The Lord High Commissioner of Canada, Lord Strathcona, finally was kind enough to interest himself in the matter and personally presented the case before the British authorities.[1] It is hoped by the Canadian company and the Bermudians that the permit will finally be granted, but this specific illustration will explain the difficulty in obtaining permits for operation.

As illustrating a different obstacle the case of Newfoundland may be taken. This is the natural point for establishing communication with Great Britain and the experiments previously referred to as having been made between Massachusetts and the West Indies showed conclusively that there would be absolutely no difficulty in operating commercially and with ease over this distance. On the other hand to operate directly from America is a much more difficult proposition for the reason that, as examination of a great circle chart will show, the whole of Newfoundland and Nova Scotia lies between any point in the United States north of Hatteras, and Great Britain.

If operation in Newfoundland were not forbidden by law half a dozen wireless stations would be at once erected, and the companies would be only too glad to pay into the Newfoundland treasury the ten or twenty thousand dollars per annum to be collected if they were put on the same footing as the cable companies in order to save the cost of the longer transmission. The Newfoundland government a number of years ago granted a monopoly of wireless telegraphy to one company, which company has never erected a transatlantic station in that island. While this monopoly has been very injurious to Newfoundland, on account of the loss of revenue entailed, it has been still more so to the wireless companies and to the public at large, which otherwise would have had cheap transatlantic telegraphy several years ago.

Another very formidable obstacle is the fact that in practically all the foreign countries referred to (and in Porto Rico) land telegraphy is a government monopoly. Consequently, the

1. Since the above was written a communication has been received from the colonial secretary stating that no decision will be given in the matter until the Wireless Company submits a plan for coöperating with the present cable companies (letter of Aug. 6, 1908).

wireless companies are entirely at the mercy of the government, are barred from collecting their own messages and must pay whatever tolls are fixed by the various governments. This, of course, also operates to prevent rapid service, since instead of communicating directly from Paris to London the messages would have to be sent from Paris by wire line to the French wireless station thence to the English wireless station and thence again by wire to London.

In a number of countries, the cable lines are also owned by their governments which makes them naturally averse to losing the invested capital or to permiting private companies to compete. It would be evident therefore that no matter to what perfection the art of wireless telegraphy is brought, years will elapse and the exercise of a great deal of political influence will be necessary before the public gets the advantages of the cheaper rates.

Ship communication. Here again the development of wireless working has been stifled by legislation. Vessel owners were at first rather slow to take up the matter of equipping their ships but after the system had proved its worth in several cases and some of the owners had had to pay large sums for salvage in cases where a wireless installation would have avoided the loss, its value began to be realized. It was at this point that the governments again stepped in with premature and injurious legislation. As a specific illustration, a United States company had arranged with the owners of some two hundred vessels to construct a line of stations from Maine to Texas, to operate with stations installed on the ships. The announcement was made that the administration proposed to recommend to Congress that wireless telegraphy be made a government monopoly.

A representative of the wireless company requested permission to submit some evidence to the effect that such a government monopoly was not necessary and that the various stations could operate without interference. A reply was received from the Administration that " information in regard to the subject was not desired ", and the administration recommended that wireless communication with ships should be made a government monopoly.[1]

It was proposed to carry this out as follows:

1. To establish Navy wireless stations at points along the coast

1. Recommendations of the Inter-departmental Board on Wireless Telegraph, 1904 submitted and approved by the Administration.

where wireless stations were needed by the merchant marine.[1-2]

2. To forbid the operation of private stations at these points.[3]

3. The Navy stations are to handle all messages to and from ships free of charge.

4. Wireless companies to be permitted, after obtaining a license from the Department of Commerce and Labor, to erect stations at points where there was no merchant marine business.[4]

The official approval and transmission of these recommendations by the Administration, although they were opposed and never went into effect, terminated, of course, all negotiations with vessel owners, since the owners would naturally not agree to contract for the transmission of their messages with the immediate prospect in view that the Government would transmit them free of charge. At the present time the masts ordered for the proposed line of stations are rotting at various points along the seaboard and the apparatus purchased for installation is deteriorating in storage.

The development of ship communication had just begun to recover from this blow when an International Wireless Telegraph Conference was arranged for by the various governments. In America no opportunity was afforded the wireless companies

1. *Ibid.* "That the maintenance of a complete coastwise system of wireless telegraphy by the Navy Department is necessary for an efficient and economical management of the fleets of the United States in time of peace and their efficient maneuvering in time of war."

2. *Ibid.* "As fast as the naval wireless telegraph stations are in operation the Navy Department shall receive and transmit through these stations free of charge all wireless messages to and from ships, providing such stations do not come in competition with commercial stations, until such time as Congress may enact the necessary legislation governing this subject". That the statement in regard to competition is disingenuous will be seen from examining the following extra Note 4, since only one station, and that a Navy one would be permitted at points where there was merchant marine business.

3. *Ibid.* "In asking for legislation on this point the board invites attention to the fact that where wireless stations are needed for the merchant marine, as a rule, the navy will also require them. The board believes it to be in the interest not only of governmental but of public economy and efficiency to permit the naval stations to handle the public service, for in the present state of the art but one station is desirable for the public interest in such places. It is admitted that there may be special cases where private stations can serve a useful purpose and the board believes that the Department of Commerce and Labor should have the duty of issuing licenses in such cases under such regulations as will prevent interference with stations necessary to the national defence."

4. *Ibid.*

of presenting the case to the delegates to the Conference, and a very stringent set of regulations was adopted. The Administration transmitted these regulations to the Senate.[1] The ratification of the treaty embodying these regulations was opposed by the Marconi Co., and by the National Electric Signaling Co. The following facts were pointed out:

1. That the proposed regulations virtually amounted to confiscation of the property of the wireless companies; that the working at present was carried on at a loss; that no wireless company was at the present time paying dividends; that the proposed rates would not permit of any return on the capital invested; and that the regulations would so limit the amount of business which it would be possible to transact that it would not pay to keep up the stations.

2. That the inventors in the art of wireless telegraphy had expended large sums of money in developing their systems, and such confiscation was therefore unjust and was thought to be unconstitutional.

3. That the regulations were impracticable in the following respects:

a. By requiring ships to use two tunes only[2] all stations were placed, so tc speak, on two-party lines, thereby producing a maximum of interference and preventing any one station working while any other was operating.

b. Allowing only five minutes per message and assuming only ten ships each with ten messages to be in the neighborhood of a given seaport, more than eight hours would have to elapse before the last station had transmitted its message. This time is believed to be underestimated, as the regulations provide that each ship before sending its message must call the coastwise station, have a number assigned to it, inform the coast station of its distance, its true bearing in degress, its true course in degrees, its speed in nautical miles, the number of words it has to transmit; must be informed how long it will have to wait, whether the transmission is to be in alternate order or in series, interrupt the sending after each 20 words, send an interrogation mark, wait for repetition of the last word, etc.[3] Hence it would be rather difficult to maintain the average time mentioned. This excessive delay would cut down the traffic to such an extent as to render it impossible for the stations to pay expenses of

1. Senate Document, Sixtieth Congress, first session.
2. Regulations II and III.
3. Regulations 19 to 26.

maintainance, and any telegraphic engineer will appreciate the difficulty of carrying on commercial business under such regulations.[1]

c. Placing all vessels on two-party lines introduces all the difficulties of the party line method and loses the only advantage, as it might easily happen that a ship in distress using one frequency might be within range of a number of vessels using the other frequency, but outside of range of any vessel using its own frequency. The obvious and practical method is legally to establish a single tune to be used exclusively for calling and distress signals but not for any other purpose; the transmission of messages to be continued by switching over to other tunes once the call has been received and accepted. In this way a ship in distress can always be sure of calling any vessel within range, while the transmission of messages can be carried on without interference and without one ship having to wait until the other is finished.

4. Its restrictions are of such a character as to prevent the future development of wireless telegraphy. For example.

a. The regulation[2] that all stations must carry a licensed wireless telegraph operator capable of receiving at twenty words per minute would prevent the installation of wireless stations on board the majority of ships since only the larger vessels can afford the additional expense of the operator. Many vessels would install wireless telephones which do not require a skilled telegraph operator, if it were not for this regulation.

b. The rules forbidding[3] the transmission of telegrams calling for repetition of messages, or for acknowledgement of receipt, or for telegrams to be forwarded, or for telegrams to be delivered by express or by mail, or for the transmission of money-order telegrams or for the transmission of telegrams with answer prepaid, or for the transmission of urgent telegrams are especially restrictive. By forbidding the transmission of telegrams of all the above classes the commercial field of wireless telegraphy is limited to such an extent as to deprive wireless telegraphy of its chief value.

1. As a practical illustration of this, on August 12, 1908, the Assistant Secretary of the Navy, on board U.S.S. Dolphin, had to wait two hours before an important message could be transmitted, as the two stations with which he was in range were occupied in sending a long message and the Dolphin was unable to cut in. Had a number of stations working on different times been available, this could not have happened.

2. Section 6, paragraph III.

3. Section XXXIII.

5. It expressly forbids the use of a number of the most important developments in wireless telegraphy. For example.

a. Section 3 in effect forbids long distance transmission in daylight. This section states that ships must not use wave lengths exceeding 600 meters. It is now well known that daylight absorption is very great for these wave lengths and that much longer wave lengths must be used during daytime. This rule therefore virtually forbids wireless telegraphy during daylight except within a very limited radius, and in case of an explosion or fire on shipboard during daylight the vessel would be unable to summon assistance unless by some fortunate chance another vessel happened to be within the radius limited by the restriction to the short wave length. It also virtually prohibits ships keeping in communication with the shore for more than twelve hours out of twenty-four.

b. Section 3 states that the system employed must be a syntonized system, thus forbidding the use of systems such as the heterodyne system which do not depend for selectivity on syntony. This would not be so injurious if it were not for the fact that the present indications are that syntony will in the near future be abandoned as a means of obtaining selectivity.

c. The rules of Section 2, 3, and 18 to 26, virtually forbid the use of duplex and multiplex systems. There is no reason why a number of ships should not communicate with the same station simultaneously, but the above rules forbid this by requiring only two wave lengths to be used and the messages to be taken one after the other.

d. It is premature. The expression "that an art is in its infancy" is a very hackneyed one but if it can be applied properly to any art it is to wireless telegraphy. The fact that the proposed regulations are unsuitable does not reflect in any way on the ability or conscientiousness of the delegates, though it would seem that it would have been advisable to consult the engineers of the various wireless telegraph companies before drafting the rules. The main difficulty, however, is that no one, no matter what his knowledge of the present state of the art, can foresee the future developments. The question of wave length and daylight absorption is an illustration of this, as is also the question of syntonized circuits. The time has not yet come for any such hard and fixed regulations as thus proposed.

6. It was also pointed out that the public had no rights in

regard to wireless telegraphy, since a patent differs from a franchise in that when the public grants a franchise it gives a right in respect to something which already exists and which it owns, and it therefore has a right to make what stipulation it chooses. In the case of a patent, however, the right is not given in respect to something which the public owns, but in regard to a new creation which exists merely in the mind of the inventor, to be called into being or not at the inventor's will, and therefore a thing in which the public has no right except as it obtains one by stipulation with the inventor. In the case of wireless telegraphy the companies invested their money under the patent law contracts with the various governments, and therefore the inforcement of regulations of the character proposed without the consent of the inventors is a breach of contract.

As a result of the hearing and of representations supporting the position of the wireless companies made by a very eminent electrical engineer the Senate Committee has decided to do nothing for the present in the matter. During the hearing the fact was brought out by the committee that the proposed regulations were passed upon the assumption that interference could not be kept out, and that the U. S. Navy had already made official reports on tests of interference preventers which showed that this was not the fact. On direct question by the Senate Committee the representative of the U. S. Navy present at the hearing freely admitted that it was a fact that interference could be kept out.

Still more recently another set of recommendations has been forwarded by the Administration to the Senate endorsing the recommendation of the Secretary of the Navy that a law should be passed[1] making it an offence punishable by imprisonment for one year of a fine of $2,000 or both for a private station to continue sending when called upon to discontinue by a Navy operator, or to produce interference with a Navy station when the latter is transmitting an official message. This recommendation was not accompanied by any recommendation to the effect that the Navy stations should use any means for keeping out interference. Before the transmission of this recommendation a conference was sought with the Navy officials with a view to drafting a form of regulation which would accomplish the results sought, without placing the wireless companies at the mercy of

1. *Congressional Record*, Feb. 14, 1908. Also H. R. bill 17719, 60th Congress, 1st Session.

the Government and without virtually confiscating their property but it was found impossible to obtain a hearing.[1]

The following memorandum of a portion of the interview between Secretary Straus of the Department of Commerce and Labor and the representative of the wireless company, asking for a hearing, will be of interest:

REPRESENTATIVE: " Will you not, Mr. Secretary, be willing to assist us in obtaining a treaty which, while giving the government all it desires in the way of intercommunication between different systems, reservation of wave-lengths for government purposes, etc., will, at the same time, avoid driving the wireless companies into bankruptcy? "

SECRETARY STRAUS: " The treaty was reported by the experts of the government departments, and we propose to carry it out, as it is the policy of the administration."

REPRESENTATIVE: " But, Mr. Secretary, these regulations virtually prevent the wireless companies from doing any commercial business. With everybody on one party line, even without the numerous other restrictions, it will not be possible to handle a sufficient number of messages to pay operating expenses, and the companies will necessarily be forced out of business."

SECRETARY STRAUS: That has nothing to do with this department. If you are injured you should go to the Congress and ask them to reimburse you.

REPRESENTATIVE: Mr. Secretary, you know that it would be practically impossible to get a bill to reimburse a private company through the Congress. Why should the government crush out a new and important method of communicating which will save the country millions of dollars yearly, when the government will gain nothing by the action. We feel that your department ought to assist us in this matter.

SECRETARY STRAUS: It has been decided by the administration that the treaty should be approved as it stands.

It will be noted that this conversation took place in the United States, and not in Russia, as might possibly be otherwise inferred. It will appear from this and the experience of others that the original object of the formation of the different government departments has been rather lost sight of in recent years.

It will perhaps be seen that the difficulties in the development of wireless telegraphy have not been wholly of a technical nature and more patience may perhaps in the future be extended to those engaged in the work.

In his book entitled " Public Ownership and the Telephone in Great Britain," Professor H. R. Meyer has treated specifically of the way in which the use of the telephone was opposed in Great Britain, by the English postal authorities with the object

1. See also appendix.

of, to quote the Postmaster General, Sir James Ferguson, "Guarding the Post Office monopoly." Professor Meyer shows how out of 77 companies which applied for licenses from 1882 to 1884 only 8 companies succeeded in obtaining permission to work, and how the various authorities prohibited the telephone companies from laying cables in the streets or from opening long-distance pay stations or from building trunk lines in order to force the public to use the telegraph instead of the telephone. It would appear that the same line of policy in a still more aggravated form has been adopted in connection with wireless telegraphy.

Considerations

The subject is, however, one which is bound to concern in the near future other branches of the engineering profession than those now affected and the present appears to be a suitable time for considering the matter more broadly.

Whatever the ultimate object of man's existence may be it is tolerably certain that it is not to occupy his entire mental activity with the question of how many grubs he can secure for food and where he can find a suitable hollow tree in which to spend the night. But whatever we have above this is due solely to the inventor (in which term I include not only the men who discovered how to produce fire and to build houses and steam engines and alternating current motors, and therefore all engineers whether they take out patents or not, but also those who discover how to distribute what is created in such a way as to make it available).

In the state of nature which Tolstoy so greatly lauds and so carefully avoids advance is impossible; all available energy of mind and body is necessarily employed in the problem of maintaining a bare existence. Before we can advance toward our goal, whatever it is, we must first have time and opportunity and a means of maintaining any advance. That we have this time and opportunity is due to the fact that by means of innumerable inventions we are rendered every day less dependent upon the accidents of nature. It would therefore appear, that whatever our ultimate goal may be, the first essential for reaching it is an increased control over the forces of nature.

This increased control can only be obtained through intense effort. When we see a performer at a circus contorting his body into apparently impossible positions we realize the peculiar aptitude and the many years of training which must have been

necessary. It is not generally realized, however, that a still more peculiar aptitude and many more years of still more intense training are necessary for those who would do useful work in any branch of mental achievement. We seldom think, in reading a mathematical paper for example, that the author has studied possibly for an average of ten or twelve hours a day for twenty or forty years before achieving sufficient proficiency in his subject to be able to accomplish the work.

To obtain results in a special line therefore a man with special aptitude and training is required. In addition to this there must be the opportunity. Hundreds of thousands, and in many cases millions of dollars are necessary for the development of an important invention. Such sums will not be furnished if there is no prospect of a return. As the success of an invention is always doubtful, the return from a successful invention must be sufficient to cover the losses from the much larger number of failures, for if the average return from one hundred inventions falls below that obtainable from mortgages or other forms of secure investment there will be no incentive.

The following question seem to me to be worthy of consideration:

1. Whether public officials, elected by the people, would consider themselves justified in expending millions of dollars on the development of inventions the success of which was uncertain.
2. Whether the best men to develop such inventions successfully would be found among the Government officials available.
3. Whether development can be expected in an art or industry entirely under Government control or ownership.
4. Whether universal Government control or ownership does not necessarily involve a fixed and non-progressive state as opposed to a state of progress and development.

Appendix

In the United States some additional hindrances on the part of the Government have been met with. For example, in the United States, and in Russia, as well, an inventor has no legal remedy in case the Government appropriates his invention.[1] It might be thought that the inventor could protect himself by suing infringing companies, but this is not so.

The wireless sets originally used by the United States Navy

1. Russel *vs.* United States, decided in 1900, 182 U. S. 516.

were imported from a country which was not at that time under the Patent Convention, and as they were purchased abroad no action could be taken. The then Secretary of the Navy, Mr. Moody, refused to require the foreign company to appoint a responsible representative in America. It was not until some years later, when, Mr. Morton being Secretary and the matter having been taken up by one of the Senators, this was done, and an injunction was obtained against the representative so appointed.

On further protest the next Secretary of the Navy, Mr. Bonaparte, stated that the patents could not be recognized as they had not been sustained. He was again approached but said that he had decided that he was not bound to respect them as he considered the price too high.[1] He declined, however, to allow the price to be fixed by arbitration, stating that he considered that the price should be fixed with reference to the cost of manufacture solely. It was pointed out that as the cost of labor and material of the particular device concerned amounted to less than a dollar and as a fair manufacturing profit on this would not be more than forty cents, this would afford no means whereby the company would be reimbursed for its expenditure of several hundred thousand dollars in developing the apparatus. To this Secretary Bonaparte replied that that was a matter which concerned the company and that his department had nothing to do with that. The principal infringing companies having been enjoined the Navy and Army began manufacturing the devices themselves in quantities.

Through the influence of one of the Senators the matter was again taken up and it was arranged that the Secretary of the Navy, Mr. Bonaparte, should obtain a legal opinion from the Attorney-General in regard to the matter. This opinion was prepared by one of the Attorney-General's assistants and proved to sustain the claims of the wireless company on every point. Before it was finally transmitted the Secretary of the Navy, Mr. Bonaparte, withdrew his request for an opinion.

The wireless company received a letter[2] from the Navy Department to the effect that by order of the Administration the patents had been turned over to the Navy Department. A written request[3] was forwarded to the Administration, pointing

1. Letter April 19, 1906.
2. Letter No. 137,244, July 11, 1906.
3. Letter April 3, 1907.

out that the above-mentioned property had been confiscated by the Government without a hearing and asking for a hearing. No reply was received.

The above is given as an illustration of the effect of the present law under which an inventor has no legal remedy against the confiscation of his patents by the United States Government. Among other recent instances of confiscation of inventions by the Government may be mentioned those of the Krupp and Armstrong Companies, the San Francisco Dry Dock, etc.

As the situation is not generally understood attention is here called to it. It should be remedied, as it operates very injuriously as regards the Government departments themselves. The Government is deprived of the services of American inventors who either place their talent at the disposal of other countries, as in the case of Hiram Maxim, or turn their attention to other lines. The general result is that the United States Government, instead of leading other nations, is obliged to follow after and copy, though the success of the United States Navy in developing submarine boats is an illustration of what can be accomplished in cases where the inventor has been able to develop his work without confiscation.

In 1906 President Roosevelt's attention was called to the above facts. He was asked if the administration would not introduce a bill to remedy this state of affairs. He replied that the administration had too many bills of its own to look after, but, on further inquiry, stated that if such a bill was introduced the administration would not oppose it.

On the strength of this promise a bill was introduced and unanimously reported, as follows:

HOUSE OF REPRESENTATIVES, 60TH CONGRESS, 1ST SESSION, REPORT No. 184

The Committee on Patents, to whom was referred the bill (H. R. 7653) to amend section 4919 of the Revised Statutes of the United States, to provide additional protection for owners of patents of the United States, and for other purposes, have considered the same, and recommend that the bill do pass with the following amendment:

In line 7, page 1, strike out the words " has been or," and insert the word " hereafter " after the word " shall."

A bill substantially the same as that now reported was passed by the Senate at the last Congress, and favorably reported to the House, but at too late a day in the session to receive consideration.

The object of the bill is to provide for owners of United States patents a remedy for the taking of their property by the United States for public use, when such taking occurs without the license or authority of such owners and without compensation.

In England and in practically all over civilized countries, except Russia and the United States, the Government can not appropriate an invention without paying a fair price for it. A regular tribunal is charged with the duty of determining what is a fair price for the use of an invention appropriated by the Government in case the Government considers the inventor's charge to be excessive. The United States habitually appropriates at its pleasure the patented inventions of its citizens and declines payment therefor. And this notwithstanding the fact that according to the decisions of the Supreme Court a patent of the United States is property within the meaning of the term as used in the Constitution and laws of the United States, and the use of a patented invention by the Government is a taking of private property, which can not be done lawfully without compensation to the owners. (Solomons *v.* United States, 137 U. S., 342, 346; McKeever *v.* United States, 14 Ct. Cls., R., 396; Affirmed S. C. 18 Ct. Cls., R., 745.)

But notwithstanding this right to protection which patentees and other property owners derive from Article V of the Amendments to the Constitution, it has been held by the Supreme Court that the owner of a patent can not restrain its infringement by the United States or an officer or agent of the Government. (Schillinger *v.* United States, 155 U. S., 163 (1894); Russell *v.* United States, 182 U. S., 516 (1900).)

In both of these cases the court held that in the absence of an express contract between the Government and the patentee, or transactions between them from which a contract may be implied, no court of the United States is vested with jurisdiction to entertain a suit or action by a patentee seeking to recover compensation for the use of his invention by the Government.

How next to impossible it would be to make a case of implied contract which would render the Government liable under the court's decision may be inferred from the following statement of the facts appearing in the Russell case just cited. It there appeared that at the Government's invitation Russell exhibited his patented invention to a board of officers appointed by the Secretary of War. The Government announced that it would adopt and use a device embodying his invention. Prior to the adoption and use of the device Russell communicated his patent to the War Department, showing that his patent covered the device and tended the use of his invention to the Government for reasonable compensation. The Government proceeded to use the device without denying Russell's right to compensation, but with the remark that he should seek his remedy by some means other than Executive action. And the Russell case is only a sample case; one of many.

It seems to be necessary and proper to provide for patentees a remedy, such as the passage of this bill will secure, for the invasion of their rights. Without such remedy, patentees are the only persons who are outside the protection of Article V of the Amendments of the Constitution. " Nor shall private property be taken for public use without just compensation."

Without such remedy a patent is not what it purports to be on its face. Many inventors have spent years of their lives and practically bankrupted themselves in developing inventions primarily of use to the Government, only to find in the end, after their property has been seized

by the Government, that they have no legal means of redress, and that the governmental Departments will not recognize the decisions of the courts.

Without such remedy there is a ridiculous discrimination between inventors. The inventor of a children's game or of a new brand of chewing gum is protected by the courts. But the inventor of a device which may save the nation from an humiliating defeat in time of war, or reduce the cost of carrying the mails, or reduce the number of shipwrecks on the coast, is afforded no protection; the governmental Departments have the power to confiscate his property and habitually exercise that power. It may be a new type of breech mechanism, or a dry dock, or a method of communicating with ships at sea; if the invention is valuable the Government can and does seize it, though the inventor may have spent years of his life and bankrupted himself and his friends in developing it.

It may be conceded that the Government ought to have the right to appropriate any invention necessary or convenient for natural defense or for beneficent public use, and that, too, without previous arrangement or negotiation with the owner. Nevertheless, the appropriation having been made it would seem that justice to the citizen demands that in due time he should receive fair compensation for his property.

The claim is made by some that the Government, being the grantor of the patent, ought to have the right to use without compensation such inventions as are necessary for its purposes.

One answer to this is that there is no such limitation or reservation in the law governing the granting of patents; and another answer is that if that were the law there would be no time, brains, or money spent by anyone in inventing those things for which there would be no remuneration.

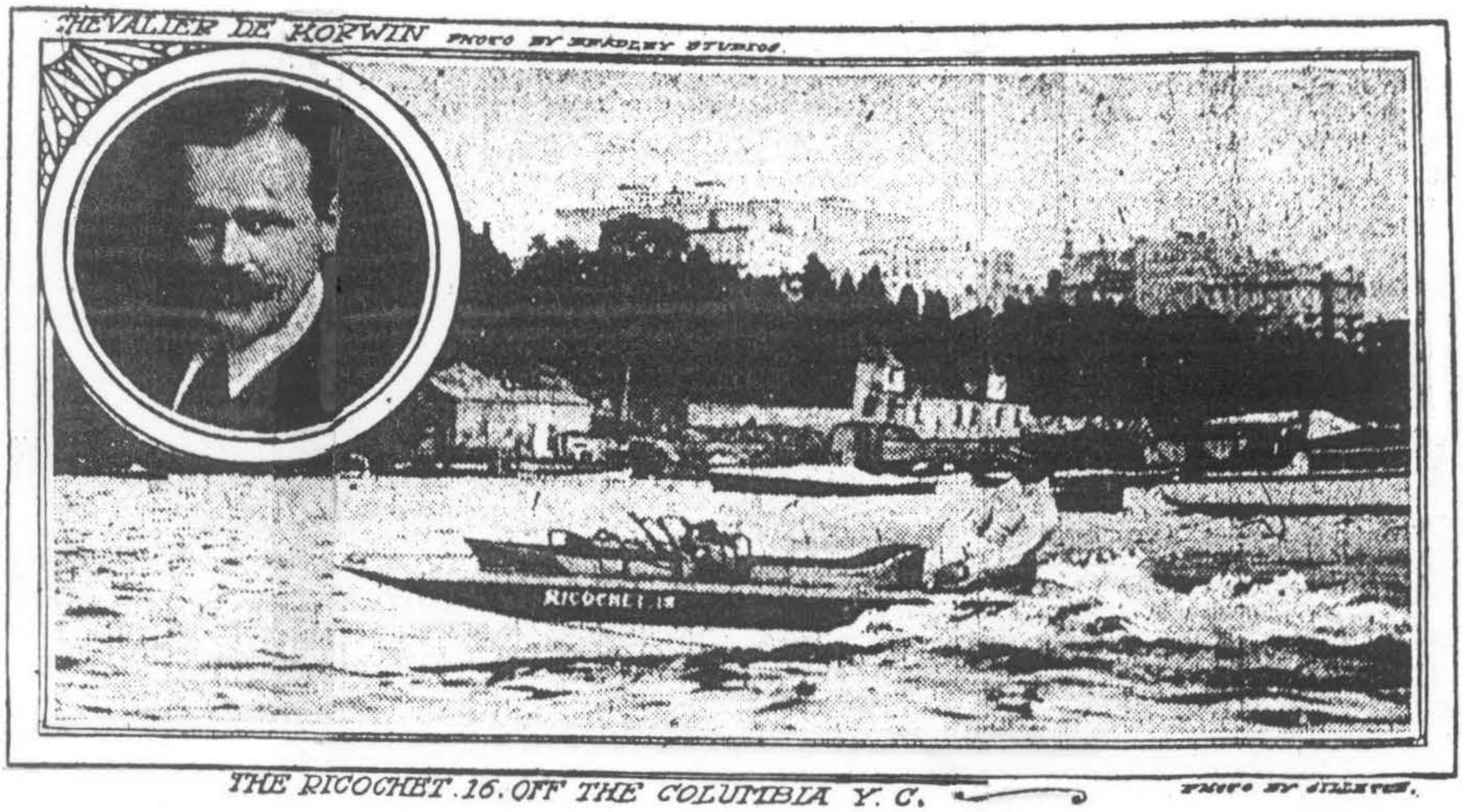
But it is useless to multiply reasons to justify the passage of the bill. The one fundamental reason already assigned is unanswerable—that no American citizen's property can be appropriated for public use by the Government or by anyone else without compensation being made therefor.

The amendment proposed, by striking out the words " has been or " and the use of the word " hereafter," in line 7, page 1, is deemed advisable, that there may be no question arising upon statutory construction that the law is not retroactive in its effect, but will apply only to future appropriations of patents by the Government.

It passed the House of Representatives by a large majority, the leaders of both the Republican and Democratic parties speaking in favor of it. It passed in the Senate unanimously. It did not become a law, however, as President Roosevelt declined to sign it, though its signature was strongly recommended by Secretary Taft, Senator Knox, and others. No reason was given by President Roosevelt for declining to sign the bill, but it is understood that his action was due to the fact that the ratification of the proposed wireless treaty had been opposed by one of those interested in the passage of this bill.

The New York Herald July 1, 1908

New Hydroplane Skims on the Hudson



THE RICOCHET 16 OFF THE COLUMBIA Y. C. PHOTO BY HADLEY.

Every one along the Hudson from Seventy-second street to Ninety-fifth street watched for an hour last night for a strange small craft that flew up and down the river at a rate varying from twenty-five to thirty miles an hour. It was not the speed of the device that attracted attention quite so much as its gait, which was more like that of a bucking bronco than of a motor boat.

The little craft was the Ricochet 16, a hydroplane, owned and driven by Chevalier Joseph de Korwin, chief of aeronautics of the Austrian army, who in the last year had devoted his attention to the development of a type of water vehicle that would make speed by skimming along the surface of the water rather than by driving through it. He arrived last week on the Provence with his hydroplane to try it in American waters, but it was not until yesterday that he succeeded in getting the craft through the Custom House.

At high speed it seemed as if the spray thrown up by the Ricochet would drench the operator, as he sat guiding the boat as much by the position of his body after the fashion of a cyclist turning a corner as by the twin rudders, the flat, scow shaped bow sending the spray high in the air at each bound. But the drenching was more apparent than real, for when after an hour's run he went aboard a yacht, the Nushka, his craft had not shipped a cup of water.

On the Nushka Chevalier de Korwin was entertained by Joseph H. Hoadley, who had as his guest Nikola Tesla, who of late has been devoting his attention to power boats, discovered that the Chevalier came from a short distance of his home in Austria and knew many of his relatives, after which they entered into a discussion of the value of relative types of propellers.

To him Chevalier de Korwin explained that his craft was twelve feet over all, four feet beam and at rest in the water drew only eight inches. In it is a 12-horse power gasolene engine, set well amidships at an angle of twenty degrees, which is also the angle at which the propeller is set. At high speed, as in all hydroplanes, this has the effect of pushing the boat upward and onward at the same time, which explains the skipping motion.

Before coming to New York Chevalier de Korwin took part in the motor boat races in the Adriatic from Fiume to Pola, a distance of 128 kilometres, for a trophy offered by the Prince of Monaco, finishing third in a heavy sea. In this race the winner had a 120-horse power engine, the second had five less and the fourth 100-horse power, as compared to his twelve.

In June two years ago the Chevalier made an attempt to go to Austria from England in a balloon and narrowly escaped being swept out over the Atlantic. After giving himself up for lost he made a landing near Dieppe, more dead than alive. Before making this trip he refused Oscar Lewisohn's offer of $50,000 to take him as a passenger, on the ground that he did not care to risk any life but his own.

Chevalier de Korwin will be in New York about a month, leaving for England to race at Cowes. He will do no racing while here.

"I came over for a chance to use the hydroplane on the Hudson," he said at the Plaza last night, "and I am glad I came, it is such a wonderful river.

"De Korwin is a wonderful fellow," said Nikola Tesla, after watching him run about the river, "and he gets every bit that is in his boat out of it, but that type will not develop the most speed. The resistance of the waves as he would strike them in a heavy sea would be greater than the resistance a boat would meet gliding through the water. He is a wonderful operator and knows every trick apparently. With my new propeller he could go twice as fast."

"Speed is largely a matter of power," said the Chevalier. "With a twenty-four horse motor in this type of boat I have travelled at the rate of mile a minute. I have made high speed in the roughest of weather; in fact, I rather like to have it some rough."

SIMPLE EXPLANATION OF HIGH FREQUENCY CURRENT.

Within recent years some very astonishing things have been done with high frequency electric current. It is extensively used by medical practitioners, for wireless telegraphy, etc., and seems to act in a manner widely different from the ordinary electric current now more or less familiar to all. The following explanation of high frequency current will be found perfectly simple and will enable the average person to understand the seemingly magical things done, which are often seen at electrical shows and like exhibitions.

When the current flows in one direction in a conductor and then reverses and flows in the opposite direction it is said to be an alternating current. The number of times per second that the current makes a complete change of the direction and comes back to its original direction of flow is called its frequency. The frequency of commercial alternating currents is seldom over a hundred per second, and generally less. A high frequency current is one in which the frequency is numbered in the thousands or millions per second, although there is no strict dividing line where high frequency begins and low frequency leaves off.

Machines that produce high frequency currents directly are called high frequency alternators. Very few of them have ever been made, other methods having been devised for changing ordinary low frequency currents into those of high frequency.

The general method used is as follows: What is known as a step-up transformer is used to raise the voltage of ordinary low frequency current to a pressure of several thousand volts. This current is used to charge a condenser which consists of either the common Leyden jar or its equivalent in plates of glass, ebonite or mica coated with tinfoil.

When such a condenser is discharged through a suitable coil, high frequency current is produced. A Tesla coil for this purpose consists of a primary winding of a few turns of heavy wire and a secondary of finer wire of many more turns spaced apart to prevent short circuits between adjacent turns. Coils of

this kind are often immersed in oil for insulation. There is no iron core of any kind in a Telsa coil. When the condensers are discharged through the primary of a Tesla coil in series with spark gap, which is simply a break in the circuit over which a spark jumps, a current of enormous voltage and frequency is produced in the secondary. With this current can be produced many interesting and peculiar phenomena. Fig. 1 shows at the left the transformer for raising the pressure or voltage of the ordinary current to several times its original value. Next is the glass plate condenser, and at the extreme right is the Tesla high frequency coil.

When one terminal of the Tesla coil is grounded, long specter like streams of sparks dart into space in all directions from the other terminal. If the capacity is increased these streams resolve themselves in flames making a striking display as shown in Fig. 2.

Nikola Tesla, while in Colorado carrying on a series of experiments, produced discharges 23 ft. in length, passing a current of 800 amperes at the tremendous pressure of 10,000,000 volts, producing a roar that could be heard for miles. At ordinary frequencies it is well known that current at a pressure of 1,000 volts and over will cause instant death. If, however, the frequency is very high, instead of producing death there is no sensation whatever and the current can be handled with impunity.

In the electrocuting of criminals a voltage of about 2,000 is used and only one-fourth ampere of current is sufficient to cause the death of any man. If an ordinary 16 c. p. lamp is held in the hand by one terminal and the other connected to only one terminal of the Tesla coil the lamp lights up brilliantly, consuming fully one-half an ampere or double the current used for electrocution, besides being painless. If any one doubts that the current passes through the body another method of holding the lamp will convince him. If the terminals of the lamp are connected to two persons and

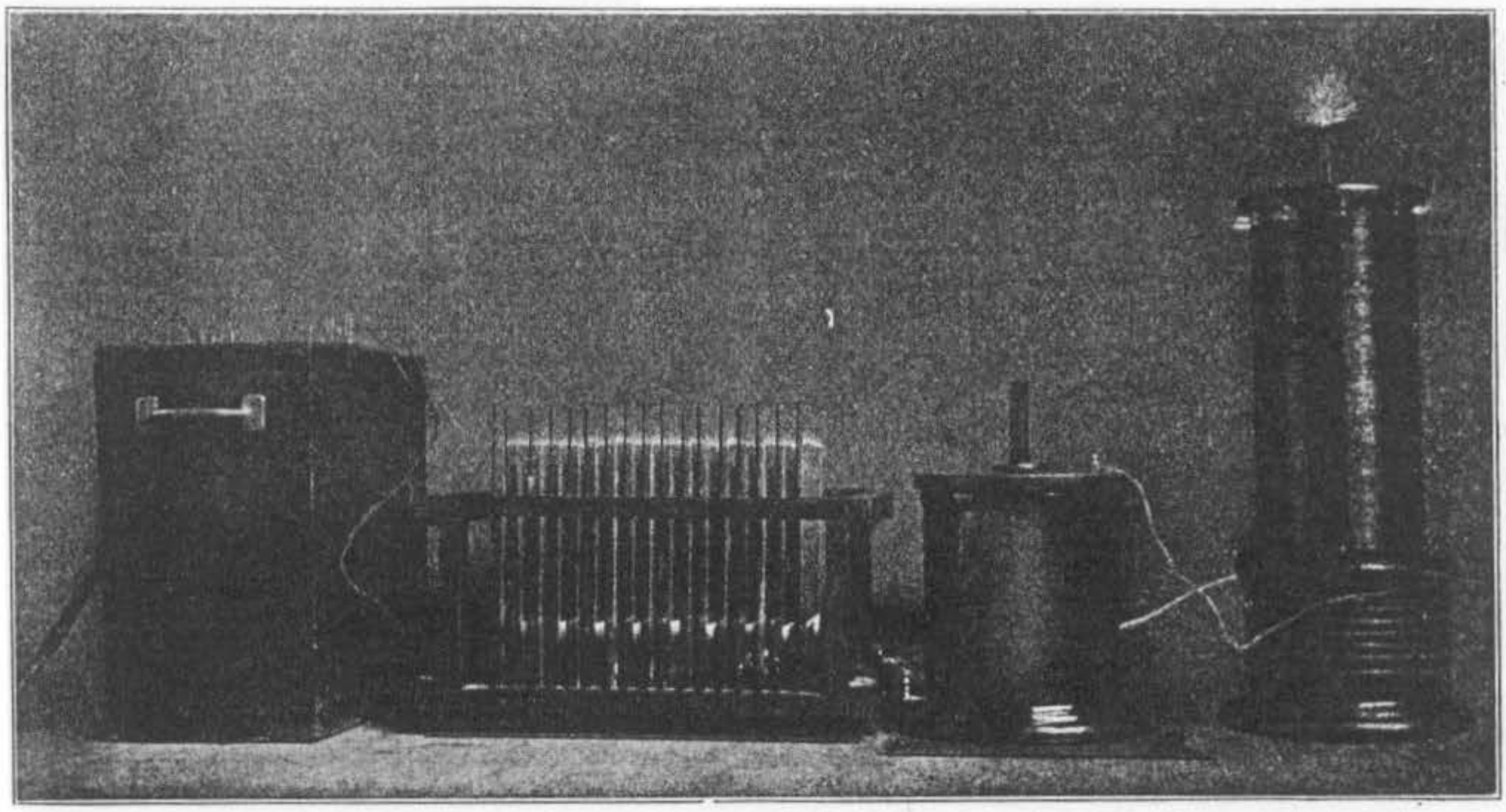


FIG. 1. APPARATUS FOR GENERATING HIGH FREQUENCY CURRENTS.

the terminal of the coil is connected to either one of them the lamp burns at full candle power. Even fine iron wire can be melted in two in the same way.

When the coil is in operation and is approached by a metal rod held in the hand the spark of the coil, which may be of over a foot long, will jump to the rod and entirely disappear if the terminal is touched, showing that all the current passed through the body.

With the pressure of this coil over 100,000 volts, if one person touches the terminal of the coil and another person comes near, sparks jump to the second person when several inches away. If a

vacuum tube is held in the hand in the vicinity of the coil it will glow with a soft white light, but if the coil is touched the effect is greatly enhanced, so that it is possible to read by it. Geissler tubes are affected the same way.

This current would rather jump a considerable distance through air than go through even a few turns of heavy wire on account of the choking effect. This effect can be shown in a remarkable manner by connecting an ordinary 16 candlepower lamp in series with a piece of heavy wire bent in a circle. This lamp, although short circuited, can be

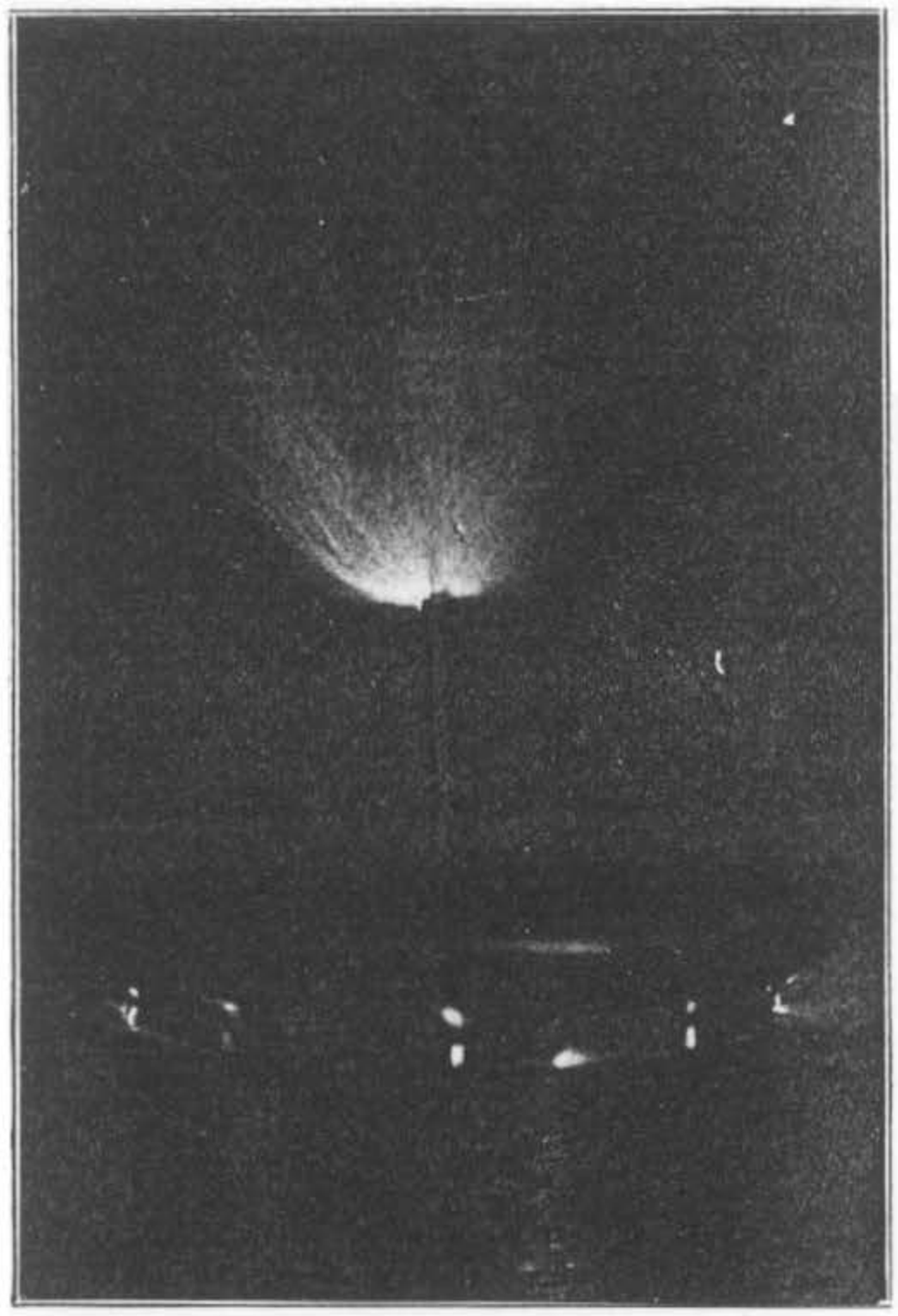


FIG. 2. DISCHARGE OF A TESLA COIL.

lighted to full candlepower by touching it to the coil, showing that the current would rather go through the lamp of high resistance than through the heavy wire whose resistance is negligible.

When a Tesla coil of considerable power is in operation sparks can be drawn from metal objects in the vicinity, although many feet away.

Wireless telegraphy is a practical application of high frequency currents.

In wireless telephony frequencies of from 100,000 to a million are used.

In electrotherapeutics the high frequency current is valuable.

Generally the source used to generate the high pressure necessary to charge the condensers is an X-ray coil, when used in electrotherapeutics.

It is held by many, Tesla among the number, that high frequency currents will work a revolution in the application of electric force, and that the electric power of the future will be produced in high frequency generating plants, will be sent out through space without transmission wires and will be collected at will at any point desired.

Problems of Aerial Motive Power.

Nikola Tesla.

PROGRESS in aerial navigation is essentially dependent on the perfection of a process of producing great mechanical effort with light machinery. Viewing the possibilities, near and remote, motive power is obtainable in four ways:—First, by transforming the heat energy of fuel in an internal combustion engine; second, by converting the electro-chemical energy of a primary or secondary battery in an electric motor; third, by harnessing, on the moving vessel itself, the energy of the surrounding medium and, fourth, by transmitting to it without wires the electrical energy of a distant source.

The first two methods are based on the use of a store of energy, which must be carried and periodically refilled, thus limiting the speed and duration of flight. The last two imply a flow of energy to the flying machine from without, the supply being continuous and inexhaustible. They are, therefore, immensely superior to the former.

Careful thought leads to the conclusion that the wireless method would be decidedly the best for the peace and welfare of men. But no matter how perfect the means for obtaining motive power, it will never be possible to go beyond certain rather narrow limits in aerial performance.

The atmospheric ocean is ideally adapted to travel, permitting, as it does, perfect freedom of movement in three directions, but the physical properties of the air make it rather unsuitable for navigation. It is a sticky or viscous substance, a hundred times more so than water,



NIKOLA TESLA

which means that it offers a relatively very great frictional resistance to a body in motion. Its small density is for many reasons detrimental to high efficiency of propulsion. Its compressibility, turbulence and perpetual unrest all cause additional specific losses of motive power. These properties forever preclude the possibility of excessive speed with reference to the surrounding air by the aeroplane as well as the dirigible balloon.

Making every allowance for future achievement, it is idle to expect that the record on land or water will be surpassed.

The question is frequently asked, Which of the two types, the heavier or lighter than air, is superior? No expert who has studied the subject thoroughly can be in doubt that the latter is by far the better of the two. The aeroplane has caught the public fancy, but such feats as those of Count Zeppelin will tell.

Many erroneous ideas relating to aerial flight have taken hold of the minds of the people. In view of this it may be useful to point out the following facts:—

1. The recent progress in aerial navigation is the direct and obvious result of the development of the internal combustion engine.

2. None of the latest flying machines, aeroplane or dirigible, contains a radically novel feature of importance.

3. The self-propelled balloon is by far superior to the aeroplane in carrying capacity, speed, cruising radius, safety and economy.

4. The aeroplane can never have more than half the propelling efficiency of the lighter than air machine.

5. The dirigible balloon is all the better the larger. The aeroplane gains nothing with size.

6. The inclined plane, that is, the rectilinear propeller, as a means of support is in all practical respects inferior to a vertical rotary propeller.

7. To produce an efficient high speed flying machine the screw propeller must be replaced by a better means for propulsion.

8. No machine, however perfect, supported in air against the force of gravity by buoyancy, dynamic effort or otherwise, can ever equal in speed a machine which derives its support from land or water.

9. The most pressing need in aerial navigation is unfailing protection against lightning.

The New York Times September 15, 1908

TESLA ON AEROPLANES.

Says Successful Heavier-Than-Air Flier Will Be Different.

To the Editor of The New York Times:

The chronicler of current events is only too apt to lose sight of the true perspective and real significance of the phases of progress he records. Naturally enough, his opinions on subjects out of the sphere of his special training are frequently defective, but this is inseparable from the very idea of journalism. If an editor were to project himself into the future and view the happenings of the present or of the past in their proper relations he would make a dismal failure of his paper.

The comments upon the latest performances with aeroplanes afford interesting examples in this respect. What is there so very different between a man flying half an hour and another, using a more powerful machine, an hour, or two, or three? To be sure, in one instance the supporting planes are larger and the gasoline tank bigger, but there is nothing revolutionary in these departures. No one can deny the merit of the accomplishments. The feats are certainly remarkable and of great educational value.

The majority of human beings are unreceptive to novel ideas. The practical demonstrator comes with forceful arguments which enlighten and convince. But they are nothing more than obvious consequences of what has preceded, steps in advance which, taken singly, are of no particular importance, but which, in their totality, make up the conquest of the world by the new idea. If any one stands out more strongly than the other it is merely because it chances to occur at the psychological moment, when incredulity and doubt are giving way to confidence and expectancy. Such work is often brilliant, never great, as some would make believe. To be great it must be original. Of such feature it is absolutely devoid.

Place any of the later aeroplanes beside that of Langley, their prototype, and you will not find as much as one decided improvement. There are the same old propellers, the same old inclined planes, rudders, and vanes—not a single notable difference. Some have tried to hide their "discoveries." It is like the hiding of an ostrich who buries his head in the sand. Half a dozen aeronauts have been in turn hailed as conquerors and kings of the air. It would have been much more appropriate to greet John D. Rockefeller as such. But for the abundant supply of high-grade fuel we would still have to wait for an engine capable of supporting not only itself but several times its own weight against gravity.

The capabilities of the Langley aerodrome have been most strikingly illustrated. Notwithstanding this, it is not a practical machine. It has a low efficiency of propulsion, and the starting, balancing and alighting are attended with difficulties. The chief defect, however, is that it is doomed if it should encounter a downward gust of wind. The helicopter is in these respects much preferable, but is objectionable for other reasons. The successful heavier-than-air flier will be based on principles radically novel and will meet all requirements. It will soon materialize, and when it does it will give an impetus to manufacture and commerce such as was never witnessed before, provided only that the Governments do not resort to the methods of the Spanish Inquisition, which have already proved so disastrous to the wireless art, the ideal means for making man absolute master of the air.

NICOLA TESLA.

New York, Sept. 13, 1908.

The St. Louis Republic November 15, 1908

ELECTRICAL CONTROL OF THE WEATHER WILL SOON BE AN ACCOMPLISHED FACT

—NIKOLA TESLA.

"For more than eighteen years I have experimented with the atmospheric effects of electrical discharges of tremendous strength. In my latest plant I expect to get a maximum rate of electrical discharge approximating 1,000,000,000 horse-power. While I am not familiar with the experiments along this line of anyone else, I have no hesitancy in declaring that the next step in the mastery of man over Nature will be the absolute control of the weather."

This statement, made by Nickola Tesla admittedly one of the greatest electricians of the age, when told of the recent experiments looking toward the control of the weather by electricity made by John A. Grahme.

"Atmospheric effects, such as Mr. Grahme claims to be able to produce," continued Mr. Tesla, "necessitate the production of electrical discharges far beyond any that have yet been obtained by artificial means. That, however, is a mere detail. I am convinced that weather conditions are of electrical origin, and so must be susceptible of electrical control.

"I believe the day is near when man will not only forecast the weather with absolute accuracy, but will control it. Any one at all familiar with the fields opened up by recent experiments with high-tension electrical currents would hesitate to draw the line between the possible and the impossible.

"At present we are at the threshold of an era pregnant with tremendous possibilities. Every new discovery opens up new lines of thought and research; and despite the wonders that have been accomplished during the past half century, the surface has hardly been scratched.

"Of course, every man exploring in an undeveloped field is a butt for the ridicule of a skeptical public. Every announcement of a step forward in the fields of science and invention has been greeted with sneers and unbelief. Public opinion crucified Christ, imprisoned Galileo and branded Columbus a lunatic.

"I know nothing of the experiments of Mr. Grahme, but from my own work along similar lines, I am positive that the results he claims are possible of accomplishment and that this great problem will be solved in the very near future."

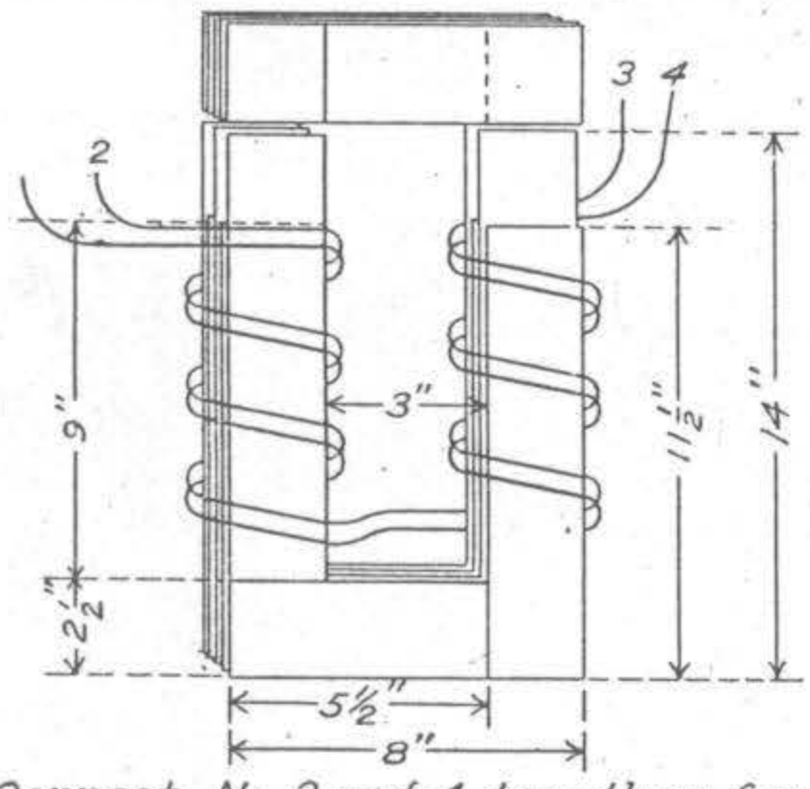
Popuular Electricity January 1909

HOW TO MAKE A HIGH FREQUENCY APPARATUS.

BY H. L. TRANSTROM.

Many readers of Popular Electricity have been interested in an article which appeared in August in which I described the general principles of an outfit producing high frequency currents, and in response to requests to give the details of construction of such an outfit this article has been written.

A transformer is needed, giving ten or 20,000 volts to charge the condenser. To construct one it is necessary to make a core from soft sheet iron strips, with a cross-section 2½ inches square, built in



Connect No.2 and 4 together for series connection and for parallel No.1 & 2, And also 3 and 4.

FIG. 1. TRANSFORMER FOR HIGH FREQUENCY WORK.

the shape of a rectangle 8 by 14 inches outside dimensions and 3 by 9 inches inside (see Fig. 1.)

Cut from the sheet iron, strips 2½ by 5½ inches and 2½ by 11½ inches, sufficient to make a mass five inches thick of each size when compressed in a vise.

Then take three strips at a time and build a core of the dimensions given in Fig. 1, leaving the top section unfinished until the secondary coils are placed in position.

To hold the core in shape after it is assembled, take two pieces of dry wood 12 by 3 by 1½ inches and bore a hole in the ends of each, nine inches apart. Put one board on each side of the bottom section and place in a vise, when the six-inch bolts can be drawn tight and then the core will be rigid.

On the vertical sections wrap tightly two or three layers of friction tape to within 2½ inches from the top. Over this wrap a couple of layers of Empire cloth.

The primary consists of 110 double turns wound in a single layer over the Empire cloth, the conductors being two No. 12 cotton-covered copper wires placed side by side, 55 double turns on each vertical section (see Fig. 1.)

Over the primary winding next wind tightly 15 layers of No. 7 Empire cloth 9 inches wide and we are ready for the secondary winding.

In winding the secondary much care must be exercised, as a transformer's insulation is no better than its weakest spot. This secondary consists of 20,000 turns of No. 32 single cotton-covered copper wire wound in eight coils of 2,500 turns each, which are connected in series, four coils on each side.

The coils are rectangular in shape 1¼ inches wide, four inches square inside and six inches square outside dimensions. They are wound on a form 1¼ inches wide and four inches square, the lateral edges being slightly rounded off to facilitate winding. This form is carefully centered and a metal rod about six inches long of any convenient size is passed through, with a small crank fastened on one end. To keep the coil from sliding out of shape make two disks seven inches in diameter, and when centered screw one on each side of the form.

Set this form between two supports and begin winding, first a layer of Empire paper and then a layer of wire alternately, until the 2,500 turns are on. It will be found very easy to wind this fine wire in layers if it is allowed to slide over a rod a foot or so away and guided with one hand while winding with the other. Leave a margin of ¼ inch in each layer.

All coils should be tested to see if there are any bare places or if the wire is in one continuous piece. If not, do not attempt to use it as it will surely

burn out when run a short time. When all coils are completed they should be dried in an oven, not too hot, and then laid flat in hot petroleum and boiled for several hours, and then left to cool in the mixture until set, which will take quite a long time.

When thoroughly cold, take carefully out of the mixture and after taking the surplus off the coils, assemble on the core over the primary, four on each side. To keep the coils insulated from each other, cut 36 squares of Empire cloth 7 by 7 inches and cut out of their centers a hole that will fit snugly over the Empire cloth on the primary. Use six thicknesses between adjacent coils, there being only six places to use these separators.

The coils should all be connetced in series as though it were one continuous wire beginning at the top of one section and ending at the top of the other. (See Fig. 1).

Connect all coils so that they have the same relation to one another as the turns in the primary. Keep the coils one inch from the bottom of the core by inserting narrow strips of birch wood across the binding boards and cover with several thicknesses of Empire cloth.

When all the coils are assembled and connected properly, the top part of the core may be completed. A sheet of micante 9 by 4 by 0.1 inch should be used to separate the vertical sets of coils. Make a box of close-grained hardwood 7 inches wide by 15 inches high by 14 inches long inside measurements and coat thoroughly with hot paraffine to make it perfectly tight.

When the transformer is set in the box it may be fastened by screws to the bottom binding boards.

Bring the ends of the primary wires to one side of the box and the secondary to the other side where they can be connected to proper binding posts. The secondary wire should be kept clear from the core and be led out through hard rubber rod binding posts. The four primary wires should be arranged so that they can be easily connected either in series or parallel.

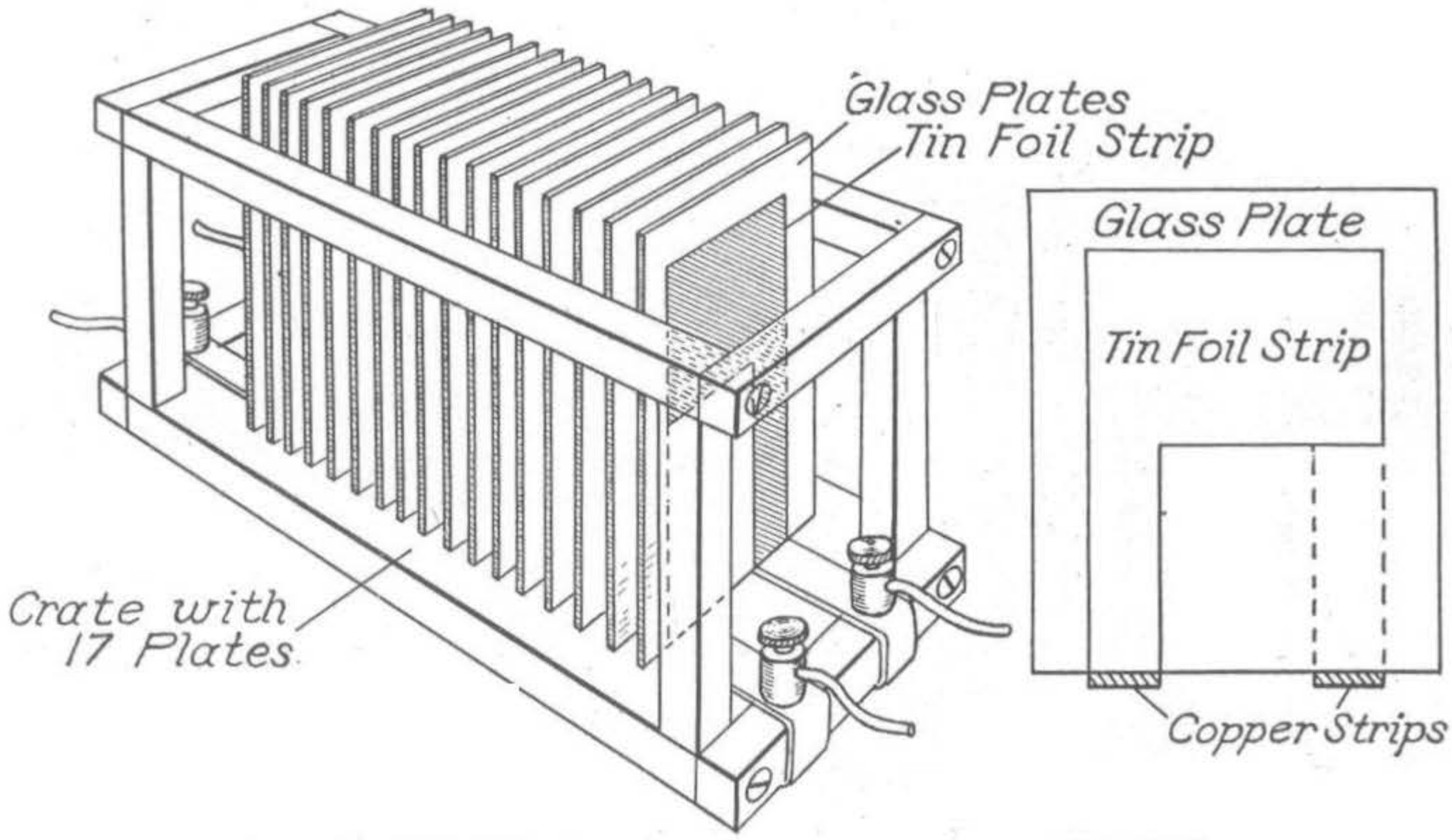


FIG. 2. CONDENSER FOR HIGH FREQUENCY APPARATUS.

Boil 40 pounds of extra amber petroleum and fill the box to the top and screw fast the cover and the transformer is complete.

Next we construct an adjustable condenser of 17 plates of double thickness window glass 10 by 12 inches. Coat all the plates with tin foil 5 by 6 inches on both sides. Leave a margin of two inches on top and sides and five inches on the bottom. On eight of these plates paste a strip of tin foil on the lower right hand corner to reach the bottom and on

the other nine paste them on the lower left hand corner of the foil. These are the connectors which rest on two copper strips laid parallel four inches apart on the bottom of the crate with binding posts on each end. The strips are fastened on and insulated from the bottom of the wooden crate, with slots in the sides to receive the plates. (See Fig. 2.)

The Tesla coil consists of a primary of seven turns of No. 6 bare copper wire and a secondary of 180 turns of No. 22 bare copper wire wound in a single layer on a drum 6 inches in diameter and

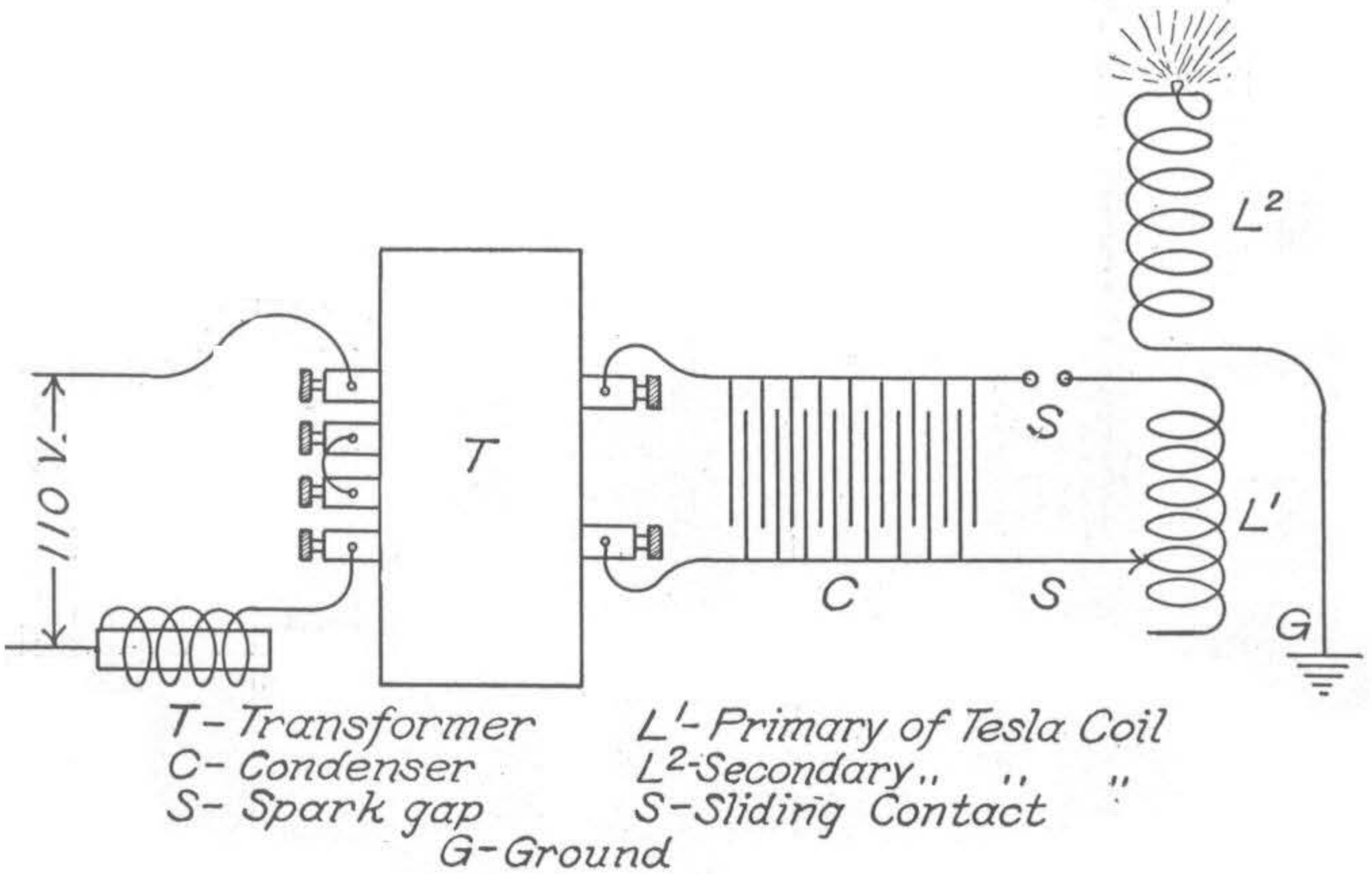


FIG. 3. CONNECTIONS FOR HIGH FREQUENCY APPARATUS.

14 inches long made of dry birch boards glued together in a circle and then turned off in a lathe. The turns of wire are carefully spaced apart 1-16 inch when winding, and leave a margin of ½ inch on the ends. The primary is wound on a wooden drum 8 inches in diameter and 4½ inches long, the turns being carefully spaced apart and fastened. The secondary coil is set on top of the primary coil and the base fastened to the bottom drum.

Give the secondary winding a coat of orange shellac, being careful not to disturb the turns while doing so. A nice turned top can be added for appearance, and a brass rod 4 inches long and ⅜-inch thick driven tightly in the center of the top and well rounded off, will be the discharge rod, being connected to the top end of the secondary wire.

The lower end of the secondary terminates in another binding post.

On the primary a binding post is fitted at only the upper end, while the other connection is a sliding contact.

For a spark gap take a glass jar about 6 inches in diameter and 8 or 10 inches in height and make a hole in the bottom ¼-inch in diameter. To do this take clay or putty and lay a thick layer over the center of the bottom of the jar. Make a ¼-inch hole in the clay down to the glass and fill with hot solder. The glass will fall out the shape of the hole in the putty or clay.

Make a cover from some nice hardwood to fit tightly in the top of the jar, and bore a hole in the center, in which fasten securely a threaded ¼-inch nut which is connected by a wire to a binding post on one edge of the cover.

A ¼-inch rod threaded the whole length is fitted with a hard rubber handle ¾ by 3 inches long. This is screwed in the threaded nut. The length of rod depends on the height of jar used. Another rod is fitted with a metal ball ¾-

inch in diameter and inserted in the hole in the bottom and then through a base of hardwood on which a binding post is placed.

Now to operate the completed apparatus connect as per diagram, Fig. 3.

Connect the lower terminal of the secondary of the Tesla coil to a good ground with stranded wire as a stranded wire is a better conductor for high frequency currents than is solid wire.

Although I obtained the results shown in the August issue by using the primary in parallel on 110 volts 60 cycles, consequently 20,000 volts secondary voltage, yet I have obtained as good results with better control by using the primary sections in series and an adjustable choke coil in series with them. The choke coil can be made from a mass of sheet iron 2½ by 2½ by 8 inches, which is inserted in a hollow coil of No. 10 copper wire of 110 turns.

By inserting the core in the coil the current can be varied according to the depth inserted. This outfit is for the unipolar or single pole method of generating high frequency currents. If all connections are correctly made the spark gap should be turned until the spark will just jump easily, then on the primary of the Tesla coil move the sliding contact on the second turn from the top. If the coil does not do as shown in the picture in the August issue move the contact on the next turn and so on until it does.

To light a lamp use the fourth or fifth turn and slide the lamp along the side until the brightest light is obtained.

Always disconnect the primary of the transformer before attempting to adjust the different parts.

By adding condenser plates or taking them out of the crate, one by one, the coils will be brought in tune under certain conditions.

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tion belongs to the United States, there being a line at Camp Bird, Colorado, which is 13,000 feet above the sea level.

[317.]—TESLA COIL.—It is quite possible that the No. 20 wire is too large for the output of your coil, or, perhaps, you have leakage. Before making alterations, try if the effect is improved by inserting the new large coil in a basin of paraffin or linseed oil. If this does not improve matters, add more wire. Insulation is an important factor. Arthur E. R. Bottone.

[500.]—TESLA APPARATUS.—To Mr. Bottone.—This is practically a transformer, which can be used either as a "step up" or step down," according to whether you connect the primary or secondary to the terminals of your spark coil. It is necessary, however, to insulate the winding much more carefully, and, having wound the primary on the iron core, insert it bodily in an ebonite tube, over which wind the secondary; then immerse the whole in a non-conducting vessel of boiled linseed oil. The iron core should be of soft iron wire, making a bundle of about ¾in. diameter and 8in. long, and wound with two layers of No. 14 guttapercha-covered wire. The secondary may consist of about thirty layers of No. 26 silk-covered wire. Full particulars and illustrations are given in S. R. Bottone's book, "Electrical Instrument Making."

Arthur E. R. Bottone.

TRANSATLANTIC WIRELESS TELEGRAPHY.[1]

ON previous occasions I have had the honour of describing before this institution some of the stages through which the application of electric waves to telegraphy through space has passed. This evening I propose to confine myself chiefly to describing the results and observations recorded during the numerous tests and experiments which my collaborators and I have been carrying out with the object of proving that wireless telegraphy across the Atlantic was possible, not merely as an experimental feat, but as a new and practical means for commercial communication (Journ. Inst. Elec. Eng., xxviii., 1899, p. 291).

In March, 1899, communication was established by means of my system of wireless telegraphy across the Channel between England and France (see Fig. 1), and the *Times*



of March 29 of that year published the first Press telegram ever transmitted to England from abroad by means of electric-wave telegraphy.

At that time a considerable discussion took place in the Press as to whether or not wireless telegraphy would be practicable for much longer distances than those then covered, and a general opinion prevailed that the curvature of the earth would be an insurmountable obstacle to long-distance transmissions, in the same way as it was, and is, an obstacle to signalling over considerable distances by means of optical signals such as flashlights, the heliograph, or the semaphore.

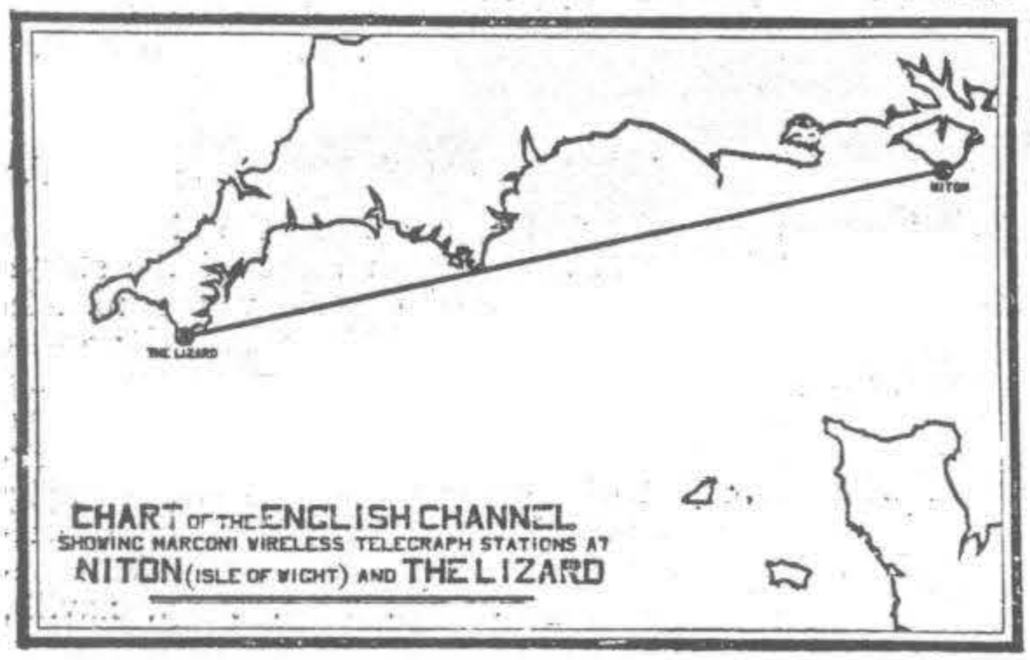
Other difficulties were anticipated as to the possibility of being able practically to employ and control a transmitter capable of radiating an amount of electrical energy large enough to actuate a receiver at really great distances, and,

[1] From a discourse delivered at the Royal Institution on Friday, March 13, 1908, by Commendatore G. Marconi.

granting the possibility of this, whether such a powerful radiator would not interfere with the working of all other wireless stations which might be established on shore or ships within the sphere of influence of the long-distance sender.

What so often occurs in most pioneer work has repeated itself in the case of long-distance wireless telegraphy—the anticipated obstacles and difficulties were either imaginary or else easily surmountable; but in their place unexpected barriers manifested themselves, and my efforts and those of

FIG. 2



my collaborators have been mainly directed to the solution of problems presented by difficulties which were not anticipated when the tests over long distances were first initiated.

In January, 1901, wireless communication was established between St. Catherine's Point in the Isle of Wight and Lizard in Cornwall, over a distance of 186 miles. The height of these stations above the sea-level did not exceed 300 feet (100 metres); whereas to clear the curvature of the earth a height of more than a mile at each end would have been necessary.

The result of these tests went far to convince me that electric waves produced in the manner I had adopted were able to make their way round the curvature of the earth, and that therefore it was not likely that this factor would constitute a barrier to the transmission of waves over greater distances. At this time I had achieved a considerable measure of success, by means of syntonic or tuning devices, in preventing mutual interference between stations, and Prof. Fleming described, in a letter to the *Times*, dated October 4, 1900, the results obtained, and which he and others had witnessed (Journ. Soc. Arts, xlix., No. 2530, 1901). The principle on which the transmitters and receivers at St. Catherine's Point and the Lizard were worked is shown in Figs. 3 and 4.

FIG. 3

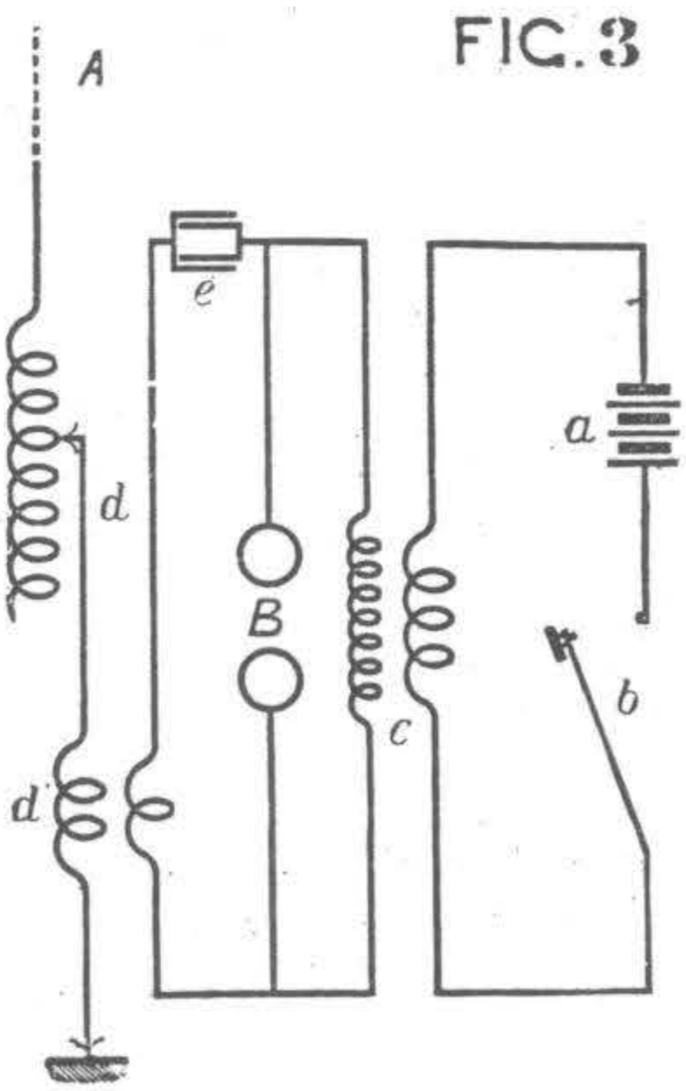
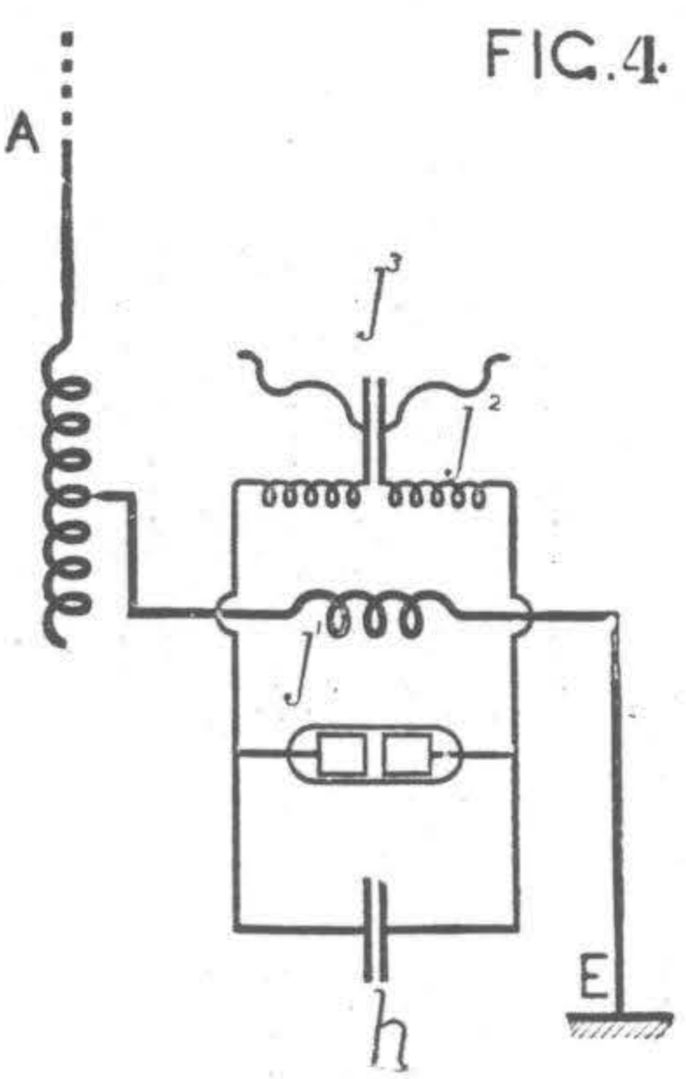


FIG. 4.



At the transmitting end a condenser, usually taking the form of a battery of Leyden jars, had one terminal connected to one spark-ball of an induction coil or transformer and the other to the primary circuit of an oscillation transformer. The opposite terminal of this transformer circuit was joined to the second spark-ball. The condenser was charged to the potential necessary to produce a suitable spark by means of an induction coil. The secondary circuit of the oscillation transformer was inserted between the vertical conductor, or aërial wire, and earth, and an adjustable inductance coil included in the circuit.

The circuits, consisting of the oscillating circuit and radiating circuit, were more or less closely "coupled" by varying the distance between the primary and secondary of the oscillation transformer. By the adjustment of the inductance inserted between the elevated conductor and earth, and by the variation of the capacity of the primary circuit of the oscillation transformer, the two circuits of the transmitter could be brought into resonance, a condition which I first found was absolutely necessary in order to obtain efficient radiation.

The receiver consisted also of a vertical conductor or aërial connected to earth through the primary of an oscillation transformer, the secondary of which included a condenser and a coherer, or other suitable detector, it being necessary that the circuit containing the aërial and the circuit containing the detector should be in resonance with each other, and also in tune with the periodicity of the oscillations transmitted from the sending station.

The energy employed to signal over a distance of 186 miles could be brought as low as 150 watts, and even less if a higher or larger aërial had been used.

The facility with which distances of more than 100 miles could be covered prior to 1900, and the success of the methods for preventing mutual interferences (Journ. Soc. Arts, xlix., No. 2530, 1901), led me to advise that two large power stations be constructed, one in Cornwall and the other in North America, in order to test whether it was possible to transmit messages across the Atlantic Ocean.

I have often been asked why I did not first endeavour to establish commercial communication between places situated at a shorter distance. The answer is very simple. The cables which connect England to the Continent, and between most Continental nations, are Government-owned, and these Governments would not, and will not, allow the establishment of any system, wireless or otherwise, which might in any way tamper with the revenue derived from these cables.

As regards Transatlantic communication, however, the conditions were different. There was no law either here, in Canada, or in the United States to impede the working of wireless telegraphy across the Atlantic.

A further potent reason, moreover, an economical reason, prompted me to attempt communication with America. Notwithstanding the cost of high-power stations, I am convinced that it is more profitable to transmit messages at 6*d.* a word to America than at, say, ½*d.* a word across the Channel, and that the economical advantage of wireless over cables and land-lines increases instead of diminishing with the distance.

A site suitable for a long-distance station was chosen at Poldhu, in Cornwall, and here in 1900 work was commenced in earnest—work in which I was ably assisted by

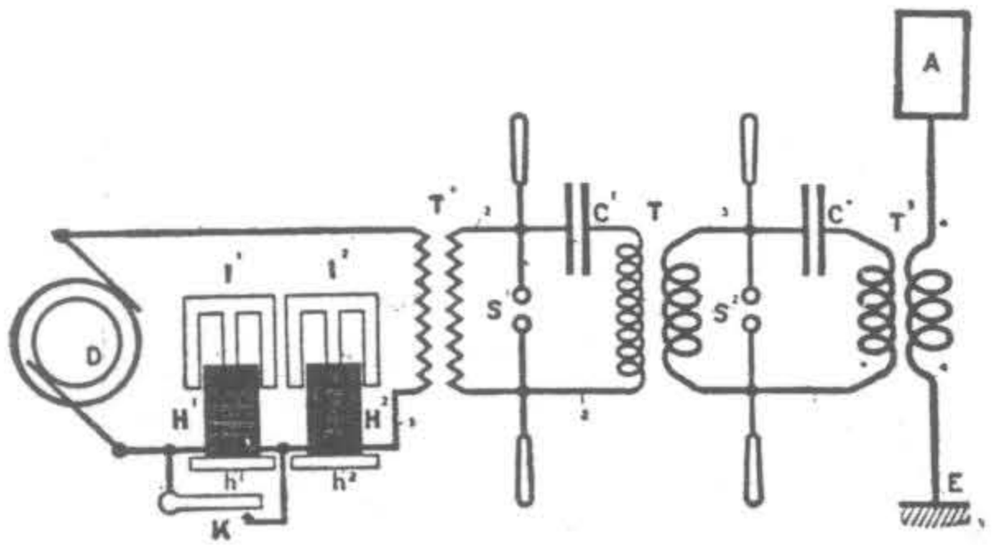
Prof. J. A. Fleming, of the University of London. The transmitter at Poldhu was similar in principle to the one I have already described, but it is obvious that the considerable distance over which it was proposed to transmit signals necessitated the employment of more powerful electromagnetic waves than those ever previously used. These were obtained by means of a generating plant consisting of an alternator capable of an output of about 25 kilowatts, which, through suitable transformers, charged a condenser having a glass dielectric of great strength.

Time does not permit me to describe in detail all the engineering difficulties which were encountered in controlling electrical oscillations of a power which at that time was certainly unprecedented, and as the tests were made possible by commercial organisation, the objects of which do not consist solely in the advancement of science, you will understand that a detailed description of the plant used at the Transatlantic stations cannot, for the present at least, be made public.

My early tests on wireless transmission by means of the elevated capacity method had convinced me that when endeavouring to extend the distance of communication it was of little utility merely to increase the power of the electrical energy applied to the transmitting circuits, but that it was also necessary to increase the area or height of the transmitting and receiving elevated conductors.

As it was economically impracticable to use vertical wires of very great height, the only alternative was to increase their size or capacity, which, in view of the facts I had first noticed in 1895, seemed likely to make possible

FIG. 5



the efficient utilisation of large amounts of electrical energy (Journ. Inst. Elec. Eng., xxviii., 1899, pp. 278–9).

The form of aërial which I first proposed to employ consisted of a conical arrangement of wires insulated at the top and gathered together at a lower point in the form of a funnel. This aërial was supported by a ring of twenty masts each 200 feet high, arranged in a circle 200 feet in diameter.

During the first tests an arrangement of circuits (Fig. 5) proposed by Dr. Fleming, and consisting of a modification of the system shown in Fig. 3, was employed. In this arrangement, in place of one high-frequency oscillation circuit, two are employed, and the constants of the two circuits are so arranged that very high-tension discharges can be obtained from one of the condensers—the one which is inductively connected with the aërial—without danger of damage to the circuits of the generator ("The Principles of Electric Wave Telegraphy," 1906, p. 506).

Simultaneously with the construction of the station at Poldhu, the erection of another one on substantially the same plan was undertaken at Cape Cod, in the United States of America.

The completion of the arrangements was delayed owing to a storm, which wrecked the masts and aërial at Poldhu on September 18, 1901, but by the end of November the aërial was sufficiently restored to enable me to complete the preliminary tests which I considered necessary prior to making the first experiment across the Atlantic.

Another accident to the masts at Cape Cod seemed likely to postpone the tests for several months more. I therefore decided that in the meantime I would use a purely temporary receiving installation in Newfoundland for the purpose of testing how far the arrangements in Cornwall had been conducted on right lines.

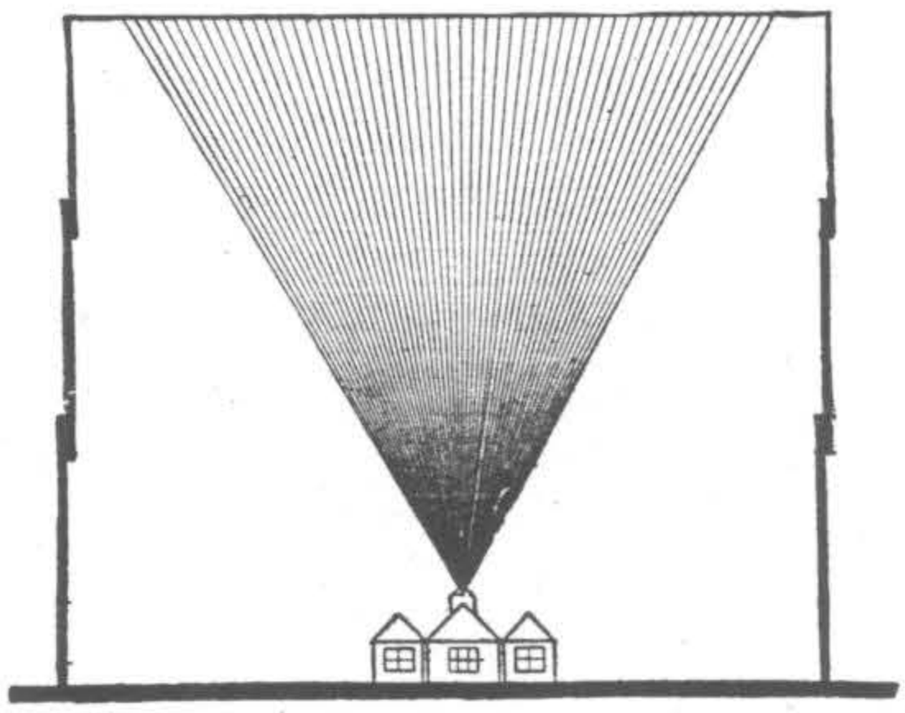
The transmitting elevated conductor employed at Poldhu during the experiments with Newfoundland consisted of fifty almost vertical copper wires supported at the top by a horizontal wire stretched between two masts 48 metres high and 60 metres apart. These wires converged together at the lower end in the shape of a large fan, and were connected to the transmitting instruments situated in a building (Fig. 6).

The transmitting condenser used with this aërial had a capacity of one-fiftieth of a microfarad, and was charged to a potential sufficient to produce a suitable spark discharge between spheres 3 inches in diameter, 1½ inches apart, the wave-length being 1200 feet. The actual power employed for the production of the waves was about 15 kilowatts.

I left for Newfoundland on November 27, 1901, with two assistants. As it was impossible at that time of the year to set up a permanent installation with poles, I decided to carry out the experiments by means of receivers connected to elevated wires supported by balloons or kites—a system which I had previously used when conducting tests across the Bristol Channel for the Post Office in 1897.[1]

It will be understood, however, that when it came to flying a kite on the coast of Newfoundland in the month of December this method was neither an easy nor a comfortable one. When the kites were got up much difficulty was caused by the variations of the wind producing constant changes in the angle and altitude of the wire, thereby causing corresponding variations in its electrical capacity and period of electrical resonance. My assistants at Poldhu, in Cornwall, had received instructions to send on and after December 11, during certain hours every day, a succession of S's followed by a short message, the whole to be transmitted, at a certain pre-arranged speed, every ten minutes, alternating with five minutes' rest.

FIG. 6



Owing to the constant variations in the capacity of the aërial wire in Newfoundland, it was soon discovered that an ordinary syntonic receiver was not suitable, although, at one time, a number of doubtful signals were recorded. I therefore tried various microphonic self-restoring coherers placed either directly in the aërial or included in the secondary circuit of an oscillation transformer, the signals being read on a telephone.

On December 12 the signals transmitted from Cornwall were clearly received, at the pre-arranged times, in many cases a succession of S's being heard distinctly, although probably in consequence of the weakness of the signals and the constant variations in the height of the receiving aërial no actual message could be deciphered. The following day we were able to confirm the result. The signals were actually read by myself and by my assistant, Mr. G. S. Kemp.

1 "Signalling through Space without Wires," lecture by Sir William Preece, Royal Institution, June 4, 1897. Proc. R.I., xv., p. 467.

I have often been asked why I adhered to the practice of transmitting series of the letter S for these tests. The reason is that the switching arrangements at the sending station at Poldhu were not constructed at that time in such a manner as to withstand long periods of operation—especially if letters containing dashes were sent—without considerable wear and tear, and that if S's were sent an automatic sender could be employed. Moreover, the immediate object of these experiments was not to transmit actual messages across the ocean, but to ascertain the possibility of detecting the effects of electric waves at a distance of 2000 miles.

The result obtained, although achieved with imperfect apparatus, was sufficient to convince me and my co-workers that by means of permanent stations (that is, stations not dependent on kites or balloons for sustaining the elevated conductor) and by the employment of more power in the transmitters it would be possible to send messages across the Atlantic Ocean with the same facility with which they were being sent over much shorter distances.

About two months later, in February, 1902, further tests were carried out between Poldhu and a receiving station on board the American liner *Philadelphia*, *en route* from Southampton to New York. The sending apparatus at Poldhu was the same as that used for the Newfoundland experiments. The receiving aërial on the ship was fixed to the mainmast, the top of which was 60 metres above sea-level. As the elevated conductor was fixed, and not floating about with a kite, as in the case of the Newfoundland experiments, good results were obtained on a syntonic

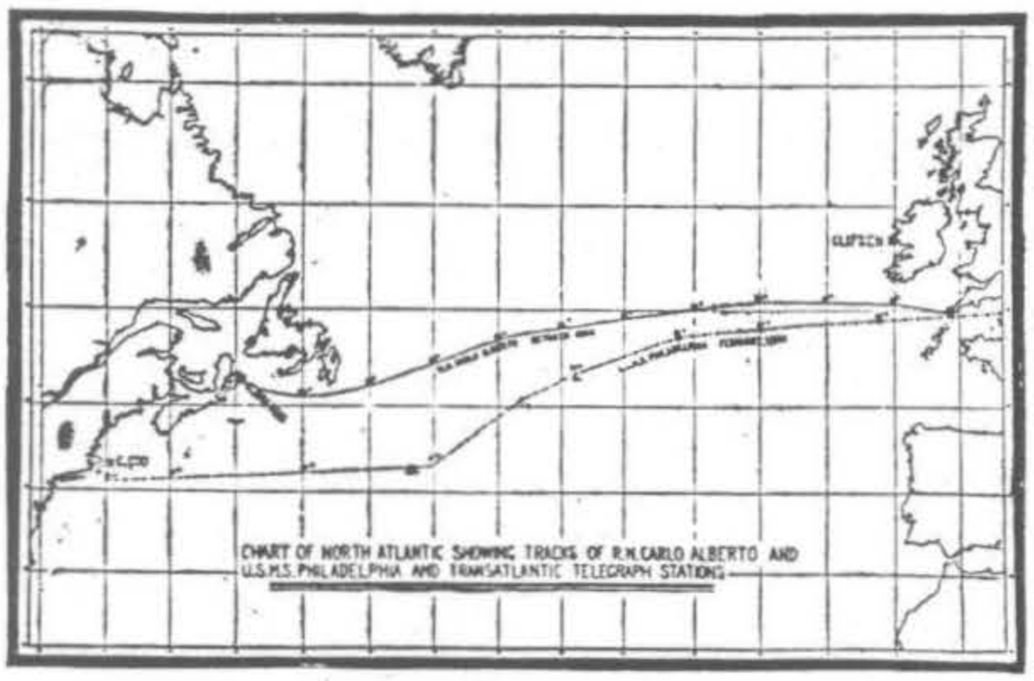


FIG. 7.

receiver, and the signals were all recorded on tape by the ordinary Morse recorder. On the *Philadelphia* readable messages were received from Poldhu up to a distance of 1551 miles, S's and other test letters as far as 2099 miles.

Although I never had the slightest doubt in my mind as to the genuineness of what was accomplished between Poldhu and Newfoundland, the results obtained on the *Philadelphia* amply prove that the station at Poldhu was capable at that time of transmitting signals to a distance of at least 2000 miles, which is the distance separating Cornwall from Newfoundland, and that if it was practicable to send a message over 2000 miles of sea from shore to ship, it should also be practicable to send it over the same space of ocean from shore to shore.

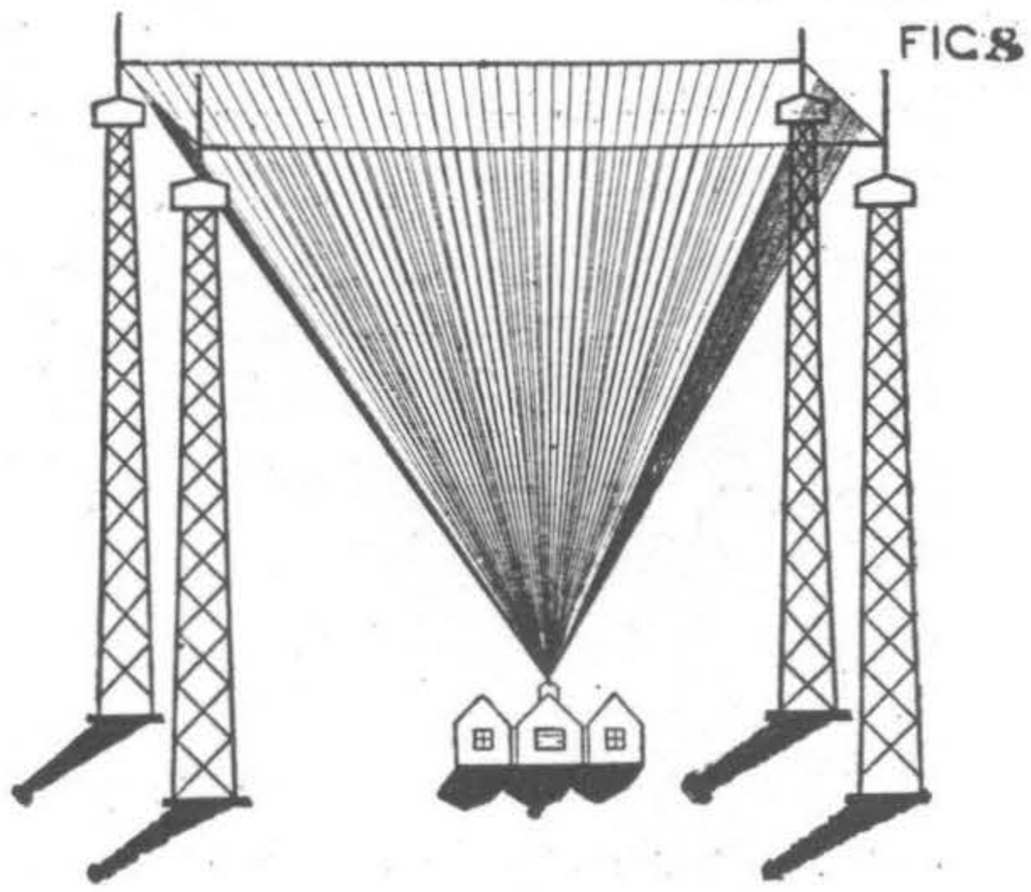
A result of some scientific interest which I first noticed during the tests on the s.s. *Philadelphia* was the very marked effect of sunlight on the propagation of electric waves over great distances.[1]

At the time of these tests I was of opinion that this effect might have been due to the loss of energy at the transmitter by daytime, caused by the dis-electrification of the highly charged transmitting elevated conductor operated by the influence of sunlight. I am now inclined to believe that the absorption of electric waves during daytime is due to the ionisation of the gaseous molecules of the air effected by ultra-violet light, and as the ultra-violet rays which emanate from the sun are largely absorbed in the upper atmosphere of the earth, it is probable that the portion of the earth's atmosphere which is facing the sun will contain more ions or electrons than that portion which is in darkness, and therefore, as Prof. J. J. Thomson (*Phil. Mag.*, August, 1902, Ser. 6, iv., p. 253) has shown, this illuminated and ionised air will absorb some of the energy of the electric waves.

The fact remains that clear sunlight and blue skies, though transparent to light, act as a kind of fog to powerful Hertzian waves. Hence the weather conditions prevailing in this country are usually suitable for long-distance wireless telegraphy.

Apparently the amplitude of the electrical oscillations and the lengths of waves radiated have much to do with the interesting phenomena, small amplitudes and long waves being subject to the effect of daylight to a less degree than large amplitudes and short waves. I never considered that this daylight effect would be an insuperable obstacle to Transatlantic telegraphy, as sufficient sending energy could be used during daytime to make up for the loss of range of the transmissions.

Turning again to Newfoundland, I ought to add that the experiments could not there be continued or extended in consequence of the hostile attitude of the Anglo-American Telegraph Company, which claimed all rights for telegraphy, whether wireless or otherwise, in Newfoundland.



However, as I had received an offer of assistance from the Canadian Government, it was decided to resume the tests between Great Britain and Canada, and these tests were very greatly facilitated by the subsidy of 16,000*l.* granted by the Canadian Government to support my experiments. The construction of another long-distance station was, therefore, commenced at Glace Bay, in Nova Scotia, and very extensive tests and experiments were carried on with Poldhu during the latter part of 1902.

Contemporaneously with the construction of the station at Glace Bay, alterations and modifications were executed at Poldhu. Four wooden lattice towers, each 210 feet high, were erected at the corners of a square of 200-feet side. The towers carried insulated triatic stays, from which was suspended a conical arrangement of four hundred copper wires forming the aërial, put up in sections, so that more or less could be employed (Fig. 8). The buildings for the generating plant were placed in the middle of the space between the towers. Additional machinery was obtained, and alterations carried out in accordance with the experience obtained from previous tests.

Identical towers and aërial arrangements were at that time adopted at the stations at Glace Bay, and at the similar installation in course of erection at Cape Cod, Mass.

In most of the experiments carried on from Poldhu the capacity of the sending condenser was one-thirtieth of a microfarad, the spark-length 1⅜ inches, and the wave-length 3600 feet. In these and subsequent tests the double con-

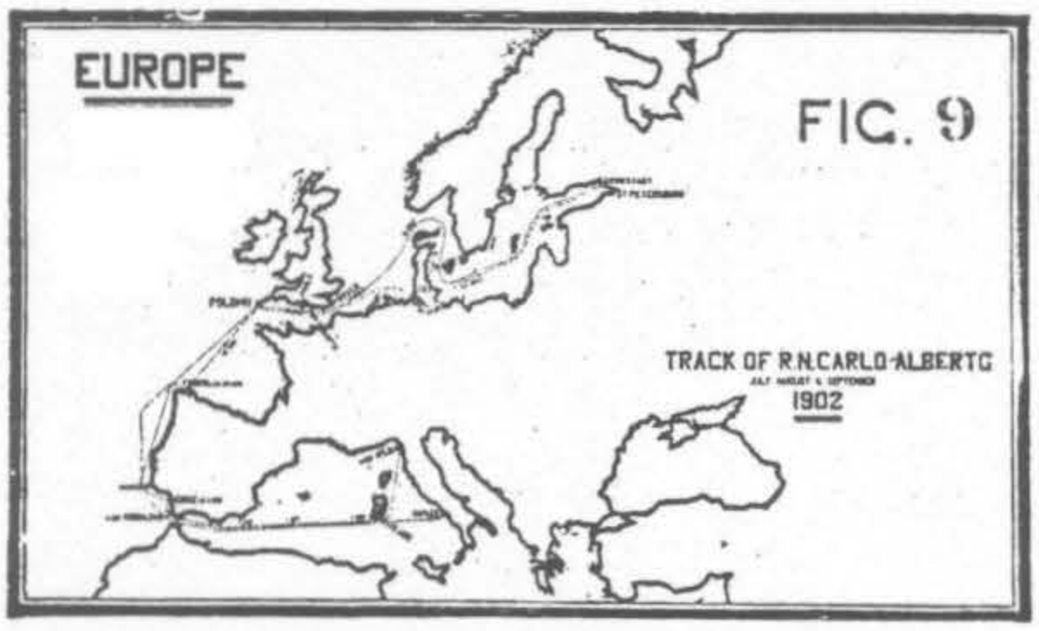
[1] Proc. Roy. Soc., lxx., p. 344, "A Note on the Effect of Daylight upon the Propagation of Electro-magnetic Impulses over Long Distances." Paper read June 12, 1902.

denser arrangement of Dr. Fleming was replaced by a single condenser, the arrangement being similar to that shown in Fig. 3.

During the time that constructional work was in progress at Glace Bay, I carried out some tests with Poldhu over considerable distances, and these tests were greatly facilitated by the interest taken in them by the Italian Government, which placed the cruiser *Carlo Alberto* at my disposal.

During these experiments the interesting fact was observed that, when using waves of more than 1000 metres in length, intervening land or mountains do not bring about any considerable reduction in the distance over which it is possible to communicate. Thus messages and Press despatches were received from Poldhu at the positions marked on the map (Fig. 9), which map is a copy of the one accompanying the official report of the experiments (*Revista Marittima*, Rome, October, 1902).

In December, 1902, messages were for the first time exchanged at night between the stations at Poldhu and Glace Bay, but it was found that communication was exceedingly difficult and untrustworthy from England to Canada, whilst it was good in the opposite direction. The reason for this is that the Glace Bay station was equipped with more powerful and more expensive machinery—a condition rendered possible by the subsidy granted by the Canadian Government; whilst as regards Poldhu, owing to



the uncertainty of what might or might not be the attitude of the British Government at that time towards the working of the station, my company was unwilling to expend large sums of money for the purpose of increasing its range of transmission.

As, however, messages could be sent then for the first time by wireless telegraphy from Canada to England, inaugural messages were dispatched to the Sovereigns of England and Italy, both of whom had previously given me much assistance and encouragement in my work, and who, by their gracious replies, attested their appreciation of the results which had been achieved. Other messages were also sent to England by the Government of Canada.

Further tests were shortly afterwards carried out with the long-distance station at Cape Cod, in the United States of America, and a message from President Roosevelt was transmitted from that station to His Majesty the King in London.

It is curious to note, in regard to the transmission of this message, that the energy employed at Cape Cod was barely 10 kilowatts, and it was not anticipated that this amount of energy would be sufficient to carry direct to Poldhu. The message was therefore transmitted from Cape Cod, instructions having been given to the operators at Glace Bay to be on the look-out, and to repeat wirelessly on to Poldhu any message received from Cape Cod, and my assistant, Mr. P. J. Woodward, at Poldhu, took in the message on one of my magnetic detectors.[1] The electromagnetic waves conveying this message travelled, therefore, 3000 miles through space over the Atlantic, which distance included about 500 miles of land, following an arc of 45 degrees on a great circle.

(*To be continued.*)

[1] Proc. Roy. Soc., lxx., p. 341, "Note on a Magnetic Detector of Electric Waves which can be employed as a Receiver for Space Telegraphy."

TRANSATLANTIC WIRELESS TELEGRAPHY.[1]

II.

IN the spring of 1903 the transmission of news messages from America to the London *Times* was attempted, in order to demonstrate that messages could be sent from America by means of the new method, and for a time these messages were correctly received and published in that newspaper.

By reference to the files of the *Times* I find that 267 words of news, transmitted across the Atlantic by wireless, were published in the London *Times* during the latter part of March and the early part of April of that year. A breakdown in the insulation of the apparatus at Glace Bay made it necessary, however, to suspend the service, and, unfortunately, further accidents made the transmission of messages uncertain and untrustworthy. In consequence of this it was decided not to attempt, for the time being, the transmission of any more public messages until such time as a trustworthy service could be maintained in both directions under all ordinary conditions.

As I found that many improvements evolved during the course of the numerous tests and experiments could not be readily applied to the plants at Poldhu and Cape Breton, it was decided to erect a completely new long-distance station in Ireland, and to transport the one at Glace Bay to a different site in the vicinity, where sufficient land was available for experimenting with aërials of much larger dimensions than had been hitherto employed.

Experiments were, however, continued with Poldhu, and in October, 1903, it became possible to supply the Cunard steamship *Lucania*, during her entire crossing from New York to Liverpool, with news transmitted direct from the shore.

In November of the same year tests similar to those carried out with the Italian cruiser took place on behalf of the British Admiralty between Poldhu and H.M.S. *Duncan*.

Communication with Poldhu was maintained during the entire cruise of this battleship from Portsmouth to Gibraltar, and further communication was established between Poldhu and the Admiralty station situated on the Rock of Gibraltar. It should be noted that the distance between Cornwall and Gibraltar is 1000 miles—500 over land and 500 over water.

[1] From a discourse delivered at the Royal Institution on Friday, March 13, 1908, by Commendatore G. Marconi. Continued from p. 237.

The aërial at Poldhu was shortly afterwards extended by the addition of wires sloping downwards, umbrella-fashion, as shown in Fig. 10. This increased the capacity of the aërial, and some further tests were carried out with a station at Fraserburgh, in the north of Scotland. From these tests considerable advantage appeared to be derived, at least for communication over land, by the adoption of much longer waves than had been hitherto employed, and with a wave-length of 14,000 feet it was found possible to telegraph over a distance of 550 miles with an expenditure of energy of about 1 kilowatt.

The operation of the long-distance stations in England and America made it possible to transmit messages to ships, whatever their position, between Europe and North

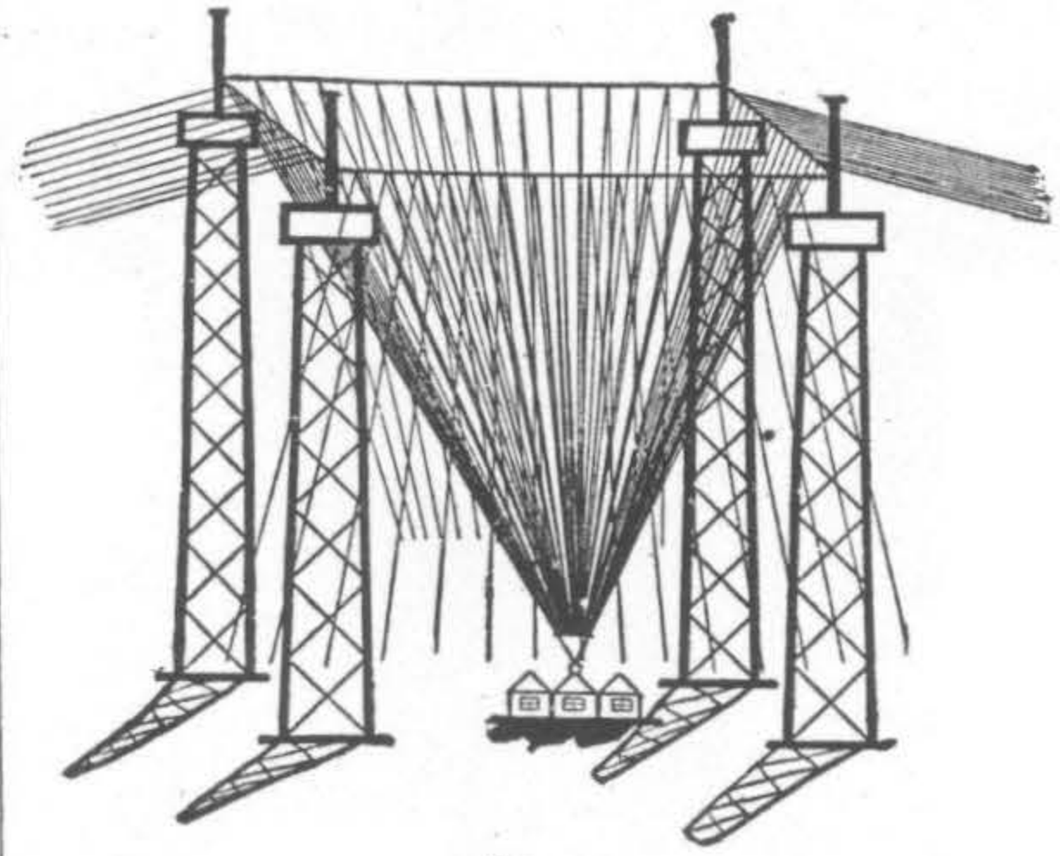


FIG. 10.

America; and to the Cunard Company belongs the credit of having greatly encouraged the long-distance tests, a circumstance which enabled them to commence, in June, 1904, the regular publication on their principal vessels of a daily newspaper, containing telegraphic messages of the latest news from Europe and America.

This daily newspaper has now been adopted by nearly all the large liners plying to New York and the Mediterranean, and it obviously owes its entire existence to long-distance wireless telegraphy. Therefore the tranquility and isolation from the outside world, which it is still possible to enjoy on board of some ships, is rapidly becoming a thing of the past; but, however much travellers may sigh over the innovations which have lately been brought about,

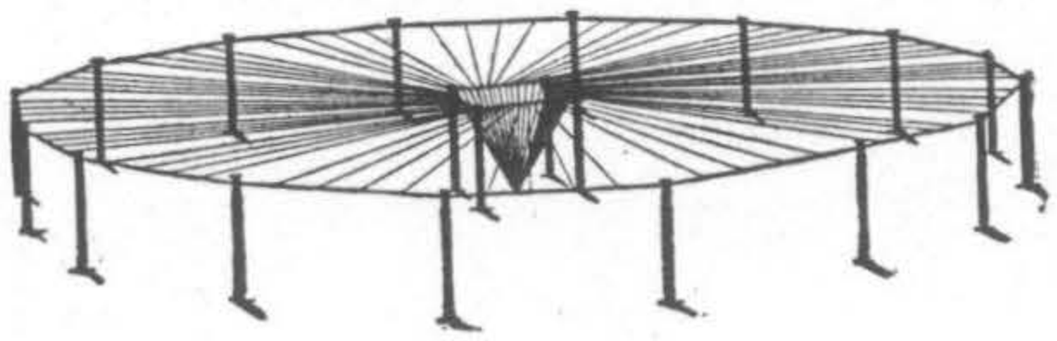


FIG. 11.

they seem anxious enough to avail themselves of the new method of communication on all possible occasions.

Early in 1905 the construction of the new station at Glace Bay was sufficiently advanced to allow of preliminary tests being carried out. The aërial was very large, and consisted of a vertical portion in the middle 220 feet long supported by four towers and attached to horizontal wires, 200 in number, each 1000 feet long, extending radially all round, and supported at a height of 180 feet from the ground by an inner circle of eight and an outer circle of sixteen masts (Fig. 11). The natural period of oscillation of this aërial gave a wave-length of 12,000 feet. The capacity employed was 1·8 microfarads, and the spark-length $\frac{3}{4}$-inch.

Signals and messages from this station were received at

Poldhu by day as well as by night, but no commercial use of the station was made at that time, in consequence of the fact that, although the signals came through by day as well as by night, they were exceedingly weak and faint, and also because the corresponding station on the same plan had not yet been erected in Ireland.

A further step in advance was the adoption at the Transatlantic stations of the directional aërial shown in Fig. 12.[1] The ordinary wireless telegraph aërials, which I have already described, send out electric radiation equally in all directions. This is, however, in many cases a disadvantage. Many suggestions respecting methods for limiting the direction of radiation have been made by various workers, notably by Messrs. Artom, Braun, and Bellini Tosi.

In some of my earliest experiments, in 1896, I used copper mirrors, by the aid of which it was possible to project a beam of electric radiation in a certain direction, but I soon found that this method would only work over short distances.

About three years ago I again took up the subject, and was able to determine that by means of horizontal aërials, disposed in a particular manner, it was possible to confine the effects of electric waves mainly to certain directions as desired. True, the limitation of transmission to one direction is not very sharply defined, but it is nevertheless very useful. The practical result of this method has been, so far, that messages can be sent over considerable distances in the desired directions, while they travel only over a comparatively short distance in other directions, and that, with aërials of moderate height, greater efficiency in a given direction can be obtained than can be obtained all round by means of the ordinary aërials.

When this type of aërial was adopted at Glace Bay a considerable strengthening of the received signals at Poldhu

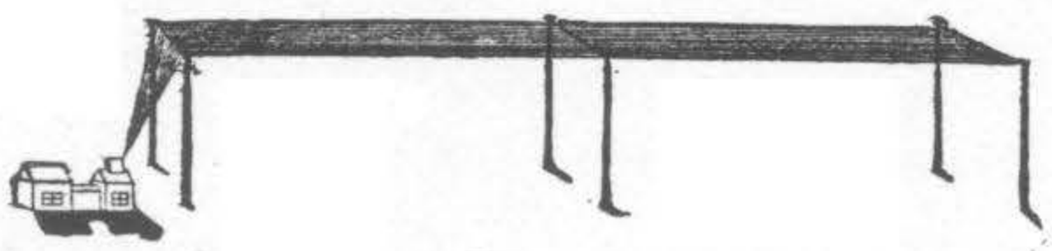


FIG. 12.

was noticed. It was therefore decided to adopt the directional aërial at all long-distance stations.

A further improvement introduced at Clifden and Glace Bay consisted in the adoption of air condensers, composed of insulated metallic plates suspended in air at ordinary pressure. In this manner it is possible to prevent the dissipation of energy due to losses caused by the dielectric hysteresis in the glass dielectric of the condensers previously employed, and a very appreciable economy in working, resulting from the absence of breakages of the dielectric, is effected. These air condensers, which have been in use since May, 1907, have been entirely satisfactory. After very considerable delay and expense, the new station at Clifden was got ready for tests by the end of May, 1907, and experiments were then commenced with Glace Bay.

The wave-length used during these tests was 12,000 feet, the capacity employed 1·6 microfarads, and the potential to which the condenser was charged 80,000 volts.

Good signals were obtained at Cape Breton from the very commencement of the tests, but some difficulty was encountered in consequence of the effects of atmospheric electricity due to the prevalence of thunderstorms in the eastern part of Canada during the first few days of the tests.

Simultaneously with these tests others were carried out from Poldhu to Glace Bay with a new system of transmitting apparatus, by means of which continuous or semi-continuous oscillations could be produced.

Proportionately to the energy employed the signals from Poldhu were so much better than those from Clifden that I decided at once to adopt this new method of transmission at Glace Bay and Clifden. The apparatus which I have been using for producing continuous or closely adjacent trains of electric oscillations is as follows[2]:—A metal disc A (Fig. 13), insulated from the earth, is caused to rotate at a very high speed by means of a high-speed electric motor or steam turbine. Adjacent to this disc, which I shall call the middle disc, are placed two other discs, C_1, C_2, which may be called polar discs, and which also can be rotated at a high rate of speed. These polar discs should have their peripheries very close to the surface or edges of the middle disc.

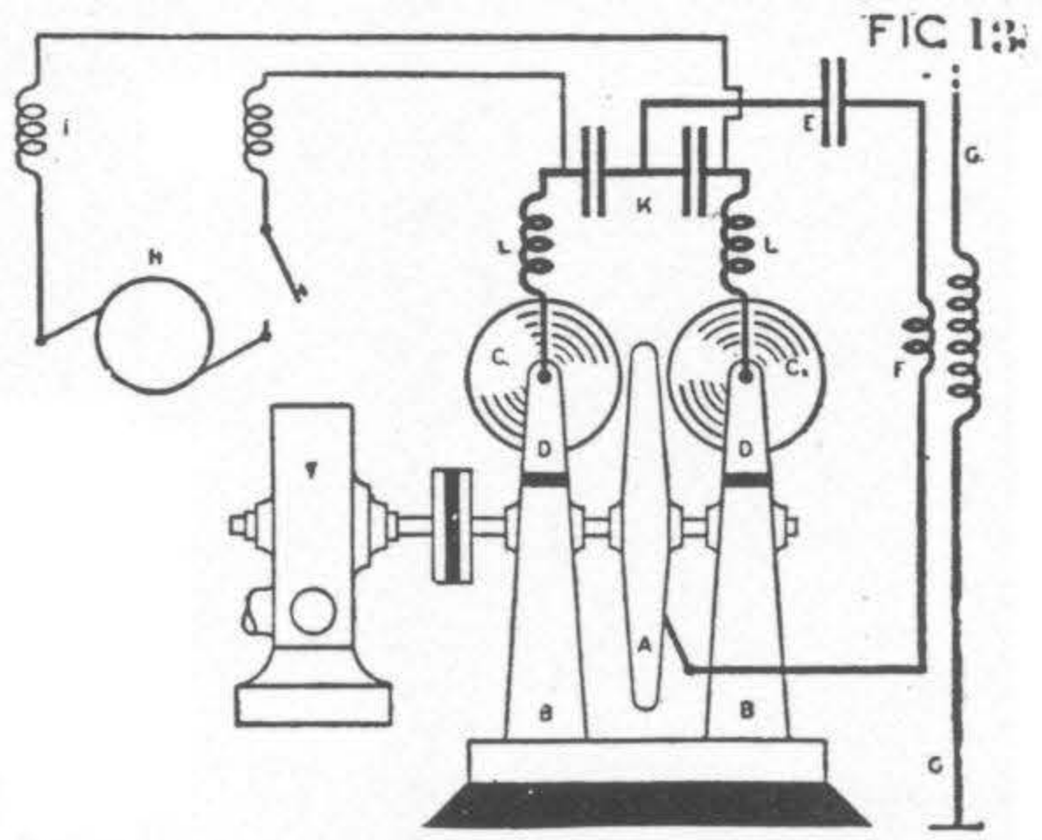
If a small amount of energy is used, stationary knobs or points may be used in place of the side discs.

The two polar discs are connected respectively through suitable brushes to the outer ends or terminals of two condensers K, joined in series, and these condensers are also connected through suitable inductive resistances to the terminals of a generator, which should be a high-tension continuous-current dynamo.

On the high-speed or middle disc a suitable brush or rubbing contact is provided, and connected between this contact and the middle point of the two condensers is inserted an oscillating circuit consisting of a condenser E in series with the inductance, which last is connected inductively or conductively to the aërial.

If the necessary conditions are fulfilled, and a sufficient E.M.F. is employed, a discharge will pass between the outer discs and the middle disc, which discharge is neither an oscillatory spark nor an ordinary arc, and powerful

FIG 13.



oscillations will be created in the signalling condenser E and oscillatory circuit F.

I have found that in order to obtain good effects a peripheral speed of more than 100 metres per second is desirable; therefore particular precautions have to be taken in the construction of the discs. Electrical oscillations of a frequency as high as 200,000 per second can be obtained.

The apparatus works probably in the following manner:—Let us imagine that the source of electricity is gradually charging the double condenser and increasing the potential at the discs, say C_1 positively and C_2 negatively; at a certain instant the potential will cause the charge to jump across one of the gaps, say between C_2 and A. This will charge the condenser E, which will then commence to oscillate, and the charge in swinging back will jump from A to C_1, which is charged to the opposite potential. The charge of E will again reverse, picking up energy at each reversal from the condensers K. The same process will go on indefinitely, the losses which occur in the oscillating circuit EF being made good by the energy supplied from the generator H. If the disc is not rotated, or rotated slowly, an ordinary arc is at once established across the small gaps, and no oscillations take place. The efficient cooling of the discharge by the rapidly revolving disc seems to be one of the conditions necessary for the production of the phenomena.

By means of this apparatus tests were carried out, but it was found, as was to be expected, that the oscillations were too continuous and of too high a frequency to affect a receiver, such as the magnetic detector, unless an interrupter was inserted in one of the circuits of the receiver.

[1] "On Methods whereby the Radiation of Electric Waves may be mainly Confined," &c. Proc. Roy. Soc., G. Marconi, A. lxxii., 1906.

[2] Patent Application No. 20,119, September 9, 1907.

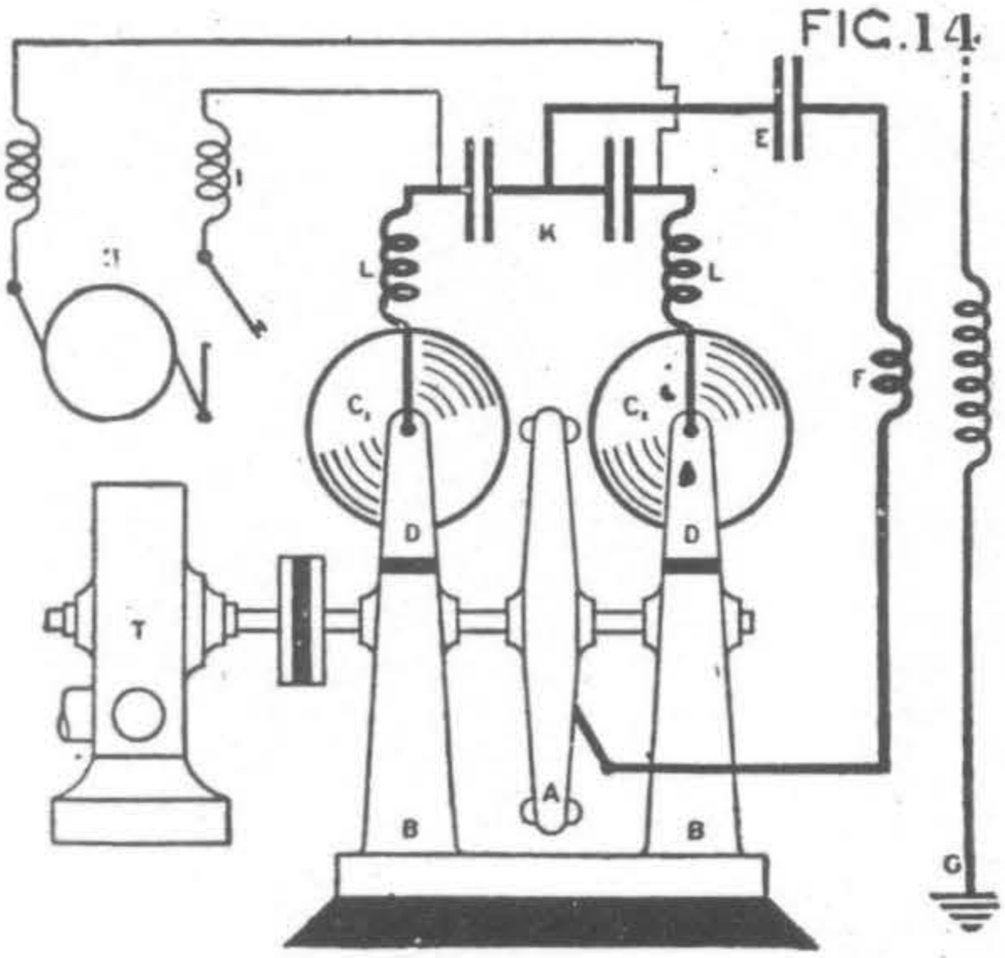
A syntonic coherer receiver would, however, work, in consequence, no doubt, of the considerable rise of potential which occurred at its terminals through the cumulative effect of resonance.

The best results over long distances have, however, been obtained by a disc as shown in Fig. 14, in which the active surface is not smooth, but consists of a number of knobs or pegs, at the end of which the discharges take place at regular intervals. In this case, of course, the oscillations are not continuous, but consist of a regular succession of trains of undamped or slightly damped waves.

In that manner it is possible to cause the groups of oscillations radiated to reproduce a musical note in the receiver, distinguishable in a telephone, and thereby it is easier to differentiate between the signals emanating from the transmitting station and noises caused by atmospheric electrical disturbances. By this method very efficient resonance can, moreover, be obtained in appropriately designed receivers.

A few tests with apparatus based on the principle described were carried out between Glace Bay and Clifden, and on October 17 of the year 1907 a limited service for Press messages was commenced between Great Britain and America. Difficulties were experienced, however, over the question of rates with the telegraph companies working the land-lines between Glace Bay and the principal towns of Canada and the United States, and at present the strange

FIG. 14.



anomaly exists that the rates for Press messages on the American land-lines are much cheaper for messages going from England to New York than in the reverse direction. On February 3, 1908, this service was extended to ordinary messages between London and Montreal.

The stations at Clifden and Glace Bay are not complete, and the necessary duplication of the running machinery has not yet been executed, but nevertheless communication across the Atlantic has never been interrupted for more than a few hours since the commencement of commercial working on October 17, 1907.

There have, however, been several serious interruptions at Clifden, due to the untrustworthiness of the land-lines connecting Clifden to the ordinary telegraph system. On one occasion one of these interruptions lasted from 5.20 p.m. to 10.30 a.m., a duration of seventeen hours, and on another occasion the land telegraph wires were struck by lightning and disabled for twelve hours. There have also been recorded numerous other interruptions of shorter duration, which resulted in delays to private and Press messages. Further delays have also been caused through interruptions on the land-lines connected with the Canadian station.

During the first months, on account of imperfections in the auxiliary apparatus connected principally with the operating keys and switches, only a fraction of the available transmitting power was used. In consequence of this the speed of transmission was slow, and short interruptions somewhat frequent. Many of these difficulties have now been overcome, and in a few more months, when it should be possible to utilise the full power available, a very much greater speed and efficiency is likely to be attained.

Messages can now be transmitted across the Atlantic by day as well as by night, but there still exist certain periods, fortunately of short duration, when transmission across the Atlantic is difficult and at times ineffective, unless an amount of energy greater than that used during what I might call normal conditions is employed.

Thus, in the morning and evening when, due to the difference in longitude, daylight or darkness extends only part of the way across the Atlantic, the received signals are weak and sometimes cease altogether.

It would almost appear as if illuminated space possessed for electric waves a different refractive index from dark space, and that in consequence the electric waves may be refracted and reflected in passing from one medium to the other. It is therefore probable that these difficulties would not be experienced in telegraphing over equal distances from north to south, or *vice versâ*, as in this case the passage from daylight to darkness would occur almost simultaneously in the whole of the medium between the two points.

In the same manner a storm area in the path of the signals often brings about a considerable weakening of the received waves, whilst if stormy conditions prevail all the way across the Atlantic no interference is noticeable. Electric-wave shadows, like sound shadows, may be formed by the interference of reflected waves with the direct waves, whereby signals may be much less effective or imperceptible in the area of such electric-wave shadow.

In the same manner as there exist periods when signals across the Atlantic are unusually weak, there exist other conditions, especially at night, which make the signals abnormally strong. Thus on many occasions ships, and stations equipped with apparatus of a normal range of 200 miles, have been able to communicate over distances of more than 1000 miles. This occurred recently when a ship in the English Channel was able to correspond with another in the Mediterranean. But the important factor about wireless telegraphy is that a service established for a certain distance shall be able to maintain trustworthy communication over that distance.

Long-distance stations are now in course of erection in many parts of the world, the most powerful of all being that of the Italian Government at Coltano, and I have not the slighest doubt but that telegraphy through space will soon be in the position of affording communication between distant countries at cheaper rates than can be obtained by any other means.

As to the practicability of wireless telegraphy working over long distances, such as that separating England from America, there is no longer need for any doubt. Although the stations have been worked for only a few hours daily, 119,945 words of Press and commercial messages had been transmitted across the ocean by this means up to the end of February, 1908, since the service was opened.

The best judges of a service are those who have made use of it, and amongst newspapers, the chief users have been the *New York Times* and the London *Times*, which have already publicly expressed their opinion of this new method of communication.

Whether the new telegraphy will or will not injure or displace the cables is still a matter of conjecture, but in my opinion it rests a good deal on what the cables can do in the way of cheaper rates. It is not, as some appear to imagine, either the business or the wish of those concerned in the development of wireless telegraphy to injure the cable industry. They are endeavouring at present to demonstrate that the new method is not only valuable for shipping, but that it should be also regarded as a new and cheaper method of communicating with far distant countries. Whatever may be the view as to its shortcomings and defects, there can be no doubt but that wireless telegraphy across the Atlantic has come to stay, and will not only stay, but continue to advance.

In seven years the useful range of wireless telegraphy has increased from 200 miles to 2500 miles. In view of

that fact, he will be a bold prophet who will venture to affirm what may not be done in seven years more.

I shall not presume to say that at the present moment the wireless telegraph service between London and New York is as efficient and as rapid as that supplied by the cables. For nearly fifty years the Transatlantic cable organisation has been in existence, and there are now sixteen cables working across the North Atlantic, so that in the case of a breakdown of one cable the traffic is sent by one of the others. Moreover, long experience has served to bring their land-line connections to a high state of perfection. Nevertheless, I am convinced that if there were only one cable and the present wireless service, interruptions would be more frequent and much more serious in the case of the cable than in that of the wireless service.

We have only to look towards those parts of the globe such as India, South Africa, and so forth, where trans-oceanic communication is dependent upon only one or two cables, and the force of my remarks will be more readily appreciated. The cases of delay in regard, not only to commercial messages, but also to Government despatches, are only too frequent, as no doubt you have observed from time to time in the daily Press.

Among many people there seems to be a rooted conviction that wireless telegraphy is not suitable for the handling of code or cipher messages. Whatever gave rise to this idea I do not know, but I wish to emphasise that it is purely fictitious. Code messages can be sent just as well by wireless as by ordinary methods of telegraphy.

I need hardly say that most of the wireless messages passing between warships are now expressed in code, as are likewise the majority of the commercial messages handled by the Clifden and Cape Breton stations.

I do not wish to claim that wireless telegraphy is infallible, and although errors do sometimes occur, it is absolutely certain that, having regard to the London and Montreal service, most of the mistakes can be traced to the land-line telegraph transmission between London and Clifden, and between Glace Bay and Montreal.

I find, however, that probably the greatest ignorance prevails in regard to what is termed "tapping," or intercepting wireless messages. No telegraph system is secret. The contents of every telegram are known to every operator who handles it. It is incorrect to suppose that anyone can at will pick up wireless messages. On the other hand, it is easy for anyone knowing the Morse code to step into many telegraph offices and read off the messages by the click of the instruments.

Further, it is practicable, but illegal in this country, to make arrangements so that messages which pass over a telegraph line can be read by persons who are not operating the line at all. It is also expensive to erect a tall pole or tower and fix up all the instruments which are necessary before wireless messages can be taken in, and, moreover, such proceeding is contrary to the law of the land.

It should be remembered, too, that any ordinary telegraph or telephone wire can be tapped, and the conversation going through it overheard, or its operation interfered with. Results published by Sir William Preece show that it is possible to pick up at a distance, on another circuit, the conversation which may be passing through a telephone or telegraph wire.

At Poldhu, on a telephone connected to a long horizontal wire, the messages passing through a Government telegraph line a quarter of a mile away can be distinctly read. In a paper on his method of magnetic space telegraphy, Sir Oliver Lodge mentions an occasion on which he was able to interfere, from a distance, with the working of the ordinary telephones in the city of Liverpool.

Many instances can be enumerated showing that electric light and tramway power-stations have interfered with cables and land-lines. Nevertheless, there are penalties attached to the tapping of a telegraph wire, and it ought to be as well known that, since the passing of the Wireless Telegraphy Act, there are penalties involved if any wireless stations are erected or worked without the consent of the Postmaster-General. In conclusion, I may say that I am very confident that it is only a question of time, and that not a very long time, before wireless telegraphy over great distances, possibly round the world, will become an indispensable aid to commerce and civilisation.

SIGNALING TO MARS.

Not since those historic flashes from Mars were received, some years ago, which were probably caused by the reflection of sunlight falling on snow-covered surfaces, and which were promptly interpreted by Tesla and some exuberantly imaginative astronomers as attempts on the part of a hypothetical race of Martians to communicate with this earth of ours, has so much excitement been created as Prof. Pickering's proposal to build a system of mirrors, by means of which light can be rhythmically flashed to Mars. According to Prof. Pickering, a system of reflecting surfaces of adequate area could be constructed at a cost of $10,000,000. If Mars is inhabited by a race more highly developed than we, on the theory that their planet is older than ours, it is argued that they will have sufficient intelligence to devise a means of answering. Prof. R. W. Wood of Johns Hopkins University suggests the simpler and cheaper expedient of employing a huge strip of black cloth, which could be wound from one roller to another, and made to appear and disappear at regular intervals. He suggests the alkali deserts of the Southwest as a suitable place for the experiment. In all probability, neither Prof. Wood nor Prof. Pickering seriously believes that Mars is inhabited.

Would it be worth while to carry out the idea? To us it seems that if the experiment proved a failure, and no answering signal were received from Mars in a reasonable time, the matter would not be conclusively settled. Knowing practically nothing of the conditions on Mars, it would naturally be unsafe to conclude from a failure that the planet is uninhabited, for which reason the habitability of Mars would still engross Flammarion, Lowell, and the host of newspapers that accept their utterances as astronomical gospel. On the other hand, if an answering signal should be received, it would be safe to say that the event would transcend in human interest and importance the most stirring occurrence in the history of the earth, and would inaugurate a new era in the progress of the human race.

Even in the face of this tremendously alluring but exceedingly remote possibility, it seems to us that the $10,000,000 stipulated by Prof. Pickering, and the smaller indeterminate sum required by Prof. Wood, could be more worthily expended, particularly so when we examine the evidence on which the theory of Martian habitability is based.

To the indefatigable studies of Prof. Lowell we owe whatever facts have been gathered that bear at all on the question. But Prof. Lowell's arguments have been riddled by the inexorable logic of geologists, astronomers, and physicists. He is wedded to the Laplacean theory of planetary evolution, although that theory is considered inadequate by many astronomers in the light of recent celestial observations. He assumes that the history of the earth is the history of Mars. He advances the theory that Mars is a planet which has shriveled up during the course of ages; that its surface is one vast parched desert, with the exception of the snow that gathers each winter about the poles; and that the chief concern of the inhabitants, if inhabitants there be, is to conserve this paltry supply of water, and to conduct it, as the snow melts in the spring, to those regions in the equatorial and temperate zones which would still blossom if they were watered. Evidence of this gigantic irrigation system, which dwarfs anything of the kind that we have ever attempted, Lowell finds in that network of lines which Schiaparelli first discovered, and which were called by him "canals" for want of a better name. As spring and summer approach, the lines slowly creep down from the poles toward the equator, and the dull red or orange of the supposed desert region changes to green. With the advent of autumn and winter, the green resumes its dull red or orange hue, and the lines or "canals" gradually disappear. In these chromatic changes Prof. Lowell sees the seasonal growth and decay of vegetation. His argument for the habitability of our planetary neighbor is based on the undeniably remarkable regularity of the "canals." It is pointed out that they are usually the shortest distance between the points that they connect, and that they meet in groups of three, five, seven, and more in well-defined spots, which he terms "oases," like so many spokes converging in a wheel-hub. In other words, there is nothing haphazard in the arrangement of these canals as Prof. Lowell sees them. They are to him so artificial that they are the symbols of an intelligent race, who have sunk all political and international disputes in the one vital problem of postponing the day when their orb must eventually dry up and they themselves perish.

To reinforce his argument, Prof. Lowell points to the earth. He argues that all terrestrial life emerged from the ocean, although no geologist will positively assert how life did originate on this planet; that the earth was once wrapped in a damp, cloudy envelope, although there is much evidence that moisture, even in geologic times, was of local prevalence only; that the earth is gradually drying up, although all geological evidence points to the fact that the proportion of land to sea has always been a fluctuating quantity, with no marked tendency in either direction; and that deserts on the earth are the harbingers of an ultimate dearth of water extending over the entire earth, although geologists maintain that deserts have always existed. Perhaps the most vigorous attack on Lowell's theories has been conducted by Prof. Andrew E. Douglass, who has studied the "canals" by the methods of experimental psychology, and has shown that there are fundamental defects in the human eye which produce faint canal illusions, and that these have worked serious injury to our observations in the past. It must be confessed, however, that Prof. Douglass has not explained away the seasonal appearance and disappearance of the "canals" and "oases."

Ingenious as Prof. Lowell's explanation of Martian phenomena undoubtedly is, so much of it is based on unsound geological reasoning, and so much on sheer conjecture, that it seems almost futile to make any attempt at signaling in the hope of obtaining something like experimental evidence that Mars is really a living world peopled by intelligent beings.

The Brooklyn Eagle May 19, 1909

TESLA'S $1,000,000 COMPANY.

Albany, May 19—The Tesla Propulsion Company of New York, organized to manufacture motive power, machinery for vessels, capital $1,000,000, was incorporated to-day. The directors include Nikola Tesla, Joseph Headley, Walter H. Knight of New York.

The New York Herald May 20, 1909

TESLA SAYS HE HAS NEW POWER SECRET

Inventor Declares He Has Discovered a Mechanical Principle of Greatest Economic Value.

Following the incorporation of the Tesla Propulsion Company, with $1,000,000 capital stock, at Albany yesterday, to exploit one of Nikola Tesla's inventions, Mr. Tesla announced the adoption of the device by the Alabama Consolidated Coal and Iron Company.

"I have discovered a mechanical principle, entirely new and of the greatest economic value," Mr. Tesla said, "but I shall not be in a position to make known the details and exhibit the principle in operation for perhaps six weeks. It is a principle which minimizes the size of the power producing plant and increases to a maximum the power produced. The apparatus we will build for the Alabama concern will not be one-third of the size of the ordinary air blast machinery equipment for such work and the air blast and other effective results will be far superior in volume and value to those at present generally used.

"In connection with this plant I will install a turbine of my own invention, and the air blast will be supplied under a turbine principle. This new mechanical principle I have discovered is applicable to air, steam, gas or water power, and may be used for locomotives, automobiles or any form of power production. With it a locomotive as powerful as any now used would need to be less than half the size."

The Tesla Propulsion Company's directors include Mr. Tesla, Joseph Hoadley and Walter H. Knight, of New York. Mr. Tesla stated that machines of several types had been built and that successful demonstrations had been given with them to his associates in the new company and to representatives of the Alabama company.

HOW TO SIGNAL TO MARS

Wireless the Only Way Now, Says Nicola Tesla—Mirror Plan Not Practicable.

To the Editor of The New York Times:

Of all the evidences of narrow mindedness and folly I know of no greater one than the stupid belief that this little planet is singled out to be the seat of life, and that all other heavenly bodies are fiery masses or lumps of ice. Most certainly, some planets are not inhabited, but others are, and among these there must exist life under all conditions and phases of development.

In the solar system Venus, the Earth, and Mars represent, respectively, youth, full growth, and old age. Venus, with its mountains rising dozens of miles into the atmosphere, is probably as yet unfitted for such existence as ours, but Mars must have passed through all terrestrial states and conditions.

Civilized existence rests on the development of the mechanical arts. The force of gravitation on Mars is only two-fifths of that on earth, hence all mechanical problems must have been much easier of solution. This is even more so of the electrical. The planet being much smaller, the contact between individuals and the mutual exchange of ideas must have been much quicker, and there are many other re sons why intellectual life should have been on that planet phenomenal in its evolution.

To be sure, we have no absolute proof that Mars is inhabited. The straightness of the canals, which has been held out as a convincing indication to this effect, is not at all such. We can conclude with mathematical certitude that as a planet grows older and the mountains are leveled down ultimately every river must flow in a geodetically straight line. Such straightening is already noticeable in some rivers of the earth.

Believes Mars Signaled Him.

But the whole arrangement of the so-called waterways, as pictured by Lowell, would seem to have been designed. Personally I base my faith on the feeble planetary electrical disturbances which I discovered in the Summer of 1899, and which, according to my investigations, could not have originated from the sun, the moon or Venus. Further study since has satisfied me that they must have emanated from Mars. All doubt in this regard will be soon dispelled.

To bring forth arguments in any attempt should be made to establish interplanetary communication would be a useless and ungrateful undertaking. If we had no other reason, it would be justified by the universal interest which it will command, and by the inspiring hopes and expectations to which it would give rise. I shall rather concentrate my efforts upon the examination of the plans proposed and the description of a method by which this seemingly impossible task can be readily accomplished.

The scheme of signaling by rays of light is old, and has been often discussed, perhaps, more by that eloquent and picturesque Frenchman, Camille Flammarion, than anybody else. Quite recently Prof. W. H. Pickering, as stated in several issues of The New York Times, has made a suggestion which deserves careful examination.

The total solar radiation falling on a terrestrial area perpendicular to the rays amounts to eighty-three foot pounds per square foot per second. This activity, measured by the adopted standard, is a little over fifteen one-thousandth of a horse power. But only about 10 per cent. of this whole is due to waves of light. These, however, are of widely different lengths, making it impossible to use all to the best advantage, and there are specific losses unavoidable in the use of mirrors, so that the power of sunlight reflected from them can scarcely exceed 5.5 foot pounds per square foot per second, or about one one-hundredth of a horse power.

A Giant Reflector Needed.

In view of this small activity, a reflecting surface of at least one-quarter million square feet should be provided for the experiment. This area, of course, should be circular to insure the greatest efficiency, and, with due regard to economy, it should be made up of mirrors rather small, such as to meet best the requirements of cheap manufacture.

The idea has been advanced by some experts that a small reflector would be as efficient as a large one. This is true to a degree but holds good only in heliographic transmission to small distances when the area covered by the reflected beam is not vastly in excess of that of the mirror. In signaling to Mars, the effect would be exactly proportionate to the aggregate surface of the reflectors. With an area of one-quarter million square feet the activity of the reflected sunlight, at the origin, would be about 2,500 horse power.

It scarcely need be stated that these mirrors would have to be ground and polished most carefully. To use ordinary commercial plates, as has been suggested, would be entirely out of the question, for at such an immense distance the imperfections of surface would fatally interfere with efficiency. Furthermore, expensive clock work would have to be employed to rotate the reflectors in the manner of heliostats, and provision would have to be made for protection against destructive atmospheric influence. It is extremely doubtful that so formidable an array of apparatus could be produced for $10,000,000, but this is a consideration of minor importance to this argument.

Light Unlimited in a Vacuum.

If the reflected rays were parallel and the heavenly bodies devoid of atmospheres, nothing would be simpler than signaling to Mars, for it is a truth accepted by physicists that a bundle of parallel rays, in vacuo, would illuminate an area with the same intensity, whether it be near or infinitely remote. In other words, there is no sensible loss in the transmission of radiant energy through interplanetary or vacuous space. This being the case, could we but penetrate the prison walls of the atmosphere, we could clearly perceive the smallest object on the most distant star; so inconceivably tenuous, frictionless, rigid, and elastic is the medium pervading the universe.

The suns rays are usually considered to be parallel, and are virtually so through a short trajectory, because of the immense distance of the luminary. But the radiations, coming from a distance of 93,000,000 miles, emanate from a sphere 865,000 miles in diameter, and, consequently, most of them will fall on the mirrors at an angle less than by degrees, with the result of causing a corresponding divergence of the reflected rays. Owing to the equality of the angles of incidence and reflection, it follows that if Mars were at half the sun's distance, the rays reaching the planet would cover an area of about one-quarter of that of the solar disk, or in round numbers, 147,000,000,000 square miles, which is nearly 16,400,000,000,000 times larger than that of the mirrors. This means that the intensity of the radiation received on Mars would be just that many times smaller.

To convey a definite idea, it may be stated that the light we get from the moon is 600,000 times feebler than that of the sun. Accordingly, even under these purely theoretical conditions the Pickering apparatus could do no more than produce an illumination 27,400,000 times feebler than that of our full moon, or 1,000 times weaker than that of Venus.

Atmosphere the Chief Obstacle.

The preceding is based on the assumption that there is nothing in the path of the reflected rays except the tenuous medium filling all space. But the planets have atmospheres which absorb and refract. We see remote objects less distinctly, we perceive stars long after they have fallen below the horizon. This is due to absorption and refraction of the rays passing through the air. While these effects cannot be exactly estimated, it is certain that the atmosphere is the chief impediment to the study of the heavens.

By locating our observatories one mile above sea level the quantity of matter which the rays have to transverse on their way to the planet is reduced to one-third. But, as the air becomes less dense, there is comparatively little gain to be derived from greater elevation. What chance would there be that the reflected rays, reduced to an intensity far below that estimated above, would produce a visible signal on Mars? Though I do not deny this possibility, all evidence points to the contrary.

Lowell, a trained and restless observer, who has made the study of Mars his specialty and is working under ideal conditions, has been so far unable to perceive a light effect of the magnitude such as the proposed signaling apparatus might produce there. Phobos, the smaller of the two satellites of Mars—from seven to ten miles in diameter—can only be seen at short intervals when the planet is in opposition. The satellite presents to us an area of approximately fifty square miles, reflecting sunlight at least as well as ordinary earth, which has little over one-twelfth of the power of a mirror.

Stated otherwise, an equivalent effect at that distance would be produced by mirrors covering four square miles, which means two square miles of the same reflectors if located on earth, as it receives sunlight of twice the intensity. Now this is an area 200 times larger than that of the ten-million-dollar reflector, and yet Phobos is hardly perceptible. It is true that the observation of the satellite is rendered difficult by the glare of its mother planet. But this is offset by the fact that it is in vacuum and that its rays suffer little diminution through absorption and refraction of the earth's atmosphere.

Mirror Signals Impossible Now.

What has been stated is thought sufficient to convince the reader that there is little to be expected from the plan under discussion. The idea naturally presents itself that mirrors might be manufactured which will reflect light in parallel beams. For the time being this is a task beyond human power but no one can set a limit to the future achievement of man.

Still more ineffective would be the attempt of signaling in the manner proposed by Dr. William R. Brooks and others, by artificial light, as the electric arc. In order to obtain a reflected light-activity of 2,500 horsepower it would be necessary to install a power plant of not less than 75,000 horsepower, which, with its turbines, dynamos, parabolic reflectors and other paraphernalia, would probably cost more than $10,000,000. While this method would permit operations at favorable times, when the earth is nearer to, and has its dark side turned toward Mars, it has the disadvantage of involving the use of reflected rays necessarily more divergent than those of the sun, it being impossible to construct mirrors of the required perfection, and, without their use, the rays would be scattered to such an extent that the effect would be much smaller.

Reflecting surfaces of great extent can be had readily. Prof. R. W. Wood makes the odd suggestion of using the white alkali desert of the southwest for the purpose. Prof. E. Doolittle advises the employment of large geometrical figures. In my opinion none of these suggestions is feasible. The trouble is that the earth itself is a reflector, not efficient, it is true, but what it lacks in this respect is more than made up by the immensity of its area. To convey a perceptible signal in this manner it might require as much as 100 square miles reflecting surface.

Wireless Offers the Best Plan.

But there is one method of putting ourselves in touch with other planets. Though not easy of execution, it is simple in principle. A circuit properly designed and arranged is connected with one of its ends to an insulated terminal at some height and with the other to earth. Inductively linked with it is another circuit in which electrical oscillations of great intensity are set up by means now familiar to electricians. This combination of apparatus is known as my wireless transmitter.

By careful attunement of the circuits the expert can produce a vibration of extraordinary power, but when certain artifices, which I have not yet described, are resorted to the oscillation reaches transcending intensity. By this means, as told in my published technical records, I have passed a powerful current around the globe and attained activities of many millions of horse power. Assuming only a rate of 15,000,000, readily obtainable, it is 6,000 times more than that producecable by the Pickering mirrors.

But, my method has other and still greater advantages. By its employment the electrician on Mars, instead of utilizing the energy received by a few thousand square feet of area, as in a parabolic reflector, is enabled to concentrate in his instrument the energy received by dozens of square miles, thus multiplying the effect many thousands of times. Nor is this all. By proper methods and devices he can magnify the receives effect as many times again.

It is evident, then, that in my experiments in 1899 and 1900, I have already produced disturbances on Mars incomparably more powerful than could be attained by any light reflectors, however large.

Electrical science is now so far advanced that our ability of flashing a signal to a planet is experimentally demonstrated. The question is, When will humanity witness that great triumph. This is easily answered. The moment we obtain absolute evidences that an intelligent effort is being made in some other world to this effect interplanetary transmission of intelligence can be considered as an accomplished fact. A primitive understanding can be reached quickly without difficulty. A complete exchange of ideas is a greater problem, but susceptible of solution. NIKOLA TESLA.

Tesla Propulsion Company.

The Tesla Propulsion Company, with $1,000,000 capital stock, has been incorporated at Albany, N. Y. The directors include Mr. Nikola Tesla, Mr. Jos. Hoadley and Mr. Walter H. Knight. Mr. Tesla said the company will manufacture apparatus constructed on a mechanical principle of his discovery, entirely new, and of the greatest economical value, the details of which he will make known in about six weeks. The principle, he says, minimizes the size of a power producing plant and increases to a maximum the power produced. A plant now being built for the Alabama Consolidated Coal & Iron Company will not be one-third of the size of the ordinary equipment for its work, while the air blast which it will include and other details will have a far superior value. In connection with this plant Mr. Tesla said he would install a turbine of his own invention, and that the air blast will be supplied under the turbine principle. The new mechanical principle involved is applicable to air, steam, gas and water-power, and may be used for locomotives, automobiles or any power application. With it a locomotive as powerful as any now used need not be half the present size.

Tesla to Furnish Motive-Power Machinery for Vessels.

Nikola Tesla has another workable invention and has incorporated the Tesla Propulsion Company, with the principal office in New York city and a capital of $1,000,000, to manufacture motive-power machinery for vessels. The other directors are Joseph Hoadley and Walter H. Knight of New York city.

The New York Times May 31, 1909

THE INHABITANTS OF MARS.

Prof GOLDWIN SMITH is concerned about the prospective attempts to converse by wireless telegraph with the inhabitants of Mars because he infers that the idea of interplanetary communication is founded on the assumption that inhabitants of the sister planet must be human beings like ourselves. Not at all. Let the Professor remain tranquil. Of course, as he says, we have long been slaves to the idea that man is the greatest, and probably the final, product of creation. We have been practically unable to conceive of a living being finer and more commendable than a quadruped mammal walk- to share their own overestimate of the opinions they express, the orders they give, and the suggestions they offer.

Such offensive fellows have always existed, and do now, but our own impression is that present conditions of service and employment create them less often than did those of other days, and tend more to restrain them after they have been created. Peremptory commands, such as masters used to issue to their bound apprentices, are no longer given, for the very good reason that they could not be enforced and would be promptly resented. Of course the office tyrant and the brutal boss survive, and both get a measure of servility from underlings who remain after those who will not endure discourtesy have been eliminated, but, on the whole, intercourse between employers and employés has made an easily measurable gain in suavity in the last twenty years.

With the gain there has been some loss, since now the employer often does not know more than a few of his employés by sight, and yet even in these cases there has been of late a marked strengthening of the sense of responsibility, and on the whole things are getting better and better. Let's talk about the good new days instead of about the good old days—which were pretty bad, as a matter of fact—and look for the Golden Age in the future, where there may be one, not in the past, where there certainly wasn't any.

CURRENT COMMENT

Tesla is to signal to Mars, according to a two-column letter to the New York Times. He believes that certain electrical disturbances which he observed in the summer of 1889 must have emanated from Mars, but that all doubt in this regard will soon be dispelled. He criticised unfavorably the various methods that have recently been proposed to convey signals to Mars, and offers one of his own which he states is simple in principle, although perhaps not easy of execution. This consists, first, of a circuit properly designed and arranged, with one of its ends connected to an insulated terminal at some height, and the other to earth. Inductibly linked with this is another circuit in which electrical oscillations of great intensity are set up, the above combination being known as the Tesla wireless transmitter. By a careful attunement of circuits, and by means of certain methods which he has not yet described, oscillations of transcending intensity can be obtained.

Adopts Tesla's Device.

The Alabama Consolidated Coal and Iron Company has adopted Nicola Tesla's new device for increasing power while minimizing the size of the power-producing plant. Mr. Tesla says that he will not be in a position to make known the details and exhibit the principle in operation for perhaps six weeks. He also states that the apparatus to be built for the Alabama concern will not be one-third of the size of the ordinary air-blast machinery equipment for such work, and the air blast and other effective results will be far superior in volume and value to those at present generally used.

Signaling to Mars.

Buffalo, May 25, 1909.

To the Editors:

I have noticed in the press recently an announcement that a suggestion had been made that, with an expenditure of ten million dollars, communication could be established with the people of Mars.

As a matter of fact, this subject is not a joking matter at all, but a question of scientific research, and I am of the opinion that it can be done by solicitation, without any great expenditure of money, and without any individual assuming any financial obligation in carrying out the work.

It occurred to me several years ago that if the people of Mars are as far advanced in civilization as some scientists have reason to believe, that they are already studying the growth of our cities by noting their illumination at night, and that the easiest, cheapest and best way for us to communicate with them is to light up certain cities after midnight.

In the United States, for instance, we could pick out all the towns that fell on a state line—from which they would get the idea that we were one nation divided into many states.

Another plan would be to pick out such towns as would spell "United States" across our country from New York to San Francisco, or just "America."

Then, if we were answered in some way, the different states could letter themselves, from which they would learn our whole alphabet.

In fact, a number of towns that are lighted by electricity could probably be found in one state in such number and proximity as to be chosen to form any capital letter of the alphabet.

An association of these lighting communities could thus elect to spell our alphabet, giving every letter five minutes and repeating the performance, say every Sunday night, from which they would learn that we observed the seventh day.

I think this idea should be studied and well considered, and that such an association of lighting communities working in conjunction with astronomers with powerful telescopes, could certainly give impetus to the idea and get something started in a practical way.

Samuel E. Hitt, M. E.

Buffalo, N. Y., June 1.

The Construction of High-Frequency Apparatus.

By George T. Hanchett.

THE average student who reads and understands the time-honored experiments of Tesla and Thomson in high-frequency work and who realizes the simplicity of the apparatus by which such startling results were reached, very often desires to reproduce the experiments on a small scale. When high-frequency phenomena were first discovered they were of academic interest only and had little practical value, except that they afforded a beautiful exemplification of the principles of inductance and capacity. The high-frequency discharge is now of commercial importance, being used in wireless telegraphy,

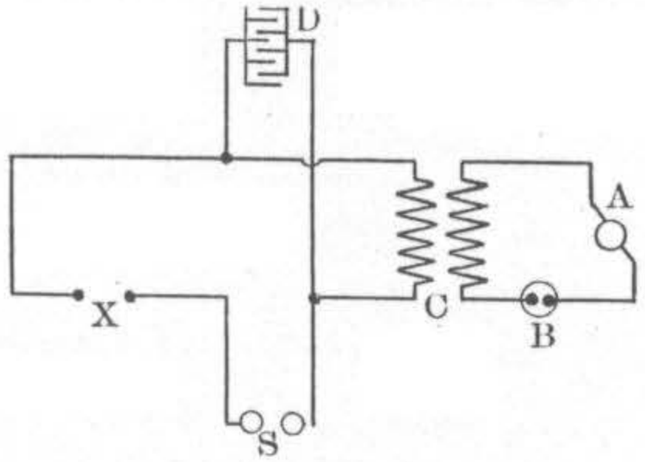


FIG. I.—DIAGRAM OF CONNECTIONS.

and in investigating the behavior of lightning arresters of various types, which are designed to deal with high-frequency condenser discharge.

The writer has had occasion to construct high-frequency apparatus and has encountered various details in construction which, if neglected, seriously impair results and may even render the efforts of the constructor futile. Some of the features are to be recommended by reason of their convenience and low cost, and although the subject is old it is believed that these considerations make a description of more or less interest.

Alternating currents of any of the commercial frequencies are best for producing the Tesla discharges. Very good results are obtained with 60-cycle current at 110 volts, using about 40 amp. It is necessary to step this potential up by a transformer of some sort from 10,000 volts to 20,000 volts. High-voltage, low-frequency current is passed directly to a condenser of the proper capacity, which is permitted to discharge across a short spark-gap, made preferably with screw adjustment and of moderately massive ball-shaped terminals. The discharge circuit of the condenser carries the high-frequency currents which it is desired to study, and the many beautiful and now familiar phenomena are obtained by connecting the different pieces of apparatus in series with this discharge circuit. An elementary diagram is shown in Fig. 1, where *A* répresents the alternating-current source of supply, suitably controlled by a rheostat or adjustable inductance *B*. C represents the step-up transformer, *D* the condenser, *S* the spark-gap, and at *X* in the condenser discharge circuit is connected the apparatus on which it is desired to impress high-frequency currents.

The most expensive and troublesome part of the apparatus is the step-up transformer. Several ordinary transformers

may be used to obtain the high-tension currents, but it will be found better, if time and means afford, to construct a special transformer of the open magnetic-circuit, oil-insulated type, of the transformer consists of a fiber tube of the dimensions given filled with fine, straight iron wire. This tube is fastened tightly to a thick cover, which may be of wood turned up in a

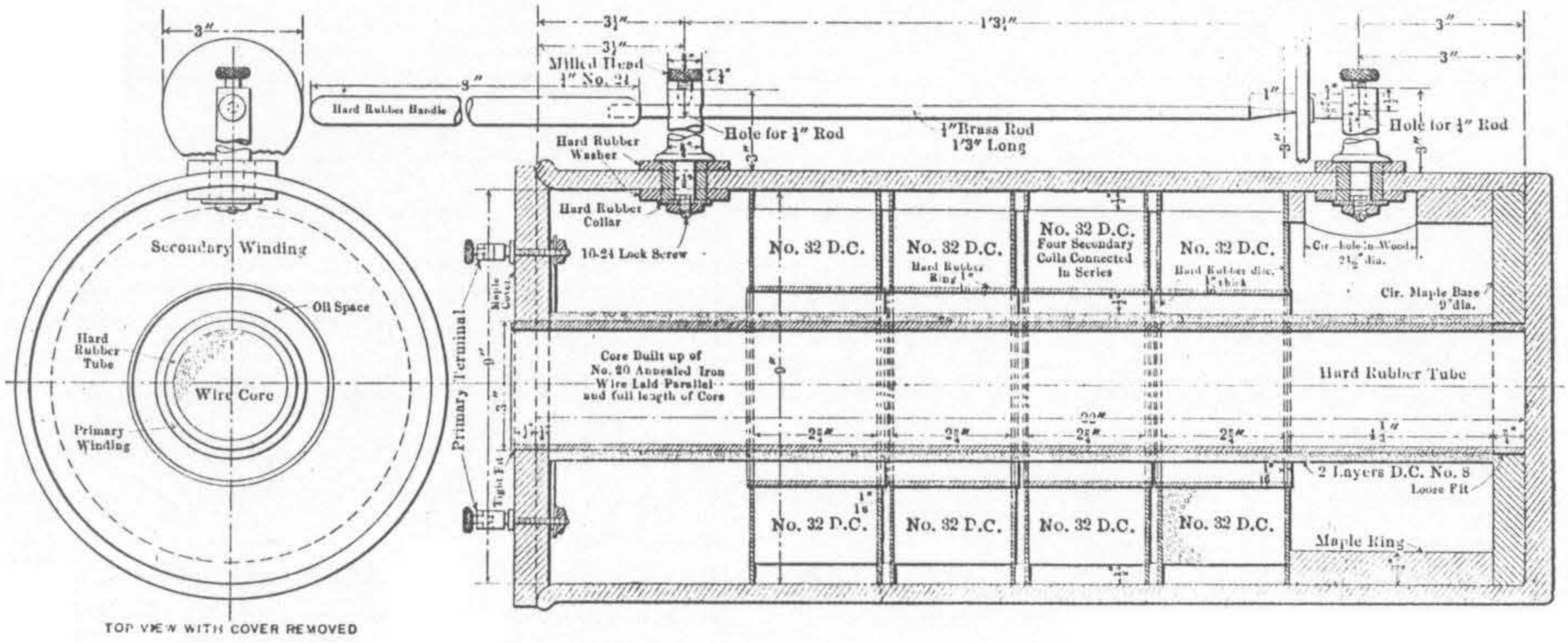


FIG. 2.—DETAILS OF STEP-UP TRANSFORMER.

for the surges that obtain in such a circuit are apt to puncture the insulation of the ordinary commercial apparatus. The writer has found a very successful arrangement in Fig. 2, which is a

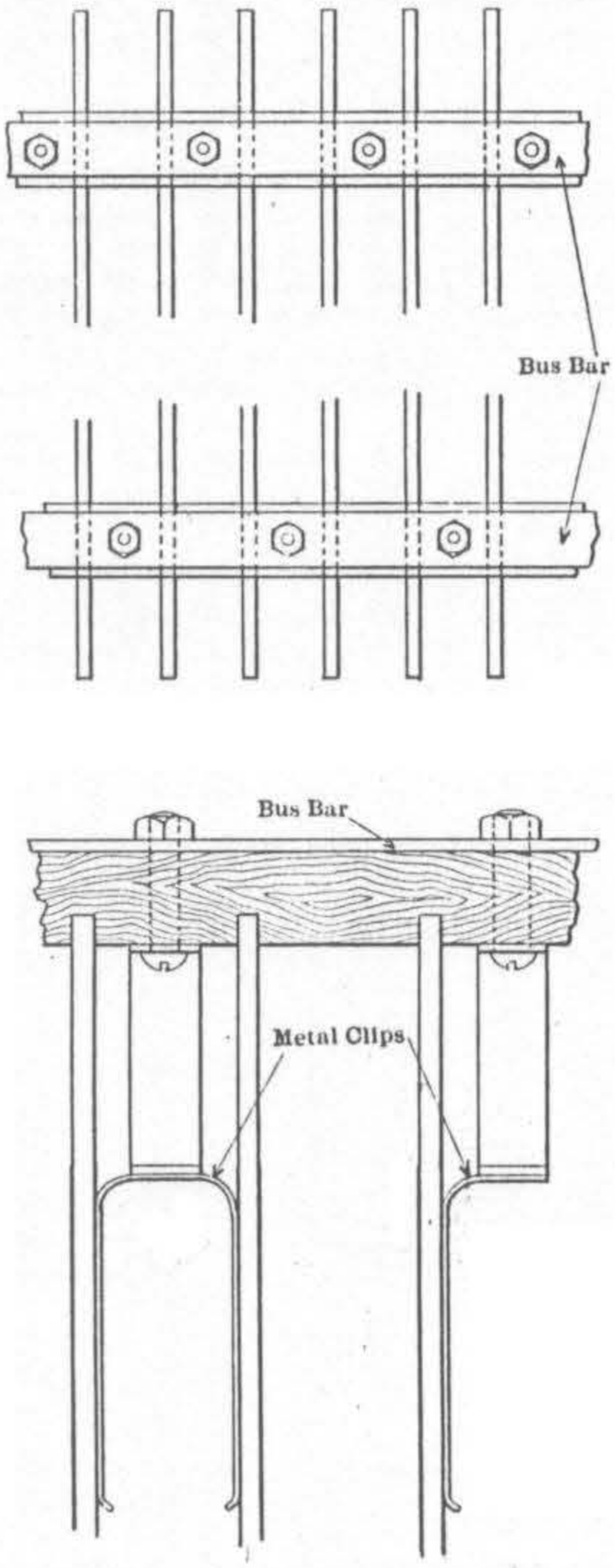


FIG. 3.—TOP AND SIDE VIEW OF CONDENSER RACK.

dimensional drawing of a transformer suitable for this purpose. The containing jar of this transformer is made of indurated fiber, which is oil tight and an excellent insulator. The primary lathe and impregnated with asphaltic compound. The two terminals of the primary may be brought to binding posts mounted on the wood. The advantage of this arrangement is found in the fact that removing the cover removes the primary coil also for inspection and also leaves the secondaries open so that they can be examined. The primary is wound with two layers of No. 8 double-cotton covered copper wire. Considerable care is necessary in insulating the layers from one another, particularly at the top where the primary coil is supported by the wood, for this top is likely to protrude out of the oil and between the layers at this point the highest difference of potential obtains. It is well, therefore, to use several layers of oiled linen to separate the primary layers at this point. The bottom of the indurated fiber jar contains a round disk of wood with a hole in the center which loosely fits the ends of the primary and keeps it central.

The secondary coils are wound on hard-rubber spools, made of tubes and collars, and using No. 32, double cotton-covered wire. Between each layer of wire should be placed a layer of unsized white paper, and care should be taken not to wind

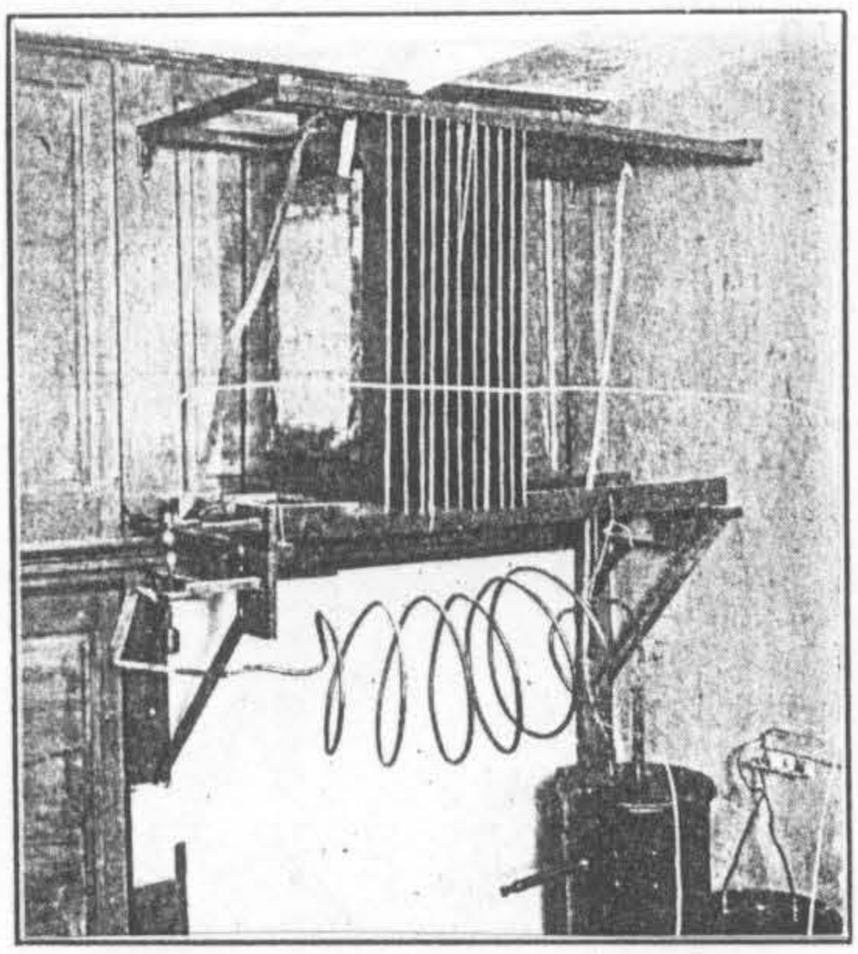


FIG. 4.—CONDENSER, SPARK GAP AND INDUCTANCE.

the layers clear across the full width of the spool. A space ¼ in. wide should be left at each end so that there will be no danger of the end turns dropping down between the spool col-

lars and the coil itself. The coils when completed should be boiled in paraffin, which should then be allowed to cool, and when the wax is of a mushy consistency the coil should be removed and pressed between two plates of glass with a weight. In this way much of the wax which would otherwise drain out between the interstices of the coil will remain there intact and afford valuable protection and insulation.

The finished coils may be assembled on the spools by slipping the latter through them, and the spools may then be placed in

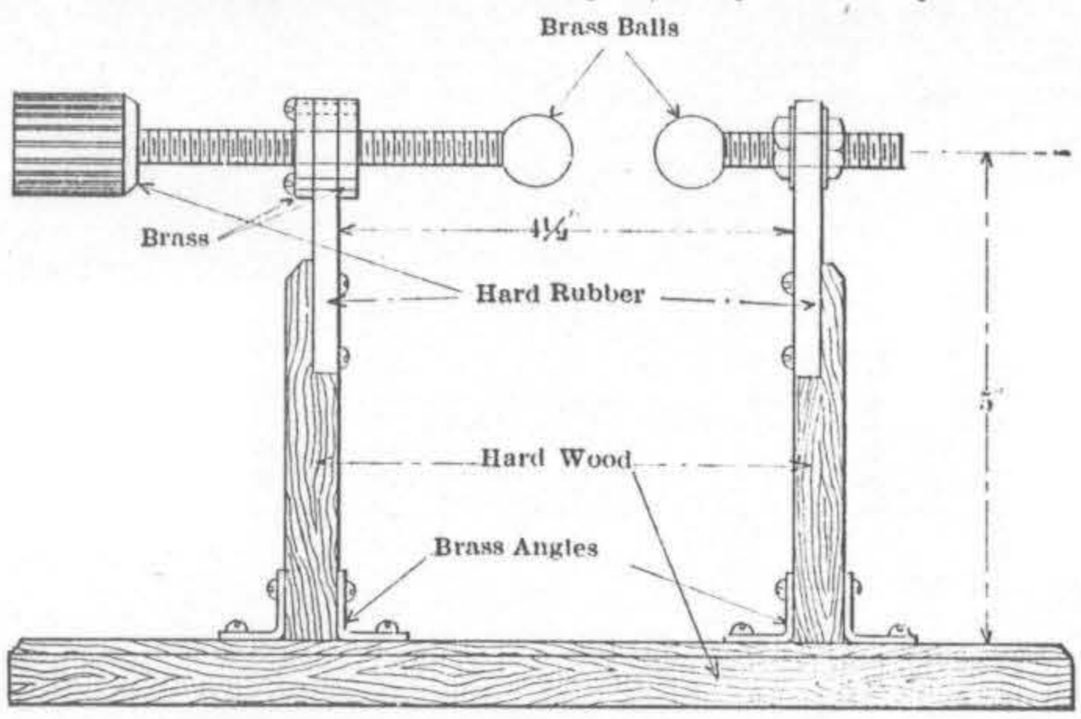


FIG. 5.—DISCHARGE CAP.

the jar, wooden rings being used as spreaders to separate them. Attention is called to the liberal spaces allowed between the primary and secondary, and when the jar is filled with a good grade of transformer oil the insulation between the primary and secondry is homogeneous and complete. An oil cock may be added at the bottom of the jar for the purpose of draining it and, as it is very hard to get the joints for the terminals tight, the jar may be placed in a metal pan which will catch all leakage.

The secondary terminals of the transformers are attached to hard-rubber tubes threaded into hard-rubber plates, which may be bent to fit the contour of the jar by placing them in hot water and securing them by bolts. The joints may be made tight with thick shellac. It may be well to bring the secondary terminals out from the ends of the coils, using a number of twisted wires for this purpose, instead of a single wire, which is likely to break and perhaps burn off.

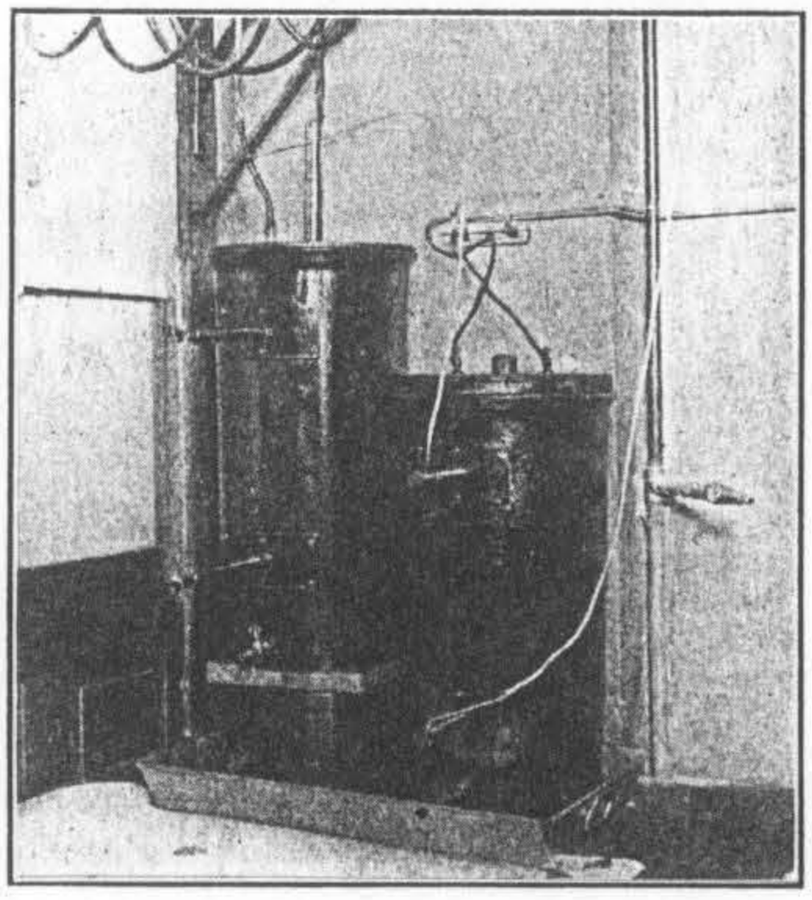
A coil constructed in this way serves not only the purpose of a transformer, but, used in connection with the electrolytic interrupter with direct current, will provide discharges of low frequency and very high tension, 75,000 volts to 100,000 volts, and may be profitably used for breakdown testing of insulating materials.

For the Tesla experiments, however, this coil should be excited with alternating current, and the current from the secondaries should be led off to charge a condenser which may be made in the following manner: A dozen plates of glass (ordinary window glass of double thickness will answer) should be provided and a wooden rack made to contain them. The plates of glass are 18 in. x 24 in. and are covered with tin foil on each side, a space being left between the edge of the glass and the tin foil of at least 3 in. It will be well to shellac the plates and the edges of the tin foil, and the tin foil can be fastened to the plates with shellac very advantageously. The plates are assembled in the rack, which may be made of strips of wood having equally spaced saw cuts, and a set of busbars may be mounted upon strips of wood with similar saw cuts and carrying clips which extend down between the plates and make contact with the tin foil. Fig. 3 shows how this may be done, and Fig. 4 shows a photograph of the actual condenser constructed in this manner. The arrangement is to be recommended rather than the more economical one of placing the plates closely together and using alternate strips of tin foil between them, for the reason that if any plate should be overheated and crack through sparking, it can be removed without disturbing the others.

The discharge gap may be mounted on a wooden frame; the discharge points being carried on light pieces of hard rubber and equipped with balls ⅝ in. in diameter. One of the discharge points should be screw controlled through a nut so that the gap may be varied. A drawing of this discharge cap is shown in Fig. 5.

The apparatus upon which high-frequency currents are to be impressed is connected at *X* and the discharge gap shortened, so that when the switch is closed, the discharge jumps across the gap making a very noisy white spark, which is inclined to be calorific and not sharply broken off, but which can be corrected by opening the discharge gap a little, after the discharge is once started. In fact, it will be found to be best to do this to obtain the maximum results. If an inductance consisting of a coil of copper wire, say No. 2-0 trolley wire, be wound 8 in. in diameter and with 6 turns, and connected across the points *X*, the oscillatory current will experience considerable difficulty in traversing it. If a spark gap be shunted around this coil, it will be found that a potential of from 8,000 to 10,000 volts exists there. A vacuum tube of any type will be brilliantly illuminated if connected in shunt around this apparent short circuit. Still





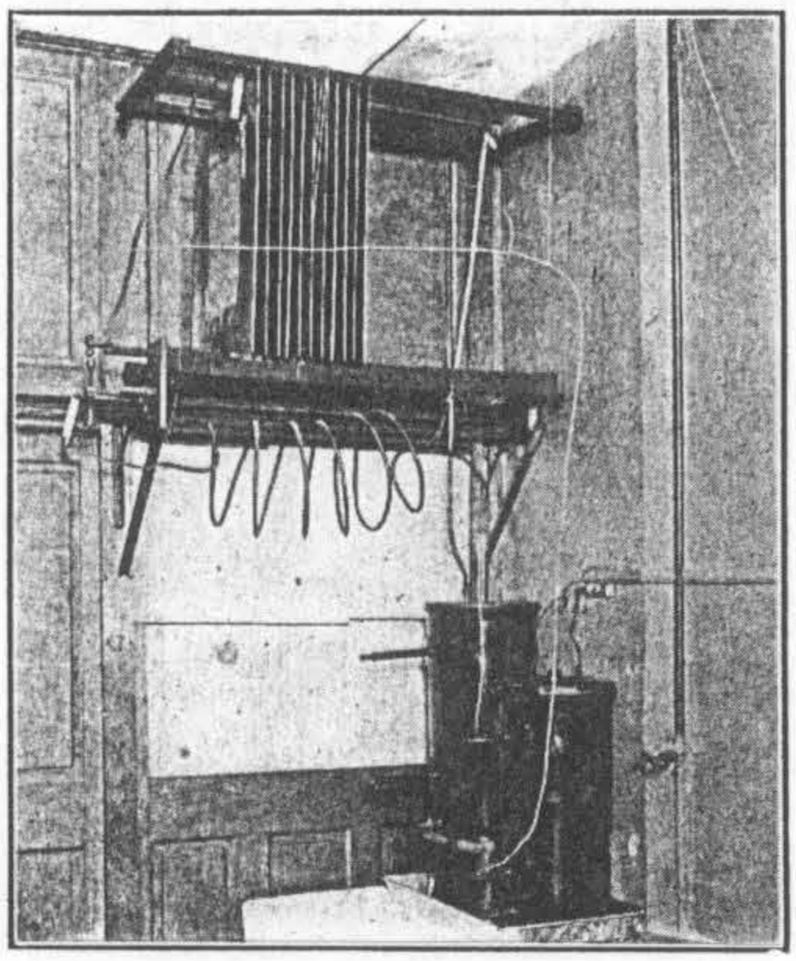


FIG. 6.—FRACTURED GLASS JAR OF TESLA COIL. FIG. 7.—TRANSFORMER AND TESLA COIL. FIG. 8.—GENERAL VIEW OF EQUIPMENT.

more puzzling is the fact that an incandescent lamp connected across the terminals of this coil, and apparently on dead short circuit, will light up brightly, but even under these conditions the experimenter will be presented with the curious phenomenon of the discharge striking across the terminals of the lamp within the bulb and also without, showing the existence of a high potential, and yet the filament will burn as it would under its normal 0.5 amp current.

A piece of No. 36 wire 3 or 4 ft. long, shunted across this coil will become red hot and burn out, and if the wire be coiled in approved magnet fashion on a glass tube with the insulated

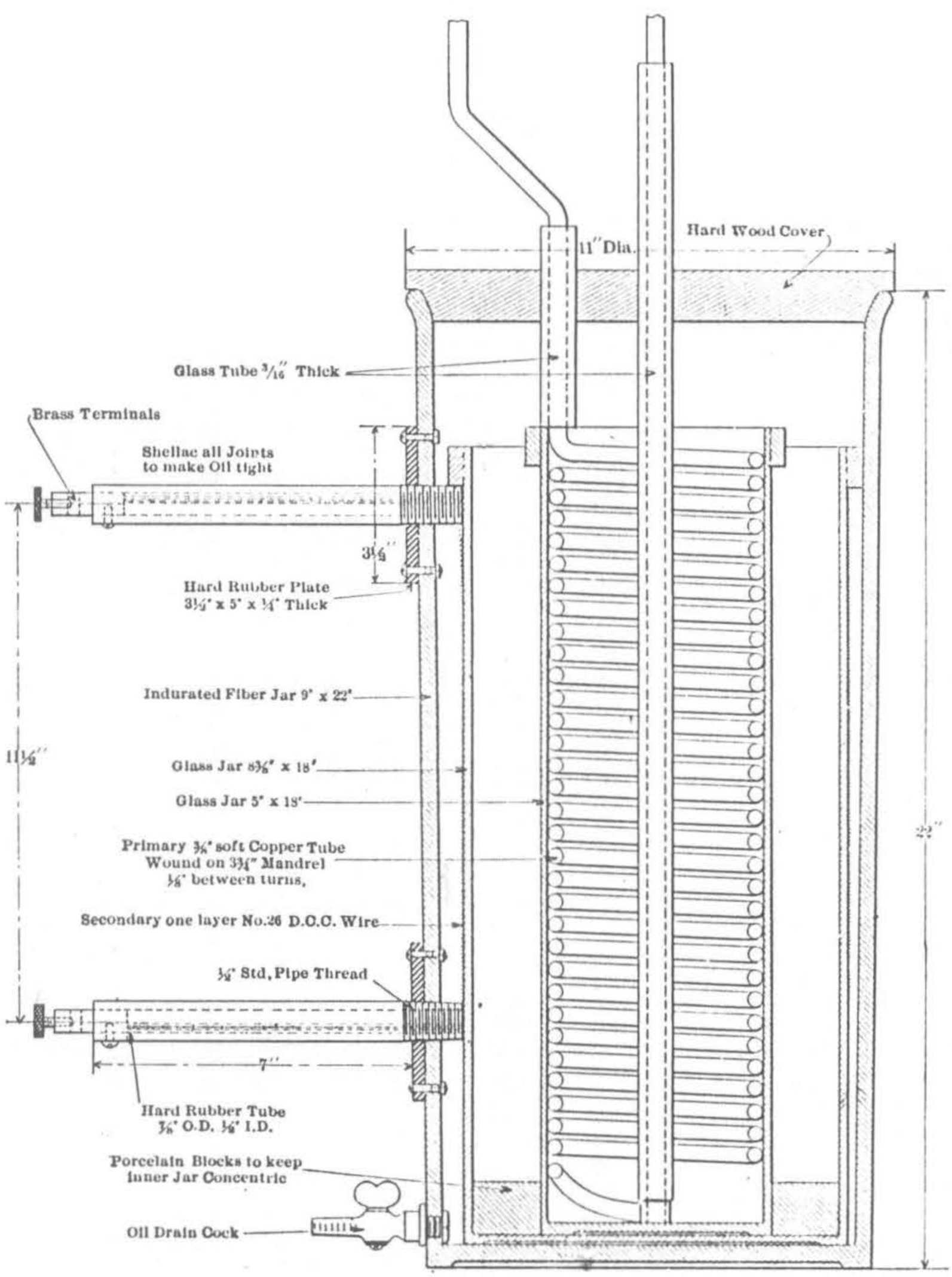


FIG. 9.—DETAILS OF TESLA COIL.

turns in close proximity and connected as above described, the current will jump from turn to turn on the coil rather than go through it. A very pretty experiment can be made by connecting at the point *X* a pair of busbars across which are shunted a spark gap, a vacuum tube, a 110-volt lamp, a 50-volt lamp, and at the extremities of the busbars a dead short circuit. With a little adjustment and manipulation, all of the lamps and tubes will light up simultaneously, while sparks will jump across the gap.

The Tesla experiments are not complete unless the step-up Tesla transformer is constructed. The coil described below is capable of producing voltages in the neighborhood of 150,000, and must, therefore, be insulated with a great deal of care. The primary coil consists of about 30 turns of No. 2-0 trolley wire, or a thin copper tube of the same diameter. This wire or tube is stiff enough to be wound in a single helix, having a return through the center, as shown in Fig. 6. The wire or tube should be coiled inside of a long glass jar, and one of those commonly employed in preserving specimens in alcohol will be found very suitable. The jar shown in the drawing is equipped with a heavy lip, the top of which is ground flat. The primary terminals are brought out through heavy glass tubes through the wooden cover, as shown in the drawing, and connected to the point *X*, Fig. 1.

The secondary coil consists of about 500 turns of No. 26 wire wound upon the outside surface of a second glass jar of considerably larger diameter than the first, but of about the same height. Care should be taken to wind these coils so that they do not pass beyond the high-tension terminals, for if this is not done, the turns beyond are likely to short-circuit against the lead brought up from the bottom of the jar or down from the top as the case may be. The coil should end at the terminals. The jar may be shellacked before winding the coil and allowed to dry, and after the coil is completed, a second coat of shellac should be given to prevent the wire from unwinding when manipulated. Double cotton-covered wire should be used.

The whole outfit may be immersed in oil in an umbrella jar of the same type as was used in the manufacture of the high-tension transformer, but it will be well to bring the terminals out farther in the case of the high-tension transformer, as the discharge is very unmanageable and will be found to strike into anything that may be within convenient reach. If the terminals are too short, the discharge will strike through the indurated fiber and oil back to the coil, and is likely to snap the wire of which the secondary is wound as neatly as if it were cut with a pair of shears. The terminals should be 12 in. apart. Like the case of the high-tension transformer, it is well to equip the jar with a drain cock.

The insulation of the Tesla coil may seem extravagant, but in the writer's opinion it is none too good, and perhaps may be improved upon. In the first experiments, the writer endeavored to construct a coil omitting the central jar, with the result that the jar was heavily punctured, the inside splintered and gnawed by the discharge, and the bottom of the jar was found to contain at least a heaping teaspoonful of powdered glass. This rupture is somewhat interesting for the reason that it was beyond all doubt the result of many successive punctures, and from the length of the rupture it was evident

that the discharge did not simply puncture one hole and enlarge it, but punctured again in another place rather than overcome the inductance of the slightly longer path through the original hole.

Owing to the fact that the high-tension terminals of the Tesla coil make everything in the vicinity of opposite polarity by electrostatic induction, this coil should be well insulated from the ground. This may be conveniently done by setting the whole jar on a heavy piece of marble or glass resting on a second indurated fiber jar. The photograph showing the high-tension coil and the Tesla coil in action illustrates a suitable arrangement. In this case both the high-tension transformer and the Tesla coil are contained in a shallow iron pan.

Vacuum tubes of any length can be illuminated by simple contact with one terminal. The current from these terminals is not dangerous, although the shock obtained by taking both terminals in the hands would probably be somewhat uncomfortable, and it is well to take the discharge, if it is to be taken into the body, through a metal rod so as to avoid burns at the point where the discharge enters. The experimenter may seat himself upon an ordinary wooden stool, keeping his feet clear from the floor, and need not fear to take from one of the terminals of the Tesla coil a fat, hot spark 6 in. long, using, of course, a metal rod to protect his fingers against burning. He may hold in his free hand a wire leading to an ordinary 8-cp incandescent lamp, another experimenter holding the second wire, but standing on the floor. Enough current will be transmitted through his body to light the lamp. Or seated upon the stool in this way, he may ignite the gas with his fingers, or may light vacuum tubes by touching them, or deliver sparks to an observer standing upon the floor; in fact, there is no end of variations of phenomena. In conclusion, the writer would earnestly caution the experimenter to confine these experiments to the discharge from the Tesla coil alone. The terminals of the high-tension transformer are highly dangerous, and any wires connected with them are, of course, equally so, and should be adequately supported and securely placed beyond the range of accidental contact.

[78.]—TESLA COIL.—I should use the larger and longer tubes, and wind the wires with air space between them if possible, to avoid "shorting." I have not found any appreciable difference between good linseed oil and others, and have often used ordinary petroleum with good results. Arthur E. R. Bottone.

Tesla Coil for X-Ray

Questions.—(A) In the high frequency apparatus in the March issue, (answer to E. H. B., Brooklyn) I wish to ask whether this coil can be used for X-ray purposes? (B) If this coil will perform the experiment on page 162 in July issue? (C) Can I use No. 35 wire in place of No. 31, and if so, what would be the effect? (D) How can I build a fluoroscope?—T. R. F., Pryor Creek, Okla.

Answers.—(A) Yes.

(B) No.

(C) Yes, but the Tesla coil would have to be varied to suit the change in the induction coil or transformer, as the coil voltage would be greater but the current less. Therefore a smaller condenser would have to be used, and the Tesla coil wound to suit the condenser. The induction coil described would require more careful insulation between secondary and primary if No. 35 wire were used as the voltage would be greater.

(D) To make a fluoroscope take a sheet of paper or other substance transparent to X-rays and cover it with a fluorescent substance such as tungstate of calcium or platino-barium-cyanide. Mount it in the large end of a stereoscope with the fluorescent surface turned toward the inside.

The New York Tribune October 2, 1909

DECIDES AGAINST AMERICA'S CLAIM.

Tesla Dashes Polar Cup from Nation's Lips—Trip by Dirigible Balloon "Easy."

To the Editor of The Tribune.

Sir: According to a Washington dispatch in your issue of the 26th ultimo, the hydrographic office of the Navy Department is preparing a new map with the North Pole as American territory. Evidently, there is a Moltke in the hydrographic office. Nevertheless, much will have to be done before the claim is recognized by other nations. Permit me to point out a few reasons why it is, for the time being, untenable:

First—"The conquest of the pole" is an act which partakes nothing of the nature of discovery conveying a moral if not legal right to national possession. For centuries the position of that imaginary point was accurately determined, hence its discovery is out of the question. To reach the pole is an achievement noteworthy only because of the hardships and perils involved. It is but a sportsman's exploit, an athletic feat, which entitles the performer to a trophy or price, and nothing more.

Second—The extent of the polar region is still to be defined. That itself may become a subject of unending dispute.

Third—The polar region is located in the centre of an ocean which, be it frozen or not, is international property.

Fourth—The claim is further weakened by the fact that there can be nothing but frozen sea in that region, for the accumulation of water there is an unavoidable consequence of physical laws. This is strikingly illustrated by the old planet Mars, where for the greater part of the year virtually all the water is held in captivity at the poles.

Fifth—The measurements of the explorers were crude and uncertain, the sextant with an artificial horizon having been entirely depended upon to locate the pole. There are numerous obstacles to accurate observation in those regions, but the chief is that the air is filled with minute electrified crystals of ice which cause colorings, mirages and other effects of refraction. Under such conditions an error of as much as fifty miles is possible.

Sixth—There are no competent witnesses to verify the readings and observations. When a truth discovered is readily demonstrable witnesses are unnecessary, but in this particular instance, when immediate repetition of the experience is impossible and all traces are effaced, a corroboration is indispensable.

It is very likely that under the circumstances scientific institutions such as the Geographical Society or Geodetic Survey will accept the reports as nothing more than unconfirmed theories, especially since it must be plain to every member that these up-to-date polar explorations have little in common with the unselfish efforts of the early pioneers, being rather undertakings of daring men attracted by adventure hazard spirited enough to take all sorts of desperate risks for achieving fame and popularity.

In view of the great popular interest, which has been intensified to a degree of national feeling, it is necessary, if this country desires to retain the claim, that another expedition be immediately organized, either by popular subscription or appropriation through Congress. The dirigible balloon has been so far perfected that the exploration of the polar regions by its means is a simple and easy task. In Germany preparations, strongly supported by the Emperor, have already been undertaken, but it is very probable that if this country would signify at once the intention to organize such an expedition its wishes would be respected, for it is an undeniable fact that, however imperfect these recent attempts have been, they go toward laying the foundation to a just national claim, and certainly are a testimony to the wonderful energy and pluck of Americans.

New York, Oct. 1, 1909. NIKOLA TESLA.

VOL. XXIII.—WHOLE NO. 8,042 NEW YORK, TUE

TESLA SAYS HE CAN HARNESS ALL THE WIRELESS CURRENTS

Make Them Operate Airships and Give You Wireless 'Phone to the Ends of the Earth—As Easy to Talk to Australia as to Hoboken.

BY AND BY YOU CAN TALK TO MEN IN AEROPLANES

Won't Need High Towers to Send or Receive the Electric Waves—Ambitious Programme of the Noted Inventor Soon to Be Completed, He Says.

Nikola Tesla, electrical scientist and inventor, is planning to build a great electric power plant which will enable him to operate all the telephone, telegraph, lighting, traction and industrial systems of the earth by wireless currents. His plan also is so far-reaching that it takes in the operation of all aeroplanes and dirigibles and the keeping of them in telegraphic and telephonic touch with the earth at all times by the same method, no matter over what part of the earth they may be sailing or with what part of it they may desire to communicate. By this system, he says, all the wires which now are used to connect telegraph and telephone instruments and electric lights will be eliminated without changing in any degree the other features of the installations, and it will be easier then for a man in New York to step to a telephone and converse by wireless with a man in Melbourne, Australia, than it now is for him to talk by wire across a room.

Tesla was interviewed yesterday in his office at No. 165 Broadway. He said that probably his utterances would be regarded by many persons as those of a visionary, but that time would vindicate them fully.

"Mr. Tesla, I understand you have perfected a system whereby it will be possible to telephone, say, from New York city to Melbourne, Australia, by wireless process without any change in the present installations made by the telegraph and telephone companies.

"I am glad to say that such is the case," Tesla replied. "I have worked persistently on the wireless transmission of energy since 1893, when I presented my paper on that subject before the National Electric Light Association in St. Louis and the Franklin Institute in Philadelphia. The popular idea is that the wireless system of transmission is just one invention, but the fact is that it involves in its present state of perfection six fundamental discoveries, or inventions, in combination. They are as follows:

"First—The method and apparatus for transforming ordinary currents into electrical oscillations of great intensity.

"Second—The apparatus for intensifying those vibrations sensibly, so they penetrate into the distance.

"Third—A receiving apparatus which collects and focuses energy which a transmitter supplies to a large territory. For instance, if such receiver, properly constructed be placed in Ireland it will collect practically the entire energy conveyed to that country from the transmitter.

"Fourth—The method and apparatus for making the electrical impulses secret and non-interferable. That is to say, making it impossible to prevent their passage or to read them. The energy of the transmitter, which is collected by the receiver, only can be released by a sort of safety lock or combination.

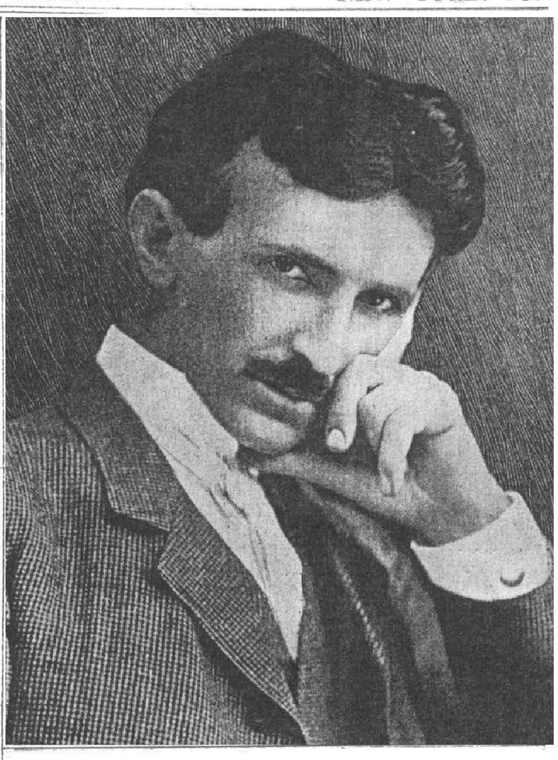
"Fifth—The production of stationary waves. That is, waves which excite the entire earth and pass through it under a vibration much the same as though you were to draw a string tight and then strike it. With these waves the distance is absolutely eliminated, as the effects are the same whether the receiver is thousands of miles away or close to the transmitter.

"Sixth—A number of inventions which cannot very well be described in a short interview, but which go together to make the system practically operative.

"With a plant constructed under the observance of these principles it will be just as easy to telephone from here to Melbourne, Australia, as across a room, and there will be absolutely no distortion of the voice, such as is observable now in communication by wire. This is not a theory, but a fact absolutely demonstrated by my experiments, which have shown that the current passes without loss over the entire extent of the globe and through the globe. I already have carried the construction of such an installation very far and hope that I shall be able to complete it during the coming summer. From that moment every telegraphic, telephonic as well as every wireless station will be ever so much more valuable, as they will be able to receive messages from any part of the world. All this will be done without the slightest change in the existing equipment."

"Will it be necessary under your plan, Mr. Tesla, to build high towers, on the shores of the countries using it, and also in interior points?" the inventor was asked.

"Not at all," Tesla replied. "In fact, large towers are comparatively ineffective. The tower I have built near Port Jefferson, L. I., is only 187 feet high, but the plant will produce an effect which can be pushed up to a rate of 1,000,000,000 horsepower, which is more than all the wireless plants that have been put up so far altogether. This enormous activity I secured by the use of certain artifices on which I have also based my confidence that it will be possible to flash signals



TESLA SAYS HE CAN HARNESS ALL THE WIRELESS CURRENTS

(Continued from First Page.)

through interplanetary space. To a majority of people such a statement would appear visionary, but I have the utmost confidence that I shall be able to do so."

"How much capital, Mr. Tesla, is invested already on the strength of your inventions bearing on the production of electrical power?"

"In the first place, I do not call these inventions altogether mine," Tesla said. "I have merely laid the foundation. Great work has been done in perfecting my inventions by the staff of engineers of the Westinghouse and General Electric companies, so that at present there are hundreds of millions invested in enterprises in which my alternating system forms the underlying foundation. We have harnessed 6,000,000 horsepower water falls. There are probably enterprises, aggregating 20,000,000 more under consideration. The enormous importance of this water power, or the so-called 'white coal,' a name given to water power, can be understood readily when it is borne in mind that one horsepower for twenty-four hours is equivalent to the average performance of twenty-four men. Therefore, the 6,000,000 horsepower which has been harnessed have virtually added to the world's population from the point of view of labor, 144,000,000 of workingmen, who consume no food and need no clothes."

"But what about the power other than that derived from the waterfalls?"

"I am happy to say that in this direction also I have been successful, having perfected a new reversible gas turbine of ideal simplicity and beauty, which will permit the harnessing of the waste of the steel and iron furnaces, in which we now are losing in the United States not less than 50,000,000 horsepower. I am just about to introduce that invention commercially."

"Will this wireless system of yours permit of the transmission of electric power for purposes of operation?"

"Certainly," the inventor said. "In fact, had it not been for unfortunate circumstances long ago a plant of this kind would have been in operation. Just one single plant, of say 10,000-horsepower, would be sufficient to drive several thousand flying machines, aeroplanes and dirigibles anywhere in the world. While supplying them with wireless power it also would keep them in constant touch with the earth by wireless telephone and telegraph."

"What encourages you, Mr. Tesla, to think that by the application of your principle you will be able to flash interplanetary signals?"

"In my experiments in Colorado, where I discovered certain planetary disturbances, I attained with my transmitter activities which surpassed in power in many ways those of lightning. In my present plant I shall be able to reach a rate of energy delivery of about 1,000,000,000-horsepower. A simple calculation will convince any expert that with such an intensity and energy reaching a certain area of the planet Mars, it is ample to produce a perceptible effect in a delicate instrument there."

"How will they flash back a signal?"

"I think they are flashing already, and waiting for us to answer their signals," Tesla replied, with a seriousness which showed that he believed confidently what he said about the inhabitants of Mars.

Tesla on Wireless Electric Power.

Mr. Nikola Tesla in an interview published Dec. 7 in the New York *Press* discussed the subject of wireless transmission of electric power. He said that he has worked persistently on the wireless transmission of energy since 1893, when he presented a paper on that subject before the National Electric Light Association in St. Louis and the Franklin Institute in Philadelphia. The popular idea, he said, is that the wireless system of transmission is just one invention, but the fact is that it involves in its present state of perfection six fundamental discoveries, or inventions, in combination. They are as follows:

First.—The method and apparatus for transforming ordinary currents into electrical oscillations of great intensity.

Second.—The apparatus for intensifying those vibrations immensely, so that they penetrate into the distance.

Third.—A receiving apparatus which collects and focuses energy which a transmitter supplies to a large territory. For instance, if such receiver, properly constructed, be placed in Ireland it will collect practically the entire energy conveyed to that country from the transmitter.

Fourth.—The method and apparatus for making the electrical impulses secret and non-interferable. That is to say, making it impossible to prevent their passage or to read them. The energy of the transmitter, which is collected by the receiver, only can be released by a sort of safety lock or combination.

Fifth.—The production of stationary waves. That is, waves which excite the entire earth and pass through it under a vibration much the same as though you were to draw a string tight and then strike it. With these waves the distance is absolutely eliminated, as the effects are the same whether the receiver is thousands of miles away or close to the transmitter.

Sixth.—A number of inventions which cannot very well be described in a short interview, but which go together to make the system practically operative.

With a plant constructed under the observance of these principles it will, he said, be just as easy to telephone from here to Melbourne, Australia, as across a room, and there will be absolutely no distortion of the voice, such as is observable now in communication by wire. This, he added, is not a theory, but a fact absolutely demonstrated by his experiments, which have shown that the current passes without loss over the entire extent of the globe and through the globe. He has carried the construction of such an installation very far and hopes to be able to complete its construction during the coming summer.

From that moment every telegraphic, telephonic as well as every wireless station will, he said, be ever so much more valuable, as they will be able to receive messages from any part of the world. All this will be done without the slightest change in the existing equipment.

"Will it be necessary under your plan, Mr. Tesla, to build high towers on the shores of the countries using it, and also in interior points?" the inventor was asked.

As to large towers these, he said, are comparatively ineffective. The tower he has built near Port Jefferson, L. I., is only 187 ft. high, but the plant will produce an effect which can be pushed up to a rate of 1,000,000,000 hp, which is more than all the wireless plants that have been put up so far altogether. This enormous activity is secured by the use of certain artifices on which he also bases a confidence that it will be possible to flash signals through interplanetary space.

Mr. Tesla added that his electric power inventions are not altogether his own, and that he has merely laid the foundation. Great work has been done in perfecting the devices by the staff of engineers of the Westinghouse and General Electric companies, so that at present there are hundreds of millions invested in enterprises in which his alternating system forms the underlying foundation. This has harnessed 6,000,000 hp waterfalls.

There are probably enterprises aggregating 20,000,000 more under consideration. The enormous importance of this water power, or the so-called "white coal," can be understood readily when it is borne in mind that 1 hp for 24 hours is equivalent to the average performance of 24 men. Therefore, the 6,000,000 hp which has been harnessed have virtually added to the world's population from the point of view of labor 144,000,000 of workingmen, who consume no food and need no clothes.

As to power other than that derived from waterfalls, he was happy to say that in this direction also he has been successful, having perfected a new reversible gas turbine of ideal simplicity and beauty, which will permit the harnessing of the waste of the steel and iron furnaces, in which we now are losing in the United States not less than 50,000,000 hp. Mr. Tesla added that he is just about to introduce that invention commercially.

As to his wireless system for the transmission of electric power, he said that if it had not been for unfortunate circumstances a plant of this kind would long ago have been in operation. Just one single plant, of, say, 10,000 hp, would be sufficient to drive several thousand flying machines, aeroplanes and dirigibles anywhere in the world. While supplying them with wireless power it also would keep them in constant touch with the earth by wireless telephone and telegraph.

Referring to interplanetary signals, he said he had in his experiments in Colorado discovered certain planetary disturbances, and attained with his transmitter activities which surpassed in power in many ways those of lightning. In his present plant he will be able to reach a rate of energy-delivery of about 1,000,000,000 hp. A simple calculation will, he said, convince any expert that with such an intensity and energy reaching a certain area of the planet Mars, it is ample to produce a perceptible effect in a delicate instrument there.

In answer to a question as to return signals, he said he believed that these signals are being flashed now and waiting for us to answer.

Nikola Tesla's New Wireless.

Mr. Nikola Tesla has announced that as the result of experiments conducted at Shoreham, Long Island, he has perfected a new system of wireless telegraphy and telephony in which the principles of transmission are the direct opposite of Hertzian wave transmission. In the latter, he says, the transmission is effected by rays akin to light, which pass through the air and cannot be transmitted through the ground, while in the former the Hertz waves are practically suppressed and the entire energy of the current is transmitted through the ground exactly as though a big wire. Mr. Tesla adds that in his experiments in Colorado it was shown that a very powerful current developed by the transmitter traversed the entire globe and returned to its origin in an interval of 84 one-thousandths of a second, this journey of 24,000 miles being effected almost without any loss of energy.

The New York World December 30, 1909

HIS WIRELESS LIGHT A FACT SAYS TESLA.



Cheap to Produce, He Explains, and Lamps Will Last Forever.

Nikola Tesla, who has been at work on a "wireless electric light" for twenty years, announced yesterday that he has practically brought it to a state of perfection. He says a plant for its production is now nearing completion at his laboratory on Long Island.

"It would be possible by my wireless transmitter of great power," said Mr. Tesla, "to light the entire United States. The current would pass into the air and, spreading in all directions, produce the effect of a strong aurora borealis. It would be a soft light, but sufficient to distinguish objects. Some day soon my idea will be carried out. I would like nothing better than to undertake to illuminate first the harbor of New York for a distance of, say, 100 miles around.

Lamps Last Forever.

"My present plan is to distribute this light from a central station, which is the most economical and also the best method of obtaining light of highest quality. My lamps will last forever, there being nothing in them to burn out. They are simply tubes or bulbs of glass hermetically sealed and containing nothing but rarefied gas.

"One advantage is the economy of production, which is greater than in any other light so far obtained. Still another is the wonderful quality of the light, which resembles sunlight so closely that it cannot be distinguished from it. It is very soothing to the eye, being diffused. A great saving will be effected by wireless distribution. I am intending chiefly to supply isolated dwellings which cannot be conveniently reached by wires or lighted in any of the ways heretofore used.

"In this system of distribution there is absolutely no difference where the dwelling is located. The force of the current is the same. The house might be 12,000 miles from the plant or 12 feet, it would be the same. The plant consists of only a little transformer which could easily be carried in the pocket, and will be sufficient to light the whole house. The current may be conveyed to the individual lamps either by wires, or all wires might be dispensed with and the lights rendered portable."

The scientist then explained that the current thus created was a "vibrating" one and was convertible for other purposes.

Other Uses of the System.

"Among other things," said he, "the same current can be used to carry the human voice or the telegraphic code. One plant will do all this without interference of one action with the other. This is done by the use of an invention which I have called the 'Art of Individualization.' This is a method and an apparatus for making signals or messages non-interfering and non-interferable, and it is based on the use of a number of vibrations in combination."

When asked how soon he expects to demonstrate his discovery in a completed form the inventor gave hint of another invention already completed.

"It will not take long to complete my plant," said he, "but I am now compelled to concentrate all my efforts on the introduction of my new steam and gas turbine, which my friends consider the most valuable result that I have accomplished. It has to do entirely with the great question of waste, and I believe, will be a tremendous money saver. Just as soon as I get it started on its way I shall devote all of my time to the wireless."

Those of our readers who have perused the long and thoroughly "documented" lecture of Mr. Marconi will turn with added interest to the words of that other happy worker in the same field. Mr. Nikola Tesla, in an interview with a representative of the New York *Press*, discussed the subject of wireless transmission of electric power. He said that he has worked persistently on the wireless transmission of energy since 1893, when he presented a paper on that subject before the National Electric Light Association in St. Louis and the Franklin Institute in Philadelphia. The popular idea, he said, is that the wireless system of transmission is just one invention, but the fact is that it involves in its present state of perfection six fundamental discoveries, or inventions, in combination. They are as follows :—

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From that moment every telegraphic, telephonic as well as every wireless station will, he said, be ever so much more valuable, as they will be able to receive messages from any part of the world. As this will be done without the slightest change in the existing equipment.

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As to large towers these, he said, are comparatively ineffective. The tower he has built near Port Jefferson, L.I., is only 187 ft. high, but the plant will produce an effect which can be pushed up to a rate of 1,000,000,000 h.p., which is more than all the wireless plants that have been put up so far altogether. This enormous activity is secured by the use of certain artifices on which he also bases a confidence that it will be possible to flash signals through interplanetary space.

Mr. Tesla added that his electric power inventions are not altogether his own, and that he has merely laid the foundation. Great work has been done in perfecting the devices by the staff of engineers of the Westinghouse and General Electric Companies, so that at present there are hundreds of millions invested in enterprises in which his alternating system forms the underlying foundation. This has harnessed 6,000,000 h.p. waterfalls.

There are probably enterprises aggregating 20,000,000 more under consideration. The enormous importance of this water power, or the so-called "white coal," can be understood readily when it is borne in mind that 1 h.p. for 24 hours is equivalent to the average performance of 24 men. Therefore, the 6,000,000 h.p. which has been harnessed have virtually added to the world's population from the point of view of labour 144,000,000 of working men, who consume no food and need no clothes.

As to power other than that derived from waterfalls, he was happy to say that in this direction also he has been successful, having perfected a new reversible gas turbine of ideal simplicity and beauty, which will permit the harnessing of the waste of the steel and iron furnaces, in which we now are losing in the United States not less than 50,000,000, h.p. Mr. Tesla added that he is just about to introduce that invention commercially.

As to his wireless system for the transmission of electric power, he said that if it had not been for unfortunate circumstances a plant of this kind would long ago have been in operation. Just one single plant of, say, 10,000 h.p., would be sufficient to drive several thousand flying machines, aeroplanes and dirigibles anywhere in the world. While supplying them with wireless power it also would keep them in constant touch with the earth by wireless telepone and telegraph.

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In answer to a question as to return signals, he said he believed that these signals are being flashed now and waiting for us to answer.

Tesla's Plan for "Wireless" Electric Lighting.

In a recent newspaper interview Nicola Tesla is reported to have said that as the result of many years' effort his "wireless electric light" has practically been brought to a state of perfection, and a plant for its production is now nearing completion at his laboratory.

"It would be possible by my powerful wireless transmitter," said Mr. Tesla, according to this account, "to light the entire United States. The current would pass into the air and, spreading in all directions, produce the effect of a strong aurora borealis. It would be a soft light, but sufficient to distinguish objects.

"My present plan is to distribute this light from a central station, which is the most economical and also the best method of obtaining light of highest quality. My lamps will last forever, there being nothing in them to burn out. They are simple tubes or bulbs of glass hermetically sealed and containing nothing but rarified gas.

"One advantage is the economy of production which is greater than in any other light so far obtained. A great saving will be effected by wireless distribution. I am intending chiefly to supply isolated dwellings which cannot be conveniently reached by wires, and in this system of distribution there is absolutely no difference where the dwelling is located. The force of the current is the same whether the house is 12,000 miles from the plant or twelve feet."

The New York World January 9, 1910

What Science May Achieve this Year.

New Mechanical Principles for the Conservation of Energy

By Nikola Tesla.



NIKOLA TESLA

THE spread of civilization may be likened to that of fire: First a feeble spark, next a flickering flame, then a mighty blaze, ever increasing in speed and power. We are now in this last phase of development.

Human activity has become so widespread and intense that years count as centuries of progress. There is no more groping in the dark or accidental stumbling upon discoveries. The results follow one another like the links of a chain. Such is the force of accumulated knowledge and the insight into natural laws and phenomena that future events are clearly projected before our vision. To foretell what is coming would be no more than to draw logical conclusions, were it not for the difficulty in accurately fixing the time of accomplishment.

The practical success of an idea, irrespective of its inherent merit, is dependent on the attitude of the contemporaries. If timely it is quickly adopted; if not, it is apt to fare like a sprout lured out of the ground by warm sunshine, only to be injured and retarded in its growth by the succeeding frost. Another determining factor is the amount of change involved in its introduction. To meet with instant success, an invention or discovery must come not only as a rational but a welcome solution. The year 1910 will mark the advent of such an idea. It is a new mechanical principle.

Since the time of Archimedes certain elementary devices were known, which were finally reduced to two, the lever and the inclined plane. Another element is to be added to these which will give rise to new conceptions and profoundly affect both the practical and theoretical science of mechanics.

This novel principle is capable of embodiment in all kinds and classes of machinery. It will revolutionize the propulsion apparatus on vessels, the locomotive passenger car and the automobile. It will give us a practical flying machine entirely different from those made heretofore in operation and control, a contrivance having nothing in common with the aeroplane or dirigible, swift, small and compact and so safe that a girl will be able to fly in it to school without the governess. But the greatest value of this improvement will be in its application in a field virtually unexplored and so vast that it will take decades before the ground is broken. It is the field of waste.

We build but to tear down. Most of our work and resource is squandered. Our onward march is marked by devastation. Everywhere there is an appalling loss of time, effort and life. A cheerless view, but true. A single example out of many will suffice for illustration.

The energy necessary to our comfort and safe existence is largely derived from coal. In this country alone nearly one million tons of this life-sustaining material are daily extracted from the bowels of the earth with pain and sacrifice. This is about seven hundred tons per minute, representing a theoretical activity of, say, four hundred and fifty million horse-power. But only a small percentage of this is usefully applied.

In heating, most of the precious energy escapes through the flue. The chimneys of New York City puff out into the air several million horse-power. In the use of coal for power purposes, we hardly capture more than 10 per cent. The exhaust of engines carries off more energy than obtained from live steam.

In many modern plants the power has been actually doubled by obviating this waste, but the machinery employed is cumbersome and expensive. The manufacture of light is in a barbarous state of imperfection and this may also be said of many industrial processes. Consider just one case, the manufacture of iron and steel.

America produces approximately 30,000,000 tons of pig iron per year. Each ton of iron requires about one and a half tons of coke and each ton of coke one and a half tons of coal, hence, in providing the iron market, 70,000,000 tons of coal per annum, or 133 tons per minute, are consumed. In the manufacture of coke a ton of coal yields, roughly, 10,000 cubic feet of gas of a mean heating value of 600 heat units per cubic foot.

Bearing in mind that 133 tons are used per minute, the total heat units developed in that time would be 798,000,000, the mechanical equivalent of which is about 19,000,000 horse-power. By the use of the new principle 7,000,000 horse-power might be rendered available. A similar condition exists in the blast furnaces, which are but gas retorts. A furnace of 200 tons produces approximately 17,000 cubic feet of gas per minute of a heat value of 100 units, corresponding to a theoretical performance of 40,000 horse-power, of which not less than 13,000 might be utilized in the improved apparatus referred to. The power derived by this method from all blast furnaces in the United States would be considerably above 5,000,000 horse-power.

The preceding figures, which are conservative, show that it would be possible to obtain 12,000,000 horse-power merely from the waste gases in the iron and steel manufacture. The value of this power, fairly estimated, is $180,000,000 per annum, and it must be made worth much more by systematic exploitation.

A part of the power could be advantageously employed for operating the blowers, rollers and other indispensable machinery and supplying electricity for smelting, steel making and other purposes. The bulk might be used in the manufacture of nitrates, aluminium, carbides and ice. The production of nitrates would be particularly valuable from the point of view of national economy. Assuming that 5,000,000 horse-power were apportioned for that purpose, the annual yield would be not less than 10,000,000 tons of concentrated nitric compound adequate to fertilizing 40,000,000 acres of land. A great encouragement would be given to agriculture and the condition of the steel and iron workers ameliorated by offering to them fertilizer at a reduced rate, thus enabling them to cultivate their farms with exceptional profit. Other conveniences and necessities, as light, power, ice and ozonized water, could be similarly offered and numerous other improvements, both to the advantage of capital and labor, carried out.

To appreciate the above it should be borne in mind that the iron and steel industry is one of the best regulated in the world. In many other fields the waste is even greater. For example, in the operation of steam railroads not less than 98 per cent. of the total energy of coal burned is lost. An enormous saving could be effected by replacing the present apparatus with new gas turbines and other improved devices for transmitting and storing mechanical energy. A study of this subject will convince that for the time being, at least, there is more opportunity for invention in the utilization of waste than in the opening up of new resources.

N. Tesla

THE
Electrical Engineer.
A JOURNAL OF ELECTRICAL ENGINEERING.
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NOTES.

"LIGHT OF THE WORLD."

Under the above alluring title, the daily Press of New York and London have been discussing Signor Tesla's latest pronouncement on his achievements in the development of lighting by electricity. Having regard to the great amount of work that has been done in the way of testing various gases stored in air-tight glass globes for the production of some phenomena equivalent to incandescence (as in the case of mercury vapour lamps), and also the not altogether unsuccessful experiments of transmitting electricity by means of air-borne waves to filament lamps placed at a distance, one must hesitate to declare the clever Italian to be a visionary. We must, however, await an official statement from the inventor before attaching great importance to the subject in its present phase. All that Signor Tesla requires are hermetically sealed glass bulbs enclosing a rarified gas, and a central station where electricity would be generated, and then sent by means of his special "wireless" transmitter through the air, in order to energise the imprisoned gas into emitting light. His light would be diffused light, as soft and generalised as the sun rays.

TESLA'S METHODS.

If he has been correctly reported, Tesla is on the eve of creating a revolution in electric lighting that will cause the metallic filament lamps to pale their ineffectual fires, and give rise to more trouble among central station men than they have ever known before. He would not hesitate to undertake the lighting of the whole of the United States by means of his wireless transmitters, and rather longs to have a shot at illuminating New York harbour, for a hundred miles or so from one station, by means of lamps that will burn for ever.

ISOLATED HOUSE LIGHTING.

Meanwhile, Tesla proposes to come to the rescue of those who live isolated, far from city conveniences. To use his, or the reporter's, words: "I am intending chiefly to supply isolated dwellings which cannot be conveniently reached by wires or lighted in any of the ways heretofore used. In this system of distribution there is absolutely no difference where the dwelling is located. The force of the current is the same. The house might be 12,000 miles away from the plant or 12 ft., it would be the same. The plant consists of only a little transformer, which could be easily carried in the pocket, and will be sufficient to light the whole house. The current may be conveyed to the individual lamps either by wires, or all wires might be dispensed with and the lights rendered portable. The current used is a 'vibrating' one, and can be used for other purposes. Among other things, the current can be utilised for carrying the human voice or the telegraphic code. One plant will do all this without interference of one action with the other. This is done by the use of an invention which I have called the 'art of individualisation.' This is a method and an apparatus for making signals or messages non-interferable, and it is based on the use of a number of vibrations in combination."

[904.]—TESLA COIL.—Make an affair similar to a three- or four-legged stool; only, choose good, dry wood, and boil it in paraffin-wax, so that you have two discs, separated by the legs. Inside the legs wind the primary spiral, and on the outside wind on the secondary wire. Connect the terminals of your coil through spark-gaps to the primary wire, and take off your high-frequency current from the secondary winding. Arthur E. R. Bottone.

The Denver Rocky Mountain News January 16, 1910

What Science May Achieve this Year.

New Mechanical Principles for the Conservation of Energy

By Nikola Tesla.



NIKOLA TESLA

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In many modern plants the power has been actually doubled by obviating this waste, but the machinery employed is cumbersome and expensive. The manufacture of light is in a barbarous state of imperfection, and this may also be said of many industrial processes. Consider just one case, the manufacture of iron and steel.

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AMERICA produces approximately 30,000,000 tons of pig iron per year. Each ton of iron requires about one and a half tons of coke, and each ton of coke one and a half tons of coal, hence, in providing the iron market, 70,000,000 tons of coal per annum, or 133 tons per minute, are consumed. In the manufacture of coke a ton of coal yields, roughly, 10,000 cubic feet of gas of a mean heating capacity of 600 heat units per cubic foot.

Bearing in mind that 133 tons are used per minute, the total heat units developed in that time would be 798,000,000, the mechanical equivalent of which is about 19,000,000 horsepower. By the use of the new principle 7,000,000 horsepower might be rendered available. A furnace of 200 tons produces approximately 17,000 cubic feet of gas per minute, of a heat value of 100 units, corresponding to a theoretical performance of 40,000 horsepower, of which not less than 13,000 might be utilized in the improved apparatus referred to. The power derived by this method from all blast furnaces in the United States would be considerably above 5,000,000 horsepower.

The preceding figures, which are conservative, show that it would be possible to obtain 12,000,000 horsepower merely from the waste gasses in the iron and steel manufacture. The value of this power, fairly estimated, is $180,000,000 per annum, and it must be made worth much more by systematic exploitation.

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A PART of the power could be advantageously employed for operating the blowers, rollers and other indispensable machinery and supplying electricity for smelting, steel making and other purposes. The bulk might be used in the manufacture of nitrates, aluminum, carbides and ice. The production of nitrates would be particularly valuable from the point of view of national economy. Assuming that 5,000,000 horsepower were apportioned for that purpose, the annual yield would be not less than 10,000,000 tons of concentrated nitric compound, adequate to fertilizing 40,000,000 acres of land. A great encouragement would be given to agriculture and the condition of the steel and iron workers ameliorated by offering to them a fertilizer at a reduced rate, thus enabling them to cultivate their farms with exceptional profit. Other conveniences and necessities, as light, power, ice and ozonized water, could be similarly offered and numerous other improvements, both to the advantage of capital and labor, carried out.

To appreciate the above it should be borne in mind that the iron and steel industry is one of the best regulated in the world. In many other fields the waste is even greater. For example, in the operation of steam railroads, not less than 98 per cent of the total energy of coal burned is lost. An enormous saving could be effected by replacing the present apparatus with new gas turbines and other improved devices for transmitting and storing mechanical energy. A study of this subject will convince that for the time being, at least, there is more opportunity for invention in the utilization of waste than in the opening up of new resources.

N. Tesla

QUESTIONS AND ANSWERS

Use of this department is free to readers of Popular Electricity, but attention will not be given to questions which do not comply with the following rules: All questions must be written in the form of a letter addressed to the Questions and Answers Department and containing nothing for the other departments of the magazine; two-cent stamp must be enclosed for answer by mail, for space will not permit of printing all answers; the full name and address of the writer must be given.

Definitions; Pupin and Tesla Coils; Mercury Vapor Lamps

Questions.—(A) What is the difference between a spark coil and an open core transformer? (B) (1) What is inductance? (2) Impedance? (3) Reluctance? (4) Admittance? (C) What is a Tesla coil? (D) What is a Pupin coil? (E) Are mercury vapor lamps made to work on both 110 volts alternating and direct current? How many watts per candle-power do they consume?—M. S., Fort Worth, Texas.

Answers.—(A) A spark coil is built along the same lines as an open core transformer, and is a transformer. The ratio of transformation is usually much lower in the ordinary transformer than in the spark coil. In the latter a make-and-break contact with a condenser connected across this contact greatly increases the length, thickness, and brilliancy of the spark which is intermittent, while in the transformer a steady flow of current from the secondary is usual.

(B) (1) In general by inductance we mean that inexplicable formation of lines about a wire or coil of wire which a magnetic needle tells us are there when a current flows in the wire or coil. These lines represent energy and exercise an inductive effect on adjacent wires. (2) Circuits always have resistance as well as inductance. The combined effect of the two is called impedance and is expressed by the formula:

Impedance in ohms =

$$\sqrt{R^2 + (2x3.1416xfxL)^2}$$

in which

R = resistance of the circuit
f = frequency
L = inductance.

(3) The term reluctance applies to the resistance offered by a magnetic path to the flow of lines of force. For example, the reluctance of wrought iron is less than that of cast iron, the former requiring less ampere-turns to produce a given flux. (4) If I represents the impedance of a circuit in ohms, $\frac{1}{I}$ is its admittance. Used in figuring problems regarding A. C. circuits in parallel, into which calculations resistance, inductance and capacity enter.

(C) A form of induction coil built to give high potentials and high frequencies. This coil and the method of operation is described fully in the January, 1909, issue.

(D) In a long telephone cable the speaking current is distorted, due to the static capacity of the conductor, and is also blurred if the frequency is high. To balance this capacity and get rid of the blurred sound effect, Professor Pupin places an ordinary coil of wire containing a laminated iron core in each circuit at intervals one-eighth of a mile apart. By the introduction of this inductance the talking current is modified so that the proper sounds are registered at the receiving end.

(E) Mercury vapor lamps are made for either direct or alternating current, but the same lamp can be used only upon the kind of current for which it is designed. Lamps requiring 110 volts take 3.5 amperes or 385 watts, the candle-power ranging according to type from 300 to 800.

[407.]—TESLA TRANSFORMER.—I don't know enough about Tesla transformers to answer the first part of the question; but alternating current can be transformed with very slight loss, either up or down, by suitable transformers. With regard to the second part of the question, I don't think any two stations use exactly the same construction of aërial. Mostly phosphor-bronze stranded wire of ⅛in. diameter is used. A large number of stations use the umbrella antenna, some the fan, some inverted L, and others T-shape. In some cases, where multiple wires are used, they are arranged in the same plane, separated by bamboo spreaders; in other stations the spreaders are arranged as a ×, and the wires, therefore, form a sort of long box. The Admiralty seem to favour the latter type. I use the former, as fewer spreaders are necessary, which makes for less windage and weight.

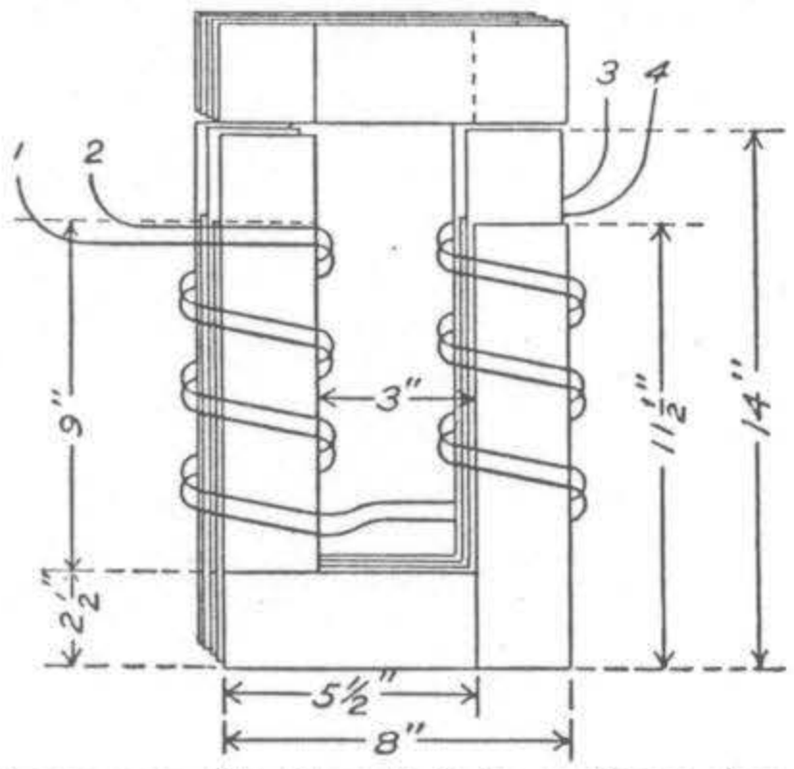
Twickenham. W. J. Shaw.

Popular Electricty December 1910

Construction of a Tesla High-Frequency Apparatus

Many requests are received for information on the construction of a Tesla coil and transformer to go with it. As this requires specific directions of some length we believe it advisable to reprint the article by Mr. H. L. Transtrom which appeared in the January, 1909, issue of Popular Electricity. This article contains all the information necessary to construct a coil and transformer with which to perform the usual high frequency experiments such as lighting a sixteen candle-power lamp one terminal of which is held in the hand and the other connected to one terminal of the Tesla coil, the production of fantastic brush discharges, the melting of fine wire by high frequency current passed through the body, lighting of a vacuum tube, etc. The outfit may also be used for medical work and wireless telegraphy. Following is a description of the apparatus:

A transformer is needed, giving 10,000 to 20,000 volts to charge the condenser. To



Connect No.2 and 4 together for series connection and for parralell No.1 & 2, And also 3 and 4.

FIGURE I. TRANSFORMER FOR HIGH FREQUENCY WORK

construct one it is necessary to make a core from soft sheet iron strips, with a cross-section 2½ inches square, built in the shape of a rectangle eight by fourteen inches outside dimensions and three by nine inches inside (see Fig. 1).

Cut from the sheet iron, strips 2½ by 5½ inches and 2½ by 11½ inches, a sufficient number to make a mass five inches thick of each size when compressed in a vise.

Then take three strips at a time and build a core of the dimensions given in Fig. 1, leaving the top section unfinished until the secondary coils are placed in position.

To hold the core in shape after it is assembled, take two pieces of dry wood twelve by three by 1½ inches and bore a hole in the ends of each, nine inches apart. Put one board on each side of the bottom section and place in a vise, when the six-inch bolts can be drawn tight and then the core will be rigid.

On the vertical sections wrap tightly two or three layers of friction tape to within 2½ inches from the top. Over this wrap a couple of layers of Empire cloth.

The primary consists of 110 double turns wound in a single layer over the Empire cloth, the conductors being two No. 12 cotton-covered copper wires placed side by side, 55 double turns on each vertical section (see Fig. 1).

Over the primary winding next wind tightly 15 layers of No. 7 Empire cloth nine inches wide and we are ready for the secondary winding.

In winding the secondary much care must be exercised, as a transformer's insulation is no better than its weakest spot. This secondary consists of 20,000 turns of No. 32 single cotton-covered copper wire wound in eight coils of 2,500 turns each, which are connected in series, four coils on each side.

The coils are rectangular in shape 1¼ inches wide, four inches square inside and six inches square outside dimensions. They are wound on a form 1¼ inches wide and four inches square, the lateral edges being slightly rounded off to facilitate winding. This form is carefully centered and a metal rod about six inches long of any convenient size is passed through, with a small crank fastened on one end. To keep the coil from sliding out of shape make two disks seven inches in diameter, and when centered screw one on each side of the form.

Set this form between two supports and begin winding, first a layer of Empire paper

and then a layer of wire alternately, until the 2,500 turns are on. It will be found very easy to wind this fine wire in layers if it is allowed to slide over a rod a foot or so away and guided with one hand while winding with the other. Leave a margin of ¼ inch in each layer.

All coils should be tested to see if there are any bare places or if the wire is in one continuous piece. If not, do not attempt to use it as it will surely burn out when run a short time. When all coils are completed they should be dried in an oven, not too hot, and then laid flat in hot petroleum and boiled for several hours, and then left to cool in the mixture until set, which will take quite a long time.

When thoroughly cold, take carefully out of the mixture and after taking the surplus off the coils, assemble on the core over the primary, four on each side. To keep the coils insulated from each other, cut 36 squares of Empire cloth seven by seven inches and cut out of their centres a hole that will fit snugly over the Empire cloth on the primary. Use six thicknesses between adjacent coils, there being only six places to use these separators.

The coils should all be connected in series as though it were one continuous wire beginning at the top of one section and ending at the top of the other. (See Fig. 1.)

Connect all coils so that they have the same relation to one another as the turns in the primary. Keep the coils one inch from the bottom of the core by inserting narrow strips of birch wood across the binding boards and cover with several thicknesses of Empire cloth.

When all the coils are assembled and connected properly, the top part of the core may be completed. A sheet of micanite nine by four by 0.1 inches should be used to separate the vertical sets of coils. Make a box of close-grained hardwood seven by

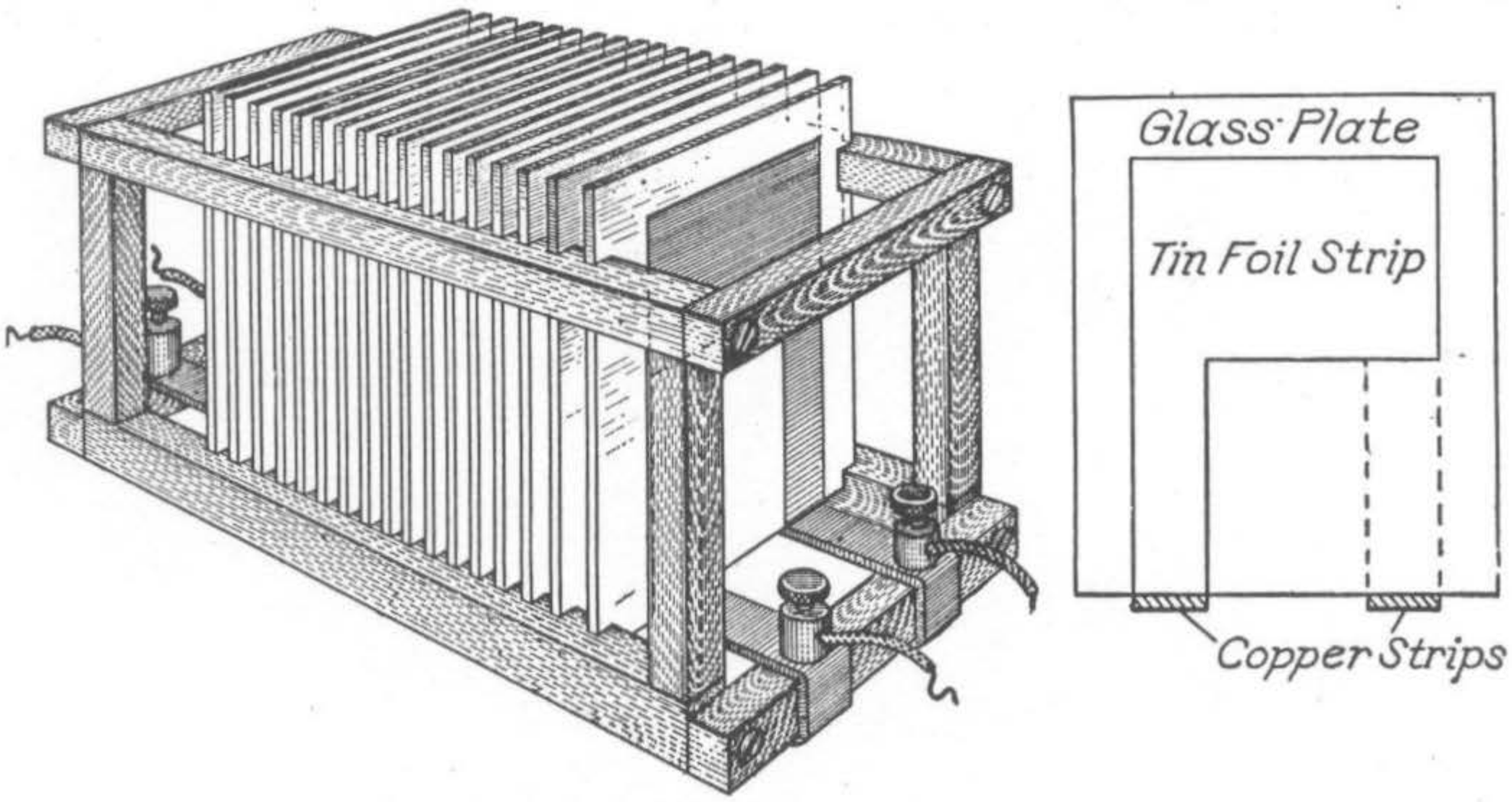


FIG. 2—CONDENSER FOR HIGH FREQUENCY APPARATUS

fifteen by fourteen inches inside measurements and coat thoroughly with hot paraffine to make it perfectly tight.

When the transformer is set in the box it may be fastened by screws to the bottom binding boards.

Bring the ends of the primary wires to one side of the box and the secondary to the other side where they can be connected to proper binding posts. The secondary wire should be kept clear from the core and be led out through hard rubber rod binding posts. The four primary wires should be arranged so that they can be easily connected either in series or parallel.

Boil 40 pounds of extra amber petroleum and fill the box to the top and screw fast the cover and the transformer is complete.

Next we construct an adjustable condenser of seventeen plates of double thickness window glass ten by twelve inches. Coat all the plates with tin foil five by six inches on both sides. Leave a margin of two inches on top and sides and five inches on the bottom. On eight of these plates

paste a strip of tin foil on the lower right hand corner to reach the bottom and on the other nine paste them on the lower left hand corner of the foil. These are the connectors which rest on two copper strips laid parallel four inches apart on the bottom of the crate with binding posts on each end. The strips are fastened on and insulated from the bottom of the wooden crate, with slots in the sides to receive the plates. (See Fig. 2.)

The Tesla coil consists of a primary of seven turns of No. 6 bare copper wire and a secondary of 180 turns of No. 22 bare copper wire wound in a single layer on a drum six inches in diameter and fourteen inches long made of dry birch boards glued together in a circle and then turned off in a lathe. The turns of wire are carefully spaced apart 1-16 inch when winding, leaving a margin of ½ inch on the ends. The primary is wound on a wooden drum eight inches in diameter and 4½ inches long, the turns being carefully spaced apart and fastened. The secondary coil is set on top of the primary coil and the base fastened to the bottom drum.

Give the secondary winding a coat of orange shellac, being careful not to disturb the turns while doing so. A nice turned top can be added for appearance, and a brass rod four inches long and ⅜ inch thick driven tightly in the centre of the top and well rounded off, will be the discharge rod, being connected to the top end of the secondary wire.

The lower end of the secondary terminates in another binding post.

On the primary a binding post is fitted at only the upper end, while the other connection is a sliding contact.

For a spark gap take a glass jar about six inches in diameter and eight or ten inches in height and make a hole in the bottom ¼ inch in diameter. To do this take clay or putty and lay a thick layer over the centre of the bottom of the jar. Make a ¼-inch hole in the clay down to the glass and fill with hot solder. The glass will fall out the shape of the hole in the putty or clay.

Make a cover from some nice hardwood to fit tightly in the top of the jar, and bore a hole in the centre, in which fasten securely a threaded ¼-inch nut which is connected by a wire to a binding post on one edge of the cover.

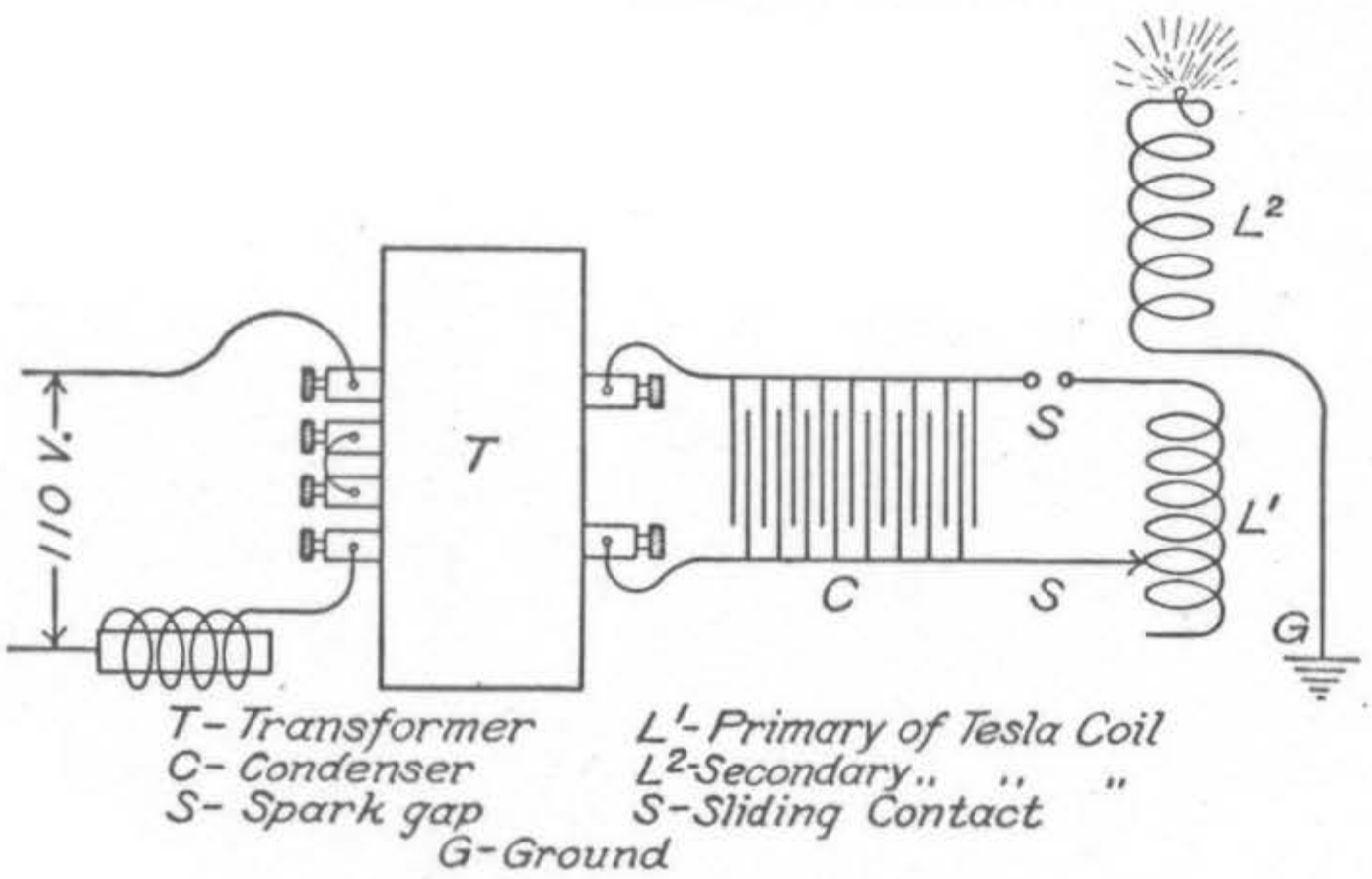


FIG. 3. CONNECTIONS OF TESLA OUTFIT

A ¼-inch rod threaded the whole length is fitted with a hard rubber handle ¾ by three inches long. This is screwed in the threaded nut. The length of rod depends on the height of jar used. Another rod is fitted with a metal ball ¾ inch in diameter and inserted in the hole in the bottom and then through a base of hardwood on which a binding post is placed.

Now to operate the completed apparatus connect as per diagram, Fig. 3.

Connect the lower terminal of the secondary of the Tesla coil to a good ground with stranded wire, as a stranded wire is a better conductor for high frequency currents than is solid wire.

Although good results can be obtained by using the primary in parallel on 110 volts, 60 cycles, consequently 20,000 volts secondary voltage, yet as good results with better control may be had by using the primary sections in series and an adjustable choke coil in series with them. The choke coil can be made from a mass of sheet iron 2½ by 2½ by eight inches, which is inserted in a hollow coil of No. 10 copper wire of 110 turns.

By inserting the core in the coil the current can be varied according to the depth inserted. This outfit is for the uni-polar or single pole method of generating high

frequency currents. If all connections are correctly made the spark gap should be turned until the spark will just jump easily, then on the primary of the Tesla coil move the sliding contact on the second turn from the top, then onto the next turn and so on until the desired results are obtained.

To light a lamp use the fourth or fifth turn and slide the lamp along the side until the brightest light is obtained.

Always disconnect the primary of the transformer before attempting to adjust the different parts.

By adding condenser plates or taking them out of the crate, one by one, the coils will be brought in tune under certain conditions.



Funnelless Ships, Engineless Aeroplanes, Rainfalls in the Deserts, Annihilation of Armies All to Be Controlled by the Man at the Button, Say the Scientists—A Dream of Wireless Energy Soon May Be Realized.

By W. S. Couch.

THE problem of energy solved!

That is the latest promise of Nikola Tesla to the world.

Within a year this wizard of the wires promises to demonstrate that he can deliver electrical energy without the help of wires from any point to any point in the world for domestic and commercial use. The Boer in Pretoria will be able to buy his house light and heat from Denver.

Tesla promises the perfection of the airship by his system.

"It will abolish war," he declares.

A recent London cable told of an address by Prof. Ferranti before the Institution of Royal Engineers, in which the scientist predicted remarkable and undreamed of developments in electricity. Prof. Ferranti talked of a universal supply at a minimum of the present cost, and he spoke of controlling weather with the cheap current thus generated.

Nikola Tesla smiled when this despatch was shown to him.

"Yes," he said, "I know Prof. Ferranti, and I know to what he refers. It is the general problem of electricity, the basic problem of wireless electricity, on which we have all been working. I am satisfied that I have solved it, and I hope to demonstrate my success within a year. The possible regulation of the weather is a comparatively easy feature. We'll harness Nature with the electric flash.

"Even a schoolboy can see how the directed use of a practically unlimited electrical current can affect the weather. Rain could be produced, for instance, without difficulty. What appeals to the imagination more is the possibility that an electrical current could be sent to any point, at any distance, without wires. You need put no limit on your imagination when you let it turn on that idea."

A talk with Nikola Tesla is like an interview with a Jules Verne, who has the scientific equipment to make his remarkable fiction come true in real life. In that connection it is worth noting again that modern science has reduced a good deal of the Verne fiction to hard, sound fact. Tesla has undertaken to supply both the fairy story and the magic touch which makes all real in the final transformation scene.

Prof. Ferranti said in his London address that "all things now achieved by coal could better be done with electricity. Consequently all coal should be converted into electricity at a few big centres and retailed from them. This would save annually 90,000,000 tons of coal."

"What Prof. Ferranti says about coal is fundamental," commented the New York scientist. "But you must not forget the water power, more important than coal, of which the professor does not speak. England has not water powers, but they are to be a most important factor in future American development. The harnessing of these water powers and the delivery of their energy is the great industrial problem of to-day."

Official Washington devoted a large part of its attention to this same problem last winter. The Ballinger-Pinchot controversy was one of the big questions for Congress and the National Administration to settle. It hinged in part on the future value to the nation of coal in Alaska, but also and to a much greater extent on the water power possibilities there and on the public lands in the West. Gifford Pinchot promised the greatest dividends to the public from this property of theirs if they would hold title to it. The "riches" and the "bank account" and the "resources" of the nation, he called those Western waterfalls.

Should Nikola Tesla succeed in making good his prophecy no glowing words that Pinchot ever spoke would equal the result. The coal and water power of Alaska are out of the reach of the United States to-day, and it is difficult for the people of Alaska to get the benefit of them. As far as that is concerned, no man has yet shown the country a way to distribute the energy of water power to any extent. The many falls of the Western mountains already harnessed have their distribution limited by the heavy wire that must carry the current, the cost of the circuit, and, still more, by the loss of the current the further it is carried.

Water power companies, as a rule, have yet to pay dividends, or at least respectable ones. The harnessing of Niagara Falls, even, has failed to produce the gold mine which was confidently expected. This present limit on water power, and the general failure of water power companies to realize on anything like their expectations, was the chief argument offered by the opposition to Gifford Pinchot's attitude. Pinchot's answer has been to hold on and wait. Tesla promises to end the waiting within the year.

"There ought to be nothing to startle people in the proposal to transmit electrical energy as I promise to do it," smiled Nikola Tesla. "The history of electrical development has been a continued story of what the public thought impossibilities becoming practical methods. It is obvious that improvement now lies along the path of transmission of the current without waste. I have contributed my current carried in hydrogen gas underground. That system guards against all loss of energy. It is underground, however.

"The people have seen wireless telegraphy grow from a theory to the practical working of the wireless. In this system, however, the wave lengths are sent broadcast. They radiate in every direction.

"If transmission without loss or waste of energy is possible and practical; and if wireless transmission is possible and practical, is the transmission of electrical energy through the air and without loss of energy an impossible feat for the imagination? Such transmission, of course, would have to have direction, and an easily controlled direction. It would not do to turn your energy loose to radiate to any point as the wireless waves are turned loose. Obviously this would mean a dissipation of the energy which it is desired to conserve.

"I do not propose now, hastily and in a interview, to describe my discovery. During the coming year I expect to give my demonstration, and then there will be time enough for its discussion in detail and in scientific and accurate terms. Take my word for it, though, the problem is solved.

"Think what possibilities it offers," added the inventor, after a moment's reflection. "What will it mean to the development of aeroplanes and aerial flight? It takes off the limit for the flyers.

"I had been studying the problem of the air with an eye to just this thing for many years before the present aviators succeeded in floating themselves, rather to the surprise of students. I had believed they must wait for just this command of electrical energy of which I have been speaking. They must wait for it now to make any real conquest of the air. The improvement of the automobile, with its improvement of the gasoline engine, has given them a motive power. This gasoline engine, if you will stop and think, is the only new thing right now in airships. The wings, the frame, the shape, everything but the light, effective motor power, had been perfected for a long time. You can find books printed many years ago, years before the Wright brothers began to experiment, with pictures of all these curious, birdlike shapes and forms built in canvas and light framework with which we are now growing daily more familiar.

"The gasoline engine, adapted from the automobile, gave the experimenters of to-day their long-desired motive power. They applied it promptly to the construction of their predecessors, and they are flying. This flying of to-day, however, is elemental, like a child learning to walk. It is strictly limited by the faults of the engine, imperfect as it is and limited in its capabilities even at its most perfect point.

"Such possibilities in the use of electrical energy as I intend to demonstrate will instantly enlarge the field of aeroplane flight to an extent which I hesitate to predict."

"Will the airman have a lighter engine?" the inventor was asked.

Tesla laughed outright.

"No engine at all," he declared. "But you must not ask for details. I am not ready to explain my discovery.

"The matter of war is easy," he replied to a question asking light on his statement that his discovery ought to end such conflicts. It does not require a diagram, does it, to see how impossible such control of electrical energy as I have described would make war, either on sea or land? I have told you that this energy can be sent from the Rocky Mountains to South Africa to light the home of some Boer. This without wires and without waste. Can you imagine the terrible result of such a power directed against an army or a battleship? It will never have to be so directed, I assure you."

It is necessary when you listen to Nikola Tesla talking electricity and the possibilities of its future use to remember that this man's hand is now in the machinerw of almost every motor in operation. That gives you an anchor for your mind in what is now an every-day something.

"But the motor was once looked upon as a visionary thing," laughs Tesla. He challenges the public to respectful attention for his prophecies on the evidence of past electrical miracles now come to be everyday realities. The new efforts at invention and application are no more impossible or bizarre, Tesla declares, than established achievements of to-day seemed to be in their inception.

Tesla's proposition to handle electrical current without wires but under control over any distance is not put forward by him as a remarkable or extraordinary thing.

"If you follow the development of study and experiment with electricity or any world force," he says, "you will not be surprised when the work reaches its logical results."

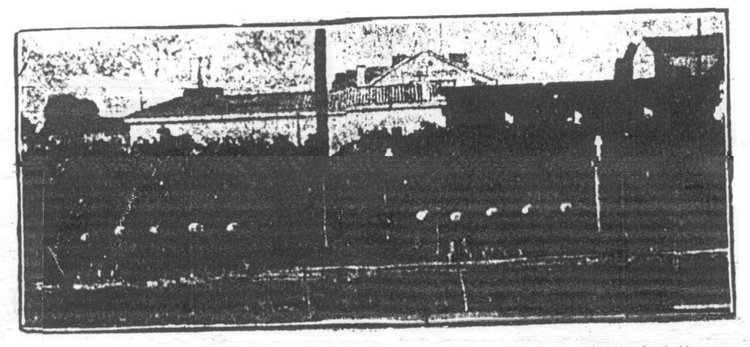
Tesla was early at the wireless. He soon proposed to transmit sight as well as sound. His proposition was not merely to send a photograph over the wires, which has been done, but actually to enable parties to a long distance telephone conversation to see each other as they talked. Perhaps his next proposal was a "cold storage" insulation of wires. By running them underground, through water, he undertook to eliminate the waste of electrical energy in transmission. Tesla was a pioneer in the study of X-rays, or Roentgen rays, as they have come to be known. He made recognized improvements here. He evolved a system of illumination without wires or globes. He devised an electrical oscillator, which he applied, or planned to apply, in connection with several of his other devices. He had a multiple motor intended to handle most economically the power of Niagara Falls.

Then broader motions attracted his attention. He argued for the use of electricity as a farm fertilizer. He discussed the use of a sea automaton for use in naval warfare. This motor boat was to be directed from the shore by a delicately sensitized plate and used with deadly and irresistible effect against the enemy. Tesla announced what he thought was a communication with Mars. At least his instruments registered what he believed he could demonstrate was a message from Mars. Tesla published a plan for the communication of sound without wires. He suggested that electricity could be used in disease for the destruction of all bacilli, that it could possibly cure consumption.

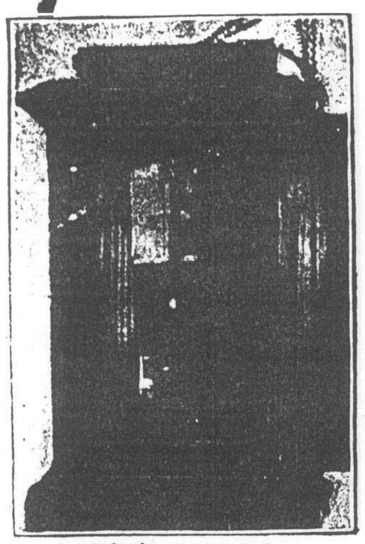
Now he proposes such a handling of electrical power as would revolutionize the world.

"Why not?" demands Tesla. "If the principle is the same, what difference does the size of the problem make?"

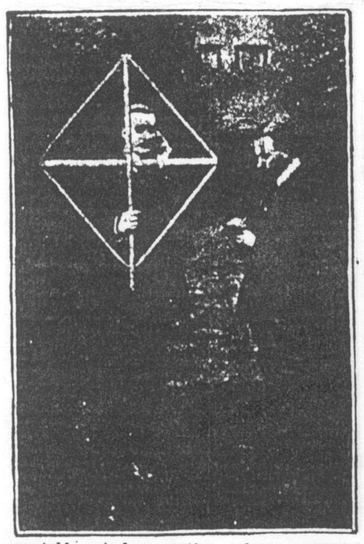
Tesla's idea, then, appealing as it is to the layman, will meet the instant challenge of many of his fellows in the world of volts and insulations.



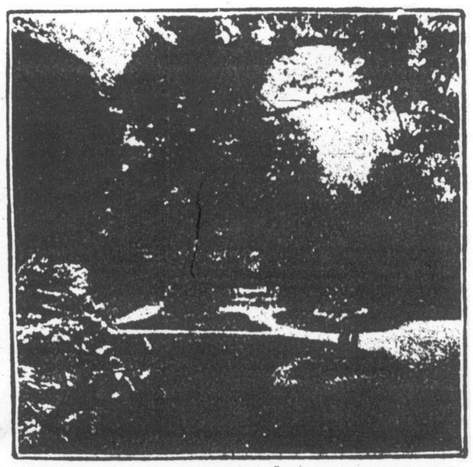
Raising plants by wireless electro-culture at one of the Italian experimental stations.



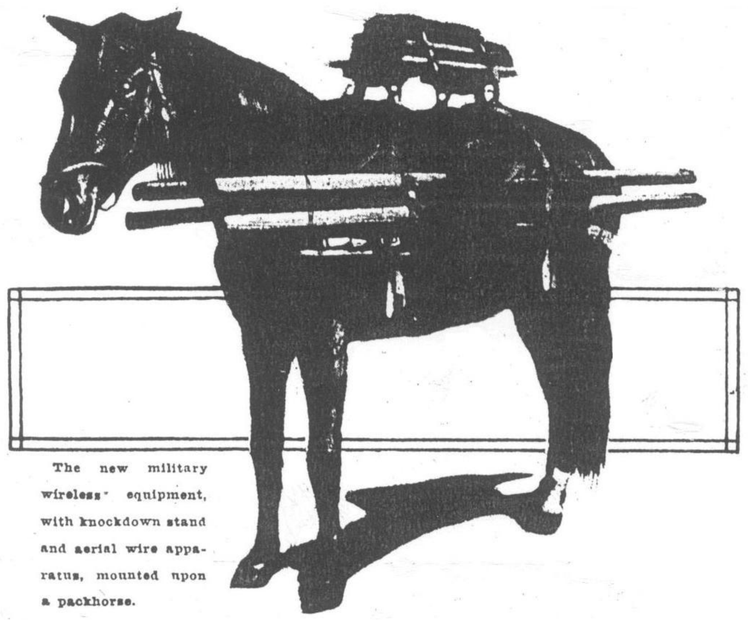
A wirelessly operated clock.



Portable wireless station, where messages are received while you walk.



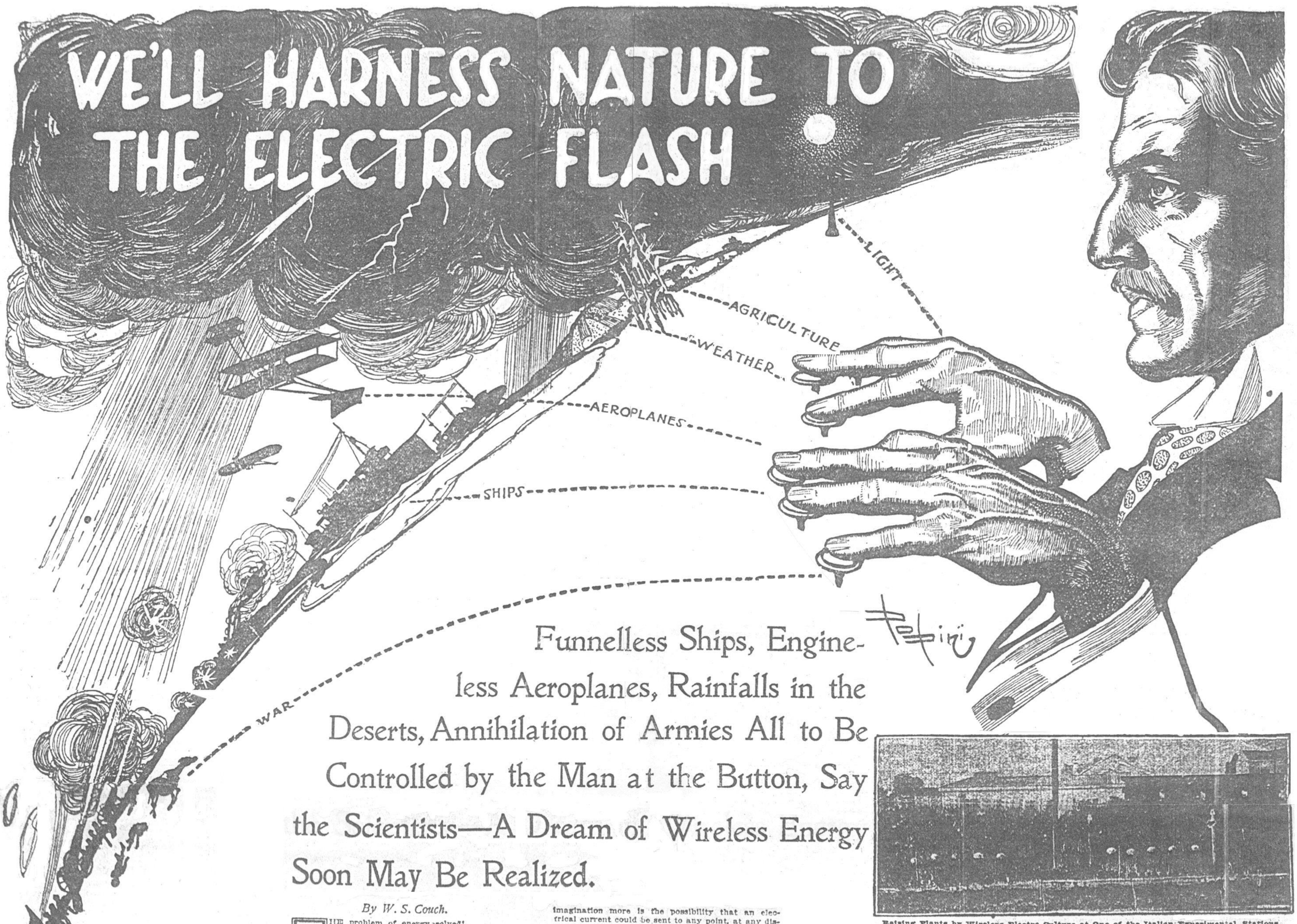
A Parisian garden with giant flowers obtained by wireless electro-culture.



The new military wireless equipment, with knockdown stand and aerial wire apparatus, mounted upon a packhorse.



The towower of Tesla's laboratory on Long Island, where his wireless experiments are conducted.



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A recent London cable told of an address by Prof. Ferranti before the Institution of Royal Engineers, in which the scientist predicted remarkable and undreamed of developments in electricity. Prof. Ferranti talked of a universal supply at a minimum of the present cost, and he spoke of controlling weather with the cheap current thus generated.

Nikola Tesla smiled when this despatch was shown to him.

"Yes," he said, "I know Prof. Ferranti, and I know to what he refers. It is the general problem of electricity, the basic problem of wireless electricity, on which we have all been working. I am satisfied that I have solved it, and I hope to demonstrate my success within a year. The possible regulation of the weather is a comparatively easy feature. We'll harness Nature with the electric flash.

"Even a schoolboy can see how the directed use of a practically unlimited electrical current can affect the weather. Rain could be produced, for instance, without difficulty. What appeals to the imagination more is the possibility that an electrical current could be sent to any point, at any distance, without wires. You need put no limit on your imagination when you let it turn on that idea."

A talk with Nikola Tesla is like an interview with a Jules Verne, who has the scientific equipment to make his remarkable fiction come true in real life. In that connection it is worth noting again that modern science has reduced a good deal of the Verne fiction to hard, sound fact. Tesla has undertaken to supply both the fairy story and the magic touch which makes all real in the final transformation scene.

Prof. Ferranti said in his London address that "all things now achieved by coal could better be done with electricity. Consequently all coal should be converted into electricity at a few big centres and retailed from them. This would save annually 90,000,000 tons of coal."

"What Prof. Ferranti says about coal is fundamental," commented the New York scientist. "But you must not forget the water power, more important than coal, of which the professor does not speak. England has not water powers, but they are to be a most important factor in future American development. The harnessing of these water powers and the delivery of their energy is the great industrial problem of to-day."

Official Washington devoted a large part of its attention to this same problem last winter. The Ballinger-Pinchot controversy was one of the big questions for Congress and the National Administration to settle. It hinged in part on the future value to the nation of coal in Alaska, but also and to a much greater extent on the water power possibilities there and on the public lands in the West. Gifford Pinchot promised the greatest dividends to the public from this property of theirs if they would hold title to it. The "riches" and the "bank account" and the "resources" of the nation, he called those Western waterfalls.

Should Nikola Tesla succeed in making good his prophecy, no glowing words that Pinchot ever spoke would equal the result. The coal and water power of Alaska are out of the reach of the United States to-day, and it is difficult for the people of Alaska to get the benefit of them. As far as that is concerned, no man has yet shown the country a way to distribute the energy of water power to any extent. The many falls of the Western mountains already harnessed have their distribution limited by the heavy wire that must carry the current, the cost of the circuit, and, still more, by the loss of the current the further it is carried.

Water power companies, as a rule, have yet to pay dividends, or at least respectable ones. The harnessing of Niagara Falls, even, has failed to produce the gold mine which was confidently expected. This present limit on water power, and the general failure of water power companies to realize on anything like their expectations, was the chief argument offered by the opposition to Gifford Pinchot's attitude. Pinchot's answer has been to hold on and wait. Tesla promises to end the waiting within the year.

"There ought to be nothing to startle people in the proposal to transmit electrical energy as I promise to do it," smiled Nikola Tesla. "The history of electrical development has been a continued story of what the public thought impossibilities becoming practical methods. It is obvious that improvement now lies along the path of transmission of the current without waste. I have contributed my current carried in hydrogen gas underground. That system guards against all loss of energy. It is underground, however.

"The people have seen wireless telgraphy grow from a theory to the practical working of the wireless. In this system, however, the wave lengths are sent broadcast. They radiate in every direction.

"If transmission without loss or waste of energy is possible and practical, and if wireless transmission is possible and practical, is the transmission of electrical energy through the air and without loss of energy an impossible feat for the imagination? Such transmission, of course, would have to have direction, and an easily controlled direction. It would not do to turn your energy loose to radiate to any point as the wireless waves are turned loose. Obviously this would mean a dissipation of the energy which it is desired to conserve.

"I do not propose now, hastily and in an interview, to describe my discovery. During the coming year I expect to give my demonstration, and then there will be time enough for its discussion in detail and in scientific and accurate terms. Take my word for it, though, the problem is solved.

"Think what possibilities it offers," added the inventor, after a moment's reflection. "What will it mean to the development of aeroplanes and aerial flight? It takes off the limit for the flyers.

"I had been studying the problem of the air with an eye to just this thing for many years before the present aviators succeeded in floating themselves, rather to the surprise of students. I had believed they must wait for just this command of electrical energy of which I have been speaking. They must wait for it now to make any real conquest of the air. The improvement of the automobile, with its improvement of the gasoline engine, has given them a motive power. This gasoline engine, if you will stop and think, is the only new thing right now in airships. The wings, the frame, the shape, everything but the light, effective motor power, had been perfected for a long time. You can find books printed many years ago, years before the Wright brothers began to experiment, with pictures of all these curious, birdlike shapes and forms built in canvas and light framework with which we are now growing daily more familiar.

"The gasoline engine, adapted from the automobile, gave the experimenters of to-day their long-desired motive power. They applied it promptly to the construction of their predecessors, and they are flying. This flying of to-day, however, is elemental, like a child learning to walk. It is strictly limited by the faults of the engine, imperfect as it is and limited in its capabilities even at its most perfect point.

"Such possibilities in the use of electrical energy as I intend to demonstrate will instantly enlarge the field of aeroplane flight to an extent which I hesitate to predict."

"Will the airman have a lighter engine?" the inventor was asked.

Tesla laughed outright.

"No engine at all," he declared. "But you must not ask for details. I am not ready to explain my discovery.

"The matter of war is easy," he replied to a question asking light on his statement that his discovery ought to end such conflicts. It does not require a diagram, does it, to see how impossible such control of electrical energy as I have described would make war, either on sea or land? I have told you that this energy can be sent from the Rocky Mountains to South Africa to light the home of some Boer. This without wires and without waste. Can you imagine the terrible result of such a power directed against an army or a battleship? It will never have to be so directed, I assure you."

It is necessary when you listen to Nikola Tesla talking electricity and the possibilities of its future use to remember that this man's hand is now in the machinery of almost every motor in operation. That gives you an anchor for your mind in what is now an every-day something.

"But the motor was once looked upon as a visionary thing," laughs Tesla. He challenges the public to respectful attention for his prophecies on the evidence of past electrical miracles now come to be everyday realities. The new efforts at invention and application are no more impossible or bizarre, Tesla declares, than established and treasured ideas of to-day seemed to be in their inception.

Tesla's proposition to handle electrical current without wires but under control over any distance is not put forward by him as a remarkable or extraordinary thing.

"If you follow the development of study and experiment with electricity or any world force," he says, "you will not be surprised when the work reaches its logical results."

Tesla was early at the wireless. He soon proposed to transmit sight as well as sound. His proposition was not merely to send a photograph over the wires, which has been done, but actually to enable parties to a long distance telephone conversation to see each other as they talked. Perhaps his next proposal was a "cold storage" insulation of wires. By running them underground, through water, he undertook to eliminate the waste of electrical energy in transmission. Tesla was a pioneer in the study of X-rays, or Roentgen rays, as they have come to be known. He made recognized improvements here. He evolved a system of illumination without wires or globes. He devised an electrical oscillator, which he applied, or planned to apply, in connection with several of his other devices. He had a multiple motor intended to handle most economically the power of Niagara Falls.

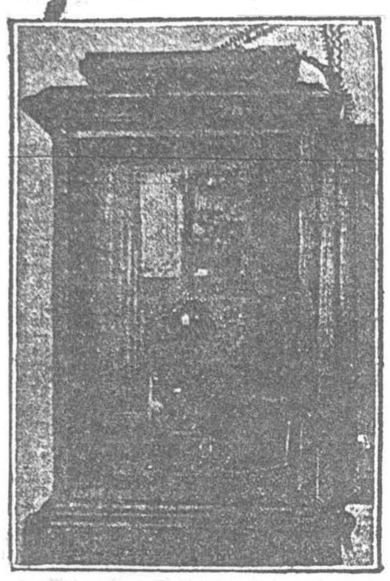
Then broader notions attracted his attention. He argued for the use of electricity as a farm fertilizer. He discussed the use of a sea automaton for use in naval warfare. This motor boat was to be directed from the shore by a delicately sensitized plate and used with deadly and irresistible effect against the enemy. Tesla announced what he thought was a communication with Mars. At least his instruments registered what he believed he could demonstrate was a message from Mars. Tesla published a plan for the communication of sound without wires. He suggested that electricity could be used in disease for the destruction of all bacilli; that it could possibly cure consumption.

Now he proposes such a handling of electrical power as would revolutionize the world.

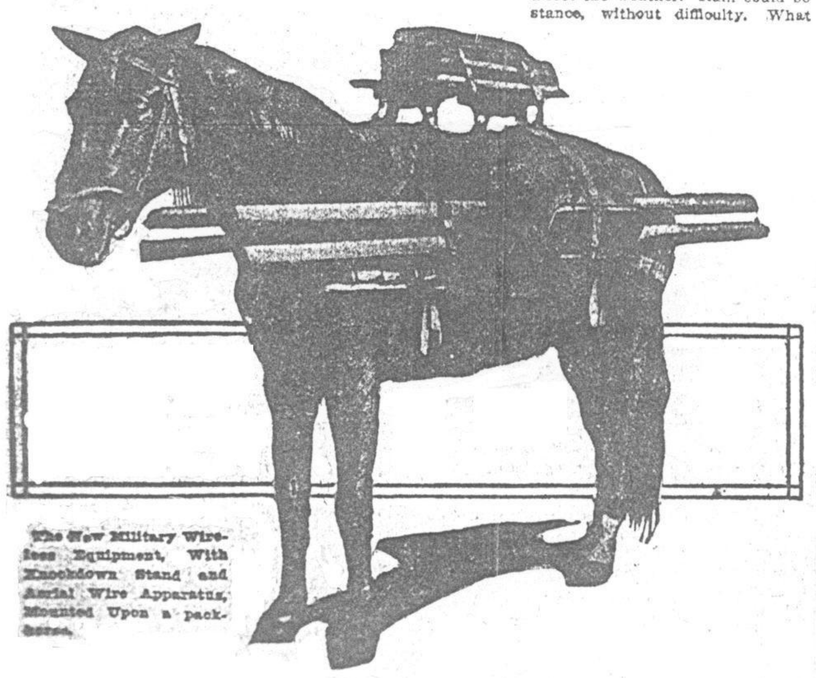
"Why not?" demands Tesla. "If the principle is the same, what difference does the size of the problem make?"

Tesla's idea, then, appealing as it is to the layman, will meet the instant challenge of many of his fellows in the world of volts and insulations.

Raising Plants by Wireless Electro-Culture at One of the Italian Experimental Stations.



Wirelessly Operated Clock.



The New Military Wireless Equipment, With Knockdown Stand and Aerial Wire Apparatus, Mounted Upon a Pack-Horse.



The Tower of Tesla's Laboratory on Long Island, Where His Wireless Experiments Are Conducted.

Expiration of the Tesla Split-Phase Patents.

Two patents, generally known as the "Tesla split-phase patents," which have excited a great deal of attention and caused much litigation in the electrical industry will expire on Dec. 26, 1910. Both of these patents were issued to Nikola Tesla on Dec. 26, 1893. They were numbered 511,559 and 511,560 and related to the same invention, the former being a "process" patent and the latter a "system" patent. Patent No. 511,559 was entitled "Electrical Transmission of Power" and patent No. 511,560 bore the title "System of Electrical Power Transmission." Applications for both were filed on Dec. 8, 1888, and both were issued to Nikola Tesla, of New York, assignor to the Tesla Electric Company.

The first patent embraced two claims relating to the split-phase rotating field in the operation of alternating-current motors. In the second patent seven claims were allowed and the principal one of these covered a generator of alternating currents, a circuit therefrom, a motor having a field with two energizing circuits, means for rendering the magnetic effects of these two energizing circuits of different phase, and an armature in inductive relation thereto.

The Tesla Electric Company was composed of Mr. A. S. Brown and some other gentlemen who were interested in the inventions of Mr. Tesla. Tesla had previously invented the rotating-field principle for alternating-current generators and the patents covering this invention were issued in 1888 and expired in 1905. The two split-phase rotating-field patents were assigned to the Westinghouse Electric & Manufacturing Company before they were issued and about the year 1898 were included in the patent arrangement between the Westinghouse Electric & Manufacturing Company and the General Electric Company by which each of these companies agreed to extend to the other the use of its patents.

The split-phase patents were of great importance in the manufacture of alternating-current watt-hour meters and of small alternating-current motors. The Westinghouse Company began the manufacture of meters and small motors, utilizing the principle of the Tesla split-phase rotating-field patents. Suits for infringement under the patents were begun about 1896 or 1897 and for ten years or more thereafter the litigation was a familiar one in the patent law courts and in the electrical industry generally. Ultimately the United States courts of appeals upheld the patents in the First, Second, Sixth and Seventh Circuits. In all perhaps twenty suits were brought under these patents.

The defendants sued for infringement made a vigorous defense, asserting that Ferraris and others anticipated Tesla's invention of the split-phase rotating field, but the courts held that the patents were valid. The patents had their greatest effect on the meter industry and under the decisions of the

courts of last resort it was necessary that the maker of every alternating-current watt-hour meter should be licensed under these patents, as it was assumed to be necessary to employ the principle of Tesla's invention to make a practicable alternating-current watt-hour meter. Patents Nos. 511,559 and 511,560 will become public property on Dec. 26, 1910, and the invention therein described can be used freely by anyone after that date. Whether, however, supporting and "protective" patents will be brought forward to prevent such use remains to be seen.

Philosophical Society London - Proceedings
February 1911

XII. *Some Resonance Curves taken with Impact and Spark Ball-Dischargers.* *By* J. A. Fleming, *M.A., D.Sc., F.R.S.* *and* G. B. Dyke, *B.Sc., A.M.Inst.E.E.*

Read January 27, 1910.

In the course of the experiments on the energy losses in condensers traversed by high-frequency currents described in the previous Paper,* we had occasion to take many measurements with the cymometer of the frequency and inductance of the secondary circuit used in which oscillations were created by a primary circuit used both with the impact and with the ordinary spark-ball discharger. It then became an easy matter to take sufficient observations to delineate a complete resonance curve in each case. As these curves give a very interesting insight into the operations taking place in the secondary circuit and as they confirm the ordinary theory of the oscillation transformer, and, moreover, exhibit the striking difference between the action of an impact and of an ordinary spark-ball discharger, we have delineated for each such case a family of resonance curves taken over a certain range of frequency and with various degrees of coupling. The arrangements for experiments were just as described in the previous Paper, only the secondary circuit was moved to or from the primary to vary the coupling and the cymometer circuit was in all cases loosely coupled to the secondary circuit. The resistance of the secondary circuit was varied so as to give in one case a small decrement of about 0·01 per semi-period and in the other case a much larger decrement of 0·09 per semi-period. The spark-gap was 1 mm. in length and acted upon by a steady blast of air to produce uniform discharges.

The current in the cymometer circuit was measured by a hot-wire thermoelectric ammeter. In the diagrams given the vertical ordinates represent this cymometer current in milliamperes. The decrement of the cymometer itself was about 0·03. The impact discharger used was that described in the previous Paper on "Energy Losses in Condensers traversed by High-Frequency Currents" (*loc. cit.*).

The curves in Fig. 1 delineate the resonance curves taken with the ordinary spark-gap and with such resistance in the secondary circuit as to give a semi-period decrement of 0·01. The different curves correspond to different degrees of coupling k of the primary and secondary circuits, as shown in the diagram. When the coupling is about 33 per cent. the resonance curve 1 shows three well-marked maxima or humps. The frequency corresponding to the middle hump is the natural free period frequency of the secondary circuit. The frequencies of the other two maxima on either side correspond to the two oscillations which are created by the reaction between the primary and secondary circuits.

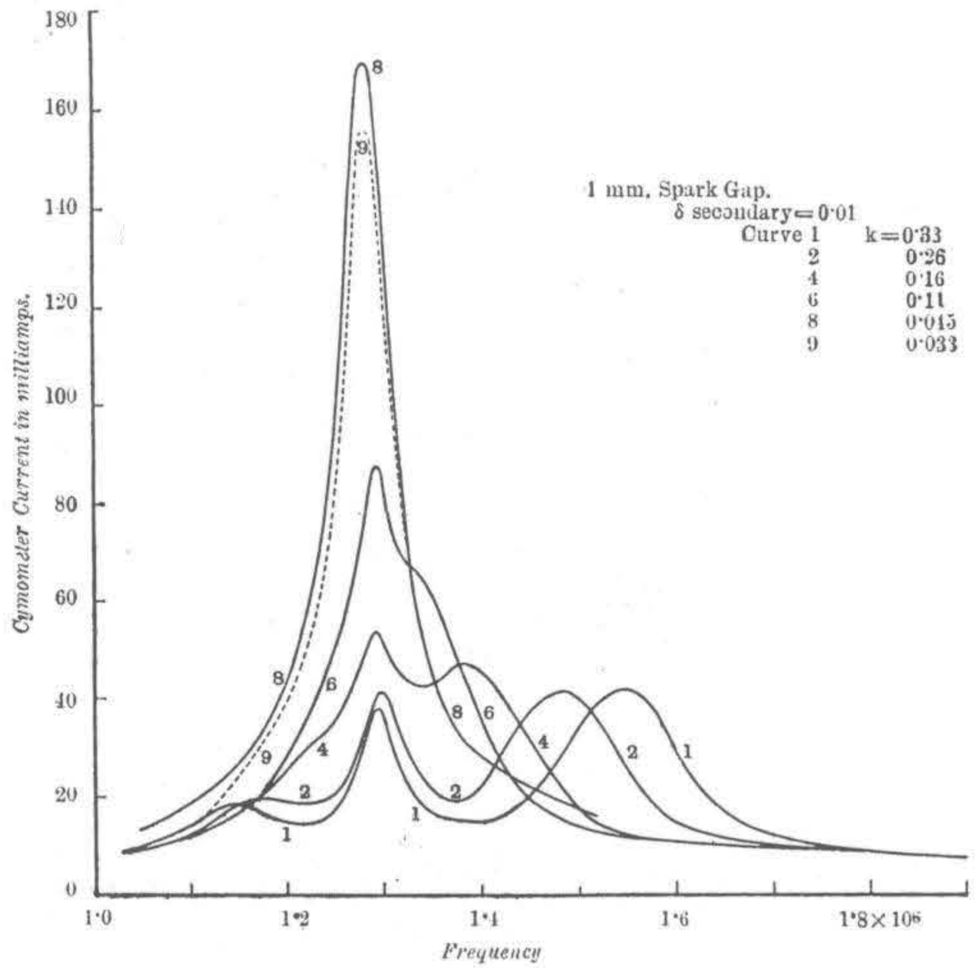


Fig. 1.

These three frequencies have such values that the square of the free frequency is the mean of the squares of the other two frequencies. This confirms and agrees with theory; also the calculated value of k agrees fairly well with that deduced from the two frequencies. As the coupling is reduced respectively to 26 per cent. and 16 per cent., we have the resonance curves 2 and

* "The Measurement of Energy Losses in Condensers traversed by High-Frequency Electric Oscillations." By J. A. Fleming and G. B. Dyke.

4 from which it is seen that the amplitudes of the two period oscillations are decreasing and the free oscillation survives. When the coupling is reduced to 11 per cent. there remains only a very slight indication of a forced oscillation. If the coupling is weakened still more we have only the free oscillation left and the secondary current comes to a maximum for a coupling of about 5 per cent. Beyond that weakening the coupling decreases the maximum current in the secondary circuit. If we take off the values of the maximum cymometer currents in each curve and plot these as ordinates of

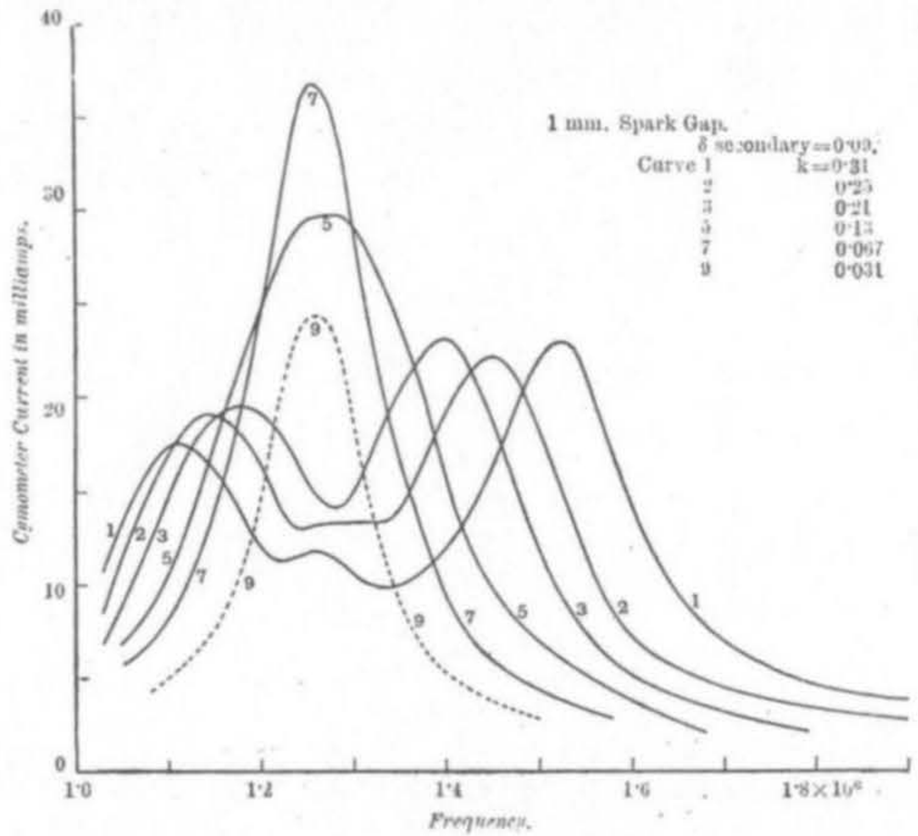


Fig. 2.

another curve to abscissæ representing the coupling, as done in Fig. 5, we have a curve (the upper dotted curve marked "spark") which shows us how the current in the secondary circuit varies with the coupling between the secondary and the primary. It has a well-marked maximum value for about 5 per cent. coupling.

The family of resonance curves in Fig. 2 is taken with the same spark-ball discharger in the primary circuit but with resistance added to the secondary circuit to increase its semi-

period decrement to 0·09. It will be seen that for a coupling of 31 per cent. there is a trace of a free vibration, but the predominant oscillations in the secondary are the two-period oscillations. As the coupling is weakened the free oscillation makes its appearance, but it is not until the coupling is weakened to 13 per cent. that the free oscillation alone survives.

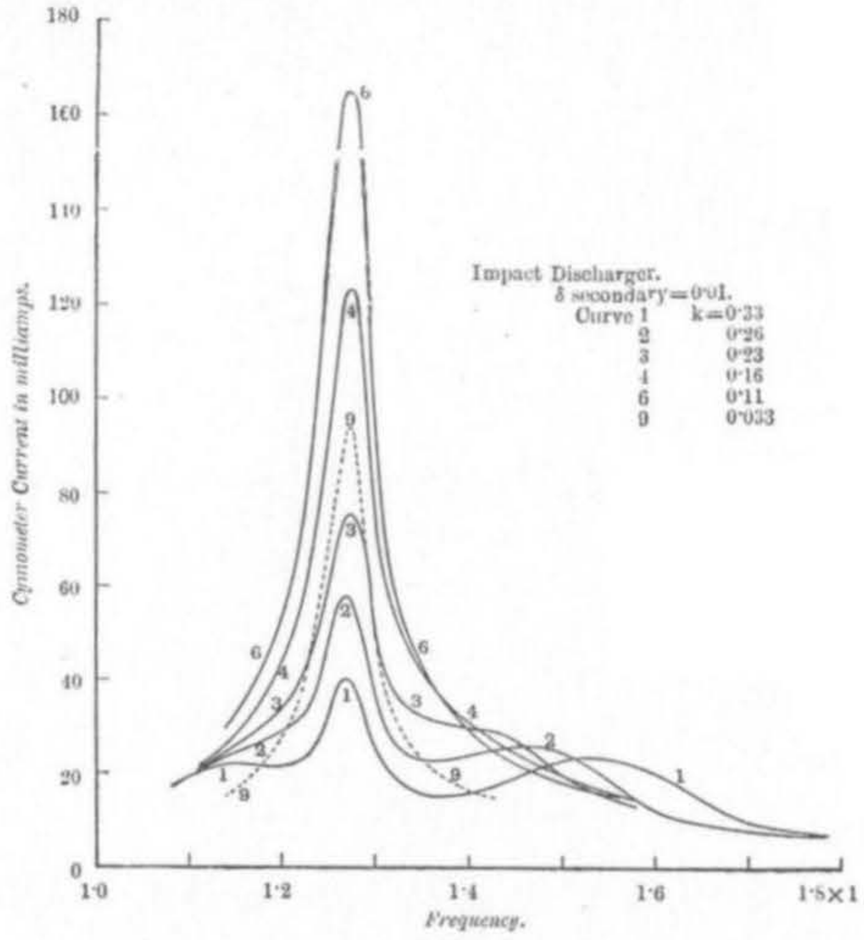


Fig. 3.

When the coupling is reduced to about 7 per cent. we have the maximum currents in the secondary circuit.

These observations were then repeated, using the impact discharger, and the same general phenomena are observed, as shown by the curves in Figs. 3 and 4, with the difference that for a secondary decrement of 0·01 the free secondary oscillation makes its appearance when the coupling is as strong as 25 per cent., and when the secondary decrement is 0·09 the free secondary oscillation alone appears even when the coupling is 20 per cent.

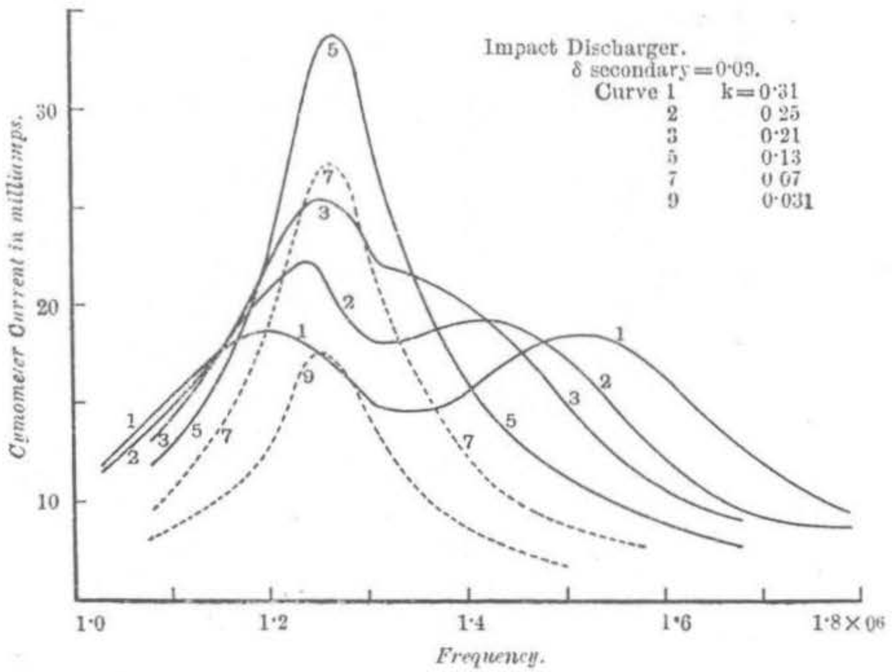


FIG. 4.

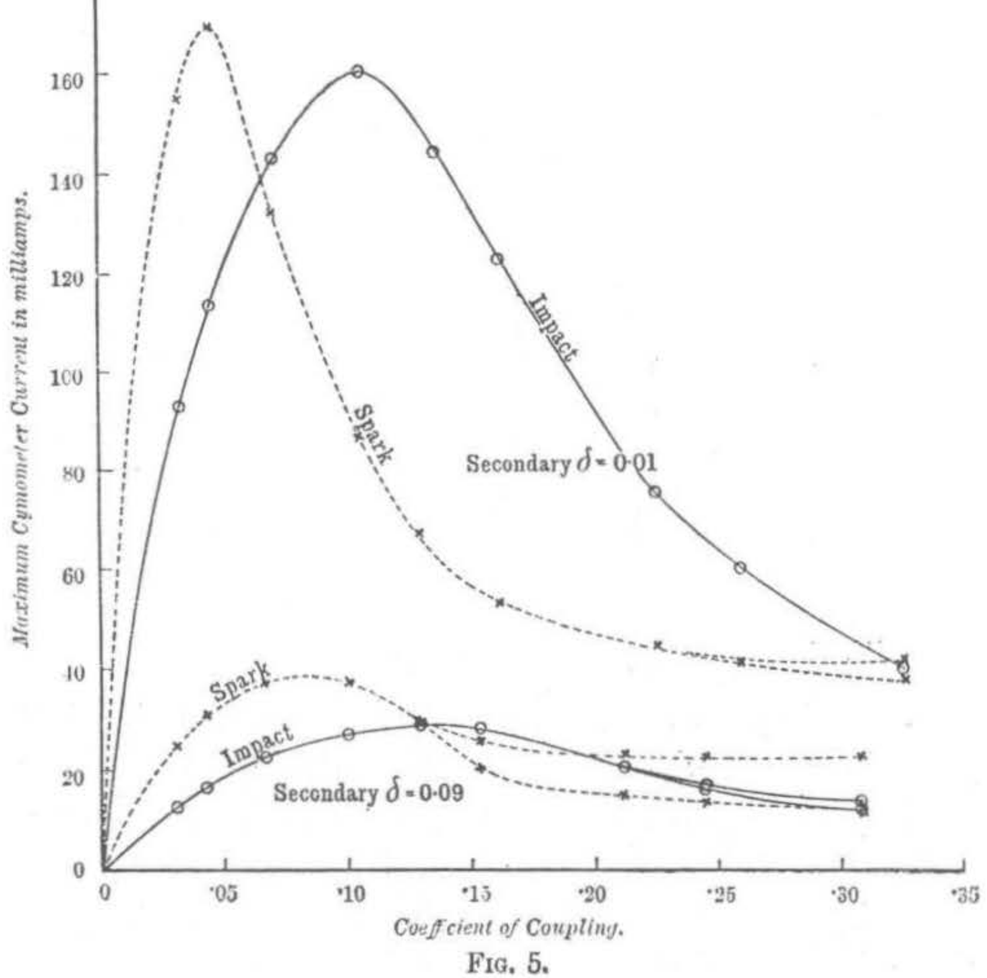


FIG. 5.

The firm line curves in Fig. 5 represent the variation of the secondary current as the coupling between primary and secondary varies. The advantages of the impact dischargers may therefore be summed up by saying that with it we can have closer coupling between the primary and secondary circuit and yet retain the advantage of having no other oscillations set up in the secondary circuit than its natural free oscillation. This, however, omits all consideration of the number of the discharges and of the efficiency of the transmitter as a whole. Closeness of coupling always is an advantage in increasing plant efficiency, provided we can secure it without setting up forced oscillations in the secondary which annihilate the sharp peak of the resonance curve and therefore render sharp tuning between a receiving station and that particular transmitter impossible.

ABSTRACT.

In the course of the experiments described in the previous Paper on the measurement of energy losses in condensers a large number of measurements had to be made with the cymometer of the frequency of oscillations in, and the inductance of, the secondary or condenser circuit. It was then an easy matter to draw complete resonance curves in each case, and this has accordingly been done with both the impac and spark ball dischargers in the primary circuit and for various resistances in the secondary circuit. The results are interesting as showing exactly what takes place in each case in the primary circuit. If we are using the spark ball discharger, and if the primary and secondary circuits are coupled with various degrees of coupling, then, for any close coupling, we find on the resonace curve three peaks which correspond, respectively, as regards frequency, with the free oscillation period of the secondary and with the two-period oscillations set up by the reaction of the secondary upon the primary circuit. As the coupling is weakened the double-period oscillations die out, and only the free oscillation of the secondary survives. There is always a certain coupling, not far from 10 per cent., which gives the maximum current in the secondary circuit in the form of a free oscillation. If the secondary circuit is more highly damped, then the two-period oscillations are more strongly marked, and the maximum free period oscillation has a lesser maximum value.

If we are using an impact discharger the double-period oscillations are only apparent when the coupling exceeds about 30 per cent., and die away with a very little reduction in the coupling, leaving the predominant free secondary oscillation as the survivor. These curves show how very quickly the primary spark is quenched when using the impact discharger. If the maximum secondary current is set up as ordinates in terms of the coupling as abscissa we obtain curves which rise up quickly to a maximum value and fall again, and which indicate that the maximum value of the secondary current is determined both by the coupling and the secondary decrements.

DISCUSSION.

Mr. A. CAMPBELL remarked that the want of constancy of the effective resistance as the current is changed seemed to be out of agreement with the results of other recent observers. Various condensers have been tested at the National Physical Laboratory at frequencies of 800 and 2,000 $\sim$ per second by Carey Foster's method. No divergence from the square law is found from 0·5 to 6 volts. It would be surprising if the square law did not hold at 500,000 to 1,000,000 $\sim$ per second. The formula employed by Dr. Fleming to give ρ can scarcely be expected to give accurate results, since so much depends upon the small difference $A_1 - A_2$. Monasch ("Electrician," June and July, 1907) has shown most conclusively that for frequencies about 80 $\sim$ per second the losses in glass and ebonite condensers (and also in cables) were exactly proportional to the square of the effective voltage between 1,000 and 8,000 volts. He has pointed out that the heating of the dielectric by the power spent in it very often appears to cause variation from the square law. Stöckly ("La Lumière Electrique," July, 1909) has recently found that the decrement of a Moscicki condenser rose from 0·0165 at 10°C. to 0·021 at 40°C.

Mr. W. DUDDELL expressed surprise that with low potential gradients the energy loss was not proportional to V^2. Increase of the losses in a rather peculiar way with the frequency—not necessarily proportional—was to be expected. He cited his experiments made with high frequencies on an aerial at Bushy. The easiest method of finding the losses was to put in a resistance to bring the current down to half value. This method was justified with an air condenser.

He remarked that he thought it was the *voltage* that was induced in the secondary that was fixed, and not the amount of *energy* that was transferred.

He pointed out that we were never certain as to how much energy was lost in each part of the secondary circuit, and drew attention to the importance of knowing just where all the energy losses took place, as then we could soon begin to make our apparatus efficient.

Mr. E. H. RAYNER suggested that a calculation of the power factors of the condensers would have given results which afforded considerably more information at a glance. If the losses varied as the square of the voltage, since they are small, the power factor would be constant at all voltages; if the losses increased faster than the square of the voltage the power factor would rise; if at a slower rate it would fall. The experimental results were not accurate enough to determine the constants of the formula employed by the authors. He had analysed the results given in the Paper, and found that some cases showed a diminishing power factor, giving an index less than 2, while the authors had given 2·15. He drew attention to some results which he had obtained on a gutta-percha cable showing a power factor practically constant from 10 volts to 4,000, demonstrating an exceedingly close approximation to the square law over a very great range of electric force.

Mr. F. JACOB remarked he had been for some time at Messrs. Siemens Bros. & Co.'s Cable Works, testing the leakance of gutta-percha cores and other dielectrics, or in other words the effective resistance of condensers, not certainly at the extra high periodicities of Prof. Fleming's most interesting and important results, but at such frequencies as obtained in telephonic transmission, say from 750 $\sim$ to 2,000 $\sim$. Their mode of testing was the bridge method, and the results obtained were correct within about 1 per cent. Two adjacent arms of the bridge are occupied by two equal resistances, the other two arms containing respectively the condenser K whose leakage resistance S is to be tested, and a variable condenser C, whose leakage is zero, in series with an adjustable resistance R. An alternating current and a telephone were employed. When balance is established

$$R - \frac{1}{ipC} = \frac{1}{S - ipK}.$$

Simplifying, and neglecting S^2 in comparison with p^2K^2 we find $K = C$ and $S/K = p^2RC$.

Hundreds of determinations on different materials show that for a given material and frequency S/K is a constant, and within ordinary electrical pressures independent of the same, and in some instances in direct proportion to the periodicity, but in others a little higher. His pressures corresponded very nearly to those given by Prof. Fleming's experiments.

S/K for air by his experiments was 0, and also for a mica condenser if of special construction.

In connection with Mr. Rayner's remarks, he stated that at 750 $\sim$ the value of S/K for the gutta-percha core of the loaded channel telephone cable was 114, and at 2,000 $\sim$, 0·320.

He hoped Prof. Fleming would apply his thermometric differential detector in a similar way, and thus obtain more directly the effective resistances of the condensers he had recently determined by comparison with an air condenser for which his experiments showed the effective resistance to be very small.

He had, on the assumption that the value S/K is proportional to the frequency, reduced Prof. Fleming's results to Messrs. Siemens standard form of S/K. He found no variation with electrical pressure. Below are excerpted values at the different frequencies comparing pairs which are at the same pressure.

EBONITE.

E.	C.	R.	$10^6 \sim$	S/K.	C 2,000 $\sim$
2·37	0·00084	1·37	2·0	182,500	182
2·39	0·00170	0·850	1·41	114,600	163
2·02	0·00170	0·704	1·41	94,900	135
1·96	0·00258	0·659	1·14	87,700	154
1·78	0·00170	0·657	1·41	88,600	126
1·82	0·00258	0·577	1·14	76,800	135

The last column of values reduced to 2,000 $\sim$ shows three values nearly identical and three differing, but no doubt further experiments will elucidate the cause.

At 2,000 $\sim$ for the best ebonite we get a value of 71, and at 800 of 29, which is practically proportional to those periodicities, but there are very different qualities of ebonite, and as there is oil also to take into account, and he did not know what part of the capacity is due to the two dielectrics in question.

The resistances found by Prof. Fleming are anyhow the effective values of these condensers, though we may not be able to separate the portion that is due to the dielectric alone. He found that the ordinary values of dielectric resistance measured after a minute, give no indication as to value of S/K.

Mr. G. L. ADDENBROOKE said his knowledge of high-frequency currents was not enough to enable him to speak authoritatively as to the accuracy of Dr. Fleming's method, but he had found that the form of the wave was of considerable importance, especially where the ammeter reading was relied on at all. Nevertheless he could support Dr. Fleming and Mr. Dyke in one point. He had himself found losses in air condensers after they had been in use for a time, and the loss increased until they might have a power factor of 1 per cent., that is in cases where the plates were about $\frac{1}{8}$ in. apart. He had intended calling attention to this before seeing Dr. Fleming's Paper.

Next as to the experiment in Dr. Fleming's formula where heating was not possible, he had always found the losses increased very nearly as the square of the current, but in a Paper sent into the Institution of Electrical Engineers some time since, the publication of which he had kept back, he had shown that excessive and long continued pressure might cause heating and greatly increase the losses, and more recently he had found the converse to

be the case, that the losses were considerably increased by heating the dielectric, though in different degrees in different dielectrics.

Dr. W. H. Eccles, referring to the Paper giving resonance curves got from a secondary circuit excited by a primary containing either an ordinary spark or a quenched spark, said there was an apparent conflict between the usual theory and the facts disclosed by these curves. A pair of coupled circuits of equal frequency form in general a system of two degrees of freedom, which therefore possesses two periods of oscillation lying one on each side of the natural period of either circuit. The fact that Dr. Fleming's curves show, for some degrees of coupling, three humps instead of two, indicates that the pair of circuits does not remain a double system throughout the oscillation. One circuit disappears at a more or less early stage of the process, that is to say, the primary spark dies out and virtually removes the primary circuit from the combination, so that thereafter the secondary circuit vibrates alone. Usually it is assumed in the case of ordinary sparks between two balls that the spark endures almost to the end of the train of oscillations, and in the case of quenched sparks it is assumed that the primary spark is stopped at the end of one or two half swings. Dr. Fleming's curves show that both of these assumptions would be wrong in the case of his apparatus: the ordinary spark dies out sooner and the quenched spark later than is usually thought. The former fact is perhaps accounted for by the spark being placed in a blast of air. The curves show that in both cases the closeness of coupling has a profound effect on the length of life of the spark; with loose coupling the spark dies out much earlier than with close coupling.

Prof. G. W. O. Howe said he would like to ask Dr. Fleming what he meant exactly by "a dead-beat spark." Dr. Fleming used this expression several times in speaking of the impact discharger. It was stated in the Paper that "it is a dead-beat discharge," and "the spark is damped out of existence instantly," and again, "the discharge is practically non-oscillatory." He did not believe that this was an accurate discription of what actually took place in the primary circuit of a so-called impact discharger.

The primary and secondary circuits having been tuned to exact resonance and coupled together, the energy set oscillating in the former circuit by the breaking down of the spark-gap is gradually transferred to the secondary. The rate of this transfer depends on the tightness of the coupling, but with the tightest coupling used by Prof. Fleming, viz. 0·33, it would take a cycle and a half to transfer all the energy to the secondary circuit. If the spark was quenched under these conditions one might perhaps be justified in speaking of the transfer of energy as an impact. The resonance curves in Fig. 3 show that the spark is not quenched at this point, but that the energy surges backwards and forwards several times just as it does in an ordinary spark-gap in air. On loosening the coupling the transfer of energy takes place less rapidly, and the interval during which the primary current has a small value may be so long that the spark is quenched sooner. To enable the spark to he quenched at the first opportunity, that is, at the moment when the energy has been transferred to the secondary circuit for the first time, it appears from Fig. 1 to be necessary to reduce the coupling to 0·11. With this weak coupling, however, about 5 complete cycles are required to transfer the energy from the primary to the secondary circuit. If the oil-gap be replaced by the 1 mm. air-blast gap, Fig. 1 shows that the coupling has to be still further reduced to 0·045 before the spark is quenched at the first opportunity. The air-gap spark is more persistent than the oil-gap spark, but the difference between the two is merely one of degree.

The train of waves that follows each spark may be divided into two parts; during the first part we have beats between two coupled circuits, giving the two outside humps on the wave-meter curves: during the second part we have a single oscillatory circuit, giving the middle hump in the curves.

In view of the nature of the phenomena involved, he did not think we could speak of a dead-beat spark or discharge, but, under the best conditions as regards coupling, we may have a dead-beat surge of energy from the primary to the secondary circuit. For this reason he thought that the term "quenched spark" was preferable to "impact" or "shock excitation."

Mr. W. C. S. Phillips remarked that he had found Prof. Fleming's Paper on "The Energy Losses in Condensers" of great interest, because it seemed to have some bearing on the results of some comparative tests of the capacities of condensers which he made some time ago.

Each condenser was in turn made part of an oscillating circuit by putting it in series with a known constant inductance, and the frequency of the oscillations was measured by means of a Fleming cymometer.

From a knowledge of the inductance of the oscillating circuit and its oscillation constant, the capacity of each condenser was obtained. When using a parallel plate condenser immersed in oil, a neon tube was quite satisfactory for the determination of the oscillation constant. Without in any way altering the adjustment of the two circuits the parallel plate condenser was replaced by a leyden-jar of equal capacity. The cymometer current was now so weak that it was impossible to detect the position of resonance by means of the neon tube. As care was taken not to alter the coupling of the circuits, nor to introduce any resistance by bad contact into the oscillating circuit, he could only explain the discrepancy by supposing that there was a considerable loss of energy in the condenser. The current supplied to the induction coil used for the production of the spark discharge was, of course, kept constant.

Dr. Fleming, in reply, said he noticed that surprise had been expressed by several speakers that the dielectric losses are not more nearly proportional to the square of the voltage or electric force. With one or two exceptions, their experiments show a loss varying as some power between 2 and 3. He did not think that we could infer from experiments at low frequency what was likely to take place at high frequency, because there are some special sources of loss in the latter case. Thus, for instance, losses due to brush discharges from points and edges of the metal coatings are by no means negligible. It was found necessary to remove a brass indicating pointer from the variable oil condenser and replace it by an ebonite one, because a very obvious electric brush formed on the metal tip. These ionization losses might vary as some power greater than 2.

It is certain that these brush discharge losses are always present in the case of high-frequency measurements. The slight departure from the square law in the case of many of the results such as 2·15 instead of 2·0, may well be due to unavoidable errors of experiment. The method employed required care in the calibration and use of the high-frequency ammeter used. The objection raised by Mr. Campbell to the fact that we have to take the difference of the squares of two nearly equal currents is not so serious as it seems. The thermoelectric ammeter used is associated with a Paul single pivot galvanometer, and the scale of this last instrument is equidivisional, and the readings proportional to the mean-square value of the alternating current passing through the wires. Hence the square value was read at once. He was glad to find Mr. Jacob's interesting results so nearly in accord with his own, for ebonite condensers.

The observations made by Mr. Phillips on the difference between the effects of a leyden-jar and an oil condenser of the same capacity, when used with a cymometer and neon tube, were quite in accord with his own experience. They are undoubtedly a proof that there is a larger dissipation of energy in the case of the leyden-jar.

Mr. Rayner's careful analysis of our Paper does much to show that there is a high degree of probability that the principal part of the dielectric loss is, at any rate, proportional to the square of the electric force. When dealing with high-frequency oscillations there is, of course, much more difficulty in getting very accurate results than with low frequency. The observations we have taken would be impossible altogether without the use of an impact discharger,

but it may be that the oscillations in the secondary circuit are not absolutely the free oscillations, and it is upon the assumption that they are free that our theory of the apparatus is based. As regards the last Paper on "Resonance Curves," Dr. Eccles puts the facts very concisely. There is undoubtedly a back effect produced, by the secondary oscillations, on the primary circuit, which results in a prolongation of the primary spark when close coupling is used, and this results in the appearance of the two-period oscillations superimposed on the free period oscillation in the secondary circuit.

Replying to Prof. Howe as to the sense in which the phrase "dead-beat spark" is used, Dr. Fleming said that it was intended to imply a spark which is very quickly quenched. The resonance curves given in their Paper prove that the quenching of the spark is not absolutely instantaneous, but that even with the so-called "impact discharger" the primary spark does endure for a very short time. If, however, the coupling does exceed a certain value, the result is to set up in the secondary only the free oscillations, and the advantages of the impact discharger are that this condition pertains for a closer coupling than is the case with the ordinary spark ball discharger. He agreed that the term "impact discharger" is perhaps not the best that could be used, but it is well understood, and as they have used it, it communicates to the secondary circuit just one non-reverberatory wave of energy which is then dissipated in the secondary circuit as heat.

NEW BOOKS

THE TESLA HIGH FREQUENCY COIL. By George F. Haller and Elmer Tiling Cunningham. New York: D. Van Nostrand Co. 1910. 179 pages with 56 illustrations. Price $1.50

Describing the construction of a twelve-inch Tesla coil, with its transformer and all other accessories and introducing interesting information concerning the uses of the coil.

CONSTRUCTION OF INDUCTION COILS AND TRANSFORMERS. By H. Winfield Secor. New York: Modern Electrics Publication. 1910. 92 pages with 56 illustrations. Price, paper, 25 cents.

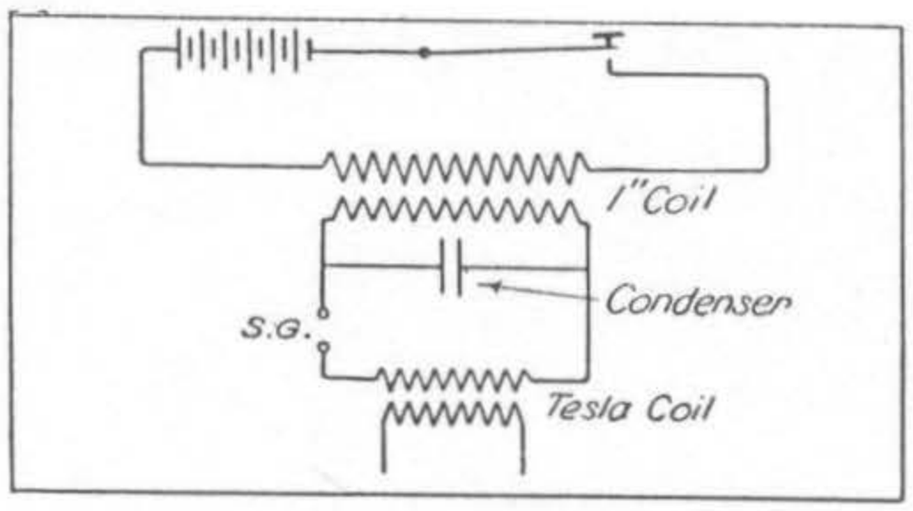
A book designed to place in ready form the latest data and tables desired by the average experimenter and builder of induction coils and transformers. A section is devoted to the Tesla coil. and instructions are given for building a large coil of this type for use on stage and lecture platforms. The construction of open and closed core transformers up to three kilowatts is given in detail.

An appendix contains practical tables covering coil and transformer dimensions, spark distances and wire values.

NEW BOOKS

THE TESLA HIGH FREQUENCY COIL, ITS CONSTRUCTION AND USES. By George F. Haller and Elmer T. Cunningham. New York: D. Van Nostrand Company. 1910. 119 pages, with 56 illustrations. Price, $1.25.

After a careful study of a twelve-inch spark coil the authors set forth in this book much information designed to save the builder of a Tesla coil time and trouble over details. One chapter of fourteen pages, is given up to the uses of the coil for lighting vacuum tubes, Roentgen ray work, etc.

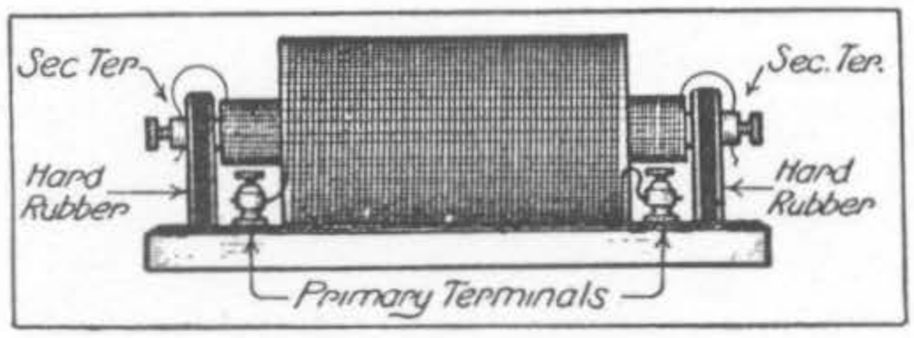


CONNECTIONS OF TESLA COIL

The condenser cuts the spark down to about ⅛ inch but it is very white and "cracky." A zinc gap with an end area ⅛ inch square worked well. With needle points on the Tesla coil spaced three inches, a bright brush envelopes the points. With two wires placed ¾ inch apart and parallel the Tesla coil caused a ladder of brushes to be formed. Other interesting experiments will suggest themselves to the builder.—HAROLD KESSLER.

A Small Tesla Coil

The illustration shows a small Tesla coil which I built at very little expense and which I have used in performing many interesting experiments. For the secondary, wind No. 22 enameled wire on a mailing tube 1½ inches in diameter and eight inches long leaving a blank space of ⅜ inch at each end of the tube. Paint this winding with several good thick coats of shellac. For the primary provide a mailing tube 3¾ inches in diameter and six inches long.



SMALL TESLA COIL

Upon this wind 18 turns of fixture wire and shellac thoroughly. Use hard rubber supports on a dry wood base to support the secondary. The primary coil may be secured to the base by shellac. This may be operated in connection with a one-inch coil.

The condenser consists of 26 7 by 5 inch glass plates using 3 by 5 inch tinfoil sheets.

The New York Herald May 16, 1911

MR. TESLA PREDICTS WONDERS

He Says Wireless Telephone Soon Will Carry Messages Around the World.

Running street cars in Ireland by electric power supplied from a station on Long Island through underground wireless transmission will soon be simple, said Nikola Tesla last night in an illustrated lecture before the National Electric Light Association in the Engineering Societies' Building, in West Thirty-ninth street.

The wireless telephone, he said, was now an assured fact. Messages will be transmitted underground, he said, and any number of persons will be able to converse with one another around the world without having messages conflict.

The New York Times May 16, 1911

TESLA TELLS OF WONDERS.

Says He Will Soon Be Able to Transmit Wireless Power Across Seas.

Queen Isabella of Spain could not have been amazed more when Christopher Columbus told her about a new world than were the members of the New York Companies' Section of the National Electric Light Association in the Engineering Societies Building, 29 West Thirty-ninth Street, last night, when Nikola Tesla, the inventor, told them that within a short time he hoped to run street cars in Dublin, Ireland, by electrical energy generated in Long Island City.

"I have annihilated distance in my scheme," he said, "and when perfected it will not be one mite different than my present plans call for. The air will be my medium, and I will be able to transmit energy of any amount to any place in the world. I will also be able to send messages to all parts of the world, and I will send words out into the world which will come out of the ground in the Sahara Desert with such force that they can be heard for fifteen miles around.

"I also hope to set up a central wireless telephone station whereby there will be a force of 1,000,000-horse power behind each word uttered into my instrument, and in which distance will play no hindrances whatever. Many hundreds of people will be able to talk at the same time and without any interference with each other."

For the use of aeroplanes the inventor has a new steam engine perfected, he says, which will be of the turbine type, and a 10-horse power engine of this kind will weigh only one pound. On a larger scale, he said, this machine is now being tested, with good results, in the shops of the New York Edison plant. The machine, he says, will be the smallest thing ever seen on wheels and will be more powerful than any automobile engine ever manufactured.

The convention of the Electrical Association will be held in this city during the week beginning May 29.

THE NEW INVENTIONS OF TESLA.

The address made by Dr. Nikola Tesla before the New York Section of the National Electric Light Association this week, and reported upon other pages of this issue, is one which will attract great attention on account of the startling statements which were made by the speaker. Mr. Tesla has been working upon the inventions now announced for a number of years, and while it is impossible to estimate their importance until further details are made known, the claims made for transmitting energy and speech to great distances point to an epoch-making discovery.

The experiments made by Dr. Tesla upon high-frequency and high-potential currents about twenty years ago were most illuminating and opened a field of vast possibilities to both the scientist and the engineer—a field which is still being explored. His other discoveries have attracted considerable attention, and this latest announcement bids fair to prove the most important of all.

Aside from his work on electrical oscillations, Dr. Tesla has invented and constructed a prime mover for which remarkable results are claimed. This engine is said to deliver ten horsepower for each pound of weight, a ratio which will mean revolution in the fields of the automobile and the flying machine.

The scientific and technical world will eagerly await the further demonstration of all these possibilities, for their practical realization will mean a most important step forward in electrical and mechanical engineering.

NEW INVENTIONS BY TESLA.

ADDRESS AT MEETING OF NEW YORK SECTION OF NATIONAL ELECTRIC LIGHT ASSOCIATION.

The meeting of the New York section of the National Electric Light Association was held at the Engineering Societies Building, New York City, on Monday evening, May 15, 1911. Chairman Williams presided. The report of Mr. Thomas, chairman of the Membership Committee, showed that the present membership of the section is approximately 1,300 and it is the aim of the committee to have the membership at least 1,500 by the time of the annual convention of the association, beginning May 29. Chairman Williams then outlined the entertainment to be tendered by the Greater New York lighting companies on the occasion of the convention.

T. C. Martin then introduced Nikola Tesla, preceding the introduction by a statement that the membership of the N. E. L. A. on May 15 was over 8,100, a growth of over 5,000 in eighteen months. Mr. Martin referred to the occasion when Mr. Tesla gave a demonstration of his earlier inventions at the time of the St. Louis Convention in 1893.

Mr. Tesla said that some time ago he experienced the necessity of testing an invention he had perfected under conditions existing in a modern plant and he approached the officers of the New York Edison Company for facilities and received most cordial co-operation, for which he was greatly indebted. He introduced the subject by saying that the gift of invention and discovery is a great one, and that there is no enjoyment that he could picture in his mind so exquisite as the triumph which follows an original invention or discovery. But the world is not always ready to accept the dictum of the inventor, and doubters are plentiful, so that discoverers have often to swallow bitter pills, and he had received an ample share of bitterness as well as pleasure.

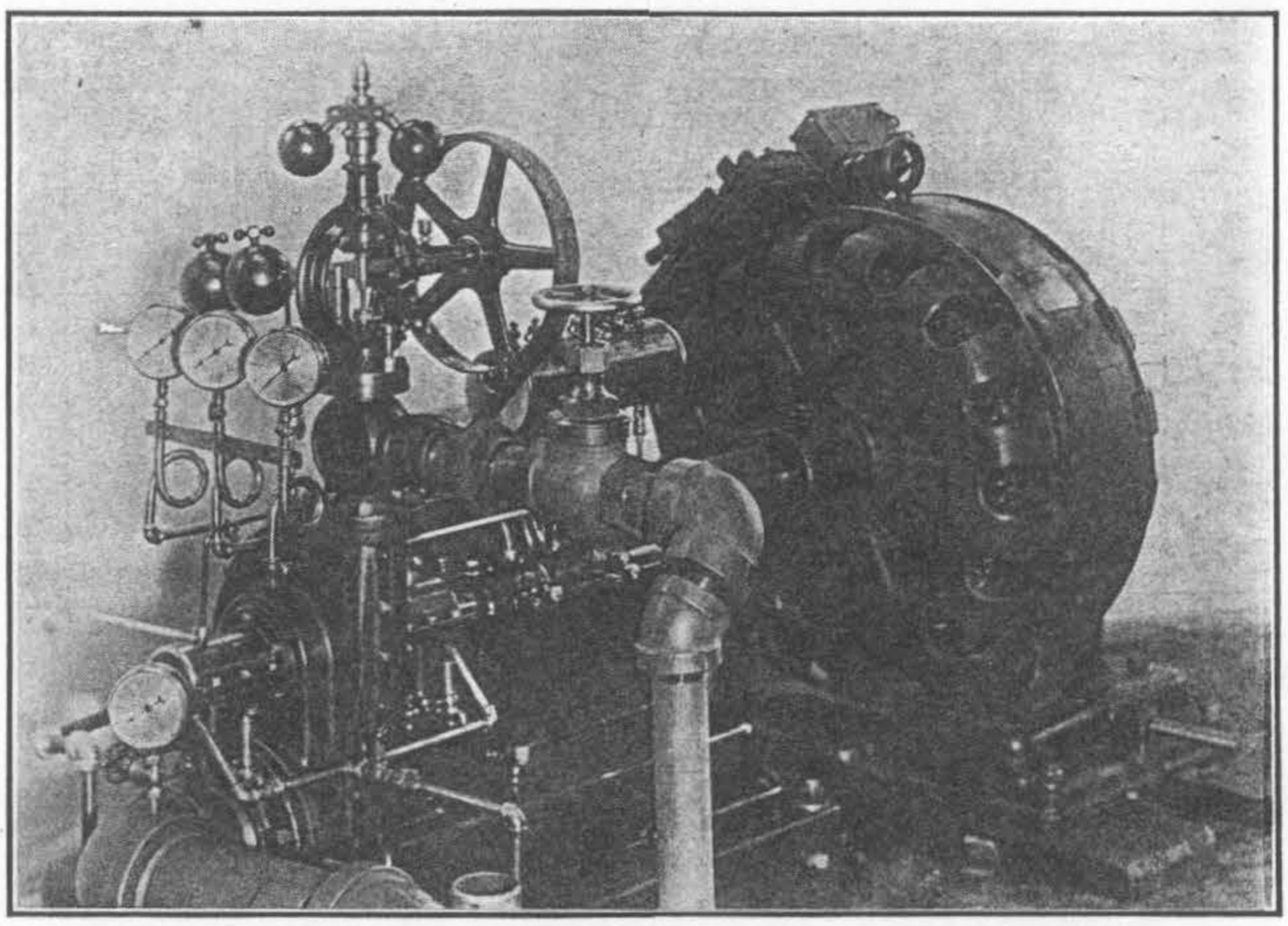
He then referred to the fact that in 1887 or 1888 he had brought out the rotating magnetic field. It was at a time when the world was not yet prepared to receive the idea and he had to stand many attacks, and when his patents were fought he had a great deal of trouble. Some went so far as to assert that he had never invented anything.

Mr. Tesla alluded to the discoveries of Hertz which startled the world. He had tried to repeat the Hertz experiments, worked on them for two or three years and had to give them up. He called on Hertz and told him of his doubts. Since that time he has satisfied himself that Hertz had seen true.

He mentioned the discovery by Roentgen in 1895. He had investigated the wonderful phenomenon which Roentgen investigated, and after long search finally ascertained the true nature of the rays and published the results in a series of papers in the ELECTRICAL REVIEW, declaring we had to deal with a new matter which was never before studied, showing that the particles projected were smaller than atoms, that they were of various sizes, that they carried electrical charges and moved with great velocities.

Mr. Tesla further said that in dealing with electrical matters, there is one branch to which he had devoted a large portion of his life, and it is proper he should speak on that subject. He referred to the wireless transmission of energy. The problem presented itself to him as follows: If we can transmit energy through a closed circuit, we should also be able to transmit it through a single wire, and return being effected through the medium.

He exhibited diagrams illustrating the electrical scheme, as well as a mechanical analog, and showed in slides experiments made in 1899 in which incandescent lamps were lighted in this manner. He then exhibited other diagrams of his wireless system and produced a slide showing a lamp lighted by wireless energy. The lamp he declared could have been lighted if it had been placed at the antipodes. Dwelling on his wireless system in detail he said that it comprised five distinct inventions. The first of these was his transformer. To convey an idea of the wonderful effects which can be produced with that instrument a slide was produced illustrating an experiment performed very frequently in the years of 1892-96. Behind a screen was placed the primary of such a transformer and before the screen a bulb of about fourteen inches in diameter and containing a drop of mercury. The experimenter holds the bulb in the air and the induction from the primary is so strong that it evaporates the mercury and produces an extremely powerful light.



TESLA TURBINE COUPLED TO FIFTY-KILOWATT WESTINGHOUSE GENERATOR.

He next described his "magnifying transmitter" and showed several striking experiments with the same on the screen. One slide showed the transmitter used by him in Colorado on an immensely large scale. Streamers were visible extending from the center of the coil and measuring fully forty feet, the width of the same being sixty-five feet. The discharge is so powerful that it goes through the open roof, being carried up by the heat produced.

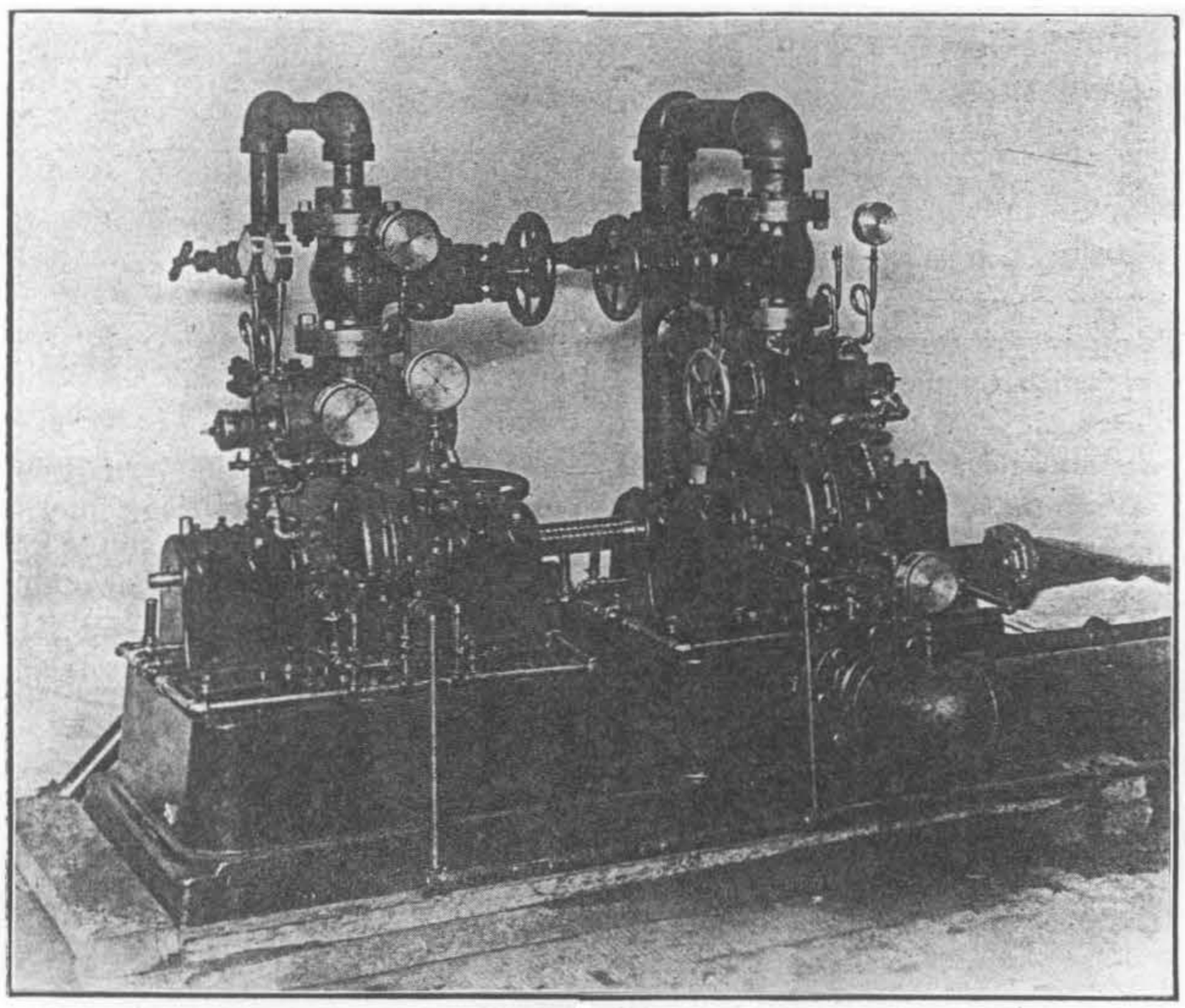
He next showed another effect of such a magnifying transmitter with a large ball, thirty-nine inches in diameter, which was placed just a little above the building, the roof of which was removable. Several of these streamers could be followed a hundred feet into the air; from a distance it looked as if the building was on fire and the roar could be heard for ten miles. He remarked that this was one of the most difficult experiments because of the great force it takes to reach the required density.

Mr. Tesla then referred to his third invention called the "art of individualization in which the nervous system of the human body was imitated in a crude way" (indicating diagram).

"I will not bother you with theories and details," he said, "but can assure you that as long as the world exists, if all men were Faradays, they could never invent a scheme which would permit as accurate a transmission of messages or quantities of energy to a distance through a wire as has been found practicable without wire by this method; for in a wire transmission the secrecy is only the result of isolation in space, while in the wireless we get the benefit of combinations which are not practicable in a transmission through artificial channels. All the statements you read in the newspapers that wireless messages are interfered with, are because the workers in that field are laboring under delusions—they are transmitting messages by Hertz waves, and in this way no secrecy is possible."

He then showed a picture of a machine exhibited in 1898, to which he first applied this art of individualization.

After stating that his fourth invention pertaining to the system was a peculiar receiver condensing the energy, he dwelt on his discovery of the stationary waves which was the last and most important. Before he could transmit energy without wire economically he found it absolutely necessary to learn how this great body, the planet, behaved, how the current would pass through the same and what are its constants, capacity, self-induction and resistance. As he could not find opportunity in the city for investigating he went to Colorado Springs and erected a laboratory for the purpose. Several views of the same were projected on the screen. One showed in the center of the building a coil fifty-one feet in diameter and many smaller ones within, which had been attuned to respond to higher harmonics.



TWO TESLA TURBINES, OF 200-HORSEPOWER EACH, COUPLED TOGETHER BY TORSION SPRING.

Another effect of the magnifying transmitter was next illustrated, showing a display with powerful streamers shooting out in all directions from a coil, as well as a ball of thirty-nine inches in diameter placed on the top.

Mr. Tesla then said: "I had not been in Colorado Springs but a few months when I made the most marvelous discovery I ever expect to make in my life. Before explaining it to you, let me say that I was not stirred at all by its practical value, though it was immense, but by its philosophical significance. You know that through ages past, man has always attempted to project in some way or other energy into space, but in all his attempts, no matter what agent he employed, he was hampered by the inexorable law of nature which says that every effect diminishes with the distance, generally as the square of the distance, and sometimes more rapidly. Now, the discovery I have made upset all that has gone before, for there was a means of projecting energy into space, absolutely without loss from any point of the globe to another, to the antipodes if desired. In fact, a force impressed at one point could be made to increase with the distance. I saw at once that distance was annihilated in all the three aspects; in the transmission of intelligence, in the transport of our bodies and materials, and in the transmission of the energies necessary for our existence. You can imagine how profoundly I was affected by this revelation. Technically, it meant that the earth, as a whole, had a certain period of vibration, and that by impressing electrical vibrations of the same period upon it, it could be thrown into oscillation of such nature that innumerable benefits could be derived from it. Let me tell you of but one application of the principle. Vessels could be equipped with simple devices enabling them to sail across the Pacific along the shortest routes and the captain of each vessel could tell the distance, from a point of reference, within a few feet. We do not today know the exact diameter of the globe. Astronomers have been unable to determine it within a thousand feet. By this discovery without any kind of surveying instrument or even without going out of the room, an electrician can determine the diameter of the globe within four feet. Thousands of such problems, which are of immense practical importance, can be solved and I have often thought that annihilation of distance is the only means of bringing about a quick understanding and universal peace between nations. It will remain for the

future to decide whether I have seen truly or not.

"On my return from Colorado I completed plans to demonstrate these principles on a larger and commercial scale, my laboraory in Colorado being only constructed for purposes of scientific demonstration. Here are some views of my plant on Long Island, erected in 1901. This plant is nothing but what I have called a magnified transmitter which, when completed, will enable you to pick up any telephone and, without the slightest change in the stations, talk as clearly as though sitting on the other side of the table to any subscriber in the world. It will make no difference where he is located, and if desired the voice may be made to come out of the ground with such force that it could be heard for miles. The plant was put up originally for the purpose of serving as such a telephone exchange, but was to serve also for other important uses. To give you an idea of the magnitude of the effects, when you speak into the telephone there will be electrical energy at the rate of one billion horsepower sending your voice across the globe, and not only this, but the plant will be so organized that hundreds of people can talk at the same time to any part of the world without the slightest interference. Of course, you will have to take my word for it now, but I hope that I shall live to realize what I have begun. I will carry out my plans exactly as they were first made.

"My project was evidently far in advance of the times. Its progress was retarded and I was compelled to devote myself for a time to other inventions which appealed more to practical men. After years of careful thinking, I found that what the world needed most, and would most readily accept, was an efficient prime mover, a converter of heat into mechanical energy. This all the more as a new world is about to be explored, the world of waste. When you consider that in the manufacture of steel and iron in this country, some thirty million horsepower could be harnessed and a proportionate income derived from that power, all of which is wasted today, you can see what value a good convertor of thermal energy into mechanical energy would have.

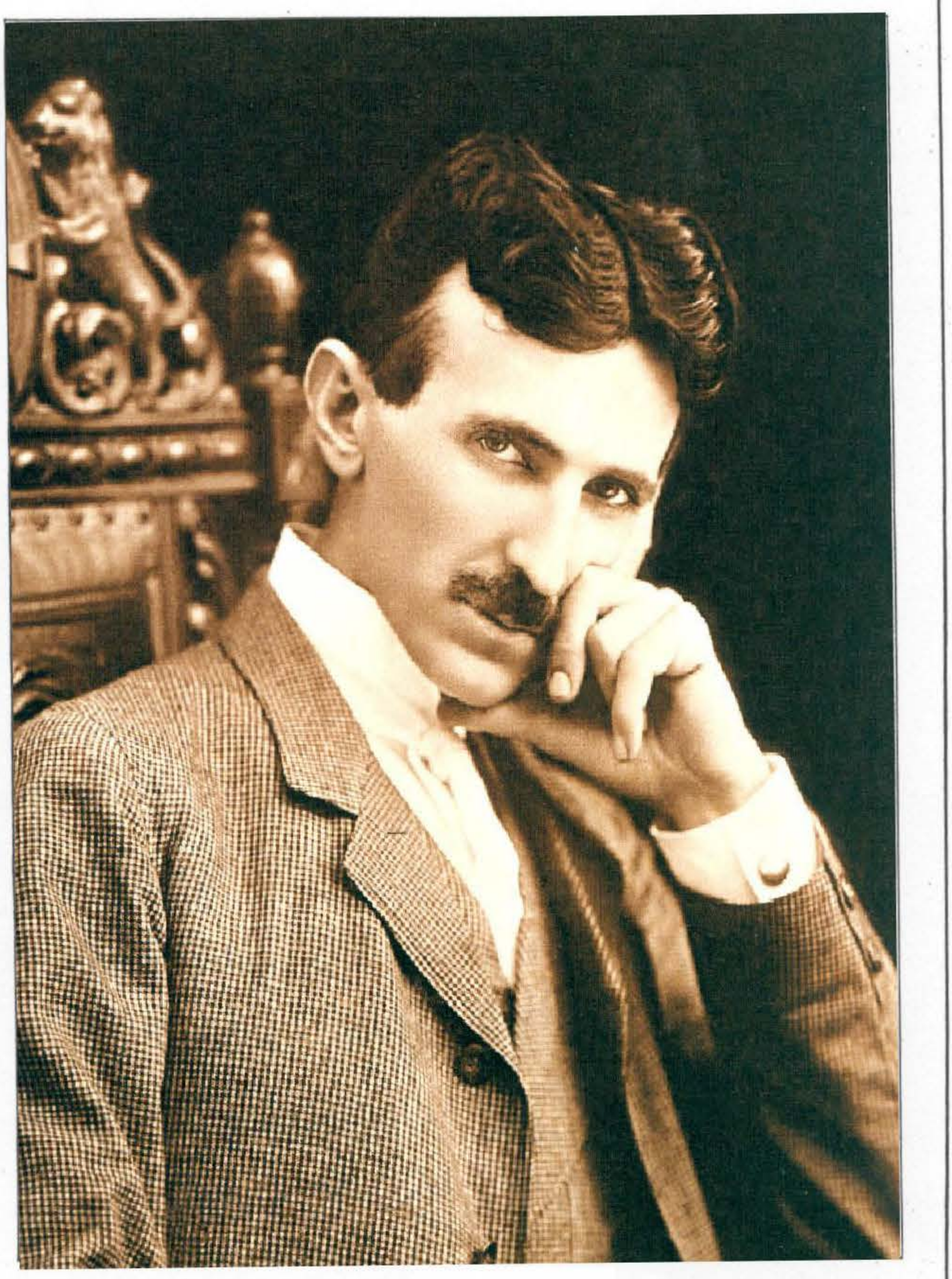
"But to conceive that a prime mover is valuable and to get up one, are two different things. After some thought I finally came to the following argument: suppose a number of plates are moved through a fluid medium, the medium will, of course, be dragged along with the plates, and a certain frictional loss will be incurred. Inside the casing are arranged on a shaft a number of disks with openings and spokes and there are orifices of entrance on the sides to produce a perfect balance, and the usual arrangement of outlets. This system of disks being rotated, the water or air is sucked into the channel, is taken hold of and moves in a logarithmic spiral with very nearly the velocity of the system. It was perfectly well known that a fluid would be dragged by rotating surfaces, but somehow nobody realized the conditions for economic working, nor has any one properly grasped the principles which could be applied to propulsion. So it happens again that it is my good fortune to come to the rescue, and I have produced a highly economical way of compressing or pumping fluids." Mr. Tesla then gave a practical demonstration of the working of the principle in a model pump.

"This is one of the early forms of blower which I constructed" (referring to diagram). "That was constructed three years ago. It is a two-stage blower. Far more important than the pump blower or compressor is the turbine. Here is a simple structure, a casing with two entrances, disks arranged on the shaft and outlets in the center for the escape. In this instance the power is applied to one of the openings and the fluid moves with decreasing velocity toward the center until its energy is exhausted and transferred to the shaft. If the theory is correct, I am able to take out the entire energy of steam in one single stage. In the present turbine, sixty-five per cent is the limit of efficiency; theoretically I should be able to get ninety-nine per cent of the total energy of the steam on the shaft in these turbines. These turbines are simple, they have a great torque, far better than other turbines, and a machine will develop ten horsepower for every pound of weight. This principle can also be applied to the gas turbine."

Several slides showing two turbines coupled together were then projected on the screen and a new method of power measurement described. Mr. Tesla then dwelt on the advantages of these machines and showed a number which were constructed and in operation. They have no ducts, nozzles or such complications which cause so much trouble, and besides the machines are perfectly reversible, working with the same efficiency back or forth, making a valuable machine for driving boats, locomotives, automobiles, etc. The accompanying illustrations show two of these turbines.

"In this new invention we have a beautiful solution of many mechanical problems. We have a prime mover which is reversible, ideally simple, of enormous torque, incomparably greater than the turbine possesses, so I am looking for a revolution in mechanics from the application of this principle."

Owing to the lateness of the hour, the other papers which were to have been presented at the meeting were laid over until the next meeting. The members of the Section and their guests were then entertained by an interesting vaudeville performance.



NIKOLA TESLA

Popular Electricity
In Plain English

VOL. IV JUNE 1911 No. 2

Tesla and His Wireless Age

By ARTHUR B. REEVE

"I have produced electrical oscillations which were of such intensity that when circulating through my arms and chest they have melted wires which have joined my hands, and still I have felt no inconvenience. I have energized with such oscillations a loop of heavy copper wire so powerfully that masses of metal placed within the loop were heated to a high temperature and melted, often with the violence of an explosion. And yet into this space in which this terribly destructive turmoil was going on I have repeatedly thrust my head without feeling anything or experiencing injurious after effects."

The speaker was a tall, spare man with a clean-cut, thin, refined face and eyes of exceptional keenness. He was sitting at a broad flat-top desk in his office on the twentieth floor of the Metropolitan Tower, and his eyes wandered restlessly in just pride from a photograph of his old friend Lord Kelvin on one wall to a large photograph of electrical streamers rivalling the lightning on the other. The speaker was Nikola Tesla.

But before describing his wonderful theories and experiments in the wireless transmission of energy, let me say something of the man and his life. And first of all, it



TESLA'S "WORLD SYSTEM" PLANT AT WARDENCLYFFE, LONG ISLAND

must not be forgotten that today over four million horsepower of water falls are harnessed by Tesla's alternating current system. That is like saying that forty million men—untiring, working without pay, consuming no food, shelter or raiment—are constantly laboring to provide for our wants. In these days of conservation, it is interesting to note that this vast electrical energy derived from waterpower saves a hundred millions of tons of coal every year. Our trolley roads, our subways, many of our electrified railroads, the incandescent lamps in our homes and offices, all use a system of power transmission of this man's invention.

Nikola Tesla was born at Smiljan, Lika, in the border country of Austria-Hungary in 1857. He was the son of a Greek clergyman and orator and Georgia Mandic, herself somewhat of an inventor like her father before her. The young Tesla attended the schools of Lika and Croatia, and later the Polytechnic at Gratz as well as the University of Prague, in Bohemia. At Gratz he saw and operated a Gramme machine for the first time, and was so struck with the objections to the use of commutators and brushes that he made up his mind to remedy that defect in dynamo-electric machines.

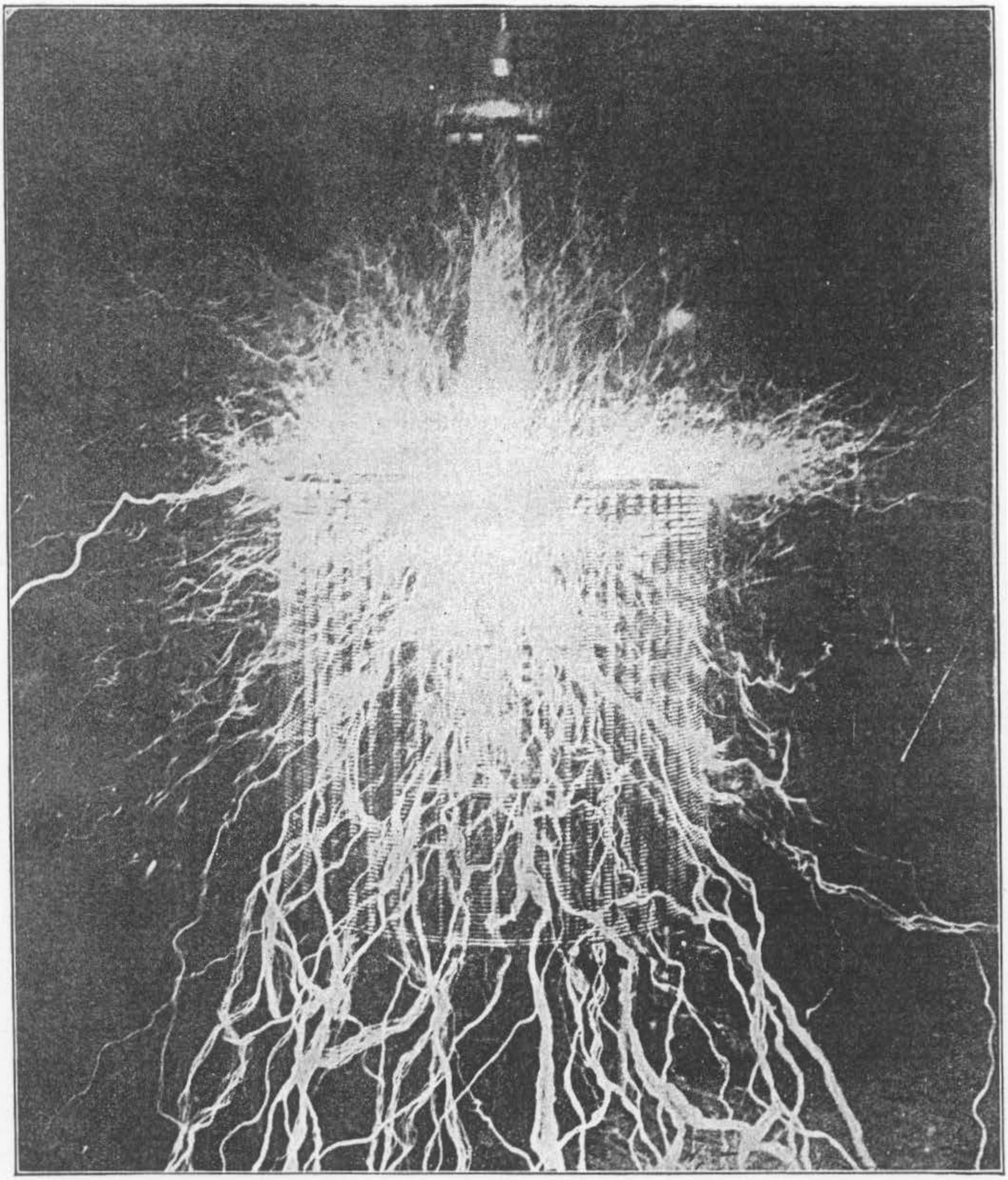
Tesla began his practical career in Buda Pesth in 1881. His first electrical invention was a telephone repeater. Later he was engaged in various branches of engineering and manufacture in Paris, and in 1884 he came to the United States. Here he found employment for a while with the Edison Company in Orange, New Jersey. After the prescribed period of residence he became a naturalized American citizen.

After numerous scientific addresses and papers and inventions like the third brush regulation he entered business for himself, the Tesla Electrical Company of New York being formed in 1887. Already he had conceived his great idea of the rotating magnetic field, which makes possible the transmission of power by alternating current, a system extensively used over long distances. His work with dynamos, transformers, induction coils, oscillators, arc and incandescent lamps, involving alternating currents of high frequency and high potential, at once brought him great fame. In fact, the immense stimulus of Tesla's work to the study of alternating current motors would alone stamp him a leader in the field of electricity if he had contributed nothing else. It has sometimes been asserted that Professor Ferraris anticipated Tesla in the rotating magnetic field, but as a matter of fact Ferraris was purely theoretical, halting and impractical in his work. The mere fact that he published a paper describing his work subsequently to Tesla's discoveries must rank only as one of those curious and frequent scientific coincidences. Ferraris himself stated some years ago that Tesla could not possibly have known of his (Ferraris's) work. These notable patents were acquired by Westinghouse, and were the subject of much litigation before being finally upheld.

A mere list of Tesla's inventions and discoveries is formidable. In 1886 he was the inventor and discoverer of a system of arc lighting, and in 1888 came the Tesla motor and system of alternating current power transmission, popularly known as the two phase and three phase multiphase, or polyphase systems. A system of electrical conversion and distribution by oscillatory discharges came in 1889, and a year later studies in the generation of high frequency currents and their effects. The transmission of energy through a single wire without return was announced in 1891, while from that year until 1893 he was engaged in investigation of high frequency effects and phenomena.

In 1893 he announced a system of wireless transmission of intelligence, and in 1894 and 1895 his work was on mechanical oscillators and generators of electrical oscillations. During the years 1896 to 1898 he was interested in research in radiation and the discovery of material streams and emanations. Finally in 1897 he first announced his "high potential magnifying transmitter" which, as he claims, makes possible a system of economical transmission of power without wires. From that date down to the present he has been constantly at work on this idea. No other human being knows anything like as much about this fascinating subject as Tesla.

Among his other inventions should be mentioned what he calls the art of telautomatics (1898-'99), a system for controlling the entire operation of, say, a boat by wireless impulses at a distance, even out of the range of vision. In 1899 and 1900 he was engaged in experiments in burning atmospheric nitrogen and the production of other



ONE OF TESLA'S "MAGNIFYING TRANSMITTERS" STRONGLY EXCITED

electrical effects of transcending intensity, while during the next two years he was working on methods and apparatus for magnifying feeble effects. From 1902 to 1903 he studied the problem and art of individualization, and since then his work has been in world telegraphy and telephony and in the designing and building of a large power plant for the transmission of power without wires, which I shall describe presently.

But as most people associate Tesla with high frequency, high potential electrical currents, rather than with such things as his electrolytic meter, his dynamo commutators and brushes without sparks, and the thousand and one other notable contributions he has made, I cannot leave the subject without another word. Prior to Tesla's inventions only direct current was used. Now we use alternating current. As one of the

justices who decided a case in his favor some years ago well put it:

"It remained to the genius of Tesla to capture the unruly, unrestrained and hitherto opposing elements in the field of nature and art and to harness them to draw the machines of man. It was he who first showed how to transform the toy of Arago into an engine of power. The Arago rotation taught the schoolboy fifty years ago how to make a plaything, and that plaything embodied the principle which Tesla discovered—that a rotating field could be used to rotate an armature. He first conceived the idea that the very impediments of reversal indirection, the contradiction of alternation, might be transformed into power, producing rotations, a whirling field of force. What others looked upon as invincible barriers, impassable currents, and contradictory forces he seized and, by harmonizing their directions, utilized in practical motors in distant cities the power of Niagara."

And now for Tesla's scheme of wireless transmission of energy. A few years ago it may be remembered he stood in the theater of the Royal Institution with oscillatory currents of unheard of voltage playing about his unharmed head. This taste for the sensational has always been one of Tesla's commanding characteristics. He prides himself on it. Others may criticise Tesla for this love of the sensational, but he himself will sit for hours talking about some of his seemingly impossible exploits, while the mention of one of the inventions which, as he says, "the world calls practical," will fail to elicit from him so much as a wink of an eyelash. As he himself told me, it is doubtful if anyone ever performed so many really dramatic, hair-raising experiments as he. He is as proud of them as a boy. The zest with which he tells of how, after showing Sarah Bernhardt his most dare-devil exploits, she hurried away almost in a state of nervous collapse, is equalled only by the offhand manner in which he mentions currents of 80,000,000 vibrations a second, and his descriptions of sparks and flames in his laboratory experiments which rival, if not equal, the lightning itself. I recall that, in referring to one of his experiments, somewhat like that in the opening paragraph of this article, he anticipated my inquiry by saying: "I don't do that any more; it is too dangerous."

But though there may be much of the pure love for the dramatic in Tesla's announcements, there is really more of what may be called truly scientific imagination. Such experiments with all their elaborate stage setting Tesla believes to be of far greater practical importance than even those of his inventions "which the world calls practical." For, as he tersely put it: "The economic transmission of power without wires is of all-surpassing importance to man."

It all began, as he will tell you, in his observations—"revelations" he calls them—during a great thunderstorm on July 3, 1899. Out of it came his "high potential magnifying transmitter," and such patents along this line of wireless transmission as Nos. 645,576 and 649,621, for transmission of electrical energy in any quantity to any distance with transmitting and receiving apparatus movable, as in ships and balloons.

"We are on a conducting body insulated in space, of definite and unchangeable dimensions and properties," he says. "It will never be possible to transmit electrical energy economically through the body and its environment except by essentially the same means and methods which I have discovered, and the system is so perfect now that it admits of but little improvement."

"Under certain conditions," says Tesla, "the atmosphere which is normally a high insulator assumes conducting properties and so becomes capable of conveying any amount of electrical energy. I would undertake to transmit through my body with such currents the energy of all the dynamos at Niagara."

To carry out his ideas he has devised a plant of which he says: "A popular error which I have often opportunity to correct is the belief that the energy of such a plant would dissipate itself in all directions. This is not so. Electricity is displaced by the transmitter in all directions equally through the earth and air, but energy is expended only at the place where it is collected and used to perform some work. A plant of 10,000 horsepower might be running full blast at Niagara, and one flying machine of 50 horsepower might be in another place. Only 50 horsepower would be furnished by the plant.

"Although the electrical oscillations would manifest themselves all over the

earth at the surface as well as high in the air, virtually no power would be consumed. My experiments have shown that the entire electrical movement which keeps the whole globe a-tremble can be maintained with but a few horsepower. Apart from the transmitting and receiving apparatus the only loss incurred is the energy radiated in the form of Hertzian or electro-magnetic waves which can be reduced to an entirely insignificant quantity."

Finally, as to the now famous Tesla Tower. This is a huge mushroom shaped tower at Wardenclyffe, Long Island, New York, a place some 60 or so miles out from the city along Long Island Sound. This tower is 185 feet high from the ground to the top of the cupola. The smallest dimension across the base of uprights is 97 feet. The height to the ledge of the cupola is 153 feet, while the cupola itself is 65 feet in diameter. The tower has eight sides, with a staircase and lift for reaching the cupola platform. It is from this cupola that wireless vibrations are to be shot out in any desired voltage to given points scattered over a very wide radius. Not only so, but Tesla dreams of making it a receiving station to which can be transmitted a ceaseless day and night service of millions upon millions of volts from such power plants as those of Niagara. Thence such a force could be transmitted to run the street cars, the elevateds, the subways, the factories, the electric lights, the railroads, the automobiles, the ferries, the trucks, the heaters in the cellars and the clocks in the parlors of the great city of New York.

Tesla's dream also includes the erection of towers similar to this at Wardenclyffe, at convenient places, everywhere, for the purpose of distributing wireless energy for all these purposes over their respective areas. Some towers would be supplied with power from such sources as Niagara Falls or Victoria Falls. Or plants will be erected alongside or between the main uprights, each distributing a huge horsepower under a tension of millions of volts. Mr. Tesla declares he can handle the most amazing voltage from such towers with absolute safety, and his dream is of an America dotted over with these towers, each supplying all the energy for, say, an area of 30 miles about and spaced from each other 60 miles in such a manner that practically every inch of ground is covered by his new wireless service.

Not only wireless power service but wireless telegraph and telephone service will be furnished by this network of towers, covering the entire earth and making it possible for a man in New York to talk directly with his friend in London. Tesla dreams of the day when a man may dictate his orders in San Francisco and they may be set up and printed directly in New York, of a day when not merely photographs will be transmitted by wireless, but when one can actually see over the wireless the friend to whom he is talking in some distant part of the earth, watch his facial movements, "see" him as plainly as if he were in the room. In fact the possibilities of the wireless age of the future as Tesla conceives it are boundless.

That is why he is more interested in schemes that are called "visionary" than in those of his inventions which "the world calls practical."

As he himself has put it in a recent statement: "A systematic research carried on for a number of years with the object of perfecting a method of transmission of electrical energy through the natural medium has led me to recognize three important necessities: First, to develop a transmitter of great power; second, to perfect means for individualizing and isolating the energy transmitted; and third, to ascertain the laws of propagation of currents through the earth and atmosphere."

All these things he now believes can be done. He believes that he has discovered a means of pouring electrical energy into the air, as it were, without loss except at the point where a properly tuned instrument will be able to draw it out, at the point where it is needed.

"When the great truth accidentally revealed and experimentally confirmed is fully recognized," he says in speaking of the inventions with which he believes he will make the wireless age a fact, "it will be seen that this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball, and that by virtue of this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment."

QUESTIONS AND ANSWERS

Rules:—Questions must be addressed to the "Question and Answer Department" and contain nothing for other departments. Full name and address of the writer must be given; only three questions may be sent at one time; 2-cent stamp must be enclosed for answer by mail. No attention will be paid to questions which do not comply with these rules.

Tesla Coil

Question.—Please explain what a Tesla coil is and what can be done with such a coil.—L. E. F., Madison, Maine.

Answer.—See "Construction of a Tesla High-Frequency Apparatus" on page 728 of the December, 1910, issue.

LXVIII. *The Induction-Coil.* *By* E. Taylor Jones, *D.Sc.*, *Professor of Physics in the University College of North Wales, Bangor, and* D. E. Roberts, *B.Sc., Fellow of the University of Wales* *

[Plates XII. & XIII.]

THE experiments described in the present paper were made with the object of determining the elements (periods, amplitudes, damping-factors, and phases) of the two electrical oscillations which are set up in the secondary of an induction-coil when the primary current is interrupted, and of calculating hence the maximum value of the secondary potential and the potential at any time during the oscillations.

The principal difficulties connected with the calculation of the secondary potential of an induction-coil are (1) the determination of the effective self- and mutual-inductances of the coils, (2) the determination of the capacity of the secondary coil; the first owing to the want of proportionality between magnetic induction and magnetizing force in the iron core, the second owing to the smallness of the capacity and to the fact that the capacity is distributed along the coil. Some attempt was made in the experiments described below to overcome these difficulties, but there are other circumstances, including condenser losses, hysteresis, and irregularities in the working of the interrupter, which will have to be taken into account, or avoided, before a complete solution of the induction-coil problem can be reached.

The papers of Oberbeck †, Walter ‡, and Lord Rayleigh §, on induction-coil potentials are well-known and are therefore only mentioned here.

* Communicated by the Authors.
† Oberbeck, Wied. *Ann.*, lxii. p. 100 (1897); lxiv. p. 193 (1898).
‡ Walter, Wied. *Ann.*, lxii. p. 300 (1897); lxvi. p. 623 (1898).
§ Rayleigh, Phil. Mag., ii. p. 581 (1901).

General Description of the Method.

In a former communication one of us * arrived at the following expression for the difference of potential at the terminals of the secondary of an induction-coil at any time t seconds after a current i_0 is interrupted in the primary:—

$$2V_2 = \frac{Mi_0T}{(T^2-T'^2)\cos\delta}e^{-\frac{t}{T^2}\left(\frac{\theta_1+\theta_2}{2}-\beta\right)}\sin\left(\frac{t}{T}-\delta\right) - \frac{Mi_0T'}{(T^2-T'^2)\cos\delta'}e^{-\frac{t}{T^2}\left(\frac{\theta_1+\theta_2}{2}+\beta\right)}\sin\left(\frac{t}{T'}-\delta'\right), \quad . \quad . \quad (1)$$

where M is the mutual inductance of the primary and secondary coils,

$$\theta_1=\tfrac{1}{2}R_1C_1, \quad \theta_2=\tfrac{1}{2}R_2C_2,$$

$1/2\pi T$ and $1/2\pi T'$ are the frequencies of the two oscillations calculated from the well-known expression for coupled circuits

$$8\pi^2n^2=\frac{1}{1-k^2}\left[\frac{1}{L_1C_1}+\frac{1}{L_2C_2}\pm\sqrt{\left\{\left(\frac{1}{L_1C_1}-\frac{1}{L_2C_2}\right)^2+\frac{4k^2}{L_1C_1L_2C_2}\right\}}\right], \quad . \quad . \quad . \quad . \quad (2)$$

k being the coupling coefficient $M/\sqrt{L_1L_2}$.

The quantity β, and the phase-angles δ, δ', are to be calculated from the constants of the circuits as described in the former paper above referred to. R_1, R_2, C_1, C_2, L_1, L_2 are the primary and secondary resistances, capacities, and self-inductances.

In the paper referred to the above expression (1) was worked out for an *air-core* induction-coil with various condensers in the primary and secondary circuits, and the curve of secondary potential plotted from the results. The curve was also obtained photographically in each case by means of an electrostatic oscillograph, and was found to agree closely in its general form with the curve calculated from (1). The differences were mainly in the damping factors, and these discrepances probably arose from losses in the primary condensers.

Strictly speaking, the expression (1) is not applicable to a coil with an iron core, owing to the variable permeability of iron; all that can be expected is that suitable mean values

* E. T. Jones, Phil. Mag. January 1909, p. 28. This expression for the secondary potential was obtained by an application of Drude's 'Theory of the Oscillation Transformer,' *Ann. der Physik*, xiii. p. 512, 1904.

of the inductances may be found which will serve for the evaluation of the periods and amplitudes during at least a portion of the time of discharge. This was borne in mind in the experiments described below, and it was intended as far as possible to determine the mean inductances corresponding to the early portion of the discharge, since this portion includes the maximum secondary potential which is the quantity of greatest importance in an induction-coil.

The inductances of the primary and secondary coils were determined by electrical oscillation methods ; a condenser of known capacity being connected to the primary (or secondary) coil, and the curve of secondary potential being photographed and measured by methods which have been described in detail in former papers *.

It was thought that by measuring that portion of the damped oscillation-curve in which the current amplitude was approximately the same as in the early part of the double-period discharge, appropriate mean values of the inductances would be obtained, since the iron core passed through the same series of magnetic states in both cases. It was scarcely to be expected that this plan would lead to very accurate results, but it was hoped that it would suffice for the purposes of an approximate estimation of the secondary potential.

The coupling coefficient of the two coils was determined by finding the period of the oscillations of the secondary circuit, connected to a condenser, with the primary open and closed. The ratio of the squares of these periods is then $(1-k^2)$.

The value of the expression (1) was worked out for two induction-coils, a 12-inch spark coil by Max Kohl, and an 18-inch coil by the same maker. In the experiments with the smaller coil a condenser was connected to the terminals of the secondary coil ; otherwise the secondary capacity would have been so small that one of the oscillations would be too rapid to be accurately recorded by the oscillograph. In the case of the larger coil it was unnecessary to connect a condenser to the secondary, but the primary capacity was larger than is generally employed with induction-coils.

In these experiments the electrostatic oscillograph was provided with a steel strip under great tension in order to bring the amplitudes of the curves down to moderate dimensions. The metallic parts of the instrument were well sheathed in ebonite, and the terminals well separated, in order to prevent sparking.

* E. T. Jones, *loc. cit.* pp. 33-35; and Phil. Mag. August 1907.

The interrupter consisted of a copper rod making contact with the interior of an iron vessel containing petroleum. The rod was raised automatically, as the reflected rays of light were crossing the photographic plate, by a lever placed beneath the rotating mirror.

Experiments with a Condenser in the Secondary Circuit.

When a condenser is connected to the terminals of the secondary, the capacity of the secondary coil only comes in as a small correction, and it is unnecessary to know its value very accurately. It consists partly of the internal capacity, depending upon the capacity of one section of the coil on the next and upon the number of sections, and partly of the external capacity which depends upon the position of the coil with respect to other bodies and especially with respect to the primary coil. The methods by which these capacities were determined were described in a previous communication *.

Case I.—In the first experiment with the smaller induction-coil the primary was drawn out of the secondary until the curve of secondary potential, as shown by the oscillograph, had a simple and well-marked form, corresponding probably to some simple ratio between the two frequencies of oscillation. This case was intended as a preliminary test of the method.

The photograph is shown in Plate XII. fig. 8. The current broken in the primary circuit was 5·05 amperes, and the ordinate of the curve represents the square of the secondary potential at any subsequent time. The curve was photographed for four different values of the primary current i_0 ranging from 2·8 to 5·05 amperes, and the general form of the curve was the same in all, only the amplitude varying with the current. The amplitude of the first wave in each was measured on the negative with a travelling microscope and the values found were, within 4 per cent., proportional to the squares of the primary currents.

The lower curve in the photographs represents the oscillations of a 768 tuning-fork photographed simultaneously. Immediately after these curves were obtained another curve was photographed showing the secondary potential for an *air-core* induction-coil with known capacities and inductances in its circuits. This curve was similar to one of those discussed in the previous paper above referred to, and to which the expression (1) may be assumed to apply. By

* E. T. Jones, Phil. Mag., August 1907, p. 248.

both measuring and calculating the maximum amplitude in this curve the electrometer may therefore be standardised.

The iron-cored induction coil was again connected to the oscillograph and photographs obtained for the purpose of measuring the primary and secondary inductances, the coupling coefficient, and the capacities if these were not already known. The values of these constants in the present case were as follows :—

$L_1 = \cdot 02342$ henries.
$L_2 = 258 \cdot 3$,,
$M = 1 \cdot 811$,,
$k^2 = 0 \cdot 5424$
$C_1 = 15 \cdot 95$ microfarads.
$C_2 = 0 \cdot 0004748$,,

This value of C_2 includes the capacity of the electrometer and of the secondary coil. The resistances of the primary and secondary coils were 0·32 and 14000 ohms.

The two frequencies of oscillation, calculated by (2), were

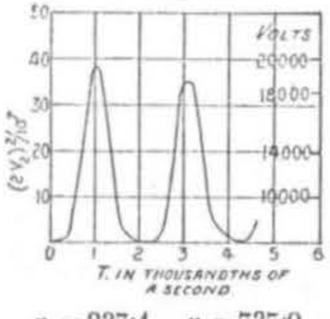
$$n_1 = 237 \cdot 4, \qquad n_2 = 737 \cdot 0,$$

and the expression (1) for the secondary potential, taking the primary current i_0 as 5·05 amperes, becomes in volts

$$2V_2 = 15230\, e^{-6t} \sin (86453t - 0 \cdot 55) - 4910\, e^{-68 \cdot 15t} \sin (266334t - 1 \cdot 72),$$

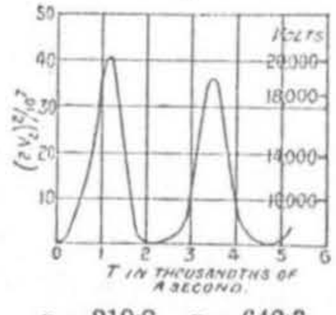
in which t is the time in seconds after the interruption of the primary current, and the angles are given in degrees. This was worked out for a number of values of t, the results squared and plotted in a curve the early portion of which is shown in fig. 1.

Fig. 1.



$n_1 = 237 \cdot 4$, $n_2 = 737 \cdot 0$,
$i_0 = 5 \cdot 05$ amp.

Fig. 2.



$n_1 = 219 \cdot 8$, $n_2 = 642 \cdot 3$,
$i_0 = 4 \cdot 02$ amp.

The agreement between this curve and the photograph in

Plate XII. fig. 8, is evidently sufficiently close to justify the application of the method to the present case. The damping of the waves is much greater in the photograph than in the calculated curve. This is also the case in the other experiments described below, and is to be expected since the only cause of damping taken into account in the calculation is that which arises from the resistances of the circuits.

The calculated maximum value of the secondary potential is 19650 volts, and the amplitude of the first wave in the photograph is 0·9276 cm. Now the standardising curve obtained with the air-core coil showed that a deflexion of 0·3032 cm. in the photograph corresponds to 10200 volts. Hence taking the deflexion as proportional to the square of the potential, the amplitude of the first wave represents a maximum potential of 17850 volts.

When it is remembered that the damping due to hysteresis and condenser losses have been entirely neglected, the agreement between the calculated and observed values of the maximum secondary potential is perhaps as close as could be expected.

Case II.—This case is similar to the first except that the primary coil with its iron core was placed further inside the secondary in order to increase the secondary self-inductance and the coupling coefficient. The secondary capacity (a variable condenser with paraffin-oil dielectric) was adjusted so as to give a form of oscillograph curve slightly different from that of *Case I.* The constants of the circuits were :—

$L_1 = \cdot 02331$ henries.
$L_2 = 428 \cdot 1$,,
$M = 2 \cdot 436$,,
$k^2 = 0 \cdot 5949$
$C_1 = 15 \cdot 95$ microfarads.
$C_2 = 0 \cdot 000499$,,
R_1, R_2 as before.

The frequencies, calculated by (2), were

$$n_1 = 219 \cdot 8, \qquad n_2 = 642 \cdot 3,$$

and, with $i_0 = 4 \cdot 02$ amperes, the expression for the secondary potential in volts is

$$2V_2 = 15320\, e^{-5 \cdot 46t} \sin (79146t - 0 \cdot 51) - 5247\, e^{-51 \cdot 85t} \sin (231221t - 1 \cdot 49).$$

The curve representing the square of this expression is shown in fig. 2, the corresponding photograph in Plate XII. fig. 9, and again there is close agreement in the form of the curve.

The maximum secondary potential (calculated) is 20085 volts, the observed value (by comparison with the curve given by the air-core coil) 17250 volts.

Case III.—The primary coil was placed fully inside the secondary so as to give the maximum values of the secondary self-inductance and the coupling coefficient. Owing to sparking between the plates of the oil condenser this was replaced by a leyden-jar. The constants for this case were:—

$L_1 = \cdot 02303$ henries.
$L_2 = 513$,,
$M = 3 \cdot 197$,,
$k^2 = 0 \cdot 8643$
$C_1 = 15 \cdot 95$ microfarads.
$C_2 = \cdot 001051$,,
R_1, R_2 as before.

The ratio of the frequencies was considerably greater than in the previous cases, their values being

$$n_1 = 170 \cdot 1, \qquad n_2 = 908 \cdot 8.$$

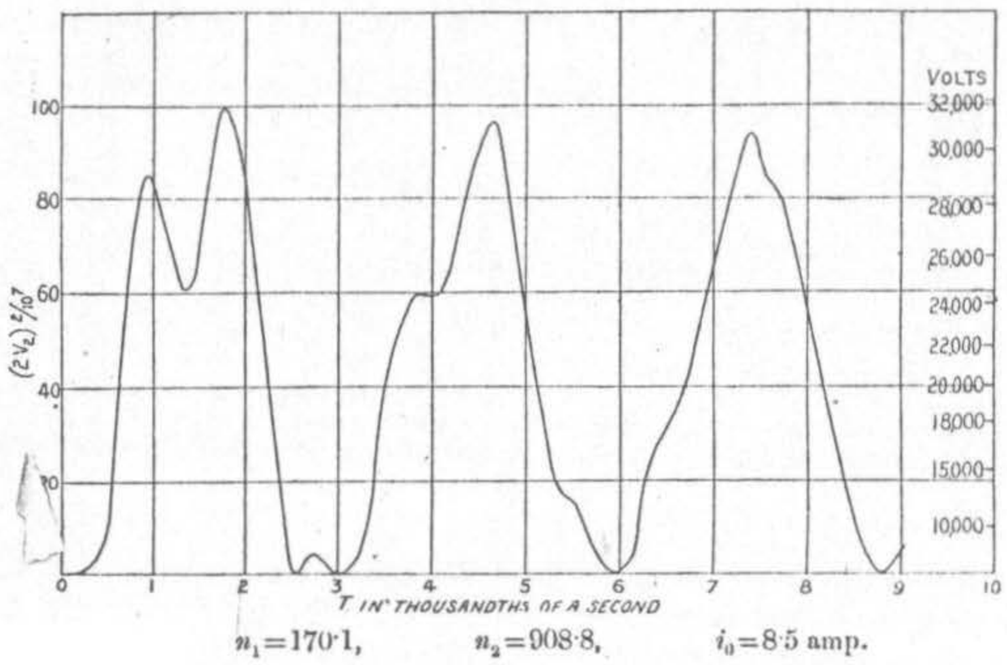
With a primary current of 8·5 amperes the expression for the secondary potential is

$$2V_2 = 30090\, e^{-6 \cdot 217t} \sin (61232t - 0 \cdot 55)$$
$$- 5640\, e^{-145 \cdot 6t} \sin (327157t - 2 \cdot 9).$$

The curve representing the square of this expression is given in fig. 3, and the corresponding photograph in Plate XII. fig. 10. Though there are differences in detail, in general form the resemblance between the two curves is close, and there is also good agreement, in this as well as in all the other cases, between the calculated and observed values of t at which the potential is zero. The calculated value of the maximum secondary potential is 31730, the observed value 26500 volts.

The greatest spark-length observed in this case between two brass spheres, each 2 centimetres in diameter, was 8·5 millimetres.

Fig. 3.



$n_1 = 170 \cdot 1$, $n_2 = 908 \cdot 8$, $i_0 = 8 \cdot 5$ amp.

Case IV.—This differs from the last only in the use of a smaller capacity in the secondary circuit, its value being ·0002213 microfarad. The frequencies were

$$n_1 = 230 \cdot 2, \qquad n_2 = 1444 \cdot 7,$$

and with $i_0 = 6 \cdot 75$ amperes the secondary potential is given by

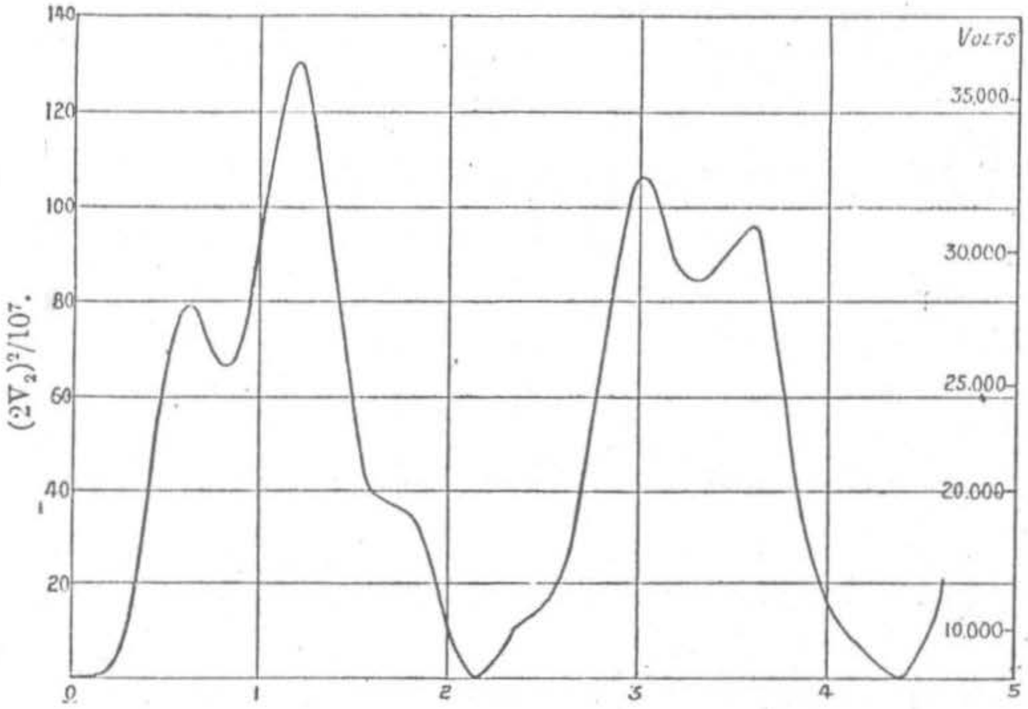
$$2V_2 = 32411\, e^{-4 \cdot 884t} \sin (82888t - 0 \cdot 29)$$
$$- 5168\, e^{-145 \cdot 6t} \sin (520086t - 1 \cdot 82).$$

The maximum value of this expression, which occurs at the second peak of the curve, is 36060 volts. The curve is shown in fig. 4 (p. 714).

Several photographs were taken for this case, and though similar in their general features they differed considerably from one another in detail. Sometimes the first peak was equal to or higher than the second, sometimes the peak in the second principal wave was higher than both maxima in the first. These differences arise apparently from irregularities in the working of the interrupter, which seem to affect chiefly the amplitude and phase of the more rapid oscillation. The photograph in Plate XII. fig. 11 shows the type which occurred most frequently. By comparison with the air-core coil the highest point of the curve was found to correspond to a secondary (observed) potential of 27560 volts.

The greatest sparking-distance between the two spheres under the circumstances of this experiment was found to be 1 centimetre.

Fig. 4.



$n_1=230{\cdot}2$, $n_2=1444{\cdot}7$, $i_0=6{\cdot}75$ amp.

It will be observed that in all the above cases the calculated value of the secondary potential is considerably greater than the observed value, and that the percentage difference increases with the potential.

Experiments with no Condenser in the Secondary Circuit.

If the condenser is removed from the secondary circuit of the smaller induction-coil, one of the oscillations becomes too rapid to be faithfully recorded by the oscillograph. The 18-inch spark coil was therefore used for the three following cases, its secondary having much greater self-inductance and capacity.

In order to work out the expression (1) for these cases it is necessary to know the value of the effective capacity of the secondary coil with greater accuracy than was required in the former cases. After several methods had been tried for the determination of this quantity, the following was finally

adopted. The condenser having been disconnected from the primary circuit, a current was passed through the primary coil and the curve of secondary potential, produced at its interruption, was photographed. Under these circumstances the oscillations of the system depend only on the constants of the secondary circuit, and should give the value of the product of the self-inductance and capacity of the secondary coil. The photograph showed, in fact, a single damped oscillation with period lengthening as the oscillations died away owing to the variation in the permeability of the core, The period was measured in the early part of the curve, where the amplitude is large, and was found to be ·001763 sec. Taking this as being equal to $2\pi\sqrt{L_2C_2}$, we have

$$L_2C_2=0{\cdot}787\,.\,10^{-7}.$$

A condenser, of small known capacity C_2', was then connected to the secondary coil and the period of this circuit, with the primary open, determined. This gives in the same way the value of $L_2(C_2+C_2')$. From these two results the values of L_2 and C_2 can be determined. The values so found were $L_2=2350$ henries, $C_2=\cdot0000335$ microfarad. These values were used in working out the expression (1) for the following three cases. It may be noticed, however, that it is not so important to know the values of L_2 and C_2 separately as it is to know their product; C_2 occurs separately only in the damping factors of the two oscillations represented by (1).

The self-inductance of the primary coil was determined by connecting to it the largest capacity available (20·73 microfarads), and photographing the curve of secondary potential produced at the interruption of a current in the primary. The curve obtained shows a double oscillation; but, since L_1C_1 is much greater than L_2C_2, one of the oscillations has a much longer period than the other, and it is not difficult to determine the frequency of the slower oscillation from the photograph. On substituting in the expression (2) we obtain the value of L_1.

As the potentials obtained in the following experiments were higher than those in the former cases, the oscillograph was made less sensitive by withdrawing the attracting plate to a greater distance from the steel strip. To prevent sparking inside the instrument the attracting plate was enclosed in a thicker sheath of ebonite. The distance of the edge of the plate from the strip was about 7 mm.

Case V.—The constants for this case were :

$L_1 = 0{\cdot}1974$ henries.
$L_2 = 2350$,,
$C_1 = 15{\cdot}95$ microfarad.
$C_2 = {\cdot}0000335$,,
$k^2 = 0{\cdot}8142$.
$M = 19{\cdot}44$ henries.
$R_1 = 1{\cdot}90$ ohms.
$R_2 = 38000$,,
$i_0 = 4{\cdot}3$ amperes.

The expression (2) gives for the frequencies

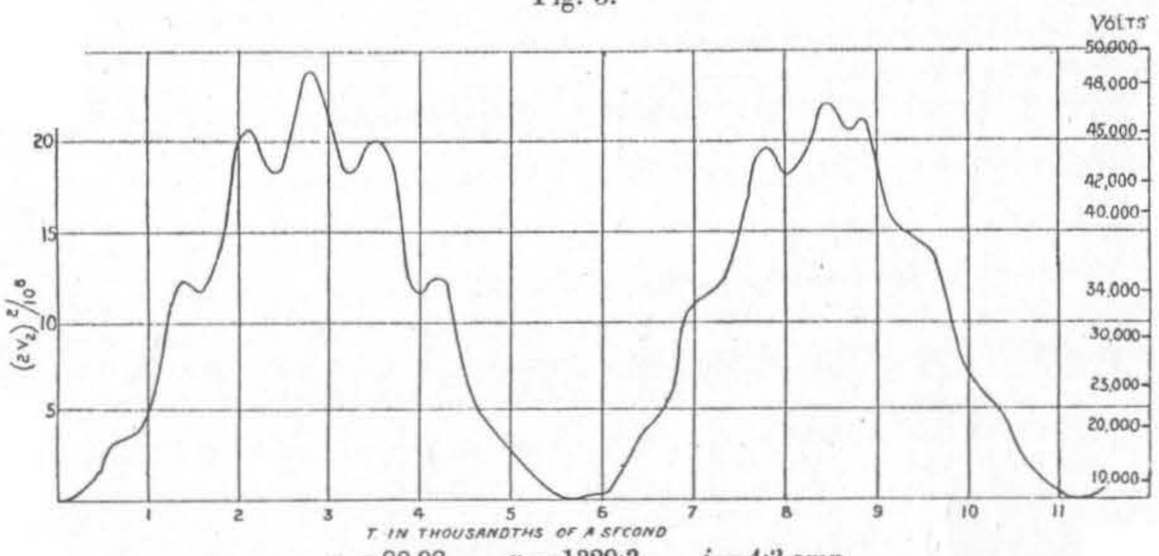
$$n_1 = 88{\cdot}98, \qquad n_2 = 1329{\cdot}3.$$

By (1) the secondary potential is

$$2V_2 = 46950\,e^{-4{\cdot}654t}\sin(32033t - 0{\cdot}05) - 3143\,e^{-62{\cdot}72t}\sin(478548t - 0{\cdot}8).$$

The curve representing the square of this expression is shown in fig. 5, and its maximum value is 48960 volts. The

Fig. 5.



$n_1 = 88{\cdot}98$, $n_2 = 1329{\cdot}3$, $i_0 = 4{\cdot}3$ amp.

photograph is given in Plate XIII. fig. 12, but it should be stated that the amplitude of the short wave varied considerably in different photographs, it being sometimes larger, sometimes smaller than is here shown. As in some other cases, these variations appear to arise from irregularities in the action of the interrupter.

The oscillograph was standardised in this and the two following cases, not directly with the air-core coil, but with the coil and condensers used in Case III., the greatest deflexion for a current of 8·5 amperes in that case being taken as representing 26500 volts. A comparison of the curves leads to 39480 volts as the greatest observed value of the secondary potential, which is again considerably below the calculated value.

The sparking-distance between the two spheres with the same primary current was found to be 1·6 centimetres.

Case VI.—In order to approximate more closely to the ordinary working conditions of an induction-coil, the primary capacity was now considerably reduced in value. This has the effect of increasing the secondary potential, and at this stage it was noticed that at high potentials a brush discharge took place freely between the ebonite sheath enclosing the attracting plate of the oscillograph and other parts of the instrument. The attracting plate and its connecting rod were therefore provided with still thicker coverings of ebonite, and the terminals of the instrument were removed to a greater distance from each other, in order to diminish as far as possible the leakage due to this cause.

The primary capacity was in the present case 3·89 microfarads, which gives, by (2), using the values given under Case V. for the other constants of the circuits,

$$n_1 = 174{\cdot}4, \qquad n_2 = 1371.$$

The expression for the secondary potential in volts is

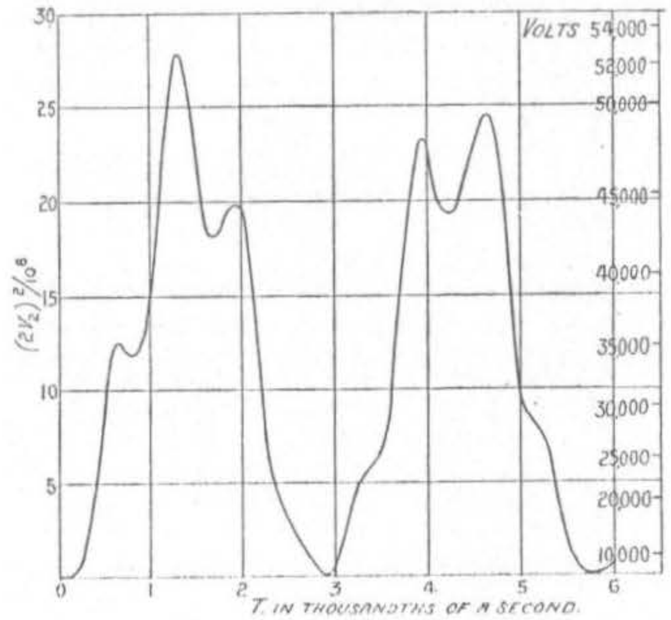
$$2V_2 = 21650\,i_0 e^{-4{\cdot}14t}\sin(62770t - 0{\cdot}1) - 2753\,i_0 e^{-65{\cdot}26t}\sin(493452t - 0{\cdot}83),$$

where i_0 is the primary current in amperes. The curve representing the square of this expression was drawn for $i_0 = 2{\cdot}25$ amperes, and is shown in fig. 6 (p. 718).

Photographs were taken at the interruption of various currents in the primary circuit. One of these is shown in Plate XIII. fig. 13. The curves obtained were all of the same type, only the amplitude varying with the primary current. The greatest ordinate in each photographic curve was measured and compared with that of the standardising curve. The results are contained in Table I., in which the first column contains the values of the current interrupted in

the primary circuit, the second the maximum potential calculated by (1), the third the maximum potential deduced by measurement of the plates.

Fig. 6.



$n_1=174{\cdot}4$, $n_2=1371$, $i_0=2{\cdot}25$ amp.

TABLE I.

i_0, amperes.	Maximum Potential in volts.	
	Calc.	Obs.
2·64	61910	72220
3·16	74110	84110
3·90	91460	101070
4·44	104120	118560
5·10	119600	132940

The greatest spark-length observed between the two spheres with the current of 5·1 amperes, was 7·3 centimetres.

The observed value of the secondary potential is in this case greater than the calculated value. Probably the calculated value is too small, owing to the fact that the expression (1) does not correctly represent the phase relation of the two oscillations, as we see by comparing the photograph Pl. XIII. fig. 13, with the calculated curve fig. 6.

Case VII. The primary capacity was further reduced, its value in this case being 2·933 microfarads. Taking the other constants as before, we have

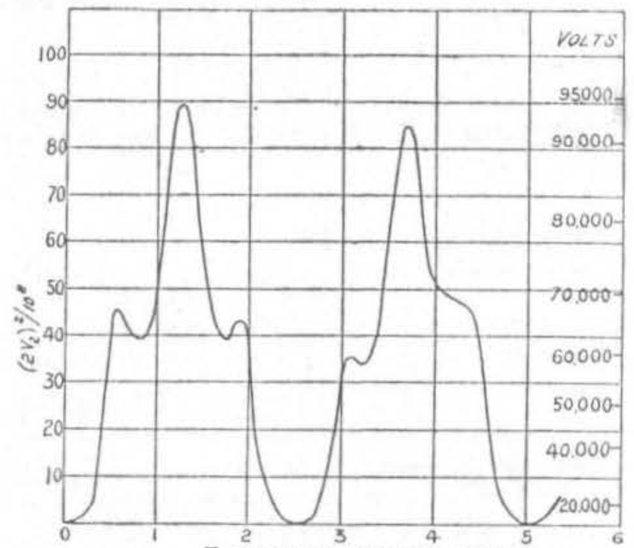
$$n_1=198{\cdot}2, \qquad n_2=1388,$$

and the expression for the secondary voltage is

$$2V_2=24730\,i_0e^{-3{\cdot}975t}\sin(71359\,t-0{\cdot}12)$$
$$-3530\,i_0e^{-65{\cdot}42t}\sin(499860\,t-0{\cdot}83).$$

The curve, calculated for $i_0=3{\cdot}4$ amperes, is shown in fig. 7.

Fig. 7.



$n_1=198{\cdot}2$, $n_2=1388$, $i_0=3{\cdot}4$ amp.

The photograph shown in Plate XIII. fig. 14 is typical of the oscillograph curves obtained in this case. It again differs from the calculated curve in the relative phases of the two oscillations, and this probably accounts in part for the differences between the observed and calculated maximum voltages given in Table II.

TABLE II.

i_0, amperes.	Maximum Potential in volts.	
	Calc.	Obs.
2·74	75630	70440
3·24	89430	76950
4·00	110400	101100
4·42	122000	112100
5·10	140800	142400

With the current 5·1 amperes the greatest sparking-distance between the two spheres was found to be 11·2 centimetres.

To sum up, the results given above show that the expression (1) represents in its main features the wave of potential at the terminals of the secondary coil when a current is interrupted in the primary, and that it also gives the order of magnitude of the maximum secondary potential. In each of the cases described above some uncertainty with regard to the maximum potential arises from the fact that the amplitude of the oscillograph curve is not always the same with the same primary current; and although each curve was photographed a number of times and the curve of greatest amplitude selected for measurement, we could never be quite certain that the greatest possible amplitude was actually obtained.

Similar differences are observed with other kinds of interrupter. In Plate XIII. fig. 15, are shown the curves of secondary potential at two successive interruptions of the primary current produced by a motor mercury-interrupter of the centrifugal type. The coils and condenser in action at the time were the same as in Case VII.

Bangor, July 1911.



"In What Was Left of the Cities Starvation Stalked Like a Gigantic Death. The Aeroplanes, Searching Like Enormous Birds for Food, Were One by One Washed Away."

How Nature with a Second Deluge Washed Earth Clean of Mankind.

EACH year some new idea concerning the way Man and his Works will be conquered finally by Nature appears. Only once in a decade, however, will be evolved some theory sufficiently striking to grip the reader.

The unusual heat of this Summer, which affected not only America, but all of Europe, the consequent drought, the destruction of immense crops, and finally on August 16, the juxtaposition of the planets Mars and Saturn

and the moon, could be depended upon to stimulate some writer to predict what these phenomena meant.

In France, where scientific men do not hesitate to place their ideas in the form of fiction, M. Marcel Roland, a member of the French Institute of Science, has written a startling book upon the Second Deluge, which in the Fall of 1911 is supposed to follow these portents. The tale is told by a survivor of the deluge and is here abridged.

By M. Marcel Roland.

THERE had been a searing drought for many months. For five years the rain fall had steadily decreased. Throughout the Summer the heat had been killing. All over the world crops had been ruined; the wheat was burned on its stalks. Many people died. The sun burned with a lurid, reddish lustre that fretted the nerves. Suicides and murders kept steadily increasing.

November dawned. The Seine was so low that the talking rock, that carved stone whose appearance always means evil, had long grown commonplace. In New York the water riots had claimed their thousands of lives. The great tongue of the city stretching into the bay was only a mass of blackened skeletons of iron.

My uncle, a great meteorologist, had predicted that in this month would come the break in the great drought. He warned the people of the world to take precautions; that there would be great and disastrous floods. Paris and the world laughed at him, called him a Twentieth Century Noah, bade him build an ark, and went about their pleasures as undisturbed as might be in that time of stress.

The skies began gradually to thicken; the heat became more intense. Blacker and blacker grew the heavens. Down and down dropped the barometer. At last came the rain.

Although it was nearing Winter the weather did not grow cold. Reports from the far North did not grow cold. Reports from the far North and the far South showed that the warmth extended even there. The great ancient fields of snow and ice were melting under the deluge and were sending their immemorial fettered floods into the air as rain and into the seas as water to swell the rising oceans.

Every one moved upstairs, for the cellars were flooded. Business stopped. Many now began to build boats and to sail for the higher lands. Then began those series of awesome tempests which must have been like those mighty winds that moved over the face of earth when it was being created. No boats could live in these hurricanes.

The great liners, bought in the emergency by the money kings of America and stocked to the limit with food, went down one by one. The American Midases each in his separate Ark were wiped from the face of the earth, or the waters.

It was John Rockefeller who conceived the idea of propitiating Deity by imitating Noah and bringing into his ocean leviathan pairs of all the animals and creatures he could find. Behind his Ark he towed thousands of barges laden with oil, to calm the waves. He kept in touch with the world by his wireless for forty days, beseeching the people to repent and pray. Then Aetna blew up, dropping the island of Sicily under the waves. Mr. Rockefeller was not far away from the volcano and his Ark. The New Olympic must have been overwhelmed in that cataclysm.

By that time all the world was afloat. In what was left of the cities, starvation stalked like a gigantic death. The aeroplanes darting hither and thither through the torrents, searching like enormous birds for food, were one by one washed away to destruction. Only Antoni, the Italian inventor, in his Triton, that wonderful combination of submarine and flying machine, remained an active fighter against this gigantic upheaval of Nature. The world starved in its garrets and drowned in its streets. It fed on floating carrion and then in madness turned into a frery of cannibalism.

We had locked ourselves in our house, my uncle and I. He was an old man, and on the hundredth day of the rains he died. Then I was alone. The earth rocked with explosions, with lightnings and the tempest. I looked over Paris. It was a sea covered with floating dead. On the first of February my provisions were exhausted I determined to break through into the garret of the next house, still standing, where I believed that a store of groceries had been placed. As I drove my axe through the last partitions a sudden light shone in the sky, and there was a terrifying roar of thunder. The walls cracked. With a cry of terror I looked into the face of a woman. It was Eva Vanhoem, the daughter of my neighbors, who had tried to escape by yacht from the Deluge.

On the eighth day at 4 o'clock I was awakened by the water creeping toward us over the floor of the roof to which we had fled.

"To the ladder!" I cried. We climbed out on the roof. There we stood cowrapped in the awful night. The water crept up and up—over the roof. I held the girl above my head. I know not why, but I began to shout again and again for help. Suddenly a gigantic black form swept over my head. Two arms seized mine, lifted from them the form of the girl, lifted me, and I was swept away into the blackness.

When I awoke I found that it was Antoni who had saved us. We were in his flying submarine.

"We will go to the Louvre," said Antoni.

"There is a necklace there that once belonged to a great Egyptian queen that I have always coveted." The Triton was filled with the rarest treasures of vanished humanity, which the Italian had taken from earth's drowned museums. We swam between the dark masses that had once been the buildings of proud Paris. We passed the obelisk, now fallen; the library, the grand opera house. Everywhere were the bodies of men and women floating about.

The Triton stopped at the doors of what had been the Louvre. He brought out some new diving suits he had invented.

Antoni, Eve and I each put one on. We carried a light rope, which connected us with the Triton. We entered the Louvre. There were its priceless treasures waiting for the water to subside and to be rediscovered by a new race of men thousands of years from now. About a group of Grecian statuary a giant sea serpent coiled. We fought it off with our electrically charged iron rods and took what we wished from the treasure house of Paris.

On the two hundredth day Antoni said: "To-morrow the rain will cease." He was right, but when we called upon Benin we found him drunk in a corner. He refused to work any longer. "There's only us four in the world," he said. "I'm as good as any of you. Who gets the woman?"

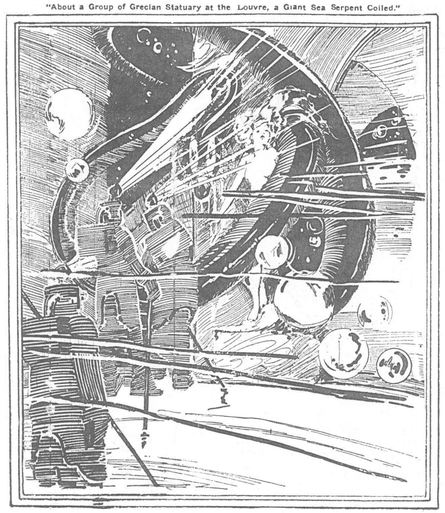
Before I could grasp the import of this we heard peculiar sound, almost like prolonged whistling. Through the port holes we saw masses of brown bones flashing past. An enormous masked face looked in at us. It was gigantic walrus. We rose to the surface. The sea was covered with walrus herds driving down from the melted north.

"Go inside!" I cried to Eve Antonio joined me. "Inside all, and close the openings!" Easier said than done. We were fighting our way through the horde when Bonin leaped upon the back of one monster. He plunged his knife into its throat. Both sank. Antonio drove at the others. I snatched Eva and threw ourselves below. As I dropped I saw Antoni, spitted on tusks, go over the side.

We closed the openings and sank. We were the last people, we thought, on the world

Now day by day the waters subsided. A stench of death was in the air. We drove South. On the two hundred and fiftieth day we saw two islands. They were all that were left of the great peaks of Java. As we drove toward them a horde of ape-like men and women rushed to meet us. They greeted us as gods. And here we have taken up our home—a new Adam and Eve to lead these people into development. We are sure that we are the last of civilized humanity to remain on earth!

But once again man will rise and conquer!



"About a Group of Grecian Statuary at the Louvre, a Giant Sea Serpent Coiled."

To Turn Earth into One Gigantic Dynamo,

The Wireless Wonders That Tesla's "World System" May Perform.

1. Television, making it possible to see any object at any distance.
2. Universal twenty-four-hour daylight by wireless illumination.
3. Instantaneous transmission of typed or hand-written characters all over the world.
4. Operation of flying machines by wireless power.
5. Navigation of ships through fogs and channels by wireless "tuned" compasses.
6. Communication with Mars.
7. Operation of all manufacturing and transportation machinery.
8. Every clock and watch in the world set and regulated by wireless at certain time each day.
9. Universal telephony, making it possible to speak to any distance.
10. A perfect government secret signal service by exclusive wireless waves.
11. Simultaneous operation of all stock-tickers throughout the world.
12. Universal system of musical transmission on atmospheric currents.
13. Irrigation and fertilization of arid lands by wireless power.
14. The magnetizing of enemy's battleships to attract torpedoes.
15. Reproduction of drawings and photographs at any distance.
16. Absolutely exclusive telegraphy and telephony.

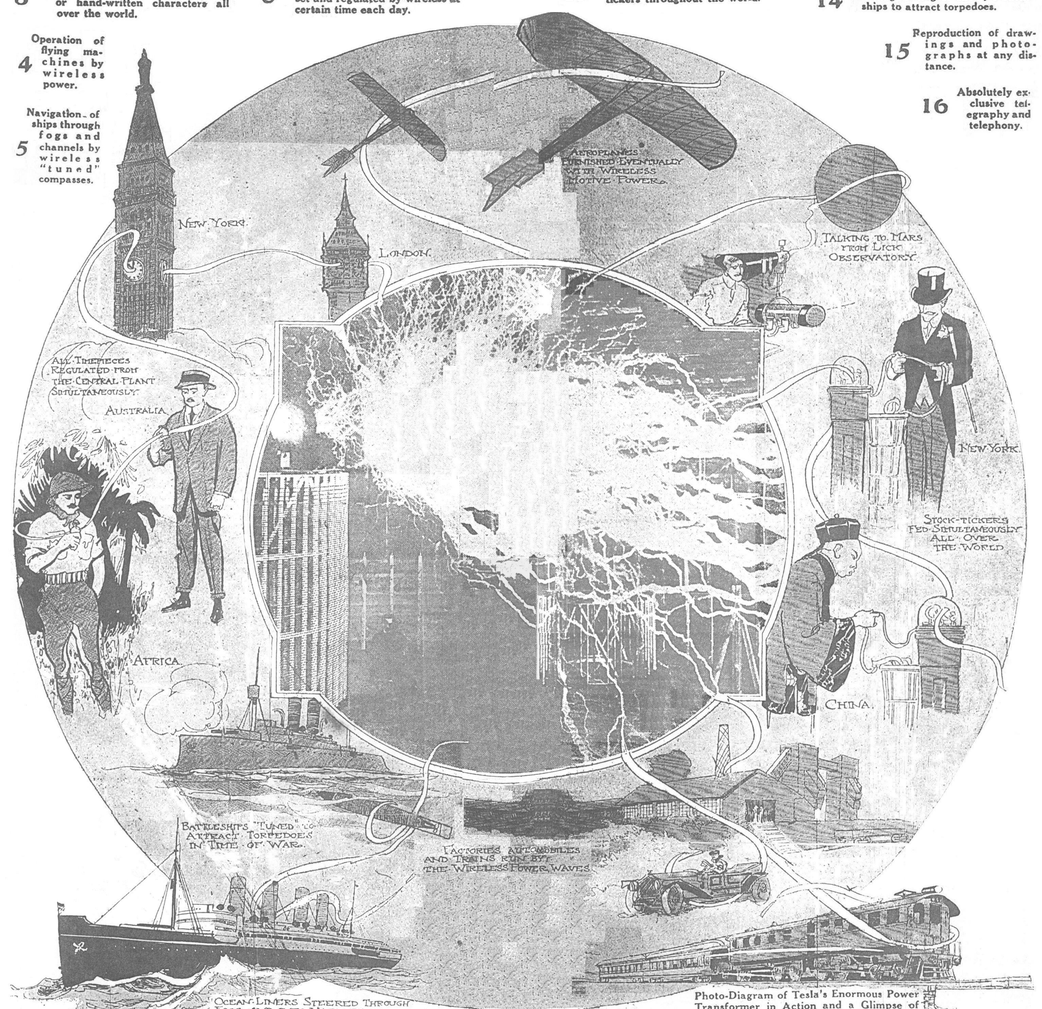


Photo-Diagram of Tesla's Enormous Power Transformer in Action and a Glimpse of What He Hopes to Accomplish With It.

How Man May Derive His Power in the Ages Still to Come.

A COUPLE of years ago James J. Hill, the railroad magnate, declared that before the end of the present century the available fuel supply of the country will be practically exhausted. This state of affairs will be brought about as a result of the destruction of our forests and the overproduction of coal.

How far this contingency might interfere with Nicola Tesla's remarkable plan to convert the earth into a huge dynamo to do the work of the universe depends entirely upon the available substitutes for coal and wood for the generation of heat. When our coal and wood are all gone, where will we get the energy to run the great earth dynamo?

In this connection, several plans which have been presented from time to time suggest themselves.

Perhaps the most remarkable is that of M. Camille Flammarion, the great French astronomer and physicist, who suggested boring a hole through the crust of the earth to sap the inexhaustible supply of heat believed to exist in its centre.

This plan is particularly interesting, because so little is known as to exact conditions to be found within the crust of the earth. The deepest shaft ever built penetrated but a mile and a quarter below the surface an insignificant distance compared with the four thousand miles between the surface and the centre.

It has been estimated that on an average the temperature increases one degree centigrade for every four yards in depth. On this basis a depth of two feet would bring us to the boiling point, while the temperature at the centre of the earth would be no less than two hundred thousand degrees! According to Flammarion. It would be necessary to bore not more than four miles before an inexhaustible supply of heat emitted might be applied to industrial purposes were real.

How would we proceed to dig this four-mile shaft? "Besides being very deep," says Flammarion, the shaft ought also to be of considerable diameter—say two hundred to three hundred yards, supported by a heavy thick, cast-iron lining.

"The excavated earth would most conveniently be disposed of by throwing it into the sea, to which it would be transported by railway.

"But, it will be asked, what of the insurmountable obstacles which will be encountered in the excavation of such a shaft? What of subterranean rivers? What of the landslips and the caving-in of the inside of the shaft?

"The reply is simple. These things can be forseen and provided against. The use of freezing mixtures, now so well understood, would here play a considerable part by freezing the moist and moving earth into rigidness and immobility."

Flammarion believes that his plan is practicable and possible, and, if so, it would, no doubt, provide the energy necessary for Tesla's great "world system."

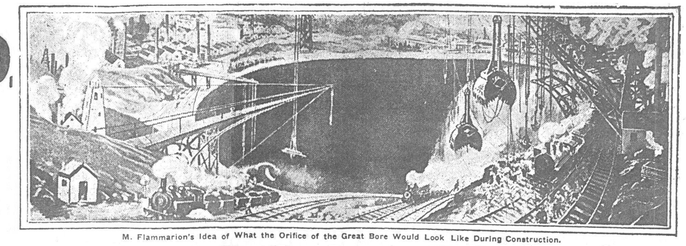
Another project which would prove equally effective, if feasible, is that of harnessing the rays of the sun. The heat radiating from the great solar body is sufficient to run the world-dynamo for millions of years, but how can we avail ourselves of it?

Sun-machines of various descriptions have been announced from time to time by ambitious inventors, but have proved either absolute failures or capable of generating only an insignificant amount of energy.

The scientists of the world have been diligently working on this problem for years, however and there seems to be no reason to believe that success will not ultimately be attained.

The newly discovered properties of radium likewise hold out great promise in this connection. At the present time, of course, the available supply of this element is too small to be of much service, but there is no doubt that it exists in almost inexhaustible quantities and scientific research will eventually discover a method of obtaining it in any amount desired. Indeed, Flammarion has suggested that his plan of boring a hole through the earth, if it had no other result, would probably reveal the existence of enormous radium mines in the bowels of the earth.

With all these possible sources of energy the state of future man on this globe would seem to be assured.



M. Flammarion's Idea of What the Orifice of the Great Bore Would Look Like During Construction.

Nicola Tesla for the First Time Describes His New System for Supplying Wireless Power to Run All the Earth's Industries.

BY a series of discoveries and inventions just perfected, Nikola Tesla, the electrical scientist, has upset what has hitherto been regarded as one of the fixed laws of nature

"Every effect diminishes with the distance," is the way the text books have expressed it. Tesla now asserts that instead of decreasing, like other forces, electricity may be made to increase in intensity with the distance travelled.

The full significance of this discovery may not be at once apparent. It is obvious, however, that it annihilates space. There can be no limit to the power of an electric wave which increases in intensity the further it travels.

For nearly twenty years Tesla has been working on his plan. He calls it his wireless "World System." If it is put into successful execution it will convert the earth into a gigantic conduit, which will pass power for all earthly activities, and make possible communication with the other planets.

From time to time Tesla has made partial announcements as his work progressed. This, however, is the first comprehensive account of his system as a whole that the inventor has consented to give to the world.

"Through ages past," Mr. Tesla declared, "man has always attempted to project in some way or other energy into space. In all his attempts, no matter what agent he employed, he was hampered by the inexorable law of nature which says that every effect diminishes with distance, generally as the square of the same, and sometimes more rapidly.

"Now the discovery I made upset all that had gone before, for there was a means of projecting energy into space, absolutely without loss from any point of the globe to another, to the Antipodes if desired. In fact, a force impressed at one point could be made to increase with the distance.

"I saw at once that space was annihilated in all the three aspects; in the transmission of intelligence, in the transport of our bodies and materials and in the transmission of the energies necessary for our existence. You can imagine how profoundly I was affected by this revelation. Technically, it meant that the earth, as a whole, had certain periods of vibration, and that by impressing electrical vibrations of the same periods upon it, it could be thrown into oscillations of such nature that innumerable benefits could be derived."

"It is difficult to convey an idea of these inventions without resorting to technical terms," Tesla continued. "The first and best known of these is my transformer, which enables the production of electrical vibrations of transcending intensities. I have already attained activities of many millions of horse power; but this is nothing compared to those which I am expecting to get with my improved apparatus.

"The second is what I have termed my magnifying transmitter, which I look upon as my best electrical invention, and with which any distance can be bridged. I have already passed a powerful current around the globe by the use of this wonderful instrument, and am confident that a message can be flashed to such a distance as the planet Mars.

"Some technical men would be disposed to look upon such statements as those of a dreamer, but it is only because they have not had opportunities to see experiments which I have actually performed. The third invention I have designated as the art of individualization,' which enables the transmission of an unlimited number of messages through a wire or wireless, without the slightest interference. Not before this improvement is universally adopted will the world fully realize the benefits of telegraphy and telephony. The fourth invention is my receiver, which concentrates the energy transmitted over a wide area into the operating device."

"What would the voltage of your transmitter be?"

"In the transmission of telegraphic and telephonic messages I shall employ from five to ten million volts, but in transmitting power in great quantities, as much as one hundred million volts will be used.

"How will your 'World System' compare with those now in use as regards cost?"

"We could easily afford to offer a transmission of telegraphic and telephonic messages to any terrestrial distance for five cents a word. In a short while no one will think it anything out of the way to dictate or to write a long letter across the Pacific."

"How long does it take for the transmission of a message by your system, around the world?"

"The exact time is, according to my measurements, 42-1000 of a second, which is a speed about 50 per cent greater than that of light.

"The impulse starts from my magnifying transmitter with infinite speed, slows first rapidly and then at a lesser rate until, when it has penetrated to a distance of six thousand miles from the transmitter, it proceeds with approximately the speed of light. From there on it accelerates, first slowly and then more rapidly, and reaches the opposite point of the globe again with infinite speed only to rebound and pass through the same phases on its way back to the transmitter.

"This movement of electricity through the earth, which takes place strictly in accordance with a mathematical law, enables a great number of accurate measurements and determinations to be made, which are of immense practical and scientific value."

"Is your universal marine service based upon this principle?"

"Largely so. In setting up and maintaining stationary waves in the earth its entire surface is subdivided in perfectly definite zones of electric activity, so that any observer of all those data



The Drills at the Base of Flammarion's Gigantic Geothermic Pit Strike a Pocket of Living Radium From Such Pits Tesla Might Draw His Power for His "World System."



Tesla's Magnifying Transmitter in Action—A Medusa Head of Lightnings.

and other place he wishes without loss of time in the transmission. It will be exactly as though he had his stenographer close by. In the same manner it will be practicable to send a hand-written letter or even a check, and what is more important, it will not be possible to falsify the signature."

"Will the transmission of complex musical productions require complicated apparatus?"

"Not at all. The apparatus at any of the master plants, transmitting a great number of musical compositions, will be of necessity complicated, but the subscriber will need only a telephone receiver, and, if he desires exclusiveness, an individualizing device in connection, which, however, will be rarely required. He will be none the less able to listen to the most complex opera played in some remote part of the world. What is more, he can carry the entire outfit with him on his walks and travels, and wherever he desires to listen to the music he can do so.

"The wireless system which I have developed does not contemplate competition with established lighting systems in densely populated districts, but it offers an ideal solution for the illumination of isolated places. The light will be furnished by exhausted glass tubes, bent in all sorts of ornamental shapes, and is of surpassing beauty, resembling closely the daylight. The lamps will last forever. The entire apparatus for lighting the average country dwelling will contain no moving part whatever, and could be readily carried about in a small valise. It will be quite immaterial in which region of the earth the house to be lighted is located. Distance will not affect the charge."

"How far from the earth's surface can power be transmitted by this wireless system?"

"To any distance; in fact, the greater the elevation above ground the easier it is to supply the power to the vehicle, such as an airship crossing the ocean."

"What do you consider the most important application of your system?"

"The transmission of power, of course. The operation of aerial machines alone will be of a revolutionizing influence, inasmuch as it will afford a perfect solution of this important problem. Another great field will be the irrigation and fertilization of the soil by wireless power. The time is not distant when a farmer will have installed on his place apparatus for continuously manufacturing, from the gases of the atmosphere, nitric compounds which will be used to fertilize, while a motor will pump the water and perform other duties, all the energy being supplied from a plant perhaps thousands of miles away. This system can be extended so as to make productive vast tracts of now barren lands located in various countries. I believe that the export of wireless power will be one of the chief resources of the United States and other fortunately situated countries in times to come."

"A business man will be able to dictate in his office a letter which will appear in type at

The New York Post September 5, 1911

Nikola Tesla Sued for $18,081.30.

Nikola Tesla, the electrical inventor, was today made the defendant in an action filed in the Supreme Court against him by the corporation of Westinghouse, Church, Kerr & Company, to recover the sum of $18,081.40 on a note. The complaint recites that on April 17 1907 the inventor executed the note to the order of the plaintiff, due in four months, and bearing six per cent. interest, "for value received."

The New York Press September 6, 1911

Sues Nicola Tesla for $18,081.30.

Nicola Tesla inventor, was yesterday made defendant in an action filed in the Supreme Court by the corporation of Westinghouse, Church, Kerr & Co. to recover the sum of $18,081.30 on a note for merchandise

FLUID PROPULSION.

On other pages of this issue we present Dr. Nikola Tesla's description of a new principle of fluid propulsion, which is the culmination of his labors of a number of years. As all generation of mechanical power involves the use of a fluid as the vehicle of energy, the underlying idea is a broad one and bears on all the branches of mechanics.

Dr. Tesla avails himself of the two fundamental properties of a fluid, adhesion and viscosity, in an effort to produce a highly efficient mechanism. The fluid, whether receiving or imparting energy, is made to pass along the surfaces of a system of rotating disks in free natural spirals—that is, along paths of least resistance. The efficacy of the machines he has constructed on this principle is evidenced by their remarkable performance, small turbines or rotary engines being run at a peripheral speed scarcely more than half of that of reaction turbines, and giving several times the output of the latter. For example, a small steam turbine exhibited at the Edison station in New York, having a rotor only nine and three-quarters inches in diameter and two inches wide, was capable of developing 110 horsepower with free exhaust. This machine had no blades, vanes, valves or sliding contacts of any kind.

On account of the great simplicity of this apparatus, reversibility and extraordinary output, it will undoubtedly find an immense variety of uses, and the commercial world can not fail to be deeply interested in this new development. The electrical industry, in particular, should be greatly benefited by this latest effort of Dr. Tesla.

TESLA'S NEW METHOD OF AND APPARATUS FOR FLUID PROPULSION.

INVENTION OF A TURBINE AND PUMP.

In an address before the New York section of the National Electric Light Association on May 15 of this year, Nikola Tesla devoted a few remarks to a new mechanical principle he had developed, and exhibited diagrams and working drawings in explanation of the same. He also alluded to the fact that several of his machines were to be seen in operation at the Waterside Station of the New York Edison Company, which had courteously extended to Dr. Tesla its facilities. The ELECTRICAL REVIEW AND WESTERN ELECTRICIAN of May 20 published an exclusive and full report of Dr. Telsa's address.

We present herewith the first authoritative description in the inventor's own words, which, on account of the great importance of the subject, cannot fail to excite interest in engineering circles the world over.

In the practical application of mechanical power based on the use of a fluid as vehicle of energy it has been demonstrated that, in order to attain the highest economy, the changes in velocity and direction of movement of the fluid should be as gradual as possible. In the present forms of such apparatus more or less sudden changes, shocks and vibrations are unavoidable. Besides, the employment of the usual devices for imparting to, or deriving energy from a fluid, as pistons, paddles, vanes and blades, necessarily introduces numerous defects and limitations and adds to the complication, cost of production and maintenance of the machine.

The purpose of the invention is to overcome these deficiencies and to effect the transmission and transformation of mechanical energy through the agency of fluids in a more perfect manner, and by means simpler and more economical than those heretofore employed.

This is accomplished by causing the propelled or propelling fluid to move in natural paths or stream lines of least resistance, free from constraint and disturbance such as occasioned by vanes or kindred devices, and to change its velocity and direction of movement by imperceptible degrees, thus avoiding the losses due to sudden variations while the fluid is receiving or imparting energy.

It is well known that a fluid possesses, among others, two salient properties; adhesion and viscosity. Owing to these a body propelled through such a medium encounters a peculiar impediment known as "lateral," or "skin resistance," which is twofold: one arising from the shock of the fluid against the asperities of the solid substance, the other from internal forces opposing molecular separation. As an inevitable consequence a certain amount of the fluid is dragged along by the moving body. Conversely, if the body be placed in a fluid in motion, for the same reasons, it is impelled in the direction of movement. The accompanying drawings illustrate operative and efficient embodiments of the idea.

Fig. 1 is a partial end view, and Fig. 2 a vertical cross-section of a pump or compressor, while Figs. 3 and 4 represent, respectively, in corresponding views, a rotary engine or turbine, both machines being constructed and adapted to be operated in accordance with the invention.

Figs. 1 and 2 show a runner composed of a plurality of flat rigid disks *1* of a suitable diameter, keyed to a shaft *2* and held in position by a threaded nut *3*, a shoulder *4* and washers *5* of the requisite thickness. Each disk has a number of central openings *6*, the solid portions between which form spokes *7* preferably curved, as shown, for the purpose of reducing the loss of energy due to the impact of the fluid.

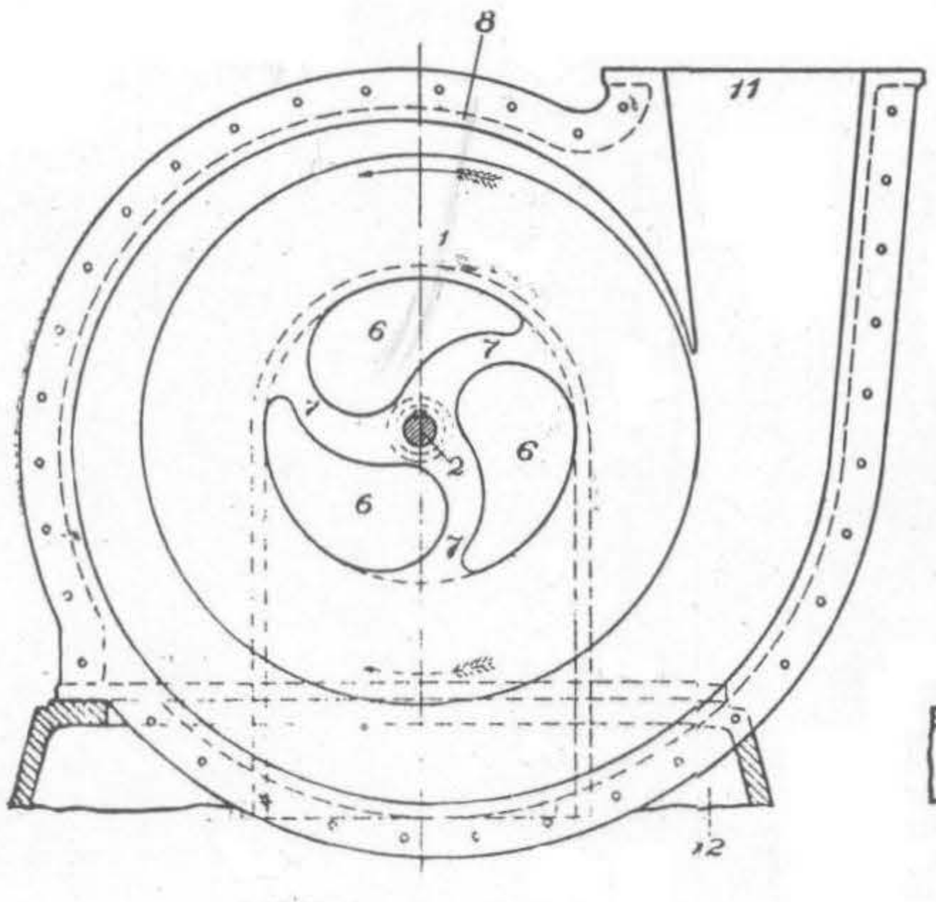


FIG. 1.

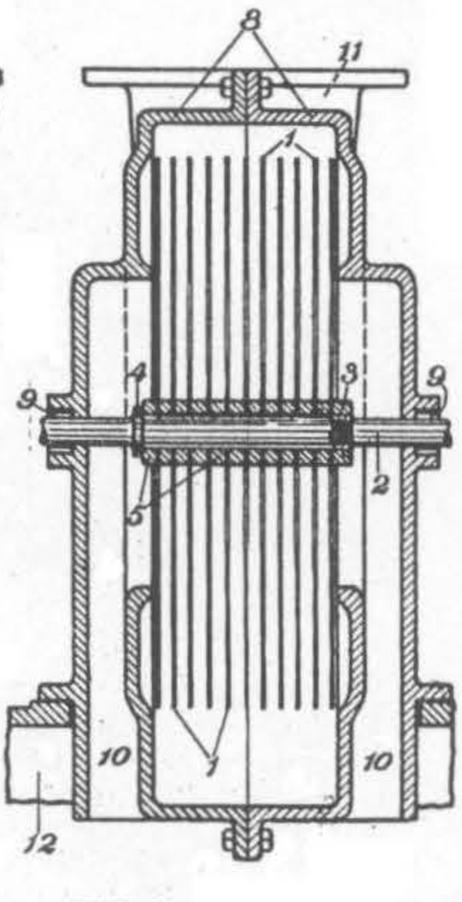


FIG. 2.

This runner is mounted in a two-part volute casing *8* having stuffing boxes *9* and inlets *10* leading to its central portion. In addition a gradually widening and rounding outlet *11* is provided formed with a flange for connection to a pipe as usual. The casing *8* rests upon a base *12* shown only in part and supporting the bearings for the shaft 2, which, being of ordinary construction, are omitted from the drawings.

An understanding of the principle embodied in this apparatus will be gained from the following description of its mode of operation.

Power being applied to the shaft and the runner set in rotation in the direction of the solid arrow, the fluid, by reason of its properties of adherence and viscosity, upon entering through the inlets *10* and coming in contact with the disks *1* is taken hold of by the same and subjected to two forces, one acting tangentially in the direction of rotation, and the other radially outward. The combined effect of these tangential and centrifugal forces is to propel the fluid with continuously increasing velocity in a spiral path until it reaches the outlet *11* from which it is ejected. This spiral movement, free and undisturbed and essentially dependent on these properties of the fluid, permitting it to adjust itself to natural paths or stream lines and to change its velocity and direction by insensible degrees, is characteristic of this method of propulsion and advantageous in its application.

While traversing the chamber inclosing the runner, the particles of the fluid may complete one or more turns, or but a part of one turn. In any given case their path can be closely calculated and graphically represented, but fairly accurate estimates of turns can be obtained simply by determining the number of revolutions required to renew the fluid passing through the chamber and multiplying it by the ratio between the mean speed of the fluid and that of the disks.

It has been found that the quantity of fluid propelled in this manner is, other conditions being equal, approximately proportionate to the active surface of the runner and to its effective speed. For this reason, the performance of such machines augments at an exceedingly high rate with the increase of their size and speed of revolution.

The dimensions of the apparatus as a whole, and the spacing of the disks in any given machine, will be determined by the conditions and requirements of special cases. It may be stated that the intervening distance should be the greater, the larger the diameter of the disks, the longer the spiral path of the fluid and the greater its viscosity. In general, the spacing should be such that the entire mass of the fluid, before leaving the runner, is accelerated to a nearly uniform velocity, not much below that of the periphery of the disks under normal working conditions and almost equal to it when the outlet is closed and the particles move in concentric circles.

It may also be pointed out that such a pump can be made without openings and spokes in the runner, as by using one or more solid disks, each in its own casing, in which form the machine will be eminently adapted for sewage, dredging and the like, when the water is charged with foreign bodies and spokes or vanes are especially objectionable.

Another application of this principle, thoroughly practicable and efficient, is the utilization of machines such as described for the compression or rarefaction of air, or gases in general. In such cases most of the general considerations obtaining in the case of liquids, properly interpreted, hold true.

When, irrespective of the character of the fluid, considerable pressures are desired, staging or compounding may be resorted to in the usual way, the individual runners being, preferably, mounted on the same shaft. It should be added that the same end may be attained with one single runner by suitable deflection of the fluid through rotative or stationary passages.

The principles underlying the invention are capable of embodiment also in that field of mechanical engineering which is concerned in the use of fluids as motive agents, for while in some respects the actions in the latter case are directly opposite to those met with in the propulsion of fluids, the fundamental laws applicable in the two cases are the same. In other words, the operation above described is reversible, for if water or air under pressure be admitted to the opening *11* the runner is set in rotation in

the direction of the dotted arrow by reason of the peculiar properties of the fluid which, traveling in a spiral path and with continuously diminishing velocity, reaches the orifices *6* and *10* through which it is discharged. If the runner be allowed to turn freely, in nearly frictionless bearings, its rim will attain a speed closely approximating the maximum of that of the fluid in the volute channel and the spiral path of the particles will be comparatively long, consisting of many almost circular turns. If the load is put on and the runner slowed down, the motion of the fluid is retarded, the turns are reduced, and the path is shortened.

Owing to a number of causes affecting the performance, it is difficult to frame a precise rule which would be generally applicable, but it may be stated that within certain limits, and other conditions being the same, the torque is directly proportional to the square of the velocity of the fluid relatively to the runner and to the effective area of the disks and, inversely, to the distance separating them. The machine will, generally, perform its maximum work when the effective speed of the runner is one-half of that of the fluid. But to attain the highest economy the relative speed or slip, for any given performance, should be as small as possible. This condition may be to any desired degree approximated by increasing the active area and reducing the space between the disks.

When apparatus of the kind described is employed for the transmission of power, certain departures from similarity between transmitter and receiver may be necessary for securing the best result. It is evident that, when transmitting power from one shaft to another by such machines, any desired ratio between the speeds of rotation may be obtained by proper selection of the diameters of the disks, or by suitably staging the transmitter, the receiver, or both. But it may be pointed out that in one respect, at least, the two machines are essentially different. In the pump, the radial or static pressure, due to centrifugal force, is added to the tangential or dynamic, thus increasing the effective head and assisting in the expulsion of the fluid. In the motor, on the contrary, the first named pressure, being opposed to that of supply, reduces the effective head and the velocity of radial flow towards the center. Again, in the propelled machine a great torque is always desirable, this calling for an increased number of disks and smaller distance of separation, while in the propelling machine, for numerous economic reasons, the rotary effort should be the smallest and the speed the greatest practicable. Many other considerations, which will naturally suggest themselves, may affect the design and construction, but the preceding is thought to contain all necessary information in this regard.

The greatest value of this invention will be found in its use for the thermodynamic conversion of energy. Reference is now made to Figs. 3 and 4, illustrative of the manner in which it is, or may be, so applied.

As in the previous figures, a runner is provided made up of disks *13* with openings *14* and spokes *15* which, in this case, may be straight. The disks are keyed to and held in position on a shaft *16*, mounted to turn freely in suitable bearings, not shown, and are separated by washers *17* conforming in shape with the spokes and firmly united thereto by rivets *18*. For the sake of clearness but a few disks, with comparatively wide intervening spaces, are indicated.

The runner is mounted in a casing comprising two end-castings *19* with outlets *20* and stuffing boxes *21*, and a central ring *22*, which is bored out to a circle of a diameter slightly larger than that of the disks, and has flanged extensions *23* and inlets *24* into which finished ports, or nozzles *25* are inserted. Circular grooves *26* and labyrinth packings *27* are provided on the sides of the runner. Supply pipes *28*, with valves *29*, are connected to the flanged extensions of the central ring, one of the valves being normally closed.

With the exception of certain particulars, which will be elucidated, the mode of operation will be understood from the preceding description. Steam or gas under pressure being allowed to pass through the valve at the side of the solid arrow, the runner is set in rotation in clockwise direction.

In order to bring out a distinctive feature assume, in the first place, that the motive medium is admitted to the disk chamber through a port, that is, a channel which it traverses with nearly uniform velocity. In this case, the machine will operate as a rotary engine, the fluid continuously expanding on its tortuous path to the central outlet. The expansion takes place chiefly along the spiral path, for the spread inward is opposed by the centrifugal force due to the velocity of whirl and by the great resistance to radial exhaust. It is to be observed that the resistance to the passage of the fluid between the plates is approximately proportional to the square of the relative speed, which is maximum in the direction towards the center and equal to the full tangential velocity of the fluid. The path of least resistance, necessarily taken in obedience to a universal law of motion, is virtually, also that of least relative velocity.

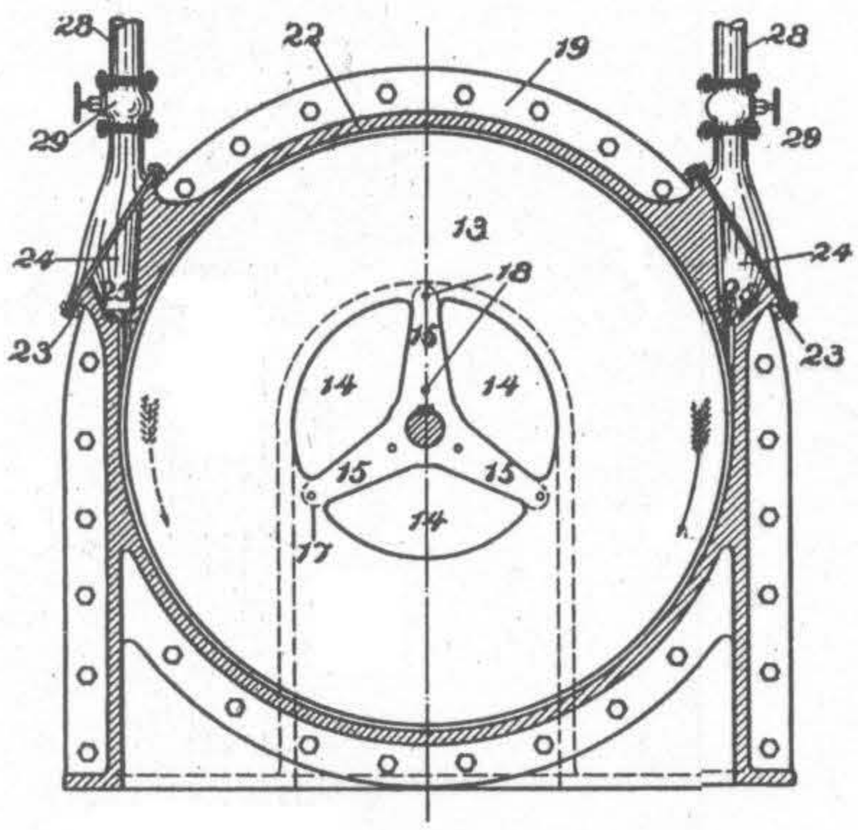


FIG. 3.

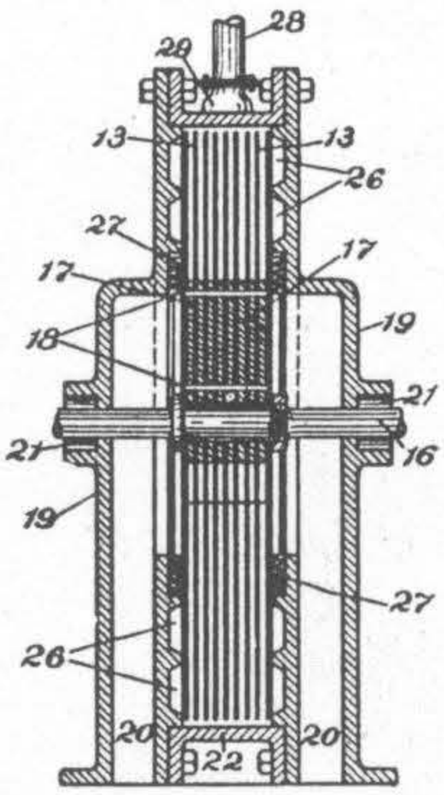


FIG. 4.

Next, assume that the fluid is admitted to the disk chamber not through a port, but a diverging nozzle, a device converting, wholly or in part, the expansive energy into velocity-energy. The machine will then work rather like a turbine, absorbing the energy of kinetic momentum of the particles as they whirl, with continuously decreasing speed, to the exhaust.

The above description of the operation is suggested by experience and observation and is advanced merely for the purpose of explanation. The undeniable fact is that the machine does operate, both expansively and impulsively. When the expansion in the nozzle is complete, or nearly so, the fluid pressure in the peripheral clearance space is small; as the nozzle is made less divergent and its section enlarged, the pressure rises, finally approximating that of the supply. But the transition from purely impulsive to expansive action may not be continuous throughout, on account of critical states and conditions, and comparatively great variations of pressure may be caused by small changes of nozzle velocity.

In the preceding it has been assumed that the pressure of supply is constant or continuous, but it will be understood that the operation will be, essentially, the same if the pressure be fluctuating or intermittent, as that due to explosions occurring in more or less rapid succession.

A very desirable feature, characteristic of machines constructed and operated in accordance with this invention, is their capability of reversal of rotation. Fig. 3, while illustrative of a special case, may be regarded as typical in this respect. If the right hand valve be shut off and the fluid supplied through the second pipe, the runner is rotated in the direction of the dotted arrow, the operation, and also the performance, remaining the same as before, the central ring being bored to a circle with this purpose in view. The same result may be obtained in many other ways by specially designed valves, ports or nozzles for reversing the flow, the description of which is omitted here in the interest of simplicity and clearness. For the same reasons but one operative port or nozzle is illustrated, which might be adapted to a volute but does not fit best a circular bore. It is evident that a number of suitable inlets may be provided around the periphery of the runner to improve the action and that the construction of the machine may be modified in many ways.

Still another valuable and probably unique quality of such motors or prime movers may be described. By proper construction and observance of working conditions the centrifugal pressure, opposing the passage of the fluid, may, as already indicated, be made nearly equal to the pressure of supply when the machine is running idle. If the inlet section be large, small changes in the speed of revolution will produce great differences of flow which are further enhanced by the concomitant variations in the length of the spiral path. A self-regulating machine is thus obtained bearing a striking resemblance to a direct-current electric motor in this respect, that, with great differences of impressed pressure in a wide open channel, the flow of the fluid through the same is prevented by virtue of rotation. Since the centrifugal head increases as the square of the revolutions, or even more rapidly, and with modern high-grade steel great peripheral velocities are practicable, it is possible to attain that condition in a single-stage machine, more readily if the runner be of large diameter. Obviously this problem is facilitated by compounding. Now irrespective of its bearing on economy, this tendency which is, to a degree, common to motors of the above description, is of special advantage in the operation of large units, as it affords a safeguard against running away and destruction.

Besides these, such a prime mover pos-

sesses other advantages, both constructive and operative. It is simple, light and compact, subject to but little wear, cheap and exceptionally easy to manufacture as small clearances and accurate milling work are not essential to good performance. In operation it is reliable, there being no valves, sliding contacts or troublesome vanes. It is almost free of windage, largely independent of nozzle efficiency and suitable for high as well as for low fluid velocities and speeds of revolution. The principles of construction and operation are capable of embodiment in machines of the most widely different forms, and adapted for the greatest variety of purposes.

TESLA POINTS WAY TO TURBINES

Famous Scientist Invents Radical Steam Engine With Gasolene Possibilities—New Principle in Fluid Propulsion.

Safe to say, no form of engine could be more attractive either to motorist or automobile manufacturer than that which Dr. Nikola Tesla has evolved in applying his new method of fluid propulsion. A simple form of casing, hardly more complicated than the housing over an emery wheel, a rotating shaft, a number of plain circular disks equally spaced apart and fastened to the shaft and suitable arrangements for the admission of the working fluid and release of the waste products—these few elements constitute the sole requisites of a complete and efficient engine, if the Servian-American scientist is correct in his reasoning. That there is nothing in the underlying principle to qualify the new form of engine more particularly for steam than for gas and that early tests have shown enormous power to be derivable from very small units lends strength to predictions that the Tesla system ultimately may exert a revolutionizing influence on the automobile industry.

So new is the invention that it is impossible to determine what are the limitations of the system nor in exactly what manner it will prove applicable. Tesla himself is authority for the statement that the action will be essentially the same whether the pressure of the working fluid be constant, fluctuating or intermittent; the latter condition being such as might obtain were the system applied to the internal combustion engine. One of the experimental steam engines, having disks, or blades, 9¾ inches in diameter and occupying a lateral space of two inches has developed 110 horsepower, as told by the Motor World last week. On the hypothesis that a practical form of gas engine ultimately may be developed it is apparent that space emonomy as well as high efficiency and low cost will be among its leading features.

In explaining the underlying method Tesla prefers to deal first with its application to pumping. The first authoritative description of the system, in which the Electrical Review quotes the inventor's own language, in part is as follows:

"In the practical application of mechanical power based on the use of a fluid as vehicle of energy it has been demonstrated that, in order to attain the highest economy, the changes in velocity and direction of movement of the fluid should be as gradual as possible. In the present form of such apparatus more or less sudden changes, shocks and vibrations are unavoidable. Besides, the employment of the usual devices for imparting to, or deriving energy from a fluid, as pistons, paddles, vanes and blades, necessarily introduces numerous defects and limitations and adds to the complication, cost of production and maintenance of the machine.

"The purpose of the invention is to overcome these deficiencies and to effect the transmission and transformation of mechanical energy through the agency of fluids in a more perfect manner, and by means simpler and more economical than those heretofore employed.

"This is accomplished by causing the propelled or propelling fluid to move in natural paths or stream lines of least resistance, free from constraint and disturbance such as is occasioned by vanes or kindred devices, and to change its velocity and direction of movement by imperceptible degrees, thus avoiding the losses due to sudden variations while the fluid is receiving or imparting energy.

"It is well known that a fluid possesses among others two salient properties: adhesion and viscosity. Owing to these a body propelled through such a medium encounters a peculiar impediment known as 'lateral,' or 'skin resistance,' which is twofold: one arising from the shock of the fluid against the asperities of the solid substance, the other from internal forces opposing molecular separation. As an inevitable consequence a certain amount of the fluid is dragged along by the moving body. Conversely, if the body be placed in a fluid in motion, for the same reasons, it is impelled in the direction of movement. The accompanying drawings illustrate operative and efficient embodiments of the idea.

"Fig. 1 is a partial end view, and Fig. 2 a vertical cross-section of a pump or compressor, while Figs. 3 and 4 represent, in corresponding views, a rotary engine or turbine, both machines being constructed and adapted to be operated in accordance with the invention.

"Figs. 1 and 2 show a runner composed of a plurality of flat rigid disks, 1, of a suitable diameter, keyed to a shaft, 2, and held in position by a threaded nut, 3, a shoulder, 4, and washers, 5, of the requisite thickness. Each disk has a number of central openings, 6, the solid portions between which form spokes, 7, preferably curved, as shown, for the purpose of reducing the loss of energy due to the impact of the fluid.

"This runner is mounted in a two-part volute casing, 8, having stuffing boxes, 9, and inlets, 10, leading to its central portion. In addition a gradually widening and rounding outlet, 11, is provided formed with a flange for connection to a pipe as usual. The casing, 8, rests upon a base, 12, shown only in part and supporting the bearings for the shaft, 2, which, being of ordinary construction, are omitted from the drawings.

"An understanding of the principle embodied in this apparatus will be gained from the following description of its mode of operation.

"Power being applied to the shaft and the runner set in rotation in the direction of the solid arrow, the fluid, by reason of its properties of adherence and viscosity, upon entering through the inlets, 10, and coming in contact with the disks, 1, is taken hold of by the same and subjected to two forces, one acting tangentially in the direction of rotation, and the other radially outward. The combined effect of these tangential and centrifugal forces is to propel the fluid with continuously increasing velocity in a spiral path until it reaches the outlet, 11, from which it is ejected. This spiral movement, free and undisturbed and essentially dependent on these properties of the fluid, permitting it to adjust itself to natural paths or stream lines and to change its velocity and direction by insensible degrees, is characteristic of this method of propulsion and advantageous in its application. . . .

"It may also be pointed out that such a

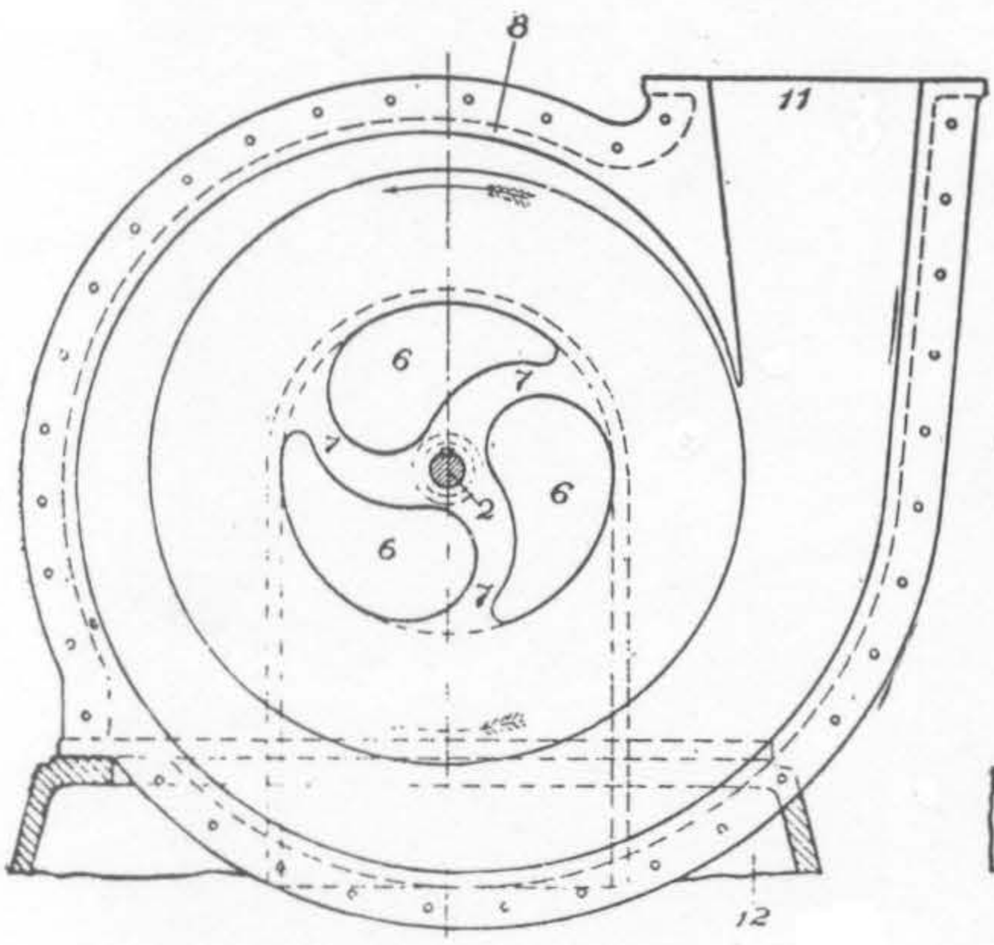


FIG. 1

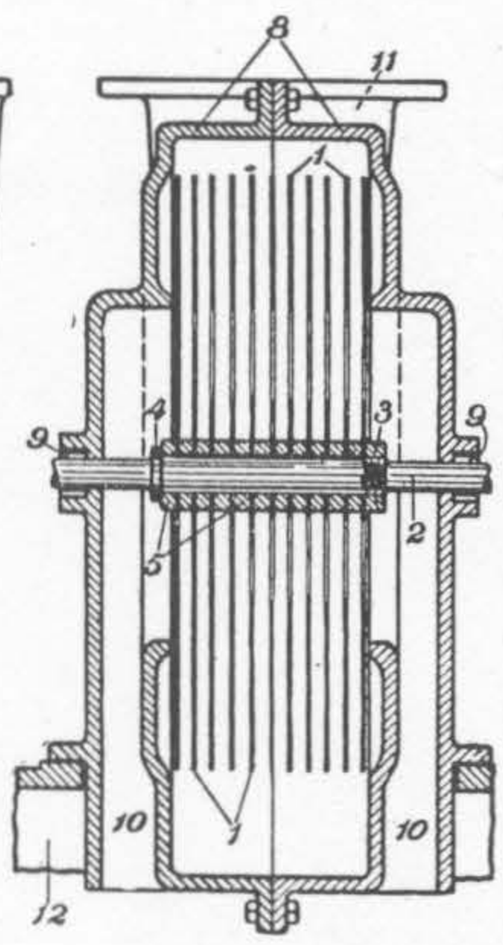


FIG. 2

pump can be made without openings and spokes in the runner, as by using one or more solid disks, each in its own casing, in which form the machine will be eminently adapted for sewage, dredging and the like, when the water is charged with foreign bodies and spokes or vanes are especially objectionable.

"Another application of this principle, thoroughly practicable and efficient, is the utilization of machines such as described for the compression or rarefication of air, or gases in general. In such cases most of the general considerations obtaining in the case of liquids, properly interpreted, hold true.

"When, irrespective of the character of the fluid, considerable pressures are desired, staging or compounding may be resorted to in the usual way, the individual runners being, preferably, mounted on the same shaft. It should be added that the same end may be attained with one single runner by suitable deflection of the fluid through rotative or stationary passages.

"The principles underlying the invention are capable of embodiment also in that field of mechanical engineering which is concerned in the use of fluids as motive agents, for while in some respects the actions in the latter case are directly opposite to those met with in the propulsion of fluids, the fundamental laws applicable in the two cases are the same. In other words, the operation above described is reversible, for if water or air under pressure be admitted to the opening, 11, the runner is set in rotation in the direction of the dotted arrow by reason of the peculiar properties of the fluid which, traveling in a spiral path and with continuously diminishing velocity, reaches the orifices 6 and 10 through which it is discharged. If the runner be allowed to turn freely, in nearly frictionless bearings, its rim will attain a speed closely approximating the maximum of that of the fluid in the volute channel and the spiral path of the particles will be comparatively long, consisting of many almost circular turns. If the load is put on and the runner slowed down, the motion of the fluid is retarded, the turns are reduced, and the path is shortened. . . .

"When apparatus of the kind described is employed for the transmission of power, certain departures from similarity between transmitter and receiver may be necessary for securing the best result. It is evident that, when transmitting power from one shaft to another by such machines, any desired ratio between the speeds of rotation may be obtained by proper selection of the diameters of the disks, or by suitably staging the transmitter, the receiver, or both. But it may be pointed out that in one respect, at least, the two machines are essentially different. In the pump, the radial or static pressure, due to centrifugal force, is added to the tangential or dynamic, thus increasing the effective head and assisting in the expulsion of the fluid. In the motor, on the contrary, the first named pressure, being opposed to that of supply, reduces the effective head and the velocity of radial flow towards the center. Again, in the propelled machine a great torque is always desirable, this calling for an increased number of disks and smaller distance of separation, while in the propelling machine, for numerous economic reasons, the rotary effort should be the smallest and the speed the greatest practicable. . . .

"The greatest value of this invention will be found in its use for the thermodynamic conversion of energy. Reference is now made to Figs. 3 and 4, illustrative of the manner in which it is, or may be, so applied.

"As in the previous figures, a runner is provided made up of disks, 13, with openings, 14, and spokes, 15. which, in this case, may be straight. The disks are keyed to and held in position on a shaft, 16. mounted to turn freely in suitable bearings not shown, and are separated by washers, 17, conforming in shape with the spokes and firmly united thereto by rivets, 18. For the sake of clearness but a few disks, with comparatively wide intervening spaces, are indicated.

"The runner is mounted in a casing comprising two end-castings, 19, with outlets, 20, and stuffing boxes, 21, and a central ring, 22, which is bored out to a circle of a diameter slightly larger than that of the disks, and has flanged extensions, 23, and inlets, 24, into which finished ports, or nozzles, 25, are inserted. Circular grooves, 26, and labyrinth packings, 27, are provided on the sides of the runner. Supply pipes, 28, with valves, 29, are connected to the flanged extensions of the central ring, one of the valves being normally closed.

"With the exception of certain particulars, which will be elucidated, the mode of operation will be understood from the preceding description. Steam or gas under pressure being allowed to pass through the valve at the side of the solid arrow, the runner is set in rotation clockwise direction.

"In order to bring out a distinctive feature assume, in the first place, that the motive medium is admitted to the disk chamber through a port, that is, a channel which it traverses with nearly uniform velocity. In this case, the machine will operate as a rotary engine, the fluid continuously expanding on its tortuous path to the central outlet. The expansion takes place chiefly along the spiral path, for the spread inward is opposed by the centrifugal force due to the velocity of the whirl and by the great resistance to radial exhaust. It is to be observed that the resistance to the passage of the fluid between the plates is approximately proportional to the square of the relative speed, which is maximum in the direction towards the center and equal to the full tangential velocity of the fluid. The path of least resistance, necessarily taken in obedience to a universal law of motion, is virtually also that of least relative velocity.

"Next assume that the fluid is admitted to the disk chamber not through a port, but a diverging nozzle, a device converting, wholly or in part, the expansive energy into velocity-energy. The machine will then work rather like a turbine, absorbing the energy of kinetic momentum of the particles as they whirl, with continuously decreasing speed, to the exhaust. . . .

"In the preceding it has been assumed that the pressure of supply is constant or continuous, but it will be understood that the operation will be, essentially, the same if the pressure be fluctuating or intermittent, as that due to explosions occurring in more or less rapid succession.

"A very desirable feature, characteristic of machines constructed and operated in accordance with this invention, is their capability of reversal of rotation. Fig. 3, while illustrative of a special case, may be

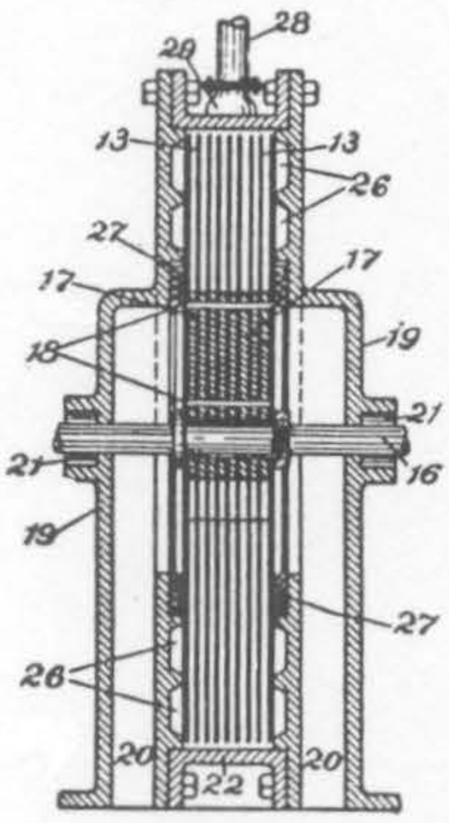


FIG. 3

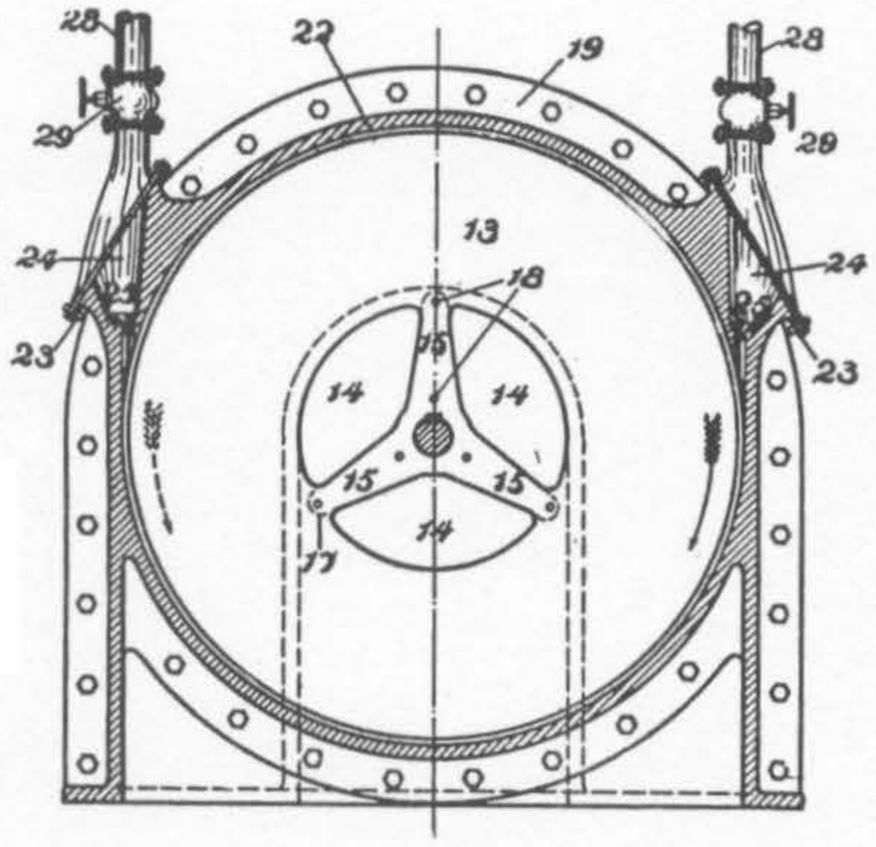


FIG. 4

regarded as typical in this respect. If the right hand valve be shut off and the fluid supplied through the second pipe, the runner is rotated in the direction of the dotted arrow, the operation, and also the performance, remaininfg the same as before, the central ring being bored to a circle with this purpose in view. The same result may be obtained in many other ways by specially designed valves, ports or nozzles for reversing the flow, the description of which is omitted here in the interest of simplicity and clearness. . . .

"Still another valuable and probably unique quality of such motors or prime movers may be described. By proper construction and observance of working condidtions the centrifugal pressure, opposing the passage of the fluid, may, as already indicated, be made nearly equal to the pressure of supply when the machine is running idle. If the inlet section be large, small changes in the speed of revolution will produce great differences of flow which are further enhanced by the concommitant variations in the length of the spiral path A self-regulating machine is thus obtained bearing a striking resemblance to a direct-current electric motor in this respect, that, with great differences of impressure pressure in a wide open channel, the flow of the fluid through the same is prevented by virtue of rotation. . . .

"Besides these, such a prime mover possesses other advantages, both constructive and operative. It is simple, light and compact, subject to but little wear, cheap and exceptionally easy to manufacture, as small clearances and accurate milling work are not essential to good performance. In operation it is reliable, there being no valves, sliding contacts or troublesome vanes. It is almost free of windage, largely independent of nozzle efficiency and suitable for high as well as for low fluid velocities and speeds of revolution. The principles of construction and operation are capable of embodiment in machines of the most widely different forms, and adapted for the greatest variety of purposes."

TESLA PROMISES BIG THINGS

PLANELESS, SCREWLESS AIRSHIP SAFE IN ANY STORM.

Says His Engine Could Convert Factory Gases Now Wasted Into Prodigious Power for Use on Land or Sea or in the Air—Believes He Proved It.

Dr. Nikola Tesla leaned back in his chair at the Waldorf last night and talked calmly of airships without planes, propellers or any of the other gear of the now familiar aeroplanes hurtling through space at tremendous speed or driving more slowly carrying great loads, and in either case always as safely as the most prosaic of wheeled vehicles.

He spoke of harnessing the energy of the gases given off by the great steel plants and producing therefrom 25,000,000 or 50,000,000 horse-power with a value of say $450,000,000 a year. He spoke of these things as of things already accomplished.

"They have called me a dreamer," he said, "but this is not a dream. It is not an experiment."

Then he went on to tell something about the new mechanical principle on the development of which he has been at work for several years and concerning which, he said, he felt free to talk since the publication yesterday of the *Electrical Review* in which Dr. Tesla's invention is described. He said:

"Virtually in all generation, transmission and transformation of mechanical power we must avail ourselves of a fluid, a liquid or a gas, either to impart or receive energy. In a steam engine, for instance, the fluid is a gas under pressure which transmits its potential energy to a mechanical system. In a pump just the reverse process takes place, the fluid, be it a liquid or a gas, having energy imparted to it by a moving material system. This invention of mine is a novel means of imparting to or deriving energy from a fluid, and therefore bears on all the branches of mechanics.

"It is rather difficult, he continued in reply to a question, "to give the average reader a correct idea of such a technical advance. But I assume that every one will understand that any fluid is possessed of two properties, one of which is to adhere to the surface of a solid and the other to hold on, as it were, to its own particles. It is a surprising fact that gases and vapors are possessed of this second property to a greater degree than are liquids such as water. Owing to these properties if a solid body is moved through a fluid more or less of the same is dragged along; conversely if a body is immersed in a fluid in motion it is impelled in the direction of movement. The new principle is based on these fundamental facts."

In reply to a question as to how the principle was applied to practical use in his new invention Dr. Tesla said:

"Let us suppose that it is desired to derive energy from steam under pressure. In this case a number of disks are mounted on a shaft and the whole is placed in a casing with an inlet for the steam tangential to the disks. The steam entering into this orifice by reason of the properties mentioned exercises a pull on the disks and sets them in rotation, circulating under the influence of the centrifugal and tangential forces in a spiral with gradually diminishing velocity, giving up its energy on the rotating system and finally escaping at a centre virtually devoid of dynamic energy.

"In this manner," continued Dr. Tesla, "an ideal rotary engine without any buckets, vanes or sliding contacts is obtained, and one which in performance surpasses by far any other mechanism yet invented. I have developed 110 horse-power with disks only 9¼ inches in diameter and making a thickness of about two inches. Under proper conditions the performance might have been as much as 1,000 horse-power. In fact there is almost no limit to the mechanical performance of such a machine."

Dr. Tesla said that his machine would work with gas, as in the usual type of explosion engine used in automobiles and aeroplanes, even better than it did with steam. "Tests which I have conducted have shown that the rotary effort with gas *is* greater than with steam," is the way he put it.

It is the utilization through his invention of energy now allowed to go to waste that seemed most to interest the inventor.

"The field of fuel waste," he said, "is the greatest of all, offering almost unlimited opportunities for exploitation. In the manufacture of steel and iron, according to data which I have carefully collected, in this country alone from 25,000,000 to 30,000,000 horse-power are wasted through the hot gases escaping into the atmosphere. These gases have a high heating value and by means of the new principle the energy could be readily and cheaply harnessed. If you place the value of one horse-power per annum at $15 this would mean an annual revenue from this source of $450,000,000 per annum.

The ability of his new engine to act in either direction—its "reversibility" the inventor calls it—and the wonderful energy that may be developed by a machine of little weight Dr. Tesa says makes the engine particularly well suited to propelling ships.

"Applied to a vessel," he said, "these engines will make the carrying of reverse turbines unnecessary and will greatly reduce the expense, weight and bulk of the others."

"How about aerial navigation?" Dr. Tesla was asked. He considered for a moment or two and then replied with great deliberation:

"The application of this principle will give the world a flying machine unlike anything that has ever been suggested before. It will have no planes, no screw propellers or devices of any kind hitherto used. It will be small and compact, excessively swift, and, above all, perfectly safe in the greatest storm. It can be built of any size and can carry any weight that may be desired."

Dr. Tesla in conclusion emphasized again his assertion that the engine that is to do all this is a fact, with its performances matters of record.

"I have built a great many machines, steam and gas turbines, pumps, compressors and other apparatus," he said, "and a number have been in practical use for some time past. Yes, it is a big thing, but it is for the big things only that I **care to work.**"

The New York Times September 13, 1911

TESLA'S NEW ENGINE.

Mr. CHARLES WILSON PRICE, editor of The Electrical Review, does not say that NIKOLA TESLA'S latest invention of a rotary engine operated by steam or gases will save most of the 30,000,000 horse power wasted annually by manufacturing plants in this country, power that is worth upward of half a billion dollars. He has not said, as Mr. TESLA is reported as saying, that the new engine will give the world a flying machine that, without planes or screw propellers, "excessively swift, and, above all, perfectly safe in the greatest storm," will be small and compact compared with present machines, but capable of being built to carry shiploads of passengers. What Mr. PRICE does say about the engine, however, arrests attention. A small turbine with a rotor two inches thick and hardly ten inches in diameter, without vanes, blades, valves, or sliding contacts, has been exhibited at the Edison station here, and has been found "capable of developing 110 horse power." In fact, several of TESLA'S engines have been tested. The Electrical Review publishes his description of them, declaring that his invention "cannot fail to excite interest in engineering circles the world over."

Sir WILLIAM RAMSAY said in his recent address before the British Association that "a good steam engine converts about one-eighth of the potential energy of the fuel into useful work; seven-eighths are lost as unused heat and useless friction." In a good gas engine two-thirds of the fuel energy is wasted. It is quite conceivable that inventions will be made to conserve the enormous energies now wasted. TESLA'S turbine, operating without the shocks or vibrations of engines that work with pistons, paddles, vanes, or blades, directs the propelling fluid along rotating disks in free spirals, and by its adhesive and viscous properties the fluid communicates its energy to the disks. By a reverse process the disks may be made to impart motion to fluids, thus acting as a pump which, if what is said about it is true, will effect great changes in mining operations. As a motor its inventor says the machine will presently be seen in automobiles, working by gas or steam, in locomotives and ocean liners, and in factories all over the world.

Mr. TESLA has acquired a reputation for revolutionary inventions that never quite arrived at the point of practical utility. But some of his inventions have proved to be practical and eminently useful. The new engine may be one of them.

The Tesla Turbine.

The accompanying illustrations which were taken at the request of the editor of this journal, give a very good idea of one of the small Tesla turbines which have been built and operated with slight changes of the rotors and accessories as steam, gas, air and water turbines or rotary engines, and also as pumps and compressors. The characteristics and the mechanical principles involved in the construction and operation of the Tesla turbine were discussed comprehensively in the



THE TESLA 110-HORSEPOWER TURBINE, CONVEYING AN IDEA OF THE SIZE OF THIS MACHINE.

ELECTRICAL REVIEW AND WESTERN ELECTRICIAN of September 9. Through the courtesy of the New York Edison Company the machine illustrated was installed at its Waterside station where long-continued tests were carried on under greatly varying conditions.

Mr. Tesla, when seen on Tuesday of this week by a representative of the ELECTRICAL REVIEW AND WESTERN ELECTRICIAN, gave the following statements respecting the operation and economy of his turbine:

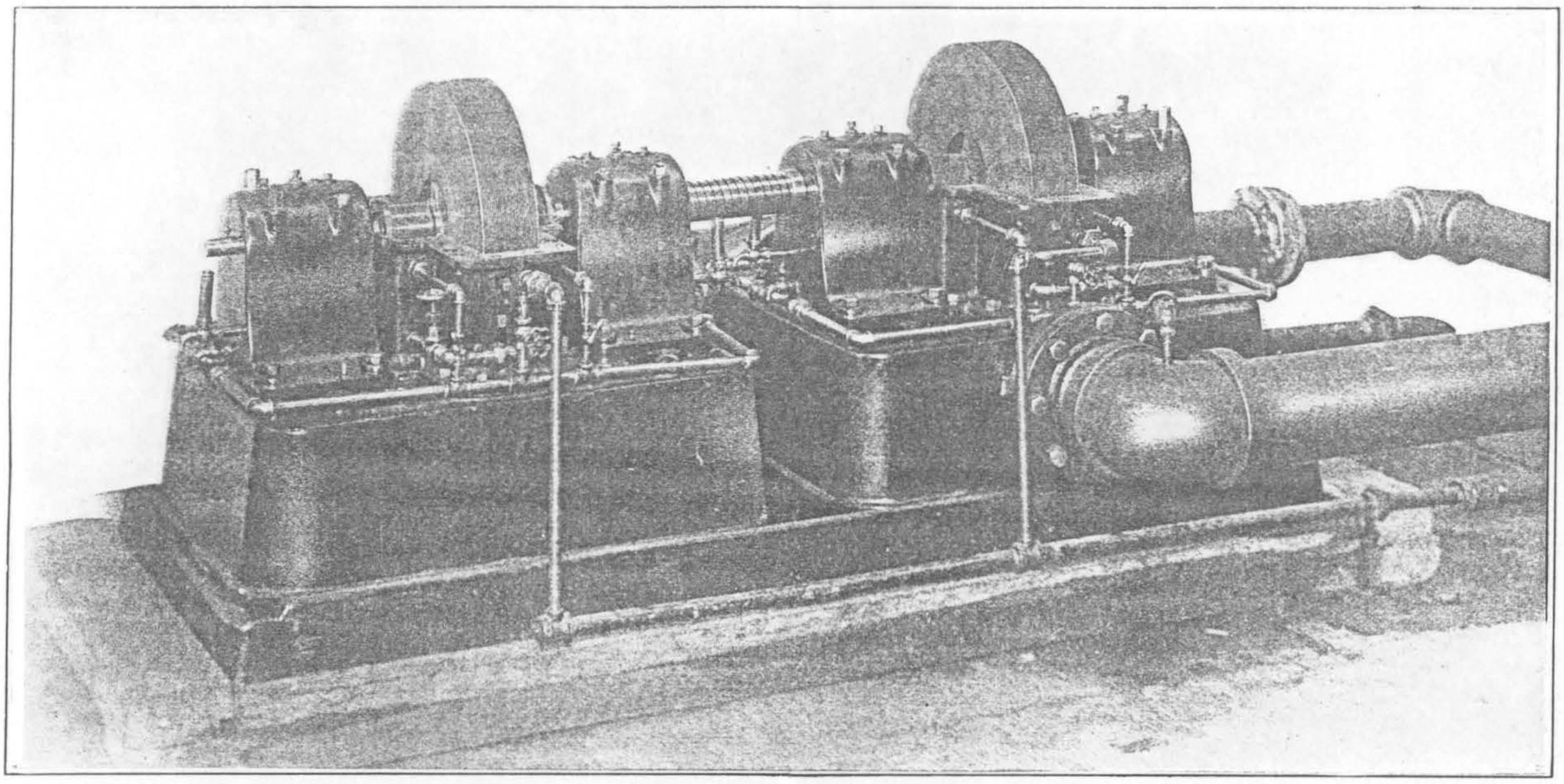
"The turbine has readily developed 110 horsepower with free exhaust, but this does not convey even an approximate idea of the possibilities offered in power production by the new principle of propulsion. It would not have been difficult to develop twice as much power were it not for the torsional stress to which the shaft was subjected. However, even with the result attained, bearing in mind that the rotor weighs only twenty pounds, and that the casing itself could have been pressed steel sheet, the weight of which together with the bearings would not exceed thirty pounds, a performance of more than two horsepower per pound of material was realized.

"As to steam economy, it is highly satisfactory, comparing well with the best turbines, the consumption being thirty-six pounds per horsepower-hour with free exhaust and back pressure of a few pounds, which would mean less than seventeen pounds for a two-stage machine of that size. This economy could still be greatly increased for the turbine was operated under conditions of maximum output and not maximum economy."

Mr. Tesla stated that there was no limit to the capacity for which this turbine could be built and said that the peculiar characteristics of this form of construction would make it possible to attain economy of operation with superheated steam not heretofore realized. When operated as a water turbine it greatly simplified the present methods of regulation and opened up a field of application which was stupendous.



THE ROTOR OF THE 110-HORSEPOWER TESLA TURBINE. WEIGHT, TWENTY POUNDS.



The top half of casings is removed, showing two rotors. Each rotor consists of 25 disks 3/16-inch thick by 18 inch diameter. The steam enters at the periphery, and flows in spiral paths to exhaust at the center of the disks. The driving turbine is to the left, the brake turbine to the right. Between them is a torsion spring. The steam inlets are on opposite sides on the two rotors; the driving rotor moving clockwise. The torsion of the spring is automatically shown by beams of light and mirrors and the horse-power is read off a scale. At 9,000 revolutions per minute, with 125 pounds at the throttle and free exhaust, this turbine develops 200 horse-power. It weighs two pounds per horse-power.

The Tesla turbine testing plant at the Edison Waterside Station, New York.

The Tesla Steam Turbine

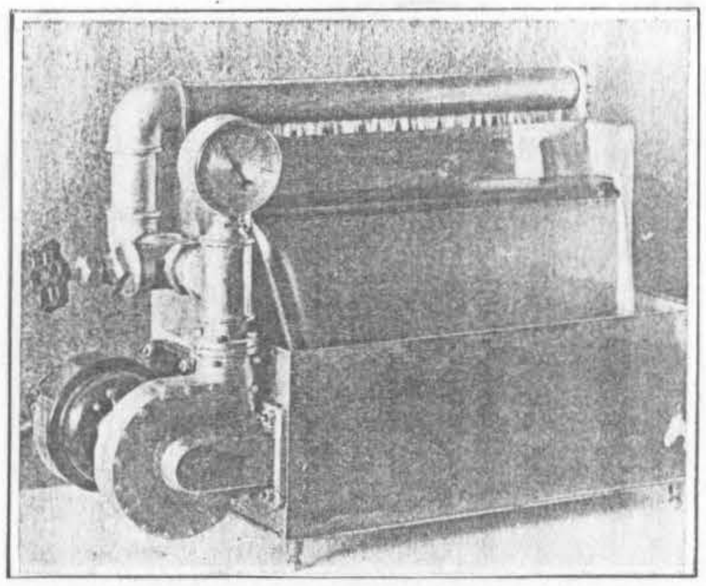
The Rotary Heat Motor Reduced to Its Simplest Terms

IT will interest the readers of the SCIENTIFIC AMERICAN to know that Nikola Tesla, whose reputation must, naturally, stand upon the contributions he made to electrical engineering when the art was yet in its comparative infancy, is by training and choice a mechanical engineer, with a strong leaning to that branch of it which is covered by the term "steam engineering." For several years past he has devoted much of his attention to improvements in thermo-dynamic conversion, and the result of his theories and practical experiments is to be found in an entirely new form of prime movers shown in operation at the Waterside station of the New York Edison Company, who kindly placed the facilities of their great plant at his disposal for carrying on experimental work.

By the courtesy of the inventor, we are enabled to publish the accompanying views, representing the testing plant at the Waterside station, which are the first photographs of this interesting motor that have yet been made public.

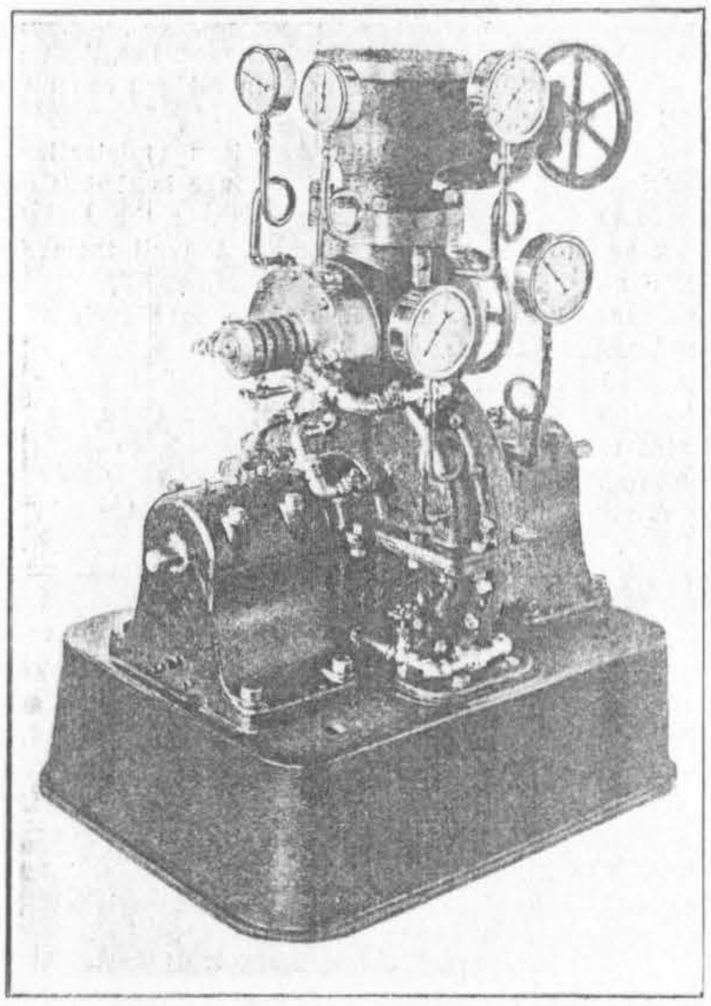
The basic principle which determined Tesla's investigations was the well-known fact that when a fluid (steam, gas or water) is used as a vehicle of energy, the highest possible economy can be obtained only when the changes in velocity and direction of the movement of the fluid are made as gradual and easy as possible. In the present forms of turbines in which the energy is transmitted by pressure, reaction or impact, as in the De Laval, Parsons, and Curtiss types, more or less sudden changes both of speed and direction are involved, with consequent shocks, vibration and destructive eddies. Furthermore, the introduction of pistons, blades, buckets, and intercepting devices of this general class, into the path of the fluid involves much delicate and difficult mechanical construction which adds greatly to the cost both of production and maintenance.

The desiderata in an ideal turbine group themselves under the heads of the theoretical and the mechanical. The theoretically perfect turbine would be one in which the fluid was so controlled from the inlet to the exhaust that its energy was delivered to the driving shaft with the least possible losses due to the mechanical means employed. The mechanically perfect turbine would be one which combined simplicity and cheapness of construction, durability, ease and rapidity of repairs, and a small ratio of weight and space occupied to the power delivered on the shaft. Mr. Tesla maintains that in the turbine which forms the subject of this article, he has carried the steam and gas motor a long step forward toward the maximum attainable efficiency, both theoretical and mechanical. That these claims are well founded is shown by the fact that in the plant at the Edison station, he is securing an output of 200 horse-power from a single-stage steam turbine with atmospheric exhaust, weighing less than 2 pounds per horse-power, which is contained within a space measuring 2 feet by 3 feet, by 2 feet in height, and which accomplishes these results with a thermal fall of only 130 B.T.U., that is, about one-third of the total drop available. Furthermore, considered from the mechanical standpoint, the turbine is astonishingly simple and economical in construction, and by the very nature of its construction, should prove to possess such a durability and freedom from wear and breakdown as to place it, in these respects, far in advance of any type of steam or gas motor of the present day.



This little pump, driven by a motor of 1/3 horse-power, is here shown delivering 40 gallons of water per minute against a 9-foot head.

The turbine used as a pump.



This view shows one complete high pressure unit, with the steam throttle above, and below it the reversing valve and the compact turbine. Note the many gages used in the tests.

A 200-horse-power high-pressure turbine.

Briefly stated, Tesla's steam motor consists of a set of flat steel disks mounted on a shaft and rotating within a casing, the steam entering with high velocity at the periphery of the disks, flowing between them in free spiral paths, and finally escaping through exhaust ports at their center. Instead of developing the energy of the steam by pressure, reaction, or impact, on a series of blades or vanes, Tesla depends upon the fluid properties of adhesion and viscosity—the attraction of the steam to the faces of the disks and the resistance of its particles to molecular separation combining in transmitting the velocity energy of the motive fluid to the plates and the shaft.

By reference to the accompanying photographs and line drawings, it will be seen that the turbine has a rotor *A* which in the present case consists of 25 flat steel disks, one thirty-second of an inch in thickness, of hardened and carefully tempered steel. The rotor as assembled is 3½ inches wide on the face, by 18 inches in diameter, and when the turbine is running at its maximum working velocity, the material is never under a tensile stress exceeding 50,000 pounds per square inch. The rotor is mounted in a casing *D*, which is provided with two inlet nozzles, *B* for use in running direct and *B'* for reversing. Openings *C* are cut out at the central portion of the disks and these communicate directly with exhaust ports formed in the side of the casing.

In operation, the steam, or gas, as the case may be, is directed on the periphery of the disks through the nozzle *B* (which may be diverging, straight or converging), where more or less of its expansive energy is converted into velocity energy. When the machine is at rest, the radial and tangential forces due to the pressure and velocity of the steam cause it to travel in a rather short curved path toward the central exhaust opening, as indicated by the full black line in the accompanying diagram; but as the disks commence to rotate and their speed increases, the steam travels in spiral paths the length of which increases until, as

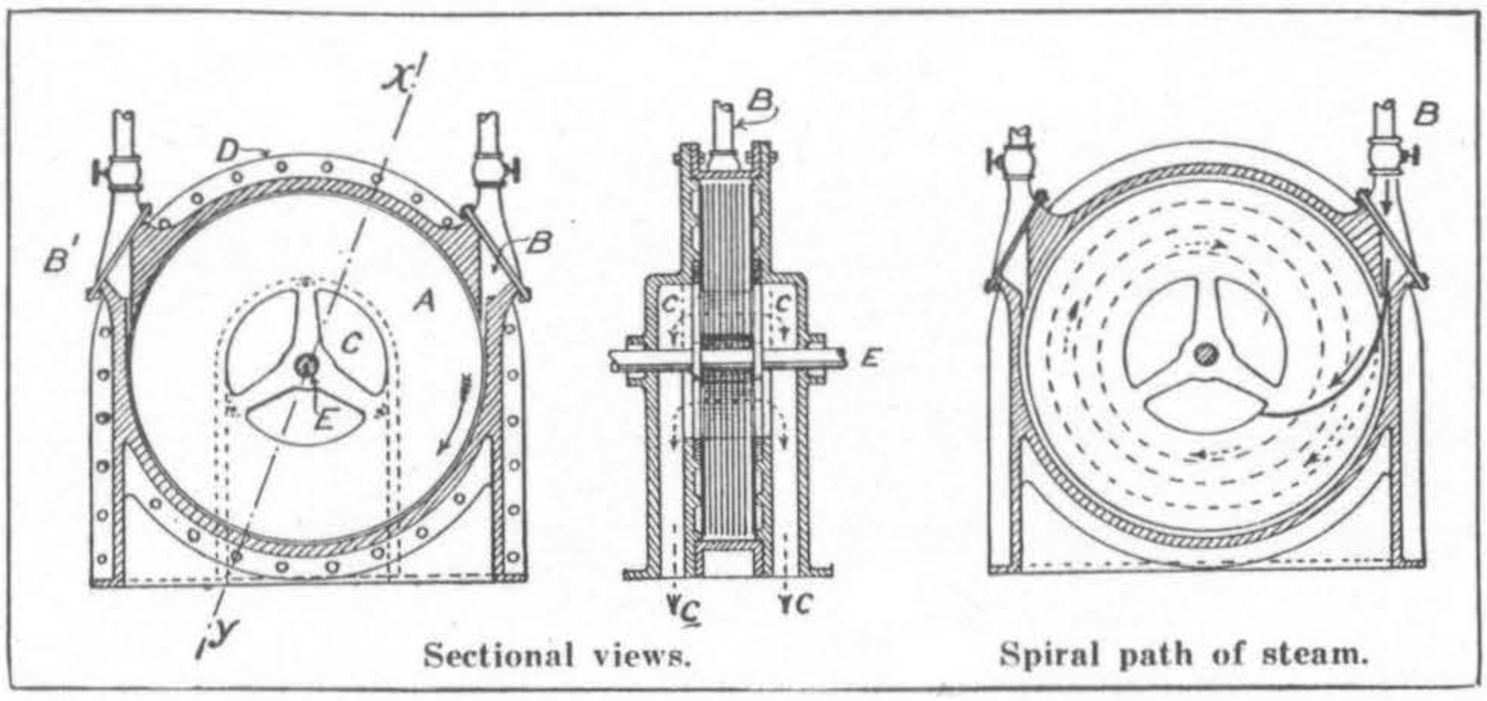
in the case of the present turbine, the particles of the fluid complete a number of turns around the shaft before reaching the exhaust, covering in the meantime a lineal path some 12 to 16 feet in length. During its progress from inlet to exhaust, the velocity and pressure of the steam are reduced until it leaves the exhaust at 1 or 2 pounds gage pressure.

The resistance to the passage of the steam or gas between adjoining plates is approximately proportionate to the square of the relative speed, which is at a maximum toward the center of the disks and is equal to the tangential velocity of the steam. Hence the resistance to radial escape is very great, being furthermore enhanced by the centrifugal force acting outwardly. One of the most desirable elements in a perfected turbine is that of reversibility, and we are all familiar with the many and frequently cumbersome means which have been employed to secure this end. It will be seen that this turbine is admirably adapted for reversing, since this effect can be secured by merely closing the right-hand valve and opening that on the left.

It is evident that the principles of this turbine are equally applicable, by slight modifications of design, for its use as a pump, and we present a photograph of a demonstration model which is in operation in Mr. Tesla's office. This little pump, driven by an electric motor of 1/12 horse-power, delivers 40 gallons per minute against a head of 9 feet. The discharge pipe leads up to a horizontal tube provided with a wire mesh for screening the water and checking the eddies. The water falls through a slot in the bottom of this tube and after passing below a baffle plate flows in a steady stream about ¾ inch thick by 18 inches in width, to a trough from which it returns to the pump. Pumps of this character show an efficiency favorably comparing with that of centrifugal pumps and they have the advantage that great heads are obtainable economically in a single stage. The runner is mounted in a two-part volute casing and except for the fact that the place of the buckets, vanes, etc., of the ordinary centrifugal pump is taken by a set of disks, the construction is generally similar to that of pumps of the standard kind.

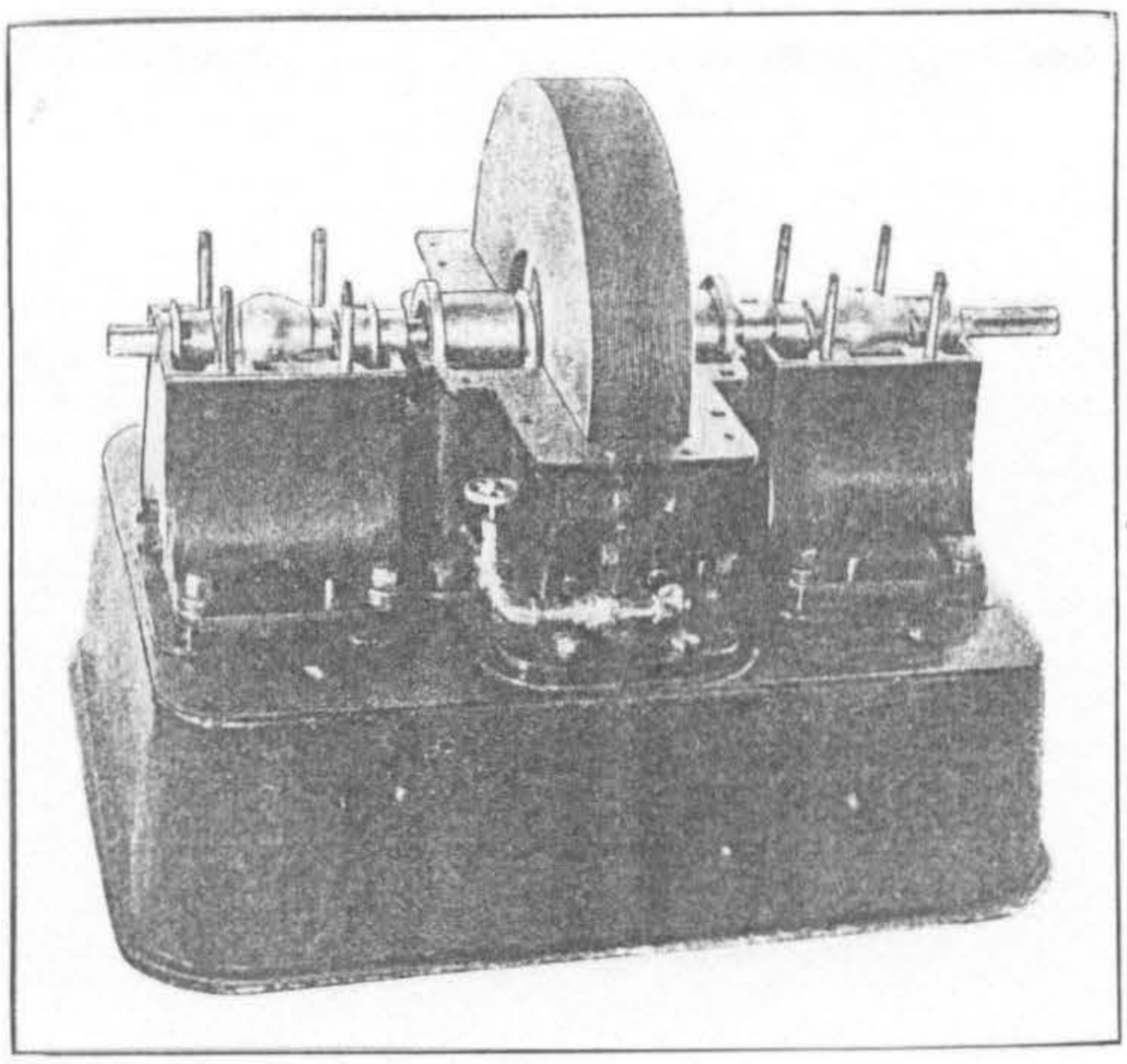
In conclusion, it should be noted that although the experimental plant at the Waterside station develops 200 horse-power with 125 pounds at the supply pipe and free exhaust, it could show an output of 300 horse-power with the full pressure of the Edison supply circuit. Furthermore, Mr. Tesla states that if it were compounded and the exhaust were led to a low pressure unit, carrying about three times the number of disks contained in the high pressure element, with connection to a condenser affording 28½ to 29 inches of vacuum, the results obtained in the present high-pressure machine indicate that the compound unit would give an output of 600 horse-power, without great increase of dimensions. This estimate is conservative.

The testing plant consists of two identical turbines connected by a carefully calibrated torsion spring, the machine to the left being the driving element, the other the brake. In the brake element, the steam is delivered to the blades in a direction opposite to that of the rotation of the disks. Fastened to the shaft of the brake turbine is a hollow pulley provided with two diametrically opposite narrow slots, and an incandescent lamp placed inside close to the rim. As the pulley rotates, two flashes of light pass out of the same, and by means of reflecting mirrors and lenses, they are carried around the plant and fall upon two rotating glass mirrors placed back to back on the shaft of the driving turbine so that the center line of the silver coatings coincides with the axis of the shaft. The mirrors are so set that when there is no torsion on the spring, the light beams produce a luminous spot stationary at the zero of the scale. But as soon as load is put on, the beam is deflected through an angle which indicates directly the torsion. The scale and spring are so proportioned and adjusted that the horse-power can be read directly from the deflections noted. The indications of this device are very accurate and have shown that when the turbine is running at 9,000 revolutions under an inlet pressure of 125 pounds to the square inch, and with free exhaust, 200 brake horse-power are developed. The consumption under these conditions of maximum output is 38 pounds of saturated steam per horse-power per hour—a very high efficiency when we consider that the heat-drop, measured by thermometers, is only 130 B.T.U., and that the energy transformation is effected in one stage. Since about three times this number of heat units are available in a modern plant with superheat and high vacuum, the above means a consumption of less than 12 pounds per horse-power hour in such turbines adapted to take up the full drop. Under certain conditions, however, very high thermal efficiencies have been obtained which demonstrate that in large machines based on this principle, in which a very small slip can be secured, the steam consumption will be much lower and should, Mr. Tesla states, approximate the theoretical minimum, thus resulting in nearly frictionless turbine transmitting almost the entire expansive energy of the steam to the shaft.



Sectional views. Spiral path of steam.

Details of turbine.



This turbine, whose rotor consists simply of a set of flat disks 18 inches in diameter, develops 200 brake horse-power on test.

Turbine with upper half of casing removed.

The Tesla Steam Turbine.

A novel design of steam turbine was mentioned before a local meeting of the National Electric Light Association in New York City, on May 15, 1911, by Mr. Nikola Tesla, whose name has become famous in connection with the rotating magnetic field and other alternating-current developments. Several different types of power apparatus, both driving and driven, embodying the underlying principle of this turbine design have now been built and tested in the Tesla laboratories, including a turbine which has been running at the Waterside Station of the New York Edison Company for several months. The general results of this early work have recently been made public by Mr. Tesla.

The following outline of the designs and the underlying principle running through them all has been made after a conversation with Mr. Tesla and a study of the apparatus. The fundamental principle underlying these several designs appears to be broadly applicable to apparatus wherein a fluid moves some device or the device causes the fluid to move. This includes hydraulic, steam and internal combustion motors, hydraulic and air pumps, etc.

The study of this most interesting line of designs may be approached through the case of either prime movers or driven devices. For the purposes of this article it is perhaps simpler to consider first a pump for a fluid like air, gas, vapor, or liquid. Fig. 1 shows, more or less diagrammatically, a rotary pump in which a series of smooth, flat disks revolves in a casing, with a volute delivery passage. The disks are fastened to a driving shaft but have central openings which serve as inlets for the fluid. On rotating the shaft and disks, the fluid film in contact with the disks is set in motion, even with perfectly smooth disks, on account of the molecular adhesion between disk and fluid. The fluid between disks is also dragged along by the molecular attraction between particles of the fluid (viscosity). The motion of each point of the disk being circular, it is evident that the particles of fluid receive impelling forces which are always tangential to the circular paths. The successive points on the disk that impel given particles of fluid are at increasing distances from the center. The fluid being mechanically unconstrained by walls or vanes except in an axial direction is free to travel in spiral paths from the axis to the periphery.

The fluid, in traversing the space from inlet to periphery, may follow a long spiral of several turns or a short one of part of a turn, depending on the quantity of fluid that is allowed to escape from the outlet. With unrestricted flow from the casing, there is little resistance to flow in a radial direction (that is from the backing up and development of pressure), and the tangential slip between disk and fluid is large. The pressure in the casing depends on the velocity with which the particles of fluid leave the periphery of the disk; the maximum pressure with the exit throttled is then proportional to the speed of the disks, the velocity head being converted to pressure head in the volute passage of the casing. The power absorbed is proportional to the square of the slip.

To one seeing such a piece of apparatus in action for the first time, the capacity of a small machine is surprising, especially in the absence of all vanes and projections of every sort which have heretofore been deemed necessary to force the fluid along. A moment's consideration, however, shows that the whole surface of each disk is effective in impelling the fluid along (solely by molecular drag), and the useful surfaces may be made very great in a machine of modest dimensions, in direct contrast with other analogous apparatus where only the relatively small area of buckets, blades, or other projections is effective.

Consideration also shows that any buckets or projecting parts that a disk might carry would constrain the fluid to travel in paths less natural or free, with the consequent development of impact and eddy friction which may be expected to decrease the efficiency over that of simple disks depending for their hold on the fluid only on natural molecular forces. In the case of the Tesla disks, the particles of fluid may be mentally pictured as rolling along on their spiral paths in orderly procession, held to the disks by some gravitation or force; whereas in the case of a disk with projections, the fluid would be pushed and crowded along by impact, with consequent disturbances.

It has been found, as theory would indicate, that the quantity of fluid discharged off the disks is proportional to the area of the disks; that is, the capacity of such machines increases nearly directly with their length along the shaft and about as the square of their diameter, the discrepancies arising naturally from the casing not having impelling surface but adding to the diameter and length of the machine.

The spacing of the disks in such a machine would depend on the conditions under which it had to operate—increasing with the viscosity and diameter and decreasing with the allowable slip. The aim of the designer would be to deliver the fluid from the disks at not much below peripheral speed under normal load conditions. When limitations of practical design would prevent the securing of desired pressures with one simple set of disks, the multiplication of stages is easily accomplished. The fluid then would pass from the exit passages of one stage to the inlet of a second, and so on.

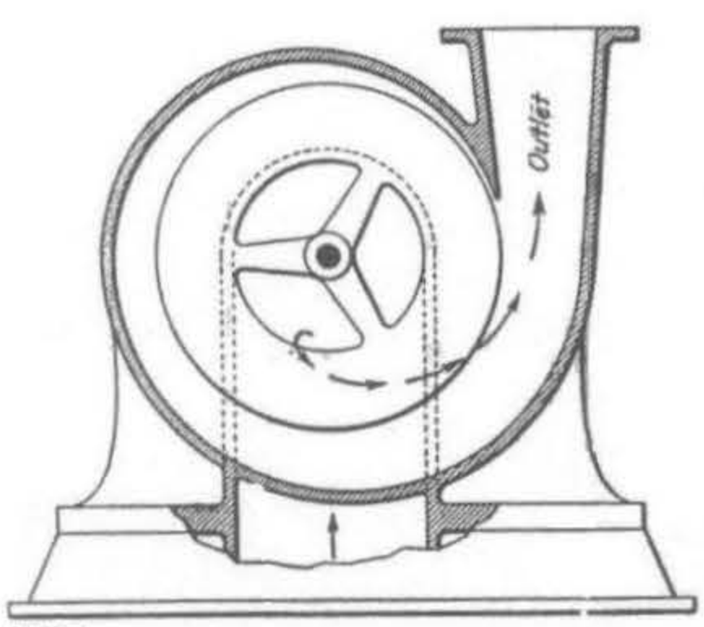
The operations of a pump, as above described, are in general reversible for the production of power from a fluid moving with considerable velocity or under pressure. If a fluid under pressure, but of low velocity, enters the casing of the device shown in Fig. 1 in order to flow along the volute of decreasing cross-section and through the inter-disk spaces to what is now the outlet, it must constantly accelerate, converting its pressure head to velocity head. This moving fluid will exert a pull on the disks on account of molecular adhesion and viscosity. If the shaft were blocked so that it could not rotate, the particles of fluid would take short spiral paths from the volute to the outlet.

If the disks are allowed to rotate, however, the particles of fluid in contact with the disks would be subjected to a force preventing travel along the shortest spirals to the outset. The resultant of the centrifugal force exerted by the disk and that coming from the velocity of the steam constrains the fluid then to follow a longer spiral path. This reminds one of the counter E. M. F. developed in the armature windings of an electric motor opposing the impressed voltage.

It is evident that the torque developed by the disk increases with the difference in peripherial velocity of the disk and of the fluid in contact As in the analogous case of the pump, the torque rises as the square of the slip. When the shaft runs free, without load, the speed rises and the centrifugal counter force on the fluid traveling in very long spirals (almost concentric circles) would cause the casing pressure to rise nearly to the supply pressure, the difference being only that required to do the work of supplying energy losses.

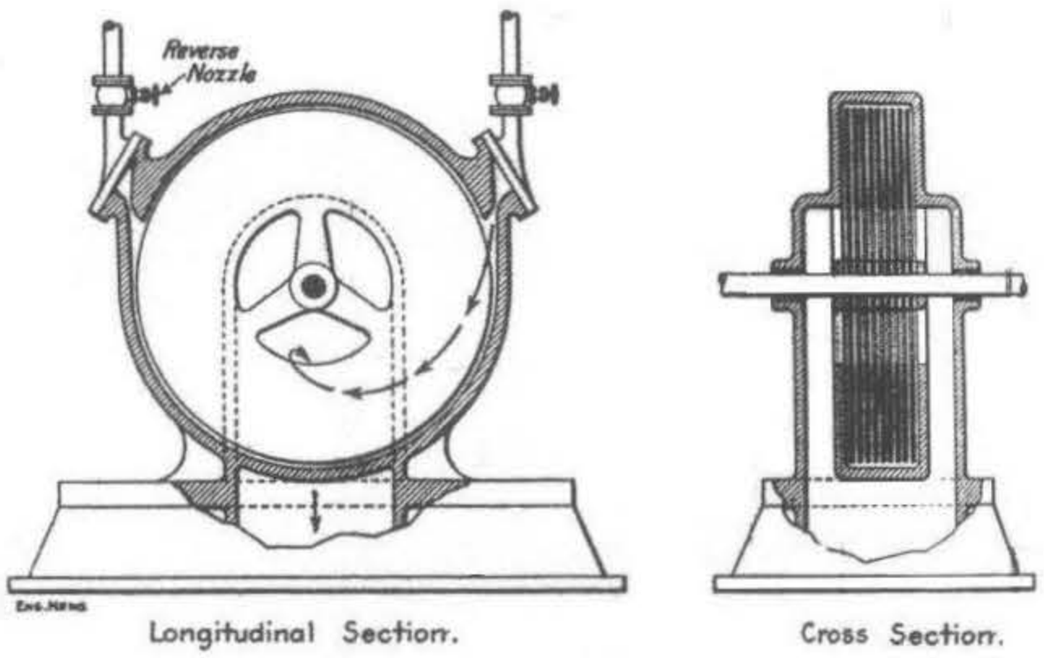
Such a prime mover would give its maximum output at about 50% average slip, but the maximum efficiency would come with a comparatively small slip, the actual figure depending upon the fluid employed, on the working conditions, and on the mechanical limitations of design.

The greatest interest in the Tesla design, as outlined above, probably centers in its application to a heat motor, such as the Tesla steam turbine. While a device like Fig. 1 would operate with steam, it probably would be advisable for obvious reasons to modify the mechanical features—for instance, to suppress the volute passage in the casing, coming down to the simple construction indicated in Fig. 2.



Longitudinal Section. Cross Section.

FIG. 1. THE TESLA DISK-IMPELLER PUMP.



Longitudinal Section. Cross Section.

FIG. 2. THE TESLA DISK WHEEL IN A STEAM TURBINE.

If the steam is expanded in a diverging nozzle it may be expanded over any of the usual ranges of pressure drop, the heat energy then being converted into kinetic energy The high velocity steam escaping from the nozzle is caused to impinge tangentially on the edges of the disks. In order to escape, it has to take a spiral path from the periphery of the disks to the center openings The velocity energy of the steam is utilized through the molecular drag on the surface of the disks. With such a nozzle it is seen that the machine is essentially of the so-called "impulse" type of turbine. The arrangement shown in Fig. 2 has a very simple and convenient means of reversing, it merely being necessary to provide a duplicate nozzle discharging against the opposite diameter of the disks and in the opposite direction. When the machine is at rest or running slowly, as in starting, steam takes a short path from the nozzle to the exhaust and develops a comparatively large torque, since this would be proportional to the square of the difference in velocity of steam and disk. As the machine speeds up, the difference in velocity between steam and disks decreases and the centrifugal forces tend to lengthen the spiral path, so that a given quantity of steam may make several revolutions before finally passing out the exhaust.

It is not necessary, however, to expand the steam before it reaches the disks, and in place

*For early statements of these developments see "Electrical Review and Western Electrician," Sept. 9 and 30, 1911; "The Scientific American," Sept. 30, 1911.

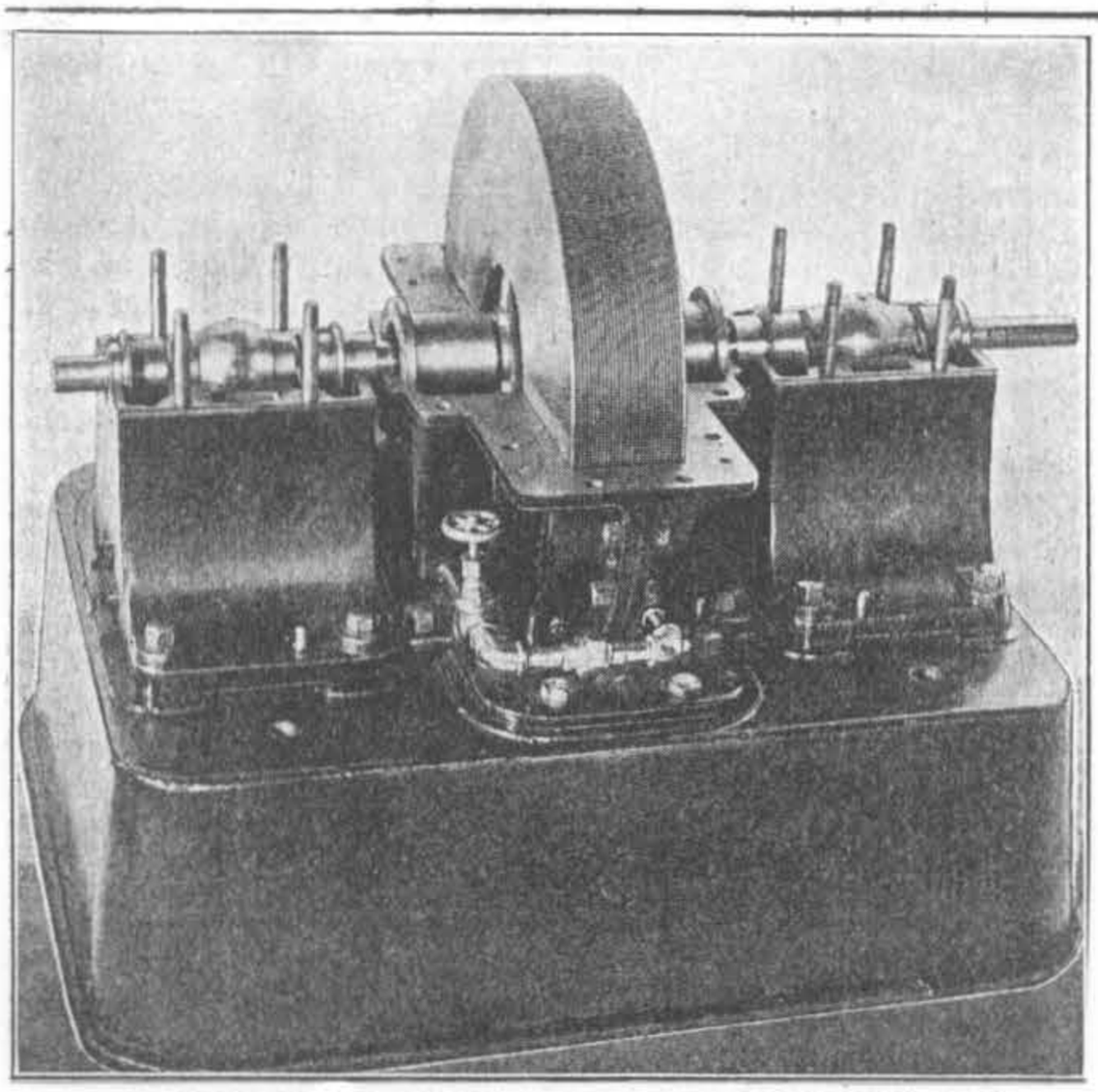


FIG. 3 A 200-HP TESLA TURBINE WITH THE UPPER CASING SECTION REMOVED.

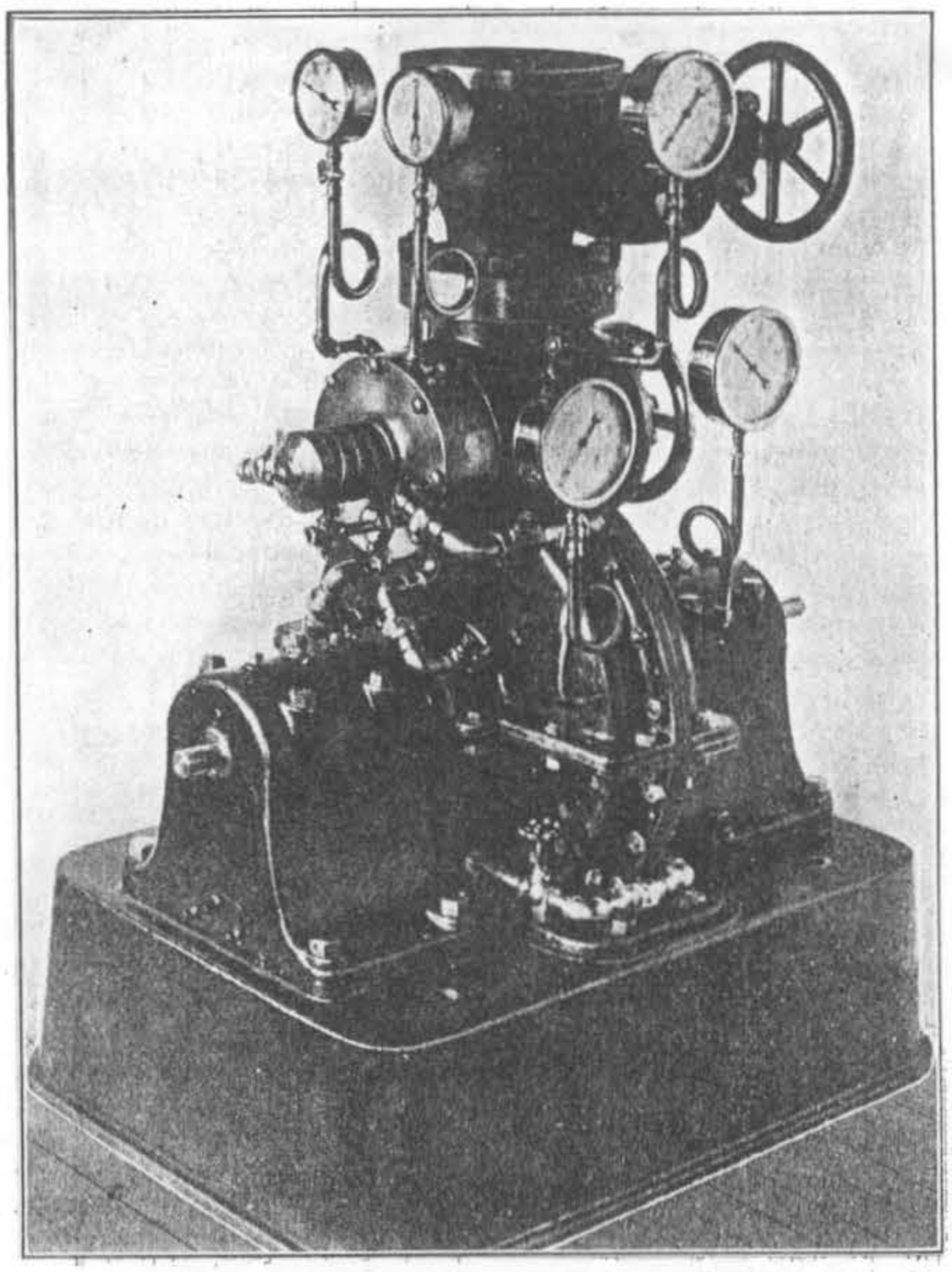


FIG. 4. A 200-HP TESLA STEAM TURBINE AS TESTED AT THE WATERSIDE STATION OF THE NEW YORK EDISON CO.

of he nozzles shown there may be simple ports. The machine then apparently will operate as a reaction type of turbine, the steam expanding as it flows in its path from port to exhaust. The expanding steam might develop a slight reactive thrust against the disk, but it would depend probably more for its influence on the peculiar action of increasing the velocity of the steam in small increments as it flows along; and absorbing the kinetic energy as fast as developed, in driving the disk.

In Figs. 3 and 4, a steam turbine tested at the Waterside Station of the New York Edison Company is shown. The rotor consists of 25 disks, 18 inches in diameter. The assembled unit, Fig. 3, occupies a floor space some 20 × 35 ins. and it stands some 5 ft. high. The numerous gages seen in Fig. 3 were attached for test purposes. With steam at 125 lbs. gage and exhausting to atmosphere, 200 HP. was developed with a speed of 9,000 r. p. m. The steam consumption under these conditions was about 38 lbs. per HP.-hr.



5. A 110-HP Tesla Steam Turbine.

Mr. Tesla states that with moderate superheat and the degree of vacuum ordinarily obtainable in a turbine plant, the consumption can be reduced to 10 or 12 lbs. per HP.-hr. The weight of the unit as shown was about 400 lbs., giving a unit weight of 2 lbs. per HP.

Through refinements in design in addition to the increase of capacity secured with superheat and vacuum, Mr. Tesla expects that the weight may be reduced to as little as ¼-lb. per HP. capacity and still allow of designs which will have rotational speeds low enough for direct connecting to the majority of services.

One of the interesting possibilities of the design of turbine shown is that of self-regulation. It has already been shown how the counter pressure due to the rotation of the disks amounted nearly to that of the impressed fluid when running idle. Since the centrifugal head increases as the square of the number of revolutions, and as with available materials great peripheral velocities of the disks are possible, a turbine may be designed which will not run away, the peripheral speed being limited to that value which corresponds to the maximum velocity of the fluid which can be developed.

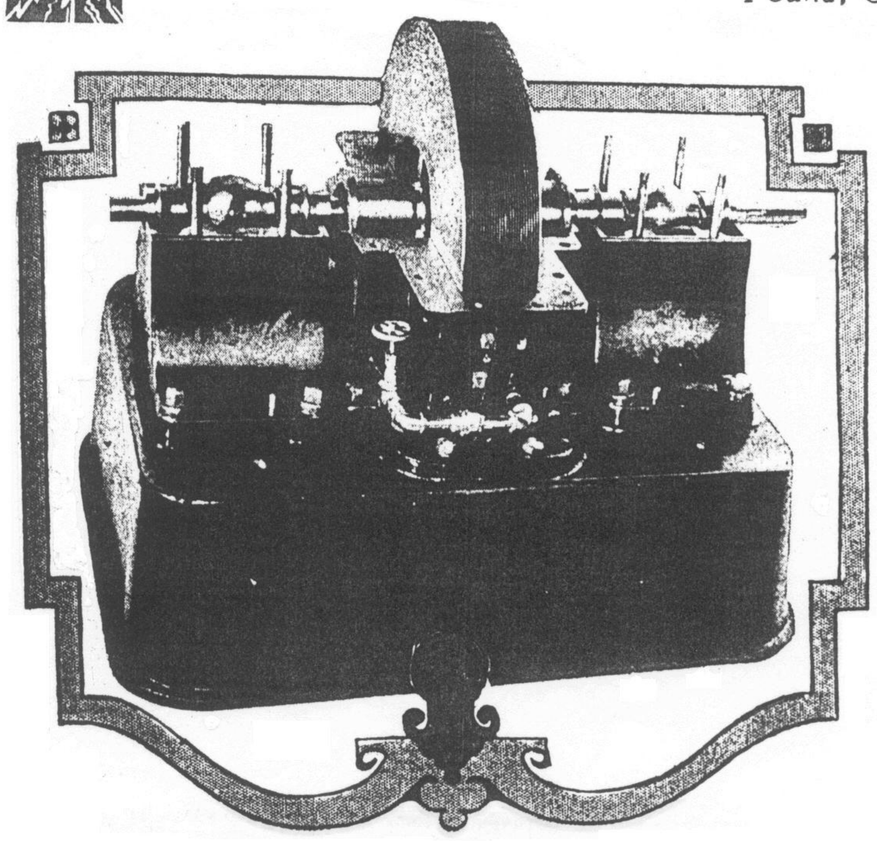
The main principle of design may be use for an internal-combustion motor. The small machine shown in Fig. 5 has been operated with gaseous fuel burned in an auxiliary chamber and the products of combustion cooled by injecting steam or water spray. This gives a mixture of superheated steam and gases which leave the combustion chamber under high pressure, but reduced in temperature so that they may be led directly to the disks, serving in the place of steam from a boiler. The machine shown developed 110 HP., and it is stated that only the small sized shaft prevented pushing the load higher. The products of combustion instead of being cooled by the formation of superheated steam may be expanded in an insulated nozzle, the temperature falling with the reduction in pressure and the increase in velocity. At the exit of the nozzle, the temperature could be sufficiently reduced so that the gases could be caused to impinge on the disks without injuring them.

SECTION. THE NEW YORK HERALD. PART I. PAGES 1 TO 8.

NEW YORK, SUNDAY, OCTOBER 15, 1911.—BY THE NEW YORK HERALD COMPANY. [COPYRIGHT, 1911. PRICE FIVE CENTS.

TESLA'S NEW MONARCH OF MECHANICS

MARVELS of the Famous Inventor's Latest Triumph, the Perfect Rotary Engine, Which, Yielding Ten Horse Power to the Pound, Opens Possibilities Dreamed of for Centuries



Two Hundred Horse Power Tesla Turbine with Part of Case Removed to Show Disks
By courtesy of the Scientific American

BY FRANK PARKER STOCKBRIDGE.

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TEN horse power from a tiny engine that a man could dangle from his little finger by a string!

Five hundred horse power in a package that a man could lift easily in one hand!

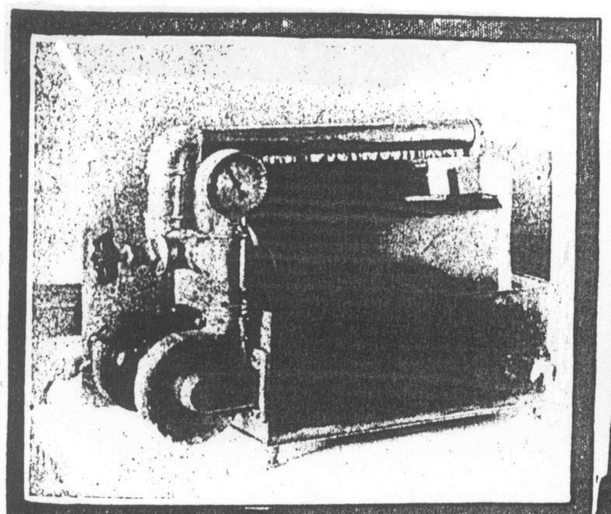
A thousand horse power motor occupying hardly more space than the cardboard box in which your hatter sent your new derby home!

Marvellous? Wait until you hear the rest of it!

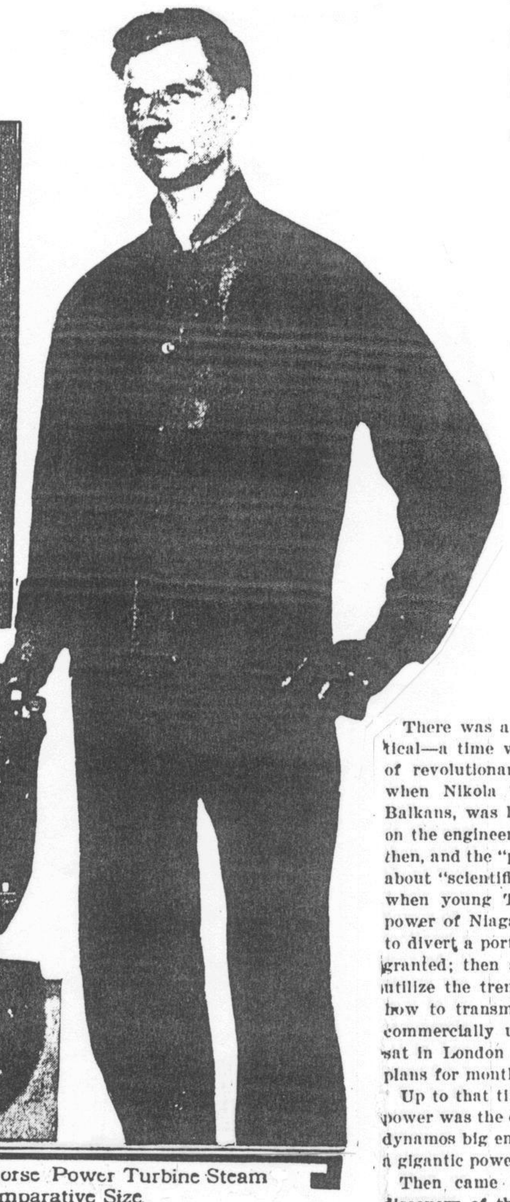
Suppose some one should discover a new mechanical principle—something as fundamental as James Watt's discovery of the expansive power of steam—by the use of which it became possible to build a motor that would give ten horse power for every pound of the engine's weight, a motor so simple that the veriest novice in mechanics could construct it and so elemental that it could not possibly get out of repair. Then suppose that this motor could be run forward or backward at will, that it could be used as either an engine or a pump, that it cost almost nothing to build as compared with any other known form of engine, that it utilized a larger percentage of the available power than any existing machine, and, finally, that it would operate with gas, steam, compressed air or water, any one of them, as its driving power.

It does not take a mechanical expert to imagine the limitless possibilities of such an engine. It takes very little effort to conjure up a picture of a new world of industry and transportation made possible by the invention of such a device. "Revolutionary" seems a mild term to apply to it. That, however, is the word the inventor uses in describing it—Nikola Tesla, the scientist whose electrical discoveries underlie all modern electrical power development, whose experiments and deductions made the wireless telegraph possible, and who now, in the mechanical field, has achieved a triumph even more far reaching than anything he accomplished in electricity.

There is something of the romantic in this discovery of the famous explorer of the hidden realms of knowledge. The pursuit of an ideal is always romantic, and it was in the pursuit of an ideal which he has been seeking twenty years that Dr. Tesla made his great discovery. That ideal is the power to fly—to fly with certainty and absolute safety—not merely to go up in an aeroplane and take chances on weather conditions, "holes in the air," tornadoes, lightning and the thousand other perils the aviator of to-day faces, but to fly with the speed and certainty of a cannon ball, with power to overcome any of nature's aerial forces, to start when one pleases, go whither one pleases and alight where one pleases. That has been the aim of Dr. Tesla's life for nearly a quarter of a century. He believes that with the discovery of the principle of his new motor he has solved this problem and that incidentally he has laid the foundations for the most startling new achievements in other mechanical lines.



Tesla Turbine with Disks Three Inches in Diameter Pumping Forty Gallons a Minute Against a Nine Foot Head.
By courtesy of the Scientific American.



Tesla's One Hundred and Ten Horse Power Turbine Steam Engine, Showing Comparative Size
By Courtesy of the Electrical Review.

There was a time when men of science were sceptical—a time when they ridiculed the announcement of revolutionary discoveries. Those were the days when Nikola Tesla, the young scientist from the Balkans, was laughed at when he urged his theories on the engineering world. Times have changed since then, and the "practical" engineer is not so incredulous about "scientific" discoveries. The change came about when young Tesla showed the way by which the power of Niagara Falls could be utilized. The right to divert a portion of the waters of Niagara had been granted; then arose the question of how best to utilize the tremendous power thus made available—how to transmit it to the points where it could be commercially utilized. An international commission sat in London and listened to theories and practical plans for months.

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That discovery, at that opportune time, decided the commission. Electricity was determined upon as the means for the transmission of Niagara's power to industry and commerce. To-day a million horse power is developed on the brink of the great cataract, turning the wheels of Buffalo, Rochester, Syracuse and the intervening cities and villages operating close at hand the great new electro-chemical industries that the existence of this immense source of power has made possible, while all around the world a thousand waterfalls are working in the service of mankind, sending the power of their "white coal" into remote and almost inaccessible corners of the globe, all because of Nikola Tesla's first great epoch making discovery.

To-day the engineering world listens respectfully when Dr. Tesla speaks. The first announcement of the discovery of his new mechanical principle was made in a technical periodical in mid-September, 1911. Immediately it became the principal topic of discussion wherever engineers met.

"It is the greatest invention in a century," wrote one of the foremost American engineers, a man whose name stands close to the top of the list of those who have achieved scientific fame and greatness.

"No invention of such importance in the automobile trade has yet been made," declared the editor of one of the leading engineering publications. Experts in other engineering lines pointed out other applications of the new principle and letters asking for further information poured in on Dr. Tesla from the four quarters of the globe.

"Oh, I've had too much publicity," he said, when I telephoned to him to ask for an interview in order to explain his new discovery to the non-technical public. It took a good deal of persuasion before he reluctantly fixed an hour when he would see me, and a good bit more after that before he talked at all freely. When he did speak, however, he opened up vistas of possible applications of the new engine that staggered the imagination of the interviewer.

Telling His Life Dream.

Looking out over the city from the windows of his office, on the twentieth floor of the Metropolitan Tower, his face lit up as he told of his life dream and its approaching realization, and the listener's fancy could almost see the air full of strange flying craft, while huge steamships propelled at unheard of speeds ploughed the waters of the North River, automobiles climbed the very face of the Palisades, locomotives of incredible power whisked wheeled palaces many miles a minute and all the discomforts of summer heat vanished as marvellous refrigerating plants reduced the temperature of the whole city to a comfortable maximum—for these were only a few of the suggestions of the limitless possibilities of the latest Tesla discovery.

"Just what is your new invention?" I asked.

"I have accomplished what mechanical engineers have been dreaming about ever since the invention of steam power," replied Dr. Tesla. "That is the perfect rotary engine. It happens that I have also produced an engine which will give at least twenty-five times as much power to a pound of weight as the lightest weight engine of any kind that has yet been produced.

"In doing this I have made use of two properties which have always been known to be possessed by all fluids, but which have not heretofore been utilized. These properties are adhesion and viscosity.

"Put a drop of water on a metal plate. The drop will roll off, but a certain amount of the water will remain on the plate until it evaporates or is removed

(CONTINUED ON PAGE TWO.)

Nikola Tesla's Revolutionary Invention, a Perfect Rotary Engine

(CONTINUED FROM PAGE ONE.)

by some absorptive means. The metal does not absorb any of the water, but the water adheres to it.

"The drop of water may change its shape, but until its particles are separated by some external power it remains intact. This tendency of all fluids to resist molecular separation is viscosity. It is especially noticeable in the heavier oils.

"It is these properties of adhesion and viscosity that cause the 'skin friction' that impedes a ship in its progress through the water or an aeroplane in going through the air. All fluids have these qualities—and you must keep in mind that air is a fluid, all gases are fluids, steam is fluid. Every known means of transmitting or developing mechanical power is through a fluid medium.

"Now, suppose we make this metal plate that I have spoken of circular in shape and mount it at its centre on a shaft so that it can be revolved. Apply power to rotate the craft and what happens? Why, whatever fluid the disk happens to be revolving in is agitated and dragged along in the direction of rotation, because the fluid tends to adhere to the disk and the viscosity causes the motion given to the adhering particles of the fluid to be transmitted to the whole mass. Here, I can show you better than I can tell you."

Dr. Tesla led the way into an adjoining room. On a desk was a small electric motor and mounted on the shaft were half a dozen flat disks, separated by perhaps a sixteenth of an inch from one another, each disk being less than that in thickness. He turned a switch and the motor began to buzz. A wave of cool air was immediately felt.

"There we have a disk, or rather a series of disks, revolving in a fluid—the air," said the inventor. "You need no proof to tell you that the air is being agitated and propelled violently. If you will hold your hand over the centre of these disks—you see the centres have been cut away—you will feel the suction as air is drawn in to be expelled from the peripheries of the disks.

"Now, suppose these revolving disks were enclosed in an air tight case, so constructed that the air could enter only at one point and be expelled only at another—what would we have?

"You'd have an air pump," I suggested.

"Exactly—an air pump or a blower," said Dr. Tesla. There is one now in operation delivering ten thousand cubic feet of air a minute. "Now, come over here."

He stepped across the hall and into another room, where three or four draughtsmen were at work and various mechanical and electrical contrivances were scattered about. At one side of the room was what appeared to be a zinc or aluminum tank, divided into two sections, one above the other, while a pipe that ran along the wall above the upper division of the tank was connected with a little aluminum case about the size and shape of a small alarm clock. A tiny electric motor was attached to a shaft that protruded from one side of the aluminum case. The lower division of the tank was filled with water.

"Inside of this aluminum case are several disks mounted on a shaft and immersed in a fluid, water," said Dr. Tesla. "From this lower tank the water has free access to the case enclosing the disks. This pipe leads from the periphery of the case. I turn the current on, the motor turns the disks and as I open this valve in the pipe the water flows."

He turned the valve and the water certainly did flow. Instantly a stream that would have filled a barrel in a very few minutes began to run out of the pipe into the upper part of the tank and thence into the lower tank.

"This is only a toy," said Dr. Tesla. "There are only half a dozen disks—'runners,' I call them—each less than three inches in diameter, inside of that case. They are just like the disks you saw on the first motor—no vanes, blades or attachments of any kind. Just perfectly smooth, flat disks revolving in their own planes and pumping water because of the viscosity and adhesion of the fluid. One such pump now in operation, with eight disks, eighteen inches in diameter, pumps four thousand gallons a minute to a height of 360 feet.

We went back into the big, well lighted office. I was beginning to grasp the new Tesla principle.

"Suppose now we reversed the operation," continued the inventor. "You have seen the disks acting as a pump. Suppose we had water, or air under pressure, or steam under pressure, or gas under pressure, and let it run into the case in which the disks are contained—what would happen?"

"The disks would revolve and any machinery attached to the shaft would be operated—you would convert the pump into an engine," I suggested.

"That is exactly what would happen—what does happen," replied Dr. Tesla. "It is an engine that does all that engineers have ever dreamed of an engine doing, and more. Down at the Waterside power station of the New York Edison Company, through their courtesy, I have had a number of such engines in operation. In one of them the disks are only nine inches in diameter and the whole working part is two inches thick. With steam as the propulsive fluid it develops 110-horse power, and could do twice as much.

"You have got what Professor Langley was trying to evolve for his flying machine—an engine that will give a horse power for a pound of weight," I suggested.

Ten Horse Power to the Pound.

"I have got more than that," replied Dr. Tesla. "I have an engine that will give ten horse power to the pound of weight. That is twenty-five times as powerful as the lightest weight engine in use to-day. The lightest gas engine used on aeroplanes weighs two and one-half pounds to the horse power. With two and one-half pounds of weight I can develop twenty-five horse power."

"That means the solution of the problem of flying," I suggested.

"Yes, and many more," was the reply. "The applications of this principle, both for imparting power to fluids, as in pumps, and for deriving power from fluids, as in turbine, are boundless. It costs almost nothing to make, there is nothing about it to get out of order, it is reversible—simply have two ports for the gas or steam, to enter by, one on each side, and let it into one side or other. There are no blades or vanes to get out of order—the steam turbine is a delicate thing."

I remembered the bushels of broken blades that were gathered out of the turbine casings of the first turbine equipped steamship to cross the ocean, and realized the importance of this phase of the new engine.

"Then, too," Dr. Tesla went on, "there are no delicate adjustments to be made. The distance between the disks is not a matter of microscopic accuracy and there is no necessity for minute clearances between the disks and the case. All one needs is some disks mounted on a shaft, spaced a little distance apart and cased so that a fluid can enter at one point and go out at another. If the fluid enters at the centre and goes out at the periphery it is a pump. If it enters at the periphery and goes out at the centre it is a motor.

"Coupling these engines in series, one can do away with gearing in machinery. Factories can be equipped without shafting. The motor is especially adapted to automobiles, for it will run on gas explosions as well as on steam. The gas or steam can be let into a dozen ports all around the rim of the case if desired. It is possible to run it as a gas engine with a continuous flow of gas, gasolene and air being mixed and the continuous combustion causing expansion and pressure to operate the motor. The expansive power of steam, as well as its propulsive power, can be utilized as in a turbine or a reciprocating engine. By permitting the propelling fluid to move along the lines of least resistance a considerably larger proportion of the available power is utilized.

"As an air compressor it is highly efficient. There is a large engine of this type now in practical operation as an air compressor and giving remarkable service. Refrigeration on a scale hitherto never attempted will be practical, through the use of this engine in compressing air, and the manufacture of liquid air commercially is now entirely feasible.

"With a thousand horse power engine, weighing only one hundred pounds, imagine the possibilities in automobiles, locomotives and steamships. In the space now occupied by the engines of the Lusitania twenty-five times her 80,000 horse power could be developed, were it possible to provide boiler capacity sufficient to furnish the necessary steam."

"And it makes the aeroplane practical," I suggested.

"Not the aeroplane, the flying machine," responded Dr. Tesla. "Now you have struck the point in which I am most deeply interested—the object toward which I have been devoting my energies for more than twenty years—the dream of my life. It was in seeking the means of making the perfect flying machine that I developed this engine.

"Twenty years ago I believed that I would be the first man to fly; that I was on the track of accomplishing what no one else was anywhere near reaching. I was working entirely in electricity then and did not realize that the gasolene engine was approaching a perfection that was going to make the aeroplane feasible. There is nothing new about the aeroplane but its engine, you know.

"What I was working on twenty years ago was the wireless transmission of electric power. My idea was a flying machine propelled by an electric motor, with power supplied from stations on the earth. I have not accomplished this as yet, but am confident that I will in time.

"When I found that I had been anticipated, as to the flying machine, by men working in a different field I began to study the problem from other angles, to regard it as a mechanical rather than an electrical problem. I felt certain there must be some means of obtaining power that was better than any now in use, and by vigorous use of my gray matter for a number of years I grasped the possibilities of the principle of the viscosity and adhesion of fluids and conceived the mechanism of my engine. Now that I have it, my next step will be the perfect flying machine."

"An aeroplane driven by your engine?" I asked.

"Not at all," said Dr. Tesla. "The aeroplane is fundamentally defective. It is merely a toy—a sporting plaything. It can never become commercially practical. It has fatal defects. One is the fact that when it encounters a downward current of air it is helpless. The 'hole in the air' of which aviators speak is simply a downward current, and unless the aeroplane is high enough above the earth to move laterally out of the downward current before striking the ground it can do nothing but fall. There is no way of detecting these downward currents, no way of avoiding them, and therefore the aeroplane must always be subject to chance and its operator to the risk of fatal accident. Sportsmen will always take these chances, but as a business proposition the risk is too great.

"The flying machine of the future—my flying machine—will be heavier than air, but it will not be an aeroplane. It will have no wings. It will be substantial, solid, stable. You cannot have a stable aeroplane. The gyroscope can never be successfully applied to the aeroplane, for it would give a stability that would result in the machine being torn to pieces by the wind, just as the unprotected aeroplane on the ground is torn to pieces by a high wind.

"My flying machine will have neither wings nor propellers. You might see it on the ground and you would never guess that it was a flying machine. Yet it will be able to move at will through the air in any direction with perfect safety, higher speeds than have yet been reached, regardless of weather and oblivious of 'holes in the air' or downward currents. It will ascend in such currents if desired. It can remain absolutely stationary in the air even in a wind for a great length of time. Its lifting power will not depend upon any such delicate devices as the bird has to employ, but upon positive mechanical action."

"You will get stability through gyroscopes?" I asked.

"Through gyroscopic action of my engine, assisted by some devices I am not yet prepared to talk about," he replied.

"Powerful air currents that may be deflected at will, if produced by engines and compressors sufficiently light and powerful, might lift a heavy body off the ground and propel it through the air," I ventured, wondering if I had grasped the inventor's secret.

Dr. Tesla smiled an inscrutable smile.

"All I have to say on that point is that my airship will have neither gas bag, wings nor propellers," he said. "It is the child of my dreams, the product of years of intense and painful toil and research. I am not going to talk about it any further. But whatever my airship may be, here at least is an engine that will do things that no other engine ever has done, and that is something tangible."

Will Tesla's New Monarch of Mechanics Revolutionize the World?

Noted Balkan Scientist Claims to Have Perfected an Engine That Will Develop Ten Horsepower to Every Pound of Weight, and Promises Soon to Give to the World a Flying Machine Without Wings, Propeller, or Gas Bag. Characterizes Aeroplanes of Today as Mere Dangerous Toys Compared With the Safe and Stable Appliance Which Will Be Used in a Short Time to Dash Through the Air at a Speed Now Unimagined.

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Tesla and Niagara Falls.

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"I have accomplished what mechanical engineers have been dreaming about ever since the invention of steam power," replied Dr. Tesla. "That is the perfect rotary engine. It happens that I have also produced an engine which will give at least 25 times as much power to a pound of weight as the lightest weight engine of any kind that has yet been produced.

"In doing this I have made use of two properties which have always been known to be possessed by all fluids, but which have not heretofore been utilized. These properties are adhesion and viscosity.

"Put a drop of water on a metal plate. The drop will roll off, but a certain amount of the water will remain on the plate until it evaporates or is removed by some absorptive means. The metal does not absorb any of the water, but the water adheres to it.

"The drop of water may change its shape, but until its particles are separated by some external power it remains intact. This tendency of all fluids to resist molecular separation is viscosity. It is especially noticeable in the heavier oils.

"It is these properties of adhesion and viscosity that cause the 'skin friction' that impedes a ship in its progress through the water or an aeroplane in going through the air. All fluids have these qualities—and you must keep in mind that the air is a fluid, all gases are fluids, steam is fluid. Every known means of transmitting or developing mechanical power is through a fluid medium.

"Now, suppose we make this metal plate that I have spoken of circular in shape and mount it at its center on a shaft so that it can be revolved. Apply power to rotate the craft and what happens? Why, whatever fluid the disk happens to be revolving in is agitated and dragged along in the direction of rotation, because the fluid tends to adhere to the disk and the viscosity causes the motion given to the adhering particles of the fluid to be transmitted to the whole mass. Here, I can show you better than I can tell you."

A Practical Demonstration.

Dr. Tesla led the way into an adjoining room. On a desk was a small electric motor, and mounted on the shaft were half a dozen flat disks, separated by perhaps a sixteenth of an inch from one another, each disk being less than that in thickness. He turned a switch and the motor began to buzz. A wave of cool air was immediately felt.

"There we have a disk, or rather a series of disks, revolving in a fluid—the air," said the inventor. "You need no proof to tell you that the air is being agitated and propelled violently. If you will hold your hand over the center of these disks—you see the centers have been cut away—you will feel the suction as air is drawn in to be expelled from the peripheries of the disks.

"Now, suppose these revolving disks were inclosed in an airtight case, so constructed that the air could enter only at one point and be expelled only at another—what would we have?

"You'd have an air pump," I suggested.

"Exactly—an air pump or a blower," said Dr. Tesla. "There is one now in operation delivering 10,000 cubic feet of air a minute. Now come over here."

He stepped across the hall and into another room, where three or four draftsmen were at work and various mechanical and electrical contrivances were scattered about. At one side of the room was what appeared to be a zinc or aluminum tank, divided into two sections, one above the other, while a pipe that ran along the wall above the upper division of the tank was connected with a little aluminum case about the size and shape of a small alarm clock. A tiny electric motor was attached to a shaft that protruded from one side of the aluminum case. The lower division of the tank was filled with water.

"Inside of this aluminum case are several disks mounted on a shaft and immersed in a fluid, water," said Dr. Tesla. "From this lower tank the water has free access to the case inclosing the disks. This pipe leads from the periphery of the case. I turn the current on, the motor turns the disks, and as I open this valve in the pipe the water flows."

He turned the valve and the water certainly did flow. Instantly a stream that would have filled a barrel in a very few minutes began to run out of the pipe into the upper part of the tank and thence into the lower tank.

"This is only a toy," said Dr. Tesla. "There are only half a dozen disks—'runners,' I call them—each less than 3 inches in diameter, inside of that case. They are just like the disks you saw on the first motor—no vanes, blades, or attachments of any kind. Just perfectly smooth, flat disks revolving in their own planes and pumping water because of the viscosity and adhesion of the fluid. One such pump now in operation, with eight disks, 18 inches in diameter, pumps 4,000 gallons a minute to a height of 360 feet.

Pump Becomes an Engine.

We went back into the big, well lighted office. I was beginning to grasp the new Tesla principle.

"Suppose now we reversed the operation," continued the inventor. "You have seen the disks acting as a pump. Suppose we had water, or air under pressure, or steam under pressure, or gas under pressure, and let it run into the case in which the disks are contained—what would happen?"

"The disks would revolve and any machinery attached to the shaft would be operated—you would convert the pump into an engine," I suggested.

"That is exactly what would happen—what does happen," replied Dr. Tesla. "It is an engine that does all that engineers have ever dreamed of an engine doing, and more. Down at the Waterside power station of the New York Edison Company, through their courtesy, I have had a number of such engines in operation. In one of them the disks are only 9 inches in diameter, and the whole working part is 2 inches thick. With steam as the propulsive fluid, it develops 110-horsepower, and could do twice as much.

"You have got what Prof. Langley was trying to evolve for his flying machine—an engine that will give a horsepower for a pound of weight?" I suggested.

"I have got more than that," replied Dr. Tesla. "I have an engine that will give 10 horsepower to the pound of weight. That is 25 times as powerful as the lightest-weight engine in use today. The lightest gas engine used on aeroplanes weighs 2½ pounds to the horsepower. With 2 1-2 pounds of weight I can develop 25 horsepower."

"That means the solution of the problem of flying," I suggested.

"Yes, and many more," was the reply. "The applications of this principle, both for imparting power to fluids, as in pumps, and for deriving power from fluids, as in turbines, are boundless. It costs almost nothing to make, there is nothing about it to get out of order, it is reversible—simply have two ports for the gas or steam, to enter by, one on each side, and let it into one side or other. There are no blades or vanes to get out of order—the steam turbine is a delicate thing."

I remembered the bushels of broken blades that were gathered out of the turbine casings of the first turbine-equipped steamship to cross the ocean, and realized the importance of this phase of the new engine.

No Delicate Adjustment Necessary.

"Then, too," Dr. Tesla went on, "there are no delicate adjustments to be made. The distance between the disks is not a matter of microscopic accuracy, and there is no necessity for minute clearances between the disks and the case. All one needs is some disks mounted on a shaft, spaced a little distance apart, and cased so that a fluid can enter at one point and go out at another. If the fluid enters at the center and goes out at the periphery it is a pump. If it enters at the periphery and goes out at the center it is a motor.

"Coupling these engines in series, one can do away with gearing in machinery. Factories can be equipped without shafting. The motor is especially adapted to automobiles, for it will run on gas explosions as well as on steam. The gas or steam can be let into a dozen ports all around the rim of the case if desired. It is possible to run it as a gas engine with a continuous flow of gas, gasoline and air being mixed and the continuous combustion causing expansion and pressure to operate the motor. The expansive power of steam, as well as its propulsive power, can be utilized as in a turbine or a reciprocating engine. By permitting the propelling fluid to move along the lines of least resistance a considerably larger proportion of the available power is utilized.

"As an air compressor it is highly efficient. There is a large engine of this type now in practical operation as an air compressor, and giving remarkable service. Refrigeration on a scale hitherto never attempted will be practical, through the use of this engine in compressing air, and the manufacture of liquid air commercially is now entirely feasible.

"With a 1,000-horsepower engine, weighing only 100 pounds, imagine the possibilities in automobiles, locomotives, and steamships. In the space now occupied by the engines of the Lusitania 25 times her 80,000 horsepower could be developed, were it possible to provide boiler capacity sufficient to furnish the necessary steam."

"And it makes the aeroplane practical," I suggested.

Flying Machine to Supplant Aeroplane.

"Not the aeroplane, the flying machine," responded Dr. Tesla. "Now you have struck the point in which I am most deeply interested—the object toward which I have been devoting my energies for more than twenty years—the dream of my life. It was in seeking the means of making the perfect flying machine that I developed this engine.

"Twenty years ago I believed that I would be the first man to fly; that I was on the track of accomplishing what no one else was anywhere near reaching. I was working entirely in electricity then, and did not realize that the gasoline engine was approaching a perfection that was going to make the aeroplane feasible. There is nothing new about the aeroplane but its engine, you know.

"What I was working on twenty years ago was the wireless transmission of electric power. My idea was a flying machine propelled by an electric motor, with power supplied from stations on the earth. I have not accomplished this as yet, but am confident that I will in time.

The Aero a Mere Toy.

"When I found that I had been anticipated, as to the flying machine, by men working in a different field, I began to study the problem from other angles, to regard it as a mechanical rather than an electrical problem. I felt certain there must be some means of obtaining power that was better than any now in use, and by vigorous use of my gray matter for a number of years I grasped the possibilities of the principle of the viscosity and adhesion of fluids, and conceived the mechanism of my engine. Now that I have it, my next step will be the perfect flying machine."

"An aeroplane driven by your engine?" I asked.

"Not at all," said Dr. Tesla. "The aeroplane is fatally defective. It is merely a toy—a sporting plaything. It can never become commercially practical. It has fatal defects. One is the fact that when it encounters a downward current of air it is helpless. The 'hole in the air' of which aviators speak is simply a downward current, and unless the aeroplane is high enough above the earth to move laterally out of the downward current before striking the ground it can do nothing but fall. There is no way of detecting these downward currents, no way of avoiding them, and therefore the aeroplane must always be subject to chance and its operator to the risk of fatal accident. Sportsmen will always take these chances, but as a business proposition the risk is too great.

"The flying machine of the future—my flying machine—will be heavier than air, but it will not be an aeroplane. It will have no wings. It will be substantial, solid, stable. You cannot have a stable aeroplane. The gyroscope can never be successfully applied to the aeroplane, for it would give a stability that would result in the machine being torn to pieces by the wind, just as the unprotected aeroplane on the ground is torn to pieces by a high wind.

Neither Wings Nor Propeller.

"My flying machine will have neither wings nor propellers. You might see it on the ground and you would never guess that it was a flying machine. Yet it will be able to move at will through the air in any direction with perfect safety, higher speeds than have yet been reached, regardless of weather and oblivious of 'holes in the air' or downward currents. It will ascend in such currents if desired. It can remain absolutely stationary in the air even in a wind for a great length of time. Its lifting power will not depend upon any such delicate devices as the bird has to employ, but upon positive mechanical action."

"You will get stability through gyroscopes?" I asked.

"Through gyroscopic action of my engine, assisted by some devices I am not yet prepared to talk about," he replied.

"Powerful air currents that may be deflected at will, if produced by engines and compressors sufficiently light and powerful, might lift a heavy body off the ground and propel it through the air," I ventured, wondering if I had grasped the inventor's secret.

Dr. Tesla smiled an inscrutable smile.

"All I have to say on that point is that my airship will have neither gas bag, wings, nor propellers," he said. "It is the child of my dreams, the product of years of intense and painful toil and research. I am not going to talk about it any further. But whatever my airship may be, here at least is an engine that will do things that no other engine ever has done, and that is something tangible."

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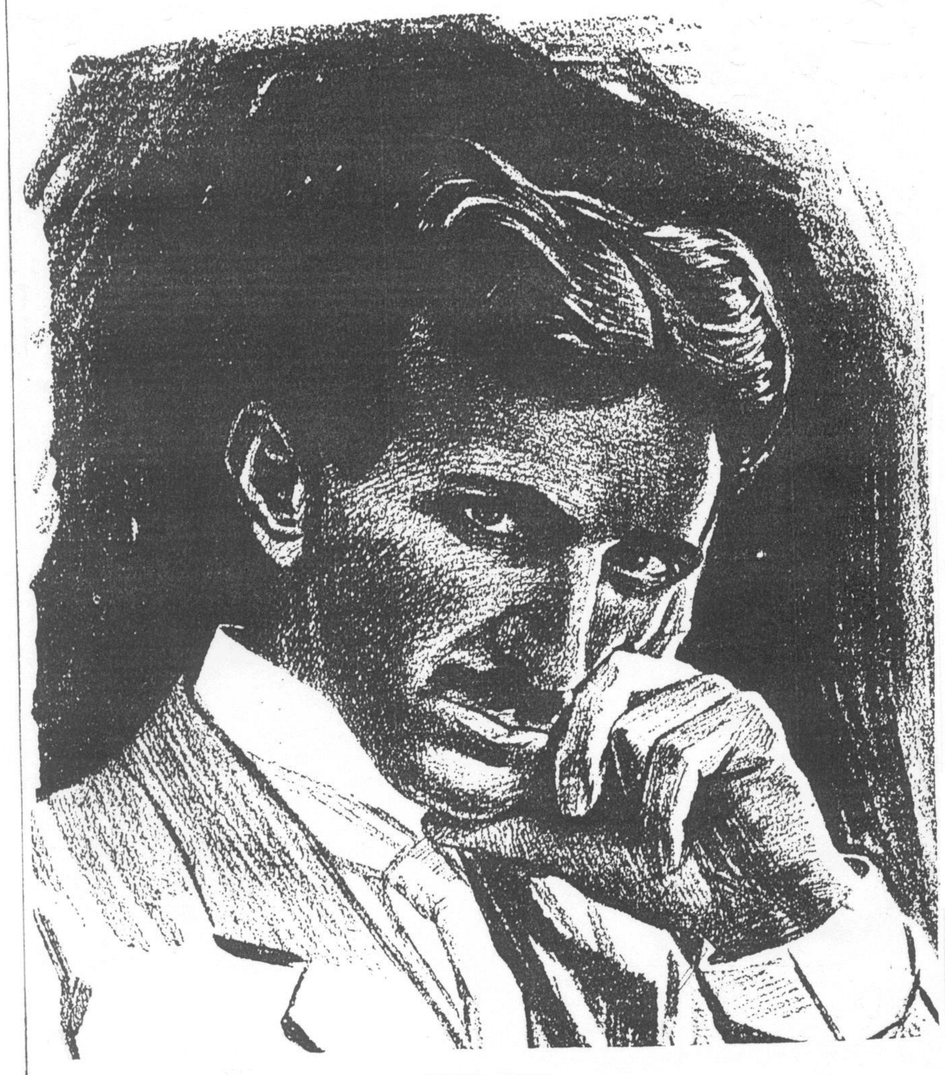
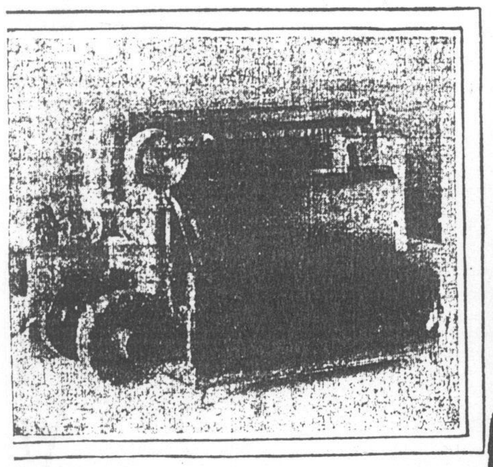


NIKOLA TESLA.



Tesla turbine with disks three inches in diameter pumping forty gallons a minute against a nine-foot head.

By Courtesy of the Scientific American.

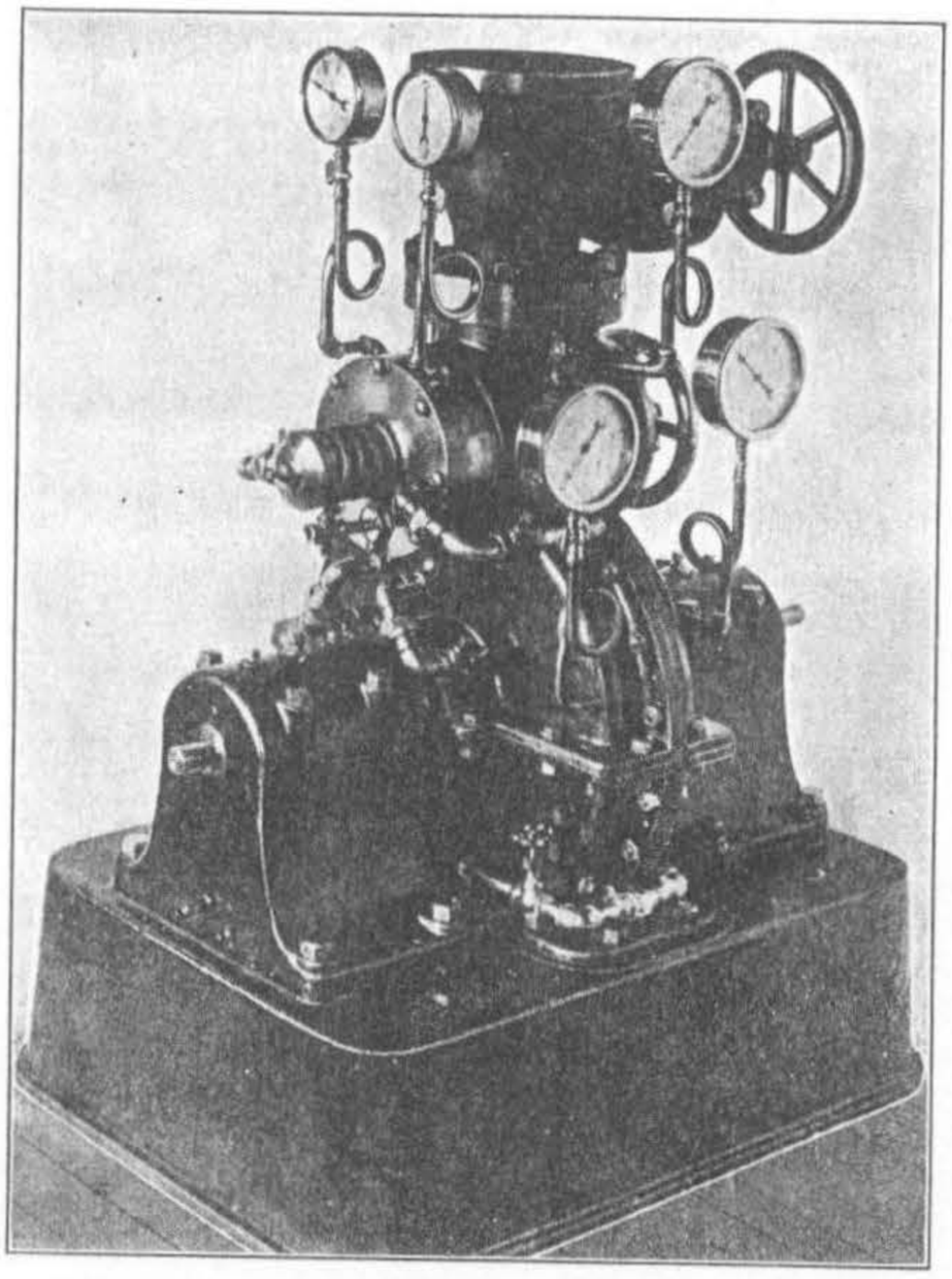
Tesla's One Hundred and Ten Horse Power Turbine Steam Engine, Showing Comparative Size

By Courtesy of the Electrical Review.

SCIENCE AND INVENTION

TESLA'S NEW ROTARY MACHINE

A MACHINE based on a new principle, for use wherever a fluid is used as a vehicle of energy, has been invented by Nikola Tesla. Apparently it is capable of a wide variety of applications, from cases where velocity is to be imparted to the fluid, as in a pump, to those where the moving fluid is itself to operate machinery, either by its velocity alone or by its expansion. The fluid may be liquid or gaseous, and its velocity may be due to simple hydrostatic or gaseous pressure or to explosive combustion. Here, then, we have evidently a device capable of use wherever engines, turbines, pumps, or power-transformers of any kind are now in use. The new principle consists simply in the utilization of the fluid's internal friction and its adhesion to a smooth surface for giving it speed or imparting to machinery its speed already acquired. This operation is thus vastly smoother than in any known pump or engine, and wasteful and injurious jerks are eliminated, as well as complicated parts. The new invention, which is in practical operation at one of the Edison Company's stations in New York, was briefly described by Mr. Tesla before the National Electric Light Association last May, and an authoritative description is now published by *The Electrical Review and Western Electrician* (Chicago, September 9). Says Mr. Tesla:



A 200-HORSE-POWER TESLA STEAM-TURBINE.

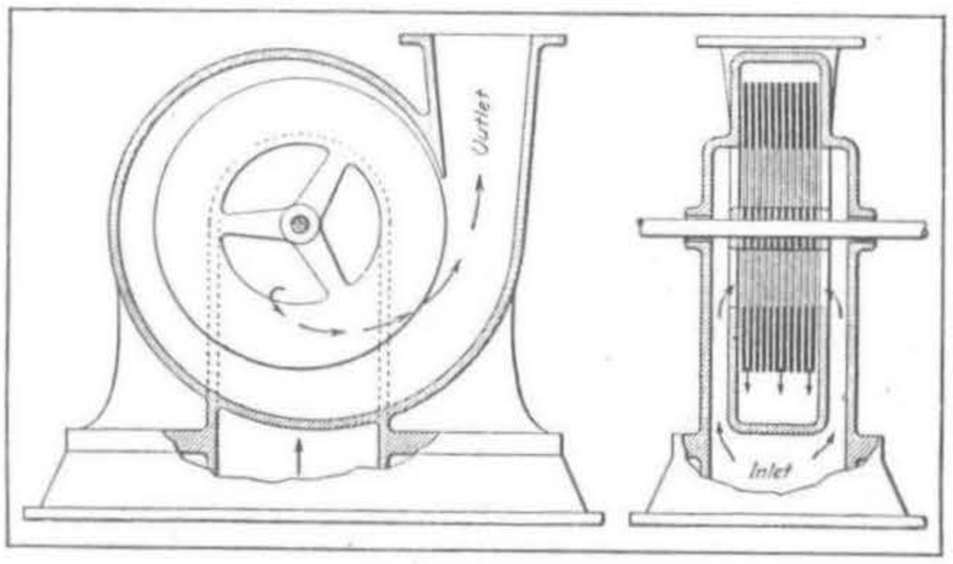
"In the practical application of mechanical power based on the use of a fluid as vehicle of energy it has been demonstrated that, in order to attain the highest economy, the changes in velocity and direction of movement of the fluid should be as gradual as possible. In the present forms of such apparatus, more or less sudden changes, shocks, and vibrations are unavoidable. Besides, the employment of the usual devices for imparting to, or deriving energy from a fluid, as pistons, paddles, vanes, and blades, necessarily introduces numerous defects and limitations and adds to the complication, cost of production, and maintenance of the machine.

"The purpose of the invention is to overcome these deficiencies and to effect the transmission and transformation of mechanical energy through the agency of fluids in a more perfect manner, and by means simpler and more economical than those heretofore employed.

"This is accomplished by causing the propelled or propelling fluid to move in natural paths or stream-lines of least resistance, free from constraint and disturbance such as occasioned by vanes or kindred devices, and to change its velocity and direction of movement by imperceptible degrees, thus avoiding the losses due to sudden variations while the fluid is receiving or imparting energy.

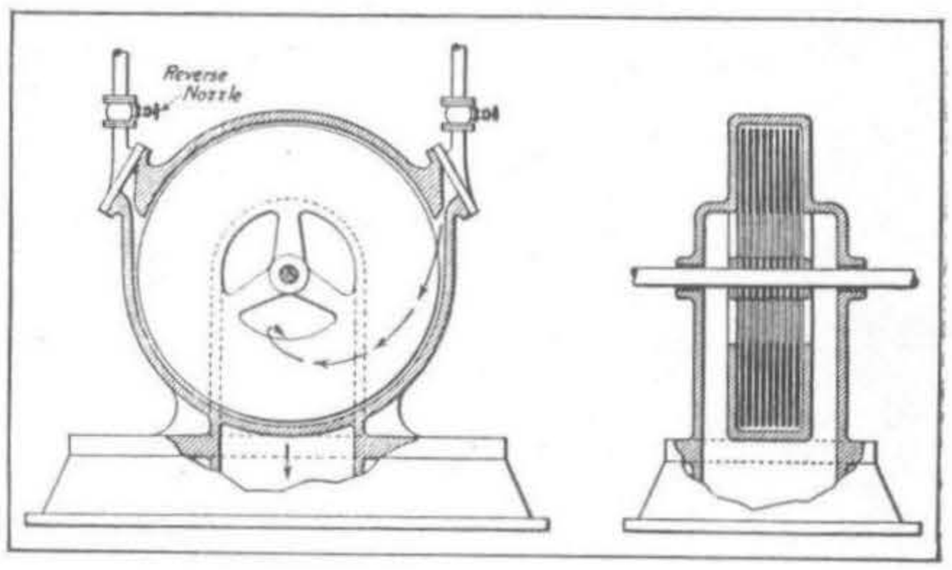
"It is well known that a fluid possesses, among others, two salient properties: adhesion and viscosity. Owing to these a body propelled through such a medium encounters a peculiar impediment known as 'lateral,' or 'skin resistance,' which is twofold: one arising from the shock of the fluid against the asperities of the solid substance, the other from internal forces opposing molecular separation. As an inevitable consequence a certain amount of the fluid is dragged along by the moving body. Conversely, if the body be placed in a fluid in motion, for the same reasons, it is impelled in the direction of movement. The accompanying drawings illustrate operative and efficient embodiments of the idea."

The illustrations show simply a set of smooth disks revolving in a case. When these are set in rotation and the fluid is admitted, it is dragged along in a spiral path, making possibly several revolutions, and is finally expelled through the outlet, having gradually gained in velocity during its trip. In this way the machine may function as a pump or as a device for the compression of air. The reversibility of the machine allows it also to function as a motor when a fluid under pressure or in rapid motion is fed to it. We read:



Longitudinal section. Cross-section.

TESLA DISK-IMPELLER PUMP.



Longitudinal section. Cross-section.

TESLA DISK WHEEL IN A STEAM-TURBINE.

INTERIOR MECHANISM OF MR. TESLA'S TURBINE.

"The operation above described is reversible, for if water or air under pressure be admitted to the opening the runner is set in rotation in the direction of the dotted arrow by reason of the peculiar properties of the fluid which, traveling in a spiral path and with continuously diminishing velocity, reaches the orifices through which it is discharged. If the runner be allowed to turn freely, in nearly frictionless bearings, its rim will attain a speed closely approximating the maximum of that of the fluid in the volute channel and the spiral path of the particles will be comparatively long, consisting of many almost circular turns. If the load is put on and the runner slowed down the motion of the fluid is retarded, the turns are reduced, and the path is shortened."

If steam be admitted, the machine will work like an engine under expansion, but if the expansion be allowed to take place before admission, it will operate like a turbine, being driven by the impact of the rapidly-moving particles. Says the inventor:

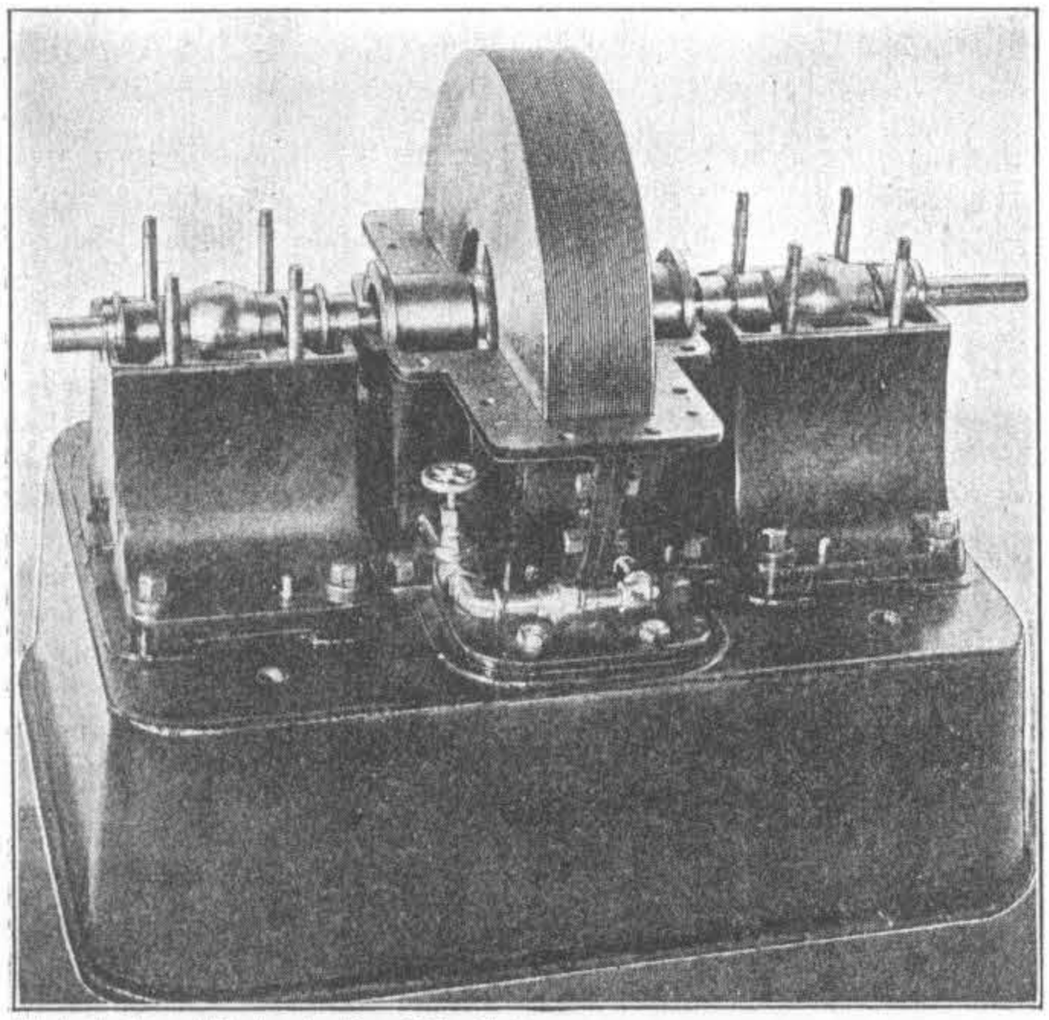
"The above description of the operation is suggested by experience and observation and is advanced merely for the purpose of explanation. The undeniable fact is that the machine does operate, both expansively and impulsively.

"When the expansion in the nozle is complete, or nearly so, the fluid pressure in the peripheral clearance space is small, as the nozle is made less divergent and its section enlarged, the pressure rises, finally approximating that of the supply. But the transition from purely impulsive to expansive action may not be continuous throughout, on account of critical states and conditions, and comparatively great variations of pressure may be caused by small changes of nozle velocity.

"In the preceding, it has been assumed that the pressure of supply is constant or continuous, but it will be understood that the operation will be, essentially, the same if the pressure be fluctuating or intermittent, as that due to explosions occurring in more or less rapid succession."

One of the special advantages claimed by the inventor for his device is its ease and simplicity of reversal, which may be effected simply by turning a valve. He says in conclusion:

"It is simple, light, and compact, subject to but little wear, cheap, and exceptionally easy to manufacture, as small clearances and accurate milling work are not essential to good performance. In operation it is reliable, there being no valves, sliding contacts,



Illustrations from "Engineering News," New York.

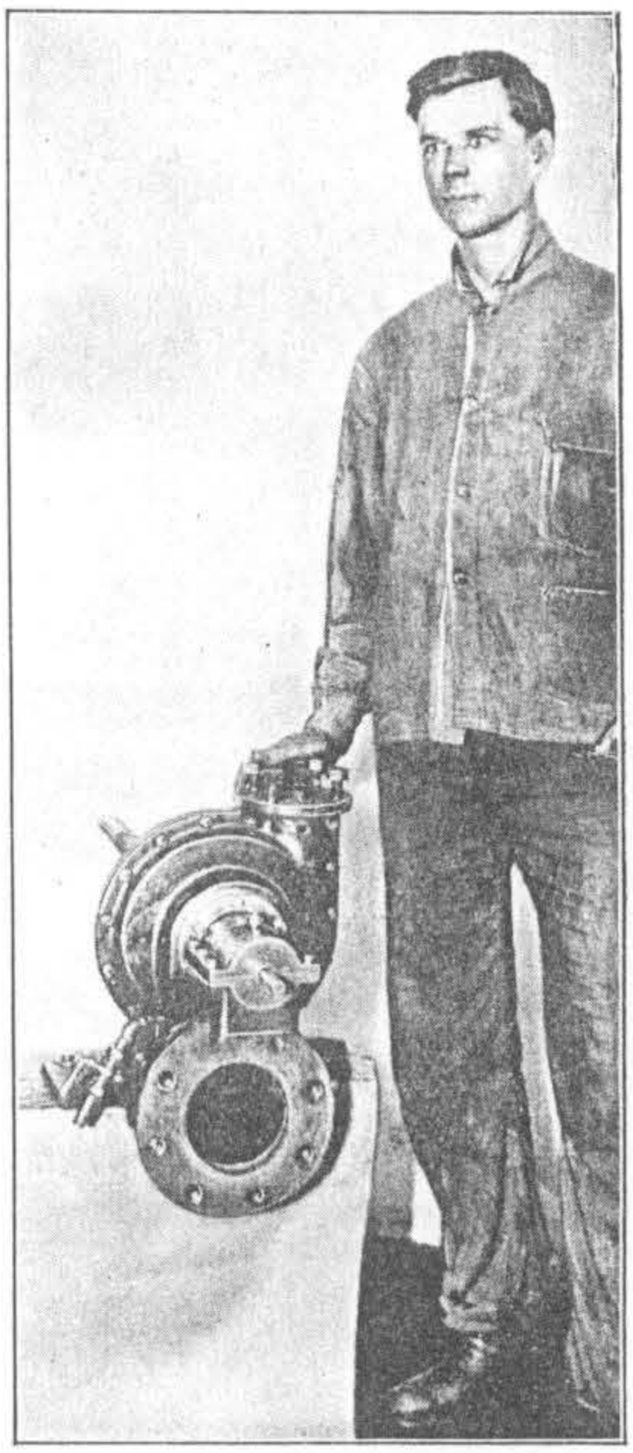
HOW THE TURBINE LOOKS WITH THE UPPER CASING OFF.

Showing the cluster of thin disks that develop 200-horse-power.

or troublesome vanes. It is almost free of windage, largely independent of nozle-efficiency, and suitable for high as well as for low fluid velocities and speeds of revolution. The principles of construction and operation are capable of embodiment in machines of the most widely different forms, and adapted for the greatest variety of purposes."

THE MACHINIST'S SENSE OF TOUCH

DESPITE the high development of automatic-machine construction, the sense of touch remains an essential factor in a large part of the operations performed in manufacturing. This is due, we are told by *The American Machinist* (New York, October 5) to the wide utilization of semi-automatic and hand-operated machinery even in the most scientifically organized plants. In the majority of shops operations are still carried on upon a scale which warrants only a limited amount of automatic machinery. So, in spite of the general departure from the earlier hand-processes, the sense of touch remains of considerable importance. We read, for instance, that



SIZE OF THE TESLA TURBINE.

A 110-horse-power machine under the hand of the man who runs it.

"The faculty known as the sense of touch that enables the operator of a hand-screw machine to follow, by the 'feel' of his lever, the cutting action of each of the tools as it is in turn run over the rotating stock, and to finish the cut with a definite pressure against the tool-slide stop, also serves as an accurate medium by which the operator of the hand-miller may gage the action of the cutter under which he feeds his work. In these cases, as with certain other machines of the hand-operated type, the practised workman can bring the tools to the work or the work to the cutter with a movement that is almost instantaneous and, throughout the extent of the cut, a feed may be maintained that is limited only by the strength of the operator or by what his sense of touch tells him is the maximum rate permissible with the speeds and tools employed.

"The dexterity of manipulation which usually develops in the hand coincident with the sense of touch, and which is an equally important consideration in modern shop practise, enables punch presses to be fed with little loss of time, and small work to be passed in and out of milling-fixtures and drilling-jigs with a similar economy of time and effort. A boy tending a certain machine of the semi-automatic type with a dial feed for carrying the work under a set of punches, has been known to develop sufficient cleverness of the fingers to enable him to drop 50,000 small blanks into holes in the dial in a day of ten hours; at the same time inspecting each blank, and this also by touch rather than visually, his attention being focused upon the general operation of the machine and not directly upon the work fed in the dial.

"Similarly, the movements of a machine-operator's foot may be developed to an extent that converts this member into a device functioning throughout the work day with the regularity of machinery itself. In fact, in certain instances on punch-press work, hand fed, and requiring foot-pressure upon a treadle to start each cycle of movements, the application of the starting pressure may occur with such clock-like regularity as to form a source of danger to the operator in that his fingers for some reason may lag for an instant and be caught under the punch, the movements of which continue as regularly as tho occurring without human intervention.

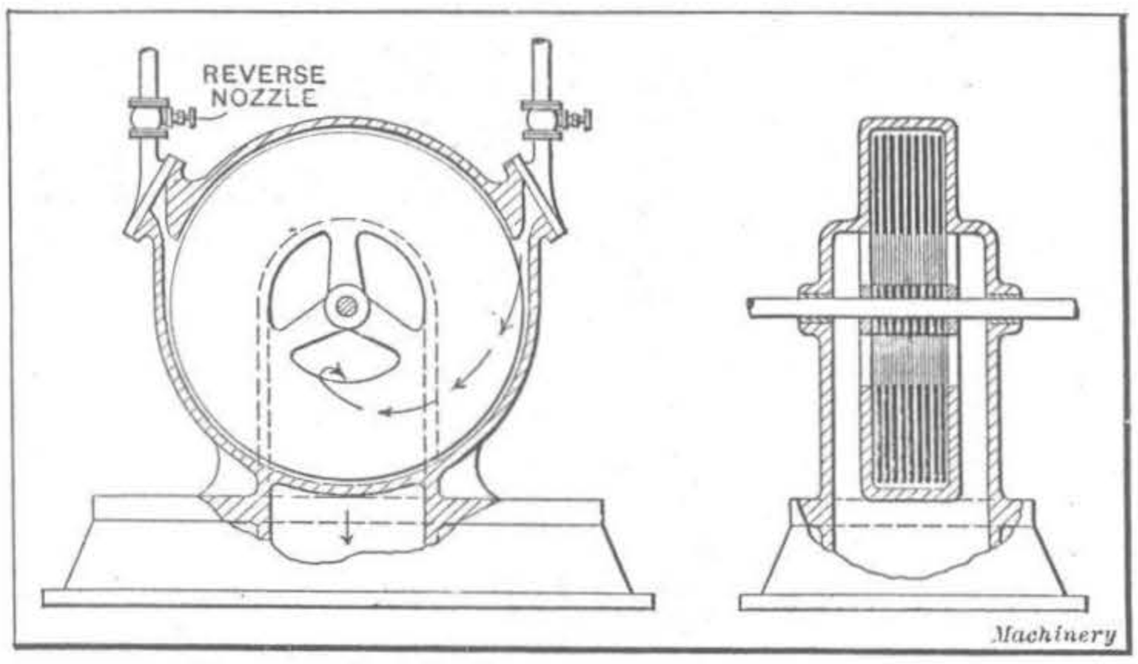
"Constituting as it does so essential a factor in modern

production, the sense of touch is likely to be developed and utilized still further, rather than dispensed with in our mechanical progress, and the legitimate field of the various hand-operated machine tools as manufacturing machines extended correspondingly along with the increase in the use of power-feed machines of both the conventional and high-power types."

* * *

THE TESLA STEAM TURBINE

Experiments with a novel design of steam turbine have been made by Mr. Nikola Tesla, who is well known in the electrical field on account of the part he has played in the developments in connection with the rotating magnetic field and other alternating current subjects. A diagrammatical section of the Tesla steam turbine is shown in the accompanying illustration. The steam is expanded in a nozzle and the heat energy is thus converted into kinetic energy. The rotor of the steam turbine simply consists of a number of thin flat disks, the inlet for the steam being at the outer periphery of these disks and the outlet being at their center, as indicated. The high velocity steam escaping from the nozzle is caused to impinge tangentially on the edges of the disks,



Diagrammatical Sections of the Tesla Steam Turbine

and in order to escape it must find a path from the periphery of the disks to the central outlet. The velocity energy of the steam produces a rotary motion of the disks, due to molecular drag on the surface, and hence the path of the steam from the outside to the inside of the disks will be a spiral one. Expressing the matter in popular terms, we may say that the action is due simply to the friction of the steam against the sides of the disks as the steam moves from the outside periphery to the center along a spiral path.

The arrangement shown in the illustration permits of easy and convenient reversal, as it is only necessary to provide a duplicate nozzle discharging against the opposite side of the disks as indicated. When the machine is at rest, or is running slowly, as in starting, the steam takes the shortest path from nozzle to exhaust, and thus develops a comparatively large torque. As the machine speeds up, the difference in velocity between the steam and the disks decreases, and the centrifugal force tends to lengthen the spiral path of the steam, so that a given amount of steam may make several revolutions with the disks before finally passing out through the exhaust opening.

A turbine of this type has been tested at the Waterside Station of the New York Edison Co. The rotor of the tested turbine has 25 disks, each 18 inches in diameter. The assembled turbine occupies a floor space of 20 by 35 inches and is about 5 feet high, completely installed. With steam at 125 pounds gage pressure per square inch exhausting into the atmosphere, 200 horsepower was developed with a speed of 9000 R. P. M. The steam consumption was 38 pounds per horsepower-hour. The weight of the turbine is 400 pounds, giving a unit weight of only 2 pounds per horsepower. While the steam consumption at present is rather high, Mr. Tesla

believes that with moderate superheat and a degree of vacuum the same as that ordinarily used in a turbine plant, the steam consumption can be reduced materially.

The principle employed is not limited to steam turbines. It can be applied as well to a type of centrifugal pump, having a series of smooth flat disks revolving in a casing, these disks having no vanes or other impelling projections. The motion of the water is produced simply by the friction or molecular adhesion between the disks and the fluid. In this case the fluid is, of course, taken in at the center of the disks and forced along a spiral path to the outside periphery.

* * *

BLADELESS TURBINES.

FROM a recent issue of the *Scientific American* it appears that Mr. Nikola Tesla has revived a method of steam-turbine construction which recalls one tried here some nine or ten years ago. The idea was patented by Mr. E. C. Thrupp in 1901, but Mr. D. J. Smith, of 58, Compton-street, E.C., informs us that at a still earlier date he assisted an Australian inventor to experiment with a similar type. The Tesla turbine is represented diagrammatically by Figs. 1, 2, and 3, which we reproduce from the *Scientific American*. As will be seen, its mechanical simplicity is extreme. The whole machine consists of a series of 25 thin discs 18 in. in diameter and $\frac{1}{32}$ in. thick mounted side by side on a shaft, with a small clearance between them. Steam is admitted tangentially through a nozzle on the right, and after flowing through the interspaces between the discs, escapes at the centre, causing the rotor to rotate by its frictional drag on the discs. To reverse the direction of rotation, the nozzle on the right is closed, and that shown on the left opened.

Mechanically nothing could be simpler, but unfortunately this mechanical simplicity is purchased at the expense of hydraulic inefficiency, as any of the various inventors, who have experimented on the device, could have ascertained had they applied to someone with a competent knowledge of theoretical mechanics. That the system is likely to be defective in this respect is obvious from the consideration that in a perfect turbine the steam must expand adiabatically. Now, in turbines of the type under consideration, the whole impelling force is due to the fact that the fluid slides over the surfaces of the discs with friction, against which it does work, and this frictional work is returned to the steam as heat. The whole impulsion of the rotor accordingly is dependent on the wasting of work by friction. If there were no friction, the steam would expand adiabatically, but would do no work, whereas, in the case of an ordinary turbine, could adiabatic expansion be secured, the efficiency would be a maximum. It can be shown, in short, that the maximum possible hydraulic efficiency of such a turbine is 50 per cent., and any experiments showing a better result than this can safely be discarded, though some allowance may be necessary for the fact that an hydraulic efficiency of 50 per cent. may, in a compound turbine, owing to the reheat factor, correspond to a somewhat higher thermodynamic efficiency, since the work wasted in friction at the high-pressure end of such a turbine is partially recoverable in subsequent stages.

Obviously, the system of maintaining a motion and doing work by the frictional drag of a fluid is not confined to cases of rotation, and the mathematical aspect of the question is, perhaps, more simply presented if we consider a case of rectilinear motion. Thus, suppose a stream of fluid moving at v ft. a second to be discharged into a tank mounted on wheels. Let the latter at the outset be held fast, then, although the jet exercises a frictional drag on the tank, no work is done, since motion of the latter is prevented. The frictional drag on the tank is equal to the momentum destroyed per second; or if W denote the weight discharged per second, the thrust on the tank is given by the relation $T = \frac{W}{g} v$.

At the same time the kinetic energy destroyed per second is $W \frac{v^2}{2g}$. Next assume the speed of the jet and the speed of the tank are both increased by the amount s. Then assuming, as before, that the fluid merely collects in the tank, the frictional drag is unaltered, since the fluid enters with an absolute velocity $v + s$, and remains there with an absolute velocity s. Hence the frictional drag impelling the tank is again $T = \frac{W}{g} v$, and the useful work done per second in propelling the tank is $T s = \frac{W}{g} v s$.

The kinetic energy supplied by the jet is now, however, $\frac{W}{g} \frac{(v + s)^2}{2}$.

Hence the efficiency of the device is

$$\frac{W}{g} v s \div \frac{W}{g} \frac{(v + s)^2}{2} = \frac{2 v s}{(v + s)^2}.$$

By differentiation, it is easily seen that this is a maximum when $v = s$, in which case the efficiency is $\frac{1}{2}$. Finally, let the speed of the jet be still further increased by an amount y, whilst the speed of the tank remains constant at s. The fluid is now delivered from the tank with an absolute velocity $s + y$, and a relative velocity y. The case, therefore, is exactly analogous to the Tesla turbine. The frictional drag remains the same as before—viz., $T = \frac{W}{g} v$, and the work done is still $\frac{W}{g} v s$.

The kinetic energy supplied is now, however, $W \frac{(v + s + y)^2}{2g}$, so that the efficiency is $\frac{2 v s}{(v+s+y)^2}$, which is less than when the whole of the fluid remained, and moved with the tank. In that case the maximum possible hydraulic efficiency was 50 per cent., so that when the fluid is delivered as it is in the case of the Tesla turbine, the hydraulic efficiency must be less than $\frac{1}{2}$. Of course, the motion in the latter is not rectilinear, but the argument above set forth applies identically, if for linear momentum we substitute moment of momentum, for frictional drag frictional torque, and for linear velocity angular velocity.

To make an efficient turbine of the device it would be necessary to provide vanes. We should then get a construction analogous to the "Jumbo" turbine patented and experimented with by Sir Charles Parsons many years ago. This was abandoned because it was found that any solid particles which might accidentally get into the turbine were kept in a constant state of flux between the rotor and the standing portion of the machine. They were carried in with the steam and flung out again by the centrifugal force, and the wear was consequently excessive.

Fig. 1.

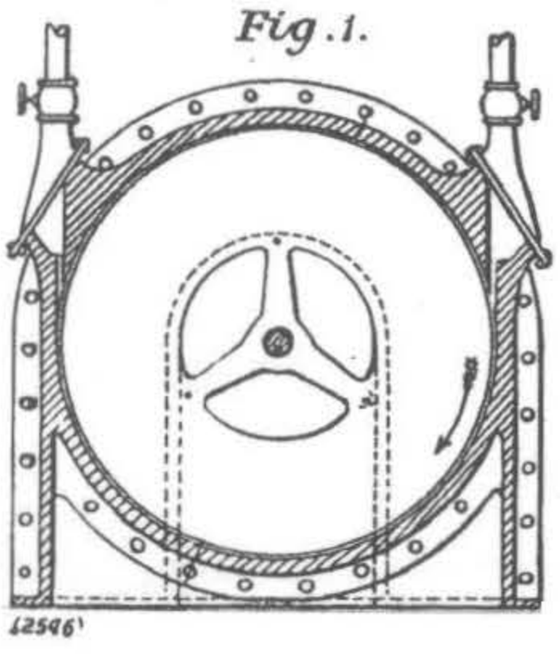


Fig. 2.

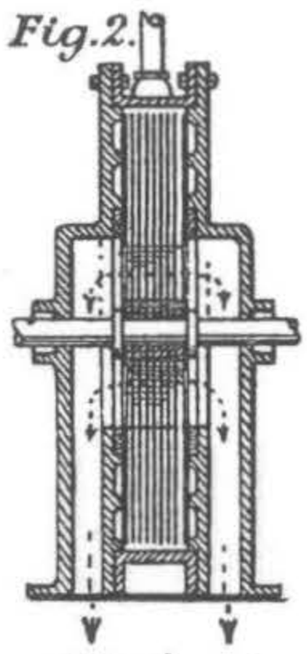
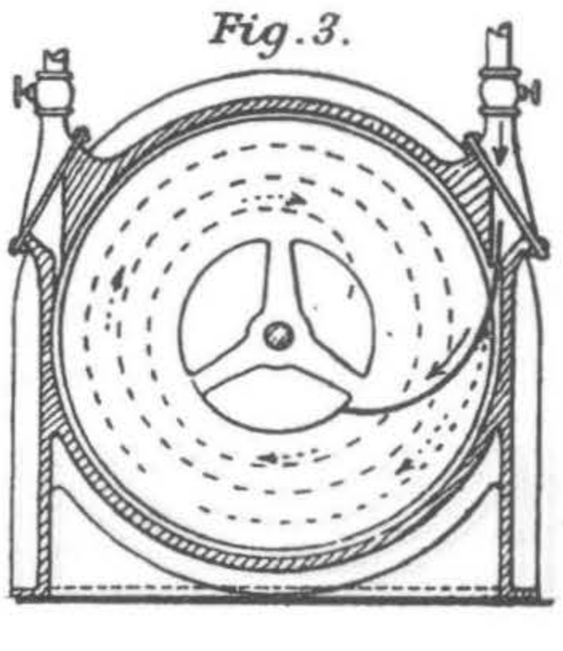


Fig. 3.



Tesla's New Mechanical Principle

Wide Field for Efficiency Increase in Motor Practice

AN engine which uses gasoline as a fuel and is capable of delivering 60 per cent. of the inherent energy of this fuel at the crankshaft instead of the customary 18 to 22 per cent. has been invented and constructed by Nikola Tesla.

"It is well known," states the inventor, "that a fluid possesses, among others, two salient properties: adhesion and viscosity. Owing to these a body propelled through such a medium encounters a peculiar impediment known as lateral or skin resistance, which is two-fold, one arising from the shock of the fluid against the asperities of the solid substance, the other from internal forces opposing molecular separation. As an inevitable consequence a certain amount of the fluid is dragged along by the moving body; conversely, if the body be placed in a fluid in motion, for the same reasons, it is impelled in the direction of movement."

Based on these observations, Nikola Tesla, the discoverer of the polyphase alternating current, has developed a new mechanical principle broadly applicable for the generation, transformation and transmission of mechanical energy. The machines constructed by Mr. Tesla are illustrated herewith, partly by photographic reproductions and partly by sectional drawings which accompanied Mr. Tesla's original treatise in the *Electrical Review and Western Electrician,* September 9.

In the development of his machines it has been the aim of the inventor to let the energated fluid *flow along its natural paths;* that is, those of least resistance, with as small a friction loss as possible. It is important to keep in mind the fact that in his, like in all other mechanical devices, *friction is inevitably equivalent to a loss in efficiency.* With these points in view Mr. Tesla uses in his construction but a few simple and economic elements creating as little resistance as possible for the fluids moving his machine or moved by them.

The machine, Fig. 1, is of simple construction and may be used as a motor or as a pump. In a steel housing, very much like to that of a centrifugal pump, is contained a runner consisting of a number of steel or bronze plates arranged in series upon a shaft, Fig. 2. Each plate or disc has three central openings A extending from the shaft to about one-third of the radius and separated by spokes. These openings are cut or stamped out of the discs and the surfaces of the latter are kept as smooth as possible.

If the device, Fig. 2, is mounted on bearings and rotated at considerable speed the following phenomenon takes place. The air, in direct touch with the metal discs, is held to them by molecular adhesion, clinging to the metal surfaces as water does to that of a solid it is brought in contact with, and therefore the air particles next to the discs are imparted motion in the direction of the rotation of the discs. Thus, some air is dragged along and its particles begin revolving about the shaft of the device. Since the movement of the air is rotary, centrifugal force causes it to move away from the central portions of the discs, the resultant between the rotary and centrifugal force being along a spiral line. This flow of air toward the periphery of the discs causes a fall of atmospheric pressure at the central regions, and these being occupied by the openings, air rushes in through the openings, and thus a continuous flow of air is maintained.

If the discs are enclosed in the casing seen in Fig. 1, and the shaft is rotated, the unit will work as a pump. In order to explain the office of the inlet and outlet pipes seen in the illustration, Fig. 3, is offered to illustrate the Tesla pump in partial end view and vertical cross-section. The air adjacent to the discs is dragged along in the direction of the arrows, approaching at the same time the periphery of the discs. In addition to this the particles not in direct touch with the discs, but with the moving air, are dragged along and imparted motion through viscosity, that is, the attraction of the particles of a fluid. The viscosity of air is about 100 times that of water. Thus, the entire body of air between the two discs—unless they are spaced too far—is transported to the peripheral portions of the interdiscular space and, after having reached the periphery, streams along the wall of the casing, which widens from the point 1 to 2, 3 and 4, until the air reaches the outlet where it is discharged. The quantity of the fluid propelled through this pump, according to tests made by its inventor, is approximately proportionate to the active surface of the runner—the total active surfaces of all the discs on the shaft—and to the effective speed of the machines; therefore, the performance of the pump is bettered with increasing size and number of revolutions per minute.

The machine, Figs. 1 to 3, has twenty-five plates 9 3-4 inches in diameter, the entire runner being 2 inches thick and the full weight including the casing of the machine being 20 pounds.

If a fluid under pressure is permitted to enter the casing

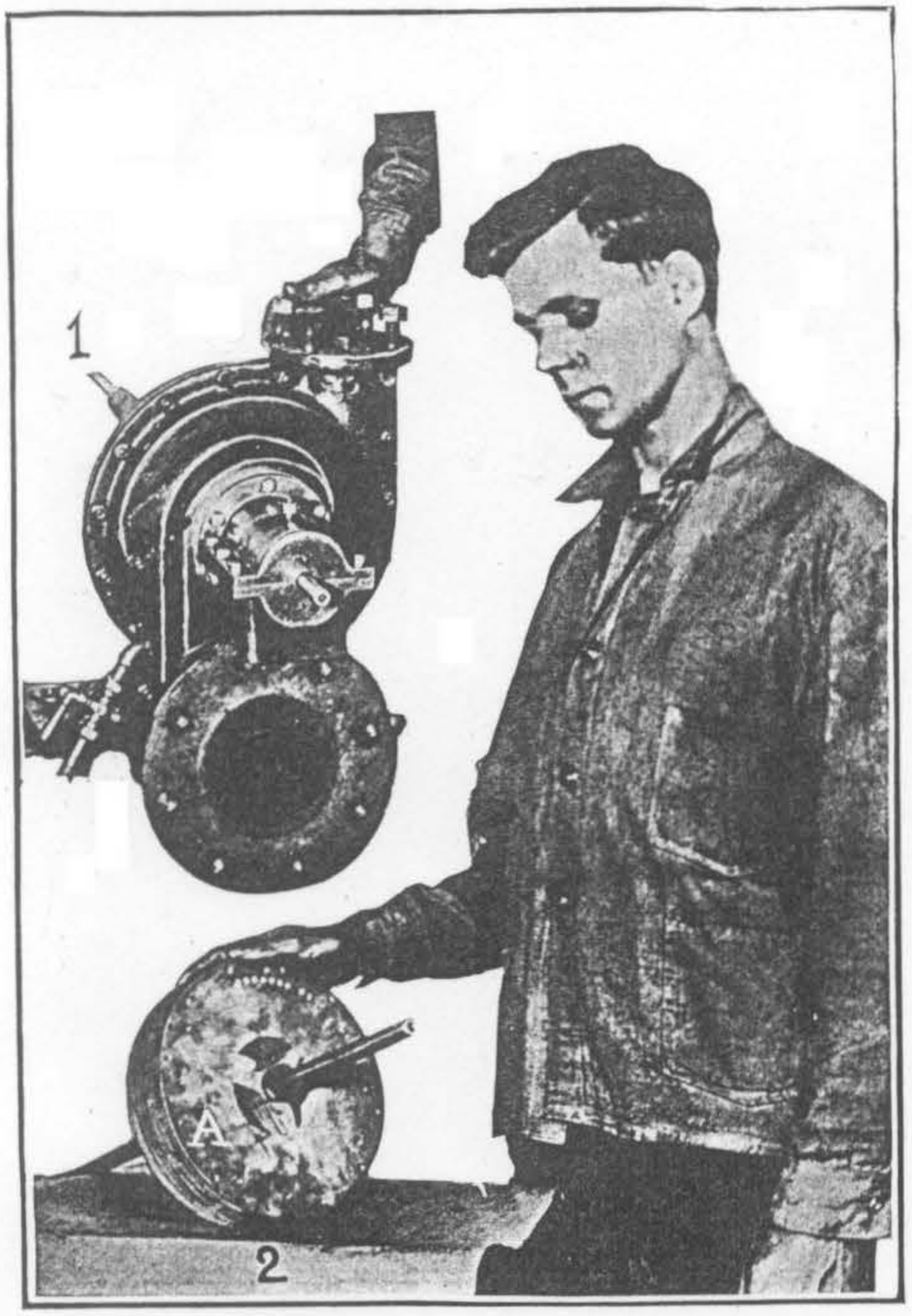


Fig. 1—110-horsepower steam-gasolene engine, weighing 20 pounds.
Fig. 2—Shaft and runner of engine

through what is marked outlet, Fig. 3, it will flow along the wall of the casing, passing the points 4, 3, 2 and 1 in the order named until, when it reaches the narrowing near the outlet, which now is the inlet, it is forced to enter the interdiscular space. In doing this the adhesion of the discs to the fluid causes the former to have motion imparted to them, so that they begin to rotate, while the fluid, which is continually giving off energy, loses in velocity. Since bodies having rotary speed imparted to them are subject to a centrifugal effect, and bodies expending energy in creating rotary motion, to a centripetal one, the fluid with decreasing speed approaches the center of rotation, and is discharged dead, without pressure, through the central openings of the discs. It is exhausted by gravity through the opening marked inlet, Fig. 3.

The engine so described, when driven by a mixture of steam and the products of a gaseous fuel burned in an auxiliary chamber showed 110 horsepower on the brake, and more load could have been sustained by it except for the small dimensioned shaft. While this instance shows that the same machine may be used as a prime mover and as a pump, it is obvious that a machine of this type specially constructed for the purpose of driving machinery may be improved upon by adapting some details to the specific needs of the situation. Thus Fig. 4 shows a Tesla rotary engine, applicable for steam or hot-air drive, having a nozzle through which the pressure of the driving steam is increased. A reversing nozzle is also provided.

As in the other engine the runner is composed of discs D, having central openings O and spokes S. The discs are held in posi-

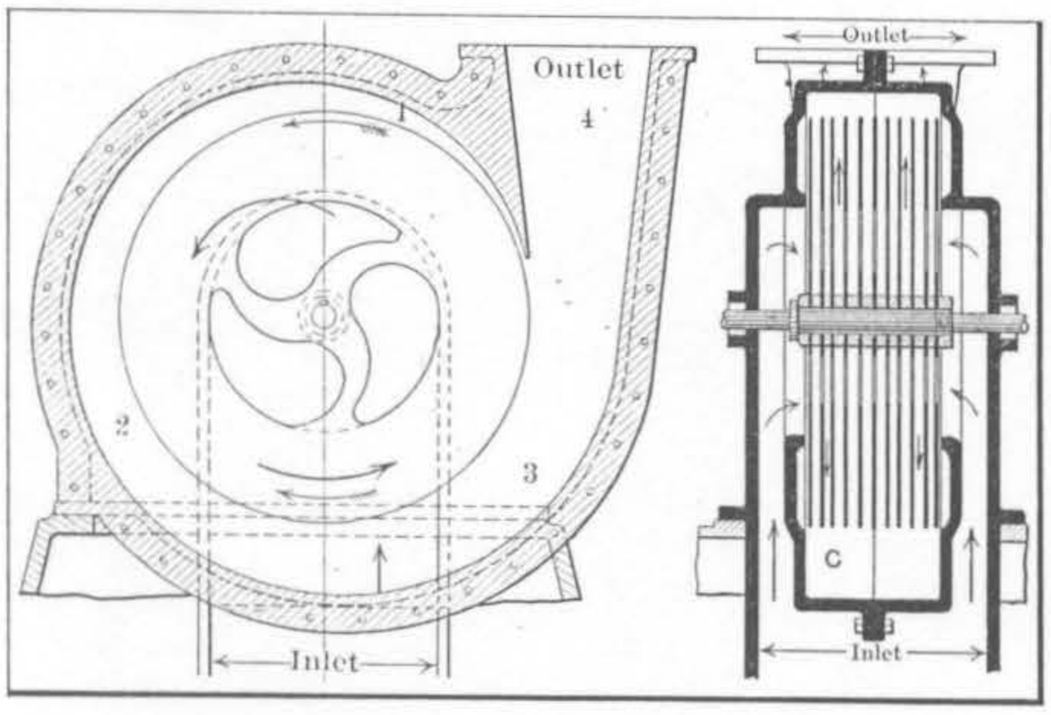


Fig. 3—Cross-section of Tesla rotary engine and pump

tion, being keyed to shaft S1 which is mounted on suitable bearings. Washers W, conforming in shape to the spokes and riveted thereto, separate the discs. For simplicity's sake, only a small number of discs is shown, with proportionally larger intervening spaces than are used in practice. The runner is mounted in a casing having two end castings S with outlets E, stuffing boxes B and a central ring R1 bored out to a circle of diameter slightly in increase of that of the discs. The ring has flanged extensions with inlets into which nozzles N are inserted. Circular grooves G and labyrinth packings P are provided on the sides of the runner.

A steam engine of this type has been installed and tested at the Waterside station of the New York Edison Company. The runner consists of twenty-five discs, diameter 18 inches, the engine base being 20 by 25 inches, and the height 5 feet. This engine developed, with steam admitted at 125 pounds pressure and exhausted at 14.7 pounds, 200 horsepower at 9,000 revolutions. About 38 pounds of saturated steam were needed per horsepower-hour, but Mr. Tesla stated that by the use of moderately superheated steam and the ordinary vacuum the consumption may be reduced to about one-third of the quantity stated.

If the motor runs without load, the fluid which enters at the periphery completes a number of circles before it has expended all its energy and it leaves through the central openings. As soon as the load is put on, the paths of the fluid are cut short, being

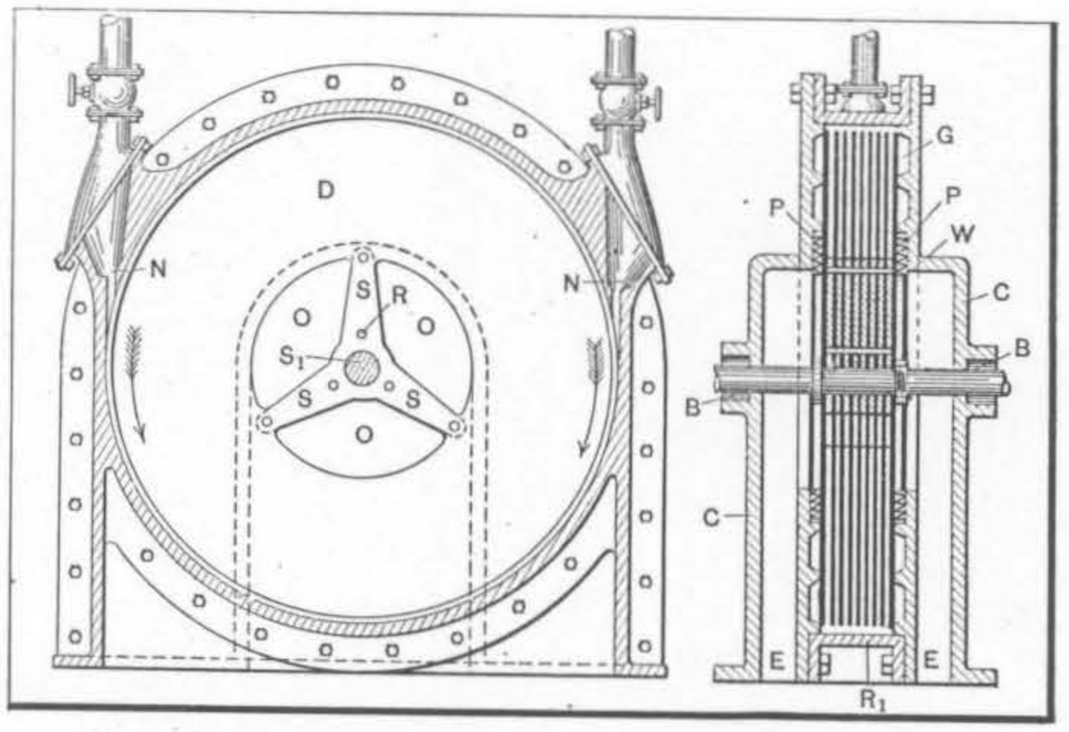


Fig. 4—Cross-section of Tesla engine for reversible steam drive

changed to a spiral with fewer turns. Despite the difficulty attending the work of determining the operating conditions in this machine, the following seems to be an established fact. The torque produced by the engine is directly proportional to the square of the velocity of the fluid relatively to the runner and to the effective area of the discs, and inversely to the distance between the individual discs. The maximum amount of work is done when the effective speed of the runner is one-half that of the entering fluid.

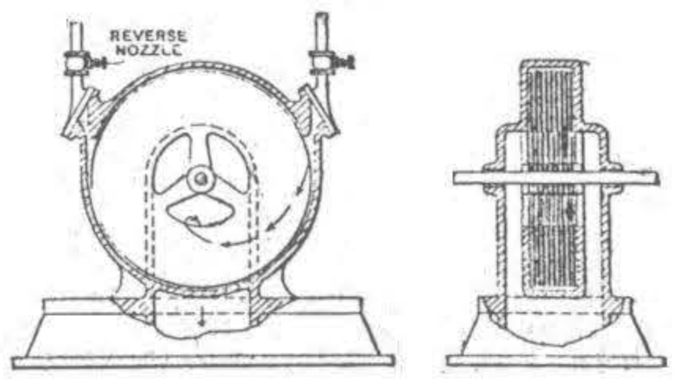
There is no unsurmountable difficulty in the construction of a light and practical motor of this type for the use of liquid hydrocarbon fuels. Of course, an auxiliary combustion chamber and carbureter have to be used in connection with the rotary engine described, and a very small pump to supply the air to the gasoline, if such be used. Mr. Tesla states that he has carried out numerous experiments along this line, and by the use of his motor transforms 60 per cent. of the energy of the gasoline into mechanical work available at the shaft. This may seem very high, but since with a rotary engine (compare steam engines and turbines) it is not necessary to encounter such vast cooling losses as in common gas engine practice, the high efficiency claimed by him might perhaps be obtained even in an average gasoline engine of his construction. It has been shown in THE AUTOMOBILE, July 27, 1911, pages 147-149, that the cooling losses in an automobile engine amount to 35.9 per cent., and the heat losses in the exhaust to 35.2 per cent. These heat losses together with other small expenditures of energies leave only 21.8 per cent. available at the motor shaft, that is, one-third of what is said to be recovered by an engine of the Tesla type.

The possibility of the enormous power output of Tesla engines in proportion to their weight may be understood when the great amount of active surface of these engines is considered. This fact also accounts to some extent for the large thermal efficiency. The 110-horsepower motor weighs 20 pounds, or 5.25 pounds per horsepower; the 200-horsepower engine at the Edison company's station weighs 400 pounds, or 2 pounds per horsepower, and by refinements of construction, the application of superheated steam and the use of vacuum exhaust Mr. Tesla expects to succeed in the building of an engine weighing 1-4 pound per horsepower.

A comparison between a Tesla pump and an ordinary pump may be of interest and not out of place here. In the laboratory of the inventor a small pump of the construction here illustrated is working. It is operated by a small electric motor, consuming 1-12 horsepower, and delivers 40 gallons per minute against a 9-foot head. The consumption of a good centrifugal pump rendering this work is about 1-3 horsepower, and in no case less than 1-4. This means one-third the power consumption for a given amount of work to be performed. As to the application of Mr. Tesla's principle to prime movers, it is stated by him that in large machines, by the use of superheated steam, high vacuum and the minimum of friction obtaining at these dimensions, about 95 per cent. of the fluid energy of the steam are delivered at the shaft.

THE TESLA STEAM TURBINE.

Experiments with a novel design of steam turbine have been made by Mr. Nikola Tesla, who is well known in the electrical field on account of the part he has played in the developments in connection with the rotating magnetic field and other alternating current subjects. A diagrammatical section of the Tesla steam turbine is shown in the accompanying illustration. The steam is expanded in a nozzle, and the heat energy is thus converted into kinetic energy. The rotor of the steam turbine simply consists of a number of thin, flat discs, the inlet for the steam being at the outer periphery of these discs, and the outlet being at their centre, as indicated. The high-velocity steam escaping from the nozzle is caused to impinge tangentially on the edges of the discs, and in order to escape it must find a path from the periphery of the discs to the central outlet. The velocity energy of the steam produces a rotary motion of the discs, due to molecular drag on the surface, and hence the path of the steam from the outside to the inside of the discs will be a spiral one. Expressing the matter in popular terms, we may say that the action is due simply to the friction of the steam against the sides of the discs as the steam moves



from the outside periphery to the centre along a spiral path.

The arrangement shown in the illustration permits of easy and convenient reversal, as it is only necessary to provide a duplicate nozzle discharging against the opposite side of the discs as indicated. When the machine is at rest, or is running slowly, as in starting, the steam takes the shortest path from nozzle to exhaust, and thus develops a comparatively large torque. As the machine speeds up, the difference in velocity between the steam and the discs decreases, and the centrifugal force tends to lengthen the spiral path of the steam, so that a given amount of steam may make several revolutions with the discs before finally passing out through the exhaust opening.

A turbine of this type has been tested at the Waterside Station of the New York Edison Co. The rotor of the tested turbine has 25 discs, each 18in. in diameter. The assembled turbine occupies a floor space of 20in. by 35in. and is about 5ft. high, completely installed. With steam at 125lb. gauge pressure per square inch exhausting into the atmosphere, 200H.P. was developed with a speed of 9,000 r.p.m. The steam consumption was 38lb. per horse-power-hour. The weight of the turbine is 400lb. giving a unit weight of only 2lb. per H.P. While the steam consumption at present is rather high. Mr. Tesla believes that with moderate superheat and a degree of vacuum the same as that ordinarily used in a turbine plant, the steam consumption can be reduced materially.

The principle employed is not limited to steam turbines. It can be applied as well to a type of centrifugal pump, having a series of smooth, flat discs revolving in a casing, these discs having no vanes or other impelling projections. The motion of the water is produced simply by the friction or molecular adhesion between the discs and the fluid. In this case, the fluid is, of course, taken in at the centre of the discs and forced along a spiral path to the outside periphery.—*Machinery.*

The Tesla Turbine

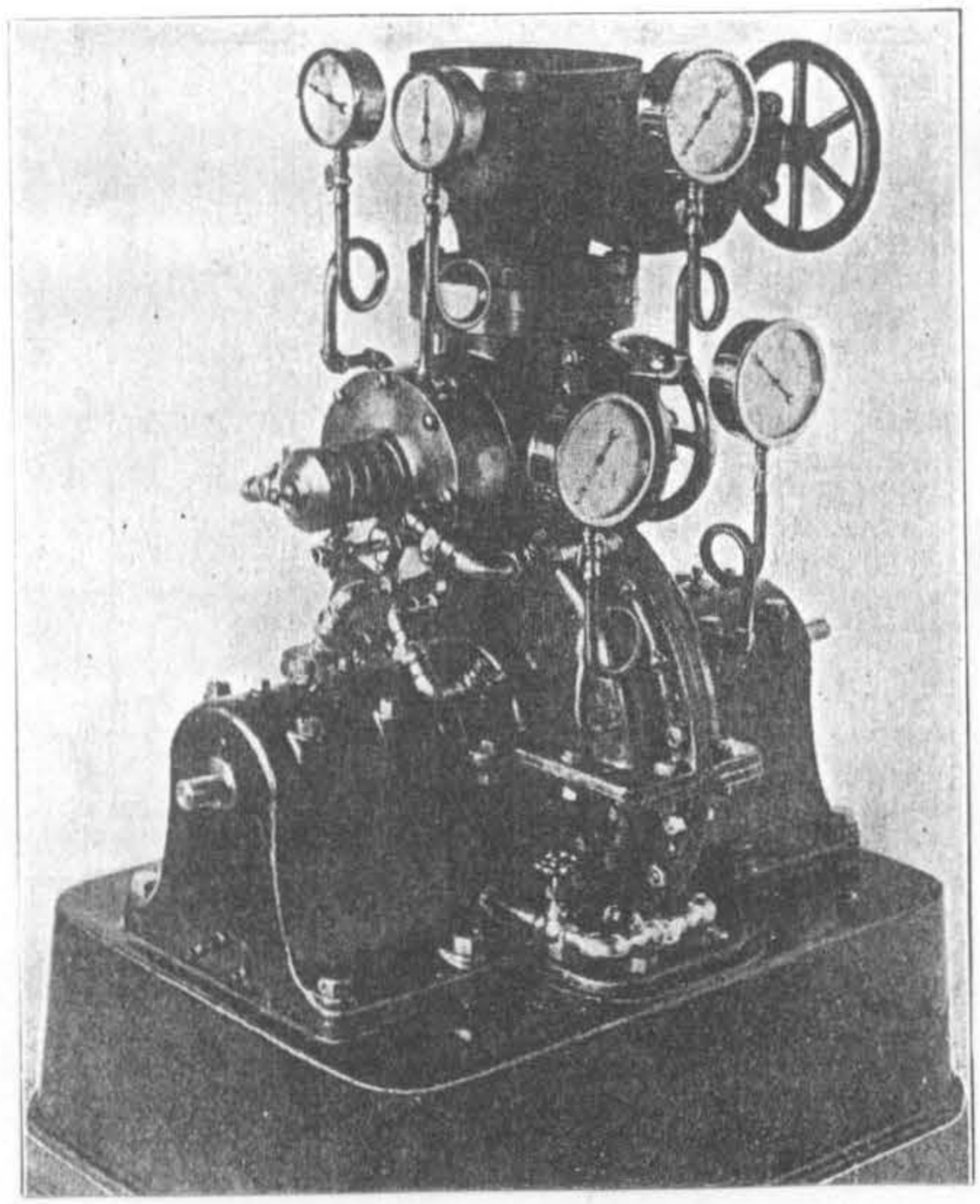
By E. F. STEARNS



A Complete 110-Hp. Turbine

ENGINEERS and men of science throughout the world are awaiting with unusual interest the completion of tests of a new steam turbine designed by Nikola Tesla, which preliminary experiments indicate will give enormous power from a comparatively small and extremely lightweight engine. Ten horsepower to a pound of weight has already been developed with the engines that have been tested and enthusiasts who have witnessed the work of the turbine declare the perfect rotor has at last been found. To what extent this is true, time and the construction of larger units than have yet been used must prove. At present, while the practical experimental stage has not yet been passed, the entire engineering world is profoundly interested in the work that has been done, and awaits future development with much concern.

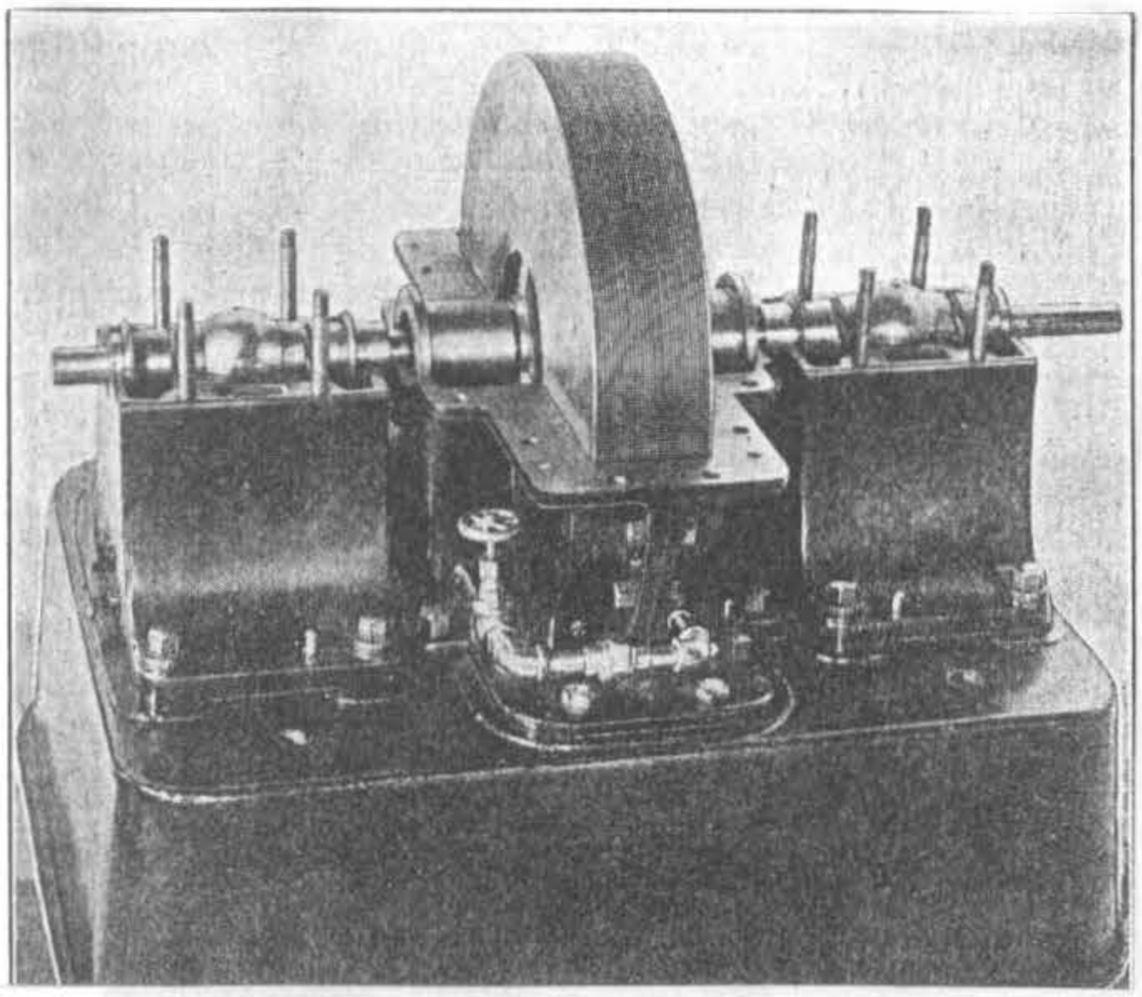
Operation of the Tesla engine depends upon two well-known properties of fluids: adhesion — the tendency, for example, of a certain amount of water to cling to a smooth metal surface, even when the bulk of the water has been shaken off; and viscosity, the resistance of fluids to molecular separation, the tendency of one drop, in a mass of fluid, to drag adjoining drops with it, if set in motion.



The Turbine, Invented by Nikola Tesla, Which is Based on a New Principle

In its simplest form, the new idea takes the shape of the inventor's little "air-diffuser." This consists of half a dozen very thin steel disks, some 9 or 10 in. in diameter, set horizontally, about ⅛ in. apart, on the upright shaft of a small, horizontal electric motor, the center of each disk being cut away in a 3-in. circle. With current switched into the motor, the disks revolve, and instantly strong suction can be felt by the hand held several inches above the axis, while a powerful current of air is blown from the spaces between the disks. The air, in short, is being sucked into the central opening and hurled out at the periphery. Consider now that disks and shaft have been inclosed in an air-tight case, with an inlet at the axis and an outlet at one point of the periphery; we have an air pump, a Tesla blower, one of which, now in operation, is delivering 10,000 cu. ft. of air per minute. Suppose again that water, instead of air, be the fluid admitted. Entering the cut-away space at the centers of the disks, the adhesion of the metal drags it, in a widening spiral, toward the spinning circumferences, there to hurl it away in a tangential direction; and since the water must now leave the case by its one outlet, we have the Tesla pump, on rather new lines.

Assume that the pumping process



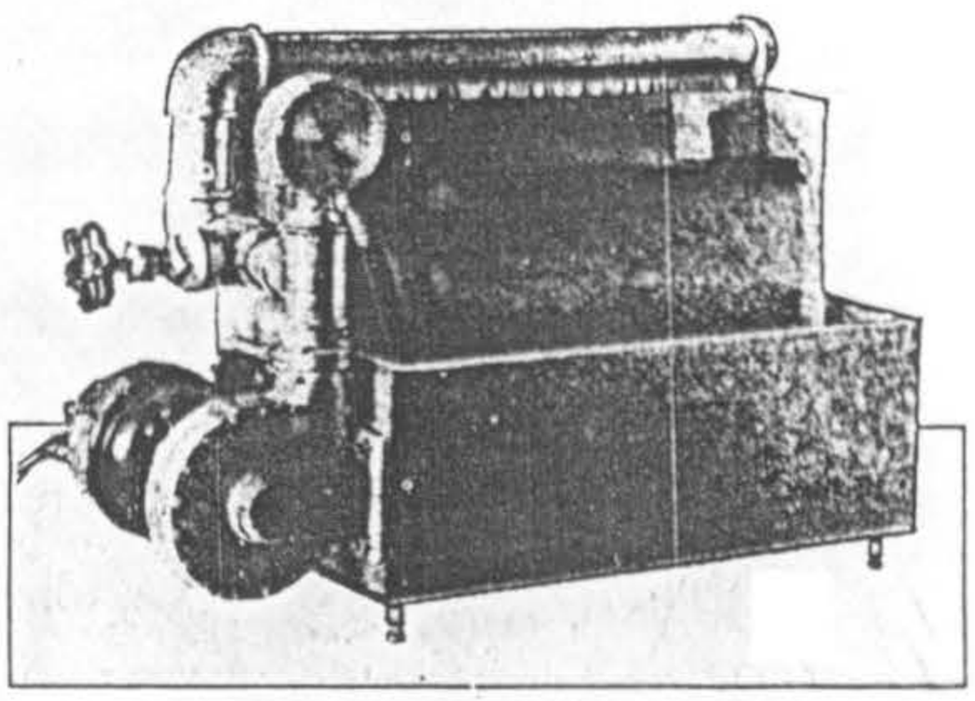
The 200-Hp. Tesla Turbine, with the Upper Section of the Case Removed to Show the Disks, etc.

is to be reversed, that the disks, instead of being turned by an outside force, are to produce power themselves, that steam under pressure has been substituted for the water. The steam, admitted to the case, strikes the edges of the disks and takes the path of least resistance between them, a narrowing spiral toward the outlet through their centers. The disks themselves are dragged around, the shaft is turned and power is being generated in an entirely new fashion.

Working under the best conditions —in the experimental laboratory— a single disk of 9¾ in. diameter, with a center outlet of 3⅝ in., will develop 5 hp. Without nearly approaching the limit of strain of the materials, the pressure could be increased so that the velocity of rotation would be doubled and the power quadrupled; so that with a single steel plate, 1/32 in. in thickness, weighing about ⅜ lb., and delivering 20 hp., we have a possible 53 hp. to 1 lb. of actually working material. Or a more concrete example can be found in a double Tesla turbine, built for practical service and nearly completed. In this there are two sets of disks, arranged to revolve in opposite directions and each set developing 200 hp.

Comparison between the old and the newest is best given in the inventor's own words:

"In most engines, a very small proportion of the total amount of material is actively employed in the production of power. For example, in reciprocating engines of the older type, the power-giving portion—cylinder, piston, etc.—was no more than a fraction of 1 per cent of the total weight of material used in construction. The present form of turbine, with an efficiency of about 62 per cent was a great advance, but even in this form of machine scarcely more than 1 per cent or 2 per cent is used in actually generating power at a given moment. The new turbine offers a striking contrast, using as it does practically the entire material of the rotor (the whole surfaces of the disks) as an active source of power, and with an efficiency of 80 per cent or even 90 per cent. Owing to this, it is possible to get an enormous amount of power from a small space. Assuming sufficient boiler capacity on a vessel such as the "Mauretania," it would be perfectly easy to develop, instead of some 70,000 hp., 4,000,000 hp. in the same space—and this is a conservative statement."



A little model pump in which five disks, 3 in. in diameter, contained in the lower front, circular case, throw 40 gal. a minute when the little electric motor is started up. The water flows out of a slit at the bottom of the upper pipe and flows back to the lower tank as seen in the foreground. This model illustrates one point astonishingly: the power can be shut off when the pump is in full operation and everything stops instantly without the slightest jar. With the power switched on suddenly, the full flow is resumed so quickly that the interval between the click of the switch and the full stream of water is too small to be determined with an ordinary watch.

ARE FATHERS OF INDUSTRY

Men Whose Discoveries Have Created New Fields of Business.

MANY GREAT NAMES

Edison, Westinghouse, Tesla, Fritz, Acheson and Others.

(Copyright, 1911, by E. J. Edwards.)

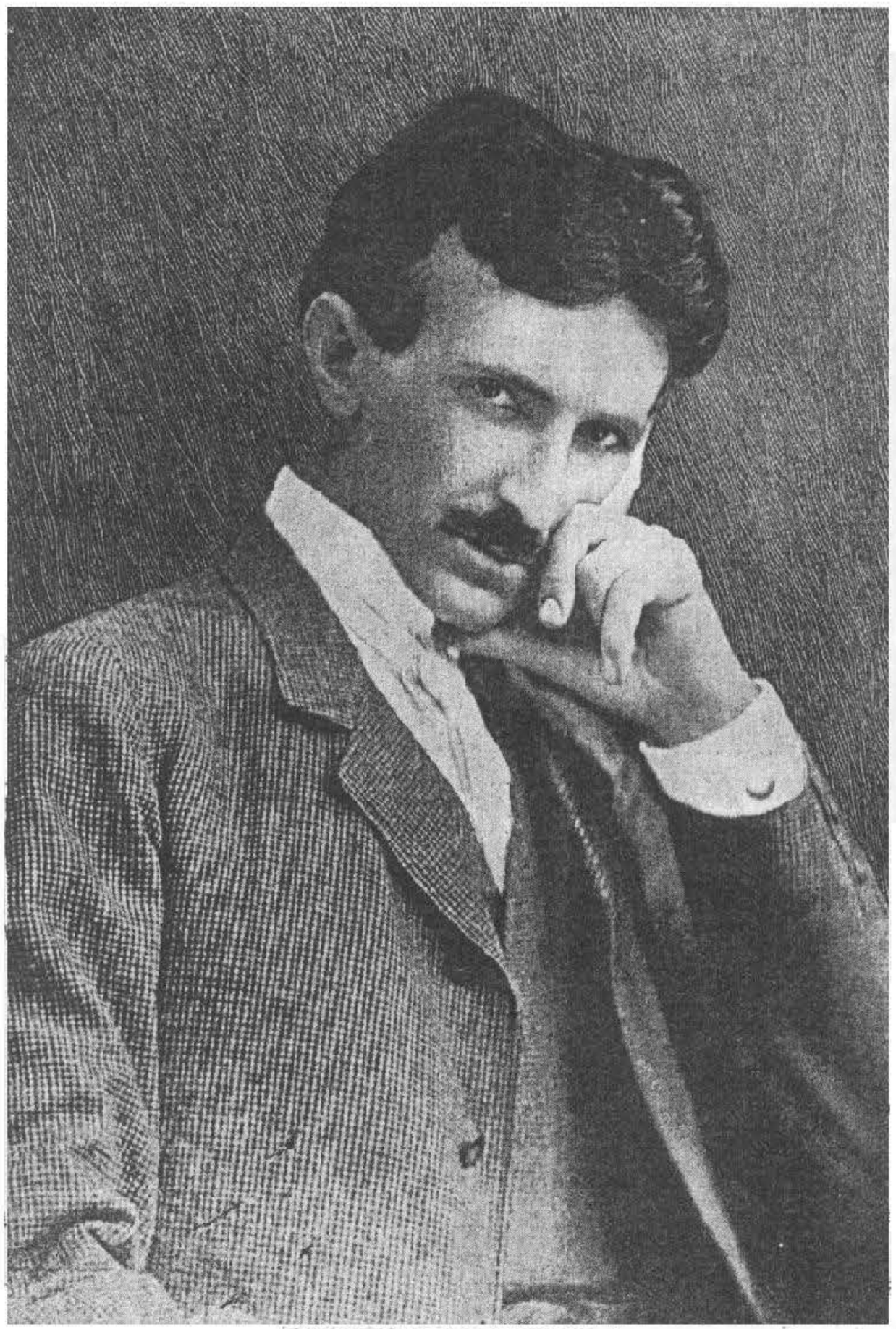
There is a considerable company of men living today to whom the title of father of industry may be accorded—men who by their inventions and discoveries and their practical application of these have created new fields of business.

Thomas A. Edison, the father of the electric-lighting industry and the phonograph business, to mention only two of his industrial creations, is undoubtedly the most illustrious of them.

Alexander Graham Bell, the inventor of the telephone, is one of the most distinguished, although with regard to the telephone business it may be said that Theodore N. Vail, a business-man rather than a man of science, is the father of it as a great unified system.

To William Marconi belongs the honor of being the father of wireless telegraphy, only a few years ago a scientific curiosity, now a regular business.

Nicola Tesla may be regarded as the father of the commercial utilization of the alternating electric current, since he invented the apparatus by which that utilization is made safe and practicable. At the same time, from another point of view, George Westinghouse, under whose patronage Tesla achieved and perfected his great inventions, may be regarded as the father of that great branch of electric industry, since he was the inspirer of its development.



NIKOLA TESLA.
Father of the alternating current.

Popular Electricity January 1912

High Frequency Apparatus to Go with a Wireless Set

By JAMES H. DORAN

Many amateurs have undoubtedly wished to use their wireless transmitting instruments for the generation of high frequency currents. The only additional

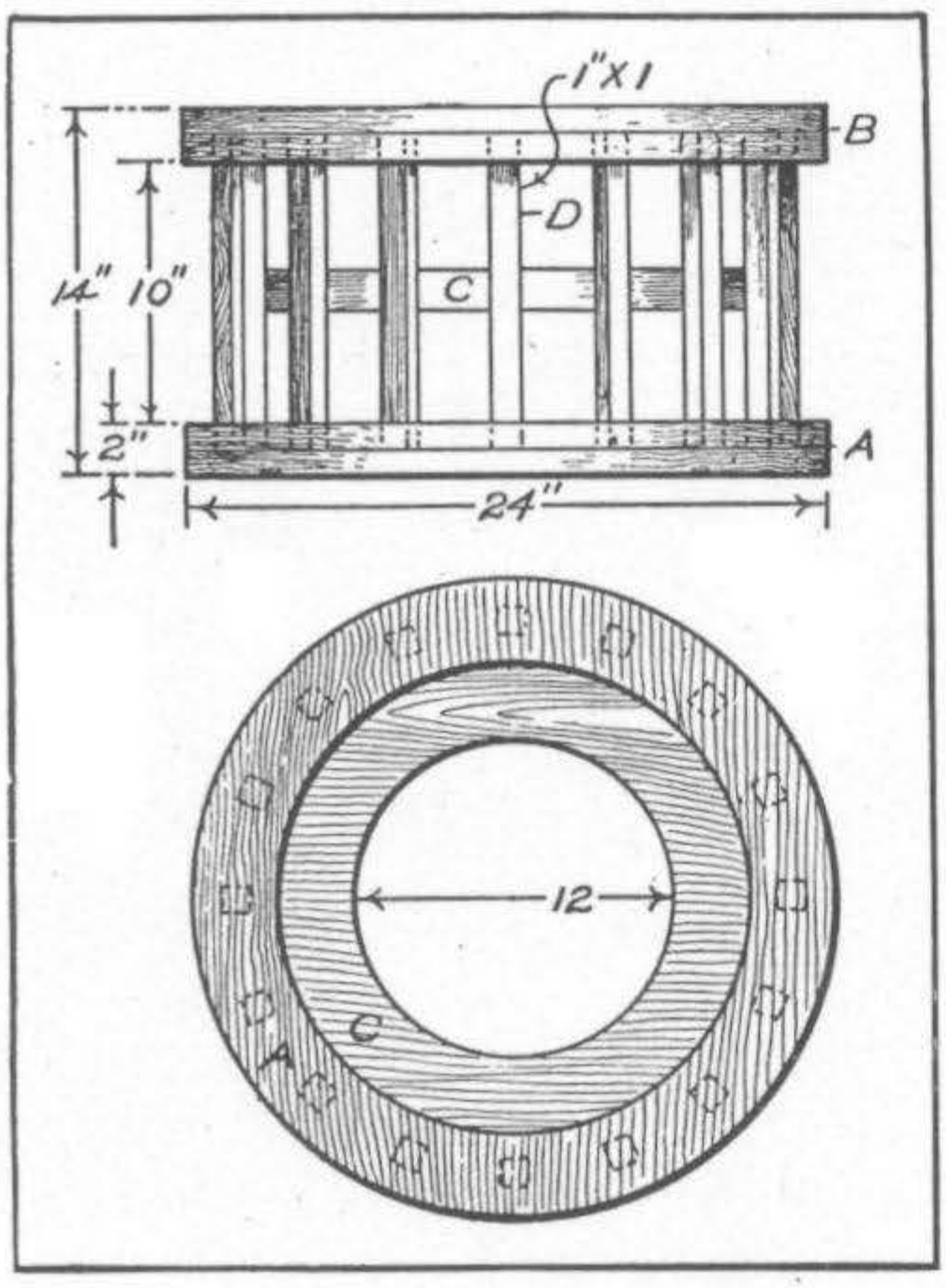


FIG. 1. PRIMARY FRAME

apparatus required is either a Tesla coil or resonator. These can be made with but little trouble and expense, and the experiments that can be performed with them are among the most instructive as well as the most spectacular in electricity.

The coils and resonators described are for use with ¾ to 1½ K. W. transformers, condensers and spark gaps.

In the construction of coils and resonators of this type the primary is placed over the secondary and is about twice the diameter of the secondary. Only one layer of wire is used on the primary, the number of turns being from five to fifteen according to size of coil and number of wire.

For the primary frame cut out of one-inch hardwood material four circular rings two feet in diameter and two inches wide. Glue these together so as to form the end pieces (A) and (B), Fig. 1. Make sixteen pieces 1 by 1 inch, in cross section and twelve inches long. These are shown by (D), Fig. 1. Fit these into recesses extending through the two inside layers of (A) and (B) and glue. This forms a cage or drum on which to wind the primary wire. Into the center of the cage fix by means of pegs a circular block (C), two inches thick and with a circular opening in the center twelve inches in diameter. This block is to hold the secondary in place inside the primary. Give the cage two coatings of oil shellac and a coating of some good stain or varnish. When dry wind on the cage twelve turns of No. 4 hard drawn bare copper wire, spacing the turns evenly apart.

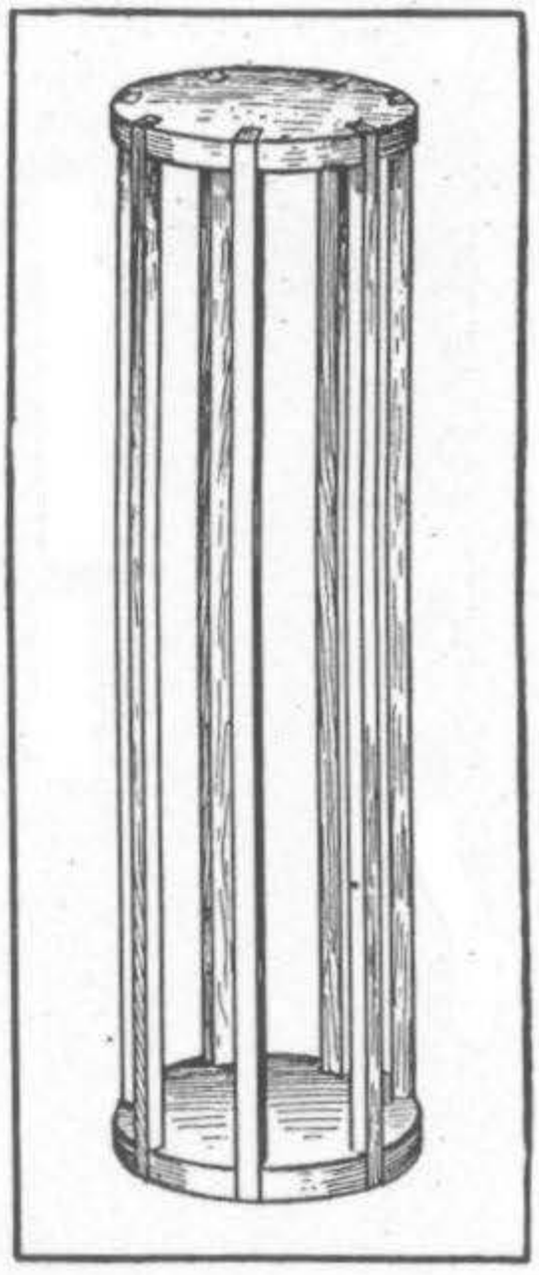


FIG. 2. SECONDARY CAGE

For the secondary make another cage 11½ inches in diameter and 50 inches long. The end pieces can be made solid and of 1⅛-inch material. The cross pieces or ribs should be 1 by 1 inches and are glued and fitted into the end pieces with the edges flush. About

ten should be used. Fig. 2 shows the complete secondary cage. Give the cage two or three coats of shellac and when dry wind on several layers of leatheroid or heavily paraffined paper so as to form a stiff drum on which to wind the secondary wire.

In the center of the end pieces bore ¾-inch holes and suspend the drum by an iron rod run through these. Wind on

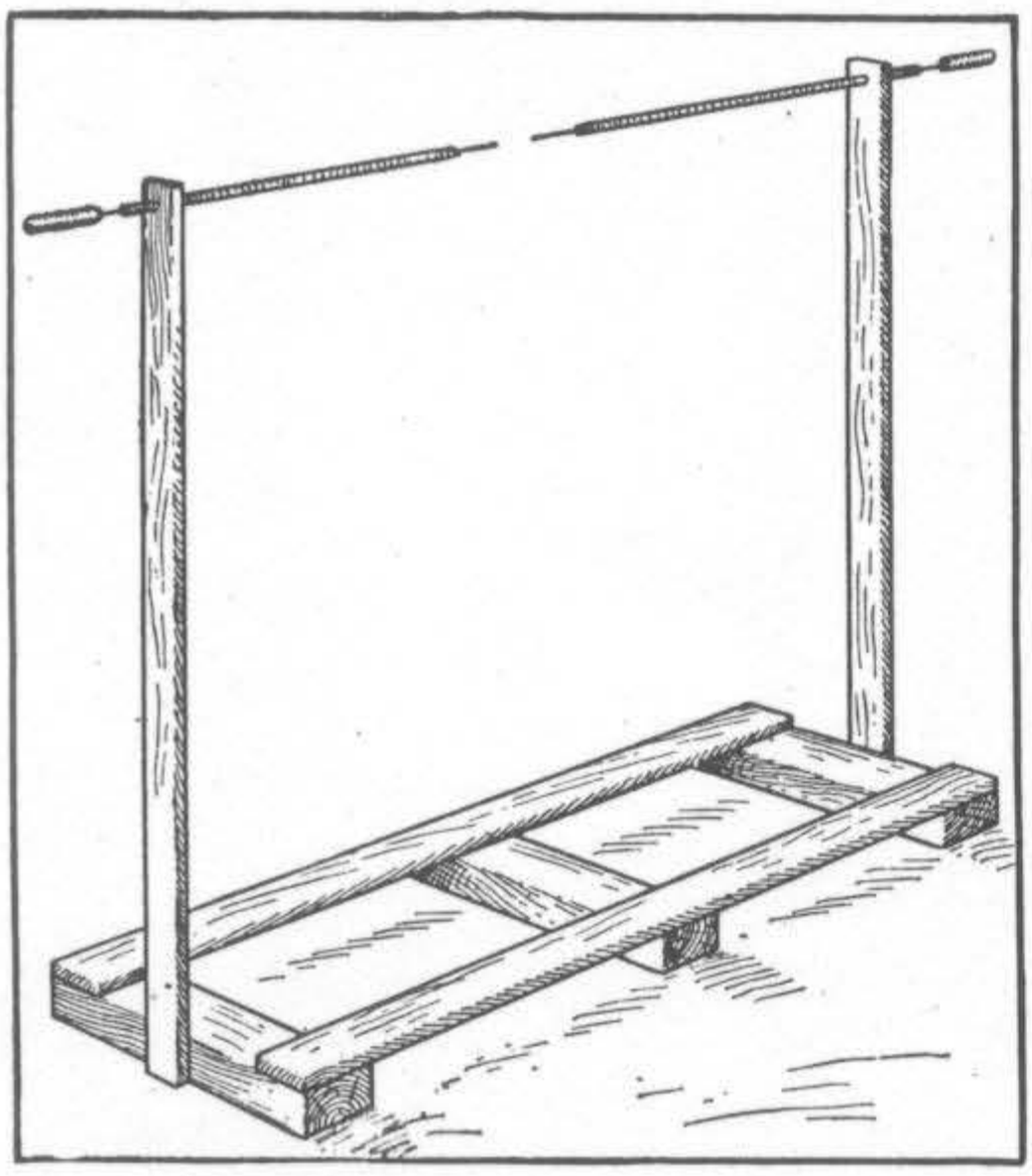


FIG. 3. BASE FOR COIL AND SUPPORTS FOR SPARK GAP

the drum 800 or 900 turns of No. 24 D. C. C. magnet wire, about five pounds will be required. Space the turns by winding in at the same time a layer of ordinary twine. When wound give the whole several coatings of shellac or micalac.

For the Tesla coil the primary should be fitted over the secondary and concentric with it. No nails or screws should be used in the construction of either the primary or secondary. The base can be made of three pieces of two by four 30 inches long and held in place by two pieces 3 by 1 inch, 50 inches long, nailed to these (see Fig. 3). To this base two uprights 3 by 1 inch, 61 inches long, are screwed and in the center of these the secondary (supporting the primary) is fastened by screws. The spark-gap is placed above the coil and is made of brass rods ¼ inch in diameter and 2½ feet long and supported by brass tubes two inches long fitted into the uprights and allowing the rods to slide freely. The ends should be filed to a sharp point, and hard rubber rods ¾ by 6 inches long should be used for handles.

The resonator is of the Oudin type. Its construction is the same as the Tesla coil except that the circular block (C) in the primary may be omitted. The secondary is placed in a vertical position and the primary at the bottom and concentric with the secondary. Instead of a spark gap of a ⅜-inch brass rod screwed into a 3-inch brass ball is used as the terminal, one end of the secondary being connected to the rod. Resonators of this kind are known as the unipolar type, the ground being used as the other terminal when two are necessary.

Fig. 4 shows the method of connecting the Tesla coil, the connections for the resonator being the same except that the bottom turn of the secondary is connected to the bottom turn of the primary and this grounded. Fig. 5 shows the resonator nearly completed.

The transformer used should give a secondary voltage of from 10,000 to 20,000, and the condenser of the best size

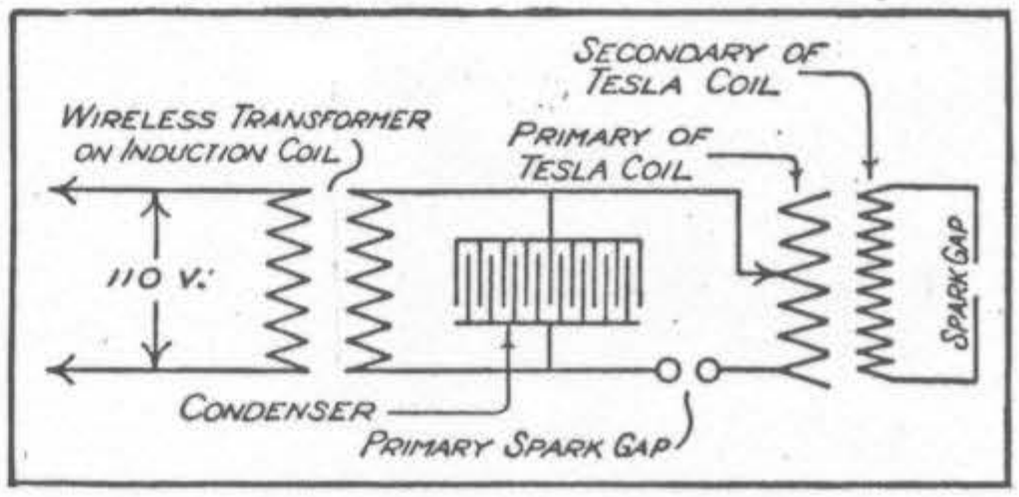


FIG. 4. METHOD OF CONNECTING TESLA COIL

suited for the transformer. The surface of the spark gap should be rather small, ½ or ¾ inch in diameter and some means should be used to keep it cool. It is preferably made of zinc disks.

The coil or resonator should be in tune with the other apparatus and this may be accomplished by varying the number of

plates or sections in the condenser and the number of turns of wire in the primary of the coil or resonator. It is best in tune when the longest sparks can be obtained from the secondary. The primary spark gap should also be carefully regulated to give the best results.

When working properly with a one to 1½ K. W. transformer, etc., the sparks should be 30 to 36 inches long for the Tesla coil and somewhat shorter for the resonator.

The frequency varies considerably according to the capacity of the condenser and the number of turns of wire used in the primary. Using a condenser of .12 M. F. capacity it varies from 225,000 to

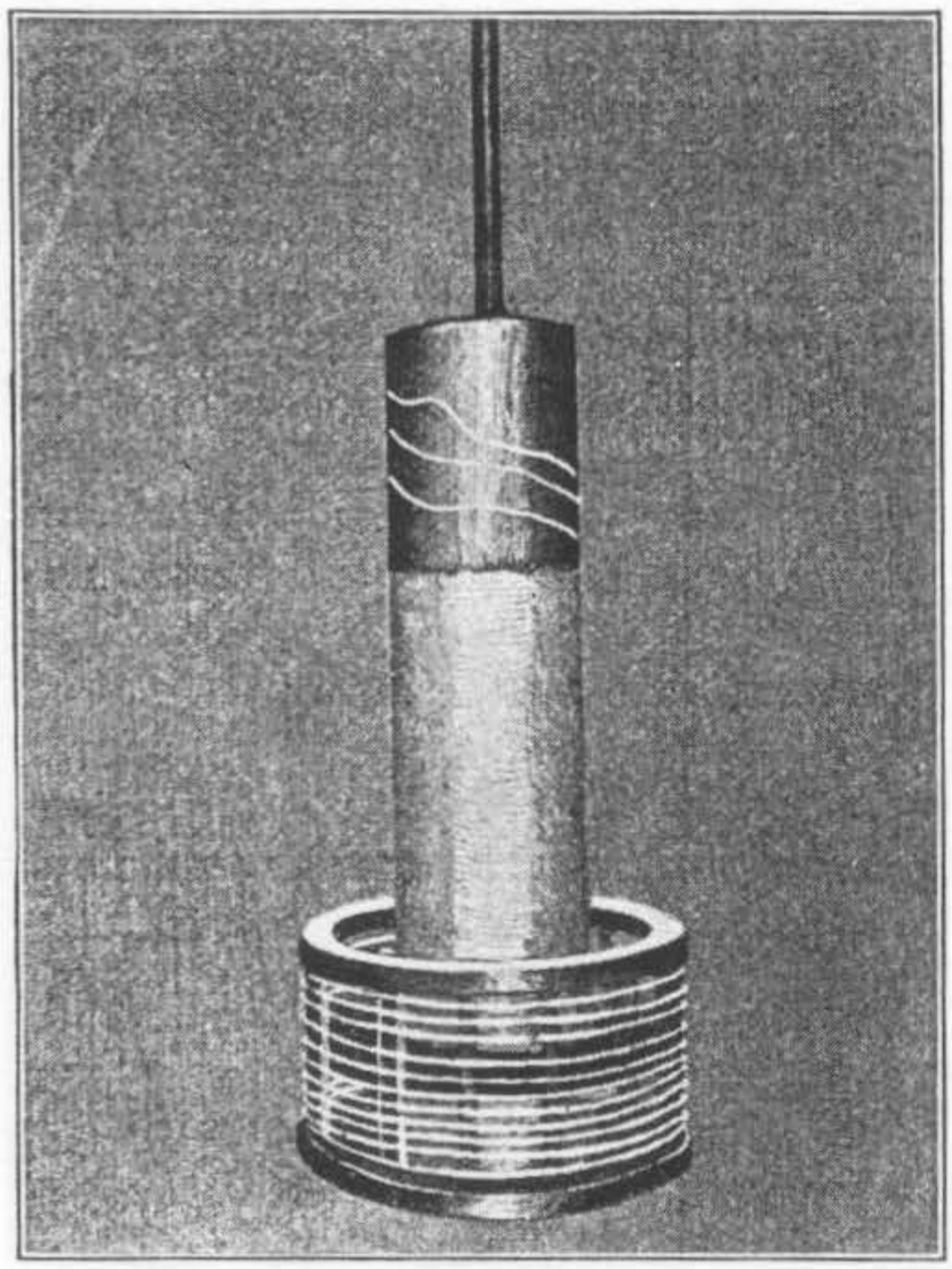


FIG. 5. RESONATOR NEARLY COMPLETED

over 1,000,000, the smaller number of turns used in the primary the greater the frequency. The voltage is difficult to calculate but runs up to about three-quarters of a million when working full force.

The above coil or resonator can be used with large induction coils (12 to 24 inch sparks) and even small ones sometimes give good results. The author has obtained sparks over 10 inches long by using a 2½ inch coil and a good electrolytic interrupter, and using about six to eight amperes on 110 volts in the primary circuit.

Smaller coils and resonators may be made for induction coils and ¼ to ½ K. W. transformers by making the secondary about four times as long as its diameter, and the primary twice the diameter of the secondary. The wire should be about No. 8 for the primary and No. 24 to 28 for the secondary. In resonators for small transformers and coils the length of the secondary should be about three to three and one-half times its diameter and the primary twice the size of the secondary. The wire in the primary should be about No. 8 and that in the secondary No. 28 to 32. However, the size of the wire makes little difference in either Tesla coil or resonator if not too small in the primary and if the instruments are tuned to resonance.

All the ordinary experiments can be performed with these coils and resonators and with the larger ones a great many uses will suggest themselves, and at present many of them are being used for research work in place of large induction coils.

An Easily Constructed Tesla Coil

Instructions for the Amateur Electrician

By Allan S. Dana

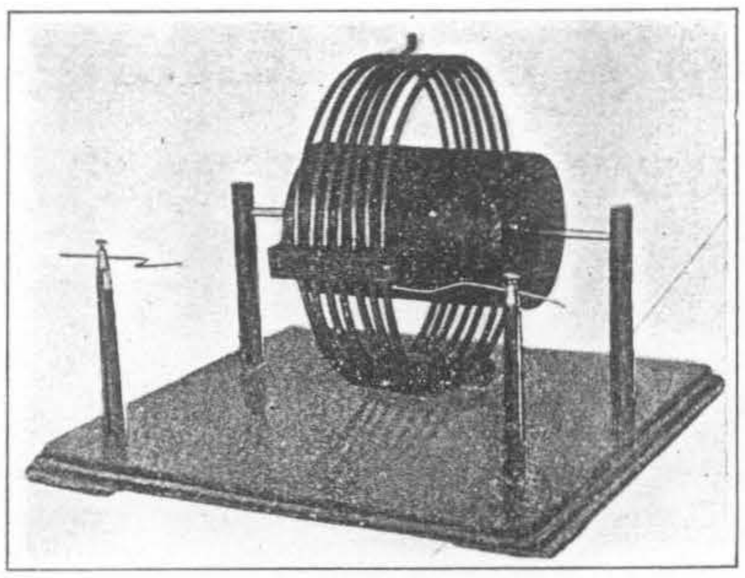
THE special advantage of the Tesla coil, here described, is that it is comparatively small and light. Therefore it can be readily carried from place to place. Most Tesla coils are immersed in oil but this is objectionable as the oil leaks or slops over, and also greatly increases the weight of the instrument. Although the oil-immersed coil is more efficient, a Tesla coil in air is more convenient and only slightly less efficient. The air Tesla coil to be described has the same advantage that a coil in oil has—that of having a fluid insulator between the primary and secondary coils, so that, if a spark passes accidentally between them, the air or oil immediately fills up the gap made by the spark. A solid insulator cannot be used because one spark between the primary and secondary would make a hole in the insulating material and the spark would easily travel through this hole thereafter. Hence a coil should be in either oil or air. But if it is to be portable, air must be the insulator.

Using this coil with a 4-inch induction coil, it gives a 5½-inch spark. This is the longest spark possible with this instrument, because the spark has to travel only a little over 5½ inches to jump from the primary to the secondary coil. Hence, if the rods where the spark discharge is supposed to take place are separated by more than 5½ inches, the spark will not jump there, but will take the shorter path to the primary coil.

The base of this coil is a piece of 1-inch whitewood, 16 inches by 15 inches, with its edges molded. Two and one-quarter inches from the front and 12⅝ inches apart bore two holes which will allow an 8/32 machine screw to pass through. Again, bore two holes of the same size 10 inches from the front and 12¾ inches from each other. Also two holes of the same size 10 inches from the front and 3¼ inches apart. Screw four rubber tips, such as used on furniture to avoid scarring polished floors, to the under side of the base board at the corners. These will keep it from scratching polished tables. The base may now be painted. A black varnish gives a good finish.

Next, wind six turns of No. 2 copper wire around a circular form so as to make a coil 10 inches in diameter. At each side of the coil, place two pieces of ½-inch oak, 1 by 4 inches, which are supplied with machine screws and nuts, and clamp the wires 3/16 of an inch apart by means of these. The machine screw heads should be toward the inside of the coil and must be countersunk until flush. At the bottom of the coil another strip of oak is used to clamp the whole coil to the base by means of machine screws passing through the oak strip and the holes already bored in the base board. This oak strip should be of ½-inch oak, 1 by 4 inches, with two holes for 8/32 screws, 3¼ inches apart. Flatten the ends of this primary coil and bore in each a hole which will allow the binding post from the carbon of an old dry battery to be put on and used as a terminal of the coil.

The secondary coil is wound on a cardboard tube 4¾ inches in diameter and 7¼ inches long. Cut two disks of 3/8-inch wood to fit tightly the ends of the tube and bore a ¼-inch hole in the center of each disk. Mount the tube so that it can be revolved and wind, side by side, a No. 36 single cotton-covered copper wire and a thread of 100 cotton, which has been soaked in paraffine and allowed to cool. In this manner the entire surface of the tube is covered with a coil of wire, whose adjacent turns are separated by the thickness of the paraffined thread. To the ends of this coil 10-inch lengths of No. 28 or No. 30 copper wire are soldered, and melted beeswax poured over the joint to hold it fast to the cardboard tube. Shellac the entire coil of wire, applying two coats of thin shellac. When this has dried, unwind the paraffined thread and give one



General View of the Tesla Coil.

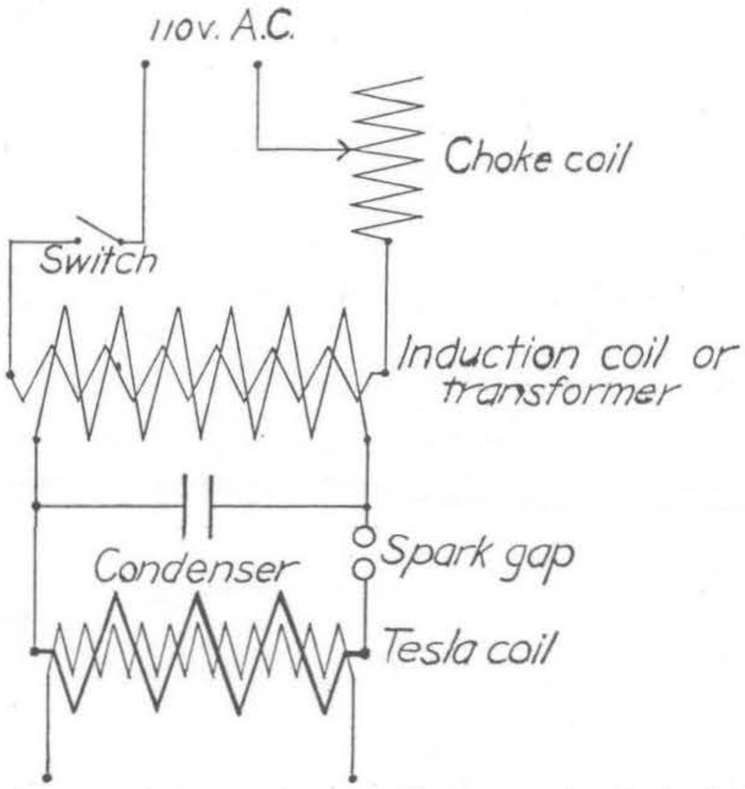


Diagram of Connections for Fitting up the Tesla Coil.

or two more coats of shellac to hold the wire onto the cardboard tube. Be sure that no two turns of the coil touch. Every turn must be separated from the next one by the width of the paraffined thread. When this is dry, pass a ¼-inch glass rod, 12¾ inches long, through the holes in the wooden disks in the end of the cardboard tube.

From a ¾-inch hard rubber rod cut two pieces 6 inches long. In one end of each bore and tap a hole for an 8/32 screw. One inch from the other end bore a ¼-inch hole half way through the rod. These last holes are to hold the ends of the glass rod, which passes through the center of the secondary coil and is used to support it. By 8/32 machine screws passing up from the under side of the base board through the holes already bored 12¾ inches apart and 10 inches from the front, these hard rubber rods are held to the base and, in turn, support the glass rod which carries the secondary coil.

Cut two 5-inch pieces of ½-inch hard rubber rod, and bore and tap each end for an 8/32 screw. At one end of each rod a binding post is screwed on, while a screw passing up from the under side of the base holds each rod perpendicular to it.

Then the ends of the secondary coil are connected to the binding posts on the top of the hard rubber rods.

The coil is now complete. If used with an induction coil on alternating current, it is best to screw the vibrator up tight, so that it will not work, and use a choke-coil in the primary circuit in order to cut down the current. Still better, a high voltage, closed core transformer, such as used to send in wireless telegraphy, may be used. The terminals of a medium-sized glass plate condenser are connected to the secondary terminals of the transformer or induction coil. Then one terminal of the transformer or induction coil is connected to one end of the coil of large wire on the Tesla coil. The other end of this coil of large wire, or primary coil, is connected to a spark gap, and the other end of the spark gap to the other end of the transformer or induction coil. When the current is turned on and the spark gap and condenser regulated, a harmless 5½-inch spark will jump between wires placed in the binding posts to which the ends of the secondary of the Tesla coil are connected.

A great many experiments may be made with this coil. Geissler tubes can be lighted by holding one end of the tube in the hand and presenting the other end to one terminal of the Tesla coil. When this is done, the electricity which lights the tube passes through the person and still does not cause any sensation. But in these days of wireless telegraphs and telephones, the most interesting experiment from the layman's standpoint is a wireless light. To make this, bend 4 feet of No. 14 B. and S. insulated copper wire to form a circle and connect a 2-volt battery lamp to the ends of this coil. If this coil is then moved near to the Tesla coil while it is in operation, the lamp will light, provided, however, that the primary coil of the Tesla and the coil of the wireless light are in the same or parallel planes.

Many other experiments can be carried out by means of this simple Tesla coil.

Technical World Magazine February 1912

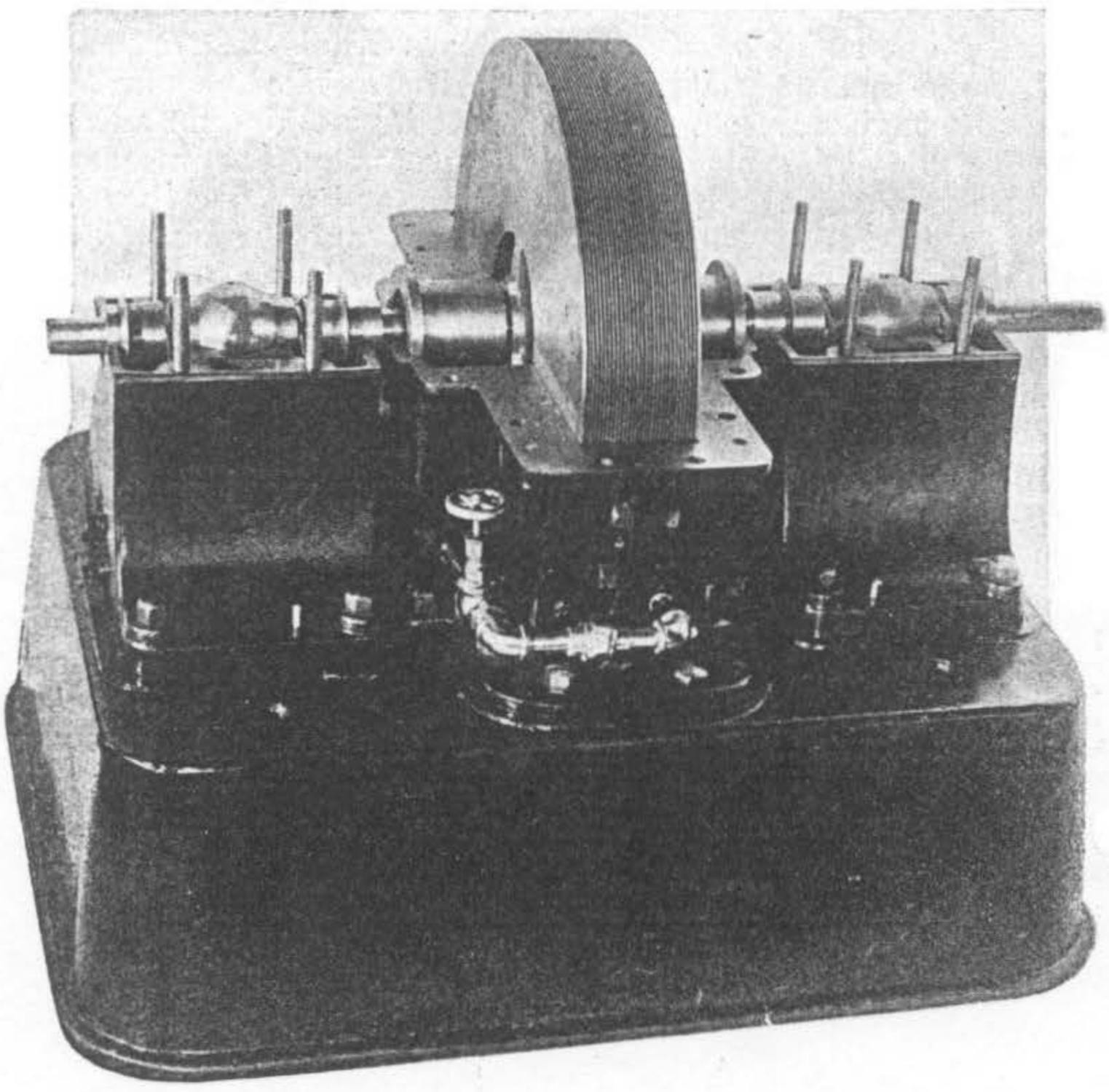
POWERFUL TURBINE A MERE TOY

By

HENRY JEVONS

ALMOST any evening last fall a tall, spare man, whose discouraged looking mustache remains a glossy black without any aid from the barber in spite of the fact that its wearer is well past his fiftieth year, might have been seen wending his dignified way down East Thirty-eighth Street toward First Avenue, New York City. He was a man who would attract attention anywhere, but especially on East Thirty-eighth Street, which is not a thoroughfare one would choose for an evening stroll, unless one chanced to be hard up for strolls. If the tall man had been shadowed he would have been seen invariably to disappear within a massive brick building which covers the entire block between Thirty-eighth and Thirty-ninth streets, First Avenue and that part of Long Island Sound miscalled "East River".

Had the phenomenon been further investigated, this building would have been found to be a place of extraordinary



THE EXPERTS LAUGHED—AT FIRST—WHEN TOLD THIS TURBINE RAN 16,000 REVOLUTIONS TO THE MINUTE.

Tesla turbine of two hundred horse power. The upper part of casing is removed to show the rotor, which is 18 inches in diameter and measures 3½ inches across the face.

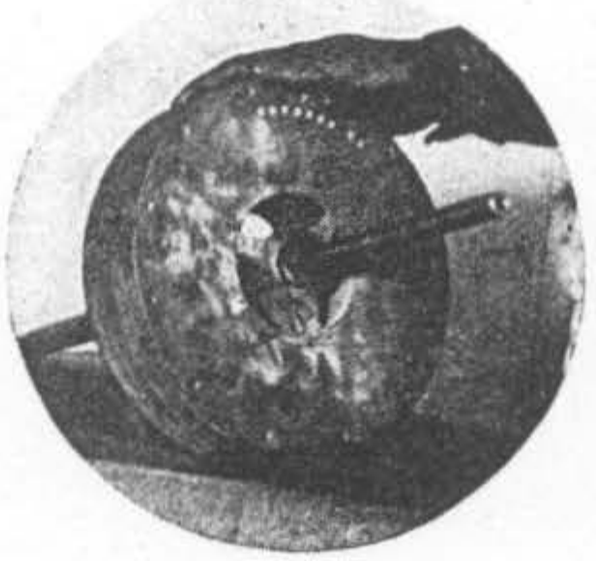
interest, for various reasons. Together with its twin covering, the next block north, it constitutes the Waterside Station of the New York Edison Company, the largest steam power plant in the world. Of still greater interest than its size is the fact that ever since it was built there could be found within its thick walls the living history of the evolution of the steam engine epitomized and in action. Unlike all other histories of the steam engine, the opening chapter did not begin with the exploits of Hero, of Alexandria, 120 years before Christ, but started in several pages ahead of October, 1901, on which date the plant sent out its first electrical impulse.



NIKOLA TESLA, THE HUNGARIAN SCIENTIST OF TREMENDOUS IMAGINATION, WHO HAS BUILT SOMETHING "PRACTICAL" FOR THE ENGINEERS.

When the New York Edison Company decided to build Waterside Station it took the bridles off the engineers and allowed them to go as far as they liked in designing a plant that would be the last word in steam engineering, for the plant was intended to be big enough to meet all demands for years to come. Power was furnished by vertical, three cylinder compound engines of 5,000 horse power, which were considered something marvelous both in size and economy, eleven years ago. But before steam had been turned on for the first time the Curtis turbine had thrown down the gauntlet to reciprocating engines of whatever size or kind, offering to give them cards and spades and beat them out in the matter of economy. So a turbine of 2,000 horse power was installed almost at the beginning to show what it could do. It did so well that a turbine of 10,000 horse power soon took its place beside the pioneer. All the various examples of different periods in the evolution of the steam engine worked together in harmony, sending their currents out over the same wires in one united stream to light the Great White Way and more useful, if less popular, places.

Before the plant could be started up the company realized that forty thousand horse power, instead of being enough to meet all demands for years, wasn't even enough to begin business with; so the architect was routed out of bed and told to get busy on an extension. Since then neither architect nor engineer have had time to go out to lunch, for the plant has been steadily increasing in capacity until now it aggregates approximately three hundred thousand horse power, and it is still growing night and day. At the present time the company is replacing its vertical compound engines of 5,000 horse power with Curtis steam turbines of 27,000 horse power, by far the largest steam engines the world has ever seen. A single one of these monsters would supply electric current enough to meet the requirements of a city of 250,000 inhabitants; yet one of them takes up no more space than that occupied by the vertical compound engines of one-fifth their power.



AN "INSIGNIFICANT TRIFLE."
Rotor of the tiny turbine that develops 110 horse power.

This may seem to be going some, yet the evolution of the steam engine is proceeding at such a terrific pace that even so persevering a corporation as the Edison Company might

be pardoned for feeling discouraged. In a gloomy corner of this titantic power plant a new idea has sprouted which may oblige the Edison Company to send the first of its 27,000 horse power Curtis turbines to the scrap heap before the last one can be installed. And this brings us back to the tall man.

He is none other than Nikola Tesla, whom the American Institute of Electrical Engineers, by vote of its members, placed seventh in the list of the greatest twenty-five names in electrical science. Tesla has invented a steam turbine. Of course this in itself is nothing worth mentioning, for everybody who is anybody has invented a steam turbine. And as there are steam turbines aggregating 5,166,000 horse power hard at work in the United States today, nearly all installed within the last six years, there is nothing sensational in the mere existence of such a prime mover.

But Tesla's turbine is different. Everything that Tesla does is different. Instead of studying for the priesthood as his father wished, Tesla went out to the stable at his home in far-off Hungary one day when he was very much younger than he is now and tried to fly from the roof with no other aid than that afforded by an old umbrella. The next six weeks he spent in bed. Since then he has been careful to keep his corporeal substance on solid ground; but his fancy essays some marvelous flights. It was Tesla, for instance, who proposed to signal from Long Island to the people on Mars by means of Hertzian waves of exceptional force. It was Tesla, too, who conceived the idea of wireless transmission of power, not to mention other enterprises daringly original. All this goes to show that while Tesla has a long list of practical achievements to his credit he is, in many things, decades, if not centuries, ahead of his times.

When such a man turns his attention to the things of every day life he may confidently be counted upon to produce something original. As every one who is informed upon the subject knows, the fundamental feature of the steam turbine is a wheel bearing upon its periphery a series of vanes or buckets. A jet of steam blowing upon the buckets pushes the wheel around and thus generates power. Many variations have been embroidered upon this elementary fea-



COULD BE COVERED WITH A HAT. YET IS AN ENGINE OF 110 HORSE POWER.

ture to produce the long list of turbines upon the market; but in none of them is the bucket dispensed with. It took Tesla to do that, though E. C. Thrupp, of England, tried to do it eleven years ago, and others have also tinkered vainly at the idea.

Tesla's turbine is the apotheosis of simplicity. Its working parts consist of nothing in the world but some smooth disks of steel only one thirty-second of an inch in thickness mounted about seven sixty-fourths of an inch apart upon a shaft. This assemblage of disks upon a shaft, called a "rotor," being placed within a steam-tight steel casing in which is an opening on the periphery to admit steam and another at the center of one side to allow it to escape, completes the turbine. Lacking the essential element of a turbine, the bucket, it really isn't a turbine; but as the inventor has not yet had time to think up a suitable name for it the familiar designation must answer present purposes.

To go into more minute particulars, the opening for the admission of steam is placed so that the jet strikes the periphery of the disks tangentially. As for the disks themselves, a part of their center is cut away as near as possible to the shaft so that there are three passages from side to side parallel with the shaft at equal distances apart. At one side of the casing opposite these openings is the exhaust port.

At first glance it might appear that when steam was admitted it would simply blow through between the disks and out at the exhaust port without causing the rotor to turn over. And really it almost does this, but not quite. Striking the periphery of the disks at a tangent the steam does follow a short curve to the center at first, but still the curve is long enough to allow the steam to begin to push the disks around. As the disks begin to revolve the steam follows them part way, thus increasing the distance it has to travel to reach the outlet and at the same time giving it a greater hold upon the surface of the disks. This process continues until the rotor has attained full speed, when the steam is pursuing a spiral course from inlet to outlet which takes it several times around the disks in a course six or seven feet long before it finally escapes.

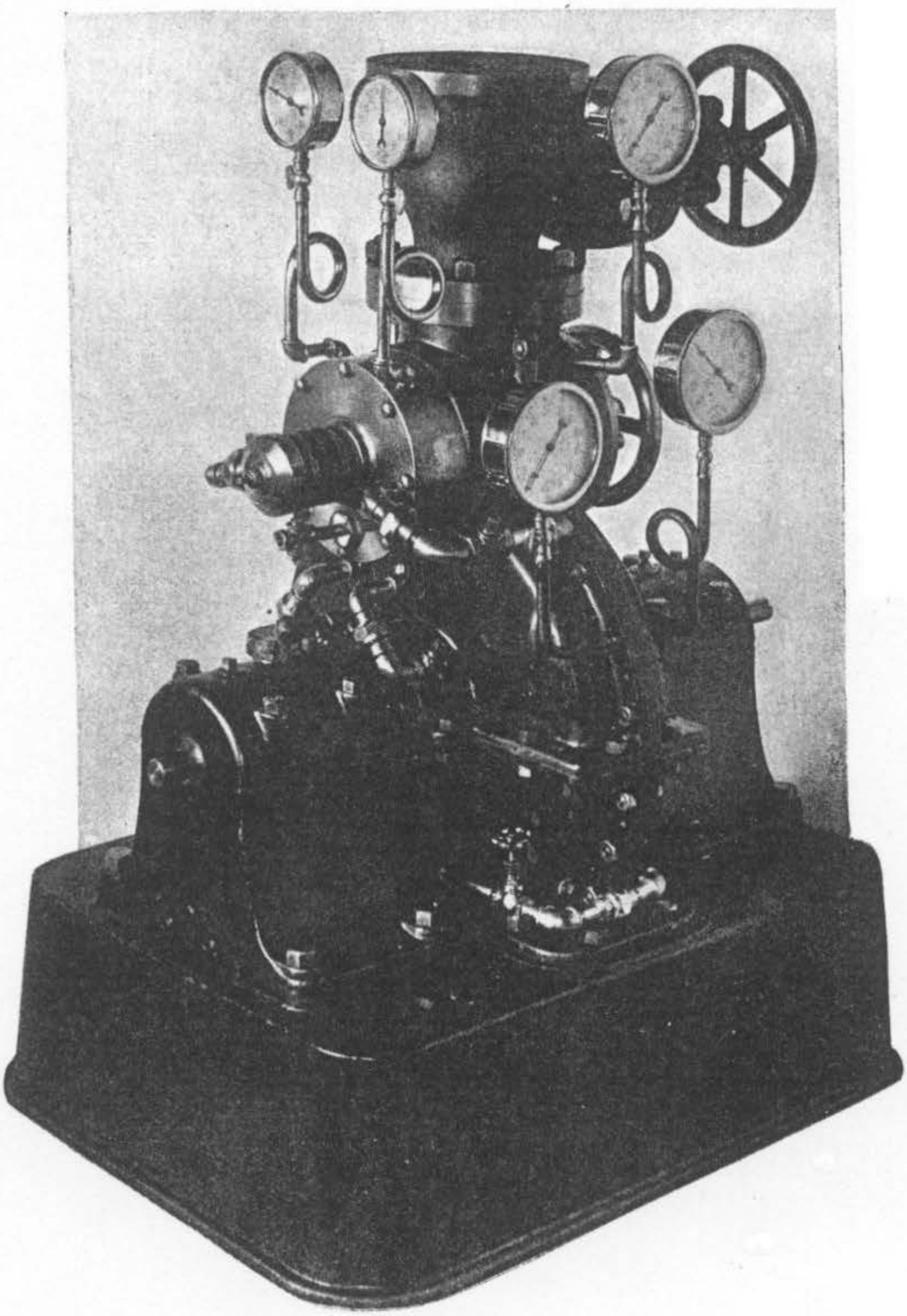
Tesla's turbine is so violently opposed to all precedent that it seems unbelievable, even when you see it at work. In the reciprocating engine the steam has the immovable cylinder head to brace itself against while it expands and pushes the movable piston ahead of it. In the reaction turbine it follows exactly the same principle, expanding between fixed buckets on the sides of a chamber and buckets on the rotor. Even in the impulse turbine there are buckets to give the steam a purchase. In the Tesla turbine there is not so much as a scratch for the steam to grip—nothing but smooth steel.

But the advantages of the earlier forms of the steam turbine and the seeming disadvantages of the Tesla motor are more apparent than real. Steam is a fluid; and when any fluid is used as the medium through which power is developed the most economical results are obtained when the changes in velocity and direction of the current are made as gradual and easy as possible. A diagram of the path followed by a jet of steam in a reaction turbine would look like the thread from an old chain stitch sewing machine ravelled out and thrown down loose. With such a zigzag course destructive eddies, vibration and shocks are inevitable. This is not saying that steam turbines are not highly efficient, for they are; but still they are a long way short of perfection. Another point that counts against the impossibility of attaining the ideal with the older forms of turbines is their delicate and difficult construction. The large ones contain many thousand blades or buckets, each one of which has to be machined and fitted separately. While turbines are much more economical than reciprocating engines in their own particular field they are, nevertheless, costly to build and maintain.

Tesla gets the cost of construction and maintenance down to an irreducible minimum by the extreme simplicity of his turbine. He can do this because he approaches the problem from an entirely new angle. Instead of developing power by pressure, reaction or impact on buckets or vanes he depends upon the properties of adhesion and viscosity

which are common to all fluids, including steam.

The characteristic of viscosity is best exemplified by cold molasses. Any one who has had to go out to the smoke house in winter to draw a pitcher of molasses for the matutinal buckwheats does not need to look in the dictionary to ascertain what viscosity is. Nor is an unduly vivid imagination required to figure out what would happen if a stream of cold molasses were directed against the rotor of a Tesla turbine. There would be such an excess of viscosity that nothing whatever would happen except the machine would be all mussed up. But by heating the molasses its viscosity would be so much reduced that the fluid

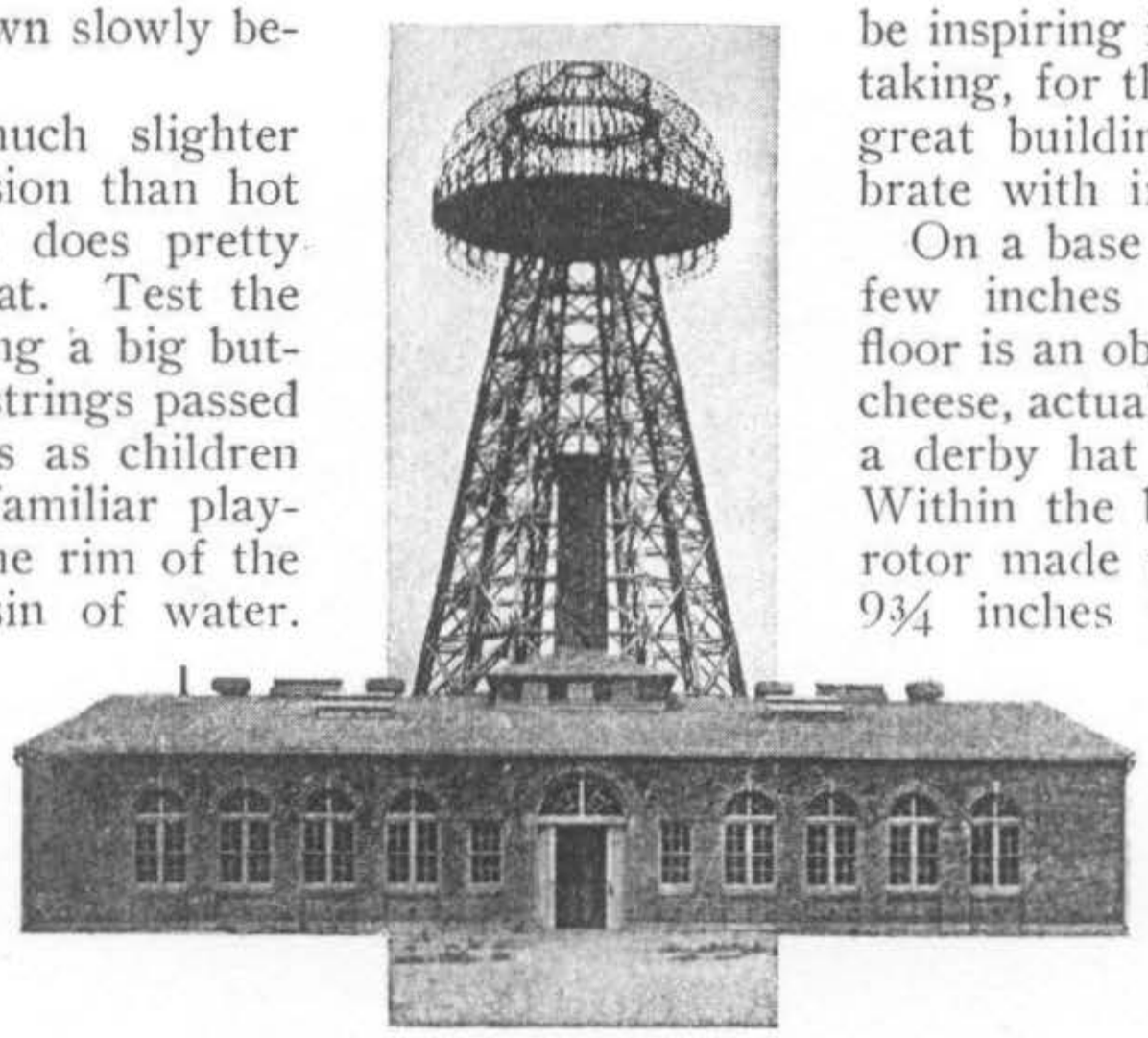


TESLA'S TURBINE OF 200 HORSE POWER EQUIPPED WITH GAUGES FOR TESTING.

It stands on a base 20 by 35 inches, and measures only five feet from floor to top of throttle valve.

might trickle down slowly between the disks.

Water has much slighter powers of adhesion than hot molasses, but it does pretty well, even at that. Test the matter by twirling a big button by twisting strings passed through the eyes as children do to make a familiar plaything, holding the rim of the button in a basin of water. The way the water will fly will show very strikingly how so thin a liquid will adhere to a smooth disk.



PLANT ON LONG ISLAND WHERE TESLA HAS MADE SOME EXTRAORDINARY EXPERIMENTS IN ELECTRICITY.

Steam is less adhesive than water, but the difference is in degree only, not in kind. When steam is admitted to the Tesla turbine a thin film of it adheres to the faces of the disks with tenacity enough to exert a pull in the direction in which the jet is moving. At the same time the steam in the thin space between the disks is also held back by the molecular attraction between its particles and those adhering to the disks, which is another way of expressing viscosity, so that all the steam between the disks is helping to drag the rotor around. Of course the disks do not move as fast as the steam, for the velocity of steam is very great.

If the disks were placed too far apart the greater bulk of the steam would flow swiftly through, like the current in a river which flows more swiftly in the center than near its banks, without doing any useful work; but the space is carefully calculated so as to make each molecule of steam exert a long pull, a strong pull and a pull all together with its neighbors, and thus do all the work it is capable of doing under the circumstances.

After Tesla had worked out the theory of his turbine he had one built, then obtained of the Edison Company permission to conduct his experiments at Waterside Station where there is an abundance of superheated steam, vacuum and all other essentials, including surroundings which might be supposed to be inspiring in such an undertaking, for the very air in the great buildings seems to vibrate with irresistible power.

On a base which raises it a few inches above the steel floor is an object shaped like a cheese, actually no bigger than a derby hat of average size. Within the black casing is a rotor made up of steel disks 9¾ inches in diameter and measuring but two inches across the face. Yet this insignificant black cheese makes a fifty kilowatt generator hump itself. Actually it is capable of developing 110 horse power. It has to be geared down, for it is too swift for any generator that ever was built.

When Tesla escorted the first installment of guests around to inspect the new turbine he remarked casually that it ran at 16,000 revolutions per minute. To ask any engineer to believe such a tall statement was putting altogether too great a strain upon credulity. The guests smiled indulgently and winked at each other behind Tesla's back. But when the inventor applied a revolution counter that bit of brass mechanism went into spasms, then calmed down enough to indicate 16,000 revolutions a minute, whereat the eyes of the visitors protruded until they were unable to wink again for a fortnight.

Beside this first Tesla turbine stand two larger ones, coupled together by a flexible shaft so that one may be used as a brake to test the power developed by the other. Taking steam at 125 pounds pressure and exhausting into the open air, making 9,000 revolutions per minute this larger turbine develops 200 horse power. At 185 pounds pressure as used by its big neighbors, it is capable of developing 300 horse power. Yet this new turbine stands on a base only 20 by 35 inches and measures but 5 feet from the floor to the top of the throttle valve. The weight is only 400 pounds, or two

pounds per horse power. The rotor is composed of 25 disks 18 inches in diameter, spaced so that they measure 3½ inches across the face. So compact is this newest of steam engines that one developing 27,000 horse power would only occupy about one-tenth of the space required for the wonderful Curtis turbines on the farther side of the room. The pair of larger turbines are thickly studded with gauges of various sorts used by the inventor in his tests and experiments.

The method of testing the capacity of the turbine is interesting. The two turbines, exact counterparts of each other, are connected by a torsion spring which has been carefully calibrated so that its strength is accurately known. Steam is admitted to the turbine used as a brake in the direction opposite to that in which the disks revolve. On the shaft of the brake turbine is a hollow pulley in which are two slots diametrically opposite each other with an electric light inside close to the rim. As the pulley revolves two flashes of light are seen which with the aid of mirrors and lenses are carried around so that they fall upon two revolving mirrors placed back to back on the shaft of the driving turbine. The mirrors are set so that when there is no torsion on the spring the light is a stationary spot at zero on a scale. As soon as a load is thrown on the spring the beam of light moves up the scale which is so proportioned to the spring that the horse power can be accurately read from it.

In various tests this turbine has consumed 38 pounds of saturated steam per horse power per hour, which is a high efficiency, considering that the steam only gave up 130 British thermal units, and that power is developed in a single stage instead of in several as in other turbines or in triple expansion reciprocating engines. This is equivalent to a consumption of less than 12 pounds per horse power per hour of the superheated steam with the high vacuum used by the monster Curtis turbines near by. Tesla declares that with a large multiple stage turbine of his own type he will be able to develop 97 per cent. of the available energy in the steam, and this with a motor weighing but a quarter of a pound per horse power capacity. Certainly he is doing remarkable things.

A notable advantage possessed by the Tesla turbine is the ease with which it can be reversed. The great drawback to the marine turbines now in use is the difficulty of reversing. It is necessary to have two turbines on each shaft: one for going ahead and one for backing. In the Tesla turbine all that is necessary is to shut off steam on one side of the casing and admit it on the opposite side. There are no ponderous levers to throw, no reversing mechanism whatever, no moving parts but the valves in the steam pipes.

Yet more marvelous is the fact that the new motor is as well adapted to the use of gas as of steam. For years dozens of inventors have racked their brains, squandered their money and sacrificed their sleep in vain efforts to produce a practical gas turbine. But the obstacles in the way appeared insurmountable. Tesla has solved the problem. He has two gas turbines now approaching completion which are to be sent to Europe. The time may not be far distant when automobile manufacturers may be announcing new models with turbine motors. The gas turbine is identical with the steam turbine, the gasoline being exploded in a separate combustion chamber and its heat reduced by a spray of steam or water when the jet is introduced at great velocity into the turbine.

As if this was not versatile enough for one invention the Tesla steam and gas turbine is also a pump and an air compressor. All that is necessary to transform the turbine into a pump is to take the rotor out of its casing and put it into another of slightly different form,—a "volute" casing, the engineers call it, and reverse the direction of the fluid. That is, the water to be pumped enters through the center of the side casing, passes through the interstices between the disks from center to circumference and flows out through the periphery of the casing.

The same molecular adhesion between the disks and the fluid and the molecular attraction between the film adhering to the disks and the fluid between them that imparts power to the steam turbine gives force to the stream of water pass-

ing through the pump or the air passing through the compressor. As the water enters at the center and as the motion of each point on the disk is circular its particles receive an impetus always at a tangent to the circular paths; and so it moves in a spiral path from center to circumference. If the outlet is wide open there is little resistance to flow in a radial direction. Pressure in the casing of the pump depends upon the velocity of the particles leaving the periphery of the rotor. By throttling the outlet the pressure is increased in proportion to the speed of the rotor, velocity being converted into pressure.

The capacity of the new pump is amazing. A nickel plated model in Tesla's office that one could carry comfortably in his overcoat pocket pumps forty gallons a minute against a head of nine feet. With a pump having disks 18 inches in diameter the inventor declares he can deliver 3,500 gallons a minute against a head of 300 feet.

But perhaps the most interesting feature about this unique invention is the use to which its proceeds are to be put. Upon being told that steps were being taken to place the turbine on the market I suggested to Tesla that he would soon be able to retire.

"Oh, no!" he exclaimed. "I shall be ready to begin work. I am going to use the money I get from my turbine to develop wireless transmission of power."

World Today Febuary 1912

Nikola Tesla, Dreamer

His Three-Day Ship to Europe and His Scheme to Split the Earth

By

Allan L. Benson

The man who lives ahead of his age is called a dreamer. Such a man is Tesla. He predicted wireless telegraphy long before it came about, and he gave the world the alternating current without which long-distance transmission of electric power would be impossible. Tesla is a man you will be glad to meet. His dreams are fascinating even if——

ALONE man dines nightly in the Rose Room at the Waldorf. For eighteen years, he has sat at the same table. The table, which stands near the wall, is just large enough for two; but it is never set for two. It is never set for more than one—and that one is Nikola Tesla.

Nikola Tesla is fifty-nine years old. Where he keeps his years, no one knows. They are not in his face, for his face looks like forty. They are not in his hair, for his hair is black. If they are anywhere, they are in his eyes, for his eyes are sad.

This lone man, who always dines across from a vacant place, has given to the world a long series of wonderful inventions. Tesla's system of electric power transmission is used by all the world, and he has a new turbine which, he says, could drive the *Lusitania* across the Atlantic at the rate of fifty miles an hour.

"That means less than three days to cross the Atlantic," he continued, "upon the same coal supply that is now used. But I have a ship in mind that my turbine could put across the Atlantic in sixteen hours.

"But the world need not wait for the fifty-miles-an-hour ship. The turbine that can drive it is here. It is a simple matter of mathematics. The best type of reciprocating engine—a quadruple expansion—yields only 51 per cent. of the energy that is contained in the steam. The turbines that drive the *Lusitania* and the *Mauretania* yield 62 per cent. My turbine yields 99 per cent. This it is enabled to do because the steam goes around and around the spiral circuits, imparting energy all along its track, while in the old type of turbine, the steam goes around but once and, when it escapes, still contains much energy."

The superior efficiency that Tesla claims for his turbine is not sufficient, of course, to bring the two-and-a-half day ship. Adding 60 per cent. to power does not add 60 per cent. to speed. The law of diminishing returns prevents that. But Tesla contends that his turbine can as well be driven by steam created by gas explosions, which give enormous pressures.

This suggested internal combustion engines and aeroplanes.

"I will guarantee," said Tesla, "to put my turbine into a Wright biplane and drive it 200 miles an hour. That is to say, the turbine will furnish sufficient power. Of course, no one could sit in a Wright biplane going 200 miles an hour. I expect to develop a new type of flying-machine that my turbine will drive at almost the speed of a bullet."

The fact that Tesla dreams of such speed is not, of course, conclusive proof that such speed will soon be attained. But it should be remembered that some of Tesla's dreams have come true. I myself have seen a clipping from a New York newspaper bearing date of 1893, in which Nikola Tesla said:

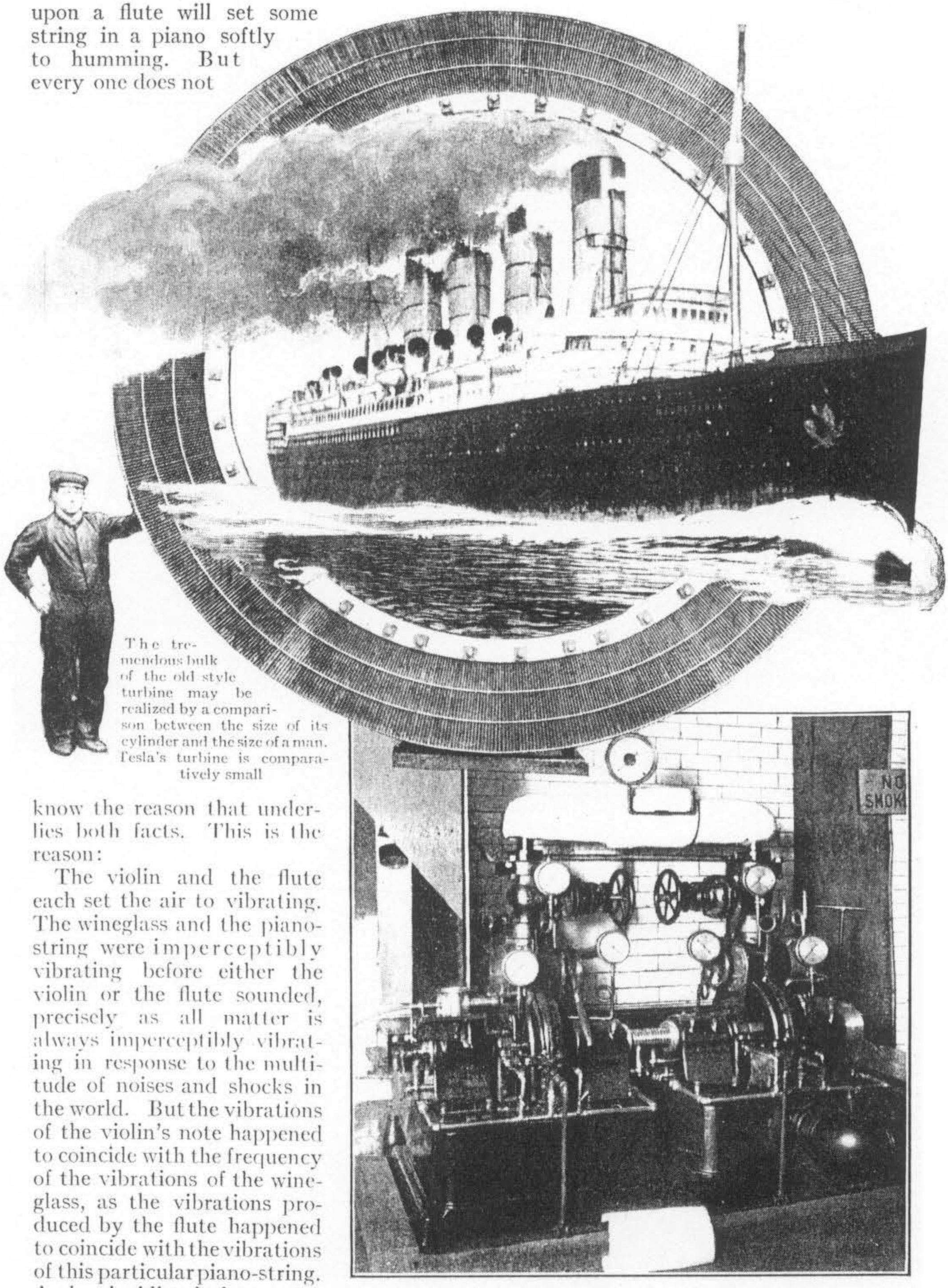
"If I cannot send a message to a ship at sea, send it without wires, and make the message understood to those aboard the ship, I am willing to lay my head on the block."

No, he was not the first to send such a message. That is true. Marconi, five years later, sent the first such message. But Tesla, years before Marconi's achievement, obtained American patents upon a system of wireless telegraphy.

While on the subject of dreams, here is a Tesla dream that, so far as I know, has never been equaled by Tesla, or by any other human being, since the world began.

Every one knows that a note upon a violin will sometimes shatter a wineglass in the same room. Every one knows that a note

upon a flute will set some string in a piano softly to humming. But every one does not



The tremendous bulk of the old style turbine may be realized by a comparison between the size of its cylinder and the size of a man. Tesla's turbine is comparatively small

know the reason that underlies both facts. This is the reason:

The violin and the flute each set the air to vibrating. The wineglass and the piano-string were imperceptibly vibrating before either the violin or the flute sounded, precisely as all matter is always imperceptibly vibrating in response to the multitude of noises and shocks in the world. But the vibrations of the violin's note happened to coincide with the frequency of the vibrations of the wineglass, as the vibrations produced by the flute happened to coincide with the vibrations of this particular piano-string. And, coinciding in frequency, as they happened to do, they

Tesla's new turbine, which, he claims, could drive the *Lusitania* across the Atlantic in less than three days, upon the same coal supply that is used now



Tesla claims that in a few weeks he could set the earth's crust into such a state of vibration that it would rise and fall hundreds of feet and practically destroy civilization. A continuation of his process would, he says, eventually split the earth in two

produced the same acceleration that a boy produces when he swings some one in an old-fashioned swing. The person in the swing may weigh 200 pounds and the boy may weigh but 50 and may push but a pound. But if he times his pushes to coincide with the turn of the swing from him and keeps adding a pound each time, he will eventually have to stop to avoid throwing out the occupant of the swing. While, on the other hand, if he did not time to coincide with the movements of the swing—in other words, if he pushed a pound against the returning swing each time it came back—the swing would soon stop.

The wineglass that is broken by a violin's note is broken because the vibrations of the air that are produced by the violin happen to be of the same

"Nikola Tesla is fifty-nine years old. Where he keeps his years, no one knows. They are not in his face, for his face looks like forty. They are not in his hair, for his hair is black. If they are anywhere, they are in his eyes, for his eyes are sad"



frequency as the vibrations of the glass. In the beginning, the glass is expanding and contracting only within infinitesimally small limits. But each time that the glass begins to contract, the vibration produced by the violin gives it a little push. After thousands or millions of such pushes, the expansion and contraction of the glass are so increased that the glass breaks.

The principle embodied in this experiment interested Tesla, and he determined to try it upon a larger scale. He ordered from a steel company a steel link, two feet long and two inches thick. He was careful to specify that the steel should be of the best quality. As a matter of fact, the link was strong enough to bear a weight of hundreds of tons.

Tesla fastened to this link an electric vibrator, no larger than an alarm-clock, but so constructed that the frequency of the vibrations could be altered at will. He set the vibrator to going and then began to vary the vibrations for the purpose of getting the vibrator in "tune" with the link. For a long time, nothing happened—the vibrations of the link and of the machine did not chance to coincide. But at last he got them together, the great steel link began to tremble, increased its trembling until it dilated and contracted like a beating heart—and finally broke!

Sledge hammers could not have done it; crowbars could not have done it, but a fusillade of taps, no one of which would have harmed a baby, did it.

By means of a little electric vibrator, a steel building could be shattered as a wine-glass sometimes is by the note of a violin

Tesla was pleased. He had learned something. He wanted to learn more. He put his little vibrator in his coat pocket and went out to hunt a half-erected steel building. Down in the Wall Street district, he found one—ten stories of steel framework without a brick or a stone laid around it. He clamped his vibrator to one of the beams, and fussed with the adjustment until he got it.

"In a few minutes," he said, "I could feel the beam trembling. Gradually, the trembling increased in intensity and extended throughout the whole great mass of steel. Finally, the structure began to creak and weave, and the steel-workers came to the ground panic-stricken, believing that there had been an earthquake. Rumors spread that the building was about to fall, and the police reserves were called out. Before anything serious happened, I took off the vibrator, put it in my pocket and went away. But if I had kept on ten minutes more, I could have laid that building flat in the street. And, with the same vibrator, I could drop Brooklyn Bridge into the East River in less than an hour."

Now comes the "dream"—or whatever it is.

Tesla says that he can split the earth in the same way—split it as a boy would split an apple—and forever end the career of man.

This seems like quite a large order—but see what he says about it.

"The vibrations of the earth," said he, "have a periodicity of approximately one hour and forty-nine minutes. That is to say, if I strike the earth this instant, a wave of contraction goes through it that will come back in one hour and forty-nine minutes in the form of expansion. As a matter of fact, the earth, like everything else, is in a constant state of vibration. It is constantly contracting and expanding.

"Now, suppose that at the precise moment when it begins to contract, I explode a ton of dynamite. That accelerates the contraction and, in one hour and forty-nine minutes, there comes an equally accelerated wave of expansion. When the wave of expansion ebbs, suppose I explode another ton of dynamite, thus further increasing the wave of contraction. And, suppose this performance be repeated, time after time. Is there any doubt as to what would happen? There is no doubt in my mind. The earth would be split in two. For the first time in man's history, he has the knowledge with which he may interfere with cosmic processes."

I asked Tesla how long he thought it would take him to split the earth in two. He said he didn't know. Months might be required; perhaps a year or two.

"But in a few weeks," he said, "I could set the earth's crust into such a state of vibration that it would rise and fall hundreds of feet, throwing rivers out of their beds, wrecking buildings, and practically destroying civilization.

"The principle cannot fail. It is as powerful when applied to the earth as it is when applied to a wineglass, a swing, or a steel link. Any one who doubts should only bear in mind the illustration of the swing. A small boy, by each time adding a pound to the force with which a 200-pound man swings, can soon set the man swinging with the force of 500 pounds. It is necessary only to keep adding a little force at the right time."

There may be flaws in this theory. Others may see them. I don't. I know that some steamship companies proceed upon this theory—reversing its application, by the way—to keep their steamships in a relative state of equilibrium. Steamships sometimes roll more violently than the ocean rolls, merely because their movements become attuned to the movements of the waves. This is offset by a system of interior water-tanks, back and forth through which water is forced out of tune with the waves, thus neutralizing them. The theory works aboard a ship.

And the possibility that it might work if applied to the earth is sufficient to stimulate the imagination, even if the improbability of its application be sufficient to allay one's fears.

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WHAT of the FUTURE IN ELECTRICTY

Dr. Nikola Tesla Looks Forward to the Era When One Hundred Horse Power Will Be Wireless Section Shall Spread Over the World—Tells of Other Developments That We Have Good Reason to Expect.



NIKOLA TESLA.

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"WHAT did the year 1911 contribute to the electrical progress of the world?"

"What does the year 1912 promise in the same direction?"

These questions, asked of Dr. Nikola Tesla, brought forth the following response:—

"While there has been no fundamental discovery announced during the year just past, progress has been steady and continuous. Almost insensibly great changes have been brought about in various departments.

"Probably the most important of these is the extension of electric transmission lines from hydro-electric central plants. Although the spectre of government restriction has had a deterrent effect on the development of this important industry, it has not inflicted a permanent injury.

"The technical records show that several million horse power have partly been and will soon entirely be harnessed to the service of man.

"Next in importance is the electrification of the railroads, the advantages of which are now thoroughly appreciated, even by the most conservative of railroad men. That which has been achieved in this field has conferred countless benefits on the community.

"Electric lighting has been greatly advanced through the introduction of the new type of incandescent lamp, which has been considerably improved in the last year and ocers greater possibilities.

"The storage battery is still waiting for some discoverer who will open up a new path; but while this is true, improvements have been made in the mechanical construction and arrangement of the elements, rendering the cells more suitable for practical service.

"Equally gratifying strides in telegraphy and telephony have been made, both in the extension of distance and improvement of transmission. Greater progress would have been made long ago had it not been for erroneous theories that have taken hold of the minds of electricians.

"Wireless communication has developed and has been considerably extended also, but here, too, progress is still hampered by the hypnotizing effect of the Hertzian wave theory. Some of the most able experts are still laboring under the illusion that messages are transmitted by these waves. As a matter of fact, it is the currents through the ground that affect the receiver. The Hertzian waves are extinguished within a small radius from the transmitter.

"Investigators in radio-activity have also yielded tangible results, though it must be stated that they have been drowned by impossible forecasts.

"Still another branch of applied electricity, electro-therapy—more particularly through the instrumentality of currents of high frequency—has been much enhanced, the most valuable results being the eradication of cancer and like malignant growths."

In discussing the possibilities of 1912 Mr. Tesla said:—

"I suppose that just at this time aviation commands the attention of the world more than any other field. For ages it has been the passionate desire of man to invade the domain of the bird, and finally it has materialized! The advent of a new motor, simpler, lighter, more powerful and efficient, and absolutely reliable in its operation, will convert the flying machine [illegible] apparatus [illegible] and useful vehicle.

"A promising departure has already been made by Dr. Tesla in this line, a description of his new motor having been given in the NEW YORK HERALD recently.

"Another As fascinating," Dr. Tesla continued, "are the possibilities of the discoveries that have been made by Mme. Curie. Though it may be safely predicted that the dreams of the enthusiasts will not be realized, enough has been achieved already to justify great expectations for this coming year."

"What do you think of wireless art in its various applications?" he was asked.

"The sensational exploitation of wireless telegraphy and telephony has naturally created in the public mind the idea that this is the chief if not the only field of its use. As a matter of fact, the world has not even at this moment the faintest conception of the really great and valuable results in other fields that are sure to be obtained in the near future.

"Far more important than communication is the transmission of power wirelessly, which will be done for innumerable purposes. To mention one comparatively insignificant application, a plant might be provided that would enable every vessel or vehicle either on land or the water or in the air to safely travel without compass or any other means of direction such as has heretofore been known. One such wireless plant would be sufficient for the needs of the whole world and the means of saving property and human lives.

One Central Plant.

"Remember," Dr. Tesla emphasized, "that I am now only mentioning one of the minor applications of wireless power. Just think what benefits could be derived in this particular phase of aerial development by the construction of one single plant from which all the flying machines of the world could be operated without fuel or other energy of any kind!"

Turning to other subjects he said:—

"Entirely new fields have already been opened up to scientific research and inventive application, but still greater possibilities lie before us.

"Think only what it would mean to disintegrate matter into its primary constituents, thus giving rise to new effects and phenomena and liberating forces heretofore unknown! One of the consequences, perhaps not the most important, would be the inexhaustible supply of radium emanations.

"Since advancing this idea I have spent much time attempting to realize it by the application of great electrical forces, but although I have attained tensions of 20,000,000 volts, sufficient to tear off particles from the toughest steel, they were found inadequate to break up the atomic structure. I am confident, though, that it will be done eventually.

"Another realm of infinite promise is that of intense cold, so ably and successfully explored by Sir James Dewar. The production of liquid oxygen and hydrogen, if economically effected, will be revolutionizing in its influence on industry and manufacture.

"Even some of the older electrical arts are still undeveloped. Take the storage battery, for instance. No radical departure has been made since the original demonstrations of Ritter and Plante. The time is ripe for a signal improvement. One can confidently announce the coming, and very soon, of a new principle which will mark an epoch in the development of this branch of electricity.

"Electrical progress," continued Dr. Tesla, in reply to a queation, "may be said to have begun with Gilbert and Leyden, respectively the discoverers of the earth's magnetism and the electrical condenser. From that period on the advancement, although very slow at first, was nevertheless continuous. It was greatly accelerated by the discovery of Galvani and the researches of Faraday, but the rapid growth comparable to that of the present day can be traced back only a quarter of a century.

"Nevertheless there are many facts indicating that at some earlier period electrical science was far more advanced than would appear from historical records. There is a large interval of unproductivity, but only in so far as it concerns actual accomplishment. The intellectual progress must have been more or less continuous.

"As to the utilization of fuel energy, I am glad to say that I have recently made a decided step forward through the perfection of my new gas turbine, or rotary engine, which will permit a much more economical use of fuel than heretofore possible.

Improving the Telephone.

"The energy supplied to the earth through the sun's rays is so great that if it could be cheaply stored and converted it would meet all our wants. But, although engines have already been operated by power so derived, all undertakings to this end have proved practical failures, chiefly because of the periodic character of the supply. I have long recognized that the true solution lies in a different direction.

"Telephoning through long submarine cables is possible and would have been accomplished long ago had the efforts of electricians been turned in the proper direction. The trouble lies in the transmitting and receiving instruments, especially the latter, which are still crude and require strong currents for operation, entailing great loss in the wire, as well as the surrounding insulating medium, and causing weakening and distortion of the impulses. Following the suggestion of the great mathematician Heaviside, the telephone lines are now being made of heavy wire and provided with induction coils, which have the effect of raising the tension and reducing the frictional waste in the wire.

"A further extension in the transmission has been effected by the use of the so-called phantom circuit, consisting of two separated lines. This is an ingenious and practical expedient, but the use of induction coils is only necessitated by the crudity of the instruments. In employing very sensitive receiving devices speech can be transmitted distinctly through the longest aerial lines and submarine cables without any change in their construction."

"How about the possibility of making that visible which is going on at the end of a wire as we are now able to converse over a wire?"

"We must distinguish between transmission of pictures and what has been termed television, or seeing at distance. The former is a comparatively old art now well established. Some of the early work in this direction was done in this country by Mr. Amstutz, an American engineer. Quite recently Professor Korn, of Munich, has perfected apparatus which is now being used with success.

"As regards the transmission of images, it is incomparably more difficult chiefly because of the complexity it involves. By the means which have been so far proposed thousands of wires would be necessary between two stations. An invention of mine permits the reduction of this number to but a few, or even to a single wire, so that there is a fair prospect of practical achievement at no remote date. What is more, I believe that seeing at a distance will be accomplished without wires."

"Will it be possible for electrical science to discover some means whereby such accidents as that of the Olympic and the Hawke can be avoided?"

"A perfect means for this purpose has been afforded through the discovery of the stationary waves, but unfortunately there is no plant as yet in operation. With these waves, which, as I have shown, pass from one to the other end of the globe without diminution of intensity, producing stationary loops and nodes, the danger of collisions at sea will be greatly reduced."

"Is electrical science also likely to provide quicker means of transportation than railroads or steamships?"

"Certainly. With the introduction of

(CONTINUED ON PAGE FIVE.)

The Future in Electricity.

(CONTINUED FROM PAGE ONE.)

wireless power it will be practicable to attain much greater speeds, particularly through the air, as the supply of power will dispense with the necessity of carrying fuel and lighten and simplify the flying machine. It may also be expected that by wireless supply of power vessels at sea will be made to travel faster for similar reasons."

Dr. Tesla was also of the opinion that the progress of electrical science in the days to come will do much toward promoting the peace of the world. On this subject he said:—

"Whether such a condition of human life as universal peace is at all possible is still a question. One thing is certain—that it cannot be attained by arbitration, any more than it is possible to carry out a perpetual motion scheme. Those who believe in this possibility confound effect and cause. Humanity must be so far advanced that peace is an accomplished fact when parliamentary resolutions will be the natural consequence and will have only the significance of formal procedures giving expression to the general desire.

"It is also a mistake to assume that by the coalition of a few great Powers a peaceful condition all the world over can be brought about. There is an essential difference between a family and a nation.

"If we conceive a world such as ours populated with beings perfectly alike the natural efforts of each will soon destroy the homogeneous character of the mass, and out of the multitude individuals will spring who will become centres of force, around which the others will gather, and in due course the communities so formed will clash. It is clear, therefore, that unless some new elements or forces come into play wars will be unavoidable.

"The opinions on this subject are widely different. There is, we must admit, in all of us a remnant of the barbarous instinct developed in the early struggle for existence. But while this is undeniable it does not appear that strife between nations and individuals must necessarily be accompanied by bloodshed. I believe that the primary cause of war can be traced to misunderstandings which are the result of the great distance separating individuals from each other and to the impossibility of getting into close touch. The progress of the electrical arts will enable one to come in instant touch with the rest of the world, and this should gradually lead to a peaceful understanding."

"Will wholesome food products be ultimately produced under the potency of electric affinities?"

"This may be positively expected—in fact, we are already producing some foodstuffs by electric currents. The manufacture of nitrates and other nitrogen compounds from the air is being carried on on a large scale and the productiveness of the soil has been greatly increased in some parts by this and other electrical means. The time is not distant when many kinds of food products will be manufactured by electricity, and a great number of specialists are already engaged on this problem."

"Is it likely that such an advance in electro-therapeutics may be looked for that human life may be prolonged and suffering alleviated, diagnosis and prognosis being aided by exact electrical measurements of the various organs of the human body?"

"Since 1891, when I published my first investigations with high frequency currents, they have been universally adopted in electro-therapy and wonders have already been achieved by their use. Of late the claim has been advanced that the application of such currents stimulates the mind and enhances growth, and experiments carried on for a considerable period seem to have borne out this fact.

"From personal experience I know that the daily use of high frequency currents greatly contributes to one's well being, and I cannot recommend it too highly. Electric currents have also been successfully applied as an anaesthetic in surgical operations and have proved invaluable, but as to whether human life can be materially prolonged is still open for conjecture."

LAWRRENCE MOTT.

The New York Herald February 21, 1912

INVENTOR SUES NICOLA TESLA.

Simon J. Schlenker Demands $61,000, Alleging Breach of Contract.

A suit to recover $61,000 from Nicola Tesla, the inventor, and Edward K. Stallo, capitalist, was begun in the Supreme Court yesterday by Simon J. Schlenker, through his counsel, Putney, Twombley & Putney. Mr. Schlenker alleges that he entered into an agreement with the defendants in November, 1907, to put on the market an electrical device known as the Nicola transformer.

It is alleged that Messrs. Tesla and Stallo refused to keep the agreement. Mr. Schlenker says he spent $3,500 after the contract was made, while the $58,000 represents the profit he would have made if the contract had not been broken.

The New York Tribune March 3, 1912

LETTERS TO THE EDITOR

TESLA ON WIRELESS.

Electrical Inventor Thinks Marconi's Plants Inefficient.

To the Editor of The Tribune.

Sir: In so far as wireless art is concerned there is a vast difference between the great inventor Thomas A. Edison and myself, integrally in my favor. Mr. Edison knows little of the theory and practice of electrical vibrations; I have, in this special field, probably more experience than any of my contemporaries. That you are not as yet able to impart your wisdom by wireless telephone to some subscriber in any other part of the world, however remote, and that the presses of your valuable paper are not operated by wireless power is largely due to your own effort and those of some of your distinguished confreres of this city, and to the efficient assistance you have received from my celebrated colleagues, Thomas A. Edison and Michael I. Pupin, assistant consulting wireless engineers. But it was all welcome to me. Difficulty develops resource.

The transmission across the Atlantic was not made by any device of Mr. Marconi's, but by my system of wireless transmission of energy, and I have already given notice by cable to my friend Sir James DeWar and the royal institution of this fact. I shall also request some eminent man of science to take careful note of the whole apparatus, its mode of operation, dimensions, linear and electrical, all constants and qualitative performance, so as to make possible its exact reproduction and a repetition of the experiments. This request is entirely impersonal. I am a citizen of the United States, and I know that the time will come when my busy fellow citizens, too absorbed in commercial pursuits to think of posterity, will honor my memory. A measurement of the time interval taken in the passage of the signal necessary to the full and positive demonstration will show that the current crosses the ocean with a mean speed of 625,000 miles a second.

The Marconi plants are inefficient, and do not lend themselves to the practice of two discoveries of mine, the "art of individualization," that makes the message non-interfering and non-interferable, and the "stationary waves," which annihilate distance absolutely and make the whole earth equivalent to a conductor devoid of resistance. Were it not for this deficiency, the number of words a minute could be increased at will by "individualizing."

You have already commented upon this advance in terms which have caused me no small astonishment, in view of your normal attitude. The underlying principle is to combine a number of vibrations, preferably slightly displaced, to reduce further the danger of interference, active and passive, and to make the operation of the receiver dependent on the co-operative effect of a number of attuned elements. Just to illustrate what can be done, suppose that only four vibrations were isolated on each transmitter. Let those on one side be respectively a, b, c and d. Then the following individualized lines would be ab, ac, ad, bc, bd, cd, abc, abd, acd, bcd and abcd. The same article on the other side will give eleven similar combinations, and both together twenty-two lines, which can be simultaneously operated. To transmit one thousand words a minute, only forty-six words on each combination are necessary. If the plants were suitable, not ten years, as Edison thinks, but ten hours would be necessary to put this improvement into practice. To do this, Marconi will have to reconstruct the plants, and it will then be observed that the indefatigable Italian has departed from universal engineering customs for the fourth time.

New York, Oct. 24, 1907. NIKOLA TESLA.

WIRELESS POWER

NEW YORK TRIBUNE MARCH 3, 1912

By RICHARD MAXWELL WINANS



A BOLT of lightning passing through the earth, and returning to the point of entry with undiminished force, was the astounding discovery made by Nikola Tesla, "Wizard of Electricity," inventor, scientist, scholar.

As the issue of this momentous discovery Professor Tesla has perfected a practical system of wireless power distribution. And the universal application of the wireless transmission of energy will speedily solve vast and far reaching problems in commerce and the industries, and will eventually revolutionize the whole structure of the world's social and political economy.

Already Tesla has advanced his discovery of the wireless transmission of electrical energy to the point of practical application. At his great experimental plant on Long Island he has secured actual and satisfactory results in wireless power transmission that go far toward making for its early and successful introduction into commercial and industrial uses. When all the details of his transmitting system are complete, and the world at large shall adopt wireless power in its general utilities, the wonders of science and invention, of dynamics and mechanics, the arts and the social scheme, that we employ and enjoy today will appear as the antiques of a primitive age.

The magic Lamp of Aladdin was never rubbed to such fruitful purpose, nor did it ever create such undreamed-of wonders, as will the application of the wireless transmission of energy to some of the most simple contrivances, the everyday utilities of the present; let alone the improved devices that will develop in its use, with which inventive genius will provide us for the future.

In recounting the incidents leading up to and the elemental details of the discovery that unexpectedly and unquestionably opened the way to this great realization, Tesla recites that during a systematic research, for which he had long trained himself, which he had assiduously conducted for several years, to the end of perfecting a system of wireless transmission of energy through the natural media, the earth and air, he came in 1898 to recognize three essential requirements. The first was to produce a transmitter of tremendous power; the second, to perfect a system for individualizing and isolating the energy transmitted; the third, to acquaint himself with the laws governing the propagation of electrical currents through the earth and air.

IN May, 1899, Professor Tesla selected, for various scientific reasons, a large plateau sixty-five hundred feet above sea level, in the vicinity of Colorado Springs, where the surroundings contributed ideal conditions for careful observations. Such were the climatic and other conditions that he could hear claps of thunder four to five hundred miles away; and he could have improved upon this record had it not been for the tedium of waiting for the sounds to arrive, in definite intervals, as shown by an electrical indicating device—nearly an hour before.

Having established his laboratory and adjusted the highly sensitive instruments necessary to the proposed experiments, he learned that the earth was literally alive with electrical vibrations. Colorado, with its dry and rarefied atmosphere, is famed for its natural displays of electricity; static electricity being abundantly developed. The discharges of lightning during storms are not only frequent, but often violent to an inconceivable degree. During his stay there were in the course of one electrical storm approximately twelve thousand discharges within an observed period of two hours, occurring inside a radius of less than thirty miles. Many of these discharges were so heavy that they resembled gigantic trees of fire.

About a month after his Colorado observations began Tesla was both surprised and puzzled to note that his instruments were affected more decidedly by discharges taking place at great distances than those nearby. This presented a perplexing problem, which was made the more mystifying when careful observation disclosed the fact that the differences were not due to intensity of discharges, nor varying relation between the periods of the receiving circuits and those of the terrestrial disturbances.

ONE night when meditating over these experiences," says Tesla, "I was suddenly staggered by a thought. The same thought had presented itself to me years ago; but I had then dismissed it as absurd and impossible. And that night when it recurred to me I banished it again. Nevertheless, my instinct was aroused, and somehow I felt that I was nearing a great revelation.

"It was on the third of July (1899) when I obtained the first decisive experimental evidence of a truth of overwhelming importance for the advancement of humanity. A dense mass of strongly charged clouds gathered in the west, and toward evening a violent storm broke loose which, after spending much of its fury in the mountains, was driven away with great velocity over the plains. Heavy and long persisting arcs formed almost in regular time intervals. My observations were now greatly facilitated and rendered more accurate by the experiences already gained. I was able to handle my instruments quickly, and was prepared. The recording apparatus being properly adjusted, its indications became fainter and fainter with the increasing distance of the storm, until they ceased altogether. I was watching in eager expectation. Sure enough, in a little while the indications again began, grew stronger, gradually decreased, and ceased once more. Many times, in regularly recurring intervals, the same actions were repeated, until the storm, as evident from simple computations, with nearly constant speed had retreated to a distance of about two hundred miles. Nor did these strange actions stop then, but continued to manifest themselves with undiminished force.

"When I made this discovery I was utterly astounded. I could not believe what I had seen was really true. It was too great a revelation of Nature to accept immediately and unhesitatingly. Subsequently I confided my discovery to my assistant, and he afterward confirmed it, as did also a noted engineer in a German university. Several opportunities were presented later which brought out still more forcibly and unmistakably the true nature of the wonderful phenomenon. No doubt whatever remained—I was observing stationary waves! Impossible as it seemed, this planet, despite its vast extent, behaved as a conductor of limited capacity.

"All effects diminish as the extreme line of their radius increases. For instance, sound effects would be exhausted within a given radius, which would be determined by atmospheric conditions. The general law is that at one-half the distance the intensity of the effect is fourfold. And this is also true of electrical activities. But this discovery demonstrated something that was altogether contradictory to all previous experience. Not only could an electrical current be passed through the earth with undiminished intensity, but, under certain conditions, its force would be even augmented with distance.

"Had this discovery been worked out at that time it would have given us practical wireless transmission of power on a commercial scale at least ten years ago. The world, however, was not then, and is not yet, ready to receive it. Man—that is, the layman, the man unversed in dynamic forces and scientific engineering—does not understand how one element is related to another. If I had attempted at that time to place upon the market an apparatus for the wireless transmission of power, the world would not have utilized it. It may be years before it is educated to receive these new ideas and the perfection of this discovery. It is difficult for the average citizen to comprehend or to form an adequate idea of the tremendous significance of this marvelous revelation of Nature, or the stupendous possibilities that the development and perfection of this discovery assure as a heritage to humanity."

THE full development of a possible twenty-five hundred millions of horsepower from the waterfalls and streams of the United States has been materially handicapped and restricted by the limited area over which hydroelectric energy may be practically transmitted by wire. The falls of Niagara alone could be made to supply a fifth of all the power used at present by industry and the railroads. At some remote day their power may be entirely utilized by diverting the full volume through tunnels to turbines at night, charging immense storage batteries with its energy for use during the next twelve hours, and again turning the water over the falls during the day to satisfy the sentiment of the people.

Aside from Niagara, however, most of the great power sites of the country are so distant from the centers of

population that it has been impracticable to transmit their energy to localities containing the heart of our industries, and in many instances, particularly among the Western mountains, they are so inaccessible as to make it difficult or inconvenient to establish industries about these sites or within reach of electrical power transmission. But with wireless transmission of power the energy of the waterfall of the Columbia River—which by the way, amounts to seven or eight million horsepower—can be employed to run the motors of industry, to light and heat homes and cook food on the Atlantic seaboard as readily as on the Pacific, in Portland, Maine, as well as in Portland, Oregon; or the five million horsepower from the Sacramento River, in Manila as easily as in San Francisco. There is millions more than enough horsepower going to waste in the streams of the North Pacific group to turn every wheel of industry and move the traffic of every railroad in the country; and with the advent of wireless power it will be developed, along with other millions of hydroelectric power otherwhere, as consumption creates a demand for it.

The greatest power site in the world, Zambesi Falls, was recently discovered in the until then unexplored heart of Africa. Over its brink has gone to waste thirty-five million horsepower every minute of each day for centuries, enough energy to provide a large part of the world with power, more than enough to supply the commerce and industry of the United States. Because of its isolated location it is useless to mankind, and will be until wireless power makes it possible to set the wheels of a thousand industries spinning anywhere on earth with its magnificent energy.

WHILE the general public has not been taken into Tesla's confidence concerning the progress of his work in the perfection of his system for the wireless transmission of power, scientific and electrical engineers in all countries have followed closely and with intense interest such developments as he has revealed to the technical world. For obvious reasons, however, it would not be prudent to disclose the actual working details of the system, or the specific nature of apparatus to be employed, until such time as he may elect to place his transmitter on the market for commercial purposes.

"There is," says Tesla, "much misunderstanding in regard to my wireless system. Some believe that the transmission is effected through the air, and others that the currents go only through the earth. The fact is both media serve as vehicles of energy. The current passes through the earth; but an equivalent electrical displacement also occurs in the air, exactly as when the transmission is effected through a single wire without return; a principle the practicability of which I demonstrated in my earlier investigations.

"By this system," he continues, "wireless power can be transmitted with absolutely the same facility to the antipodes as it can to a distance of a few blocks. The quantity of energy the transmitter delivers is immaterial; but, in view of the fact that the earth is immense, and that there are practical limits in the amount of energy collected in any individual receiver, it is necessary to have a very powerful transmitting plant.

"However," he explains, "the volume of energy—the indicated horsepower of the generating plant—will not in the least affect the limit of transmission. That is, a plant generating two hundred horsepower will transmit its energy to the same unlimited terrestrial distance as that of a plant generating two hundred thousand horsepower. Neither will the energy or power decrease in efficiency as the distance of transmission increases, as is the case with electrical energy transmitted by wire. The efficiency of transmission will be the same, irrespective of the distance or the amount.

"When conveying power through a wire," Professor Tesla points out, "a certain loss is incurred, due to the resistance of the conductor; but the earth is a conducting body of such enormous dimensions that there is virtually no loss, so that distance means nothing. To the average intelligence this will appear incomprehensible. We are continuously confronted with limitations, and those truths which are contradicted by our senses are the hardest to grasp. For example, one of the most difficult tasks was to satisfy the human mind that the earth rotated round the sun; for to the eye it seemed just the opposite."

IN regard to the cost of wireless power, an estimate is made that places it at about one-sixteenth that of the present means and sources of supply. At any rate, Tesla says that it will be far cheaper than any other source known to man. "With wireless energy," he continues, "we could avail ourselves of the waste power of the present: the transmission would involve but little expense, and the apparatus would be of the simplest and cheapest."

The cost of wire transmission varies with the ratio of distance between point of generation and consumer, as determined by investment in and maintenance of conveying mains, which increases with distance. Also, over long lines, as from Niagara Falls to points some two hundred miles distant, the loss of current increases with each mile, and would, if the line were carried far enough, so decrease in volume that eventually the current would lose practical power producing energy. With the most improved means of wire transmission the limit of distance is placed by the most optimistic engineers at not much beyond five hundred miles. With wireless transmission there will be no limit, except that of terrestrial space, nor will the cost be greater in transmitting power to the antipodes than to the factory a block distant from the generating plant.

Tesla is assured that it will be absolutely unnecessary to have relay or transforming stations, since the consumer can receive the power direct, no matter where he may be situated. Also, there will be no conflict or interference of currents. Two factories situated in the same block, for instance, or two parallel railroads, or two competing steamship lines, could receive their power independently from separate sources, one from Africa, the other from Niagara. And his perfected system of positive selectivity will absolutely prevent an unscrupulous consumer from stealing his power from the air, any more than he could use the key to his barn door for manuipulating the time lock on a bank safe, so complete will be the individualization of currents. Also, this eliminates the element of power monopoly.

IN the field of transportation wireless power will work some of the greatest changes in things as they are. First among all, the steam-driven train and ship will pass into history along with the cradle, the flail, and the spinning wheel. And the noisy chugging of the smoking, foul smelling automobile will soon be a memory.

Professor Tesla has so far perfected his original system of isolation in the transmission of wireless energy that he is able to control, for instance, an automaton in the form of a miniature submarine ship, which he can readily direct and maneuver at will,—starting, stopping, speeding, turning, reversing, diving, rising, by the simple manipulation of wave impulse.

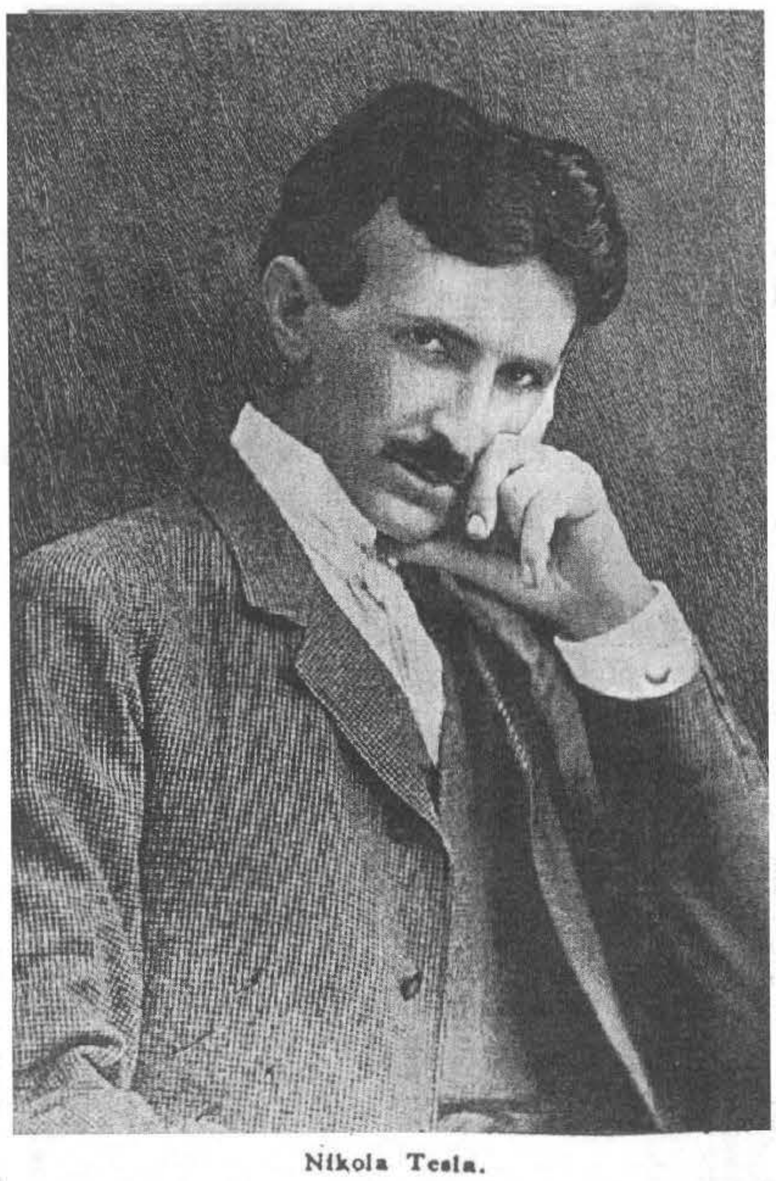
"When my system is complete," says he, "a crewless ship may be sent from any port in the world to any other port on the Seven Seas, propelled by wireless energy from a power plant anywhere on the face of the earth, and controlled and maneuvered absolutely and positively by telautomatics."

The ship in its actual position on the sea would not alone be visual to the telautomatic operator, but there also would be reproduced through the visualizing apparatus or aërocamera a detailed and faithful scene picturing her surroundings and the conditions of sea and weather.

Given wireless power and telautomatic control of ships at sea, that ever menacing *bête noire* of the mariner, the danger of collision in fog and night, or of going on the rocks or shoals, will be eliminated. For the crewless ship the operator, seated in his despatching office on land, surrounded by sensitive devices, with which any point he may elect of earth or sea may be visualized before him, would also "feel" the approach of another ship or the proximity to an iceberg or shoals, when he would easily deflect the course of his ship from danger. Ships carrying only cargo will be crewless, and they will be as water- and air-tight as a submarine, made buoyant by vacuum, and practically nonsinkable.

The future of wireless power development may render it folly for any nation to have afloat a vessel of war. The secret of another nation's scheme of selectivity might be disclosed to the enemy, when the guns of their own vessels might be turned against sister ships and a whole fleet destroyed by shells from their own guns, or their magazines might be exploded by the enemy at will. However, should there be battleships in the wireless future, they will be crewless. They will be maneuvered, their guns will be loaded, aimed, and fired, and their torpedoes discharged with unerring accuracy, by the director of naval warfare seated before a telautomatic switchboard on land.

"The time will come, as a result of my discovery," said Tesla, "when one nation may destroy another in time of war through this wireless force: great tongues of electric flame made to burst from the earth of the enemy's country might destroy not only the people and the cities, but the land itself. I realize that this is indeed a dangerous thing to advocate. At first thought it might mean the annihilation of the nations of the world by evilly disposed individuals. The public might at first look upon the perfection of such an invention as a calamity. We say that all inventions assist the criminal in his work. Today the safe burglar despises the use of dynamite, turning to electrical contrivances to cut the lock from a safe. It is fortunate for the world, therefore, that ninety per cent. of its people are good, and that only ten per cent. are evilly disposed: otherwise, all invention might be turned more greatly to evil than to good."



Nikola Tesla.

As with the ships of the sea, so also the gigantic freight ships of the aërial highways will be controlled, lifted in air, sent whizzing along at two hundred miles—the through express and mail possibly at three or four hundred miles—an hour, lowered to scheduled landing places en route, the progress of the discharge and loading being visible to the operator, and again raised and put to flight by the telautomatic control despatcher at the headquarters of the line. The possibilities of the part crewless warships of the air may play by dropping earth-rending bombs upon the cities of the enemy, is obvious.

WITH wireless propelled passenger air carriers, having decks closed or protected against the strangling, lung drowning rush through the air, traveling three or four hundred miles an hour through routes in high altitudes, one may have a six o'clock dinner in New York and breakfast next morning in San Francisco or London or Paris, or have luncheon in San Francisco and tea next day in Canton or Tokio.

The airship of Tesla's invention will be neither aëroplane nor dirigible, nor will it have wings or gasbags or propeller blades. All these things, he says, are impossible in the construction of a commercially practicable airship. The aëroplane he classes as no more than an amusing toy, a vehicle for exhibition by the venturesome sportsman; nor will it ever be anything more, because in its essential principles it has irremediable flaws that are absolutely fatal to commercial success. Tesla's airship will be proportionately as substantial, as staunch and dependable, and altogether as airworthy as the steamship of today is seaworthy. It will maintain a steady, even keel, and will not be in the least affected by air currents or any sort of weather conditions.

The size of these ships of the air may be limited only by the area of accommodations provided for their landing. Or they may be made small enough, being so easily and simply handled, that the school girl and boy may ride them to and from school, and in greater safety than walking in the city streets. The single or double or triple passenger aërocar of Professor Tesla's type will be more popular, too, for individual and independent transit, either for business or pleasure, than was the bicycle in its heyday, or the gasolene automobile at its best. Then the city commuter of the future may go and come between business and residence on his wireless aërocar, and he may go many miles farther afield, into the uncrowded hills and valleys and sea and lake shore, to make his home.

HOWEVER, before the general public is fully educated to the popular use of aërial navigation as a common utility, wireless power will have been generally, if not universally, applied to the railroads. It is very probable, in fact, aside from the industries and ocean commerce, that wireless power will find its first application to rail traffic. It will be an ideal source of power, and the resulting advantages and economies will be, more truly than tritely, too numerous to mention in anything less than a volume.

Millions of tons of coal will be saved that are now consumed in hauling fuel to coaling points. The use of hydroelectric power will conserve the coal resources. The ponderous, track wearing steam locomotive will be abandoned to the scrapheap. The smoke and soot and grime of travel will be eliminated. Direct wireless connection with the motors under each car will discard the deadly third rail and the hundred-ton electric engine. Wireless controlled safety devices will make collision impossible, and the wireless trains will provide every comfort and electrical convenience of the latest thing in hotels.

The maximum of speed will be determined by the capacity of the track to withstand strain. And wireless power will make it cheaper to cut through mountains, fill valleys and bridge cañons, than to operate on curves and grades. With these abolished and with roadbeds laid on approximate levels, straightaway as the crow flies for hundreds of miles, and with Tesla's gyroscopic mechanism to provide stability and prevent lateral impact, two or three hundred miles an hour may be maintained with safety and comfort. Then one might have breakfast overlooking the Golden Gate and attend a Broadway theater in the evening, and be home again before noon the next day.

Wireless power will make it possible to despatch crewless, light, cigar shaped steel mail cars on curveless, gradeless elevated or overhead tracks across country at an inconceivably terrific rate of speed. It may be telautomatically operated from a terminal switchboard, from where the train may be started, speeded, and stopped, or a "local" car dropped off and another taken on without pause at cities or junctions en route. Letters posted in New York in the morning may then be handed to the addressee by the postman in San Francisco on the afternoon delivery, or to the Chicago business man when he comes down to his office in mid-forenoon.

ONE of the great handicaps to the existing system of wireless telegraphy is the serious interference with messages on account of imperfect control of selectivity, secured principally by tuning. Realizing that such inter-

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WIRELESS POWER

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terence limited its greatest usefulness, Tesla has long since been conducting experiments along altogether different lines of transmission, in which he has developed perfect isolation and selectivity. He has discovered that any desired degree of individualization of aërograph and aërophone messages may be attained by employing a large number of coöperative elements and arbitrary variations of their distinctive features and order of succession, so that not only many thousands, but even millions, of simultaneous aërograph and aërophone messages may be sent through one conducting medium without the slightest interference.

The general term "World Telegraphy" has been suggested for Tesla's scheme of intelligence transmission, although "World Aërophony" would be as applicable, since his system will make it as practicable to talk as to telegraph through or round the globe, and as easily to a person using his aërophone at the antipodes as one in an office in the next block. Nor will it require a great, unwieldy contrivance for sending or receiving either aërograph or aërophone messages; such, for instance, as required in the present wireless system. Instead, Tesla assures us, for this purpose a small, cheap, and extremely simple device, so compact and portable that it may be carried in one's pocket, may be set up or held in one's hands anywhere on land or sea while it sends through intermediary transmitting plants messages to any part of the terrestrial universe or receives such special messages as may be intended for it, or records the news of the world as constantly despatched from the various news distributing stations.

Professor Tesla is confident that his system of intelligence transmission constitutes, in its principles of operation, means employed, and capacities of application, a radical and fruitful departure from what has been done before. "I have no doubt," he adds, "that it will prove very efficient in enlightening the masses, particularly in still uncivilized countries and less accessible regions, and that it will add materially to general safety, comfort, and convenience, and maintenance of peaceful relations. It involves the employment of a number of plants, all of which are capable of transmitting individualized signals to the uttermost confines of the earth. Each of them will be preferably located near some important center of civilization, and the news it receives through any channels will be flashed to all points of the globe. Thus the entire earth will be converted into a huge brain, as it were, capable of response in anyone of its parts. Since a single plant of one hundred horsepower can operate hundreds of millions of instruments, the system will have a virtually infinite working capacity, and it must needs immensely facilitate and cheapen the transmission of intelligence."

WITH universal aërophony available by the use of a convenient pocket instrument, the balloonist dropping into the far interior of uninhabited Canada need never be featured in the news as "lost." The explorer straving to reach the earth's poles, or venturing into the wilds of the world's untraveled regions, will be able to keep in hourly touch with his friends, to report his progress to the world, or to send out a call for relief or rescue over bleak fields of ice, the desert wastes, or jungle fastnesses. Also, the man hunting in the big woods, or on a solitary journey on land or sea, can spend an otherwise lonely evening talking with the folk at home. There will never be any reports of "line's busy" by Central on this aëroline. Nor will there be any eavesdropping on "party lines", or delays through an inattentive Central; for, lo! there will be no Central. Each instrument and its operator will constitute an aërophone central in themselves; all calls being direct from the instrument calling to the one called. And any operator with his individual pocket instrument may call any other instrument anywhere on the face of the earth, simply by adjusting the selective device on his instrument to correspond with that of the one desired.

"At my plant on Long Island," says this magician, "when all the apparatus is perfected for commercial use, I shall be able from my aërophone there to call up any 'phone in the universe, and, although apparently inconceivable, it is nevertheless true that my small voice through the delicate apparatus I am completing will be able to set the utmost confines of the whole world trembling with the vibrations of its force. As to the wireless telegraph of today and the incipient wireless telephone, they are but a puny step in the field of wireless transmission.

"Another valuable application of my wireless system," he continues, "will be the driving of clocks and watches from a master wireless time transmitter. These timepieces will be exceedingly simple, will require absolutely no attention, and will indicate rigorously correct time."

THE farmer will be one of the greatest beneficiaries of the wireless transmission of electrical energy; and through him, as a result of increased yields and decreased cost of production, the people of the cities and the public at large.

Some years ago one of the great American inventors claimed the discovery that worn-out soils could be made surprisingly productive by a more or less simple process of electrical treatment, and he rendered the world an immeasurable service in disclosing the process. But it ended there. To deliver a supply of electricity sufficient to consummate the process on the six million farms of the country was quite another problem; for in this case neither the valleys, the plains, nor the hillsides could go to Mohammed to be run as grist through his electric apparatus, but Mohammed must needs go with his equipment to wherever the land to be treated lay.

Through the perfection of his discovery Tesla will provide a way to deliver to every farm, not alone in the United States, but in the universe, enough electricity to apply the treatment effectively. And, presto! the farmer who today rides a plow behind a team of horses or draws a gang behind a tractor, may tomorrow in similar fashion ride an implement operated by wireless power, by which the soil, instead of being turned over as with the plow, will be lifted in furrow-deep slices and run through a wonderfully contrived machine in an endless ribbon, broken up into minute particles and made loose as ashes as it undergoes the necessary treatment by electricity, furnished as part of the wireless transmission, thoroughly pulverized and made firm as it leaves the implement into a perfect seed or plant bed, charged with sufficient available and soluble plant food to produce a quantity and quality of crop yield beyond the present expectations of the most sanguine of modern scientific agriculturists. It is claimed, too, as one of the advantages of wireless electricity, that it will be possible to control the weather in any locality to the extent of either preventing or producing rainfall to meet soil and crop requirements.

Of the two thousand million acres in continental United States, about half is estimated as being capable of cultivation in its present condition. Some of this is so dry you wouldn't think of raising even an umbrella on it. In 1910 our improved farm lands amounted to four hundred and seventy-five million acres. Irrigation and drainage are the principal factors that must solve the problem in the cultivation on most of the remaining vast areas that may be reclaimed and made tillable.

WIRELESS power offers the means of solution. Location presents no bar. Whether current is supplied from a power site in the community, or by a hydoelectric plant in the jungles of Africa, will be of no consequence; the cost will be the same. From distant streams or from great wells on the land the farmer may draw water in literal floods to irrigate his fields, through powerful rotary pumps, another of Tesla's inventions, which have many times greater capacity for their size and require less power than any pump heretofore produced. Or, on the other hand, he may drain semi-submerged and otherwise impossible marsh land, usually the richest of all soil in natural fertility. With the coming application of wireless power to this end, our millions of acres of parched desert lands and dismal swamps may be converted into Gardens of Eden, whence will come billions of tons of grain and fruit and vegetables and millions of cattle from knee-deep pasture lands to meet the demands of an ever growing population.

More than that, every farmstead, wherever located, may have its own individual wireless terminals to operate its field implements, to drive its machinery,—its cutters, grinders, threshers, mills,—and also to lighten the labor in the home, by running the electric washer, wringer, dryer, ironer, the sewing machine, the dough mixer and baker, the chopper, spice mills, cream separator, churn, freezer, and do all the cooking, as well as heat the house in winter and run a refrigerating plant to cool it and manufacture ice in summer.

"In each instance," says Tesla, "a small

terminal placed a little above the roof will be sufficient to furnish light, heat, and power for the isolated farm dwelling."

What farm dweller could feel isolated from the world with such conveniences, especially when there is included in the equipment of the country home a wireless "lineonews" continuously typing the important events of a universe, a wireless recordophone through which, as the operator may elect, may be heard the Sunday morning melody of the choir in St. Paul's or old Trinity, the grand operas of any city, the sermon in any church, the lecture in any lyceum, or may be seen clearly visualized the simultaneous reproduction of the best dramas, while listening to the lines of the actors who may be playing hundreds or thousand of miles distant?

With such readily available sources of entertainment, to be had by turning a switch and pressing a key, the story of the erstwhile dreary winter's eve on the still lone but far from lonely farm, will soon be among the romances to be retold; for with the advent of perfected wireless transmission the farm life of the future may be made far more alluring than life in the cities.

And old Dobbin! Framed and hung somewhere in the farm home will be the picture of a horse, in reverent memory of a noble and worthy service done, that he may not be altogether forgotten in the new age of an energy that will not consume half the crops of a farm to run it, and with better success and profit than ever before.

The World's Work March 1912

THE TESLA TURBINE

A MACHINE AS BIG AS A DERBY HAT THAT GENERATES 110 HORSEPOWER

BY

FRANK PARKER STOCKBRIDGE

WE FOLLOWED Dr. Nikola Tesla through the Waterside Power Station of the New York Edison Company —along narrow passages lined with huge electric switches, the turning of any one of which would throw a whole section of Manhattan into darkness or a blaze of light. We stumbled in the shadows of whirring dynamos, skirted great Corliss engines that seemed to rise from the very bowels of the earth beneath us and détoured past thundering

turbines. Before the largest turbine we paused for a moment.

"Here," said Dr. Tesla, pointing to the huge machine, "is a triumph of engineering skill. This turbo-dynamo, the largest ever made, developing 30,000 horsepower, was built from plans worked out on paper. It was never tested until it was erected here and it worked perfectly from the first turning on of steam. That is engineering. But that is not what we are here for."

We pressed on until we reached an open space where a mechanic in blue jeans was wiping the oil and grease from a machine so tiny in comparison with the gigantic turbine we had just inspected that it seemed like a toy.

"Here it is," said the tall, thin man — or rather he shouted, for the noise of a hundred thousand horsepower of moving machinery is not conducive to free vocal expression. "Better take off your coats," he continued, "for it is a cold night and it gets pretty hot in here."

We followed his advice and example and stripped down to shirt-sleeves.

"Turn on the steam," said the inventor to the mechanic. The workman gave a valve a short turn. From inside the little machine, which seemed to be composed of two identical parts connected by a spiral spring, came a humming sound; the connecting spring began to revolve so rapidly that it looked like a solid bar of steel and the floor under our feet shook with rapid vibrations which died down. I glanced at a speed-gauge attached to what seemed to be the main shaft of the device and saw that it was registering 7,000 revolutions a minute. I looked up at the main steam gauge overhead and saw a pressure of ninety pounds to the square inch indicated.

Dr. Nikola Tesla, inventor of the alternating-current motor, and pioneer in research into high-tension electric currents generally, was demonstrating his latest invention — a steam turbine, different in principle from any heretofore in use and one which will take less room and less coal per horsepower than the best engines now running. "It's up to its normal speed now — about nine thousand revolutions," said Dr. Tesla, and the tachometer bore out his statement. "You see, for testing purposes, I have these two turbines connected by this torsion spring. The steam is acting in opposite directions in the two machines. In one, the heat energy is converted into mechanical power. In the other, mechanical power is turned back into heat. One is working against the other, and by means of this beam of light we can tell how much the spring is twisted and consequently how much power we are developing. Every degree marked off on this scale indicates twenty-two horsepower." We looked at the scale. The beam of light stood at the division marked "10."

"Two hundred and twenty horsepower," said Dr. Tesla. "We can do better than that." He opened the steam valves a trifle more, giving more power to the motive end of the combination and more resistance to the "brake" end. The scale indicated 330 horsepower. "These casings are not constructed for much higher steam pressures, or I could show you something more wonderful than that. These engines could readily develop 1,000 horsepower," he said, as we watched the turbine running smoothly, steadily, almost noiselessly except for that single clear, musical note.

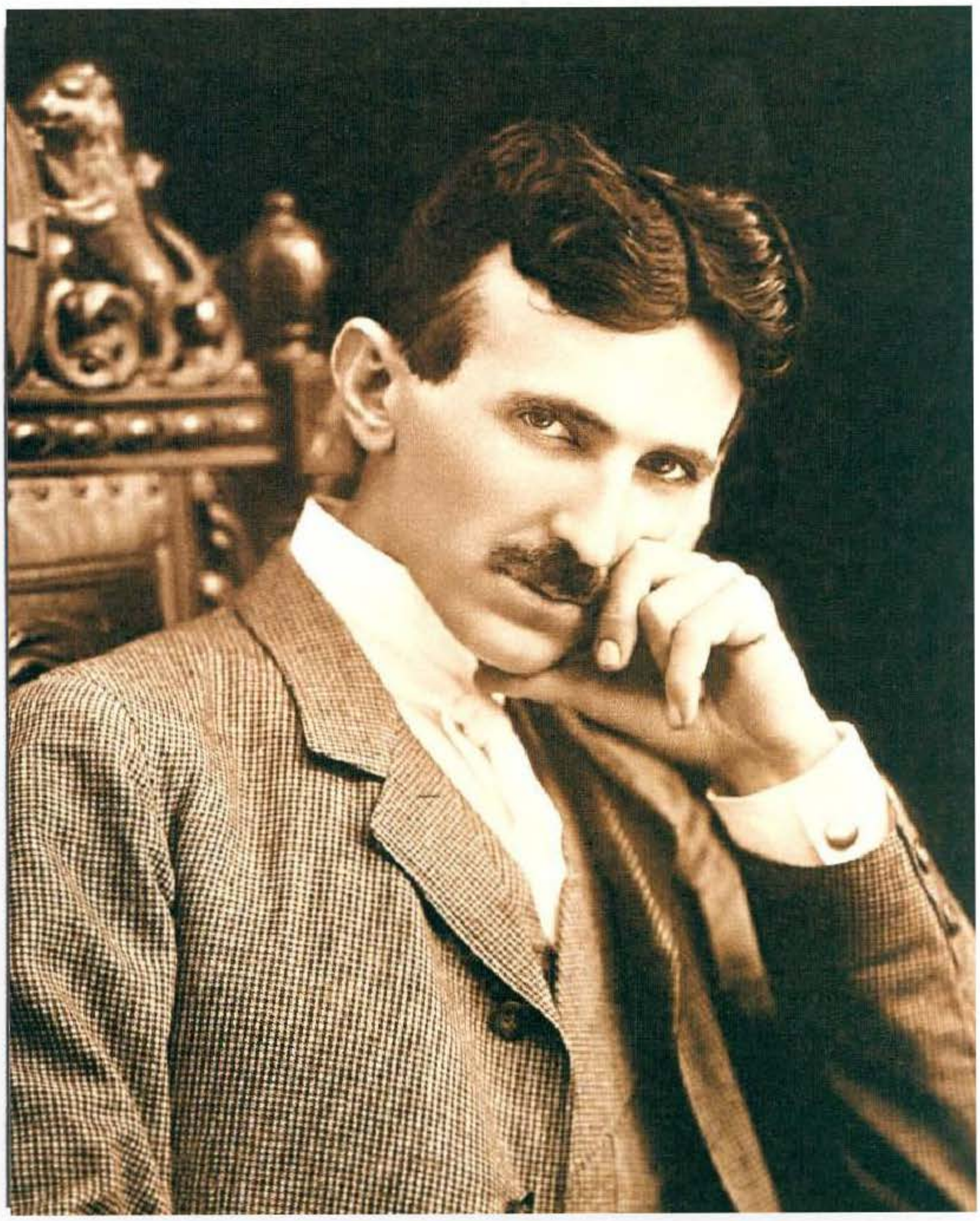
Standing nearby was another and smaller machine of the same type, connected through a gear-box with a dynamo. The engine itself would almost go into an ordinary hat-box. At a signal from Dr. Tesla the mechanic turned on the steam. Instantly, without the fraction of a second's apparent delay, the dynamo was under full speed, and from the end containing the motor rose the same clear note, indicating a well-balanced machine running freely at its normal speed.

"This little turbine has developed 110 horsepower under tests," said Dr. Tesla. It was about the size of a derby hat.

"Careful tests have shown that the single-stage turbine, running at 9,000 revolutions per minute, with a steam pressure of 125 pounds at the inlet, developing 200 brake horsepower, consumes

38 pounds of saturated steam per horse-power hour," said Dr. Tesla.

"But I can do better than that by compounding," he added. "The heat-drop under the conditions I named is only 130 British thermal units, and that is less than one third of the amount available under



DR. NIKOLA TESLA

WHO, IN HIS SEARCH FOR AN ENGINE SUFFICIENTLY LIGHT AND POWERFUL TO OPERATE THE IDEAL FLYING MACHINE, HAS INVENTED A WONDERFUL LITTLE TURBINE MOTOR, FOR GENERAL USE, THAT IS AN ENTIRELY NEW APPLICATION OF MECHANICAL PRINCIPLES

modern conditions of superheated steam and high vacuum. By compounding the turbines I shall get a steam consumption of not more than eight pounds per horse-power hour.

"The most efficient steam engines in America, big, slow-moving pumping engines working under ideal conditions and constant load, use about eleven pounds. I have undertaken a contract to produce one which will consume less than nine.

"The idea on which all steam engines — gas engines, too — have been built in the past was that there must be something solid and substantial for the steam to push against. The piston of a reciprocating engine and the blades and buckets of modern turbine engines are examples of what I mean. That idea has made them rather complicated devices, requiring careful fitting for efficient operation, great expense for repairs, and, especially in the case of turbines, great liability to

damage. It has also made them bulky and heavy.

"What I have done is to discard entirely the idea that there must be a solid wall in front of the steam and to apply in a practical way, for the first time, two properties which every physicist knows to be common to all fluids (including steam and gas) but which have not been utilized. These are adhesion and viscosity.

"You know that water has a tendency to stick to a solid surface. That is the property of adhesion which every fluid — gas, steam, water, or whatever it be — possesses. You also know that a drop of water tends to retain its form, even against a considerable force, such as gravity. That is viscosity, the tendency to resist molecular separation, and all fluids have this property, too.

"It occurred to me that if I should take circular disks, mount them on a shaft through their centres, space them a little distance apart, and let some fluid under pressure, such as steam or gas, enter the interstices between the disks in a tangential direction, the fluid, as it moved, owing to these properties of adhesion and viscosity, would tend to drag the disks along and transmit its energy to them. It happened just as I had thought it would, and that is the principle of this turbine. It utilizes the very properties which cause all the loss of power in other turbines.



THIS ABSURDLY SMALL ENGINE — TESLA'S SMALLEST MODEL — DEVELOPS 110 HORSE POWER

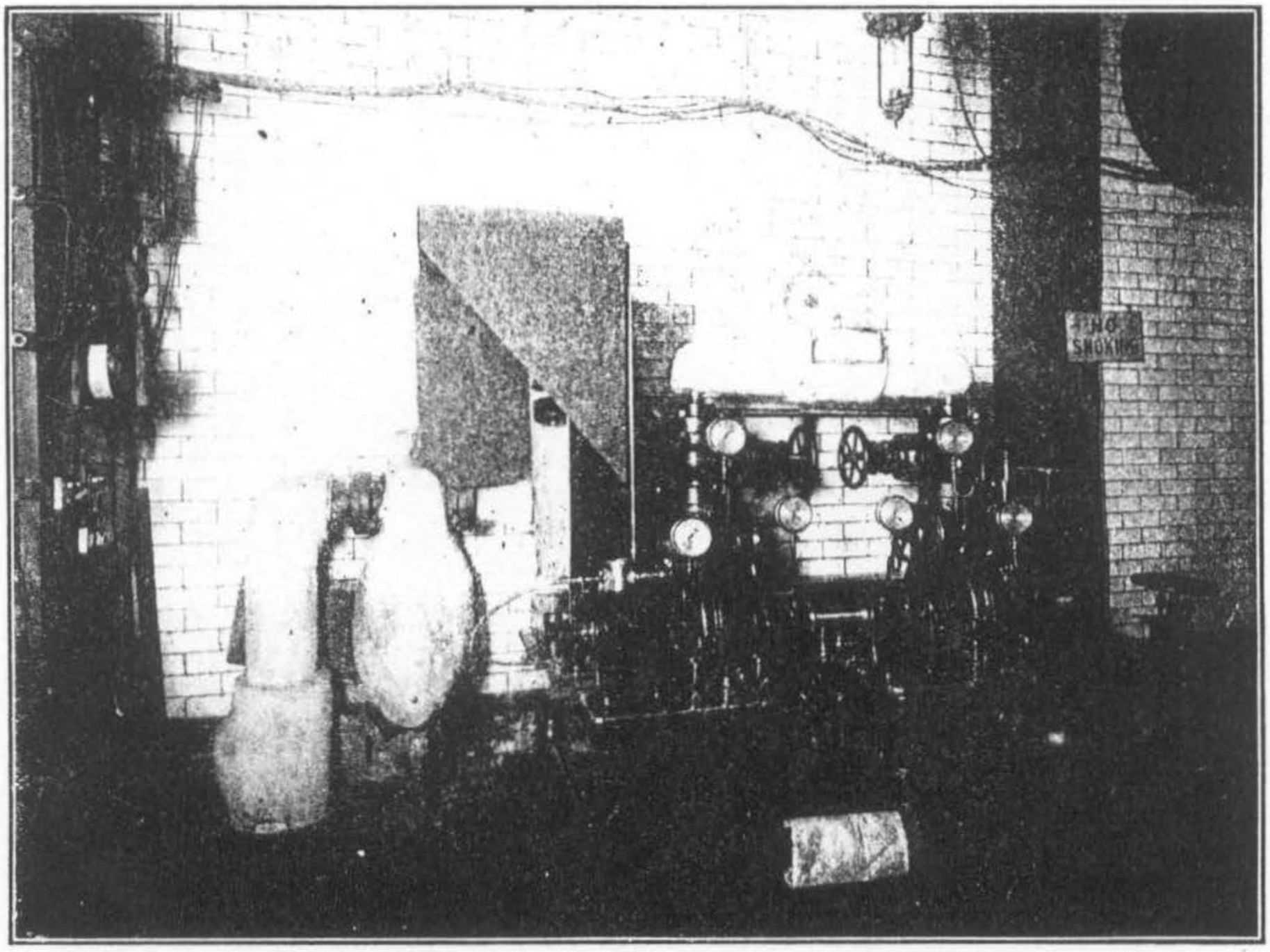
"Inside of the casings of those engines you saw — instead of buckets or blades or vanes on the edge of a wheel, there are simple disks of steel mounted on the shaft. In the two larger turbines these disks are eighteen inches in diameter and one thirty-second of an inch thick. There are twenty-three of them, spaced a little distance apart, the whole making up a total thickness of three and one half inches. The steam, entering at the periphery, follows a spiral path toward the centre, where openings are provided through which it exhausts. As the disks rotate and the speed increases, the path of the steam lengthens until it completes a number of turns before reaching the outlet — and it is working all the time. In the ordinary turbine the steam passes only around the periphery and the central portion of the wheel is useless. Moreover, every engineer knows that, when a fluid is used as a vehicle of energy, the highest possible economy can be obtained only when the changes in the direction and velocity of movement of the fluid are made as gradual and easy as possible. In previous forms of turbines more or less sudden changes of speed and direction are involved."

Later, in his laboratory in the Metropolitan Tower, discussing the commendations which eminent engineers, many of them with international reputations, have expressed concerning his turbine, Dr. Tesla summarized the points that make it a long step in advance in mechanical engineering.

"To say nothing of it being a new application of mechanical principles," he said; "it has many decided advantages. First of these is its simplicity. It is comparatively inexpensive to construct, be-

cause nothing but the bearings need be accurately fitted, and exact clearances are not essential. Then there is nothing in it to get out of order and the disks can easily be replaced by any competent mechanic. It can be reversed without complex or cumbersome apparatus — all that is needed is a two-way valve to let the steam in at one side or the other, as desired. Reversing an ordinary turbine is next to impossible.

"My machine occupies, as you saw



TESTING THE SPEED, POWER, AND STEAM PRESSURE OF A TESLA TURBINE

THE PICTURE SHOWS TWO ENGINES, EACH CAPABLE OF PRODUCING 330 HORSE-POWER, WORKING AGAINST ONE ANOTHER FOR TEST PURPOSES, THE TORSION SPRING CONNECTING THE TWO BEING USED TO INDICATE THE AMOUNT OF POWER DEVELOPED

little space — the 110 horsepower turbine has disks only $9\frac{3}{4}$ inches in diameter — and in consequence it weighs very little. The lightest engines now in use weigh $2\frac{1}{2}$ pounds to the horsepower, while these, in their crudest forms, weigh less than that, and I expect to be able to produce 10 horsepower to the pound. Using gas instead of steam it gives most gratifying results, doing away with the complicated valves and springs of the prevailing types of gas engines. Another interesting application of it is as a pump, either for water or for air. The same disk arrangement is used, but the casing is so arranged, when built as a pump, that the fluid enters at the centre and is ejected at the periphery." He led the way into an adjoining room where a tiny turbine pump, with disks only three inches in diameter, operated by a one twelfth horsepower electric motor, was pumping 40 gallons of water a minute against a 9-foot head.

"How did you happen to turn your attention to mechanics instead of electricity?" I asked.

"I was a mechanical engineer before I ever took up electricity," replied Dr. Tesla. "I went into electric science years ago because I thought, in that direction, I was going to solve the problem I have been working on all my life — the production of an engine sufficiently light and powerful to operate the ideal flying machine. All my work in the wireless transmission of power, which has at-

tracted more public attention than anything else I have ever done, was toward that end. I do not expect to build that ideal machine to-morrow, any more than I expect every steam engine in the world to be thrown into the scrap-heap because of this new application of mechanical principles, but such a flying machine will come some day, and meantime I have succeeded in developing something new in prime movers. I am young yet and have plenty of time ahead of me."

I remembered that it was twenty-seven years ago that he had come over from Lika with the principle of the rotating field for alternating current motors already worked out, and began some mental calculations, which Dr. Tesla noticed.

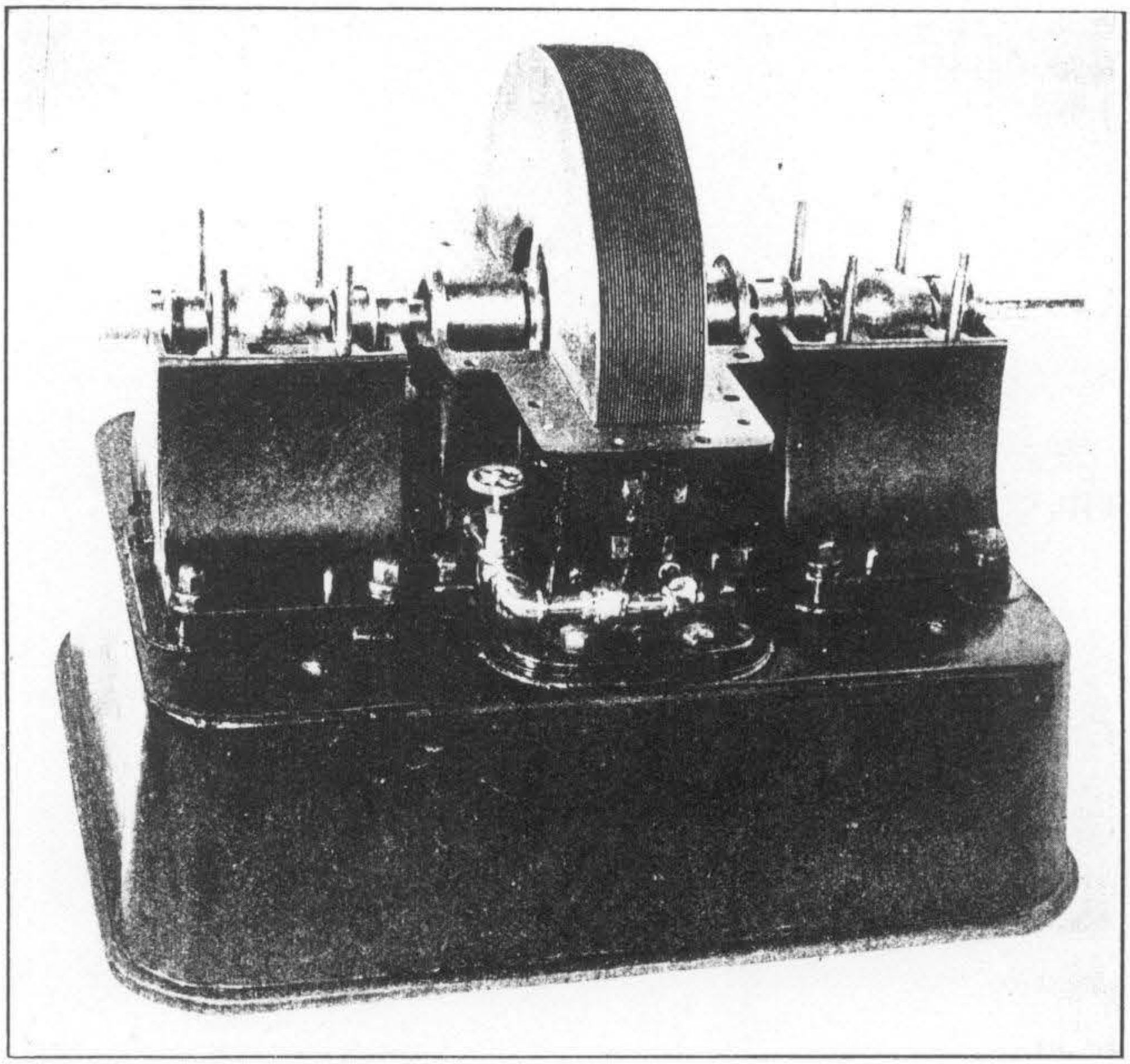
"My age? What do you think it is?" he asked.

"If I didn't know better, I'd say around forty," I ventured. "Fifty, for a guess."

"Fifty-four," was the answer.

"And you still expect to perfect your flying machine?"

"Why not? I have half a century yet to live, if no accident happens. One of my grandfathers lived to be 118, the other past 100. One of my mother's grandfathers won a footrace at the age of 73. I hope it will not take me fifty years to perfect the flying machine, but if it does, I expect to be young enough at 104 to make a flight in it. The Tesla turbine will be on the market long before that, however."



A TESLA TURBINE WITH THE TOP OFF

SHOWING THE SERIES OF THIN DISKS BETWEEN WHICH THE STEAM PASSES AND WHICH, BY THE POWERS OF ADHESION AND VISCOSITY, THE STEAM DRAGS WITH IT IN ITS REVOLVING COURSE

Electric Show Ready For Week of Triumph

Exposition Will Open to he Public Again at 10 o'Clock This Morning.

Rotary Club Members We ing Full Dress to Appear Tonight.

Nikola Tesla, the Man Who "Dreamed," to Be Paid Homage Today.

Following one of the most successful opening nights in the history of the Northwestern Electric Show association, and an entire Sunday spent in perfecting and arranging belated exhibits the third annual Northwest electrical exposition will again be thrown open to the public at 10 o'clock this morning.

Electrical experts from all over the country are present and some of the most noted speakers in the electrical world will address the four electrical conventions which are being held in connection with the show.

Complete exhibits from the Edison laboratories at Orange, N. J., are being explained and demonstrated by Miller Reese Hutchinson Thomas A. Edison's chief engineer and his personal representative who arrived here Saturday, and he is assisted by a corps of Edison factory representatives, two of whom have traveled all the way to Minneapolis from the plant of the General Electric company at Schenectady, N. Y. Nelson C. Durand, second vice president of the Thomas A. Edison company at Orange, N. J., arrived Saturday to take charge of the Edison talking machine, dictagraph and dictaphone exhibits.

W. D. W. Ryan, one of the foremost illuminating engineers of the day, who has just completed an inspection of the Panama canal where he was sent by the United States government to investigate the illuminating possibilities of the great inter-oceanic highway, will come to the show direct from Colon.

He was slated to address the convention of the American Institute of Electrical Engineers today on "Lighting From the Early Ages to the Present Time," but a telegram from his received last night by Manager Clark announced that he had missed train connections in New Orleans and would not reach here until tomorrow morning. His address will be delivered at tomorrow afternoon's session.

Many Visitors Here.

The many electrical conventions and the electric show are filling the hotels with electrical visitors and there are already delegations here from Chicago, Duluth, Superior, Milwaukee, La Crosse, Winona, Red Wing and all of the vicinity cities, while every train is bringing electricians from the East, from Canada and far Western points.

Miss Blanche Mehaffey, soprano soloist from Cincinnati who opened her engagement at the show Saturday afternoon, spent yesterday with the First regiment and at the Armory rehearsing the special St. Patrick's day music which will be a feature of today's program. Miss Mehaffey will sing two numbers both afternoon and evening and there will be special cornet solos by Professor Carl Carcifini. The band numbers will include such appropriate selections as Bennett's "Irish Echoes," "The Green Flag," by Claus, Bennett's "Wearing of the Green" and similar numbers.

Tonight will also be Rotary club night at the show, 200 members of the organization having decided to visit the show with their families. They will wear full dress. This action was decided upon at a dinner of the club held at the Hotel Radisson Friday, when Manager Clark and Mr. Burns of the Flour City Iron Works addressed the members on the value of the electrical exposition from an educational standpoint. There are six exhibitors at the Armory show who are members of the organization.

Nikola Tesla Honored.

Nikola Tesla, the man who "dreamed" of the wireless telegraph and announced its possibilities to the world more than 10 years before the time of Marconi, the man who proved his ability to wreck tall buildings by the vigrations of an electric machine of his own invention, the "dreamer" who declared he was able to split the earth in twain by similar vibration, is the man honored by the electrical exposition today. Today is named Tesla day after him.

Mr. Tesla gave to the world the alternating current, without which long distance transmission of power would have been impossible. He now is working on the transmission of power by wireless, and says if he cannot accomplish his purpose he is willing to lay his head upon the block. He is again "dreaming," but in his dreams are as well founded as those he previously made public, the next 10 years will show an electrical revolution which will far outshine anything to date.

Demonstrations of Tesla's wonderful coils and inventions will be the order of the day, and his message to the people will be received by Archbishop John Ireland.

Archbishop Praises Electric Exposition

Stamp of Approval Is Placed on the Show by St. Paul Prelate.

Messages Exchanged With Tesla, Who Makes Prophecies for Future.

Night Is Turned Over to Rotary Club and St. Patrick Program.

TUESDAY, WESTINGHOUSE DAY.

Afternoon.

March, "Italian Songs" ..... Panella
Overture, "Light Cavalry" ..... Suppe
Waltz, "Artist's Dream" ..... Vollstedt
Chilian dance ..... Missud
Vocal selection, with orchestra .....
Miss Blanche Mehaffey.
Fantasia, "Napolitana" ..... Boccalari
Characteristique, "The Dawn of Love" .. Bendix
Barn dance, "Mandy, How Do You Do?" . Lampe
Finale, "The Old Town Is Looking Good Tonight" ..... Mills

Evening.

Maren, "Nieblungen" ..... R. Wagner
Waltz, "Don't Be Cross" ..... Zeller
Overture, "Les Dragons De Villars" .. Hilbrecht
Selection, "Chocolate Soldier" ..... Strauss
Vocal selection, with orchestra .....
Miss Blanche Mehaffey.
Selection, "Lucretia Borgia" ..... Donezitti
Idyl, "The Mill in the Forest" ..... Ellenberg
Patrol, "Southern" ..... Voelker
Finale, "The Red Rose Rag" ..... Wenrich

Archbishop John Ireland, of St. Paul, put his stamp of approval on the Northwestern Electrical Exposition yesterday by presiding at the opening of the afternoon show and receiving in person the message of the great inventor, Tesla, which he read from the rostrum.

Despite the fact that it is Lent the Archbishop very willingly consented to open the afternoon's exposition, declaring that on account of its educational value the show deserved the cooperation of every resident in the great Northwest which had produced it.

Mr. Tesla's message, which was directed personally to Archbishop Ireland, made great promises for the future of electricity. He said in part: "Mysterious as ever before, nature yields her precious secrets more readily and the spirit of man asserts his mastery over the physical universe. The day is not distant when the very planet which gave him birth will tremble at the sound of his voice; he will make the sun his slave; harness the inexaustable and terribly intense energy of microcosmic movement; cause atoms to combine in predetermined form; he will draw the mighty ocean from its bed, transport it through the air and create rivers and lakes at will; he will command the wild elements; he will push on and on to greater deeds, until with his intelligence and force he will reach out to spheres beyond the terrestial."

Religion Salutes Science.

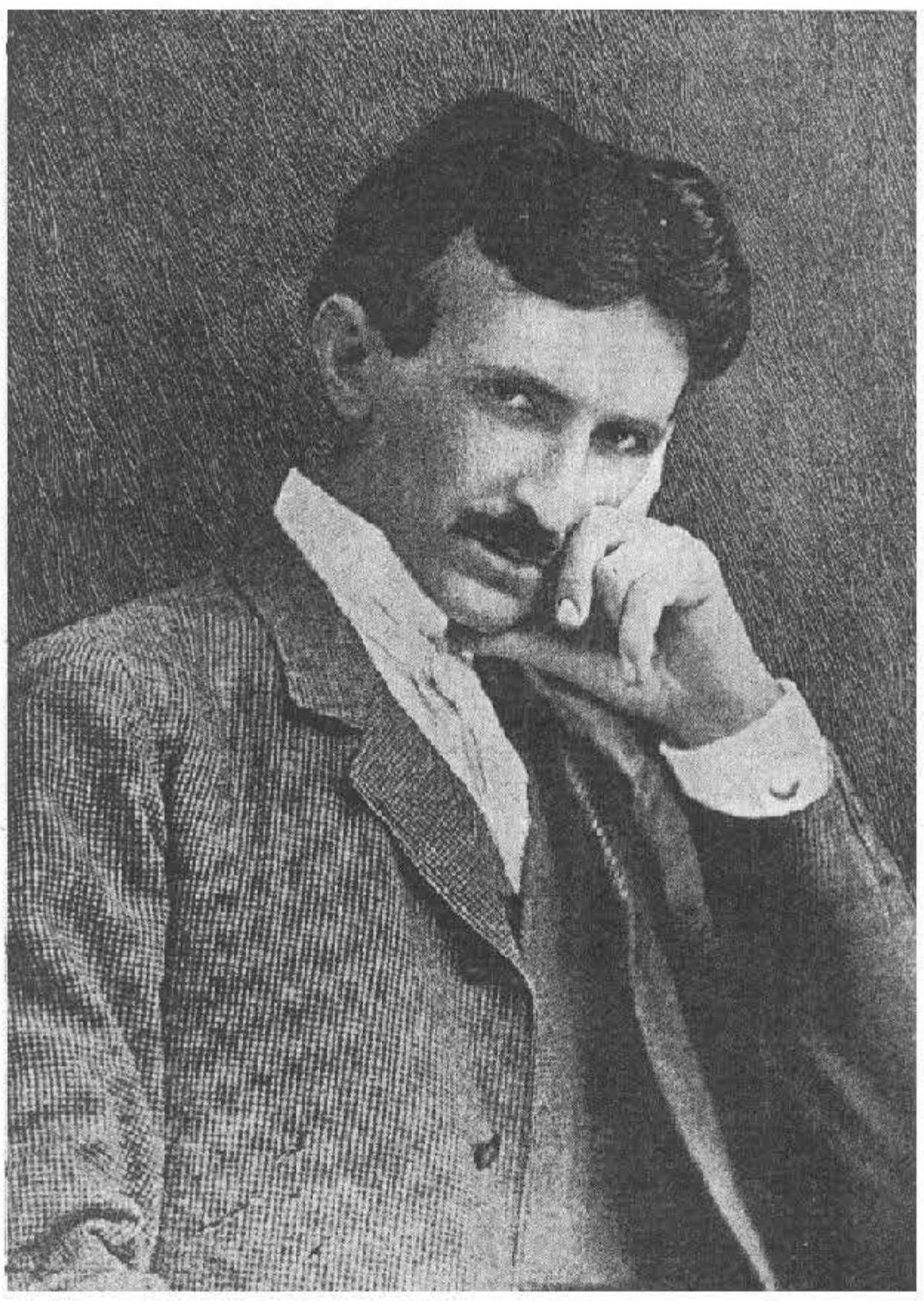
Commenting on the message, the Archbishop said: "It is pleasing to listen to the prophecies of so great a man as Tesla. It shows what man with persistent effort and application can do. The laws of nature are wondrous but what are laws without the Law Giver? The more we know of nature the more we admire the Great Being who fashioned the world, and so religion salutes science and bids it go forward. As a representative of religion I bid all success to science—true science is a tribute to the immortal God."

Last night was Rotary club night, more than 200 members of the club, in full dress, with their families attending the exposition as a tribute to six members of the club who are exhibitors at the show. Last night, also, was St. Patrick's night and the "Wearing of the Green" was not only a feature of the St. Patrick's day musical program, but also was characteristic among visitors at the show.

The American Institute of Electrical engineers opened their convention at the Armory yesterday afternoon when Miller Reese Hutchinson delivered a paper on the "Edison Storage Battery."

NIKOLA TESLA

Eminent Electrical Engineer, Physicist and Inventor, Whose Work Has Attracted World-wide Attention.



Nikola Tesla, whose name is familiar in every part of the globe where scientific research is conducted, was born in 1857, in Smiljan, Lika, border country of Austria-Hungary; the son of a distinguished clergyman and orator, and of Georgiana Mandic, a famous woman and inventor, whose father was also an inventor. His education began in the elementary school of his native place, continued four years in the public school in Gospic, Lika, four years in Lower Real school in Gospic, and three years in Higher Real school, Carlstadt, Croatia, where he was graduated in 1873. Originally destined for the clergy, he prevailed upon his parents to send him to the Polytechnic School in Gratz, where, for four years, he studied mathematics, physics and mechanics, following with two years of philosophic studies at the University of Prague, Bohemia. He started on his practical career in 1881, in Budapest, Hungary, where he made his first electrical invention, a telephone repeater, and conceived the idea of his rotating magnetic field; thence he went to France and Germany, where he was successively engaged in various branches of engineering and manufacture. Since 1884 he has been a resident of the United States, of which he is a naturalized citizen, and here his subsequent inventions originated.

Among his inventions and discoveries are: System of arc lighting, 1886; Tesla motor and system of alternating current power transmission, the "Tesla coil" of transformer, which has proved an indispensable adjunct in many electrical arts, 1891; investigations of high-frequency effects and phenomena, 1891-93; system of wireless transmission of intelligence, 1893; mechanical oscillators and generators of electrical oscillations, 1894-95; researches and discoveries in novel radiations, material streams and emanations, were published in a series of papers in the "Electrical Review," New York, 1896-1898, in which he announced all the salient phenomena later attributed to radium; high-potential magnifying transmitter, 1897; system of transmission of power without wires, 1897-1900; economic transmission of energy by refrigeration, 1898; art of Telautomatics, 1898-99; discovery of stationary electrical waves in the earth, 1899; burning of atmospheric nitrogen, and production of other electrical effects of transcending intensities, 1899-1900; method and apparatus for magnifying feeble effects, 1901-1902; art of individualization, 1902-1903. The development of his system of world-telegraphy and telephony and of the transmission of power without wires has engaged much of his attention since that time. His most important recent work is the discovery of a new mechanical principle, which he has embodied in a great variety of machines, as reversible gas and steam turbines, pumps, blowers, air compressors, water turbines, mechanical transformers and transmitters of power, hot-air engines, etc. This principle enables the production of prime movers capable of developing ten-horsepower, or even more, for each pound of weight. By their application to aerial navigation, and the propulsion of vessels, high speeds are practicable.

TESLA PREDICTS MORE WONDERS

Annihilation of Space Will Be Work of the Coming Generation.

WIRELESS WILL DO IT

Transmission of Intelligence and Energy and Transport of Materials.

EXTENSION OF SIGHT

One Person Will See Another as Though That Other Were by His Side.

SOLUTION FOR AIR TRAVEL

Inventor Also Declares Electricity Will Cure Mental Ills of Children

A past generation saw the invention of the steam engine and the epochal change which it wrought in the world of industry. Methods and appliances which were regarded as permanent as the mountains passed with the coming of steam. Many of them are remembered only as curious remnants of a cruder mechanical age.

Then came the introduction of electricity to practical purposes. Now the world depends on this invisible agent as the nerve force sustaining it on its onward march. Scientific primers that were printed within the recollection of older men and women speculated about this development of electrical force and guardedly discussed its possibilities. Predictions made as to the future use of the electric current and its commercial possibilities seem absurdly conservative now, when scientists reread them in the light of actual developments.

What is to be the big change of the coming age? Has science reached the limit of its resources? Along what line will the next developments come?

Man has overcome many of his physical limitations, scientists explain, by chaining the forces of nature and making the earth and the air work for him. He has multiplied his muscular strength a billion times, but there is one problem the solution of which will be the great work of the coming generation. That is the annihilation of distance. Wireless will do this, says Nikola Tesla, the inventor.

"In the last few years many wonderful possibilities have presented themselves," explained Mr. Tesla, "but, in my opinion, none will be of such far reaching consequence as the complete annihilation of space. This will be accomplished in three fields, the transmission of intelligence; the ransport of bodies and materials and the conveying of the energy necessary to the sustenance of modern life.

"If carefully analyzed all the clashes between individuals and nations and their disastrous results can be traced to the physical impossibility of getting into close contact. Annihilate distance in thought and action and you will give unbounded opportunities to the economic, healthful and peaceful development of mankind. This annihilation of distance will be brought about by the transmission of energy without wires.

"As regards intercommunication a great step has already been made, but a fuller realization will come when a system is introduced enabling any person to reach any other on the globe, and not simply through a spoken word, but visually. I mean by this that not only must there be a telephone connection from one to any other point, but also a perfect transmission of images which will enable one person to see another as though that other were by his side.

"The next step will be the transportation of bodies and materials through the medium of flying machines operated from wireless plants. The introduction of power for this purpose will do away with all the limitations that now confront aerial navigation and make travel through the air entirely safe and comfortable. The third step will take a much longer time for realization but will ultimately be accompliahed by the general introduction of wireless power for all necessities."

Mr. Tesla pictured an age where the great operations of commerce and industry would be vitalized by central distributing wireless stations. There are in the world many natural sources of tremendous power. The falls of Niagara alone might be made to supply a fifth of all the power used in the United States. The present difficulty is that of electrical transmission by wire. It is not only the heavy cost of long lines of copper wire that hampers the distribution of the energy that might be generated at the great falls, but power can only be carried over wires for a comparatively limited distance. Wireless transmission would take that power and carry it to the ends of the earth with little loss.

The scientist points out that the power that could be derived from the waterfall of the Columbia River and the great falls of Zambesi in the heart of Africa could be brought to New York city and made to run the subway trains.

Ocean going boats would no longer need to carry their thousands of tons of coal. This fuel might be consumed in a central station, where the expense and waste of a dozen different handlings would be eliminated. If the ship were delayed by accident to her machinery in midocean there would be no fears that the coal supply might not hold out. The ship would be in constant touch with her source of enrgy supply as well as in communication with the outside world at every point of her course.

The possibilities of airship travel have so far been limited by the fact that aeroplanes and airships have no room or carrying capacity for the fuel necessary to an extended trip where there was no possibility of reaching a base of supplies. Such a trip would be a flight over the ocean. Wireless power would end this difficulty, Mr. Tesla explains. The aeroplane would be drawing energy from a central source, and it would make no difference whether it remained in the air an hour or a year so far as power supply went. Such airships might be controlled from the land as easily as though the operator were seated at the steering wheel. This, however, would not be as satisfactory an arrangement, Mr. Tesla thinks, as to have an engineer with the machine at all times.

But why tranamit power when the sun gives it so abundantly at every point? Why not harness sunlight?

"It is true that the sun's energy might be captured and made useful at any spot," said Mr. Tesla, "but it does not take long to see that it would not be as useful as the transmission of energy from a central plant, for the former would lead to individual independence, while the latter would tend to bring about a close union of interests and harmonious cooperation. It would make war impossible."

Anybody whose imagination is vivid enough can make a prediction. It is easy enough to think up situations which would be pleasant and make for the betterment of the world. Mr. Tesla states his forecasts are founded on a sound experimental basis.

"These are not forecasts," he replied in response to this objection, "they are facts. Experiments and demonstrations to this effect have already been made by me, and if it were not for the unavoidable inertia of human movement the idea would have materialized and I would be telling you of still greater wonders.

"I have demonstrated in actual tests that a powerful current from a wireless transmitter properly organized sets the entire plant into vibration like a wire, with the result of producing stationary nodes and loops. To the electrician this means that the current wave traverses the globe without appreciable loss and that, therefore, all kinds of impulses from the feeble electrical tremors caused by the human voice and affecting the sensitive diaphragm of a telephone to the powerful waves of a trolley wire can be transmitted integrally from one end of the globe to the other.

"For some years this discovery has been ready for commercial application, but you must understand that any idea so revolutionary as this one must meet with a proportionate resistance. his is the law of nature. Every effort in a new direction creates antagonism, which can only disappear when the world as a whole grasps the new truth and learns to appreciate it. Take the Panama Canal as an example. What troubles and delays have occurred and are still happening and retarding the undertaking's successful termination!

"One thing of great practical value that is being done now is the training of wireless experts, without whom such results as I have forecast would be impossible. There are 100,000 wireless amateurs in the United States. Some of these will develop into men who will bring these new ideas to their full fruition.

"In the meantime wireless communication is being extended and plans are being perfected for transmitting energy on a larger scale. I should think it would be safe to say that in the next three years a word spoken in New York city will be carried around the world. With proper instruments it could be made audible at any other point of the globe and intensified so as to be heard for miles.

"An objection is raised that the wireless art is fatally limited in the number of the signals transmissible and in their liability to interference. But this is a great popular mistake. It is true that in conveying signals through the earth we are availing ourselves of only a single medium, but it is infinitely more perfect than any artificial channel. The privacy of a message over a wire is solely based on the isolation of the conductor in space, which can be broken down. In the transmission through the earth the secrecy of the transmission is resting on the much safer basis of an arbitrary combination, which can be so intricate that it is as inscrutable as thought. Far from being less perfect, the wireless in its highest perfection is ever so much superior to the wire.

"As to the question of what effect wireless transmission of energy would have on the burning and transportation of coal it is hard to give a definite answer. One cannot tell to what perfection the means of transportation may be brought. Of course we shall never be able to overcome the inertia of mass and, therefore, limits to speed will forever be imposed even in transportation through the air. But we may learn how to concentrate the energy of coal and multiply the rate of transported energy.

"Water power alone is not sufficient for the needs of man, although it will go far toward increasing his opportunities. Coal is still our chief source of power, and a small part of its wasted energy is greater than all the water power available in the world. For instance, the manufacture of iron and steel in this country entails, according to my computation, an annual loss of power which would yield if properly exploited an annual income of not less than $300,000,000. I feel that a solution has been found, and in the near future a new resource will be opened up which will be of incalculable effect."

Nikola Tesla does not think that Prof. Ramsay's notion of burning coal in the mines or as it is found in the earth would be practical.

"The idea is ingenious," Mr. Tesla went on, "and not at all unrational, but on careful computation it will be found that more power can be derived by mining coal and burning it under proper conditions than by using it in the manner proposed by Prof. Ramsay. Another problem presented by his scheme would be that of finding employment for countless thousands who are now earning their living in mining."

He believes high frequency currents will have an important use in the future. He explains he has noticed that he has derived great physical benefit in working with them. The suggestion is made that here is a possible means for improving the mental makeup of children. The problem of the defective child has been one that has long baffled social workers, Mr. Tesla points out.

Will it be possible by these very currents which are used for wireless purposes to increase these children's mental powers and give them a fairer chance in life? Mr. Tesla thinks so.

On this point there have been already a series of experiments. Prof. Svante Arrhenius, the noted physicist of Stockholm, it is announced, has completed a series of investigations to prove that electricity has a marvellous effect on the growth of children. Two groups of children, it is stated, of about the same physique, age and mentality were placed in two rooms which were exactly alike except that in the walls of one of the rooms there were wires concealed which carried high frequency, alternating electrical currents. This was done at a school, and neither the teachers nor the pupils knew any such experiment was being conducted.

Despatches from Stockholm state that at the end of six months the electrically treated children had grown 2 inches on an average and the children who were not subjected to the electrical influence had grown only 1.16 inch. Making twenty the standard of perfection, the electrified children reached in their studies an average of 18.4 and fifteen attained a perfect mark. The unmagnetized children attained an average of 15 and only nine of them got perfect marks. When questioned the teachers who had classes in the electrically influenced room said their faculties were quickened and their powers of endurance increased.

"Ever since my first demonstration with these currents, which attracted world-wide interest, I have noticed their beneficial action," said Mr. Tesla, referring to the Stockholm experiment. "They are undoubtedly destined to create a great revolution in theraphy and medical treatment. Dr. Arrhenius is a skilful experimenter and his announcements may be relied upon. I have long been convinced that high frequency currents are useful in certain nervous afflictions and that they assisted mental effort. But that growth can be increased through their agency is an entirely new observation.

"If what already has been done can be used as safe foundation in predicting what is to come we are certainly on the verge of realizations which may completely change our mode of life. I am a little pessimistic, however, as to the part that radium is to play in the new advancement. Believing as I do that radium is much the same sort of an illusion that phlogiston was a century ago, I am forced to this conclusion. It was the accepted belief at that time that a social element designated as phlogiston was involved in combustion and the error persisted until Lavoisier discovered oxygen and showed the part it played in this phenomena.

"In my papers published in the *Electrical Review* in 1896 and 1897, several years before the discovery of radiferouse ores, I described radiations of this sort, although produced in a different manner, and pointed out their salient properties, and I still hold the same opinion, believing radium to be due to a process akin to combustion in which not oxygen but an all pervading medium much finer is involved. According to this view, there is no virtue in the radium ore itself, but it is merely the result of its combination with a medium. I think one may safely discount many of the claims made for the future uses of radium."

Mr. Tesla says he has perfected a practical system of wireless power transmission and that he has secured actual results at his experimental plants in Colorado and Long Island. He holds that he has made satisfactory demonstrations which guarantee its commercial application. This has been the cumulative work of years.

"When I was a boy," Mr. Tesla said, "I lived near a mountain and one of my pleasures was to build small water wheels and set them in motion in the streams that came down the sides of the mountain. I would use the power from these wheels for turning small machines. It was always my ambition to see the power of a waterfall chained and made to work. I used to tell my uncle that some day I would see the greatest falls in America. He laughed at me and said I would probably never get to America, let alone see Niagara Falls.

"That was a good many years ago and I thought of it again when I delivered an address at Buffalo at the introduction of Niagara power and saw in actual operation what I had dreamed of when I was a boy."

There has been a good deal said, Mr. Tesla explains, about electrical treatment of soil, which scientists claim will reclaim land. The inventor points out that with

TESLA PREDICTS MORE WONDERS

Continued from First Page.

wireless power transmission it would be an easy matter to reclaim vast tracts of land. Nikola Tesla was born at Smiljan, Lika (border country of Austria-Hungary), in 1857, the son of a Greek clergyman. After his elementary school training, he spent four years at the Lower Realschule at Jospic. He was graduated from the Higher Realschule at Carlstadt in Crotia in 1873. He took his mathematical course at the Polytechnic School at Gratz and afterward spent two years at the capital in Prague. He began his practical career at Budapest in 1881, where he invented a telephone repeater and then conceived the idea of his rotating magnetic field. Since 1884 he has lived in the United States.

The theory that sight can be made to accompany the electrical wave was advanced by Mr. Tesla in an interview published in 1896.

"This problem of transmitting sight by wires or otherwise to any distance is as difficult as it is fascinating," he says. "It must not be compared as to its technical difficulties with the transmission of pictures or even colors by such means. These are comparatively easy tasks.

"The solution of this problem has been attempted very many times and more recently a further stimulus has been given to research in this direction by the magnificent inventions of Alexander Graham Bell. As soon as it became possible to transmit the strains of an entire opera over a wire the mind jumped immediately to the conclusion that seeing by similar methods will also become an accomplished fact. This appeared the more reasonable as Bell succeeded in transmitting speech through the medium of no more than a ray of light. The activities in this direction have not abated, but on the contrary have increased, especially since we have learned more about the nature of light through the discoveries of Heinrich Hertz.

"I could hardly name two or perhaps three other problems or lines of investigation which have taxed my own powers of thinking as much as this. As yet, while in these other lines I have realized considerably, as regards this problem of transmitting sight I am still very far from positive demonstration by experiment. You should not infer from this that all my efforts to find a solution have been futile, only experience has made me more exacting and even pessismistic as to the final carrying out of my ideas; why, I am happy to say, I have remained as optimistic as ever I was in their first conception. Very often during the day I conceive ideas which give me pleasure and hope, but in the clam retirement of the night my practical sense deals mercilessly with the projects I have formed."

MR. TESLA ON THE FUTURE

On Tesla Day, at the Northwest Electric Show, held at Minneapolis, Minn., March 16th to 23rd, Mr. Tesla sent, through Archbishop Ireland, the following message to the people of the Twin Cities and the Northwest:

New York, N. Y., March 18, 1912.

His Grace, The Most Reverend Archbishop Ireland:

I bespeak your Grace's far-famed eloquence in voicing sentiments and ideas to which I can give but feeble expression. May the exposition prove a success befitting the cities of magical growth, the courage and energy of western enterprise, a credit to its organization, a lasting benefit to the communities and the world through its lessons and stimulating influence as a bewildering, unforgetable record of the triumphant progress of the art. Great as are the past achievements, the future holds out more glorious promise. We are getting an insight into the essence of things; our means and methods are being refined, a new and specialized race is developing with knowledge deep and precise, with greater powers and keener perceptions. Mysterious as ever before, nature yields her precious secrets more readily and the spirit of man asserts its mastery over the physical universe. The day is not distant when the very planet which gave him birth will tremble at the sound of his voice; he will make the sun his slave, harness the inexhaustible and terribly intense energy of microcosmic movement; cause atoms to combine in predetermined forms; he will draw the mighty ocean from its bed, transport it through the air and create lakes and rivers at will; he will command the wild elements; he will push on and on from great to greater deeds until with his intelligence and force he will reach out to spheres beyond the terrestrial.

I am your Grace's most obedient servant.

NIKOLA TESLA.

An Adjustable Tesla Coil

By Moore Stuart.

Every so often there appears an article on how to make a Tesla coil, of approved construction. Not one of the many articles which the writer has seen to date has described a coil which is in the least adjustable, consequently the secondary voltage must be regulated directly from the primary of the high tension transformer, by regulating the voltage supplied, either by resistance or by means of an adjustable choke coil. Both methods are very wasteful of the current.

The writer has the coil described herewith in operation on a 1½ K. W. transformer and same is easily controllable, directly from the Tesla Coil primary. The output from such a coil may be varied within large limits.

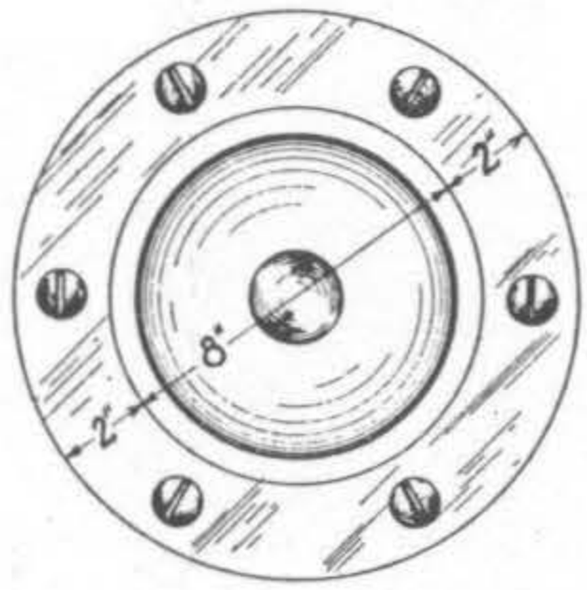
The core, A, must be of hard wood, thoroughly seasoned and varnished. Wound with as many turns as possible of No. 32, or thereabouts, enameled wire. If it is impossible to get the use of a lathe to turn this core out of wood, same may be made up of several thicknesses of heavy wrapping paper and thus forming a cylinder of the required size and thoroughly shellacking and drying. With this form of cylinder there is much more trouble in winding, as there is no way in which it can be placed on the lathe or winding machine. Winding the core is really the only difficult part in the making of this Tesla Coil.

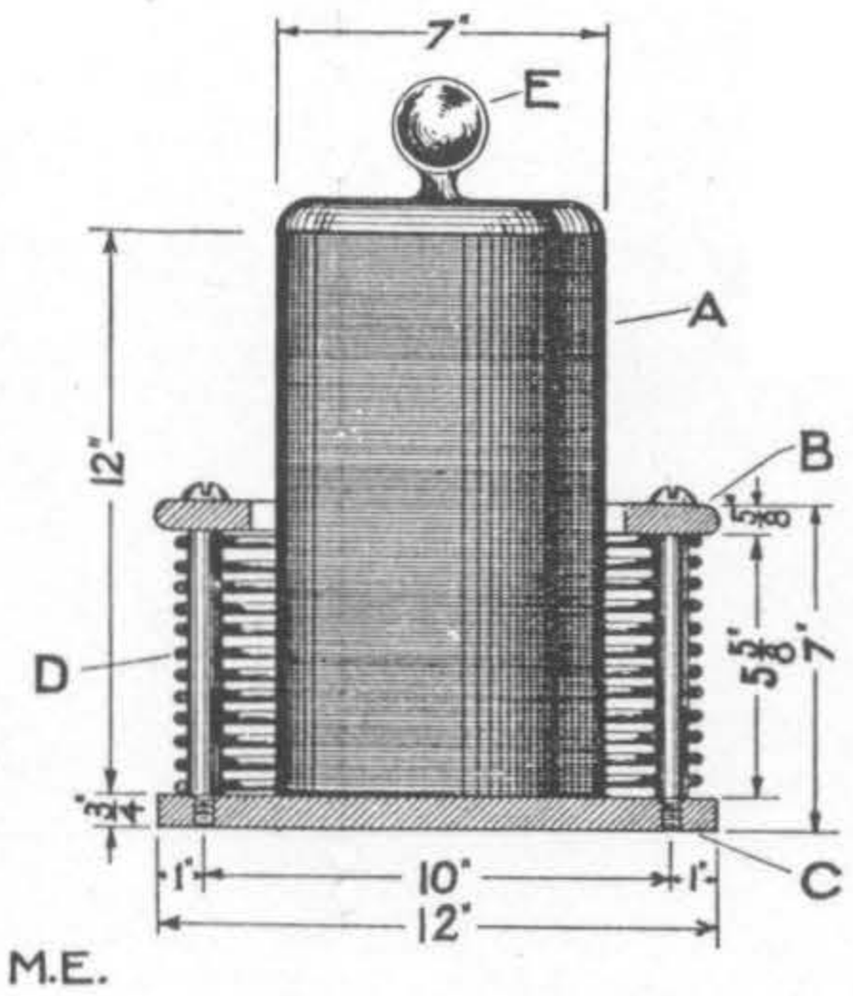
The top flange of the Primary should be turned up out of ⅝ inch stock, in either mahogany or walnut and polished. It is 12 inches outside diameter, with a hole 8 inches in diameter in the centre for the Secondary Coil to pass through.

The Base, C, should be of the same material as the top flange and should be finished and polished the same. There is no hole in this base, as the core of the secondary is screwed directly to this. The rods, D, are also screwed to this by means of flat head wood screws, counter sunk from the under side of the base. Round head brass wood screws are used to hold the rods in position from the top for the sake of appearances, although flat head may be used with the same results as to strength.

The primary winding should be about 12 turns of heavy copper wire, approximately ¼ inch in diameter. About twenty-two feet will be required. The ends should be drilled to receive a small wood screw to hold the wire in position after once winding. The screws may be screwed into the rods at either end of the coil.

The ball, E, should be of metal, or if that is not obtainable a wooden ball may be turned and covered with tin foil. The top end of the secondary winding should





M.E.

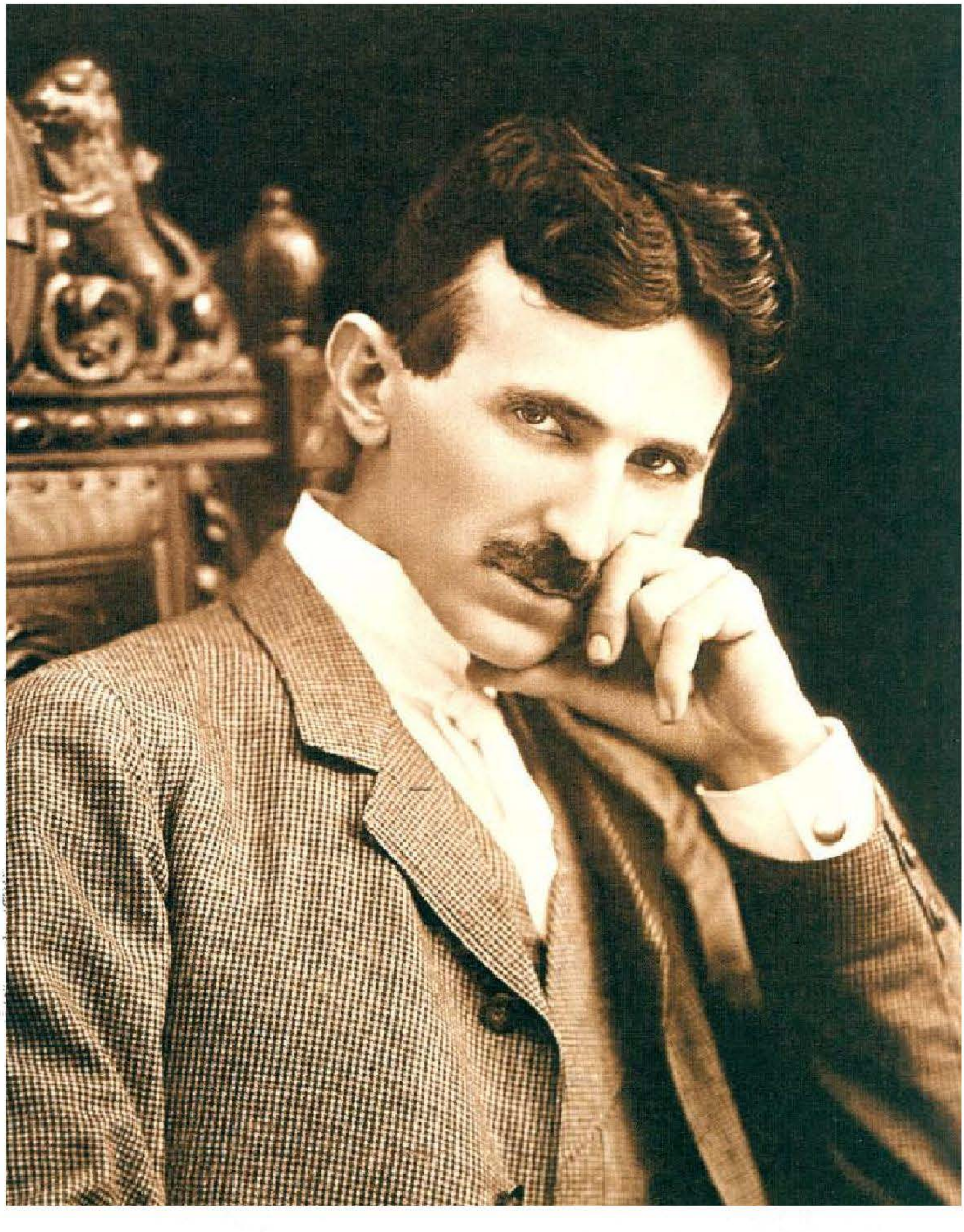
be soldered to this ball. A metal spike may also be used in place of the ball. The other, or lower end of the secondary winding may be soldered to the lower end of the primary winding, or may be taken out through the bottom, depending upon the use to which the completed coil will be put. Clips may be used to connect the primary winding with the secondary of the transformer. It will be readily seen that a connection may be made at any point of the winding after the manner of a wireless helix.

The completed coil should be mounted

on four insulators to insulate it from the earth.

This coil may be adapted to be used for wireless telephonic purposes by merely placing a slider upon the secondary for the adjustment of same. It will be readily understood that this winding should not be adjusted while working the coil, especially if used for wireless purposes with a large condenser, as the number of oscillations per second will be so low as to be dangerous to human life.

If used as a Tesla Coil, many weird and interesting experiments may be carried out. If used with a small condenser on a 1 K. W. transformer, with the entire circuit in resonance, an 8 inch spark may easily be drawn to the hand, if a small piece of metal is held in the hand, without any sensation whatever. However, it is not well to try and receive the current from such a coil unless one is experienced in the action and use of such apparatus, as there are so many factors to be considered, before the current from the secondary is not dangerous to life. Even though the voltage from such a coil be enormous, it will be remembered that but 250 milliamperes or ¼ ampere is generally conceded to be enough to destroy the heart action of a man in average condition, and sometimes very much less current will have the same destructive effect.



Nikola Tesla

Supplement to Modern Electrics. May 1912

Nikola Tesla

NIKOLA TESLA, whose name is familiar in every part of the globe where scientific research is conducted, was born in 1857, in Smiljan, Lika, border country of Austria-Hungary; the son of a distinguished clergyman and orator, and of Georgiana Mandic, a famous woman and inventor, whose father was also an inventor. His education began in the elementary school of his native place, continued four years in the public school in Gospic, Lika, four years in Lower Real school in Gospic, and three years in Higher Real school, Carlstadt, Croatia, where he was graduated in 1873. Originally destined for the clergy, he prevailed upon his parents to send him to the Polytechnic School in Gratz, where, for four years, he studied mathematics, physics and mechanics, following with two years of philosophic studies at the University of Prague, Bohemia. He started on his practical career in 1881, in Budapest, Hungary, where he made his first electrical invention, a telephone repeater, and conceived the idea of his rotating magnetic field; thence he went to France and Germany, where he was successively engaged in various branches of engineering and manufacture. Since 1884 he has been a resident of the United States, of which he is a naturalized citizen, and here his subsequent inventions originated.

Mr. Tesla is the author of numerous scientific papers and addresses, and honorary or regular member of many scientific societies, institutions and academies in the United States and abroad; he is a life member of the British Association for the Advancement of Science and a member of the Royal Institution of Great Britain, M. A. of Yale, L. L. D. of Columbia, and Doctor of Science of the Vienna Polytechnic School, the latter distinction being conferred upon him in acknowledgment of his discoveries of the rotating, magnctic field and principles of wireless energy transmission; the Elliott Cresson gold medal was awarded him in recognition of his original work first presented before the Franklin Institute and the National Electric Light Association in 1893, in which one of the most important chapters was devoted to a description of his wireless method. Mr. Tesla's rank among those who have led in advance in knowledge and appreciation of electrical forces is among the foremost.

Among his inventions and discoveries are: System of arc lighting, 1886; Tesla motor and system of alternating current power transmission, popularly known as two-phase, three-phase, multi-phase, or poly-phase systems, which have created a revolution in electrical engineering and are now universally adopted, 1888; system of electrical conversion and distribution by oscillatory discharges, 1889; generators of high-frequency currents and effects of these, 1890; transmission of energy through a single wire without return, 1891; the "Tesla coil" or transformer, which has proved an indispensable adjunct in many electrical arts, 1891; investigations of high-frequency effects and phenomena, 1891-93; system of wireless transmission of intelligence, 1893; mechanical oscillators and generators of electrical oscillations, 1894-95; researches and discoveries in novel radiations, material streams and emanations, published in a series of papers in the "Electrical Review," New York, 1896-1898, in which he announced all the salient phenomena later attributed to radium; high-potential magnifying transmitter, 1897; system of transmission of power without wires, 1897-1905; economic transmission of energy by refrigeration, 1898; art of Telautomatics, 1898-99; discovery of stationary electrical waves in the earth, 1899; burning of atmospheric nitrogen, and production of other electrical effects of transcending intensities, 1899-1900; method and apparatus for magnifying feeble effects, 1901-1902; art of individualization, 1902-1903. The development of his system of world-telegraphy and telephony and of the transmission of power without wires has engaged much of his attention since that time. A number of discoveries in the electrical field, made by Mr. Tesla, which he has not yet announced, he considers of greater moment than any electrical work he has so far done. His most important recent work is the discovery of a new mechanical principle, what he has embodied in a great variety of machines, as reversible gas and steam turbines, pumps, blowers, air compressors, water turbines, mechanical transformers and transmitters of power, hot-air engines, etc. This principle enables the production of prime movers capable of developing ten-horsepower, or even more, for each pound of weight. By their application to aerial navigation, and the propulsion of vessels, high speeds are practicable.

The Solar Eclipse and Radio-telegraphy.

During the recent solar eclipse an interesting test was undertaken between the radio station of the Royal Dock Yard in Copenhagen and the Blaavandshuk station on the coast of Jutland, so as to ascertain the effect of the eclipse upon wireless transmission. It transpired that the telegraphing became more distinct and reliable as the eclipse progressed, and that it was most distinct shortly after the culmination of the eclipse. The view that it is the effect of the solar light upon the atmosphere which is the cause of radio-telegraphy being much better at night than during the day was thus confirmed.

WIRELESS TRANSMISSION.

Ever since the celebrated experiments of Heinrich Hertz, the possibility of radiating electric energy from an oscillator to a receiving apparatus was realized. At first it seemed as if the feebleness of such radiation would prevent its transmission to any considerable distance, but the persistent work of Marconi and other investigators showed that transmission to a considerable distance is quite possible by this method. With the further developments of the art it was found, however, that the practical results in wireless transmission did not entirely agree with the laws which were theoretically derived on the basis of the Hertz-wave theory.

Another phenomenon which has puzzled experimenters and practical operators in wireless telegraphy is the fact that the distance of transmission of wireless signals, which of course depends upon the rate of attenuation, depends upon atmospheric conditions and most notably upon the time of day; that is to say, whether the portion of the earth over which the signals are being transmitted is experiencing day or night.

There has been an attempt to connect the latter phenomenon with the state of ionization of the atmosphere, which is naturally assumed to be different when the sun is shining upon it than at night time. The ionization effect of ultra-violet light is well known and the radiation of the sun is known to contain a considerable proportion of these important wave-lengths. There has been no satisfactory relation established, however, between the conditions of ionization and the strength of the received signals.

In an article which will be found upon pages 34 and 35 of this issue, Dr. Nikola Tesla has propounded a theory, which is supported by his experimental observations, to account for the practical results which have been observed. He has come to the conclusion that the Hertzian waves are responsible for but a small part of the energy which is transmitted from a wireless antenna, the main consideration in such transmission being conduction through the earth. Of course it is not maintained that signals cannot be and are not transmitted by Hertzian waves, as in some cases, notably in transmission to and from balloons and aeroplanes, earth currents are eliminated and dependence must be placed entirely upon radiation through the atmosphere. In most cases of long-distance signaling, however, earth connections are found essential to the best results and it cannot be doubted that the currents flowing into and out of the earth at the point of connection of the antenna or the auxiliary apparatus are important incidents in the operation.

Regarding the effect of sunlight upon transmission, Dr. Tesla presents a unique explanation which experts in this field would probably not be willing to accept without further demonstration. He attributes the change in facility of transmission to the evaporation of moisture from the earth's surface in places which are exposed to the sun's rays. Of course such evaporation is increased by the heat absorbed from the sun's radiation, a phenomenon which affects the conditions in the superficial layer of the earth's crust. Conduction through the earth could itself scarcely be effected in this way, but the explanation given by Dr. Tesla is that the evaporated particles of moisture carry off with them an electrical charge which affects the electrical distribution on the earth. He states that the dissipation of energy is proportional to the cube of the frequency, which would indicate that the best condition for transmission would be a low frequency and consequently large wave-length.

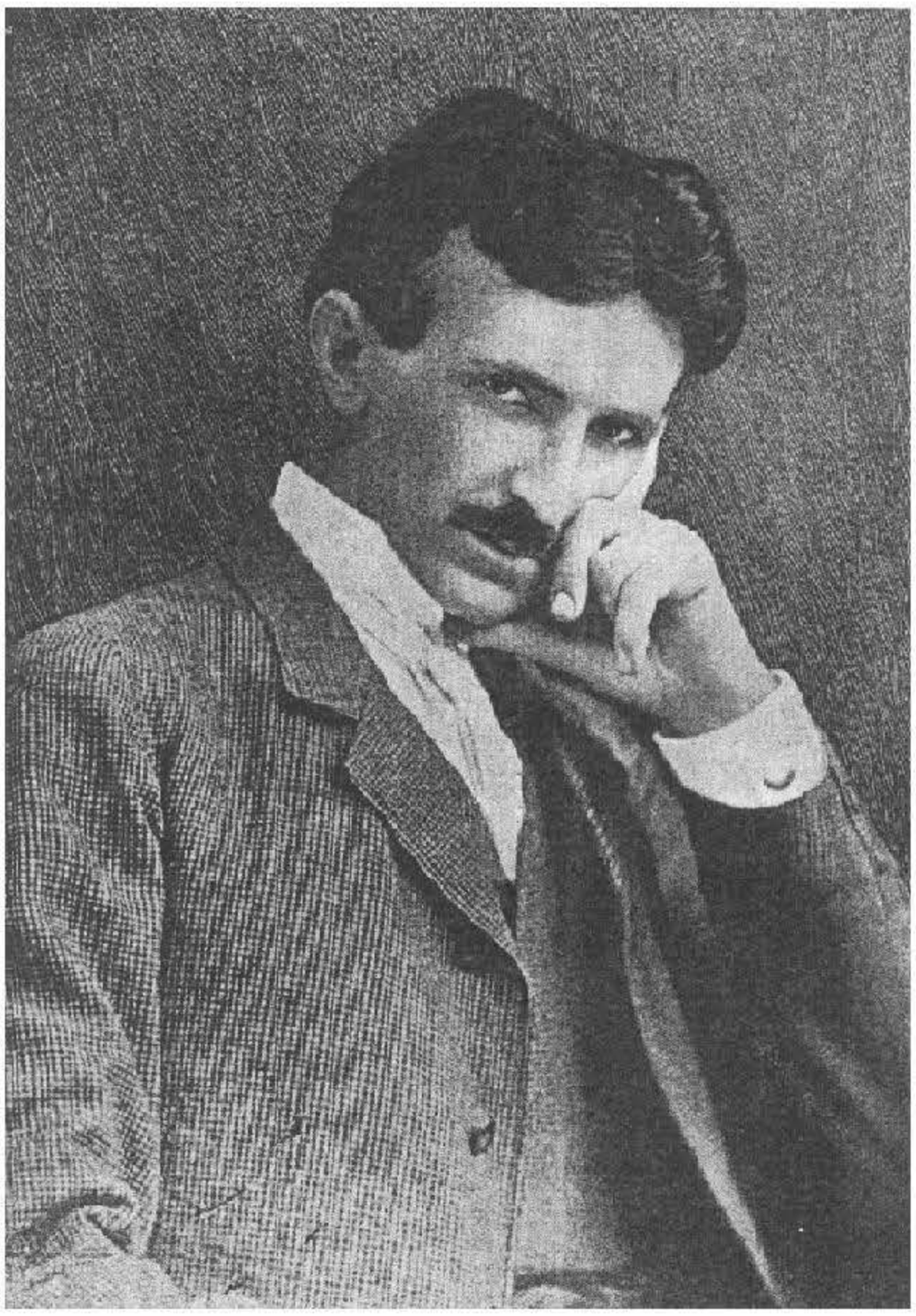
Dr. Tesla promises at some future time to contribute a more extensive discussion of this subject, disclosing the lengthy investigations which have led him to these important conclusions. The scientific and technical world will eagerly await a fuller demonstration of the truth of this theory.

Nikola Tesla.

In the realm of electricity and physics few men have striven for such mighty achievements and attained such prominence through the working out of ideas greatly in advance of current thought as has Nikola Tesla, the subject of this sketch.

Nikola Tesla was born at Smiljan, Lika, the border country of Austria-Hungary, in 1857, the son of a Greek clergyman and orator, and Georgina Mandic, who was an inventor, as was her father. Tesla was educated for a year in the elementary schools, for four years at the lower Realschule, Gospic, Lika, and for three years at the higher Realschule, Carlstadt, Croatia, graduating in 1873. He was a student for four years at Polytechnic School, Gratz, in mathematics, physics and mechanics. After this he studied two years in philosophic studies at the University of Prague, Bohemia. He has received the honorary degree of Master of Arts, from Yale, in 1904, and Columbia, N. Y., conferred the degree of L.L.D. in 1894.

Nikola Tesla began his practical career at Budapest, Hungary, in 1881, where he made his first electrical invention, a telephone "repeater," and conceived the idea of his rotating magnetic field. He later engaged in various branches of engineering and manufacture, and, since 1884, has been a resident of the United States, becoming a naturalized citizen. Dr. Tesla is the author of numerous scientific papers and addresses, and his inventions and discoveries cover a wide range. Speaking chronologically, his chief work may be summed up as follows: systems of arc lighting, 1886; Tesla motor and system of alternating-current power transmission, 1888; system of electrical conversion and distribution by oscillating discharges, 1889; generation of high-frequency currents and effects of these, 1890; transmission of energy through a single wire without return, 1891; Tesla coil or transformer, 1891; investigations of high-frequency effects and phenomena, 1891-1893; system of wireless transmission of intelligence, 1893; mechanical oscillators and generators of electrical oscillations, 1894-1895; researches and discoveries in radiations, material streams, and emanations, 1896-1898; high-potential magnifying transmitter, 1897; system of transmission of power without wires, 1897-1905; economic transmission of energy by refrigeration, 1898; art of "Telautomatics," 1898-1899; burning of atmospheric nitrogen and production of other electrical effects of transcending intensities, 1899-1900; method and apparatus for magnifying feeble effects, 1901-1902; art of individualization, 1902-1903. Since 1903, Dr. Tesla has been chiefly engaged in the development of his system of world telephony and telegraphy, and the design of a large plant for the transmission of power without wires. He has also devoted a great deal of energy to the development of a perfected system for the electrical production of nitrates from the atmosphere and quite recently announced the development of a remarkable form of turbine, the perfecting of which when realized will mean practically a revolution in our application of mechanical principles. In the current issue of the ELECTRICAL REVIEW AND WESTERN ELECTRICIAN Dr. Tesla discusses with characteristic candor and vigor some new ideas with regard to the propagation of electrical impulses through the air without wires.



Nikola Tesla,
Noted Electrical Inventor and Scientist.

THE DISTURBING INFLUENCE OF SOLAR RADIATION ON THE WIRELESS TRANSMISSION OF ENERGY.

By Nikola Tesla.

When Heinrich Hertz announced the results of his famous experiments in confirmation of the Maxwellian electromagnetic theory of light, the scientific mind at once leaped to the conclusion that the newly discovered dark rays might be used as a means for transmitting intelligible messages through space. It was an obvious inference, for heliography, or signalling by beams of light, was a well recognized wireless art. There was no departure in principle, but the actual demonstration of a cherished scientific idea surrounded the novel suggestion with a nimbus of originality and atmosphere of potent achievement. I also caught the fire of enthusiasm but was not long deceived in regard to the practical possibilities of this method of conveying intelligence.

Granted even that all difficulties were successfully overcome, the field of application was manifestly circumscribed. Heliographic signals had been flashed to a distance of 200 miles, but to produce Hertzian rays of such penetrating power as those of light appeared next to impossible, the frequencies obtainable through electrical discharges being necessarily of a much lower order. The rectilinear propagation would limit the action on the receiver to the extent of the horizon and entail interference of obstacles in a straight line joining the stations. The transmission would be subject to the caprices of the air and, chief of all drawbacks, the intensity of disturbances of this character would rapidly diminish with the distance.

But a few tests with apparatus, far ahead of the art of that time, satisfied me that the solution lay in a different direction, and after a careful study of the problem I evolved a new plan which was fully described in my addresses before the Franklin Institute and National Electric Light Association in February and March, 1893. It was an extension of the transmission through a single wire without return, the practicability of which I had already demonstrated. If my ideas were rational, distance was of no consequence and energy could be conveyed from one to any other point of the globe, and in any desired amount. The task was begun under the inspiration of these great possibilities.

While scientific investigation had laid bare all the essential facts relating to Hertz-wave telegraphy, little knowledge was available bearing on the system proposed by me. The very first requirement, of course, was the production of powerful electrical vibrations. To impart these to the earth in an efficient manner, to construct proper receiving apparatus, and develop other technical details could be confidently undertaken. But the all-important question was, how would the planet be affected by the oscillations impressed upon it? Would not the capacity of the terrestrial system, composed of the earth and its conducting envelope, be too great? As to

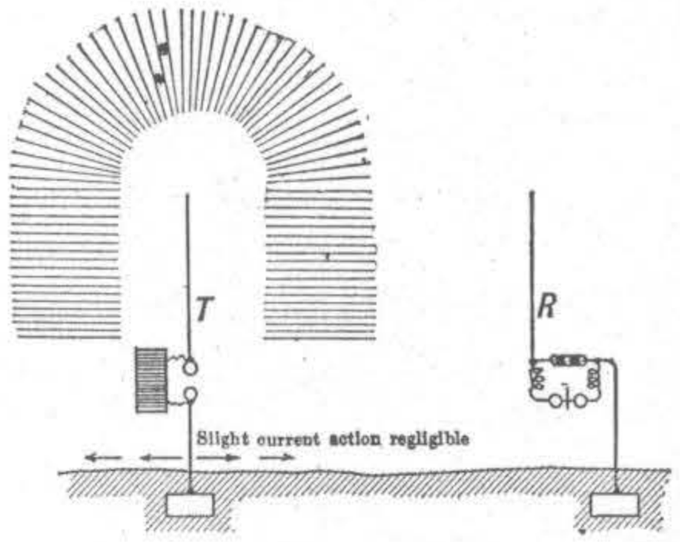


Fig. 1.—Hertz Wave System.

this, the theoretical prospect was for a long time discouraging. I found that currents of high frequency and potential, such as had to be necessarily employed for the purpose, passed freely through air moderately rarefied. Judging from these experiences, the dielectric stratum separating the two conducting spherical surfaces could be scarcely more than 20 kilometers thick and, consequently, the capacity would

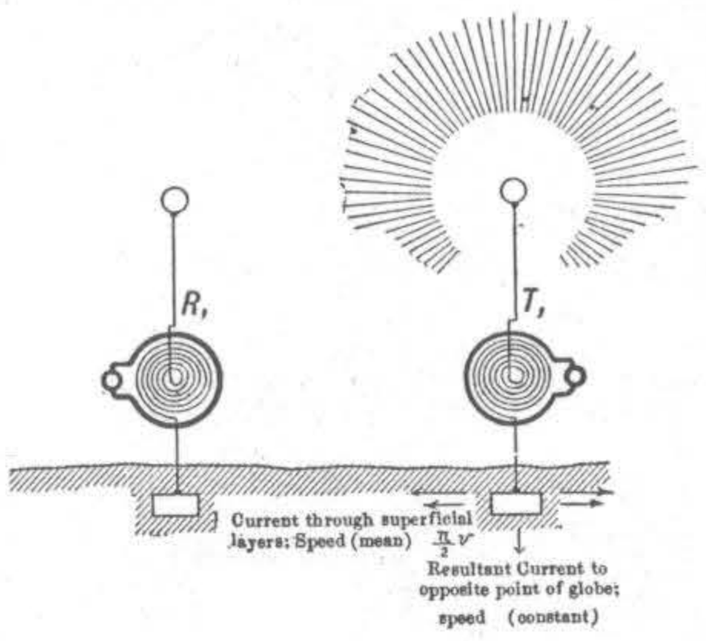


Fig. 2.—System Devised By Tesla.

be over 220,000 microfarads, altogether too great to permit economic transmission of power to distances of commercial importance. Another observation was that these currents cause considerable loss of energy in the air around the wire. That such waste might also occur in the earth's atmosphere was but a logical inference.

A number of years passed in efforts to improve the apparatus and to study the electrical phenomena produced. Finally my labors were rewarded and the truth was positively established: the globe did not act like a conductor of immense capacity and the loss of energy, due to absorption in the air, was insignificant. The exact mode of propagation of the currents from the source and the laws governing the electrical movement had still to be ascertained. Until this was accomplished the new art could not be placed on the plane of scientific engineering. One could bridge the greatest distance by sheer force, there being virtually no limit to the intensity of the vibrations developed by such a transmitter, but the installment of economic plants and the predetermination of the effects, as required in most practical applications, would be impossible.

Such was the state of things in 1899 when I discovered a new difficulty of which I had never thought before. It was an obstacle which could not be overcome by any improvement devised by man and of such nature as to fill me with apprehension that transmission of power without wires might never be quite practicable. I think it useful, in the present phase of development, to acquaint the profession with my investigations.

It is a well known fact that the action on a wireless receiver is appreciably weaker during the day than at night and this is attributed to the effect of sunlight on the elevated aerials, an explanation naturally suggested through an early observation of Heinrich Hertz. Another theory, ingenious but rather fine-spun, is that some of the energy of the waves is absorbed by ions or electrons, freed in sunlight and caused to move in the direction of propagation. The ELECTRICAL REVIEW AND WESTERN ELECTRICIAN of June 1, 1912, contains a report of a test, during the recent solar eclipse, between the station of the Royal Dock Yard in Copenhagen and the Blaavandshuk station on the coast of Jutland, in which it was demonstrated that the signals in that region became more distinct and reliable when the sunlight was partially cut off by the moon. The object of this communication is to show that in all the instances reported the weakening of the impulses was due to an entirely different cause.

It is indispensable to first dispel a few errors under which electricians have labored for years, owing to the tremendous momentum imparted to the scientific mind through the work of Hertz which has hampered independent thought and experiment. To facilitate understanding, attention is called to the annexed diagrams in which Fig. 1 and Fig. 2 represent, respectively, the well known arrangements of circuits in the Hertz-wave system and my own. In the former the transmitting and receiving conductors are separated from the ground through spark gaps, choking coils, and high resistances. This is

necessary, as a ground connection greatly reduces the intensity of the radiation by cutting off half of the oscillator and also by increasing the length of the waves from 40 to 100 per cent, according to the distribution of capacity and inductance. In the system devised by me a connection to earth, either directly or through a condenser, is essential. The receiver, in the first case, is affected only by rays transmitted through the air, conduction being excluded; in the latter instance there is no appreciable radiation and the receiver is energized by currents conducted through the earth while an equivalent electric displacement occurs in the atmosphere.

Now, an error which should be the focus of investigation for experts is, that in the arrangement shown in Fig. 1 the Hertzian effect has been gradually reduced through the lowering of frequency, so as to be negligible when the usual wave-lengths are employed. That the energy is transmitted chiefly, if not wholly, by conduction can be demonstrated in a number of ways. One is to replace the vertical transmitting wire by a horizontal one of the same effective capacity, when it will be found that the action on the receiver is as before. Another evidence is afforded by quantitative measurement which proves that the energy received does not diminish with the square of the distance, as it should, since the Hertzian radiation propagates in a hemisphere. One more experiment in support of this view may be suggested. When transmission through the ground is prevented or impeded, as by severing the connection or otherwise, the receiver fails to respond, at least when the distance is considerable. The plain fact is that the Hertz waves emitted from the aerial are just as much of a loss of power as the short radiations of heat due to frictional waste in the wire. It has been contended that radiation and conduction might both be utilized in actuating the receiver, but this view is untenable in the light of my discovery of the wonderful law governing the movement of electricity through the globe, which may be conveniently expressed by the statement that the projections of the wave-lengths (measured along the surface) on the earth's diameter or axis of symmetry of movement are all equal. Since the surfaces of the zones so defined are the same the law can also be expressed by stating *that the current sweeps in equal times over equal terrestrial areas.* (See among others "Handbook of Wireless Telegraphy," by James Erskine-Murray.) Thus the velocity of propagation through the superficial layers is variable, dependent on the distance from the transmitter, the mean value being $\pi/2$ times the velocity of light, while the ideal flow along the axis of propagation takes place with a speed of approximately 300,000 kilometers per second.

To illustrate, the current from a transmitter situated at the Atlantic Coast will traverse that ocean—a distance of 4,800 kilometers—in less than 0.006 second with an average speed of 800,000 kilometers. If the signalling were done by Hertz waves the time required would be 0.016 second.

Bearing, then, in mind that the receiver is operated simply by currents conducted along the earth as through a wire, energy radiated playing no part, it will be at once evident that the weakening of the impulses could not be due to any changes in the air, making it turbid or conductive, but should be traced to an effect interfering with the transmission of the current through the superficial layers of the globe. The solar radiations are the primary cause, that is true, not those of light, but of heat. The loss of energy, I have found, is due to the evaporation of the water on that side of the earth which is turned toward the sun, the conducting particles carrying off more or less of the electrical charges imparted to the ground. This subject has been investigated by me for a number of years and on some future occasion I propose to dwell on it more extensively. At present it may be sufficient, for the guidance of experts, to state that the waste of energy is proportional to the product of the square of the electric density induced by the transmitter at the earth's surface and the frequency of the currents. Expressed in this manner it may not appear of very great practical significance. But remembering that the surface density increases with the frequency it may also be stated that the loss is proportional to the cube of the frequency. With waves 300 meters in length economic transmission of energy is out of the question, the loss being too great. When using wave-lengths of 6,000 meters it is still noticeable though not a serious drawback. With wave-lengths of 12,000 meters it becomes quite insignificant and on this fortunate fact rests the future of wireless transmission of energy.

To assist investigation of this interesting and important subject, Fig. 3 has been added, showing the earth in the position of summer solstice with the transmitter just emerging from the shadow. Observation will bring out the fact that the weakening is not noticeable until the aerials have reached a position, with reference to the sun, in which the evaporation of the water is distinctly more rapid. The maximum will not be exactly when the angle of incidence of the sun's rays is greatest, but some time after. It is noteworthy that the experimenters who watched the effect of the recent eclipse, above referred to, have observed the delay.

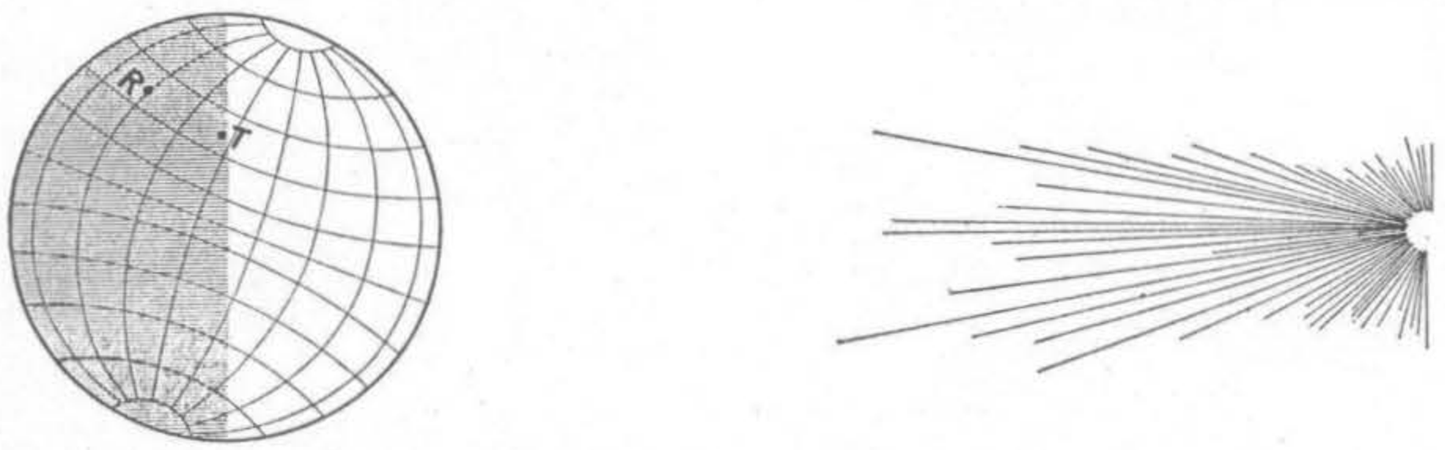


Fig. 3.—Illustrating Disturbing Effect of the Sun on Wireless Transmission.

The New York Sun July 7, 1912

WHY WIRELESS DOES BEST WORK AT NIGHT

Nikola Tesla Says Solar Radiation Causes the Air to Lose Moisture.

ELECTRIC ENERGY LOST

Evaporation Lessens the Power of the Earth in Aiding Transmission.

Nikola Tesla believes he has discovered the reasons for the phenomena long noticed by wireless folks that the wireless receiver is appreciably weaker in the day than it is at night.

In the *Electrical Review and Western Electrician* of Chicago, published yesterday, appears an article by the electrical inventor on "The Disturbing Influence of Solar Radiation on the Wireless Transmission of Energy." In this article Tesla accounts for this condition on the theory that as moisture in the air is dissipated by the sun's rays, and as particles of water in evaporating carry with them charges of electricity, the earth is thus deprived of some of the electrification which resides upon its surface at night. This, he claims, causes a dissipation of energy which necessarily interferes with the transmission of the electrical signals and prevents them from being observed at so great a distance as in the night time.

Tesla has long maintained that the earth plays as important a part in wireless transmission as the air and has contended as the results of demonstrations, he says, that the results accomplished are not due merely to Hertzian waves, whose existence was discovered by Heinrich Hertz, the German physicist. Tesla writes:

"Bearing, then, in mind that the receiver is operated simply by currents conducted along the earth as through a wire, energy radiated playing no part, it will be at once evident that the weakening of the impulses could not be due to any changes in the air, making it turbid or conductive, but should be traced to an effect interfering with the transmission of the current through the superficial layers of the globe.

"The solar radiations are the primary cause, that is true, not those of light, but of heat. The loss of energy, I have found, is due to the evaporation of the water on that side of the earth which is turned toward the sun, the conducting particles carrying off more or less of the electrical charges imparted to the ground.

"At present it may be sufficient for the guidance of experts to state that the waste of energy is proportional to the product of the square of the electric density induced by the transmitter at the earth's surface and the frequency of the currents. Expressed in this manner it may not appear of very practical significance. But remembering that the surface density increases with the frequency it may also be stated that the loss is proportional to the cube of the frequency."

The New York Telegram July 16, 1912

GREAT INVENTIONS AND THEIR ORIGINATORS



NIKOLA TESLA, the noted physicist, electrician and inventor, was born at Smiljan, Luka, in Austro-Hungary, in 1857.

Tesla's father was a distinguished clergyman and orator, and his mother was the daughter of an inventor and herself an inventor. His father intended to educate Nikola for his own profession, but the boy prevailed upon his parents to send him to the Polytechnic school in Gratz, where for four years he studied mathematics, physics and mechanics. Two years of philosophic studies at the University of Prague followed.

It was in 1881 that he began his practical career in Buda-Pesth, and here he made his first electrical invention, a telephone repeater, and first conceived the idea of the rotating magnetic field.

A few years later he was led to come to this country, where he desired to develop motors on the basis of his own discovery of the rotating magnetic field. This he completed in 1888.

Among his inventions are a number of methods and appliances of electrical vibrations aiming at the production of efficient light with lamps without filaments and the production and transmission of power without wires.

It was on his discovery of the action of air on gaseous matter when subjected to rapidly alternating electrostatic stresses that the modern art of insulating currents of very high tension is based.

Among his other achievements is the construction of steam engines and electrical generators or oscillators with which results otherwise unattainable have been achieved.

He is now a citizen of the United States,



NIKOLA TESLA

and is an ardent advocate of the country under whose flag most of his inventions were originated.

He has written a number of scientific works and has addressed many scientific societies.

The New York Times July 21, 1912

NICOLA TESLA SUED.

Shlenker Claims $61,500 Interest in Inventor's Transformer.

Nicola Tesla, the inventor, and Edmund K. Stallo, son-in-law of the late Alexander McDonald, the Standard Oil man, were sued yesterday in the Supreme Court by Simon Shlenker, who claims an interest in the "Tesla transformer," a machine which was patented by the inventor.

Mr. Shlenker alleges that he invested $61,500 in the machine, on the understanding that it was to be placed on the market and the prifits shared. Instead of doing as he had contracted, Shlenker accuses Tesla of having used his investment for personal experiments and of having failed to finance the enterprise.

The New York Evening Sun July 30, 1912

PLAN TO QUICKEN DULL CHILDREN

School Authorities Consider Electrical Experiment.

MAY WIRE CLASSROOM

Remarkable Results From Trial in Sweden.

A novel experiment in the classes of defective children in the public schools of this city is to be tried this fall, provided the sanction of the Board of Education is obtained. This experiment consists of electrifying a school room, which process, it is maintained by experts, arouses the children to greater mental and physical ability and tends to make them brighter in every respect. It is proposed to experiment with the subnormal pupils first, since they have more need of a brain stimulator.

Provided the school commissioners are willing to allow the tests the work is to be in charge of Nikola Tesla, the inventor. The scientist, City Superintendent of Schools William H. Maxwell and Dr. L. B. Blan have had several conferences on the matter, and when the subject was thoroughly explained to Dr. Maxwell he expressed his willingness to have the scheme tried out. It is likely that the proposition will be put up to the Board of Education at an early fall meeting, perhaps the first, on Sept. 11.

City Superintendent Maxwell said that since the electrifying process is still in the experimental form, his first demand was an assurance from Mr. Tesla that, let alone helping the pupils, the test would in no wise be detrimental.

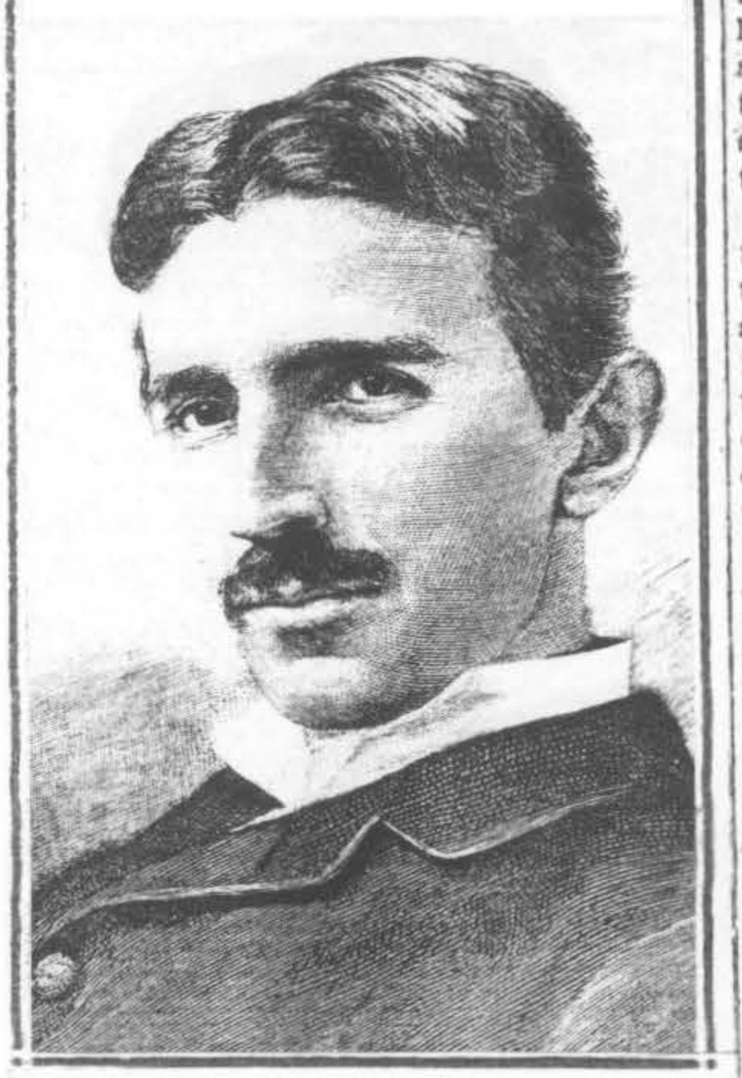
"Mr. Tesla stated that there is no possibility of the experiments having anything but a good effect on the pupils. If this electrification of school rooms will improve the ability of the children it should be thoroughly tried out. The inventor told me that the process has been used with great success in Europe and after a number of conferences with him I came to the conclusion that the system should be tested in the New York schools."

The European experiments with the electrifying machine have taken place in Stockholm, Sweden. The work in that city was carried on under the supervision of Prof. Svante Arrhenius, the noted physicist. Mr. Tesla followed the tests across the water and then consulted with Dr. Maxwell. The scientist claims that the main apparatus used in the foreign experiments was originally devised by him. Mr. Tesla explained that it was reported another man was responsible for the invention.

The machinery used in the electrification consist of a series of wires hidden in the walls of the school room. It is proposed to take two rooms, as nearly alike as possible, and at the end of the proper period compare the

SUPERINTENDENT MAXWELL.





NIKOLA TESLA

results obtained in the electrified and unelectrified rooms. About fifty pupils will make up the classes and the tests are to be conducted without the knowledge of the children or the teachers.

Mr. Tesla has volunteered to take charge of the installation of the apparatus and conduct the tests himself. The wires, concealed in the walls of the class room, are to be charged with high frequency currents.

"I am certain," said Mr. Tesla, "that the experiment will prove that these currents will assist cerebration and arouse the children to greater ability. The stimulation of the nerve cells helps the physical as well as the mental condition of the child. With Dr. Maxwell's cooperation very thorough tests of the process are likely to be made. The only thing remaining is to get the sanction of the Board of Education."

It is estimated that the proper appli-

(Continued on Fourth Page.)

PLAN TO QUICKEN DULL CHILDREN

(Continued From First Page.)

cation of the currents will necessitate the expenditure of $10,000. This matter, however, will be settled later. It is thought quite unlikely that a lack of funds will hinder the work.

The Stockholm experiment with the electrifying process has been closely watched by scientists throughout the United States. The novelty of the plan aroused considerable interest, but through Mr. Tesla's services, New York will probably be the first American city to try it. It is said that the local test will follow closely along the lines of the foreign experiment.

For the work abroad two sets of fifty children, each averaging the same age and physical condition, were placed in separate class rooms, exactly alike except for the concealed wires installed in the walls of one room. The regular school work was taken up and the test lasted for six months. Frequent observations of the pupils were recorded to ascertain the effect of the high tension wave on the children under electrical treatment.

At the end of the experimental period the children in the magnetized room, the official report of the tests says, showed an increase in stature of two inches, while in the unmagnetized room the average increase was only one and one-fourth inches. The pupils in the electrified room likewise showed a weight increase and proportionate physical development greater than the children in the other. Then the investigators looked to the mental side of the question.

According to the report this examination showed that the children exposed to the electrical waves averaged 92 per cent. in their school work, fifteen being marked 100 by the teacher, while in the unmagnetized room the pupils were credited with an average of 75 per cent. and only nine obtained perfect ratings.

The electrified children, so the report says, appeared generally to be more active during the experiment and less subject to fatigue than those in the other room. The instructors likewise benefited by the treatment, it is said, and positively attested to the fact that their faculties were quickened and their powers of endurance stimulated by the waves.

Experimental psychologists, however, recommend cautious tests with the new process. Prof. W. C Bagley, head of the department of psychology of the University of Illinois, said on the subject:

"Such tests would certainly need to be repeated under carefully controlled conditions before we reached any conclusion. Not only this, but one would necessarily have to wait some years to see whether there were any deleterious results with the children subjected to the experiments. It would be the height of folly to encourage a wholesale application of this treatment prior to a most cautious and prolonged investigation within restricted areas."

This statement from Prof. Bagley was presented to Mr. Tesla. On reading it carefully the scientist said:

"After experimenting on myself and my assistants steadily during the past ten years, employing my most powerful coil, very much stronger than that used in the Stockholm test, I noted absolutely no ill after effects. On the contrary, many beneficial physiological effects of a lasting nature were recorded."

Magazine Section
Part Five

The New York Times.

Magazine Section
Part Five

SUNDAY, AUGUST 18, 1912.

ELECTRIFIED SCHOOLROOM TO BRIGHTEN DULL PUPILS

Experiment Will Be Tried in New York with Superintendent Maxwell's Consent to See if High Potential Currents Will Help Defectives---Remarkable Results Reported Abroad.



Supt. W. H. Maxwell of New York's Public Schools.

NEW YORK will try an experiment next Fall which, if successful, will completely overturn all methods hitherto applied in its schools and introduce a new era in education.

It is so sensational that at first sight, it seems like the impossible dream of a mad inventor. Yet it has the thorough approval of men who are by no means identified with anything sensational and unpractical, among them Superintendent of Schools William H. Maxwell and Dr. Louis Blan of Columbia University while the inventor of the scheme, Nikola Tesla, can point for corroboration of what he claims, to the extremely successful results already obtained by means of his invention in the schools of Stockholm, capital of Sweden.

Currents in the Walls.

Fifty mentally defective school children will be the first subjects of the experiment. They will enter and seat themselves in what will look, to all intents and purposes, like an ordinary schoolroom. But it will be far from that. Through the walls invisible electrical currents will run, by means of which, it is declared, the brains of the children will receive artificial stimulation to such an extent that they will be transformed from dunces into star pupils.

Six months is the time limit set for the experiment. At the end of that period, if the inventor and those who have studied his work are to be believed, the fifty backward pupils will leave the electric schoolroom and hold their own thenceforth with ease against their cleverest comrades, whom they had never even dreamed of emulating six months before.

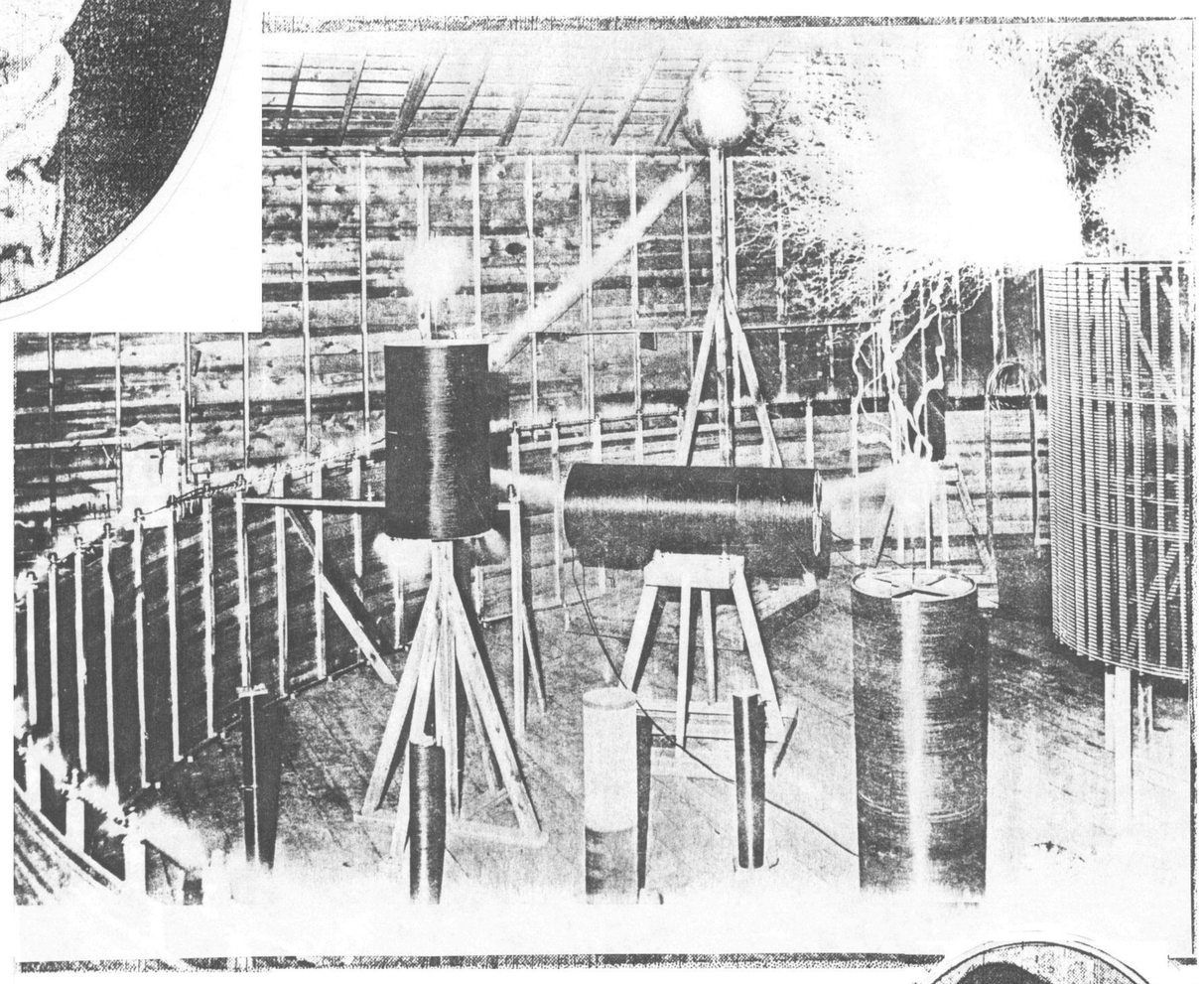
The work is to be in charge of Mr. Tesla, who, by means of the Tesla electric coil, secreted in the walls of the classroom, will permeate its atmosphere with high frequency electric currents. It is expected that Dr. S. H. Monnell of Chicago, famous as an electro-therapist, will volunteer his services in carefully examining the children before, during, and after their exposure to the high-voltage current. Dr. Blan will assist him by making a record of the progress of each case.

City Superintendent of Schools William H. Maxwell said in confirming the report that the experiments are to be made.

"I am convinced that the high-frequency current has no deleterious effect; that, on the contrary, it is positively beneficial, and that the experimental tests should be and in all probability will be carried out in the Fall."

Cost of the Apparatus.

The cost of installing the apparatus and properly applying the tests is $10,000. Several men, including a New York philanthropist, have offered the amount. At the same time Mr. Tesla hopes himself to be able to finance this first experiment, and when its advantages are demonstrated, to then allow some interested person to step in and install appliances in every schoolroom of the city. All school children both normal and defective, would then be subject during their classroom periods to the stimulation of this pervasive high-frequency current. When asked about the cost of such a project, Mr. Tesla replied that it would be very moderate, about $100 to install the apparatus in each room.



Coils for the Transmission of the High Frequency Current. Photograph Represents a Powerful Machine. Effect Will Be Much Modified in a Schoolroom.

Use May Become General.

According to the inventor this experiment in the schools will be merely an opening wedge, a suggestion to the people that by the use of high potential electricity they may do away with the use of bromides, phosphates, pepsin tablets, and all kinds of drugs taken for disorders of the nervous and digestive systems. If his dream comes true, ten years from now people will inquire when renting an apartment or a house "Is it electrified?" Every one will have at least one room in his house furnished with a coil generating high frequency currents. By that time the appliances will be inexpensive, so that at a moderate cost people will be able to obtain superb health and mental brilliancy. Ordinary conversation will then be carried on in scintillating epigrams, and the mental life of the average adult will be so quickened as to equal the brain activity of the most brilliant people living before the time when a generator of high-frequency currents was a household essential.

Leading experimental psychologists assert that the high-frequency current intensifies cerebration. It is a mental stimulant, just as alcohol is a mental stimulant, the difference being that the electricity is harmless and confers lasting benefits. It is related that during certain high-frequency tests performed by Mr. Tesla one of his assistants was exceedingly stupid in carrying out instructions concerning the laboratory adjustments. The laboratory was equipped with a coil generating high voltage currents. After a time Mr. Tesla noticed that the man grew brighter and did his work better. He supposed for a time that this was because the man was learning, but after watching him closely he discovered that his assistant's quickness was much deeper than merely learning to make the tests. His mental life had been stimulated and instead of being slow to learn, as at first, he now showed remarkable acumen.



Form of Apparatus to be Used in a Schoolroom.

The tests made on school children in Europe were with the Tesla apparatus, and were carried on under the supervision of Prof. Svante Arrhenius at Stockholm, Swedep. The results were watched with keen interest by scientists, especially psychologists, in the United States, for, although scientific experimenting with school children is customary in Europe, it has as yet been untried in this country.

Suspicion of Experiments.

As Dr. Blan pointed out, over here there has until recently been a suspicious attitude on the part of people with reference to experiments of an elaborate nature performed on school children. Fear of deleterious effects has had something to do with this, as well as a general skepticism, on the part of educators, of the value of such tests. In this respect we in America have been far behind Europe, and especially Scandinavia, which is one of the most advanced countries in the world in its educational methods. The experiment about to be performed in the Fall in New York City will be the first of its kind in the United States, and so marks an epoch in our methods of handling school children.

The question of a possible deleterious after-effect has, of course, been the crucial one on which opposition to the work has hinged. However, it is the consensus among psychological experts and electro-therapists that there is absolutely no danger attending such experimentation.

The Stockholm Experiment.

In Stockholm two sets of fifty children, each, averaging the same age and physical condition, were placed in separate class rooms exactly alike except for the concealed wires installed in the walls of one of the rooms. The regular school work was pursued and the test lasted for six months. Frequent observations of the children were recorded to ascertain the effect of the high-frequency waves upon them. At the end of the experimental period the children in the magnetized room, according to the official report, showed an increase in stature of two and a half inches, while in the unmagnetized room the average increase was only one and one-fourth inches. The pupils in the electrified room likewise showed a weight increase and proportionate physical development greater than that of the children in the other.

On the mental side, according to this report, the children exposed to the electric waves averaged 92 per cent. in their school work, as opposed to an average of 75 per cent. in the children of the other room. Fifteen pupils in the electrified room were marked 100 by their teacher, while only nine obtained perfect ratings in the other class.

The report continues that the electrified children appeared generally more active and less subject to fatigue than those that were not electrified, and that the teachers also experienced from the treatment a quickening of the faculties as well as an increase of powers of endurance.

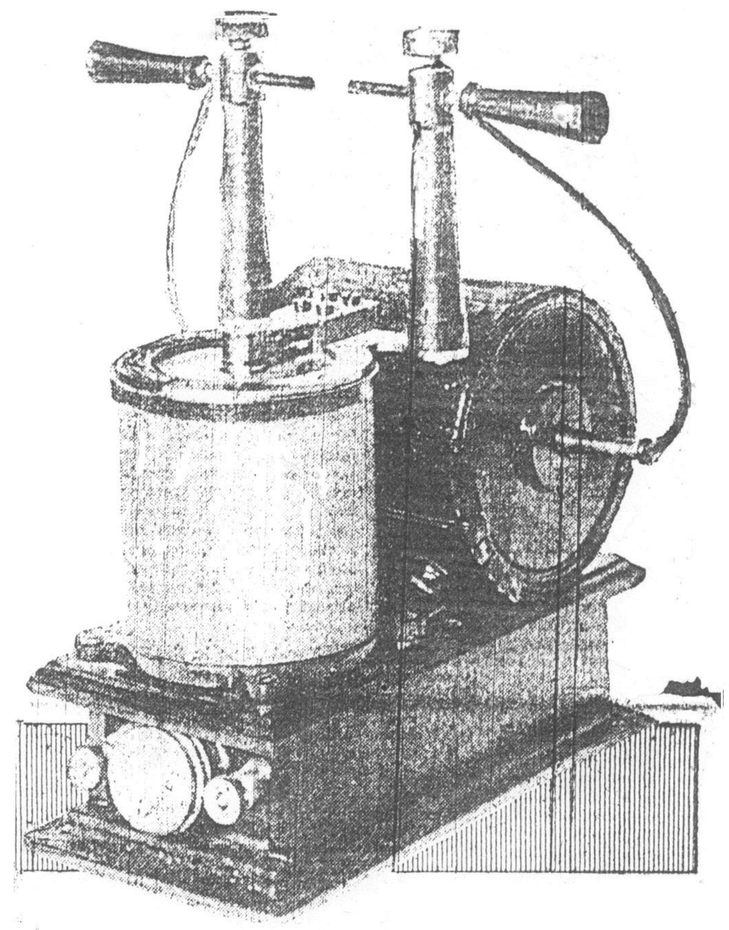
Abroad these scientific tests are as likely to be made on average children as on defectives. In fact, the tests in Sweden were applied on normal pupils. "Here," comments Dr. Blan, "the custom seems to be to try everything on the goat first, and so sub-normal or defective children are to be used, whereas it would be just as well, perhaps even better, to electrify normal children and note the results."

When asked if there were any injurious effects whatsoever from high frequency electricity, Mr. Tesla replied that the effects of the rays of light issuing from the ordinary incandescent lamps in our houses were positively more harmful than those proceeding from the high potential coil. He added that the increasing prevalence of baldness may be largely due to the effect on the scalp of the electric rays from incandescent lamps.

Details of the Apparatus.

The apparatus is called the Tesla coil from its inventor. It consists of a primary made up of a few turns of coarse wire, and differs from the official coil of the X-ray machine largely in this coarseness of the primary. Whereas, using the X-ray coil, one may obtain from 50 to 150,000 volts, with the Tesla coil millions of volts may be generated. Carefully insulated wires will be inserted in the walls of the experimenting classroom and the tests will be carried on without the knowledge either of the teachers or the pupils. The air of the room will be completely saturated with incalculable millions of infinitesimal electric waves vibrating at a frequency so great as to be unimaginable and capable of measurement only by a most delicate volt meter.

The experts find that the higher the voltage and the lower the amperage the less harmful is the electric wave. High frequency currents never kill.



Instrument for Electrification Used by Physicians.

The low frequency currents with high amperage are the kind used in executions. The X-rays, produced by high-frequency currents, but through specially devised tubes, are, as is well known injurious. They are of lower frequency than the currents generated by the Tesla coil. The X-ray passes through the body like a bullet and actually makes microscopic holes. The high frequency currents from the Tesla apparatus do not pass through the body, but bathe it and permeate it very much as does alcohol when rubbed on the skin.

The fifty defective New York children who will be subjected to the experiment will in reality have an electric bath lasting for six months.

Dr. J. P. Sutherland, Dean of the Boston University School of Medicine, says: "I have been interested for some time in the subject of high frequency electricity, particularly in the effect of high frequency currents on metabolism, (that is, tissue-change.) My work has been confined almost wholly to adults. High frequency currents produce ozone, the properties of which as a tonic and a stimulant are well known. Although the effect of the current on the human body is not thoroughly understood as yet, it has a decided effect on its chemical processes."

Prof. Sutherland also predicts that one of these days the high frequency current will be a commonplace in the home. He says further that it is now possible to imbue persons with this electric tonic without their coming in contact with any apparatus whatever, or their even knowing that they are being exposed to the electrifying process.

Electricity's Effect on Women.

The effect of electricity upon women as compared to men calls to some interesting comments from Dr. Blan. "Women," he says, "are more sensitive to the electric wave than are men because of their inherent organic constitution. Women's hearts are smaller and pulsate more rapidly; their brains are smaller and their skin is thinner, which explains their shorter time reaction to electric stimulus.

"Further, women in their mental traits are more variable than men. This has been demonstrated by leading psychologists throughout the country, among them T. B. Thompson, a brilliant woman psychologist from the University of Chicago, who has written a book on 'The Mental Traits of Sex.' This means that in any random choice or select[illegible] of a group of men and women, the men are the most stupid and the brightest. In the scale of mental ability the women will occupy an average position.

In a series of tests carried out last year by Dr. Blan on school children of the City of New York, he discovered this new fact with respect to the position of women in the scale of mental ability by taking as his criteria the records of promotion and repetition for the boys and the girls. He found that on the average boys were brighter than girls, and that they were also more stupid. Girls occupied a middle position between the two extremes of intelligence represented by the two divisions of the group of boys.

In relating this fact to the application of high frequency currents, Dr. Blan said that in so far as the girls are more sensitive to the electric wave than the boys, the electric friction by means of high frequency currents will tend to raise the girls from their average position in the scale of intelligence into the class occupied by the exceptional boys.

Mr Tesla was asked to make a statement as to the manner in which his electrical experiments with the school children were to be carried out. He replied:

"The high frequency currents can be applied in three distinct ways. One is to pass the currents directly through the body, bringing the part to be treated in contact with the terminal or source of the current. Another way is to establish an electrostatic field in the room and expose the person to the influence of the alternating stresses of high potential. The third way is to act on the person by induction.

"When the experiment is made in this city the electricity will be applied in all three ways, but the third method will in all probability be given greatest prominence." In this case a cable will be laid around the room and high frequency currents passed through the same, creating a rapid-changing electro-magnetic field. The experiment in Stockholm was performed in this manner. The apparatus was in all essentials the same as the one I used in this city many years ago when I had an installment of that kind in continuous use."

Mr. Tesla said further that it was not essential to the, success of the tests that the wires be hidden or that the work be done without the knowledge of the teachers and the pupils, but nevertheless it would be done secretly so as to properly compare results with the experiment of Prof. Arrhenius.

No Danger to the Pupils.

When asked if there would be danger if for some reason or other the current passing through the cable were too strong, the inventor said no, and continued: "The apparatus is so designed that this will never happen. Yet, even if the current were a thousandfold increased, no untoward effect would result. I have frequently, in the presence of visitors in my own laboratory, energized a loop of wire with high frequency currents so strongly that when a piece of metal, such, for instance, as a sheet of tin, was approached to the loop, it was melted instantly, and the process of melting was so instantaneous that the metal would explode with the report of a gun. Into this same loop of wire so energized that the metal near it would come to white heat, melt, and burst with a report, I have repeatedly thrust my head and felt no inconvenience. My explanation is that human tissues act as electrical condensers, which means that the heating effect such as is produced in a conductor is excluded."

The New York Times August 26, 1912

ELECTRIFIED SCHOOLROOMS.

Reader Has No Faith in Fads That Promise Royal Road to Learning.

To the Editor of The New York Times:

With a somewnat deep-seated distrust of new-fangled devices in school keeping, I read the full-page article on electrified schoolrooms in SUNDAY'S TIMES. The Montessori method, exploded by a visit to Rome of a committee sent thither by Columbia for the express purpose of investigating it, promised, just as the new device from Sweden does, to make dull pupils bright and bright pupils superlative. Not a single new device has been brought out these twenty years, and they have been numerous, that did not promise wonders in the same words with which Rome and Stockholm now cajole us. "With our device," so evefybody with one has been saying, "we can get the child to attain 20 per cent, more in lessons and in less time." And when each new device has been favorably reported on (Page 251, Eleventh Report,) quite regardless of facts, and has served its purpose of advancing the "professional" fortunes of its sponsors, it is quietly dropped and another taken up.

If this new device is really tried, it is safe to say that it will be done in a school whose Principal (a title always printed with small letters in annual reports for years past) knows enough to report favorably, (XI., 251,) on new devices regardless of facts and for the purpose of seeking favor at headquarters—the exact words of the page quoted.

What in the world do we want of more improvement, anyhow? The promotions are now 92 per cent. of all pupils, (Page 82, Thirteenth Report,) and dozens of schools promote the pupils to the extent of 95 per cent. and more and, mirabile dictu, no less than seventeen promote from 99 per cent. to 110 per cent. of their pupils, (or victims.) These figures are official and may be read on Pages 410-470 of the Thirteenth Report. What per cent. of promotions may we anticipate if we advance on those figures? Surely we who went to school in the bad old times and were told there was no royal road to learning have a grievance so great that we should join the Bull Moosers to have it redressed. They alone can do it.

ROBERT P. KNOX.

New York, Aug. 20, 1912.

"The solar radiations are the primary cause, that is true, not those of light, but of heat. The loss of energy, I have found, is due to the evaporation of the water on that side of the earth which is turned toward the sun, the conducting particles carrying off more or less of the electrical charges imparted to the ground.

"At present it may be sufficient for the guidance of experts to state that the waste of energy is proportional to the product of the square of the electric density induced by the transmitter at the earth's surface and the frequency of the currents. Expressed in this manner it may not appear of very practical significance. But remembering that the surface density increases with the frequency it may also be stated that the loss is proportional to the cube of the frequency."

Why Wireless Does Best Work at Night

Nikola Tesla believes he has discovered the reasons for the phenomena long noticed by wireless folks that the wireless receiver is appreciably weaker in the day than it is at night.

In the *Electrical Review and Western Electrician* appears an article by the electrical inventor on "The Disturbing Influence of Solar Radiation on the Wireless Transmission of Energy." In this article Tesla accounts for this condition on the theory that as moisture in the air is dissipated by the sun's rays, and as particles of water in evaporating carry with them charges of electricity, the earth is thus deprived of some of the electrification which resides upon its surface at night. This, he claims, causes a dissipation of energy which necessarily interferes with the transmission of the electrical signals and prevents them from being observed at so great a distance as in the night time.

Tesla has long maintained that the earth plays as important a part in wireless transmission as the air and has contended as the results of demonstrations, he says, that the results accomplished are not due merely to Hertzian waves, whose existence was discovered by Heinrich Hertz, the German physicist. Tesla writes:

"Bearing, then, in mind that the receiver is operated simply by currents conducted along the earth as through a wire, energy radiated playing no part, it will be at once evident that the weakening of the impulses could not be due to any changes in the air, making it turbid or conductive, but should be traced to an effect interfering with the transmission of the current through the superficial layers of the globe.

The Disturbing Influence of Solar Raditaion on the Wireless Transmission of Energy

By Nikola Tesla

Editorial Note.—In the following interesting article, Dr. Tesla presents a theory to account for the diminished intensity of wireless signals on account of bright sunlight, which differs radically from the commonly accepted assumption that the effect is due to the ionization of the upper layers of the atmosphere by the ultra-violet rays of the sunlight. It will also be noticed that he does not accept the notion that the signals are transmitted by means of Hertzian or electro-magnetic waves, but explains the phenomenon on an altogether different basis.

When Heinrich Hertz announced the results of his famous experiments in confirmation of the Maxwellian electromagnetic theory of light, the scientific mind at once leaped to the conclusion that the newly discovered dark rays might be used as a means for transmitting intelligible messages through space. It was an obvious inference, for heliography, or signalling by beams of light, was a well recognized wireless art. There was no departure in principle, but the actual demonstration of a cherished scientific idea surrounded the novel suggestion with a nimbus of originality and atmosphere of potent achievement. I also caught the fire of enthusiasm, but was not long deceived in regard to the practical possibilities of this method of conveying intelligence.

Granted even that all difficulties were successfully overcome, the field of application was manifestly circumscribed. Heliographic signals had been flashed to a distance of 200 miles, but to produce Hertzian rays of such penetrating power as those of light appeared next to impossible, the frequencies obtainable

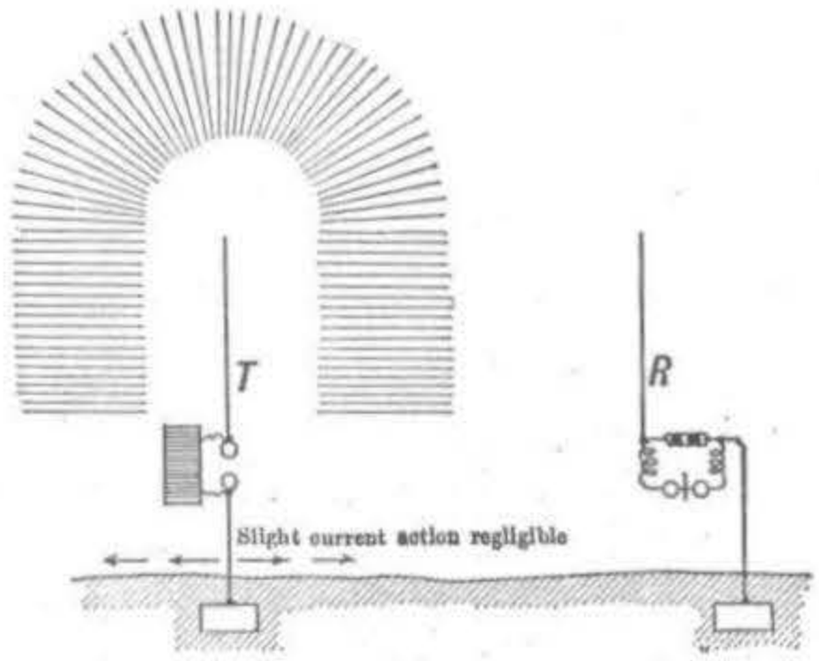


FIG. I.

through electrical discharges being necessarily of a much lower order. The rectilinear propagation would limit the action on the receiver to the extent of the horizon and entail interference of obstacles in a straight line joining the stations. The transmission would be subject to the caprices of the air and, chief of all drawbacks, the intensity of disturbances of this character would rapidly diminish with the distance.

But a few tests with apparatus far ahead of the art of that time satisfied me that the solution lay in a different direction, and after a careful study of the problem I evolved a new plan, which was fully described in my addresses before the Franklin Institute and National Electric Light Association in February and March, 1893. It was an extension of the transmission through a single wire without return, the practicability of which I had already demonstrated. If my ideas were rational, distance was of no consequence and energy could be conveyed from one to any other point of

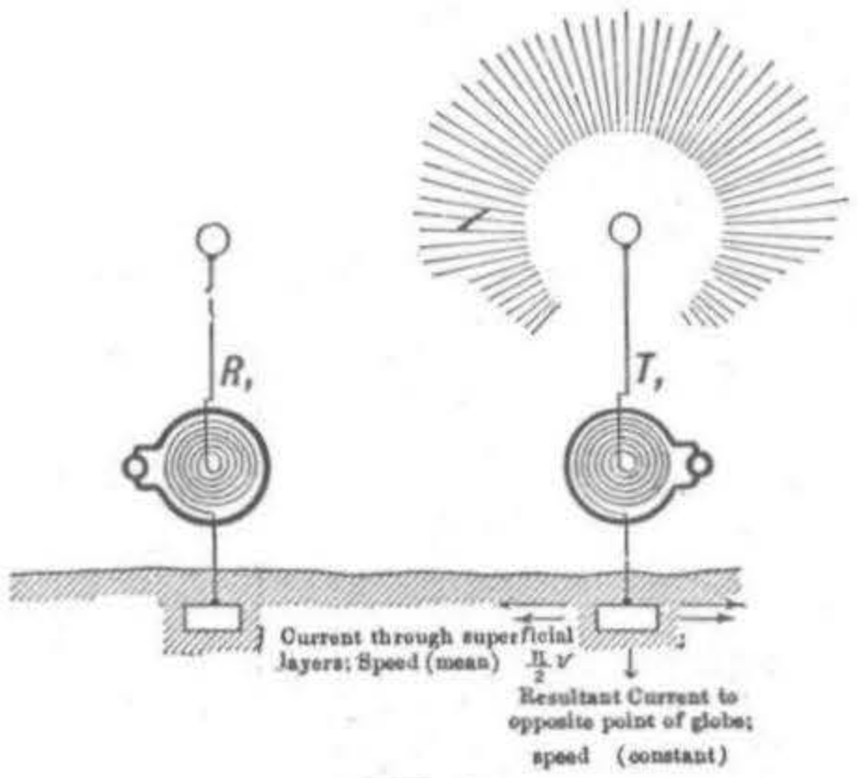


FIG. 2.

the globe, and in any desired amount. The task was begun under the inspiration of these great possibilities.

While scientific investigation had laid bare all the essential facts relating to Hertz-wave telegraphy, little knowledge was available bearing on the system proposed by me. The very first requirement, of course, was the production of powerful electrical vibrations. To impart these to the earth in an efficient manner, to construct proper receiving apparatus, and develop other technical details could be confidently undertaken. But the all-important question was, how would the planet be affected by the oscillations impressed upon it? Would not the capacity of the terrestrial system, composed of the earth and its conducting envelope, be too great? As to this, the theoretical prospect was for a long time discouraging. I found

that currents of high frequency and potential, such as had to be necessarily employed for the purpose, passed freely through air moderately rarefied. Judging from these experiences, the dielectric stratum separating the two conducting spherical surfaces could be scarcely more than 20 kilometers thick and, consequently, the capacity would be over 220,000 microfarads, altogether too great to permit economic transmission of power to distances of commercial importance. Another observation was that these currents cause considerable loss of energy in the air around the wire. That such waste might also occur in the earth's atmosphere was but a logical inference.

A number of years passed in efforts to improve the apparatus and to study the electrical phenomena produced. Finally my labors were rewarded and the truth was positively established: the globe did not act like a conductor of immense capacity and the loss of energy, due to absorption in the air, was insignificant.

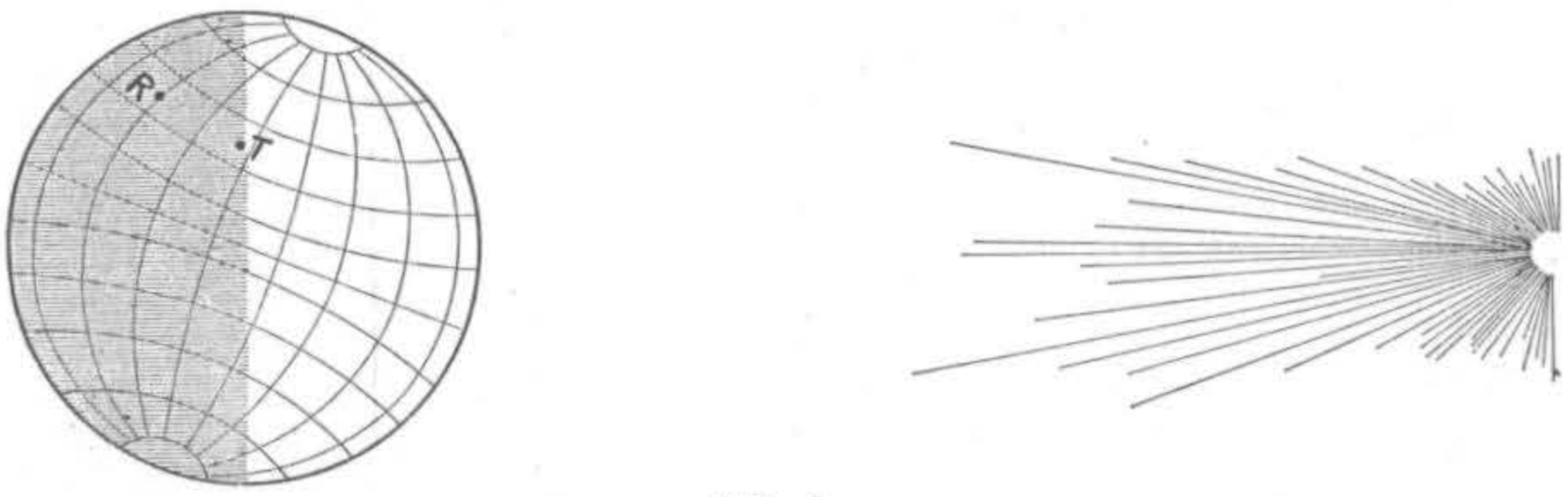


FIG. 3.

The exact mode of propagation of the currents from the source and the laws governing the electrical movement had still to be ascertained. Until this was accomplished the new art could not be placed on the plane of scientific engineering. One could bridge the greatest distance by sheer force, there being virtually no limit to the intensity of the vibrations developed by such a transmitter, but the installment of economic plants and the predetermination of the effects, as required in most practical applications, would be impossible.

Such was the state of things in 1899 when I discovered a new difficulty of which I had never thought before. It was an obstacle which could not be overcome by any improvement devised by man and of such nature as to fill me with apprehension that transmission of power without wires might never be quite practicable. I think it useful, in the present phase of development, to acquaint the profession with my investigations.

It is a well known fact that the action on a wireless receiver is appreciably weaker during the day than at night, and this is attributed to the effect of sunlight on the elevated aerials, an explanation naturally suggested through an early observation of Heinrich Hertz. Another theory, ingenious but rather fine-spun, is that some of the energy of the waves is absorbed by ions or electrons, freed in sunlight and caused to move in the direction of propagation. The *Electrical Review and Western Electrician* of June 1, 1912, contains a report of a test, during the recent solar eclipse, between the station of the Royal Dock Yard in Copenhagen and the Blaavandshuk station on the coast of Jutland, in which it was demonstrated that the signals in that region became more distinct and reliable when the sunlight was partially cut off by the moon. The object of this communication is to show that in all the instances reported the weakening of the impulses was due to an entirely different cause.

It is indispensable to first dispel a few errors under which electricians have labored for years, owing to the tremendous momentum imparted to the scientific mind through the work of Hertz, which has hampered independent thought and experiment. To facilitate understanding, attention is called to the annexed diagrams, in which Fig. 1 and Fig. 2 represent, respectively, the well known arrangements of circuits in the Hertz-wave system and my own. In the former the transmitting and receiving conductors are separated from the ground through spark gaps, choking coils, and high resistances. This is necessary, as a ground connection greatly reduces the intensity of the radiation by cutting off half of the oscillator and also by increasing the length of the waves from 40 to 100 per cent., according to the distribution of capacity and inductance. In the system devised by me a connection to earth, either directly or through a condenser, is essential. The receiver, in the first case, is affected only by rays transmitted through the air, conduction being excluded; in the latter instance there is no appreciable radiation and the receiver is energized by cur-

rents conducted through the earth while an equivalent electric displacement occurs in the atmosphere.

Now, an error which should be the focus of investigation for experts is, that in the arrangement shown in Fig. 1 the Hertzian effect has been gradually reduced through the lowering of frequency, so as to be negligible when the usual wave-lengths are employed. That the energy is transmitted chiefly, if not wholly, by conduction can be demonstrated in a number of ways. One is to replace the vertical transmitting wire by a horizontal one of the same effective capacity, when it will be found that the action on the receiver is as before. Another evidence is afforded by quantitative measurement, which proves that the energy received does not diminish with the square of the distance, as it should, since the Hertzian radiation propagates in a hemisphere. One more experiment in support of this view may be suggested. When transmission through the ground is prevented or impeded, as by severing the connection or otherwise, the receiver fails to respond, at least when the distance is considerable. The plain fact is that the Hertz waves emitted from the aerial are just as much of a loss of power as the short radiations of heat due to frictional waste in the wire. It has been contended that radiation and conduction might both be utilized in actuating the receiver, but this view is untenable in the light of my discovery of the wonderful law governing the movement of electricity through the globe, which may be conveniently expressed by the statement that the projections of the wave-lengths (measured along the surface) on the earth's diameter or axis of symmetry of movement are all equal. Since the surfaces of the zones so defined are the same the law can also be expressed by stating *that the current sweeps in equal times over equal terrestrial areas.* (See among others "Handbook of Wireless Telegraphy," by James Erskine-Murray.) Thus the velocity of propagation through the superficial layers is variable, dependent on the distance from the transmitter, the mean value being $\pi/2$ times the velocity of light, while the ideal flow along the axis of propagation takes place with a speed of approximately 300,000 kilometers per second.

To illustrate, the current from a transmitter situated at the Atlantic Coast will traverse that ocean—a distance of 4,800 kilometers—in less than 0.006 second with an average speed of 800,000 kilometers. If the signalling were done by Hertz waves the time required would be 0.016 second.

Bearing, then, in mind that the receiver is operated simply by currents conducted along the earth as through a wire, energy radiated playing no part, it will be at once evident that the weakening of the impulses could not be due to any changes in the air, making it turbid or conductive, but should be traced to an effect interfering with the transmission of the current through the superficial layers of the globe. The solar radiations are the primary cause, that is true, not those of light, but of heat. The loss of energy, I have found, is due to the evaporation of the water on that side of the earth which is turned toward the sun, the conducting particles carrying off more or less of the electrical charges imparted to the ground. This subject has been investigated by me for a number of years, and on some future occasion I propose to dwell on it more extensively. At present it may be sufficient, for the guidance of experts, to state that the waste of energy is proportional to the product of the square of the electric density induced by the transmitter at the earth's surface and the frequency of the currents. Expressed in this manner it may not appear of very great practical significance. But remembering that the surface density increases with the frequency it may also be stated that the loss is proportional to the cube of the frequency. With waves 300 meters in length economic transmission of energy is out of the question, the loss being too great. When using wave-lengths of 6,000 meters it is still noticeable though not a serious drawback. With wave-lengths of 12,000 meters it becomes quite insignificant, and on this fortunate fact rests the future of wireless transmission of energy.

To assist investigation of this interesting and important subject, Fig. 3 has been added, showing the earth in the position of summer solstice with the transmitter just emerging from the shadow. Observation will bring out the fact that the weakening is not noticeable until the aerials have reached a position, with reference to the sun, in which the evaporation of the water is distinctly more rapid. The maximum will not be exactly when the angle of incidence of the sun's rays is greatest, but some time after. It is noteworthy that the experimenters who watched the effect of the recent eclipse, above referred to, have observed the delay.

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The New York Herald October 26, 1912

PRINCESS SEEKS AID FOR SERBS

American Actress Whose Husband Is of Old Balkan Family Asks for Subscriptions.

Among the Servians who have arrived in New York from the West is Prince Lazarovich-Hrebellanovich. He came from Los Angeles, Cal., accompanied by his wife. Although he says his title is only a courtesy one, Prince Lazarovich takes pride in an ancestral tree which he traces back to the rulers of the Servian Empire before the advent of the Turk.

The Princess was Miss Eleanor Calhoun, the American actress. They were married in London. When in California she began to raise money to aid the Balkan allies. In New York she contemplates a similar undertaking. Her idea is to have some well known bank undertake to receive funds which could be transmitted directly to banking institutions in the Balkans. In this matter she has obtained the co-operation of Mr. Nikola Tesla, the inventor, himself a Serb by birth, though for many years an American citizen. Mr. Tesla said yesterday that he is enthusiastic for the work on behalf of Servia which Prince and Princess Lazarovich have done and are doing, and said he believes that the Servian cause will be materially aided by some of his American friends.

Several hundred Montenegrins and Servians are expected to leave New York to-day. A number of them will go on board the steamship La Touraine, of the French line. A party of two hundred young men came from Bisbee, Ariz. There are two organizations of Serbs there and, together with subscriptions from individuals, they raised $5,000, which is being spent in providing transportation for this contingent.

Showing that the enthusiasm to go back and fight for their country continues unabated among the Greeks and Montenegrins as well as the Servians and Bulgarians, the steamship Sant' Anna, of the Fabre line, which leaves port this morning, will take out 1,200 Greeks in one party. Reservations for 200 more men who could not be accommodated on board that steamship have been made for the Niagara, of the French line, which, it is expected, will take a total of 1,000 men for the Greek army.

Though there are not many of them in this country, the Montenegrins are polling their full strength, 600 of them going out of the country to-day on board steamships of French, Italian and American lines. Three hundred more natives of that country are to arrive in this city to-day from various points in the Western States and Canada. All are paying their own way and are doing so enthusiastically.

Funds that have been started by natives of the four warring Balkan States are being rapidly increased, not only by subscriptions received from persons of their own nationality, but by Americans. The fund in aid of the Greek Red Cross Society, which is being collected by Miltiades Melachrino and Anthony P. Ralli, of No. 15 William street, was increased yesterday by subscriptions which totalled $2,200, bringing the total sum received up to date to about $7,200. This money is cabled directly to Athens.

The Daily Atlantis, the Greek daily newspaper, has a subscription list open to aid the Greek army's field hospital and cables the money directly to Crown Princess Sophie of Greece. Several large subscriptions, totalling $2,000, were received yesterday.

Funds in aid of the Bulgarian field hospital service are coming in slowly to the committee, of which Mr. Angelinoff, Consul General, is in charge. This is explained by the fact that the circulars that have been mailed extensively throughout the Western portion of the United States, where the greatest Bulgarian population in this country resides, have not yet been received by them.

The New York Herald November 15, 1912

MR. TESLA FEARS A EUROPEAN WAR

Says Balkan Struggle Was Made Possible by Diplomacy of His Uncle, Metropolitan Nikola.

Mr. Nikola Tesla, the electrician and scientist, who was born in Smiljan, on the borders of Austria-Hungary, and who has made a close study of European conditions, declared to a reporter for the HERALD last night that the situation created by the present war in the Balkans was one of extreme danger to the European Powers.

"If it comes to a clash of the Powers," said Mr. Tesla, "the result will be a war compared to which the greatest wars of history will be mere skirmishes. The improvement in the machines of war and the power of destruction which science has given to these engines would make such a war appalling. It is difficult to predict what the result would be, but one fact is certain—Germany would get the lion's share.

"Any one who knows of German science, thoroughness, discipline and the marvellous organization of its war force will concede that no two European Powers combined could fight Germany successfully. Russia, with its immense territory and resources, might be impregnable on the defence, but a battle on the open field between these two great Powers would undoubtedly be decided in favor of Germany."

Mr. Tesla asserted that the present war would not have been possible except for a stroke of diplomacy on the part of his uncle, the metropolitan Nikola, many years ago. He declared that the Balkan provinces would have been absorbed by Austria in 1878, when Servia was their enemy, except for the work of the metropolitan Nikola. He refused to discuss the fate of Constantinople, although he said that he had received confidential advices from friends in the war zone. He strongly advocated liberality to the Turks.

"The Balkans," said Mr. Tesla, "are not opposed to Austria, but to its policies. How can Austria be opposed when the majority of the Austrian population is Slav? But Austria has maintained its unity through the popularity of the House of Hapsburg. With the death of the present Emperor the bond that has kept the branches together will be dissolved. I believe that Austria, without a revolution and without bloodshed, will then fall apart. The Slav population will drift to the Slav centre, the German provinces will be absorbed by the German Empire and the Hungarians will win independence. It will be a Hungarian kingdom.

"Servia should have a seaport, and, in the event that the Powers should interfere, that much undoubtedly will be granted to her. In so far as England is concerned, there is only one opinion, and its attitude is significant. The United States should naturally have a voice in the proceedings, and very likely this country will be invited to mediate because there are so many Servians here. It is considered by all races that the Americans are fair.

"I do not believe in harsh measures, advocated by so many with prejudice against the Turks. The Balkan allies have now won great victories, but the greatest victory would be to show that they are dealing in the twentieth century and consider human beings all alike, Turk or Christian. I believe it best for the world that the Powers should interfere at this moment. Among intelligent persons there is only one opinion, and that is that the war should be over. If a hundred years had elapsed without this war civilization would have pushed the Turks out of Europe without any war."

Tesla's Plan of Electrically Treating School Children

By E. Leslie Gilliams

Nikola Tesla believes he has found an electrical way of lessening the burdens of school life and the difficulties of acquiring education. A few months ago Mr. Tesla laid before the superintendent of the schools of New York, William H. Maxwell, a plan for making dull pupils bright by saturating them unconsciously with electricity.

Mr. Maxwell, an eminently progressive and practical man, after a careful investigation of Mr. Tesla's plan, arrived at the conclusion that the experiment could not possibly do the pupils any harm, seemed feasible, and to promise the accomplishment of great good.

Therefore he endorsed it for a six months' trial.

News of the new electrical project has leaked out in the school world, and the eyes of progressive schoolmasters all over the United States are now turned towards New York, and many inquiries have been received by Mr. Maxwell, requesting particulars regarding this novel electrical educational experiment.

Nothing in detail, however, will be furnished for awhile, as after the test has been made, careful calculations must be undertaken and conclusions and deductions drawn therefrom. It has been announced that the experiment is first to be conducted on a class of mentally defective children, the most difficult of all pupils to handle, and the bane and trial of every school teacher's life.

Mr. Tesla's plan for the arrangement of the experimental electrical school room, which has received Mr. Maxwell's approval, calls for the installation in this

room of a number of insulated cable wires through the walls. These wires will be so carefully concealed as not to be noticeable to the pupils. Every effort will be made to keep the knowledge of the experiment from them. In general appearance the room will not differ from the ordinary bright, sunny, cheerful school room with its desks and other useful fixtures.

A high frequency current of millions of volts will be generated in an apartment properly arranged for the purpose outside of the school room. When school begins, by simply turning a switch, the high frequency current will be turned on, by one of the instructors, and shortly afterwards the school room will become completely saturated with infinitesimal electrical waves vibrating at high frequency. The whole room will thus, Mr. Tesla claims, be converted into a health giving and stimulating electro-magnetic field, or "bath."

When the inventor's plan was first brought to the attention of the Board of Education in New York, a lively controversy over the benefits of the proposition ensued. A fear existed on the part of some of the members of the board that the stimulation of the defective children, during the experimental period of six months, might be followed by a more or less prolonged or permanent reaction. These educators based their view upon the position taken by Professor W. C. Bagley of the Department of Physiology of the University of Illinois, who has made the statement that it would be years before it could be determined whether bad effects followed such an electrical experiment. Mr. Tesla and other noted electrical experts, who have had great experience with high frequency currents, claim that Professor Bagley is at fault in his presumption.

As proof they point to the fact that Mr. Tesla's project is more than a plan as, in Stockholm, it has already been carried out by Professor Savante Arrhenius with school children and proved most successful. No after effects except those of a beneficial nature have been observed, although they have been carefully looked for.

According to Tesla the high frequency current sets up in the body what he describes as a sort of molecular massage or tissue gymnastics. The tiny particles of which the body is composed are constantly in motion, and the high frequency current causes them to move about in a livelier fashion and increase in number. This unusual activity of the molecules of the human body brings about increased oxidation—the burning up of the waste product of the body by oxygen.

He acknowledges that his plan of stimulating dull pupils by saturating them with electricity is based on the well known theory of stimulating plant growth by electricity—a theory which has been successfully carried out in England by Sir Oliver Lodge, and has also been tried with favorable results by scientists in Denmark and Belgium.

The up to date home of the near future, Mr. Tesla believes, will not only be a place of rest, ease and comfort, but a health resort and a sanitarium as well, making seaside vacations unnecessary.

It will be equipped with high frequency electrical apparatus which will without the knowledge of the inmates keep them constantly charged with electricity, thereby warding off many ills and aches now common, and making the workers always fit for the battle of life. By means of the high frequency currents, he says, all the benefits of the seashore may be obtained right in the crowded city. Instead of spending a few weeks by the sad sea waves every summer, a man and his family may derive all the benefits of the seaside in his own home all the year around.

The New York Times September 4, 1912

SERVIAN PRINCE DEFENDED.

Nikola Tesla Denounces Attack on Lazarovich-Hrebellanovich.

To the Editor of The New York Times:

I am in receipt of a printed statement purporting to express the sentiments of the Serbs of New York. It is an attack on Prince Lazarovich-Hrebellanovich, so vulgar and libelous that its distribution through the mails constitutes a flagrant crime. I understand that thousands have been sent out, and that all the papers in the city have received them. While publicity was refused, much harm has been done, and this is the reason for my asking you the privilege of saying a few words in your columns in the interest of fairness and truth. My motive, however, is not only the just indignation of a man who has done so much for the Balkan cause and the pain and injury inflicted upon a noble American woman, his wife, but the discredit which is cast on my countrymen. I maintain that few of them will be found willing to indorse such an act, and that all those who are endeavoring to live up to Servian ideals will condemn it as emphatically as I do myself.

To make these malicious attacks which have unfortunately found some reflection in the papers effective, misinformation is designedly spread in regard to the status of Servian nobility. On this point it is necessary to enlighten the American public. The political and social changes in Servia bear no semblance to those which took place in America, because of the radically different racial and national traits, customs, and traditions. At the close of the fourteenth century, when the great Servian Empire, under Lazar-Hrebellanovich, fell, the rights of the dynastic family and those of nobility were not lost, although this privileged class was shorn of its worldly power and influence. In the succeeding few hundred years of Turkish rule it almost disappeared through assimilation and emigration. At the beginning of the nineteenth century, when Servia obtained freedom through a revolution, a law was passed forbidding the sovereign to bestow distinctive titles, but nobility still existed, and no special article provided for its extinguishment. Moreover, the modern free State of Servia comprised only a very small part of the mediaeval empire, and any law to this end would be limited to its own territory, and, in any event, would not be retroactive and of effect on those who had emigrated after the battle of Kossovo Polje. So it comes that there are still a few families in Austria, France, Russia, and other countries who can trace their ancestry back to the old Servian nobility, and if they choose to use their titles they can do so with full propriety.

As regards Prince Lazarovich-Hrebellanovich, his title matters little, for he has won a better claim to distinction through his labors and rare intelligence. In his capacity as publisher, editor, lecturer, and author he has rendered great services to the Servian people, which I trust will be fittingly recognized, despite all intrigue and opposition.

NIKOLA TESLA.

New York, Dec. 2, 1912.

Nicola Tesla Talks of the Future of the Greatest Problems Now Confronting the Scientific World.

TO begin, will you tell me, Mr. Tesla, which of the modern discoveries or inventions do you think will have the greatest effect on the future development of human interests?

There is no limit to human ingenuity and the possibilities of accomplishment. New advances, one more astonishing than the other, are being announced in rapid succession, each contributing to our comfort, convenience and safety of our existence. It is not impossible that some stupendous discovery might be made of greater effect on human life than any that has gone before, but, judging from what we know at present, I have no doubt that the perfection of the wireless art and its application for innumerable purposes to which it lends itself will be of greater significance in our future development than any other technical advance. This departure naturally means to me more than most others, for just at this moment I am enjoying the supreme satisfaction and happiness in seeing the principles I discovered and the ideas for which I fought, against the most violent opposition generally recognized and adopted.

Q. This new invention is certainly wonderful, but why should it be so much more important than others?

It is not new, and it is not an invention, in the ordinary acceptance of the term. The art is as old as the memory of man; only the methods and devices are novel. It is not a single invention, as commonly believed, but the result of a number of discoveries and improvements. It is revolutionary and far-reaching because of the fact that the greatest impediment to human progress is the immensity of the globe on which we live and consequent difficulty of bringing individuals in close contact, conducive to mutual understanding and harmony. In this is to be found the principal cause of most of our troubles and conflicts. This also is the chief reason for our limitations and the existence of conditions retarding our advancement. The telescope has enabled us to explore other worlds. The microscope has revealed to us many of nature's mysteries. The benefits we have derived from these inventions are inestimable. The wireless art gives still greater promise. It will be the means of completely annihilating distance and thereby affording unprecedented opportunities for intellectual and material advancement.

Wireless Art In Its Infancy.

Q. Would you not more clearly indicate how this is to be brought about?

By its universal application for all purposes in the three great departments of human activity which are: The transmission of intelligence, the transport of our bodies and materials and the transmission of energy necessary to our existence. Such great change will naturally consume considerable time. So far we have seen only the first and crude beginnings, confined to the field of intelligence transmission. But the experts have now freed themselves of illusionary ideas, which have delayed practical consummation, and it may be confidently expected that the time is not distant when signals, written characters, pictures, musical plays and spoken words will be conveyed from one to any other point of the globe and our facilities of communication and exchange of thought immensely improved. As regards transportation, the applications will come more slowly because they involve installments of plants on a large scale and the vanquishing of greater engineering difficulties. With the increasing skill and number of experts and commercial encouragement, which will naturally come when the rationality of such undertakings is practically demonstrated and their possibilities appreciated, the obstacles will be finally overcome and a new epoch in transport and travel will be inaugurated.

It is in the third department that the greatest revolution will be wrought, however, for cheap power will become available at any place in the world. This will put an end to a sinful waste of energy which is now going on in this country perhaps more so than in any other. Think only that in the manufacture of iron and steel in America the coke ovens and blast furnaces discharge through the flues excellent fuel sufficient to develop at least 20,000,000 horse power, which could yield a revenue of $300,000,000 a year. The natural gas and oil wells are another instance of such barbarous waste, particularly the former. In many places enormous quantities of gas are permitted to escape uselessly into the air when they might be employed for the production of power and manufacture of valuable compounds. In the mining, transportation and use of coal, on which we are now absolutely dependent, the losses incurred are appalling. But, however great the economies effected through the extensive use of this art they are of small consequence as compared with its advantages in connection with a great many problems for which it offers ideal solutions.

To Illumnate The Ocean.

Q. Can you illustrate this by specific examples?

Certainly. Consider, for instance, the safety of ocean travel. In the terrible disaster of the Titanic wireless messages have proved instrumental in saving life. This is gratifying enough, but the calamity might have been entirely avoided through the scientific application of the same underlying principles. Numerous devices have been proposed to prevent collisions with icebergs, and I have myself invented not a few, but after years of thought and reflection, with due consideration of these later developments, I have come to the conclusion that the best, if not the only radical remedy, is to illuminate the ocean. This can be done through wireless transmission of power. It is my earnest hope that in the near future a concerted effort will be made to this end. To name another instance, I may refer to the operation of aeroplanes and dirigibles by this method. The purely mechanical solution of the problem, on which all experts are concentrating their efforts, can lead to but limited success on account of the necessity of carrying fuel or other store of energy. A wireless flying machine, besides being simpler, could maintain itself indefinitely in the air. The civilizing potency and practical importance of this improvement alone are inestimable.

To mention other examples, I might dwell on various uses of a stationary waves. This unique terrestrial phenomenon was discovered some years ago. Popularly explained, it is based on the sympathetic response of the earth to electrical oscillations of great intensity and definite pitch. The phenomenon manifests itself through the presence of electrical forces or activities in perfectly fixed positions in space. When such conditions obtain, distance, in the transmission of electrical energy, ceases to have a meaning and many results of the greatest scientific and commercial importance become readily attainable. Vessels can be guided along any route without a compass and with unfailing precision, the speed of a moving object and its distance with reference to another point can be determined, and the diameter of the earth and many other geographical data ascertained with great accuracy and without the employment of the usual means of observation and measurement.

To Fight Wars With Electricity.

Q. What do you think will be the effect of the dirigible balloon and the aeroplane on warfare? Will advance in this direction ultimately result in doing away with wars?

For many years, and especially since the development of the more practical types of aerial machines, I have carefully followed the articles and discussions of experts in endeavoring to form my own opinion on this subject. Some military authorities belittle the possibilities of the aerial vessel in this respect, but we have seen in the recent conflicts that the aeroplane has already exercised a marked influence on the tactics and general conduct of war. There can no longer be any doubt that a vessel on the plan of the Zeppelin dirigible would be a formidable instrument in a battle between armies as well as encounters at sea.

I believe, though, that there is absolutely no reason for a panic on that ground, for it should be borne in mind that in the same measure as we are perfecting aerial machines we are likewise improving the instruments for their destruction. There are already guns especially constructed for this purpose. Remember, however, that aerial machines will be equally available to both combatants, thus leaving the equilibrium undisturbed. It is difficult to say what the outcome will be in the next few years, but we may feel sure in making one prediction, namely, that the means of defense will always outstrip the means of attack. This is in the very nature of things, for it is a fundamental law that it takes less effort to disintegrate than to put in form.

Personally, I believe that wars in the distant future, if they do come, will be decided not by mechanical appliances but by electrical forces. I can see the day when it will be possible to direct from a power plant to any point on the globe, destructive energy of such intensity that the most terrible engines of war so far invented will be mere playthings in comparison. When this becomes possible, wars should cease. In the meantime, the enormous cost and sacrifice involved in warfare will be a powerful deterrent, compelling nations to choose the peaceful course.

Predicts New Storage Battery.

Q. Is there any prospect that the electric motor will in the end displace the gasoline engine in the operation of automobiles?

That, of course, is a woman's question. You are afraid of complication and believe that to simplify the apparatus is an essential requirement. The mechanical engineer does not look upon this in the same light. Although the present gasoline engine is far from being ideally simple, it has proved itself eminently practical, as is evidenced by the enormous extent of the automobile industry founded on its use. To replace this engine, and particularly the much improved type which is surely coming, will call for a new principle in primary or storage batteries. In these fields we have advanced but little since the discoveries of the early pioneers, but the announcement of a new principle may come any day, and it will be the death knell of the heat automobile engine, for no such machine can ever equal the electric motor in simplicity, safety and ease and perfection of control.

Q. Do you believe that printing will ever be replaced by a photographic process?

Photography, from its first inception, was a great triumph of invention. It has been of immense assistance in the study of all the phases and phenomena of nature. But while wonders have been achieved in this department, we are still far from replacing printing by photography. Printing machinery has been perfected to an incredible degree, as is well exemplified in the production of the daily papers. It is conceivable that by the use of a photographic method records could be made much quicker and cheaper. Photography seems to lend itself more especially to the reproduction of pictures, and in this particular line much is being done at present. A far-reaching improvement achieved of late years is color photography, and it is now a burning problem to devise a cheap and simple process for the reproduction of color photographs. The task is very difficult, but it will be undoubtedly accomplished.

Radium as Power Factor, a Dream.

Q. How about the dictagraph?

This is not a great invention, though a very useful instrument. It is popular with people who are not worrying about the form of expression, but it will never supplant an intelligent secretary or stenographer. My interest in this and similar devices resides chiefly in the possibility of their use in connection with the wireless system. Very soon it will be possible to make such records at any distance, and then the full value of this improvement will be demonstrated.

Q. What do you think of radium and the prospect it opens for the future?

My views on the subject are probably not in agreement with those of many men of science who have devoted themselves to this branch of investigation. It may not be generally known that in my papers published in the Electrical Review of New York from 1896 to 1897, long before the discovery of radium by Mme. Curie, I demonstrated the existence and described the salient properties of emanations of the same nature. My views were received with skepticism at that time, but I am glad to say that now they are adopted in their entirety. I see no reason for changing the opinions I then expressed. The so-called radium emanations are not an isolated phenomenon, but are universal. There is, according to my ideas, no such element as radium or polonium, although spectral analysis, the theory of Mendeleff, and various experimental observations, support this modern view. I believe, that as to this, scientific opinion is in error, as it was a century ago, in assuming that there was such a substance as phlogiston concerned in combustion until Lavoisier discovered oxygen. Similarly the radium manifestations are, in all probability, due to the action of a universal medium on certain volatile substances. Much of the speculation based on Mme. Curie's discovery is necessarily erroneous, being in direct contradiction to well established principles. The claims of some enthusiasts that in radium lies the possibility of future power development are nothing but a dream. But solid fact is that we are in the presence of new and wonderful effects the study of which is leading us gradually to a better and deeper understanding of the mechanism of the universe.

Harnessing Nature

Can the Free Energy of Space be Utilized?

By Waldemar Kaempffert

IN a few centuries the world's coal mines will be exhausted. Whence shall we derive the energy to turn the wheels of industry? By harnessing nature, is the answer. Long before we took stock of our fuel supply and found that we must husband what little we have left, scientific dreamers wondered whether natural forces could not in some way be utilized. To be sure, the potential energy stored up in every combustible is a natural force; however artificial our engines may seem, their power is nevertheless ultimately obtained from the sun. But that power is released and applied only by complicated and cumbrous mechanism that wastes many times more energy than it delivers. Why should it not be possible to tap the free energy of space, the energy with which the sun, for example, incessantly bombards us? Can not some engine be devised to transform and make available the apparently inexhaustible supply of energy liberated by every atom of radium? To answer questions such as these with anything like satisfaction is impossible. Yet they are discussed by the most distinguished physicists of the day, and therefore they acquire a dignity with which they might not otherwise be invested. At the fourth annual meeting of the British Science Guild, for example, the whole vast subject of harnessing nature was considered and a committee of seventeen was appointed to report upon it. Among the members of that committee were such distinguished scientific men as Sir William Ramsay, Hon. R. J. Strutt, Prof. Vivian B. Lewes, Sir Charles A. Parsons, Mr. Dugald Clerk, and Dr. Hele Shaw. The committee has not yet handed in its final report, but it has done enough to show how wonderful are the possibilities of engineering when combustibles will no longer be available and along what lines the investigator must work if success is to be attained.

Water Power.

The only natural source of free energy that engineers have thus far successfully utilized is water power. How they have gone to work is so old a story that it need not be retold here. Their task was simple. The crudest kind of bladed wheel ground corn centuries ago. The great turbines of Niagara Falls are merely improvements upon it.

A water fall is a ready-made solar engine, the only commercial solar engine that man has succeeded in utilizing. No machine has ever been designed or ever will be designed that will surpass the water fall in efficiency. The sun pumps the water of ocean, lake and river on mountain tops, and the force of gravity drops the water again to its original level. The cycle is endless. Because there are no valves, no shafts, no connecting rods, no thermal losses, the efficiency is one hundred per cent. It has been calculated that the total energy of these atmospheric deposits amounts to 100,000,000 horsepower. With the advent of electricity and its introduction into industry part at least of this energy is being used—the sole example of the successful use of nature's free energy.

Putting the Sun to Work.

But why not go directly to the sun? Its radiation has been measured and expressed in engineering units. In his Royal Institution lectures of 1911, Sir J. J. Thomson stated that, shining from a clear sky, the sun sends to the earth energy at the rate of 7,000 horsepower an acre. Moreover, as the temperature of the sun is at least 6,000 deg. Cent. this energy must arrive in a highly available condition; theoretically it ought to be almost wholly convertible into mechanical work. No wonder that the construction of a commercial solar engine has been one of the most fascinating problems that ever engaged the attention of inventors.

Up to within recent years the most elaborate experiments on record were those of Capt. John Ericsson, designer of the famous "Monitor." On a rainless strip eight thousand miles long and one mile wide, extending almost continuously from Africa into Asia and from South America into the United States, solar heat enough is wasted, he figured, to drive 22,300,000 solar engines of one hundred horse-power each, nine hours a day.

In endeavoring to utilize a very small part of this truly staggering amount of wasted energy, Ericsson worked persistently from 1865 to 1878 and built in that time no less than seven sun engines. He adopted the rather obvious method of concentrating the sun's rays on a boiler when he was driving his engine by steam, and on an air chamber when he employed one of his "caloric" engines. Eventually he succeeded in obtaining about one horse-power for every one hundred square feet of reflecting surface. Finally he came to the conclusion that the scheme was impracticable. "The fact is," he frankly admitted, "that although the heat is obtained for nothing, so extensive, costly and complex is the concentration apparatus that solar steam is many times more costly than steam produced by burning coal."

Since Ericsson's day other attempts have been made along different lines. Readers of the SCIENTIFIC AMERICAN are familiar with the proposals of Mr. Frank Shuman, Prof. Reginald Fessenden, and Messrs. Willsie and J. Boyle, Jr. Because their apparatus has been described in these columns at sufficient length it is unnecessary to dwell upon it again. In all these three solar power plants, the "hot box" of de Saussure, Langley and other pioneer solar physicists is employed. In other words, a film of water is heated in a glass-covered trough. The heat impounded by the trough is sufficient to raise the water to the boiling point, or very near it. Mr. Shuman has designed a low-pressure steam engine in which this hot water is flashed into steam. Messrs. Willsie and Boyle employ their hot water to vaporize a liquid, which has a boiling point lower than that of the water, a liquid such as sulphur dioxide. The vapors which are given off from the sulphur dioxide at a pressure of 215 pounds to the square inch drive a specially designed engine and are then returned to be used over again. The water which has given up its heat to the sulphur dioxide is sent through the hot-box again to absorb more heat from the sun.

Since the sun does not shine by night even in the desert of Sahara, a storage system must be devised—a piece of apparatus that can be charged with excess power and tapped at will in sunless periods. Compressed air tanks, storage batteries charged by dynamos driven by the solar engine, water pumped into a reservoir by a solar pump and used later to drive a water wheel, have all been proposed. Messrs. Willsie and Boyle store their hot water in a well insulated tank, so that it retains its heat over night and is always hot enough to vaporize sulphur dioxide. Mr. Shuman has also designed an insulated tank or boiler for storing hot water.

Prof. Fessenden, in the solar power scheme described and illustrated in the SCIENTIFIC AMERICAN two years ago, considered it more expedient to pump water into a reservoir and let it drop a considerable height against a water wheel. He, too, heats his water in a thin film under glass, causes the steam thus generated to drive a low-pressure pump directly, and thus fills his reservoir with water. In the plant illustrated in the SCIENTIFIC AMERICAN he showed a way of lifting Channel water to the top of the Dover Cliffs, so that it would flow back through a pipe and drive a water turbine at the bottom of the cliff. In conjunction with each solar plant a windmill is to be operated, so that, as he explains, "much better all-day and all-year efficiency will be obtained, because the wind is, as a rule, more effective during cloudy weather and at night time, i. e., when solar radiation is diminished or absent."

If we can extract heat from anything we can perform work. Water can be boiled without fire simply by reducing the pressure of the atmosphere. Since the atmosphere contains a certain amount of heat, why not extract it, as it were, and drive an engine? That is a proposal which Mr. Nikola Tesla has made. The direct utilization of the sun's heat after the manner of Ericsson, Shuman, and others seems to him commercially hopeless, however practicable it may be on an experimental scale. Moreover, he cannot reconcile himself to the idea that the entire manufacturing interests of the world must be transplanted to Arizona, southern California, Egypt, or the Sahara desert when the world's coal supply is exhausted and the solar engine is at last realized. Industry seems to be identified with the temperate zones, where sunshine is intermittent. The periodicity of sunshine, with which all solar engineers must reckon, he finds an insuperable difficulty. Moreover, it seems inept to him to convert the intense heat of the sun into low-temperature heat, of which only a small fraction can ever be recovered as mechanical work. In his opinion, the only direct way of converting solar energy into work is to tap the heat units of the atmosphere, heat units available at all times, in fair weather as well as foul, in summer as well as in winter. There is no need to invent storage systems; for the atmosphere is its own storage tank. This is, to be sure, but a thermodynamic dream as yet, but a dream which, however wild it may seem, is nevertheless worthy of at least academic discussion.

The Photo-chemical Power Transformer.

Every living organism is a crude kind of solar engine. We are all dependent on the product of the soil for our existence, and that product in turn represents so much solar energy chemically stored up. A grazing cow is a living engine that converts solar energy into work. The solar energy that has caused grass to grow is turned to practical account whenever she flicks a fly from her back. Prof. V. Coblentz has suggested that perhaps a chemical substance may be discovered, which, when exposed to the sun, is transformed into a stable substance capable of giving up its energy for subsequent consumption, a substance more highly efficient than grass and capable of releasing its energy perhaps in an electrical way.

This idea was further developed in a profound analysis of photo-chemical problems before the recent International Chemical Congress by the distinguished Italian chemist, Prof. Ciamician. An obvious cycle, he suggested, was the use of mineral fertilizers to raise a harvest, which, dried by the sun, could be converted entirely into gaseous fuel, the ammonia being fixed and returned to the soil as fertilizer, together with the ash. He also deemed it possible to produce the things we need directly without the intervention of much factory machinery. If ammonia can be directly obtained from atmospheric nitrogen and hydrogen—the recent technical achievement of a great German chemical manufacturing company—why should it not be possible, he asks, to utilize solar energy in connection with catalytic substances and thus artificially reproduce plant processes on an unprecedented scale? A photochemical laboratory in northern Africa might thus produce immediately useful substances now supplied only after much coal-burning, engine-driving and mechanical handling of raw material. A meadow is not a highly efficient transformer of solar energy, but the manner in which it synthesizes the chemical elements stored up in the earth with the aid of sunshine might well be artificially reproduced, and the solar engine itself abandoned except for purely thermodynamic purposes. If a plant can reverse the process of combustion, if it can transform the carbon dioxide of the atmosphere into starch, simultaneously setting free oxygen, why can't man adopt the same principle with success? At all events, Prof. Ciamician holds that it lies within our power to make plants produce abundantly the things we need. The possibility is indicated when we consider the ease with which we have increased the amount of sugar in the sugar beet and the percentage of protein in wheat.

The Energy of the Rotating Earth.

In an introductory lecture to the engineering classes at University College, London, Prof. J. A. Fleming, in considering the sources of energy available to mankind, pointed out that the earth is a great flywheel. It whirls along in its orbit with a velocity of about twenty miles a second or 1,200 times that of an express train. Its rotational energy is a hundred thousand million billion horse-power hours; but the total orbital energy or energy of motion in its orbit is ten thousand times greater. "Suppose," said Prof. Fleming, "suppose we could in some way or other slow down its rotation so as to make the day just five minutes longer. . . . This would decrease the earth's angular velocity by about one third of one per cent and decrease the angular energy by about two thirds of one per cent, or say by 1/150 part. If then we could capture and store up the difference in the rotational energy in the two cases, it would give us about six million billion horse-power hours, or a billion horse-power for seventy thousand years. The energy we can obtain by the combustion of all the one thousand million tons of coal at present raised per year, sinks into insignificance compared with the enormous energy which would be set free by an almost imperceptible lengthening of the earth's diurnal rotation."

Prof. Fleming was not rash enough to indicate in what manner this unthinkable amount of energy could be utilized. Those who will attempt that will find themselves engaged in the mad task of designing perpetual motion machines.

The Energy of the Atom.

If Ramsay is correct in stating that copper and lead can be disintegrated, have we not here a source of energy? Sir William Ramsay has himself effectually disposed of that possibility. First, all metals, except gold and platinum, he has pointed out, are produced by the combustion of fuel, or, it may be, by electric power derived from turbines and dynamos. Hence they must be more costly than the means used in their produc-

tion; to produce them, not merely must energy be used, but also some must be degraded, and lost as heat. Labor, too, is expended in their production. On the supposition of change with evolution of energy, they would give out no more than has been put in, in converting the ores into the metals. Lastly, supposing that this compound can be induced to change, under the action of ultra-violet light for example, the change is too slow to be effective as a source of energy; and ultra-violet light itself is produced only after much energy is expended.

Experiments conducted by Mr. Nikola Tesla with electromotive forces of 20,000,000 volts have convinced him that if 100,000,000 volts could be produced it might be possible to break down the atomic structure of any element and thus liberate a certain amount of energy. "But," he told the writer of this article, "even if the feat could be accomplished and sufficient energy set free, there still remains the enormously difficult problem of devising a means of utilizing the energy in a practical way."

Prof. J. A. Fleming suggests a somewhat similar course. "It is now pretty generally recognized," he argues, "that an atom is a complicated structure, a sort of solar system in miniature composed of revolving electrons. It may be possible to break down the structure by the action of impulses due to concentrated electric waves of the right period, setting up vibrations, which are resonant with some natural period of the atom, just as it is possible to break down a suspension bridge by a number of men jumping on it in time with its natural period of oscillation. If then the atom were to break down, the energy liberated might be far greater than that applied to it in the form of the resonant impulses."

Sir William Ramsay is undoubtedly right in maintaining that no source of energy, capable of being converted into work on a large scale, can be looked for, so far as the transmutation of matter is concerned. "The question is not—can it be done? but—does it pay to do it? And to the last question the answer is emphatically *no*."

Radium as a Source of Energy.

So minute a quantity of pure radium as one gramme (one twenty-eighth of an ounce) yields 118 calories an hour, 2,900 a day, or nearly one million a year. A ton of radium, according to Sir William Ramsay containing a million grammes, would give one million million calories per year. As one gramme of coal in burning evolves about 8,500 calories, one ton would evolve one million times as much, or 8,500,000,000, which is only the 117th part of that evolved by the radium in a year. Moreover, the radium after the year has suffered merely a minute loss of weight; roughly speaking, about 1/3,500th of its weight has disappeared; hence before it was all "consumed" it would have evolved $117 \times 3{,}500 = 460{,}000$ times as much heat as an equal weight of coal. Add to this the fact that coal is utterly consumed in a few hours, but that rate of change of radium is all but imperceptible, and the superiority of radium over coal, weight for weight, is still more apparent.

Unfortunately, radium is about the scarcest producer of energy in the whole world. Radium is the offspring of uranium; it does not occur apart from uranium. Sir William Ramsay places the supply of uranium in its ores at about one million tons. Since the amount of uranium contained in the "kulm" shale of Sweden is under 0.5 per cent he concludes that the amount of radium metal in the whole world is not more than 500 pounds—too insignificant, in a word, for serious consideration as a substitute for coal. Not more than 125,000 tons of coal would be saved by utilizing the energy in 500 pounds of pure radium. The railway locomotives of the United States burn more than that quantity of fuel in a year. Besides, the energy in the five hundred pounds of radium cannot be liberated quickly, but must be spread over a period of centuries. The late Prof. Curie once remarked that he would not venture into a room containing only a pound of radium, so extraordinarily intense is its action. Hence, even if it were possible to hasten the discharge of radioactive energy, the engineers of a radium power plant would have to be recruited from the members of Stevenson's Suicide Club.

The Internal Heat of the Earth.

It is a matter of common knowledge that in sinking mining shafts there is a rise in temperature of about 1 deg. Fahr. for every 69 feet, down to a certain depth. Active volcanoes afford still more striking evidence of the earth's internal heat. Have we not here an inexhaustible source of energy? We have, but it is difficult, if not impossible, to utilize it. If the prime requisite in making use of any source of heat is to obtain good conditions of thermal interchange with it, an insuperable obstacle would be found in the poor conducting qualities of rock. Only by fluid convection would it be remotely possible to obtain communication with the earth's stores of heat. In considering these possibilities, the Hon. R. J. Strutt points out that hot springs, while they have been utilized from time immemorial, are too diminutive. The perpetual streams of molten lava that flow into the sea in certain localities, as at Stromboli, might perhaps be utilized, he ventures, "but the opportunities for applying the method would scarcely be extensive enough to encourage inventors."

Why not pump water down to the heated interior and return it to the surface at a high temperature? Here again Strutt sees no possibilities. The pipes would have to be kept immersed in molten lava; no sufficiently rapid transference of heat to them from solid rock would be possible. For the same reason, he states, the pipes must not be cooled down by the water flowing through them sufficiently to cause the surrounding lava to congeal. Can the pipes endure the prolonged action of molten basalt? Wrought iron might in Strutt's opinion. "On the other hand, the margin of difference between the melting point of basalt and of iron is not very great, and lack of stiffness in iron pipes at such temperatures would undoubtedly introduce the most serious difficulties." Even if the attempt be made by directly attacking a volcanic crater the engineering difficulties would be enormous.

Similar conclusions were reached by Sir Charles A. Parsons in a presidential address to the engineering section of the British Association for the Advancement of Science. He discussed the feasibility of constructing a bore hole twelve miles deep. While the feat could be accomplished, and while the temperature of the rock at that depth is probably 272 deg. Fahr., the undertaking would involve an expenditure of millions.

HIGH-FREQUENCY CURRENTS.[1]

By W. D. Duddell.

The methods of producing high-frequency currents may be divided broadly into three classes, namely: (1) alternator methods; (2) methods based on the oscillatory discharge of a Leyden jar; (3) arc methods.

In a little special machine which I have here there are 15 magnets—that is to say, 30 poles alternately north and south—and it runs at 8,000 revolutions per minute or 133.3 revolutions per second, so that frequency in this case is 2,000. The peripheral speed of this machine is just over three miles per minute. From this example it will be pretty obvious that if I attempt to obtain high frequencies—that is to say, frequencies well above 10,000—I shall have to run either at enormous speeds or have a very large number of poles. One of the very earliest high-frequency machines ever constructed in this country, and following shortly after Tesla's high-frequency machine, was made by Messrs. Pyke and Harris for Sir David Salomons.

The machine ran at 1,500 revolutions per minute, but as both the armature and the field magnets are free to move, their relative rate was 3,000 revolutions per minute, or 50 revolutions per second. The number of pairs of poles is 174, so that frequency is 8,700.

At about the same date that Sir David Salomons had his machine constructed, Mr. Parsons constructed for Professor Ewing at Cambridge University a high-frequency alternator in which the high frequency—namely, 14,000—was obtained by using a high speed of 12,000 revolutions per minute.

If, instead of moving the wires across the faces of the magnets, or moving the soft iron cores on which they are wound, the wires be wound on the poles of the magnets and a piece of soft iron moved past the magnet poles, an alternating current will be produced as before, with this difference—that for a given number of poles and a given speed this type of alternator will produce twice the frequency of the previous type. Alternators depending on this principle are usually called inductor alternators. Many high-frequency alternators have been constructed on this principle by using 204 polar projections or teeth and a speed of 35,400 revolutions per minute. I have obtained a frequency of no less than 120,000 in a machine I constructed in the laboratories of the Central Technical College, but the output of the machine was microscopic.

Turning to modern high-frequency machines, we have the alternator designed by Mr. Alexanderson, with which frequencies as high as 200,000 have been obtained.

A high-frequency alternator on quite a different principle is due to Dr. Goldschmidt. I have mentioned in Sir David Salomon's early machine that the two disks forming the field and armature were rotated in opposite directions. It is possible, however, to produce a rotating field electrically without the disk moving at all. When this is accomplished the frequency of the machine depends as before upon the relative speed of the rotating field and the armature.

Consider for simplicity, a machine having only two poles, so that it gives one complete cycle per revolution, and suppose I supply the fixed part or stator with an alternating current of 100 frequency and so connect it that it will produce a rotating field (we will assume the alternating current to be three phase for the sake of simplicity), if now I rotate the rotating part in the opposite direction to that of the rotating field I shall have induced in the rotor an alternating current whose frequency will depend on the relative speeds. For instance, if the speed of the rotor is such that with a stationary field it would give 100 frequency, then as my field is actually rotating in the opposite direction at 100 frequency the actual frequency produced will be 200 per second. Using this 200-per-second frequency by means of another machine running at the same speed one could increase it to 300, and so on indefinitely. This would, however, lead to a very complicated machine, and Dr. Goldschmidt has arranged matters so that instead of requiring a number of machines the successive additions to the frequency can all go on in the same machine.

The simplest way to explain this is to suppose that the alternating current at 200 frequency obtained from the rotor is passed back into the stator of the same machine so as to produce a rotating field of 200 frequency without in any way interfering with the original rotating field of 100 frequency. This rotating field of 200 frequency will induce an alternating current of 300 frequency in the rotor, which could in turn be transferred back to the stator and produce a rotating field having 300 frequency, and so on.

This is what Dr. Goldschmidt calls the electrical method of transferring the currents from the rotor to the stator. He has also devised a magnetic method which is simpler. Turning again to our two-pole machine whose stator is supplied with current at 100 frequency, there will be induced in the rotor a current of 200 frequency. Now, if the rotor be short-circuited there will be produced in it a rotating field having 200 frequency, which will induce in the stator a current having 300 frequency, which in turn can be short-circuited and will induce in the rotor a current having 400 frequency, and so on. I have spoken of the machine as if the rotating field was produced by a three-phase current. A single-phase field may be looked upon, theoretically, as two rotating fields in opposite directions, one of which will have no effect as far as we are concerned, and therefore a single-phase machine will do just as well. Further, it is not really necessary to supply the stator of the machine with an alternating current. If it is excited with a direct current it will induce an alternating current in the rotor which will react on the stator, and backwards and forwards in the same way as I have already described.

It would seem at first sight as if by this means an indefinitely high frequency could be very easily obtained. There are, however, certain practical difficulties.

By this method Dr. Goldschmidt has obtained 12 kilowatts at a frequency of 30,000, and at high frequencies a lesser output.

The present position of the generation of high-frequency currents by means of alternators may be stated by saying that it is now practically possible to generate by means of a machine alternating current up to and over 200,000 frequency. At frequencies of 100,000 several kilowatts are obtainable, and at the lower frequencies machines can be built for greatly increased outputs. Where large amounts of power at high frequencies are required, such as in wireless telegraphy, the question is now becoming a commercial one as to the efficiency of the different types of alternator, their cost and their reliability. Is it possible to run these machines continuously day in and day out and to supply power at high frequencies? If so, how much does it cost per kilowatt-hour to produce this high-frequency power, taking into account not only the coal consumption, but also the wear and tear on the machine and all the other running and capital charges?

Leyden-Jar Discharges.

Turning next to the second method of producing high-frequency currents—namely, by the discharge of a Leyden jar—it was quite early inferred by Helmholtz and Henry that the discharge of a Leyden jar did not always flow in the same direction, and we owe to Lord Kelvin the mathematical investigation of this subject, and to Feddersen its experimental demonstration. If I charge a Leyden jar, or any other condenser, and allow it to discharge through a very high resistance, a current will flow, which gradually dies away as the jar discharges. If, however, I discharge the condenser through a sufficiently low resistance, it will be found that the current continues to flow in the same direction after the jar is completely discharged, and then charges it up in the opposite direction, the current gradually getting smaller.

1. Portion of an address to the Royal Institution of Great Britain.

When the jar is charged to a certain extent in the opposite direction to its original direction it starts to discharge again, this time in the opposite direction. The current again continues to flow after the jar is discharged, and charges it up in the original direction. This cycle of operation is repeated, the energy of the charge in the jar gradually getting less and less, until it dies away. The frequency of these oscillations is determined by the capacity of the condenser and the self-induction.

It is quite easy to obtain by this method almost any frequency—for instance, anything between 1 and 100,000,000 are comparatively easily obtainable, and I have even demonstrated frequencies as low as one-half.

The fundamental difference between these high-frequency currents and those generated by alternators is that they die away—that is to say, that the amplitude gradually decreases and comes to zero. The condenser then has to be re-charged, and the process repeats itself. Now, a single discharge of this sort is not of much practical use. It is necessary to charge the condenser and repeat the discharges in rapid succession if any useful work is to be done. Many methods have been proposed for this purpose. Some of the early successful experiments were those of Tesla.

The condenser is allowed to discharge through a circuit which consists of the necessary self-induction and a spark gap in series. The spark gap will stand a certain electrical pressure, and then let the electricity pass. When once the electrical pressure or voltage has been raised to a sufficiently high value to break down the spark gap, the spark gap changes from being an insulator which prevented the flow of electricity to being a comparatively good conductor, and it remains conducting in the ordinary way until the current finally ceases. If the condenser be charged to a sufficiently high voltage, the spark gap will break down, a spark will take place, and during the time that the gap is conducting, oscillations will take place. In order, therefore, to produce the repeated sets of discharges of the condenser, all we have to do is to repeatedly charge the condenser to a sufficiently high voltage, and this is easily accomplished by charging it from a transformer connected to an ordinary low-frequency alternator.

This is the usual method of producing high-frequency currents. It will be evident, however, that the high-frequency currents obtained by this means differ fundamentally from those obtained from an alternator; for instance, with an oscillation frequency of 1,000,000 per second, such as I am using, and 50 oscillations for each discharge of the jar, the whole discharge will last 0.00005 second. As we are only obtaining 170 discharges per second, there is something like 0.005 second between the end of one discharge and the beginning of the next, which is a comparatively long time, about 100 times as long as the oscillations last.

It is obvious that if the discharges can be caused to take place with greater rapidity by using a higher-frequency alternator to charge the jars, the gaps will be closed up, and this is the method originally used by Tesla, and which is now being used in many of the wireless transmitters, though in this case there is another reason for using a greater number of discharges per second. For instance, the Marconi Company, in their musical spark transmitters, use a frequency of some 300—that is to say, some 600 discharges per second—and the Telefunken Company as many as 1,000 discharges per second.

I now come to another class of method which still depends upon the discharge of a condenser. If I have a body like a pendulum or a spring capable of oscillations, I can make it oscillate by pulling it away from its position of rest and then letting it go. I can also make it oscillate by giving it a blow or shock, and I can make it oscillate by applying to it a number of impulses at properly timed intervals. All three of these methods are employed in the production of high-frequency currents. The first is the simple discharge of the Leyden jar without any auxiliary apparatus; the third is the method usually employed in wireless telegraphy for obtaining and maintaining a long series of oscillations in the aerial by tuning it and loosely coupling it to the Leyden-jar circuit in which the discharge takes place. The second method also involves a discharge of a condenser. In this case the spark gap is so arranged that it suppresses the oscillations of the condenser—that is to say, it breaks down, allows a larg rush of current, and then becomes insulating and stops anything further from happening.

It might be thought at first that in this method of producing oscillations there was no relationship between the nature of the swing in the first, or discharge, circuit and the frequency of the oscillations in the second circuit. Without going into the theory of coupling, which would take me too far, I would point out that for the best result there is a relationship, and this can be easily seen if one considers the question of starting oscillations in, say, a short and a long pendulum. The long pendulum will be set swinging easier with a blow which comes on and off comparatively slowly, whereas the short pendulum will require a short, quick tap to start it swinging.

This method of shock excitation, due to Max Wien, is employed by the Telefunken Company in its wireless transmitter, and also in its therapeutic apparatus; a special type of spark gap being used consisting of large flat metal plates, a very short distance apart, the object being to suddenly cool the spark to cause it to go out, and the gap to become insulating again at the earliest possible moment.

A spark gap of this type connected to a condenser and self-induction can be supplied in the ordinary way, when the frequency of the spark will naturally depend upon the frequency of the alternator.

If an attempt be made to employ the successive discharges of a condenser when charged from continuous current, a difficulty is encountered if large powers are dealt with. This difficulty seems to reside in the properties of the spark gap, which tends to become completely conducting, or, what is technically called "arcs," when large powers, say 10 kilowatts or over, are employed.

Mr. Galletti set himself to get over this difficulty by employing a number of such circuits, each with its own spark gap, and connecting these together so that they would all help to produce the oscillations.

By combining a number of circuits and using the high-voltage continuous current supplied by the Moutier-Lyons transmission—some 40,000 volts—Mr. Galletti was able to deal with many kilowatts, the spark frequency being very high, about 10,000 per second. Corresponding to each of these sparks there is a series of oscillations, so that in this case the oscillations must be completely joined up, and the result almost the same as if an alternator were employed.

Mr. Galletti has been able to employ still larger numbers of sparks per second, up to 100,000. In this case one arrives at the interesting result that the oscillations can be maintained by impulses from the condenser circuit every other oscillation, or even each individual oscillation. This should maintain a true alternating current, such as is produced by an alternator, with no waste intervals.

Arc Methods.

If an ordinary direct-current arc is produced between solid carbon or metal electrodes, it is unstable—that is to say, it cannot be burnt unless a resistance is placed in series with it. The current can be kept at any desired value by putting sufficient resistance in series with the arc, so that when the current is increased the potential difference between the terminals of the arc and the resistance taken together increases, and the circuit as a whole becomes stable. If such an arc be shunted with a capacity and self-induction in series oscillations will be set up in this shunt circuit, the frequency of the oscillations being mainly determined by the periodic time of the shunt condenser circuit.

When the oscillations are taking place, the oscillatory current flows through the arc, and consequently tends to increase and decrease the arc current. Any increase in the current tends to make the

vapor column of the arc larger, and any decrease makes it smaller, so that the vapor column of the arc pulsates in size. This pulsation in the size of the vapor column moves the air in the neighborhood of the arc, and, if the frequency is suitable, produces sound; hence this experiment is known as the musical arc. By varying either the capacity or the self-induction, the frequency of the oscillations can be varied, and hence the pitch of the notes given out by the arc, and by this means a tune can even be played on it.

The frequency of the currents produced when using an ordinary arc between solid carbon electrodes is comparatively low, at the most a few thousands per second. The reason for this is that the characteristic of the arc—that is to say, the relationship between the potential difference and the current—depends to some extent on how quickly the current is varied. If the current is varied very quickly, then an increase of current is accompanied by an increase in the potential difference; the arc is no longer an unstable conductor, and oscillations cannot be produced.

There are various ways of rendering the arc unstable, even when the current varies rapidly. One of these consists in using very small currents. For instance, metal arcs using currents under one-half ampere are extremely unstable, and remain so even under high frequencies.

Another method is to energetically cool the electrodes; for instance, to make one of the electrodes consist of a vessel containing water, or squirt a jet of water through the arc. The third method, due to Mr. Poulsen, consists in placing the arc in hydrogen, or some hydrogen compound, such as coal gas or alcohol vapor. By this means high-frequency oscillations can easily be produced up to about a million per second, and at the lower frequencies of, say, 100,000, considerable powers can be dealt with.

To render the arc still more unstable, Mr. Poulsen places it in a strong transverse magnetic field. With an apparatus of this sort I am informed that 30 kilowatts or more can be dealt with by a single arc, and if several arcs are placed in series, large powers can be transformed.

If the apparatus is properly adjusted the high-frequency currents produced are very nearly true alternating currents, such as are obtained from an alternator.

The only difficulty I find in working the apparatus is to maintain the frequency absolutely constant, as it appears that the frequency depends to a small extent on the current through the arc and on the arc length. In the actual apparatus employed for wireless telegraphy the electrodes are kept in rotation so as to ensure a greater constancy in the arc length.

In using a generator of this sort for wireless telegraphy, messages have been transmitted and recorded from a distance of about 1,000 miles at the speed of over 100 words per minute.

A large number of modifications of the arc method have been produced, practically all of which consist in changing the nature of the electrodes or the surroundings of the arc, so as to try and make it still more unstable at high frequencies and large currents. Most arcs seem to lose their stability after the current has passed a certain limit. For this reason there is generally a best working current for any arc. If it is required to deal with more power than one arc can transform, it is better to put the arcs in series.

A very interesting generator of high-frequency currents is that invented by S. G. Brown. It is difficult to say whether it is an arc or a spark or what. The unstable conductor which takes the place of the arc consists of an aluminum wheel, on the edge of which a copper block rests. The wheel is kept rotating, and the contact is shunted by a condenser and self-induction. This arrangement produces high-frequency currents quite easily, but I have never been able to make it deal with any large powers.

In conclusion, it is of interest to review in general terms the present position of the three main methods of producing high-frequency currents. The most important application at the moment for high-frequency currents is wireless telegraphy. For this purpose frequencies in the range between 30,000 and 1,000,000 are required. A few kilowatts of high-frequency energy is generally sufficient for practical purposes at the higher frequencies. At the lower frequencies, which are mainly used on long-distance working, large amounts of power are required. In fact, one of the great problems in long-distance wireless telegraphy is to produce several hundred kilowatts of high-frequency energy with certainty and regularity, and at a reasonable price.

The alternator method, as far as the information at my disposal goes, has never yet been applied to very large powers. There is no doubt that it is from many points of view an ideal method.

The spark method has been successfully employed over a wide range of frequency and up to very large powers, and there is no doubt that it is capable of satisfactory operation. The spark method used with very-high-frequency sparks and continuous current, as proposed by Mr. Galletti, is still in its experimental stage. There seems no reason why the principle should not be extended so as to deal with larger powers. The practical difficulties may be great, but I think they should be able to be overcome.

The arc method is in a much more advanced condition. A large amount of work has been done, and practically all the details have been worked out. There is no doubt that fairly large powers can be successfully generated and utilized.

The position is therefore a very interesting one. No one of the methods seems at the moment to have so many advantages as to make it *the* one method above all others for producing high-frequency currents. The final decision as to which is the best will probably in the end be determined by the regularity with which the apparatus works, and by that governing factor in all commercial enterprises—the cost of production.

APPRAISEMENT OF ESTATE REVEALS ASTOR'S PERSONALITY

Interesting Sidelights Thrown on the Character of Victim of the Titanic Disaster by the Record of His Effects. Comparatively Modest in His Personal Luxuries, an Inventor and a Good Investor.

THE appraiser's report of the estate of Col. John Jacob Astor, filed in the Surrogate's Office last Monday, throws a flood of light on a great American fortune in a way which can hardly be paralleled in court records of the sort. The dimensions of this fortune of $87,000,000 and over, the importance to New York City of the Astor real estate holdings, the intricate system of trusts and a fabric of family tradition which amounts to a rule of primogeniture among the Astors for five generations, and the picturesque interest attaching to Col. Astor and his stripling heir excited public attention and found a response in elaborate newspaper reports of the appraisal. Yet these reviews, owing to the intricacy of the subject, could not touch upon details which, when segregated and analyzed, form a fascinating character study of the man whose enjoyment of three millions ended with the Titanic disaster. John Jacob Astor seemed to be an obvious personality to those who read of the appraiser's report. The obvious was most deceptive. Behind the summary of millions lurked another man, neo-philosopher and mystic, bound as completely by family tradition as some Spanish prisoner of simple tastes, though with surroundings that might be called regal—a span who could have been a scientist if he had been given a chance—the dreams of the poet traveling, by this case, that of the multimillionaire.

Such is the story told in legal documents which seem to be, at first glance, as dry as dust, though found on closer scrutiny to embody a unique human document.

The simplicity of Col. Astor's personal, intimate surroundings is one of the most forceful impressions gathered from the appraisal. With a fortune of more than $87,000,000 and an income estimated at not less than $3,000,000 a year, his immediate belongings, including wearing apparel, jewelry and dressing requisites, did not rise above more than $10,000.

At Fernehff, his estate on the Hudson, Col. Astor slept in a room that could be furnished for $1,625, in an enamelled bed appraised at $85. He walked on a $75 carpet, looked from walls ornamented with pictures worth $35 to the most costly ornament of the room, a "grandfather's clock," appraised at $150. All of his apparel, desk and toilet utensils and other personal effects at Fernehff, said the appraisers, could be duplicated for $412.

No Pomp in His Rooms.

More elaborate surroundings might be expected in Col. Astor's residence in upper Fifth Avenue. Yet here his personal appointments were the least costly of any occupied by the Astor family. A $5,000 Japanese screen in the library would more than pay for the furniture of his bedroom and the dressing closet adjoining. The Hotel St. Regis, when he finished it, gained notoriety from reports of a $10,000 bed. Col. Astor was sleeping in one worth $450. The most valuable thing in his bedroom is a Persian rug valued at $500. All of the furnishings, said the appraiser, would be purchased for $3,000.

These figures might be confusing unless a distinction were made between the things that entered intimately into Col. Astor's daily life and those which came to him on the death of his mother, Mrs. William Astor, and passed from him to his wife and eldest son, in accordance with a well-defined family tradition. Col. Astor had possession of most of the latter class of property for only five years, or between his mother's death and his own. That he enjoyed these hundreds of paintings, porcelains, and art objects with a sense of tangible personal ownership is a debatable question. The internal evidence of the appraiser's report and Col. Astor's career indicate that he did not.

The distinction is emphasized by the appraisal. The art objects purchased by Col. Astor are segregated from those which passed to him from his mother, thus adding to the impression of Col. Astor's simple tastes. His bedroom furnishings were not more costly than would be those of a man whose entire fortune was represented by the ornaments of the adjoining apartments. Compared with the valuation of $3,000 placed on the contents of "Col. Astor's room," for example, are those of other rooms in the residence:

Entrance hall	$16,067
Library	69,589
Drawing room	69,275
Picture gallery	22,357
Morning room	120,005
Dining room	75,400
North reception room	16,790
South reception room	15,470

The contrast is also marked in the appraisal of the family jewels and of Col. Astor's personal ornaments. The jewels in the estate vaults were valued at $161,920. Of this sum $150,000 was represented by a diamond sunburst, a necklace, and earrings which are subjects of family dispute. Aside from Col. Astor's Santiago and society medals, the remaining articles, appraised at $11,920, seem to be family and personal accumulations. Among the watches, rings, lockets, and pins are a number bearing the initials of Col. Astor's father, William Astor.

His Jewelry.

Col. Astor's personal jewelry, on the other hand, was appraised at only $4,612. The inventory chiefly creates an impression of a man who went in very strongly for cuff links and waistcoat buttons. There are eight sets of sleeve buttons, ranging from simple gold links to squares of rubies and disks of platinum and diamonds. The cuff links represent an investment of $900. Six pairs of waistcoat buttons, some of them studded with sapphires, diamonds, rubies, and pearls, represent an investment of $6,500. Four watches and as many more jeweled stickpins, in addition to pencils, chains, and desk and toilet accessories, could be matched on the dressing tables of many American men with far less pretentions to wealth than Col. Astor. The same might be said of his wearing apparel at the Fifth Avenue house. Three fur coats, valued at $1,170, buck large, but $800 worth of other wearing apparel is matched by uniforms appraised at a similar amount.

Though the art collection of Col. Astor represents a fortune of no mean proportions, the appraiser's report shows that Col. Astor bought very few pictures or bronzes. The paintings of Millet, Corot, Schreyer, Meissonier and Van Marcke, the tapestries and similar treasures described in the newspapers a few days ago were not purchased by Col. Astor, but came to him from his father. When William Astor died in 1892, they were valued at $398,610. Now the entire collection is said to be worth $464,810. Of this sum, $99,500 represents Col. Astor's purchases; the paintings being appraised at $9,000 and the bronzes at $37,500. Even these were not numerous. The paintings consist of a portrait of Col. Astor, by Leon Bonnat, a decorative panel called "The Guitar Player," and F. S. Church's "Dancing Bears."

The most important of the bronzes is Houdon's "Head of Voltaire," valued at $13,000. The others comprise a "Flying Mercury" by Rinaldi, figures of Neptune, Apollo and Venus and Louis XIV, mounted on a charger and "Satyr and Bacchante," by Chodieu.

Let us penetrate these externals and seek John Jacob Astor alone in his sanctum. There hints may be obtained of what he really wished to be and might have been.

To do this, one must leave behind the showrooms of the Fifth Avenue residence and lay aside for the moment the portrait of Col. Astor in its conventional pose as he became more or less familiar to the reading public.

Seeking this more intimate man, attention must be directed to three rooms in the Fifth Avenue residence which have been ignored in the newspaper reports of the appraisal and the existence of which was possibly realized only vaguely by those who dined at Col. Astor's table and danced in his ballroom.

Two of these rooms are in the basement, the third on the third floor. One basement room is set down in the appraiser's report as the laboratory. Its contents are valued at $1,000, none of the details being given. Adjoining it is a bedroom with an enameled bed and oak furniture worth not more than $100.

The room on the third floor was Col. Astor's library; those who entered it would not be likely to find much to excite their wonder. A flat top oak desk, armchairs in leather and velours, a globe, an old self-playing piano, an inexpensive carpet, a carved Italian armchair and their accessories might be purchased for $2,000 or so. On the bookshelves were no first or early editions or bindings demanding special attention.

In this room and the laboratory in the basement Col. Astor spent much of his time. His friends regarded him as a man with a serious turn of mind in matters relating to science and invention.

As an Inventor.

He invented a pneumatic machine to remove material from worn-out roads and was awarded a prize for it at the Chicago World's Fair in 1893. Another of his contrivances was a "vibratory disintegrator" to manufacture gas fuel from peat. A bicycle brake based on the principle of reduced friction, and a variation of a turbine engine represented other experiments. In 1910 he came forward with a device for a steamship chair with vacuum cups to hold it securely to the floor of a deck or cabin, thus supplanting fixed chairs on steamships.

For more than twelve months a mysterious craft lay in the Harlem River several years ago. It seemed to embody some idea to combine an airship with a practical water craft. Nothing seemed to come of the enterprise, and finally the boat disappeared. Col. Astor was mentioned at the time as the man who was behind the enterprise. On another occasion his application for a patent for an elaborate raisemaking machine was not granted owing to an objection that it anticipated the use of natural forces that could not be called exclusive.

Hidden away, too, in the list of stocks and bonds of the appraiser's report is another indication of Mr. Astor's enthusiasms in matters scientific. The item enumerates 500 shares of stock in the Nikola Tesla Company, of "nominal" value. Commenting on this investment Nicholas Biddle, who was closely associated with Col. Astor in his business affairs, had this to say:

"Impossible to Sell."

"This stock was not carried on Col. Astor's books. It was purchased by Col. Astor under an agreement made with Mr. Tesla personally of which his office had no information. The stock has never paid any dividends, and it is my understanding that the proceeds from the sales of the stock were used in certain experimental work which has not developed into a paying industry, and in my judgment it would be impossible to sell this stock."

In Col. Astor's library is also a reminder of his adventure in authorship which led to his election as a member of the Authors' Club, but resulted otherwise in a newspaper sensation of the moment rather than a permanent addition to science or literature. In 1910 appeared his romance, "A Journey in Other Worlds." He coined the word "apergy" to describe a force counteracting gravitation, and described a fantastic journey to Jupiter and Saturn.

In the appraisal of Col. Astor's private library are 165 copies of his book. In the main library on the first floor are stored another 100 unsold volumes. They go into the appraiser's report at a valuation of $1.50 each.

Was Col. Astor a good business man? On the death of his father, William Astor, in 1890, the family fortune was generally estimated to be about $65,000,000, compared with the gross valuation of $87,218,794 at Col. Astor's death, twenty years later. Seeking a reply to the question, the published outlines of the appraiser's report are also found to be deceptive.

As a man of 20 years, Col. Astor assumed the responsibility of his property at the estate offices, in West Twenty-sixth Street, and managed it for nearly twenty years. Nor was he merely a figurehead, dependent on his co-trustees and expert advisers, according to the testimony of Mr. Biddle which accompanies the appraisal.

His Hotel Properties.

In his large building projects Col. Astor followed the example of his cousin, William Waldorf Astor, rather than assumed an aggressive initiative. Thus his portion of the great hostelry at Thirty-fourth Street and Fifth Avenue, the Astoria, was put up after the Waldorf, at Thirty-third Street. In Times Square his cousin built the Hotel Astor before Col. Astor erected the Knickerbocker Hotel. In upper Fifth Avenue the New Netherland of William Waldorf Astor long antedated his cousin's Hotel St. Regis.

Among Col. Astor's stocks and bonds the appraisal shows many of standard values. With others there is an impression that Col. Astor was "stung." In the eighty-nine separate items appear thirty-nine, or more than one-fourth, appraised as having a nominal value or doubtful value.

A careful analysis, however, shows that a number of these securities represent contributions which men in Col. Astor's position might be expected to make to social or public enterprises, that others were losing ventures of his father, and that a third class represent Col. Astor's personal losses.

Among the securities, for example, are those of the New Theatre, Col. Astor's holdings comprising a box-holder's certificate, 100 shares of stock of a par value of $10,000, and $25,000 in bonds. Their value is appraised as "nominal."

"That value was fixed," testified Mr. Biddle, "by Mr. Henry Rogers Winthrop, who was an officer of the New Theatre, and he advised me that the New Theatre, as what I might call a going concern, is out of business. The box owner's certificates would be valuable only as works of art, and, of course, they have no value, as the New Theatre is not conducted by the former management, and I understand that the property is leased at an amount sufficient only to cover the interest on the first mortgage bonds and cannot even pay the interest on the income bonds."

The other securities of Col. Astor's estate traceable to his social and public activities are the following:

One share of the Alumni House Association, $100. This was a benevolent association in connection with St. Paul's School, at Concord, N. H., which Col. Astor attended. His affection for the school is shown by his will, a $30,000 legacy being his sole bequest to an institution.

A 1-450th share of the net assets on final liquidation of the Country Club of Westchester County valued at $150.

Twenty-five shares of the Dutchess County Agricultural Society, of a par value of $250.

Five shares of the Livestock Society of America, of a par value of $250.

Forty-five shares of preferred and twenty-two shares of common stock in the Long Island Motor Parkway, valued at $6,700.

Five thousand dollars of gold income bonds in the Colony Club.

In addition to these are stocks and bonds of a similar class of appraised values as follows:

The 300 shares of the Metropolitan Opera and Real Estate Company of a par value of $15,000 are appraised at $100,000.

Four shares in the Newport Casino of a par value $2,000 are said to be worth $1,200.

The 108 shares of the Newport Country Club stock of a par value $10,800 are appraised at $2,700.

Two shares in the Newport Reading Room of a par value of $200 show a handsome premium in an appraised value of $700. Par value was allowed on four shares, of a par value of $2,000, in the Spouting Rock Beach Association, representing an interest in the bathing beach at Newport.

Five thousand dollars in first mortgage bonds of the Automobile Club of America are appraised at $4,000, and $12,000 second mortgage bonds of the same club are appraised at $7,700.

The $5,000 bonds of the Sleepy Hollow Club are appraised at par.

Col. Astor was apparently solely responsible for the following:

Certificates for 200 shares in the Amphere Electro Company of a par value of $20,000. "From information received a number of years ago," testified Mr. Biddle, "we have carried it on our books as worthless, and it appears in the records of obsolete securities that the charter of this company was forfeited for unpaid taxes in 1907."

Two hundred shares in the Atmospheric Products Company of a par value of $20,000. "That company has also ceased to do business, and this stock has been carried on our books for a number of years as worthless."

A certificate for 35 shares of Chestnut Ridge Railroad Company stock of a par value of $1,500. "A mortgage was foreclosed and the stock rendered worthless about 1901."

A certificate for 20 shares of the College World Company, of a par value of $100. "The charter of this company was forfeited for unpaid taxes, I am informed, about 1906."

Two hundred and fifty shares of the Commercial Bank of Honduras, of a par value of $2,500. "The charter of that bank has been revoked by the Government of Honduras. They have no assets. It also has been carried on the books of Col. Astor as valueless for some years."

Two thousand shares of the Depew Improvement Company, of a par value of $200,000. "This company went into the hands of a receiver in 1904 and is now out of existence, as it was taken over by the Lands Company of Depew." Further down in the inventory 1981 shares in the Lands Company of Depew, of a par value of $198,100, which is appraised at $99,050. This was received in exchange for the bonds.

A certificate for 1,500 shares of the Honduras Railroad Company, of a par value of $150,000. "That company is out of existence. I understand their charter has been forfeited by the Government of Honduras."

"That was the company that Col. Astor went into some fifteen years ago?" Mr. Biddle was asked.

Various Securities.

"About that," he replied. "I might add that in the New Jersey transfer tax upon this estate this stock was appraised as of nominal value and the New Jersey authorities acquiesced in such an appraisal."

A certificate for 25 shares of the Honduras Syndicate, 10 per cent paid, of a par value of $1,750. "The same condition exists as in regard to the Honduras Railroad," commented Mr. Biddle. "The charter of this company was forfeited for unpaid taxes about 1908."

A certificate for 500 shares of International Power Storage Company of a par value of $25,000. "The charter of this company was forfeited for unpaid taxes about 1909."

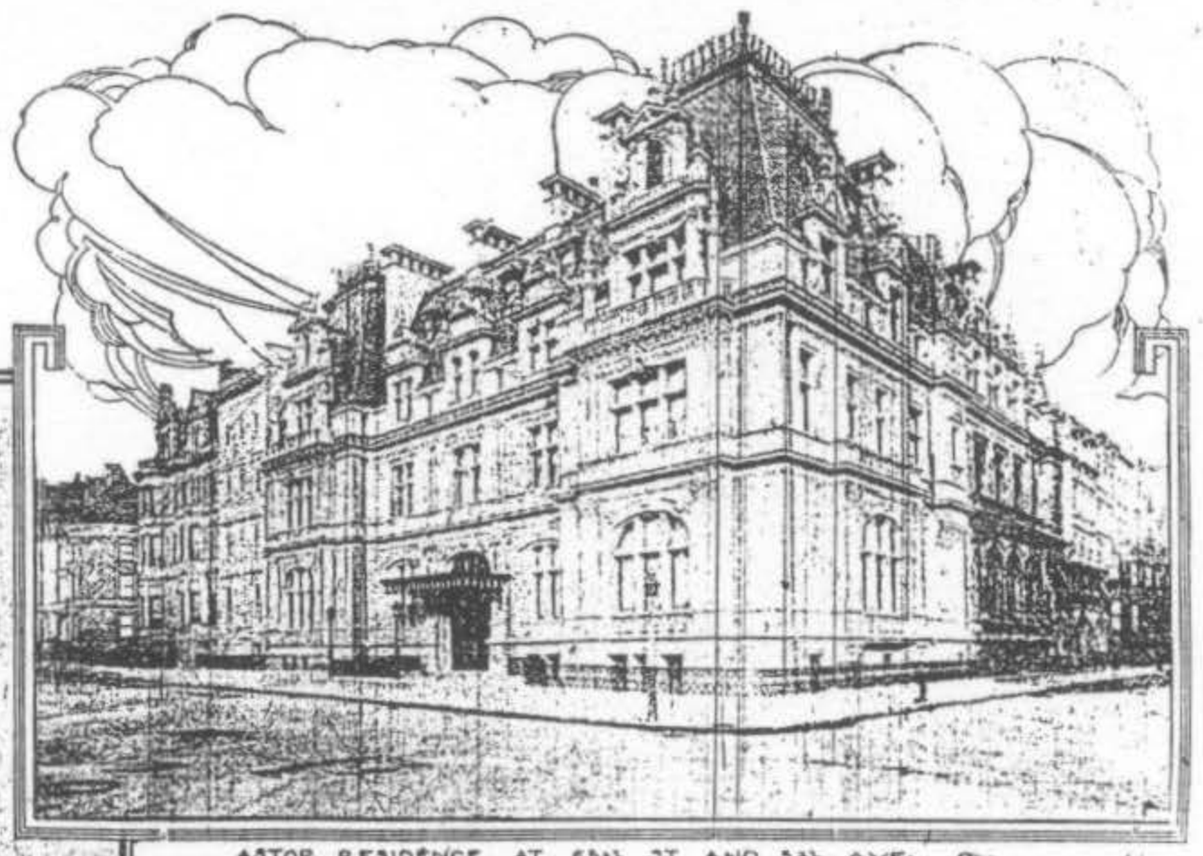
One hundred shares of Mutual Automatic Telephone Company stock, of a par value of $10,000. "This company is no longer doing business, as I am informed."

Seventy-five shares New York and Pennsylvania Brick, Tile and Terra Cotta Company, of a par value of $7,500. "I can find no record of that company," explained Mr. Biddle. "I have sent to an address in New York at which it formerly did business and it is not there any longer and I could find no record of where it has gone to."

Certificates for 600 shares in the Fair Chester Chemical Company. "I have been unable to obtain any information with regard to this company."

A certificate for 104 shares of Rider and Driver Publishing Company. Mr. Biddle said he had been unable to obtain definite information from the company regarding the value of the stock.

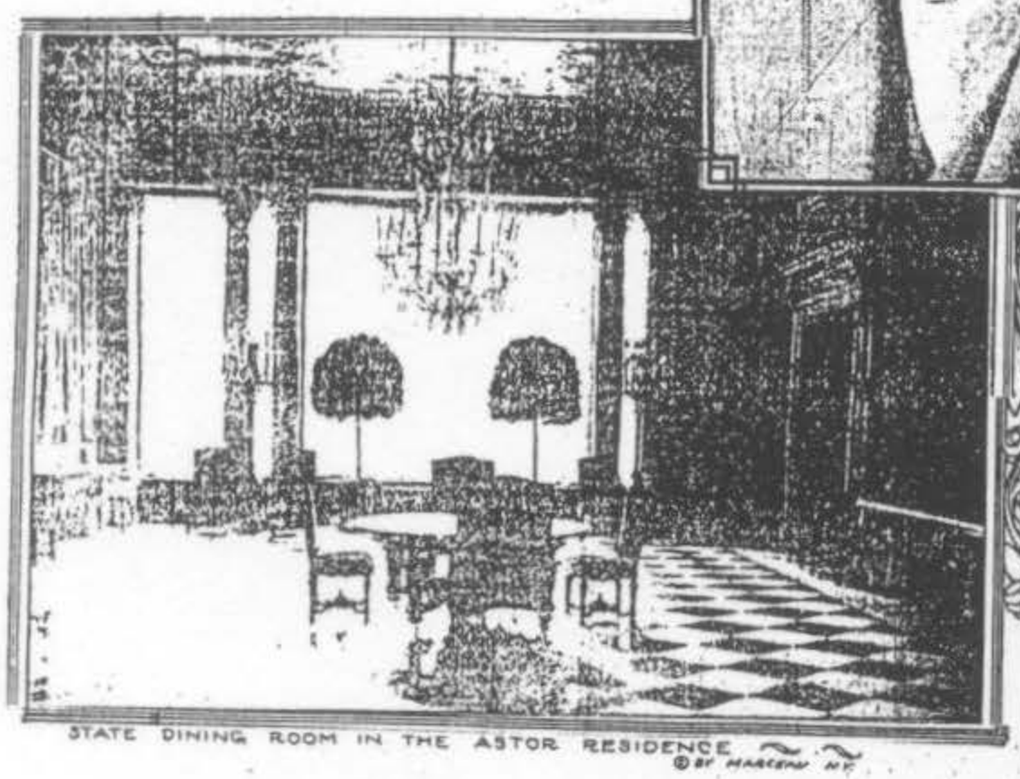
A certificate for 100 shares of the Union Car Company, of a par value of $10,000. "This company is out of existence," said Mr. Biddle. "I don't remember whether it was carried on Col. Astor's books or not."



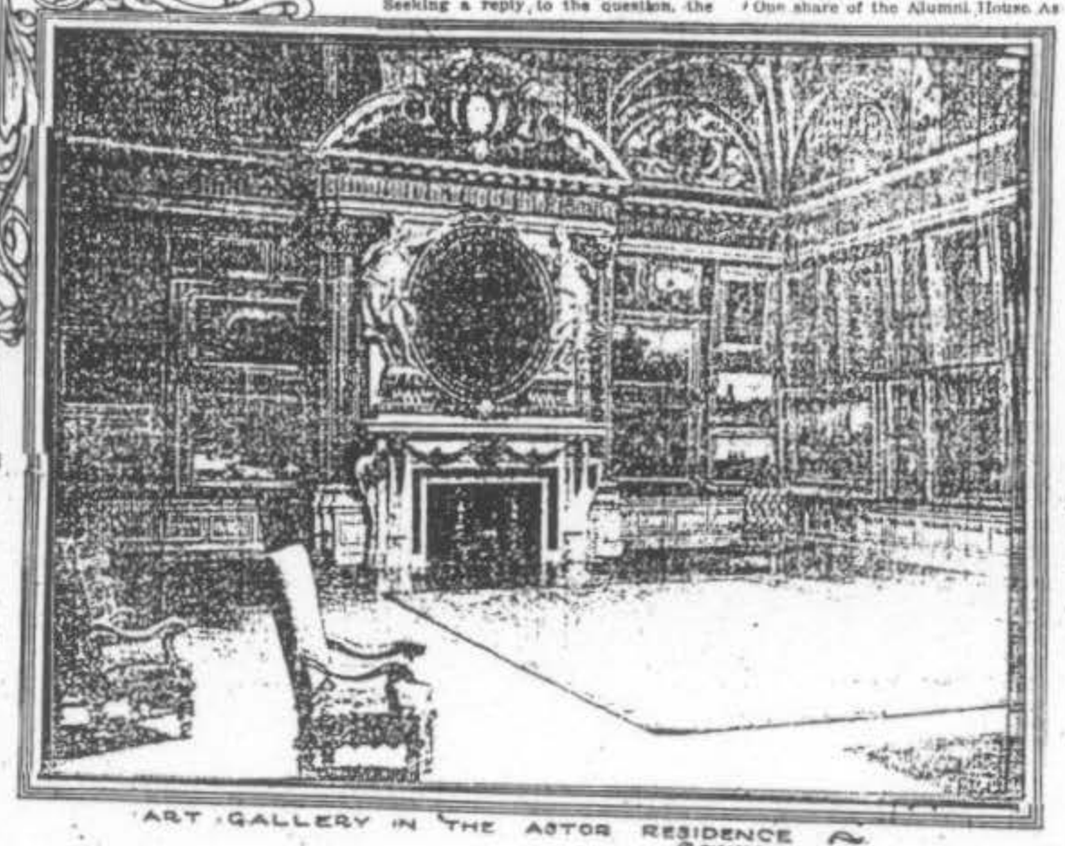
ASTOR RESIDENCE AT 65th ST. AND 5th AVE.



JOHN JACOB ASTOR



STATE DINING ROOM IN THE ASTOR RESIDENCE
© BY HARCEAU N.Y.



ART GALLERY IN THE ASTOR RESIDENCE
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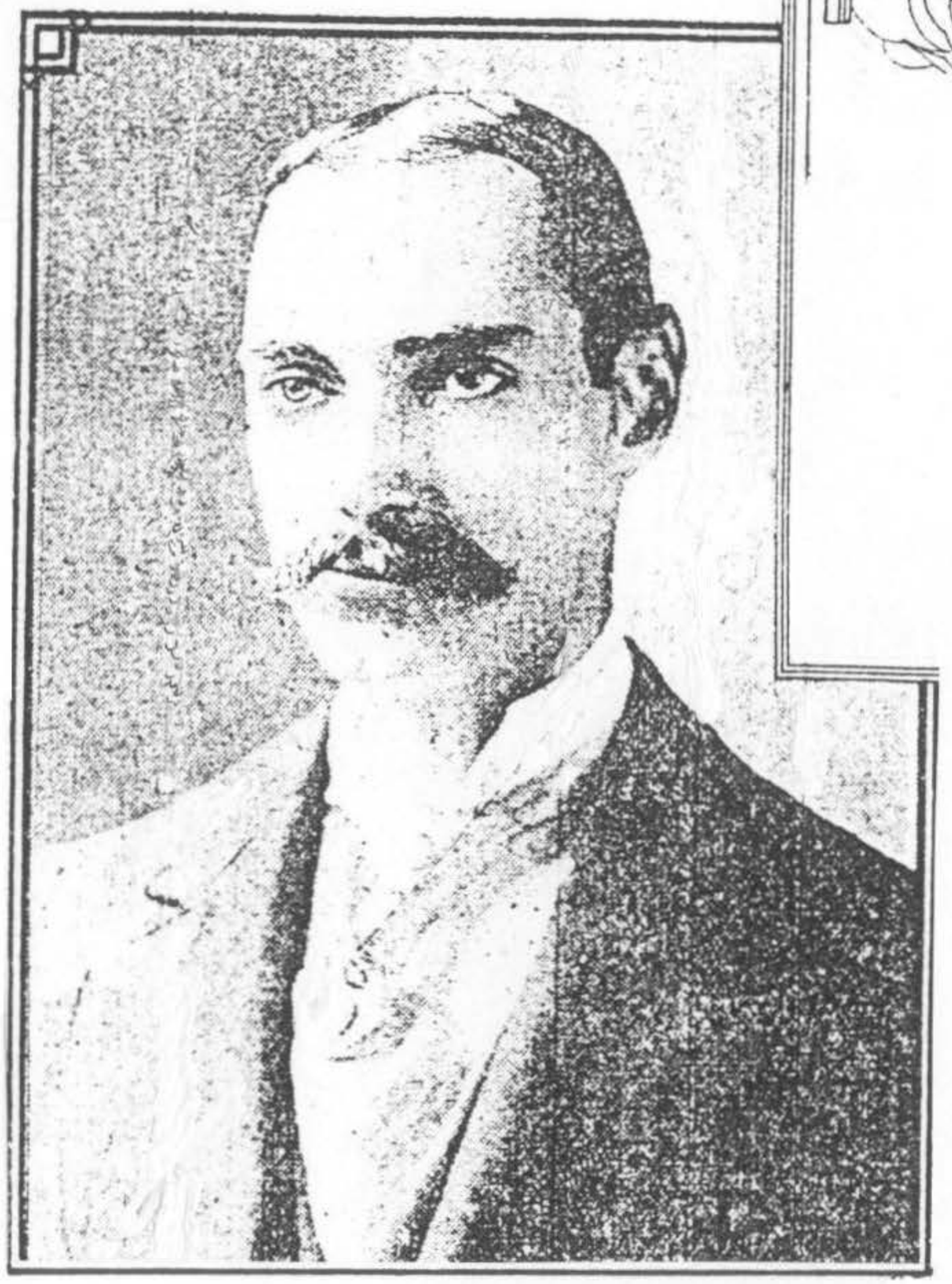
APPRAISEMENT OF ESTATE REVEALS ASTOR'S

Interesting Sidelights Thrown on the Character of Victim of the Titanic Disaster by the Record of His Effects. Comparatively Modest in His Personal Luxuries, an Inventor and a Good Investor.



Hidden away, too, in the list of stocks and bonds of the appraiser's report is another indication of Mr. Astor's enthusiasm in matters scientific. The item enumerates 500 shares of stock in the Nikola Tesla Company, of "nominal" value. Commenting on this investment, Nicholas Biddle, who was closely associated with Col. Astor in his business affairs, had this to say:

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"This stock was not carried on Col. Astor's books. It was purchased by Col. Astor under an agreement made with Mr. Tesla personally, of which his office had no information. The stock has never paid any dividends, and it is my understanding that the proceeds from the sales of the stock were used in certain experimental work which has not developed into a paying industry, and in my judgment it would be impossible to sell this stock."

An Air Insulated Tesla Coil

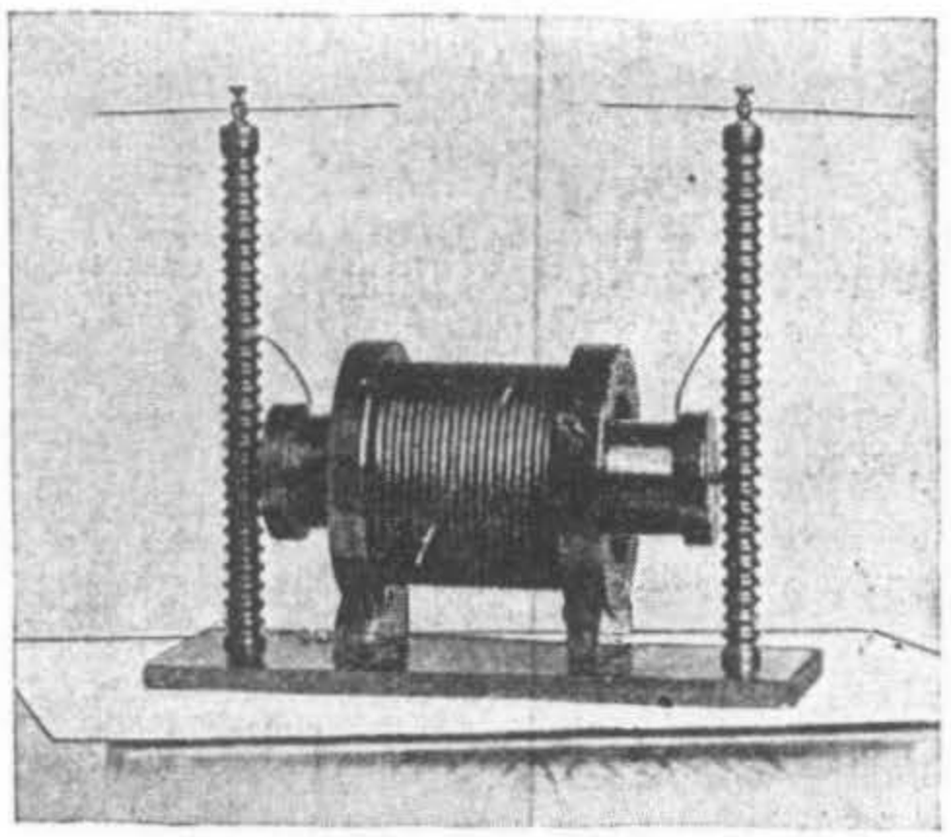
Experimenters who have wireless sending stations have all the apparatus necessary for the operation of an air insulated Tesla coil.

The coil here described is suitable for use with spark coils giving from a two to six inch spark or with a ¼ k. w. transformer. It is not advisable to make a larger coil unless oil is used for insulating. The coil shown in the photograph will give a seven inch spark when used in connection with a ¼ k. w. closed core transformer (magnetic leakage type), glass plate condenser and a rotary spark gap. When a stationary gap is used the sparking distance is about five inches.

The drawing gives the necessary dimensions. Part of the primary and secondary tubes are cut away in the drawing in order to make the construction clearer. The post in the end view is also cut away for the same reason. The primary consists of 20 turns of No. 14 B. & S. gauge rubber insulated wire wound on a paper or fiber tube six inches outside diameter. The length of the tube is not shown in the drawing because there is a great variation in the thickness of the insulation of different kinds of wire. There should be just space enough between the end pieces to accommodate 20 turns of the wire used. If stranded wire can be obtained it is preferable.

The secondary coil consists of one layer of No. 32 B. & S. gauge enameled wire wound on a tube three inches outside diameter. The winding should be eleven inches long. The other dimensions may be changed somewhat to suit the builder. The posts, however, must not be lower or the spark will jump into the primary winding.

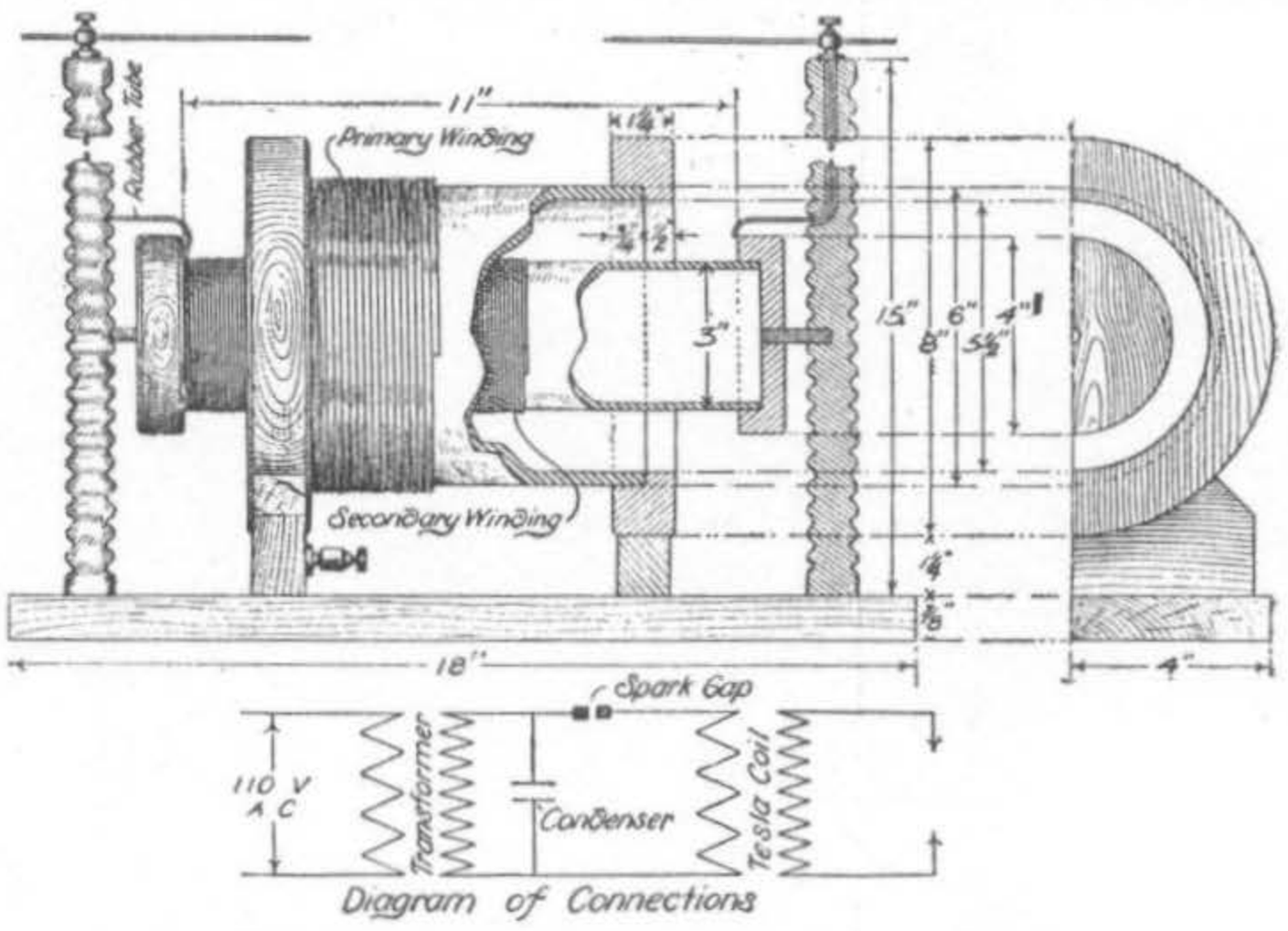
The framework may be made of any hard wood. It should be put together entirely with dowels, for if nails or screws are used the spark will jump into them. The tubes may be fastened to the end pieces with glue. The wood-



AN AIR INSULATED TESLA COIL

work may be finished with any substance which is a good insulator. A good imitation of hard rubber can be made by using maple and finishing with black shellac.

Very beautiful experiments may be performed with this coil in a dark room. The spark may be allowed to jump to



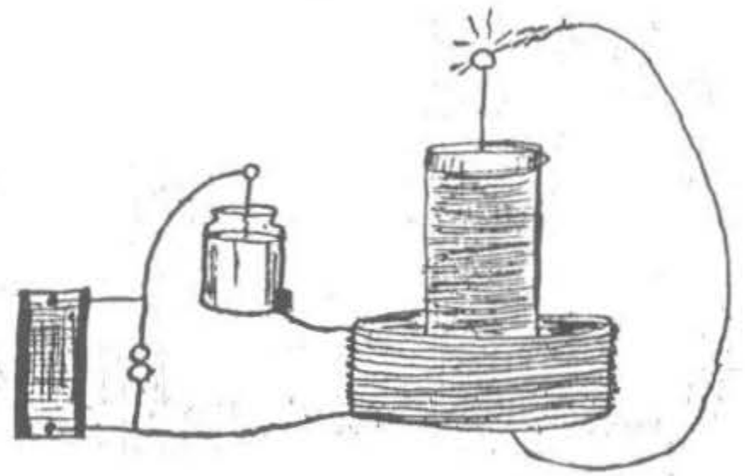
DETAILS AND CONNECTIONS OF TESLA COIL

a piece of metal held in the hand but no sensation of pain will be experienced. If the spark jumps directly into the body only a slight burning sensation will be felt. Lubricating oil may be placed on the end of the finger and lighted by means of the spark without burning the finger.—L. S. UPHOFF.

[1170.]—TESLA COIL.—Wireless amateurs generally use a "jigger" (which is really a Tesla coil) with small coils, but only a short spark, suitable, however, for wireless, is obtained. If wound with longer secondary it would probably give more, but with small coils we have been unable to get a longer spark from the Tesla than that of the ordinary induction coil alone. A primary of No. 12 and secondary of No. 22, about four turns of p. and 30 turns of s. might give good results; only a few ounces of wire are necessary, so it is easy to experiment. A 2in. coil is about the smallest to give good results.

Derby Wireless Club.

[153.]—TESLA COIL.—I have made several Tesla coils to work with a half-inch induction coil, and have found the following to be the best, a spark of about 2in. being obtained



between the secondary terminals. (a) Primary twelve turns of lighting cable on cardboard tube, 6in. diameter; (b) Secondary: 150 turns 36 s.s.c. wound on paraffin waxed tube, 2in. diameter, 6in. long; (c) Primary should be outside secondary; (d) a suitable condenser can be made from a 3lb. glass jar coated to within an inch of the top with tinfoil inside and out.

G. W. Hale.



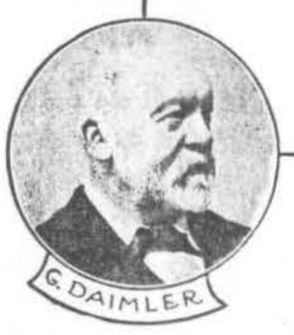




Invention Contest — First Prize Article

What Are the Ten Greatest Inventions of Our Time?

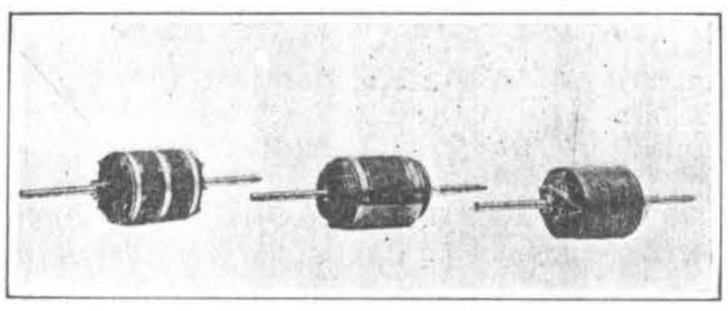
By "Esam" (William I. Wyman, Washington, D. C.)



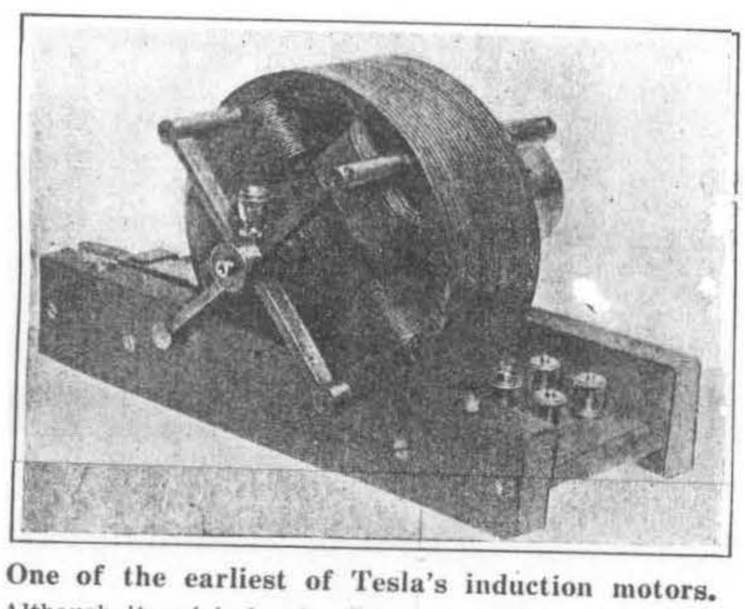


"Five-and-twenty years ago is a hundred years off—so much has our social life changed in those five lusters."—Thackeray in "The Newcomes."

NO single invention of the last twenty-five years initiated an industrial epoch in the sense that the locomotive or Bessemer converter did, yet no former period has been so rich in developments of striking importance or so productive of improvements whose aggregate so vitally affected our economic and social life. In this short space of time the dreams of ages have come true—man has been able to fly, opaque bodies rendered transparent, and intelligence transmitted between distant points without material communicating means.



Three rotors used with the early Tesla induction motor shown below.



One of the earliest of Tesla's induction motors.

Although it weighed only a little over 20 pounds, it developed ¼ horse-power at a speed of 1,800 revolutions, a performance considered remarkable at the time.

This short quarter century has seen the world-wide acceptance of electrical transportation, the introduction of high-power generation and transmission of electricity, the radical changes in construction due to the use of steel and re-enforced concrete, and innumerable valuable improvements in chemical and allied arts. Perfected during this period were such epoch-making inventions as smokeless powder, high-speed steel, contact method of making sulphuric acid, electrolytic refining of copper, the quick-acting brake, automatic telephone exchange, centrifugal cream-separator, tungsten lamp, Diesel oil-motor, and Harveyized armor-plate, which changed existing practices so radically or induced economies of such vast degree as to make it difficult to exclude them from any list except by the adoption of a standard so high as to be unthought of at any other time.

In making a selection from the bewilderingly opulent array of creative activities of the period, only such inventions were included as were most revolutionary in character in the broadest fields, which affected most our mode of living, or which opened up the largest new sources of wealth. So weighing the merits of the different inventions, it is concluded that the ten greatest and their approximate date of successful commercial introduction are: (1) Electric furnace, 1889; (2) steam turbine, 1894; (3) gasoline automobile, 1890; (4) moving pictures, 1893; (5) wireless telegraphy, 1900; (6) aeroplane, 1906; (7) cyanide process, 1890; (8) linotype machine, 1890; (9) induction motor, 1890; (10) electric welding, 1889.

The Induction Motor of Nikola Tesla and How it Revolutionized Power Transmission.

Ninety per cent of electric current generated is alternating because larger generating units can be utilized and the current more easily transmitted. The induction motor, constructed by Tesla in 1888, and independently suggested in principle by Ferrari, was the first satisfactory medium to transform this current into power.

This epoch-making invention is mainly responsible for the present large and increasing use of electricity in the industries. It is working a revolution for economy and comfort in the mill, factory and workshop. In making the motor an individual power unit, it has made power arrangement elastic, drawing upon energy only when needed and applying it directly only where wanted, and has abolished line shafting and belting. It conserves thirty to sixty per cent of the energy formerly wasted in uselessly whirling line shafting. It saves overhead space and increases productivity by making the shop lighter, safer, cleaner and less noisy. And so well recognized are these advantages that establishments in every big industry are installing these motors as a measure of economic self-defense.

Nikola Tesla's Plan to Keep "Wireless Thumb" on Ships at Sea

Suggests Transmitters Powerful Enough to Cause the Earth to Vibrate at the Poles and Equator.

Nikola Tesla has come forward to refute the claims of men who recently excited the scientific world with announcements of discovery and invention calculated to crowd the bugbear of scientific warfare back into the primer class, and to safeguard the lives of seafarers. First he takes up and disposes of the announcement of an invention said to enable a receiving ship equipped with wireless to tell the longitude and latitude of a sending ship without the latter vessel offering its own calculations. "It hasn't been done, and it probably will be years before the means for so doing can be applied successfully," he says. As to the power of ultra-violet rays to explode the powder magazine of a warship from a distance, he insists it can't be done through that medium. If charges of powder have been so exploded, he contends, the detonation was accomplished with the familiar waves now utilized by the wireless. But Mr. Tesla admits that in all probability there will come a time when science has so harnessed and developed the means at hand that such results may be obtained. Mr. Tesla sets forth for readers of The Press his views on the two subjects as follows:

By NIKOLA TESLA.

THE first and incomplete announcements of technical advances should always be taken with a grain of salt. It is true that the newspapers are getting more and more accurate and reliable in putting forth such information, but, nevertheless, the news frequently is misleading.

For instance, not long ago reports were widely circulated that powder had been exploded at distance by infra-red or ultra-violet rays, and that a British battleship had been used in a test of this kind, which proved successful. The dispatches gave great opportunity to sensational speculation, but the truth is that there was no novelty whatever in what was done.

A mine or magazine may have been blown up, but this was accomplishd in a well-known manner through the application of a kind of electrical waves which are now generally adopted in the transmission of signals without wires. Similar experiments were performed in this country many years ago by myself and others, and quite recently John Hays Hammond, Jr., has done creditable work in this direction through the application of an art which has been named "Telautomatics," or wireless control of moving mechanism at a distance.

By means of such telautomatic vessels, surface, submarine or aerial, a perfect system of coast defense can be established. Torpedoes on this plan also can be controlled from battleships, and there is no doubt they sooner or later will be adopted and their introduction will have a revolutionary effect on the methods of warfare.

The results described are, however, not impossible. It is quite practicable to explode by rays of light a mine at a distance, as by acting on a mixture of chlorine and hydrogen. Certain dark rays also can be employed to produce destructive effects. As far back as 1897, I disclosed before the New York Academy of Sciences the discovery that Roentgen, or X-rays, projected from certain bulbs have the property of strongly charging an electrical condenser at a distance. The energy so accumulated readily can be discharged and cause the ignition of some explosive compound

Says They Can't Penetrate Steel..

But ultra-violet rays are of very short wave lengths and cannot penetrate steel shells, while the longer and more penetrative waves of the infra-red rays are chemically much less active. There is no doubt in my mind that we soon shall be able to project energy at a distance not only in small, but in large amounts, and what the effect of such an achievement will be on existing conditions words cannot express.

As regards the determination of latitude and longitude of a vessel at sea by wireless, there is nothing in use as yet which would make such direct observation possible. Some suggestions, however, which I have since many years advocated, have been adopted. They are the flashing of time signals over a wide area and the employment of an instrument known as a wireless compass.

Plan for Finding Locations.

These means enable an expert on a vessel to ascertain the exact hour at any sending station within reach, and also, in an imperfect manner, the direction in which it is situated, and from these data it is possible to get a rough idea of the position of the ship relative to the points of reference.

A perfect means for determining not only such and other data important to the navigator already is available, but it may require years to apply it. I refer to the use of the stationary waves, which were discovered by me fourteen years ago. The subject is too technical to be explained in detail, but the average reader can be made to understand the general principle.

The earth is a conductor of electricity, and as such has its own electrical period of vibration. The time of one complete swing is about one-twelfth of one second. In order words, this is the interval the current requires in passing to, and returning from, the diametrically opposite point of the globe.

Now, the wonderful fact is, that notwithstanding its immense size, the earth responds to a great number of vibrations and can be resonantly excited just like a wire of limited dimensions. When this takes place there are formed on its surface stationary parallel circles of equal electrical activity, which can be revealed by properly attuned instruments.

Transmitter at One of the Poles.

Imagine that a transmitter capable of exciting the earth were placed at one of the Poles. Then the crests and hollows of the stationary waves would be in parallel circles with their planes at right angles to the axis of the earth, and from readings of a properly graduated instrument the distance of a vessel carrying the same from the Pole could be at once read, giving accurately the geographical latitude.

In like manner, if a transmitter were placed at a point on the Equator, the longitude could be precisely determined by the same means. But the best plan would be to place three transmitters at properly chosen points on the globe so as to establish three non-interferable systems of stationary waves at right angles to one another. If this were done, innumerable results of the greatest practical value could be realized.

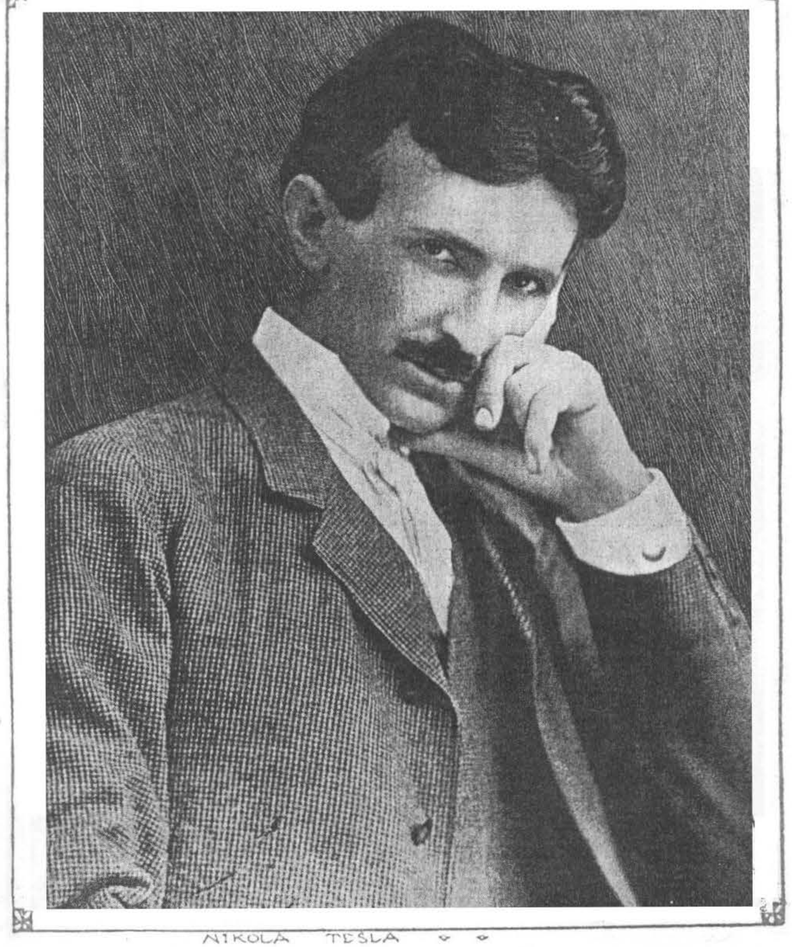
Tesla's Plan to Learn Positions by Wireless

STATIONARY waves discovered by me fourteen years ago are the means for determining longitude and latitude by wireless. But it may be years before they will be successfully utilized.

Notwithstanding its immense size, the earth responds to a great number of vibrations. When thus excited there are formed on the surface stationary parallel circles, with their planes at right angles to the axis of the earth.

Imagine that a transmitter capable of exciting the earth were placed at one of the poles. Then the crests and hollows of the stationary waves would be in parallel circles, with their planes at right angles to the axis of the earth, and from readings of a properly graduated instrument the distance of the vessel carrying the same from the poles, could be read at once, giving accurately the geographical latitude.

In like manner, if a transmitter were placed at a point on the equator, the longitude could be precisely determined by the same means. The best plan would be to place three transmitters at properly chosen points on the globe, so as to establish three non-interferable systems of stationary waves at right angles to one another. If this were done innumerable results of the greatest practical value could be realized.



NIKOLA TESLA

He Would Determine Vessel's Latitude and Longitude by Measuring the Length of Electric Waves.

Electric Journal January 1914

The Engineering Evolution of Electrical Apparatus—I

THE BEGINNINGS OF THE ALTERNATING-CURRENT SYSTEM

CHAS. F. SCOTT

One of the features of the JOURNAL *for the year 1914 is to be a group of articles outlining in reminiscent style, the history of the electrical industry. They will review the important steps in the development of various types of apparatus, indicating the important changes which have taken place and pointing out the engineering reasons why they were considered advisable. These articles, prepared by prominent engineers who have been in the fore-front in electrical progress, will naturally be, to a certain extent, of a personal nature and will thus have the feature of human interest as well as technical accuracy.—(Ed.)*

HISTORY may be abstract, or it may be concrete and personal; it may record events simply as facts, or it may show a continuous sequence of cause and effect. Electrical history is high-speed history. Men still live who were boys when Faraday discovered the principles of electromagnetic induction, the basis of nearly all that has followed. In the fifty years since the ring armatures of Gramme and Pacinnotti, and the drum armature of Siemens were invented, have come our dynamos and motors and our electric light and power systems. Nearly everything electrical that we have today has come from forms that were crude and elementary a generation ago or from inventions then unknown. It is a wonderful picture—this moving picture of some thirty years of electrical progress. The successive types of generators and motors, of transformers and meters and lamps, of circuit breakers and lightning arresters, of insulators and transmission lines have not come haphazard; they are forward steps to overcome difficulties or to meet new demands; there has been logical succession and true evolution. Nothing can be more impressive and instructive than to trace this development and to bring into a few pages the story of the development of a turbo-generator or a wattmeter, for example, from its prototype of a score of years ago.

Electricity was demonstrating its commercial usefulness in the early eighties; an electric car thirty years earlier, and arc and incandescent lighting, shown by Davy seventy years earlier, had been operated by costly batteries and had lain commercially dormant awaiting cheap electric power. The dynamo was brought to usefulness in the preceding decade. Edison's incandescent lamp with high resistance carbon filament came in 1879. A new problem was pressing for solution—how to get the current from the dynamo to the lamp and how to supply commercially a number of lamps from one dynamo in such a way that some of them could be turned off without affecting others.

Several lamps were at first connected in series and operated by current of constant strength, as are street arc lamps today. The method of multiple connection was then proposed, requiring constant potential mains—the system by which over 99 percent of the electric power now generated is distributed. Nothing shows more clearly how far from present practice were the electrical ideas of a generation ago than the following quotation from a lecture in 1878 by one of the most eminent electrical engineers in England. After describing certain experiments in which the candle-power of lamps connected in multiple decreased very greatly as each lamp was added, he said, "Hence, a subdivision of light is an absolute ignis fatuus."

To maintain constant potential requires dynamos which produce constant potential and circuits causing small loss. Lamps of five or ten volts can be operated only a few feet from the source of power without large line loss unless the conductors be very heavy; the Edison lamp for 100 volts increased the practical distance to five hundred or a thousand feet. This was increased by the three-wire system and the feeder-main system. But the permissible cost of conductors was reached well within a mile. Four-wire and five-wire systems and various series systems which would enable 100 volt lamps to be served by circuits carrying 300 or 400 volts or more were found to be unsafe or unsuccessful. Electrical distribution seemed limited to a mile or less, except by the series system. A large part of the early edition of Kapp's "Electrical Transmission of Energy" is devoted to the characteristics of constant current series motors, the only method in view by which the high pressures necessary for long distances could be secured. The central stations for incandescent lighting, therefore, seemed doomed to mere spot lighting—the maps of a large city would show spots a mile or so in diameter each with its own central station.

About 1885 the attention of Mr. George Westinghouse, was called to the alternating-current transformer as an instrument by which current transmitted at high voltage could then be transformed to low voltage for the operation of incandescent lamps. He sent an investigator to England and then acquired the Gaulard and Gibbs patents. These involved induction coils or "inductoriums," which were open magnetic circuit transformers.

They were connected with their primary windings in series, while their secondary windings had the same number of turns as the primary and supplied independent circuits. The system employed constant current, and the lamps on the secondary circuits were subject to serious changes in voltage when the number of lamps on a transformer secondary circuit was varied.

Mr. William Stanley, who was then engaged principally in the development of the incandescent lamp for Mr. Westinghouse in Pittsburgh, had been much interested in the alternating current. A contract arrangement was made by which Mr. Stanley should undertake the development and adoption of the alternating system for commercial service. In the fall of 1885 he set to work in an old rubber mill at his home in Great Barrington, Mass., and constructed a number of transformers, each wound to reduce the 500 volt main line potential to 100 volts in their secondary circuits. These transformers differed from the Gaulard "inductoriums" in having the primary wound for a relatively high potential and in having the primary terminals connected in parallel to a constant potential circuit. The coils were made with a closed magnetic circuit and the general proportions of the transformers were remarkably similar to those of the modern "shell type." The idea of connecting a primary coil having a resistance of only one ohm between the mains of a 500 volt circuit was so palpable a violation of Ohm's Law as to shock the convictions and the experience of those who were familiar only with direct-current phenomena. It was a bold idea of a daring inventor who first did that with which all are now so familiar. Regardless of popular ideas, however, the transformers gave good promise and a Siemens machine which had been imported from England for tests at Pittsburgh was employed as a generator. The transformers were erected in the spring of 1886 and properly connected, and supplied a number of stores in Great Barrington with current on a commercial basis. The plant continued in operation for several months until a screw driver was accidentally dropped into the dynamo and wrecked the coils. The success of the initial plant led to the commercial adoption of the alternating-current system by the Westinghouse Electric Company. The misgivings of experts, the apprehensions of the dangers of high voltage, the antagonism of opposing commercial interests did not prevail and the little "twenty-five light" transformers opened the way for a new era in electric development.

After the wrecking of the Siemens machine, a new alternator, originating in plans made by Mr. Stanley, and worked out in detail designs by Mr. Shallenberger and Mr. Schmid, was built in Pittsburgh. A full equipment of commercial apparatus was quickly designed and manufactured, and soon alternating-current central stations appeared, first at Greensburg, then at Buffalo and elsewhere. Two years after the starting of the Great Barrington plant there were about a hundred alternating-current installations.

THE ALTERNATING CURRENT IN 1888

Having been asked to write the first of a series of historical articles on "The Engineering Evolution of Electrical Apparatus," it is but natural for me to go back to my own early experiences as a starting point. I have already given a preliminary survey of the electrical situation, and I shall now make a sort of an inventory of the kinds of apparatus which were being made when I took up electrical work in Pittsburgh about twenty-five years ago, and shall comment upon various points.

In the early part of August, 1888, I went to Pittsburgh and happily found that a personal application was more effective than correspondence in securing a position with the Westinghouse Electric Company. I had a slight acquaintance with Mr. L. B. Stillwell, then assistant electrician, as I had met him nearly a year before when he came to the Baldwin Locomotive Works where an alternating-current lighting plant was being installed and where I was then employed as wireman. Mr. Stillwell showed me about the laboratory in Pittsburgh, pointing out particularly two new kinds of apparatus which had recently been invented. One of these was the Shallenberger meter, an induction meter for registering the current used by the consumers on alternating-current circuits. At that time the chemical meter was generally used on direct-current circuits, and there was no commercial alternating-current house meter. The Shallenberger meter (which was already in substantially the same form which it maintained for a dozen years, during which time enormous numbers of meters were made) was the outcome of the observation of the peculiar motion of a spring lying upon an alternating-current arc lamp about four months earlier. Mr. O. B. Shallenberger, who was working with the lamp, investigated the motion of the little spring. He substituted other things in place of the spring and determined that the motion was due to the joint action of the magnetic fields set up by two circuits, in one of which the current lagged slightly in time behind the current in the other. Close observation, careful analysis, intelligent experiment, remarkable ability in designing and proportioning the new apparatus, which was to embody in commercial and useful form the principle exhibited by the moving spring, resulted in a few months in a meter which was the forerunner of the many types of induction meters which are now in general use.

The other new invention was the Tesla motor. Nikola Tesla had secured his patents and had presented a paper before the American Institute of Electrical Engineers, in the preceding May, describing the

rotating magnetic field produced by polyphase currents and the means of employing this in induction motors. The patents had been acquired by the Westinhouse Company and Mr. Tesla was then employed

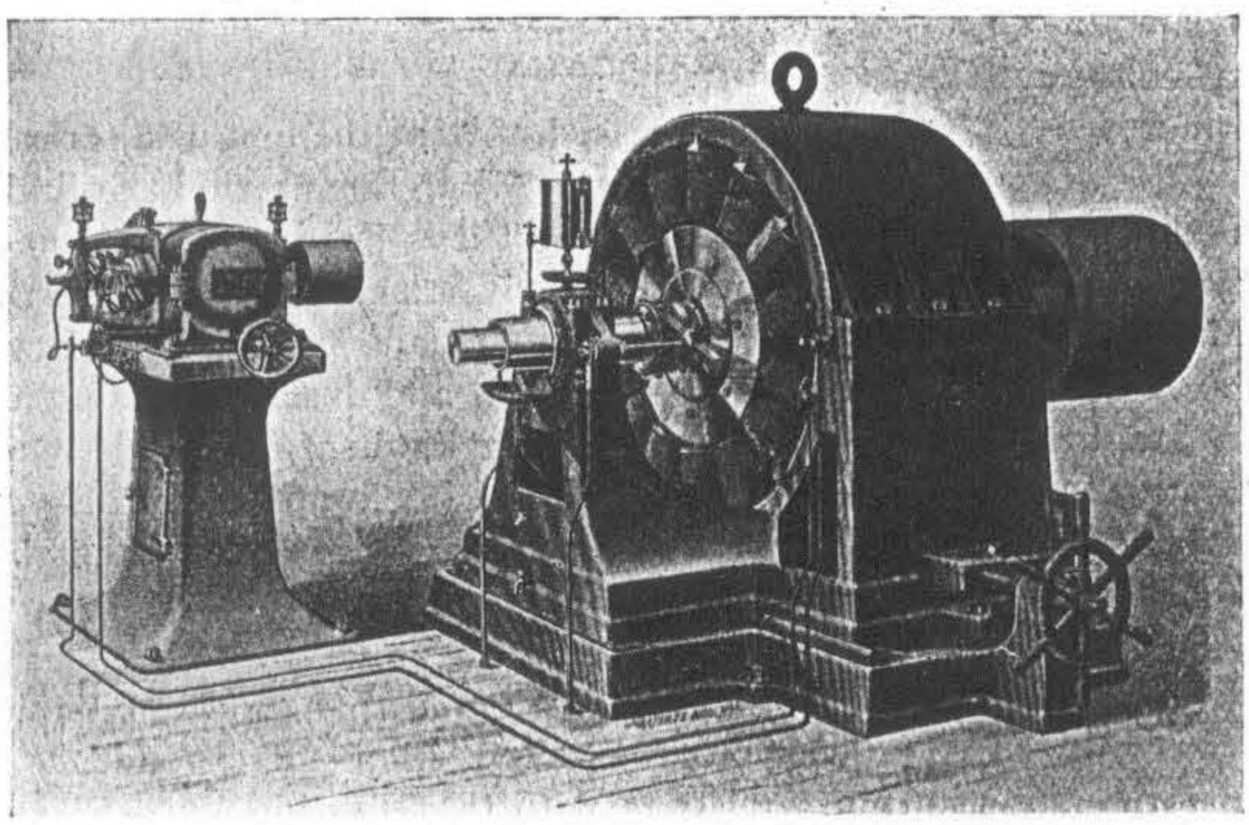


FIG. 1—1 500 LIGHT ALTERNATING-CURRENT DYNAMO WITH EXCITER—1888

in the development of the apparatus into commercial form. The previous year had been fertile in the study of alternating-current phenomena. Patent litigation has since shown that the development of motion by currents differing in phase was shared by Tesla and Ferraris and Shallenberger and Stanley, and the priority of Tesla to the motor and Shallenberger to the meter were matters involving differences of only a few months, or even less.

EARLY ALTERNATORS

In the summer of 1888 the Westinghouse Company was making three sizes of alternators. To these a fourth and smaller size was soon added. These machines were belt driven and operated nominally at 1 000 volts and 16 000 alternations per minute, corresponding to 133 cycles per second. Further particulars are as follows:—

No. 0— 400 lights, 8 poles, 2 000 r. p. m.
No. 1— 700 lights, 10 poles, 1 600 r. p. m.
No. 2—1 350 lights, 14 poles, 1 150 r. p. m.
No. 3—2 500 lights, 16 poles, 1 050 r. p. m.

The machines were driven by high-speed belts, in many cases from Westinghouse automatic engines. The noise and whir of the great belts in stations where there were a number of generators inspired a kind of awe in the visitor, which is entirely lacking in the modern beltless power house. These alternating-current dynamos had cast iron field magnets and rotating drum armatures, as shown in the accompanying illustrations. The construction was simple in general and in detail. It was simple electrically, as compared with the direct-current dynamo with its intricate armature winding and commutator. An argument then presented was that brushes for collecting the current for a 1 500 light alternating-current dynamo have a width of 7/8 inch, whereas, the brushes for a 1 500 light dynamo of the direct-current type would have an aggregate width of 20 inches. This ratio is fairly illustrative of the relative requirements of the two systems in all their transmitting parts. The direct-current brushes of that day were of copper and were vastly more delicate and liable to injury by sparking and flashing than the carbon brushes which are now used. The alternators were simple mechanically. To appreciate this fact one has to go back to some treatise on dynamos published twenty years ago and observe the multitude of forms of machines. Each system and each inventor seemed to require a peculiar form. Now there are few types, many parts are common to machines of different kinds and the name plate instead of the form of the machine must be consulted to discover the maker. But nowhere is found the general simplicity and rigidity and the grace of form of this early alternator of Albert Schmid. The little exciter near the alternator in Fig. 1 looks peculiar while the alternator does not. The first was of an ephemeral type, while the latter is the prototype of many machines of today. It is a wise man who can devise the types which will continue. The bearings were supported directly by parts of the great casting which formed the base; they were large and amply lubricated

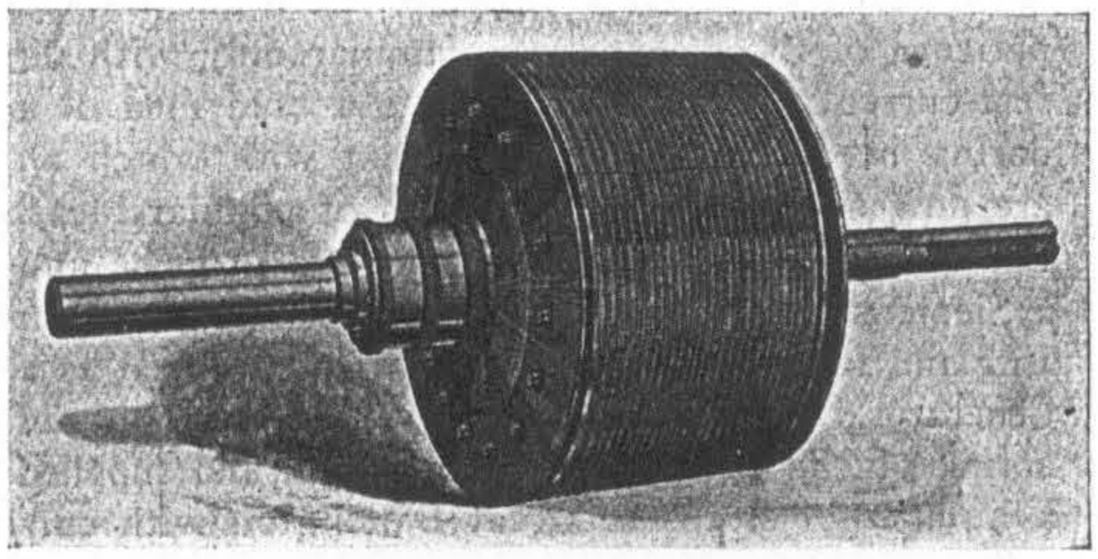


FIG. 2—ARMATURE OF ALTERNATING-CURRENT DYNAMO

"An alternating-current armature is a structure of great directness and simplicity. The body of the armature is of laminated iron plates freely perforated for ventilating purposes. A single layer of wire is wound in flat coils back and forth across the face of the armature in a direction parallel to the shaft, being retained by stops on the ends of the armature. Mica and other adequate insulation is provided and the whole is wrapped with binding wire. A ventilator is attached to each end of the armature and draws a strong current of air through it. The total weight of copper on a 750-light armature is 16 lbs., disposed in a single layer, which being on the surface is readily kept cool, and can be inspected for deterioration or flaws of any character. A direct-current armature of the type most generally in use, of 750 lights capacity on the other hand, carries more than 10 times this amount of wire.

"We would call particular attention to the absence of a commutator, the place of which is supplied by two plain collecting rings without breaks of any kind. Narrow collectors rest upon these rings and serve to take off the current as it is generated. No practical operator of an electric light plant need be told of the annoyance due to the maintenance of a commutator, the brushes of which require exact adjustment, any departure being followed by destructive sparking."—1889.

by the dripping of oil from large brass reservoirs. Excellent as this may be, if testimony be needed as to the superiority of self-oiling bearings over the kind which needed fairly constant inspection to see that the oil dripped properly, which had to be filled frequently

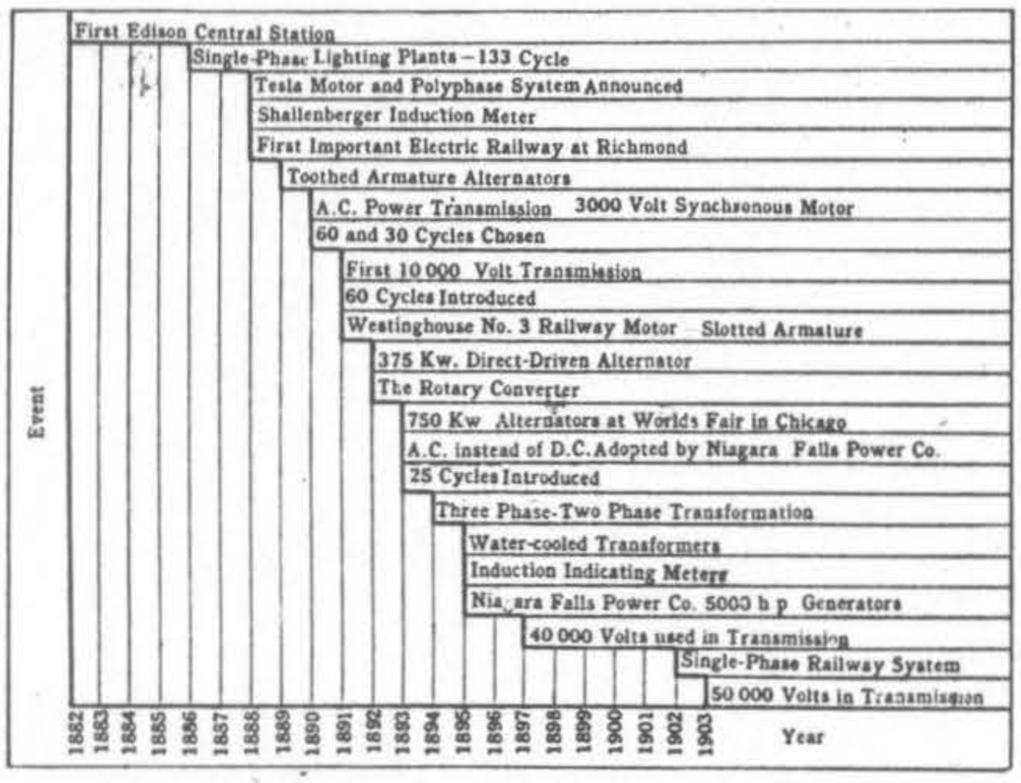


FIG. 3—CHRONOLOGICAL CHART OF SOME IMPORTANT EVENTS IN ELECTRICAL ENGINEERING HISTORY

and polished every night, the writer is prepared to testify from personal experience.

What were some of the limitations of the alternator which produced the current in hundreds of central stations for many years? It was heavy and expensive. Between the cylindrical surface of the iron core of the armature and the faces of the field poles must be space for insulation, for conductors, for insulation again and for band wires as well as free space between the band wires and the pole faces. Mechanically the space should be large; magnetically it should be small. If the armature got slightly out of center, it would strike the field poles, the band wires would give way and the "blowing up" of an armature was an exciting event. The life of the armature depended upon the integrity of a goodly fraction of a mile of steel band wire, wound under tension and subject to unknown stresses. The copper conductors could not be wound conveniently in more than a single layer, and the large conductors necessary for heavy currents in large alternators were heated by eddy currents generated in their motion through the magnetic field between the pole faces and the armature core. The band wires, being grouped together into bands in which the adjacent wires were soldered togther had heat producing currents induced in them in the same manner. Magnetic fields are apt to cause trouble when outside of their native element—iron. Winding in slots in modern armatures has replaced the old surface winding. Wires lying on a smooth cylindrical surface in a magnetic field have a "side force" on short-circuit which is hard to resist by any practical form of anchoring. Hence, a short-circuit used to cause mechanical damage followed by internal electrical distress and a season in the repair shop. In those days the skilled armature winder was the autocrat of the electrical industry. The slotted armature and the machine wound coil marked his doom.

The armature which immediately succeeded the first form was the toothed armature, which had a large tooth corresponding to each field pole, around which the armature coils were placed. The teeth had small projections at the circumference which served as a mechanical support for the coils. An armature of this kind was made for the field of the smallest alternator and was turned over to the writer to test. The air-gap was very small and the wire was large compared with that for the old drum armature; hence, a large output was anticipated. After obtaining the proper voltage and applying the load, the field current was increased as more and more lamps were added until presently there were a thousand lamps on what had been a 400 light machine. It was noted that the field current with the large load was three times what it had been with no load. The question came as to what would happen if all but a few lights were suddenly removed; would the voltage go to three times normal? This brought an appreciation for the first time of the significance of inherent regulation. Subsequently, the air-gap was made much larger and the regulation was very much improved. After a time the slotted armature con-

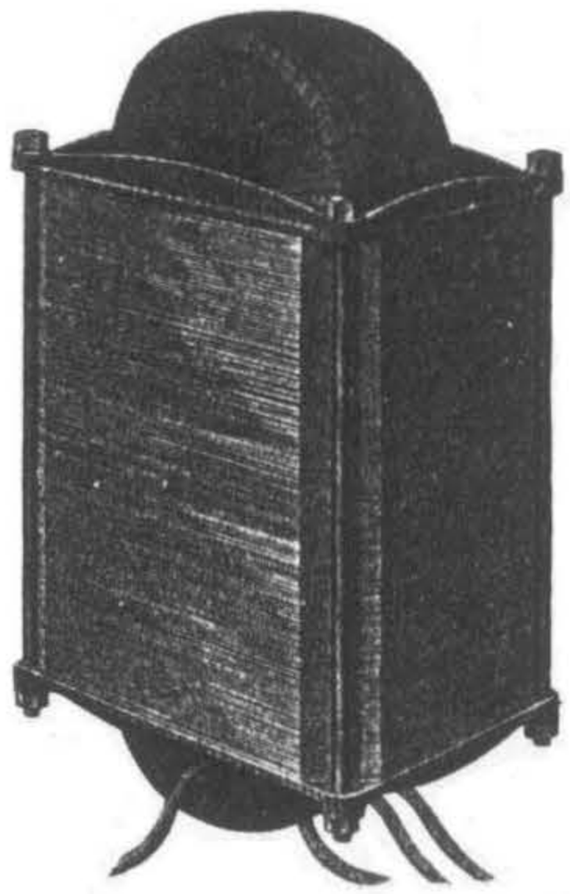


FIG. 4—THE CONVERTER OR TRANSFORMER

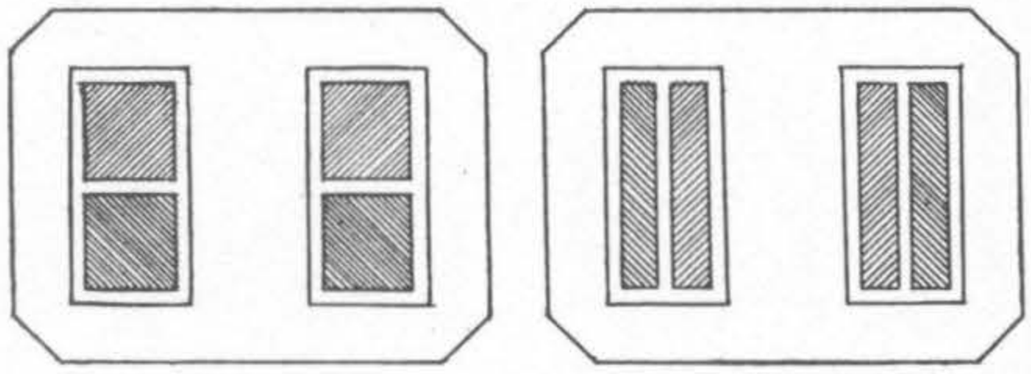
"It is a device of the simplest possible construction, having no moving parts whatever, its functions being purely electrical. It consists essentially of two coils, one of a great length of fine wire, called the 'primary coil' and receiving the current from the dynamo; the other of a short length of large wire, in which is induced the secondary current for lamp service."

struction, first finding favor in railway motors, was incorporated into generators and motors of all kinds.

TRANSFORMERS

The transformers (then called converters) which were made by the Westinghouse Company in

1888 were of five sizes, viz., of 5, 10, 20, 30 and 40 lamps the largest size being two kilowatts though the term kilowatts was not applied to them for several years. The transformers were wound for a primary e.m.f. of 1 000 volts and 50 volts secondary in most cases while a few were wound for 100 volts, usually with a tap at the middle point. The coils were separately wound and taped; they were approximately square in cross-section, so that the open-



PARALLEL COILS CONCENTRIC COILS

FIG. 5—FORMS OF COILS IN EARLY TRANSFORMERS

In parallel form the magnetic leakage between coils is considerable as there is a short wide path compared with that in the later concentric form, which therefore had much improved regulation.

ing in the iron was approximately a double square. The accompanying illustration shows such a transformer built up. Bare lead fuses, either wire or links, were placed between brass terminals on fibre bases in iron boxes on the case. Materials and construction of this sort would be wholly inadmissable today, though they were fairly satisfactory with the lesser currents, the lower e.m.f.s and the smaller generators which were then employed.

One of the difficulties with these transformers was the large drop in secondary voltage between no load and full load. This drop was partly caused by the resistance of the windings and partly by something else which was termed "drop due to iron." The latter was hard to measure accurately, as it seemed to vary from time to time. This factor was of serious importance when incandescent lamps constituted the only load, and it rose to very disagreeable proportions when there was a lagging current or, in modern terms, when the power-factor was low. The fact that the square coils were placed side by side in parallel form permitted a considerable magnetic leakage between the coils, the effect of which was very pronounced with the frequency of 133 cycles. The first modification in the transformer was to change the form of the coils, making them concentric by winding each coil with approximately twice the number of turns per layer and half the number of layers. This changed the path for the magnetic leakage, making it about twice as long and of one-half the cross-section that it was in the former arrangement, thereby improving the regulation.

The testing of transformers consisted of an insulation or a ground test and a running test. If the insulation was sufficient to prevent enough current from flowing through the primary of another transformer to light a lamp on its secondary, it was considered adequate. In other words, the insulation test was really made at an e.m.f. of 1 000 volts or less. The running test was made by coupling transformers in parallel to a large bank of lamps and running them for several hours.

AUXILIARY APPARATUS

While the generator and the transformer were the essential apparatus in the alternating system, various auxiliaries were necessary to make the system operative, such as switches, fuses, measuring instruments and the like. Past experience was limited to low voltage, direct-current service and to arc light circuits. Auxiliaries for alternating current and for 1 000 volt use had to be devised quickly. In the light of present knowledge they were simple and almost rudimentary. On the other hand, when one considers the limited experience there was to guide and the necessity for producing these instruments quickly, one cannot but admire the results. To Mr. Shallenberger and to Mr. Philip Lange, who was in charge of the construction of detail apparatus, belongs this credit in large measure. A number of points relating to this detail apparatus are of interest.

The rheostats had wooden face plates back of which were mounted wooden frames holding spirals of German silver wire.

The switches for the switchboards employed wooden bases and the contacts were open and exposed. Double-pole, double-throw switches were ordinarily employed for connecting a dynamo or an outgoing feeder to either of two sets of bus-bars. The transfer was made by throwing the switch quickly, resulting in only a momentary interruption of the circuit.

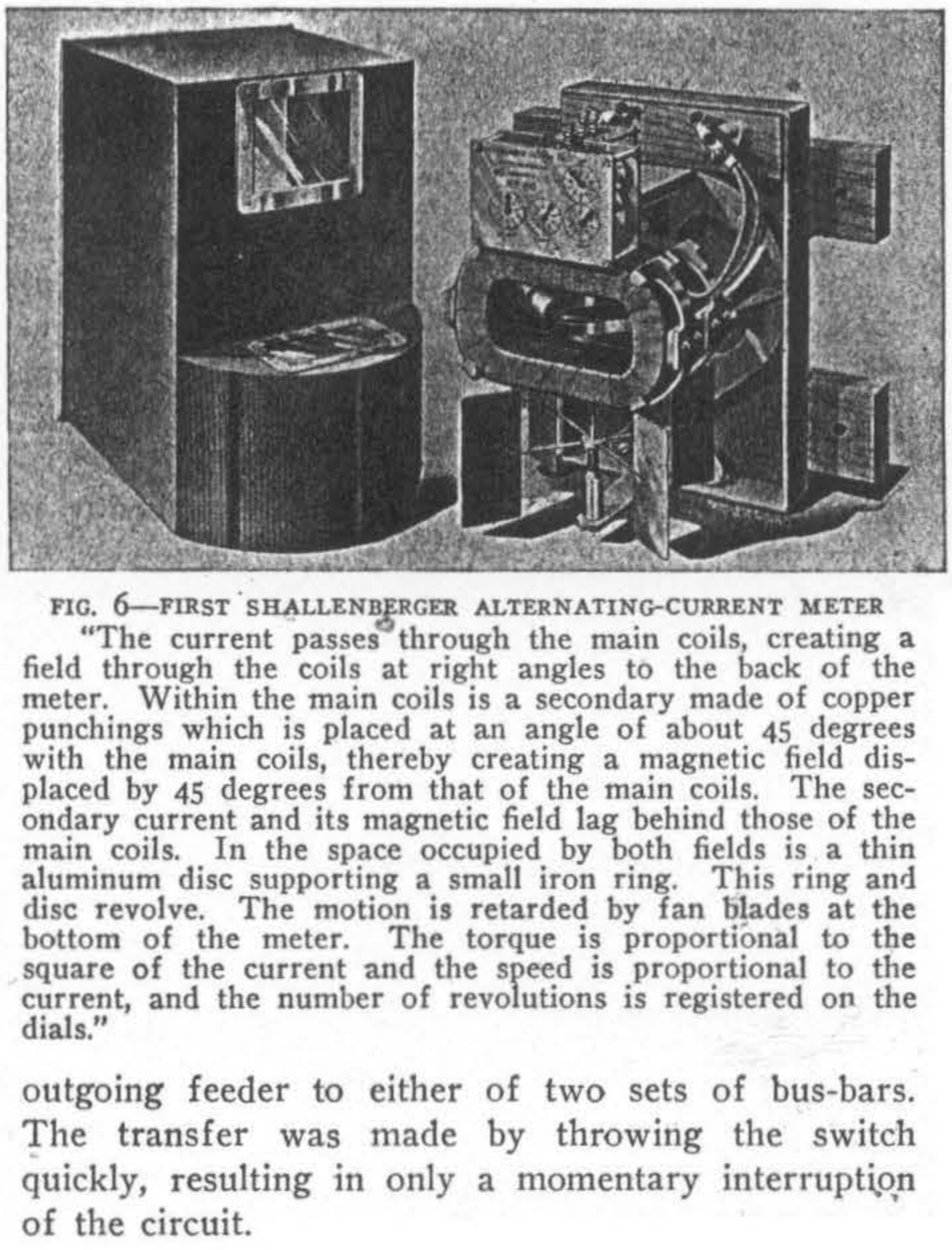


FIG. 6—FIRST SHALLENBERGER ALTERNATING-CURRENT METER

"The current passes through the main coils, creating a field through the coils at right angles to the back of the meter. Within the main coils is a secondary made of copper punchings which is placed at an angle of about 45 degrees with the main coils, thereby creating a magnetic field displaced by 45 degrees from that of the main coils. The secondary current and its magnetic field lag behind those of the main coils. In the space occupied by both fields is a thin aluminum disc supporting a small iron ring. This ring and disc revolve. The motion is retarded by fan blades at the bottom of the meter. The torque is proportional to the square of the current and the speed is proportional to the current, and the number of revolutions is registered on the dials."

The bus-bars for 1 000 volts were usually bare copper rods held by wooden supports on the front of the board. On one occasion a young electrician whose experience had been with batteries, joined the bars by a wire to see if he could get a spark. He did, but fortunately was not seriously burned. The

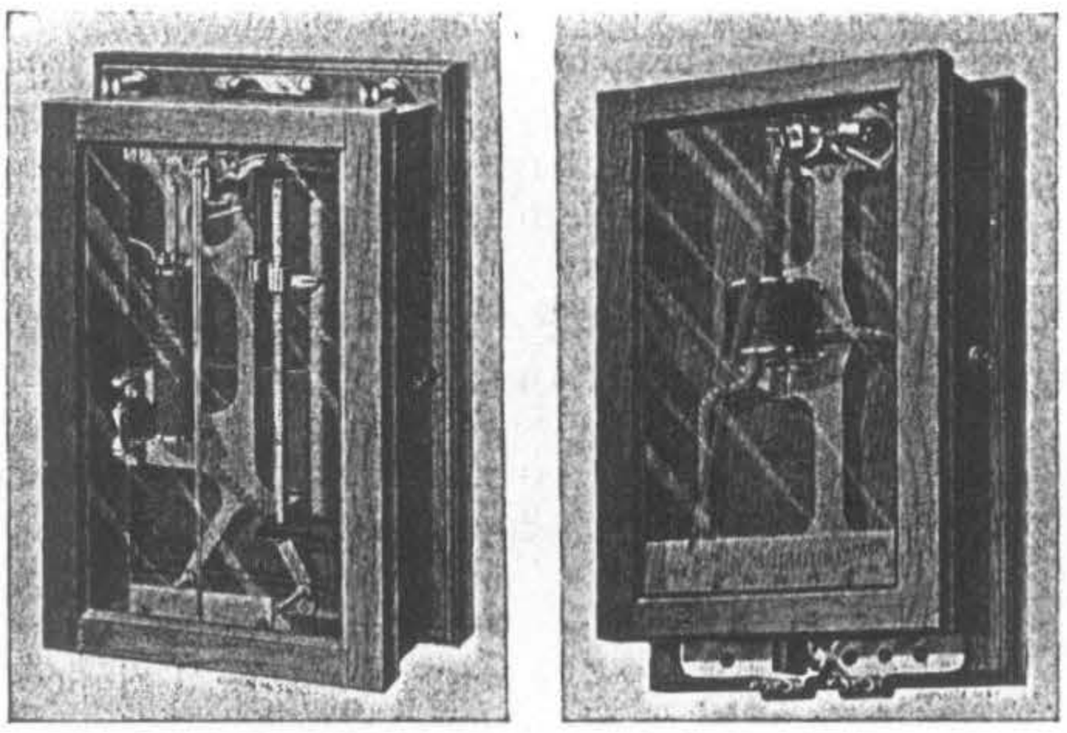


FIG. 7—STATION VOLTMETER AND AMMETER

"A solenoid pulls a soft iron wire plunger which is attached to one end of a lever which carries a weight at its other end. The e.m.f. necessary for causing the voltmeter pointer to come to the arrow is determined by the setting on the fixed resistance in the right hand side of the case."

safety catch or fuse was a wooden block about four inches square on which were mounted two lead fuses, one or both of which could be used, depending on the arrangement of the plugs which completed the circuit. The switchboard transformers were placed in wooden boxes and were mounted at the top of the

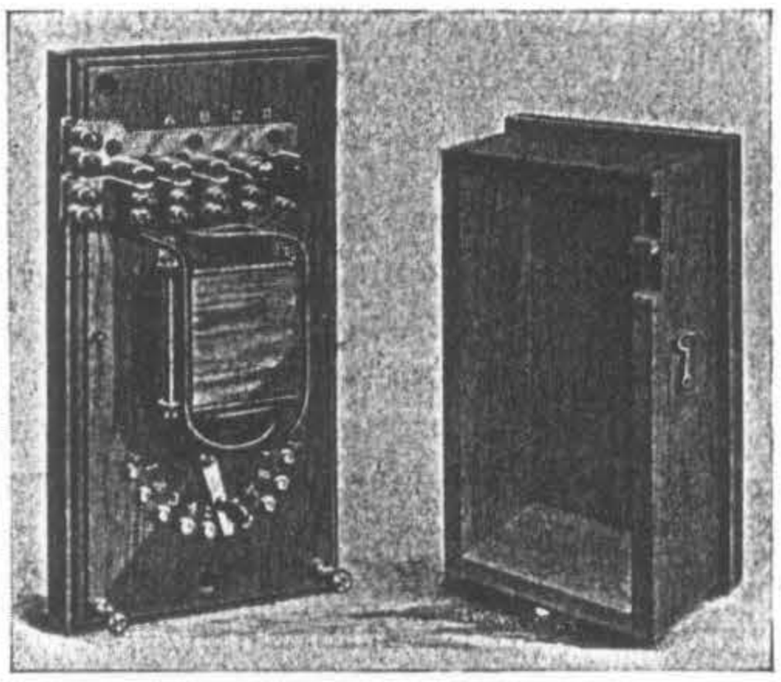


FIG. 8—VOLTMETER COMPENSATOR

"The number of turns through which the primary current passes is determined by the position of the plug near the top. The number of turns in the secondary winding which is in series with the voltmeter is adjusted by the switch near the bottom. In this manner the instrument can be adjusted to reduce the voltmeter reading by the same percentage as the line drop reduces the pressure at the lamps."

board. The board on which the apparatus was mounted was either of matched flooring or was an open wood framework.

The early voltmeter had a lever on one end of which was a weight (adjustable by the number of shot in a brass cylinder), and on the other an iron wire plunger which extended into a solenoid. Incandescent lamps were used as a resistance in series with the solenoid. When the applied e.m.f. was at normal value, the pull by the solenoid was just sufficient to cause the pointer attached to the lever to point vertically. There was no graduation on the scale. This voltmeter was soon superseded by another in which German silver resistance replaced the lamps.

The ammeter needle traversed a circular dial under the action of a plunger in a solenoid which carried the main current. In a later form the mechanism was simpler, the deflection being indicated on a scale near the bottom of the instrument.

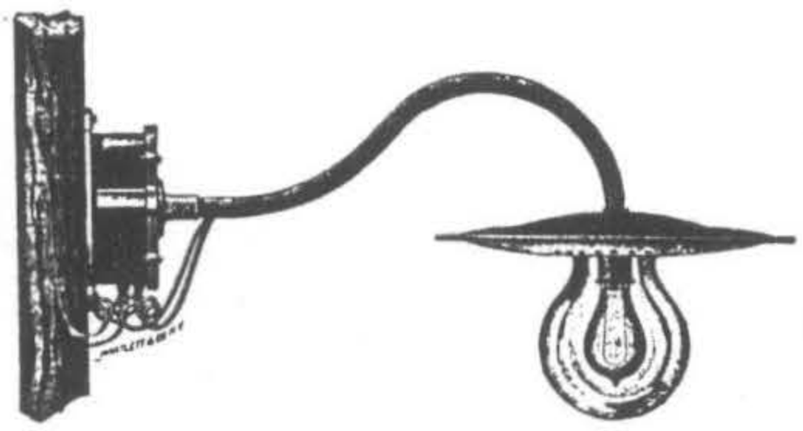


FIG. 9—STREET LAMP COIL, 1888

"These coils are so wound that twenty of them are placed in series when 1 000 volts are used. A 50 volt incandescent lamp is connected in shunt across each coil. When the lamp is burning the coil is 'not in action'; when it is broken the total current passes through the coil, which practically replaces the lamp. The brilliancy of the remaining lamps is not appreciably affected until five or six lamps are broken and then it is dimmed. This result is accomplished without any of the magnets or fusible connections or any of the moving parts or contacts which are annoying and crude accompaniments of many so-called series systems."

On the feeders were voltmeter compensators. These were series transformers, the primary circuit being in series with the feeder, and the secondary in series with the voltmeter. Outgoing current caused the voltmeter to read low, and it was necessary to

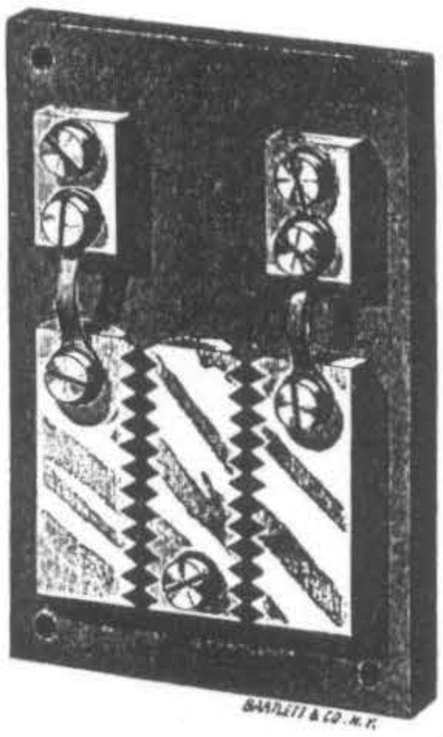


FIG. 10—LIGHTNING ARRESTER, 1888

This arrester was installed on 1 000 volt circuits. The middle section was grounded and the other two were connected to the dynamo terminals. It worked well if there was no lightning; but a spark was apt to be followed by dynamo current which volatilized the spark points and short-circuited the dynamo.

raise the bus-bar e.m.f. in order that the voltmeter might give normal indication. The compensator caused a drop in the voltmeter circuit proportional to that in the feeder, so that when the voltmeter reading

was normal the e.m.f. at the end of the feeder was normal also. When several feeders ran from the same bus-bars it was impossible to get the proper voltage for each one when the line losses were different, but a mean value could be selected. Recognizing this limitation, Mr. Stillwell devised, in the fall of 1888, the regulator which bore his name. A transformer had its primary coil connected between the two wires of the outgoing circuit and its secondary coil in series with the circuit, thereby increasing (or decreasing) the e.m.f. delivered to the circuit by the

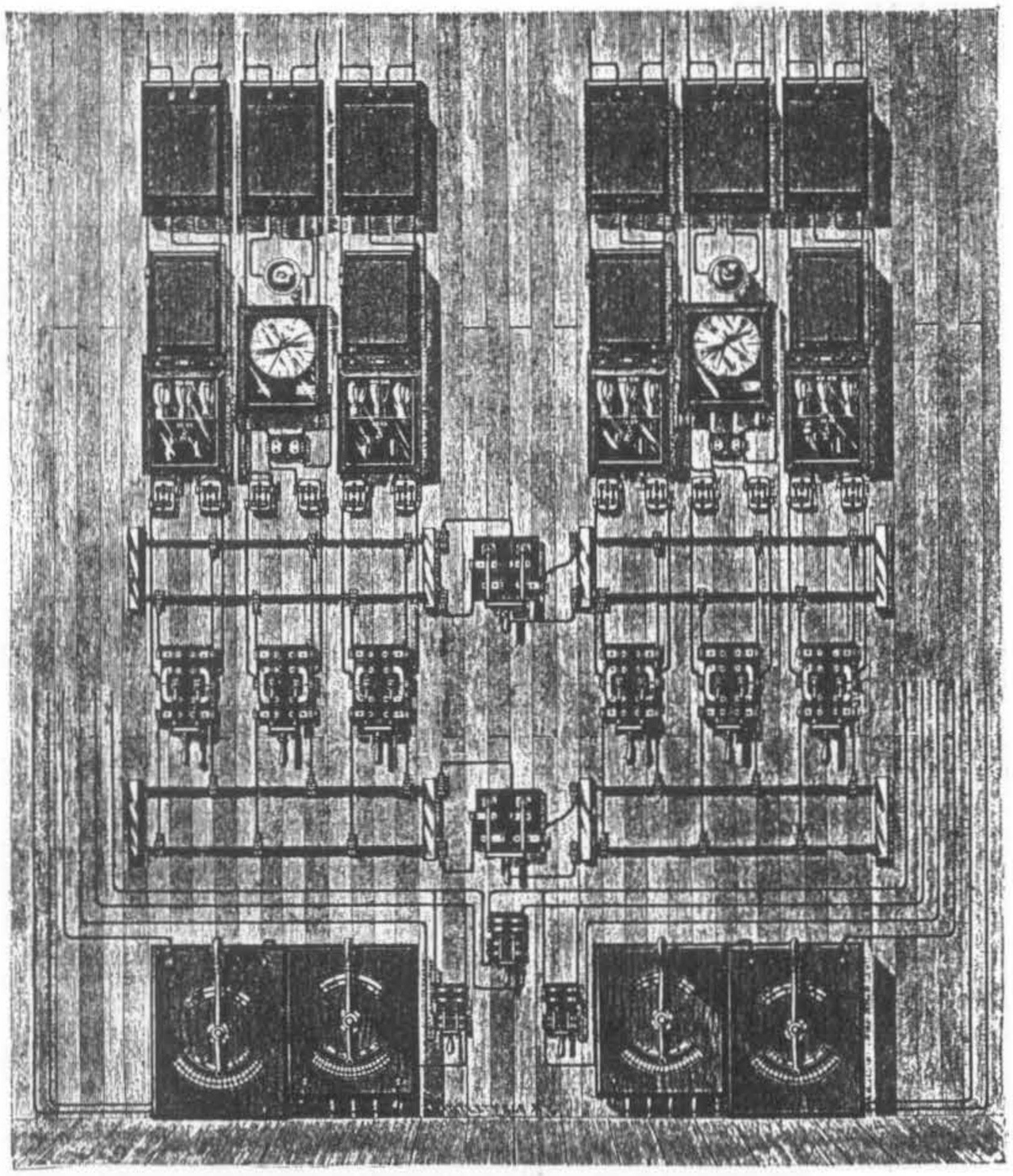


FIG. 11— TYPICAL SWITCHBOARD OF 1888

"This switchboard accommodates two exciters, two 1 000 volt alternators and four feeders. The exciter control circuits are at the bottom of the board. The alternators are connected to the middle point of the middle switches of the right hand and left hand side of the board, and may be connected to the upper or the lower pairs of bus-bars. The right hand and left hand sections of each pair of bus-bars may be separate or connected in parallel by multiple arcing switches. The generator circuit is provided with a transformer, supplying a pilot lamp, and an ammeter with short circuiting plugs and fuse. Each feeder may be connected to the upper or lower bus-bars by a double throw switch and is provided with fuses, a voltmeter, a compensator and a transformer. Wood is the only insulating material used, except in the internal parts of transformers and instruments."

amount of the secondary e.m.f. The latter was adjustable by a change in the number of turns; hence the e.m.f. on an individual feeder could be adjusted to such a value that when reduced by the line drop the desired e.m.f. would be delivered to the load.

The early lightning arrester was a number of spark gaps in parallel between brass plates on a rubber base. This form was useful for the protection of telegraph circuits, but was utterly inadequate when current from a dynamo was ready to follow a spark. The researches and notable inventions of Wurts were the early chapters in the story of modern lightning protection. He began his work on the improvement of fuses and lightning arresters about 1888.

The change which has come about in measuring instruments is best indicated by a question which was recently asked by a young man who had spent a year or more in a large commercial testing room. He saw a Siemens electro-dynamometer in a college laboratory and inquired whether they were put to any practical use. He was told that in early testing room and laboratory work the dynamometer was the only instrument for measuring current with the exception of station instruments and a few small imported direct-current ammeters of doubtful quality. Even after the Weston direct-current ammeters came into general use in the early nineties, it was some time before there was a substitute for the dynamometer for the measurement of alternating current. During this early period practically the only voltmeter was the Cardew voltmeter, a hot wire instrument in which the fine wire was protected by a brass tube three or four feet long, the expansion of the wire being indicated by a pointer on a circular dial. This voltmeter was made for 60 volts and 120 volts, the former requiring about one-third of an ampere and the latter a somewhat less current at full deflection. For alternating-current power measurements, a dynamometer was used in which the series current passed through one coil and the shunt current passed through the other coil and a suitable non-inductive resistance. These were the best measuring appliances available. Sometimes the brilliancy of an incandescent lamp was used for indicating voltage, and Mr. Telsa insisted that he could determine the number of amperes taken by a fan motor by breaking the circuit and noting the size of the arc.

TESLA MOTORS

The first Tesla motors were made with definite iron field poles, similar in general form to a multipolar direct-current machine of the present day. The magnetic circuits were laminated; coils were placed around the individual poles. In a two-phase motor, alternate poles were connected as one circuit and the remaining poles as the second circuit. In each circuit

the coils were first positive and then negative. When current was passed through one circuit alone, alternate coils were energized, producing positive and negative poles. When the current through the first circuit decreased and that in the second increased, there was produced a succession of positive and negative poles, shifting from the angular position of the first circuit to that of the second. This shifting magnetic field acted upon an internal secondary member or armature. In the early motors this consisted of a smooth cylindrical core with wires wound in coils on



FIG. 12—SAFETY CATCH HOLDER OF SWITCHBOARD FUSE BLOCK

"This is used on 1 000 volt circuits. If the upper plug be removed, the right hand fuse alone is in circuit. If this fuse melts due to excessive current, a plug may be inserted in the upper position, thereby immediately placing the left hand fuse in service." In case of short-circuit, however, the whole block was apt to be enveloped in an arc which destroyed the metal terminals, as well as the wood base.

the surface, these coils being short-circuited. There were usually as many windings as there were total field poles in the two primary circuits. Motors of this type would usually start fairly well and were able to carry a fair load. They took, however, a large magnetizing current due to the limited pole surface and to the relatively large air-gap between the iron of the stationary poles and the iron surface of the rotating core.

Furthermore, as the magnetic fields from the two primary circuits enter the secondary at definite independent positions, a coil on the rotating member in certain positions would confront one field pole only and in other positions might confront one field pole of each circuit and receive induction from both. Hence there was lack of uniformity of action and dead points sometimes resulted. Furthermore, if the rotating member were made with definite poles, so that the air-gap might be reduced, the excellence of the magnetic circuit varied for different angular positions of the secondary. These difficulties were in large measure overcome by making the secondary core with a large number of small slots and small teeth. In the slots were placed the coils with windings so distributed that the resultant action in the secondary was practically the same, whatever the angular position of the secondary. Later on the primary was also provided with a large number of small slots in which the windings were so distributed that several primary circuits produced a practically uniform rotating magnetic field. In such a field the secondary winding does not need to be specially distributed and the squirrel cage type can be employed in which each conductor is connected to a ring at each end of the secondary.

The method of winding in small slots, instead of placing the windings on the surface of an armature or around large poles made a radical change in the design of alternators, induction motors and direct-current generators. The first important machine of this type which was made in Pittsburgh was the No. 3 railway motor which combined a large number of characteristic features, making it the prototype of the modern railway motor. This new type of winding apparently sacrificed some of the best features of the induction motor. The simplicity of the early machine was unique. The primary windings were in a few coils as simple as ordinary field coils, readily wound, easily put in place and replaced. To separate this winding into many small coils to be placed in small slots was unfortunate from the standpoint of simplicity and insulation.

The early endeavor was to adapt the induction motor to 133 cycles and by "split phase" or other methods to operate it on the existing single-phase circuits. It is no wonder that little headway was made in solving a problem which scarcely any one would attempt today. The motor could not be adapted to the frequency, and so the frequency was adapted to the motor.

FREQUENCY

The frequency of the early apparatus was 133 cycles, or 16 000 alternations per minute as it was then ordinarily designated. About the time the writer

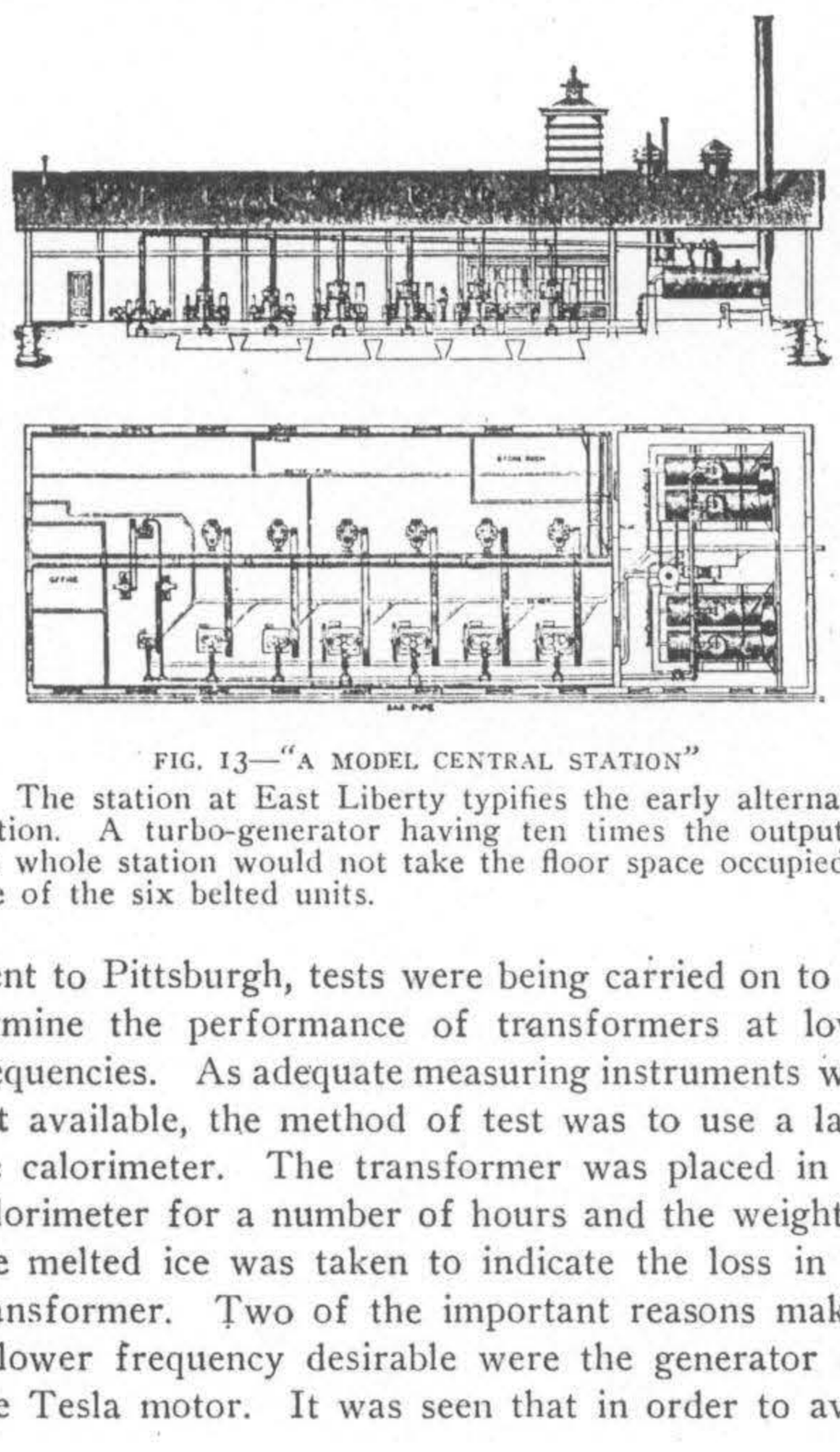


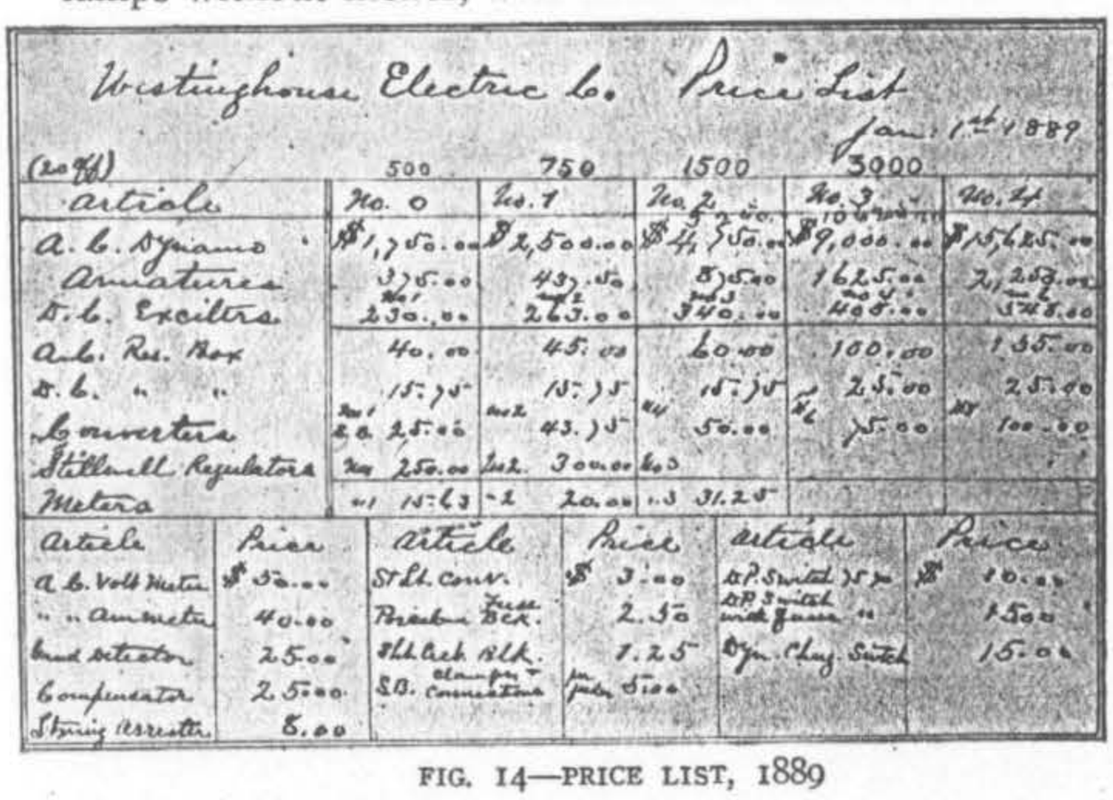
FIG. 13—"A MODEL CENTRAL STATION"

The station at East Liberty typifies the early alternating station. A turbo-generator having ten times the output of the whole station would not take the floor space occupied by one of the six belted units.

went to Pittsburgh, tests were being carried on to determine the performance of transformers at lower frequencies. As adequate measuring instruments were not available, the method of test was to use a large ice calorimeter. The transformer was placed in the calorimeter for a number of hours and the weight of the melted ice was taken to indicate the loss in the transformer. Two of the important reasons making a lower frequency desirable were the generator and the Tesla motor. It was seen that in order to avoid

belts, it would be necessary to run alternators at a low speed for direct connection to engines. This made desirable a less number of poles than would be necessary for the high frequency, for instance, at 100 r.p.m. 160 poles would be necessary. Furthermore, the induction motor operated much more satisfactorily at a low frequency.

In the fall of 1890 Mr. Stillwell returned from a visit to Europe. He had seen alternators direct connected to slow-speed engines. After carefully studying the American situation he prepared a report on which the subsequent engineering policy of the company was based, in which a frequency of 60 cycles was proposed as a general standard for lighting service and 30 cycles for power service. The higher frequency met the requirements of engine speed; it permitted transformers to be made at reasonable cost (the cost increased as the frequency was lowered) and it was high enough to permit the operation of arc lamps without flicker, with American carbons. Abroad



Westinghouse Electric Co. Price List Jan. 1st 1889

(2000#)	500	750	1500	3000	
Article	No. 0	No. 1	No. 2	No. 3	No. 4
A.C. Dynamo	$1,150.00	$2,500.00	$4,250.00	$9,000.00	$15,625.00
Armatures	375.00	437.50	875.00	1625.00	2,250.00
D.C. Exciters	230.00	265.00	340.00	405.00	545.00
A.C. Reg. Box	40.00	45.00	60.00	100.00	135.00
D.C. " "	15.00	15.00	15.00	25.00	25.00
Converters	25.00	43.75	50.00	75.00	100.00
Stillwell Regulators	250.00	300.00	400		
Meters	15.63	20.00	31.25		

Article	Price	Article	Price	Article	Prices
A.C. Volt Meter	$ 30.00	St. Lt. Conv.	$ 3.00	D.P. Switch 75 A	$ 10.00
" " Ammeter	40.00	Breaker Box.	2.50	D.P. Switch with fuses "	15.00
Hand Exciter	25.00	Std. Lock Blk.	1.25	Dyn. Chg. Switch	15.00
Compensator	2.50.00	S.B. clamps for Commutators		Field 5.00	
Storing Arrester	8.00				

FIG. 14—PRICE LIST, 1889

This list, torn from an ordinary note-book, included prices, not only on all types of apparatus manufactured by the company, but on all the ratings of each type.

soft carbons permitted a slightly lower frequency. The lower frequency of 30 cycles seem a desirable one from the standpoint of the induction motor and power work generally. In 1892 an exhibition of alternating apparatus was made at Pittsburgh which was viewed by Prof. George Forbes of England, Prof. Henry A. Rowland and Dr. Coleman Sellers members of the commission for determining the system to be adopted by the Niagara Falls Power Company. They were shown rotary converters operating at 30 cycles. The matter of frequency was discussed. The effect on incandescent lamps was determined to be unobservable at 30 cycles, very pronounced at 20 cycles and somewhat in question at 25. Prof. Rowland remarked that the way to make a test was to have some old woman read by the light and note whether or not her eyes became tired. This seemed a remarkable statement from the leading physicist of America with regard to what seemed to be a physical phenomenon, but after all it is not physical condition but physiological effect that is of importance. The commission of American and foreign engineers which determined the system to be used at Niagara was at first in favor of direct current by a considerable majority. The final decision in favor of alternating current was not made until the summer of 1893 when polyphase alternating current was choosen and a little later 25 cycle alternators of 5 000 horse-power, delivering two phase current were purchased from the Westinghouse Company. The design of the alternators favored either a 12 pole or a 16 pole alternator. The water turbines had been purchased; they ran at 250 r.p.m. Hence the choice lay between 25 and 33 1/3 cycles and it was impossible to secure 30 cycles. The 12 pole machine giving 25 cycles was chosen. This was a notable event. The adoption of polyphase alternating current and the use of 25 cycles by the largest power undertaking of the time set a precedent which is now almost universally followed. Frequencies of 40 and 50 and 66 cycles have been advocated and used, but (with few exceptions) are now obsolete.

THE IMPORTANCE OF TRANSFORMER AND POLYPHASE SYSTEM

In the early days, say from 1880 to 1895, there were many systems and many types of apparatus. This is well illustrated by one station which had machines for arc lighting at 6.6 amperes, for arc lighting at 10 amperes, for incandscent lighting by the three-wire system, for power by 500 volts direct current, and for incandescent lighting by alternating current. Each kind of service required its own individual circuits and the arc lighting required individual circuits from each machine. Subsequently current for all kinds of service was derived from alternators far greater in capacity than a score of the former machines.

If we were to trace the electric development of the past twenty-five years, we should find the transformer as the simple factor which has determined the whole course of that development. With few exceptions in which direct current from relatively small plants is used locally, practically all of the electric energy now used for lighting and for power purposes passes through one or more transformers.

A second factor in shaping the course of electrical development was the Tesla motor and the polyphase system. To accommodate the motor with a proper supply of current, single-phase generators gave way to polyphase alternators, and high frequency was followed by low. The Tesla invention proved to be not merely a motor, as was first assumed, but a system. Polyphase apparatus is now practically universal. All of the long distance systems of power transmission and practically all of the great central stations for street railway and lighting and power service produce polyphase alternating current, even when the consumption circuits require direct current. When the polyphase system was first introduced, the parallel operation of alternators was unusual, but it is now universal.

Without the transformer and the polyphase system there is no means at present known by which the extension of the use of electricity could have made one-tenth of the progress that it has made. It is easy to recognize this now, but it was not so easy to foresee. In fact, there was criticism and condemnation of the alternating current by experts, and there was antagonism and opposition by commercial interests. The foresight, the courage and the wonderful constructive ability, persistence and power of Mr. Westinghouse made him the great human factor in the recognition, introduction and development of the alternating system, and, therefore, in the electrical development of the past twenty-five years.

Those only who were associated with the company before the writer went to Pittsburgh have been mentioned. Among the first of those who followed and who have had a great deal to do with the subsequent development of apparatus, including some of the types to which reference has already been made, were Messrs, Lamme and Storer and Skinner and Davis. It is anticipated that further articles by various men will trace the engineering steps which have led up to the efficient apparatus of to-day. Present practice is the outcome of the efforts of many workers in many places. The particular thing which may bear the impress of a particular inventor or may be put forward with energy by one company or another may flourish for a time, but merit determines its final disposition. Among the types of apparatus which are now in common use and in many cases are manufactured by several companies it will be interesting to note that a considerable number had their origin Pittsburgh. In many cases the idea originated with a Pittsburgh inventor. In other cases an acute engineering instinct has selected, combined and put into operating form apparatus or methods which were previously undeveloped or experimental.

Electric Journal February 1914

The Engineering Evolution of Electrical Apparatus—II

THE ALTERNATING-CURRENT GENERATOR IN AMERICA

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Westinghouse Electric & Mfg. Company

FOREWORD—The following article contains a fairly complete brief history of the evolution of the alternating-current generator in so far as the Company with which the writer is connected is concerned, as drawn from the writer's memory principally. Reference is made incidentally to the work of other manufacturing companies, but this cannot be very complete, as the writer naturally does not have the necessary material available for describing such developments, except in a very general way. Therefore, the inadequacy of this history, outside of the Westinghouse part, should be charged to the lack of data rather than to lack of respect for the work of others.

IN the early days of the alternating-current generator, it was constructed in almost as many types as there were designers. The principal endeavor of each designer appeared to be toward the development of a new alternator which would bear his name. A few of these early types were of the rotating field construction, while a much greater number were of the rotating armature type. Some had iron core armatures, while others had coreless armatures, and there were many discussions as to whether the core or the coreless type was superior and would survive. Many of the early predictions would now form quite interesting reading, in view of the fact that present practice is so far removed from the early anticipations. Here and there among the early machines was one which contained some of the important elements of recent apparatus, but in many cases such machines disappeared in the general course of development, the meritorious features being insufficient to save the type.

SURFACE WOUND ARMATURES

In America, the principal early type of alternator had a rotating armature with surface windings and an external cast iron multipolar field. This type was used very considerably or, in fact, almost exclusively, from 1886 to 1890. This was the type built by the Westinghouse and the Thomson-Houston Companies. There were only minor differences in the construction of the machines built by these two companies which, however, at that time, appeared to be very great. These differences consisted principally in the way the end windings of the armature coils were supported, in the construction of the end bells and ventilating openings in the armature core, in the method of attaching the armature core to the shaft, in the winding of the field coils in metal bobbins, etc. Both machines had surface windings with concentric coils, one layer deep in the radial direction. In the Westinghouse construction, the end windings were turned down toward the shaft and were supported by radial wooden clamps, as indicated in Fig. 1. In the Thomson-Houston armature, the end windings were arranged in an axial instead of a radial direction, and were supported by bands or external clamps. This construction is also indicated in Fig. 1. The Slattery machine, which was also on the market at that time, was of the same general type as the above machines. Presumably these two different methods of end winding were used on account of the patent situation. At that time there was much discussion of the respective merits of the two constructions.

These early machines were built principally for frequencies of 15 000 and 16 000 alternations per minute (125 and 133 cycles per second). In those days, everything was rated in alternations per minute, as this represented the product of the number of poles by the number of revolutions. Such high frequencies were selected, mainly, on account of transformer conditions, and not alternator design. Practically all alternating service consisted of house to house lighting, and in relatively small units, and the higher frequency was supposed to be of great advantage in transformer design and operation, which presumably was the case with the very small amount of data and experience available at that time.

About the only commercial voltage for alternating work at that time was 1 000 or 1 100 volts. This was supposed to be excessively high and dangerous, and there was much question whether such an excessive voltage should be permitted. This matter was actually taken before a number of the state legislatures for the purpose of obtaining laws prohibiting or limiting the use of such voltage. Another reason why no higher voltage was used was in the construction of the alternators and transformers. With the experience and materials available at that time, together with the high speed rotating armature construction and the surface windings, even 1 100 volts was a very serious problem in the generator. About 1889 or 1890, there appeared some slight demand for higher voltages, and a few 2 000 or 2 200 volt surface-wound alternators, of the then standard type, were built. However, even then it was recognized that the surface-wound type of alternator was not well adapted for higher voltages, and there was much question whether a different type winding should not be developed for 1 100 volts. This gradually led to the next big step, namely, the development of the "toothed" type of alternator with one big tooth per pole, in distinction

from the slotted type of armature with a number of slots per pole, which was a considerably later development.

TOOTHED ARMATURES

The first commercial toothed type of armature appears to have been gotten out by the Westinghouse

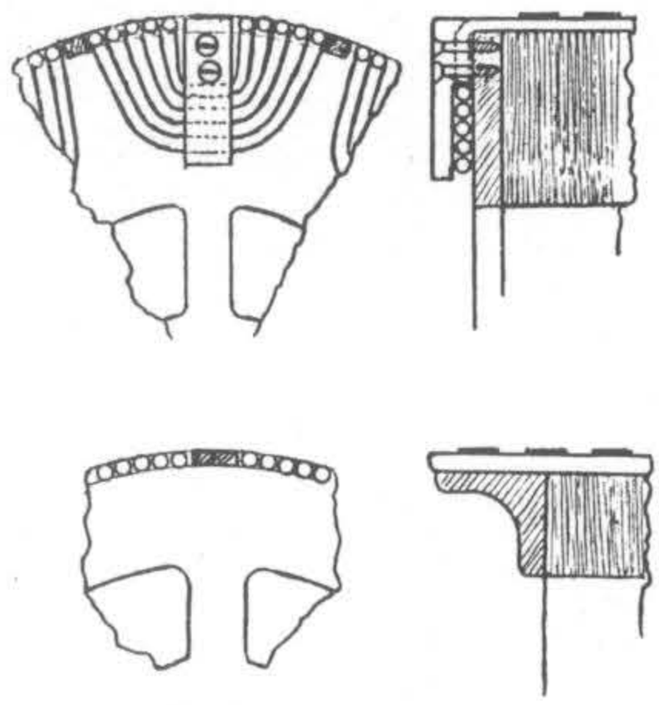


FIG. 1—SURFACE WOUND ARMATURE WITH RADIAL CLAMPS (UPPER) AND WITH AXIAL CLAMPS (LOWER)

Company. These first machines were radically different, in details of construction, from the later toothed armature types of machines which came into general use. The first toothed armatures were small air-gap machines. In the surface-wound armatures, the clearance between the armature surface and the field poles was comparatively small, although the total air-gap (iron to iron) was large on account of the surface winding. In constructing the new toothed armature, the actual clearance (iron to iron) between armature and field was kept about the same as in the surface-wound alternators (bands to iron), but this clearance actually represented the total air-gap in the toothed type. Moreover, in sinking the windings below the

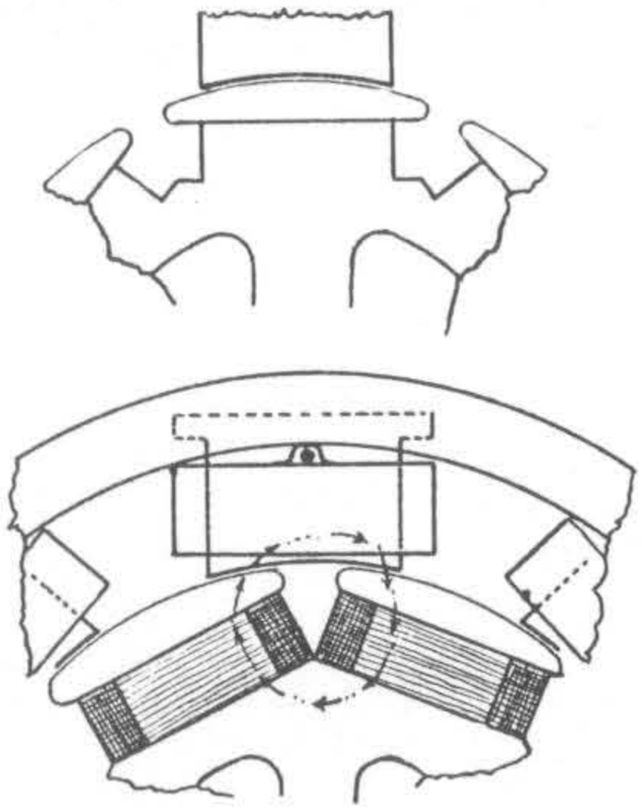


FIG. 2

surface, it was endeavored to maintain a practically uniform outside surface, so that overhanging tooth tips were used with relatively narrow slots for putting in the windings. The general construction was similar to Fig. 2. On account of the small clearance, and consequent higher magnetic conditions, it was found necessary to use laminated poles with these machines in order to avoid excessive field heating.

The self-induction of the armature windings on these machines was very high compared with the old surface-wound armatures and, therefore, in order to obtain passably good regulation, fewer armature turns had to be used, with correspondingly higher inductions, and this made the use of solid poles impracticable on account of heating. Furthermore, on account of the overhanging tooth tips, the small air-gap and the high induction per pole, this early type of toothed armature was very noisy. In one instance, it was credibly reported that one of these machines could be heard two miles away on a quiet night. However, several machines of this construction were put out by the Westinghouse Company, and operated for many years.

Meanwhile, the possibilities of the toothed armature construction in the old cast iron field were being given consideration. The writer made a special study of this matter, and finally decided that, in order to make this construction possible with solid cast iron poles, it would be necessary to work at relatively low

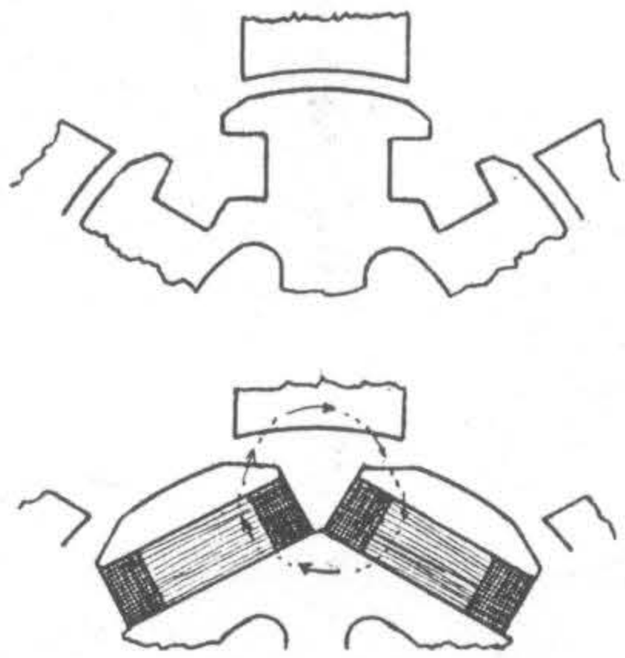


FIG. 3

inductions per pole, and with a very large air-gap, (fully as large as on the old surface-wound machines) and with a shape of tooth tip which did not have such great width compared with the pole tip as shown in Fig. 2. This meant that a pole tip and air-gap as shown in Fig. 3, should be used. With this arrangement, the armature self-induction would still be relatively high, and the regulation correspondingly bad, necessitating some form of compounding for regulating the voltage, similar to the compounding of a direct-current generator. This armature construction was worked out in detail for a 37.5 kilowatt field (that is, for the standard field of the 37.5 kw surface-wound type of machine). The armature teeth were similar to those in Fig. 3, in shape, and the air-gap or clearance from iron to iron, was made 3/8 inch on each side of the machine. The field was also compounded. When this machine was put on test, it was found at once that it could be loaded to 60 kilowatts without undue heating of the armature and field iron, and the problem of perfecting this machine then became one merely of increasing the amount of arma-

ture copper to carry the current at the 60 kilowatt rating. This, therefore, represented a big step in the development of the American type alternator. It was found that all the other Westinghouse standard cast iron machines of the rotating armature type could readily be changed in line with the above improvement.

COMPOUNDING ALTERNATORS

The compounding of the 60 kilowatt machine was not a new feature, for already some of the laminated field toothed-armature type of machines had been compounded, in order to improve their regulation. Two different methods of compounding alternators had been developed by the Westinghouse and Thomson-Houston Companies, respectively. In the Westinghouse armature construction, the armature discs were punched in single pieces, with spokes, and were threaded directly on the armature shaft, no spider being used. This construction is illustrated in Fig. 4. In the assembled armature, the spokes were therefore of laminated material. These laminated spokes were utilized as the core of a compounding transformer. One lead from the armature winding was carried around the spokes of the armature before passing to the collector ring. This winding formed the primary of a series transformer. The secondary was also wound on the spokes, and the two ends were carried to the bars of a rectifying commutator on the shaft. The number of commutator bars was equal to the number of poles. The alternating current from the secandary winding was by this means changed to a pulsating direct current.

In the Thomson-Houston method of compounding, the main armature current was carried directly to a rectifying commutator, and, after being commutated, was passed to the field-compound winding, and back to

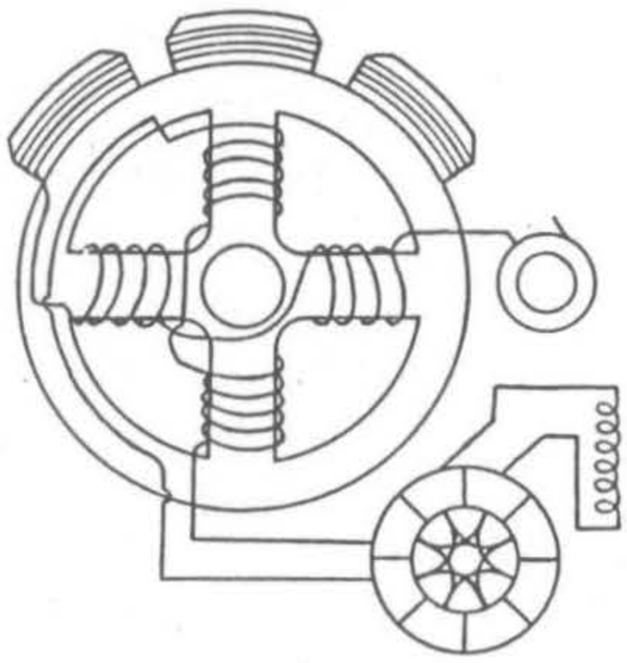


FIG. 4—SKETCH OF COMPENSATED TYPE OF WINDING

the commutator, and then to a collector ring. The main armature current therefore passed directly through the field, while in the Westinghouse method the secondary current from a series transformer was passed through the field. Both methods represented series compounding, and gave practically equal results, but there was much discussion as to the merits of the two methods. Both of these methods delivered pulsating direct current to the field winding. There was considerable inductive e.m.f. set up in the field windings by this pulsation, and this tended to cause inductive discharges across the rectifying commutators. In the Thomson-Houston method this trouble was overcome to a considerable extent by the use of a non-inductive shunt in parallel with the rectifying commutator, i.e.,

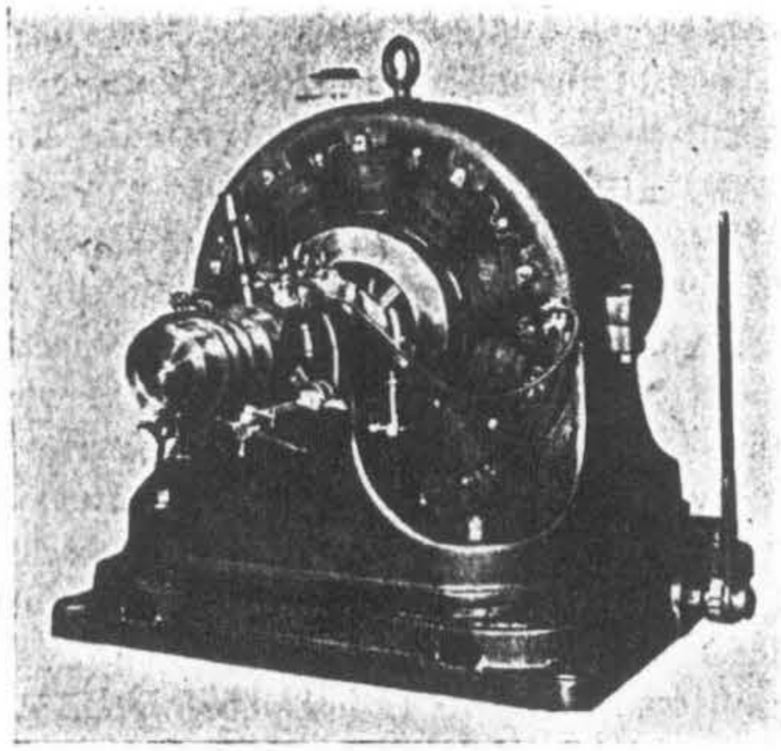


FIG. 5—EARLY WESTINGHOUSE 60 KILOWATT ALTERNATOR WITH COMPENSATING WINDING

across the compound winding. In the Westinghouse method a similar result was accomplished by saturating the series transformer (or armature spokes) to such a high point that the inductive kick from the field could readily discharge through the secondary winding of the transformer without giving high enough voltage to flash across the commutator.

The details of this method of compounding have been gone into rather fully, as this compounding was, at that time, an important step in our progress. The fact that of all these machines were built for single phase, allowed us to use such compounding. With the advent of polyphase generators, such methods of compounding soon disappeared, principally for the reason that a great majority of the early polyphase machines handled separate single-phase loads on the different phases, and it was not practicable to compound for these independently.

The above toothed type generator came into use about 1890 and lasted for several years, or practically until polyphase generators actually came into fairly general use before true polyphase loads became common. These toothed type generators allowed the use of relatively high voltages, as far as the armature winding was concerned, so that 2 200 volts became comparatively common, and even 3 300 volts or higher was used in some cases. In fact, the limit in such machines appeared to be at the collector rings, rather than in the armature winding.

Something may be said regarding the type of winding used on the armatures of these machines. In the Westinghouse construction the armature coils were machine-wound and taped before placing on the armature core. Each coil was made wide enough to slip

over the top of the armature tooth, as shown in Figs. 6 and 7. This made the coil considerably wider than the body of the armature tooth, so that, after slipping over the tooth top the coil had to be reduced in width by special clamping tools. Supporting wedges were then driven in between adjacent coils.

Something may be said regarding the temperatures of these early alternators, both of the surface-wound and of the toothed types. In those days temperature measurements were very crude compared with present practice, which is admittedly still only approximate. In some of the surface-wound armatures excessively high temperatures must have been encountered in many instances, judging from the appearance of the insulation on the individual wires, after a year's service, for instance. However, it was difficult to obtain reasonably correct temperature of the armature windings, for the actual temperature of the conductors was undoubtedly reduced very greatly before the armature could be brought to a standstill. Even after this, temperature rises of 50 or 60 degrees C. were not considered as excessively high. Without doubt, some of these early machines, at times, attained actual internal temperatures of 120 to 130 degrees C., or even higher, with insulation on the conductors consisting of untreaded cotton fibre. No overloads were possible, for each size of machine was rated in as many "lights" as it could carry on a shop test without breaking down. The first few minutes, while starting up a new alternator in the testing room, were always anxious ones for the operators, especially so if any "improvements" had been made on the armature winding. Any defect in winding, or wrong connection usually resulted in a stripped armature and much flying copper. If nothing happened within the first few minutes after the machine was put on load, the attendants all came out from behind posts and other protections and went on with their work.

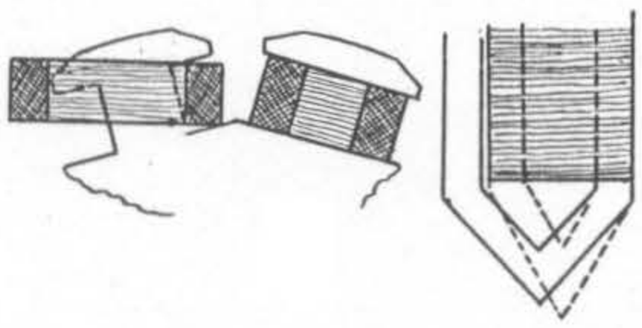


FIG. 6—SKETCH SHOWING METHOD OF PUTTING MACHINE WOUND COILS ON THE POLES

When the toothed armature came into use the above conditions were much alleviated. Defects in construction, or short-circuits, could not strip such armatures, and thus the danger and excitement were removed. However, it was found that the first short run did not tell the story of excessive heating as promptly as in the case of the surface-wound type. Experience showed that the toothed construction apparently could stand a severe shop test and still go wrong under similar loading within a short time after being installed. It was found that a given size of conductor would not carry as much current in the concentrated coils of the toothed construction as was the case in surface-wound coils. However, the method of testing the temperature did not show this, as the main part of the toothed armature coil was so embedded and so covered with insulation that the thermometer readings did not indicate nearly the true temperatures. The size of wire and the amount of copper in the coils then had to be increased until the machines did stand up in service. The true explanation of the discrepancies was not well understood at that time. In these toothed alternators, as in the surface-wound machines, the first machines were rated in "lights," but gradually the kilowatt rating came into use and became standard practice.

INTRODUCTION OF POLYPHASE ALTERNATORS

In 1892 and 1893, polyphase alternators began to be considered seriously. In 1889 and 1890, a few such alternators had been built for the operation of Telsa induction motors. These early polyphase alternators were of the surface-wound, rotating armature type. These machines were very special in construction, and, like the Telsa motors, did not find much of a market. However, in 1892 and 1893, it began to be recognized that the best way to encourage the development of the induction motor would be by creating a demand for it, and it was decided that a good way to create a demand would be by encouraging the general adoption of polyphase alternators and supply circuits, with the idea that, when a suitable supply circuit was available, there was eventually bound to be a demand for motors to operate upon such circuits. With this general policy in view, there was great activity in the development of polyphase generators. This very quicky led to a very considerable departure in armature construction from the usual toothed armature as used in single-phase machines. The polyphase winding, requiring two or more coils per pole, naturally tended toward the slotted armature construction with two or more slots per pole. It was soon recognized that, in general, the larger the number of slots per pole and the smaller the number of conductors per slot, the better would be the general characteristics of the machine, so that the construction naturally tended toward the modern slotted type. Moreover, practically all the development in polyphase alternators was at relatively low frequency, compared with former practice. It so happened that there had been a well-defined tendency toward lower frequency in the period from 1890 to 1892. This tendency was largely independent

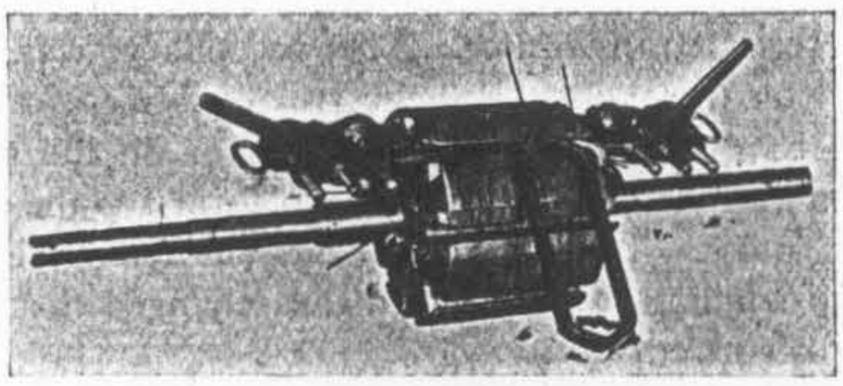


FIG. 7—VIEW OF ARMATURE IN PROCESS OF PLACING COILS AND CLAMPING THEM INTO SHAPE IN THE SLOTS

of the induction motor problem for, at the time it became most pronounced, there was no true induction motor problem. It was becoming recognized that 125 to 133 cycles per second was too high for certain classes of work and for engine type generators, and that, in general, a very considerably lower frequency must eventually be adopted. A great many lower frequencies were tried by the different manufacturing companies, ranging from 50 to 85 cycles. However, 60 cycles seemed to have the preference at the time polyphase alternators began to come in.

The early polyphase generators were mostly of the rotating armature type, and usually with a fairly large number of slots per pole. One notable exception was the "monocycle" machine which usually had only two slots per pole, one large slot for the main armature winding, and one smaller slot for the so-called "teaser" winding. Also, the early two-phase alternators of the "inductor" type, built by the Stanley-Kelly Company, frequently had only two slots per pole. However, it may be said that, from 1893 to about 1898, the great majority of the American built alternators were of the rotating armature type with distributed armature windings. The principal exceptions were the Stanley inductor type of machines and a few special "rotating field" machines, as distinguished from the inductor type.

The rotating armature machines were usually of 1 100 or 2 200 volts, although a few of considerably higher voltage were constructed. A few cases may be cited where special constructions were used. For instance, the principal lighting plant at the Chicago World's Fair in 1893, consisted of a large number of Westinghouse "twin" type generators. Each unit had two single-phase, standard toothed type armatures side by side on the same shaft. The teeth of the two armatures were staggered 90 electrical degrees with respect to each other, so that the two together could deliver currents having 90 degrees relation to each other. The object of this construction was to obtain polyphase current with standard single-phase types of machines without any radically new development. This type of unit did not persist and, in fact, was simply an expedient for this particular occasion.

THE FIRST NIAGARA GENERATORS

Also, in 1892 and 1893, the first large Niagara electrical development was worked out. The advisory engineers of this plant proposed 5 000 horse-power generators, having stationary internal armatures and rotating external fields to obtain large flywheel capacity. In fact, the construction was not unlike the usual rotating armature machine of that period, as far as general appearance of the armature and field cores and windings were concerned. However, the method of supporting and rotating the heavy external field at a speed which, at that time, was considered excessively high, required an "umbrella" type of field support, which gave these machines a distinctive appearance. This type of construction did not persist, although these early machines are still in operation.

A further distinctive feature in these first Niagara machines was in the frequency employed. A speed of 250 revolutions per minute was decided upon. The engineers of the power company proposed eight pole machines, giving 2 000 alternations per minute or 16 2/3 cycles per second. The Westinghouse Company proposed, as an alternative, 16 poles, giving 33 1/3 cycles, the advantages claimed for this frequency being that it was better suited for motors and rotary converters, which were then promising to become of importance. One advantage claimed for the 16 2/3 cycle machine was that it would permit the use of commutator type alternating-current motors. After much discussion, and weighing and balancing of all the various arguments for and against these two frequencies, it was finally decided to use 12 poles, giving 3 000 alternations per minute, or 25 cycle polyphase current and, as far as the writer knows, this was the origin of the present 25 cycle standard.

Considering what a radical departure from ordinary construction was made in these first Niagara generators, it is self-evident that many curious and interesting conditions developed during their design, construction and tests. As far as the writer knows, these were the first large alternators which were deliberately short-circuited at their terminals when running at full speed and at normal field charge. There were no instruments available to measure the first current rush, but it was obvious that this current was far greater than the steady short-circuit current of the machine under similar field charge, for there were ample evidences of a terrible shock at the moment of short-circuit. It was suspected at that time that the first rush of current was only limited by the armature impedance, and not by the so-called synchronous impedance which fixes the value of the steady short-circuit current.

This also was the earliest machine of which the writer predetermined the field form and wave form by analysis of the flux distribution. Later, when making shop tests on one of these machines, the e.m.f. wave form was measured directly by rotating the field at normal field charge at such an extremely low speed that a voltmeter connected across the armature terminals showed such gradual variations in e.m.f. that readings taken at regular intervals could be plotted to form the voltage wave. Slow rotation was obtained by means of a steel cable wrapped about the outside of the external field and with one end of the cable attached to a small diameter spindle around which it was wrapped at a very slow rate. This was a very crude method, but the wave form thus abtained checked very accurately with tests made some years later.

Also, the early Niagara machines embodied one of the first distinct attempts to ventilate alternators artificially. Early belted machines had had small ven-

tilating bells on each end. But these Niagara machines were designed primarily with a view to setting up an abnormal air circulation by means of special "scoops" or ventilators on the umbrella supports. Very much thought and discussion were given to this subject of artificial ventilation. The results of our tests led to the arrangement of thte scoops so that they acted as exhaust pipes.

Also, water cooling of the armature spider was tried on some of these early machines, but proved ineffective, due to the fact that the cooling medium was applied too far away from the point of development of the larger part of the armature iron and copper losses.

INFLUENCE OF DIRECT-CURRENT DESIGN

It must be kept in mind that the general trend of direct-current development had a certain influence on alternating-current generator work. For example, there had been a slow, but positive tendency in direct-current generators, toward the engine type construction. Also, from 1890 to 1893, direct-current generator armature construction had changed from the surface wound to the slotted type. This doubtless had some influence in changing alternator design toward the slotted type, especially when the polyphase type of windings came into use. Also, there was a pronounced tendency toward the engine type, slow speed alternator, accompanying direct-current practice. Practically all of these early engine type alternators, except the induotor type, had rotating armatures. Meanwhile, an interesting development took place in the armature construction of some of these machines. In most of the smaller belted machines, open armature slots were used with machine-wound armature coils. However, many of the early larger machines, especially of the engine type, were built for relatively low voltage, such as 440 volts, two or three phase. This admitted in many cases of simple bar windings with one or two conductors per slot. This allowed partially closed armature slots with shoved-through straight conductors, and bolted-on end windings, giving a very strong substantial type of winding for resisting the rotational stresses. The partially closed slot became a sort of standard in Westinghouse machines, and endured for a number of years, and was even carried into the stationary armature type of machine when rotating fields came into general use. This partially closed slot arrangement was a very good one as long as the generator voltages were relatively low. The same may be said of the rotating type of armature as a whole. However, when high voltages came into more general use, a different construction was preferable.

In reviewing the period of the rotating armature, slotted types of machines, the monocyclic system should be briefly described. Apparently this was gotten out with the idea that it avoided the patented features of the Tesla polyphase system. The armature circuits on this monocyclic system were so arranged that, when carrying load, one phase carried nearly all of the energy load, while both phases supplied magnetizing current for the operation of induction motors. During the period when this machine was in vogue, single-phase lighting work represented the principal service, while induction motor loads were relatively small. With increased use of polyphase loads, and with the elimination of the patent situation, the monocyclic system gradually dropped out.

It was early recognized that a stationary armature winding would be an ideal one in some respects, but it was thought that any rotating field construction was bound to be a difficult and expensive one. The inductor type construction was supposed by some engineers to overcome the objections to the rotating field, but many others considered that this type was not a final one, as it did not use the magnetic material in the machine to the best advantage. In the earlier alternators, with insufficient ventilation through the armature core, relatively low magnetic densities were necessary to avoid excessive iron heating, and the inductor alternator, with its non-reversal of armature flux, was worked at almost double the induction of the rotating armature type of machine, and thus the disadvantages of the non-reversal of flux of the inductor type were masked. In other words, the inductor alternator was worked well up toward saturation, while the other types were worked at only about half saturation. However, with improvements in ventilation due to radial ventilating ducts, improvements in iron by better annealing and painting of the laminations, etc., the flux densities in the rotating armature machines were gradually increased until high densities, approaching saturation, were reached. A corresponding increase in flux densities in the inductor type was not possible, on account of saturation. Therefore the rotating armature type of machine, in the later designs, was much more economical than the inductor type, although the latter had a very considerable advantage, especially at high voltages, in its stationary armature construction. Due to the merits of the stationary armature construction, the present rotating field type of machine was gradually evolved, which possesses the advantages of the stationary armature of the inductor type machine and the reversing flux of the rotating armature alternator. It was the development of this type of machine which sounded the death-knell of the inductor type. However, the Westinghouse Company, about 1897, decided to bring out a line of inductor type alternators to meet market conditions, although such decision was contrary to the recommendations of the designing engineers of the company, whose recommendation in particular was in favor of the rotating field construction as a more permanent type. However, as the rotating field type was not yet established, except in a very minor way, and as the inductor type had been on the market for years, it was decided to build the inductor type, although the design adopted was somewhat different from the Stanley type. Three sizes of these machines were built, two belted and one engine

type, but the inductor type, as a commercial proposition, soon died out.

One of the interesting peculiarities of the inductor type alternator, as usually built, was in the enormous stray field appearing in the shaft, bearings, bedplate, and sometimes in the engine-governing mechanism in engine type units, necessitating in at least one case, the use of brass governor balls. In the usual construction of inductor alternator, there was but one exciting winding. The magnetic circuit and the field winding were arranged as in Fig. 8, which show both the Stanley and the Westinghouse constructions. The normal or useful path of the magnetic flux is indicated by the dotted lines *a, a.* Obviously, the field coil which set up flux through these paths could also send magnetic fluxes through the shaft, bearings and bedplate along the dotted lines *b, b.* Moreover, if the two bearings were not connected by a magnetic bedplate, as might be the case in engine type machines, then, in two-crank engines the engine cylinders and other parts became opposite poles of a very powerful electro-magnet, when the field coil was excited. The

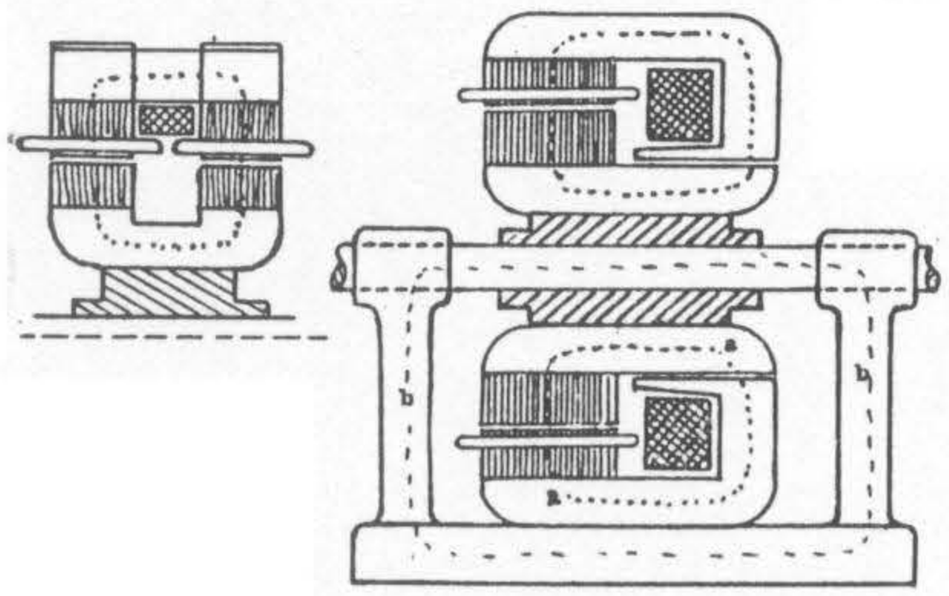


FIG. 8—SKETCH OF MAGNETIC CIRCUIT OF AN INDUCTOR ALTERNATOR

stray magnetic field set up in engine type units was sometimes so strong as to interfere with the governing mechanism. Also, with a strong undirectional flux between the bearings and shaft, each bearing became part of a small unipolar generator, of which the bearing surfaces formed the brushes. In some machines, quite heavy currents were generated in the bearings, sufficient to "eat away" the bearing surfaces or to pit them so that bad bearing operation resulted. As this was primarily a magnetic trouble, insulating the bearings from their pedestals would not stop the action. To overcome this trouble, the Stanley Company added a "bucking" coil placed around the shaft at one side of the generator, this coil being in series with the main field winding and magnetizing in the opposite direction. The ampere-turns of this bucking coil being made equal to those of the field coil, the resultant ampere-turns between the two bearings would be zero. Obviously, in an alternator with a bedplate and two bearings in which the armature frame rested directly on the bedplate, a single bucking coil at one side of the machine would not neutralize the stray field through both bearings.

ROTATING FIELD GENERATORS

Considering next the rotating field type of machines, possibly the earliest example was the Niagara type, mentioned before. This had an internal stationary armature, with windings on its outer periphery like the ordinary rotating armature. Outside this was the rotating field, consisting of a heavy forged steel ring with inwardly projecting poles. However, this type of construction was relatively expensive, and was never adopted generally. The more modern rotating field type of alternator, with external stationary armature, was a rather gradual development and, during this period, there was much heated discussion as to the relative advantages of the rotating field and rotating armature types. The rotating field gradually superseded the rotating armature construction for a number of reasons, the principal one having to do with the armature windings and voltages. In the rotating armature, the end windings were more difficult to support than in the stationary armature. Also, with the gradual advent of higher voltages, the stationary winding proved to be far superior. However, as a goodly proportion of the alternators built during this transition period were of the engine type and for low voltage, in which heavy bar windings could be used, (such being conditions under which the rotating armature made its best showing,) this type persisted for several years after the rotating field type became commercial. Gradually increasing voltages, however, necessitated the use of stationary armature machines, for at least part of the business. The manufacture of two types of apparatus for the same general purpose could not persist, and eventually that type was adopted exclusively, which allowed both high and low voltages. By 1900, the rotating field alternator had come into very general use, and the rotating armature type was disappearing. This rotating field type has persisted until the present time, although many minor modifications have been brought out from time to time, due largely to change in speed conditions, etc.

In the rotating field development, the tendency for a number of years was strongly toward the engine type construction and relatively low speeds in many cases. The construction was carried to the extreme, in some cases, where the usual flywheel capacity required for the slow speed engines was incorporated in the field structure of the alternator itself. In some cases, this meant enormously large machines for the output. A prominent example of this is found in the seventeen 6 000 kilowatt engine-type machines designed in 1899 and 1901 respectively, and installed in the Fifty-ninth and Seventy-fourth street power stations of the Interboro Rapid Transit Company of New York City. As an indication of the changes taking place in the electrical field, it may be stated here that arrangements have been made recently to take out a number of these machines and install in their place 30 000 kw turbo-generator units. The exist-

ing engine type machines are probably in as good condition now as when first installed, and are being replaced simply because they occupy too much space in proportion to their output.

The rotating field alternator of the early days was not radically different from the rotating field alternator of today, the principal differences being in the type of armature windings, methods of ventilation, etc.

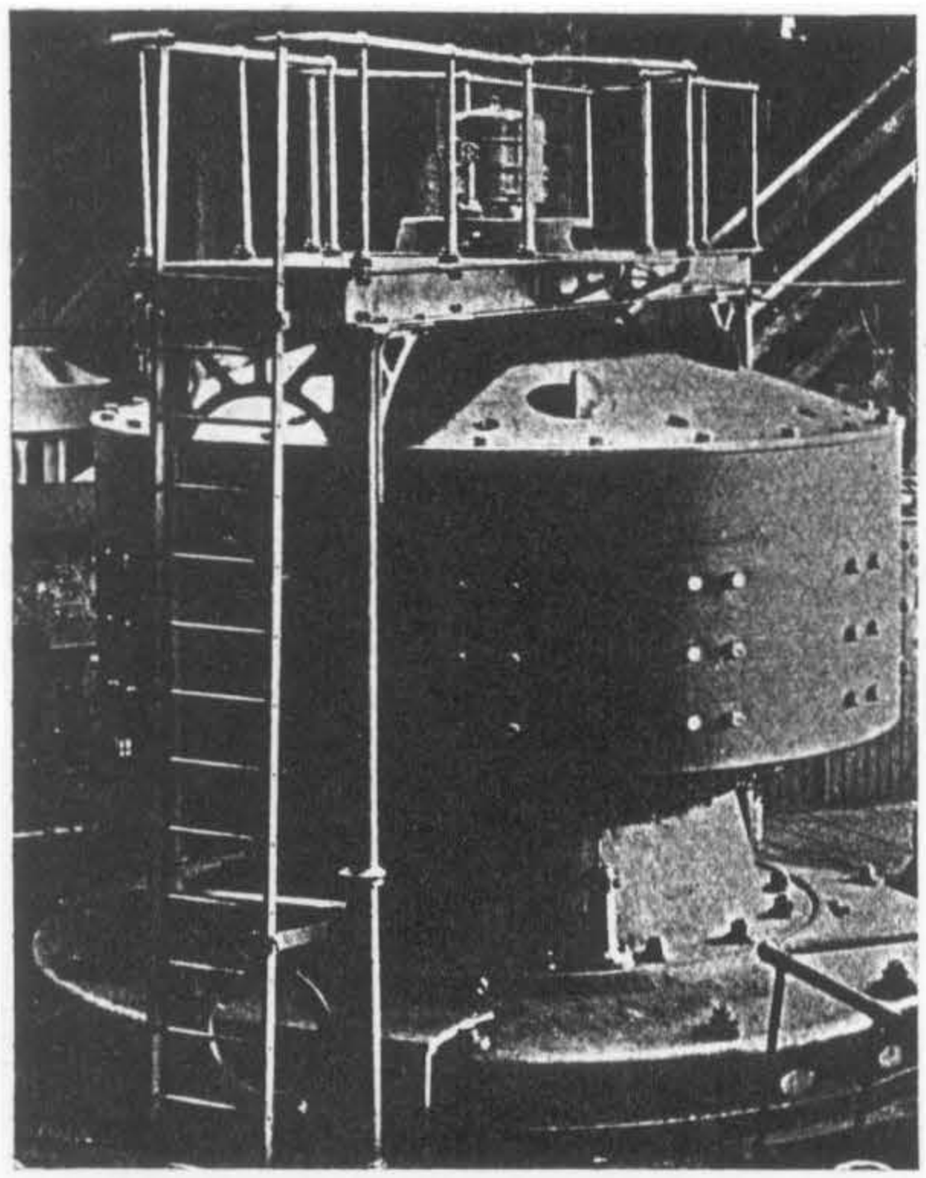


FIG. 9—SHOP VIEW OF 5 000 HORSE-POWER TWO-PHASE NIAGARA ALTERNATOR

FIELD CONSTRUCTION

In the types of field windings there has been but little change. In many of the old stationary field machines of large capacity, the field windings consisted of strap wound on edge, one layer deep. For smaller machines, either square or round wire was commonly used In the later rotating field machines, similar constructions are used. In the construction of the field itself, there have been some variations and modifications. In many of the older machines the poles were laminated as at present. The method of attaching the poles varied in different constructions. In many of the earlier Westinghouse rotating fields the laminations were punched with two or more poles in one piece, the poles having no overhanging tips, and the field coils being held in place by metal wedges between pole tips, fitted into notches or grooves at the pole tips, each pole being attached to the field ring or yoke by means of bolts or dove-tails. This latter construction possesses numerous advantages, in that cheap dies can be used, and the same pole punchings can be used for a number of different designs, in which either the diameter or the number of poles is varied.

WATER WHEEL TYPE GENERATORS

With the advent of the turbo-generator on a large scale, the engine type rotating field alternator almost disappeared from the manufacturing field, except in the smaller size units. However, during this period there has been a gradual development in the use of water powers, and water-wheel driven generators have come into much greater prominence in the past few years. In this line of development, speeds and capacities, unheard of in the earlier days, have become accepted practice with the development of both high-head and low-head water powers. In the former the tendency has been toward very high speeds for a given capacity such as the 17 000 k.v.a., 375 r.p.m., Westinghouse machines, built for the Pacific Light & Power Company, and the 10 000 k.v.a., 600 r.p.m., Westinghouse generators, built for the Sao Paulo plant in Brazil. Typical examples of low-head, slow-speed practice are found in the 60 cycle, 75 r.p.m., 96 pole, 2 700 k.v.a. Westinghouse generators for the Stevens Creek development, and the 25 cycle, 58 r.p.m., 52 pole, 9 000 k.v.a. General Electric generators for the Keokuk plant. The former are abnormal in the very large number of poles required for moderate output, while the latter are abnormal in the very low speed. Both of the above machines are of the vertical type, and are examples of a very pronounced tendency toward vertical machines, which has been apparent in the later water wheel practice.

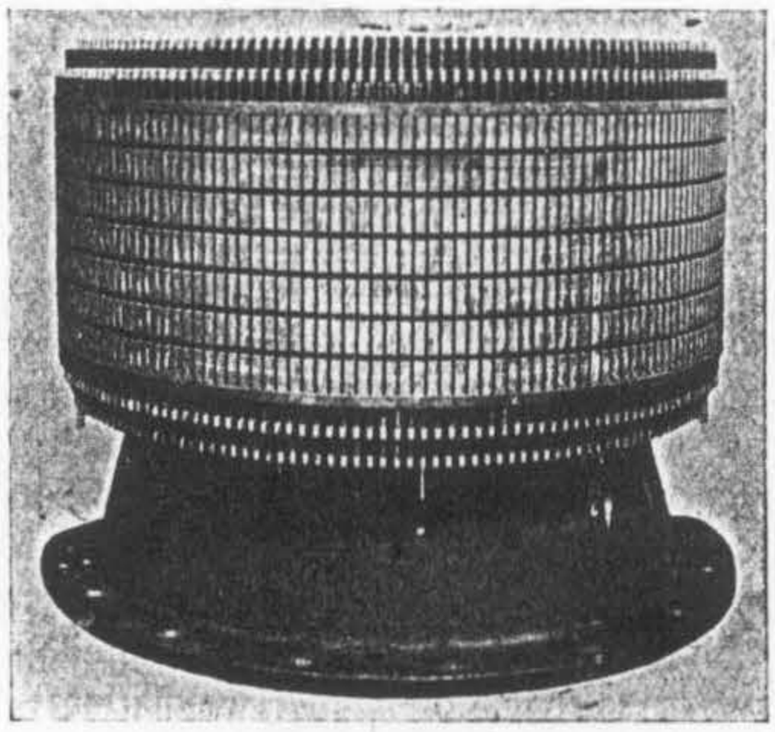


FIG. 10—STATOR OR ARMATURE OF NIAGARA ALTERNATOR

On account of the high speeds of some of the modern rotating field alternators, mechanically stronger spiders have come into general use. Even in moderate speed units the usual high runaway overspeed of 100 percent has necessitated the use of very substantial spiders.

(*To be continued*)

Electrical Journal March 1914

The Engineering Evolution of Electrical Apparatus—III

THE ALTERNATING-CURRENT GENERATOR IN AMERICA (Cont.)

B. G. LAMME

DURING the past few years, some very interesting spider constructions for the rotating fields of large high speed alternators have been built to meet the severe speed requirements. Some of these have been made up of cast steel centers or spiders with cylindrical rims built up of overlapping laminated punchings, thoroughly bolted together and attached to the spider by dove tails. The outer periphery of the laminated ring carries dove-tail grooves for poles. In another construction, the entire spider consists of thick rolled iron plates, bolted together, and with dove-tail grooves on the outside for the poles. In still other constructions, the rim of the spider consists of a heavy steel ring in one or more sections to which the cast spider is bolted. Usually with this cast rim the poles are bolted to the spider. In some cases the rim forms an integral part of the spider itself, being cast with the spokes and hub. The type of construction adopted in each case is, to a large extent, dependent upon the stresses to be taken care of, so that no one type seems to fit all cases to best advantage.

THE PROBLEM OF VENTILATION

In the later rotating field alternators the problem of ventilation has received much consideration, especially in the case of machines operating at abnormal speeds. In very high speed machines of very large output the armature and field cores have a ratio of width to diameter which is relatively much greater than in ordinary machines, and this has necessitated abnormal conditions of ventilation. Something may be said here regarding the general problem of ventilation of alternators and its influence on the evolution. Back in 1891 or 1892, radial ventilating ducts or passages came into use commercially on certain direct-current machines. The results being quite satisfactory, it was natural that alternators should have the same method of ventilation. The use of such ducts was in reality one of the great steps forward in the evolution of dynamo-electric machinery, although but little recognition has been given to this fact in electrical literature. The use of radial ventilating ducts has continued to the present time with little change except in the construction of the spacers themselves, which have been many and varied in design and materials. With the change from the rotating armature to the rotating field construction of alternators this feature was retained in full. In some of the earlier Westinghouse rotating field machines the field structure also had numerous ventilating ducts, principally for the purpose of supplying ample air to the armature ducts. Also, about ten years ago, special ventilating end bells and vanes began to be used on rotating fields, in order to set up an extra air circulation through the armature end windings, etc., due largely to the fact that the slow-speed engine-type machines of that period did not have much natural blowing action. Following this, and partly as an outgrowth of turbo-generator enclosing, came the semi-enclosed alternators, mostly for high-speed water-wheel driven units, and this practice is not uncommon at present.

The proper ventilation of an alternator or, for that matter, of any dynamo-electric machine, is very much of a problem, for no two cases, in different sizes or types of machines, are quite alike. The problem lies first, in furnishing the proper quantity of air to carry away the heat developed, and in then distributing such air in proper proportion through the complex multiple paths in the machine. The proper distribution of the ventilating air is usually the most serious part of the problem. The present solutions of the problem are based largely upon past experience, and no really workable rules have yet been developed. In arriving at the present practice many disheartening experiences have been undergone by all designing engineers. The writer has known many cases where totally unexpected results, both good and bad, have been developed and, in some of these cases, no logical explanation was forthcoming, so that the results could not be taken advantage of, with any assurance, in future work. This has been one of the most discouraging features in the general problem of ventilation.

ARMATURE WINDINGS

Something might be added here on the subject of armature windings. There have been probably as many types of armature windings developed as there have been types of alternators. The windings for the earliest smooth body and the toothed armature constructions have already been described. In the early Westinghouse polyphase alternators, two-phase was used mostly, due principally to the fact that single-phase lighting circuits formed the principal load, and, with two-phase machines, there were only two circuits from a machine instead of three circuits with the three-phase winding. Moreover, many of these very early polyphase alternators were used in reality as straight single-phase machines, taking current off one phase only. For this purpose a closed coil armature winding, like that of a direct-current generator or rotary converter, with four taps for taking off the two phases, gave about the most economical type of winding, as far as armature copper losses were concerned. When such an armature is used for single phase it

can deliver seven-tenths as much output as a single-phase machine as it can give two-phase with the same total copper loss per coil. It was partly for this reason that many of the early Westinghouse polyphase

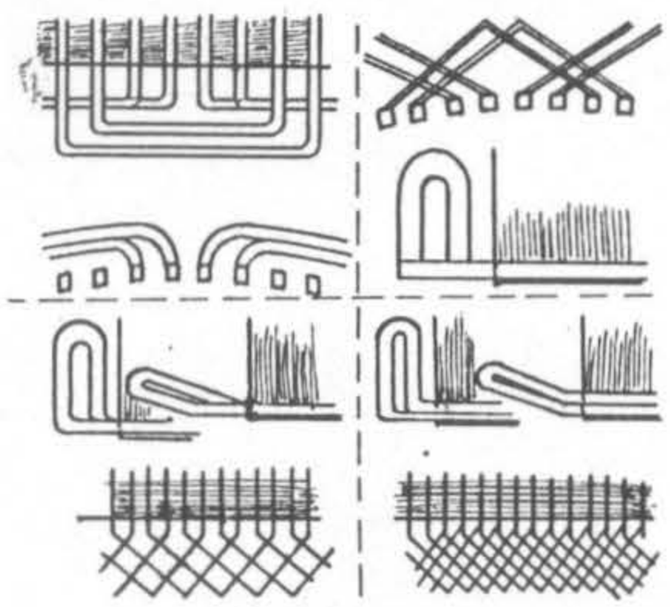


FIG. 11—VARIOUS TYPES OF EARLY STATIONARY ARMATURE WINDINGS

machines had a single closed coil winding. Another reason for such winding was that there were no definite phase groups and no high potential between phases. Furthermore, the arrangement of the end windings was such that the coils tended to interlock and support each other, thus assisting in resisting centrifugal forces. This winding was used mostly for two-phase machines, but was also used to a considerable extent on three-phase armatures.

With the advent of the rotating field type of machine, this closed coil type of armature winding was not used to any great extent, open-coil two-phase and star-connected three-phase taking its place. Delta-connected three-phase was used in very rare cases, as there was danger of circulating current with such windings.

In the construction of armature windings possibly more radical changes have taken place than in the types of windings. Many of the larger low speed rotating armature alternators had bar windings with separate end connectors, soldered or bolted on. Many of the earlier stationary type armatures had either built-up bar or strap windings, or concentric type windings in which each phase winding was arranged in a concentric group, and the groups of the different phases overlapped each other. Some of these were made with partially closed slots and others with open slots. The built-up bar or strap windings were frequently of the partially closed slot type, while the concentric windings were more usually of the open slot type. Gradually, however, both these types of windings were superseded by the "duplicate coil" type of winding, similar in appearance to the usual direct-current armature and induction motor primary windings. This later type of alternator winding was arranged in two layers of coils at the ends, in either one or two layers in the slots. The two-layer, two-coil per slot arrangement is now practically the standard. These types are illustrated in Fig. 11.

In the rotating field machines, partially closed slot construction was carried to comparatively high voltages. For instance, the 6 000 kilowatt, 75 r.p.m., 11 000 volt, three-phase generators built for the Manhattan Elevated Railway in 1900 had three bars side by side, in each slot, with soldered-on end connectors.

As the partially closed slot and the open slot constructions are radically different from each other, something should be said regarding the reasons which prompted the use of either type. As already indicated, the partially closed slot type came in with the larger rotating-armature low-voltage alternators in which bar windings could be used. This construction gave good mechanical support for the bars in the slots, thus avoiding the use of bands. Moreover, with the very narrow slot openings at the top of the slots, there was very little "bunching" of the magnetic flux at the armature tooth tips with the consequent low pole face losses, even with very small air-gaps, and high gap flux densities. The disadvantages of the partially closed slot is found largely in the type of windings required.

In these early machines, it was not found practicable, in general, to use completely formed and insulated coils with such slots, and therefore, either hand windings or built-up types of windings were used. While these were possible and practicable in a manufacturing establishment, yet such types of

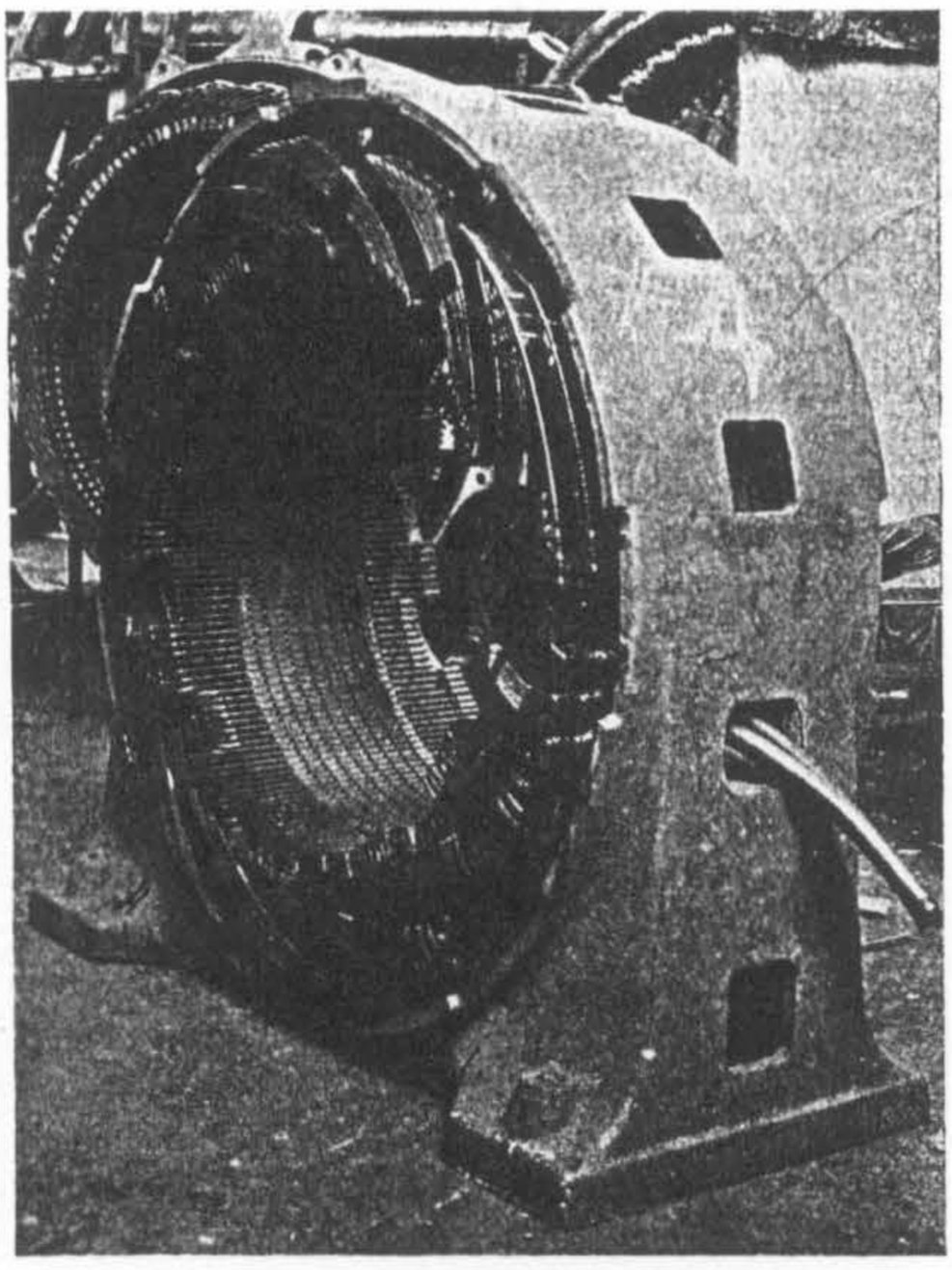
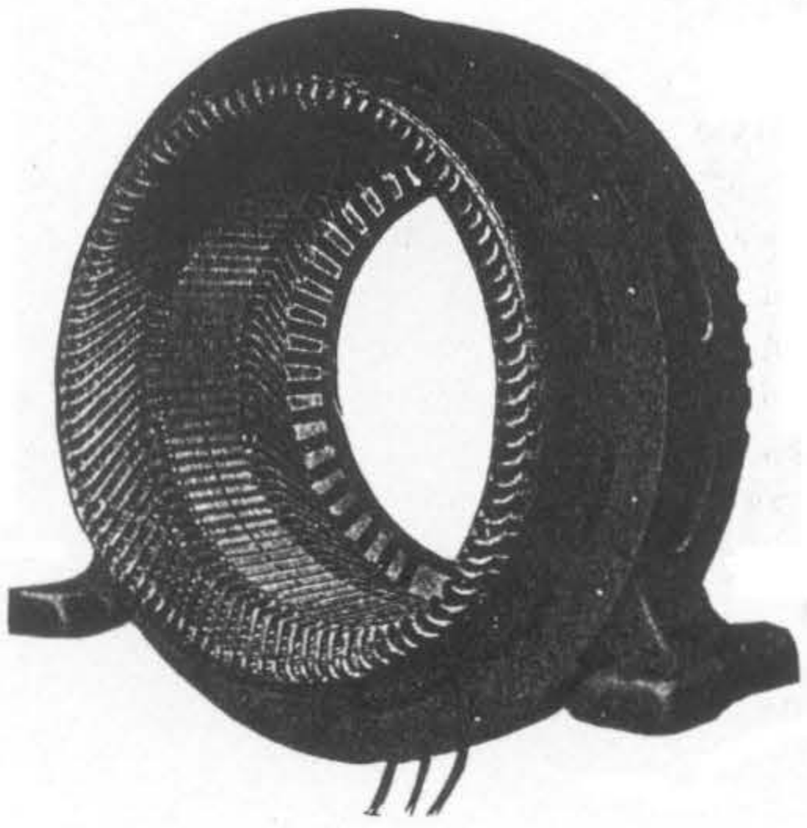


FIG. 12—BAR AND END CONNECTOR TYPE OF WINDING WITH PARTIALLY CLOSED SLOTS

windings are usually difficult to repair by the ordinary operator inexperienced in the refinements of armature winding. When it comes to repairs, the usual machine-wound coil, which is completely insulated before being placed on the armature core, is very superior

but, in general, this type of winding requires an open slot construction. However, when the stationary armature construction came into general use, the advantages of the overhanging tooth tips in supporting the coils largely disappeared. There remained there-



FIGS 13—DUPLICATE COIL TYPE OF WINDING, TWO COILS PER SLOT

fore the disadvantages of the flux bunching, against the advantage of coil construction, if open slots were used. However, the use of laminated poles, and the judicious proportioning of the air-gaps and flux densities, to a great extent eliminated the losses due to open slots. In consequence, the open slot construction and the duplicate type of armature coil, have apparently come to stay, in this country.

Various attempts have been made to obtain the advantages of both the open and the partially closed slot arrangements. Probably all large manufacturers of alternators have tried some form of magnetic wedge, instead of the usual fibre or wood wedges which serve to retain the coils in the slots. Another arrangement is the equivalent of combining two or more open slots in one, with an over-hanging tooth tip, which covers the slot with the exception of the width of one coil. Two or more completely insulated coils are fed successively into the slot opening and arranged side by side. This does not give any narrower slot opening than with the open slot construction, but the number of openings is reduced to one-half, or one-third. This construction is used rather extensively in the rotors of large induction motors, but apparenty is but little used in generators.

Bracing of the end windings against short-circuit shocks has been a comparatively recent practice. The necessity for such bracing has been dependent to a considerable extent upon the output per pole, and the old time machine seldom had such a large output per pole that the short-circuit current-rushes were sufficient to cause dangerous distortions of the end windings. However, such bracing was used on the Niagara machines, previously described, and also on the Manhattan generators above referred to. These, however, were very rare instances. However, with the recent high-speed, high-output water-wheel generators, the outputs per pole have become such that some form of end bracing has become rather common.

Modern Westinghouse machines of this kind are braced to stand a dead short-circuit across the terminals without damage to the windings. Under this condition, these large machines may give a momentary current rush of from ten to twenty times the rated full-load current. However, the bracing required on the end windings of such machines is of relatively much less importance than on turbo-generators of corresponding capacity, due to the fact that, in the former class of machines, the end windings are relatively short compared with those of turbo-generators.

The above description brings us practically up to date, as far as the ordinary synchronous alternator is concerned. No description of the development of the turbo-alternator has yet been given. This forms a rather distinct development which should follow at this point presumably, but it is thought advisable to interpolate here some description of the problems of parallel operation, e.m.f. wave form, regulation, etc., which came into prominence and were practically taken care of previous to the advent of the turbo-generator on a large scale.

PARALLEL OPERATION OF ALTERNATORS

One of the great problems which developed in the operation of alternators was that of the parallel running of two or more units. At one time this was a very serious question, but in recent years, it is very

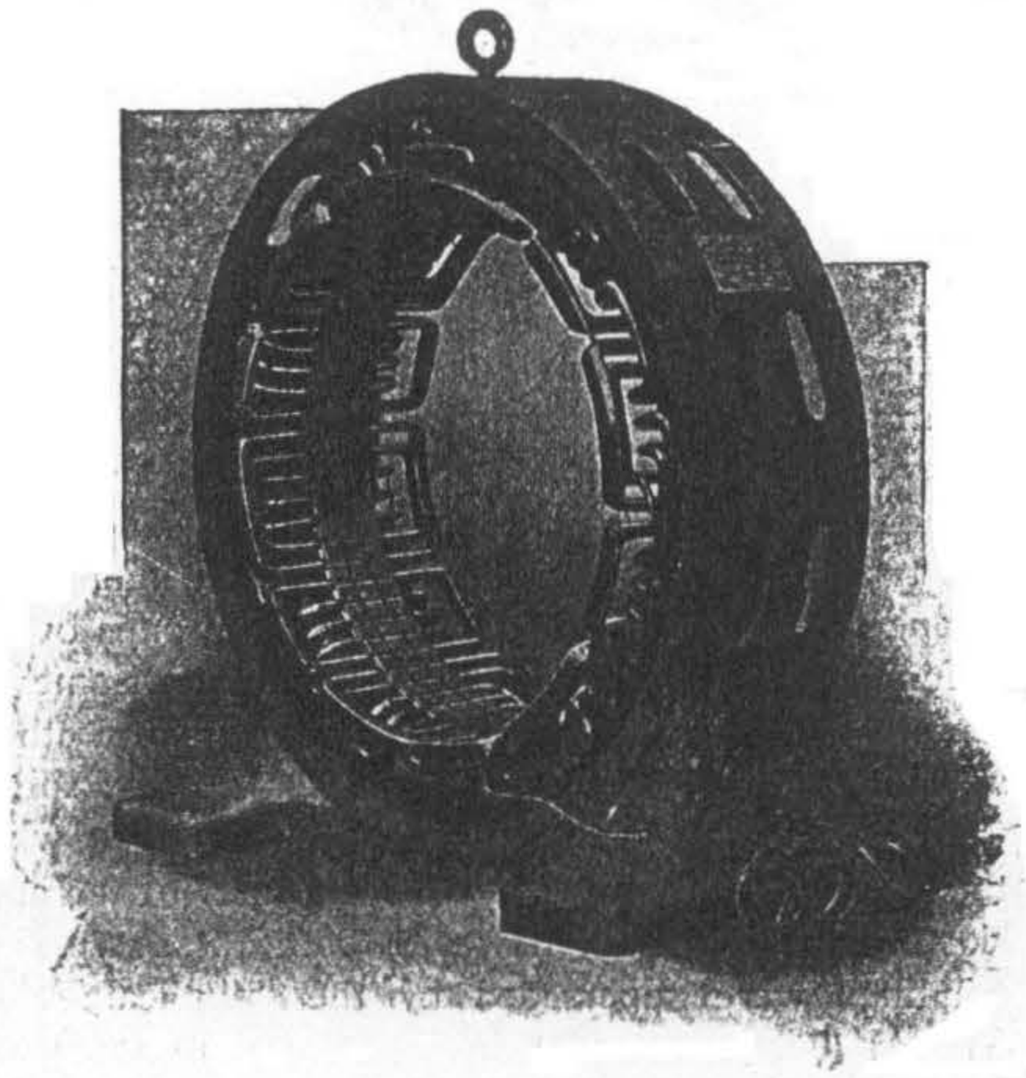


FIG. 14—DETAIL VIEW OF THREE-PHASE CONCENTRIC WINDING

seldom heard of. Considering the almost universal practice of paralleling alternators, which holds at the present time, one might be led to wonder why there ever was any trouble. Far back, in the days of the high-frequency surface-wound alternators, paralleling was attempted in many cases and, not infrequently,

with considerable success. However, a failure in an attempt to parallel, in those days, usually meant the destruction of the apparatus. Those old time surface-wound alternators usually had very low self-induction,

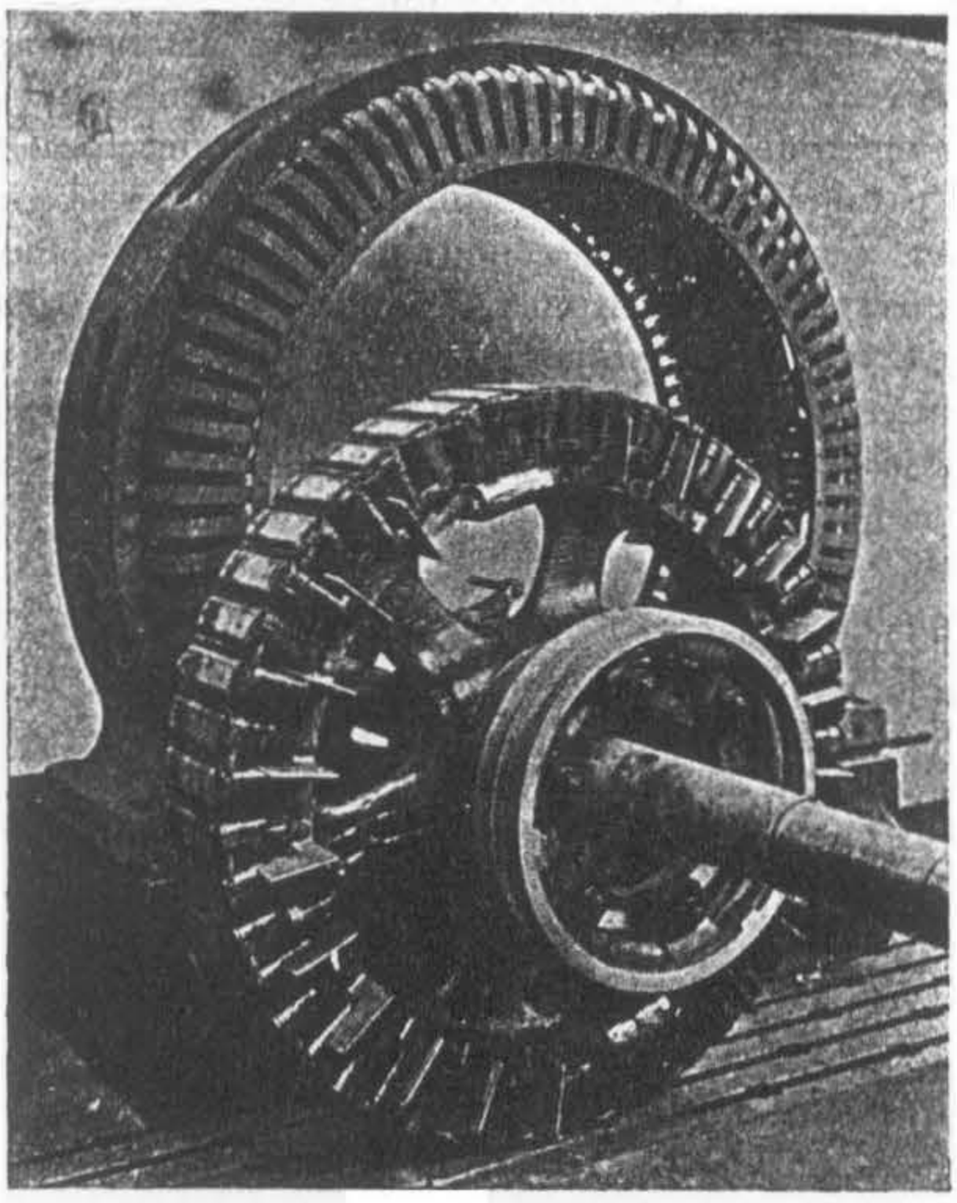


FIG. 15—75 K.V.A., THREE-PHASE, 60 CYCLE, 2 300 VOLT, 150 R.P.M. ROTATING FIELD ENGINE TYPE ALTERNATOR

so that, in case of sudden short-circuit, an enormous current could flow, sufficient usually to strip the armature winding from the core, by bursting the bands, or otherwise. A failure in an attempt to parallel two machines was practically equivalent to a short-circuit, and this usually meant destruction of the apparatus. However, if once paralleled successfully, the machines usually did not act badly. One favorable condition, not then appreciated, was that all these early machines were belt-driven. It may be said, however, that in those days parallel operation, while considered possible, was also considered more or less risky. In the period immediately following the surface-wound alternator, parallel operation was very much the exception, rather than the rule and, when engine-type alternators came into use, paralleling was considered for several years as very questionable. At this time the situation was as follows:—Belted alternators could be paralleled in many cases. Direct-coupled alternators, if flexibly driven, could be paralleled almost as well as belted machines, while direct-coupled or engine type generators, without flexible coupling or drive, could not be relied on to parallel without hunting. It thus became recognized that some flexibility between the generator and its prime mover was an important adjunct to parallel operation. This led to the consideration that the engine might be back of the difficulty in many instances, and it was then assumed that inequalities in the regular rotation resulting from insufficient flywheel or from hunting governors, tended to cause hunting in the generators. Investigation showed that such conditions did tend to produce hunting, but that the magnetic conditions in the machine itself would oftentimes maintain, or even accentuate, the hunting. Obviously, therefore, the trouble was both in the prime mover and in the generator. It was noted further that if the angular fluctuations in the driving power were relatively small, hunting usually would be very small, or would not be apparent at all. It was further recognized that, with belt or flexible drive, which tended to smooth out the speed fluctuations due to the prime mover, the hunting tendency tended to disappear. Attention was then turned toward improvement of the prime movers, especially in engine-type machines, in order to reduce fluctuations in angular velocity by means of heavy flywheels, and by means of dampers of some sort, such as dashpots, on the governing mechanism of the engine. Much improvement was accomplished in this way.

The Introduction of Dampers—During this period many attempts were made to lessen the tendency of the alternator to maintain hunting. Investigation showed that, during hunting, the magnetic flux in the field poles shifted back and forth across the pole faces in time with the hunting, while such action did not occur when there was no hunting. This at once led to the theory that a low resistance winding on the pole face , or imbedded in the poles, would prevent or oppose this flux shift, and thus assist in overcoming hunting. However, about this time, rotary converters were coming into use, and it was found that, in such machines, hunting was usually more severe than in alternators, so that, in this country, the first true application of damping windings or devices to stop hunting were applied on rotary converters. It was also noted at this time that solid pole generators and rotary converters did not hunt to the same extent as did laminated pole machines, and it was correctly assumed that the solid pole faces gave an effect similar to that of low resistance damping windings. However, as it was desirable to use laminated pole tips, copper dampers on the poles gradually came into use. Some of these early dampers were very crude in form and type compared with present constructions. However, imperfections in the construction of the dampers were balanced to some extent by the large section of copper used

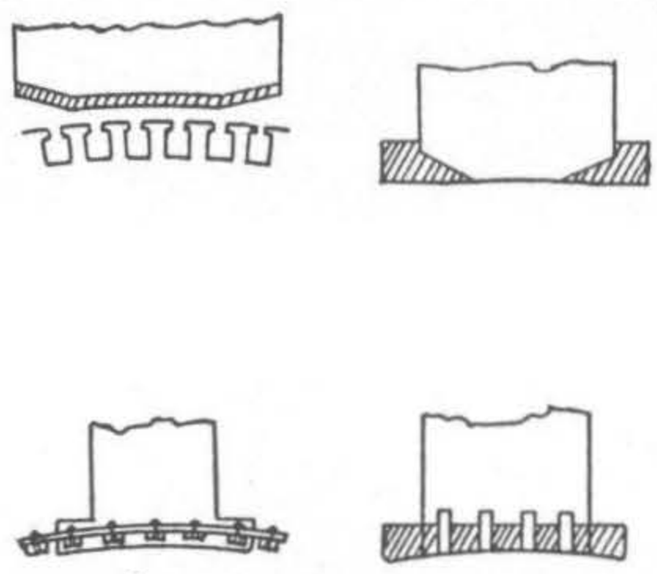


FIG. 16—VARIOUS FORMS OF DAMPERS

and consequent low resistance. The earliest form of damper used in this country consisted of copper rings surrounding the poles and copper tips overhanging the beveled pole edges. This was the form most commonly used on converters. On alternators, in some cases, the damper consisted simply of a low resistance ring around each pole. In still other cases the damper consisted of a heavy copper plate covering the pole face. This latter construction was only possible in machines with large air-gaps and very narrow or partially closed armature slots. These crude forms of dampers were gradually superseded by the so-called "grid" damper which consisted of a copper grid surrounding the pole and with ribs which lay in slots in the pole face. These various types of dampers are shown in Fig. 16. In very few cases were these old types of dampers so interconnected as to form a complete cage winding around the field.

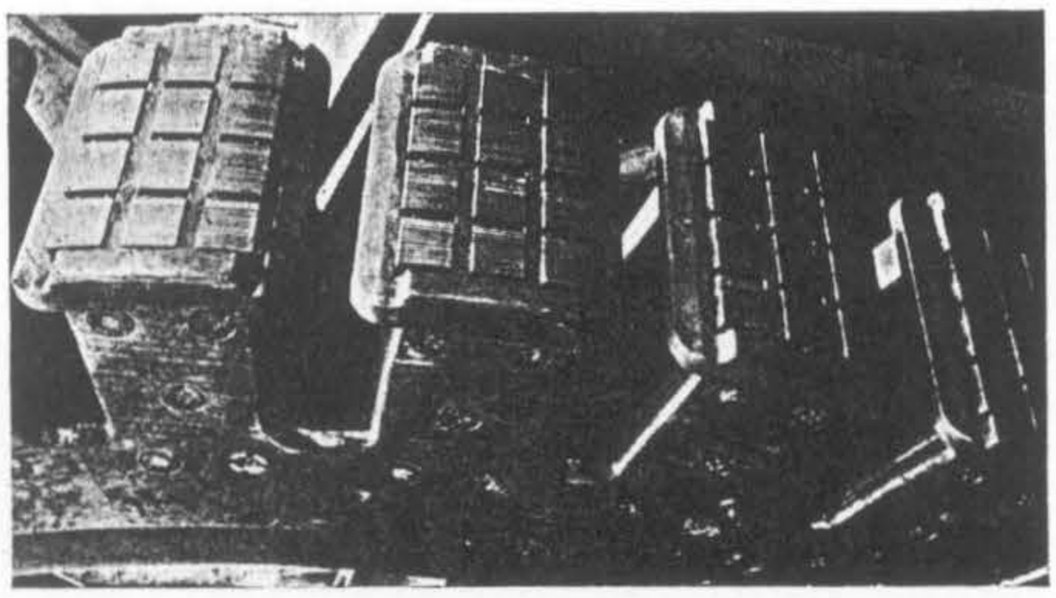


FIG. 17—GRID DAMPERS ON FIELD POLES

Many tests were made at various times to determine the effect of interconnecting the grids on the different poles to form one complete cage. As a rule, there was no appreciable gain, and it was then assumed that such interconnection had no material advantages. However, it later developed that the reason why interconnection of the dampers did not improve the damping action very materially, was due largely to the very great amount of copper in those parts of the grid dampers lying between the poles.

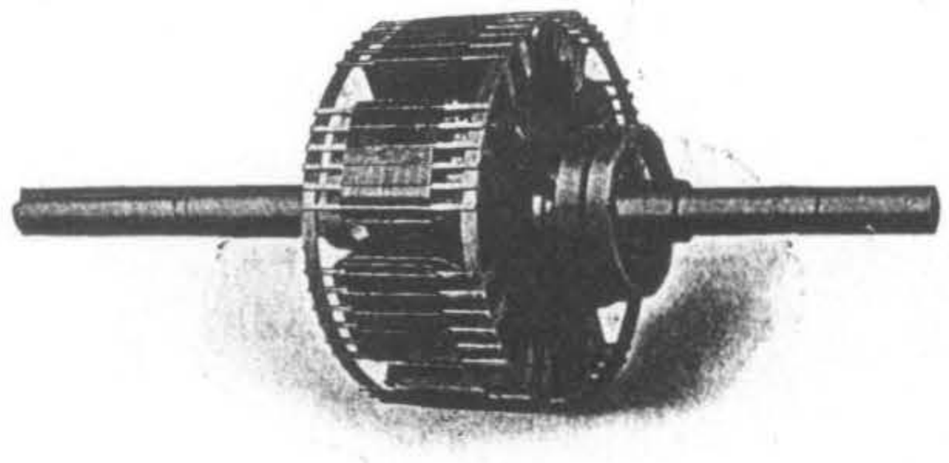


FIG. 18—CAGE WINDING TYPE OF DAMPER

The grid damper was very effective, but was expensive in material, and was not easily applied on poles with overhanging pole tips. This type of damper was gradually superseded by one smilar to the usual cage winding on the secondaries of induction motors, and this is the type which is in most general use at the present time. This construction has practically the same effectiveness as the old grid type, but is much more economical in material and, being placed in partially closed slots, it does not as greatly affect the iron losses in the machine, as was liable to be the case with the open slots, generally used with the grid damper.

With the gradual introduction of dampers and improvements in angular rotation of the prime movers, hunting troubles in alternators practically disappeared, and parallel operation presented no difficulties, except under very abnormal conditions. Apparently these dampers or "amortisseurs," as they are sometimes called, were first proposed by the French engineer, Maurice LeBlanc, about 1891. However, they were "rediscovered" in this country by engineers who were not familiar with the above engineer's work.

VOLTAGE WAVE FORM

The e.m.f. wave form of alternating-current generators has been a matter of much discussion since the early days of alternator design. The old surface-wound machines gave a very close approximation to a perfect sine shape, due to the arrangement of the winding and to the very large air-gap. The first toothed armatures, with their very small air-gaps, gave e.m.f. waves which departed very widely from a

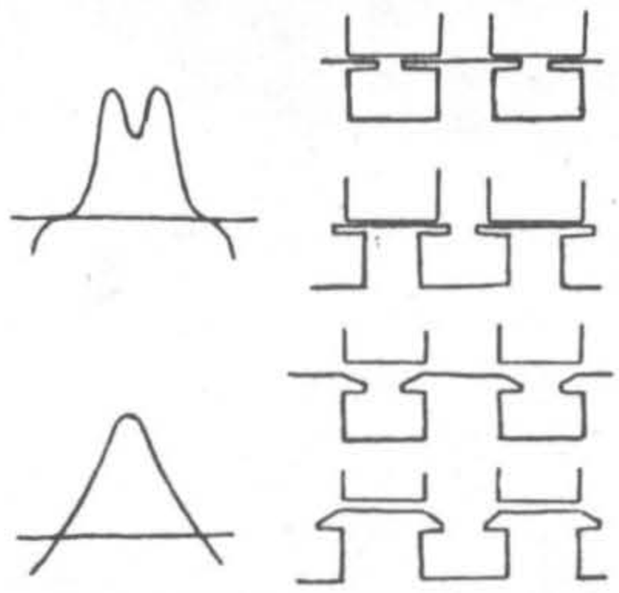


FIG. 19—VOLTAGE WAVE FORMS
Of early toothed armature machines and of later toothed armatures with larger air gaps and beveled poles.

true sine. In fact, this had about the worst wave form of any of the alternators which have been put out by the Westinghouse Company. Its shape was somewhat like that shown in Fig. 19, as would now be expected when the configuration of the armature tooth tips is taken into account. The later toothed armatures with large air-gaps and beveled tooth tips gave much better wave shapes.

With the advent of the true polyphase windings and the slotted armatures with several slots per phase per pole, fairly close approximation to sine shaped e.m.f. waves became common. In the first Niagara Falls 5 000 horse-power, two-phase alternators, the voltage wave was slightly flattened on the top due to the fact that the pole face width was somewhat greater than the width of each phase group in the armature. . When very high voltages came into general use, and especially in machines with small pole pitch, the number of armature slots per phase per pole was reduced to a minimum in order to lessen the total insulation space. In extreme cases, but one slot per

phase was used, giving but two slots per pole for two-phase and three slots per pole for three-phase. Such windings required special shaping of the field pole tips in order to approximate even roughly a smooth wave form of the sine shape. Later practice, however, has tended toward the equivalent of at least two slots per phase per pole, in order to obtain better results. Sometimes the desired result is obtained by the use of one extra idle or "hunting" tooth per phase.

In the early days of parallel operation of engine type alternators which, as described before, represented the most difficult conditions, great stress was laid upon the question of wave form in some of the discussions of parallel operation, and particularly, in the operation of rotary converters without hunting. Gradually, however, this question disappeared and it became recognized that all the cases of hunting encountered could be explained in some other way than by the e.m.f. wave forms, and it is now generally accepted that about the only effect on parallel operation due to wave form lies in possible circulating currents of higher frequency than the fundamental.

At the present time, a very close approximation to the sine shaped wave is considered preferable for general purposes, especially in transformation and transmission work. There have been some instances of telephone disturbances due to wave form but, as a rule, some local peculiarities of the distribution circuits have been involved in this trouble, for, in other cases, similar or even worse shaped waves have given absolutely no telephone disturbances.

REGULATION AND COMPOUNDING

Something should be said on the subject of regulation of alternators, for this is a very important characteristic, and has had considerable influence on types and designs. The old surface-wound alternators had extremely good regulating characteristics due to their low armature self-induction and low armature reaction consequent upon their large air-gaps. The writer does not know what value the current rose to, on steady short-circuit, compared with the normal rated current, but it was probably four or five times full load. The current rush on short-circuit was probably five times as great as the steady value. It is not to be wondered at that such armatures not infrequently wrecked themselves in case of a dead short-circuit. In the later toothed armature types, the armature self-induction and reaction on the field were very much larger, proportionately, than in the surface-wound machines. This, however, spoiled the regulation and some method of compounding was used, as already described. This compounding was common practice until larger capacity machines, especially the engine type, came into use. Even some of these latter were compounded by commutating the armature current (either directly or from a series transformer) and compounding the exciter field by means of the commutated current. A few of the smaller size alternators were both self-excited and compounded by commutating derived alternating-current circuits from the armature. This, however, was found to be very delicate, as the excitation and compounding were greatly affected by changes in the power-factor of the load, and by changes in speed.

One early attempt was made to compound single-phase alternators to correct for power-factor. In this case the commutated armature current was sent through the series or compound winding of the exciter. The brushes on the alternating-current commutator were so set that at 100 percent power-factor they were commutating about the middle of each voltage wave. In consequence, the current delivered to the brushes was not a true direct current but consisted of a double number of half waves, half of which were inverted, and the direct-current component of this commutated current was small and had but little compounding effect. However, with change in power-factor of the load, the phase of the current shifted, so that at some reduced power-factor, commutation occurred at the zero point of the current waves and the resultant current was all effective for magnetizing the exciter field. The total commutated voltage was very low and the commutator bars were shunted by a resistance so that there was no bad sparking, even when commutating at the middle of the current wave. This method did actually compound fairly well for change in power-factor, but the field for such method proved to be very limited, for compounding of alternators fell into disuse shortly after this.

The usual method of compounding on the early alternators was simple series current compounding, just as in direct-current apparatus. Where the commutated current was supplied directly to the field compound winding, voltages of about 30 to 60 volts were most common at rated full load. With much higher than 60 volts, there was a liability of short-circuiting the compounding by arcing between bars on the commutator. There was also a liability of arcing or flashing when the phase of the current shifted due to change in power-factor.

When polyphase rotating armatures came into use, similar methods of compounding were resorted to. However, the secondary current was a resultant of the two, or three primary currents, for each of the primary phases was carried around the compensating transformer (or spokes of the armature) and the secondary winding carried a current in phase with the resultant of the primary ampere-turns. In the case of three-phase windings, the direction of one lead was reversed around the compensating transformer. Some curious conditions arose from the phase relations of the secondary current when parallel operation was practiced. It was necessary, when parallelling the main winding, to parallel also the compound winding. As the compounding current from each machine pulsated from zero to maximum value in each alternation, it was necessary to so parallel the terminals that all the commutated currents had zero value at the

same instant, otherwise, the brushes on one commutator would, at times, short-circuit the current from the other commutator.

With the advent of larger belted machines, and of engine-type machines in particular, the compounding of polyphase machines was more or less unsatisfactory and was practically abandoned. To compensate for the lack of compounding, better inherent regulations were aimed at in the designs. This meant, primarily, machines which would give comparatively large currents on steady short-circuit, three to four times full load being rather common, and even six times full load being attained in some machines. The momentary current rush at the instant of short-circuit must have been excessive on some of these machines, due to their very low armature self-induction. However, due to the relatively small ampere-turns per pole, no very destructive distortions were found in practice. This characteristic of the short-circuit currents was carried into the rotating field construction, and even into the early turbo-generator work.

This practice of giving the alternators good inherent regulation was expensive in a number of ways, as it usually meant higher iron losses and less output than was possible otherwise, with a given size machine, or a given amount of material. Even at this early date, it was recognized that some form of automatic field current regulator which would maintain the terminal voltage constant, regardless of the inherent regulation, would be a very useful piece of apparatus. Some form of regulation which would take care of change in power-factor, as well as load, was the aim of many designers. Among the different schemes brought out, the Rice method of compounding, brought out by the General Electric Company, is of interest. This was used principally with rotating field alternators. In this scheme, the exciter was usually placed on the same shaft as the alternator field, and, in such case, had the same number of poles as the alternator. The leads from the alternator armature were carried through the exciter winding in such a way that a lagging current, carried by the alternator, tended to strengthen the field of the exciter by shifting the armature reaction with respect to the exciter field poles. In this way a compounding action on the exciter was obtained which was practically in proportion to the demands of the alternator field with varying power-factor. In the case of engine-type machines of comparatively low speed, the exciter was geared to the alternator shaft, so that it ran at a considerably higher speed and the number of poles in the exciter was correspondingly reduced.

This method of compounding was effective, but the whole combination was apparently unduly complicated and expensive. Furthermore, it did not give the desired compensation under all conditions of operation, as it would not correct for changes in speed.

A later method of compensation for power-factor was devised by Alexanderson, and was used on a limited number of General Electric machines. In this scheme a derived current from the alternator itself was commutated in such a manner that compensation, proportional to the power-factor, was obtained. This was a purely self-excited alternator scheme and, like all self-exciting schemes in such apparatus, it was sensitive to speed changes, probably to a much greater extent than the Rice arrangement above described. A fundamental defect in all self-exciting compensated alternator schemes lies in the fact that stability of excitation is dependent upon having considerable saturation in the alternator magnetic current and, coincidently, if there is such saturation, the compound current has no direct relation to the load or power-factor. Thus such machines are either sensitive to speed changes, or their compounding is only approximate.

Following these scheme came the use of automatic regulators of which the Tirrill is best known. This regulator acts directly on the exciter field by short-circuiting a resistance in series with the field winding, the range of exciter voltage being controlled by the length of time the rheostat is short-circuited. Instead of cutting the resistance out in steps, which tends to give sluggish action in the fields, the Tirrill regulator cuts the whole resistance out each time, and the length of time is varied. This results in quick action. As the regulator tends to hold constant voltage at the alternator terminals, or on the line, change in power-factor or in speed does not modify the action. This type of regulator has proven very effective, especially in the case of alternators subjected to sudden and violent changes in load, power-factor and speed.

With the advent of larger alternator units, in proportion to the changes in load, the inherent regulation has been made relatively poorer, primarily because better machines otherwise are thus obtained. The short-circuit currents are reduced, and relatively lower iron losses, and lower temperatures or, higher outputs with a given temperature, are obtained. This has been carried further in turbo-generator design than in any other class of alternators, due partly to fundamental limitations in design. However, this poorer inherent regulation has proven to be of no practical importance, where suitable automatic regulators have been used with the machines.

One fallacy which was frequently found in the past, and which still persists to some extent, is that alternators should have equal inherent regulation to parallel properly. This is based partly on the feeling that the field currents of the alternators should vary over equal range when carrying their proper proportion of load, together with the knowledge that the variations in field current are dependent, to some extent, upon the inherent regulation. However, the fact that the shape of the saturation curve, in a given alternator, may have much more influence on the excitation, especially at high saturations, is usually overlooked.

(*To be continued*)

Electrical Journal April 1914

The Engineering Evolution of Electrical Apparatus—IV

THE ALTERNATING-CURRENT GENERATOR IN AMERICA (Concl.)

B. G. LAMME

TURBO-GENERATORS

THE ADVENT of the turbo-generator has had a predominant influence on alternator design. After the turbo-alternator once became established commercially in this country, it quickly revolutionized conditions by driving the large engine-type alternators out of the field. The evolution of all electrical apparatus has been comparatively rapid, but that of the turbo-alternator has possibly exceeded anything else in the electrical field. This evolution therefore merits a fairly complete description.

The first turbo-alternators, built by the Westinghouse Company, were installed in the power plant of the Westinghouse Air Brake Company about 1898. There were three rotating armature machines of 300 kilowatts capacity, which ran at a speed of 3 600 r.p.m.,

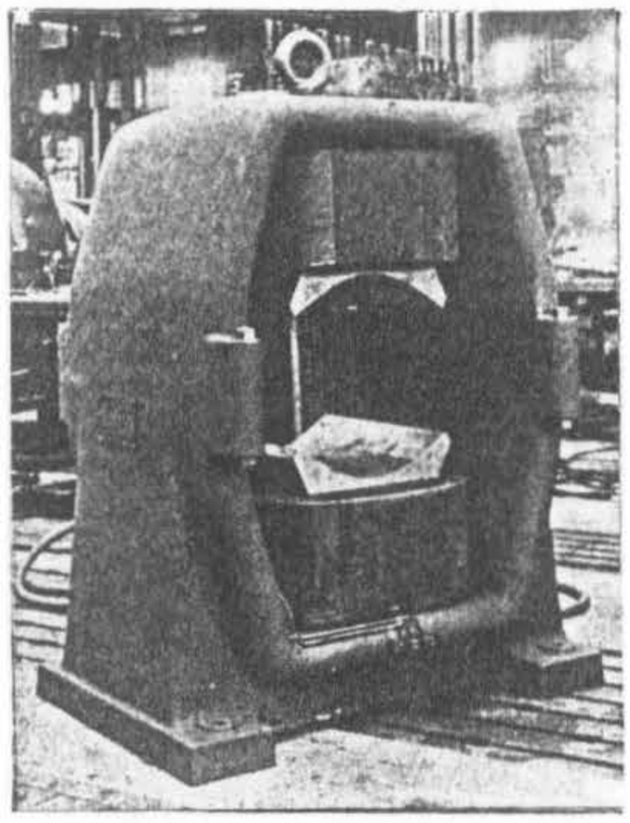


FIG. 20—FIELD OF EARLY ROTATING ARMATURE TURBO-GENERATOR

giving 7 200 alternations per minute, or 60 cycles per second. They were coupled to Parsons turbines, built by The Westinghouse Machine Company. The Parsons Company in England had been building rotating armature alternators for a number of years, and the Westinghouse Company simply followed the Parsons' precedent. These first machines were operated for several years, but it was obvious, soon after their installation, that the rotating armature type of machine would not serve for general turbo-alternator purposes. It was evident that, for voltages even no higher than 2 200, the rotating armature construction, at the necessary turbo-generator peripheral speeds, would become almost impracticable. Attention therefore was soon turned toward a 3 600 revolution, two-pole, rotating field type, and a very large number of possible constructions were considered. Finally one like that shown in Fig. 23 was worked out and built in 1899. This had the field windings completely embedded in a number of parallel slots, with supporting metal wedges at the tops of the grooves or slots. One machine of this type was built and tested. It operated in a satisfactory manner, except as regards windage and noise. The machine was not closed at the ends, like modern turbo-alternators, and thus any noise generated in the ma-

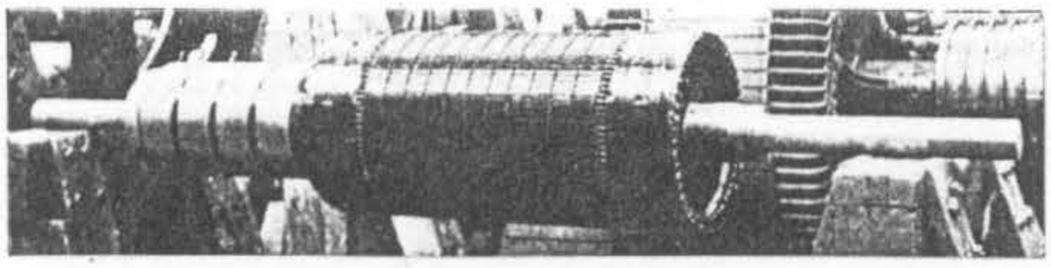


FIG. 21—ARMATURE FOR TURBO-GENERATOR OF TYPE SHOWN IN FIG. 20

chine could be readily transmitted to the outside. The noise was caused largely by the two flat sides of the rotor. It was so shrill and penetrating that it was very disagreeable to be around the machine, and was even painful to the ears after a short time. This construction was therefore abandoned temporarily, but after a few months it was taken up again and a new rotor was built which was entirely round, as shown In Fig. 24, but was otherwise very similar to that shown in Fig. 23. This new rotor, although noisy compared with modern machines, was so quiet, compared with the first construction, that it was immediately adopted as a standard construction. This is the now well-known parallel slot construction which has been used very extensively by the Westinghouse Company, although many very radical changes have been made in the constructive features of the rotor itself. This type of rotor was used originally only for

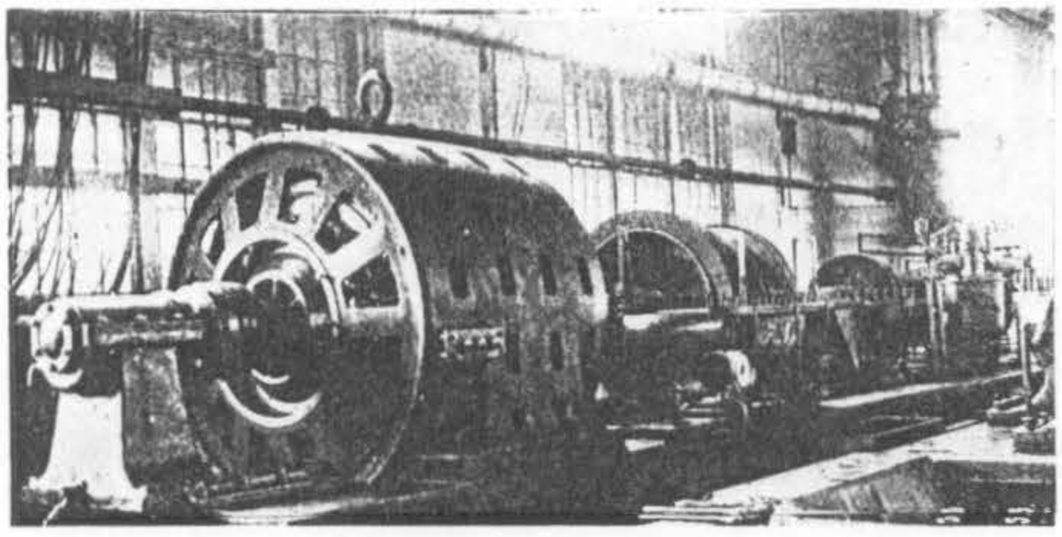


FIG. 22—1 000 KW OPEN TYPE TURBO-GENERATOR

the 400 kilowatt size at 60 cycles.

In the earlier machines of this type a number of very curious conditions developed. In the first machines the rotors were built of a number of thick discs or "cheeses" side by side, which were put on the shaft at high pressure. The two end discs were thicker

than the others in order to accommodate the grooves in which the rotor end windings lay. The discs were made of high grade forgings. After some of these machines had been in operation for a considerable period it was found that some of the discs in the field core were traveling axially, i.e., quite appreciable gaps

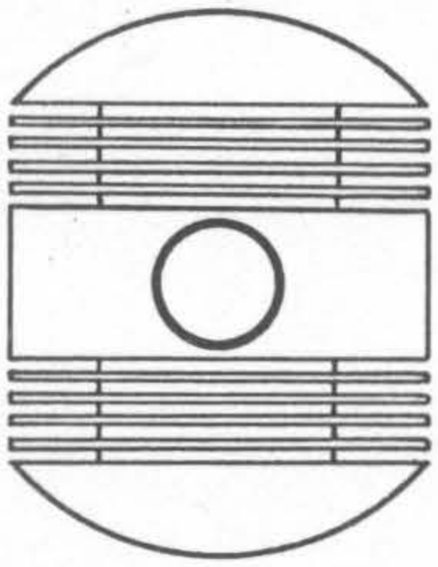


FIG. 23—EARLY TWO-POLE ROTATING FIELD

or spaces were showing between adjacent discs. In one instance they traveled to such an extent that the field windings were stretched longitudinally at the openings between the discs, until the conductors were actually attenuated to an extent visible to the eye. Obviously, the stretching force must have been enormous.

Eventually, the construction was changed on these two-pole rotors to a single disc of forged steel. Still later, steel castings were used quite extensively instead of forgings although, later still, the castings were abandoned in favor of forgings. There was much adverse opinion regarding the advisability of using castings for the 3 600 revolution machines, as some engineers held that they were more liable to contain flaws than would be the case with forgings. An interesting fact in connection with this is that, while a number of these early high speed machines "exploded," generally during runaways, yet in no instance was a cast steel field wrecked from this cause. This, however, does not constitute a proof of the superiority of cast steel, for it so happened that all the serious runaways were on machines with forged rotors. However, the record is a clear one as far as cast steel fields

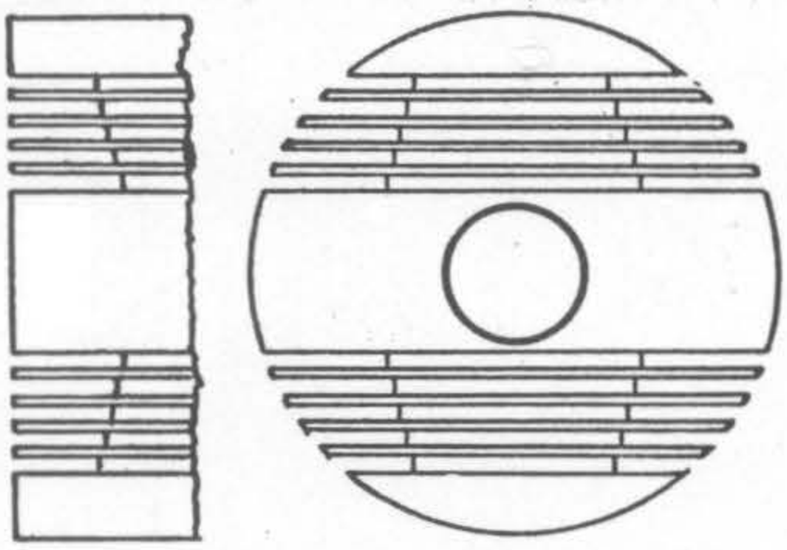


FIG. 24—ROUND TYPE TWO-POLE ROTOR

are concerned, for, of all the sizes and speeds of steel rotors which the Westinghouse Company has put out, not a single cast steel disc has burst. Present speed and output requirements have now carried the construction up to a point where special forged materials are the accepted practice.

Soon after the two-pole, 400 kilowatt rotating field machine was put on the market, a four-pole, 750 kilowatt, 1 800 revolution machine was built. The rotor of this machine had four salient poles bolted on. These poles were provided with overhanging pole tips, and the field winding consisted of four coils wound with strap-on-edge. In fact, this first construction was very similar to the present type of rotor fields now used for other than turbo work. This construction proved difficult and expensive, but was applied to a number of six-pole, 1 200 revolution machines. However, the parallel slot construction used in the two-pole machines was so satisfactory that it was soon adopted for the four and six-pole machines, as shown in Fig. 25. In the six-pole machine it was not possible to make the poles integral with the central core, on account of the inability to machine the parallel slots in the sides of the poles, or put in the windings. Therefore, separate poles were constructed, with parallel slots, and these

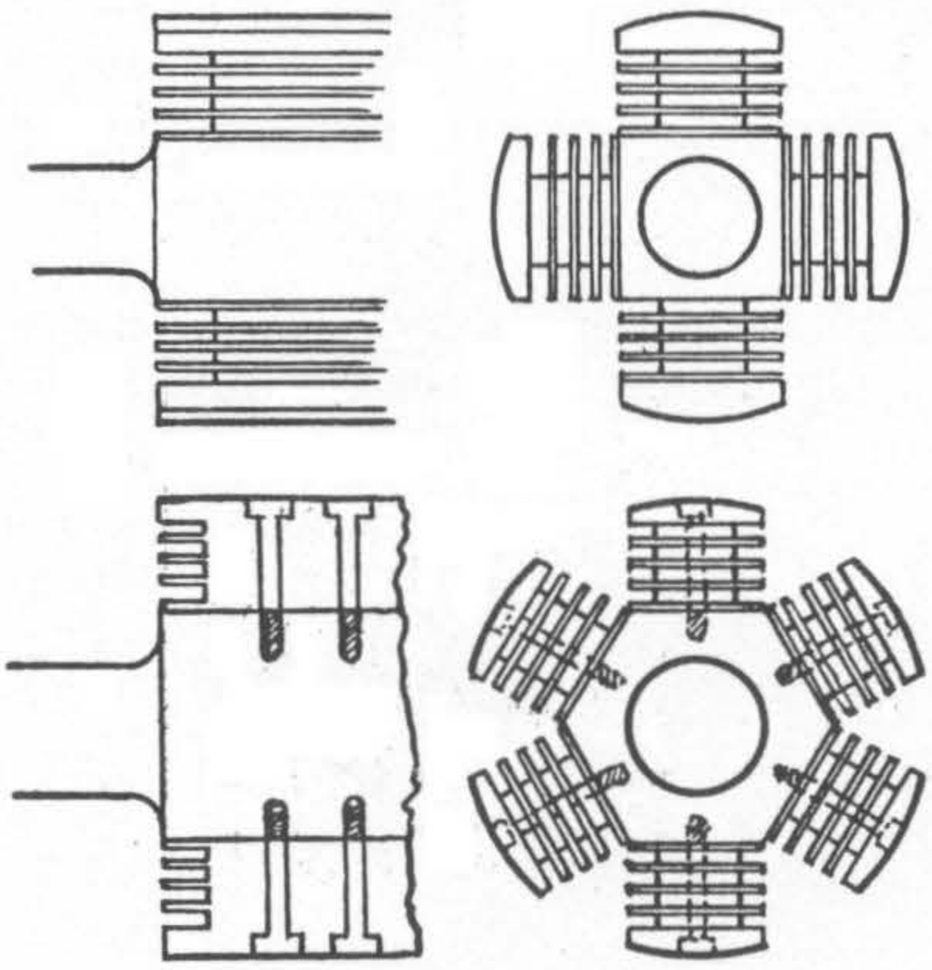


FIG. 25—PARALLEL SLOT FOUR-POLE AND SIX-POLE FIELD CONSTRUCTION

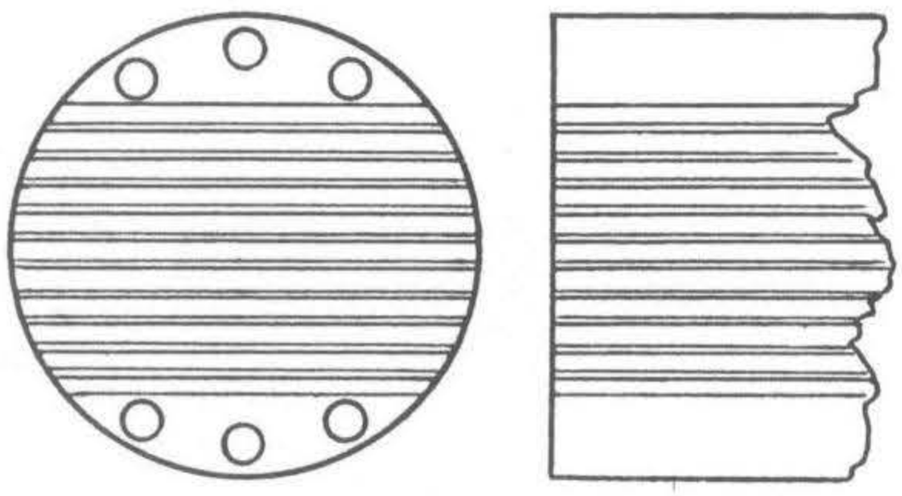
were first wound and then bolted into place on the central core which, in this case, was made integral with the shaft. The four-pole machine was constructed for 750 and 1 000 kilowatts capacity, and the six-pole construction was made for 1 500 to 3 000 kilowatts.

Meanwhile, there had grown up some demand for moderate capacity 25 cycle machines at 1 500 revolutons. These were constructed along exactly the same lines as the two-pole, 3 600 revolution machines above described.

In this early work one order for four 5 500 kw, four-pole, 1 000 revolution machines was taken. This was entirely beyond the constructions undertaken before by the Westinghouse Company. The parallel slot type of rotor was adopted. An attempt was made to get forgings in a single piece large enough for these rotors, but they were found to be glass hard and brittle, except at the outer surface. As very large steel castings were frowned upon, it was decided to make

these rotors of discs turned out of very thick steel plates, somewhat like the early 400 kw machines already described. Parallel slots were used as in the smaller four-pole machines. This construction proved to be feasible but was very expensive, and shortly after this large cast steel discs were used, two discs side by side being used to form one rotor. This construction was satisfactory, and was used for many years.

Shortly after turbo-generators came into general use, there was considerable complaint regarding the noise due to windage. All these machines were equipped with some form of ventilating device, which formed either part of the normal construction of the rotor or consisted of some special blowing device at the ends of the rotor. Both the high speed and the large quantity of cooling air required, tended to make a noise which was very objectionable. A series of



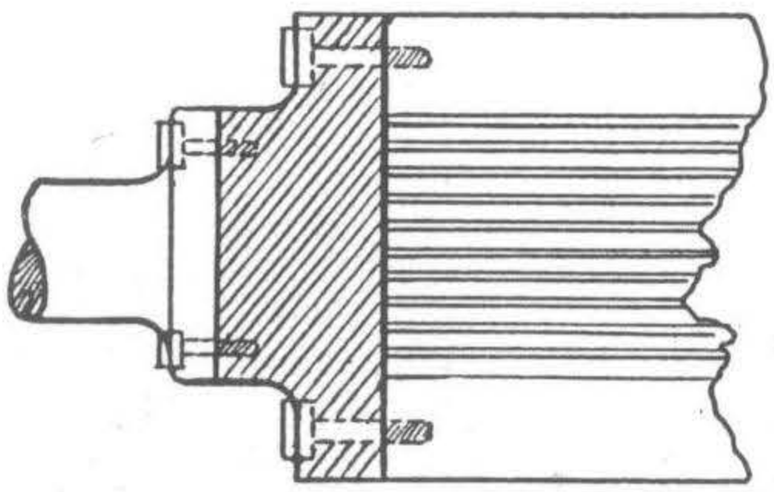


FIG. 26—TWO-POLE FIELD OF THE BOLTED ON CONSTRUCTION

experiments with covers over various parts of the machines, showed that, by completely enclosing the two ends of the machine and by enclosing the field frame except at the top and bottom, (in a horizontal machine) the windage noise could be so deadened as to be practically unobjectionable. However, the tests also showed that artificial ventilation was necessary under this condition. This very quickly led to the practice of enclosing and artificially cooling turbo-generators, which practice has been maintained to this day. The first Westinghouse enclosed machines were built about 1903.

The use of artificial cooling marked a great step in advance in turbo-generator work, for the results indicated that, by supplying a sufficient quantity of air and properly distributing it through the machine, very marked increase in capacity was possible, and a point was soon reached where the possible capacities were beyond the mechanical limitations of the construction. This led to radical modifications in the type of rotor, with a view to taking advantage of the increased capacity. Apparently all manufacturers did more or less development work along such lines. In the Westinghouse constructions, the use of a through shaft was found to be one of the serious limitations, and this led to types of rotors without any through shaft. In the two-pole machines, this was particularly important, and the problem was especially difficult with the parallel-slot construction, provided ample space was allowed for the field winding. The old through shaft two-pole construction lost considerable winding space, due to the shaft space, as shown before in Fig. 24. Attempts to construct such a machine with the shaft forming part of the core, resulted in still less efficient use of the possible winding space. It was obvious that if the whole possible winding space were taken up with slots, then the capacity of the field winding would be greatly increased. In consequence, a rotor construction, such as shown in Fig. 26, was designed and constructed. In this, bronze end supports or "heads" were bolted to each end of the field core, and the shaft proper was attached to these bronze heads. Bronze, or a similar non-magnetic material, was necessary to prevent magnetic short-circuiting of the field flux. This design was constructed and tested on a 1 000 k.v.a., 3 600 revolution machine, and then was built successively for 1 500, 2 000, 3 000. 4 000 and 5 000 k.v.a. machines, all at 3 600 r.p.m. The same construction was also applied to two-pole machines of 25 cycles, up to 12 000 k.v.a. capacities. This construction of rotor has given an extremely good account of itself. However, it proved to be expensive on small capacity machines, as the bronze heads formed an undue proportion of the cost of material. For higher capacities of 3 600 r.p.m. machines, increase in capacity is obtained largely by increasing the length of the rotor core, and thus the bronze heads form a relatively lower percentage, and the construction becomes more reasonable in cost.

From the preceding, it may be seen that only two types of turbo-generators have been used very extensively, namely, the parallel-slot type and the radial slot. Each of these types has some very pronounced advantages. The principal advantage of the parallel-slot type is in the arrangement and support of the field coils. Each coil can be wound directly in place, with the conductor under tension, and the finished winding is completely encased, and is thoroughly protected against dirt, movement of the conductors, etc. Against this, the radial slot machine allows more room for copper, and is magnetically more economical in material. However, the field windings are more difficult to apply and must be supported at the ends by auxiliary means, such as separate external steel rings.

The enormous increase in output of turbo-generators, within very recent years, has made the electric

and magnetic proportions of the rotors a feature of first importance in the design, so that the radial slot type for two-pole machines has become the standard construction, almost universally. This will be referred to again under the four-pole construction.

While the two-pole parallel slot construction was being developed for larger capacities, the four-pole construction for 60 cycle machines has been

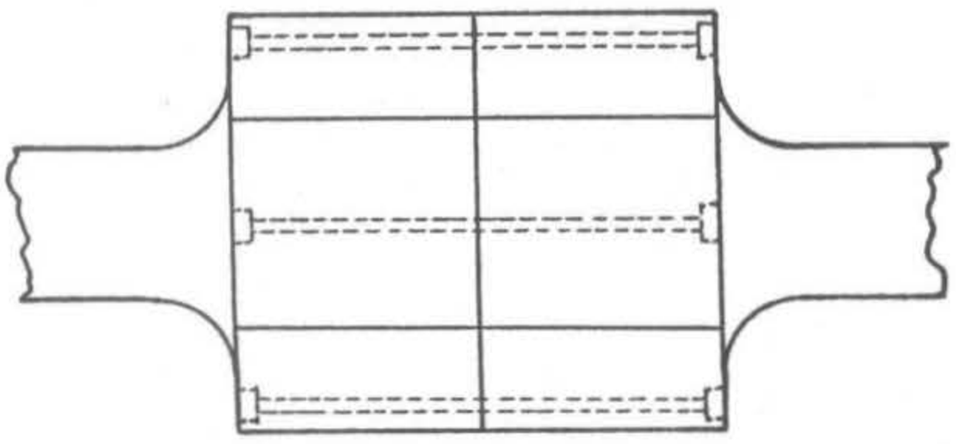


FIG. 27—FIELD CONSTRUCTION WITH TWO HALVES HELD TOGETHER BY HEAVY BOLTS

pushed up to capacities of about 12 000 k.v.a. with the parallel slot, cast steel rotors. In order to do away with the through shaft construction, the rotor was made of two castings or discs, each of which was cast solid with the shaft, as shown in Fig. 27. The two discs, after machining, were bolted together by a number of very heavy bolts located near the pole tips and, in some cases, shrink links were placed in the pole face, connecting the two halves together. The parallel grooves were then machined in the steel core, just as in the through-shaft type. In this four-pole construction, the problem of armature ventilation was comparatively simple. Air-gap ventilation (that is, all air through the armature core supplied from air-gap) was easily accomplished, due to the open spaces between the poles, which could admit an ample air supply. However, the same construction tended toward high windage losses due to air "churning."

This problem of ventilation has had much to do with the evolution of turbo-generator design.* In the two-pole, parallel slot machine for 3 600 r.p.m., in which the diameter of the rotor is relatively small, the amount of air which can be forced into the air-gap from each end is rather limited. Assuming, for example, a rotor diameter of 24 inches, which is almost as large as we can go for a 3 600 r.p.m. machine, then, with an air-gap (iron to iron) of ¾-inch, which is also a fairly large gap, the total cross-section of the air inlet at the air-gap at both ends of the rotor will be 112 sq. in. With the very high air velocity of 10 000 ft. per minute, this means a total air supply of less than 8 000 cu. ft. per minute. This may be sufficient for a moderate capacity turbo-generator, but for machines of high capacities, such as 3 000 to 5 000 k.v.a., this is not nearly enough cooling air. Obviously, either much larger inlets through the air-gap are required, or some additional method of cooling is necessary. Larger air-gaps usually mean either more expensive machines, or reduced output with a given machine, due to lower flux densities. Therefore, the tendency, in machines of the very high capacities, and very high speeds, has been toward a combination of air-gap with other methods of ventilation. In the 25 cycle, two-pole machine with a maximum speed of 1 500 r.p.m., rotors of larger diameter are possible and, as a rule, much larger air-gaps are practicable than in 60 cycle machines. In consequence, air-gap ventilation comes nearer being practicable but, in the larger capacities, even this is insufficient and auxiliary methods have been necessary in some cases.

This need for auxiliary methods of ventilation led to the axial method of ventilating armature cores in distinction from the radial method, in which the air was carried out through numerous radial air ducts or passages. In the axial method, a large number of ventilating holes are arranged in the armature core parallel to the axis of the machine. These form ventilating paths in parallel with the air-gap path With the small diameter long cores necessary for 3 600 r.p.m., high capacity machines, the development of this method of ventilation was contemporaneous with the development of the higher capacities. The same has proven to be the case for the later types of Westinghouse four-pole, 60 cycle, 1 800 r.p.m. machines, which departed very considerably in rotor construction from the four-pole cast steel type already described.

As the capacities of the 3 600 r.p.m., 60 cycle machines were gradually pushed up, a corresponding development occurred in the 1 800 r.p.m. machines. At 10 000 to 12 000 k.v.a., the four-pole cast steel construction was apparently approaching its limits. For larger sizes, therefore, a different construction was adopted which allowed more suitable material to be obtained. For the largest diameters and highest

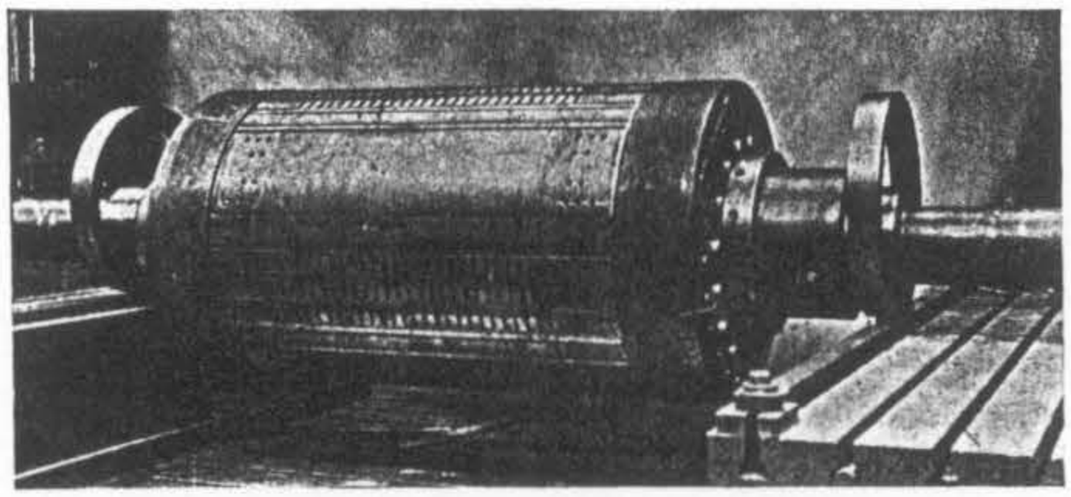


FIG. 28—MODERN ROTATING FIELD ON BALANCING WAYS

speeds, a plate construction was adopted by the Westinghouse Company, in which the end discs and the shaft ends were forged as units, and the intermediate discs were made of rolled plate material, the whole construction being bolted together permanently to form a solid core. This core was then slotted with radial slots, and the usual radial slot type of field winding is used. A similar construction was adopted on the

*A more complete exposition of the subject of "Turbo-Alternator Ventilation," etc., is contained in a paper by the author, read before American Institute of Electrical Engineers, January, 1913.

larger 25 cycle machines. For intermediate capacities, both 60 and 25 cycles, solid discs are used in some cases instead of the plate construction. This brings the larger turbo development up to the present date.

In the comparatively small 60 cycle turbo-generators, where the parallel slot construction with the bronze driving heads was relatively expensive, as already described, the later development has been to-

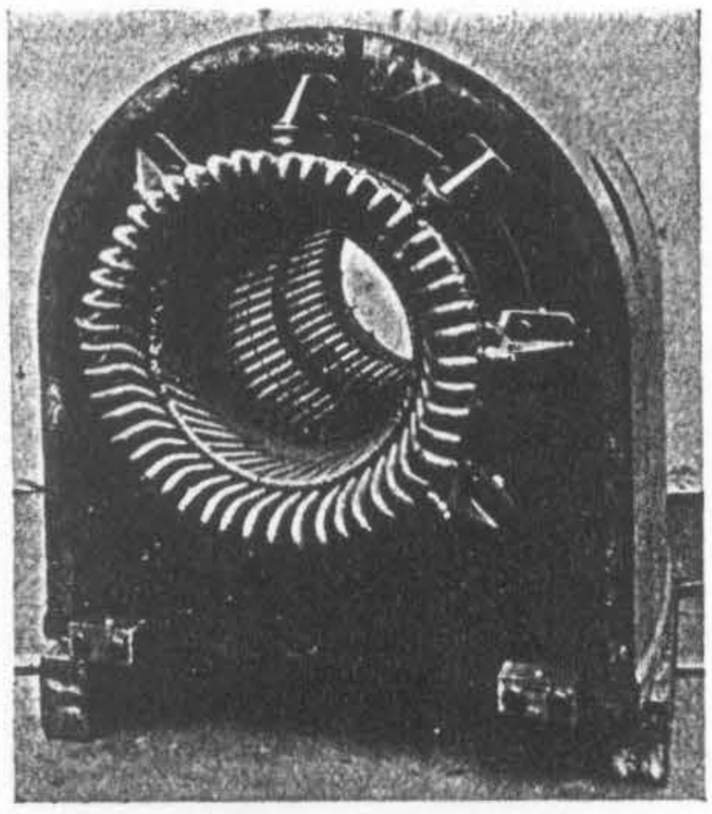


FIG. 29—STATOR OF 625 K.V.A., 2 300 VOLT, 3 600 R.P.M. TURBO-GENERATOR

With axial ventilation and central duct. Supporting ring both inside and outside the end windings. Typical method of bracing smaller machines.

wards core and shaft forged in one piece, and with radial slots, and eventually this construction may be carried up to the largest practicable size of 3 600 r.p.m. machines. It is difficult to predict the limit in capacity which may be reached eventually in 3 600 r.p.m. generators but 6 250 k.v.a. appears to be practicable.

Some special radial slot machines had been developed for the New Haven Railroad about 1907. As these machines were designed to deliver 25 cycle single-phase current, and as the pulsating armature reaction of such machines would be relatively high, the rotors were designed with laminated cores, with a view to lessening core losses. The rotors were made of single disc lamminations shrunk on the shaft. The discs were provided with radial slots. The construction was very similar to the later radial slot rotors, except that the rotor end windings were also embedded in slots, and supported by wedges embedded in the periphery of the core, whereas, in the later radial slot rotors, the end windings are supported by external rings. These early radial slot rotors showed very considerable overheating in single-phase operation, and it was found necessary to apply a very complete cage damper embedded in the periphery of the rotor. Later experience showed that the solid core parallel slot rotor with an equal damper applied to its surface was just as effective, and many of the later single-phase machines were built in this manner. However, some recent 11 250 k.v.a. single-phase generators are being built of the plate construction already described.

REGULATION AND SHORT-CIRCUIT CURRENTS OF TURBO-ALTERNATORS

Like the ordinary synchronous generator, the modern turbo-alternator is designed with a comparatively high inherent regulation. In fact, in order to avoid excesive short-circuit currents, the inherent regulation must be made comparatively poor by making the armature self-induction as high as practicable. Even under the best condition, such machines are liable to give 12 to 15 times rated current during the first current rush. Furthermore, the solid plates or discs, of which most turbo-rotors are now made, tend to prolong the period of maximum short-circuit current. The consequence of these conditions is a tremendous racking force acting on the end windings during a short-circuit current rush, which tends to distort the winding badly unless it is very strongly braced. The Westinghouse Company encountered such a difficulty on some of their earliest turbo- alternators and there has been a practically continuous development along the lines of more substantial bracing which has kept pace with the increased requirements of the higher speeds and the higher capacities. The bracing used on the modern machines is designed to resist distortion of the end windings, under dead short-circuit, without reactances interposed, and each new size as it is developed is given such a short-circuit test. A 20 000 k.v.a. 60 cycle, 1 800 r.p.m. high voltage alternator was recently subjected to such short-circuit tests at full voltage without injury.

The preceding gives a brief history of the development of the turbo-generator, insofar as carried out by the Westinghouse Company. The General Electric Company went through a corresponding course of development, in general, although not in

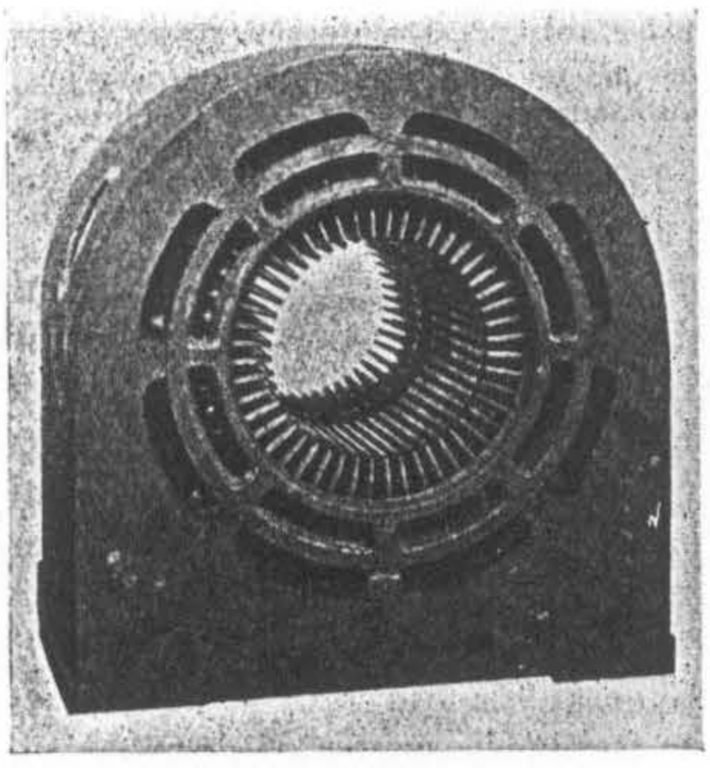


FIG. 30—SAME MACHINE AS SHOWN IN FIG. 29 BEFORE WINDING

the specific constructions described, and a number of interesting types or constructions have been brought out. The gradual increase in speed has undoubtedly had much to do with the evolution of their various types, just as in the case of the Westinghouse evolution. One of the most radical steps which the General Electric Company has made in the past few years is in the change from the vertical to the hori-

zontal type of machines. Presumably the very high speeds which later came into use have had much to do with this change. In the earlier turbo-generator practice, the speeds of the General Electric Company's machines were relatively lower than the Westinghouse, presumably on account of the type of steam turbine used. Many of the early rotor constructions were of the salient pole type for four poles and higher. Gradually these were superseded by constructions leading up to a radial slot type in which the slots were formed by teeth inserted in dovetail grooves in the rim of the spider. This type was very similar in appearance to the later types, except that the slots had overhanging tooth tips, thus giving a partially closed slot construction. More recently, with greatly increased speeds, this construction has been superseded by solid forged cores with shaft forged on, and with radial grooves milled in the surface for the field

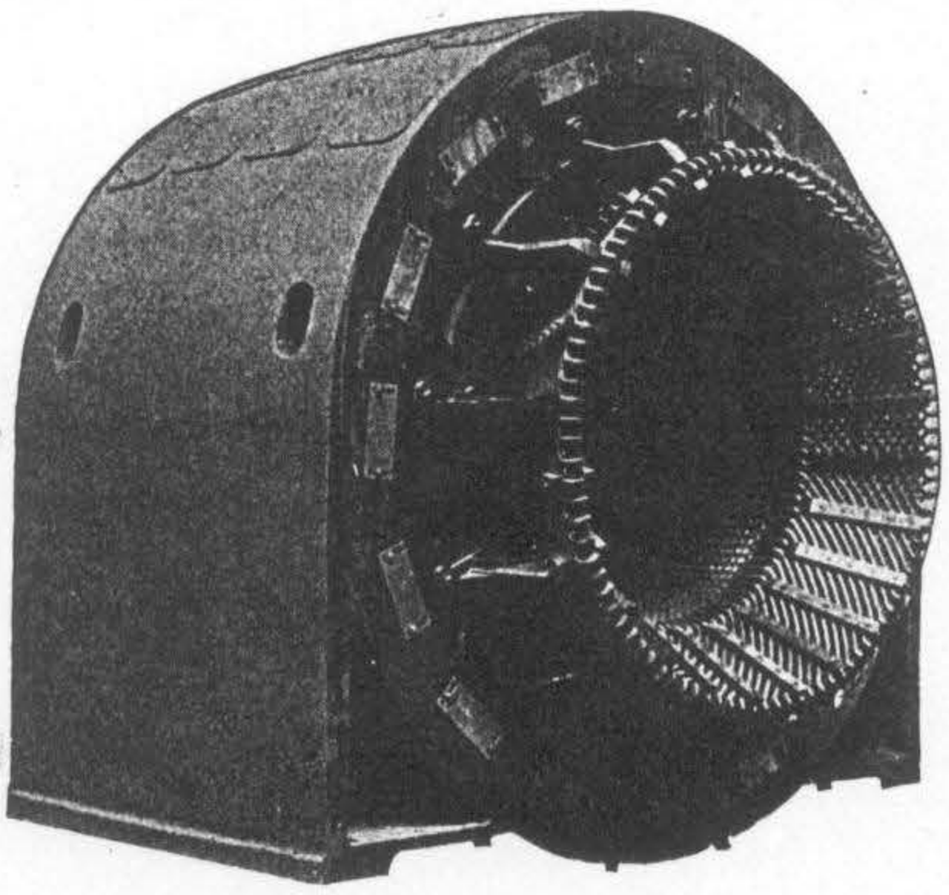


FIG. 31—STATOR OF LARGE MODERN TURBO-ALTERNATOR
Showing end winding and method of bracing large machines to withstand short circuits.

winding. These latter rotors are used largely in the horizontal type high speed machines.

In the Allis-Chalmers construction, in the larger machines having four or more poles, the earlier construction of the rotor consisted of forged discs with through shafts. These discs had radial slots for the windings very similar to the present construction of all manufacturers. The smaller machines generally had cores forged in a single piece with the shaft, and with radial windings. As regards methods of ventilation, both the General Electric and Allis-Chalmers Companies went through a course of development leading up to their present practices.

As regards parallel operation, turbo-generators have been particularly free from this old time difficulty, due largely to the uniform rotative effort of the steam turbine, and partly to the high flywheel capacity of the turbo-generator and turbine rotors, which tends to limit any speed oscillations, due to the governors, to a relatively low period, such as would not tend to accentuate the hunting action in the generators themselves. Moreover, in those rotors which have been built with solid cores or of thick plates, the solid material tends to act as a damper circuit. As a consequence, hunting in turbo-generators, or difficulties in parallel running, have been extremely rare.

INDUCTION TURBO-GENERATORS

This type of turbo-generator has been proposed commercially a number of times during the past ten years, and a few installations have been built. The first of any importance, consisting of a 1 250 kilowatt generator of 30 cycles, 1 800 r.p.m., two poles, was installed in the plant of the Baltimore Copper Smelting & Rolling Company. This generator was a true polyphase induction motor, direct connected to a steam turbine. The construction of the generator was exactly the same as would have been used at that time in a two-pole, 1 800 r.p.m. induction motor of the same capacity. The entire load of this machine consisted of a 1 200 kilowatt rotary converter connected directly to the terminals of the generator. The generator and converter were brought up to speed separately and the rotary converter, with its field excited, was connected directly to the generator and furnished the excitation for the generator. There was no other synchronous apparatus in circuit except the converter.

Several years ago, a number of much larger induction generators were built by the General Electric Company for the Interborough Rapid Transit Company of New York City. These machines are of 6 000 k.v.a. nominal capacity and operate in parallel with the 11 000 volt, three-phase, engine-type generators previously installed in the same power house. The engine-type generators furnish the excitation for the induction generators. The entire load of this station is represented by rotary converters. There have been no prominent instances of the use of induction generators for other than steam turbine drive. Apparently this type of generator has no very wide field.

CONCLUSION

This history is admittedly far from complete, in that it has not mentioned the work of some of the earlier, and also some of the later manufacturing companies. The field is far too large to permit everything to be covered. Moreover, no attempt has been made to describe European constructions and developments in alternating-current generators. It may be stated, however, that in some very important features, European engineers antedated the Americans, while in other equally important constructions American designers were first in the field. As a rule, the representatives of the electrical manufacturing companies have been so wide awake and ready to adopt new principles when they contained any promise, that it is sometimes very difficult to give any company or individual proper and deserved credit for being first in any given development. Furthermore, no attempt has been made to give credit to the various engineers who have been closely identified with alternator development, for it would be impossible to do justice, or give deserved credit to all of them.

THE CONSTRUCTOR

Currents of Ultra-High Frequency and Potential

With a Description of the Usual Apparatus Involved In Their Production.

H. Winfield Secor.

EXPERIMENTS with electric currents of ultra-high frequency and potential, form probably the most interesting phase of electrical science, both for the layman and experienced electrician as well . The apparatus for producing these interesting currents is fortunately of low first cost, and thus it is well within the reach of every electrical student.

Our first photograph, Fig. 1, illustrates a large size Tesla high frequency apparatus, recently built by the E. I. Co. for theatrical purposes. Of course, most of our readers have possibly seen one or more of the so-called "Electrical Conquerors," touring the country, who style themselves variously as "Masters of the Electric Current," or "The Man Who Cheated the Electric Chair," etc., etc. Anyone can cheat the electric chair, if the Electrocution authorities would only be so kind as to charge the chair with half a million volts, at a "frequency of 500,000 cycles per second, or so." In other words, when we deal with such electrical currents as this, they may be readily taken through the body, without feeling them to any appreciable extent.

In the usually accepted meaning of the term, "high frequency," the number of cycles occurring per second is not

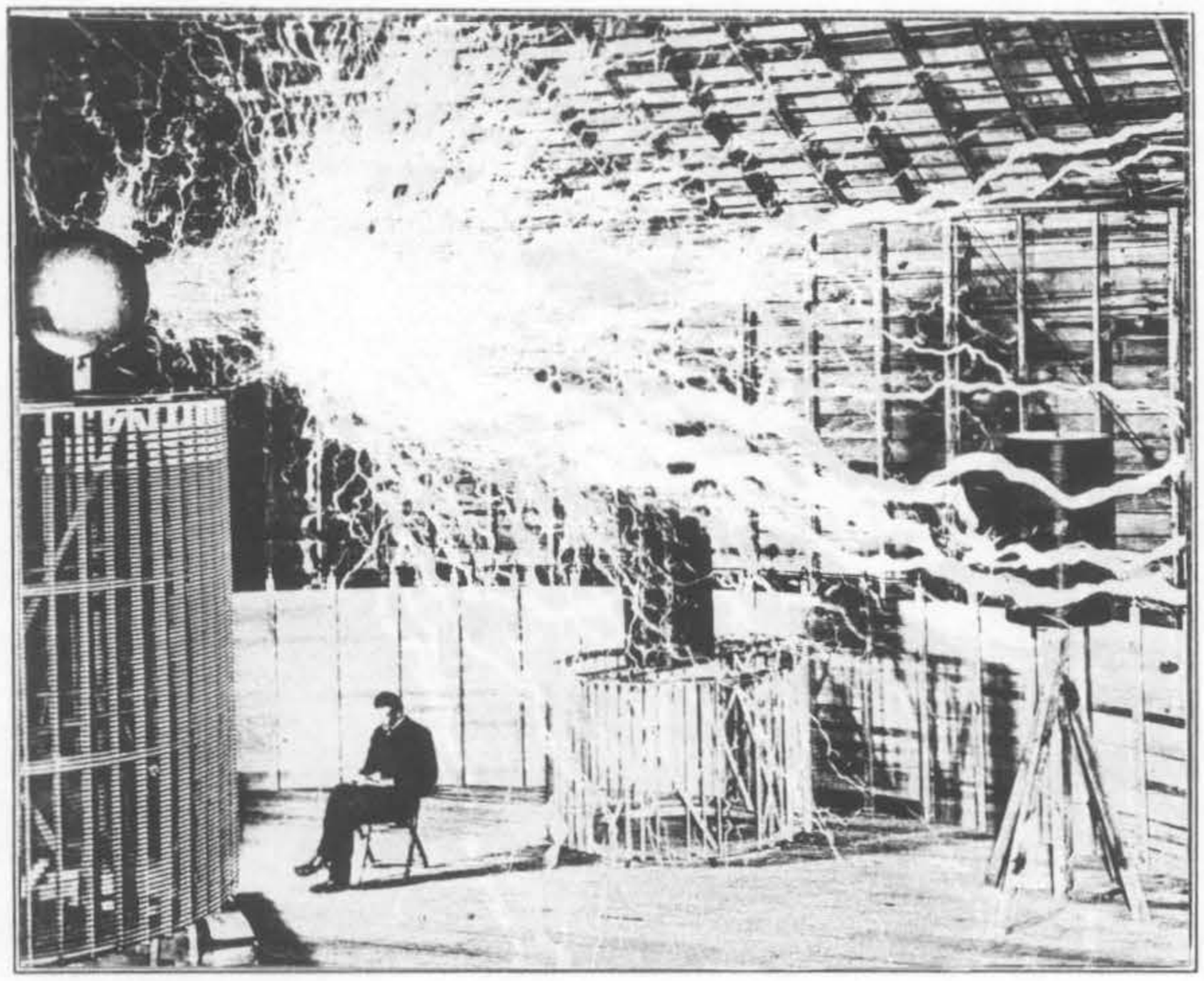
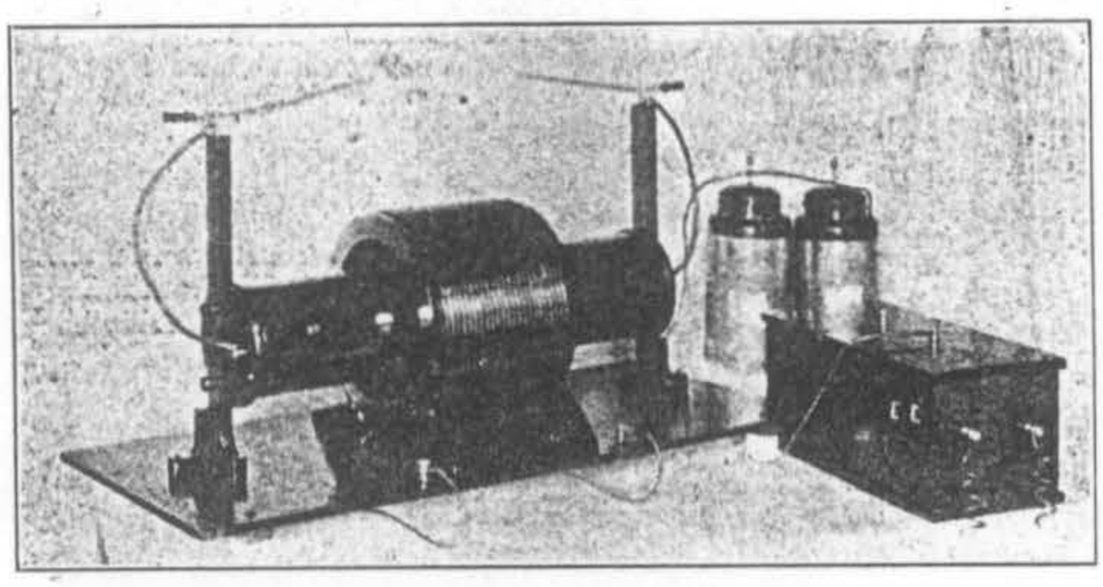


Fig. 4.



A Large Tesla Coil.

any such low figure as found on lighting circuits, viz., 60 cycles, but in the order of 100,000 to 1,000,000 cycles per second.

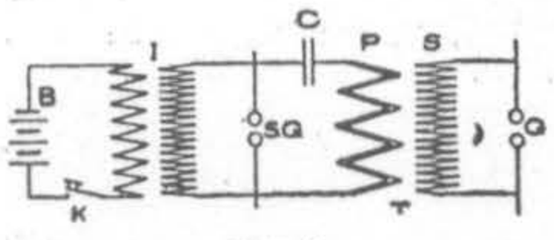


Fig. 2.

When such high frequency currents as these are employed, many wonderful and unlooked for phenomena take place; among other things the currents of such a frequency can be handled with impunity, and even passed through the body, notwithstanding that the voltage may be several million, and the amperage several amperes (½ ampere through the body at 2,000 volts D. C., or low frequency, A. C. means death).

High frequency currents of this order no longer obey the rules governing the ordinary low frequency oscillating currents. For one thing, they travel only on the surface of conductors, not through them, penetrating only a few thousandths of an inch below the surface, this phenomena being known in electrical parlance as the "skin effect" which accounts for the reason that these currents do not hurt the body when handled, i. e., they possibly do not reach far enough below the skin of the body, to shock or destroy the nerves and muscles. This is the theory in general acceptance to-day.

A great part of our knowledge of these high frequency currents is due to the untiring and exhaustive researches of Nikola Tesla, a well-known Electrical Engineer and Scientist, after whom the Tesla coil, which is used to produce high frequency currents with, is named. To the student interested in this little known field of electrical science, it is recommended that he procure a copy of Mr. Tesla's book, "Experiments with Currents of High Potential and High Frequency."

High frequency alternating currents may be produced by a special dynamo, such as Prof. Fessenden's, or by a regular high frequency disruptive discharge set, as shown at Fig. 1, employing a step-up transformer excited by another high voltage transformer or induction coil, coupled with a spark gap and condenser in the exciting circuit, after the manner depicted in Fig. 2, which is the commonest arrangement.

In the diagram shown, I is the induction coil of not less than 2 inch spark capacity. T is the air core, Tesla or high frequency transformer, serving to step-up the voltage delivered by the induction coil secondary to many times its original value. C is a condenser composed of glass plates, coated with tin foil on both sides, or regular Leyden jars. S G is the spark gap, in which the disruptive discharge of the condenser takes place. G is the discharge gap of the Tesla

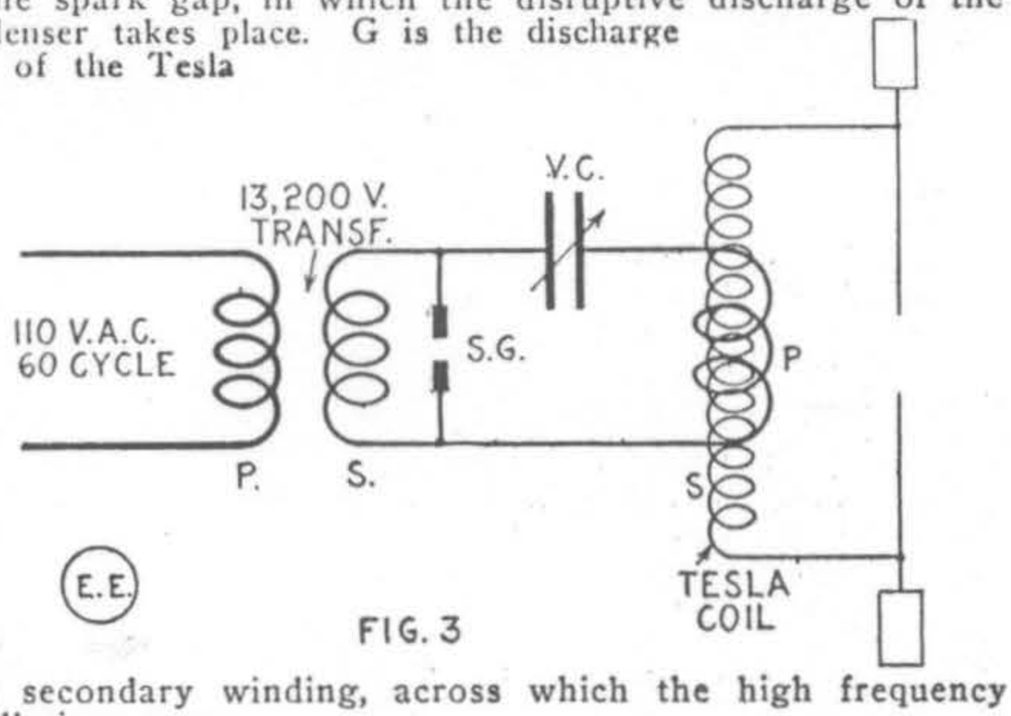


FIG. 3

coil secondary winding, across which the high frequency oscillations surge.

The action of the apparatus is as follows:—The induction coil or transformer I, is excited from the battery shown at B or the regular line wires, and its secondary current at

10,000 volts pressure or more, is caused to charge the condenser C, which immediately discharges itself through the primary coil of the Tesla transformer P, and the spark gap S G; and due to the conditions imposed by such a circuit, the condenser discharge becomes not a single oscillation for each cycle of induction coil current, but many thousand, so that with certain proportions to the circuits as regards their inductance and capacity, the frequency of the current passing through the Tesla coil primary, may reach a million or more cycles per second, rendering the current harmless owing to the "skin effect" already mentioned. The currents thus produced are, of course, highly damped, i. e., the series of oscillation corresponding to each cycle of primary transformer current, dies down to zero before the next series of oscillations start.

Referring again to the cut, Fig. 1, the large Tesla coil here pictured is capable of delivering 10 to 15 inch high frequency sparks at its secondary terminals, when excited by a ¼ to ½ K.W. set-up transformer or a large induction coil of 8 to 12 inch spark capacity. In this particular set of apparatus, the exciting transformer is of special design, and of the open core type, so that it may be operated on 110-volt direct current circuits by means of a "Gernsback" Electrolytic Interrupter, or on 110-volt, 60 to 120-cycle, alternating current circuits directly. This is necessary for stage equipment, as the service available is sometimes *Direct,* and sometimes *Alternating Current.* This is the cheapest manner of arranging a universal Tesla Coil outfit. The better way is to employ one of the Electro ¼ K.W. step-up wireless transformers, wound 110 volts primary, to 13,200 volts secondary, and of the closed-core type. On A. C. circuits the transformer just mentioned is simply connected as in the manner indicated at Fig. 3. In the outfit shown at Fig. 1, two 2-qt. Leyden jars are used for the oscillation condenser. In the set just being outlined and utilizing the closed-core transformer, a special adjustable $10.00 E. I. Co. No. 531A, type H. F., glass plate condenser, is preferably used. The spark gap in these particular sets is an ordinary fixed one. A rotary gap is in every way superior, however, and the "Electro" $15.00 rotary type, fitted with 110-volt universal D. C. or A. C. motor is highly recommended. With the fixed gap, the discharge often tends to arc and this destroys the proper discharging of the condensers. Lowering of the frequency is then most liable to occur, and so a rotary gap should always be used. The connections of the high frequency generating circuit, including the spark gap, condenser, and Tesla coil primary circuit, should all be made with a large *low-resistance high frequency* electrical conductor, such as 1/32 in. x ⅞ in. copper strip; or also stranded copper cable, about No. 4 B. & S. gauge capacity or larger, as the high frequency current only traverses the outer skin of any conductor. Hence the greater the skin surface, the better. The penetration at radio frequency is but a few hundredths of an inch.

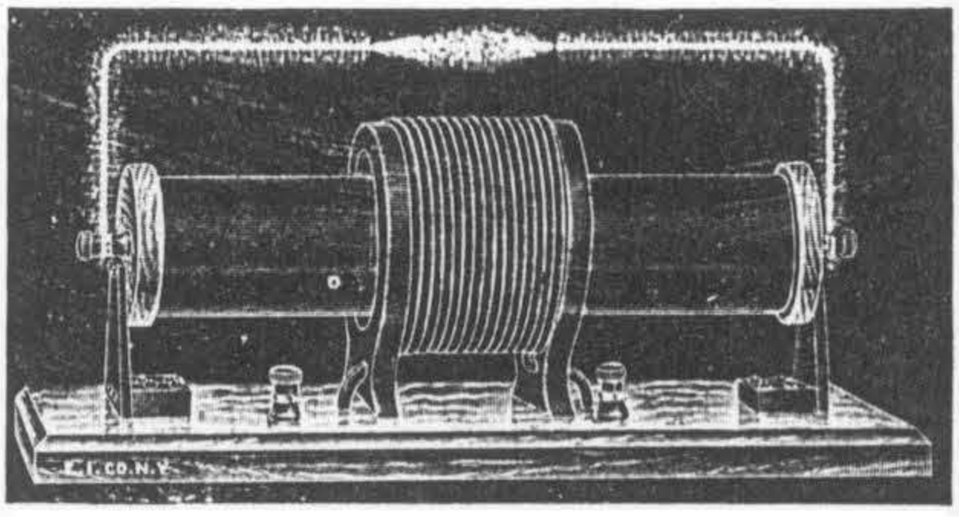
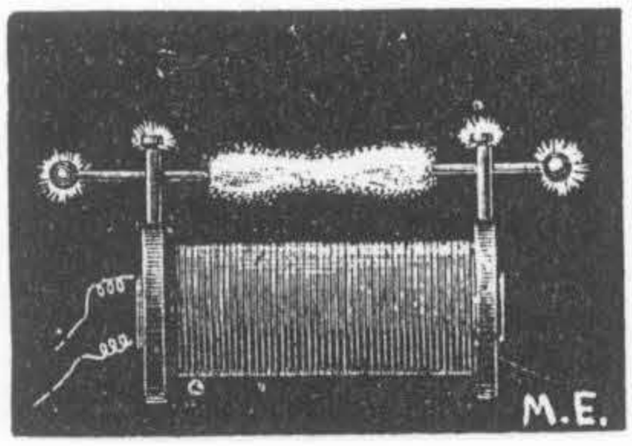
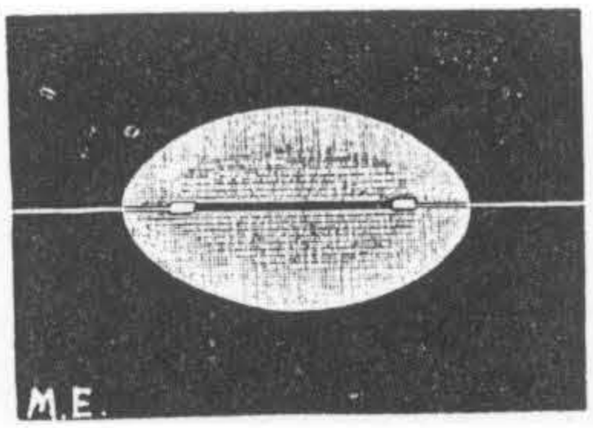
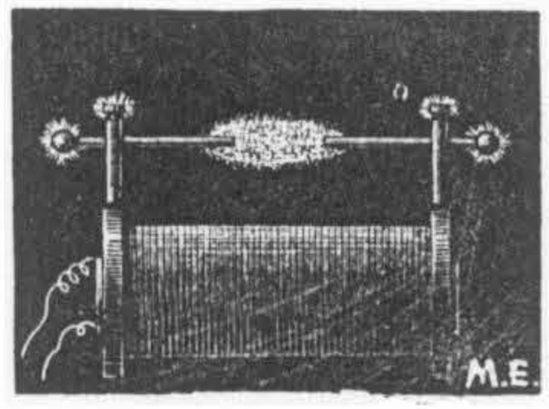


Fig. 5.

The large Tesla coil here portrayed has an inner secondary coil, about 2 feet long and 5¼ inches in diameter. It is wound with comparatively fine magnet wire in a special manner, to give the highest possible dielectric strength; as this winding has generated in its potentials approximating 700,000 to 1,000,000 volts. The primary coil on this particular coil is formed of several turns of finely stranded copper cable, insulated with pure para rubber. Its turns, of course, do not have the potential stress imposed on them that the secondary coil has. The frequency and character of the Tesla secondary discharge, is made variable by charging the number of primary turns, and also the amount of condenser capacity in circuit. The mathematical expression for computing this frequency is as follows:







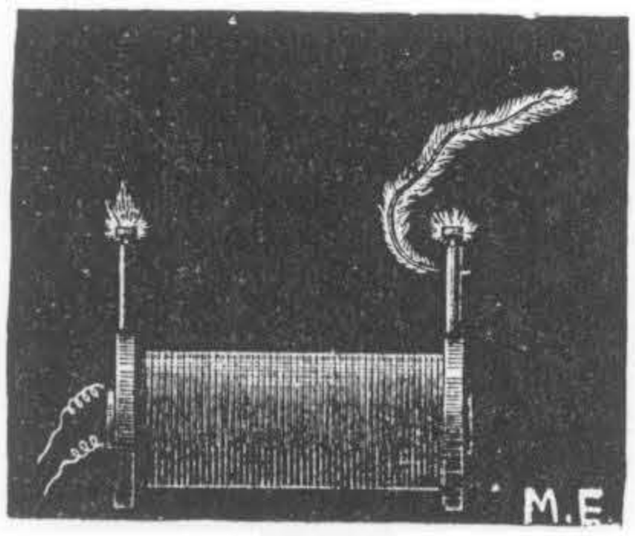
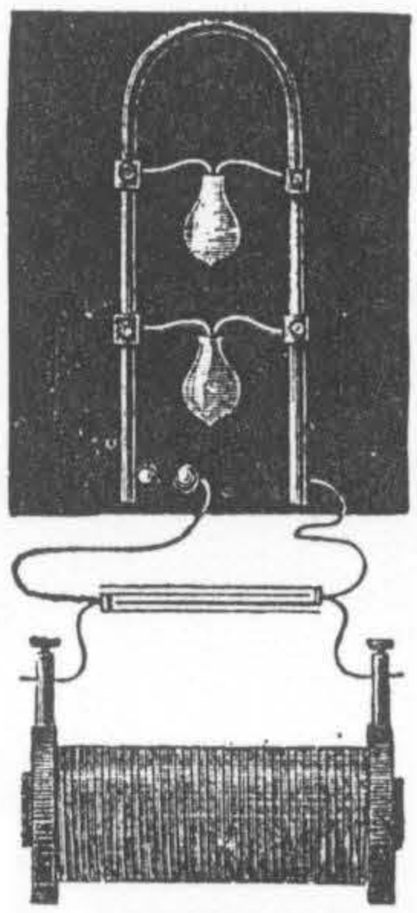


Fig. 6.



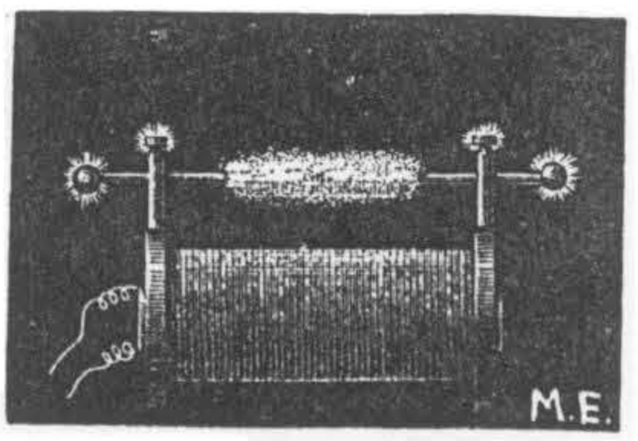


Fig. 7.

$$F = \frac{5{,}033{,}000}{\sqrt{L \times C}};$$

Where F is the frequency in cycles per second, L is the inductance of the exciting circuit in Cm. and C is the capacity of the circuit in M.F.

Decreasing the number of Tesla Primary turns or the condenser capacity thus increases the frequency; which also is an inverse function of the wave length. If the wave length of the circuit is ascertained by means of a wave meter, then the corresponding frequency is found by dividing the wave velocity through ether, viz., 300,000,000 meters, by the wave length in meters, and the result is "frequency in cycles per second."

For the open core transformer shown at Fig. 1, it is necessary to also connect in the primary 110 volt A. C. or D. C. circuit and adjustable impedance coil.

For operating the second mentioned set with 13,200 volt closed-core transformer, on direct current service, a dynamotor delivering 110 volts A. C. 60 cycles, is most adaptable. This would cost $51.00 from the E. I. Co. The Tesla coil alone sells for $15.00 and is finely finished. This set is very

(Continued on Page 154.)

away. The voltage of this discharge was up in the billions, and the amperage 800.*

The object of all these experiments by Nikola Tesla, was along his line of work regarding the wireless transmission of electrical energy, for useful purposes. It may seem like a dream to-day, but then it is only a little over fourteen years ago that man only dreamed about the wireless telegraph, and at the end of this short space of time, there are laws passed which compel its use on all ships that travel the high sea.

Tesla, in his first book, published over twenty years ago, advocated the cause of the wireless transmission of energy, for the lighting of lamps and running of motors, and at that time, in a lecture before the Institute of Electrical Engineers, at London, England, he demonstrated wireless lights and a "no-wire" motor operating over short distances.

The form of the energy was to be in high frequency oscillations stepped up to many million volts, and radiated from extra high aerial wires, extending into the upper strata of rarefied air, through which the high voltage currents travel easily.

The aerial wire would of necessity be quite high, probably more than 50 miles.

A very neat and efficient Tesla transformer designed especially for experimental research, is built by the Electro Importing Company, of New York City.

A cut showing their instrument in full activity is portrayed at fig. 5, which shows the wonderful display it gives when excited from a two inch spark coil run on batteries. A larger exciting spark coil will of course increase the activity of the Tesla coil considerably. The same company also build large size Tesla transformers, complete with condensers, rotary spark gaps, and exciting transformers, upon request, from six to thirty-six inch Tesla spark. In fig. 2, is shown the wiring connections from the Tesla transformer mentioned above. The transformer itself sells for an extremely low price and should certainly commend itself to experimenters, school laboratories, and demonstrators.

Some of the marvelous and mysterious experiments that can be performed with this Tesla coil are reproduced in the cuts figs. 6 and 7. These experiments and numerous others, together with the manner of making them are fully explained in a brochure supplied with the Tesla coil.

This size of high frequency coil, which is capable of delivering three to four inch sparks at its secondary terminals when excited by a two inch spark coil, employs a simple fixed spark gap, fitted with ball or pointed electrodes, flat faced one having not been found suitable in the small sets. This Tesla high frequency set will produce an oscillatory high potential current of several hundred thousand volts, at a periodicity of half a million cycles per second or more.

The application of high frequency currents to the body in various ways was first developed by Prof. d'Arsonval of Paris, and he made a number of different tests, to ascertain the effects of various currents applied to the body, and having different frequencies. When the current applied did not have a frequency greater than 15 cycles per second it was found that a succession of separate on "Clonic" Muscular Contractions were produced. With a frequency of 20 to 30 cycles per second a series of continuous contractions or in other words, a "Tetanus," or "Tonic Spasm," occurred. When the frequency of the oscillations or currents were increased beyond this point, the Tetanus effect was also increased. When a Periodicity of alternation approximating 3000 cycles per second, was employed, the maximum intensity in the muscular contractions took place; and a further increase of frequency caused a decrease in the strength of the contractions, until at a frequency of 10,000 cycles per second absolutely no effect was produced upon either the Motor or Sensory Nerves. Therefore an alternating or oscillating current, which alternates at 10,000 or more cycles per second, is termed a "High Frequency Current" from a therapeutical point of view, and sensibly also, from an electrical point of view.

*See Sewall's "Wireless Telegraphy," $2.25 postpaid from the E. I. Co.

CURRENTS OF ULTRA-HIGH FREQUENCY AND POTENTIAL.

(Continued from Page 152.)

well suited to Physician's Electrotherapeutical requirements also, as well as stage or Experimental work.

While on the subject of large Tesla disruptive discharges, it may be of interest to refer to Fig. 4, which shows some of the stupendous sparks obtained by Nikola Tesla, some years ago, in experiments carried out by him.

Tesla, in some of his researches, had these high frequency discharges developed to such a degree that, in one test he was able to make the current leap a gap, twenty-five feet long, the sparks being two to three feet in diameter, and accompanied by a roar, which could be heard ten to twelve miles

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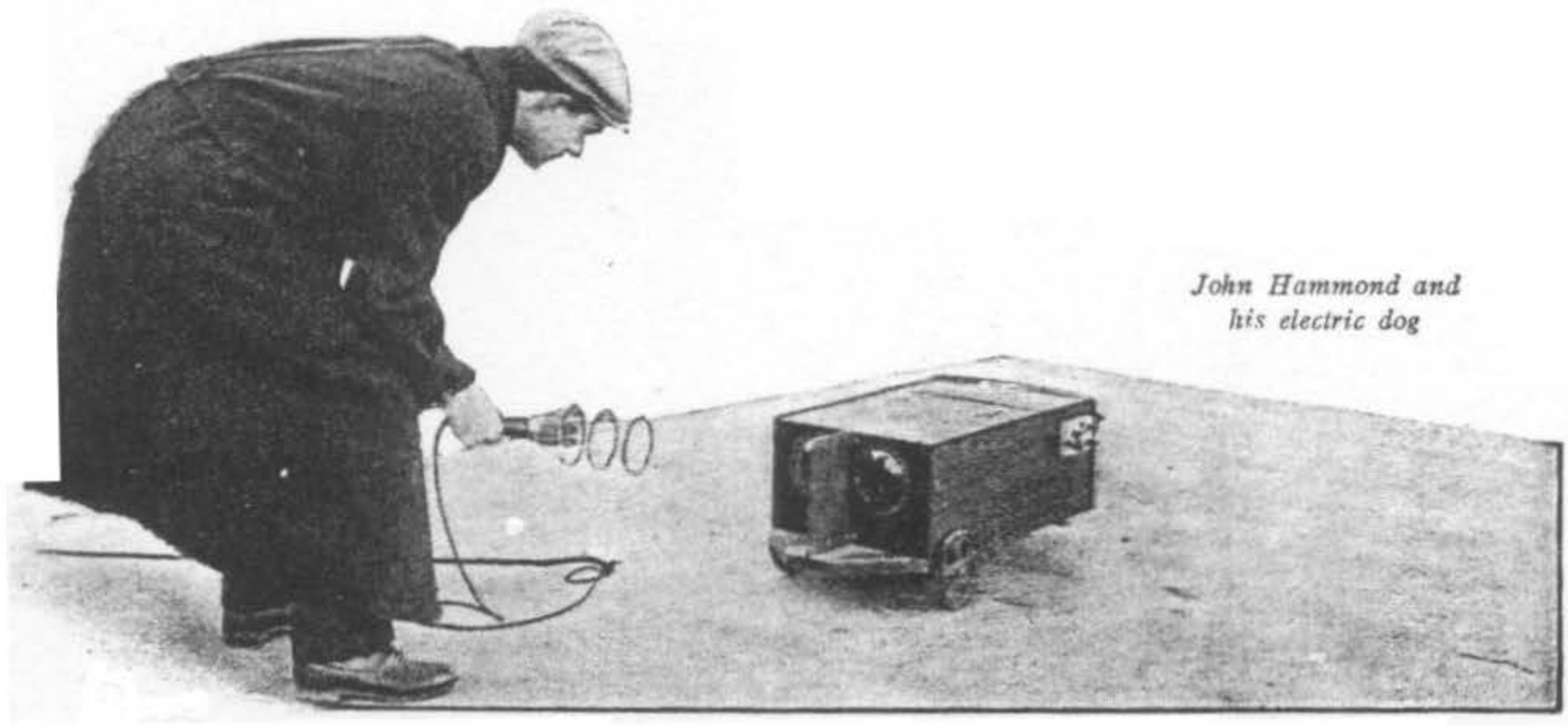

John Hammond and his electric dog

STEERED BY WIRELESS

The Triumph of a Man of Twenty-five

By CLEVELAND MOFFETT

A BOAT WITH NOT A SOUL ABOARD, HER LIGHTS BLAZING, HER ENGINE POUNDING, SHOOTING OUT TO SEA AT NIGHT WITH THE SPEED OF A RAILROAD TRAIN. . . . . .

. . . That is the achievement of young John Hays Hammond, Jr., who, working alone in Gloucester harbor, has evolved perhaps the most spectacular war device of history. As a school-boy, young Hammond made a written prediction that he would some day control a moving body at a distance by the sound of his voice. His boat "Radio" — the fulfilment of this prediction — represents a terrible new weapon for the navies of the world; a new kind of torpedo, so sure and so deadly that it will revolutionize war-making.

ONE of the first things a newcomer at Gloucester, Massachusetts, notices, as he glances across the marshes toward the sea, is the imposing height of two enormous masts that rise on a wooded cliff overhanging the harbor. Three hundred and sixty feet they tower above their granite base. No higher wooden masts have ever been erected (they are insured at Lloyd's for $10,000), and the traveler looks at them wonderingly.

"What are they? What are they for?" he asks, and learns that they are part of the wireless station from which John Hays Hammond, Jr., has, for some years now, been operating boats by wireless control, thus making for himself a local, a national,

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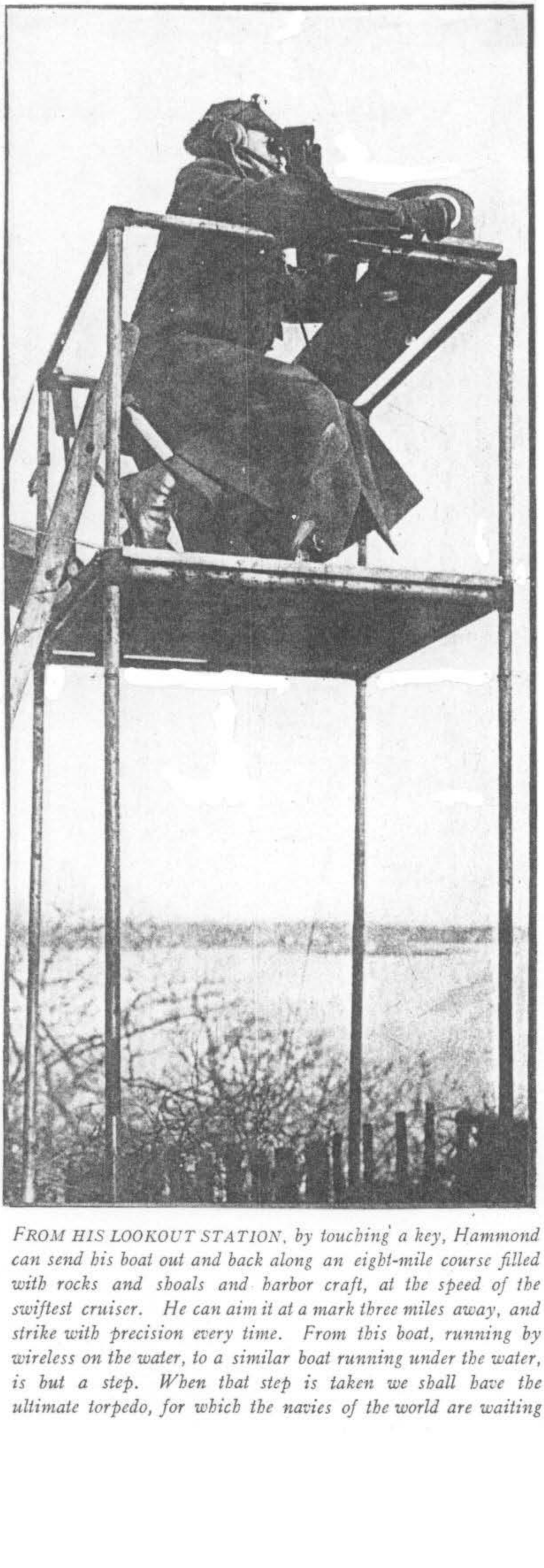


FROM HIS LOOKOUT STATION, by touching a key, Hammond can send his boat out and back along an eight-mile course filled with rocks and shoals and harbor craft, at the speed of the swiftest cruiser. He can aim it at a mark three miles away, and strike with precision every time. From this boat, running by wireless on the water, to a similar boat running under the water, is but a step. When that step is taken we shall have the ultimate torpedo, for which the navies of the world are waiting

and what promises to be an international reputation.

One night in December I had the unusual privilege of standing beside the lookout man on the cliff, the wireless steering man (in this case Captain Behr of the United States Army, stationed here by the coast defense authorities) who directs this far-flung guidance, and of observing what happened as he steered Mr. Hammond's boat out and back through the winter darkness, along an eight-mile tortuous way, steered her safely among rocks and shoals and harbor craft.

It must be understood that this wireless boat runs by the power of her own engines, as we walk by the power of our leg muscles, although the brain directs. The steering man on the cliff is the brain of this plunging boat that is miles away and helpless without him, but she carries her engine muscles with her.

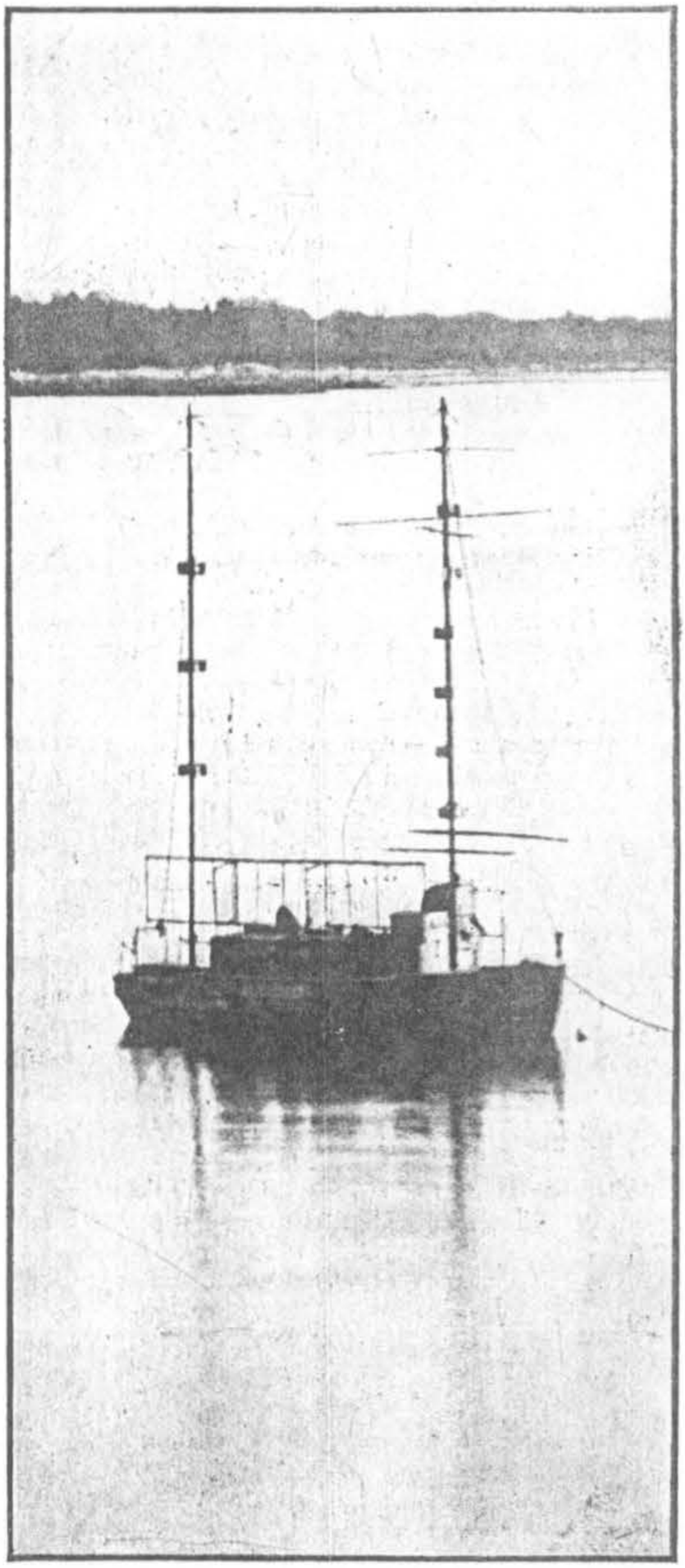
The lookout house is a bare box of a place scarcely large enough for two to turn around in, and bitter cold of winter nights, so we are bundled in heavy coats. The steering man wears a telephone headpiece over his ears, so that he can hear the sounds of the wireless waves as they pulse from the antennae, a network of copper wires that stretch between the great masts behind us.

Now the lookout man touches a key that a child could press, and straightway the miracle begins. That touch has released a store of energy measured by the strength of hundreds of straining horses. We see nothing except some purple fringes of darting flame; we hear only a hissing breath of the wires, that comes each time as the key is touched; yet the whole power of whirling generators, that hum tirelessly in the power-house down the hill, has been hurled forth into space through the quivering antennae. It is this power that does the steering — that is, a small fraction of this power: for only a billionth part of it, Mr. Hammond says, ever reaches the boat. The rest is dissipated into space.

The boat lies below us at her moorings, ready to start. She is dazzling white in a cloud of steam from her exhausts, as the great searchlight plays over her. No battleship can boast such a searchlight. Five feet across is the spread of the silvered parabolic mirror that throws the brilliance of one hundred and eighty-six million candles seven miles out to sea. With a turn of his hand the lookout man directs this immense beam. One little crank lifts and lowers it, another moves it to right or left, these cranks being electrically connected with motors in the searchlight house some distance from us. If this searchlight were near, its dazzling light would blind the lookout man, who must work here in darkness (save for a tiny electric light that illumines his record page), so as to see with all his eyes out over the ocean. He is like the companion of a blind man — upon his vigilance depends the boat's safety, upon his spying out dangers in her course.

Now the boat is starting. Her engines sputter. Her two forty-foot masts shine like slim Christmas trees with clusters of electric lights. This is to make sure that the lookout man does not lose the boat in the ocean darkness, or confuse her with other vessels. In these practice runs, several experts, including Mr. Hammond himself, are aboard, watching the work of shore control, but taking no part in it. On occasions they let the wireless boat run ahead without a soul aboard her, and follow in a launch, to be present in case of an emergency.

Now she is moving at a good speed, headed toward the intermittent light that flashes its red warnings from Eastern Point. We zigzag her down the harbor course, steering her by spars and buoys, as a pilot steers. With a touch of the wireless key the captain turns her aside for a low-lying cargo-boat, and presently has her off the breakwater, where the steady white line shines. Far down the coast I make out white flashes that come — one, four, three — every ten seconds. It



THE FIRST WIRELESS BOAT. To demonstrate his spectacular invention, Hammond afterward built the "Radio," a forty-foot craft with a guaranteed speed of thirty-three miles an hour. Aboard this boat was everything that was known in the way of radio-dynamic apparatus, and much that was unknown; for the young inventor was facing new problems in electrical engineering, in marine engineering, and in radio engineering. Night after night, the wireless boat makes her trips with experts aboard

takes the greatest concentration of mind to count these flashes.

"We must watch out for that spar buoy off the breakwater," mutters the captain. "We ran into it one night — broke it clean off. Hello!"

He peers out intently through his binoculars, and sweeps the searchlight to the left. There is a beautiful effect of sea-mist drifting down the broad beam, like a river of silver, full of strange shapes and eddies, flowing far off into the sky and the sea and the night.

"What is it?"

"A sailboat 'way beyond the breakwater — three miles out. Those are the brutes we've got to look out for. They have the right of way, you know, and half of 'em come creeping along without any lights. We're headed straight toward her. See!"

"How far out is our boat?"

"Nearly three miles. I'll send her to the right a little. There she goes! See, her masts turn! Now she's running straight out in the open sea — two miles beyond the breakwater. Ah! She passed the sailboat two hundred yards to the left!"

From time to time the lookout man busies himself with his chart, noting down every significant phenomenon of the run for future study and comparison.

"She's getting her juice fine to-night. I'd hear it if she wasn't. There's the Boston boat — going to Portland. See her lights? She's five miles out. Hello!"

He sweeps the searchlight vigorously to the left. "What's that crazy tugboat trying to do — run into us? I'll turn our boat to the right. She's towing a cargo-boat with three hundred yards of towline for us to drag on. There!"

"How far out is our boat now?"

"Four miles easy. Would *you* like to turn her?"

"*Would* I?"

"Which way?" he asks.

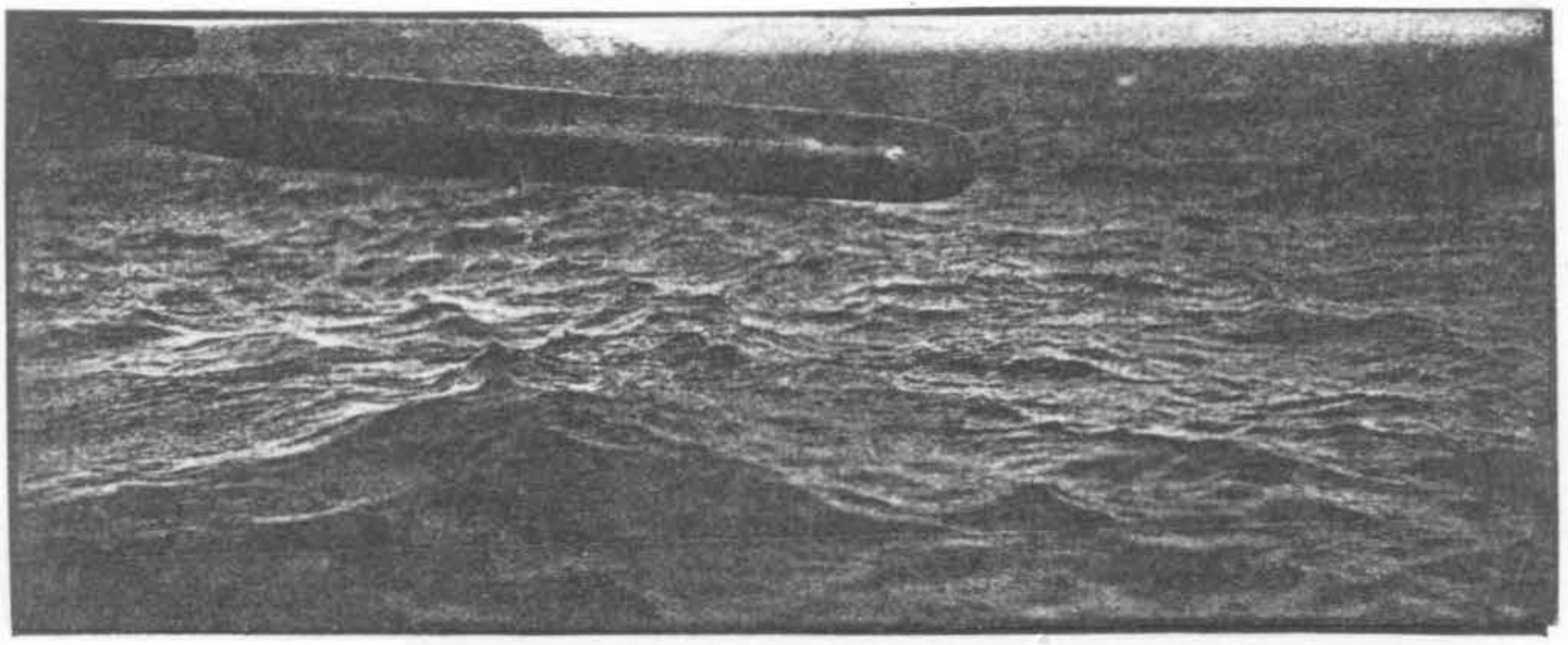
"To the right."

"Good. Press your finger on the key — like this — just lightly. That's enough. Let her go. Now watch the boat."

Sure enough, as I touch the key, the patch of light that marks our boat swerves sharply to the right full forty-five degrees. With the gentlest contact of my finger I have turned a vessel weighing five or six tons and four miles out in the Atlantic — I have turned her four points off her course!

The Second Chapter in Wireless

On another December night I was a fascinated passenger aboard this strangely conducted craft as she fared about the bay and out into the open sea, steered from the wireless station miles away. I saw her swing obediently to right and left, as a distant intelligence commanded, and thread her way unharmed over an eight-mile course among moving craft and perils of the darkness. I saw her aimed for a four-masted schooner lying at anchor half a mile away, and steered at the vessel unerringly, running up close to the side as if this were an enemy's battleship and we a torpedo trying to "make a strike." It was a startling experience — one that ranks in importance, no doubt, with another that I recall fourteen years ago, when, in Boulogne, France, I received, as the representative of McCLURE'S MAGAZINE, the first wireless message sent across the Channel. This message came from no less a person than Marconi himself, in Dover, England, who assured me that the time would come



PHOTOGRAPHS showing a moving torpedo of the old, wire-controlled kind,

when boats and torpedoes would move about the ocean under effective shore control. It is a pleasant coincidence that I am now able, in the same pages, to record the realization of that prophecy.

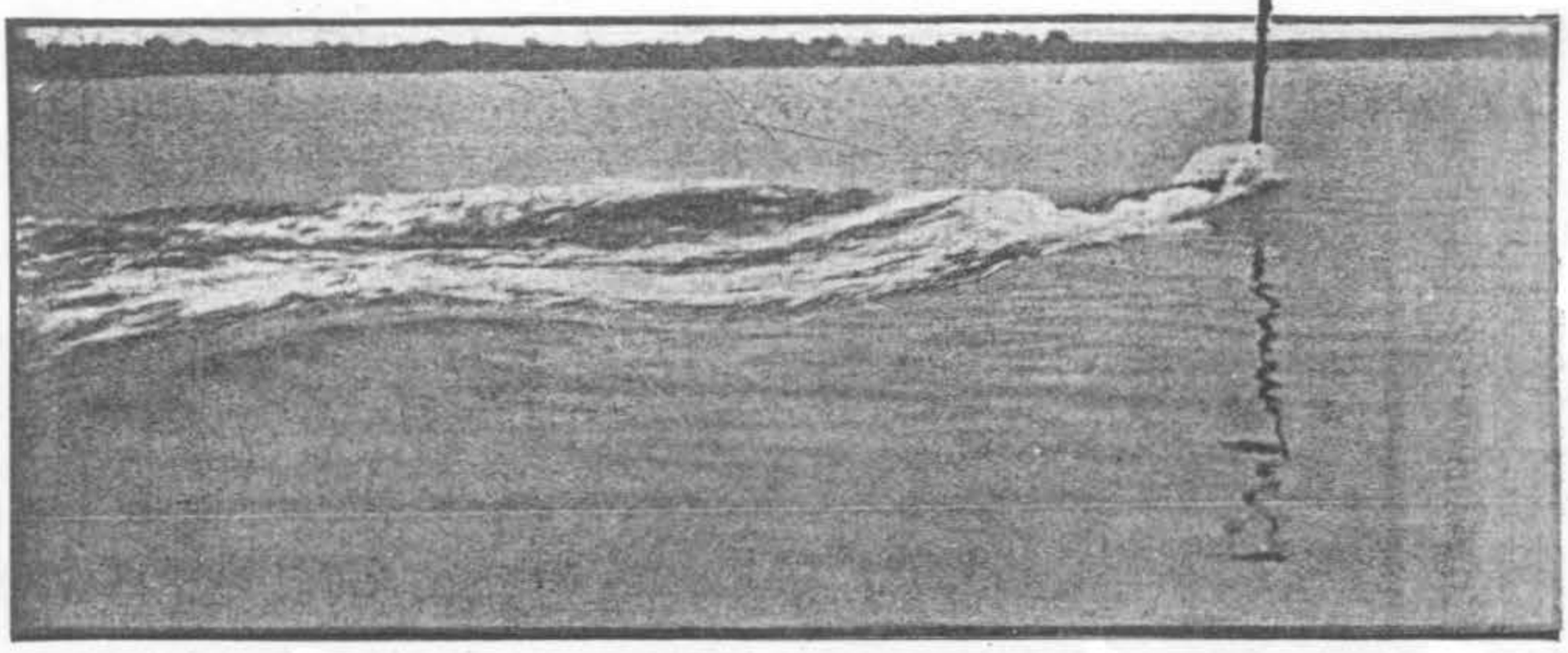
As to these new wonders, I may explain briefly that wireless control of a distant vessel (boat or torpedo) is accomplished by allowing wireless waves from a shore station to act upon a system of receivers and relays and motors in the vessel, each motor exercising some control over engine or rudder. Thus one turns the rudder to the left, another sets the engines at half speed, another at full speed, while another stops them. The current that operates these motors comes from generators carried by the vessel itself, and not from the wireless station on shore, which merely sends power enough to unlock the motor gates, as it were, by a delicate receiving apparatus, and let the current from the generators flow through.

This will seem clearer if one imagines a clock-hand made to turn (by wireless) over the face of a sort of dial. This clock-hand can be stopped, by movements of the sending key on shore, at any desired number on the dial, and, wherever it stops, current flows into a motor connected with that particular dial number. Thus the finger, stopping at three o'clock, might increase the boat's speed, or stopping at six o'clock might turn her to the left, or at nine o'clock might stop her, etc. If there are, let us say, five main controls on the boat,— "full speed," "half speed," "right," "left," and "stop," — then the wireless impulses from shore play upon these controls like fingers on a keyboard, invisible fingers. As the sending key is pressed in one way or another, the moving hand, stopping here or there on the dial, actuates this or that motor, and a definite work with rudder or engine is performed for the safe guidance of the vessel.

Hammond Prophesies His Own Career

In order to make this record of Mr. Hammond's achievement more complete, let us glance back over the inventor's earlier years and aspirations, and observe what manner of man John Hays Hammond, Jr., is, and how he came to conceive of this invention. It is certainly remarkable that a young man of twenty-five, scarcely four years out of college, should have attracted the attention of military authorities on the ground that he is in a fair way to change the conditions of naval warfare. That Hammond is taken seriously is indicated by the fact that in 1912 he was one of the American delegates to the Radio-Telegraphic Congress held in London, the other delegates being Rear-Admiral John R. Edwards, Captain David W. Todd, Dr. Louis W. Austin, Major George O. Squier, Commandant Edgar Russel, Commandant C. McK. Saltzman, John I. Waterbury, Dr. Arthur G. Webster, W. D. Terrell, Professor Willis L. Moore, John Q. Walton, and F. A. Kolster. Mr. Hammond is also a member of the Smithsonian Institution, and was recently made a member of the Royal Society for the Encouragement of Arts, Manufacturers, and Commerce.

John Hays Hammond, Jr., is the son of a rich and distinguished father who has given him every possible advantage in life. As a boy he traveled widely and studied in various foreign countries, including South Africa. He has a lively imagination, a keen sense of humor, and a decided literary taste. Once he wrote an epic poem.



as it is being launched and as it goes through the water toward a mark

Hammond pursued his studies at the Sheffield Scientific School, from which he was graduated in 1910. An incident here shows the bent of his genius and his faith in his own destiny. One day he was chatting with a teacher of higher mathematics, when the talk turned upon inventions, with speculation about the future, dreams of possibilities. Suddenly Hammond said: "Some day I will control a moving body at a distance by the sound of my voice." He said this quite seriously, and asked that his prophecy, written down and duly witnessed, be given to the director of the school and preserved in the safe. This was accordingly done, a diagrammatic sketch of the proposed apparatus being furnished and duly filed away.

After his graduation Hammond decided to give his life to scientific work, not only because of an aptitude in that direction, but because he felt that here lay the best chance of giving to the world something of permanent value in return for what the world had given him.

With a fine concentration on work, Hammond settled down in Gloucester and devoted himself to the new and fascinating science of radio-dynamics or telautomatics, which means the operation of mechanisms by energy sent from a distance. And, presently, rumors began to spread of strange experiments at Lookout Hill, the Hammonds' summer home. A mast and cross-yard on the lawn were seen to do inexplicable things when a searchlight was thrown upon them. At the flash of this searchlight a horn on the mast would sound, or a charge of dynamite would explode, or electric lamps on the yard-arms would mysteriously change from red to green or from green to red.

The explanation of these mysteries on the lawn was simple enough. There was no connection between Hammond and the mast except the searchlight — no wires or hidden mechanism. There was, however, fixed to the mast, a piece of delicate electrical apparatus that received the searchlight rays and was stimulated by them, as will be presently explained, so that a magnet was energized or a motor was made to turn. By these agencies it was possible to do almost any kind of simple work like blowing a horn or exploding a charge of dynamite or moving a system of lamp switches. Hammond declared that, with this system, he could stand on the shore and steer a boat all around Gloucester harbor by simply throwing a searchlight upon her. And he did it, as we shall see.

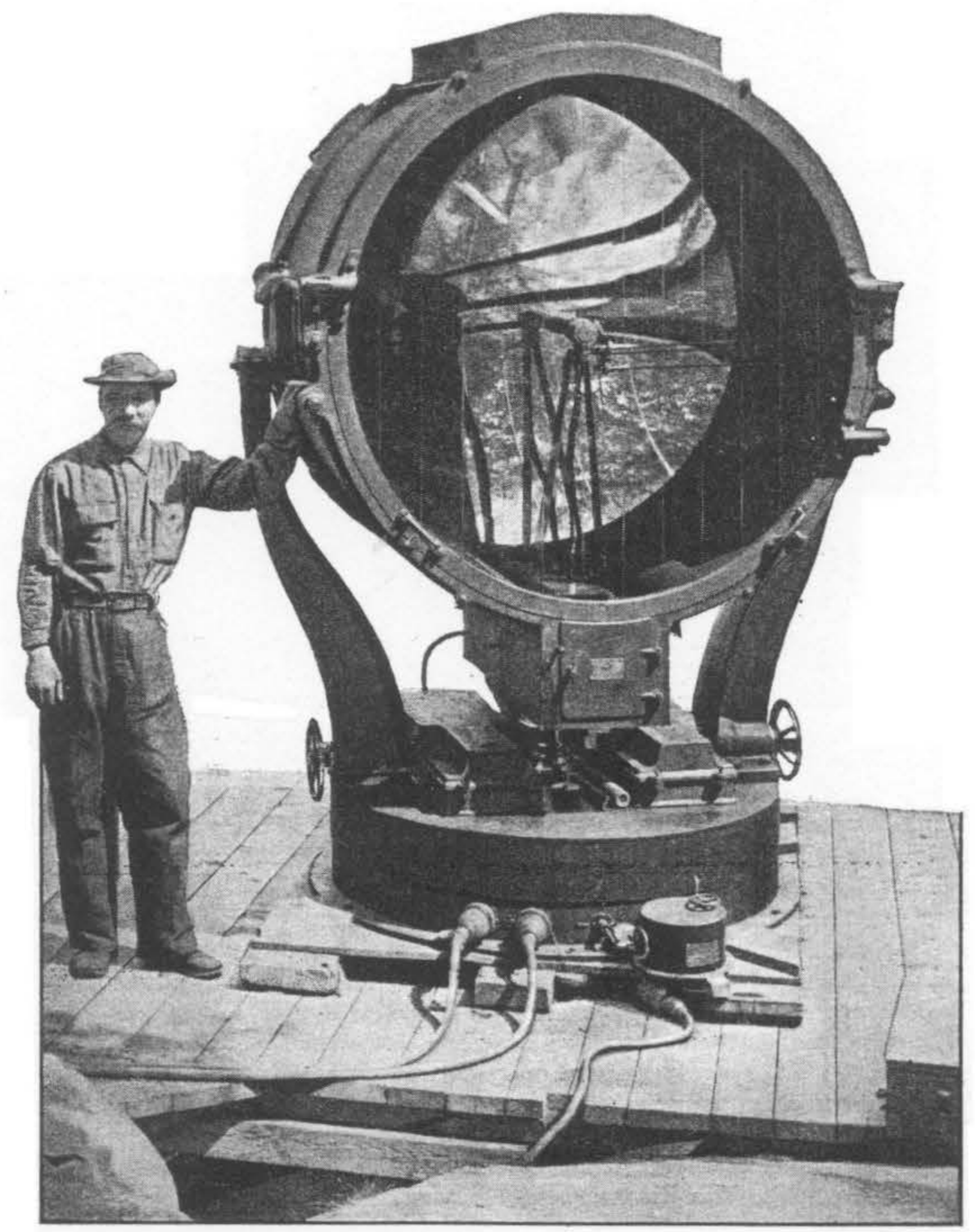
Hammond's Electric Dog

Among other things that puzzled the visitors was a half toy (embodying the same scientific principle) that Hammond called his electric dog. The eyes of this melancholy creature are of bulging glass as large as saucers. His nose is a long thin strip of brownish reddish board. His body is an oblong mahogany box, and contains an electric motor, a storage battery, two selenium disks, two relays, and two solenoid magnets. This dog has no tail except an electric switch, and he runs on three brass wheels, two in front and one behind.

When the motor inside of the dog is started he will do some extraordinary things. If you walk before him carrying a lantern, he will follow you, turning to the right or left as you turn, although you neither touch him nor control him in any way that you can understand. Briskly he steers himself after you with a fidelity that is positively uncanny until you learn that what guides him is the lantern, through the sensitiveness to light of that strange element, selenium. If you move your lantern to the left, the left selenium cell receives more light and more stimulation than the right cell, and so allows more current from the storage battery to flow into the left-hand magnet, which then deflects the hind wheel to the left and the dog turns in that direction. For the same reason, when you move to the right the dog follows you. And, if you reverse the motor by pushing over the tail switch, you can make the dog back away most surprisingly in either direction when you advance upon him with the light.

Steering a Boat by Light Alone

In this experiment (which greatly interested Professor Jacques Loeb) Hammond had inadvertently made a mechanical demonstration of Loeb's theory that the attraction of moths and insects for light is due to the presence in their bodies of a photochemical substance that steers them as selenium steered the dog. Hammond subsequently applied this ingenious method in operating a boat from shore, using a powerful searchlight to stimulate selenium cells aboard her. He was entirely successful here, and steered his boat repeatedly all over the harbor by selenium, one might say; but, owing to the physical limitations of light due to the shadow effect,



THE GREAT SEARCHLIGHT which plays on the wireless boat when she is manoeuvering at night. No battleship can boast such a searchlight. The mirror is five feet across, and throws a light of 186,000,000 candle-power seven miles out to sea

ne soon discarded this plan in favor of control by wireless.

On another occasion Hammond invited some friends to a preliminary demonstration of his present boat-steering idea. In the big room of his Gloucester bungalow he had suspended a wireless transmitter from a rafter over the mezzanine gallery, while on a table underneath was a piece of apparatus like the steering parts of a boat with the rudder swung between two magnets. By manipulating a key he was able to energize these magnets from the transmitter overhead, and thus deflect the rudder to right or left, as he pleased, by means of wireless ir through the ether.

This was the first step in Hammond's effort to steer a vessel by wireless energy. He had not yet accomplished his purpose of voice control,— indeed, he saw that there was only a spectacular value in this,— but he had controlled a distant moving body by a wireless key, which was something. If he could move that rudder on the bungalow table by wireless impulses from the ceiling, why could he not steer a boat out in Gloucester Bay by wireless impulses from shore?

The Young Inventor's First Failures

When it came, however, to carrying out this purpose, the young inventor found that there is a vast difference between experiments with a laboratory model and experiments on a large scale. And for months, while he experimented with an open launch, his efforts failed entirely.

Hammond finally decided that he must have a larger boat to work with and an entirely new set of apparatus, the whole to be covered over against the weather and to form a sort of floating laboratory. So he picked up an old house-boat, the *Pioneer*, a queer craft with no more shape than a bale of hay, and proceeded to transform her into one of the most scientific vessels afloat, fitting her up with gas-engines, generators, batteries, relays, condensers, induction coils, micrometers, not to mention a new keel and two big receiving masts. Many a night this house-boat has threaded her course about the harbor, flopping along bravely, with wireless waves pursuing her and the searchlight dazzling her, wondering, perhaps, if this was the sort of thing a house-boat was intended for.

All this involved great expense and labor, but in the end Hammond triumphed. There came a day when, after months of groping and discouragement, the old house-boat responded to a wireless impulse. Hammond at the time was steering the boat from shore; and when he saw the distant craft answer his call, turn to the touch of his finger, he was so overjoyed that he almost ran her on the rocks. Later in the day he steered her all about the harbor by wireless, and it looked as if the problem was solved — Hammond had made good.

But alas for human hopes! Shortly after this early successful trip there came a great disappointment. The Marconi coherers that Hammond had used on his boat to receive wireless impulses from shore suddenly refused to function properly. They became quite unreliable, so that when the lookout man pressed his key for "right," the boat was as likely as not to go to the left; or, at other times, she would not receive the wireless impulses at all, but would plow straight ahead at the risk of smashing herself to pieces on the rocks. Without reliable receivers of the wireless impulses it was impossible to operate the boat. What was to be done?

In vain Hammond consulted the greatest authorities in the country on radio-telegraphy. He could find no substitute for the Marconi coherers. And finally, in desperation, he set forth on a pilgrimage abroad, visiting London, Paris, Berlin, St. Petersburg, where he sought out the men who had worked on lines similar to his own, and tried to discover what they had actually accomplished in the direction of wireless control for a moving vessel. He found that they had accomplished practically nothing except to make plans and claims very much like his own original project. They had not perfected their plans or justified their claims, nor could they tell him what to use as a substitute for the Marconi coherer.

So Hammond returned from Europe with only negative encouragement. It was true, these foreign scientists had come no nearer than he to the realization of their common dream of the ultimate torpedo, to be steered by wireless; indeed, he had outdistanced them, so far as he could learn, in actual achievement. He, at least, had steered by wireless a real boat on real water, holding her under perfect shore control over a two-mile course, while their steering had been done mostly on paper, or, if on the water, then in an unsatisfactory way for only a few hundred yards. This showed a field free from serious competition, but it showed nothing helpful in the matter of the defective coherer, and if Hammond was to operate a swift and delicately turning torpedo with any hope of success, he must have something better than this to receive the wireless impulses, something far more reliable than this. And he could find nothing; he could devise nothing.

In this emergency, the troubled inventor went to Washington, resolved to lay his case before one of our army authorities. For his own peace of mind he must know whether it was worth while continuing the struggle — whether his invention would be valuable, even if perfected; and, in some trepidation, he sought out General Weaver, Chief of the United States Coast Artillery.

General Weaver's Promise

"Would it interest you, General," the young man asked, "if I could show you a boat running thirty miles an hour that I could steer from shore without any physical connection and ——"

"*Did* you say thirty miles an hour?" interrupted General Weaver.

"Yes, sir. And make her do whatever I wanted, turn her against a battleship or — or anything? Would that interest you, sir?"

There was an anxious pause. The answer meant everything. It would have been easy for General Weaver to be sarcastic or discouraging; but he was not that kind of man. The General smiled good-naturedly, and assured his anxious visitor that if he could do what he said, or half as much, he would have accomplished something of real value in the military world.

Hammond's heart bounded with joy. These were the words he had been hungering for.

"And if I go away now, sir, and work hard at this, and after a while get something ready to show you, will you come up and see it?"

"I certainly will," promised the General. "I'll be glad to come."

That was all, but it made a world of difference to Hammond. Back he went to Gloucester with new courage in him, and worked for a whole year as he had never worked before. Nothing could stop him now. Starting with a promising detector that he had devised in New York for other electrical experiments, he was able, with the help of his laboratory staff and an expert from Harvard University, to perfect this detector so that it received the wireless impulses from shore with great reliability. When the lookout man on the cliff manipulated his key for "right" or "left," the boat went to right or left unfailingly. Needless to say, the construction of this new detector is one of Mr. Hammond's jealously guarded secrets, since his success depends upon it. The point is that this improved piece of electrical apparatus is efficient and reliable, whereas the old coherer, while admirable for the transmission of wireless messages, was inefficient and unreliable when used (as most inventors had tried to use it) for the wireless control of boats or torpedoes.

The Building of the "Radio"

This was an immense step forward, and it gave Hammond such exultant faith in his invention that he immediately set about equipping his wireless station on a larger scale, with a view to greater efficiency. The power-house was supplied with the fastest electric generators in the world, some of them turning seven hundred miles an hour — that is, they would cross the Atlantic in four hours if run on tracks. And he replaced the 150-foot sending masts with two monsters 360 feet high. Here is a sending station that can transmit ordinary wireless messages over a radius of two thousand miles, the most important private sending station in the world.

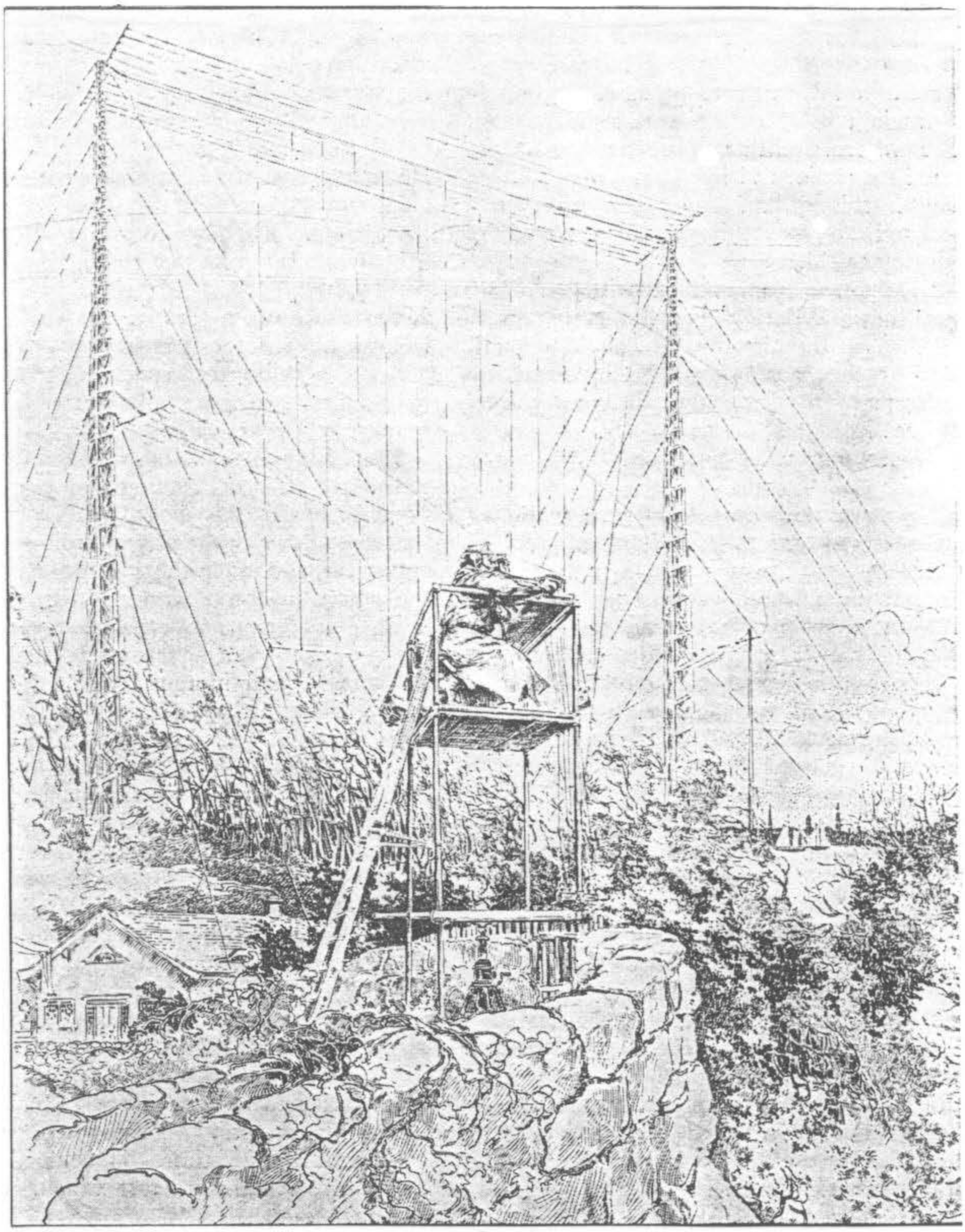
Hammond also proceeded to build a swift vessel to replace his slow-going house-boat. He must have a boat that would dart about the harbor with the speed of a railroad train. If they could control such a boat as that from the shore, they would have something worth showing. And so the *Radio* was born, a slim, rakish craft, forty feet long, with 180-horse-power engines in her, and a guaranteed speed of thirty-three miles an hour — three miles better than the promise to General Weaver.

There followed strenuous weeks in Gloucester harbor after the *Radio* began her evolutions. Aboard this boat was everything that was known in the way of radio-dynamic apparatus, and much that was unknown; for the young inventor, working with feverish energy, was facing new problems in electrical engineering, in marine engineering, in radio-engineering, and in military strategy, and was taking out a new patent every week as new discoveries called for protection. Again and again the flashing craft shot forth and manoeuvered about the harbor under invisible control, while natives of Gloucester gasped in amazement, ready to believe in any miracle — by wireless.

"That gol-derned feller," declared a grizzled fisherman, "if he saw a big liner comin' on the rocks in a storm, he'd jest ketch hold of her by wireless and turn her right plumb around and steer her out to sea again — by wireless, by gosh!"

At last everything was ready, and Hammond wrote to General Weaver, reminding him of his promise. Whereupon there was an anxious waiting time. Had the General forgotten? Had his interest waned? Would he come?

The General had not forgotten. He came, bringing with him Colonel R. P. Davis of the Coast Artillery Corps, an expert in these matters. Together they witnessed the demonstration. They saw a boat swifter than the swiftest cruiser dart about the harbor under perfect control. They saw her circle this way and that, turning instantly at the touch of a distant key. They saw her headed for a definite mark a mile away, two miles, three miles away, and strike it with precision every time — a mark that must have been blown into eternity had it been an enemy's battleship and the boat a torpedo loaded with dynamite.



Power Station *Control*

JOHN HAMMOND in his lookout station, steering his fast boat "Radio" about Gloucester of Hammond's wireless station — the most important private sending station in the world. on the "Radio" as she is sent about the harbor at night. The boat in motion is the "Radio," his wireless experiments, and with which he demonstrated to General Weaver, Chief of the United

General Weaver himself told me how, as he watched this wonderful boat, his sensations changed from skepticism to awakened interest, then to surprise, and finally to absolute amazement.

"Hold on!" he said. "I must understand this. Can you make her go to the right — now, when I say the word?"

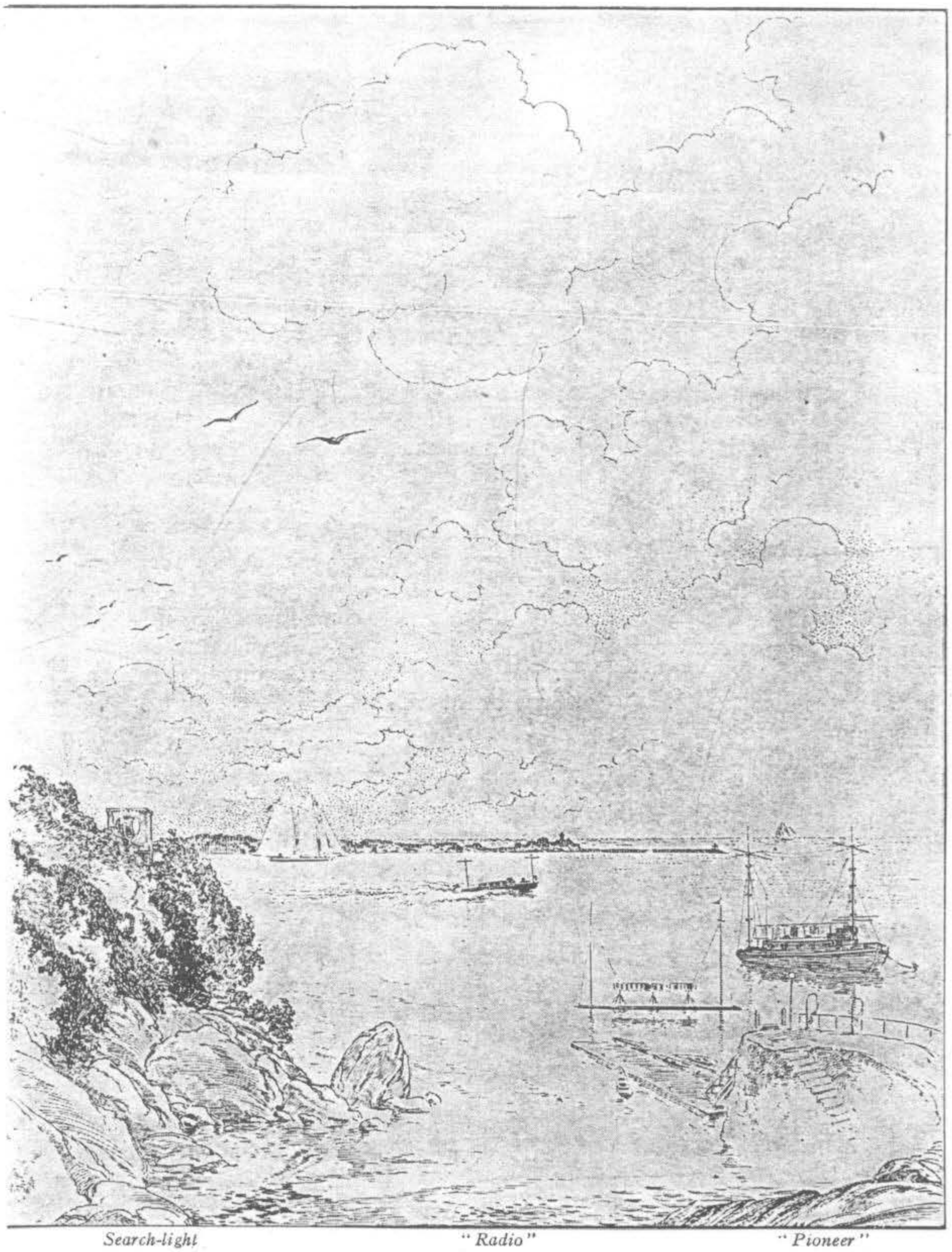
"Certainly," said Hammond, and immediately the boat swung sharply to the right.

"Now make her go to the left."

"Left it is," said Hammond, touching the control key, and the boat obeyed.

"Make her cross the bow of that schooner."

"There, sir." As he spoke, the boat darted swiftly around the fishing-vessel, while the General stared.



Search-light *"Radio"* *"Pioneer"*

Bay by wireless. Behind Hammond are seen the power-house and the 360-foot sending masts Directly in front is the great search-light — greater than that of any battle-ship — which plays with a guaranteed speed of 33 miles an hour, which Hammond had specially constructed for States Coast Artillery, the practicability of a wireless torpedo which would revolutionize coast defense

Then Colonel Davis took a hand. "Now stop her," he said. "Now make her circle around in the opposite direction." And so on, while the boat obeyed each time.

More tests followed, full and severe tests. General Weaver himself took the key and steered the distant boat about the harbor by wireless, putting her through her evolutions with the touch of his own hand. Then Colonel Davis steered her. Then they both went aboard the *Radio* and watched, with keenest scrutiny, as she responded to the command of the distant key, as she turned swiftly this way or that with no hand directing her, but only the impulses from shore. There was no longer any possibility of doubting. The thing was done. The effective wireless control of a moving boat was an accomplished fact.

At the end of this demonstration General Weaver said things that made Hammond blush like a boy and thrill with the pride of achievement. The General was absolutely convinced. This was a most important invention. If nations could send out from their shores, at comparatively small cost, engines of destruction capable of outrunning and annihilating, one by one, the units of a hostile fleet, then the value of torpedo defense would be immensely increased. Even in the present state of the invention it would be possible to use in attack a swift boat like the *Radio*, carrying ahead a downward slanting spar with a mass of explosive at the end (this being under water) that could be steered against an enemy's ship and destroy it.

Since General Weaver's visit to Gloucester, the work has proceeded steadily under army supervision and great strides have been made along the lines of military effectiveness. Day by day and night by night, the wireless boat makes her trips with experts aboard and ashore, recording the results, noting every slightest fault in the transmitting or receiving apparatus, every error or inadequacy, so that these may be remedied and this invention stand upon a solid engineering basis. When that is accomplished (and the time is near) the wireless torpedo, running under water, will be built and operated in the same way, with the same machinery, the same electrical contrivances, and the same method of shore control.

How the Wireless Boat Will Be Used in War

"How far from shore will you be able to control a boat or a torpedo by wireless?" I asked Mr. Hammond.

"About seven miles," he said; "but that is only because of the limitation of human vision. The lookout man can see only seven miles over the ocean, and, of course, he can not steer a boat or a torpedo unless he can see it. As far as our sending station goes, we can throw out efficient guiding impulses over a radius of, say, fifty miles. Which means, from a military point of view, that one sending station is sufficient to defend a hundred miles of coast-line, fifty miles to the right and fifty miles to the left, but for each sending station there must be many lookout stations, each connected with a central source of electrical [wireless] supply."

"Could an enemy's ships disable a sending station by shooting at its high masts?"

"No; because our sending stations will be placed sufficiently inland to be out of range, or they will be protected by intervening hills. In certain cases it may be possible to equip a station with disappearing masts. I have patented such a device."

"How about counter-attack by an enemy's fleet upon these shore-controlled torpedoes?"

"That will be extremely difficult. It is true our torpedoes will be partly exposed above the water, that is, they will show two short receiving masts and a low white framework to carry guiding lights by night and to be seen itself by day. Of course, we must see our torpedoes in order to steer them; but there is a great difference between seeing a torpedo and hitting it. And if one torpedo should be struck, in spite of its speed and smallness, we would send out another and another. Or we would send out a whole flock of them at the same time, which would confuse the enemy. A dozen of these torpedoes will not cost one tenth as much as a single battleship."

The New Coast Defense

"Will this method of torpedo attack change the existing equipment of our coast defenses?"

"Only to the extent of becoming a valuable addition. Shore-controlled torpedoes, used conjointly with the existing system of coast defense, will constitute a practically impregnable barrier against an enemy."

"Is it possible to blow up a ship's powder magazines by projecting upon them wireless waves sent through the ether?"

"That is absolute nonsense. The experiments of an Italian engineer along this line, that have been so widely noticed in the American press, have been shown to be pure fakes. The man was ordered out of French territory as an impostor."

"How about interference with the wireless waves by opposing wireless waves? Could not an enemy create disturbances in the ether that would confuse or nullify the shore control?"

"You are asking a rather delicate question," answered Mr. Hammond, "but I will say this: that a land station has a great advantage over a vessel, because the electrical power and the electrical wave lengths that it can throw forth are unlimited, whereas in a vessel (owing to space restrictions) these are very decidedly limited. Furthermore, it is

possible for a land station to set up in the ether such a confusion of wave lengths that it would take the enemy hours or days, under favorable conditions, to discover which was the controlling wave length, and meantime the torpedo attack would have been made and the damage done. That, you know, is a matter of minutes."

Mr. Hammond went on to explain that he and his laboratory staff have studied every electrical move that an enemy could make against the attack of shore-controlled torpedoes, and have devised answering electrical moves to meet them.

Hammond Steers His Boat by the Sound of His Voice

I may note here, as an interesting fact, that Mr. Hammond, in fulfilment of his college promise, has finally succeeded in steering his wireless boat by the sound of his voice. He does this when the boat is several miles out at sea, standing on the cliff and speaking quietly into a telephone receiver, saying: "Right!" whereupon the distant boat turns instantly to the right, then saying, "Go left!" and she obeys his word, swinging sharply to the left.

This sounds like an impossible fairy tale; but it is a plain statement of fact. Nor is there anything complicated or mysterious in this operation. It is a perfectly simple thing to do. I did it myself. Mr. Hammond's cook did it. Any one could do it, the explanation being that, by a sound-amplifying device, the vibrating energy of spoken words (*any* words) is made to do the work usually done by the wireless key under pressure of a finger.

Similarly, Mr. Hammond has amused himself, and vastly astonished an audience, by saying, "Fire!" into the telephone receiver, whereupon a charge of dynamite in a distant room has promptly exploded. It would have exploded just the same if he had said, "Artichoke!" It could have been made to explode by a fly walking across a window-pane; for an infinitesimal force may close an electric circuit that will set free energy enough to blow up the Panama Canal.

A few weeks ago, in Washington, I had a talk with General Weaver regarding Mr. Hammond's invention.

"These shore-controlled torpedoes, if perfected," said the General, "will be an important addition to our means of coast defense. At present these means are threefold, namely: guns that fire directly at a vessel and aim to penetrate her side armor, mortars that fire high in the air and aim to penetrate her deck armor with falling projectiles, and mines laid to blow up a vessel passing over them. Of course the efficiency of submarine mines is limited by the fact that a vessel must come to them, whereas a dirgible torpedo will go to the vessel.

"We have always realized the desirability of submarine torpedoes controlled from shore, as affording a means of attack upon a vessel's submerged parts, but the difficulty has been to control these torpedoes in their courses. We have tried to steer them by wires unreeled from the torpedo or unreeled from shore, but the results have been unsatisfactory, owing to the disturbing influence of tides and currents. This wireless method of Hammond's, however, promises real precision in attack."

Here, then, is a very definite result of a school-boy's dream. The shore-controlled torpedo is passing through the last stages of its evolution. It is an easy step from the swift boat running *on* the water to a similar swift boat running *under* the water. Who can doubt that this step will be successfully taken? Think of the wonders of wireless already achieved! Clocks are run by wireless. The exact time is sent around the world by wireless. Photographs have been transmitted hundreds of miles by wireless. Bells on buoys have been made to ring their warnings to approaching vessels by wireless energy sent from those vessels. Locomotives have been operated by wireless, with no engineer at the throttle. Train signals are set by wireless. Soon, beyond question, we shall have the torpedo operated by wireless — the ultimate torpedo — and the navies of the world are waiting apprehensively for its appearance.

Tributes of Former Associates

It is not in one profession alone that the memory of Westinghouse will live. Kelvin said of him: "George Westinghouse is in character and achievement one of the great men of our time." Physically he was a big man; he also was great in character and mind. Interesting sidelights on his brilliant career contributed by men formerly associated with him and published herewith show how highly he was esteemed, and what was lost in his passing away.

From William Stanley

I can only add my appreciation of the great qualities of leadership that Mr. Westinghouse possessed. His strong, vigorous purpose, his wonderful grasp of the opportunities of life and his high courage overcame all obstacles and were of inestimable value to the electrical engineering profession and the world.

Great Barrington, Mass. WILLIAM STANLEY.

From Peter Cooper Hewitt

In George Westinghouse the world has suffered the loss of a great and valued citizen and much should be said in honor of his accomplishments and advancement of modern industry. Essentially an American, he had universal reputation and respect.

The vast and divers works which he pioneered give an idea of his force and energy and illustrate dominant characteristics. Every effort of his genius was expended for humanity in advancing the arts of civilization. As the problems involved in nature's secrets unfolded themselves before him he strained every effort and means at his disposal to turn their use to the benefit of mankind.

He appreciated the enormous danger to humanity that accompanies the harnessing of vast forces of nature for public use, and by his foresight and skill prevented disasters which might conceivably have been of enormous extent.

The memory of George Westinghouse will live through his appreciation of nature's forces and his love of mankind.

New York. PETER COOPER HEWITT.

From Nikola Tesla

The first impressions are those to which we cling most in later life. I like to think of George Westinghouse as he appeared to me in 1888, when I saw him for the first time. The tremendous potential energy of the man had only in part taken kinetic form, but even to a superficial observer the latent force was manifest. A powerful frame, well proportioned, with every joint in working order, an eye as clear as a crystal, a quick and springy step—he presented a rare example of health and strength. Like a lion in a forest, he breathed deep and with delight the smoky air of his factories. Though past forty then, he still had the enthusiasm of youth. Always smiling, affable and polite, he stood in marked contrast to the rough and ready men I met. Not one word which would have been objectionable, not a gesture which might have offended—one could imagine him as moving in the atmosphere of a court, so perfect was his bearing in manner and speech. And yet no fiercer adversary than Westinghouse could have been found when he was aroused. An athlete in ordinary life, he was transformed into a giant when confronted with difficulties which seemed unsurmountable. He enjoyed the struggle and never lost confidence. When others would give up in despair he triumphed. Had he been transferred to another planet with everything against him he would have worked out his salvation. His equipment was such as to make him win easily a position of captain among captains, leader among leaders. His was a wonderful career filled with remarkable achievements. He gave to the world a number of valuable inventions and improvements, created new industries, advanced the mechanical and electrical arts and improved in many ways the conditions of modern life. He was a great pioneer and builder whose work was of far-reaching effect on his time and whose name will live long in the memory of men.

New York. NIKOLA TESLA.

The New York Herald March 23, 1914

MR. TESLA'S PATENTS

TO THE EDITOR OF THE HERALD:—

The reports contained in the HERALD and other journals regarding the issue of a recent wireless patent suit are of a nature to create an erroneous impression in of the patents mentioned, namely, No 11,913 and No. 609,154, granted, respectively, to William Marconi and Sir Oliver Lodge, are of no importance. but another patent of the former expert, dated June 25, 1900, contains arrangements on which I obtained full protection more than three years before. * * *

The apparatus described by me comprises four circuits, peculiarly tuned and carefully attuned so as to permit greatest possible flow of electrical energy through them. The generator is a transformer of my invention and the oscillations employed are of a kind which is now known in technical literature as the Tesla currents. Every one of these elements, even to the last detail is contained in the Marconi patent which was involved in the suit, and its use constitutes an infringement of all the fundamental features of my wireless system.

NIKOLA TESLA

NEW YORK CITY, March 20, 1914

LXV. *Induction-Coil Potentials.*

By E. Taylor Jones, *D.Sc., Professor of Physics in the University College of North Wales, Bangor* *.

[Plate VIII.]

THE present paper contains some further applications of the theory of electrical oscillations in coupled circuits, and is a continuation of two former papers † on the subject.

In the first of these it was shown that if a given current is interrupted in the primary of two coupled oscillatory circuits, the potential-difference, V_2, at the terminals of the secondary at any subsequent time t is theoretically given by an expression of the form

$$A_1 e^{-k_1 t} \sin(2\pi n_1 t - \delta_1) - A_2 e^{-k_2 t} \sin(2\pi n_2 t - \delta_2), \quad . \quad . \quad (1)$$

where n_1, n_2 are the frequencies of the two oscillations of the system, and the other six constants can be calculated from the capacities, inductances, and resistances of the circuits. This result was illustrated by a number of examples in which coupled air-core coils connected to condensers were used. The wave of potential represented by (1) was worked out for each case and compared with the experimental curve obtained with an electrostatic oscillograph.

In the second paper referred to, the expression (1) was further illustrated by experiments with an ordinary induction-coil with iron core, a number of cases being worked out in some of which the secondary coil, as well as the primary, was connected to a condenser. In these experiments, however, the primary (paraffin-paper) condenser was of considerably greater capacity than that generally used with an induction-coil.

Recently an expression of the form (1) has been given in an important paper by Dibbern ‡ for the potential-difference at the plates of the *primary* condenser, and the theoretical curves of both primary and secondary potential compared with the experimental curves obtained with a pendulum interruptor. In his experiments Dibbern used coils with air-cores, cores of iron-filings in paraffin-wax, of iron wire, and of solid iron. Good agreement was found between the

* Communicated by the Author.

† "Electrical Oscillations in Coupled Circuits," E. T. Jones, Phil. Mag. xvii. p. 28 (1909); "The Induction-Coil," E. T. Jones and D. E. Roberts, Phil. Mag. xxii. p. 706 (1911). These two papers will be referred to as *l. c.* (1) and *l. c.* (2).

‡ E. Dibbern, *Ann. d. Physik*, xl. 4, p. 935 (1913); Inaug.-Diss., Kiel.

theoretical and experimental curves for the coils with air-core and with the core of iron-filings, fair agreement in the case of the iron-wire core.

In the present paper further tests are described of the applicability of the theory to the case of an induction-coil. In these, smaller primary capacities were used, and the constants of the circuits were determined in actual working conditions. The effect of varying the primary capacity is specially considered, and a view is put forward which differs from that usually held as to the function and the most effective value of this capacity.

There are two things which should be borne in mind in determining the constants of the primary and secondary circuits of an induction-coil. The first is that, owing to the variable permeability of the core, it is necessary to use mean values of the induction-coefficients, which can only be expected to give correct values for the secondary potential over a limited range of values of the primary current.

The other is that the induction-coil as generally used has the terminals of its secondary coil connected to bodies of very small capacity, *e. g.* spark-gap terminals, the electrodes of an exhausted tube, or an electrometer or electrostatic oscillograph of very small capacity. In these circumstances, the capacity of the secondary circuit is mainly distributed along the secondary coil, and when the oscillations are taking place and no discharge is passing, the current is not uniform throughout the length of this coil, but is greatest at the central winding and very nearly zero at the terminals *. The system is in fact similar to that of the oscillation transformer, or Tesla coil, the theory of which was given by Drude †.

The expression "mutual inductance" is not appropriate to such a system, but if (in Drude's notation) L_{12} is the coefficient of induction of the secondary on the primary, and L_{21} that of the primary on the secondary, then L_{12} is less than L_{21}. L_{12} is defined as the magnetic induction through the primary coil due to the secondary current divided by the value of the latter in the central winding. On the other hand, the terminals of the primary coil are connected to a condenser of considerable capacity, so that the current in this coil is uniformly distributed. The coefficient L_{21} is

* As the current varies (in its fundamental oscillation) as the cosine of an angle proportional to the distance from the central winding, this distribution of current will be referred to as a cosine distribution.

† Drude, *Ann. d. Physik*, xiii. p. 512 (1904).

therefore equal to the "mutual inductance" of the coils as usually defined, *i. e.* the induction through the secondary due to the primary current divided by the value of the latter.

For similar reasons the self-inductance L_2 of the secondary coil is less than the value for steady or for uniformly distributed currents, while L_1 has the usual meaning. The coefficient of coupling, k, of the coils is defined by

$$k = \sqrt{L_{12} \cdot L_{21}/L_1 L_2}.$$

The value of the secondary capacity, C_2, depends upon the manner in which the charge is distributed in the secondary coil, but it is unnecessary to determine it. For the purpose of calculating the secondary potential V_2 from the expression (1) it is sufficient to know the values of the six quantities L_1C_1, L_2C_2, L_{21}, k, R_1/L_1, R_2/L_2. R_1 and R_2 are the effective resistances of the primary and secondary circuits.

These six quantities were determined as described below for an 18-inch-spark coil *, with three primary condensers of capacities about 3, 2, and 1 microfarad respectively. These condensers had mica insulation, and for the sake of definiteness were connected directly across the terminals of the primary coil. If the condenser is connected across the interruptor in the usual manner, the primary circuit then includes the battery, amperemeter, and rheostat, and the self-inductance and resistance of the primary circuit will, therefore, be different in different experiments.

The secondary terminals were connected directly to the oscillograph, in parallel with which was a variable spark-gap consisting of two brass spheres, each 2 cm. in diameter, supported on ebonite pillars. The oscillograph has been described in a former paper †. The instrument has very small electrostatic capacity, and in its present form it can be used directly for potentials sufficient to give a 24-cm. spark between the ball electrodes.

Determination of L_{21}.

This coefficient, which, as explained above, is equal to the mutual inductance of the primary and secondary coils, was determined by two methods. In the first it was compared with a known mutual inductance by the ballistic galvanometer

* The primary coil was in four sections. Except where otherwise stated these were all in series.

† E. T. Jones, Phil. Mag. xiv. p. 238 (1907). *Cf.* also *l. c.* (2), p. 708.

deflexion method. The value so found was 20·4 henries for a primary current of 5 amperes. By comparison with this, the same method being used, values of L_{21} were then obtained for other values of the primary current i_0. The results are given in Table I.

TABLE I.

i_0, amperes.	L_{21}, henries.	i_0, amperes.	L_{21}, henries.
0·195	12·9	2·49	20·0
0·395	14·7	3·00	20·2
0·57	16·0	3·52	20·3
0·75	16·9	4·00	20·4
1·00	17·8	5·00	20·4
1·25	18·6	6·86	20·3
1·50	19·0	8·01	19·9
1·75	19·2	10·06	19·0
2·00	19·6	11·04	18·4

It will be seen from the table that L_{21} has its maximum value at 4 or 5 amperes, and that over the range 3 to 7 amperes it does not vary by more than 1 per cent. As most of the experiments described below were within this range, the value 20·4 was adopted for L_{21} in working out the theoretical expression (1) for the secondary potential.

The other method of determining L_{21} is to take the value of k^2 measured with a condenser of considerable capacity in the secondary circuit, as described in the next section, in which case

$$k^2 = M^2/L_1L_2 = L_{21}^2/L_1L_2.$$

The values of L_1, L_2 being found from the periods of oscillation of the primary and secondary circuits when connected to condensers of known capacity, L_{21} can then be calculated from

$$L_{21} = \sqrt{k^2 L_1 L_2}.$$

The values found were

$$k^2 = \cdot 839, \quad L_1 = \cdot 194 \text{ henry}, \quad L_2 = 2540 \text{ henries}.$$

Hence $$L_{21} = 20\cdot 3 \text{ henries},$$

which is almost identical with the maximum value found by the other method. It may be concluded that up to the frequencies used in this experiment the induction coefficients of the coils are not very different from their values for steady currents.

The Coefficient of Coupling.

The coupling coefficient, k, was determined by finding the frequency of the oscillations of the secondary coil (connected only to the oscillograph and ball electrodes), with the primary coil open and with the primary terminals connected by a short piece of wire. The ratio of the squares of these frequencies is $1-k^2$. These oscillations were started by sparking to the ball electrodes with two pointed conductors connected to a second induction-coil, and the curve of potential was photographed in the usual way. With the primary closed the oscillation curve only appeared with great difficulty, and many exposures were taken before a photograph sufficiently good for measurement was obtained. The amplitude of the curve was small, but was sufficient to allow the period to be determined with fair accuracy. The frequency was found to be 1246. With the primary open the frequency was 599·4. This was measured near the end of the curve where the amplitude, and consequently the magnetizing current, is small, in order to minimize as far as possible any error arising from the difference in the degree of magnetization of the core in the two experiments due to the shielding action of the induced current in the primary when on closed circuit.

These frequencies give the value ·768 for k^2. The value given in the former paper* for the same two coils was ·8142. This was determined by a similar method, in which, however, a condenser was connected to the terminals of the secondary coil. It appears, therefore, that the coefficient of coupling of the coils (for natural oscillations) is less when the terminals of the secondary coil are free or connected to bodies of very small capacity, than when they are connected to a condenser of considerable capacity, in which case the oscillating current in the secondary is more nearly uniformly distributed.

The matter was further tested by determining the coupling coefficient with the secondary coil connected to various capacities, the largest being a leyden-jar of about ·001 microfarad, and the smallest consisting of two tinfoil sheets, 19·94 square centimetres in area, separated by a glass plate

* *L. c.* (2), p. 716.

0·61 cm. thick. The results are given in Table II., the capacities being in descending order of magnitude.

TABLE II.

Condenser.	Frequency with primary open.	Frequency with primary closed.	k^2.
A	99·1	247·3	·839
B	218·0	519·0	·824
C	276·0	630	·808
D	355·6	792	·798
E	408·0	897	·793
F	455·0	989	·788
none	599·4	1246	·768

Specimens of the photographs used in these measurements are shown in Plate VIII. figs. 4 & 5. In fig. 4 the first three waves correspond to the exciting spark, the remainder to the free oscillation. The lower wave is the trace of a 768 tuning-fork photographed simultaneously. The numbers in the fourth column show a gradual falling off of the coefficient of coupling as the capacity connected to the secondary coil diminishes, *i. e.* as the current changes from the uniform to the cosine distribution. The question, however, arises whether this diminution of k^2 is due to the change in the distribution of the current, or whether it is not due to some other cause, *e. g.* to a falling off in the intensity of magnetization of the core as the frequency of the oscillation increases. For a given potential at the terminals of the secondary condenser the magnetizing current diminishes as the capacity of the condenser diminishes, being in fact inversely proportional to the frequency of the oscillations. Hence it might be expected that the permeability of the core, for oscillations of given amplitude, would fall off as the capacity of the condenser diminishes. The question whether this appreciably affects the value of k^2 was tested by repeating the experiment with the largest capacity (condenser A) with a much smaller potential. The method was the same, but a much smaller discharge was employed for starting the oscillation, and the most sensitive form of electrometer * was used for obtaining the curve. The potential and current in this experiment were not more than one-fifth of those employed in the former determination, and the value of k^2 obtained was ·820. Hence the

* *Cf.* Phil. Mag. xiv. p. 240 (1907).

diminution of the intensity of magnetization of the core with increasing frequency is not sufficient to account for the large falling off in the value of k^2 shown in Table II.; and we may conclude that the drop in k^2 is due to the change in the distribution of the current in the secondary coil, *i. e.* that as the current changes from the uniform to the cosine distribution, the coefficient L_{12} diminishes more rapidly than L_2. It would be interesting to make similar measurements of k^2 for coils of different dimensions and forms, especially coils with non-magnetic cores.

In the above method for measuring k^2 the oscillations were all started by sparking to the terminals of the secondary coil. There is, however, another way of setting up the oscillations with the primary coil closed, which may be referred to here. If the interruptor of an induction-coil is connected in a shunt across the primary coil, instead of being in the main circuit as usual, when contact is made the primary coil becomes short-circuited and its current begins to decay exponentially. At the same moment oscillations of small amplitude are set up in the secondary, and these are the natural oscillations of the secondary with the primary closed. The potential at the terminals of the secondary coil may be represented by the expression $ae^{-kt} + b \sin nt$, and the electrometer (being connected idiostatically) shows a deflexion which is proportional to the square of this quantity. This includes a term proportional to $\sin nt$, and another proportional to $\cos 2nt$. The curve should therefore show an oscillation of frequency $n/2\pi$ and another of twice this frequency. As a rule the slower oscillation is much the more prominent, though traces of the octave appeared in some of the photographs.

The most prominent feature of the curves obtained was, therefore, an oscillation of frequency $n/2\pi$, *i. e.* the frequency of the oscillations of the secondary with primary closed, and not twice this frequency as is the case in the sparking method.

This "short-circuiting" method was tried with various capacities in the secondary circuit. Owing to the smallness of the amplitude of the oscillations, the most sensitive form of electrometer had to be used. The potential at the secondary terminals was in fact not sufficient to produce a 1 mm. spark between the ball electrodes.

The frequencies obtained by both methods are given for comparison in Table III., and one of the curves obtained by the short-circuiting method (no condenser) is shown in Plate VIII. fig. 6.

TABLE III.

Condenser.	Frequency of secondary.	
	Sparking method.	Short-circuiting method.
A	247·3	245·9
B	519·0	517·8
C	630	636
F	989	1026
none	1246	1266

It will be seen that there is no great difference between the results obtained by the two methods. Such differences as exist are to be accounted for by the difference in the circumstances of the experiments. In the sparking method the iron core is initially unmagnetized, and the oscillations are accompanied by reversals of the induced magnetism. In the short-circuiting method the core is initially strongly magnetized, and as the magnetization decays the oscillations produce small fluctuations in its intensity. The difference between the two cases may be illustrated by saying that, if N is the total flux of induction in the core and i the current in the secondary coil, then in the sparking method the frequency depends upon the coefficient N/i, whereas in the short-circuiting method it depends upon dN/di, and the value of this latter coefficient will be modified to some extent by the hysteresis of the core.

The circumstances of the sparking method are in closer accord with those of the actual case of an induction-coil, and the result obtained by that method, viz. $k^2=\cdot768$, is therefore adopted in the calculations of potential described below.

Determination of L_1C_1, L_2C_2, R_1/L_1, R_2/L_2.

The expression (1) for the secondary potential was worked out for three cases in which mica condensers, of capacities stated to be 3, 2, and 1 microfarad respectively, were connected across the primary coil. These values were, however, not assumed, but rather the value of the product L_1C_1 was determined for each case. This was done by coupling the primary (with the condenser across its terminals) loosely with a secondary of many windings to the terminals of which the electrometer was connected. The most sensitive electrometer

was used in order that the coupling of the two coils might be made as loose as possible. The oscillations were started by interrupting a current of 5 amperes in the primary, and the curves were photographed and measured in the usual way. The product L_1C_1 was calculated from the frequency, the ratio R_1/L_1 from the logarithmic decrement, of the oscillation curve. The results of these measurements are given in Table IV. The corresponding quantities for the secondary circuit, L_2C_2 and R_2/L_2, were determined from the period and logarithmic decrement of the oscillation produced in the secondary when a current of 5 amperes in the primary was interrupted. In this experiment the primary condenser was removed, and the secondary coil was connected only to the electrometer and the ball electrodes, so that the secondary capacity was the same as in the final experiments. The values so determined are given under Table IV. It should be observed that these values of L_1C_1 and L_2C_2 are maximum values, *i. e.* they correspond to a magnetizing current of about 5 amperes in the primary coil.

The effective resistances of the coils in the circumstances of the present experiments, as determined from the damping of the oscillations, are much greater than their resistances for steady currents. The influence of these resistances on the periods of oscillation is, however, neglected in all calculations in the present paper, *i. e.* both in the determination of L_1C_1 and L_2C_2 described above, and in the calculation of the frequencies of the coupled system given in the next section. That no great error is thereby introduced is shown by the close agreement between the observed and calculated periods in the final experiments.

TABLE IV.

	$1/L_1C_1$. c.g.s.	R_1/L_1. c.g.s.
Case I.	$1{\cdot}718.10^6$	149
Case II.	$2{\cdot}654.10^6$	360
Case III.	$5{\cdot}593.10^6$	390
$1/L_2C_2=8{\cdot}974.10^6$ c.g.s. $R_2/L_2=215$ c.g.s.		

Calculation of the Secondary Potential.

The formulæ used in the calculation of the frequencies, amplitudes, and damping factors of the two oscillations are collected here :—

$$8\pi^2(n_1^2, n_2^2) = \frac{1}{1-k^2}\left[\frac{1}{L_1C_1} + \frac{1}{L_2C_2} \pm \sqrt{\left(\frac{1}{L_1C_1} - \frac{1}{L_2C_2}\right)^2 + 4k^2 \cdot \frac{1}{L_1C_1} \cdot \frac{1}{L_2C_2}}\right],$$

$$A_1 = \frac{2\pi L_{21} i_0 n_1 n_2^2}{(n_2^2 - n_1^2)\cos\delta_1},$$

$$A_2 = \frac{2\pi L_{21} i_0 n_1^2 n_2}{(n_2^2 - n_1^2)\cos\delta_2},$$

$$k_1 = 4\pi^2 n_1^2 \left(\frac{\theta_1+\theta_2}{2} - \beta\right),$$

$$k_2 = 4\pi^2 n_2^2 \left(\frac{\theta_1+\theta_2}{2} + \beta\right),$$

where

$$\theta_1 = \frac{1}{2} R_1C_1 = \frac{1}{2}\frac{R_1}{L_1} \cdot L_1C_1,$$

$$\theta_2 = \frac{1}{2} R_2C_2 = \frac{1}{2}\frac{R_2}{L_2} \cdot L_2C_2,$$

$$\beta = -\frac{2\pi^2 n_1^2 n_2^2}{n_2^2 - n_1^2}(\theta_1 - \theta_2)(L_1C_1 - L_2C_2),$$

and i_0 is the current interrupted in the primary.

These expressions are, with a change of notation, the same as those used in the former papers.

In the case of the phase-angles δ_1, δ_2, however, new formulæ are required owing to the fact that in the former papers no account was taken of the difference between the effective resistances and the steady-current values. This affects the initial conditions of the problem, which now become at $t = 0$,

$$-C_1\frac{dV_1}{dt} = i_0, \quad V_1 = R_0 i_0 *, \quad \frac{dV_2}{dt} = 0, \quad V_2 = 0,$$

where R_0 is the resistance of the primary for steady currents.

* If the condenser is connected across the interruptor in the usual way the corresponding initial condition is $V_1=0$, and the solution for this case may be obtained by putting $\theta_0=0$ in the final equation given below.

V_1 is the difference of potential at the terminals of the primary condenser which, for the reasons stated above, was connected directly across the primary coil.

The expression for V_2 was accordingly worked out afresh for these new initial conditions, and the results show that the values of δ_1 and δ_2 are considerably modified by the change in the conditions. The expressions arrived at are

$$\tan\delta_1 = 2\pi n_1\left\{2\beta \cdot \frac{n_1^2+n_2^2}{n_2^2-n_1^2} - (\theta_1 - 2\theta_0 - \theta_2)\right\},$$

$$\tan\delta_2 = \frac{n_2}{n_1} \cdot \tan\delta_1.$$

These reduce to the expressions used in the former papers if θ_1 is made equal to θ_0, *i. e.* R_1 to R_0.

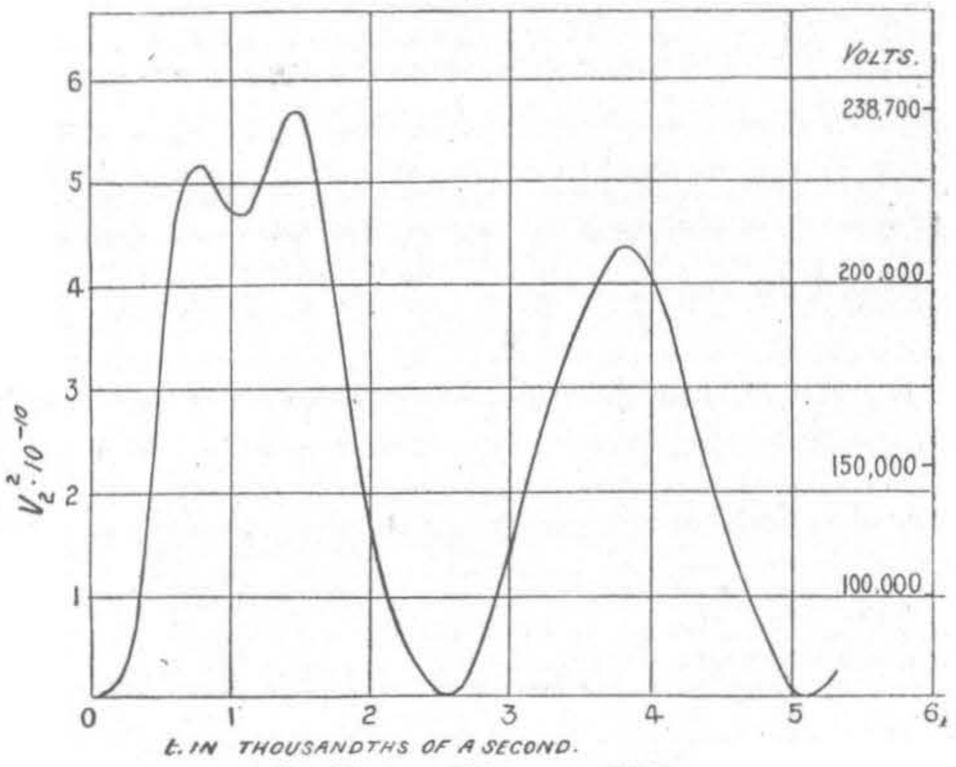
In arriving at the above expressions the squares and product of θ_1, θ_2 are neglected. The fuller expressions for $\tan\delta_1$, $\tan\delta_2$, including these second order terms, were also, however, worked out for each of the three cases, and found to give values not differing greatly from those calculated from the above formulæ. The difference in δ_1 was in each case quite negligible, and in δ_2 less than 1° except in Case II., where it amounted to 2°·5. The values of δ_1, δ_2 given in Table V. are those given by the more exact formulæ. This table contains the values of the eight constants of the formula (1) for each of the three cases, the amplitudes being given in volts for $i_0 = 10$ amperes.

TABLE V.

	n_1.	n_2.	A_1.	A_2.	k_1.	k_2.	δ_1.	δ_2.
Case I.	194·3	1063	258000	49420	58	728	−3°·5	−17°·7
Case II.	232·8	1102	314600	75270	120	1130	−7°·1	−28°·8
Case III. ...	304·4	1224	416500	105400	96·5	1210	−3°·03	−11°·4

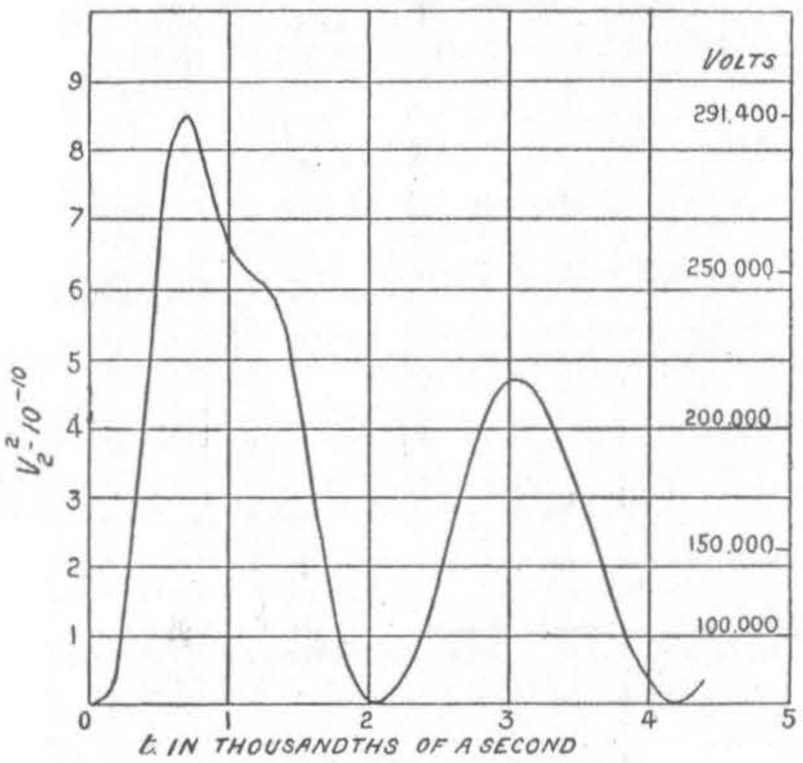
Values of the secondary potential were calculated from these by (1) for various values of t, squared (for comparison with the photographic curves), and plotted over one period of the slower oscillation. The curves are shown in figs. 1, 2, and 3, the maximum potentials indicated being in the three cases 238700, 291400, and 419000 volts respectively.

Fig. 1.



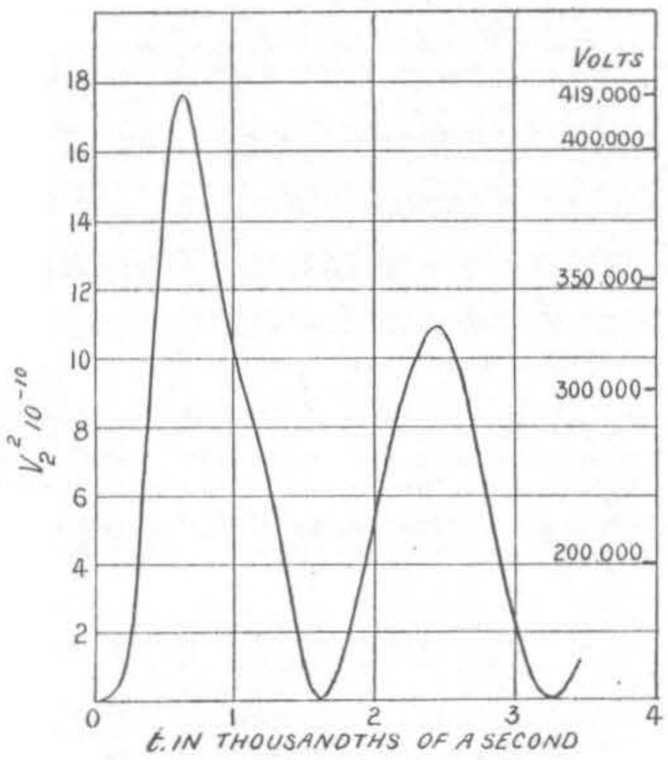
Case I. $n_1=194{\cdot}3$, $n_2=1063$.

Fig. 2.



Case II. $n_1=232{\cdot}8$, $n_2=1102$.

Fig. 3.



Case III. $n_1=304{\cdot}4$, $n_2=1224$.

Final Experiments and Conclusions.

One of the experimental curves for each case is shown in Plate VIII. figs. 7, 8, 9 *. In obtaining them the external circuit (*i. e.* the battery branch) was made as nearly non-inductive as possible, the connecting wires being well twisted together and the current being varied by changing the number of battery cells, rather than by inserting resistance coils. This was necessary because the primary condenser was connected directly across the coil. If a large battery and rheostat is used there is much sparking at the interruptor, and the maximum secondary potential is small and not even approximately proportional to the primary current. Two forms of interruptor were used, one consisting of a steel rod making contact with an iron plate, the other of an amalgamated copper rod dipping into mercury, in each case under paraffin oil. Even when the external circuit was nearly non-inductive there was generally sparking at the interruptor with the stronger currents, but occasionally a sparkless interruption occurred, accompanied by an exceptionally high potential in the secondary coil. The amplitude of the electrometer curve

* The three photographs shown were obtained on different occasions, on which the electrometer had different degrees of sensitiveness.

was then unusually large, and these large amplitudes were alone selected for measurement. The iron-steel interruptor gave much more variable results than the other, but at its best was quite equal to the mercury interruptor.

A number of curves was first taken for different values of the primary current, in order to see whether the amplitude of the curve is proportional to the square of the current. Table VI. contains a set of results for Case I., the current being given in amperes and the amplitude A of the curve in millimetres.

TABLE VI.

i_0.	A.	$\sqrt{A}/i_0$.
1·83	3·1	·962
2·81	7·8	·994
3·75	14·0	·998
4·91	23·3	·983
4·91	10·5	·660
6·41	16·9	·641

The last two plates were taken after the sensitiveness of the electrometer had been reduced by tightening the strip. In cases where the deflexion on the plate is over 3 cm. the photograph is generally very faint, and such large angular deflexions of the reflected ray probably cease to be proportional to the deflecting force.

The numbers in the third column of Table VI. show that over the range of this set of readings the maximum potential V_m at the electrometer is within 4 per cent. proportional to the current interrupted in the primary coil. Similar results were obtained, within the same limits, from the plates taken for Cases II. and III. The numbers given in the table also point to a maximum value of the ratio V_m/i_0, in the neighbourhood of 4 amperes, a result which might be expected from the manner in which L_{21} varies with i_0, as shown in Table I.

A set of three plates was next taken for the three cases with the same primary current, in order to see whether the maximum potentials are proportional to the calculated values. The results are given in Table VII. in which V_c represents the calculated value in volts of the maximum potential. In each case i_0 was 3·0 amperes.

TABLE VII.

	A.	V_c.	$V_c/\sqrt{A}$.
Case I.	4·4	71610	34130
Case II.	6·9	87420	33310
Case III.	14·0	125700	33590

To within about 2·5 per cent., therefore, the calculated values of the maximum secondary potential are proportional to the values indicated by the electrometer.

With regard to the estimation of the absolute values of the potentials, no source of high potential suitable for standardizing the electrometer was available, and recourse was had to the method of spark potentials. It appears to be agreed that the potential difference required to produce a 1-centimetre spark, in air at atmospheric pressure, between ball electrodes 2 cm. in diameter, is not far from 31000 volts *.

The above theoretical expression for V_2 gives in Case I. a maximum value of 31000 volts at $i_0 = 1{\cdot}298$ amperes, but this is calculated on the assumption that the inductances are constant and equal to their maximum values. At this current, however, L_{21} is (from Table I.) about ·916 of its maximum value, and we may assume that L_1 and L_2 are altered approximately in the same proportion. Hence from the expressions for n_1, n_2, A_1, and A_2 we find that V_2 is approximately proportional, as far as small variations in the permeability of the core are concerned, to the square root of L_{21}. Assuming this result, the calculated value of the current required to give a maximum voltage of 31000 is $1{\cdot}298/\sqrt{\cdot 916}$, *i. e.* 1·356 amperes.

The least current observed to give a 1-cm. spark in Case I. was 1·36 amperes. This was repeated on many occasions and with both forms of interruptor, and found to be fairly definite. Sometimes the spark would not pass at less than 1·38 amperes, but on most occasions the result was as given above.

In Case II. the current giving 31000 volts, calculated

* Heydweiller (Wied. *Ann.* xlviii. 1893) gives 31290 volts, while according to C. Müller (*Ann. d. Physik*, xxviii. 1909) the voltage is 30240. An account of the results of different observers is given in Fleming's 'Principles of Electric Wave Telegraphy and Telephony,' 2nd ed., pp. 203–8.

with correction for permeability, was 1·132 amperes. The observed least current giving a 1-cm. spark was 1·13 amperes, but generally a little more current was required. In Case III. the values were ·815 ampere calculated, and ·86 ampere observed. The difference is much greater in this case, but the correction for permeability is also greater and probably not so reliable.

Of the three cases Case I. gives the most definite value for the least sparking current, and is the most suitable to adopt as a standard, while the numbers in Table VII. show that the potentials in the other two cases are fairly closely proportional to the calculated values. The above results show therefore that, so far as the 1-cm. spark potential may be taken as a guide, the theoretical expression (1) leads to approximately correct values (within about 2·5 per cent.) of the maximum secondary potential over the range of current and primary capacity covered in the present experiments.

Further support of the theory is afforded by the similarity in the forms of the calculated and experimental curves (figs. 1, 2, 3, and Plate VIII. figs. 7, 8, 9), and by the agreement between the observed and calculated values of the frequency of the longer wave in each case. Thus the calculated frequencies are (from Table V.) 194·3, 232·8, 304·4 ; the observed values, obtained by measurement of the photographs, 193·9, 232·3, 301·6.

Possibly still closer agreement between the calculated and observed results would have been found if second-order quantities (*e. g.* θ_1^2, θ_2^2) had been retained throughout, but the additional labour involved in the calculations would make the method too cumbersome to be of much value. What is more required at present is a simplified expression which will give approximately the maximum secondary potential, or an upper limit to its value which is not very greatly in excess of the actual value.

Such an upper limit may be arrived at by neglecting the resistances of the circuits so that k_1, k_2, δ_1, and δ_2 all become zero. If we further assume that the maxima of the two potential waves in the secondary occur simultaneously, the expression for the maximum potential becomes

$$2\pi L_{21} i_0 \frac{n_1 n_2^2 + n_1^2 n_2}{n_2^2 - n_1^2},$$

i. e.

$$2\pi L_{21} i_0 \frac{n_1 n_2}{n_2 - n_1}.$$

This may also be expressed in terms of the ratio $L_2C_2L_1C_1$.

Calling this m, and writing a for $1/8\pi^2 L_2 C_2(1-k^2)$, we have

$$n_1^2 = a\left(m+1-\sqrt{(m-1)^2+4k^2m}\right),$$
$$n_2^2 = a\left(m+1+\sqrt{(m-1)^2+4k^2m}\right).$$

Thus

$$\begin{aligned} n_1^2+n_2^2 &= 2a(m+1), \\ n_1^2 n_2^2 &= a^2\{(m+1)^2-(m-1)^2-4k^2m\}, \\ &= 4ma^2(1-k^2), \\ (n_2-n_1)^2 &= 2a(m+1)-4a\sqrt{m(1-k^2)}, \\ \frac{n_1^2 n_2^2}{(n_2-n_1)^2} &= \frac{2ma(1-k^2)}{m+1-2\sqrt{m(1-k^2)}}, \end{aligned}$$

and the upper limit to V_2 is, for given L_{21}, L_2C_2, and i_0, proportional to the square root of this quantity.

If we wish to consider the effect of varying the primary capacity only, then the upper limit to V_2 is proportional to the square root of

$$\frac{m}{m+1-2\sqrt{m(1-k^2)}},$$

or if

$$u = \frac{1}{m} = \frac{L_1C_1}{L_2C_2},$$

to the square root of

$$\frac{1}{1+u-2\sqrt{u(1-k^2)}}.$$

This expression has a maximum value of $1/k^2$ at $u=1-k^2$, and is equal to unity when $u=0$, *i. e.* when $C_1=0$. Consequently, if the resistances of the coils were negligible, the secondary potential might be expected to be greatest when the primary capacity C_1 has a value of about $L_2C_2(1-k^2)/L_1$, and this maximum value would be about $1/k$ times the value the potential would have if the primary condenser were removed altogether.

It is well known that for a given primary current there is a certain value of the primary capacity that gives a maximum secondary sparking distance with an ordinary interruptor *, but it has been usual to attribute the inferiority of smaller capacities to their failure to prevent sparking at the interruptor, and the view appears to be generally accepted that with a sufficiently rapid interruption of the primary current

* *Cf.* Walter, Wied. *Ann.* lxii. 1897; Mizuno, Phil. Mag. xlv. 1898.

the best effects would be obtained without any condenser. The above theory, however, points to a maximum spark-length with a certain condenser, at any rate in the case of negligible resistances, even with a perfectly sudden interruption.

The following experiments were therefore undertaken with a view to testing this point by observing the lengths of spark obtained with various capacities and different forms of interruptor. The condenser used was a subdivided mica microfarad, in which the fractions could be connected either in parallel or in cascade. This was in each case connected directly across the interruptor. The electrometer, though not used in these experiments, was left connected to the secondary coil in parallel with the ball electrodes, so that L_2C_2 and k^2 had the same values as in the experiments described above.

Experimenting first with the mercury interruptor and one secondary cell (i_0 about 1·1 amperes), no amperemeter or rheostat being included in the circuit, it was found that the mica condenser was as a rule sufficient to prevent any visible spark at the interruptor, even when all its sections were in cascade. There was occasionally a spark at the interruptor but no account was taken of the result when this occurred. The capacities were taken in pairs, each two being tried alternately many times at the same distance. Thus ·5 mfd. was found to give a longer spark than 1 mfd., ·3 longer than ·5. The longest spark was given by ·05 mfd. Special attention was given to this capacity and ·025 mfd., which were tried on many occasions. A distance could always be found at which ·05 gave a spark every time, while ·025 always failed. The distance was not the same on all occasions but was generally about 19·5 mm., and the difference of the sparking distances for these two capacities was about 1·5 mm. A longer spark was given by ·05 than by ·1 mfd., while ·025 and ·02 did not show any appreciable difference. A smaller capacity, in the form of an oil condenser of about ·002 mfd., was tried, but in this case there was always sparking at the interruptor.

With the mercury break and one cell, therefore, the most effective capacity was about ·05 mfd.*, but there were indications of a second (smaller) maximum at about ·3 mfd. this capacity giving consistently a rather longer spark than ·2 mfd.

When tried with two cells, an amperemeter and a rheostat being connected in the primary circuit and the current kept at 2·0 amperes, similar results were obtained. At 103 mm. sparks passed freely with ·05 mfd., none with ·025. The smaller capacity also failed at 98 mm. At this current also ·05 was superior to ·1, and there was again a smaller maximum at about ·3 mfd.

* The same result was found with a motor interruptor of the centrifugal type.

In the next experiments Lord Rayleigh's method of cutting the primary circuit with a projectile was followed, the object being to compare the two cases $C_1 = ·05$ mfd., and $C_1 = 0$. An air-gun was first used, which fires a pellet at about 500 feet per second. With one cell 19-mm. sparks were obtained every time with the condenser, none without the condenser at this distance or at 18 mm.

Still following Lord Rayleigh's plan * a service rifle was next used. It was said to fire a bullet at 2000 feet per second. Again with one cell, at 19 mm. there was sparking every shot with the condenser, none with the condenser removed. With the condenser sparks also passed at 2 cm. Similar results were obtained with bullets reduced to about one-half, sparks passing at 19·6 mm. with the condenser, none without. At this distance ·025 mfd. also failed.

With two cells (i_0 about 2·2 amperes) the sparking distance was not so steady, and it was consequently more difficult to fix upon a distance which enabled one to decide in favour of the presence or absence of the condenser. The results were therefore not so conclusive, but whenever a difference was shown at consecutive shots it was always in favour of the condenser. Thus, of three successive shots with the balls at 125 mm., the first and third being without, the second with the condenser (·05 mfd.), the second alone gave a spark. The longest spark obtained without the condenser was 120 mm.

When an amperemeter and rheostat were connected in the primary circuit, and the current was kept at 2·0 amperes, the same condenser gave a spark at 111 mm., while at shots immediately before and after no spark appeared without the condenser. Again, at 107 mm. (reduced charge) no spark passed without the condenser, while at two shots with the condenser (before and after) a spark passed each time. In other instances two consecutive shots at the same distance showed a superiority of the condenser; in no such case did a spark pass without the condenser when it failed with the condenser †.

* Phil. Mag. ii. p. 593 (1901).

† I am indebted to my colleague Mr. A. H. Ferguson, and to Mr. J. A. Owen, who joined me in the rifle experiments and verified the observations. I also wish to thank Sergt.-Major McCracken, of the College O.T.C., for his assistance in these experiments.

As far as these experiments go they do not support the view that the longest spark can be obtained without any primary condenser, but rather indicate a most effective capacity at about ·05 mfd.

The theory also points to this result. For, returning to the expression for the upper limit to V_2, which may be written $L_{21}i_0U/\sqrt{L_2C_2}$, where

$$U^2 = \frac{m}{m+1-2\sqrt{m(1-k^2)}},$$

and $m = L_2C_2/L_1C_1$, we find that in the present case U has a maximum at $m = 4{\cdot}31$, *i. e.* $C_1 = {\cdot}144$ mfd., but that it does not vary by more than 3 per cent. over the range $C_1 = {\cdot}3$ to ·05 mfd.

Now the expression for U is arrived at on the supposition that the maxima of the two waves occur simultaneously, and these coincidences will take place (the resistances being neglected) when $n_2/n_1 = 3, 7, 11, \ldots$. The values of n_2/n_1 for various values of m can be calculated from the equation

$$\frac{n_2^2}{n_1^2} = \frac{m+1+\sqrt{(m-1)^2+4k^2m}}{m-1-\sqrt{(m-1)^2+4k^2m}}.$$

The least value of n_2/n_1 occurs at $m=1$ (*i. e.* $L_1C_1 = L_2C_2$), and is 3·896 at $C_1 = {\cdot}62$ mfd. The ratio $n_2 = 3n_1$, therefore, does not occur.

The next coincidence ($n_2 = 7n_1$) occurs at $m = 9{\cdot}798$, giving $C_1 = {\cdot}063$ mfd., and this is the coincidence which comes nearest to the maximum value of U. It is also within the range over which U is practically constant and equal to its greatest value. The longest spark should therefore be given by a primary capacity of about ·06 mfd. As described above the value actually found was ·05 mfd.

At $n_2 = 5n_1$, ($C_1 = {\cdot}154$ mfd.) the maximum of the long wave occurs simultaneously with a minimum of the other, and a shorter spark is to be expected. At $C_1 = {\cdot}3$ mfd. ($n_2/n_1 = 4{\cdot}194$) the maximum potential will be rather greater than at ·154 mfd. in consequence of the closer proximity of the maxima. These two cases were worked out by the expression (1), the damping factors k_1, k_2, and the phase angles δ_1, δ_2 being neglected, with the result that ·3 mfd. gives a maximum potential about 5 per cent. higher than that given by ·154 mfd. A similar calculation shows that the maximum potential in the case $L_1C_1 = L_2C_2$, *i. e.* $C_1 = {\cdot}62$ mfd., is about 10 per cent. less than that given by ·3 mfd. The theory thus accounts for the observed

principal maximum spark-length at about $C_1 = {\cdot}05$ mfd., and for the second (smaller) maximum at about $C_1 = {\cdot}3$ mfd.

Other cases may be obtained by varying the self-inductance of the primary circuit. If, for example, the four sections of the primary coil are connected in parallel L_1 is reduced to approximately one sixteenth, L_{21} and L_{12} to one quarter, of their former values, and k^2 is unaltered. Calculating as above, we find that the maximum value of U is given by $m = 4{\cdot}31$, *i. e.* $C_1 = 2{\cdot}304$ mfd. The nearest coincidence ($n_2 = 7n_1$) occurs at $m = 9{\cdot}798$, or $C_1 = 1{\cdot}013$ mfd., and the longest spark should be given by a capacity of about this value. By experiment the longest sparks were found to occur at $C_1 = 1{\cdot}025$ mfd., the variation being however very slight over the range 1·0 to 1·05 mfd.

A case of special interest is obtained by diminishing the coefficient of coupling so as to bring in the ratio $n_2/n_1 = 3$. The least possible value of n_2/n_1 is $\sqrt{(1+k)(1-k)}$, consequently in order that n_2 should be equal to $3n_1$, k must not be greater than ·8. In this case it is also possible to make the maximum value of U, and the ratio $n_2/n_1 = 3$, occur at the same value of the primary capacity. The necessary value of k^2 is found by eliminating m between

$$m = \frac{1}{1-k^2}$$

and

$$\frac{m+1+\sqrt{(m-1)^2+4k^2m}}{m-1-\sqrt{(m-1)^2+4k^2m}} = 9.$$

This leads to the equation

$$91k^4 - 164k^2 + 64 = 0$$

for k^2, giving $k^2 = {\cdot}571$, the other root being greater than unity.

Consequently with $k^2 = {\cdot}571$ ($k = {\cdot}756$), and $L_1C_1 = {\cdot}429\ L_2C_2$, an exceptionally high secondary potential should be given by an induction-coil.

The most effective way of diminishing k^2 is to introduce external self-inductance into the primary circuit, since this does not involve any diminution of L_{21}. In the present case (primary sections in series) the value of L_1 required to give $k^2 = {\cdot}571$ is ·241 henry, and the primary capacity ($C_1 = {\cdot}429\ L_2C_2/L_1$) is ·198 mfd. On trying the experiment it was found that by introducing the necessary external self-inductance the maximum spark-length for a given primary current was considerably increased. Thus at

$i_0 = 1{\cdot}25$ amp. and without the external inductance the maximum spark-length ($C_1 = {\cdot}05$ mfd.) was 2·81 cm.; with the external inductance and the same primary current the longest spark was 5·36 cm., and the most effective capacity for this case was ·2 mfd.

The experimental results therefore agree with the theory in indicating that the most effective adjustment of the system (from the point of view of spark-length) is that in which $n_2 = 3n_1$, and U is at its maximum. It is probable that most induction-coils have coefficients of coupling which are greater than ·8, and in such cases the method here described may be used for making the coil give a longer spark with a given primary current, or a given spark-length with a smaller current.

The actual values of the secondary potential can only be calculated when the effective resistances are determined for each case, but it is not probable that these latter results would be greatly modified by their introduction. On the whole the evidence tends to show that the theory described in this and the two former papers is sufficient for the calculation of the secondary potential of an induction-coil and the most effective value of the primary capacity.

Bangor, February 1914.

The New York Post June 29, 1914

TESLA DOES NOT SEE WAR

INVENTOR, A SERVIAN, TALKS OF THE ASSASSINATION.

He Thinks That Fighting Will Not Follow the Death of Archduke Francis Ferdinand, but if There Is War He Believes It Will Assume European Proportions.

Nikola Tesla, the inventor, who was born in Servia, said to-day that if fighting followed the demonstrations against Servians, resulting from the assassination of the Archduke Francis Ferdinand, the war would quickly assume European proportions. Incidentally, Mr. Tesla said that his uncle, the Metropolitan of the Greek Church in Sarajevo, had been instrumental in bringing about the annexation of Bosnia and Herzegovina in 1908 by Austria—a political change that rankles in the breasts of the Servians.

Mr. Tesla deprecated the assassin's act, saying he was profoundly sorry that an irresponsible fanatic, one of his own countrymen, should have committed such a crime. He believed that the excitement would soon subside. At the same time, he pointed out that Servia was a hotbed of bitterness, and that hatred engendered by the Balkan war still smouldered, largely because Servia's efforts to gain an Adriatic port were frustrated by the attitude of Austria-Hungary.

He said also that Archduke Ferdinand realized the hatred of the Servians, and had proposed liberal reforms in regard to the Slavs, which should have made him more popular.

"My uncle," he added, "was a Metropolitan in Sarajevo, where the Archduke was assassinated. That title is held by the small group of men next in power to the Patriarch of the Greek Church. He was largely responsible for the annexation to Austria-Hungary of Bosnia and Herzegovina, and through his skill, it is currently believed to-day, war was averted at a time when Servia had no army to speak of, and when all of the Balkan states could have been easily conquered.

"Previous assassinations have shown, as I hope this one will, that bomb-throwing and shooting at royal personages rarely precipitate war. They create excitement, which soon dies away. The assassins are deluded and irresponsible young men, acting in the belief that they are giving up their lives for a great cause. Yet the situation is very serious because of popular tension in Servia, and a war now is unthinkable which does not assume the proportions of a European war.

'In 1908 Servia was on the brink of war. The people themselves were emphatically opposed to annexation, but one or two persons high in the Church saw that this was the only means of saving the country. At that time the Croatians, who are virtually the same people, were in favor of annexation, because they believed that ultimately Dalmatia, Croatia, and Bosnia Herzegovina would be united under the nominal rule of Austria-Hungary, while remaining actually independent."

The New York Post June 30, 1914

PUPIN REPLIES TO TESLA

INSISTS THAT ASSASSIN WAS AN AUSTRIAN SUBJECT.

Head of Serb Alliance in This Country Asserts that Inventor Confused the Terms "Serb" and "Servian" in His Interview on the Killing of Archduke Francis Ferdinand.

Prof. Michael Pupin, of Columbia University, president of the Serb Federation of America, and president of the Serbo-American Educational Alliance, sends to the *Evening Post* the following letter, dated yesterday, in answer to the interview with Nikola Tesla, published in last evening's edition of this newspaper. Professor Pupin's letter is as follows:

"In your issue of to-day appears an interview with Mr. Tesla regarding the tragic death of the Archduke Ferdinand of Austria. In this interview Mr. Tesla is described as a native of Servia, and he is quoted as expressing a profound sorrow that an irresponsible fanatic, one of his own countrymen, should have committed such a crime. The inference is, that a native of Servia assassinated the heir to the Austrian throne. Such, however, is not the case; it was a Serb, a native of proud Herzegovina, who committed this violent act. Servia and the Serbs of Servia, that is, the Servians, stand with their hands clean.

"This violent act of assassination should not be placed at their door by a misleading interchange of the words 'Serb' and 'Servian.' Serb is a racial name, and applies to the people living in Bosnia, Herzegovina, Dalmatia, Croatia, Slavonia, Servia, Montenegro, Macedonia, etc. The name Servian, on the other hand, is a political name, and belongs specifically to the Serbs who live in the kingdom of Servia, just as the name Montenegrin belongs to the Serbs who live in the kingdom of Montenegro. It was a Serb of Herzegovina, a province of Austria; that is, it was a subject of the Austrian Empire who shot the heir to the Austrian throne.

TRIALS OF THE SERBS.

"It looks as if the misleading interchange of the two words might be indulged in intentionally, in order to cast a shadow of suspicion upon the kingdom of Servia and the men who guide its destinies. Recent dispatches from Vienna display this tendency in an increasingly marked degree, where the word Servian is substituted in seven cases out of ten for the word Serb and where, also, violent attempts are made to connect the tragedy of Sarayevo with Belgrade and Servia. If the Serbs of Bosnia and Herzegovina believe in acts of violence, let them be responsible for it, and let them appeal to their own local conditions to furnish proof which will, in their opinion, justify their crime.

"The Servians, that is, the Serbs of Servia, have been sorely tried during the last two years, and it is still fresh in the memory of everybody that they stood their trials with wonderful patience and heroic tact. To conquer impenetrable Albania in the face of a raging winter, and to seize the Albanian coast after incredible hardships and enormous sacrifices required an heroic spirit of the most extraordinary kind on the part of the Servian peasant soldier. He rose equal to the occasion and astonished the whole civilized world. But he did it because economic slavery to Austria for centuries made him look to the ancient Serb town of Durazzo on the Adriatic coast for a gate which leads to a road of economic freedom. Then, suddenly, Austria's warlike trumpets sound the command that the Servian peasant soldier must leave the Adriatic coast and give up the dream of his life.

THE PEASANT'S SAD RETREAT.

"The brave fellow discovers presently that Austria's arrogant command is the wish of Europe, and he bows to it without a murmur. He admits, with Christian fortitude, that the interests of Europe are more momentous than his own long-cherished hopes and aspirations, and he retraces his steps over the bleak and hostile crags of Albania. The retreat of Napoleon's army from Moscow is a gay wedding procession in comparison with the sad march of retreat of the Servian peasant army from Albania. It has no parallel in all history, and it represents the greatest moral victory that any army ever achieved. Let not shadow of dark suspicion, produced by misleading interchange of words 'Servian' and 'Serb,' connect the Servian peasant soldier with the tragedy of Sarayevo. He undoubtedly has much cause to long for revenge, but if he should ever seek revenge he will get it by open war and not by assassination.

"I permit me, also, to express my astonishment at Mr. Tesla's reference to his uncle, the late Orthodox Metropolitan of Sarayevo, as being chiefly responsible for the Austrian annexation of Bosnia and Herzegovina in 1908. The whole world understands to-day that this annexation is and always was considered by every true Serb as one of the greatest national calamities, and nobody felt this more than the Serbs of Bosnia and Herzegovina who represent the finest flower of the Serb race. If Mr. Tesla's uncle, the late Orthodox Metropolitan of Sarayevo, was instrumental in bringing about this awful national calamity then he will certainly be considered forever after the Benedict Arnold of the Serb race. Does not Mr. Tesla see that he is compromising the Orthodox Church of Bosnia, and preparing another tragedy for the golden city of Sarayevo?

"Mr. Tesla's startling information about the high dignitaries in the Orthodox Church and their connection with the Austrian annexation of Bosnia and Herzegovina may be sweet music to the ears of the Austrian diplomats, but where does it leave the influence of the Serb Orthodox Church with the Serb people of Austria-Hungary?"

The New York Evening Sun July 6, 1914

News of the Theatres

Rehearsing While You Wait at the Longacre Theatre.

Electrified Dressing Room Coming to the Palace.

Manager Frazee has hit upon a happy way of obtaining the "A Pair of Sixes" players for the companies that will tour the country this fall. Instead of looking around the theatrical world and selecting a host of promising actors and actresses in May, signing contracts with them then with orders to rehearse in August with the expectation of releasing some of them in that late summer month and leaving them high and dry with no engagement in sight, Mr. Frazee is able to play the part of a philanthropist, the role of a lover of his professional brothers and sisters. He is able to be so altruistic through the happy fact that "A Pair of Sixes" is now playing at the Longacre Theatre. Here is the programme that is followed for engaging men and women to act in the new "A Pair of Sixes" companies.

Applicants for the different positions are put through their paces at once. There is no delay. First, they are invited to see the play acted by the New York company. After that, they read the play through carefully at home. Then some one hears each one go through his part and if he is not too awful he soon gets an opportunity to rehearse with the understudies of the company. If he is the right person for one of the parts he receives a contract and can rest in peace until the season begins. If he is the wrong person, he has lost only a week or ten days instead of being kept on tenterhooks for three or four months.

Eighty-four people are going through this sifting out process now at the Longacre Theatre. This includes persons for all the parts except the principal one. To fill these players are engaged whose work is well known. But this weeding out plan for filling the other characters of the several casts gives a good opportunity for discovering really clever people who have not attracted much attention because of lack of opportunity.

The cast for the Chicago company now includes Frank McIntyre, Joseph Kilgour, Sam Hardy, Oza Waldrop, Elizabeth Nelson, Louie Emery as *Toddles*, Jack Jarrett, Jack Raffael and Elmer H. Brown. Those engaged thus for for the Western company are Paul Nicholson, Miss Norton, Reginald Fife, Helen Hilton and Katherine Blair. Joseph Coyne will be in the London company and so will Orlando Daly and Thomas Meighan. Mr. Frazee leaves for England on Aug. 11, via the Mauretania, and will engage the rest of the English company after he arrives in London.

An experiment that would have been tried out in one of the public schools of this city if the parents of the school children had not proved highly sensitized on the subject is to be attempted in the Palace Theatre. A high tension dressing room is being installed for the electrifying of performers before they go upon the stage. The room will contain a powerful Tesla coil and the walls will be wound with heavy insulated copper wire carrying high frequency currents. Tired artists, it is predicted, will enter this room and emerge filled with ozone and thoroughly electrified. It is declared that a short visit to the so-called "pop house" by performers will start any act on the stage keyed up to blowing off steam pressure.

Here are a few of the things that Mortimer Norden, chief electrician for the B. F. Keith circuit, says about the experiment after taking a trip to Walter J. Kingsley's own high tension press room:

"The high tension dressing room at the Palace Theatre will be an entering wedge for the greatest blessing electricity has brought to mankind. High potential electricity will do away with bromides, phosphates, pick-me-ups, pepsin tablets and all the other dope that people take for nervous and stomach troubles. Every theatre will be wired for high frequency currents and both the performers and the public will be keyed up to dazzling pitch. There is nothing harmful in all this. We simply take a short cut to nature's reservoir of power and instead of getting all our vitality from food and air and sunshine, we get it in delightful dosage direct from electric currents which intensify cerebration, make one talk in epigrams, give a keen sense of humor, bring happiness, and kindle brain activity to a point equalling that of the most brilliant. Living in an electrified room is to receive lasting benefits and to make life burn with a bright and steady flame."

Now, who ever heard an electrician talk like that before? One holds one's breath when one considers what might happen if Walter Kingsley should take a dose of the electrified ozone. It would be a case of electrifying a "live wire." But Nikola Tesla's plan seems to be a scientific success. The Palace Theatre management is to be congratulated upon its enterprise in placing at the service of its vaudeville artists this latest and highest form of electric massage.

Carl Stail, who was one of the boys in the original "Florodora" sextette, will sing and act the part next season of *Racz*, the Gypsy musician, in the operetta "Sari."

Henry W. Savage will have two "Sari" companies for the new season, one company in the comedy, "Along Came Ruth," and one company in the morality play, "Everywoman."

Rozsika and Yansci Dolly, featured entertainers at William Morris's Jardin de Danse, will take one hundred Hungarian children from the Madison street settlement, in two large tallyhos, to Central Park to-morrow. Later the children will be brought to the New York Theatre, where the Dolly Sisters, Harry Fox and others will provide a special vaudeville entertainment, in addition to the regular performance.

The New York Press July 26, 1914

"Pep Room" in the Palace Is Much Better Than Champagne

VAUDEVILLE artists playing in the Palace Theatre are enthusiastic over the benefits derived from the gigantic electrical installation for medical purposes which was opened in Room 19 last Monday. In this "electrical cage" sick or tired actors and actresses are given from 100,000 to 1,000,000 volts of electricity and saturated with enormous volumes of "juice" vibrating hundreds of millions of times a minute. The huge coil generates liberal quantities of ozone, which opens up the throat and lungs, and artists who enter the room unable to go on the stage quit it in a few minutes prepared to give the best performance of their lives.

Eddie Foy, who has christened the plant the "pep room," swears by it, and has arranged with House Electrician Edwards to visit the Palace weekly for treatments when he is playing elsewhere. Joan Sawyer, who is exhausted from overwork, goes to the high tension electric bath before every performance, and has grown so enthusiastic that she brings parties of her friends to the Palace for high potential treatment. Chief Electrical Inspector Timmany has passed the apparatus, and declares that it meets with his hearty approval and will prove a blessing to the artists. "I wish," he says, "that every school and every home had a plant for producing high frequency currents. They are healthful in the highest degree."

Electrical experts visit the Palace "pep room" daily, and its use bids fair to become a fad. The gigantic resonator is a startling spectacle when in action, as it throws off five-foot sparks and makes a deafening roar. Artists have to be convinced by demonstration that they can take the tremendous discharges with entire safety. Once convinced they return again for treatment.

The current from the street service is received at the transformer, 220 volts, A. C., 60 cycles. The transformer is 3,000 Watt closed core, dry type. There is a variable secondary on these two windings, one of 20,000 volts and the other of 30,000 volts. There is also a condenser, consisting of 6½-gallon Leyden jars filled with a saturated solution of salt and water. Connected to this condenser is a large resonator 3 feet high by 9 inches in diameter. This resonator has a variable primary winding of the heavy wire type, consisting of 14 turns of No. 8 aluminum wire. The secondary winding of the resonator is 2,500 turns of No. 22 wire. The E. M. F. of the transformer is 1,000,000 volts.

There is a brush discharge when in operation of about 7 feet at the top of the resonator, which seeks a path on the side of the machine to copper wire gauze frames 10 feet long by 3 feet wide, which makes an electrical lane. These frames are suspended alongside of the apparatus, placed about 3 feet apart, making a lane 10 feet long and 3 feet wide between the gauze frames.

When the machine operates the entire space between these gauze frames is saturated with electrical waves jumping from frame to frame across the resonator. The air is highly charged with ozone and the effect of the entire treatment is very pleasant. On the left hand side of the room there is a switchboard for regulating the intensity of the current, which can be reduced or increased at will.

Nikola Tesla, the first man to demonstrate the efficacy of high voltages, and Superintendent Maxwell of the New York Public Schools, are watching the experiments with great interest. It has long been Superintendent Maxwell's ambition to install a similar room in each public school for backward children.

The plant in the Palace Theatre, though expensive, has already proved its value, and will be retained as a permanent addition to the stage. It bids fair to inaugurate a craze for high potential bathing that will be taken up all over the country. There is no denying the fact that a visit to the spectacular room all ablaze with fiercely crackling blue flames invigorates one, stimulates the brain and gives renewed efficiency to tired cells.

Servians Here Believe War Would Be the Greatest in History

Serb Consul Considers Conflict Inevitable as Result of Intolerable Demands Made by Austria, and Predicts That Other Powers Would Be Drawn Into the Clash.

If the excitement and enthusiasm which have stirred the Servians in New York into a warlike mood is a criterion there will be thousands ready to return to the fatherland to bear arms in case of war. Not only was the Servian colony in a turmoil, but the Bulgarians and the Greeks also were excited. The chief centre of Servian interest, however, was at the consulate at No. 143 West Twenty-second street. Through the afternoon and far into the evening the throngs of Servians came there in search of the latest news from Europe and to discuss the developments in the strained situation.

That Austria had acted without due provocation and had made demands with which no country would comply was the opinion of all. Although there are only 800 Servians in this city, there are many thousands scattered throughout the country, and it was the opinion everywhere that Servia had been so insulted by Austria's actions that all would rally to the defence of their country.

Believes War Inevitable.

Although he did not care to say anything authoritative for fear of exaggerating the seriousness of the situation before he received official despatches, Paul H. Pavlovitch, secretary in charge at the Servian Consulate, said:—"From what we know here there is no doubt that war between Austria-Hungary and Servia is inevitable. It has come down to the question of whether Austria will recede from her domineering position, or Servia give in to her demands. I am sure that the latter will not be the case.

"If it had not been for Austria there would have been no war between Servia and Bulgaria. The empire started that contest for her own ends, thinking that the Servians would be beaten. They were not, and therefore Austria feels that she has suffered. Since that time she has been searching for an excuse to further trouble us.

Of the many Servians seen yesterday Nikola Tesla, the famous engineer and electrician, seemed to think that there would be no war. When seen at the Waldorf he told the HERALD:—"Austria has created a very dangerous situation through her peremptory note to Servia, which reads like a document of the Napoleonic régime.

"It is wrong of the imperial government in Vienna to implicate the Servian government in the assassination of Prince Ferdinand, for it must be apparent to all intelligent men of both parties that this deplorable act was altogether against Servian interests.

Between Slav and Teuton.

"Although the state of things forebodes a national imbroglio, it must be recognized that if it comes to a war it will be a clash between Slav and Teuton. Therefore if this calamity is to be averted we must look to Berlin and St. Petersburg. Personally I am convinced, despite all indications to the contrary, that there will be no war, and I think my faith is largely in the Emperor of Germany.

"This is a man of extraordinary powers, whose ambiton seems to be to achieve greatness by maintaining peace. If it were otherwise Germany would long ago have clashed with other nations, for she has a military organization and war equipment such as the world has never seen before. There are, however, other forces which will tend to prevent a conflict against which the greatest wars in history would be like mere skirmishes. When we consider that Russia has available from five million to six million men, Germany five million, France four million, Austria two million, Italy nearly as much and the Balkans about two million, an international struggle of this kind would involve more than twenty million combatants. And the expenditure would be from $300,000,000 to $400,000,000 a day.

"In view of this, no man in power in any country would dare to take so consequential an initiative. And it is precisely because of this that one is amazed to read Austria's dictatorial note.

"In every difficulty suddenly precipitated the most important thing is to avoid immediate explosion. If shots are not exchanged across the Danube within the next forty-eight hours the war is as good as averted. In all probability Austria will make some modifications in her demands and the Servian government will make every effort to comply as far as possible."

Herald View Indorsed by Mr. Tesla; Sees Peace Near

Inventor Believes Magnitude of the Great European Struggle Makes It Almost Impossible—Resources of Nations Soon Would Be Exhausted.

THINKS THAT AUSTRIA WILL SOON BACK DOWN

Indorsing the HERALD's editorial as summarizing the situation in Europe, that war inevitably means devastation, destruction and death, Mr. Nikola Tesla, the inventor, last night at the Waldorf-Astoria Hotel made a plea for peace. He believes it appalling that a political condition could be brought about through local disturbances that would ultimately cause the loss of millions of lives, millions of dollars and a physical reconstruction or absorption of nations.

"I have been following very closely the events of the week and up to this very hour," said Mr. Tesla, "and while they are serious and while actual reprisals have been reported, I am convinced that war will be averted. The mobilization of armies must be looked upon so far merely as demonstrative and unavoidable in the circumstances. The very immensity of the danger involved is the best guarantee for peace.

"The situation with which we are confronted so suddenly is a great lesson to the world, showing how far we have progressed. The ideal theoretical conditions for the maintenance of peace would require that any local disturbances would have as a result the division of the whole power of nations into equal halves, one standing for one contestant and the other for the second.

Germany's Shrewd Move.

"That we are approximating a condition in which a slight disturbance will involve the whole world is manifest. Only a few days ago Austria declared war against Servia. The papers reported that Austria had Germany's support. This could not have been true. The first overt act of Germany was her refusal of interference. It was a shrewd move, calculated to obtain the advantage for Germany and her ally merely by potential energy without dynamic effort. This would have confined the war to Austria and Servia and enabled the former country to carry on its unfair designs. But the scheme did not work, for Russia decided to interfere.

"In an editorial on July 29 the HERALD asked the pertinent question:—'Can war be localized?' This was answered in the negative by Russia's mobilization, and from that moment the only possibility was a European war or no war at all. The interceding of Russia made it necessary for Germany to decide for peace or war. And in this lies one of the chief assurances that there will be no international conflict.

"In the first place the Germans are a peace loving people and the policy of the Emperor has been so far eminently pacific. Germany has everything to gain from peace. During the last forty years she has advanced steadily, commercially and industrially, to such a point that her superiority is conceded everywhere. Why should Germany go into a hazardous struggle when she is conquering the world slowly but surely by arts of peace?

An Unfavorable Time.

"But suppose that she were bent upon war, could she have chosen a more unfavorable time? The Triple Entente is in every way superior to the Triple Alliance, the existence of which is now doubtful in view of the attitude of Italy. Germany is hemmed in on land and sea. In the west she has her bitter enemy who has been preparing for years for revenge; a nation highly cultured and resourceful, capable of putting 4,000,000 men in the field. In the east, her opponent is three times greater in population, incomparably greater in resource, absolutely unconquerable. Germany's superior army would in all probability obtain great victories, but she could not wrest from Russia any territory or obtain indemnity. Any injury she might inflict would involve injury to herself which would be felt all the more because she is smaller.

"This only goes to show her objective point of attack, France. But she is not strong enough to conquer that country and expose herself at the same time to Russia. In Austria she has an ally of doubtful capacity, so the entire burden falls upon her shoulders. Although her navy is efficient it is pretty safe to conclude that she is not able to grapple with England successfully. The English have no aversion toward the Germans as a people, but the bitter feeling exists and England will not feel safe until the danger of German invasion is disposed of.

"The second guarantee for peace lies in the fact that Austria will recognize in the withdrawal of her army from Servia the only means of saving herself. A European war will have as the unavoidable result the dismemberment of the dual monarchy. The crossing of the border by the Russian army will create a wave of enthusiasm throughout the Slav population and the entire fabric will crumble. Austria has undertaken to crush Servia, not so much with the view to acquiring territory as to wreak vengeance on a small nation striving for freedom, whose resistance to the Asiatic hordes has made the present monarchy possible. In trying to destroy Servia she has plunged headlong to her own destruction. This is admirably forecasted in the HERALD editorial.

"I would repeat that, all indications to the contrary, an international conflict on such a scale is impossible from purely physical reasons. The expense involved in maintaining the forces and the destruction of life and property are such that in a few weeks all resources would be exhausted. It is impossible to believe that with this realization before the eyes of the leaders common sense would not prevail."

A Huge Tesla Apparatus

A Coil With a Seven-foot Spark Gap

By Father Francois Magri, S. J.

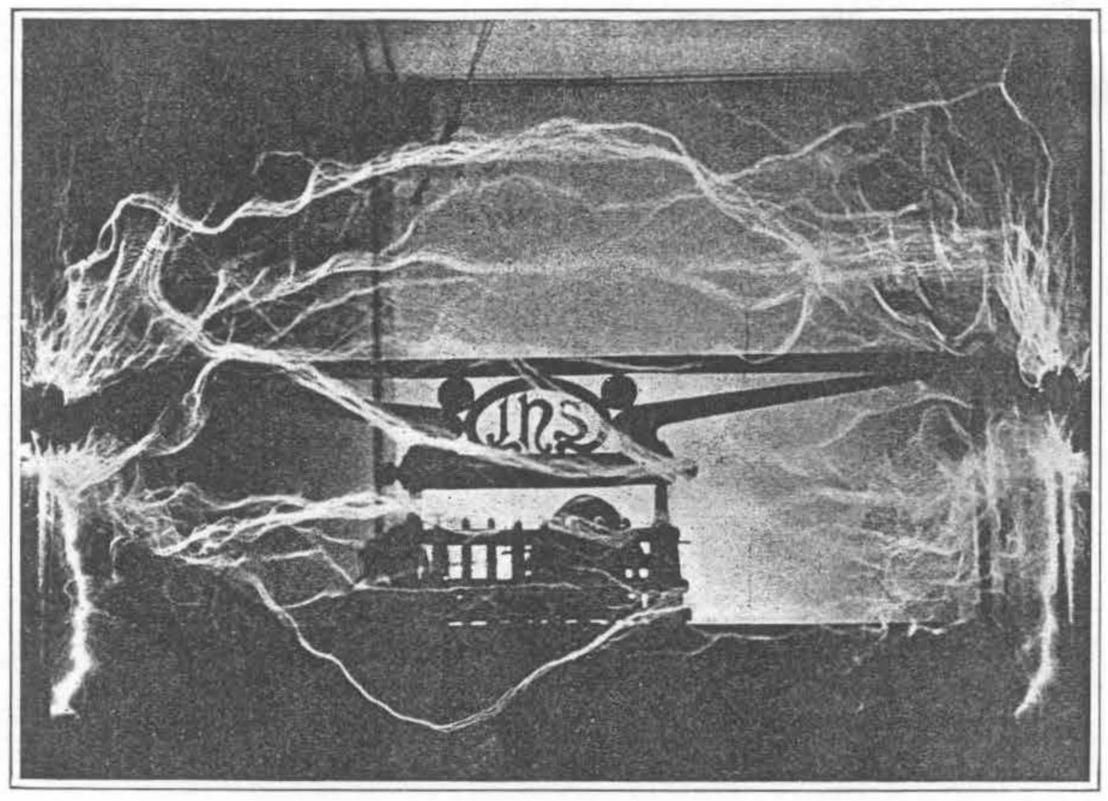
THE great Tesla apparatus of our physical laboratory, at the College of the Immaculate Conception, Montreal, was designed by my predecessor, Father Gendreau, and was constructed by his pupils.

The current of low frequency which energizes the Tesla coil proper, is furnished by a 7-kilowatt transformer, entirely immersed in insulating oil in a glass case, which measures 27 inches in length, and 17 inches in width and height. Its primary coil is connected to the city lighting circuit of 115 volts and 60 cycles, from which it takes a current of 60 amperes. The voltage of the secondary current exceeds 65,000 volts, as is proved by the length of the spark, which has the flame-like appearance shown in one of the photographs. This secondary current passes into the primary coil of the Tesla transformer, which is connected with a condenser of 144 Leyden jars. These jars are filled with and surrounded by salt water, which takes the place of the customary metallic coatings, and which is covered by a thin layer of oil to prevent evaporation and incrustation. A rotary interrupter, driven by an electric motor, is employed in order to increase the frequency.

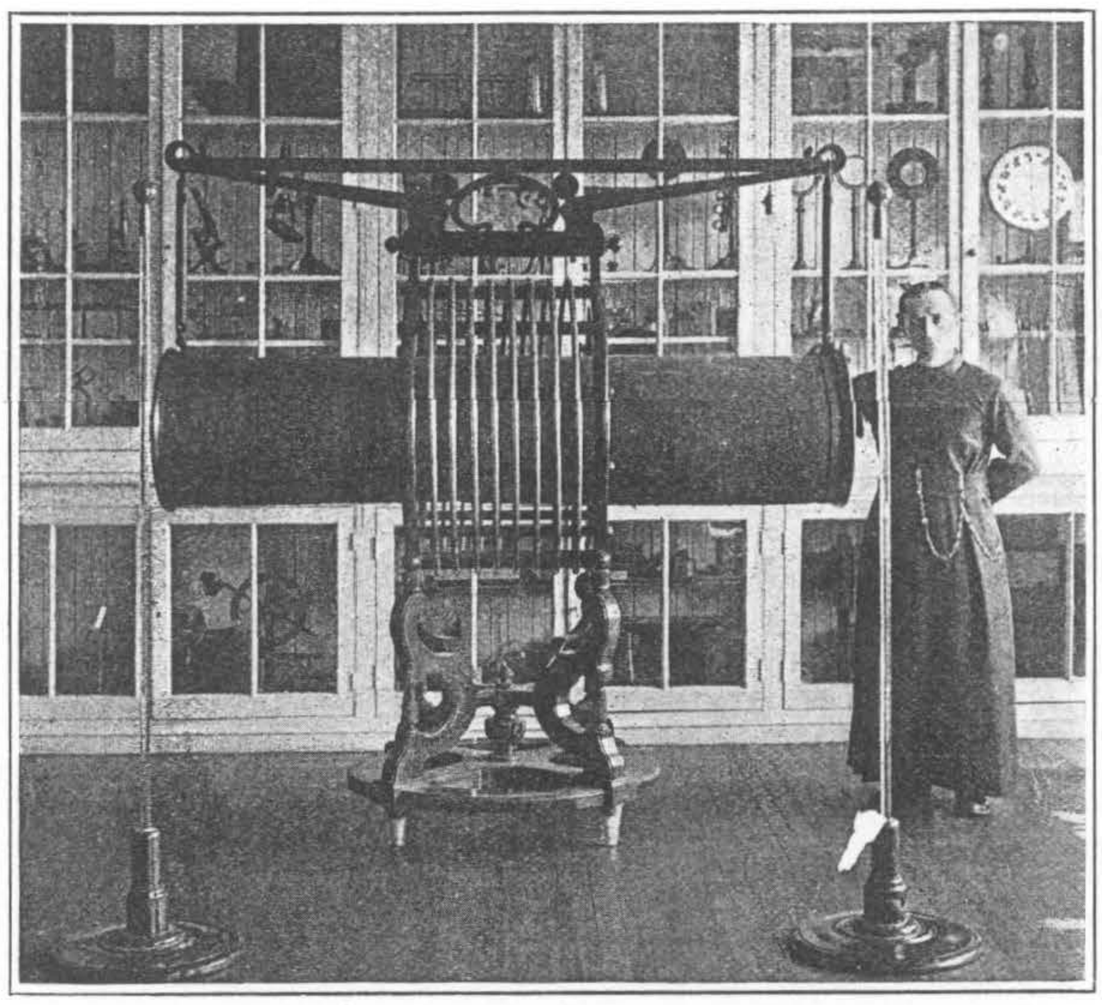
I have made important changes in the apparatus, entirely reconstructing the primary of the Tesla, and improving the insulation by mounting the wooden base on glass supports. The apparatus is more than 7 feet long. A cylindrical cage, 33 inches in diameter, composed of 12 longitudinal bars, 22 inches long, carries the primary coil, which consists of 8 turns of brass tubing, separated by intervals of 1½ inches. The diameter of the tube is ⅔-inch, and its total length is 74 feet. Its ends are connected with the condenser and the rotary interrupter. Above this coil is a bridge, from the ends of which the secondary coil is suspended inside the primary by means of two ebonite rods 19 inches long. The secondary coil is nearly 7 feet long and more than 17 inches in diameter. It is composed of more than 1,000 turns of fine, enameled copper wire, insulated by layers of tarred paper and cloth. The maximum sparking distance is 6 feet 8 inches usually, but it has exceeded 7 feet. The spark resembles a flash of lighting and, with its deviations, attains a total length of nearly 10 feet. It produces a sound like a thunder clap that startles persons in the street, 400 feet distant. Although the apparatus is not connected either with an antenna or with the earth, the sound of the discharge is heard very distinctly through the telephonic receiver at the wireless station of the Polytechnic School, a mile and a half away, this receiver also being disconnected from its antenna and the earth.

What, then, would be the result of connecting this powerful apparatus to earth and to our experimental antenna, consist- of three wires, each 700 feet long? The discharge would certainly produce a potential difference of at least five million volts, but we have no apparatus with which this theoretical deduction can be verified.

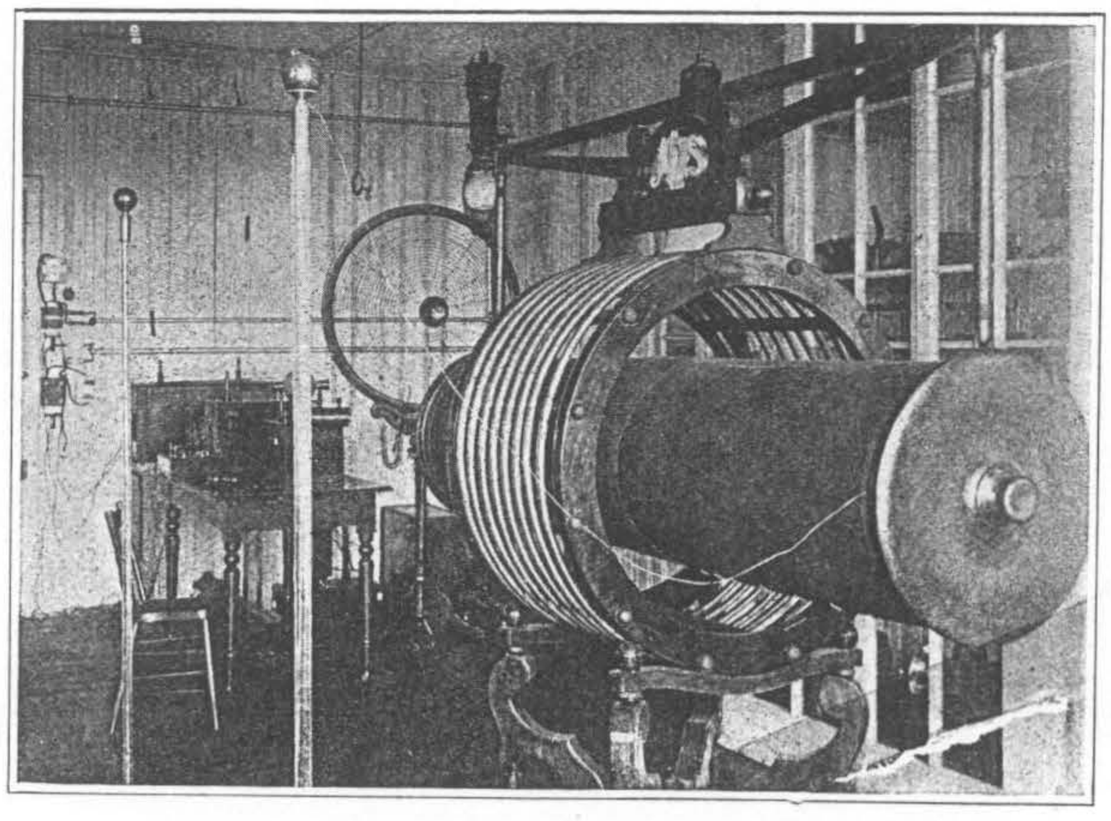
The discharge of the primary coil alone produces a deafening noise. This coil, by induction alone, heats to incandescence a 50-volt lamp, inserted in a little coil of three turns at a distance of 3½ feet. A 25-volt lamp glows brightly at the same distance, and a 12-volt lamp is heated to whiteness at a distance of 5¼ feet. When the terminals of the primary are connected by a coarse iron wire 8 feet long, the wire is almost instantly heated to incandescence and fused. Sixteen 115-volt lamps glow white when they are connected in series between the terminals of the primary.



Discharging across a seven-foot gap.



Giant Tesla coil capable of giving a seven-foot spark.



View of the primary and movable electrodes.

The New York Herald August 19, 1914

$70,000,000,000 Waste Is Mr. Tesla's Estimate

Inventor Figures War's Damage Will Equal Almost One-Quarter of the Total Wealth of the World if the Conflict Continues for Six or Seven Months.

After a careful study of the financial and sociological questions involved in the present European war, Nikola Tesla, the inventor, estimates that the waste incident to it cannot be less than $70,000,000,000, or almost twenty-five per cent of the total wealth of the world. He takes issue with Professor Charles Richet in the latter's estimate of $50,000,000 a day, stating that would cover the cost of military operations. In connection with the matter Mr. Tesla said last night:—

"The HERALD of August 2 contains an itemized estimate by Professor Charles Richet of the cost of the war on a colossal scale such as the present, which may involve 20,000,000 combatants. He finds a total of $50,000,000 a day. While most of the figures, given may be correct, it is certain that some are altogether too low. For instance, he places the number of those disabled through wounds and disease, at 500,000.

"This is less than two and one-half per cent. It will be recalled that in the recent war in the Balkans, which furnishes the best data in this respect, the casualties were more than twenty-five per cent that is, ten times greater in proportion. He values the public and private properties destroyed at $2,000,000 a day. Observe that according to reports only in Belgium a loss of $300,000,000 resulted from less than two weeqs' fighting.

"There were no large cities in the path of the total force engaged in this stupendous conflict. Professor Richet also ignores the time element, which has a very decided bearing on the cost, and considers a purely hypothetical case of constant performance. It is evident that before such an estimate can be made the duration of the war must be known, from which the daily average can be computed.

Estimating Energy of War.

"Armed conflict is essentially a discharge of accumulated war energy. The rate at which this energy is released determines what may be called the power of war. An international combat may be of great energy and yet of small power, or it may be of small energy and still of great power, and the daily cost will vary accordingly.

"Conceive that a definite quantity of war energy is expended in perpetual strife. Then the daily cost will be nil. Assume, on the other hand, that the same energy is all used in, say one day. Then the daily cost would be nearly equal to the total cost, which might amount to several billion dollars.

"The Franco-German and Balkan wars may serve to fix these conceptions. The former was of greater energy, but the latter was of much greater power. The development of military science and perfection of arms is ever tending to increase the intensity and to reduce the duration of the struggle, and in times to come, when the comparatively crude implements of today will be replaced by subtle and infinitely more effective electrical means of destruction, and time and space are annihilated, wars, if they do happen, will be settled with a swiftness now inconceivable.

"The chief thing to point out is, however, that Professor Richet's estimate is not one of the cost of war, as put forth, but rather the cost of military operation, which represents but a small fraction of the total waste.

"To measure the losses due to war merely by statistical standards is absurd. An example will make this clear. The strain imposed upon a country in a state of siege is compelling of strict economy. The savings thus affected go to offset the drain of war. Theoretically, it is possible for a nation, by living on bread and water and curtailing all expenses, to accumulate enough for not only meeting the cost of military operations but leaving a surplus besides. From the point of view of the statistician such a war, far from being costly, would be the very means of creating wealth!

Figuring Excess of Waste.

"It is equally unreasonable to define the waste of international conflict as the excess of waste in time of war over that in time of peace. A quantity 'b' may be deducted from a quantity 'a,' and the difference will be 'a—b' on the supposition, however, that the quantities are composed of identical units.

"Now, while the same human beings are concerned both in peace and war, thes two states bear no resemblance to each other. In one, reason and sober sense, a feeling of safety and desire to do justice prevail; in the other these beneficial influences are weakened, and folly, fear and greed assert themselves. War changes individuals as well as values.

"A true appreciation of the enormous losses which are likely to result from this unprecedented calamity can only be gained by taking into account its effect on all phases and conditions of individual and national existence. Stated in the order of their magnitude these losses may be enumerated as follows—

"First, temporary or permanent shrinkage of the wealth of nations as distinct from negotiable securities. The total wealth of the countries involved is about three hundred billions of dollars. Assume only a moderate production of ten per cent, and suppose further that the war should last from six to seven months, or about 200 days, as forecast by experts, then the daily shrinkage will amount to $150,000,000. To be sure such depreciation of physical possessions is mostly due to ignorance and faintheartedness of the people, for the properties are there and some are indestructible. But just the same the warring nations will lose credit and purchasing power and will be subjected for an indefinite period to sufferings and privations, all of which must be interpreted as loss of so much money.

Losses in Industrial Pursuits.

"Second—All losses, individual and collective, caused by interference of war with the wheelwork of manufacture, industry and commerce. These reflect particularly on the market value of negotiable securities, which constitute from twenty to thirty per cent of the whole national wealth. For obvious reasons they are apt to be very large, and the shrinkage may easily amount for the above period to $100,000,000 a day.

"Third—Specific losses due to destruction of existing private and public property, including implements and materials of war. These will greatly depend on the circumstances, but may be placed at from $50,000,000 to $75,000,000 a day.

"Fourth—Loss of life and disabling through wounds and disease. Judging from the data of the Balkan War, the casualties cannot be taken at less than fifteen per cent, making the total of 3,000,000. Assuming an average of $2,500 per individual, this waste will be nearly $14,000,000 a day.

"Fifth—Daily cost of military operations, which may amount from $25,000,000 to $50,000,000.

"According to this rough estimate the total waste cannot be much less than $70,000,000,000, making almost twenty-five per cent of the total wealth of the countries in the world. In the best circumstances it will take from forty to fifty years to repair the financial damage, not to speak of the injury to the races and retardation of social progress in all directions."

The New York Sun August 29, 1914

NIKOLA TESLA TO FIGHT MARCONI PATENT SUIT

Noted Inventor to Aid German Alleged to Have Used Infringement.

Lawyers for Fritz Lowenstein, a German engineer, against whom the Marconi Wireless Telegraph Company has begun suit for an injunction, alleging that certain wireless parts he has sold to the United States Navy Department for use on its battleships are infringements on its patents, may subpœna Nikola Tesla, the noted electrician, as a witness for Mr. Lowenstein when the case comes to trial in the United States Circuit Court, Brooklyn.

Mr. Tesla said yesterday that a careful search of the patent records at Washington will show that he was the first to invent certain wireless devices used by Mr. Lowenstein in his apparatus, on which the Marconi company claims there has been an infringement. Mr. Lowenstein was formerly Mr. Tesla's assistant.

"Mr. Lowenstein operates under broad patents granted to me on the wireless art," says Mr. Tesla in a letter to THE SUN. He has, however, with rare ingenuity and skill worked out certain practical details, and how much the advantages of the apparatus he manufactures are appreciated is best evidenced by the statement of the Secretary of the Navy, which you have quoted.

"My patents referred to bear the numbers 645,576 and 649,621 and describe a new and original wireless system characterized by the employment of four circuits in perfect resonance, a condition essential to successful practice. Long after their grant to me Marconi filed an application and secured a patent (No. 763,772) which covers exactly the same fundamental arrangements and forms the basis of the present suit.

"Such cases happen occasionally, as it is quite impossible for the examiners in the Patent Office to keep abreast with workers in new and special fields. A notable instance of this kind is my single phase induction motor, on which a celebrated inventor obtained a patent which was subsequently invalidated through my earlier application.

"In a recent suit in France involving the same or corresponding patents the highest court, acting on a statement submitted by me, decided against Marconi and recognized fully my priority of invention in all the important features. I have every reason to expect that when the same facts are presented here a similar conclusion will be reached by the Supreme Court."

Experimental Electricity Course

By S. Gernsback and H. Winfield Secor

LESSON 13.

THE X-RAY (Concluded).

In practice, however, the concentration is never accurate in ordinary tubes, a compromise being made between the sharpness of focus, and the heating effect. From this it is evident, that anything which enables the anode to lose its heat rapidly, or to stand a high temperature without being damaged, also allows of a more accurate concentration of

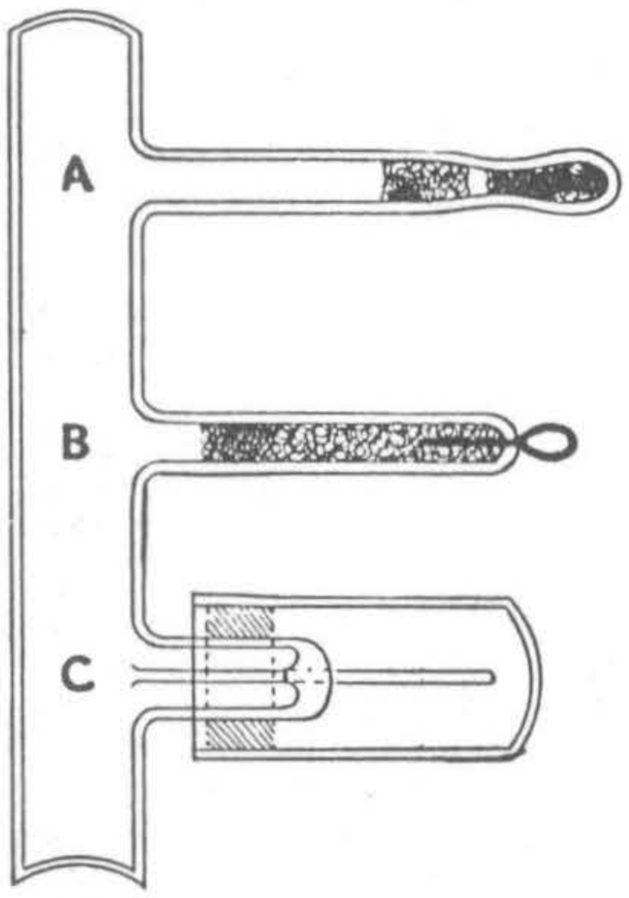


Fig. 9

the cathode stream, and a greater sharpness in the effects produced. Also, such non-damageable anodes permit of a

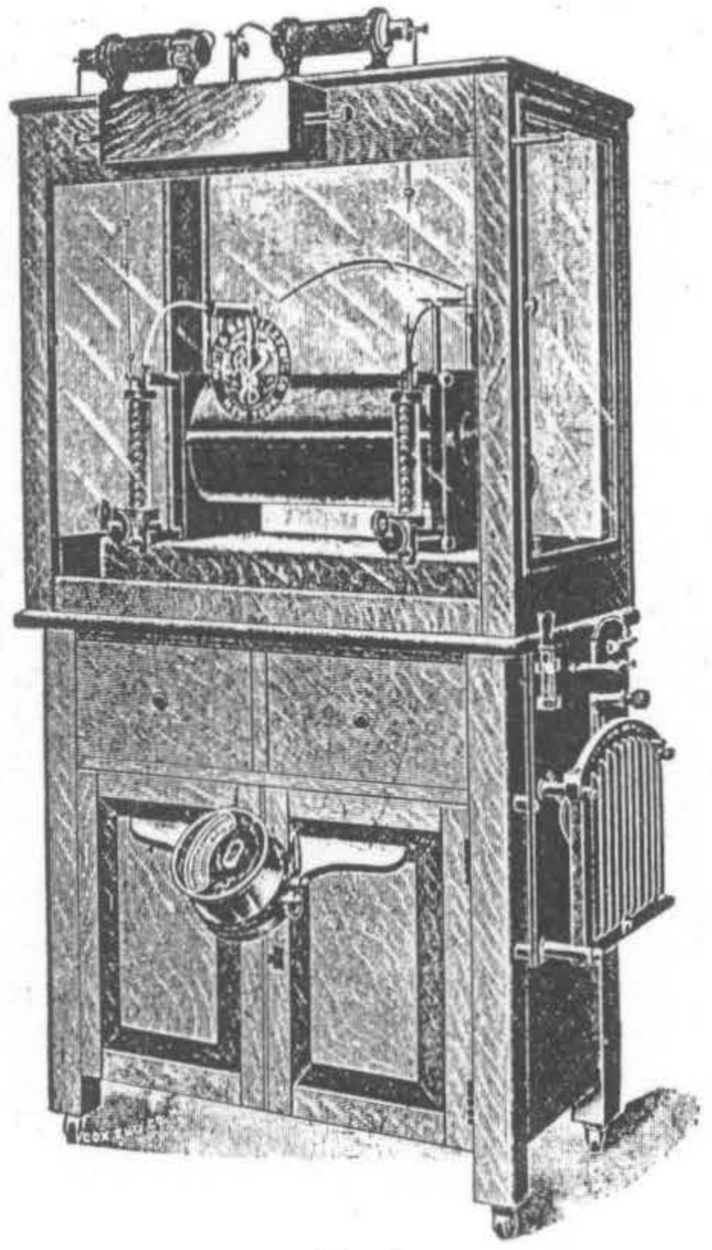


Fig. 10

heavier discharge thru the tube and therefore of greater energy of radiation.

The anode or anti-cathode as it is sometimes called, consists usually of a small plate of metal fixed opposite to the centre of the cathode, and mounted at an angle of about 45 degrees with the axis of the tube.

The X-Rays which are produced radially from it, are thus directed outwards through the side of the bulb, where no electrodes, thickened glass, or other obstructions are met with.

The material employed for the construction of the anode electrode makes a considerable difference in the efficiency of the tube, as found by Roentgen. He states that there is a difference in degree of X-Ray emission, by anodes of different materials, and that at the point of impact of the cathode stream, platinum radiates much more powerfully than aluminum; platinum having a very high melting point (3,000 degrees Fahrenheit), is usually chosen for the material out of which to make the anode electrode.

Excellent results have been obtained with iridium used as a small centre in a disc of platinum.

X-Ray bulbs tend to raise their vacuum after continued use, and change from a soft low vacuum, to a hard high vacuum. There are various methods in vogue for regulating the vacuum of tubes automatically and otherwise. Three principal schemes employed are depicted by the cut fig. 9, at A, is represented the chemical regulator, which requires the application of external heat to them, to become operative. The sealed glass chamber shown, contains potassium chlorate or manganese dioxide, which liberates oxygen gas when heated by the application of a spirit lamp to the outer surface of the glass tube.

The construction shown at B is like the one just described with the exception that a platinum wire is sealed into the portion of the tube containing the chemical. Sparks from the exciting apparatus are allowed to pass into the tube thru the platinum wire, and gas is formed and liberated. The tube can thus be regenerated at will.

The vacuum regulator illustrated at C, is known as the "Osmotic type." It is comprised of a very small tube of metallic Palladium sealed into the side of the X-Ray bulb. The inner end of the metal tube is open and the outer end closed. The tube is covered ordinarily by a glass cap. If this cap is removed, and the flame of a spirit-lamp applied to the closed outer end of the Palladium tube, hydrogen Ions from the interior of the flame will be drawn thru the intermolecular spaces of the heated metal, into the exhausted X-Ray bulb. This form of regulator has the advantage over the proceeding two types, in that the vacuum of the X-Ray bulb, can be adjusted any number of times, but the first two are limited by the amount of chemical in the end of the regulator tube, which is sealed off air tight.

X-Rays present a very entrancing field for unlimited experiment and study, but caution should be observed in subjecting the skin to long exposures of the rays, as they have a property of producing serious sores or growths, which if not checked quickly are incurable. Grave effects are caused on the trophic nerves, and vital resistance of the superficial tissues of the body, followed in a week or more by severe inflammation and necrosis.

A large X-Ray generator with regulating rheostat, ammeter, etc., are shown in fig. 10.

LESSON 14.

HIGH FREQUENCY CURRENTS.

HIGH frequency currents represent the most advanced field of electrical experimentation, and but very few of the wonders of these currents, especially when produced at high potential are known. Hence, a wide scope is given to the investigator and experimenter, in the evolving of new laws and phenomena, from researches in this most interesting and growing branch of the electrical art.

The production of high frequency currents for experimental research, is usually accomplished by the aid of a Tesla coil, which takes its name from Nikola Tesla, a famous authority and investigator on this subject. Two of the principal scientists who have given us data and explanations of these currents are Tesla and Elihu Thompson, who independently and simultaneously obtained practically similar results.

Before delving into the more intricate details concerning the arrangement and operation of Tesla coils, Oudin coils, etc., a few paragraphs will be devoted to the elucidation of the meaning and scope of high frequency as applied to the

currents in question. It may be stated firstly, that high frequency currents are invariably oscillatory in Nature, or alternating from positive to negative, and back again, many hundred times per second. In the diagram, fig. 1A, is given a graphical representation of the "wave form" and time value, of an ordinary alternating current, such as used for commercial lighting, running motors, power transmission, etc. This current is known as a standard 60 cycle current; one cycle meaning the time consumed for the current to rise from zero to maximum positive value, back to zero, then to negative maximum to zero again. The time consumed by the current rising from zero to positive maximum then to zero, is referred to as an alternation; two alternations comprising a cycle. Hence, a 60 cycle current is one having also 120 alternations, and the time for this series of changes to take place is one sixtieth of a second. Also 60 cycles will take place in 1 minute. One alternation or ½ cycle requires for its transpiration 1/120 of a second.

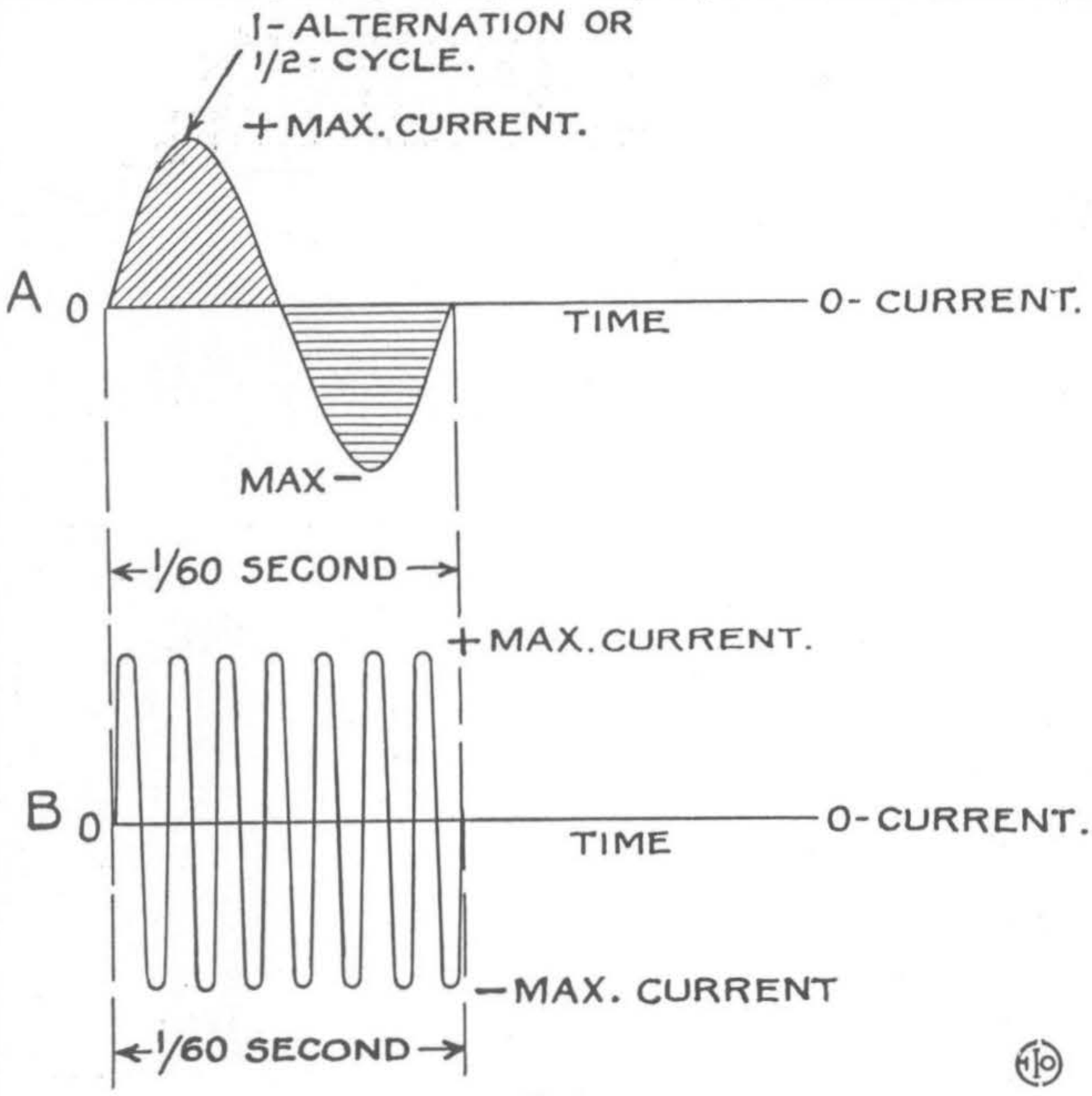


Fig. 1

In the curve of fig. 1 B, is depicted a higher frequency current than the 60 cycle just discussed, or as seen in the same time interval, viz., 1/60 second, seven times as many complete cycles have occurred, or the frequency per second is 7 times 60 or 420 cycles per second. Likewise, this frequency is equivalent to 840 alternations per second, or also 25,200 cycles per minute. Commercial lighting currents usually have a frequency of 3,600 cycles or 7,200 alternations per minute.

This explanation is for the purpose of making clear the exact meaning of the term high frequency. In actual practice, the term high frequency is invariably understood to mean a current whose frequency is somewhere between 10,000 and 1,000,000 cycles per second.

When such frequencies as these are employed, many wonderful and hitherto unlooked for phenomena appear. Among other features which they possess, are those permitting of passing it thru or rather over the human body, at a potential of half a million volts, or more. Tesla, Thompson and others have often demonstrated the feat of passing a million volts thru the body from hand to hand without experiencing the slightest harm or ill feeling. Ordinarily as in the electrocution of criminals, where low frequency alternating current of 60 to 120 cycles is employed, such potentials as 2,000 volts are sufficient to kill the subject. Generally but ¼ to ½ ampere passed thru the heart is sufficient to cause death. With high frequency currents, however, the current strength as indicated by a hot-wire ammeter may easily reach several amperes.

Currents of such frequencies as these, no longer obey the laws governing those of low frequency. For one thing, they travel principally over the surface of conductors, not thru them; penetrating but a few thousandths of an inch, this depending upon the frequency value. The higher the frequency, the less the penetration. From this it is evident that solid conductors for high frequency currents are a waste of material and thin walled or hollow ones of large diameter, are the best. Stranded conductors are always better than solid ones of similar capacity, as the former has much greater surface area for a given cross-section, and this is what counts in this case.

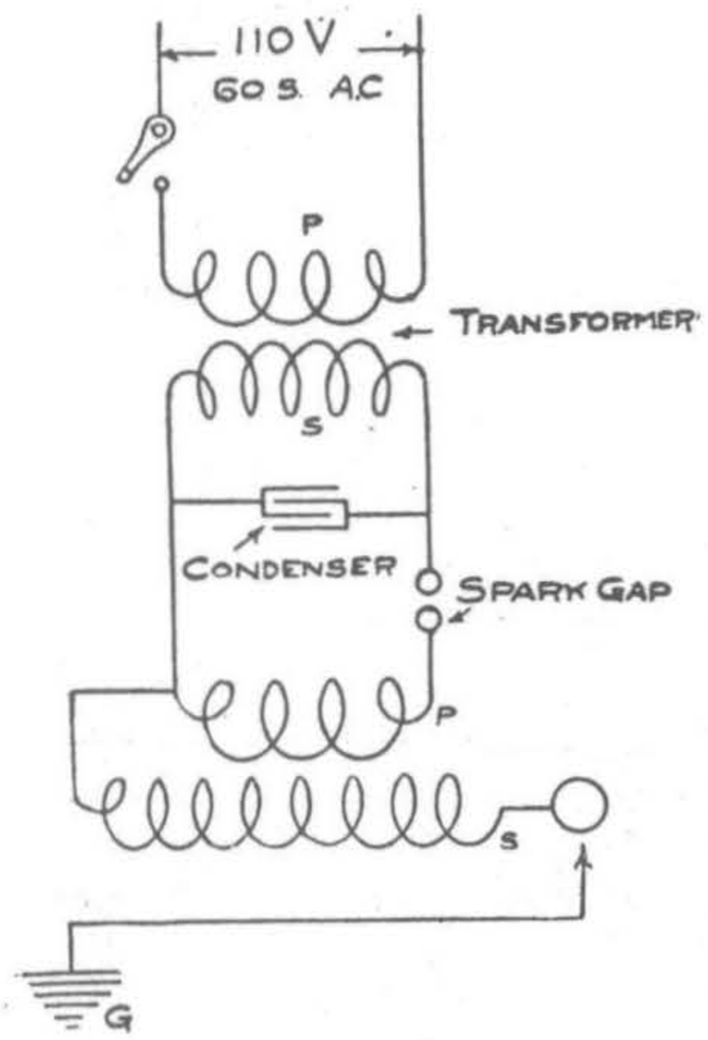


Fig. 3

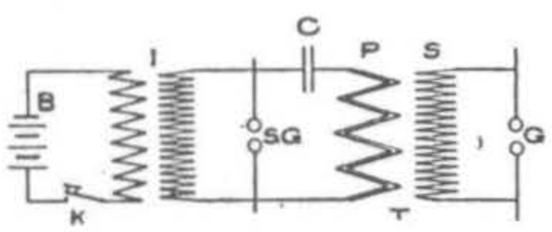


Fig. 2

High frequency currents can be produced in several ways, the principal methods being those involving the use of an Elihu Thompson generator, a Fessenden high frequency dynamo, or by means of the Tesla disruptive discharge set.

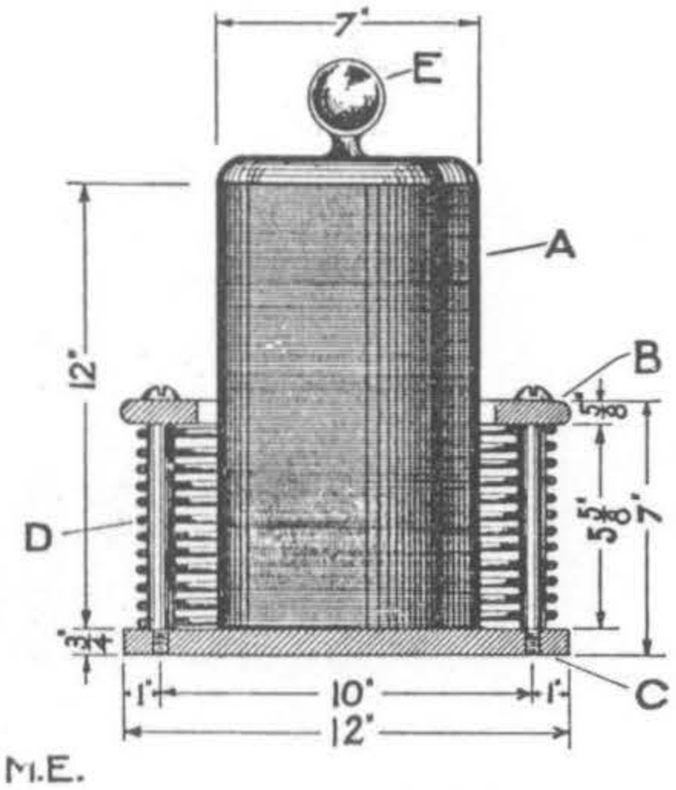


Fig. 3. An Oudin Coil

(To be Continued)

The New York Herald September 1, 1914

Letters from Herald Readers

Mr. Tesla Asserts Priority in Patent on Which Mr. Marconi Has Brought Action.

TO THE EDITOR OF THE HERALD:—

The HERALD of even date contains a report to the effect that the Marconi Wireless Telegraph Company has begun a suit for infringement against Mr. Fritz Lowenstein, the well known German engineer, formerly my assistant. Mr. Lowenstein operates under broad patents granted to me on the wireless art; he has, however, with rare ingenuity and skill, worked out certain practical details, and how much the advantages of the apparatus he manufactures are appreciated is best evidenced by the statement of the Secretary of the Navy which you have quoted.

My patents referred to bear the numbers 645,576 and 649,621 and describe a new and original wireless system, characterized by the employment of four circuits in perfect resonance, a condition essential to successful practice. Long after their grant Mr. Marconi filed an application and secured a patent (No. 763,772), which covers exactly the same fundamental arrangements and forms the basis of the present suit. Such cases happen occasionally, as it is quite impossible for the examiners of the Patent Office to keep abreast with workers in new and special fields. A notable instance of this kind is my single phase induction motor on which a celebrated inventor obtained a patent which was subsequently invalidated through my earlier application.

In a recent suit in France involving the same or corresponding patents the highest court, acting on a statement submitted by me, decided against Marconi and recognized fully my priority of invention in all the important features. I have every reason to expect that when the same facts are presented here a similar conclusion will be reached by the Supreme Court.

NIKOLA TESLA.

NEW YORK, Aug. 28, 1914.

Experimental Electricity Course

By S. Gernsback and H. Winfield Secor

LESSON 14.

HIGH FREQUENCY CURRENTS (Concluded).

High frequency currents can be produced in several ways, the principal methods being those involving the use of an

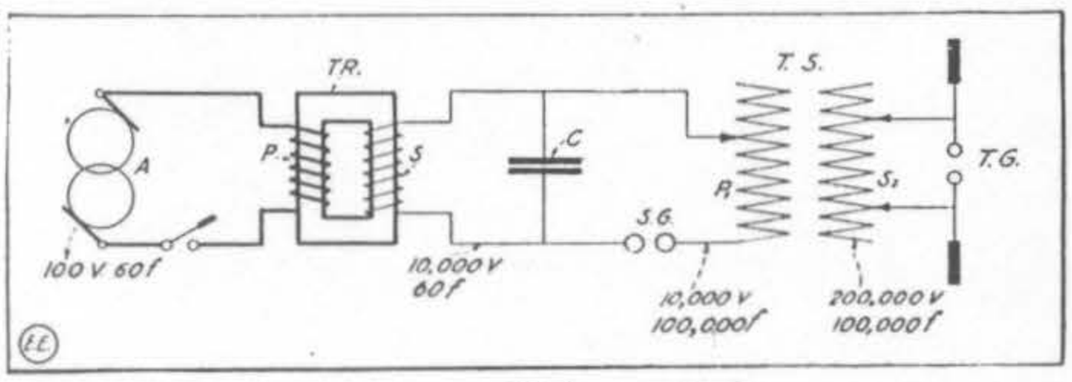


Fig. 4

Elihu Thompson generator, a Fessenden high frequency dynamo, or by means of the Tesla disruptive discharge set. The latter is the commonest and easiest method of producing such currents, and is widely utilized for lecture work, electro-therapeutics, exciting X-Ray tubes, etc.

The general arrangement of the functional parts composing the complete set is outlined in fig. 2.

Referring to the diagram, I is an induction or spark coil, preferably of not less than 2″ spark capacity. T is an air-core transformer, which serves the purpose of stepping up the voltage of the current delivered by the secondary of the induction coil, to many times its original value. At C is a condenser composed of Leyden jars, or glass plates, coated on both sides with tinfoil. A spark gap is placed at S G between whose electrodes the disruptive discharge of the condenser takes place. G is the discharge air gap of the Tesla coil secondary, across which the high frequency oscillations surge.

The functions of the various parts of the apparatus and their inter-relation is as follows: The induction coil or transformer I is excited from the battery shown at B, or the regular line feed wires; and its secondary current at 10,000 volts or more pressure is caused to charge the condenser C, which immediately discharges itself thru the primary coil P of the Tesla transformer and the spark gap SG. Now due to the conditions imposed by such circuit, the condenser discharge becomes not a single discharge for each cycle of induction coil secondary coil, but many times greater; so that with certain proportions to the circuits, as regards the capacity and inductance, the frequency of the current passing thru the Tesla coil primary may easily reach a million and more cycles per second; rendering the current harmless owing to the "skin effect" already mentioned. The currents thus produced are of course highly damped, i. e., the series of oscillations corresponding to each cycle of exciting current, dies down to zero, before the next series of oscillations start.



Fig 5

The frequency of the Tesla currents produced obey a certain law, which is as follows: They vary as the square root of the product of the capacity and inductance in the closed oscillating circuits. The frequency in cycles per second is found by dividing 10^6 times 5.033 by the square root of the capacity, multiplied by the inductance; where the capacity is in microfarads, and the inductance in centimeters. For further particulars see "Wireless Course" chapters 17 and 19. Also "Construction of Induction Coils and Transformers," by H. W. Secor.

Another form of high frequency transformer employed extensively for electro-therapeutical applications, is the Oudin coil. Its appearance and connections are given at fig. 3. As

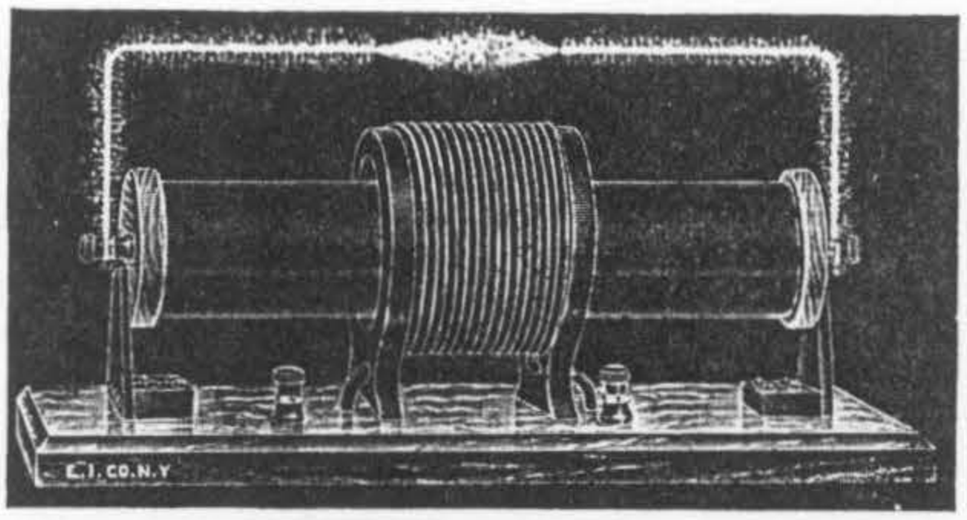


Fig 6

seen the bottom of the primary and secondary coils are joined together. Any Tesla coil becomes an Oudin type, if the primary or heavy wire winding is simply placed at the end of the secondary, instead of at the center as usual.

The relation of the frequencies and voltages will be more readily understood quite probably by inspecting fig. 4. It is seen that the coils or transformers do not change the frequency in themselves at all but only the voltage, which is dependent upon the relative amount of turns of wire upon the different coils. (See Lesson No. 4 in Nov., 1913, *Electrical Experimenter*, on "Transformers.") A cut of a powerful high frequency generator designed by Dr. Frederick Strong, for electro-therapeutical purposes, is illustrated by fig. 5.

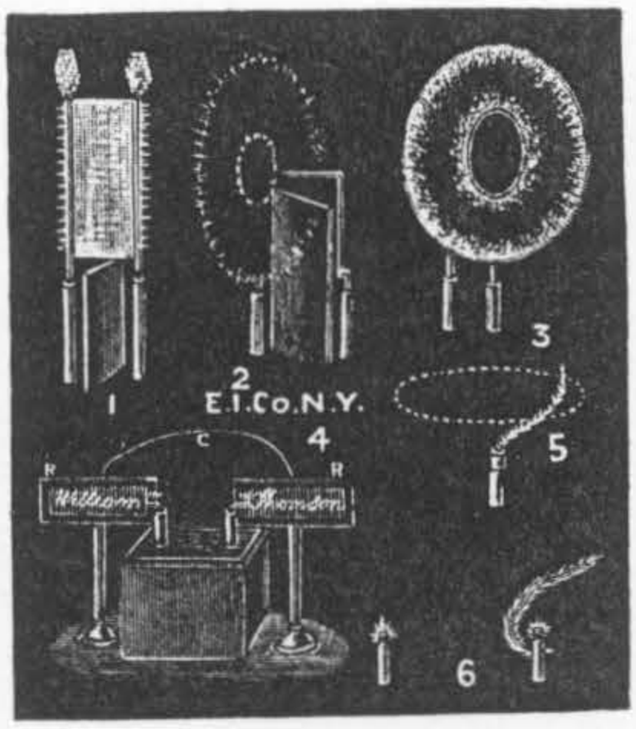


Fig. 7

For experimental research a very neat and efficient form of Tesla transformer is depicted at fig. 6. It is built by the well known electrical firm, The Electro Importing Co., of New York City, and sells for a very reasonable price, in comparison to the wonderful results attainable with it. In full activity, when excited from a 2″ spark coil operating on batteries, it takes on the appearance displayed in fig. 6, but the life and beauty of the discharge can only be fully appreciated by actual observation, and not from a mere black and white print. This coil is admirably suited to the requirements of the private laboratory, the School lecture platform, and demonstrations in general. A larger exciting coil may be employed than that mentioned, and of course the effect is greatly enhanced. (See the Feb., 1914., E. E. for a special article on "Currents of Ultra-High Frequency and Potential.")

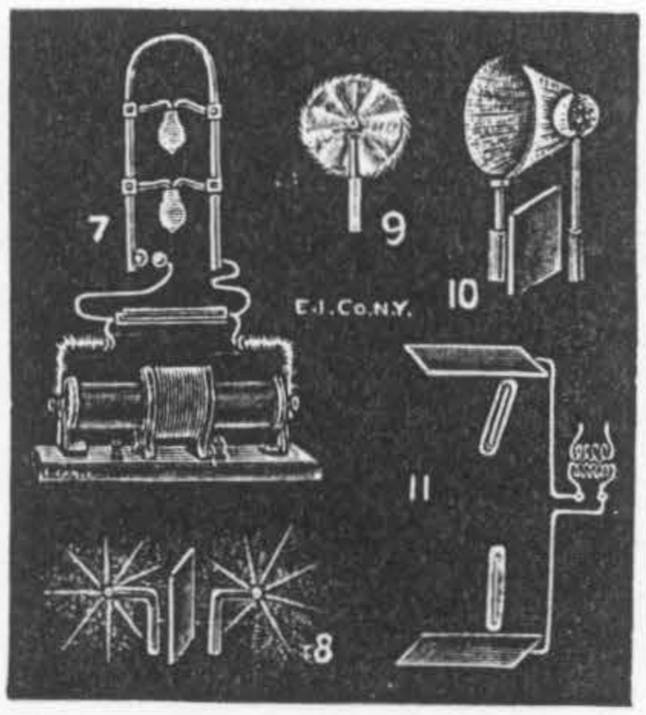


Fig. 8

The adjustment of the circuits of Tesla or Oudin coils has

to be carefully tried out by experiment to attain the maximum results. The length of the spark gap, the amount of condenser capacity and number of Tesla coil primary turns in circuit, all have a direct influence upon the final high frequency discharge, and they should be carefully adjusted simultaneously or successively, until the best high frequency discharges are obtained.

A rotary spark gap is best for the oscillating circuit, as it keeps very cool, and prevents the gap from arcing, which lowers the frequency. The shorter the gap the higher the frequency, and vice versa.

Having described the Tesla transformer, its action and connections, a few experiments of interest will be given: It may be well to state that the most spectacular results are only obtainable in a good dark room or hall. When the high frequency current is to be handled by the body, an unpleasant shock is experienced if the Tesla spark is allowed to jump direct to the skin; and a piece of metal held in the hand, or a Geissler tube, or even an incandescent lamp is best; the brush or spark being absorbed by them, and communicated to the body without shock. Geissler tubes and the like are very useful for demonstration, as whenever the discharge is absorbed thru them they light up brilliantly, making visible the great activity occurring. Several people may be placed in a circle and a Geissler tube placed in the hands of every couple. When the current is applied to the persons at the ends of the circle, the Geissler tubes all way around will simultaneously light up, making an impressive effect.

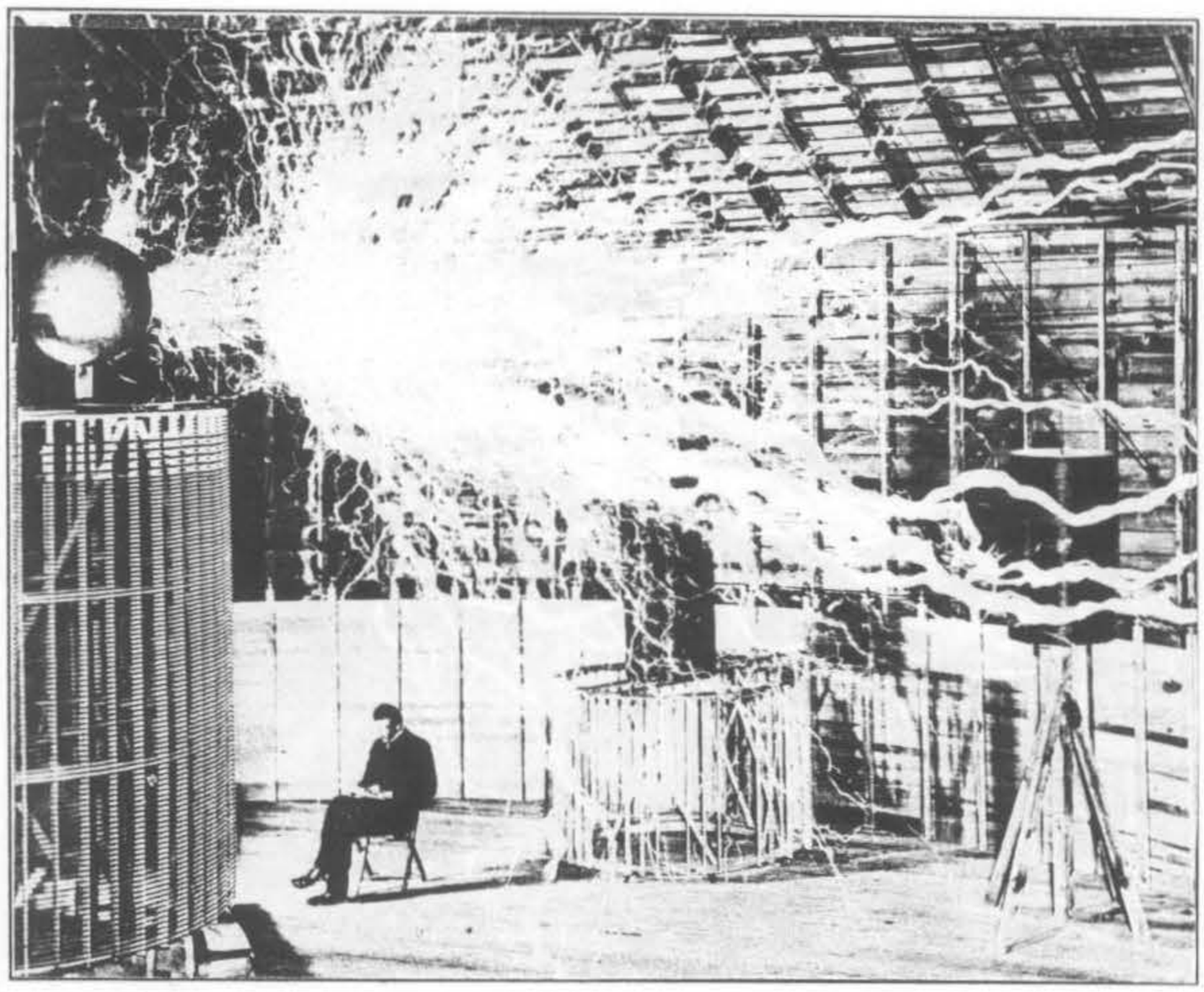


Fig. 9

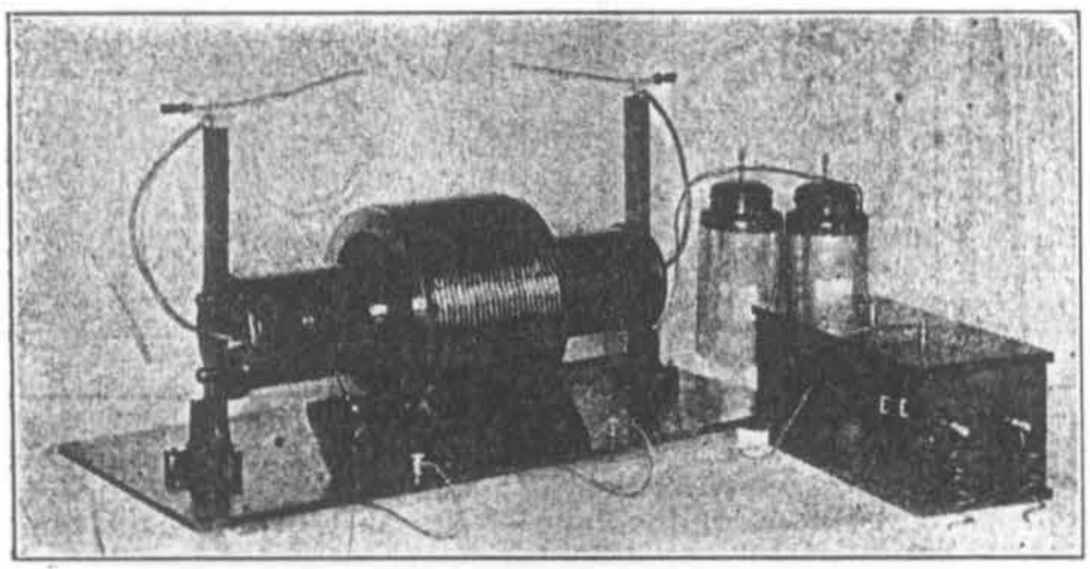


Fig. 11. A Large "Electro" Tesla Coil

In Fig. 7 are shown a number of interesting experiments which can be performed with the Tesla coil illustrated in fig. 6. At 1, fig. 7 is an experiment requiring the use of two vertical copper wires as nearly parallel as possible. When the apparatus is working in good shape, with the frequency high, the space (2-4 inches) between the two wires is filled with light, while the ends show a heavy brush discharge.

The experiment seen at 2 is performed by arranging two loops of copper wire, and attaching them to the secondary terminals of the Tesla coil. A similar arrangement is that seen at 3, but here the inner loop is 30 centimeters in diameter (1 inch equals 2½ cms.), while the larger loop is 80 centimeters in diameter. The space between the concentric loops is filled with millions of fine sparks, presenting a very pretty effect.

Illuminated names are produced as shown at 4, fig. 7. The names are made of fine copper wire, placed on one side of glass plates. The backs of the glass plates are coated with tinfoil a little smaller than the glass itself. One terminal of the Tesla secondary is connected to the wire name, and the other terminal to the opposite wire name. The tinfoil coatings on the back of the glasses are connected together by a piece of copper wire. When the current is turned on the names are illuminated. Hard rubber may be employed in place of the glass.

The rotating wire, 5, at fig. 7, is very amusing to observe. The wire must be quite fine, and the length determined by experiment. When of the right length, the wire will swing around a circle continually. It is connected to one terminal. A short piece of thin, cotton covered copper wire when attached to one terminal of the coil, gives out a beautiful flame effect, seen at 6.

One of the most astounding stunts performed with high frequency, high potential currents, is that known as "The impedance bridge or shunt," seen at 7, fig. 8. A heavy piece of copper wire or brass rod may be bent into a U-shape as shown, and when shunted by a low voltage lamp bulb, the lamp will light up brightly; the high frequency current preferring to traverse the comparatively high resistance path of the lamp instead of the low resistance offered by the brass rod. This is

(Continued on page 87)

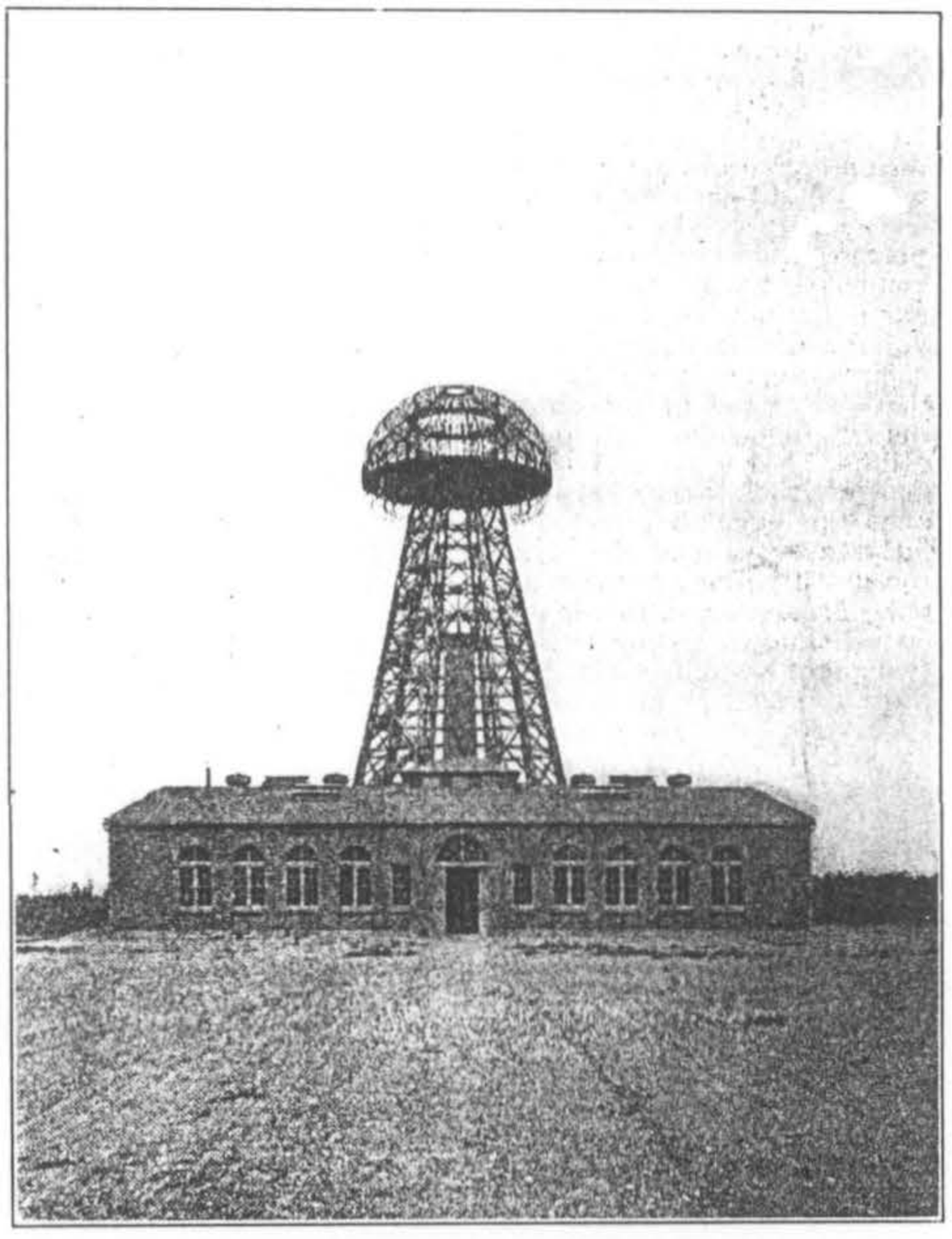


Fig. 10. Tesla's "World Wireless" Tower on Long Island, N. Y.

EXPERIMENTAL ELECTRICITY COURSE.

(Continued from page 85)

probably similar to lightning effects, etc., where it is seen that such high frequency surges, tend to take the shortest path, irrespective of resistance. For this reason lightning rods are always run in as short and straight a path as possible, avoiding sharp bends. In the Tesla coil experiment here mentioned, a Leyden jar or other condenser is connected across the secondary coil terminals, with a spark gap in one of the leads going to the copper bar. The terminals of the 20 volt lamps are tried in different positions, until the maximum brightness is obtained.

At 8, Fig. 8, is a display of weird appearance, called the "Electrical Phantom." Two thin metal discs, about 1" diameter, are connected to the two secondary terminals of the Tesla Transformer. Their edges are ground thin. With the voltage at a high value, white rays or threads of light strike out from the edges of the discs, which are sometimes of considerable length.

Electrical wind, as performed with static machines, is also reproduceable from the Tesla coil. Its effect is illustrated at 9. A small sharp toothed aluminum disc, about 1/64 inch thick, is mounted on an axle, having very little friction, and when the current is turned on, the little disc will rotate at high speed, becoming enveloped in sparks.

An illuminated cone of light is made by having a wire ring connected to one terminal of the Tesla coil and a metal ball of ¼ the ring diameter, connected to the other terminal. When current is applied the space between the ring and ball is filled with multitudinous fine sparks, giving a unique and beautiful display.

At 11 is depicted Nikola Tesla's ideal wireless light for illumination. Evacuated glass tubes are placed in proximity to the charged metal plates, connected to a source of high frequency, high potential electric current. The lamps are thus illumined by induction, without any metallic connections whatever being made to them.

Just what can be accomplished when large amounts of electrical energy is transformed into high frequency, high potential form, may be gleaned from the photograph of some electrical discharges of this nature, at fig. 9. This is from some of Tesla's experiments. The sparks shown were 25 feet long, the potential several billion and the amperage 800. Tesla's laboratory and tower erected some years ago on Long Island, for experimenting with world wave telegraphy, is depicted at fig. 10.

(To be continued)

The New York American December 6, 1914

Tesla Has Wireless to Light Whole Ocean

"I have invented and patented an apparatus for transmitting electrical energy without wires which will not only revolutionize the present wireless systems, but will make it possible to cast light from shore that will make the Atlantic steamship lanes safe," declared last night Nikola Tesla, on his return from Washington, where the invention was patented.

He said that his apparatus would give the wireless unlimited sending power and messages around the world would be a matter of course.

The New York American December 7, 1914

TESLA LIGHT TO ROB OCEANS OF EVERY DANGER

Electric Waves Will Also End War, Make Rain and Transform the Earth, Inventor Says.

Nikola Tesla, scientist and inventor, at the Waldorf last night told the New York American that he saw the end of war in the application of new principles of electrical construction he has discovered and with which he expects to revolutionize many of the activities of life.

"Apparatus designed in accordance with my invention, even if it be of small dimensions, is capable of transforming energy of tens and hundreds of thousands horsepower," said Mr. Tesla.

"The lighting of the ocean, which was mentioned in The American of this morning, is only one of the less important results to be achieved by the use of this invention. I have planned many of the details of a plant which might be erected at the Azores and which would be amply sufficient to illuminate the entire ocean so that such a disaster as that of the Titanic would not be repeated. The light would be soft and of very small intensity, but quite adequate to the purpose.

"A very timely application could just now be made in England, where a plant could be provided for illuminating London and the country in general at night to rob an attack by Zeppelins of its principal terrors. I have calculated that a plant of 75,000 horsepower would be required for the Azores, but much less power would do for the London application.

"One of the even more valuable uses to which this invention can be put is the transmission of the human voice or any kind of picture or image from one to any other point of the globe, absolutely irrespective of distance. Lighting of isolated and inaccessible places on land or sea can be effected by this new means in cheap and satisfactory manner.

"The employment of apparatus involving the same principles will, I am satisfied, lead to undreamed of achievements. For example, it will be the power of man to precipitate rain, to draw unlimited quantities of water rfom the ocean. Lakes and rivers will be created in this manner and the whole globe transformed, all the work being performed by the sun, men simply controlling the process.

"Perhaps the greatest results will be in the destruction of the atom and the release of its immense energy. This discovery will make the gun obsolete. The battles of the future will be fought with electrical waves. The destructive power under control will be so prodigious that on this account alone war will become an impossibility."

The New York Herald December 28, 1914

Letters from Herald Readers

Thanks the Herald for Editorial and Calls Attention to Needs of Servia.

TO THE EDITOR OF THE HERALD:

I feel sure that I am voicing the sentiments of all my countrymen in thanking you heartily for your timely and helpful editorial of yesterday calling attention to the present urgent needs of Servia. Hardly ever was there a people so sorely tried or one which has more valiantly fought for individual uplift and national independence. The American press has been unanimous in bestowing unstinted praise upon the little nation for its energy and courage in resisting a powerful enemy, but precisely because of their marvellous successes the impression has been created here that the Servians are fully able to take care of themselves. It should be remembered, though, that Servia's victory is like that of Fabricius. She might survive one more like the last, but no more than one.

The great perfection of modern arms equalizes individuals as fighting units, and forced defensive has but a slight advantage over offensive. This is well shown in the present conflict. The French are certainly excellent in the defensive and admirably well led, yet they have lost almost as many men as the invaders. So too, in Poland every German advance is invariably turned into a German defeat. The ultimate victory must inevitably be with the greater number. The Austrian casualties in the Servian campaign are estimated at 140,000 men, a loss great, to be sure, but one which can be easily borne by a power having still millions in reserve. For Servia half of that number means one-third of her active force.

Not only has Servia to meet now all the terrible difficulties resulting from war, but she has to use every ounce of her strength to train a new army and make ready for a fresh assault of an infuriated enemy twenty times stronger.

As to prisoners, of the eighty thousand which the Servians have captured at least sixty thousand are their own brethren. They are not prisoners, but rather unwelcome guests, and a burden hard to carry.

NIKOLA TESLA

NEW YORK CITY, Dec. 27, 1914.

THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[SIXTH SERIES.]

JANUARY 1915.

I. *On the most Effective Adjustment of an Induction-coil.* *By* E. TAYLOR JONES, *D.Sc., Professor of Physics in the University College of North Wales, Bangor* *.

[Plate I.]

IN a recent paper † it was shown that the secondary potential and spark-length developed by an induction-coil, when a given current is interrupted in the primary circuit, are greatest under the following conditions :—

(1) The ratio n_2/n_1 of the two frequencies of electrical oscillation of the system has one of the values 3, 7, 11, ... ;

(2) $L_1C_1=(1-k^2)L_2C_2$ ‡.

The first is the condition that maxima of the two potential waves in the secondary circuit should occur simultaneously, the second that the sum of the amplitudes of the two waves should be a maximum for a given value of k.

It was further stated that the most effective of the ratios specified in (1) is $n_2/n_1=3$, and that in this case the conditions are satisfied by the adjustment $k=\cdot756$, $L_1C_1=\cdot429\ L_2C_2$.

* Communicated by the Author.

† Phil. Mag. xxvii. pp. 580–586, April 1914.

‡ L_1, L_2 are the self-inductances, C_1, C_2 the capacities, and k is the coupling coefficient of the primary and secondary circuits.

The physical meaning of the above results may be further considered in the light of what goes on in the *primary* circuit after the interruption of the current. An expression for the potential-difference V_1 of the plates of the primary condenser, at any time t after the interruption of the current i_0, has been given by Dibbern *. If the resistances of the circuits are neglected, Dibbern's expression becomes

$$V_1=\frac{2\pi i_0 n_1 n_2^2}{C_1(n_2^2-n_1^2)}\left(\frac{1}{4\pi^2 n_2^2}-L_1C_1\right)\sin 2\pi n_1 t - \frac{2\pi i_0 n_1^2 n_2}{C_1(n_2^2-n_1^2)}\left(\frac{1}{4\pi^2 n_1^2}-L_1C_1\right)\sin 2\pi n_2 t.$$

If n_2/n_1 has one of the values 3, 7, 11, ..., then at the time $t=1/4n_1$, $\sin 2\pi n_1 t=1$, and $\sin 2\pi n_2 t=-1$. Consequently the value of V_1 becomes at this instant

$$\frac{i_0}{2\pi C_1}\cdot\frac{1}{n_2-n_1}-2\pi i_0 L_1\cdot\frac{n_1 n_2}{n_2-n_1}.$$

This may be expressed in terms of the ratio L_2C_2/L_1C_1. Calling this m, and writing a for $\dfrac{1}{8\pi^2 L_2C_2(1-k^2)}$, we have

$$n_1n_2=2a\sqrt{m(1-k^2)},$$

$$n_2-n_1=\sqrt{2a(m+1)-4a\sqrt{m(1-k^2)}}\ \dagger.$$

Hence $$V_1=\frac{i_0\{1-8\pi^2 L_1C_1 a\sqrt{m(1-k^2)}\}}{2\pi C_1\sqrt{2a(m+1)-4a\sqrt{m(1-k^2)}}}.$$

Inserting the value of a and condition (2), *i. e.* $m=\dfrac{1}{1-k^2}$, we find that this expression vanishes.

It appears, therefore, that if conditions (1) and (2) are satisfied, the amplitudes of the two potential waves in the primary circuit are equal, and that at the instant in question the potentials are at their maxima, but in opposite phase. The primary condenser is therefore uncharged, while at the same moment the secondary potential is at its maximum ‡, the two waves in the secondary circuit being then at their maxima and in the *same* phase. Further, since $dV_1/dt=0$, and $dV_2/dt=0$, there is no current in either circuit. The whole of the energy therefore exists at this moment in the

* E. Dibbern, *Ann. d. Physik*, xl. 4, p. 938 (1913); Inaug. Diss., Kiel.

† *L. c.* p. 581.

‡ *L. c.* p. 581.

electrostatic form in the secondary circuit, and the secondary potential must in these circumstances have its greatest possible value for a given initial energy-supply $\frac{1}{2}L_1i_0^2$.

It was shown in the previous paper to which reference has been made * that the value of this maximum secondary potential, still on the assumption that the resistances are negligible, is

$$V_{2m}=i_0\cdot\frac{L_{21}}{\sqrt{L_2C_2}}\cdot\frac{1}{k} \quad . \quad . \quad . \quad . \quad (3\,a)$$

$$=i_0\sqrt{\frac{L_{21}}{L_{12}}}\cdot\sqrt{\frac{L_1}{C_2}}. \quad . \quad . \quad . \quad (3\,b)$$

The energy equation is therefore

$$\tfrac{1}{2}L_1i_0^2=\tfrac{1}{2}C_2V_{2m}^2\cdot\frac{L_{12}}{L_{21}}.$$

The factor L_{12}/L_{21} arises from the manner in which the capaciiy C_2 of the secondary circuit is defined. It is the charge on one-half of the secondary coil (and the bodies connected to its terminal), divided by the difference of potential of the terminals. The charge on this portion of the secondary circuit is C_2V_{2m}, but as some of this charge is at a lower potential than that of the terminals, the energy must be less than $\frac{1}{2}C_2V_{2m}^2$. The correcting factor is L_{12}/L_{21}.

There are many values of k and L_1C_1/L_2C_2 which satisfy the above conditions. The first four, probably the only ones having any practical importance, are given in Table I.

TABLE I.

n_2/n_1.	k.	$\frac{L_1C_1}{L_2C_2}=1-k^2$.
3	·756	·429
7	·914	·164
11	·950	·098
15	·965	·070

If we define the efficiency of an induction-coil as the ratio of the maximum electrostatic energy in the secondary to the electrokinetic energy in the primary circuit just before the interruption of the current (*i. e.*, $\frac{1}{2}L_1i_0^2$), then the efficiency

* *L. c.* pp. 581, 584.

is unity in each of the adjustments specified in Table I. if the resistances of the circuits are negligible. But it is easy to see that of these adjustments the first (*i. e.*, $n_2/n_1=3$, $L_1C_1=\cdot429\,L_2C_2$) is the one which gives the longest spark *for a given primary current*. For let us suppose that an induction-coil is so constructed, and the primary condenser so chosen, that $k=\cdot914$ and $L_1C_1=\cdot164\,L_2C_2$. This is the second adjustment of Table I., and it allows the whole of the primary energy $\frac{1}{2}L_1i_0^2$ to be converted at a certain moment after the interruption into electrostatic energy in the secondary circuit. Now by inserting coils of suitable self-inductance, say l_1, in the primary circuit (coils which do not act inductively on the induction-coil) we can reduce the coupling coefficient to ·756 ; and if the primary condenser is chosen so that $(L_1+l_1)C_1=\cdot429\,L_2C_2$, we then have the first adjustment, with $n_2/n_1=3$. The system has again unit efficiency, but the maximum electrostatic energy in the secondary is now $\frac{1}{2}(L_1+l_1)i_0^2$, and is greater than the former value in the ratio of L_1+l_1 to L_1. The capacity C_2 of the secondary coil being unaltered, the secondary potential is increased in the ratio $\sqrt{L_1+l_1}$ to $\sqrt{L_1}$. The 3/1 adjustment is thus more effective (though not more efficient) than the others because it allows a greater quantity of initial energy to be converted into electrostatic energy in the secondary circuit, in which therefore the charge and potential developed are greater than in the other cases.

There are other ways in which the coupling coefficient could be reduced (*e. g.*, from ·914 to ·756), but none of them are so effective as the plan of introducing external inductance into the primary circuit. For instance*, external inductance may be introduced in the *secondary* circuit. This increases C_2, and to some extent L_{12}, without altering L_1 and L_{21}, and therefore, by (3 *b*), lowers the secondary potential. Again, k may be reduced by removing a part of the iron core. This diminishes L_1 without causing any increase in L_{21}/L_{12}, or any change in C_2, and therefore, by (3 *b*), reduces V_{2m}. The reduction of the coupling may also be effected by withdrawing the primary coil with the core to a suitable distance along the axis of the secondary. This process reduces L_{12}, L_{21}, and L_2, without changing L_1, and should cause no change in the secondary potential except such as may be due to a slight diminution of C_2 or of the ratio L_{21}/L_{12}.

It should be clearly understood that these reductions of the coupling are supposed to bring the system from

* In each of these supposed modifications the primary capacity is to be adjusted so that $L_1C_1=(1-k^2)L_2C_2$.

one state of unit efficiency to another, *e. g.* from the second to the first adjustment of Table I., for it is only in these states that equations (3 *a*), (3 *b*) hold. If, on the other hand, k lies between two of the unit-efficiency values, the spark-length for a given current may be increased by withdrawing the primary coil and core to a suitable distance along the axis of the secondary. For example, the coil with which I have experimented has a coupling coefficient of ·876, and the longest spark occurs when the primary capacity is about ·06 microfarad*. A marked increase is, however, produced in the spark-length by withdrawing the primary coil and core to a distance of 36·5 cm. from its nearly symmetrical position in the secondary, and increasing the capacity to ·15 microfarad.

We may conclude that any induction-coil in which the coupling is greater than ·756 can be improved in spark-length by connecting external series inductance in the primary circuit so as to reduce the coupling to this value. An induction-coil should not be constructed so that the coupling is less than ·756, for there is no convenient way of increasing the coupling to this value. Nor should the coupling coefficient of the primary and secondary *coils* have precisely this value, though if no external coils are used this is the best arrangement. Better effects are obtained by coupling the coils more closely than this, and adding series inductance to the primary circuit so as to reduce k to this value. The ratio L_1/C_2 is thereby increased, and it is upon this quantity, when the adjustments (1) and (2) are effected, that the maximum secondary potential for a given primary current chiefly depends.

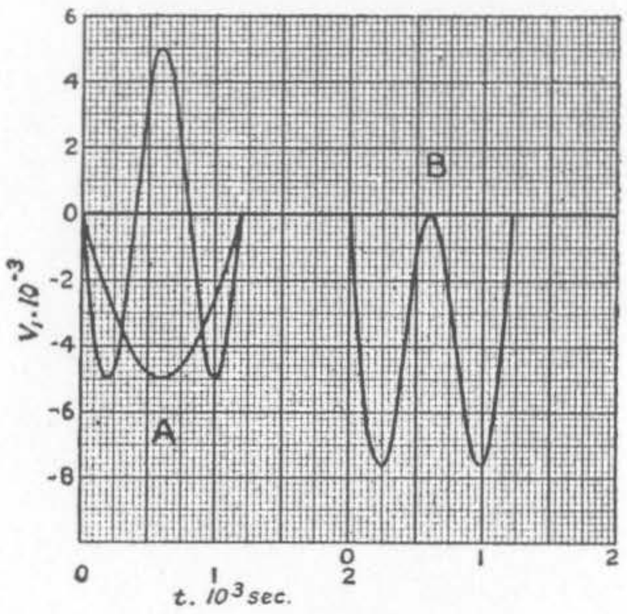
In fig. 1 (A) are shown curves representing the two potential waves in the primary circuit of an induction-coil in which the above adjustment has been effected, and in which the damping of the oscillations is negligible. The amplitude of each wave is taken as 5000 volts, and the periods are ·0024 sec. and ·0008 sec. These values are chosen so as to correspond approximately (for $i_0=10$ amperes) with those found in an actual case, as described below. Fig. 1 (B) shows the result of superposing the two curves of (A). The equation to curve (B), the ordinate of which represents the potential of the primary condenser t seconds after the interruption, is

$$V_1=-5000\sin 150{,}000\,t-5000\sin 450{,}000\,t,$$

the angles being given in degrees.

* It was explained in the previous paper (*l. c.* pp. 584, 585) how the most effective primary capacity in any such case can be calculated.

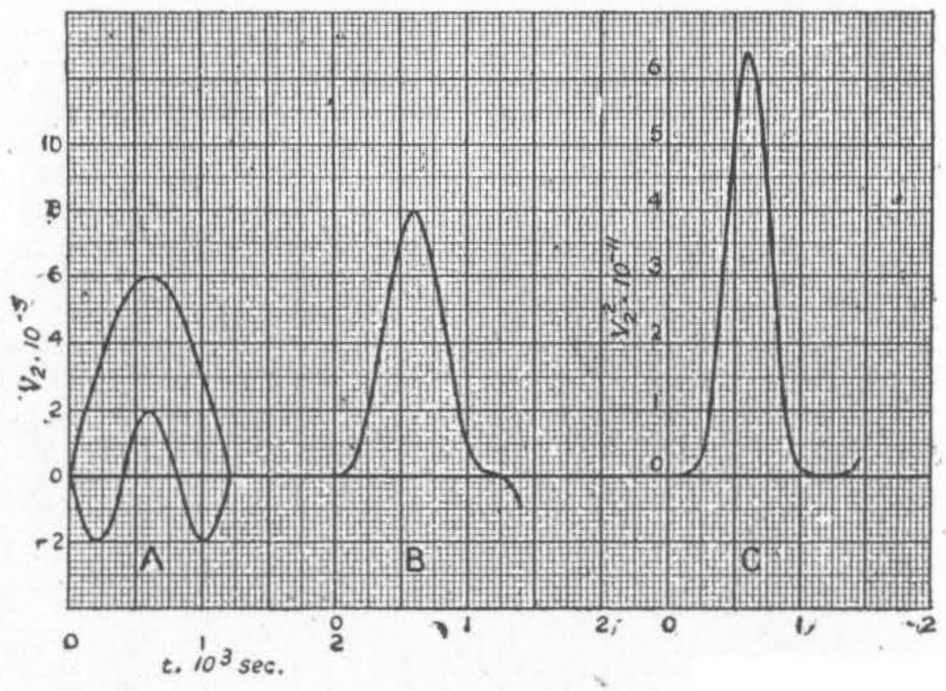
Fig. 1.



Primary potential.

The curves in fig. 1 cover one half-period of the longer wave ; their continuation in the second half-period is merely a repetition with the ordinates reversed in sign.

Fig. 2.



Secondary potential.

Fig. 2 (A) shows the corresponding potential waves in the secondary circuit ; fig. 2 (B) the effect of their superposition. The amplitudes here are taken as 600,000 and 200,000 volts

respectively. It will be seen that the two positive maxima coincide at ·0006 sec. after the interruption, giving the maximum potential of 800,000 volts at the secondary terminals. At this moment the potential of the primary condenser is zero. Fig. 2 (C) shows (for comparison with the oscillograph curves described below) the curve obtained by squaring the ordinates of fig. 2 (B).

The above theoretical conclusions apply strictly only to the case of an ideal induction-coil, in which the resistances of the circuits and other causes of damping of the oscillations are negligible. Some applications of the theory were, however, given, in the former paper referred to *, in which it was shown that the results of the theory agree closely with experiment in so far as they concern the *conditions* under which the greatest spark-length is given by an induction-coil. The *value* of the secondary potential is of course greatly modified by the damping.

Another experiment will now be described, from the results of which some further information may be gathered as to the working of an induction-coil when in its most effective adjustment.

The coil experimented upon was the one employed in the previous experiments, viz. : an 18-inch coil in which the coefficient of coupling of the primary and secondary coils (the secondary terminals being connected to the oscillograph and to a variable spark-gap) is ·876. The primary circuit was fed by a number of storage-cells, and included an amperemeter, a rheostat, and a slow interruptor which broke the current about once per second. The condenser was connected directly across the interruptor.

The experiment consisted in increasing the self-inductance of the primary circuit by the addition of air-core coils, and varying the capacity of the condenser, until the longest spark was produced by a given primary current. The curve of secondary potential was then photographed, and the constants of the circuits determined. The best effect was found to be obtained with four extra coils in the primary circuit, and with a condenser of ·2 microfarad capacity. It was not very easy to decide with great exactness upon the best self-inductance and capacity, owing to the fact that the spark-length varies slowly with these quantities in the neighbourhood of the maximum. A difference of ·025 mfd. either way in C_1 caused no appreciable change in the spark-length. From the practical point of view this slow variation near the maximum is in itself no disadvantage, since very exact

* *L. c.* pp. 582–586.

adjustment is not necessary in order to produce a spark-length practically equal to the maximum.

The constants of the circuits were measured by methods which were fully described in the previous paper, and found to be as follows :—

$$\frac{1}{L_1C_1} = 19{\cdot}57 \,.\, 10^6 \text{ c.g.s.},$$

$$\frac{1}{L_2C_2} = 8{\cdot}763 \,.\, 10^6 \quad ,,$$

$$k = {\cdot}748,$$

$$L_{21} = 20{\cdot}4 \text{ henries},$$

$$\frac{R_1}{L_1} = 680,$$

$$\frac{R_2}{L_2} = 825.$$

R_0, the resistance of the primary circuit for steady currents, was 8 ohms.

Hence

$$\theta_1 = \tfrac{1}{2}R_1C_1 = 1{\cdot}738 \,.\, 10^{-5} \text{ c.g.s.}$$

$$\theta_2 = \tfrac{1}{2}R_2C_2 = 4{\cdot}709 \,.\, 10^{-5} \quad ,,$$

$$\theta_0 = \tfrac{1}{2}R_0C_1 = \quad 8 \,.\, 10^{-7} \quad ,,$$

The quantities R_1/L_1, R_2/L_2, were determined from the decay factors of the circuits when oscillating separately. The effective resistances R_1, R_2, are much greater than the steady-current values ; they depend also upon losses due to leakage, hysteresis, and absorption. A considerable part of R_2 is probably due to leakage through the electrometer. The decay factors are not constant ; the values of R_1/L_1, R_2/L_2 given above prevail during oscillations of fairly large amplitude in the primary and secondary circuits respectively.

The calculated frequencies are :

$$n_1 = 413{\cdot}9,$$

$$n_2 = 1208,$$

giving $$n_2/n_1 = 2{\cdot}919.$$

Also $$L_1C_1/L_2C_2 = {\cdot}448,$$

while $$1-k^2 = {\cdot}440.$$

The differences between these values and those of the ideal case ($n_2/n_1=3$, $k={\cdot}756$, $L_1C_1/L_2C_2={\cdot}429$) are within the limits of experimental error, and may be due to the above-mentioned difficulty of adjusting L_1 and C_1 accurately

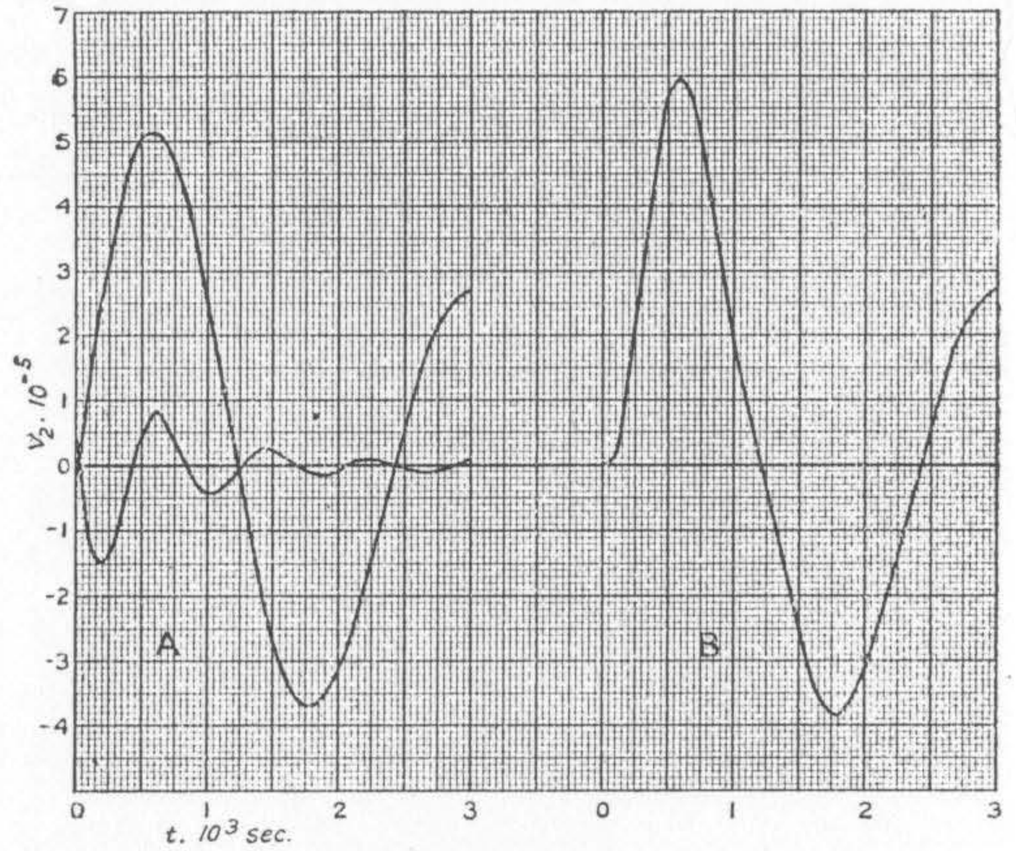
to give the best effect. If L_1 and C_1 were reduced, by amounts which would cause no appreciable change in the spark-length, the differences would disappear.

From the above data the secondary potential can now be calculated *, and the result, expressed in volts for $i_0=10$ amperes, is

$$V_2 = 601300 \,.\, e^{-2\epsilon 6\, t} \sin (149000\, t - 1{\cdot}95)^\circ$$
$$- 206900 \,.\, e^{-1410 t} \sin (435000\, t - 5{\cdot}7)^\circ.$$

From this expression values of V_2, the difference of potential at the secondary terminals t seconds after the interruption of the primary current, were calculated for

Fig. 3.



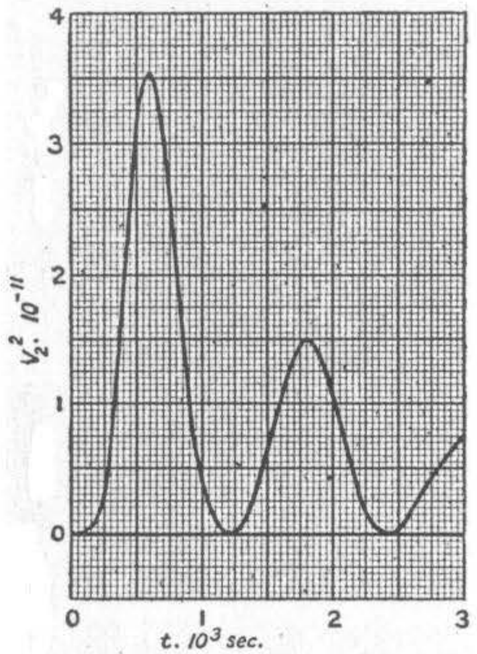
Secondary potential.

various values of t up to ·003 second, a time covering rather more than one whole period of the longer wave. The results are exhibited in fig. 3, in which (A) shows the two oscillations

* The general expression for V_2 is given in the previous paper, *l. c.* pp. 565, 574. The statement in the footnote on p. 574 requires correction. When the condenser is connected directly across the interruptor, so that the battery (e.m.f. E) is included in the primary oscillating circuit, we have initially $V_1=0$, but finally $V_1=-E$. The results as given on pp. 574, 575, apply to this case provided V_1 is taken as E+the potential-difference of the primary condenser.

of the secondary circuit separately, and (B) the result of their superposition. It will be seen that two positive maxima in the oscillations agree at about $t=\cdot0006$ sec., giving rise to the maximum secondary potential (596900 volts) at this time. Fig. 4 shows the square of the secondary

Fig. 4.



Square of secondary potential.

potential plotted against the time. This curve shows clearly the peaked maxima and the flattened zeroes which are characteristic of the 3/1 ratio.

In Plate I. figs. 6 and 7 are shown photographic records of the secondary potential wave obtained with the oscillograph. In these curves the ordinates are proportional to the square of the secondary potential, owing to the idiostatic connexion of the instrument, and these curves are therefore directly comparable with fig. 4. The currents interrupted when these photographs were taken were 1·5 and 2·0 amperes respectively *. It will be seen that the greatest ordinates of the curves are proportional to the squares of the currents. In period †, rate of decay, and form the calculated curve of fig. 4 agrees well with the photographs. The photographic curves are perhaps rather more

* The greatest spark-length for 2 amperes, between spark-balls 2 cm. in diameter, was 18·2 cm. The external inductance being removed, and the primary coil being still in its symmetrical position within the secondary, the greatest spark-length at 2 amperes ($C_1=0·6$ mfd.) was 12·8 cm. No sparks passed when the photographs shown were taken.

† The time curve shown on the photographs has a period of 1/768 sec.

peaked at the summits, and more flattened at the zeroes, than the calculated curve, which indicates that the calculated damping factor of the shorter wave is rather too great in comparison with that of the slower oscillation. This may possibly be due to the existence of an appreciable difference (arising from various causes) between the values of the effective resistances of the circuits when oscillating separately, and their values when the circuits are oscillating as a coupled system.

Turning now to the primary circuit, Dibbern's formula allows the potential wave in the primary condenser to be calculated *. Using the values given above for the constants of the circuits, and taking i_0, the primary current interrupted, as 10 amperes, Dibbern's expression becomes in the present case

$$V_1\dagger = -5020\, e^{-266\,t} \sin (149000\,t+8·02)^\circ$$
$$-4940\, e^{-1440\,t} \sin (435000\,t-9·07)^\circ, \quad . \quad . \quad (4)$$

where V_1 is the primary potential in volts.

The amplitudes of the two oscillations in the primary circuit are thus nearly equal, as required by condition (2).

The two oscillations represented by (4) are shown in fig. 5 (A), the result of their superposition in fig. 5 (B). It will be seen that the negative potential‡ of the primary condenser reaches a maximum of 6800 volts at about ·00025 sec., and a minimum of 2250 volts at about ·00065 sec. after the interruption. Thus, at the moment at which the secondary potential reaches its greatest value the primary condenser, instead of being uncharged as would be the case in an ideal induction-coil, is still charged to about 2250 volts, and this is due almost entirely to the difference in the damping factors of the two oscillations.

The effective resistances of the circuits therefore act in two ways in reducing the efficiency of the arrangement. First, they give rise to dissipation of energy and consequent decay of the amplitudes of both oscillations. Second, owing to the difference between the damping factors of the two oscillations, there is some energy stored in the primary condenser at the moment when the secondary potential is at its maximum.

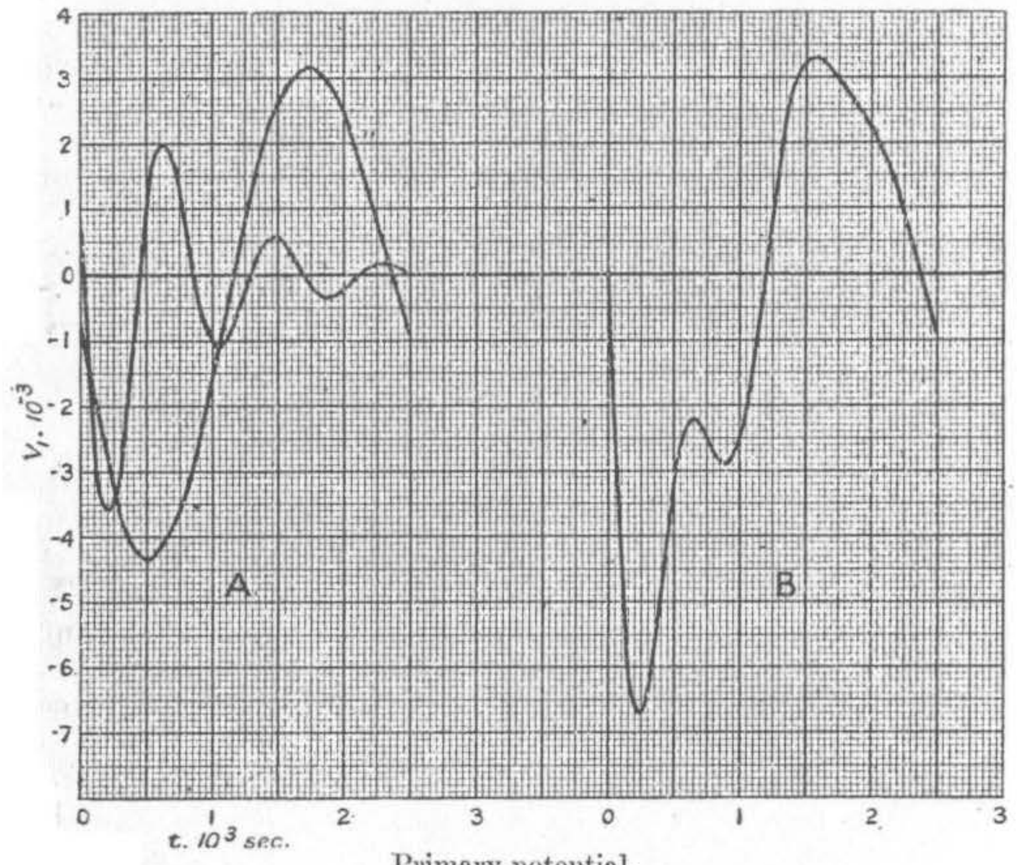
* The existence of the two oscillations in the primary circuit after the interruption is well shown by a current oscillogram taken by Wertheim-Salomonson, *Physik. Zeitschr.* xi. p. 539, fig. 1 (1910).

† As explained in the footnote on p. 9 above, V_1 here means E+ the potential of the condenser. E is here 80 volts.

‡ The potential of the primary condenser is taken negative when it opposes the battery E.M.F.

The efficiency is easily calculated in the present case. The maximum secondary potential, for $i_0=10$ amperes, is 596900 volts. If the resistances were negligible, and if the system

Fig. 5.



Primary potential.

were exactly in the first unit-efficiency adjustment, the maximum secondary potential would be, by (3*a*), 798700 volts. Consequently the efficiency is $\left(\frac{5969}{7987}\right)^2 = \cdot 559$.

The energy originally in the system is $\frac{1}{2}L_1 i_0^2$, *i. e.* since L_1 is about ·255 henry, 12·75 joules. The maximum electrostatic energy in the secondary circuit is therefore $\cdot 559 \times 12 \cdot 75$, or about 7·1 joules. The energy then stored in the primary condenser (capacity ·2 mfd.) is $\frac{1}{2} . \cdot 2 . 2250^2 . 10$ ergs, or about ·5 joule.

Consequently of the original 12·75 joules rather over 5 are dissipated, half a joule is stored in the primary condenser, and the remaining 7 joules are available to provide for the secondary discharge at the moment of maximum potential.

The charge then on the secondary is C_2V_2 and may be calculated when the capacity C_2 is known. If we knew the value of the ratio L_{21}/L_{12} the capacity could be at once

determined from the known values of k^2, L_1, L_{21}, and L_2C_2, since

$$C_2 = \frac{L_{21}}{L_{12}} . \frac{L_1}{L_{21}^2} . k^2 . L_2C_2. \quad . \quad . \quad . \quad . \quad (5)$$

With regard to the ratio L_{21}/L_{12}, this differs from unity because the current in the secondary coil during the oscillations is not uniformly distributed, but is greatest at the central winding and nearly zero at the ends. If all the windings of the secondary had equal inductive effects on the primary, when reckoned per unit current, and if the current in a turn of the secondary at a distance z from the central winding were proportional to $\cos\frac{\pi z}{h}$, where h is the length of the secondary coil, it is easily seen that L_{21}/L_{12} would be equal to $\pi/2$. In the actual case, however, the inductive effect of the secondary windings (per unit current) diminishes from the centre towards each end. This was tested by ballistic galvanometer experiments in which the mutual inductance of the primary and a single turn of wire, wound on the secondary (or primary) in various positions, was compared with its value for the central position. From the results of these measurements it was found that this mutual inductance could be represented approximately by the expression $a-bz^2-cz^4$ *. Consequently L_{12} is proportional to

$$\int_{-h/2}^{+h/2} (a-bz^2-cz^4) \cos\frac{\pi z}{h} dz,$$

while L_{21} is proportional to

$$\int_{-h/2}^{+h/2} (a-bz^2-cz^4) dz,$$

since the current in the primary coil is uniformly distributed. The value of L_{21}/L_{12} is thereby reduced from $\pi/2$, and becomes in the present case $\cdot 95\,\pi/2$.

Another correction is necessary if, as in the present experiments, the secondary terminals are connected to a capacity which is not negligible in comparison with that of the coil. In this case the secondary current is not quite zero at the ends of the coil, but should be represented as proportional to $\cos\frac{\pi z}{h'}$, where h' is greater than h. The value

* The dimensions of the coils are:—primary, length 90 cm., mean diameter 6·9 cm.; secondary, length (between the terminals) 51 cm., diameter (outside) 24 cm.

of h' may be estimated if we know the ratio of the external capacity C_e to the total capacity C_2. If C_e is small in comparison with C_2 the approximate value of the latter (obtained from equation (5) by neglecting the present correction) may be used here. If the current in the secondary windings varies as $\cos \frac{\pi z}{h'}$, the charge per unit length will be proportional to $\sin \frac{\pi z}{h'}$. Hence the ratio of C to C_2 is equal to the ratio of

$$\int_{h/2}^{h'/2} \sin \frac{\pi z}{h'} . dz \qquad \text{to} \qquad \int_{0}^{h'/2} \sin \frac{\pi z}{h'} dz,$$

$$i.\,e. \qquad \frac{C_e}{C_2} = \cos \frac{\pi h}{2h'}.$$

This determines h'/h, and we then have

$$\frac{L_{12}}{L_{21}} = \frac{1}{h}\int_{-h/2}^{+h/2} \cos \frac{\pi z}{h'} dz$$

$$= \frac{2}{\pi} \cdot \frac{h'}{h} \cdot \sin \frac{\pi h}{2h'}.$$

In the present experiments C_e is the capacity of the electrometer and the spark-gap terminals, and this is about one-sixth of the total secondary capacity C_2, the value of which is already known approximately. Hence $\cos \frac{\pi h}{2h'} = \frac{1}{6}$, and $\frac{h'}{h} = 1{\cdot}12$, from which $\frac{L_{12}}{L_{21}} = 1{\cdot}10 \cdot \frac{2}{\pi}$. The effect of this correction is therefore further to reduce L_{21}/L_{12} by about 10 per cent.

Taking both corrections into account we have approximately

$$L_{21}/L_{12} = {\cdot}85\pi/2 = 1{\cdot}335,$$

from which by (5)

$$C_2 = {\cdot}000052 \text{ microfarad.}$$

The charge of the secondary circuit at the moment of maximum potential is therefore $5{\cdot}2 \times 5{\cdot}969 \times 10^{-7}$ c.g.s., or $31 . 10^{-6}$ coulomb. If the whole of this charge escaped from the terminals, in the form of a spark or other discharge, the discharge current would be, at n interruptions per second, nC_2V_2. Further experiments are, however, required in order to decide whether this complete discharge takes place, or whether some of the electricity does not return through the secondary coil and continue to oscillate in it.

The conditions for maximum potential are the same when a rapid interruptor is employed as for the slow break used in the above experiments. They also hold whether the primary current is supplied by a small storage-battery, a 100-volt battery, or the 200-volt mains. Plate I. fig. 8 shows the course of the secondary potential at two successive "breaks" effected by a motor mercury interruptor. The effect of the small potential at the "make" is also noticeable. On this occasion the 100-volt battery was used to supply the primary current, the total (steady-current) resistance in the primary circuit being 11 ohms. The greatest spark-length was 18·4 cm., and the mean primary current, as indicated by an amperemeter in the primary circuit, was ·3 ampere. The current immediately before interruption would, however, be over 2 amperes.

Bangor, November 1914.

NEW YORK AMERICAN FEBRUARY 7, 1915

Did the War Cause the Italian Earthquake?

"The Explosion of Mines, Torpedoes, Mortars and Guns Develops Reactive Forces on the Ground Which Are Measured in Thousands of Tons and Make Themselves Felt all Over the Globe. If the Concussions Happen to Be Properly Timed Their Combined Action Could Start Tectonic Adjustments in Any Part of the Earth and the Italian Calamity May Thus Have Been the Result of Explosions in France," *Mr. Tesla Declares.*

By Mr. Nikola Tesla

The Distinguished Scientist, Electrical Expert and Inventor.

EVERY living being is an engine geared to the wheelwork of the universe. Though seemingly affected only by its immediate surrounding, the sphere of external influence extends to infinite distance. There is no constellation or nebula, no sun or planet, in all the depths of limitless space, no passing wanderer of the starry heavens, that does not exercise some control over its destiny—not in the vague and delusive sense of astrology, but in the rigid and positive meaning of physical science.

More than this can be said. There is no thing endowed with life—from man, who is enslaving the elements, to the numbiest creature in all this world that does not sway it in turn. Whenever action is born from force, though it be infinitesimal, the cosmic balance is upset and universal motion results.

Herbert Spencer has interpreted life as a continuous adjustment to the environment, a definition of this inconceivably complex manifestation quite in accord with advanced scientific thought, but, perhaps, not broad enough to express our present views. With each step forward in the investigation of its laws and mysteries our conceptions of nature and its phases have been gaining in depth and breadth.

In the early stages of intellectual development man was conscious of but a small part of the macrocosm. He knew nothing of the wonders of the microscopic world, of the molecules composing it, of the atoms making up the molecules and of the dwindlingly small world of electrons within the atoms. To him life was synonymous with voluntary motion and action. A plant did not suggest to him what it does to us—that it lives and feels, fights for its existence, that it suffers and enjoys. Not only have we found this to be true, but we have ascertained that even matter called inorganic, believed to be dead, responds to irritants and gives unmistakable evidence of the presence of a living principle within.

Thus, everything that exists, organic or inorganic, animated or inert, is susceptible to stimulus from the outside. There is no gap between, no break of continuity, no special and distinguishing vital agent. The same law governs all matter, all the universe is alive. The momentous question of Spencer, "What is it that causes inorganic matter to run into organic forms?" has been answered. It is the sun's heat and light. Wherever they are, there is life. Only in the boundless wastes of interstellar space, in the eternal darkness and cold, is animation suspended, and, possibly, at the temperature of absolute zero all matter may rife.

Man as a Machine.

This realistic aspect of the perceptible universe, as a clockwork wound up and running down, dispensing with the necessity of a hypermechanical vital principle, need not be in discord with our religious and artistic aspirations those undefinable and beautiful efforts through which the human mind endeavors to free itself from material bonds. On the contrary, the better understanding of nature, the consciousness that our knowledge is true, can only be all the more elevating and inspiring.

It was Descartes, the great French philosopher, who, in the seventeenth century, laid the first foundation to the mechanistic theory of life, not a little assisted by Harvey's epochal discovery of blood circulation. He held that animals were simply automata without consciousness and recognized that man, though possessed of a higher and distinctive quality, is incapable of action other than those characteristic of a machine. He also made the first attempt to explain the physical mechanism of memory. But in his time many functions of the human body were not as yet understood, and in this respect some of his assumptions were erroneous.

Great strides have since been made in the art of anatomy, physiology and all branches of science, and the workings of the man-machine are now perfectly clear. Yet the very fewest among us are able to trace their actions to primary external causes. It is indispensable to the arguments I shall advance to keep in mind the main facts which I have myself established in years of close reasoning and observation and which may be summed up as follows:

1. The human being is a self-propelled automaton entirely under the control of external influences. Willful and predetermined though they appear, his actions are governed not from within, but from without. He is like a float tossed about by the waves of a turbulent sea.

2. There is no memory or retentive faculty based on lasting impression. What we designate as memory is but increased responsiveness to repeated stimuli.

3. It is not true, as Descartes taught, that the brain is an accumulator. There is no permanent record in the brain, there is no stored up response to disturbances directly received on the knowledge. Knowledge is something akin to an echo that needs a disturbance to be called into being.

4. All knowledge or form conception is evoked through the medium of the eye, either in retina or to their fainter secondary effects and reverberations. Other sense organs can only call forth feelings which have no reality of existence and of which no conception can be formed.

5. Contrary to the most important tenet of Cartesian philosophy that the perceptions of the mind are illusionary, the eye transmits to it the true and accurate likeness of external things. This is because light propagates in straight lines and the image cast on the retina is an exact reproduction of the external form and one which, owing to the mechanism of the optic nerve, can not be distorted in the transmission to the brain. What is more, the process must be reversible, that is to say, a form brought to consciousness can, by reflex action, reproduce the original image on the retina, just as an echo can reproduce the original disturbance. If this view is borne out by experiment an immense revolution in all human relations and departments of activity will be the consequence.

Natural Forces Influence Us.

Accepting all this as true let us consider some of the forces and influences which act on such a wonderfully complex automatic engine with organs inconceivably sensitive and delicate, as it is carried by the spinning terrestrial globe in its lightning flight through space. For the sake of simplicity we may assume that the earth's axis is perpendicular to the ecliptic and that the human automaton is at the equator. Let his weight be one hundred and sixty pounds, then, at the rotational velocity of about 1,520 feet per second with which he is whirled around, the mechanical energy stored in his body will be nearly 5,780,000 foot pounds, which is about the energy of a hundred-pound cannon ball.

This momentum is constant as well as the upward centrifugal push, amounting to about fifty-five hundredth of a pound, and both will probably be without marked influence on his life functions. The sun, having a mass 332,000 times that of the earth, but being 23,000 times farther, will attract the automaton with a force of about one-tenth of one pound, alternately increasing and diminishing his normal weight by that amount

Though not conscious of these periodic changes, he is surely affected by them.

The earth in its rotation around the sun carries him with the prodigious speed of nineteen miles per second and the mechanical energy imparted to him is over 25,160,000,000 foot pounds. The largest gun ever made in Germany hurls a projectile weighing one ton with a muzzle velocity of 3,700 feet per second the energy being 429,000,000 foot pounds. Hence the momentum of the automaton's body is nearly sixty times greater. It would be sufficient to develop 762,400 horse-power for one minute, and if the motion were suddenly arrested the body would be instantly exploded with a force sufficient to carry a projectile weighing over sixty tons to a distance of twenty-eight miles.

This enormous energy is, however, not constant, but varies with the position of the automaton in relation to the sun. The circumference of the earth has a speed of 1,520 feet per second, which is either added to or subtracted from the translatory velocity of nineteen miles through space. Owing to this the energy will vary from twelve to twelve hours by an amount approximately equal to 1,533,000,000 foot pounds, which means that energy streams in some unknown way into and out of the body of the automaton at the rate of about sixty-four horse-power.

But this is not all. The whole solar system is urged towards the remote constellation of Hercules with a speed which some estimate at twenty miles per second, and owing to this there should be similar annual changes in the flux of energy, which may reach the appalling figure of over one hundred billion foot pounds. All these varying and purely mechanical effects are rendered more complex through the inclination of the orbital planes and many other permanent or casual mass actions.

The automaton is, however, subjected to other forces and influences. His body is at the electric potential of two billion volts, which fluctuates violently and incessantly The whole earth is alive with electrical vibrations in which he takes part. The atmosphere crushes him with a pressure of from sixteen to twenty tons, according to barometric conditions. He receives the energy of the sun's rays in varying intervals at a mean rate of about forty foot pounds per second, and is subjected to periodic bombardment of the sun's particles, which pass through his body as if it were tissue paper. The air is rent with sounds which beat on his eardrums and he is shaken by the unceasing tremors of the earth's crust. He is exposed to great temperature changes, to rain and wind.

What wonder then that in such a terrible turmoil, in which cast iron existence would seem impossible, this delicate human engine should act in an exceptional manner? If all automata were in every respect alike they would react in exactly the same way, but this is not the case. There is concordance in response to those disturbances only which are most frequently repeated, not to all It is quite easy to provide two electrical systems which, when subjected to the same influence, will behave in just the opposite way.



MR. NIKOLA TESLA.

So also two human beings, and what is true of individuals also holds good for their large aggregations. We all sleep periodically. This is not an indispensable physiological necessity any more than stoppage at intervals is a requirement for an engine. It is merely a condition gradually imposed upon us by the diurnal revolution of the globe, and this is one of the many evidences of the truth of the mechanistic theory. We note a rhythm, or ebb and tide, in ideas and opinions, in financial and political movements, in every department of our intellectual activity.

How Wars Are Started.

It only shows that in all this a physical system of mass inertia is involved which affords a further striking proof. If we accept the theory as a fundamental truth and, furthermore, extend the limits of our sense perceptions beyond those within which we become conscious of the external impressions, then all the states in human life, however unusual, can be plausibly explained. A few examples may be given in illustration.

The eye responds only to light vibrations through a certain rather narrow range, but the limits are not sharply defined. It is also affected by vibrations beyond, only in a lesser degree. A person may thus become aware of the presence of another in darkness, or through intervening obstacles, and people laboring under illusions ascribe this to telepathy. Such transmission of thought is absurdly impossible.

The trained observer notes without difficulty that these phenomena are due to suggestion or coincidence. The same may be said of oral impressions, to which musical and imitative people are especially susceptible A person possessing these qualities will often respond to mechanical shocks or vibrations which are inaudible.

To mention another instance of momentary interest reference may be made to dancing, which comprises certain harmonious muscular contractions and contortions of the body in response to a rhythm. How they come to be in vogue just now can be satisfactorily explained by supposing the existence of some new periodic disturbances in the environment, which are transmitted through the air or the ground and may be of mechanical, electrical or other character.

Exactly so it is with wars, revolutions and similar exceptional states of society.

Though it may seem so, a war can never be caused by arbitrary acts of man.

It is invariably the more or less direct result of cosmic disturbance in which the sun is chiefly concerned.

In many international conflicts of historical record which were precipitated by famine, pestilence or terrestrial catastrophies the direct dependence of the sun is unmistakable. But in most cases the underlying primary causes are numerous and hard to trace.

In the present war it would be particularly difficult to show that the apparently wilful acts of a few individuals were not causative. Be it so. The mechanistic theory, being founded on truth demonstrated in everyday experience, absolutely precludes the possibility of such a state being anything but the inevitable consequence of cosmic disturbance.

The question naturally presents itself as to whether there is some intimate relation between wars and terrestrial upheavals. The latter are of decided influence on temperament and disposition, and might at times be instrumental in accelerating the clash, but aside from this there seems to be no mutual dependence, though both may be due to the same primary cause.

What can be asserted with perfect confidence is that the earth may be thrown into convulsions through mechanical effects such as are produced in modern warfare. This statement may be startling, but it admits of a simple explanation.

Earthquakes are principally due to two causes—subterranean explosions or structural adjustments. The former are called volcanic, involve immense energy and are hard to start. The latter are named tectonic; their energy is comparatively insignificant and they can be caused by the slightest shock or tremor. The frequent slides in the Culebra are displacements of this kind.

War and the Earthquake

Theoretically, it may be said that one might think of a tectonic earthquake and cause it to occur as a result of the thought, for just preceding the release the mass may be in the most delicate balance. There is a popular error in regard to the energy of such displacements. In a case recently reported as quite extraordinary, extending as it did over a vast territory, the energy was estimated at 65,000,000,000,000 foot tons. Assuming even that the whole work was performed in one minute it would only be equivalent to that of 7,500,000 horse-power during one year, which seems much, but is little for a terrestrial upheaval. The energy of the sun's rays falling on the same area is a thousand times greater.

The explosions of mines, torpedoes, mortars and guns develop reactive forces on the ground which are measured in hundreds or even thousands of tons and make themselves felt all over the globe. Their effect, however, may be enormously magnified by resonance. The earth is a sphere of a rigidity slightly greater than that of steel and vibrates once in about one hour and forty-nine minutes.

If, as might well be possible, the concussions happen to be properly timed their combined action could start tectonic adjustments in any part of the earth, and the Italian calamity may thus have been the result of explosions in France. That man can produce such terrestrial convulsions is beyond any doubt, and the time may be near when it will be done for purposes good or evil.

Nikola Tesla's Fountain

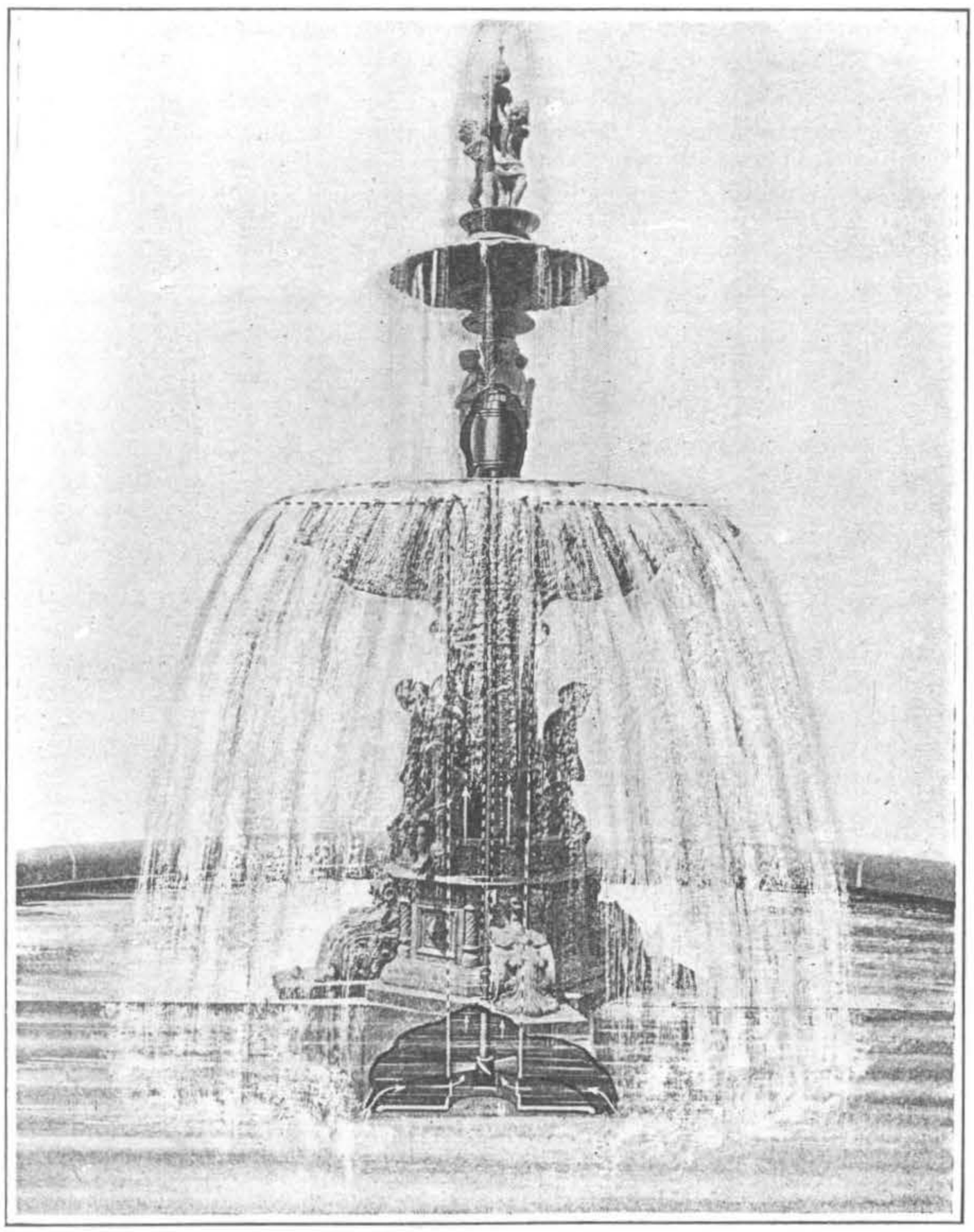
IT is a curious fact that, old as fountains are, they have remained essentially unchanged in principle for centuries. Artists have lavished all their skill upon them to make them beautiful, but engineers have neglected them. To be sure independent pumps of small volumetric capacity have been used to create artificial waterfalls and to use the same water over and over again. But this principle is old and the spectacle offered to the eye not a great improvement over the fountains of olden times.

Two types of fountain have chiefly prevailed—the cascade in which a moderate volume of water falls in thin but brilliant sheets over multiplied obstructions—steps, basins, rocks, etc.—always in a framework of architecture with abundant obstructive accessories; and the isolated or central fountain, in which one or many jets, spouted upward, fall into the highest of a series of superposed bowls of marble or bronze and then into a larger one below and so on into a broad basin at the ground level. Although every effort was made to save water and to obtain the maximum effect, still we find that in most European cities, fountains are allowed to play only on certain days of the week, and then only for a few hours. It may be safely said that not since the days of the Italian Renaissance has any really startling improvement been made in the hydraulics of fountains.

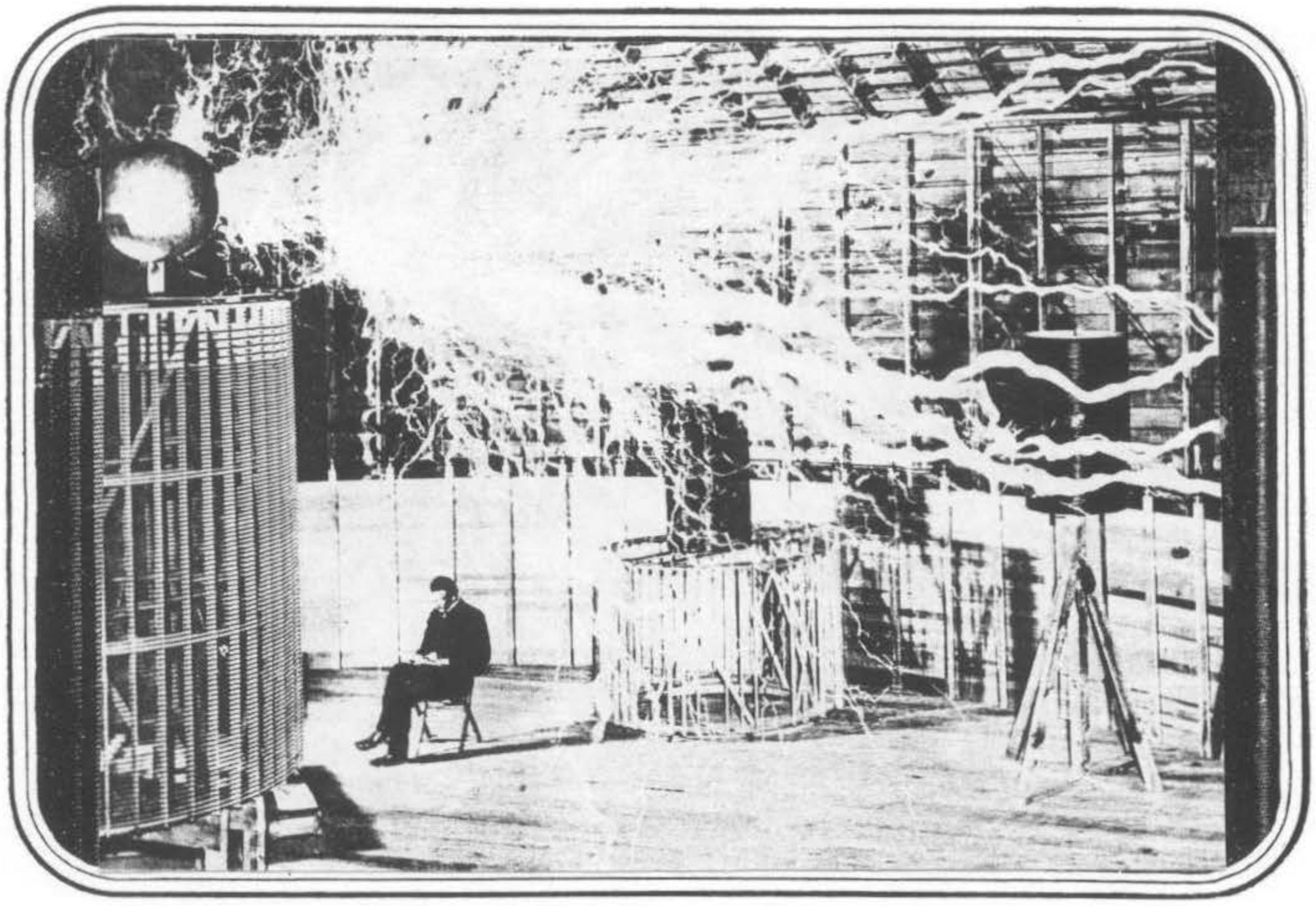
Into this neglected field, Mr. Nikola Tesla, the distinguished engineer, has entered, and as might be expected of him, with very strikng results. He has recently patented a fountain of entirely new principle, and one moreover in which imposing effects are obtained with very simple apparatus and with a very small volume of water. The accompanying illustration pictures the very simplest form of fountain which can be constructed, according to Mr. Tesla's ideas. A shaft runs vertically through the central column of the fountain, carrying at its lower end a propeller, and at its upper end an electric motor, suitably braced. In our illustration we show this propeller shaft contained in a tube, the bottom of which is provided with inlets for the water in the main bowl. As the propeller is made to revolve the water is sucked in by the propeller blades through the inlets, and is urged upward in the direction of the arrows. It fills the upper bowl and then overflows in a miniature waterflow of impressive size.

As the circulation is extremely rapid, the total quantity of water required is comparatively small. About one tenth of that delivered per minute will be generally sufficient. In this fountain then, we find a great mass of water propelled by the use of only such power as is required to lift it from its normal level through a relatively short space to that from which it overflows and descends as a waterfall or cascade. In that sense it is a radical departure from historic fountains.

The apparatus not only makes the breeding of insects impossible, but is in a sense a very efficient trap.



Nikola Tesla's fountain, in which remarkable results are obtained with little water.



Discharge of a Tesla induction-coil of great power

The tension is about twelve million volts. The volume of the current that leaps across the air space is equal to eight thousand 16-c.p. incandescent lamps, and the roar of the discharge can be heard for miles

To-morrow's Wireless

By Waldemar Kaempffert

EDITOR'S NOTE—This article describes the most recent developments of telautomatics, or telemechanics, the art of performing work at a distance from the source of power, which is transmitted by ether-vibrations known as "wireless waves." It takes one to the very limits of the imagination to picture the transformation of every-day life that will follow upon the successful application of Mr. Tesla's new invention, while the achievements of Mr. Hammond and others in this field of science foreshadow novel apparatus and processes of great usefulness and value to engineering and the other practical arts.

TO flash electricity wirelessly through the globe, not in driblets but in millions of horse-power, and to transform this earth from a globular crust, on which men move and live, into a planetary power-house from which Fiji Islanders and Parisians alike may draw what energy they need is a vision which has haunted Nikola Tesla for years. When it comes, that wireless millennium, the cumbrous machinery and the tangle of electric conductors that serve us now will be swept away. In far-off Tibet or near-by Chicago, in northern Hammerfest or southern Melbourne, we shall warm ourselves, cook our food, drive our street-cars, and light our houses with energy generated in stations which have a horse-power twice that of Niagara Falls, and which is transformed into electric currents undulating through the earth with the speed of light. We shall converse with one another with telepathic directness and swiftness; we shall see one another with keen, scientifically constructed eyes, although oceans and continents separate us; we shall travel through the air in marvelously constructed air-craft which will derive their power from the earth; we shall convert night into day with illuminants which will be mere tubes and globes of cold light—gas-filled or vacuum tubes through which currents measured by millions of volts will flash.

Part of the mechanism with which these stupendous results are to be achieved was disclosed in a United States patent granted

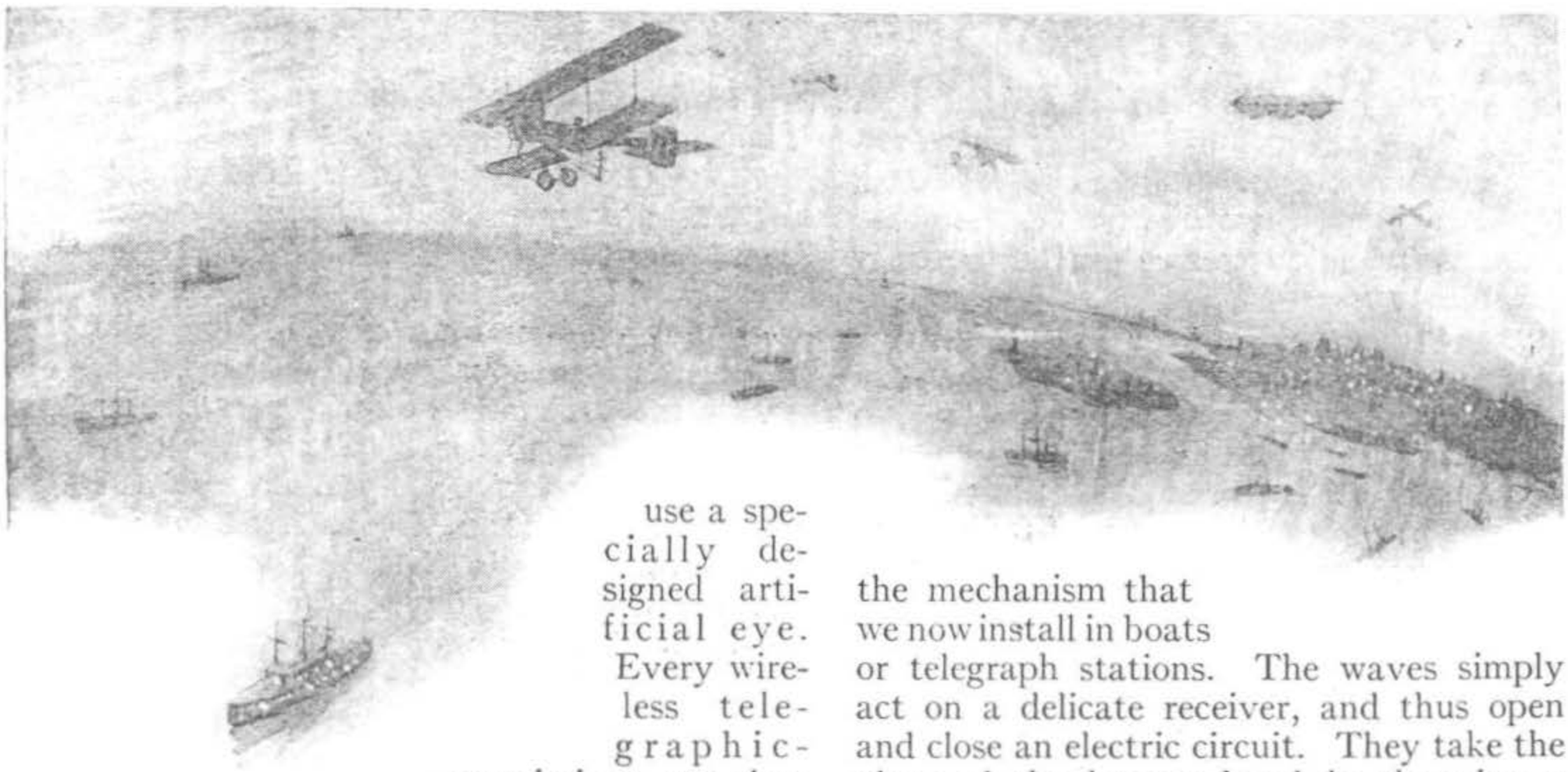


Steel tower, designed by Tesla to contain induction-coils which will transmit electrical energy to the greatest distances on the earth

to Tesla on December 1, 1914. That patent bears the simple title, "Apparatus for Transmitting Electrical Energy." To the government officials who granted it and to the university physicist who troubled to read it, the document must have seemed like many another of its kind. Yet this "apparatus for transmitting electrical energy" is the principal element in a whole system of artifices which, when developed to their fullest possibilities, will make electricity as essential in our lives as the air we breathe.

To understand this transformation of the future, we must begin with wireless telegraphy—not because it bears any similarity to the principles which Tesla seeks to apply but because it is so different.

Throw a pebble into a pool of water. Little waves will ripple out in ever-widening circles and finally die away. An electric spark—a miniature artificial flash of lightning—sends forth similar ever-widening electrical waves at the tremendous velocity of one hundred and eighty-six thousand miles a second. Because our retinas are not constituted to see these waves, we must



use a specially designed artificial eye. Every wireless telegraphic-receiving station contains such an eye to visualize the Morse signals flashed by the electric spark in the transmitting station.

Because electrical waves represent energy, not a few inventors have tried to use them for other purposes than flashing the dots and dashes of the Morse code. Probably the most conspicuous of these men is John Hays Hammond, Junior, whose crewless, wirelessly directed boat and electric "dog" have attracted much attention. Although he is not the first in the field, he has progressed far in what has been called "telautomatics" and "telemechanics." His unmanned boat proceeds in the direction wirelessly willed by the operator on land with a precision that is uncanny, and his "dog" is far more obedient to the electric waves which he sends out than the average domestic bull pup to his master's call. Others who have experimented in this field are Branly, a wireless pioneer, who has succeeded in firing guns, starting and stopping machine-tools, controlling clocks, and lifting heavy weights with the aid of electric waves; Knudsen, who has made some imperfectly successful attempts to transmit pictures by wireless, and Hirth, who is working along the same lines as Hammond.

But all this is scarcely a world-wide distribution of power. Without exception, these inventors are dealing with wireless signals. The waves sent out from their transmitters are not directly utilized to run a motor or light a lamp but to control electrical machinery with which we are all familiar. In crewless submarine boats, in picture-recording apparatus wirelessly operated, we find, in the receiving station, all the mechanism that we now install in boats or telegraph stations. The waves simply act on a delicate receiver, and thus open and close an electric circuit. They take the place of the human hand in throwing a switch—nothing more.

In a large sense, all these men are sending energy without wires through space. But what a wasteful method—wonderful as it is! Of all the energy rippling out from the transmitting spark, not one part in one hundred million parts reaches the particular receiver to be affected. When the key of the transmitter is depressed, as much as fifty horse-power must be projected into space in order that an infinitesimal part of it may be feebly detected as a signal by an instrument three thousand miles away.

Other wastes, too, must be reckoned with by the designer of wireless-telegraph apparatus besides the waste in electric waves. When a powerful spark is to be employed for long-distance signaling, there is a leakage of current which it is impossible to control. Besides, every building, every obstacle on the face of the earth absorb part of the energy sent forth.

If there were only some way of sending this energy into the earth, of directing it from South Africa to Buenos Aires, there to be tapped off and utilized, what a saving there would be! But waves of a different kind would have to be generated—how, is partially told in the patent that has now been granted to Tesla after years of waiting and laboring.

If you would understand, in a general way, the manner of realizing this amazing possibility, you must understand the full meaning of resonance. Begin with the swinging pendulum of your clock. What keeps it going? Nothing but a little push mechanically delivered at the right time. Any freely swinging object can be kept in

motion, even though it weigh tons, if it is given the slightest push by a single finger, but always at the right moment. Indeed, the amount of swing can be increased enormously by successive pushes correctly timed.

Everything in the world has a natural period of vibration. A hundred men can capsize a twenty-thousand-ton battle-ship by running rhythmically from one side of the deck to the other and carefully timing their movements to the frequency of rolling. If the natural period of a fifty-story sky-scraper's vibration were known, a boy with a tack-hammer might shake down the entire structure by persistent tapping at correct intervals. Such is the cumulative effect of many little blows.

This principle of timing small impulses so as to produce large effects is the principle of resonance. When you rub the rim of a wine glass with your finger and make it ring with a clear musical note, you apply it in producing sound-waves. You can also apply it in producing electrical waves, and that is what Tesla has done.

TESLA'S GREAT INVENTION

Sixteen years ago, while conducting some experiments in the high altitude of Colorado, Tesla found that the entire earth is electrically resonant to certain vibrations. Suppose it were possible to construct an apparatus which would set up electrical waves in the earth, with an apparatus which would be the electrical equivalent of the boy's tack-hammer that could throw down the monster sky-scraper; suppose that it were possible to pile electric impulse on electric impulse until the accumulation of them all would represent millions of horse-power in electric oscillations; suppose that you had a way of turning a tiny part of that unthinkable amount of power into a motor to run a street-car, light electric lamps, and perform other useful work; suppose that you could impress the faint modulations of your voice upon the electrically vibrating globe—surely that would be the millennium of electricity; surely that would be the most stupendous achievement in the annals of engineering. Yet that dry, uncommunicative patent granted to Tesla discloses a means of setting up the waves to which the earth is electrically resonant.

Preliminary experiments have been made which convince Tesla that power can be wirelessly transmitted through the earth. They have enabled him, so he assures us, to light electric lamps at short distances without any metallic conductor between them and the source of power. So far cheaper will this system be that, even if it were only one per cent. efficient, it would deserve every encouragement.

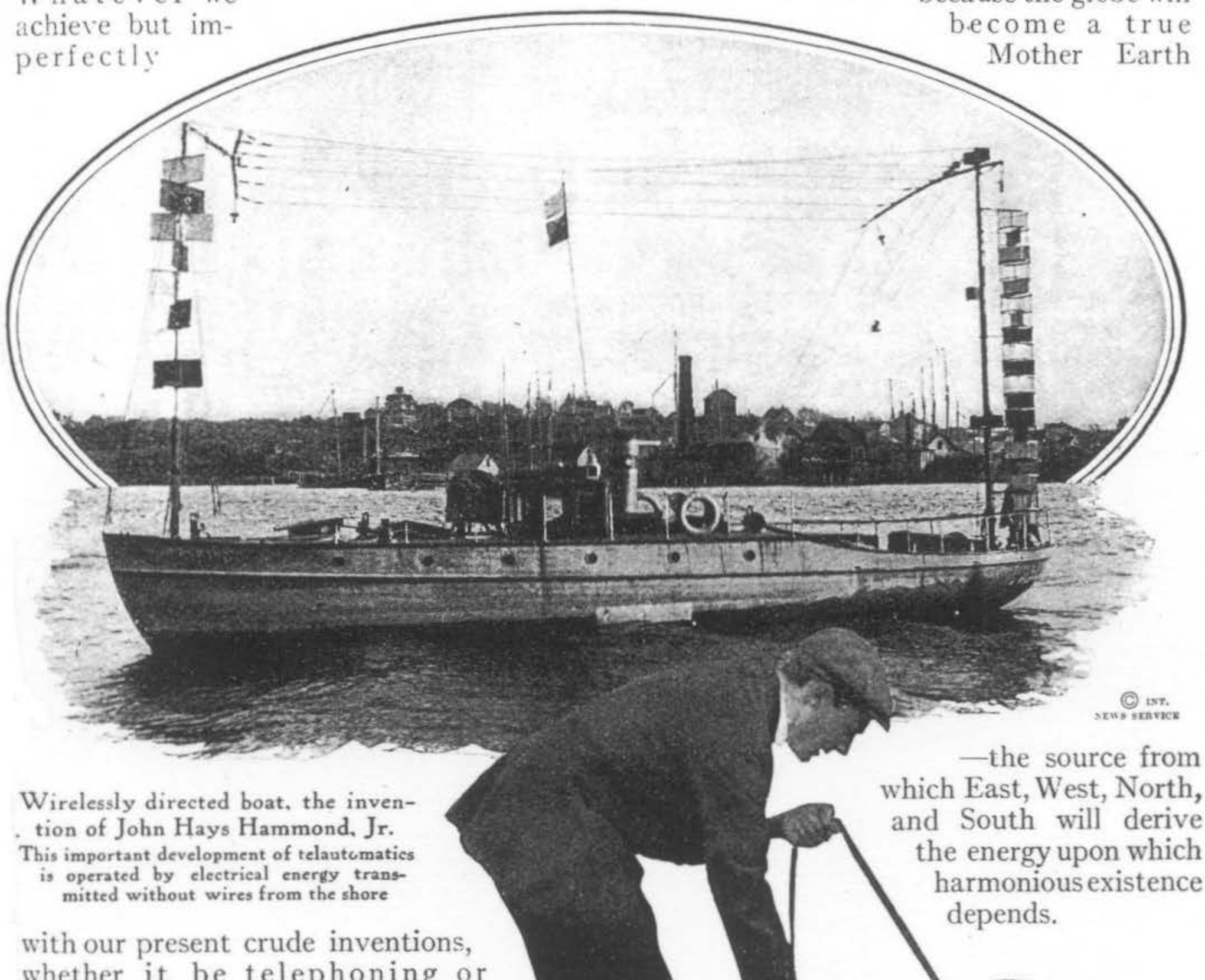
But the designing of an apparatus for emitting waves to which the earth is electrically responsive is only a part of the inventor's task. He must transmit his energy without loss to the point where it is wanted, which he claims is feasible. He must invent some way of individualizing the energy intended for you and for me—some way, for example, of confining a telephone conversation between New York and Peking to the speaker and his listener. In that, too, he has made progress. Strike a tuning-fork, so that it vibrates and emits a musical note, bring that vibrating fork near a piano, and you will find that of all the strings in the piano just one will sing in sympathy. A similar but much more elaborate system, a combination of sympathetic receivers, must be employed. Spencer's clear and suggestive exposition of the human nerve-mechanism gave him "the fundamental idea of employing a number of distinctive elements, cooperatively associated for the purpose of isolating the energy transmitted," Tesla states.

A NEW VISION OF THE FUTURE

It will be a marvelously different globe from that which we know if Tesla's vision is realized. As a wine-glass vibrates with sound when its rim is rubbed, so the earth will vibrate electrically when it is subjected to the action of millions of impulses correctly timed. And those impulses will be imparted by gigantic induction-coils incorporated in immense, towering steel cages, each not unlike the steel skeleton of a huge office-building in course of construction. In every large city, you will see such a steel frame, projecting far up into the sky, overtopping houses and buildings—an electrically throbbing heart whose electric beat can be felt like a pulse in the uttermost confines of the earth. In each home, you will find cheap devices for utilizing what small portion of the power thus transmitted it may need. Wherever you will go, there you will witness a marvel of wireless engineering. In smokeless factory-towns, thousands of

wheels will be turned—all with power taken from a conductor that runs into the ground. Canal-digging exploits will be performed compared with which the excavating of a waterway across the isthmuses of Suez and Panama will seem as slow as the picking of a granite wall with a needle—so limitless are the possibilities of designing machinery driven by earth-power. Farming will become as easy as gardening with the aid of mechanism so cheaply operated that less energy will be consumed in plowing an acre than is now required to operate a vacuum cleaner. Whatever we achieve but imperfectly with our present crude inventions, whether it be telephoning or transmitting pictures electrically, railroading or automobiling, housekeeping or mining, will be accomplished with wireless energy with a completeness and simplicity that will seem positively esthetic.

The greatness of an invention or an engineering project may often be measured by its sociological effect. It brings alien races closer together, which, in turn, means better propagation of knowledge. But what may not be expected when the new branch of electrical engineering that Tesla has created is fully developed, when every one of us will have as much and more power at his command as New York requires to propel trains through its subway? Electrically considered, the earth shrinks to a little ball on which Zulus and Frenchmen, Maoris and Russians, Patagonians and Eskimos are mere neighbors. A complete community of interest will prevail on the earth when his power-plants are installed, Tesla imagines, not because a distant extinction stares us in the face but because the globe will become a true Mother Earth—the source from which East, West, North, and South will derive the energy upon which harmonious existence depends.



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Wirelessly directed boat, the invention of John Hays Hammond, Jr.
This important development of telautomatics is operated by electrical energy transmitted without wires from the shore



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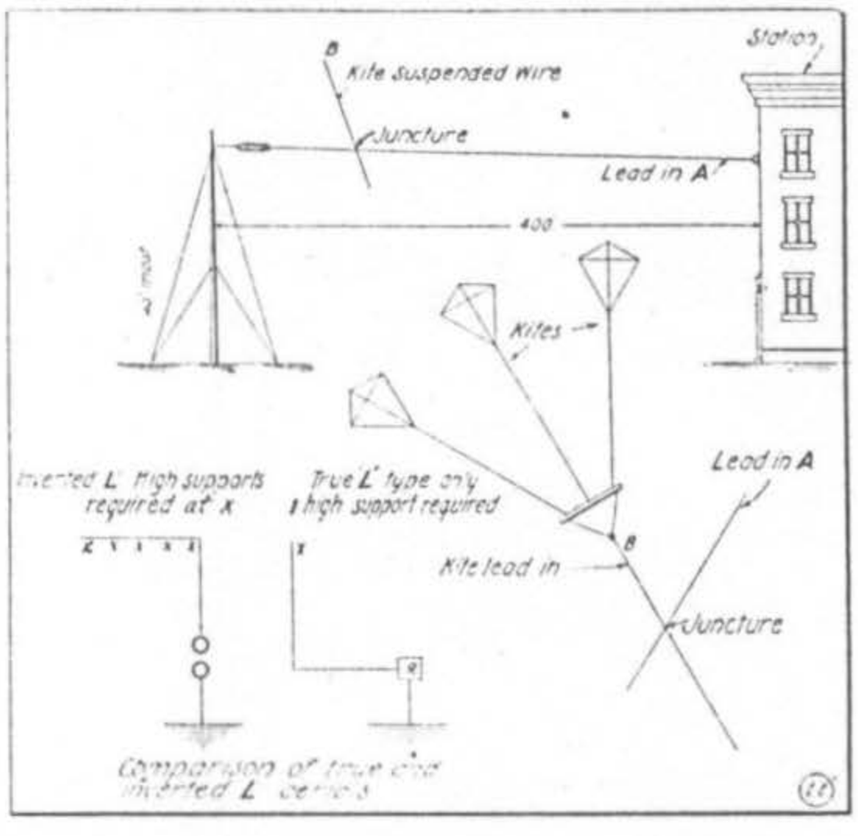
John Hays Hammond, Jr. operating his electric "dog"—a telautomatic device moved by energy wirelessly transmitted from an electric lamp

WIRELESS DEPARTMENT

TESLA HAS WIRELESS TO LIGHT WHOLE OCEAN.

"I have invented and patented an apparatus for transmitting electrical energy without wires which will not only revolutionize the present wireless systems, but will make it possible to cast light from shore that will make the Atlantic steamship lanes safe," declared Nikola Tesla, on his return from Washington recently, where the invention was patented.

He stated that his apparatus would give the wireless unlimited sending power and messages around the world



would be a matter of course. With a plant in the Azores he said he could project light rays over the Atlantic Ocean.

THEORY OF THE TESLA TURBINE.

IN our issue of November 10, 1911, we gave a short account of the Tesla turbine, and showed that even under ideal conditions the hydraulic efficiency of a turbine of this kind cannot possibly exceed 50 per cent. In a paper published last June in the *Revue de Mécanique*, and since reproduced in a number of the French technical journals, Professor E. Mérigeault, of the École Nationale des Mines de St. Etienne, combats this conclusion, maintaining the contrary view, that the efficiency may be very high, and will be the higher the higher the friction! This extraordinary conclusion is arrived at in an article with numerous equations occupying in all over seven pages of the journal in which it appeared. Nevertheless it merely demonstrates once more that the value of the result finally delivered by the mathematical process depends entirely on the legitimacy of the original hypotheses to which it is applied. It is here that Professor Mérigeault has gone wrong, and as his results are being quoted by those who are apparently too impressed with his analysis to venture to question his premises, it may be well if we point out exactly the nature of the fundamental error serving as the basis for his mathematical superstructure. To clarify ideas, we reproduce from ENGINEERING, *loc. cit. supra*, three views illustrating the construction of the Tesla turbine. It consists of a series of twenty-five discs, 18 in. in diameter, mounted side by side on a shaft and having a small clearance between them. Steam is admitted tangentially by the nozzle on the right, and flowing through the interspace between the discs, finally escapes at the centre, carrying the rotor round by its frictional drag on the surface of the discs. The appliance is, it will be seen, a true turbine. The potential energy of the steam is converted into kinetic energy, and this, again, into useful work. The steam enters the moving element at a high speed, and passing through it without change of pressure, is delivered at a reduced velocity at the inner periphery.

Fig. 1.

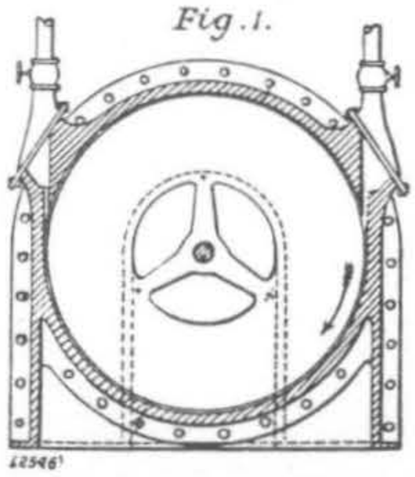


Fig. 2.

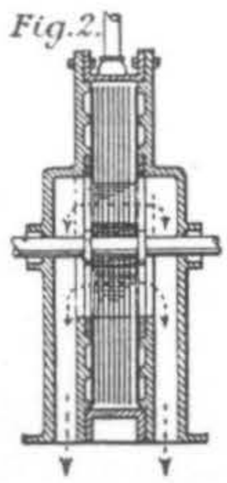
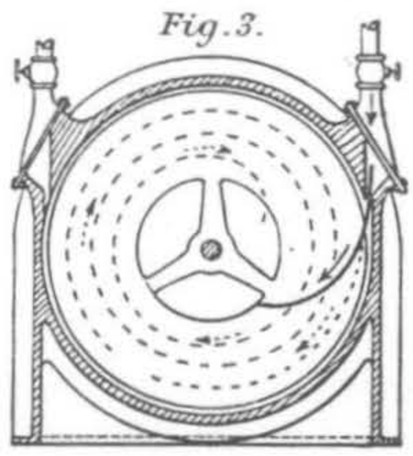


Fig. 3.



The mechanical analogue on which Professor Mérigeault bases his reasoning satisfies none of these conditions. It is not merely not analogous to the Tesla turbine, but is not analogous to any turbine of any kind, but to a pressure engine. He assumes, in fact, that the Tesla turbine can, for the purpose of mathematical treatment, be replaced by the tank A, fixed pipe B, and moving pipe C. The latter is supposed to slide without friction and without leakage in the horizontal part of B, and to be connected in any suitable way to the mechanism to be driven. The pipe B may, for the purpose of argument, be considered frictionless, while C is a rough pipe. As the water flows through C, the frictional drag on its rough walls provides the force needed to drive the mechanism to which it is supposed to be connected. Then by a series of equations Professor Mérigeault demonstrates that the higher the friction between the water and the wall of the moving element the greater is the efficiency of the appliance. This, however, is sufficiently obvious without any mathematics at all. Assume, for example, that the friction is so great that there is no slip between the moving water and the wall. The two will therefore move together exactly as if C were closed with a solid plug, and the efficiency then is unity. The appliance has, however, at the same time become a water-pressure engine of a very common type.

If, without going to the extreme of assuming no slip between the fluid and the walls, we admit that slip exists, we are obviously working in the same condition as if the pipe C were smooth, but closed with a leaky plug, and the efficiency will obviously be smaller the greater the slip or the greater the leakage. In short, Professor Mérigeault's analogue is not a turbine at all, but a water-pressure engine with a leaky plunger, and obviously the efficiency will be higher the smaller the leakage—that is to say, the smaller the slip and the greater the friction. In fact, the fluid passes through his moving element without change of velocity, but merely with change of pressure. The true analogy to the Tesla turbine is represented in Fig 5, where a jet of water issuing from a nozzle D enters a pipe E sliding without friction in the sleeve F. As in Professor Mérigeault's analogue, the pipe E constitutes the moving element, and is to be coupled in any appropriate manner to the machine to be driven. Falling to the bottom of this pipe, the water travels on, its velocity being continually reduced by the friction until it finally escapes at the outer edge as indicated. The frictional drag between the water and the pipe provides the force necessary to overcome the resistance of the machine driven. In the conditions stated the pressure of the fluid is atmospheric at both ends of E, which is, in fact, traversed without change of pressure, the energy required to drive it being obtained at the expense of the kinetic energy of the jet.

The efficiency of this device is easily calculated.

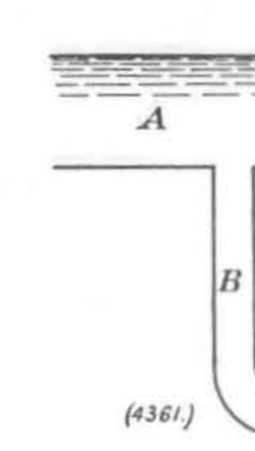
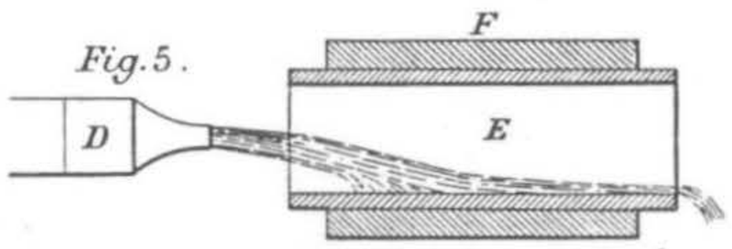


Fig. 4.

Fig. 5.



Let v_0 be the absolute velocity of the fluid as it issues from D, and v_1 its final absolute velocity as delivered at the further end of the pipe E. Then if W be the weight of the water discharged per second, the change of momentum effected per second by the friction of the pipe is $\frac{W}{g}(v_0 - v_1)$. Hence the force F, which has acted on the fluid so as to change its momentum by this amount, is $F = \frac{W}{g}(v_0 - v_1)$, and since action and reaction are equal and opposite, this is also the propelling force which acts on the pipe. Hence, if the latter moves at the speed s, the useful work done per second will be $F\,s = \frac{W}{g}(v_0 - v_1)\,s$.

Now v_1 must always be greater than s, or the water could not escape from the delivery end. Assume that in the limit it may be equal to s, a condition which can be approximated to by using a sufficiently large pipe. Then, in this limiting condition, the useful work done is $\frac{W}{g}(v_0 - s)\,s$, which is easily seen to be a maximum when $s = \frac{v_0}{2}$. Adopting this value, the useful work done becomes $\frac{W\,v_0^2}{4\,g}$, whilst the kinetic energy expended is $\frac{W\,v_0^2}{2\,g}$. Hence, in the stated limiting condition of $v_1 = s$, the maximum possible efficiency is 50 per cent. That the efficiency will be reduced if v_1 is equal to s is easily shown as follows:—Keeping s constant, assume v_0 to be increased to $v_0^1 = v_0 + y$. Then, by reducing the length of the pipe to compensate for the increase of friction with the increased velocity, we can make $v_1^1 = v_1 + y = s + y$, since v_1 was equal to s.

Hence the propelling force acting on E is now

$$F = \frac{W}{g}\left(v_0^1 - v_1^1\right) = \frac{W}{g}\left(v_0 + y - s - y\right)$$
$$= \frac{W}{g}(v_0 - s),$$

or exactly the same as before.

Hence, s being constant, the useful work done is also exactly the same as before, but the energy expended has gone up from

$$\frac{W\,v_0^2}{2g} \text{ to } \frac{W\,(v_0^1)^2}{2g}.$$

The efficiency is therefore reduced by making v_1 greater than s. It cannot be less than s, or the fluid could not escape, and since, when it has a limiting value equal to s the efficiency is only 50 per cent., the hydraulic efficiency of any turbine of the Tesla type must in practice be less than 50 per cent.

As stated, the Tesla turbine is of the impulse type. It hardly seems feasible to construct a reaction turbine operating by frictional drag, but were it possible to do this, the efficiency would be even lower than it is with the impulse form. The frictional drag and the reaction of the jet would, in a reaction machine, act in opposite directions and mutually oppose each other.

The Los Angeles Examiner May 13, 1915

Prof. Pupin Now Claims Wireless His Invention

(By International News Service)

NEW YORK, May 12.—Testifying in the suit of Wm. Marconi against the Atlantic Communication Company, the Telefunken System, Prof. Michael Pupin of Columbia University declared that he had invented the wireless before either Marconi or Nicola Tesla had discovered it and had given it unreservedly to the world.

Prof. Pupin said that in his experiments he had found a wireless wave but had not realized its importance. Tesla, he declared, had given his discoveries to mankind, and this is one of the points on which the Atlantic Company experts expect to deny the clams of Marconi to certain wireless patents.

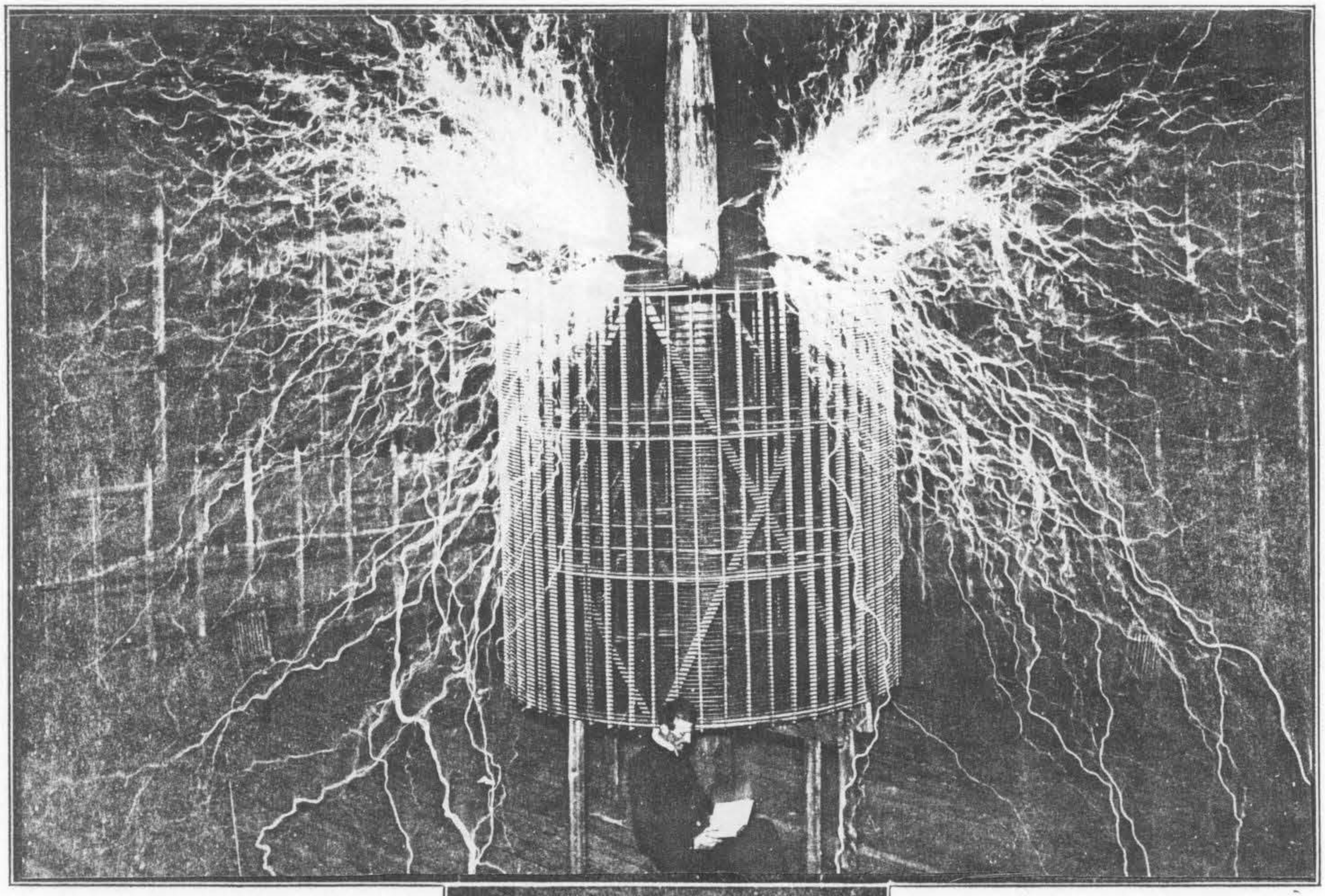
An Interview With Nikola Tesla, Electrical Wizard

By Samuel Cohen

THERE is no doubt about it—your heart does beat faster when you are about to meet a famous electrical scientist, one of the foremost in the world. Before you go you don't think so. It didn't beat a second faster when you entered the outer office, perhaps; but as I stood on the threshhold of the big waiting room where Mr. Nikola Tesla does his day's work my nerves were highly strung. Why? Why hadn't I felt like this when I had talked to other great inventors and scientists? I had been impressed, truly, by these men, but not to any such extent as when I entered the room where the master electrical wizard lives; he who has produced electrical discharges resembling lightning bolts.

After a few minutes, I was ushered into the presence of Mr. Nikola Tesla, who stood in the corner of the room awaiting me. I asked him regarding his latest achievements, but Mr. Tesla only smiled and told me first of some of his experiences some years ago, when he produced some of the largest electrical discharges ever attempted by man. He spoke of some of his wonderful experiments with high frequency currents at high potentials, which he made in 1899. The photograph Fig. 1, herewith shown, is one of the large Tesla apparatus for the production of very high frequency, high tension currents. This apparatus was built in 1899 for his plant at Colorado Springs. At this plant and in the same year he made a number of valuable discoveries. Among these was one on which a patent was recently granted to him. This patent covers the method of production of extra large electrical discharges, such as here shown.

This display of sparks will be the more appreciated when it is stated that the streamers from end to end measure 70 feet and the current leaping into the air is





Top Photo Shows Largest Sparks Ever Produced by Man. Mr. Tesla is Seen Sitting. Seventy Feet Across Spark Streamers. Lower Photo. Mr. Tesla and His Marvelous Wireless Light.

800 amperes, with a maximum potential of 12,000,000 volts. The power supplied to this machine was 300 kilowatts. These voltages are high enough, but Mr. Tesla designed larger apparatus capable of reaching a tension of 100,000,000 volts. A machine of such power must be handled with the utmost care, as the slightest carelessness may kill the experimenter; even if he were at a considerable distance from the machine. Mr. Tesla stated that he had had several narrow escapes while experimenting in 1899, caused by "balls of fire" striking out into the atmosphere.

The metal balls of the coil here shown are 80 cm. in diameter. The current oscillates at a frequency of 75,000 cycles per second. Some of these discharges were two and one-half times as large as common lightning discharges, and they could be heard twelve miles away from the apparatus. Mr. Tesla is observed seated and reading one of Faraday's scientific books.

This remarkable man has spent a fabulous amount of time and money in perfecting his apparatus for the transmission of electrical energy without the aid of any wires. The smaller photo, Fig. 2, shows Mr. Tesla holding in his hands a 14-inch glass bulb, which is highly exhausted and containing a drop of mercury. The electrical power received by this tube is obtained from a loop of wire located behind the screen, which is supplied with an ultra-high frequency current. The tube was not connected in any way to the apparatus. As soon as the current was sent through the wire loop a high potential current was induced in the bulb, which vaporized the drop of mercury, causing it to give forth a blinding light of thousands of candle-power. The photograph was taken by the light of this tube, with an instantaneous or snap-shot exposure. Mr. Tesla has a

(*Continued on page* 45.)

AN INTERVIEW WITH NIKOLA TESLA.

(*Continued from page 39.*)

number of startling new discoveries and inventions in the electrical field, which he does not care to announce at present, and he considers these latter of greater moment than any electrical work he has so far done. He intends in the near future to transmit wirelessly speech and energy around the world from his very powerful electric wave station on Long Island, which is as yet not completed, but which will be finished soon undoubtedly. Mr. Tesla stated, "that the day will soon come when he will show the world that the transmission of power and speech without the aid of any wires is possible."

Mr. Tesla was the first inventor of the induction motor and the system of alternating current power transmission, popularly known as two-phase, three-phase, or poly-phase systems, which created a revolution in electrical engineering and are now universally adopted.

His most important recent work is the discovery of a new mechanical principle which he has embodied in a great variety of machines, such as reversible gas, steam and water turbines, mechanical transformers and transmitters of power, etc. This principle enables the production of prime movers capable of developing ten horsepower, or even more, for each pound of weight in the machine. His present prime mover could be very successfully used in the propulsion of vessels at extremely high speeds, he explained.

The allotted time grew short, and in a few minutes the great inventor bid me adieu and I left the presence of one of the world's most distinguished scientists of whom it has rightly been said: "He lives a hundred years ahead of his time."

Some Personal Recollections

An Autobiographical Sketch

By Nikola Tesla

I AM glad to be accorded this opportunity for two reasons. In the first place I have long since desired to express my great appreciation of the SCIENTIFIC AMERICAN and to acknowledge my indebtedness for the timely and useful information which its columns are pouring out in a steady stream. It is a publication remarkable for the high quality of special articles as well as for the accurate review of technical advances. The knowledge it conveys is always reliable and rendered still more valuable through the scrupulous observance of literary courtesy in the quotation of the sources. The services it has rendered in helping invention and spreading enlightenment are inestimable. The SCIENTIFIC AMERICAN is a periodical ably and conscientiously conducted, measured and dignified in tone to the point of serving as a model, and in these features, as much as in the wealth and excellence of its contributions, it reflects great credit, not only on its staff and publishers, but on the whole country. This is not an idle compliment, but a genuine and well-deserved tribute to which I add my best wishes for continued success on this memorable occasion.

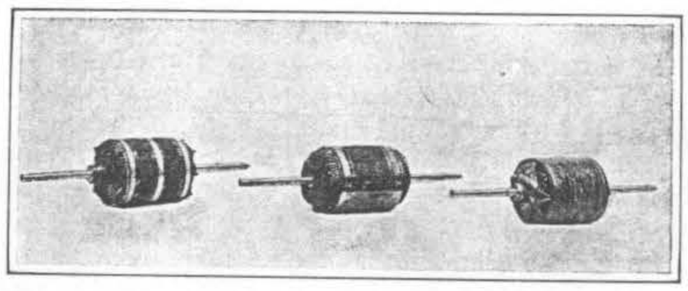
The second reason is one that concerns me personally. Many erroneous statements have appeared in print relative to my discovery of the rotating magnetic field and invention of the induction motor which I was compelled to pass in silence. Great interests have waged a long and bitter contest for my patent rights; commercial animosities and professional jealousies were aroused, and I was made to suffer in more than one way. But despite of all pressure and efforts of ingenious lawyers and experts, the rulings of the courts were in support of my claims for priority in every instance without exception. The battles have been fought and forgotten, the thirty or forty patents granted to me on the alternating system have expired, I have been released of burdensome obligations and am free to speak.

Every experience which I have lived through bearing on that early discovery is vividly present in my memory. I see the faces of the persons, the scenes and objects of my attention, with a sharpness and distinction and in a fullness of light which is astonishing, and is a measure of the intensity and depth of the original impressions. I have always been fortunate in ideas, but no other invention, however great, could be as dear to me as that first one. This will be understood if I dwell briefly on the circumstances surrounding it and some of the phases and incidents of my young life.

From my childhood I had been intended for the clergy. This prospect hung like a dark cloud on my mind. After passing eleven years at a public school and a higher institution, I obtained my certificate of maturity and found myself at the critical point of my career. Should I disobey my father, ignore the fondest wishes of my mother, or should I resign myself to fate? The thought oppressed me, and I looked to the future with dread.

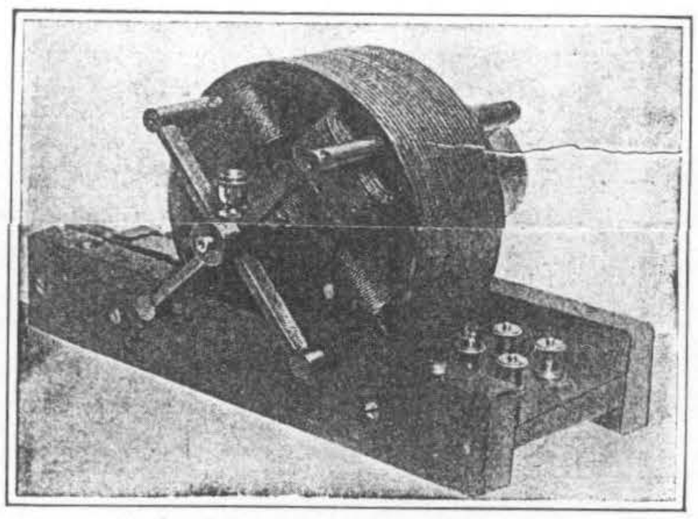
Just at that time a terrible epidemic of cholera broke out in my native land. People knew nothing of the character of the disease and the means for sanitation were of the poorest kind. They burned huge piles of odorous shrubbery to purify the air, but drank freely of the infected water and died in crowds like sheep. Contrary to peremptory orders from my father I rushed home and was stricken down. Nine months in bed with scarcely the ability to move seemed to exhaust all my vitality, and I was given up by the physicians. It was an agonizing experience, not so much because of physical suffering as on account of my intense desire to live. On the occasion of one of the fainting spells my father cheered me by a promise to let me study engineering; but it would have remained unfulfilled had it not been for a marvelous cure brought about by an old lady. There was no force of suggestion or mysterious influence about it. Such means would have had no effect whatever on me, for I was a firm believer in natural laws. The remedy was purely medicinal, heroic if not desperate; but it worked and in one year of mountain climbing and forest life I was fit for the most arduous bodily exertion. My father kept his word, and in 1877 I entered the Joanneum in Gratz, Styria, one of the oldest technical institutions of Europe. I proposed to show results which would repay my parents for their bitter disappointment due to my change of vocation. It was not a passing determination of a light-hearted youth; it was iron resolve. As some young reader of the SCIENTIFIC AMERICAN might draw profit from my example I will explain.

When I was a boy of seven or eight I read a novel entitled "Abafi"—The Son of Aba—a Servian translation from the Hungarian of Josika, a writer of renown. The lessons it teaches are much like those of "Ben-Hur," and in this respect it might be viewed as anticipatory of the work of Wallace. The possibilities of will-power and self-control appealed tremendously to my vivid imagination, and I began to discipline myself. Had I a sweet cake or a juicy apple which I was dying to eat I would give it to another boy and go through the tortures of Tantalus, pained but satisfied. Had I some difficult task before me which was exhausting I would



Three rotors used with the early Tesla induction motor shown below.

attack it again and again until it was done. So I practised day by day from morning till night. At first it called for a vigorous mental effort directed against disposition and desire, but as years went by the conflict lessened and finally my will and wish became identical. They are so to-day, and in this lies the secret of whatever success I have achieved. These experiences are as intimately linked with my discovery of the rotating magnetic field as if they formed an essential part of it:

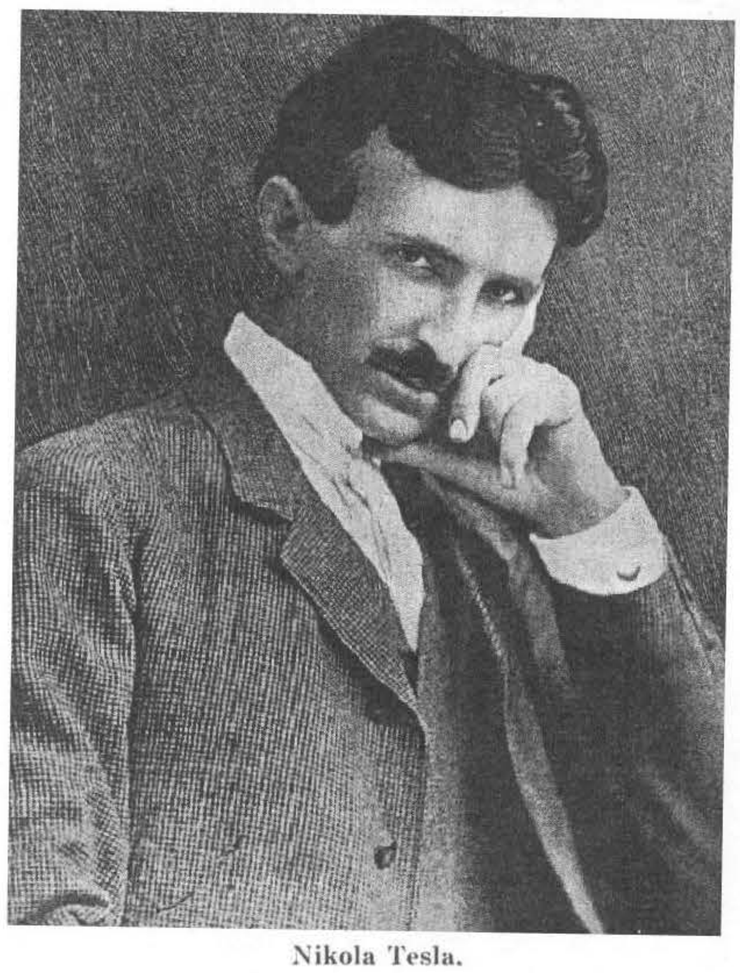


One of the earliest of Tesla's induction motors.

Although it weighed only a little over 20 pounds, it developed ¼ horse-power at a speed of 1,800 revolutions, a performance considered remarkable at the time.

but for them I would never have invented the induction motor.

In the first year of my studies at the Joanneum I rose regularly at three o'clock in the morning and worked till eleven at night; no Sundays or holidays excepted. My success was unusual and excited the interest of the professors. Among these was Dr. Allé, who lectured on differential equations and other branches of higher



Nikola Tesla.

mathematics and whose addresses were unforgetable intellectual treats, and Prof. Poeschl, who held the chair of Physics, theoretical and experimental. These men I always remember with a sense of gratitude. Prof. Poeschl was peculiar; it was said of him that he wore the same coat for twenty years. But what he lacked in personal magnetism he made up in the perfection of his exposition. I never saw him miss a word or gesture, and his demonstrations and experiments always went off with clocklike precision. Some time in the winter of 1878 a new apparatus was installed in the lecture room. It was a dynamo with a laminated permanent magnet and a Gramme armature. Prof. Poeschel had wound some wire around the field to show the principle of self-excitation, and provided a battery for running the machine as a motor. As he was illustrating this latter feature there was lively sparking at the commutator and brushes, and I ventured to remark that these devices might be eliminated. He said that it was quite impossible and likened my proposal to a perpetual motion scheme, which amused my fellow students and embarrassed me greatly. For a time I hesitated, impressed by his authority, but my conviction grew stronger and I decided to work out the solution. At that time my resolve meant more to me than the most solemn vow.

I undertook the task with all the fire and boundless confidence of youth. To my mind it was simply a test of will-power. I knew nothing of the technical difficulties. All my remaining term in Gratz was passed in intense but fruitless effort, and I almost convinced myself that the problem was unsolvable. Indeed, I thought, was it possible to transform the steady pull of gravitation into a whirling force? The answer was an emphatic no. And was this not also true of magnetic attraction? The two propositions appeared very much the same.

In 1880 I went to Prague, Bohemia, carrying out my father's wish to complete my school education at a university. The atmosphere of that old and interesting city was favorable to invention. Hungry artists were plentiful and intelligent company could be found everywhere. Here I made the first distinct step in advance, by detaching the commutators from the machines and placing them on distant arbors. Every day I imagined arrangements on this plan without result, but feeling that I was nearing the solution. In the following year there was a sudden change in my views of life. I realized that my parents were making too great sacrifices for me and resolved to relieve them of the burden. The American telephone wave had reached the European continent, and the system was to be installed in Budapest. It appeared an ideal opportunity, and I took the train for that city. By an irony of fate my first employment was as a draughtsman. I hated drawing; it was for me the very worst of annoyances. Fortunately it was not long before I secured the position I sought, that of chief electrician to the telephone company. My duties brought me in contact with a number of young men in whom I became interested. One of these was Mr. Szigety, who was a remarkable specimen of humanity. A big head with an awful lump on one side and a sallow complexion made him distinctly ugly, but from the neck down his body might have served for a statue of Apollo. His strength was phenomenal. At that time I had exhausted myself through hard work and incessant thinking. He impressed me with the necessity of systematic physical development, and I accepted his offer to train me in athletics. We exercised every day and I gained rapidly in strength. My mind also seemed to grow more vigorous and as my thoughts turned to the subject which absorbed me I was surprised at my confidence of success. On one occasion, ever present in my recollection, we were enjoying ourselves in the Varos-liget or City Park. I was reciting poetry, of which I was passionately fond. At that age I knew entire books by heart and could read them from memory word by word. One of these was Faust. It was late in the afternoon, the sun was setting, and I was reminded of the passage:

"Sie rückt und weicht, der Tag ist überlebt,
Dort eilt sie hin und fördert neues Leben,
Oh, dass kein Flügel mich vom Boden hebt
Jhr nach und immer nach zu streben!

* * * * * * *

Ach, zu des Geistes Flügeln wird so leicht
Kein körperlicher Flügel sich gesellen!"

As I spoke the last words, plunged in thought and marveling at the power of the poet, the idea came like

(*Concluded on page 576.*)

Some Personal Recollections

(*Concluded from page 537.*)

a lightning flash. In an instant I saw it all, and I drew with a stick on the sand the diagrams which were illustrated in my fundamental patents of May, 1888, and which Szigety understood perfectly.

It is extremely difficult for me to put this experience before the reader in its true light and significance for it is so altogether extraordinary. When an idea presents itself it is, as a rule, crude and imperfect. Birth, growth and development are phases normal and natural. It was different with my invention. In the very moment I became conscious of it. I saw it fully developed and perfected. Then again, a theory, however plausible, must usually be confirmed by experiment. Not so the one I had formulated. It was being daily demonstrated every dynamo and motor was absolute proof of its soundness. The effect on me was indescribable. My imaginings were equivalent to realities. I had carried out what I had undertaken and pictured myself achieving wealth and fame. But more than all this was to me the revelation that I was an inventor. This was the one thing I wanted to be. Archimedes was my ideal. I admired the works of artists, but to my mind, they were only shadows and semblances. The inventor, I thought, gives to the world creations which are palpable, which live and work.

The telephone installation was now completed and in the spring of 1882 an offer was made me to go to Paris, which I accepted eagerly. Here I met a number of Americans whom I befriended and to whom I talked of my invention, and one of them, Mr. D. Cunningham, proposed to form a company for exploitation. This might have been done had not my duties called me to Strasburg, Alsace. It was in this city that I constructed my first motor. I had brought some material from Paris, and a disk of iron with bearings was made for me in a mechanical shop close to the railroad station in which I was installing the light and power plant. It was a crude apparatus, but afforded me the supreme satisfaction of seeing, for the first time, rotation affected by alternating currents without commutator. I repeated the experiment with my assistant twice in the summer of 1883. My intercourse with Americans had directed my attention to the practical introduction and I endeavored to secure capital, but was unsuccessful in this attempt and returned to Paris early in 1884. Here, too, I made several ineffectual efforts, and finally resolved to go to America, where I arrived in the summer of 1884. By a previous understanding I entered the Edison Machine Works, where I undertook the design of dynamos and motors. For nine months my regular hours were from 10:30 A. M. till 5 A. M. the next day. All this time I was getting more and more anxious about the invention and was making up my mind to place it before Edison. I still remember an odd incident in this connection. One day in the latter part of 1884, Mr. Bachelor, the manager of the works, took me to Coney Island, where we met Edison in company with his former wife. The moment that I was waiting for was propitious, and I was just about to speak, when a horrible looking tramp took hold of Edison and drew him away, preventing me from carrying out my intention. Early in 1885 people approached me with a proposition to develop an arc light system and to form a company under my name. I signed the contract, and a year and a half later I was free and in a position to devote myself to the practical development of my discovery. I found financial support, and in April, 1887, a company was organized for the purpose, and what has followed since is well known.

A few words should be said in regard to the various claims for anticipation which were made upon the issuance of my patents in 1888, and in numerous suits conducted subsequently. There were three contestants for the honor, Ferraris, Schallenberger and Cabanellas. All three succumbed to grief. The opponents of my patents advanced the Ferraris claim very strongly, but any one who will peruse his little Italian pamphlet, which appeared in the spring of 1888, and compare it with the patent record filed by me seven months before, and with my paper before the American Institute of Electrical Engineers, will have no difficulty in reaching a conclusion. Irrespective of being behind me in time, Prof. Ferraris's publication concerned only my split-phase motor, and in an application for a patent by him priority was awarded to me. He never suggested any of the essential practical features which constitute my system, and in regard to the split-phase motor he was very decided in his opinion that it was of no value. Both Ferraris and Schallenberger discovered the rotation accidentally while working with a Gaullard and Gibbs transformer, and had difficulty in explaining the actions. Neither of them produced a rotating field motor like mine, nor were their theories the same as my own. As to Cabanellas, the only reason for his claim is an abandoned and defective technical document. Some over-zealous friends have interpreted a United States patent granted to Bradley as a contemporary record, but there is no foundation whatever for such a claim. The original application only described a generator with two circuits which were provided for the sole purpose of increasing the output. There was not much novelty in the idea, since a number of such machines existed at that time. To say that these machines were anticipations of my rotary transformer is wholly unjustified. They might have served as one of the elements in my system of transformation, but were nothing more than dynamos with two circuits constructed with other ends in view and in utter ignorance of the new and wonderful phenomena revealed through my discovery.

The New York Times July 23, 1915

TORPEDO BOAT THAT FLIES.

Admiral Fiske Invents a Craft to Attack Fleets in Harbors.

WASHINGTON, July 22.—An aerial torpedo boat for attack on ships in protected harbors is projected in patents just issued to Rear Admiral Bradley A. Fiske of the Navy War College. The plan contemplates equipping a monster aeroplane with a Whitehead torpedo of regulation navy type. Swooping down at a distance of five miles from the object of attack, the air craft would drop its deadly passenger into the water just as it would have been launched from a destroyer. The impact sets the torpedo's machinery in motion and it is off at a speed of more than 40 knots toward the target.

Admiral Fiske believes the flying torpedo boat would make it possible to attack a fleet even within a land-locked harbor. The range of the newest navy torpedoes is 10,000 yards, and even the older types will be effective at 7,000 yards. Carried on a huge aeroplane, the 2,000-pound projectile would be taken over the harbor defenses at an altitude safe from gunfire. Once over the bay, the machine would glide to within 10 or 20 feet of of the water, the torpedo rudders would be set, and it would be dropped to do its work while the aeroplane rose and sped away.

Aeroplanes to carry a ton of dead weight have been perfected by several countries.

It is proposed to drop from aeroplanes a torpedo that can be guided by radio impulses during its fall and sent with absolute certainty to its mark.

The New York Times July 24, 1915

ADMIRAL EXPLAINS AIR TORPEDO BOAT

His Invention Requires Considerable Space for Attacks, Says Bradley A. Fiske.

STUDIED WIRELESS IN 1897

At That Time He Devised Plan to Guide Projectiles Since Developed by Hammond.

Rear Admiral Bradley Allen Fiske of the Navy War College yesterday explained to THE NEW YORK TIMES some of the details of his recently patented invention, which is in effect an aerial torpedo boat—a hydroplane from which a torpedo may be discharged into the water. He also discussed another invention of his, which he said had been since elaborated by John Hays Hammond, Jr., and which enables an operator on shore, on the deck of a ship, or even on an aeroplane to steer by wireless a torpedo after it has been launched.

"I want to correct a misapprehension in the first place," said Admiral Fiske, "about the possibilities of an aerial torpedo boat. It was stated in a dispatch from Washington to today's TIMES that it could be used to attack a fleet in a landlocked harbor. This would, of course, be difficult to achieve without the destruction of the aeroplane which probably would be destroyed before reaching the fleet. What I had in mind was rather an attack on a fleet in the open sea, or one which had taken refuge in a large inland body of water of considerable size, where the aeroplanes could rise over the intervening hills and would have plenty of room and some opportunity to discharge their torpedoes before the gunners of the fleet could attack them.

"With regard to steering torpedoes by wireless—I first became interested in this matter in July, 1897, when I was stationed at Chemulpo, Korea, and read of the work that had been done by various scientists in sending an electric spark across space. Edison and Sims had already worked on the plan of steering a torpedo by wire, and it occurred to me that this could be simplified by doing it without wires.

Had Device to Steer Torpedoes.

"I invented at that time a device for wireless steering of torpedoes, and sent it to the offices of the Western Electric Company at Chicago, with which firm I had already had some relations. They thought it too visionary at the time, however, and let it pass. But after the battle of Manila Bay, when the whole country was enthusiastic, President Barton of the Western Electric Company decided that he would take the matter up and try to have my device patented simply because I was a naval officer. So my application was submitted to the Patent Office on Sept. 7, 1898, and that was the last I heard of it for the time.

"In 1900 I read that Nicola Tesla had just patented a device for the same purpose—the steering of torpedoes by wireless. I then began to wonder what had become of my application, and went to Washington with some officials of the Western Electric Company. We found at the Patent Office that my application had simply been overlooked; and to make amends the authorities decided to give me a broader patent—two patents, in fact—one covering the method and one the apparatus which I had devised. These were issued in October, 1900.

"I had neither the time, nor the money, to follow up this invention, but since then Mr. John Hays Hammond, Jr., has done splendid work based on my original patent. A torpedo is steered by wireless through the means of two solenoids which are affected by impulses transmitted by Hertzian waves of varying periodicity. Thus the touching of one key at the sending station will turn it to the right and another to the left. Mr. Hammond, I understand, can control torpedoes by wireless at a distance as great as twenty-eight miles if need be; he can make any ordinary torpedo into a dirigible by the use of certain slight modifications. I understand that as a matter of experiment he has found that he can even control torpedoes by his voice, pitching it on different notes to affect the steering apparatus in various ways.

Don't Have to Trust to Luck.

"Now the uses of such a torpedo are obvious. You do not have to aim a torpedo and trust to luck that the ship you are shooting at will be in the line on which the torpedo is going when the torpedo gets there. You can even fire a torpedo from the opposite side of your ship to that on which the enemy is situated, directing the torpedo clear around your own ship and then sending it at the enemy. As he turns, you can turn your torpedo. Besides from a ship it could be operated from shore or from an aeroplane. In coast defense, especially of some such body of water as Chesapeake Bay, it would be invaluable, for from small hidden stations on the shore torpedoes could be discharged as well as from destroyers or submarines. It may be said that under such conditions the chances of hitting the mark would be slight. That difficulty will be obviated by the use of 'spotting' aeroplanes, such as are now used in artillery firing—an airman high above the enemy's position signals back to the battery far away in his rear, what changes in elevation should be made in order to drop the shells with better effect. So a spotting aeroplane could signal back to the shore station from which the torpedo is directed; or when a torpedo is once launched from shore it could be steered by an apparatus in the aeroplane.

"The hydroplane torpedo boat after rising to a great height could direct its own torpedo in this way."

Admiral Fiske said he had some reason to believe that torpedoes had been launched from aeroplanes during the present war. "It is the natural tendency of the American people," he continued, "to expect their inventors in time of war to think up devices which will offset the initial superiority of their enemies."

Admiral Fiske has taken out fifty-seven patents already and has three more pending. In 1890 he invented what has come to be known as the Sir Percy Scott method of pointing guns on shipboard, and in 1904 he invented the turret range finder.

Philosophical Magazine August 1915

XIX. *On the most Effective Primary Capacity for Induction-coils and Tesla Coils.* *By* E. Taylor Jones, *D.Sc., Professor of Physics in the University College of North Wales, Bangor*†.

IN the theory put forward in recent papers‡ by the writer the induction-coil is regarded as an oscillation transformer, in which the two circuits are closely coupled, and in which the secondary potential arises from the superposition of two oscillations differing in amplitude,

* J. Chadwick, Phil. Mag. vol. xxiv. p. 594 (1912).

† Communicated by the Author.

‡ Phil. Mag. xxii. p. 706 (1911) [with D. E. Roberts]; xxvii. p. 565 (1914); xxix. p. 1 (1915).

frequency, and damping coefficient. The expression for the secondary potential was worked out in certain cases from the "constants" of the circuits, and found to agree closely with experiment both in wave-form and in maximum potential as deduced from the observed spark-length.

According to this theory the secondary potential at time t after the interruption of the primary current is represented, if the resistances of the circuits are neglected, by the expression

$$V_2=\frac{2\pi L_{21}i_0n_1n_2}{n_2^2-n_1^2}(n_2\sin 2\pi n_1t-n_1\sin 2\pi n_2t), \quad . \quad (1)$$

in which L_{21} is the coefficient of induction of the primary coil on the secondary, i_0 is the primary current interrupted, and n_1, n_2 are the two frequencies of oscillation of the system ($n_2 > n_1$). For given values of L_{21}, i_0, n_1 and n_2, the value of V_2 is stationary at times given by $dV_2/dt=0$, *i. e.*

$$\cos 2\pi n_1t-\cos 2\pi n_2t=0, \quad . \quad . \quad . \quad . \quad (2)$$

or

$$\sin \pi(n_1+n_2)t\,.\,\sin \pi(n_2-n_1)t=0. \quad . \quad . \quad . \quad (3)$$

The stationary values of V_2 therefore occur at the times

$$\left.\begin{array}{ll} & t=0,\ \dfrac{1}{n_1+n_2},\ \dfrac{2}{n_1+n_2},\ \dfrac{3}{n_1+n_2},\ \ldots\ldots \\ \text{and} & \dfrac{1}{n_2-n_1},\ \dfrac{2}{n_2-n_1},\ \dfrac{3}{n_2-n_1},\ \ldots\ldots \end{array}\right\} \quad . \quad (4)$$

At any stationary value we have, by (2),

$$\sin 2\pi n_2t=\pm\sin 2\pi n_1t, \quad . \quad . \quad . \quad . \quad (5)$$

the upper sign giving the numerical minima of V_2, the lower sign the maxima.

Substituting in (1) we find that the numerical maxima lie on the (t, y) curve

$$y=2\pi L_{21}i_0\frac{n_1n_2}{n_2-n_1}\sin 2\pi n_1t, \quad . \quad . \quad . \quad . \quad (6)$$

the minima on the curve

$$y=2\pi L_{21}i_0\frac{n_1n_2}{n_1+n_2}\sin 2\pi n_1t. \quad . \quad . \quad . \quad . \quad (7)$$

In dealing with the greatest sparking potential of an induction-coil we are only concerned with the greatest maximum of V_2 in the first half-period of the slower oscillation. Even though there should be a closer coincidence of maxima of the two waves in some subsequent half-period, the amplitudes are by this time so much reduced by the

damping that the potential seldom, if ever, reaches a value equal to the greatest in the first half-period.

The *principal maximum* of V_2 is the maximum which occurs nearest to the first summit of the curve (6), *i. e.* at the time nearest to $t=1/4n_1$. The first maximum occurs at the time $t=\dfrac{1}{n_1+n_2}$, and this is the principal maximum if the frequency-ratio n_2/n_1 is between 1 and 5. If $n_2=5n_1$ the first maximum is equal to the second, and they occur at times $\dfrac{1}{n_1+n_2}$, $\dfrac{2}{n_1+n_2}$. If n_2/n_1 is between 5 and 9 the second maximum is the principal maximum, occurring at the time $\dfrac{2}{n_1+n_2}$. If $n_2=9n_1$ the second and third maxima are equal, and if n_2/n_1 is between 9 and 13 the third maximum is the principal maximum, and it occurs at $t=\dfrac{3}{n_1+n_2}$; and so on.

Consequently the principal maximum secondary potential is given by the equation

$$V_{2m}=2\pi L_{21}i_0\frac{n_1n_2}{n_2-n_1}.\sin\phi, \quad . \quad . \quad . \quad . \quad (8)$$

where

$\phi=\dfrac{2\pi n_1}{n_1+n_2}$ if $\dfrac{n_2}{n_1}$ is between 1 and 5,

" $\phi=\dfrac{4\pi n_1}{n_1+n_2}$ " " " 5 " 9,

" $\phi=\dfrac{6\pi n_1}{n_1+n_2}$ " " " 9 " 13,

. . . .

If n_2/n_1 has one of the values 3, 7, 11, . . . the maxima of the two oscillations occur simultaneously, the principal maximum occurring at the time $1/4n_1\left(\phi=\dfrac{\pi}{2}\right)$, and being equal to the sum of the amplitudes of the oscillations. These cases may be called the *coincidences*.

If the resistances of the circuits were taken into account the value of the maximum secondary potential would be considerably less than that given by (8), chiefly owing to the damping effect of the resistances*. In certain cases

* The full expression for V_2, with damping factors and phase-angles, was given in the Philosophical Magazine for April 1914, pp. 565, 574. Several examples of the (V_2, t) curve were given in the papers referred to above.

examined by the writer, in which an 18-inch coil was used, the damping was found to be sufficient to reduce the maximum secondary potential by about 25 per cent. It is, however, useful to consider the simpler theory in which the oscillations are regarded as undamped, since it enables us to trace with sufficient accuracy the general nature of the effect of varying one or more of the induction coefficients or capacities of the system. The other effects of the resistances, viz. on the frequencies, initial amplitudes, and phase relations of the oscillations, are generally small, and no serious error is introduced by neglecting them. Thus, while the value of the maximum secondary potential given by (8) is considerably in excess of the value found by experiment, the conditions in which it occurs do not differ greatly from those deduced from the simpler theory. For example, in three cases worked out in a former paper*, in which the damping and phase-angles were taken into account, the values of the angle $2\pi n_1t-\delta_1$ at which the maximum secondary potential occurred were 107°·4, 65°·8, and 74°·3 respectively. The values of ϕ for these cases, calculated as explained above, are 111°·3, 62°·8, and 71°·7.

The calculation of the most effective primary capacity.

One important problem connected with the induction-coil is that of determining the optimum primary capacity for a given coil, *i. e.* the capacity which, connected across the interruptor, allows the greatest secondary potential to be developed, when the induction coefficients of the circuits, the secondary capacity, and the primary current interrupted are all given.

In considering this problem, and other problems of this kind, it is convenient to express the sum of the amplitudes of the two oscillations in the secondary circuit in terms of $u\left(=\dfrac{L_1C_1}{L_2C_2}\right)$ and $k^2\left(=\dfrac{L_{12}L_{21}}{L_1L_2}\right)$. We have then for the principal maximum

$$V_{2m}=2\pi L_{21}i_0\frac{n_1n_2}{n_2-n_1}.\sin\phi$$

$$=\frac{L_{21}i_0}{\sqrt{L_2C_2}}\cdot U\sin\phi, \quad . \quad . \quad . \quad . \quad . \quad (9)$$

where

$$U^2=\frac{1}{1+u-2\sqrt{u(1-k^2)}}\dagger \quad . \quad . \quad . \quad . \quad (10)$$

* Phil. Mag. xxvii. pp. 572–577 (1914).

† Phil. Mag. xxvii. p. 584 (1914).

The angle ϕ can be calculated from the ratio of the frequencies, which is given by the equation

$$\frac{n_2^2}{n_1^2}=\frac{1+u+\sqrt{(1-u)^2+4k^2u}}{1+u-\sqrt{(1-u)^2+4k^2u}}. \quad . \quad . \quad . \quad (11)$$

In the present problem, in which the primary capacity C_1 alone is varied, we have to determine the conditions in which $U \sin \phi$ is a maximum, u varying while k is constant.

The function U has a maximum value of $1/k$ at $u=1-k^2$, and there is a series of values of k for which the maxima of U and $\sin \phi$ occur at the same value of u. If k has one of these values the optimum primary capacity is that which makes u equal to $1-k^2$. The necessary values of k may be calculated from (11) by putting in this equation $u=1-k^2$, and n_2/n_1 successively equal to 3, 7, 11, . . . The first four values of the series were given in a recent paper* by the writer, in which it was shown that this series of adjustments has the further property that in any one of them the system has unit efficiency, *i. e.* the maximum electrostatic energy in the secondary circuit is equal to the initial electrokinetic energy ($\frac{1}{2}L_1 i_0^2$) in the primary circuit, on the assumption of negligible resistances and perfect suddenness of the interruption of the primary current.

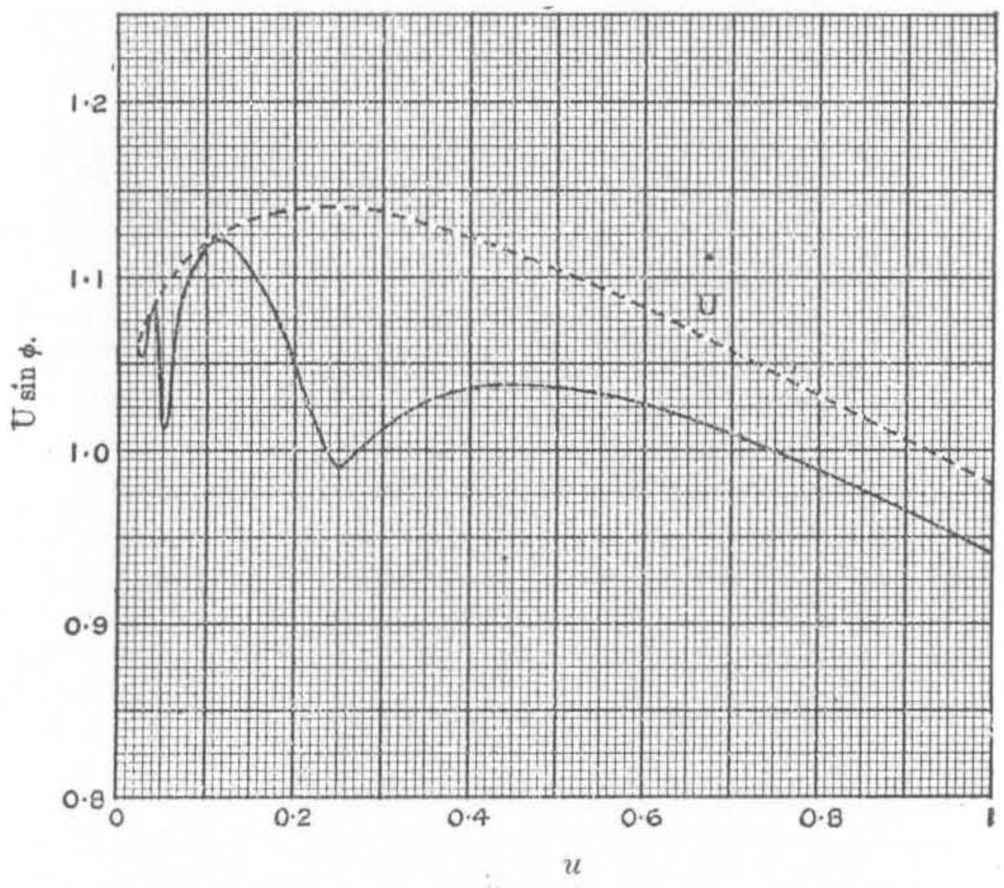
If k has not one of these special values the maximum value of $U \sin \phi$ does not occur when ϕ is exactly $\pi/2$, *i. e.* when the maxima of the two waves occur simultaneously. If, however, one of these coincidences occurs at a value of u not far from $1-k^2$, dU/du is small, and this coincidence determines very approximately a maximum of V_2. The *greatest maximum* secondary potential for any value of k^2 is then determined by that coincidence which comes nearest to the maximum value of U. The matter may be illustrated by the curves shown in figs. 1 and 2, in which the full line represents values of $U \sin \phi$, the broken line those of U, for various values of u. The full-line curve therefore shows how the principal maximum secondary potential changes when the primary capacity alone is varied. The points of contact of the two curves determine the coincidences, corresponding to $\phi=\pi/2$.

Fig. 1 refers to the case in which k^2, the square of the coupling coefficient, is equal to 0·768, the value for an 18-inch coil with which the writer has experimented. In this case the maximum value of U occurs at $u=0{\cdot}232$, and the greatest maximum of $U \sin \phi$ at $u=0{\cdot}11$ ($n_2/n_1=6{\cdot}801$), *i. e.* nearly

* Phil. Mag. xxix. p. 3 (1915).

at the 7/1 coincidence. As u diminishes from this value $U \sin \phi$ goes through a series of maxima and minima, the maxima corresponding approximately to the ratios $n_2/n_1=11, 15, 19, \ldots$ There is also another maximum of $U \sin \phi$ at about $u=0{\cdot}46$ ($n_2/n_1=4{\cdot}237$), and a marked minimum near $u=0{\cdot}25$ ($n_2/n_1=5$).

Fig. 1.



Curve showing the variation of maximum secondary potential of an induction-coil when the primary capacity is varied, k^2 being 0·768. The abscissa represents u ($=L_1C_1/L_2C_2$), the ordinate of the full-line curve $U \sin \phi$, of the broken-line curve U.

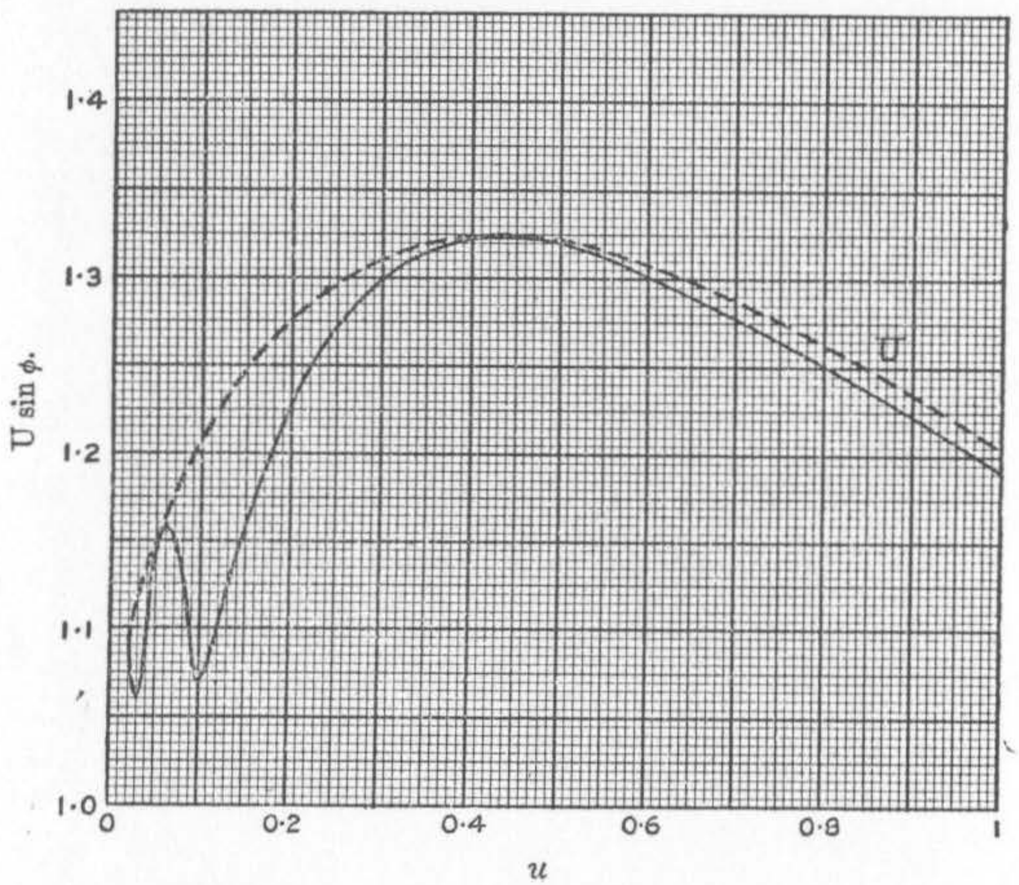
Some of the chief features of the $U \sin \phi$ curve may be traced experimentally by observing the spark-lengths obtained with various primary capacities. Thus, with the 18-inch coil, the greatest spark-length is found to occur near $u=0{\cdot}1$ ($C_1=0{\cdot}06$ mfd.*), there is a minimum spark-length when u is about 0·25 ($C_1=0{\cdot}15$ mfd.), and a second

* These spark-length measurements were described in a former paper (Phil. Mag. April 1914, pp. 582, 583), in which 0·05 mfd. was given as the optimum capacity. At that time I was not able to try 0·06 mfd., but I have since found that this represents more accurately the optimum.

(smaller) maximum near $u=0{\cdot}46$ ($C_1 \doteqdot 0{\cdot}28$ mfd.). The maxima corresponding to the higher ratios 11, 15, . . . are more difficult to demonstrate experimentally owing to the smallness of the primary capacities required and the consequent difficulty of obtaining good interruptions.

Fig. 2 shows the curves for the case $k^2=0{\cdot}571$, the first

Fig. 2.



Curve showing the variation of maximum secondary potential of an induction-coil when the primary capacity is varied, k^2 being 0·571.

of the unit-efficiency values. In this case the greatest maximum of U sin ϕ ($n_2/n_1=3$, $\phi=\pi/2$) agrees with the maximum of U, both occurring at $u=0{\cdot}429$. There is a minimum of U sin ϕ at $u=0{\cdot}1$, and a series of diminishing maxima at smaller values of u, the first of which occurs at $u=0{\cdot}06$, near the 7/1 coincidence. In this case also some of the main features of the U sin ϕ curve can be followed by observing spark-lengths. The coupling coefficient of the 18-inch coil being reduced, by the addition of series inductance to the primary circuit, so that $k^2=0{\cdot}571$, the greatest spark-length is found to be given by the primary capacity

which makes u equal to 0·429, a minimum occurs when $u=0{\cdot}1$, and a secondary maximum when u is about 0·06. At this last value of u, however, the primary capacity is only 0·025 mfd., and good interruptions are rare if the primary current is as great as 1 ampere.

For certain values of k^2 there are two equal greatest maxima of U sin ϕ, one corresponding to a value of u greater than, the other less than, $1-k^2$. This happens, for example, when k^2 is about 0·71, the two equally effective values of n_2/n_1 being in this case 3·767 and 6·595. It also happens when k^2 has the approximate values 0·87 and 0·92 (see Table I.). From the point of view of efficiency these adjustments are not so advantageous as those in which the maxima of U and sin ϕ occur together.

The values of u which give the greatest maxima of U sin ϕ have been calculated in the same way for other values of k^2 ranging from 0·92 to 0·5. The results of these calculations are given in Table I., in which the first column contains the

Table I.

Adjustments for maximum secondary potential.

k^2.	$u\left(=\frac{L_1C_1}{L_2C_2}\right)$.	$\frac{n_2}{n_1}$.	U.	U sin ϕ.	Efficiency. $k^2U^2\sin^2\phi$.
0·92	0·0628	15	1·042	1·042	0·999
,,	0·1297	11	1·040	1·040	0·995
0·90	0·0965	11	1·054	1·054	1·0
0·87	0·075	10·79	1·067	1·067	0·990
,,	0·21	7·183	1·066	1·066	0·989
0·835	0·165	7·0	1·094	1·094	1·0
0·768	0·11	6·801	1·125	1·124	0·970
0·71	0·09	6·595	1·142	1·138	0·919
,,	0·44	3·767	1·174	1·137	0·918
0·70	0·445	3·68	1·183	1·153	0·950
0·64	0·45	3·299	1·246	1·238	0·981
0·60	0·435	3·12	1·290	1·288	0·996
0·571	0·429	3·0	1·323	1·323	1·0
0·5	0·41	2·752	1·408	1·401	0·981

values of k^2, the second column the values of u required for the greatest maxima of U sin ϕ, the third column the corresponding values of the frequency-ratio n_2/n_1. The fourth and fifth columns contain the values of U and U sin ϕ, corresponding to these values of k^2 and u, and the last column gives the product $k^2U^2\sin^2\phi$, which is equal to the efficiency of the arrangement, *i. e.* the ratio of the greatest maximum electrostatic energy in the secondary circuit, $\frac{1}{2}C_2V_{2m}^2.\frac{L_{12}}{L_{21}}$, to the initial energy-supply $\frac{1}{2}L_1i_0^2$.

For any one of these values of k^2 the greatest maximum secondary potential is found (on the assumption of negligible resistances and perfect interruptions) by multiplying the corresponding value of U sin ϕ (fifth column) by the factor $L_{21}i_0/\sqrt{L_2C_2}$. If this factor is constant in all these adjustments the numbers in the fifth column are proportional to the greatest maximum secondary potential. This case is considered in the next section.

The greatest maxima of U sin ϕ are also shown in fig. 3 plotted as a curve, from which may be found the value corresponding to any degree of coupling within the same range.

It will be seen from the Table that for the higher values of k^2 the greatest maxima of U sin ϕ correspond very closely to coincidences ($\phi=\pi/2$), and that this applies with considerable accuracy down to the value 0·71 of k^2. Even at this degree of coupling the 7/1 coincidence value of U sin ϕ (approximately 1·134 at $u=0·078$) only differs by 4 parts in 1100 from the neighbouring maximum value (1·138) given in the Table. The rule, already stated in a former paper*, that the optimum primary capacity is that which determines the coincidence nearest to the maximum value of U, applies therefore with sufficient accuracy for all values of k^2 between 0·92 and 0·71.

The more exact value of the optimum capacity, or rather of the optimum ratio L_1C_1/L_2C_2, for any value of k^2 within these limits may be found by plotting the (k^2, u) curve from the values given in the Table. This curve has two distinct segments, one covering the range $k^2=0·92$ to 0·87, the other running from 0·87 to 0·71. At those values of k^2 for which there are two equal greatest maxima of U sin ϕ, it is better in practice to choose the greater of the two values of u, since the larger capacity involved does not so readily allow troublesome sparking at the interruptor.

Over the lower range of values of k^2, viz. 0·71 to 0·5, the greatest maxima of U sin ϕ do not correspond so closely with the 3/1 coincidences, except near the value $k^2=0·571$. For this range, however, a simpler and more accurate rule may be stated. It will be noticed from Table I. that there is, within these limits, no great variation in the optimum value of u. It should also be noted that, for such values of k^2, U sin ϕ varies very slowly with u near the greatest maximum: these portions of the (u, U sin ϕ) curves are very flat-topped. We shall therefore make only a very slight error if we take u as constant and equal to the mean value

* Phil. Mag. xxvii. p. 584 (1914).

over this range. The values of U sin ϕ obtained in this way do not in fact differ by more than 1 in the third place of decimals from the maximum values given in the Table. Hence the rule may be stated:—If k^2 lies between 0·71 and 0·5 the optimum primary capacity is that which makes $L_1C_1=0·43\ L_2C_2$.

Of the adjustments specified in Table I. three give unit efficiency when the resistances are neglected, and the efficiency is least at $k^2=0·71$, one of the cases of equal greatest maxima. In this case rather over 8 per cent. of the initial energy $\frac{1}{2}L_1i_0^2$ appears as electrostatic energy in the primary condenser and electrokinetic energy in the primary circuit at the moment when the secondary potential reaches its greatest value. It can be shown that of this 8 per cent. about one quarter represents the energy of charge of the condenser, the remainder the energy of the primary current. How this percentage is affected in practice by the resistances may be considered on a future occasion.

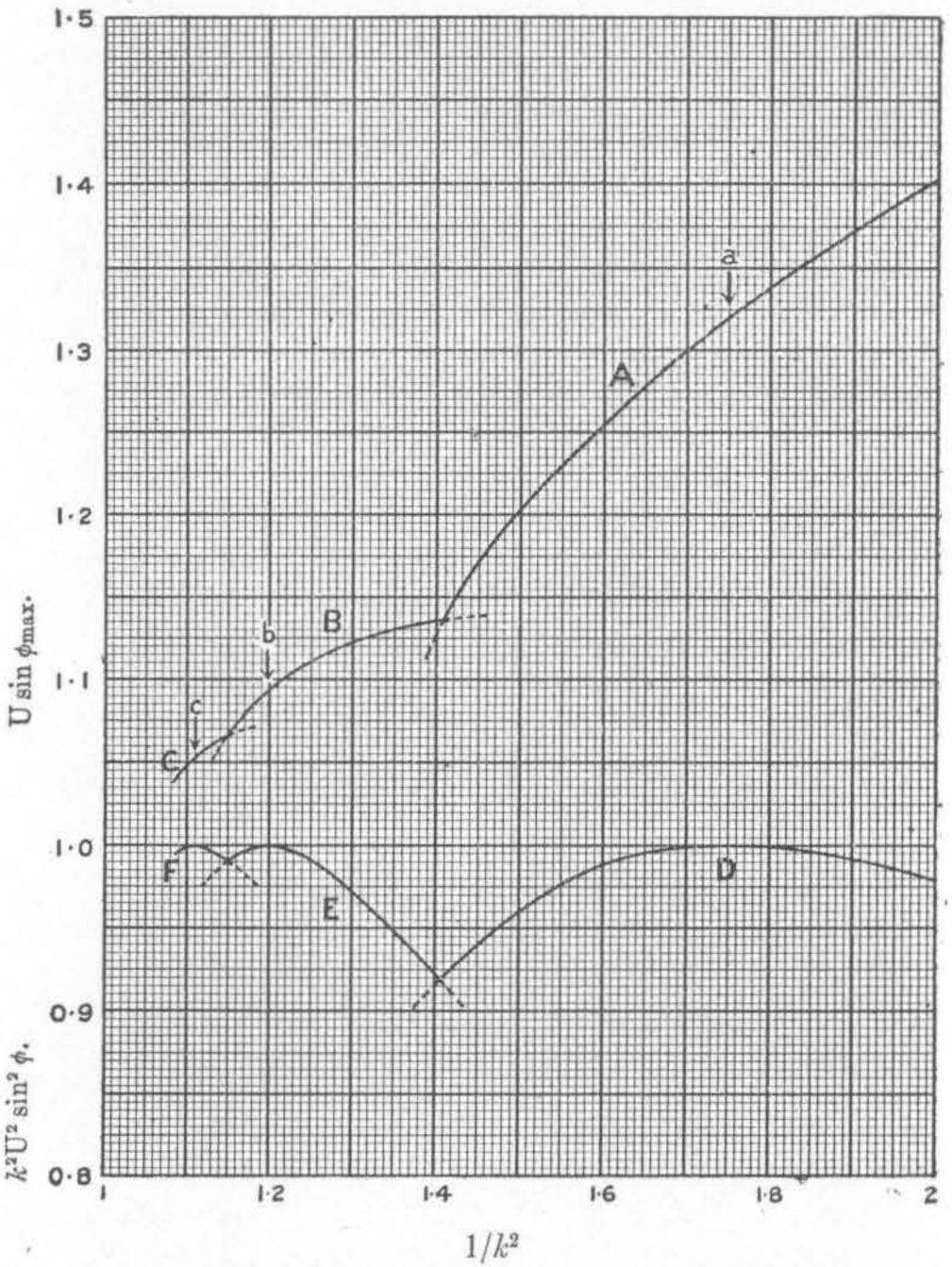
On the use of Series Inductance in the Primary Circuit.

The series of adjustments given in Table I., or a portion of the series, may be effected with an induction-coil in various ways, among which the method of reducing k^2 by the addition of series self-inductance to the primary circuit is the most important if we keep in view the object of obtaining the greatest spark-length with a given current. In this process the quantities L_{21} and L_2C_2 are constant, so that the values of U sin ϕ in the fifth column of the Table are proportional to the maximum secondary potential attainable at the interruption of a given primary current. The optimum value of the ratio L_1C_1/L_2C_2 for any value of k^2 is given in the second column.

In fig. 3 the greatest maxima of U sin ϕ are plotted as a curve the abscissa of which represents $1/k^2$, this quantity being proportional to the total self-inductance of the primary circuit. The full-line curve, the ordinate of which is proportional to the greatest maximum secondary potential at each stage, consists of three portions A, B, C, corresponding to adjustments in which the frequency-ratio n_2/n_1 is near 3, 7, 11 respectively. The points at which these sections of the curve meet represent those cases in which there are two equal greatest maxima of V_2. The broken-line continuations of the curves at these points correspond to secondary maxima in the (u, U sin ϕ) curves. At each of these points of intersection also the efficiency is a minimum for "optimum" adjustments.

At the points marked a, b, c on the curve the frequency-ratio has the exact values 3, 7, 11, and the efficiency in these adjustments is a maximum. The efficiency curve is also shown in fig. 3, by the line DEF, the ordinate of which represents $k^2U^2 \sin^2\phi$.

Fig. 3.



Curve CBA shows the increase of maximum secondary potential accompanying the addition of series self-inductance to the primary circuit of an induction-coil. The abscissa $1/k^2$ is proportional to the total self-inductance of the primary circuit. The ordinate represents the greatest maximum of U sin ϕ (see figs. 1 and 2) at each stage. Curve FED shows the variation of efficiency.

The curve CBA shows how the maximum secondary potential for a given primary current may be increased by adding series inductance to the primary circuit, in the case of an ideal induction-coil with negligible resistances. In practice the curve is, owing to the damping effect of the resistances, considerably below the curve CBA of fig. 3. It may sometimes bend downwards near the point corresponding to a, as I found in some experiments described recently *. I was then under the impression that this is theoretically correct in all cases, but curve A shows that this view is erroneous ; and on repeating the experiments, using for the series inductance only air-core coils of low resistance, I found that the spark-length continued to increase when the self-inductance was increased beyond the value corresponding to the point a †. If suitable coils are used for the series inductance, and if the interruptions are good, the experimental results therefore conform in this respect with the theory as represented by the curve in fig. 3. The fact is that as the primary self-inductance is increased more energy is being put into the system, and, while the efficiency falls off from the point a, the maximum secondary potential continues to increase. This increase becomes, however, less and less rapid as L_1 is increased, and the facts that it is accompanied by loss of efficiency, that under less favourable circumstances it is converted into a diminution, and that a large increase of self-inductance gives rise to troublesome sparking at the interruptor, indicate that it is inadvisable to continue the process beyond the above-mentioned point.

In the *Annalen der Physik*, vol. v. p. 837 (1901), an induction-coil is described by Klingelfuss in which the primary and secondary coils are wound on a nearly closed magnetic circuit. The instrument is said to give a very long spark with a comparatively small number of turns in the secondary coil. The advantage of such an arrangement appears to arise from the low electrical resistance of the secondary coil and the low magnetic reluctance of the core. Since L_{21} is approximately proportional to the number of secondary turns, and L_2 to its square, the factor $L_{21}/\sqrt{L_2}$ of equation (9) is not changed by a reduction of the number of turns, but the lowering of secondary resistance, due both to the reduction of the length of wire and to the use of thicker wire for the secondary coil, diminishes the damping of the oscillations and thus tends to allow a higher secondary potential to be

* Phil. Mag. January 1915, p. 7.

† This effect was not found when coils with iron-wire or sheet-iron cores were used. Probably Maxwell's coil of maximum self-inductance for given length and diameter of wire is the best form for the purpose.

developed. Again, L_{21} and L_2 are inversely proportional to the magnetic reluctance of the core, and the factor $L_{21}/\sqrt{L_2}$ is therefore increased by closing, or nearly closing, the magnetic circuit of the core*.

On the other hand, the conditions do not seem so favourable from the point of view of the other factor of (9), viz. $U \sin\phi$. The values of the inductances and of the coupling coefficient are not stated, but from the description it would seem that the primary and secondary coils are very closely coupled. If this is the case $U \sin\phi$ cannot be large (see Table I. or fig. 3), and according to the present theory the instrument should give a longer spark for a given primary current, or the same spark-length at a smaller current, if suitable self-inductance were connected in series with the primary coil. If, for example, the instrument is so adjusted that $k^2=0{\cdot}835$ and $u=0{\cdot}165$ ($n_2/n_1=7$), and if L_1 and C_1 are increased, the former by 46 per cent. and the latter by 78 per cent., we should then have $k^2=0{\cdot}571$, $u=0{\cdot}429$, and the maximum secondary potential for a given primary current should—apart from any effect due to change in the logarithmic decrements of the oscillations—be increased by over 20 per cent. without loss of efficiency.

The Tesla Coil.

In the case of the Tesla coil the difference of potential v_2 of the terminals of the secondary coil, at time t after the beginning of the discharge in the primary circuit, is (neglecting resistances)

$$V_2=\frac{L_{21}C_1V_0}{\sqrt{(L_1C_1-L_2C_2)^2+4k^2L_1C_1L_2C_2}}(\cos 2\pi n_1t-\cos 2\pi n_2t), \quad . \ . \ . \quad (12)$$

where V_0 is the initial (discharge) potential of the primary condenser. The primary potential difference is given by

$$V_1=V_0\frac{n_1^2n_2^2}{n_2^2-n_1^2}\left[\frac{1-4\pi^2n_2^2L_1C_1}{n_2^2}\cos 2\pi n_1t-\frac{1-4\pi^2n_1^2L_1C_1}{n_1^2}\cos 2\pi n_2t\right]. \quad . \ . \ . \quad (13)$$

These results may be deduced from the solutions given in Fleming's 'Principles of Electric Wave Telegraphy and Telephony,' 2nd ed. p. 264. The full expression for V_2, in

* See du Bois, 'The Magnetic Circuit,' p. 276, 1896.

which the resistances are included, was given by Drude in a well-known paper*, but the above expressions will serve for the present purpose.

Drude considers the problem in which the secondary coil is given, and in which it is required to find what arrangement of the primary circuit gives the highest secondary potential†. After remarking (*l. c.* p. 539) that it is necessary to distinguish between the two cases in which (*a*) the capacity C_1 is varied, and (*b*) the self-inductance L_1 is the variable quantity, he apparently comes to the conclusion (p. 540) that in either case the highest secondary potential is attained when L_1C_1 is equal (or nearly equal) to L_2C_2, *i. e.* when the periods of the primary and secondary circuits, separated from each other, are equal. This is the case of so-called "resonance," and all the subsequent calculations and conclusions given by Drude, including the tables and curves (*l. c.* pp. 546–551), are based on the assumption that this condition ($L_1C_1=L_2C_2$) is satisfied. Drude finally arrives at the result that, if the damping of the oscillations is small, the secondary potential is greatest when the coupling coefficient is 0·6 and the primary capacity is so adjusted as to bring the primary circuit into "resonance" with the secondary, this adjustment of the system giving the frequency-ratio $n_2/n_1=2$.

The reasoning by which Drude arrives at the above result is, I think, not perfectly clear, and the result does not hold in case (*a*). Denoting the ratio L_2C_2/L_1C_1 by m, the expression (12) for V_2 becomes

$$V_2=\frac{L_{21}V_0}{L_1\sqrt{(1-m)^2+4k^2m}}(\cos 2\pi n_1t-\cos 2\pi n_2t). \quad . \quad (14)$$

If the primary capacity C_1 alone is varied (L_1, L_{21}, k^2, V_0, and L_2C_2 being constant), the denominator of this expression has a minimum value when

$$m=1-2k^2. \quad . \ . \ . \ . \ . \ . \ . \quad (15)$$

If also n_1 and n_2 are suitably related, the maxima of the two waves in the secondary coil will occur simultaneously, so that at time $1/2n_1$, $\cos 2\pi n_1t=-1$, $\cos 2\pi n_2t=1$. This happens, for example, when $k^2=0{\cdot}265$‡, $m=1-2k^2=0{\cdot}47$, which adjustment makes the frequency-ratio n_2/n_1 equal to 2.

It follows from (14) that if $k^2=0{\cdot}265$ the most effective primary capacity is that which makes $m=0{\cdot}47$, *i. e.* $L_1C_1=2{\cdot}128\ L_2C_2$. At this degree of coupling, therefore,

* P. Drude, *Ann. d. Physik*, xiii. p. 512 (1904).

† The primary sparking potential V_0 is also supposed to be given.

‡ More exactly $k^2=9/34$.

the optimum primary capacity should be more than twice as great as the value necessary for "resonance." The maximum value of V_2 in this case is numerically, by (14),

$$V_{2m}=2\cdot267\frac{L_{21}V_0}{L_1}*. \quad . \quad . \quad . \quad . \quad . \quad (16)$$

The adjustment recommended by Drude ($k^2=0\cdot36$, $L_1C_1=L_2C_2$) gives for the maximum secondary potential

$$V_{2m}=1\cdot667\frac{L_{21}V_0}{L_1}. \quad . \quad . \quad . \quad . \quad . \quad (17)$$

Even at this degree of coupling, however, a higher secondary potential may be obtained with a larger primary capacity. For example, the adjustment $k^2=0\cdot36$, $L_1C_1=2L_2C_2$, gives the frequency-ratio $n_2/n_1=2\cdot197$, and a maximum secondary potential, at time $t=0\cdot925/2n_1$, the value of which is

$$V_{2m}=1\cdot998\frac{L_{21}V_0}{L_1}. \quad . \quad . \quad . \quad . \quad . \quad (18)$$

From these examples it will be seen that Drude's rule does not in general give even approximately the correct value of the optimum primary capacity. The most effective capacity is generally greater than the "resonance" value.

In some preliminary experiments made by the writer last summer, it was found that in certain cases the best effect was obtained with a primary capacity considerably greater than that required to make the periods of the two circuits equal when separated, but a more extended series of experiments is in progress in the laboratory with the object of determining the best value of m for various values of k^2.

The conditions are very different if the primary capacity is kept constant and L_1 is varied, *e. g.* by means of variable series inductance in the primary circuit. In this case L_{21} is constant, k^2 is inversely proportional to L_1, and the coefficient of $(\cos 2\pi n_1 t-\cos 2\pi n_2 t)$ in (14) has a maximum value of $\frac{V_0}{2}\sqrt{\frac{L_{21}}{L_{12}}\cdot\frac{C_1}{C_2}}$ when $m=1$. If in addition $n_2=2n_1$ ($k^2=0\cdot36$) the numerical maximum of V_2 is given by

$$V_{2m}=V_0\sqrt{\frac{L_{21}}{L_{12}}\cdot\frac{C_1}{C_2}},$$

* The adjustment $k^2=0\cdot265$, $m=1$, gives approximately

$$V_{2m}=1\cdot88\,L_{21}V_0/L_1.$$

consequently

$$\tfrac{1}{2}C_2V_{2m}^2\cdot\frac{L_{12}}{L_{21}}=\tfrac{1}{2}C_1V_0^2,$$

i. e. the maximum electrostatic energy in the secondary coil is equal to the initial energy in the primary condenser.

In Drude's adjustment, therefore, the efficiency is unity if the resistances are negligible. This result may also be seen from the expression (13) for the primary potential, which reduces, if $\cos 2\pi n_1 t=-1$, $\cos 2\pi n_2 t=1$, to

$$V_1=V_0\frac{m-1}{\sqrt{(m-1)^2+4k^2m}},$$

and therefore vanishes when $m=1$. At the moment when the secondary potential reaches its maximum value, therefore, the primary condenser is uncharged, and, since $\frac{dV_1}{dt}=0$, $\frac{dV_2}{dt}=0$, there is no current in either circuit, so that the whole of the energy exists as electrostatic energy in the secondary coil.

In this kind of variation, in which L_1 alone is varied, the initial energy supplied to the system is constant, and the adjustment which gives maximum efficiency must also give the greatest secondary potential. But when the primary capacity is increased the energy supplied to the system becomes greater, and the secondary potential may be increased to a certain extent beyond the point corresponding to maximum efficiency.

Both forms of the problem may present themselves in practice. If, for example, the Tesla coil is given, and ample energy is available for charging the condenser, the capacity of the condenser may always be adjusted to the "optimum" value, whatever be the value of k^2. But if, on the other hand, the energy is limited and it is required to construct a Tesla coil which will make the fullest use of it in generating high secondary potential, the primary capacity is then constant, viz.: the greatest that can be charged to the required sparking potential with the energy available at each discharge of the induction-coil. In this case maximum efficiency and small secondary capacity should be the chief considerations borne in mind in the construction of the Tesla coil.

Bangor, May 1915.

The New York Times August 1, 1915

TESLA VISIONS WIRELESS WONDERS

Declares They May Simplify National Defense and Solve Some of World's Greatest Problems

By Edward Marshall.

THOMAS A. EDISON, in one of these interviews, made a suggestion which will revolutionize the naval history of the United States. Already it has resulted in the appointment of a wonderful civilian consulting board.

Now comes Nikola Tesla with another plan which may revolutionize the nation's system of communication.

I went to him, the world's greatest expert, to learn what wireless had accomplished in this war and what of peculiar benefit to this country it might accomplish in the future. I was astonished by the richness of the field of thought into which the queries led.

He believes that wireless transmission might be adapted, without great expense so that it would decrease the outlay for our defense and, at the same time, immensely increase the efficiency of our means of protection against invasion.

He also holds that by the same network of Government-owned radio stations which would be required for this task we might so decrease the cost of the dissemination of useful information that every citizen of this country, resident no matter how remotely from the populated centres, could be kept continually in touch with the outer world occurrences, weather prospects, and all that helpful information which the Government already gathers, or might gather if it had at hand the means by which to make it public.

Indeed, he thinks that the impetus toward practical and rapid development which this war has given radio communication may result in the solution of some of the greatest problems confronting humanity, and announces as a fact that simple scientific application of the knowledge already at hand well may produce at slight cost electrical power wherever needed and for whatever purpose, from the electric operation of machines in factories to that of the farmers' plows.

"Is it not the fact that even in the present war the wireless telegraph has proved of immense value?" I asked the world-famous electrical inventor.

"This new and revolutionary method of flashing energy through space," he answered, "although, as yet, not much more than inaugurated, has profoundly modified methods of warfare, and, in both the constructive and destructive sense, has proved itself to be a factor of such potency that it must be reckoned with in all future naval and military operations.

"It has made surprises impossible, for instance, and that undoubtedly is one of the reasons why no decisive battle has been fought, so far, upon land or sea. To what degree this has been instrumental in saving human life, human effort and treasure, cannot be estimated."

"What are your ideas, in general, about government control of wireless?" I inquired.

"The mere fact that wonders can be achieved through the application of this subtle agent," Mr. Tesla answered, "makes some kind of governmental supervision of all wireless operations imperative, not only in this country, but throughout the world.

"In my opinion, however, governmental control should not be of a nature to hamper that legitimate commercial development which alone can lead to the ultimate perfection of the science.

"Systematic improvement and application of this new means of communication is, without doubt, imperative to our welfare as a nation.

"I cannot think of any one influence which would do more to aid our progress than a network of wireless stations, checker-boarding, as it were, the entire country. The expense of such a system would be relatively small and inestimable benefits would be derived therefrom.

"A high-power plant would cost less than $250,000 and its range would cover all of the United States.

"I am convinced that one year's service of such an installation would more than pay its first cost and the expense involved in its operation. There is scarcely any interest in all the nation which would not feel the benefit of a rightly planned and managed wireless service.

"Every Winter storms interrupt both telephonic and telegraphic transmission in many sections of the country. The sum total of any one year's damage would more than equal the original cost of the entire network of wireless plants which I suggest, and they would be beyond the reach of such destruction if constructed with reasonable care.

"Every one appreciates the value of our weather report service, but it is not as generally available as it would be if such a wireless network, under Government control, existed.

"Every year forest fires destroy millions upon millions worth of valuable property, which is a permanent loss. The existence of such wireless stations as I contemplate, operating in spite of obstacles, unaffected by rain, snow, wind, flood or fire, would constitute an incalculable gain.

"In this connection one of the most important advantages of the system would be the fact that the receiving apparatus would be so small and inexpensive that it could be placed anywhere and would be within the means of almost every one.

"For if we are to get the full benefits of a system of the sort, wireless telephonic transmission must be practically achieved, and when this is an accomplished fact the only apparatus necessary for the reception of perfectly intelligible, spoken messages, would be very inexpensive telephonic receivers.

"Imagine not only the value, but the comfort, which would accrue to dwellers in the isolated spots of the United States if, at certain hours each day, they knew that they could listen through such instruments to weather reports, crop advice, important general news, and, at stated intervals and times, through the same means could find relaxation.

"Operas, speeches, sermons — anything which can be made perceptible through the ear and is desirable—could be conveyed to them from the most remote centres of civilization and culture at a trifling cost.

"The educational effect of such service, alone, could not fail to bring about within a few years what would amount to an educational and psychological revolution in the rural districts of this country. This takes no account whatever of the immense commercial value and domestic convenience which, as a matter of course, would result from the use of such a system.

"And if a plan of this kind would do much for safety upon land, imagine what it would accomplish toward safety upon the oceans and the great lakes.

"We are now in a position to erect a plant which, when required, would emit peculiar waves, by means of which any navigator, no matter where his ship might be, could determine accurately his distance from and position in relation to any given point.

"The general installation and use of such devices on shore and at sea would enable seamen to exactly steer their courses, without dependence upon compasses or observations of the sun and stars.

"Once such a system is in operation it will be possible by law to closely define such navigation routes as will be certain to reduce to a minimum the dangers of marine adventure.

"There is one momentous desideratum which must especially appeal to every thinking human being at this particular time and would be brought infinitely nearer to consummation by the perfection of such a system.

"All these forces and influences inevitably must make for peace because, by annihilating distance they will bring men into intimate contact one with another. This will mean acquaintance, acquaintance will mean friendship, friendship will preclude misunderstandings and wars.

"Now, when all the rest of the world seems to be thinking in terms of destruction we of this republic should think in terms of construction.

"The first requisite of this is the perfection of our means of national self-preservation. There, again, the wireless would be of immense value if used as it easily might be.

"I have been always opposed to the manufacture of expensive war engines and implements of destruction, but the study of the awful spectacle which unfolds in Europe has taught me much.

"It is my present belief that no effort or expense should be spared which could help toward putting this country in a position not only to resist attack, but to make all the world respect those broad humanitarian principles for which the American people ever have been willing to fight."

This statement from the famous electrician astonished me. "How could this be done without incurring the same danger which has existed in Europe during many years, and which at last has culminated in the present calamity?" I asked.

"We can maintain peace for ourselves and help to maintain it for the world only by adopting methods radically different from those which so signally have failed in Europe," he replied. "Hitherto it has been humanity's plan to preserve peace by creating forces for offense.

"But I am sure it is true that this country can do more toward promoting the world's progress and insuring its own tranquillity by making itself invulnerable than it could by making itself invincible.

"So, I believe that the United States, with every possible speed and energy, should attack the task of insuring its own safety by means more scientific and advanced than those which so lamentably have failed in Europe.

"This, I think, is rendered comparatively easy by our exceptionally favorable geographical position, and we already have means at hand, not merely theoretical but demonstrable and in a measure experimentally proved, which, if consequentially employed, would make it impossible for any hostile force to imperil our tranquillity.

"Even now, wireless control from the shore of crewless and therefore doubly offensive vessels is a possibility, though, with their automatic engines, automatic steering gear, and automatic weapons, they be well out at sea.

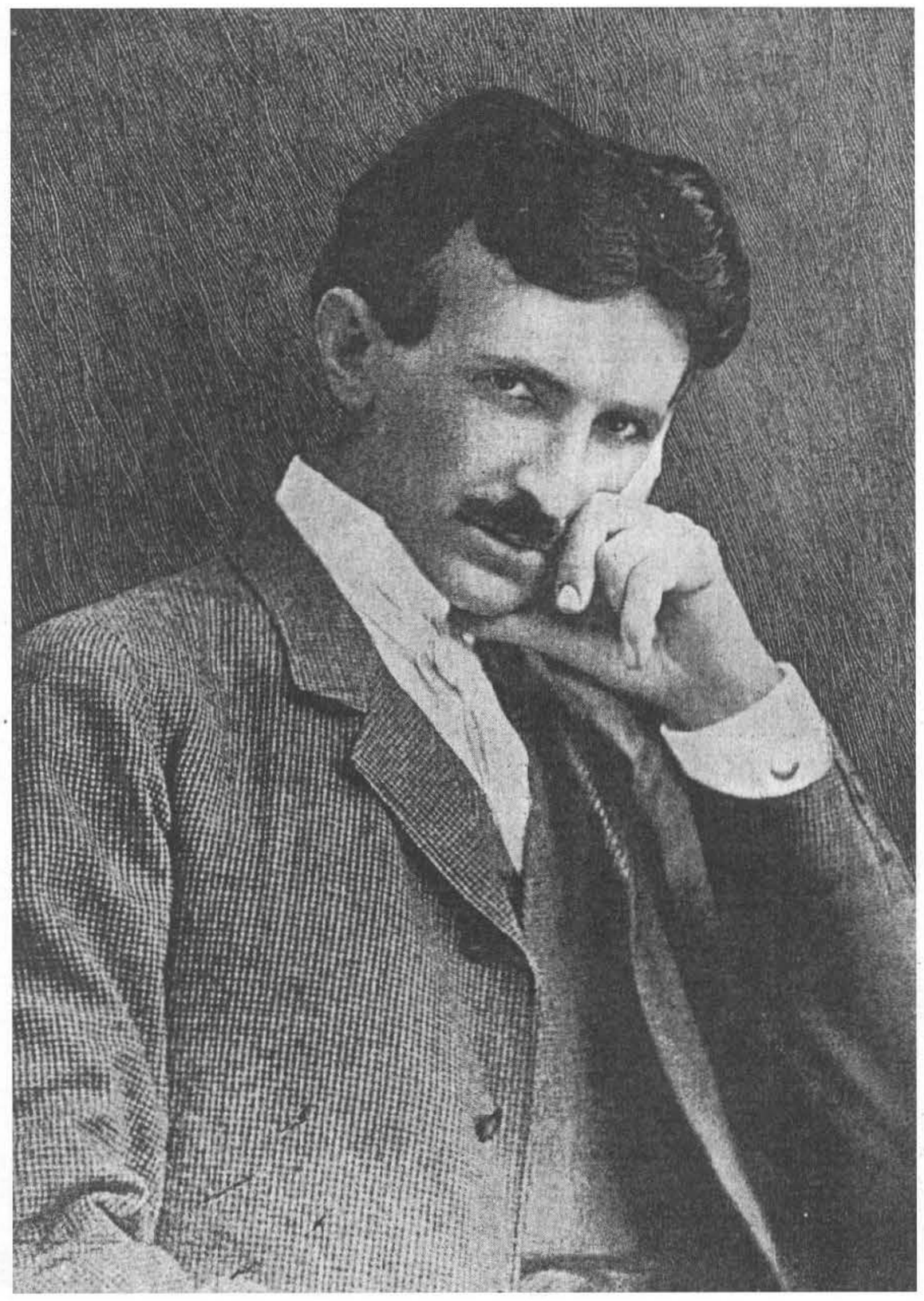
"It is my belief that we should install along both of our ocean coasts, upon proper strategic and elevated points, numerous wireless controlling plants under the command of competent officers, and that to each should be assigned a number of submarine, surface, and aerial craft.

"From the shore stations these vessels, of whatever character, could be perfectly controlled at any distance at which they remained visible through powerful telescopes.

"With proper refinements, all now well known to experts and fully developed, such operations could be put absolutely beyond the reach of interference, except such as might come through injury or destruction of the machinery.

"If we were properly equipped with such devices of defense, it is inconceivable that any battleship or other vessel of an enemy ever could get within the zone of action of these tel-automatic craft without incurring a risk of annihilation amounting almost to certainty.

"And such a danger never would be braved. In fact, the mere knowledge that such craft existed would determine all possible aggressors to give these peaceful shores of ours a wide berth."



Nikola Tesla.

The Invention Board --- Symbol of America's Future

This Is a Prophecy---That the Mobilization of the Inventive Genius of Industrial America Initiates a Period of Zest for Creating New Things That in Vision Is An American "Age of Pericles."

By George Henry Payne

NECESSITY, better known as the mother of invention, has called her sons as an aid to soothe the troubled world-mind.

The inventor works for peace—his greatest war triumphs have been Industry's greatest prizes.

America will find through her call to invention a Nation Spirit, as France found it in Art, and Germany has found it in Kultur. Peace and progress are but little half-sisters of Invention. They come after Invention, never before it.

"HUTCH," said the "Old Man,"—for so he is known through the antonomastic habit of those who work with him—"Hutch," and the light of assurance and prophecy came into Edison's eyes, "we're the biggest nation on earth, and I tell you we ought to have the biggest, damnedest navy in the world. There's no reason why we should be second to any nation. We don't want war, we want peace; but we ought to be in a position to see that no one interferes with our desire for peace."

And then the "Old Man," "Hutch" tells me, having uttered these sentiments, which to tender souls may seem very vigorous, turned abruptly and went back to his twenty-hour-a-day job of enabling America to produce her aniline dyes without regard to where war happens to raise its hoary head—a very practical kind of peace work.

"Hutch," in scientific and naval circles, in the patent office, the technical magazines, the government reports and even to the Queen of England, who once gave him a medal, is Miller Reese Hutchison, chief engineer of that city known as the Edison Manufacturing Plant and Laboratories, and personal representative of Thomas A. Edison. To "Hutch," this unassuming and modest scientist who is even less inclined to talk that Edison himself, the "Old Man" had relegated the task of setting forth his views as to what the new Board of Invention and Development that has been called to the aid of the Navy Department means.

In the first place, it is more or less essential to clear up certain misunderstandings about this innovation of having a board of inventors and civilian experts assist the regular navy authorities.

Such men as Colonel W. C. Church, the editor of "The Army and Navy Journal," have looked at the suggestion of the formation of this board with little favor, for they believe that the navy needs bolstering up in other and more important lines. Others have seen in it an invocation to the war spirit, through turning the attention of some of America's most conspicuous and able citizens to the manufacture and invention of weapons of destruction.

The Board of Invention will interfere with no other line of naval development, and it is the opinion of Edison himself that it will make more for peace and the inventions of peace than any other single movement.

As Mr. Edison's personal representative it was Mr. Hutchison himself who arranged the meeting between Secretary Daniels and the great inventor. A very modest man is this same Mr. Hutchison, refusing to speak at all of his own inventions or his refusal to go on the board himself, and even requesting that the naked facts of "Who's Who," with its long list of honors, be omitted in commenting on what he had to say.

"All over the country," said Mr. Hutchison, "men are working at inventions of all kinds. Necessarily, the main tendency of this feverish activity at present is to produce means of defence for the country. The Board of Invention will have to do simply with that division of the body politic, and will in no way interfere with the work or the plans of the navy.

"As I understand the matter of the proposed Board of Experts:

"First. When ideas are submitted by civilians or personnel of the navy, such communications will be addressed to the Secretary of the Navy.

"Second. The Secretary will turn these suggestions over to the Naval Board, consisting of an officer of rank, having a staff of experts selected from the personnel of the navy. This officer in charge will in turn turn the suggestions over to such of his aids as are competent to separate the chaff from the wheat, and who will make such recommendations to their chief as they see fit and proper.

"Third. If the staff is impressed with an idea as being logical and highly desirable, it will so advise their chief. He will then confer with such of them as are best qualified for expert opinion, or will communicate with such other officers of the navy as may be qualified to advise the naval head of the board.

"Fourth. If it is the consensus of opinion that the idea presented is of value, and if the Naval Board desires advice from any of the experts of the consulting board, such expert as is best qualified to pass on the feasibility of the idea, or give expert opinion regarding it, is communicated with by the head of the Naval Board.

"Fifth. When this expert, or these experts, receive a request from the head of the Naval Board for an opinion as to the feasibility of the idea and suggestions as to whether or not, in their estimation, it would pay to investigate the matter further experimentally, he or they will so advise the head of the board, without entering into any long-winded discussion as to the pros and cons. An affirmative answer from such an expert will then justify the Naval Board in turning the proposed invention over to the laboratory head, who will in turn assign such man or men as he may have on his corps of assistants to work the idea up with a view of embodying it for use by the navy into a concrete, practical apparatus.

"As I see it, the Board of Experts will not be a board at all, but simply a number of highly qualified specialists in their particular lines who, by reason of their intimate knowledge of the various arts and sciences, will give the government the benefit of the experience and knowledge gained by simply passing on and suggesting lines of research concerning new ideas presented. I do not see that this will entail very much work on the part of members of the board of consulting engineers (whichever they may be called). Neither do I think that they should be called upon to spend a great deal of time on each subject. They serve in the same capacity as a specialist in stomach troubles serves when called in for consultation.

"Before an invention is turned down by the Naval Board, unless it is a foolish suggestion and on the face of it a waste of time for further consideration, the Secretary of the Navy should be advised that same is being turned down and the reasons briefly stated. He will then be able to consult with such experts as he may deem qualified to give him a personal opinion. This to act as a check on the Naval Board.

"Similarly, when the Naval Board approves of and desires to further investigate, by experimentation, after the civilian board of experts has favorably passed on the proposition, the matter should be submitted to the Secretary, with the reasons briefly stated as to why the matter is to be investigated further.

"I therefore do not feel that the experts appointed by the engineering societies should be detail men at all. They should be men of very large calibre, with great breadth of vision and keen insight, rather than of accurate detail knowledge of and long actual working experience on given subjects. Naturally, a man who is fitted to go on such a board must have had long detailed experience with a subject regarding which he is supposed to be an expert, but he should have arrived at the point where he is no longer called upon to do detail work, but because of knowledge gained by such long experience and study he is qualified as an adviser.

"The plan is to have the present adequate and very able Naval Board look over every invention and when in doubt simply refer to a member of the consulting board.

Continued on seventh page.



Thomas Edison, the grand old dean of American inventive science talking ideas with Miller Reese Hutchison, his young "right arm

THE NEW NAVAL BOARD IN PROSPECTUS

Continued from first page.

"The need of such an experimental station is absolute. Even the little laboratory at Annapolis, with its sixty thousand dollars' appropriation, has saved the government hundreds of thousands of dollars. Here in Orange, in this very building, we spend four hundred thousand dollars a year on laboratory work. The United States government should have a laboratory and a laboratory appropriation befitting the nation and the people. Not only would that be a great benefit in developing a defence, but think of the industrial possibilities; for, after all, invention is a thing of peace and not of war, and almost every great invention that has been brought about in war times has been afterward developed in such a way as to bring about an industrial revolution.

"Take the case of the Monitor; that was supposed to be a purely warlike invention, born of the necessity to destroy the Merrimac, and yet the connection between the Monitor and Harveyized steel and the great development of the steel industry to-day is direct.

"With the war just a year old, there have already been many evidences of invention contributions to the industrial progress of the country. Mr. Edison is now manufacturing aniline oil from which dyes are made, not in large quantities, but up to a year ago nobody thought of this country doing it at all."

"I understand that you are also making carbolic acid, Mr. Hutchison; how about that?"

"That is a specific case in point," answered Mr. Hutchison, "and shows the value of developing the spirit of invention."

"When the war broke out we were notified from England and Germany that we would not be able to get any more carbolic acid. We had to have it for our records, and Mr. Edison went to work and in seventeen days he was producing carbolic acid, by a secret process, which had never before been manufactured commercially in this country. Inasmuch as the navy had to have carbolic acid also, we agreed to furnish them all they wanted, and have already contracted for four hundred thousand pounds at 56 cents a pound, which is the cost of manufacture. In the market those who had saved up some were asking the government a dollar a pound, but Mr. Edison's belief is that it is a citizen's duty in time of stress to stand by his country to the limit.

"It may be interesting to know that carbolic acid is extracted from coal-tar in England and Germany, but especially in England, where the coal tar in the gas mains is very rich in carbolic. It is also made from benzol. Benzol is absorbed from the coal smoke as a by-product of coke ovens. Now we are working not only to produce carbolic acid but benzol and toluol, which is found in benzol. Benzol is necessary for the production of perfumes and of pharmaceutical compounds, the production of saccharine, and in causing illuminating gas to give the white light, which otherwise would be a smoky yellow. It is also used as a substitute for gasolene for motor purposes, and mixed with toluol it produces a non-carbonizing fuel, and is non-freezing under ordinary circumstances.

"For years the Germans have been manufacturing carbolic acid out of benzol, and have had a law prohibiting the erection of a by-product coke oven without an absorber for taking over the benzol and toluol. That is the reason why Germany is now provided with munitions and fuel for submarines, etc. To-day you cannot buy a pound of coal in Germany. The coal is all used to produce benzol and toluol, and the by-product (coke) is now sold to the people instead of coal. All the German locomotives have been changed to coke burners.

"From this very same process, and these very same chemicals, Germany is able to hold her own in the production of explosives. Picric acid, the well known substance used in the manufacture of high explosives, is made from carbolic acid; and from toluol, tri-nitro toluol, a safer and better explosive, is made.

"When the war put a ban on the exportation of carbolic acid from England, and prevented its exportation from Germany, Mr. Edison was caught, as we used carbolic in quantity, as I have said, in the manufacture of our phonograph records. So Mr. Edison purchased all the benzol he could find in the market, about sixty thousand gallons, and invented a process to make carbolic acid, after finding it impossible to get any information on the subject, and in less than three weeks he had a plant installed and running and turning out two hundred and fifty pounds of pure crystal white carbolic per day. Its capacity has been greatly increased since then.

"But soon he ran out of benzol. Then he erected absorbers at several steel mills where they make coke for the manufacture of steel. To-day he is making all the carbolic we need and all the United States army and navy need.

"In the United States there are sixty-eight hundred by-product coke ovens that throw away annually twenty-nine million six hundred thousand gallons of benzol. The price of benzol per gallon has varied all the way from twelve cents to three dollars during the past thirty-five years, yet with a properly and comprehensively constructed absorption plant it should be absorbed and refined at a total cost of about six cents per gallon, including fixed charges, etc. It costs much more in our hastily constructed temporary absorbers.

"Coming to the aniline dyes, Mr. Edison, as soon as the war broke, was beset by the cloth manufacturers to produce aniline oil from which aniline dyes are made. He has finished a small plant and is about to put into operation a larger one on which he has been working. His point of view is that while he is interested more in other things, and has a great many calls on his time, it is his duty to work on these things, and that I think will be the spirit of the entire Board of Invention."

I went from Edison and Hutchison to Nicola Tesla.

These are days when the opinions of the foreign born citizens are of unusual interest and the foreign born inventor would seem to single himself out for conspicuous attention. Nicola Tesla was born in Austrian Croatia in 1857, and he speaks with the weight of the man who invented the modern principle of the rotary magnetic field, embodied in the transmission of power from Niagara Falls. Strangely, too, he speaks forcibly of the waste that awaits invention's magic wand to rise to useful life.

Thoughtful and hopeful he sat in the lounge room of the Waldorf the other night and talked:

"That America, the greatest inventive country in the world—in fact, when you look back, you can truthfully say the greatest inventive country in the history of the world—should have an official or semi-official inventive board, or board of inventors associated with the government, is one of the finest signs of the times and one of the most hopeful.

"It is not merely a matter of exploitation, although exploitation has many uses other than those that insure immediate and direct benefits. France's exploitation of her art, scientifically done, has other and finer uses than merely bringing to France millions of dollars every year. Switzerland, like a beautiful woman, living purely on the tourist tribute—without agriculture or industries—on the money of those who come from all over the world to see her marvellous beauty, has through the exploitation of her beauty given her people a solidarity.

"While before the world we saw France inharmonious and disjointed, the celerity with which the nation has settled into unanimity and furnished an army that is not second to even the German army in efficiency and oneness, is due to the fact that the race has had long and frequently recurring periods of what might be called psychological homogeneity.

"Invention is in the air in America, and while I am a very strong advocate of peace and abhor the idea of ever seeing this country become a militaristic nation, I am glad to see a movement inaugurated that will bring the civilian inventor in touch with the defence of the nation—that will bring him in touch with the government, which means all of the people, and thereby lead, I believe, to the development of a nation spirit, something in which we have been lacking, and which we need, especially in these times when there is such flux and counter-flux of political, social and economic ideas.

"Bismarck, who had many sides, and who is only thought of as the man of iron and blood, said that it would set the world back a thousand years if this country should ever become a military nation.

"It was not the size of this country that he was thinking of, nor yet of its millions of people, but of its resources. Russia, too, is a big nation, but there is no comparison, for this country, with its great resources and the character of its people, breathes invention. And because it is so big, because it has such wonderful possibilities and its character among nations is so vital to the peace and progress of the world, it must be made impregnable that it may be kept a peace nation and a power among nations for peace. Such a country is naturally a tempting prize, and what we think or believe must not stop us from making her secure.

"It is not inventions for warlike purposes alone that will be fostered by the creation of a board of inventions. The spirit of the government itself changes when it embarks on a move such as the one contemplated. Think of it—there are to-day in America over 250,000 amateur wireless operators, mostly young men, experimenting in their own way with a practical invention that only a short time ago was laughted at as an impossibility. There are a quarter of a million possible inventors. Who knows what may come out of that great self-educating school when they grow up or in the years to come?

"Take the matter of the automobile—it is not only a convenience and a pleasure, but it is a great school for millions of citizens. Men who would never think of learning the rudiments of electricity and mechanics are now, as part of their daily routine, called on to exercise judgment on what would once have been considered highly technical and difficult matters. The probable result will be that the next generation will consider it an essential part of education to be able to drive a motor and understand it, just as essential in fact as the ability to read and write.

"It isn't a war spirit that will dominate invention, but a peace spirit. We do not want war; but if we prepare for a defence we may seem to European nations to be following in their footsteps. But if the soul of our movement is the optimism of America, it will not be warlike. Instead of industry gaining through the by-products of warlike invention, it will gain directly because out of the encouragement of invention will come the cure of America's greatest evil—extravagance and waste.

"It is to do away with this great waste that I am turning my own mind just now. Think of it, the United States Steel Company alone loses fifty million dollars a year through waste; I am working on an invention now that will check this, and I believe that the young and inventive mind of America has no greater problem than the stoppage of waste, no more encouraging problem, for it is one to which the capitalist will give his aid. We all know, and I have had my own personal disappointing experiences, that the revolutionary invention that disturbs large investments has a hard row to hoe. But the stoppage of waste means encouragement from every one, capitalist and public alike."

The Boston Post August 1, 1915

"LET WIRELESS GUARD U. S."—TESLA

World-Famous Expert Outlines Plan of Crewless Warships

The wireless might become the savior of America in war time. This is the opinion of Nikola Tesla, our famous expert. He proposes a gridiron of stations covering both coasts, in an exclusive interview with Edward Marshall, the noted newspaper writer.

War and the Wireless

By Edward Marshall

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He also holds that by the same network of government owned radio stations which would be required for this task, we might so decrease the cost of the dissemination of useful information that every citizen of this country, resident no matter how remotely from the populated centres, could be kept continually in touch with the outer world occurrences, weather prospects and all that helpful information which the government already gathers, or might gather if it had at hand the means by which to make it public.

Indeed, he thinks that the impetus toward practical and rapid development which this war has given radio-communication may result in the solution of some of the greatest problems confronting humanity and announces as a fact that simple scientific application of the knowledge already at hand well may produce at slight cost electrical power wherever needed and for maturer purpose, from the electric operation of machines in factories to that of the farmers' plows.

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"This new and revolutionary method of flashing energy through space," he answered, "although, as yet, not much more than inaugurated, has profoundly modified methods of warfare, and, in both the constructive and destructive sense, has proved itself to be a factor of such potency that it must be reckoned with in all future naval and military operations.

MADE SURPRISE NIL

"It has made surprises impossible, for instance, and that undoubtedly is one of the reasons why no decisive battle has been fought, so far, upon land or sea. To what degree this has been instrumental in saving human life, human effort and treasure, cannot be estimated."

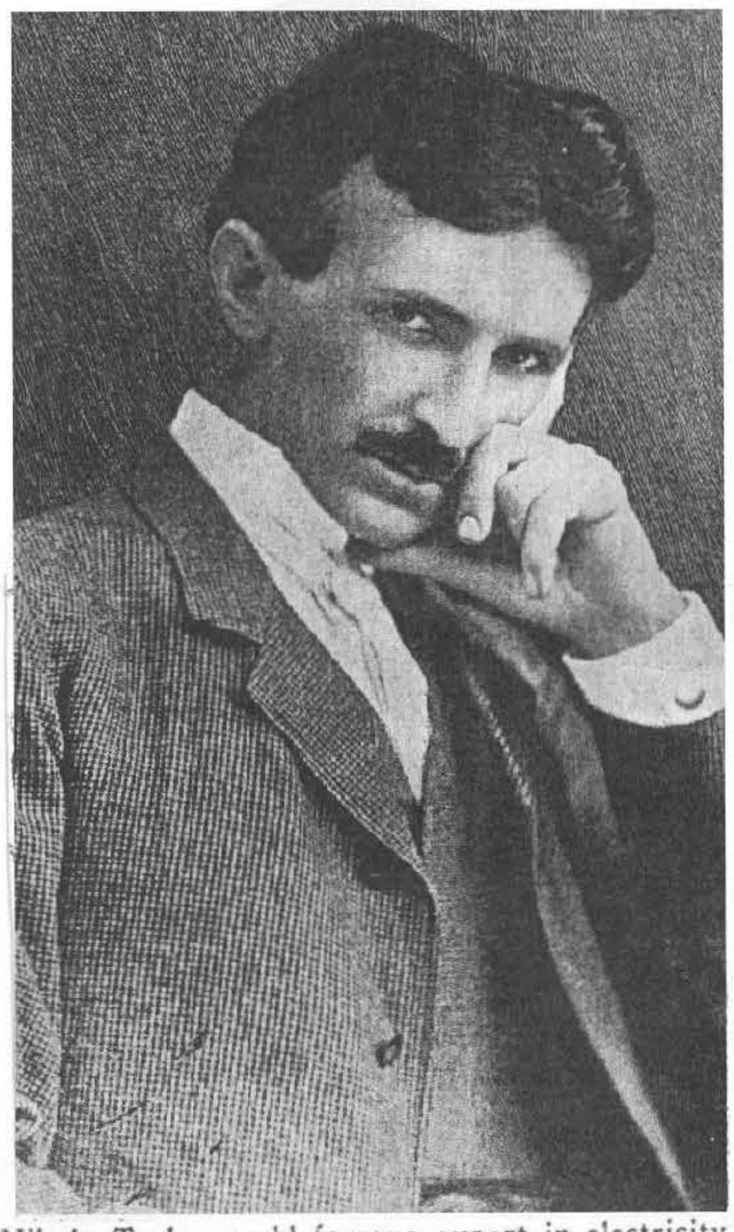
I then asked Mr. Tesla to express himself concerning the importance to the fortunes of Germany in this war of the Sayville and Tuckerton wireless plants.

"The work of these two plants affords a striking example of the practical value of the wireless," he replied.

"Without them Germany would have been completely isolated from all the nations of the world except those which are at war with her.

"Under-sea cables are cut almost as easily as overhead wires can be, but it is impossible for an enemy to interrupt communication by this new method. Its medium is all pervading, invisible, intangible. It cannot be destroyed or even blocked, for it is space itself.

"The German stations which, possibly, thus have preserved from dire disaster the nation which claims them as its own, really are not more than one-tenth as powerful as some other existing plants and are scarcely a twentieth as powerful as others, although much has been printed about their enormous activity.



Nikola Tesla, world-famous expert in electricity, who says wireless may be salvation of the United States.

"In these stations, however, so far as I have seen, every detail has been scientifically developed with great skill, and it is because of this that through them communication between Germany and North America, across the 3000 and more miles of intervening sea, has been possible with the expenditure of energy amounting to no more than 30 kilowatts."

"Has not the lack of secrecy somewhat hampered their usefulness?" I inquired.

SECRECY HAS HAMPERED

"Undoubtedly. As messages now are transmitted by these and other wireless stations, there is no such thing as actual secret operation, for the reason that the system is dependent upon simple tuning of circuits.

"When this primitive method is used, any inquisitive outside expert, by quick manipulation of a wavemeter, can ascertain the rate of vibration and 'cut in' without the knowledge of either of the communicating operators.

"Not only this, but if he so desires and has at hand the necessary apparatus, he even can start, with his own instrument, a vibration similar to that of the other instruments and thus interfere with their successful operation.

"Thus, at present, the only possible guarantee of privacy at the German stations and others is the use of a code, which at best must be very inconvenient and time-consuming at both ends, for it entails codification at the sending and translation at the receiving station, with all the possibilities of error inseparable from both processes.

"This is a clumsy and unnecessary expedient. We in America have a well-developed means whereby we can render wireless messages absolutely safe against outside interruption.

"It completely protects them from meddlers of any sort, making them secret and inviolable. I have called this method the 'art of individualization.'

"I will try to illustrate for the lay reader the difference between the old 'tuning' as now practised and the 'individualizing' method which is coming into use.

"It is a matter of common understanding that an electric circuit, properly conducted, has a certain distinctive period of vibration, as has, for instance, a bell or tuning fork.

"If this particular vibration is emitted from a distant generator of oscillations, the circuit will readily respond and will absorb a relatively very great amount of energy.

"This wonderful phenomenon is called resonance, or resonant response, and its possibilities ages and ages ago captured man's imagination. Remember, for example, the trumpets which are credited with having 'crumbled the walls of Jericho.' If this actually occurred, it was a phenomenon of resonant response.

"The mechanical and electrical phenomena of response are entirely the same in general principle and obey identical laws—so much so that the mechanical engineer needs no special electrical knowledge in order to calculate accurately the effect of electrical resonant response.

"Lord Kelvin, England's great electrical genius, put this tersely when he said that a mechanical engineer can become an electrician within a month.

"Now to make the distinction clear it should be understood that while resonant response in tuned circuits is based upon a single feature or property of the same, in individualized circuits the dependence is not upon one, but upon numerous features or characteristics in combination.

"In this lies the tremendous difference between the old and imperfect method of wireless telegraphy permitting tapping and interference, and the new and absolutely safeguarded mode based on individualization.

"Unfortunately, the practice of this new art requires very skilful execution. This, and this alone, at present stands in the way of its general adoption.

"Here in the United States, where these improved methods and devices have been organized we should at once begin to protect our future by training many experts. The government, especially, should look to this."

"I cannot think of any one influence which would do more to aid our progress than a network of wireless stations, checker-boarding as it were, the entire country. The expense of such a system would be relatively small and inestimable benefits would be derived therefrom.

"A high-power plant would cost less than $250,000 and its range would cover all of the United States.

"I am convinced that one year's service of such an instalment would more than pay its first cost and the expense involved in its operation. There is scarcely any interest in all the nation which would not feel the benefit of a rightly planned and managed wireless service.

"Now, when all the rest of the world seems to be thinking in terms of destruction, we, of this republic, should think in terms of construction.

"It is my present belief that no effort or expense should be spared which could help toward putting this country in a position not only to resist attack, but to make all the world respect those broad humanitarian principles for which the American people ever have been willing to fight."

"Even now wireless control from the shore of crewless, and, therefore, doubly offensive vessels, is a possibility, though, with their automatic engines, automatic steering gear and automatic weapons they be well out at sea.

SHOULD PROTECT COAST

"It is my belief that we should install along both of our ocean coasts, upon proper strategic and elevated points, numerous wireless controlling plants under the command of competent officers and that to each should be assigned a number of submarine, surface and aerial craft.

"From the shore stations these vessels, of whatever character, could be perfectly controlled at any distance at which they remained visible through powerful telescopes. Thus they could be guided to any desired point and there made to perform such work as might be necessary.

"With proper refinements, all now well known to experts and fully developed, such operations could be put absolutely beyond the reach of interference, except such as might come through injury or destruction of the machinery.

"If we were properly equipped with such devices of defence it is inconceivable that any battleship or other vessel of an enemy ever could get within the zone of action of these tel- automatic craft without incurring a risk of annihilation amounting almost to certainty.

(Copyright, 1915, by Edward Marshall.)

Tesla Sees Wireless Big Factor in Defense

Great Expert Proposes Gridiron of Stations

Predicts Cheap System for Communication

Says That It Is Possible to Control Crewless Warships and Fire Guns by Radio-Waves—Declares That Germany Without Wireless Would Have Been Nearly Helpless.

BY EDWARD MARSHALL.

THOMAS A. EDISON, in one of these interviews made a suggestion which will revolutionize the naval history of the United States. Already it has resulted in the appointment of a wonderful civilian consulting board.

Now comes Nikola Tesla with another gem which may revolutionize the nation's system of communication.

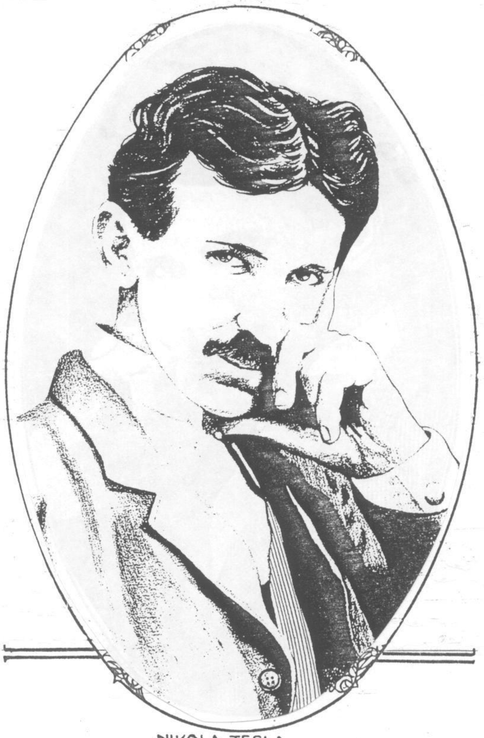
I went to him the world's greatest expert, to learn what wireless had accomplished in this war, and what of peculiar benefit to this country it might accomplish in the future.

He believes that wireless transmission might be adapted, without great expense, so that it would decrease the outlay for our defense, and at the same time immensely increase the efficiency of our means of protection against invasion.

"Is it not the fact that even in the present war the wireless telegraph has proved of immense value?" I asked the world-famous electrical inventor.

"This new and revolutionary method of flashing energy through space," he answered, "although as yet not much more than inaugurated, has profoundly modified methods of warfare and, in both the constructive and destructive sense, has proved itself to be a factor of such potency that it must be reckoned with in all future naval and military operations.

"It has made surprises impossible, for instance, and that undoubtedly is one of the reasons why no decisive battle has been fought so far upon land or sea. To what degree this has been instrumental in saving human life, human effort and treasure, cannot be estimated."



NIKOLA TESLA

In War Wireless Is Indispensible.

I then asked Mr. Tesla to express himself concerning the importance to the fortunes of Germany in this war of the Sayville and Tuckerton wireless plants.

"The work of these two plants affords a striking example of the practical value of the wireless, he replied.

"Without them Germany would have been completely isolated from all the nations of the world except those which are at war with her.

"Undersea cables are cut almost as easily as overhead wires can be, but it is impossible for an enemy to interrupt communication by this new method. Its medium is all pervading, invisible, intangible. It cannot be destroyed or even blocked, for it is space itself.

"The German stations which, possibly, thus have preserved from dire disaster the nation which claims them as its own, really are not more than one-tenth as powerful as some other existing plants and are scarcely a twentieth as powerful as others, although much has been printed about their enormous activity.

"In these stations, however, so far as I have seen, every detail has been scientifically developed with great skill, and it is because of this that through them communication between Germany and North America, across the 3,000 and more miles of intervening sea, has been possible with the expenditure of energy amounting to no more than 30 kilowatts."

"Has not the lack of secrecy somewhat hampered their usefulness?" I inquired.

"Undoubtedly. As messages now are transmitted by these and other wireless stations, there is no such thing as actual secret operation, for the reason that the system is dependent upon simple tuning of circuits.

"When this primitive method is used, any inquisitive outside expert, by quick manipulation of a wave meter, can ascertain the rate of vibration and 'cut in' without the knowledge of either of the communicating operators.

"Not only this, but if he so desires and has at hand the necessary apparatus, he can even start, with his own instrument, a vibration similar to that of the other instruments and thus interfere with their successful operation.

"Thus, at present, the only possible guarantee of privacy at the German stations and others, is the use of a code, which at best must be very inconvenient and time consuming at both ends, for it entails codification at the sending and translation at the receiving station, with all the possibilities of error inseparable from both processes.

U. S. Has Solved Problem of Secrecy.

"This is a clumsy and unnecessary expedient. We in America have a well-developed means whereby we can render wireless messages absolutely safe against outside interruption.

"What are your ideas, in general, about Government control of wireless?" I inquired.

"The mere fact that wonders can be achieved through the application of this subtle agent," Mr. Tesla answered, "makes some kind of governmental supervision of all wireless operations imperative, not only in this country, but throughout the world.

"In my opinion, however, governmental control should not be of a nature to hamper that legitimate commercial development which, alone, can lead to the ultimate perfection of the science.

"I cannot think of any one influence which would do more to aid our progress than a network of wireless stations, checker boarding, as it were, the entire country. The expense of such a system would be relatively small and inestimable benefits would be derived therefrom.

"A high-power plant would cost less than $250,000 and its range would cover all of the United States.

"I am convinced that one year's service of such an instalment would more than pay its first cost and the expense involved in its operation. There is scarcely any interest in all the nation which would not feel the benefit of a rightly planned and managed wireless service.

"Every winter storms interrupt both telephonic and telegraphic transmission in many sections of the country. The sum total of any one year's damage would more than equal the original cost of the entire network of wireless plants which I suggest, and they would be beyond the reach of such destruction if constructed with reasonable care.

"Everyone appreciates the value of our weather report service, but it is not as generally available as it would be if such a wireless network, under government control, existed.

"Every year forest fires destroy millions upon millions worth of valuable property, which is a permanent loss. The existence of such wireless stations as I contemplate, operating in spite of obstacles, unaffected by rain, snow, wind, flood, fire, would constitute an incalculable gain.

"In this connection one of the most important advantages of the system would be the fact that the receiving apparatus would be so small and inexpensive that it could be placed anywhere and would be within the means of almost everyone.

"For if we are to get the full benefits of a system of the sort, wireless telephonic transmission must be practically achieved, and when this is an accomplished fact the only apparatus necessary for the reception of perfectly intelligible, spoken messages, would be very inexpensive telephonic receivers.

"Imagine not only the value, but the comfort, which would accrue—to dwellers in the isolated spots of the United States, if, at certain hours each day, they knew that they could listen through such instruments to weather reports, crop advice important general news, and, at stated intervals and times, through the same means could find relaxation.

"Operas, speeches, sermons — anything which can be made perceptible through the ear and is desirable, could be conveyed to them from the most remote centers of civilization and culture at a trifling cost.

"The general installation and use of such devices on shore and at sea would enable seamen to exactly steer their courses, without dependence upon compasses or observations of the sun and stars.

Would Minimize Danger at Sea.

"Once such a system is in operation it will be possible by law to closely define such navigation routes as will be certain to reduce to a minimum the dangers of marine adventure.

"I have been always opposed to the manufacture or expensive war engines and implements of destruction, but the study of the awful spectacle which unfolds in Europe has taught me much.

"It is my present belief that no effort or expense should be spared which could help toward putting this country in a position not only to resist attack, but to make all the world respect those broad humanitarian principles for which the American people ever have been willing to fight."

"We can maintain peace for ourselves and help to maintain it for the world only by adopting methods radically different from those which so signally have failed in Europe," he replied. "Hitherto it has been humanity's plan to preserve peace by creating forces for offense.

"Had there been the slightest possibility of the success of this old method, Europe never would have known another war. Therefore, it is plain that this is the time and I am sure that we are the people, to cut loose from that traditional illusion.

"Other forces and implements different from those of war must be found for settlement of international disputes and he who finds these instrumentalities must first render himself invulnerable before he can force others to accept his suggestions.

"The task undoubtedly is ours.

"The underlying idea of war is fundamentally wrong, although it has been sanctioned by the theory of the survival of the fittest and, in earlier civilizations, may have been one of the necessities of advance.

Wireless Control of Vessels Possible.

"But I am sure it is true that this country can do more toward promoting the world's progress and insuring its own tranquility by making itself invulnerable than it could by making itself invincible.

"So I believe that the United States, with every possible speed and energy, should attack the task of insuring its own safety by means more scientific and advanced than those which so lamentably have failed in Europe.

"This, I think, is rendered comparatively easy by our exceptionally favorable geographical position, and we already have means at hand, not merely theoretical but demonstrative, and in a measure experimentally proved, which, if consequently employed, would make it impossible for any hostile force to imperil our tranquillity.

"Even now wireless control from the shore of crewless, and, therefore, doubly offensive vessels, is a possibility, though with their automatic engines, automatic steering gear and automatic weapons they be well but at sea.

"It is my belief that we should install along both of our ocean coasts, upon proper strategic and elevated points, numerous wireless controlling plants; under the command of competent officers and that to each should be assigned a number of submarine, surface and aerial craft.

"From the shore stations these vessels, of whatever character, could be perfectly controlled at any distance at which they remained visible through powerful telescopes. Thus they could be guided to any desired point and there made to perform such work as might be necessary.

"With proper refinements, all now well known to experts and fully developed, such operations could be put absolutely beyond the reach of interference, except such as might come through injury or destruction of the machinery.

"If we were properly equipped with such devices of defense it is inconceivable that any battleship or other vessel of an enemy ever could get within the zone of action of these tel-automatic craft without incurring a risk of annihilation amounting almost to certainty.

"And such a danger never would be braved. In fact the mere knowledge that such craft existed would determine all possible aggressors to give these peaceful shores of ours a wide and respectful berth.

The New York Times August 4, 1915

TESLA SUES MARCONI ON WIRELESS PATENT

Alleges That Important Apparatus Infringes Prior Rights Granted to Him.

BASIC PRINCIPLES INVOLVED

Marconi Company Manager Claims Ownership of All Underlying Wireless Inventions.

A suit brought by Nikola Tesla against the Marconi Wireless Telegraph Company of America, seeking the annulment of one of the chief Marconi patents, will have its first public argument in the United States District Court tomorrow, when counsel for Mr. Tesla will seek to have the court strike out nine paragraphs in the Marconi Company's answer to Mr. Tesla's complaint. Simultaneously with the suit for the annulment Mr. Tesla has brought a suit against the Marconi Company for infringement of his patents.

This litigation is a new development in the Marconi Company's claim to ownership of all basic patent rights in the transmission of wireless messages. In a number of other wireless patent suits against companies and individuals the Marconi Company is the plaintiff, and, though a defendant in this latest litigation, Edward J. Nally, Vice President and General Manager of the Marconi Company, believes that Mr. Tesla's suit will serve as one of the mediums through which the Marconi Company hopes to establish the broad claim of its right to all basic wireless patents.

The dispute over patent rights between the Marconi Company and Mr. Tesla began in August, 1914, when the Marconi Company sued Fritz Lowenstein, a German engineer, alleging that certain wireless apparatus sold by him to the United States Navy was made in violation of Marconi patent 763,772. It was announced then that Mr. Tesla would testify for Mr. Lowenstein, alleging that the Lowenstein devices were developed from Tesla patents 645,576 and 649,621, which were granted prior to the Marconi patent.

In the present suit, Mr. Tesla bases his action on the allegation that his two patents were granted in 1900, and that the Marconi patent was not granted until 1904. The bill of complaint asks for a decree adjudging the Marconi patent null and void, and asserts that the Marconi patent covers the inventions and combinations of apparatus described and claimed in the Tesla patents.

The answer of the Marconi Company denies that the Marconi patent covers the inventions or combination of apparatus described by the Tesla patents, and also denies that it is guilty of any infringement. The company claims that its patent was granted to Guglielmo Marconi on the proof of independent invention by Mr. Marconi, not in any way due to or based on any invention of Mr. Tesla's. The paragraphs of the answer which Mr. Tesla seeks to have stricken out deal with details which, according to Mr. Tesla's counsel, "are not proper and are not defenses to a suit to annul a subsequent patent by a prior patentee."

Regarding the alleged infringement of his patents, Mr. Tesla said:

"My patents describe a new and original wireless system characterized by the employment of four circuits in perfect resonance, a condition essential to successful practice. Long after their grant to me Marconi filed an application and secured a patent which covers exactly the same fundamental arrangements. Such cases happen occasionally, as it is quite impossible for the examiners in the Patent Office to keep abreast with workers in new and special fields. A notable instance of this kind is my single phase induction motor, on which a celebrated inventor obtained a patent which was subsequently invalidated through my earlier application.

"In a recent suit in France, involving the same or corresponding patents, the highest court, acting on a statement submitted by me, decided against Marconi and recognized fully my priority of invention in all the important features."

Mr. Nally, however, said last night that he had no reason to fear the Tesla suit.

"The Marconi Company has a right to its patent," he said, "and can establish that right in the courts. Many individuals and companies have infringed the Marconi patents, and others have attempted to disprove the originality of our inventions, but when our present litigation shall have gone through the courts, I am confident that the leadership of the Marconi Company in the invention and development of wireless communication will be established."

In his suit for annulment of the Marconi patent, Mr. Tesla is represented by George H. D. Foster and Samuel E. Quigg of 32 Liberty Street. The Marconi Company is represented by Sheffield & Betts of 52 William Street.

The original papers in the annulment suit were filed on April 16, 1915, and the answer of the Marconi Company on May 25 following.

The New York World August 4, 1915

NIKOLA TESLA SUES MARCONI FOR FULL WIRELESS CONTROL

Serbian Inventor Claims to Have Patent Which Will Confine Any Amount of Electrical Energy Without Use of Insulation.

Nikola Tesla has appealed to the law to declare that he and not William Marconi is the inventor of wireless telegraphy. Many millions in money and world-wide control of the commercial use of the wireless transmission of energy are involved in the struggle.

The suit has been brought in the United States District Court here in the name of the Nicola Tesla Company, of which the Serbian inventor is the President, and to which he has transferred all of his fundamental patent rights in wireless telegraphy. The defendant in the action is the Marconi Wireless Telegraph Company of America.

Mr. Tesla announced last night, in connection with the suit, that he recently has been granted a patent by the United States Government which will supersede and revolutionize all present forms and applications of wireless telegraphy and will enable him and the financiers who are associated with him to obtain and keep a hold on commercial wireless telegraphy, no matter what may be the outcome of the litigation he has begun against the Marconi interests.

Mr. Tesla, when seen last night at the Waldorf-Astoria, appeared very confident as to the outcome of his suit to wrest the wireless patents from his Italian rival, and enthusiastic over the possibilities of his latest patent, by which he expects to send wireless messages with an intensity and to a distance impossible under any of the present systems.

"My earlier experiments in Colorado in 1899," he said last night, "demonstrated that I was on the right track, and with a transmitter of my invention of not more than thirty inches in diameter I succeeded in concentrating and applying an amount of electrical energy twice as strong as is contained in an ordinary stroke of lightning.

"Since then I have pursued my experiments with that one point in view, namely, the discovery of a way of concentrating and absolutely controlling electrical energy. This result has been attained under the workings of the apparatus for which the Government granted me a patent last December.

"I now claim that I can confine any amount of electrical energy,

The New York Sun August 6, 1915

TESLA'S FIGHT ON MARCONI UP.

Court Reserves Decision on Motion Aimed at Answer.

Judge Augustus N. Hand of the United States District Court reserved decision yesterday on motion to strike out certain portions of the answer of the defendants in the suit brought by Nikola Tesla to prove that he, not William Marconi, was the inventor of wireless telegraphy.

The special paragraph in the Marconi answer to which Tesla took exception was in a letter in which it was asserted that Judge Van Vechten Veeder of the Federal District Court in Brooklyn had ruled in the patent litigation brought by the Marconi Wireless Telegraph Company of America against the National Electric Signalling Company that the Marconi patents were not an infringement of the Tesla devices.

The New York Times August 6, 1915

MOTIONS IN TESLA SUIT.

Plaintiff Asks That Parts of Marconi Answer Be Stricken Out.

In the suit brought by the Nikola Tesla Company for the annulment of the patent owned by the Marconi Wireless Telegraph Company of America and for infringement of the Tesla patent, Judge Augustus N. Hand, sitting in the Federal District Court, yesterday heard arguments on technical motions based on the pleadings. The Tesla Company asked Judge Hand to order several paragraphs stricken from the defendant company's answer to the complaint.

In the first paragraph objected to the plaintiff asked for the elimination of a letter in which it was asserted that the validity of the Marconi invention was sustained by Judge Van Vechten Veeder in the infringement suit against the National Signaling Company. Two other paragraphs alleged that the complaint does not set forth sufficient facts to indicate that the defendant's patent in any way interfered with the plaintiff's patent and the remaining six paragraphs objected to contained the usual allegations to be found in infringement suits brought under section 4918 of the United States Revised Statutes.

In support of the motions it was contended that Tesla was the first inventor of the patent in suit and the only issues to be decided were priority of invention and whether the patent covered the infringement.

For the Marconi Company it was urged that the paragraphs objected to were responsive and material as answers to the bill, and as to the assertions in the letter, it was explained that Judge Veeder, before he rendered his decision, considered the question as to whether or not the Tesla patent anticipated the Marconi patent and had found that it did not because the inventions were not the same.

At the conclusion of the argument Judge Hand reserved decision.

COAST PORTS BASIC FACTOR

Resistance of Invasion Rests on Adequate Defences on Shore.

By NIKOLA TESLA,

Wireless Inventor Famous for Tesla Currents and Various Electrical Inventions.

I AM in entire sympathy with the general idea that has taken such powerful hold of the minds of the country to fortify our coasts in such a way that no enemy has the slightest chance of assailing us successfully.

The lessons of the European war are such that no expense should be spared in strengthening our navy and installing a perfect system of coast defences, comprising guns and earthworks and all kinds of vessels.

The submarine craft has shown itself so surprisingly effective in the present war that this type should receive particular attention.

It is really the inventors of this country who have done the best work along these lines and it would be folly not to exploit their advanced ideas.

I have since 1898 advocated coast defence by tel-automatic torpedoes and ramming vessels, by means of which I believe that the coast could be rendered impregnable. In recent publications I have described my latest advancements in the production of wireless waves which make it possible to attain almost unlimited intensities; and with such powerful transmitters placed on proper points along our coast lines, east and west, all kinds of craft could be controlled with precision at such distances as it is possible to detect them by telescope from elevated points on shore.

They could also be guided to their destination from dirigibles and aeroplanes and then the distance could be extended at will.

It is a popular error to believe that such a properly constructed boat could be interfered with by electrical waves from an enemy side. I have long ago discovered an invention which makes it possible to so individualize the impulses which guide the vessel that the disturbing influences have absolutely no effect.

Another erroneous idea is that submarines cannot be controlled under water. It is a fact that this can be accomplished with ease.

I may say, however, that I have made another wonderful discovery, which I cannot yet announce, by means of which a country can be so defended that its borders will be as impassable to the enemy as granite walls 100 feet thick.

What we need as much as that, however, is the systematic and intelligent cooperation of all the forces in the country, in which Germany gives us such a marvellous example.

As regards the possibility of stopping warfare altogether, I used to think, but don't think now, that the perfection of modern implements of war will ever bring about that result.

The elimination of war from civilization will be a slow process and we must begin first by eradicating from our hearts the idea of patriotism.

Human beings should have no conception whatever what it means and it should be taken out of the dictionaries.

We must abolish the lines of demarcation between countries and nations and gradually harmonize our views so that we all shall have the same ideas.

I believe such a result only possible through the annihilation of distance, and the most perfect if not the only means to do it is the wireless art in all its departments.

When we shall have all the world over plants transmitting wireless power, driving our flying machines all over the earth; when we shall have installations permitting the transmission of the human voice, likenesses and pictures of people to any distance instantaneously, then we shall be prepared to consider this great globe shrunk down in size to a pea as the one and only country, equally for all, without preference to a race or nation.

Then we shall have forgotten patriotism and we shall prepare for universal peace.

The New York Times August 11, 1915

RULES ON MARCONI ANSWER.

In Tesla Suit Judge Strikes Out Paragraph as Impertinent.

Judge Augustus N. Hand, in an opinion filed yesterday in the United States District Court, ordered struck out as impertinent the eleventh paragraph of the answer of the Marconi Wireless Telegraph Company of America made to the annulment and patent infringement suit brought by the Nikola Tesla Company. The paragraph objected to stated that certain claims of the Marconi patents were sustained by Judge Van Vechten Veeder in the Brooklyn Court in the infringement suit brought against the National Electric Signaling Company, and that the same Court decided that the Tesla patents did not anticipate and were not for the same inventions as the Marconi patents. In his ruling, Judge Hand said.

"I can see no principle under which that decision rendered between wholly different parties is binding here or relevant except as a mere legal precedent. It can only be presented as argument in relation to the legal issues involved, but not as a fact to be pleaded or proved. The motion to strike out the eleventh paragraph of the answer as impertinent is, therefore, granted."

Judge Hand refused to strike out paragraphs thirteen and fourteen, which alleged that the complaint did not state facts sufficient to constitute a cause of action, and that the complainant is not entitled to any answer or to have the Marconi patents declared void.

Tesla Sues Marconi on Wireless Patent.

A suit has been brought by Nikola Tesla against the Marconi Wireless Telegraph Company of America, seeking the annulment of one of the chief Marconi patents. Simultaneously with the suit for the annulment Mr. Tesla has brought a suit against the Marconi Company for infringement of his patents.

This litigation is a new development in the Marconi Company's claim to ownership of all basic patent rights in the transmission of wireless messages.

The dispute over patent rights between the Marconi Company and Mr. Tesla began in August, 1914, when the Marconi Company sued Fritz Lowenstein, a German engineer, alleging that certain wireless apparatus sold by him to the United States Navy was made in violation of Marconi patent 763,772. It was announced then that Mr. Tesla would testify for Mr. Lowenstein, alleging that the Lowenstein devices were developed from Tesla patents 645,576 and 649,621, which were granted prior to the Marconi patent.

In the present suit Mr. Tesla bases his action on the allegation that his two patents were granted in 1900, and that the Marconi patent was not granted until 1904. The bill of complaint asks for a decree adjudging the Marconi patent null and void, and asserts that the Marconi patent covers the inventions and combinations of apparatus described and claimed in the Tesla patents.

The answer of the Marconi Company denies that the Marconi patent covers the inventions or combination of apparatus described by the Tesla patents, and also denies that it is guilty of any infringement. The company claims that its patent was granted to Guglielmo Marconi on the proof of independent invention by Marconi, not due to or based on any invention of Tesla.

A hearing took place before Judge A. N. Hand, in the federal district court in New York City on August 5.

The Wonder World to Be Created by Electricity

By Nikola Tesla.

[Nikola Tesla, inventor, physicist, electrical wizard and seer, is a native of Austria-Hungary, but has lived in the United States since 1884, with headquarters in New York City, and is a naturalized citizen. He studied technology and various scientific subjects in a number of European universities and began a practical career at Budapest, Hungary, in 1881, where he made his first electrical invention. His laboratory is at Shoreham, Long Island.

A long list of inventions is credited to Mr. Tesla, and he is as incessant a worker as even Thomas A. Edison himself. He is the inventor and discoverer of the alternating current power transmission, the system of arc lighting, the system of electrical conversion and distribution by oscillatory discharges, generators of high frequency currents, transmission of energy through a single wire without return, Tesla coil or transformer, etc.—Editor Manufacturers Record.]

Whoever wishes to get a true appreciation of the greatness of our age should study the history of electrical development. There he will find a story more wonderful than any tale from the Arabian Nights. It begins long before the Christian era, when Thales, Theophrastus and Pliny tell of the magic properties of electron—the precious substance we call amber—that came from the pure tears of the Heliades, sisters of Phaeton, the unfortunate youth who attempted to run the blazing chariot of Phoebus and nearly burned up the earth. It was but natural for the vivid imagination of the Greeks to ascribe the mysterious manifestations to a hyperphysical cause, to endow the amber with life and with a soul.

Whether this was actual belief or merely poetic interpretation is still a question. Even at this very day many of the most enlightened people think that the pearl is alive; that it grows more lustrous and beautiful in the warm contact of the human body. So, too, it is the opinion of men of science that a crystal is a living being, and this view is being extended to embrace the entire physical universe since Prof. Jagadis Chunder Bose has demonstrated, in a series of remarkable experiments, that inanimate matter responds to stimuli in exactly the same manner as plant fiber and animal tissue.

The superstitious belief of the ancients, if it existed at all, can therefore not be taken as a reliable proof of their ignorance, but just how much they knew about electricity can only be conjectured. A curious fact is that the ray or torpedo fish was used by them in electrotherapy. Some old coins show twin stars, or sparks, such as might be produced by a galvanic battery. The records, though scanty, are of a nature to fill us with conviction that a few initiated, at least, had a deeper knowledge of amber phenomena. To mention one, Moses was undoubtedly a practical and skillful electrician far in advance of his time. The Bible describes precisely and minutely arrangements constituting a machine in which electricity was generated by friction of air against silk curtains and stored in a box constructed like a condenser. It is very plausible to assume that the sons of Aaron were killed by a high-tension discharge, and that the vestal fires of the Romans were electrical. The belt drive must have been known to engineers of that epoch, and it is difficult to see how the abundant evolution of static electricity could have escaped their notice. Under favorable atmospheric conditions a belt may be transformed into a dynamic generator capable of producing many striking actions. I have lighted incandescent lamps, operated motors and performed numerous other equally interesting experiments with electricity drawn from belts and stored in tin cans.

That many facts in regard to the subtle force were known to the philosophers of old can be safely concluded. The wonder is, why 2000 years elapsed before Gilbert in 1600 published his famous work, the first scientific treatise on electricity and magnetism. To an extent this long period of unproductiveness can be explained. Learning was the privilege of a few and all information was jealously guarded. Communication was difficult and slow, and a mutual understanding between widely-separated investigators hard to reach. Then again, men of those times had no thought of the practical; they lived and fought for abstract principles, creeds, traditions and ideals. Humanity did not change much in Gilbert's time, but his clear teachings had a telling effect on the minds of the learned. Friction machines were produced in rapid succession and experiments and observations multiplied. Gradually fear and superstition gave way to scientific insight, and then the world was thrilled with the new and then Mr. Leyden had succeeded in imprisoning the uncanny agent in a phial, from which it escaped with an angry snap and destructive force. This was the birth of the condenser, perhaps the most marvelous electrical device ever invented.

Two tremendous leaps were made in the succeeding 40 years. One was when Franklin demonstrated the identity between the gentle soul of amber and the awe-inspiring bolt of Jupiter; the other when Galvany and Volta brought out the contact and chemical battery, from which the magic fluid could be drawn in unlimited quantities. The succeeding 40 years bore still greater fruit. Oersted made a significant advance in deflecting a magnetic needle by an electric current, Arago produced the electro-magnet, Seebeck the thermo-pile and in 1831, as the crowning achievement of all, Faraday announced that he had obtained electricity from a magnet, thus discovering the principle of that wonderful engine, the dynamo, and inaugurating a new era both in scientific research and practical application.

From that time on inventions of inestimable value have followed one another at a bewildering rate. The telegraph, telephone, phonograph and incandescent lamp, the induction motor, oscillatory transformer, Roentgen ray, radium, wireless and numerous other revolutionary advances have been made and all conditions of existence profoundly modified. In the 84 years which have since elapsed the subtle agents dwelling in the living amber and loadstone have been transformed into cyclopean forces, turning the wheels of human progress with ever-increasing speed. This, in brief, is the fairy tale of electricity from Thales to the present day. The impossible has happened, the wildest dreams have been surpassed and the astounded world is asking, What is coming next?

Electrical Possibilities in Coal and Iron.

Many a would-be discoverer, failing in his efforts, has felt the regret to have been born at a time when everything has been already accomplished and nothing is left to be done. This erroneous impression that, as we are advancing, the possibilities of invention are being exhausted, is not uncommon. In reality it is just the opposite. Spencer has conveyed the right idea when he likened civilization to the sphere of light which a lamp throws out in darkness. The brighter the lamp and the larger the sphere the greater is its dark boundary. It is paradoxical, yet true, to say, that the more we know the more ignorant we become in the absolute sense, for it is only through enlightenment that we become conscious of our limitations. Precisely one of the most gratifying results of intellectual evolution is the continuous opening up of new and greater prospects. We are progressing at an amazing pace, but the truth is that, even in the fields most successfully exploited, the ground has only been broken. What has been so far done by electricity is nothing as compared with what the future has in store. Not only this, but there are now innumerable things done in old-fashioned ways which are much inferior in economy, convenience and many other respects to the new method. So great are the advantages of the latter that whenever an opportunity presents itself the engineer advises his client to "do it electrically."

Consider, in illustration, one of the largest industries, that of coal. From this valuable mineral we chiefly draw the sun's stored energy which is required to meet our industrial and commercial needs. According to statistical records, the output in the United States during the past year was 480,000,000 tons. In perfect engines the fuel would have been sufficient to develop 500,000,000 horse-power steadily for one year, but the squandering is so reckless that we do not get more than 5 per cent. of its heating value on the average. There is an appalling waste in mining, handling, transportation, store and use of coal, which could be very much reduced through the adoption of a comprehensive electrical plan in all these operations. The market value of the yearly product could be easily doubled and an immense sum added to the revenues of the country. What is more, inferior grades, billions of tons of which are being thrown away, might be turned to profitable use.

Similar considerations apply to natural gas and mineral oil, the annual loss of which amounts to hundreds of millions of dollars. In the very near future such waste will be looked upon as criminal and the introduction of the new methods will be forced upon the owners of such properties. Here, then, is an immense field for the use of electricity in many ways, vast industries which are bound to be revolutionized through its extensive application.

To give another example, I may refer to the manufacture of iron and steel, which is carried on in this country on a scale truly colossal. During the last year, notwithstanding unfavorable business conditions, 31,000,000 tons of steel have been produced. It would lead too far to dwell on the possibilities of electrical improvements in the manufacturing processes themselves, and I will only indicate what is likely to be accomplished in using the waste gases from the coke ovens and blast furnaces to generate electricity for industrial purposes.

Since in the production of pig-iron for every ton about one ton of coke is employed, the yearly consumption of coke may be put at 31,000,000 tons. The combustion in the blast furnaces yields, per minute, 7,000,000 cubic feet of gas of a heating value of 110 B. T. units per cubic foot. Of this total, without making special provision, 4,000,000 cubic feet may be made available for power purposes. If all the heat energy of this gas could be transformed into mechanical effort, it would develop 10,389,000 horse-power. This result is impossible, but it is perfectly practicable to obtain 2,500,000 horse-power electrical energy at the terminals of the dynamos.

In the manufacture of coke approximately 9400 cubic feet of gas are evolved per ton of coal. This gas is excellent for power purposes, having an average heating value of 600 B. T. units, but very little is now used in engines, largely because of their great cost and other imperfections. A ton of coke requires about 1.32 tons of American coal; hence the total coal consumption per annum on the above basis is nearly 41,000,000 tons, which give, per minute, 733,000 cubic feet of gas. Assuming the yield of surplus or rich gas to be 333,000 cubic feet, the balance of 400,000 cubic feet could be used in gas engines. The heat contents would be, theoretically, sufficient to develop 5,660,000 horse-power, of which 1,500,000 horse-power could be obtained in form of eletric energy.

I have devoted much thought to this industrial proposition, and find that **with new, efficient, extremely cheap and simple thermo-dynamic transformers not less than 4,000,000 horse-power could be developed in electric generators by utilizing the heat of these gases, which, if not entirely wasted, are only in part and inefficiently employed.**

With systematic improvements and refinements much better results could be secured and an annual revenue of $50,000,000 or more derived. The electrical energy could be advantageously used in the fixation of atmospheric nitrogen and production of fertilizers, for which

the power of the transmitter is dissipated in all directions, I wish to be emphatic in my statement that such is not the case. The energy goes only to the place where it is needed and to no other.

When these advanced ideas are practically realized we shall get the full benefit of water-power, and it will become our chief dependence in the supply of electricity for domestic, public and other uses in the arts of peace and war.

Economy in Light and Power—Electric Propulsion.

In the great departments of electric light and power immense opportunities are offered through the introduction of all kinds of novel devices which can be attached to the circuits at convenient hours for the purpose of equalizing the loads and increasing the revenues from the plants. I have myself knowledge of a number of new appliances of this kind. The most important among them is probably an electrical ice machine which obviates entirely the use of dangerous and otherwise objectionable chemicals. The new machine will also require absolutely no attention and will be extremely economical in operation, so that the refrigeration will be effected very cheaply and conveniently in every household.

An interesting fountain, electrically operated, has been brought out which is likely to be extensively introduced, and will afford an unusual and pleasing sight in squares, parks, hotels and residences.

Cooking devices for all domestic purposes are being provided, and there is great demand for practical designs and suggestions in this field. The same may be stated of electric signs and other attractive means of advertising which can be electrically operated. Some of the effects which it is possible to produce by electric currents are wonderful and lend themselves to exhibitions, and there is no doubt that much can be done in that directions. Theaters, public halls and private dwellings are in need of a great many devices and instruments for convenience and offer ample opportunities to an ingenious and practical inventor.

A vast and absolutely untouched field is the use of electricity for the propulsion of ships. The leading electrical company in this country has just equipped a large vessel with high-speed turbines and electric motors and has achieved a signal success. Applications of this kind will multiply at a rapid rate, for the advantages of the electrical drive are now patent to everybody. In this connection gyroscopic apparatus will probably play an important part, as its general adoption on vessels is sure to come. Very little has yet been done in the introduction of electrical drive in the various branches of industry and manufacture, and the prospects are unlimited.

A Few of the Wonders to Come.

Books have already been written on the agricultural uses of electricity, but the fact is that hardly anything has been practically done. The beneficial effects of electricity of high tension have been unmistakably established, and a revolution will be brought about through the extensive adoption of agricultural electrical apparatus. **The safeguarding of forests against fires, the destruction of microbes, insects and rodents will, in due course, be accomplished by electrical means.**

In the near future we shall see a great many new uses of electricity aiming at safety, particularly of vessels at sea. **We shall have electrical instruments for preventing collisions, and we shall even be able to disperse fogs by electric force and powerful and penetrative rays.** I am hopeful that within the next few years **wireless plants will be installed for the purpose of illuminating the oceans.** The project is perfectly feasible, and if carried out will contribute more than any other provision to the safety of property and human lives at sea. The same plant could also produce stationary electrical waves and enable vessels to get at any time accurate bearings and other valuable practical data without resorting to the present means. It could also be used for time signaling and many other purpuoses of similar nature.

Electrotherapy is another great field in which there are unlimited possibilities for electrical applications. High-frequency currents especially have a great future. The time will come when this form of electrical energy will be available in every private residence. I consider it quite possible that through their surface actions we may do away with the customary bath, as the cleaning of the body can be instantaneously effected simply by connecting it to a source of currents or electric energy of very high potential, which results in the throwing off of dust or any small particles adhering to the skin. Such a dry bath, besides being convenient and time-saving, would also be of beneficial therapeutic influence. New electric devices for use of the deaf and blind are coming and will be a blessing to the afflicted.

In the prevention of crime electrical instruments will soon become an important factor. In court proceedings electric evidence will often be decisive. **In a time not distant it will be possible to flash any image formed in thought on a screen and render it visible at any place desired.** The perfection of this means of reading thought will create a revolution for the better in all our social relations. Unfortunately, it is true, that cunning lawbreakers will avail themselves of such advantages to further their nefarious business.

Telegraphic Photography and Other Advances.

Great improvements are still possible in telegraphy and telephony. The use of a new receiving device which will be shortly described, and the sensitiveness of which can be increased almost without limit, will enable telephoning through aerial lines or cables however long by reducing the necessary working current to an infinitesimal value. This invention will dispense with the necessity of resorting to expensive constructions, which, however, are of circumscribed usefulness. It will also enormously extend the wireless transmission of intelligence in all its departments.

The next art to be inaugurated is that of picture transmision by ordinary telegraphic methods and existing apparatus. This idea of telegraphing or telephoning pictures is old, but practical difficulties have hampered commercial realizations. A number of improvements of great promise have been made, and there is every reason to expect that success will soon be achieved.

Another valuable novelty will be a typewriter electrically operated by the human voice. This advance will fill a long-felt want, as it will do away with the operator and save a great deal of labor and time in offices.

A new and extremely simple electric tachometer is being prepared for the market, and it is expected that it will prove useful in power plants and central stations, on boats, locomotives and automobiles.

Many municipal improvements based on the use of electricity are about to be introduced. **We have soon to have everywhere smoke annihilators, dust absorbers, ozonizers, sterilizers of water, air, food and clothing, and accident preventers on streets, elevated roads and in subways. It will become next to impossible to contract disease germs or get hurt in the city, and country folk will go to town to rest and get well.**

Electric Inventions in War.

The present international conflict is a powerful stimulus to invention of devices and implements of warfare. An electric gun will soon be brought out. The wonder is that it was not produced long ago. Dirigibles and aeroplanes will be equipped with small electric generators of high tension, from which the deadly currents will be conveyed through tin wires to the ground. Battleships and submarines will be provided with electric and magnetic feelers so delicate that the approach of any body under water or in darkness will be detected. Torpedoes and floating mines are almost in sight which will direct themselves automatically and without fail get in fatal contact with the object to be destroyed. The art of telautomatics, or wireless control of automatic machines at a distance, will play a very important part in future wars and, possibly, in the next phases of the present one. Such contrivances which act as if endowed with intelligence will be used in innumerable ways for attack as well as defense. They may take the shape of aeroplanes, balloons, automobiles, surface or under-water boats, or any other form according to the requirement in each special case, and will be of greater range and destructiveness than the implements now employed. **I believe that the telautomatic aerial torpedo will make the large siege gun, on which so much dependence is placed at present, obsolete.**

A volume might be filled with such suggestions without exhausting the possibilities. The advance even under the conditions existing is rapid enough, but when the wireless transmission of energy for general use becomes a practical fact the human progress will assume the character of a hurricane. So all-surpassing is the importance of this marvelous art to the future existence and welfare of the human race that every enlightened person should have a clear idea of the chief factors bearing on its development.

The Power of the Future.

We have at our disposal three main sources of life-sustaining energy—fuel, water-power and the heat of the sun's rays. Engineers often speak of harnessing the tides, but the discouraging truth is that the tide-water over one acre of ground will, on the average, develop only one horse-power. Thousands of mechanics and inventors have spent their best efforts in trying to perfect wave motors, not realizing that the power so obtained could never compete with that derived from other sources. The force of wind offers much better chances and is valuable in special instances, but is by far inadequate. Moreover, the tides, waves and winds furnish only periodic and often uncertain power and necessitate the employment of large and expensive storage plants. Of course, there are other possibilities, but they are remote, and we must depend on the first of three resources. If we use fuel to get our power, we are living on our capital and exhausting it rapidly. This method is barbarous and wantonly wasteful, and will have to be stopped in the interest of coming generations. The heat of the sun's rays represents an immense amount of energy vastly in excess of water-power. The earth receives an equivalent of 83 foot-pounds per second for each square foot on which the rays fall perpendicularly. From simple geometrical rules applying to a spherical body it follows that the mean rate per square foot of the earth's surface is one-quarter of that, or 20¾ foot-pounds. This is to say over one million horse-power per square mile, or 250 times the water-power for the same area. But that is only true in theory; the practical facts put this in a different aspect. For instance, considering the United States, and taking into account the mean latitude, the daily variation, the diurnal changes, the seasonal variations and casual changes, this power of the sun's rays reduces to about one-tenth, or 100,000 horse-power per square mile, of which we might be able to recover in high-speed low-pressure turbines 10,000 horse-power. To do this would mean the instalment of apparatus and storage plants so large and expensive that such a project is beyond the pale of the practical. **The inevitable conclusion is that water-power is by far our most valuable resource. On this humanity must build its hopes for the future.** With its full development and a perfect system of wireless transmission of the energy to any distance man will be able to solve all the problems of material existence. Distance, which is the chief impediment to human progress, will be completely annihilated in thought, word and action. Humanity will be united, wars will be made impossible and peace will reign supreme.

The Brooklyn Eagle September 12, 1915

Wireless to Light Oceans And Make War Impossible

Nikola Tesla, Inventor, Predicts Amazing Future for Electricity—Will Be the World's Industrial Power, Even to Driving Big Ships, and Will Operate Typewriter by Means of Voice Alone.

Baltimore, Md., September 11—A typewriter electrically operated by the human voice, thus doing away with the operator and saving much time and labor in offices, is to be one of the wonders of the near future, says Nikola Tesla, the inventor, in the Manufacturers Record, reviewing the progress of electricity and forecasting its future. The amazing possibilities of electricity also include wonderful achievements in telautomatics, Tesla says.

In the way of devices and implements of warfare, a new electric gun will soon be brought out. Dirigibles and aeroplanes will be equipped with small electric generators of high tension, from which the deadly currents will be conveyed through tin wires to the ground. Battleships and submarines will have electric and magnetic feelers so delicate that the approach of any body under water, or in darkness, will be detected.

There will be torpedoes and floating mines that will direct themselves automatically, and without fail get in fatal contact with the object to be destroyed. The art of telautomatics, or wireless control of automatic machines at a distance, will play a very important part in future wars and, possibly, in the present one.

Such contrivances may take the shape of aeroplanes, balloons, automobiles, surface or under-water boats, and will be of greater range and destructiveness than the implements now employed.

"I believe that the telautomatic aerial torpedo will make the large siege gun on which so much dependence is placed at present, obsolete, Tesla says.

Wars Will Be Made Impossible, Says Tesla.

In discussing the power of the future, tides, waves and winds are dismissed as uncertain and inefficient; fuel as now used is branded as a barbarous and wantonly-wasteful method, and the utilization of the sun's heat beyond the pale of the practical. The inevitable conclusion, therefore, is that water power is by far our most valuable resource. On this humanity must build its hopes for the future.

With its full development and a perfect system of wireless transmission of the energy to any distance, man will be able to solve all the problems of material existence. Distance, which is the chief impediment to human progress, will be annihilated in thought, word and action. Humanity will be united, wars will be made impossible, and peace will reign supreme.

Moses, so Tesla says, was undoubtedly a practical and skilled electrician, and he thinks it may be assumed that the Vestal fires of the Romans were electrical, and yet there was no progress made in the practical uses of electricity from early times until recent years.

The telegraph, telephone, phonograph and incandescent lamp, induction motor, oscillatory transformer, Roentgen ray, radium, wireless and numerous other revolutionary advances that have been made within the last century may suggest the thought that nothing is left to be done in electricity. Tesla says all this is as nothing as compared with what the future has in store, and which, in brief, may be outlined from his forecast, as follows:

Hundreds of millions of dollars may be saved annually by a comprehensive electrical plan for the mining, handling, transportation, storage and use of coal, and this applies also to natural gas and mineral oil.

Passing by the possibilities of electrical improvements in the processes of manufacturing steel, it is pointed out that not less than 4,000,000 horsepower could be developed annually in electrical generators, with new, efficient, extremely cheap and simple thermo-dynamic transformers, by utilizing the heat of the gases evolved in the manufacture of coke for blast furnaces, which gases are now wasted or only in part and inefficiently employed.

Electrical energy could be used advantageously in the fixation of atmospheric nitrogen and production of fertilizers, for which there is an unlimited demand. The harnessing of waterfalls is the most economical method known for developing power. So far, about 7,000,000 horsepower have been developed in this country. This is equal to the mechanical performance of 150,000,000 men.

Although there are limitations to water power development at present, the time is very near when the precipitation of the moisture of the atmosphere will be under control, and then it will be possible to draw unlimited quantities of water from the oceans, develop any desired amount of energy, and completely transform the globe by irrigation and intensive farming.

The wireless transmission of power is now an accomplished fact.

In the departments of electric light and power an electrical ice machine, economical and efficient, to provide refrigeration for every household, is an important new appliance, ready to be introduced.

A vast and absolutely untouched field is the use of electricity for the propulsion of ships. An electrical company has just equipped a large vessel with high-speed turbines and electric motors, and has achieved a signal success.

Wireless to Illuminate the Ocean.

There will be electrical instruments for preventing collisions, and fogs will be dispersed by electric force and powerful and penetrative rays. Within the next few years wireless plants probably will be installed for the purpose of illuminating the oceans.

The beneficial effects of electricity of high tension have been established unmistakably, and a revolution will be brought about through the extensive adoption of agricultural electrical apparatus. The safeguarding of forests against fires, the destruction of microbes, insects and rodents, in due course, will be accomplished by electrical means.

By the development of electrical instruments, it will be possible to flash any image formed in thought on a screen and render it visible at any place desired.

In telegraphy and telephony, new inventions will dispense with expensive constructions, and will extend enormously the wireless transmission of intelligence in all its departments. A number of improvements of much promise have been made in the art of telegraphing or telephoning pictures, and it is expected that complete success will be achieved soon.

Another valuable novelty will be a typewriter electrically operated by the human voice, thus doing away with the operator and saving much time and labor in offices.

Many municipal improvements based on the use of electricity are about to be introduced. We are to have everywhere smoke annihilators, dust absorbers, ozonizers, sterilizers of water, air, food and clothing, and accident preventers on streets, elevated roads and in subways. It will become next to impossible to contract disease germs or get hurt in the city, and country folk will go to town to rest and get well.

The New York Times September 16, 1915

The Inventor of Wireless.

To the Editor of The New York Times:

THE NEW YORK TIMES last week reported an interview with Marconi, in which he said: They [the Germans] have even stolen my invention." I question whether Mr. Marconi is justified in making such a statement. Does he owe nothing to the inspiration of Heinrich Rudolf Hertz, that great German genius, or to K. A. Steinheil and Gauss of Munich? And has Mr. Marconi not heard of the Tuckerton wireless, the most improved of all the systems? And has Nikola Tesla no claim on the attention of scientists? I remember well the great English scientist, Sir Robert Ball, saying that he considered Tesla the more ingenious inventor.

M. U.

Greystone-on-Hudson, N. Y., Sept. 14, 1915.

The New York Sun September 24, 1915

TESLA SUES FOR $250,000.

Makes Counter Claim Against Lawyers in Patent Case.

Nikola Tesla filed an answer in the Supreme Court yesterday to a suit started by Kerr, Page & Cooper, patent attorneys, to recover $10,000 for legal services. Tesla denies he owes the attorneys anything and asks judgment on a counter claim for $250,000.

Tesla alleges that between 1900 and 1914 he engaged the attorneys to obtain certain patents for him, and because of their failure to do so he has been damaged in the amount claimed.

The New York Times October 3, 1915

NIKOLA TESLA SEES A WIRELESS VISION

Thinks His "World System" Will Allow Hundreds to Talk at Once Through the Earth.

ENDS STATIC DISTURBANCE

Inventor Hopes Also to Transmit Pictures by the Same Medium Which Carries the Voice.

Nikola Tesla announced to THE TIMES last night that he had received a patent on an invention which would not only eliminate static interference, the present bugaboo of wireless telephony, but would enable thousands of persons to talk at once between wireless stations and make it possible for those talking to see one another by wireless, regardless of the distance separating them. He said also that with his wireless station now in the process of construction on Long Island he hoped to make New York one of the central exchanges in a world system of wireless telephony.

Mr. Tesla has been working on wireless problems for many years. Yesterday he exhibited an article published in The Electrical World eleven years ago, in which he predicted not only wireless telephony on a commercial basis but that it would be possible to identify the voice of an acquaintance over any distance. That its operator in Hawaii was able to distinguish the voice of an engineer friend at Arlington, Va., was announced by the American Telephone and Telegraph Company as the most marked triumph of its communication by wireless telephone from the naval radio station at Arlington to Pearl Harbor, Hawaii, a distance of 4,600 miles.

The inventor, who has won fame by his electrical inventions, dictated this statement yesterday:

"The experts carrying out this brilliant experiment are naturally deserving of great credit for the skill they have shown in perfecting the devices. These are of two kinds: First, those serving to control transmission, and, second, those magnifying the received impulse. That the control of transmission is perfect is plain to experts from the fact that the Arlington, Mare Island, and Pearl Harbor plants are all inefficient and that the distance of telephonic communication is equal to that of telegraphic transmission. It is also perfectly apparent that the chief merit of the application lies in the magnification of the microphonic impulse. It must not be imagined that we deal here with new discoveries. The improvement simply concerns the control of the transmitted and the magnification of the received impulse, but the wireless system is the same. This can never be changed.

"That it is practicable to project the human voice not only to a distance of 6,000 miles, but clear across the globe, I demonstrated by experiments in Colorado in 1899. Among my publications I would refer to an article in the Electrical World of March 5, 1904, but describing really tests I made in 1899. The facts which I pointed out in the article were of much greater significance than that of the experiments reported, although this should be taken in a scientific sense, as he experiments were simply scientific demonstrations. I pointed out then that the modulations of the human voice can be reproduced more clearly through the earth than through wire. It is difficult for the layman to understand, but it is an absolute fact that transmission through the earth with the proper apparatus is not more difficult than the sending of a message on a wire strung across a room. This wonderful property of the planet, that, electrically speaking, is through its very bigness small, is of incalculable significance for the future of mankind.

"These tests made between Washington and Honolulu will act as an immense stimulus to wireless telephony and would be of much more value to the world if the principles of the transmission were understood. But they are not. Even now, fifteen years after the fundamental principles have been demonstrated and the possibilities shown, there are many experts in the dark.

"For instance, it is claimed that static disturbance will fatally interfere with the transmission, while, as a matter of fact, there is no static disturbance possible in properly designed transmission and receiving circuits. Quite recently I have described, in a patent, circuits which are absolutely immune to static and other interferences—so much so that when a telephone is attached, there is absolute silence, even lightning in the immediate vicinity not producing a click of the diaphragm, while in the ordinary telephonic conversation there are all kinds of noises. Transmission without static interference has many wonderful properties besides, first of which is that unlimited amounts of power can be transmitted with very small loss.

"Another contention is that there can be no secrecy in wireless telephone conversation. I say it is absurd to raise this contention, when it is positively demonstrated by experiments that the earth is more suitable for transmission than any wire could ever be. A wireless telephone conversation can be made as secret as a thought.

"I have myself erected a plant for the purpose of connecting by wireless telephone the chief centres of the world, and from this plant as many as a hundred will be able to talk absolutely without interference and with absolute secrecy. The plant would simply be connected with the telephone central exchange of New York City, and any subscriber will be able to talk to any other telephone subscriber in the world, and all this without any change in his apparatus. This plan has been called my 'world system.' By the same means I propose also to transmit pictures and project images, so that the subscriber will not only hear the voice, but see the person to whom he is talking. Pictures transmitted over wires is a perfectly simple art practiced today. Many inventors have labored on it, but the chief credit is due Professor Korn of Munich.

"His apparatus can be attached to a wireless plant and at any other wireless plant can be reproduced. I have undertaken this in the hope of establishing a service which would greatly facilitate the work of the press. A picture could be sent from a battlefield in Europe to New York in five minutes if the proper instruments were available.

"A further advantage would be that the transmission is instant and free of the unavoidable delay experienced with the use of wires and cables. As I have already made known, the current passes through the earth, starting from the transmission station with infinite speed, slowing down to the speed of light at a distance of 6,000 miles, then increasing in speed from that region and reaching the receiving station again with infinite velocity.

"It's all a wonderful thing. Wireless is coming to mankind in its full meaning like a hurricane some of these days. Some day there will be, say, six great wireless telephone stations in a 'world system' connecting all the inhabitants of this earth to one another, not only by voice but by sight. It's surely coming."

The New York Times October 4, 1915

CORRECTION BY MR. TESLA.

Of Wireless Apparatus He Meant to Say "Ineffective," Not "Inefficient."

THE TIMES received last night from Nikola Tesla a letter saying the inventor wished to correct a statement in his forecast of the possibilities of wireless, published in THE TIMES of yesterday morning, when he was quoted as saying that the apparatus used by the American Telephone & Telegraph Company to talk from Arlington to Hawaii was "inefficient." The inventor wrote that he wished to say that the apparatus was "ineffective."

"Although I can guess the character of the apparatus which was employed in projecting the human voice through 4,600 miles of space," Mr. Tesla wrote, "I am unable to judge of its efficiency, but from the technical particulars available I know that the plants are ineffective, inasmuch as they would have furnished currents of much greater volume and tension had they been differently designed. Incidentally, they would then have been immune against static disturbances, unfailing in their operation and adapted to secure secrecy of messages.

"In calling attention to this fact I have meant to give testimony to the excellence of the means of control and magnification resorted to by the experimentors. Had the same devices been used in connection with plants designed for maximum effect the results would have been such as to cause a most profound sensation and to stir great commercial interests all the world over, perhaps to the point of powerfully effecting and hastening the finish of the awful struggle in which nations of the earth are now engaged."

DAWNING OF AN AGE OF THE MIRACULOUS.

TALKING by wireless to a man nearly 5000 miles away seemed to the average reader like a tale from the Arabian Nights, and when the newspapers last week chronicled the feat that had been performed by operators in Arlington and Pearl Harbor, 4600 miles apart, there was a gasp of wonder as to what new miracle would be announced next.

To Nikola Tesla, however, this is merely the arrival at a way station along a road which he has completely mapped out.

"This wonder in wireless telephony, of which the papers are full, is no wonder at all, but a perfectly simple result of the application of my wireless system," says Mr. Tesla in a letter to the MANUFACTURERS RECORD. "Both the plants in Washington and Honolulu are equipped with my apparatus, but the engineers are, of course, entitled to credit for the particular devices of controlling the transmitted and recording the received impulses. These, however, are only accessories of the system, which can be varied in many ways by inventive and experienced experts. I have, myself, contrived more than two dozen of such devices before settling on what I considered the best. Please note that all this was done prior to 1902.

"I am sending you under enclosure an article descriptive of my discovery made in July, 1899, which furnished absolute demonstration that the human voice, by means of the system I have devised, could be readily carried around the globe. In fact, I had performed at that time feats described in my patents which involved the overcoming of greater difficulties than those confronting the experts in these tests just reported."

The article Tesla sent was an extended description of discoveries made by him in 1899, as a result of which he found that "not only was it practicable to send telegraphic messages to any distance without wires, as I recognized long ago, but also to impress upon the entire globe the faint modulations of the human voice, far more still, to transmit power, in unlimited amounts to any terrestrial distance and almost without any loss."

Concluding, he declared: "When the great truth accidentally revealed and experimentally confirmed is fully recognized, that this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball, and that by this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment; when the first plant is inaugurated and it is shown that a telegraphic message, almost as secret and non-interferable as a thought, can be transmitted to any terrestrial distance; the sound of the human voice, with all its intonations and inflections, faithfully and instantly reproduced at any other point of the globe; the energy of a waterfall made available for supplying light, heat or motive power anywhere—on sea, or land, or high in the air—humanity will be like an antheap stirred up with a stick. See the excitement coming!"

In an interview in the New York Times of the 3d Tesla foretells a time when thousands of persons will be talking at once between stations, without regard to distance, these wireless conversations entirely safe from eavesdroppers—"as secret as a thought," he says. "Some day there will be, say, six great wireless telephone stations in a 'world system' connecting all the inhabitants of this earth to one another not only by voice, but by sight."

The human intellect finds it well-nigh impossible to comprehend the unseen, to visualize the unknown. Thus it comes about that much greater excitement is caused by the bare announcement of a conversation between Washington and Honolulu than was aroused by the description of greater wonders Mr. Tesla foresaw nearly twenty years ago.

That the perfection of the wireless transmission of speech and power was then at hand was the declaration made by Tesla in an article he wrote for the MANUFACTURERS RECORD and which was printed in this newspaper a few weeks ago.

"The use of a new receiving device which will be shortly described, and the sensitiveness of which can be increased almost without limit," said he, "will enable telephoning through aerial lines or cables however long by reducing the necessary working current to an infinitesimal value. This invention will dispense with the necessity of resorting to expensive constructions, which, however, are of circumscribed usefulness. It will also enormously extend the wireless transmission of intelligence in all its departments.

"The next art to be inaugurated is that of picture transmission by ordinary telegraphic methods and existing apparatus. This idea of telegraphing or telephoning pictures is old, but practical difficulties have hampered commercial realizations. A number of improvements of great promise have been made, and there is every reason to expect that success will soon be achieved.

"Another valuable novelty will be a typewriter electrically operated by the human voice. This advance will fill a long-felt want, as it will do away with the operator and save a great deal of labor and time in offices.

"A new and extremely simple electric tachometer is being prepared for the market, and it is expected that it will prove useful in power plants and central stations, on boats, locomotives and automobiles.

"Many municipal improvements based on the use of electricity are about to be introduced. We have soon to have everywhere smoke annihilators, dust absorbers, ozonizers, sterilizers of water, air, food and clothing, and accident preventers on streets, elevated roads and in subways. It will become next to impossible to contract disease germs or get hurt in the city, and country folk will go to town to rest and get well."

That there has been great destruction of German submarines through the use of electrical devices which tell of the proximity of the boats is reported from abroad. This is merely one of the electrical inventions foretold by Tesla in his marvelous résumé of electrical progress made for the MANUFACTURERS RECORD.

"Battleships and submarines," said he, "will be provided with electric and magnetic feelers so delicate that the approach of any body under water or in darkness will be detected. Torpedoes and floating mines are almost in sight which will direct themselves automatically and without fail get in fatal contact with the object to be destroyed. The art of telautomatics, or wireless control of automatic machines at a distance, will play a very important part in future wars and, possibly, in the next phases of the present one. Such contrivances which act as if endowed with intelligence will be used in innumerable ways for attack as well as defense. They may take the shape of aeroplanes, balloons, automobiles, surface or under-water boats, or any other form according to the requirement in each special case, and will be of greater range and destructiveness than the implements now employed. I believe that the telautomatic aerial torpedo will make the large siege gun, on which so much dependence is placed at present, obsolete."

Among the most amazing predictions made by Mr. Tesla in his article in the MANUFACTURERS RECORD was the one that, within a short time, it will be possible for mankind to completely control the precipitation of the moisture of the atmosphere. He foresees the time when it will be possible to draw unlimited quantities of water from the oceans, giving moisture to the crops as required, and supplying any amount of energy to water-powers that may be desired, thus completely transforming the globe by irrigation, intensive farming and the development of unlimited hydro-electric power.

"We are progressing at an amazing pace," says Mr. Tesla, "but the truth is that even in the fields most successfully exploited the ground has only been broken. What has been so far done by electricity is nothing as compared with what the future has in store."

THE WHITE EAGLE OF POLAND: THE EMBLEM OF STRENGTH AND COURAGE



HE national characteristic of Poland is chivalry, and, with her love of the great and beautiful, she has that other inevitable essential to chivalry, tenderness. Her vision of what is great and fine has never failed her, even back to the ninth century, where her history trails off into the midst of confused European struggles. No other nation probably has lived so steadily at the point of the sword, but out of suffering she has developed a soul that in expressing itself has given the world great music, acting of the highest order, singing that has ravished all hearts, patriots not only for her own nation but for Austria, for America, for every struggling land. Poland has never been without her warriors, and alas! has never been without her need of them. She has been the battlefield not only for nations, but for art, religion, science; her sympathetic valiant people have given their lives by the thousands and hundreds of thousands in their long, vain struggle for political unification.

Poland has been the university, the academy, the hospital for all of struggling Europe for many centuries, and in return she has received little other than treachery, cruelty and torture. In the fifteenth century the great university of Cracow was the Mecca of the thoughtful world. Kosciuszko and the great astronomist Copernicus, "who stopped the sun and put the earth in motion," were both educated and taught in this university. It was in Poland, too, that the first state university of education was established and that universal public education was organized: this in seventeen hundred.

Over and over again Poland has repulsed the great invasions of the East which have threatened to destroy Christianity and civilization; she has held back the Tartar, the Turk and the Mongol. The Poles under John Sobieski saved Vienna from the terrible hordes of Musco vites. Austria has forgotten this, the Jews have forgotten Poland's hospitality and kindly refuge, Prussia and Russia have forgotten their promises and Poland's faith in them. The White Eagle of Poland has been borne through every great battlefield of the Middle Ages, and always on



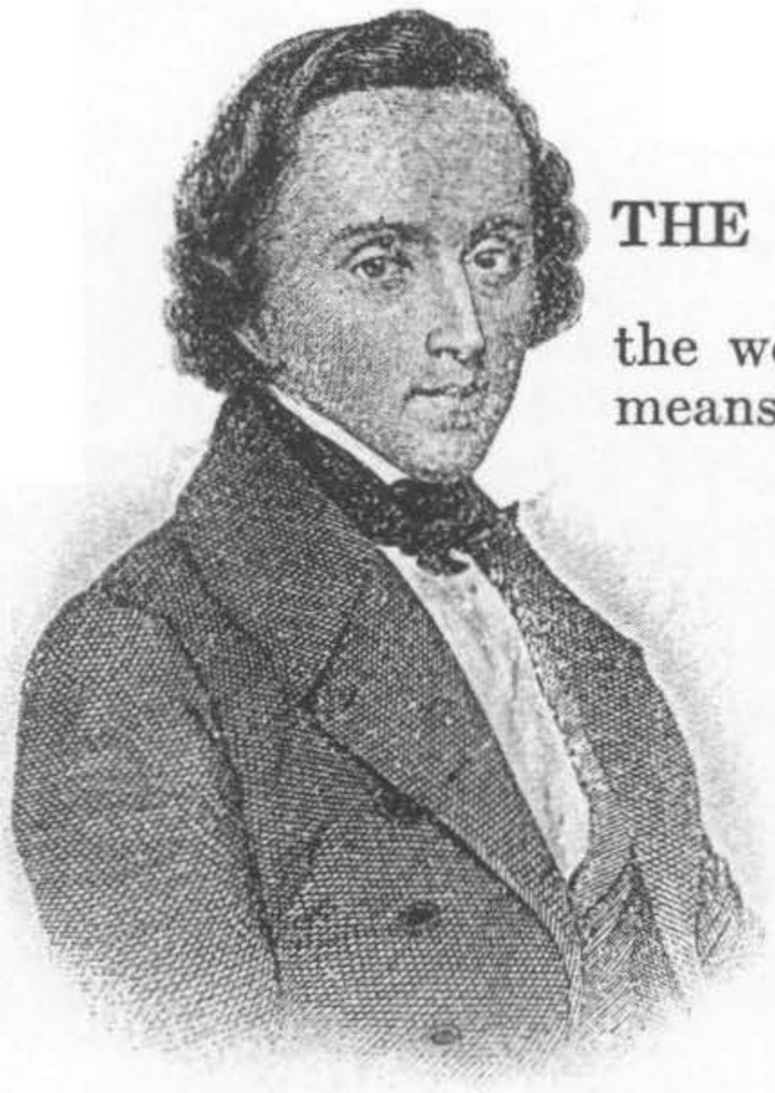


Kosciuszko, "Father of American Artillery."

the side of honor, righteousness and freedom—the White Eagle of Poland which alights on the heart of every Polish child. Because of the sound of the wings of the White Eagle, little Polish children have been beaten to death in public squares of Polish streets, and the mothers who mourned for them flogged publicly. But whatever happens to the nation, however terribly she is dismembered, even when her own sons come back doing battle under foreign flags, the White Eagle rests over the nation, and under its wings Poland's soldiers are comforted and in her breast her children rest and gain strength to struggle once more for their freedom, their power, their beauty. Whatever may be done to the men, women and children of Poland, the White Eagle cannot be maimed or wounded or soiled, and until the nation of which it is the emblem is free or dead it will hover over the stricken people—a symbol of national motherhood.

Those who know Poland love her; she has been called a hero and a knight, and she has borne patiently yet not complainingly her great suffering; she has lived her life in the battlefield, in the dungeon; her patriots have been martyrs, her heroes have quickly rested in the graveyard; but her great intellect has never weakened and the splendid fire of her vision has never been extinguished.

It was only in Poland that Chopin could have been born, it was only a Pole with heart throbbing with the anguish of his nation who could have interpreted the music of this great composer. Chopin and Paderewski have both suffered for their country, they are both great nationalists as well as great artists. Indeed, this is true of all Polish genius. Madame Sembrich is suffering profoundly with her country, Hofmann plays today for Poland's benefit, the de Reszkes are working heart and soul for their nation. Jean de Reszke is in Paris, his only son, a writer and painter, serving as a volunteer in the French army; Eduard de Reszke is in the battleground near Warsaw. He has recently written to America, saying: "We spend most of



Chopin, the great lyric composer of the world, a Pole by birth: From an old steel engraving.

the week in our cellars. We have no coal, no means of lighting—for there are neither candles nor oil—no salt and no sugar. The coffee ran out long ago, but we have some tea left. When that goes we must drink water. Prince and Princess Lubomirski, whose palace has been razed to the ground, have come to us, so have our nieces and nephews. We all keep together, wondering whether we shall live through the day or not. The nights are the worst, for we are in darkness all the time, and the roar of the guns seems worse then. But we put our trust in God and hope for the best." A most courageous expression for a man of years, once the idol of the world for his beautiful singing.

Quite rightly the weeping willow is the chosen floral emblem of Poland; the willow which is used for shade, for fuel, which protects the rivers, the source of life, a symbol of courage, a symbol, too, of tragedy, with her boughs bending sorrowfully to the earth. The White Eagle and the Weeping Willow sum up the history, the romance, the beauty and the sorrow of this country, at once the world's hero and victim.



Jean de Reszke, the Polish tenor whom America loved.

I HAVE recently seen that the first King of Poland was a peasant, Piast, chosen to rule over the country in eight hundred and fifty. It is an interesting fact that the most democratic of the European countries should have been ruled in the first place by a peasant king; it is equally interesting to remember that such an aristocracy as Poland's should have had birth in the nation of a peasant ruler. Undoubtedly throughout her national experiences Poland has been the true democrat of Europe, at least in spirit, for always the people have been in the vanguard of progressive movements. In the very earliest days of the Government, when serfdom prevailed in all the countries of Europe, the Polish peasant did not belong to the lord; he could not be sold; even when an estate passed into other hands,

the peasant was not obliged to leave his farm. He was well off, he could raise money on his property; he really possessed a home and land. Back as far as seventeen ninety-one, Poland had reached the point of giving universal suffrage to the people; and while in all other countries the citizens' rights depended chiefly on income and taxes, in general on some economical condition, in Poland the suffrage was for every man, and the poorest citizens could become nobles if they accomplished individually or collectively something fine for the nation.

In Poland the intercourse between the peasants and the nobles has always been cordial to a degree, with no special deference to the rich and powerful. Owing to the simple life led by the Polish people, there was formerly but little poverty. The form of address, "Brother," which early came into existence between all people of the nation, still survives. The general tendency of the Polish constitution from the beginning has been to have the great officers and dignitaries of state *elected*, and the repeated effort to make them hereditary was rendered futile by the general body of the people. And Poland is the only European state which down to the sixteenth century boasted no martial force except its armed and mounted nobles. An old German writer, Widukind, said back in the tenth century that the Germans made war for fame and conquest, the Poles to defend their liberty and avoid slavery. It is an extraordinary thing how national attributes persist through centuries.



Nicholas Copernicus, the Polish astronomer, "who stopped the sun and put the earth in motion."

The Poles took no part in the early religious wars which devas-

tated Europe, but Calvinists, Lutherans, Greeks were welcome to make their home there, and for a long time Poland was called the "Promised Land " of the Jews. Indeed, the Poles actually forced their kings to swear that they would tolerate all sects.

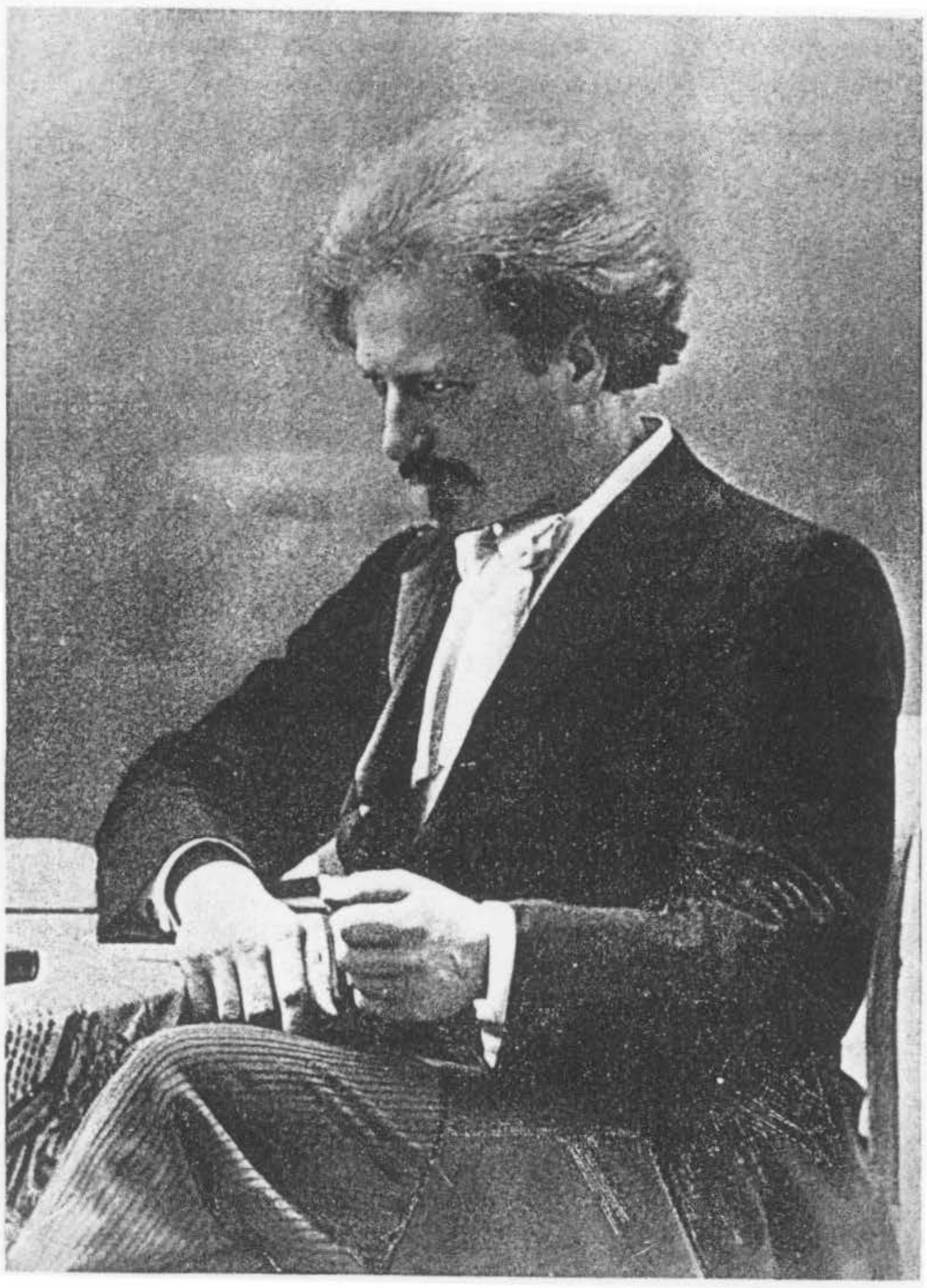
The Polish love of liberty implies a love of liberty for others. In no other country have foreigners been given such privileges as in Poland. Poland was the largest republic in Europe after the fall of the Roman republic, and to it came for refuge all the advanced reformers persecuted in their own countries. The Hussites fled to Poland from Bohemia after their defeat at the White Mountain; the Armenians came from the Caucasus in large numbers.

America perhaps more than any other nation has reason to remember the generosity of the Poles to people in trouble. She is indebted to Poland for the services of her illustrious sons—Kosciuszko and Pulaski. Kosciuszko has been called the "Father of American Artillery," and Pulaski the "Father of American Cavalry." The Polish heroes fought for independence and helped the Colonies "to form a more perfect union, establish justice, insure domestic tranquillity, provide for the common defense, promote the general welfare, and secure the blessings of liberty."

ALTHOUGH the Poles are a thoughtful people, acquainted with sorrow, they have as a race a love of natural gaiety, including dance, song and social intercourse, which spreads through every phase of society. The Slavs throughout Europe are a sincere, simple and hospitable people, and the one thing in which they differ most from their immediate neighbors, the Germans and Muscovites, is their cult for women. The influence and the independence of Polish women are evident in all their tradition, history, romance and art.

Poland early freed her womanhood from the primitive shackles of barbarism and prejudice. At the beginning of the seventeenth century, in the reign of Wladyslaw, a delegation of women from great and little Poland and from Lithuania presented a petition to the National Diet demanding legal protection of their rights, the abolition of laws designed for the exploitation of women, the granting of broader rights to mothers and the restriction of rights of fathers. And the women of Poland in turn have shown great heroism and self sacrifice for their country; they have been the inspiration of the men, sharing intellectual, political, artistic and scientific interests.

In going through the Polish "legion-of-honor" names in the world of art and science, we encounter not only many that are very familiar, but quite a number whom we have not perhaps always associated with Poland, for it seems that Fahrenheit, Kant, Nietzsche,



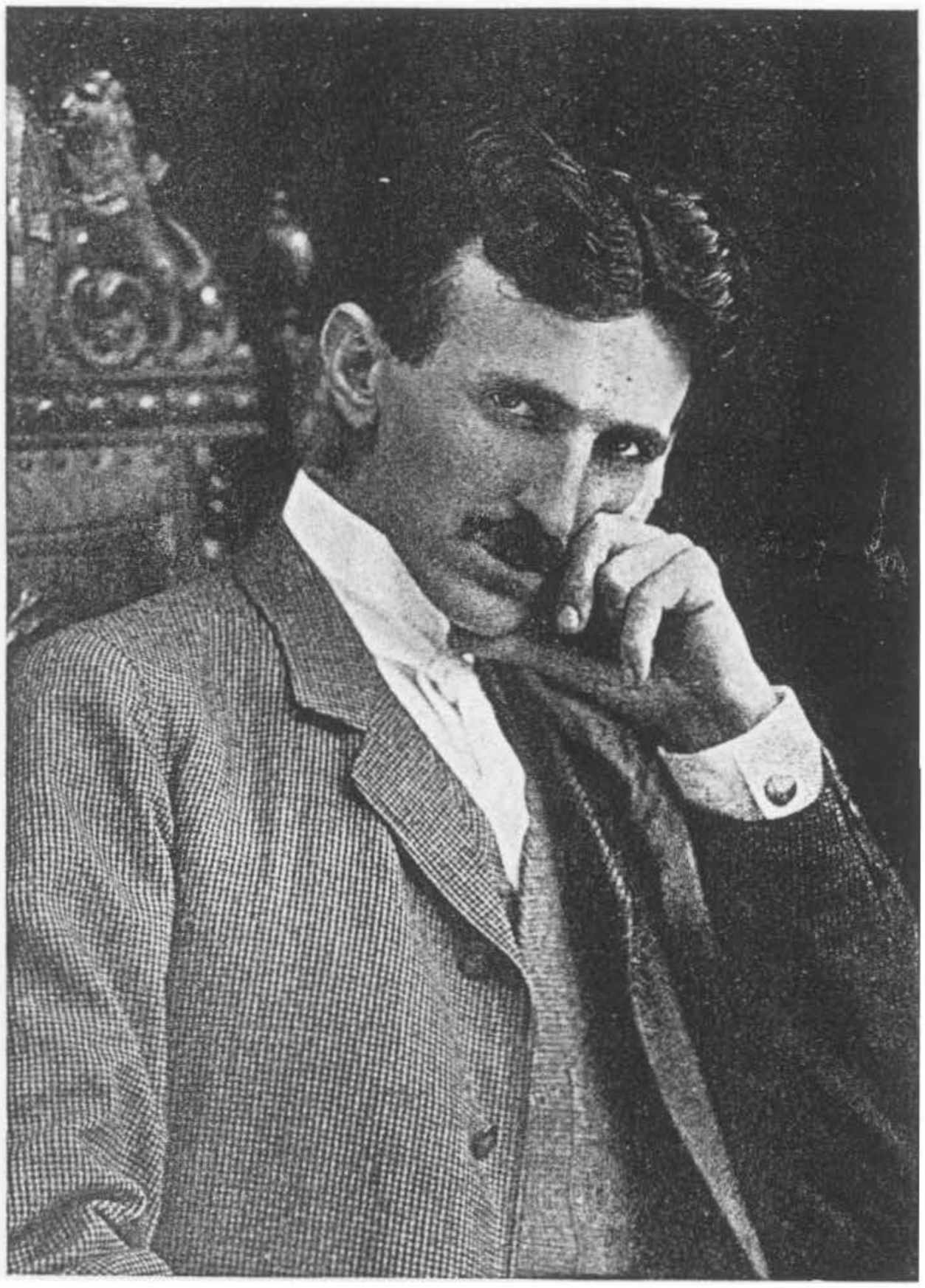
IGNACE JAN PADEREWSKI: The latest photograph of this great Polish composer and pianist.



HELENA MODJESKA, Poland's radiant actress, as well-known in America as in her native land.



MARCELLA SEMBRICH,
Poland's song bird, one of
the world's best loved artists.



NIKOLA TESLA, famous electrician, born in Austro-Poland: One of the electrical geniuses of the world.

Hauptmann, Sudermann, as well as Madame Curie, were all either of Polish descent or born on Polish soil; and Josef Conrad, the literary light of Europe today, is also a Pole, although he has lived much of his life in England and is often spoken of as an English writer. The most popular lyric poet in all Poland is a woman, Marya Konopnicka, and the most read novelist of the times is also a woman.

IT is not necessary to visit Poland in order to come in contact with her essential greatness. It is only necessary to sincerely study the art of this land of genius. In addition to some of the world's greatest musical composers, we have the singing of the de Reszkes and Sembrich, the acting of Helena Modjeska, the pictures of Matejko, Wyspianski which are inspired by Poland's beauty, Polish architecture and poetry, and Poland's most vital and inspiring dancing. The *polonez*, the *mazur* and the *krakowiak* are the three national Polish dances and they are the nation, the race in epitome. The *polonez* gives the color, the ceremony, the grace, the rhythm of the Polish aristocracy; the *mazur* brings vividly before one the gallantry, the recklessness of the landed gentry; the *krakowiak*, which is the best known in America, shows the quick, passionate abandon so characteristic of the Polish peasant; and the music for these dances produced by Polish genius seems to be out of the very bone and sinew of the dance of the nation.

With all the national and individual tragedy that Poland has experienced in the last century, and which seems to have culminated in the past months, she still has the impulse, the courage, the wisdom to continue to improve the condition of her social life. A "sociological" park has been established near Warsaw, subsidized by the Government, where to the accompaniment of an excellent orchestra, Polish plays are given every night in the year. The state official who is in charge of the plays declares that they are growing in popularity. They are at present presented in Polish, with an occasional Russian play. In Praga, one of the surburbs of Warsaw, there is a public park visited by thirty thousand people on Sundays and holidays. Here there is every opportunity in the world for wholesome merrymaking for children and old people, and the old Slav love of color, music and pleasure is to be seen. In these parks there are dancing pavilions where the national dances are enjoyed by peasant folk. There are acrobatic shows and Punch and Judy pavilions. There are also kindergarten schools in these parks, and the children are brought clean and presentable for their chance at education.

Today Poland is being crushed between the upper and the nether millstone. Russia has made her great promises and sought her co-

operation. Prussia has said, "We will make you into a great, thriving country;" but Russia has fought her battles on Polish soil, and Germany has swept through the great cities of the Poles with sword and fire. Many of her twenty-five million are fighting against her in the Prussian army, many have been conscripted in Galicia to fight with Austria, and when today Poland is at war, she does not know whether she is battling to save herself from the enemy or is destroying her own sons. It would seem as though no country had ever been so oppressed, so tortured, had ever shown such courage in facing tragedy and in holding and developing a certain national splendor.



Eduard de Reszke, the famous Polish basso, one of the most distinguished singers of the Metropolitan Opera House, New York.

There is no doubt in the minds of the most thoughtful students of political economy that Poland united and free, with her twenty-five million population and her great natural resources, would very speedily be able to maintain industrial and commercial establishments. She is, as we have already said, instinctively and by tradition a democracy, she is also possessed of the finest of all aristocracies, that of art and literature. Her people are inventive, profoundly sincere in their scientific activities, imaginative in their music, painting and sculpture, still possessing the primitive fire which means a land of singing, dancing people. With the deepest respect for the achievements of other nations, with the widest sympathy for their sorrows or disasters, with an absolutely unconquerable patriotism, Poland stands today the saddest, most gifted, most splendid of small nations, begging only for her freedom and offering the world rich returns in hospitality, beauty and progress. Poland now turns to America. What will she receive?

Editor's note:—Just as we are going to press we hear that both Sembrich and Paderewski are starting out on a campaign for the relief of Poland. Paderewski has lectured and played at Carnegie Hall and Mme. Sembrich is really devoting her life to the raising of a fund for the helpless, sick and starving in her native land. It is a spectacle of some fineness when the great of the land, the great artistically, give their genius and strength to aid and ameliorate the sorrows of the very desolate of their own country.

The New York Herald November 6, 1915

NOBEL PRIZES FOR EDISON AND TESLA

American Inventors Get Award in Physics and Professor Svedberg in Chemistry.

London, Saturday.—The Copenhagen correspondent of the Daily Telegraph sends the following:—

"The Swedish government has decided to distribute the Nobel prizes next week, as follows:—

"Physics, Mr. Thomas A. Edison and Mr. Nikola Tesla; literature, Mr. Romain Rolland, French; Mr. Hendrik Pontoppidan and Mr. Troels Lund, Danes, and Mr. Verner von Heidenstam, a Swede; chemistry, Professor Theodor Svedberg."

The New York Times November 6, 1915

Edison and Tesla To Get Nobel Prizes

LONDON, Nov. 6.—The Copenhagen correspondent of The Daily Telegraph sends the following:

"The Swedish Government has decided to distribute the Nobel prizes next week, as follows:

"Physics—Thomas A. Edison and Nikola Tesla.

"Literature — Romain Rolland, French; Hendrik Pontoppidan and Troels Lund, Danes, and Verner von Heidenstam, a Swede.

Chemistry — Professor Theodor Svedberg."

The New York Times November 7, 1915

TESLA'S DISCOVERY NOBEL PRIZE WINNER

Transmission of Electrical Energy Without Wires, Which Affects Present-Day Problems.

TO ILLUMINATE THE OCEAN

Scientist Says Collisions Will Be Avoided and Unlimited Water Drawn to Irrigate Deserts.

Nikola Tesla, who, with Thomas A. Edison is to share the Nobel Prize in Physics, according to a dispatch from London, said last evening that he had not yet been officially notified of the honor. His only information on the matter was the dispatch in THE NEW YORK TIMES.

"I have concluded," he said, "that the honor has been conferred upon me in acknowledgment of a discovery announced a short time ago which concerns the transmission of electrical energy without wires. This discovery means that electrical effects of unlimited intensity and power can be produced, so that not only can energy be transmitted for all practical purposes to any terrestrial distance, but even effects of cosmic magnitude may be created."

Mr. Tesla said the discovery had a direct and vital bearing on the problems now foremost in the public mind. For instance, he said, wireless telephony would be brought to a perfection undreamed of through the application of this discovery. He added:

"We will deprive the ocean of its terrors by illuminating the sky, thus avoiding collisions at sea and other disasters caused by darkness. We will draw unlimited quantities of water from the ocean and irrigate the deserts and other arid regions. In this way we will fertilize the soil and derive any amount of power from the sun. I also believe that ultimately all battles, if they should come, will be waged by electrical waves instead of explosives."

Mr. Tesla refused to go further into the matter. He said he thought Mr. Edison was worthy of a dozen Nobel prizes. He knew nothing of the discovery, he said, that induced the authorities in Sweden to confer the great honor on Mr. Edison.

The St. Louis Post Dispatch November 12, 1915

HARVARD SCIENTIST WINS 1914 NOBEL CHEMISTRY PRIZE

Prof. Theodore W. Richards Fixed the Atomic Weights of Chemical Elements.

LONDON, Nov. 12.—The Nobel prize for physics for 1914, says a Reuter dispatch from Stockholm, has been awarded to Prof Max von Lade of Frankfort-on-Main for his discovery of the diffraction of r·ys in crystals.

The chemistry prize for the same year has been awarded to Prof. Theodore William Richard of Harvard University, for fixing the atomic weights of chemical elements.

The prizes for 1915 will be awarded today.

Prof. Richards Is Director of Gibbs Memorial Laboratory at Harvard.

CAMBRIDGE, Mass., Nov. 12.—Prof. Theodore William Richards of Harvard University, 1914 Nobel prize winner, is director of the Gibbs Memorial Laboratory. He is an investigator in physical and inorganic chemistry and the author of papers concerning the significance of changing atomic volume. With assistants he has revised the atomic weights of oxygen, iron, New York calcium, sodium and many other elements.

Prof. Richards is a member of the International Commission on Atomic Weights. He was awarded the Davy medal by the Royal Society in 1910 and the Gibbs medal by the American Chemical Society in 1912. He is a member of many of the leading scientific societies of Germany, Sweden and the United States.

The New York Times November 13, 1915

NOBEL PRIZE FOR RICHARDS

Chemistry Award for 1914 Goes to the Harvard Investigator.

LONDON, Nov. 12.—The Nobel Prize for Physics for 1914, says a Reuter dispatch from Stockholm, has been awarded to Professor Max von Laue of Frankfort-on-Main for his discovery of the diffraction of rays in crystals.

The chemistry prize for the same year has been awarded to Professor Theodore William Richards of Harvard University for fixing the atom weights of chemical elements. The prizes for 1915 will be awarded today.

Professor Richards was born in Germantown, Penn., and is in his forty-seventh year. He was educated in this country and abroad, and has many degrees, both from universities of this country and Europe.

Since 1894 he has been connected with the chemistry department of Harvard University, and in 1907 became an exchange professor at the University of Berlin. Professor Richards has long been prominent in atomic weight research, and, with the help of assistants, has determined the atomic weight of nineteen important substances, including silver and oxygen. He has a high reputation as an investigator in physical and organic chemistry, and is the author of recent papers on the significance of changing atomic volume and a new atomic theory, as well as on thermo-chemistry and electro-chemistry.

Professor Richards is a member of the International Commission on Atomic Weights, a Davy Medalist of the Royal Society, an ex-President of the American Chemical Society, a member of the Chemists' Club of this city, and is affiliated with a number of other foreign and local scientific organizations.

Electrical World

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The Nobel Prize

ANNOUNCEMENT of the award of the Nobel prize in physics to Edison and Tesla will give great satisfaction to the engineering profession in our country, to which both have contributed distinguished services. It is gratifying also to realize that, aside from pioneer work in engineering, both have done notable work in the advance of science. The name of Thomas Alva Edison has been long associated with the invention and development of the incandescent electric lamp. When he brought his inventive genius to bear on the incandescent-lamp problem results followed which have built up an enormous industry. His indefatigable persistence won where all others had failed, and not only did he solve the fundamental problem of the lamp but he turned out almost simultaneously a complete system for its practical utilization. But Mr. Edison would still rank as one of the very greatest inventors of modern times if someone else had done this splendid work and his reputation had to rest solely on other achievements. His well-known labors in purely telegraphic matters were triumphs of ingenuity, but yet more striking and original was his now almost forgotten invention of the electrolytic relay, which is reputed to have won for him one of the largest payments ever made for a patent. Later his ingenuity was lent to develop the telephone transmitter, and at about the same time came the beginnings of the phonograph, by all means his most brilliant contribution to physics. And later yet have come his contributions to art and science in the invention and development of motion pictures. There is no space here to recite the long list of what Edison has accomplished, but the Nobel foundation honors itself in appreciating what he has done for science, to say nothing of his prodigious activity in the industrial arts.

To Nikola Tesla the world owes that great impulse which has resulted in the whole modern art and science of power transmission. The use of alternating current for practical electrical distribution began with his development of the induction motor, which at once gave the general flexibility and usefulness of the system its due place in the practical world. With that invention the struggle between direct and alternating currents presently ceased, and each fell into its proper sphere of usefulness, of which the boundaries are still expanding. The development of the art was rapid, for the seed that Tesla sowed fell upon good ground. Those who followed the development of the art in its earlier years remember to their sorrow the number of times they found their earnest efforts at improvement just a lap or two behind Tesla's inventive genius in the running. His later pioneering work in the development of high-frequency currents in theory and practice displayed brilliant resourcefulness. In wireless telegraphy, on which he spent a long period of tireless research, inventors of the present and future will find themselves often confronted with the results of his inventive energy and keen scientific insight. His grasp of alternating-current phenomena has left the indelible mark of his originality on the progress of the electrical arts, and his participation in the Nobel prize is a proper and worthy appreciation of his genius. Those who remember Tesla's lecture before the Institute of Electrical Engineers on high-frequency phenomena, now nearly a quarter of a century ago, realize the extent to which his investigations opened the way to a field of which we have not even yet seen the full fruition. The country may well be proud of the recognition given in this award to men who thus have been in the front rank of its victorious march in applied science.

A Chronicle of Events of the Industry and of Important Movements in the Field

NEWS OF THE WEEK

Reports of Conventions and Meetings of Electrical Associations and Societies

Edison and Tesla Win Nobel Prize

Under date of Nov. 6, the Copenhagen correspondent of the London *Daily Telegraph* sends the following:

"The Swedish government has decided to distribute the Nobel prizes next week as follows:

"Physics, Thomas A. Edison and Nikola Tesla; literature, Romain Rolland (French), Hendrik Pontoppidan and Troels Lund (Danes), and Verner von Heidenstam (Swede); chemistry, Prof. Theodor Sveberg."

No confirmation of the story could be obtained, and neither Mr. Edison nor Mr. Tesla has received any intimation of the award except through the daily press account.

America does not produce so many Nobel prize-winners that a man thus singled out might not be supposed to have first reached a considerable popular reputation. But another evidence of the Cinderella part played by abstract science in this country appears in the necessity for printing a short identifying biography with the announcement that Prof. Theodore W. Richards has been awarded the belated 1914 prize for the most important chemical discovery or invention. It would be easy to name a half-dozen men in America who have become well known in industrial chemistry, but there is no path to popular fame in the revision of the atomic weights of the more common elements, or in investigations of changing atomic volume. In Germany, where the award to Professor Richards has been noted with a satisfaction born of the fact that he studied under Nernst and Ostwald, and made public his first discoveries under the auspices of the German Chemical Society, he was probably better known than anywhere outside New England. In the scientific world international recognition of marked achievement is prompt, and the Harvard chemist had already received a large number of honors from British and Continental sources. In few other lands would such a prophet have been without more honor at home.

The Electrical Experimenter

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Edison and Tesla

If the recent cabled reports be correct, every American will note with great satisfaction the awarding of this year's Nobel prize in physics to Thomas A. Edison and to Nikola Tesla.

When Alfred Nobel, the multi-millionaire inventor of dynamite and nitroglycerine died in 1896, his will provided for a series of five annual prizes to the most deserving persons in physics, chemistry, medicine, literature and for the best work done in the interest of universal peace.

These prizes have been regularly awarded since 1901, and the learned Academies of Sweden while admittedly well informed and fair as to the award of the prize, have in the past, we believe, overlooked several scientists who by all means were entitled to the prize long ere this.

We are quite convinced, for this reason, that this year's choice of Edison and Tesla will not only be acclaimed in the United States, but in the world over. For, if the world is indebted to two physicists, Edison and Tesla are certainly the biggest single creditors.

The awarding of the Nobel prize in a single year to these two world renowned inventors naturally leads to the question: Who is the greater man, Edison or Tesla? A natural question such as this which surely will arise in the popular mind is manifestly unfair, because the two illustrious scientists have been working in dissimilar fields and their accomplishments are vastly different. Besides, Edison as well as Tesla are hard at work at this minute, and for that reason it is impossible to foretell what they might not still accomplish.

Without wishing to minimize Edison's tremendous amount of work, the fact is well known that he is not so much an original inventor as a genius in perfecting existing inventions.

In this respect Tesla has perhaps been the reverse for he has to his credit a number of brilliant as well as original inventions which, however, have not been sufficiently perfected to permit commercial exploitation.

If the average man were asked what Mr. Edison's greatest gifts to the world are, his choice probably would fall on the Incandescent lamp, the Phonograph and the Cinematograph. Undoubtedly this is a good selection, but it is but a small fraction of the 1,400 inventions which Mr. Edison has patented up to this date. The incandescent lamp would not have been much of avail to humanity had not Edison perfected at the same time the necessary adjuncts to feed the current to the lamp. He had to make dozens of inventions to accomplish this; the lamp itself was the least of his troubles. Exactly so with the phonograph and the cinematograph, several hundred inventions were necessary before either was ready to leave the laboratory. Thus it is a far cry and a weary road from his first tin foil phonograph record to his gold moulded unbreakable Amberol record.

Equally as great as the three above inventions are Edison triumphs in the field of telegraphy, which he revolutionized. His quadruplex telegraph, his telephone transmitter, his alkaline storage battery, his stock printer, his machine for separating magnetic ores, his Portland cement process, his concrete building standardization, are all inventions of the first order.

While Tesla's inventions have not been so numerous as Edison's the world nevertheless owes Tesla a tremendous debt. The modern transmission of power electrically is due entirely to Tesla. Perhaps his greatest invention is the alternating current induction motor, whose wonderful flexibility and vast usefulness have made electrical power what it is to-day. His pioneer work in high frequency currents showed the true genius of the man. This art is as yet but in its infancy and no one can foretell where it will lead us, but it certainly has already opened the way towards the transmission of power without wires. It is not popularly known, but the fact remains that Tesla invented a system of transmitting wireless impulses through the ether in 1893, three years before Marconi began his historical wireless experiments. His wonderful researches on vacuum tubes under the influence of high frequency Tesla currents have practically demonstrated that the day is not far off when the 95 per cent. of electrical energy now wasted in heat in all incandescent lamps will be turned into *cold* light, that is light without heat. In the long list of brilliant inventions of Tesla, we particularly wish to mention the following: His Sun motor for the utilization of solar energy, his new fluid propulsion turbine, the Tesla high-frequency coil, his rotary transformer, etc. Mr. Tesla's patents now number above 100.

H. GERNSBACK.

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THE ELECTRICAL EXPERIMENTER

H. GERNSBACK EDITOR
H. W. SECOR ASSOCIATE EDITOR

Vol. III. Whole No. 32 DECEMBER, 1915 Number 8

The Radio League of America

HONORARY MEMBERS

Captain W. H. G. Bullard, U. S. N. **Prof. Reginald A. Fessenden.**
Nikola Tesla. **Dr. Lee de Forest.**

Manager, H. Gernsback

A Retrospect.

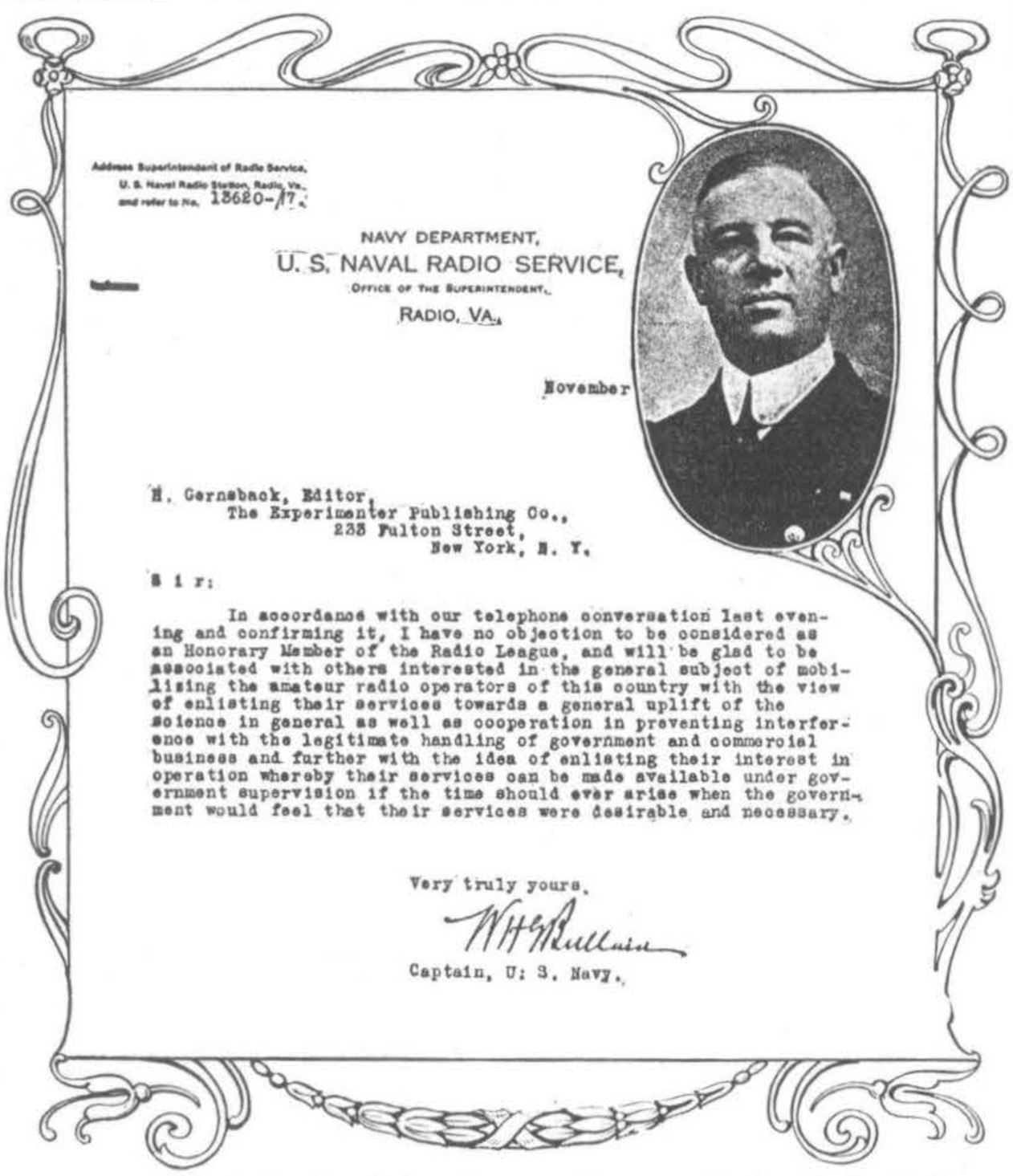
DURING the past year the need of a national body to champion the cause of the wireless amateurs in the United States has become more and more pressing. There are now over 300,000 radio amateurs and about 350 local clubs in existence in the United States, but there is no national body to safeguard the interests of the amateurs.

When H. Gernsback, in 1909, organized the *Wireless Association of America,* there did not exist at that time a wireless club in the United States. There were then, of course, numerous radio amateurs in this country, but the wireless art—as far as the amateur was concerned—was only in its earliest infancy. Mr. Gernsback, who at that time sensed approaching danger to the wireless amateurs in the form of hostile legislation, succeeded in banding together the majority of wireless enthusiasts, and the membership of the association grew rapidly till at the end of 1912 there had been enrolled no less than 22,300 members.

In those early days the wireless amateurs in this country were a rather reckless sort of element and became more and more disliked on account of their growing mischief. False distress and alarm calls by perverted "humorists" were the usual "smart" acts, and when a coastal station received a C.Q.D. call in those days the thought was always uppermost in the operator's mind that the call was one of the usual amateur hoaxes. Despite Mr. Gernsback's vigorous warnings through his editorials in *Modern Electrics,* of which publication he was editor, the mischief continued, till in 1910 several bills were introduced in Washington which fairly promised to throttle the activities of every wireless enthusiast in the country.

This, of course, brought the amateurs to their senses speedily, but had it not been for the formation of the *Wireless Association of America* a year earlier, all efforts would have been in vain and the amateur would to-day be as dead an issue as he is at present in Europe. Through the Association Mr. Gernsback caused thousands of letters to be written to Washington officials by the wireless amateurs, and he furthermore succeeded in enlisting the press of the country in taking up the cry to save the amateurs from hostile legislation. All this had the desired effect, and when finally in 1913 the Alexander Wireless bill, *amended,* was signed by President Taft, thereby becoming law, it contained almost word for word Mr. Gernsback's historical recommendation of his editorial in the February, 1912, issue of *Modern Electrics.* As is well known, that editorial called the attention to the lawmakers that in case the amateurs were to be restricted the latter should be allowed to operate their stations at a wave length below 200 meters, and they should furthermore be allowed the use of power up to one kilowatt. This suggestion saved the day, and the amateur at last had come into his own.

With the passing of the wireless act in 1913 the usefulness of the *Wireless Association of America* had come to an end, and thus matters rested.



Address Superintendent of Radio Service,
U. S. Naval Radio Station, Radio, Va.,
and refer to No. 13620-17.

NAVY DEPARTMENT,
U. S. NAVAL RADIO SERVICE,
OFFICE OF THE SUPERINTENDENT,
RADIO, VA.,

November

H. Gernsback, Editor,
The Experimenter Publishing Co.,
233 Fulton Street,
New York, N. Y.

Sir:

In accordance with our telephone conversation last evening and confirming it, I have no objection to be considered as an Honorary Member of the Radio League, and will be glad to be associated with others interested in the general subject of mobilizing the amateur radio operators of this country with the view of enlisting their services towards a general uplift of the science in general as well as cooperation in preventing interference with the legitimate handling of government and commercial business and further with the idea of enlisting their interest in operation whereby their services can be made available under government supervision if the time should ever arise when the government would feel that their services were desirable and necessary.

Very truly yours,

W. H. G. Bullard

Captain, U. S. Navy.

Captain Bullard's Letter of Acceptance as Honorary Member in the Radio League of America.

A Formidable Defense Weapon.

THE advent of the great European war in 1914 found the United States in an unprepared condition as regards its defenses and vigorous steps were promptly taken to wake us up from our lethargy. President Wilson's recommendation to the country for a vast increase of our army and navy has been so much discussed of late that no further reference to his valuable advice is required here. It suffices to say that probably a vast majority of citizens indorse the President's defensive military program.

But there exists to-day a formidable defense weapon, which up to now has not been exploited by Uncle Sam. We refer

to the thousands of amateur radio stations scattered broadcast through the entire length and breadth of this fair land. There is hardly a hamlet today which does not boast of several amateur wireless stations, and their number is increasing by many hundreds each day.

As the European war has so thoroughly demonstrated quick transmission of intelligence is of paramount importance. Telegraph and telephone lines are put out of order with ridiculously small effort by the


COMPAGNIE FRANÇAISE DES CÂBLES TÉLÉGRAPHIQUES

The following MESSAGE is received via FRENCH TELEGRAPH CABLE, subject to the terms and conditions printed on the back hereof, which are ratified and agreed to.

GD 18 PARIS 14

EXPUCO NY

WILL ACCEPT HONORARY MEMBERSHIP IN RADIO LEAGUE OF AMERICA

DE FOREST






Nikola Tesla's Acceptance as Honorary Member in the Radio League of America.

Professor Reginald A. Fessenden's Acceptance as Honorary Member in the Radio League of America.

Above: Dr. Lee de Forest's Acceptance as Honorary Member in the Radio League of America.

enemy and whole sections of country are thereby isolated. Such sections are then helpless and no important messages can be safely transmitted in either direction. All this helps the enemy enormously, and the thus isolated section is then entirely at his mercy. If France or Belgium had possessed an effective amateur wireless scout service there might possibly be a different story to tell to-day. In these days of fast military movements, quick reporting of war intelligence is of incalculable importance, and if this is true of Europe, it is even truer in the United States, the country of such vast and undefended coast lines.

One needs not be a dreamer in order to appreciate how easily a hostile fleet could approach our long, badly patroled coasts and try a landing of an armed force. There might not be a telegraph or telephone line around for miles, or if it did exist, it is certain that spies operating on land would have found little trouble in putting it out of commission beforehand.

But there will be a lone radio amateur on the alert who has seen the approaching fleet and within 30 seconds Washington will have the priceless intelligence. Vice versa, there might be a handful of poorly equipped United States militia holding the enemy at bay temporarily. It is conceivable that this small body of men might have neither sending nor receiving radio apparatus. Somewhere back of the hills the United States regulars are coming to the rescue of the sorely pressed militia men. They want the latter to hold out for a few short hours and want to tell them of their coming. The radio message containing this intelligence is flashed over the hills, but is not received by the exhausted men. However, just as all hope is given up, a lad of 17 years with streaming hair runs up to the major of the small band and breathlessly conveys the cheering news to him. He caught the message over his pitiful 30-foot aerial on top of his barn, but it saved the day. He did not even have a sending station. His outfit comprised only a cheap home-made receiving "set"! But it did the work, just the same.

Such occasions are almost certain to arise in the future, and it is thus of the utmost importance that every patriotic radio amateur should offer his station to his country.

The Duty of the Amateur.

IF Uncle Sam grants the amateur the free use of the ether it is certainly up to the amateur to give something in return for the privilege. It was with this thought uppermost in his mind that Mr. Gernsback in July, 1915, first conceived the idea of organizing the Radio League of America.

By referring to the 1915 Government book, *Radio Stations of the United States*, it will be seen that only 3,723 amateurs have been licensed since 1913. The reason for this surprisingly small registration is found in the fact that the law does not require receiving stations to be licensed, nor small sending stations located in the interior of large States, where the effect of a weak spark coil would not extend over the State borders. Such stations are exceedingly numerous and have been estimated to run above 300,000. Now, then, there appears no reason for doubt that sooner or later the Government would pass a new law requiring the registration and licensing of such stations in order to have such stations available in case of national stress.

No one can foretell what surprises such a new law will bring the amateurs, and for that reason it cannot be denied that it is far better and more patriotic to give this necessary information voluntarily to the Government, instead of waiting till a new law is passed which might perhaps be detrimental from the viewpoint of the amateur.

The League's Charter.

THE Radio League of America was organized at New York under the laws of the State of New York in October, 1915.

Its charter follows:

NAVY DEPARTMENT,

U. S. NAVAL RADIO SERVICE.

OFFICE OF THE SUPERINTENDENT.

RADIO, VA..

H. Gernsback, Editor,
SIR:

I beg leave to acknowledge the receipt of your letter of November 8, 1915, submitting information concerning the *Radio League of America,* together with a copy of the Certificate of Membership.

It seems to me that you have undertaken to carry through a very patriotic motive in banding together the great number of amateur wireless operators in the United States, which, as you state, now number probably over 50,000, of which only about 3,000 have been licensed; it being presumed that the remainder operate receiving stations only, and under the law are not required to have licenses. This latter proposition I regard as a very serious detriment to the proper government control of wireless stations, and am of the belief that legislation should provide that all stations, whether for transmitting or receiving, should be licensed by the Federal Government. Although the Radio Act provides penalties for divulging any information received by means of wireless receiving circuits, yet the fact that important government messages might be received by unscrupulous amateurs not friendly to the home government renders some form of protection necessary, and, I might add, will be advocated this coming Congress.

The Naval Radio Service is particularly anxious to increase its operating personnel in time of public peril when many private stations, ship and shore, would probably be taken over by the general government, and the thought has arisen that through co-operation with the *Radio League* many of its members would like to enroll themselves for active service under the Navy Department at such times as their services might be required.

You can readily understand that any information collected by the Radio League will be of the greatest value to this service and this office will be glad to avail itself of your kind offer to furnish such free of all cost, this to contain the names, locations, etc., of all amateurs in the United States.

I should like further to take advantage of this opportunity to ask your co-operation in enrolling members of the *Radio League* for government (Navy Department) operation in time of war, and take this opportunity to enclose a circular prepared in this office which we have sent out to operating wireless companies in the United States, who in turn have distributed them to their operators, with the result that many civilian operators have engaged themselves to enlist in the Navy in time of war. Could we not do something similar to enlist members of your *League,* and would you lend your efforts to co-operate along these lines by giving the matter a little publicity? From the monthly list you propose to furnish we can get the names and addresses of many amateurs, among whom we might find many who would wish to enroll themselves. Of course, the forwarding letter accompanying the circular would have to be modified, but that could easily be done to call the attention of amateurs to how they can really serve their country in time of need.

Please accept my thanks for thus being allowed to bring to your attention certain views in connection with the *Radio League,* an organization which can be made to be of the utmost help to the government, and by focusing the attention on existing laws bring home to every amateur the desirability of co-operation all along the line to correct the great question of interference with proper government, commercial and other legitimate correspondence handled by means of the wireless art.

Very truly yours,
(Signed) *W.H.G. Bullard,*
Captain U. S. Navy,
Supt. Radio Service.

---

as a wireless amateur, **for he obviously refused to pledge his station to his Government.**

Privileges of the League's Members.

INASMUCH as the League has been organized for the benefit of the wireless amateur, its members are entitled to the following privileges:

Introduction to other members.

All members are registered on cards at the headquarters of the League. The names are filed geographically by State and town. Let us suppose you live in Plattsburg, O., and that you own a wireless receiving outfit. You very much desire to know several radio amateurs in your vicinity, but you have no means of making their acquaintance. As a member of the League you mail a letter to headquarters asking for the names of any wireless amateurs located in your vicinity. Such information will be given free to members, providing a two cent stamp is inclosed with the inquiry to cover postage. As a member of good standing in the League the other members will receive you gladly, and the future relationship between you and these members depends entirely upon yourself. Thus the



The League's Official Button.

League will be highly instrumental in bringing together members and cementing their friendship.

Associations and Clubs.

A LOCAL wireless association, or radio club, to be officially recognized by the League must have at least six members. There should be a president, a treasurer and a secretary. The address where such a body meets should be stated. Clubs and associations should meet at least once a month. The above requirements are necessary to secure publication in the *Electrical Experimenter,* as well as recognition in the "Radio League of America's Official Year Book."

In this book, to be issued once a year, will be found all the important League news, a full listing of all the clubs and associations, as well as a complete list of all the members.

The League particularly indorses and encourages the rendering of scientific lectures by their members. The latter should write scientific papers, particularly those that have a wireless subject as its theme. The president of the club should select the best paper in his opinion, and it should be sent then to the editors of the *Electrical Experimenter.* If it has sufficient merit it will be published in due course in the *Electrical Experimenter.* It will show the title of the author as well as a sub-title, giving the name of the club to which the author belongs.

Once a year the best paper from among those that were published in the *Electrical Experimenter* will be selected by the editors and this prize paper will be published in the official year book. This honor will only be accorded to one paper.

Official League Insignia.

AN official button securable only by the League's members is illustrated herewith. This distinctive, as well as striking, design measures ¾ inch in diameter. It is inlaid in real, hard enamel in the three national colors, red, white and blue. The aerial design as well as the mast is in gold on a dark blue background. The button is heavily gold filled and is guaranteed by the makers not to tarnish for two years. It will positively not turn brassy. You will be proud to wear one of these distinctive buttons.

The League furnishes the button at cost; the price, including mailing, being 20c. Both the membership certificate and the button will be sent for 25c. prepaid.

A solid gold button as described above is furnished for $2 prepaid to those not desiring a gold filled one. The solid gold button and the membership certificate will be furnished for $2.05 prepaid, the actual cost of both.

All communications should be addressed to

THE RADIO LEAGUE OF AMERICA,
233 Fulton Street, New York City.

Description of My Station and Apparatus

Sending .....

.....

.....

.....

.....

Receiving .....

.....

.....

.....

.....

(OVER)

CERTIFICATE OF INCORPORATION
OF THE
RADIO LEAGUE OF AMERICA, INC.

State of New York
City of New York } ss.:
County of New York

We, The Undersigned, of full age, citizens of the United States, a majority of whom are citizens of the State of New York and resident therein, being desirous of associating ourselves together for our mutual welfare and advancement, as hereinafter is more particularly described, pursuant to and in conformity with Chapter Forty (40) of the Laws of 1909 and known as the Membership Corporations Law, do hereby certify and declare as follows:

First—That the name by which the said corporation hereby to be formed shall be known and distinguished is and shall be *Radio League of America, Inc.*

Second—That the purposes for which the corporation is to be formed are as follows:

To promote the art of amateur wireless telegraphy and telephony in the United States among the members of the said corporation; to have available for the Government of the United States or any of its officials a complete list of all the amateur radio stations in the country pledged to the service of the Government for use in times of national danger or need; to establish a uniformity in the transmission of wireless messages by amateurs; to uphold the provisions of a law known as the Wireless Act of 1912 and all subsequent laws pertaining to wireless telegraphy; to assist the Government of the United States or any of its officials in apprehending offenders thereof; to prevent the sending of misleading wireless messages; to give information to the members of the said corporation concerning new and useful devices in the operation of wireless telegraphy and telephony and to provide an organization for the interchange of ideas concerning wireless telegraphy and telephony for the benefit of the members and the public at large.

Third—That the number of directors of the said corporation shall be and are five (5) in number; and that the names and residences of such directors who shall manage its concerns until the first annual meeting are as follows: (See below.)

Fourth—That the territory in which the operations of the corporation are to be principally conducted is the entire United States, and that its principal office shall be and is located in the Borough of Manhattan, City, County and State of New York.

Fifth—That the said corporation shall hold its annual meetings on the first Monday in October in each and every year beginning with the year 1916 (October 2, 1916), and annually thereafter.

In Witness Whereof we have made and signed this certificate in duplicate and have hereunto set our hands and seals this 25th day of October, 1915.

Hugo Gernsback, Sidney Gernsback, Milton Hymes, Harry W. Secor, Frederick H. Pruden.

As will be seen, the League is a purely scientific organization. There are no dues, no membership fees to be paid. It has been organized under the auspices of the world's greatest wireless men, who thoroughly indorse its principles. It is not a money making organization, nor is it conducted by a commercial wireless company for its benefit.

The *Electrical Experimenter* has been selected as the league's official organ, as this journal, with the largest circulation of any wireless publication at present, reaches either directly or indirectly almost every wireless amateur in the country to-day. It will publish the league's news from month to month, thereby keeping up the interest of its members.

The League's Rules.

EVERY wireless amateur of good standing, whether he has a sending or a receiving station, is eligible for membership. There are but two conditions:

1. He must be a citizen of the United States.
2. He must own either a sending or receiving station, or both.

Each member will be supplied with an official membership certificate furnished free by the Radio League of America. Our illustration gives a good idea of this beautiful certificate, but it must be seen to be fully appreciated. It is lithographed on a heavy bond paper in green and gold, and its size is 15x11¼ inches. The text follows:

CERTIFICATE OF MEMBERSHIP
TO THE
RADIO LEAGUE OF AMERICA.

A membership organization organized under laws of State of New York.

I, the undersigned, a radio amateur, do hereby apply for membership in the Radio League of America, upon the express condition that by so doing I do not assume or incur any liability either for dues, assessments or any financial obligations whatsoever, and, if accepted, I do agree to follow and abide by the rules and regulations of the league as set forth herein, and all other rules and regulations which may hereafter be adopted.

Rule 1. To observe all rules and regulations of the *Wireless Act* of 1912 (as set forth on the back of this certificate).

Rule 2. That I will at all times have my station in readiness and at the service of the United States Government for use in any defensive or offensive purpose in periods of war, riot or disaster.

Rule 3. That I will at all times allow my station and equipment to be used by the United States Government or any of its officials, and will assist, if possible, in apprehending offenders violating the Wireless Act.

Rule 4. I furthermore solemnly and distinctly pledge myself not to send out at any time whatsoever, a misleading call, particularly a distress call (S. O. S. . . . — — — . . .) nor knowingly allow another to use my station for sending out such a call.

Rule 5. That I will at all times, in case of necessity transmit a distress call to the nearest official, either by wireless, by wire, or in person, and that I will do everything in my power to bring assistance to the party or parties thus in danger.

Rule 6. That I will communicate to the League such information concerning the operation and construction of my radio station as will be helpful or instructive to the other members of the League.

Rule 7. That I will, when requested, furnish information concerning my radio station and observations, which information is to be used by the League in its compilation of wireless statistics.

Rule 8. That I will carefully read and adopt any suggestions published by the League for the benefit of its members, and the transmission of wireless communications.

Rule 9. That in case of my removal to another address, or in case of the permanent discontinuance of my station, I will immediately communicate such facts to the manager of the Radio League of America.

Rule 10. That I will display my membership certificate in the League in a conspicuous place in my radio station.

In witness whereof I have signed my name and address, etc.

Each certificate is numbered and a member is entitled to one membership certificate only. Before the League can furnish a certificate it is necessary that the prospective member shall fill out an *application for membership;* a convenient blank being printed below. (If it is not desirable to cut up the magazine, a blank will be promptly mailed on receipt of a 2c. stamp to cover necessary mail charges.)

No blank is valid nor can it be accepted unless it is filled out properly as prescribed. Two persons must sign as witnesses to the signature and these may be two friends, or your father and your mother, or a sister and a brother, etc.

Upon receipt of the application blank the official membership certificate will be mailed. Ten cents in stamps or in coin should be inclosed to cover mail charges, handling, as well as the heavy cardboard tube to insure safe delivery.

Upon receipt of the membership certificate by the member it must be signed at once in ink in its proper place, and it should then be suitably framed and hung up in the station in a conspicuous place.

It will give your station official recognition, and within the next few months the amateur who cannot produce an official membership certificate *will hardly be looked upon on a par with officially recognized amateurs.* He will have but little standing

Application for Membership in the Radio League of America

I, THE UNDERSIGNED, a Radio Amateur, am the owner of a Wireless Station described in full on the back of this application. My station has been in use since....., and I herewith desire to apply for membership in the RADIO LEAGUE OF AMERICA. I have read all the rules of the LEAGUE, and I hereby give my word of honor to abide by all the rules, and I particularly pledge my station to the United States Government in the event of war, if such occasion should arise.

I understand that this blank with my signature will be sent to the United States Government officials at Washington, who will make a record of my station.

Witnesses to signature: Name.....

..... City.....

State.....

..... Date.....191

Describe the apparatus of your station on the back of this application.

In the event of national peril, you will volunteer your services as a radio operator in the interest of the U. S. Government?.....

This last question need not be answered unless you so desire it.

CERTIFICATE OF MEMBERSHIP

TO THE

RADIO LEAGUE OF AMERICA

A MEMBERSHIP CORPORATION
ORGANIZED
UNDER LAWS OF STATE OF NEW YORK

Honorary Members

Dr. Lee De Forest — Nikola Tesla
Dr. Reginald Fessenden — Capt. W. H. G. Bullard

I, the undersigned, a radio amateur, do hereby apply for membership of the RADIO LEAGUE OF AMERICA, upon the express condition that by so doing I do not assume or incur any liability either for dues, assessments or any financial obligations whatsoever, and if accepted, I do agree to follow and abide by the rules and regulations of the LEAGUE as set forth herein, and all other rules and regulations which may hereafter be adopted.

Rule 1. To observe all rules and regulations of the Wireless Act of 1912 (as set forth on the back of this certificate).

Rule 2. That I will at all times have my station in readiness and at the service of the United States Government for use in any defensive or offensive purpose in periods of war, riot or disaster.

Rule 3. That I will at all times allow my station and equipment to be used by the United States Government or any of its officials, and will assist, if possible, in apprehending offenders violating the Wireless Act.

Rule 4. I furthermore solemnly and distinctly pledge myself not to send out at any time whatsoever, a misleading call, particularly a distress call (S. O. S. ···———···) not knowingly allow another to use my station for sending out such a call.

Rule 5. That I will at all times, in case of necessity transmit a distress call to the nearest official, either by Wireless, by Wire, or in person, and that I will do everything in my power to bring assistance to the party or parties thus in danger.

Rule 6. That I will communicate to the LEAGUE such information concerning the operation and construction of my radio station as will be helpful or instructive to the other members of the LEAGUE.

Rule 7. That I will, when requested, furnish information concerning my radio station and observations, which information is to be used by the LEAGUE in its compilation of wireless statistics.

Rule 8. That I will carefully read and adopt any suggestions published by the LEAGUE for the benefit of its members, and the transmission of wireless communications.

Rule 9. That in case of my removal to another address, or in case of the permanent discontinuance of my station, I will immediately communicate such facts to the Manager of the RADIO LEAGUE OF AMERICA.

Rule 10. That I will display my membership certificate in the LEAGUE in a conspicuous place in my radio station.

In witness whereof I have signed my name and address this 16th day of Nov. 1915

Name John Peter Doe

Address 1915 Washington Ave.

State Washington D.C.

Countersigned

Manager Radio League of America

1603

The Handsome Membership Certificate of the Radio League of America Engraved in Green and Gold. The size is 15"x11¼". Every member is assigned a number.

PERSONAL GLIMPSES

DREAMS THAT COME TRUE

WHATEVER the attitude of the incredulous on the subject of dreams, it can not be denied that one man's dreams have developed a habit of coming true. That man is Nikola Tesla, the inventor of the wireless telephone. His latest dream, based on the success of a transcontinental and transoceanic wireless telephone, is that we shall before many decades be ringing up Venus or Mars and talking across millions of miles of space with creatures whose physical structure is unknown to us and whose very existence has been a myth. "My demonstrations in Colorado Springs in 1899," said Tesla in a recent interview, "proved that not only could telegraphic signals be sent across the globe, as I predicted in 1892, but that the faintest modulations of the human voice could be imprest upon the planet as a whole and reproduced at any point irrespective of distance." When this theory has been worked out, as the inventor promises it shall be shortly, we shall have a "world-system" telephone, on which we may call up any other subscriber in any country on the globe. Perchance we shall have also an interplanetary system as well! Remember!—Tesla's dreams come true. What of these other dreams of his, given in an interview recently published in *The Manufacturers' Record?*—

The next art to be inaugurated is that of picture-transmission by ordinary telegraphic methods and existing apparatus. This idea of telegraphing or telephoning pictures is old, but practical difficulties have hampered commercial realizations. A number of improvements of great promise have been made, and there is every reason to expect that success will soon be achieved.

Another valuable novelty will be a typewriter electrically operated by the human voice. This advance will fill a long-felt want, as it will do away with the operator and save a great deal of labor and time in offices.

A new and extremely simple electric tachometer is being prepared for the market, and it is expected that it will prove useful in power-plants and central stations, on boats, locomotives, and automobiles.

Many municipal improvements based on the use of electricity are about to be introduced. We are soon to have everywhere smoke-annihilators, dust-absorbers, ozonizers, sterilizers of water, air, food, and clothing, and accident-preventers on streets, elevated roads, and in subways. It will become next to impossible to contract disease-germs or get hurt in the city, and country folk will go to town to rest and get well.

We are progressing at an amazing pace, but the truth is that even in the fields most successfully exploited the ground has only been broken. What has been so far done by electricity is nothing as compared with what the future has in store.

The New York Times December 8, 1915

TESLA'S NEW DEVICE LIKE BOLTS OF THOR

He Seeks to Patent Wireless Engine for Destroying Navies by Pulling a Lever.

TO SHATTER ARMIES ALSO

"Impractical," He Says of Westerner's Plan to Circle Country with Electric Fire.

Nikola Tesla, the inventor, winner of the 1915 Nobel Physics Prize, has filed patent applications on the essential parts of a machine the possibilities of which test a layman's imagination and promise a parallel of Thor's shooting thunderbolts from the sky to punish those who had angered the gods. Dr. Tesla insists there is nothing sensational about it, that it is but the fruition of many years of work and study. He is not yet ready to give the details of the engine which he says will render fruitless any military expedition against a country which possesses it. Suffice it to say that the destructive invention will go through space with a speed of 300 miles a second, a manless airship without propelling engine or wings, sent by electricity to any desired point on the globe on its errand of destruction, if destruction its manipulator wishes to effect.

Ten miles or a thousand miles, it will be all the same to the machine, the inventor says. Straight to the point, on land or on sea, it will be able to go with precision, delivering a blow that will paralyze or kill, as is desired. A man in a tower on Long Island could shield New York against ships or army by working a lever, if the inventor's anticipations become realizations.

"It is not the time," said Dr. Tesla yesterday, "to go into the details of this thing. It is founded upon a principle that means great things in peace; it can be used for great things in war. But I repeat, this is no time to talk of such things.

"It is perfectly practicable to transmit electrical energy without wires and produce destructive effects at a distance. I have already constructed a wireless transmitter which makes this possible, and have described it in my technical publications, among which I may refer to my patent 1,119,732 recently granted. With transmitters of this kind we are enabled to project electrical energy in any amount to any distance and apply it for innumerable purposes, both in peace and war. Through the universal adoption of this system, ideal conditions for the maintenance of law and order will be realized, for then the energy necessary to the enforcement of right and justice will be normally productive, yet potential, and in any moment available, for attack and defense. The power transmitted need not be necessarily destructive, for, if existence is made to depend upon it, its withdrawal or supply will bring about the same results as those now accomplished by force of arms.

"But when unavoidable, the same agent may be used to destroy property and life. The art is already so far developed that great destructive effects can be produced at any point on the globe, determined beforehand and with great accuracy. In view of this I have not thought it hazardous to predict a few years ago that the wars of the future will not be waged with explosives but with electrical means."

Dr. Tesla then said that it would be possible with his wireless mechanism to direct an ordinary aeroplane, manless, to any point, over a ship or an army, and to discharge explosives of great strength from the base of operations.

Asked to express an opinion upon the announcement last Sunday of Charles H. Harris, an electrical engineer of Los Angeles, that he would be able to surround this country with an electrical wall of fire in time of war, Dr. Tesla gave it as his opinion that Mr. Harris was not practical.

"It is hard to stamp as impossible such results as those described in the press dispatches to which you refer. Granted, however, that the project is feasible, it would take more than all the motive power obtainable in the United States to throw a wall of fire around the country. In fact, even the passage of small currents at considerable distances through air consumes a great deal of energy on account of the immense pressure required. So, for instance, in lightning discharges, energy may be delivered at the rate of billions of horsepower, though the currents are of smaller volume than those developed by electrical generators in our power houses."

Correspondence.

NOBEL PRIZE-WINNERS IN AMERICA.

To the Editor of The Nation:

Sir: In your very just observations on the conferring of the Nobel prize on Prof. Theodore William Richards you put your finger on a sore point when you state that "America does not produce so many Nobel prize-winners that the man thus singled out might not be supposed to have first reached a considerable popular reputation." America has so far produced *two* such prize-winners, for I omit the peace prizes, which have gone to two of our prominent politicians, and are conferred by a different body. The Stockholm Academy of Sciences does not award the Nobel prizes to newspaper wizards, nor by vote of newspaper readers. How many such readers had ever heard the name of Michelson when he received the first prize? And how many will have heard the name of the next one? How many had ever heard the name of Henry A. Rowland, or of Simon Newcomb, or of George William Hill, and how many papers published notices of their deaths? A few years ago one of the Paris popular papers took a vote of its readers as to who was the greatest Frenchman. I have not the results before me at present, but I remember that Napoleon came in eighth, and that the first choice was Pasteur. Well up on the list was Poincaré, not the President of the republic, but his cousin, the great mathematician, whose work was Greek to the voters, but whose reputation was a household word. And yet we pride ourselves on our education, and we spend untold sums on our colleges.

An interesting discussion has recently been held at Harvard on the subject of what students talk about at table, with somewhat discouraging conclusions. I should like to extend this to cover the question what American men in general talk about. Many times, having attended dinners of college clubs, only to be entertained with lectures by Walter this and Big Bill that on the manœuvres of football, and having complained that college graduates should submit to such subjects, I have been informed that athletics is the only common subject of interest to all sorts of college men. If this is true, I think it time that our colleges were closed and that the few desiring an education go to Europe to get it, for the colleges are a portentous and unnecessary expense.

I wish to call attention to the vastly greater interest in the conversation of educated men in any European country than in that of the same class here, and to point out the fact that any sensational statement of a pseudo-scientific nature made in our papers, no matter how absurd, will be eagerly swallowed by the great majority of readers, as is evidenced by the success of President Jordan's hoax perpetrated a few years ago under the title of "The Astral Camera Club of Alcalde."

Nobel prizes will come when the *milieu* of American life is more propitious for the pursuit of abstract science, and when the public learns the difference between scientific research and commercial invention.

Arthur Gordon Webster.

Worcester, Mass., November 21.

THREE NOBEL PRIZES FOR AMERICANS

ANNOUNCEMENT is made in the daily press that the Nobel prize for great discoveries in physics is to be awarded this year to two Americans—Edison and Tesla—and the chemistry prize to another American, Prof. Theodore W. Richards, of Harvard. The physics award, we are told editorially by *The Electrical World* (New York, November 13), will give especial satisfaction to the engineering profession, to which both the recipients have rendered distinguished service, tho the successes of both in contributing to the advance of pure science have been no less notable. Among many other familiar scientific feats, those performed by Edison include the perfection of the incandescent electric lamp and its utilization, his improvements in telegraphy and telephony, and his invention of the phonograph; while to Tesla our thanks must be given for the invention of the induction motor, the foundation of our present use of alternating currents for distribution, for brilliant experimental work with the high-frequency current, and for pioneer investigation in wireless telegraphy. Says the journal named above, in substance:

"The name of Thomas Alva Edison has been long associated with the invention and development of the incandescent electric lamp. But Mr. Edison would still rank as one of the very greatest inventors of modern times if some one else had done this splendid work and his reputation had to rest solely on other achievements. His well-known labors in purely telegraphic matters were triumphs of ingenuity, but yet more striking and original was his now almost forgotten invention of the electrolytic relay, which is reputed to have won for him one of the largest payments ever made for a patent. Later his ingenuity was lent to develop the telephone-transmitter, and at about the same time came the beginnings of the phonograph, by all means his most brilliant contribution to physics. And later yet have come his contributions to art and science in the invention and development of motion-pictures.

"To Nikola Tesla the world owes that great impulse which has resulted in the whole modern art and science of power-transmission. The use of alternating current for practical electrical distribution began with his development of the induction motor, which at once gave the general flexibility and usefulness of the system its due place in the practical world. With that invention the struggle between direct and alternating currents presently ceased, and each fell into its proper sphere of usefulness, of which the boundaries are still expanding. His later pioneering work in the development of high-frequency currents in theory and practise displayed brilliant resourcefulness. In wireless telegraphy, on which he spent a long period of tireless research, inventors of the present and future will find themselves often confronted with the results of his inventive energy and keen scientific insight. Those who remember Tesla's lecture before the Institute of Electrical Engineers on high-frequency phenomena, now nearly a quarter of a century ago, realize the extent to which his investigations opened the way to a field of which we have not even yet seen the full fruition."



A WEIGHER OF ATOMS.

Prof. Theodore W. Richards, a Harvard professor of chemistry, stands with Edison and Tesla as a 1915 Nobel prize-winner because of his success in determining atomic weights.

The award to Professor Richards is for chemical-research work that in all its essentials was completed ten years ago and has since been of high practical value in both analysis and theory. The particular work covered by the award is Professor Richards's method for ascertaining atomic weights. Says a writer in *The Christian Science Monitor* (Boston, November 17):

"By this system the smallest unit of nature, the atom, has been weighed with an accuracy not approached by any investigator preceding Professor Richards, say chemists. By this method, which has been widely accepted and put into use, new ratios have been established in the assaying of ores. Copper ore, for example, is bought upon a metal value, established by chemical analysis, a value based upon the weight of atoms in the ore. Until the Harvard experiment results were announced, this atomic weight was represented as 63.2; whereas, the experiments showed the figure to be 63.6. This difference of two-fifths of 1 per cent. means an increase in value to the seller of about $6,000 on $1,000,000 worth of ore, it is said. Conditions of sale of other metals commercially handled were similarly affected by the discoveries of the new system.

"The revised tables of atomic weights have been arrived at by determining the relative weight of the atoms tested in different elements, not by attempting to weigh the atoms themselves, an impossible task in view of the fact that there are millions of atoms in a single drop of water. . . . . .

"Highly accurate apparatus is needed, it goes without saying, in weighing units so minute, apparatus that is freed from the influences of atmospheric variations in heat and moisture. Allowances must also be made for altitude.

"At the Gibbs Memorial Laboratory, Cambridge, Mass., where Professor Richards works, the balance used in this field weighs down to a millionth of a milligram, or one three-millionth part of an ounce. As an illustration of such a breath of weight, a short light mark by a lead pencil may be cited as something that this balance will weigh. Care is taken to have the platinum receptacle in which the material is to be weighed the same temperature as the rest of the balance, since an ascending current of air would be generated if the crucible were even slightly warmer than the rest of the apparatus, making it lighter on the balance, and thus making a difference of a fraction of a milligram in the weight recorded. For this reason the balance works in atmosphere of its own, confined within a glass case containing dried air.

"In the case of nickel and cobalt the chemist is obliged to contend with untoward qualities in the bromids of these elements in that they are decomposed by exposure to the air. In Professor Richards's experiments they had to be bottled, therefore, in the tubes in which they were made, so that they should not be exposed to the air for an instant.

"The bromid of nickel, for example, was made in a porcelain tube containing dry gas. Thence it was pushed into a glass attachment in which was a weighing-bottle. After it had been got into the weighing-bottle the stopper, which lay on a bulge of the tube, was shaken out and pushed into place with a glass rod—thus performing the operation absolutely under cover.

"This is one of many devices Professor Richards has perfected. Each experiment with a single compound is repeated, moreover, four or five times for the sake of accuracy, and then the element which is being studied is tested in other compounds and in connection with various different substances, until the series, as it is called, consisting of twenty-five or even fifty determinations, is concluded, and the element dismissed in favor of another.

"The experiments have been so uniformly successful that all atomic weights determined by them have been accepted by the scientific world and incorporated in the international tables used by all chemists in making analyses."

Philosophical Magazine January 1916

VII. *On the most Effective Primary Capacity for Tesla Coils.* *By* W. MORRIS JONES, *B.Sc.*, *Research Student of the University of Wales**.

IT is generally assumed that a Tesla coil gives the best effect (*i. e.* the highest secondary potential for a given primary discharge potential) when the two circuits are so adjusted that, separated, their periods of oscillations are equal. This condition is expressed by the relation $L_1C_1=L_2C_2$, and is commonly called the condition for "resonance" or "synchronism," though it does not mean that the two periods of the system are equal when the circuits are closely coupled. The above condition appears to have been first arrived at by Drude† in a well known memoir on the Tesla coil, and has received general acceptance.

In a recent paper Professor Taylor Jones‡ has shown that the above condition does not apply if the adjustment is made by varying the primary capacity alone, but that in this case the "optimum" value of C_1 is considerably greater than the resonance value. Taking the secondary potential, when the

* Communicated by Prof. E. Taylor Jones, D.Sc.
† *Ann. de Physik*, xiii. p. 512 (1904).
‡ Phil. Mag. xxx. p. 224 (1915).

resistances are neglected, as given by the expression

$$V_2=\frac{V_0L_{21}}{L_1\sqrt{(1-m)^2+4k^2m}}(\cos 2\pi n_1t-\cos 2\pi n_2t)^*, \quad (1)$$

it is shown in the paper referred to that if $k^2=0{\cdot}265$ the optimum primary capacity is 2·128 times the "resonance" value; and that if $k^2=0{\cdot}36$ (a value specially recommended by Drude along with the "resonance" condition) the optimum capacity is at least twice as great as the resonance value.

It was suggested to me by Professor Taylor Jones that I might test the conclusions by experiment, and also determine experimentally the optimum primary capacity and relative values of the maximum secondary potential for various values of k^2, with a view to obtaining data for a complete test of the theory.

In the experiments about to be described the coupling coefficient was varied by removing turns from the secondary of the Tesla coil. In this process the primary self-inductance L_1 remains constant, and the variation of L_{21} can be easily determined and allowed for. The value of k^2 and the optimum value of m were determined at each stage. The same spark-length was maintained throughout the experiments, so that V_0 could also be regarded as constant.

The Apparatus.

At the beginning of the series of experiments the secondary of the Tesla coil consisted of 192 turns of bare wire (No. 16 S.W.G.) wound on a wooden octagonal frame smeared with paraffin-wax, the immediate supports of the coil being covered with indiarubber tape. Initially the coil was 80 cm. long and the turns were 25 cm. in diameter. The primary coil was of 5 turns of bare wire (No. 12 S.W.G.). The turns, about 30 cm. diameter, were 1 cm. apart and wound on an ebonite frame of the same shape as that supporting the secondary. The primary coil could be removed altogether from, or put into any position over, the secondary, which was always used with its axis vertical. The primary circuit of the Tesla coil contained the primary coil in series with an oil condenser of variable capacity charged by an induction-coil and discharged across a spark-gap. The primary current of the induction-coil was interrupted by a mercury break driven

* In this expression V_0 is the induction-coil discharge potential, L_{21} is the induction coefficient of the primary on the secondary, k is the coefficient of coupling, m is the ratio L_2C_2/L_1C_1, and n_1, n_2 are the frequencies of oscillation of the system.

by a motor, and the discharge terminals of the coil were made of zinc.

To diminish damping due to brush discharge from the terminals of the secondary of the Tesla coil, and to prevent sparking between secondary and primary, the spark-length used was only 1 mm., and this was kept constant throughout the whole series of experiments. Brush discharge was not altogether prevented even by the use of such a short spark-length.

A few preliminary experiments were made to ascertain whether the primary discharge potential was independent of the primary capacity and remained constant provided the spark-length was constant. For this purpose two condensers of widely different capacities were respectively put in series with the spark-gap. Measurements of the discharge potential were taken by means of an electrostatic oscillograph*. From the results obtained for the two capacities used, the discharge potential appeared to be independent of the primary capacity.

Measurement of Frequencies.

All frequencies were measured by a wavemeter. These were usually too high to be registered by the wavemeters in common use in wireless telegraphy, and one suitable for the purposes of the experiments was constructed as follows. A standardized variable condenser was connected in series with a single circular turn (58·16 cm. diameter) of copper wire (·6376 cm. diameter) the self-inductance of which could be calculated from the formula $L=4\pi R\left(\log_e \frac{8R}{r}-2\right)$. By means of a suitable switch two other coils of two and three turns respectively could be substituted either separately or in series for the single-turn coil. The range of the wavemeter was thus widened, and all the frequencies required to be measured came within this range. The extra coils were standardized by comparison with the single-turn coil. A carborundum detector with telephone connected across the terminals of the condenser was used in all the experiments. The frequencies of the oscillations in these experiments were within the range $\cdot 710\times 10^6$ to $3\cdot 28\times 10^6$.

Measurement of Maximum Potential.

In these experiments comparative measurements were required of the maximum secondary potential that could be developed for various degrees of coupling of the Tesla coil

* E. T. Jones, Phil. Mag. xiv. p. 238 (1907).

circuits, the adjustment being made by varying the primary capacity.

A number of methods were tried for ascertaining when the potential in the secondary was a maximum. One of these consisted in sparking from a secondary terminal to an insulated electrode. The distances at which the sparks just failed to pass to the electrode were taken as indicating the maximum terminal potential for each adjustment of the capacity in the primary circuit. This method, though giving comparative values of the terminal potential, did not appear sensitive enough for the determination of an optimum capacity*.

The method finally adopted consisted in measuring the distance from the terminal at which a neon tube just failed to glow when held horizontally opposite the upper terminal of the coil, the end of the tube remote from the terminal being well earthed. This method, although the most sensitive of those tried, was not capable of great exactness; and as the potential of the secondary varied slowly in the region of the maximum, the adjustment of the primary capacity to its most effective value was a difficult matter, and could not be made very accurately. The method, however, is one in which practically no disturbance of the conditions is introduced, owing to the fact that the tube glows when at a considerable distance from the terminal of the coil.

To ensure that the distance of the tube from the coil depended upon the terminal potential alone and not upon the length of the coil, a wire about 2 metres long was attached to the upper secondary terminal. This wire projected horizontally from the coil and was suspended by silk cords from the ceiling. The neon tube was held opposite this wire at right angles to its length. Distances were always measured when the tube was in this position. The glow of the tube was affected by the presence of earthed bodies. It was important that the disposition of these bodies near the wire should remain constant during the experiments. This condition was secured by the projecting wire being at a fixed height from the floor, all other conducting bodies (including that of the experimenter) being kept in a fixed position when readings were being taken.

* It may be mentioned that an aluminium-leaf electroscope connected to one of the secondary terminals also shows a distinct maximum as the primary capacity is varied, such that if the capacity is increased or diminished from this value, the deflexion of the leaf falls. There is thus an optimum capacity for "mean square," as well as for "maximum" secondary potential.

The method of taking a reading was as follows:—The tube was first placed at a moderate distance from the secondary terminal, and it was found that it glowed continuously over a considerable range of values of the primary capacity. The distance of the tube was then increased, the range of C_1 diminishing, until the tube failed to glow continuously but flashed out only at the good primary discharges. By this time the range of C_1 was reduced to fairly narrow limits, and the middle point of the range was taken as the optimum primary capacity. The tube was further removed until these isolated flashes just ceased to appear. The distance of the tube from the terminal was then measured, and this distance was taken as a measure of the maximum secondary potential for the given degree of coupling and the given length of spark-gap.

The frequency-ratio of the electrical oscillations of the system, when so adjusted, was found by means of the wavemeter.

Period of the Primary Circuit.

After the capacity had been adjusted to its most effective value, the period of the primary circuit was determined. This was done by means of a "dummy" primary. This coil was similar in all respects to the primary of the Tesla coil. It had the same number of turns and was made of the same wire. The turns were also of the same diameter as those on the primary, and both coils gave the same reading on the wavemeter when connected up respectively to a constant capacity and spark-gap.

The reading obtained with the wavemeter when the "dummy" had been substituted for the primary of the Tesla coil, gave L_1C_1.

Determination of k^2 and L_2C_2.

The coupling coefficient of the primary and secondary circuits was next found. The "dummy" primary coil having been substituted for the primary of the Tesla coil, and the latter removed to a distance of two or three feet, the primary capacity was varied until the circuit came into tune with the secondary, resonance being indicated by the glow of a neon tube attached for the purpose to the lower secondary terminal. By removing the Tesla coil to a sufficient distance, the range of the capacity in the "dummy" circuit over which the tube glowed could be cut down to very narrow limits, and the "dummy" circuit adjusted fairly accurately to resonance with the secondary. This tuning

adjustment was made when the primary circuit of the Tesla coil was open and also when it was closed by a short wire of sufficient length to allow for the self-inductance of the leads used when the primary was connected up in series with the condenser and spark-gap. The resonance capacity in the dummy circuit was noted in each case. The ratio of the periods when these capacities were respectively in the circuit were obtained from the wavemeter readings. If T_0^2 and T_1^2, to which the wavemeter readings are directly proportional, represent the periods of the secondary when the primary was respectively open and closed, then $T_1^2/T_0^2 = 1 - k^2$ from which k^2 can be immediately obtained. The value of k^2 was also verified in some instances by determining the minimum ratio of the oscillation-frequencies of the Tesla coil system.

The reading of the wavemeter when the "dummy" circuit had been tuned to resonance with the secondary of the Tesla coil, the primary being open, gave the period of the secondary, and therefore the value of L_2C_2. The capacity in the "dummy" circuit for this case was the "resonance" capacity satisfying the condition $L_1C_1 = L_2C_2$. The "optimum" primary capacity was found to be always greater than the resonance value.

The above completed the set of determinations required for one value of k^2. The coupling was next increased a little by removing turns from both ends of the secondary, and the primary capacity again adjusted to the "optimum." The whole set of observations was then repeated. These adjustments and observations were made both with the primary coil at the middle of the secondary and the secondary terminals insulated, and with the primary at the lower end of the secondary and the lower terminal of the latter well earthed.

In the earlier part of the series of experiments all the five turns of the primary coil were used; but when about 100 turns had been removed from the secondary, it was found that the "resonance" value of C_1 became inconveniently small for the range of the oil condenser. Consequently, in the latter part of the series only four turns of the primary coil were used. This reduces L_1 and proportionately increases the "resonance" value of C_1, thus making it more suitable for the range of the oil condenser employed.

The removal of a turn from the primary has, however, another effect. It diminishes L_{21} and L_1, but L_1 is reduced in a greater proportion than L_{21}. Thus the ratio L_{21}/L_1 is increased; and according to the expression (1) the maximum

secondary potential (for given values of m and k^2) should be increased by the removal of one of the primary turns. This was found to be the case, the greatest distance at which the tube glowed being considerably greater with the 4-turn than with the 5-turn primary for the same value of k^2.

It was thought desirable to reduce the results of the later experiments (those made with the 4-turn primary) so as to show what the tube-distance d would have been if the primary coil had remained at 5 turns. In making this correction it was assumed that the maximum secondary potential was proportional to L_{21}/L_1. The correction was therefore made by multiplying the later values of d by the ratio of the old to the new value of L_{21}/L_1.

This was determined as follows:—The change in L_1 was found with the help of the wavemeter, the ratio of the periods of a condenser being found when its terminals were connected to 4 turns and 5 turns respectively of the "dummy" coil. The change in L_{21} was found by ballistic galvanometer experiments, the secondary being connected to the galvanometer and the deflexion observed on the reversal of a given current in the primary, this being done both for 4 turns and for 5 turns.

In this way it was found that the ratio of the old to the new value of L_{21}/L_1 was $\frac{9}{10}$: consequently, in the results given below the values of d obtained with the 4-turn primary have all been reduced by 10 per cent.

At the beginning of the series of experiments the number of turns on the secondary was 192, and this number was reduced by small stages until there remained only 54. During this process the induction coefficient L_{21} gradually diminished, very slowly at first, more rapidly as the number of turns became smaller. Since it was part of the object of the present experiments to determine how the maximum secondary potential varies with k^2, it was necessary to make allowance for the variation of L_{21}, which is one of the factors to which V_2 is proportional. The value of the coefficient L_{21} was therefore determined (in arbitrary units) at each stage by ballistic galvanometer experiments, in which the primary was connected to the galvanometer, and the reversed current sent through the secondary. This was done with the primary at the middle, and also at the lower end of the secondary. Curves were drawn showing how the deflexions varied with the number of turns on the secondary. They showed that the mutual induction between primary and secondary was not sensibly altered until the number of turns had been reduced to 100 when the primary

was at the middle, and 65 with the primary at the lower end of the secondary. By means of these curves corrections could be applied to the values of d due to change in L_{21} caused by the removal of turns from the secondary coil.

TABLE I.

Primary coil over middle of secondary.
Secondary terminals insulated.
Primary spark-length = 1 mm.

k^2.	$m(=L_2C_2/L_1C_1)$.	n_2/n_1.	Max. distance d in cm.
0·147	0·740	1·53	65·0 ?
0·166	0·725	1·52	69·0
0·182	0·694	1·53	67·0
0·206	0·588	1·65	63·7
0·222	0·608	1·67	58·0
0·259	0·553	1·80	48·5
0·276	0·551	1·83	48·0
0·307	0·420	2·08	40·0
0·336	0·447	2·08	29·0
0·314	0·437	2·10	40·3
0·368	0·310	2·43	28·8
0·374	0·294	2·50	23·0

TABLE II.

Primary at lower end of secondary.
Lower terminal of secondary earthed.
Primary spark-length = 1 mm.

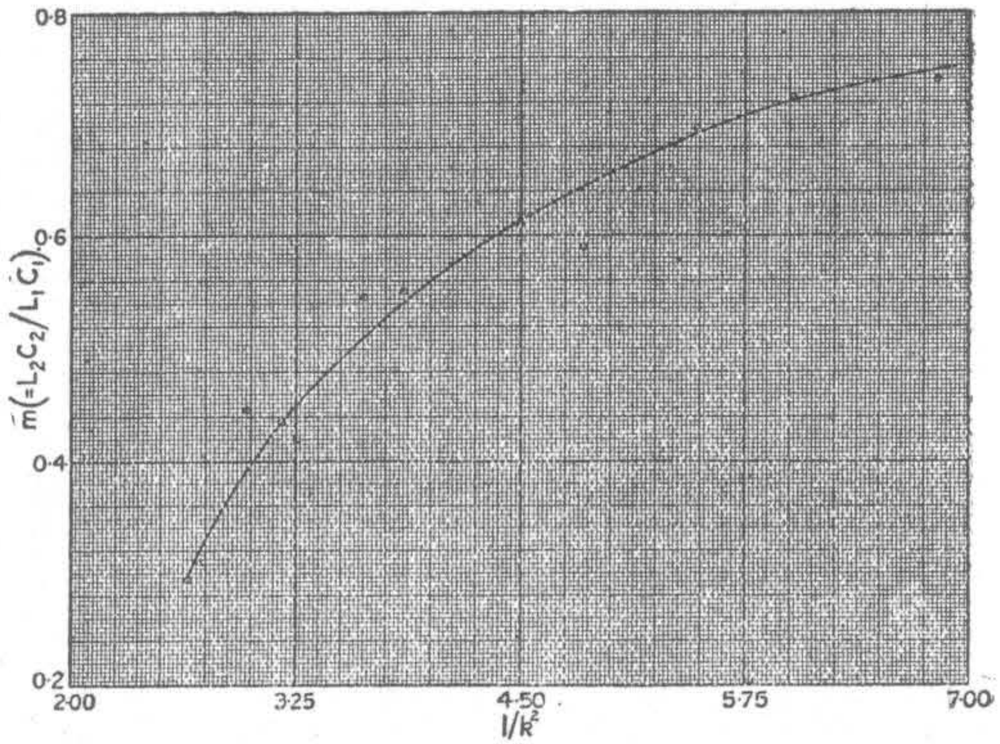
k^2.	$m(=L_2C_2/L_1C_1)$.	n_2/n_1.	Max. distance d in cm.
0·115	0·830	1·48	146
0·138	0·793	1·50	137
0·154	0·619	1·61	125
0·170	0·580	1·71	115
0·181	0·560	1·73	110
0·200	0·585	1·73	99
0·226	0·470	1·89	94
0·247	0·553	1·87	88
0·237	0·480	1·92	85
0·266	0·373	2·18	77
0·325	0·250	2·56	63

The results obtained are given in Tables I. and II. The first column gives the values of k^2, the second the values of m required to produce the maximum secondary potential, and the third column the values of the frequency-ratio n_2/n_1 when the primary capacity was at the optimum value. The

fourth column gives the maximum distances at which the neon tube glowed. The last three values of d in each table have been reduced, as explained above, by 10 per cent. The distances are measures of the maximum potential that can be developed in the secondary for the corresponding values of k^2 and m, and a primary spark-length of 1 mm.

The results in column 2 of the tables are plotted as curves in figs. 1 and 2, in which the abscissæ represent $1/k^2$ and the ordinates the values of m. Some of the points do not lie well on the curves. This is due to the difficulty of accurately adjusting the primary capacity to its optimum value.

Fig. 1.



However, the curves show that, for all the degrees of coupling obtained, L_2C_2/L_1C_1 was less than unity. It is clear from these results that, if the adjustment of the Tesla coil is made by varying the primary capacity alone, then the optimum value of C_1 is greater than the resonance value, the difference between them diminishing with k^2 in accordance with the theory. The tables also show that the frequency-ratio n_2/n_1, when the primary capacity is adjusted to the optimum value, passes through 2 in the neighbourhood of the value $k^2=0{\cdot}265$. This is also in accordance with the theory.

Fig. 2.

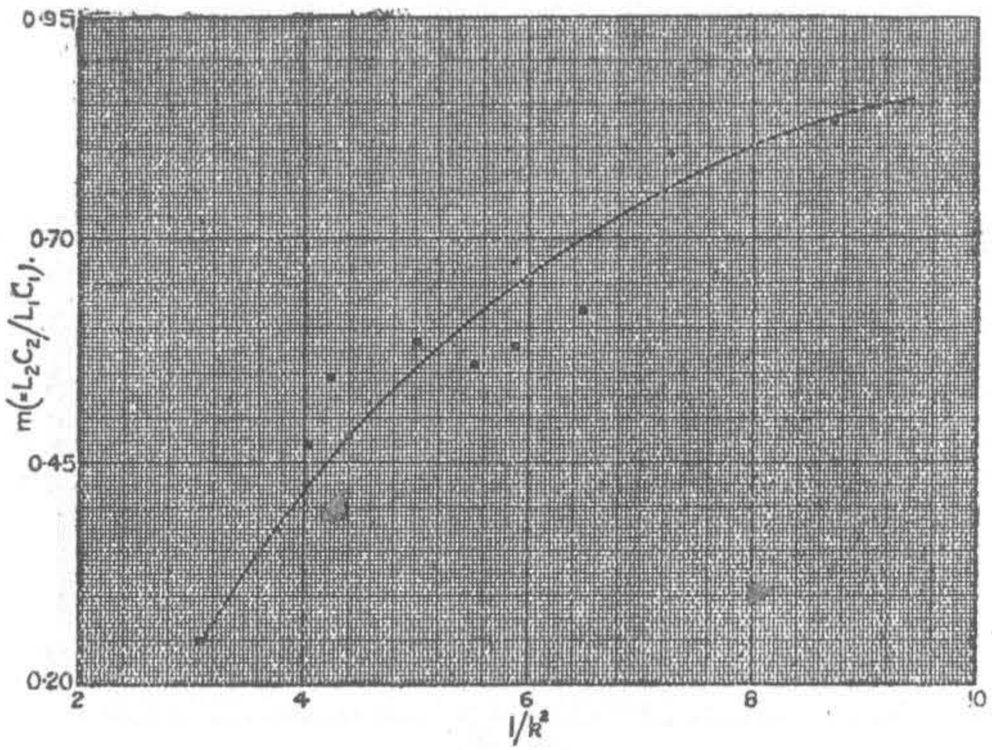
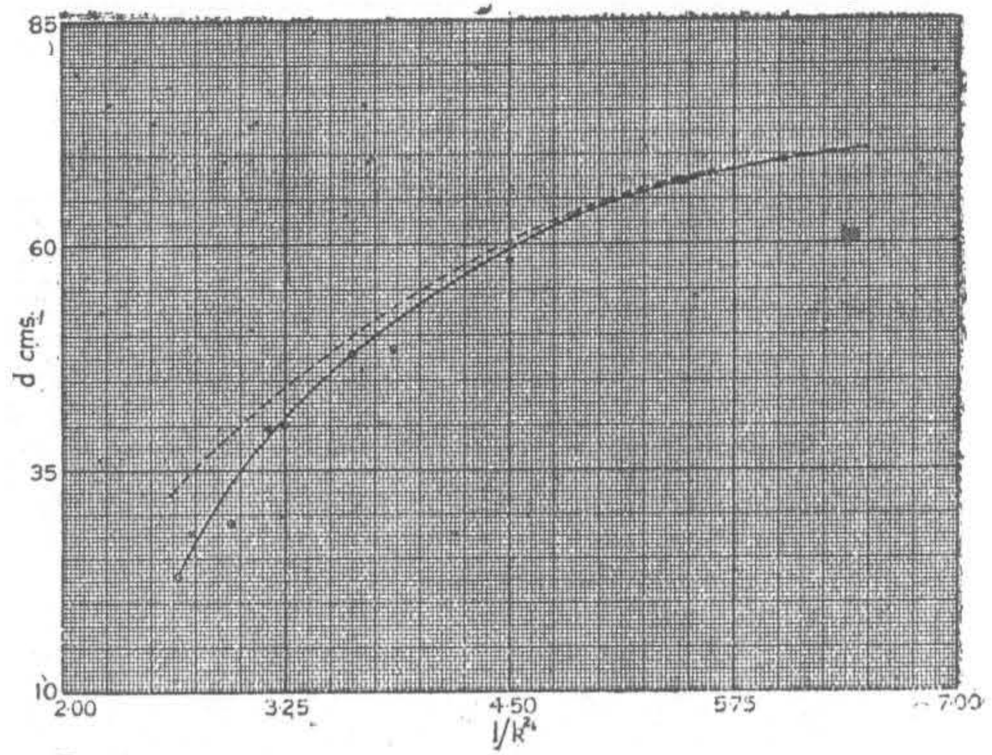


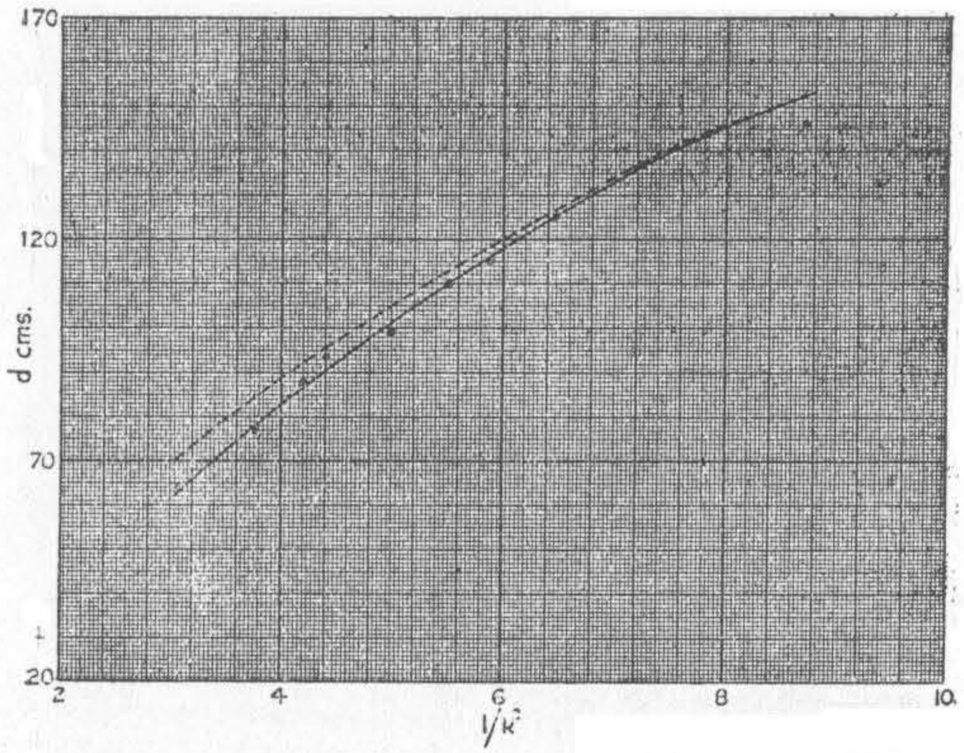
Fig. 3.



In figs. 3 and 4 the full-line curves show the tube-distances d (Tables I. and II., fourth column) plotted against $1/k^2$. When the correction due to the variation

of L_{21}, caused by removing turns from the secondary coil, is applied, the curves take the form shown by the broken line. The curves show that if V_0, L_{21}, and L_1 are constant, the maximum secondary potential increases as k^2 diminishes.

Fig. 4.



This result also might be anticipated from the theory. By (1) the amplitude of the potential waves in the secondary coil is in this case proportional to $\frac{1}{\sqrt{\{(1-m)^2+4k^2m\}}}$. For any value of k this expression has, when $m=1-2k^2$, a maximum value of $\frac{1}{2k\sqrt{(1-k^2)}}$. Within the range of the present experiments this quantity increases as k diminishes.

In fig. 5 the curve shows the variation of the maximum tube-distance d with the primary capacity C_1. In this experiment the coils and their coupling coefficient were kept constant, k^2 being 0·348—nearly equal to the value recommended by Drude. The curve shows a maximum tube-distance near the value $m=0{\cdot}3$, *i. e.* at a primary capacity much greater than the resonance value given by $m=1$.

Fig. 5.

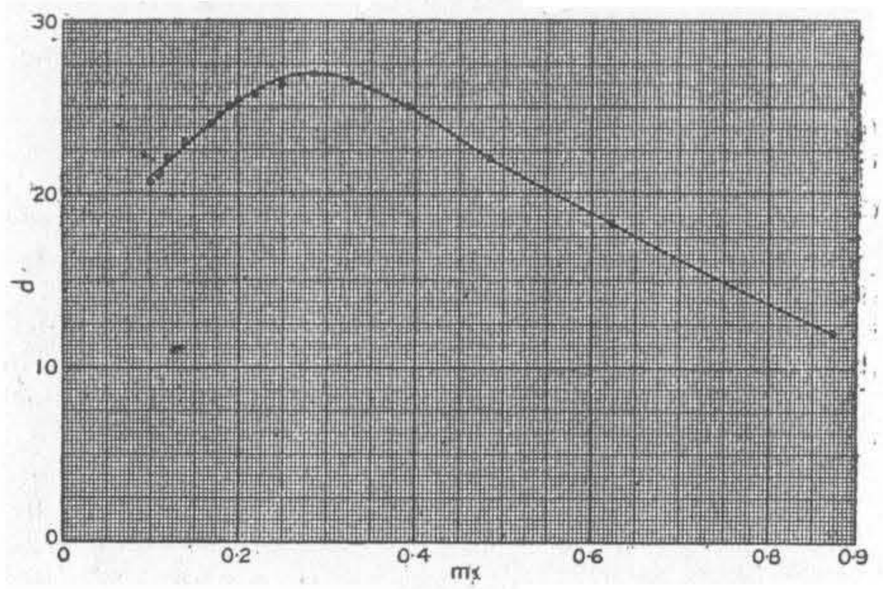
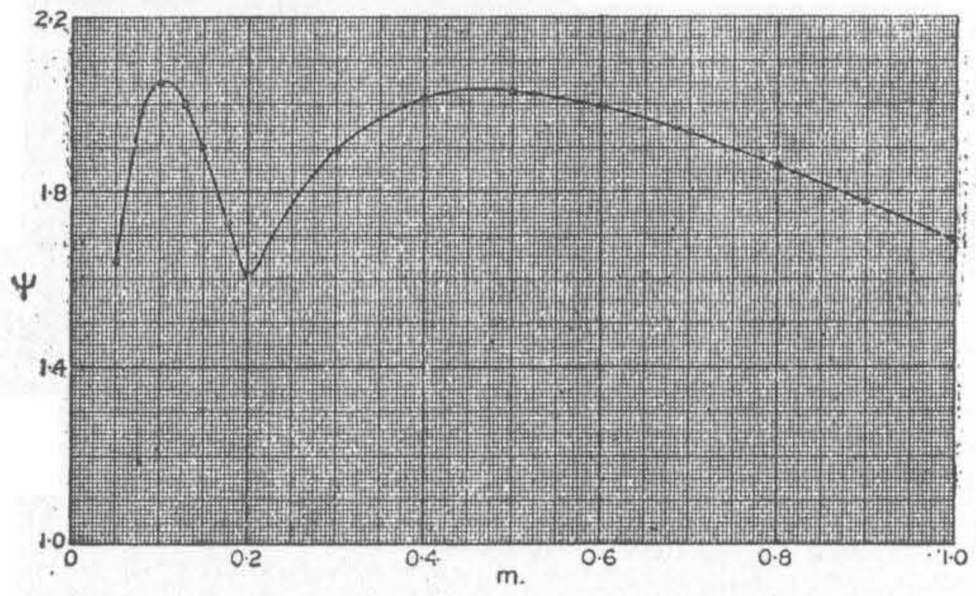


Fig. 6.



The theoretical curve, obtained by calculation from the expression (1), is shown in fig. 6, also for the case $k^2=0{\cdot}348$. In this curve the ordinate represents the maximum value of the quantity

$$\psi=\frac{1}{\sqrt{\{(1-m)^2+4k^2m\}}}(\cos 2\pi n_1 t-\cos 2\pi n_2 t)$$

for each value of m, and is therefore proportional to the

maximum secondary potential, since V_0, L_{21}, and L_1 are constant during the experiment. The frequency-ratio n_2/n_1 is calculated from the relation

$$\frac{n_2^2}{n_1^2} = \frac{m+1+\sqrt{\{(m-1)^2+4k^2m\}}}{m+1-\sqrt{\{(m-1)^2+4k^2m\}}}.$$

There are important differences between the experimental and theoretical curves, figs. 5 and 6. The theoretical greatest maximum occurs at about $m=0{\cdot}1$, and corresponds approximately to the frequency-ratio $n_2/n_1=4$. This does not appear at all in the experimental curve, in which also the maximum shown occurs at a smaller value of m than does the secondary maximum in the theoretical curve.

It should be remembered, however, that in the expression (1) for the secondary potential, damping due to all causes is neglected, and that the theoretical curve of fig. 6 represents only those maxima which occur near the time $1/2n_1$.

It is possible that in the experiment the damping might be so great in some cases as to diminish these maxima, so that they would not appear as such in the experimental curve. Possibly also the continuation of the experimental curve (fig. 5) to smaller values of m would have revealed some trace of another maximum.

Time did not allow me to determine and allow for the damping factors of the oscillations. With these taken into account better agreement would probably have been found between the curves of figs. 5 and 6.

Similar curves were obtained for the case $k^2=0{\cdot}255$ and the primary at the lower end of the secondary, and the experimental and calculated curves showed differences similar to those of figs. 5 and 6.

The above experiments were carried out in the Physical Laboratory of the University College of North Wales; and in conclusion, I desire to record my obligation to Professor E. Taylor Jones for bringing the subject of the above investigation to my notice and for much valuable help and advice during its progress.

TESLA SAYS ELECTRICITY WILL END WARS

Science Will Bring Nations Closer and Peace Will Follow

The Medium Will Not Be Employed Through Destructive and Frightful Machines, but by Bringing All Nations in Close Contact With One Another, Thus Creating Mutual Understanding and Sympathy and the True Spirit of Brotherhood.

NIKOLA TESLA, the inventor, has his own ideas as to how universal peace may eventually be achieved. Because he is a scientific man and an electrical expert, the solution he gives brings in science and electricity. But Mr. Tesla does not believe that war can be stopped by any new destructive weapon that man's mind might create.

"I do not subscribe to the theory that you can make war impossible by making it too terrible," the inventor said to the Sunday Eagle representative. "All wars, and especially the present conflict, have shown that you cannot make the struggle too frightful for those participating in it. New and deadly explosives, poison gas, aeroplanes, 42-centimeter guns and the like cannot convince men that they should not fight one another. No sooner is an engine of death invented than another invention comes along that acts as an antidote."

"So you do not think that men can be scared into abandoning war?"

"No. The deadly engine of war makes a scientific appeal, not an intellectual or mental appeal. That is, poison gas does not educate a man to the point where he can understand his foe and so forgive the latter's shortcomings instead of choking him for them. If you want to prevent war, you must educate the various peoples up to the point where they will intimately understand each other's ways and points of views."

"And you say, Mr. Tesla, that you would do that scientifically? I thought you said that a scientific appeal was of no value?"

"We shall make a mental appeal through the agency of electricity. The scientist will eventually annihilate distance. The various races will be brought into such marvelously close contact with one another that the languages will even tend to merge into one. At least, there will probably be an attempt to adopt some common language. Germans will understand the ways of Englishmen, and vice versa. With knowledge, distrust and hatred will disappear. You will find that where people become closely acquainted, they do not readily fight."

Ignorance Is the Cause of War.

"Ignorance is the cause of war," continued the inventor. "That is an old theory of mine, and I expounded it exactly ten years ago in an article in the Electrical World. At that time the Russo-Japanese War was being fought out, and the question of universal peace was being debated somewhat as now."

Mr. Tesla produced the article, and showed it to his interviewer. Here are some characteristic excerpts:

"A world composed of crass specialists would be perpetually at war. The diffusion of general knowledge through libraries and similar sources of information is very slow. As to individual correspondence, it is principally useful as an indispensable ingredient of the cement of commercial intrest, that most powerful binding material between heterogeneous masses of humanity. It would be hard to over-estimate the beneficial influence of the marvelous and precise art of photography, nor can that of other arts and means be ignored. * * * Our senses enable us to perceive only a minute portion of the outside world. Our touch, taste and smell require actual contact. Our hearing extends to a small distance. Our sight is impeded by intervening bodies and shadows. To know each other, we must reach beyond the sphere of our sense perceptions." And Mr. Telsa says that electricity will solve the problem by effecting the complete annihilation of distance.

Close Communication and Contact Make for Peace.

History seems to bear out the inventor's theory. When, in the days of Athens' greatness, communication from one part of Greece to another was very difficult, a Spartan could not understand Athenian Kultur; Athenians could not comprehent the ways of Corinthians; Corinthians found the ways of the Thebans very puzzling, and so on, ad infinitum. As a result, there were always wars going on within Greece, a country half the size of New York State. It was as if the people of Kings County came in so little contact with those of New York County that they regarded them as strangers, rivals and enemies; and hence sent frequent warlike expeditions to pillage Wall Street and bombard the Flatiron Building and Madison Square.

As communication between the different districts in Greece improved, the various Greek peoples began adopting one another's customs and ways, and began looking at one another as friends rather than as treacherous enemies. Spartans began to find the Athenians weren't so different from them, after all; Athenians discovered that the Corinthians were pretty reasonable fellows, and so peoples of the various Greek city-states began to form a homogeneous and friendly people. They realized that they had common interests, spoke the same language, looked a good deal alike and should be friends.

The next step was when the various city-states and petty principalities and feudal states, being merged into great nations, began to view other nations with distrust, hatred and fear. Germany, united or in the process of union, found inspiration in fighting France. Italy, in a like position, found that the common enemy, Austria, was the one influence that could bring about a union of all Italians.

Mr. Tesla contemplates that the next step will be the development of a world consciousness. First, there was the tribal consciousness of common aims and ideals; then there was that of the petty state; now there is a national consciousness everywhere. It is time that we should begin to have a planet consciousness. That is, all the people of the earth, bound together by the marvelous means of communication provided by electricity, will come to the conclusion that mankind pursues common aims and ideals and should not exhaust and ruin itself by fighting internecine wars.

Mr. Tesla thinks that the improvement in wireless telephonic and telegraphic apparatus is an important step forward in the general education of man. He is one of the first men to experiment with the wireless, and he demonstrated a system for the transmission of enormous volumes of electric power as long ago as 1900.

In 1905 Mr. Tesla wrote:

"But the ideal solution of the problem of transportation will be arrived at only when the complete annihilation of distance in the transmission of power in large amounts shall have become a commercial reality. That day we shall invade the domain of the bird. When the vexing plan of aerial navigation, which has defied his attempts for ages, is solved, man will advance with giant strides."

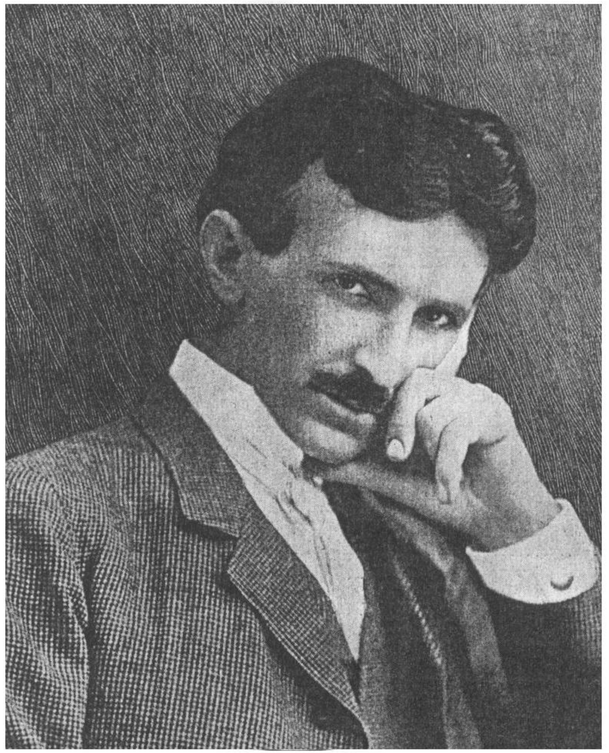
We seem to have arrived at the stage where we have invaded the domain of the bird, and it remains now to be seen how true was Mr. Tesla's prediction of ten years ago.

Tesla's Idea Reprinted In 30,000 Journals.

In June, 1900, Nikola Tesla wrote an article for the Century on the problem of increasing human energy the world over by harnessing the infinite electric power at man's disposal. This article created a sensation, and was reprinted or commented upon in 30,000 periodicals and newspapers the world over. Among the illustrations accompanying the article was one of a crewless boat, the first practical telautomaton, as the inventor called it, which could be handled and steered from a distance by the transmission of electrical waves. The boat contained its own motive power, propelling and steering machinery, and numerous other accessories, all of which could be controlled by transmitting from a distance, without wires, electrical oscillations to a circuit carried by the boat and adjusted to respond only to these oscillations.

Other photographs showed the successful experiments which Mr. Tesla had carried out for the purpose of transmitting electrical power. By making electricity do man's work, and perfect communication between men, the inventor hoped to achieve his ideal. He still believes that electricity will lead the way to universal peace.

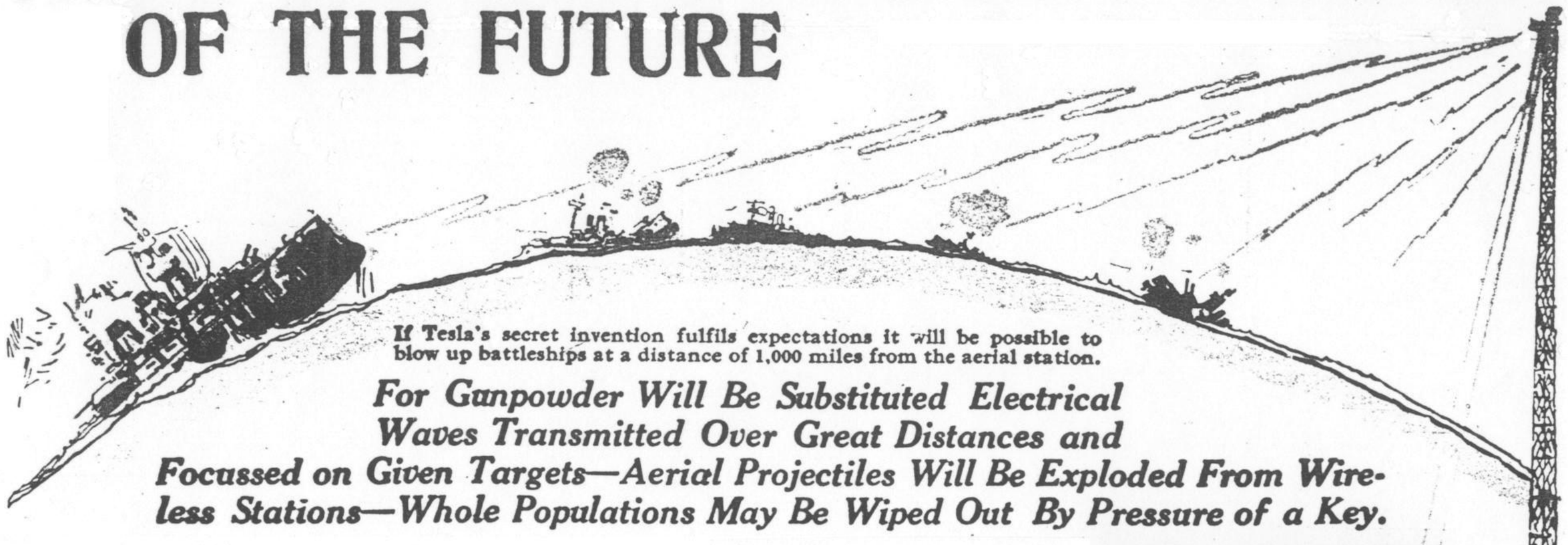
"It is not a dream," he said. "It is a simple feat of scientific electrical engineering. Humanity is not yet sufficiently advanced to be led by the discoverer's keen searching sense. But who knows? Perhaps it is better in this world of ours that a revolutionary idea or invention, instead of being helped and patted, be hampered and ill-treated in its adolescence. So do we get our light. So all that was great in the past was ridiculed, condemned, combatted, suppressed—only to emerge all the more triumphantly, from the struggle."



NIKOLA TESLA

Best Primary Capacity for Tesla Coils.—It has generally been assumed that to produce a maximum voltage on the secondary terminals the resonance relation $L_1C_1=L_2C_2$, as proposed by Drude, was sufficient, these symbols referring to the inductance and capacity of the primary and secondary respectively. Recently, however, Dr. Taylor Jones has shown that the above condition does not apply if the primary capacity alone is varied. If the coupling coefficient has the value $k^2=0{\cdot}36$, favoured by Drude, the best capacity is at least twice as great as the resonance value. Mr. W. Morris Jones, B.Sc., in an interesting communication to the "Philosophical Magazine," has experimentally tested these results. With $k^2=0{\cdot}348$, this value nearly agreeing with that which Drude recommends, he found that the maximum was obtained with a ratio of $3{\cdot}3L_1C_1=L_2C_2$, and the primary capacity was much greater than for the resonance value given by the expression first referred to above. He also found that the experimental curve differed considerably from the theoretical curve.

TESLA DESCRIBES WIRELESS WARFARE OF THE FUTURE



If Tesla's secret invention fulfils expectations it will be possible to blow up battleships at a distance of 1,000 miles from the aerial station.

For Gunpowder Will Be Substituted Electrical Waves Transmitted Over Great Distances and Focussed on Given Targets—Aerial Projectiles Will Be Exploded From Wireless Stations—Whole Populations May Be Wiped Out By Pressure of a Key.

By Edward H. Smith.

IN the imagination of every electrical expert in the world—from the famous Marconi, Edison and Tesla to the prospective aspirants to glory—there is to-day one vision. This is that of a little machine with a key by means of which a wave of electric energy will be flashed through the air to explode the enemy's bombs, torpedoes, cartridges and magazines.

The man who will perfect a device whereby an electric wave can be aimed and steered through the air in one direction only, all its force concentrated on a given target, will go down in history as the greatest inventor of all time, for his machine will make gunpowder and dynamite obsolete and will send rifles and cannon to the junk-heap.

In an interview published in a Paris newspaper recently Marconi speculated upon the possibilities of such an invention, saying it would mean the abolition of firearms and a reversion to hand-to-hand fighting.

A Dutch engineer named Lanzius, now in New York, claims to have invented such an apparatus. He is by no means the first to make such a claim. An Italian engineer won for himself much notoriety two years ago with his demonstrations of a machine that seemed to do just that, until he was exposed as a fraud. A young New Yorker, who already has several valuable and authentic inventions to his credit, claims to have perfected a way of emitting a wireless electric current that will instantly melt all metals within a certain radius. He, however, has been unable to demonstrate it, except on a small scale, owing tothe difficulty of banishing every bit of metal from the persons of the experimenters. These would have to wear buttons and studs of bone, suspenders with fabric buckles, shoes with wooden nails, and would have to lay aside all money, pocket knives, steel or gold-mounted eyeglasses, watches, chains and scarfpins, and their teeth would have to be innocent of gold, silver or amalgam fillings!

TO-DAY the Russians report that "the Germans have melted down their barbed entanglements from distant trenches." Yesterday a Californian pretended to defend the country from invasion by wireless energy.

The electrical wizards whose names are household words admit that they are busy along just these lines, but they refuse to commit themselves as to the precise object of their research. It is a race between experts and the side whose experts first discover the secret of directing powerful wireless waves will win the war, for it will mean annihilation for its enemies on land and sea.

The idea is real and fascinating; it has the romance of the startling possibility. Who? What? How? I have just talked with Nikola Tesla, that genius product of Serbian soil and Austrian training, who has just been awarded a partnership in this year's Nobel prize for physics, surely one of the first inventive imaginations of the world, a unit of the miraculous. And he has told me that:

1. Probably no revolutionary invention will decide this war, unless one counts the provision of internal needs in Germany by scientific substitution.

2. This is the last war in which gunpowder will decide the issue.

3. The whole aspect and conduct of war will change. Electricity will be the force of organized murder to-morrow.

4. It is not unlikely that that ignis fatuus, an invention so terrible as to make war impossible, will be found. Has been found, perhaps!



Inventors are working to perfect a device which, by the emission of wireless currents, would explode the cartridges in soldiers' belts.

We sat in the inventor's offices, near Fifth Avenue, looking at a picture of his new wireless telephone plant, designed to develop unlimited, undreamed of electrical energy for wireless transmission, a Merlin's tower, overshadowing the imagination. From the desk Lord Kelvin watched us from his portrait, and there gleamed elusively a thing the size of a watch and the power of ten horses.

"The next war will be fought with electricity," he said. "Cannon will be impotent compared with what is to come."

In other words, the Promethean struggle now taxing the vitality of a hemisphere will mark the end of the potency of gunpowder. The invention of Schwartz and Bacon, which first unthroned the armored knight at Crecy in 1346, if there be not some fiction in history, was to give way after 600 years of dominance in the affairs of men and their nations.

The career of this old monarch of mortal destinies has waxed through the centuries. His kingdom has become ever wider and more terrible. The conquering Turks used a cannon or two, hurling 600 pound stones, in their sieges of Europe's capitals. At Marignana, in 1515, the French under Francis I. fought the first real artillery battle of history, defeating the Swiss and Milanese with his 350 primitive cannon. Since then battles have come to be, more and more, the applications of gunpowder to great arms. Now whole nations devote their complete industrial resources to feeding these cannon, to supplying their deadly loads. "The limit has been reached. War can be no worse," say the hopeful.



The wireless transmitting tower which Nikola Tesla built at Wardenclyffe, N. Y., and in which many of his wireless experiments have been conducted. The tower is 185 feet high.

"The limit has no more been reached in the great cannon than in the two-handed sword," says Mr. Tesla. "The world will merely change arms. But the change will not come in time to decide this war, because it takes time to develop great, revolutionary things."

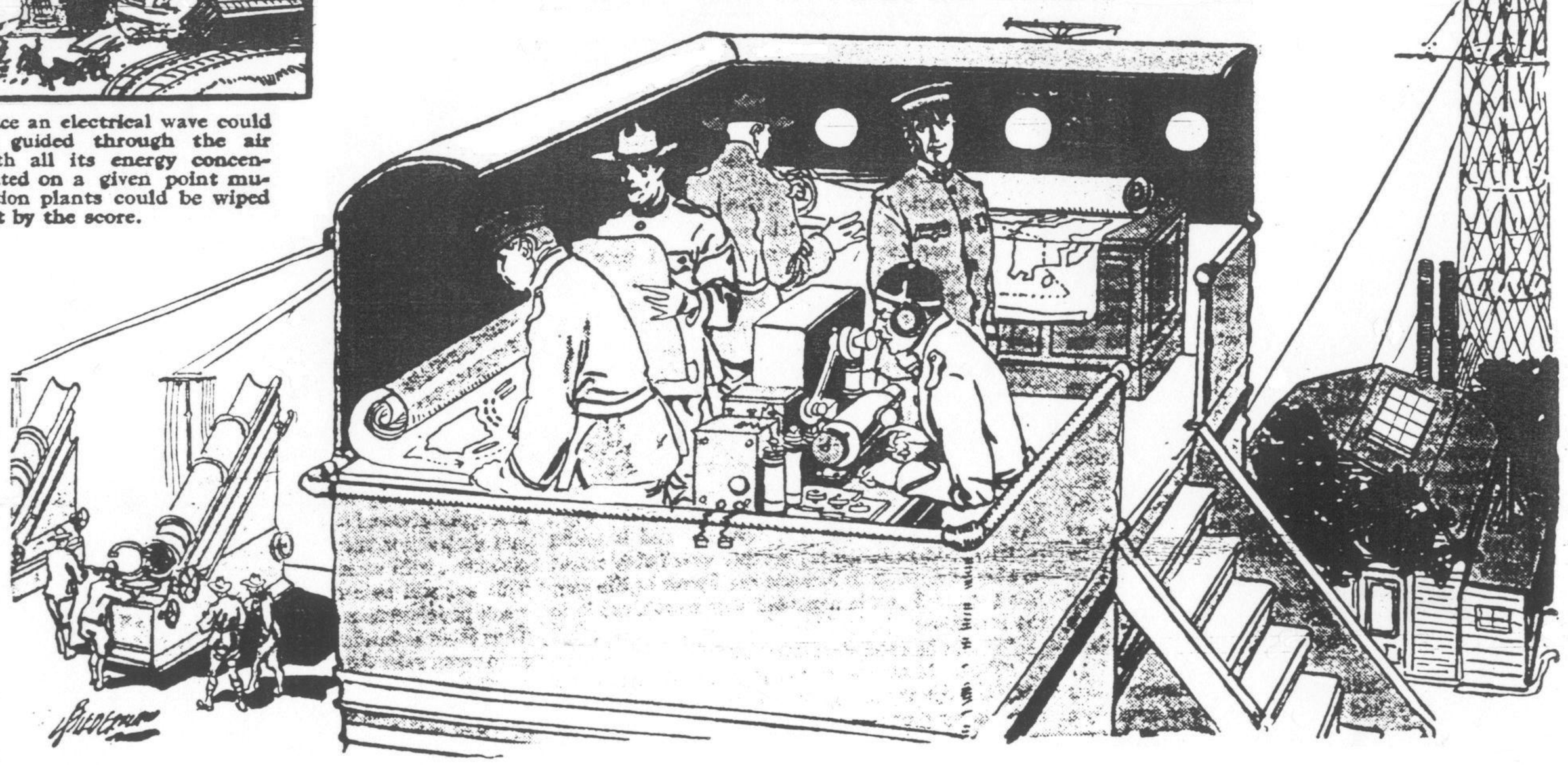
I SHOWED the inventor a clipping reporting that the Germans had cut down Russian entanglements with heat, supposed to have been applied from their trenches by the use of reflecting mirrors. It gave the impression that troops themselves might be thus incinerated from afar.

"In my opinion," said Mr. Tesla, "the melting of barbed wire from a dis-



Once an electrical wave could be guided through the air with all its energy concentrated on a given point munition plants could be wiped out by the score.

The operator's tower as it might be at Tesla's wireless station. Below are the aerial projectile tubes trained on battleships hundreds of miles distant. The projectile—flying many times faster than an aeroplane is exploded by electrical waves as it reaches its target.



The New York World January 30, 1916

TESLA DESCRIBES WIRELESS WARFARE OF THE FUTURE

[CONTINUED FROM PRECEDING PAGE]

tance is entirely feasible, the result was achieved, I think more likely, by the projection of a hot flame produced by gas under high pressure. The Germans are experts in the manufacture and use of hydrogen, and it is very likely that they have used this gas on account of its enormous heat value. Such a flame can readily be projected for 100 feet, which is ample for the uses involved, on account of the nearness of trenches. Saps can be run out to the needed proximity where intervals between trenches are wider. The action of such a flame in instantaneous. Barbed wire will melt under it like wax.

"As to the use of a reflector for the same purpose, it is, of course, not impossible to concentrate enough heat at 100 feet to melt a wire. The great natural philosopher, Buffon, in order to test the probability of the achievement of Archimedes (setting fire to the ships of Marcellus with mirrors and the sun's rays), constructed a composite mirror of 128 plane mirrors 8 inches high and 5 wide. With this he was able to ignite wood at 210 feet. But such a device would be too cumbersome and too fragile for us in a trench. Modern means would do much better than did Buffon, but it must be remembered that heat reflected by mirrors will fuse a wire only at the point of focus, so that the destruction of an entanglement would be very slow and difficult."

Thus, if the Germans are going to burn their way through the entanglements of their enemies, they must do it by the aid of the chemists, not the physicists.

AN inventor in California, so the announcements said recently, had found a new way of creating a wireless flame by wireless power, and hoped his invention would be potent to defend the coast against attacking war vessels.

"To do that," said the inventor, "the entire power in the United States is not sufficient. The report likely came from some novice in the art of wireless transmission of energy. But it is, nevertheless, possible to produce electrical effects at a distance by means of wireless energy. This is an old subject to me. I have been working on the problem for more than twenty years."

The electrical miracle man stopped and considered as one facing a delicate revelation.

"You can say," he resumed, "that I have just made a wonderful advance in this direction. In my twenty years of application to the problem of the transmission of energy by wireless, gradual improvements have been made. Now the stage has been reached where it is possible to use this force in war and with an effect from which it is safe to infer that this means will be used in future battles instead of guns."

But I wanted specific details. The inventor, however, was not to be persuaded or overcome with attacks or stratagems.

"It is impossible for me to give details at this time. It would jeopardize my own interests and it would contribute ideas to the belligerents which they might be able to develop to increase the horror of the war. But I can tell you in a general way what there is to the invention:

"It can be applied in three ways:

"First. It will make it possible to send an explosive body through the air—an aerial projectile flying many times faster than an aeroplane—and direct this object to the spot desired, where it can be exploded from the seat of the wireless operator. Other aerial machines can be directed in the same way and made to perform other work at a distance. This cannot be done by wireless as it is understood now, but by means of my invention it will be possible to direct the projectile I mention, without seeing it at all. It is, moreover, so accurate that it is possible to reduce the error to a few feet in a flight of a thousand miles.

"Second—It will be possible to produce with this invention local actions at a distance; such actions as will interfere with the enemy and render him ineffective.

"Third—It will actually produce at a distance, effects of electrical tension (electrical effects of great intensity) to interfere with life and property."

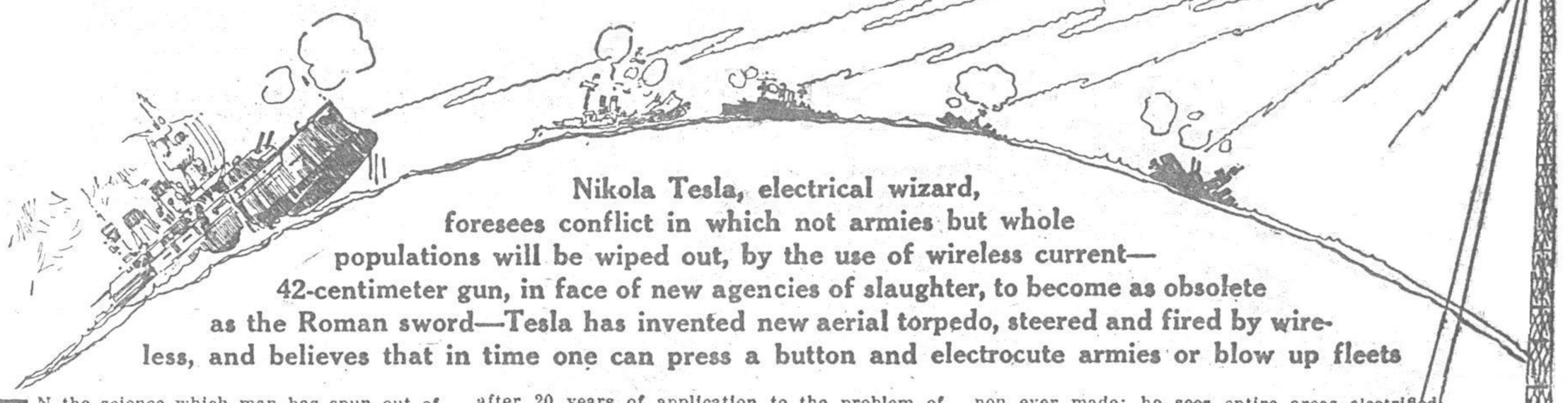
THE inference was that death, fire and explosion at great distances were to be dealt out by wireless, but this the inventor would not put into specific words.

"It is safer," he said, "to be specific after the fact."

Summing up the inventor-scientist's future war, it is to be one in which electrical appliances more deadly than all the cannon on earth will be the dominant arms. It is not unlikely that whole areas will be electrified and made untenable to any living creature. Death and destruction may be dealt out at undreamed of distances, with zones of destruction as yet unfancied. This war will be a conflict in which not armies but whole populations may be destroyed in a single action. Thus there is foreshadowed a conflict of such horror as to recoil even the twentieth century imagination.

"I hope it is the invention that will make war impossible," said the electrician, perhaps with a thought of Nobel, who had dreamed as much, whose prize this new aspirant had won.

What Part Will Science Play in the Next War?



Nikola Tesla, electrical wizard, foresees conflict in which not armies but whole populations will be wiped out, by the use of wireless current—42-centimeter gun, in face of new agencies of slaughter, to become as obsolete as the Roman sword—Tesla has invented new aerial torpedo, steered and fired by wireless, and believes that in time one can press a button and electrocute armies or blow up fleets

IN the science which man has spun out of his brain he has created a monstrous Frankenstein, which is now rending him limb from limb on the battlefields of Europe. But one of the fatal qualities of science is that it always progresses. What part will it play in the next world war? Will the inventive intellect by then have unloosed forces which, compared to the 42-centimeter howitzer of today, will be as the 42-centimeter gun is to the two-handed sword of the Roman legions? Yes, reply the experts; the present war is based on chemistry; but future warfare will wield the enormously more gigantic power of destruction provided by electricity.

Then it will not be a question of the annihilation of armies; it will be one of the extermination of whole populations. It will not be a matter of demolishing cities and fortresses, but of wiping whole nations at one stroke from the face of the earth. The scientists, in fact, offer us one ultimate alternative: Either man must conquer his innate murderous instincts and cease from war, or else in the end the human race will perish in a universal act of suicide such as Schopenhauer foretold—self-slain by the unspeakable agencies of destruction with which science will inevitably arm us.

For 600 years, gunpowder and its derivatives have ruled the destinies of mankind. A flash from the pestle of the scientist-monk, Roger Bacon, blew feudalism off the globe, and made possible the coming of democracy. Gunpowder gave to the European races sway over the whole world; it subjected to them America, Asia and Africa. Little did Bacon dream of these consequences from his experiment with saltpeter and sulphur. Perhaps as little do we today realize the possibilities of the wireless current which in an instant bears the spoken word from Arlington to Honolulu.

In the imagination of every scientist in the world today there is a vision of a machine with a key by means of which a wave of electricity will be flashed through the air to explode the enemy's bombs, torpedoes, cartridges and magazines. The man who first perfects this device will go down in history—if any historians are left alive—as a greater man than Roger Bacon, for his invention will make lyddite and picric acid obsolete, and will send rifles, cannon and dreadnoughts to the junk heap.

Only one scientist so far makes a claim to have advanced some steps towards the perfect electric man-killer. But that man is no other than Nikolo Tesla, electrical wizard, who has just been awarded a part of this year's Nobel prize for physics. In an interview the other day he laid down these prophesies:

1. This is the last war in which the explosive power of chemicals will decide the issue.
2. In the next war electricity will be the force of organized slaughter.

The confidence with which Tesla uttered these predictions is based upon an invention which he says he has just completed, but the details of which he is for the present jealously guarding, for fear they might be worked out by one of the belligerents in the present war. In case the United States were involved in war, however, he says he would place his device unreservedly at the disposition of the military authorities.

"It is, of course, possible," he said to a representative of the Post-Dispatch Sunday Magazine a few days ago, "to produce electrical effects at a distance by means of wireless energy. But the insurmountable difficulty thus far has been to aim an electric wave in one direction only, with all of its force concentrated on a given target.

"I will go so far as to say that after 20 years of application to the problem of transmitting energy by wireless, I have just made a valuable advance in this direction. The stage has been reached where to an extent it is practicable to use this force in war, and to predict such a development as will make electricity supplant cannon in battle.

"It is impossible to give details at this time, but in a general way my invention can be used in three methods.

"In the first place, it will be possible to send an explosive body through the air—an aerial torpedo flying many times faster than an aeroplane—and to direct this projectile to the spot desired, where it can be exploded by wireless. It will be possible to guide the projectile by wireless after it has passed beyond the range of the eye, and the aim is so accurate that it is possible to reduce the error to a few feet in a thousand miles.

"In the second place, it will be practicable with this apparatus to produce effects at a distance which will interfere with the enemy and tend to make him ineffective.

"In the third place, it promises to be able to produce at a distance such effects of electrical tension as will jeopardize life and property."

The inventor declined to go into specific details, saying that it is safer to be specific after the fact. But one would gather from the words he did speak that he has contrived a torpedo of the air flying under its own power as a torpedo swims in the water, which can be steered by wireless and exploded by the same force. Such a projectile would have a range not of some 20 miles, like the highest power cannon, but one limited only by its own flying endurance. It would be harder to hit with shell and rifle fire than an aeroplane, because of its smaller size and swifter velocity, and it need not be manned by a crew who would be exposed to death at every instant.

Such a missile, aimed according to the mathematical formulas used today by gunners whose target is beyond the range of eye and telescope, could be dispatched for the destruction of a battleship long before her own guns would be able to come into play. Safe from the shells of the greatest ordnance, it could start from a point miles beyond their range and destroy the batteries without the possibility of a reply.

The second and third methods of which Tesla speaks are discussed in rather cryptic language, but leave the inference that he believes himself already able, in some degree, to produce at a distance by wireless an electric shock similar to that produced by touching a charged wire. One can think of no other way in which effects perilous to life and property could be obtained with electricity.

With this idea worked out to its ultimate perfection, one might foretell such appalling events in warfare as this: An entire army, in its trenches, is without warning seized with the death agonies of a wretch in the electric chair, and is exterminated by a silent enemy, using no bullets. Or, at a given moment, every living thing in a great city is struck dead as if by lightning, by means of a force unleashed hundreds of miles away by an officer who merely pulls a lever in a wireless tower.

Tesla appears to see in the future a warfare of electric appliances more deadly than all the cannon ever made; he sees entire areas electrified and made untenable for any living creature. Death and destruction will be dealt out at unheard of distances, with zones of action more spacious than we now dream of. There is foreshadowed a conflict in which not armies but nations may be destroyed in a single action, by men armed with thunderbolts more mighty than those of the heavens. No wonder that Tesla, his own imagination recoiling in horror, says:

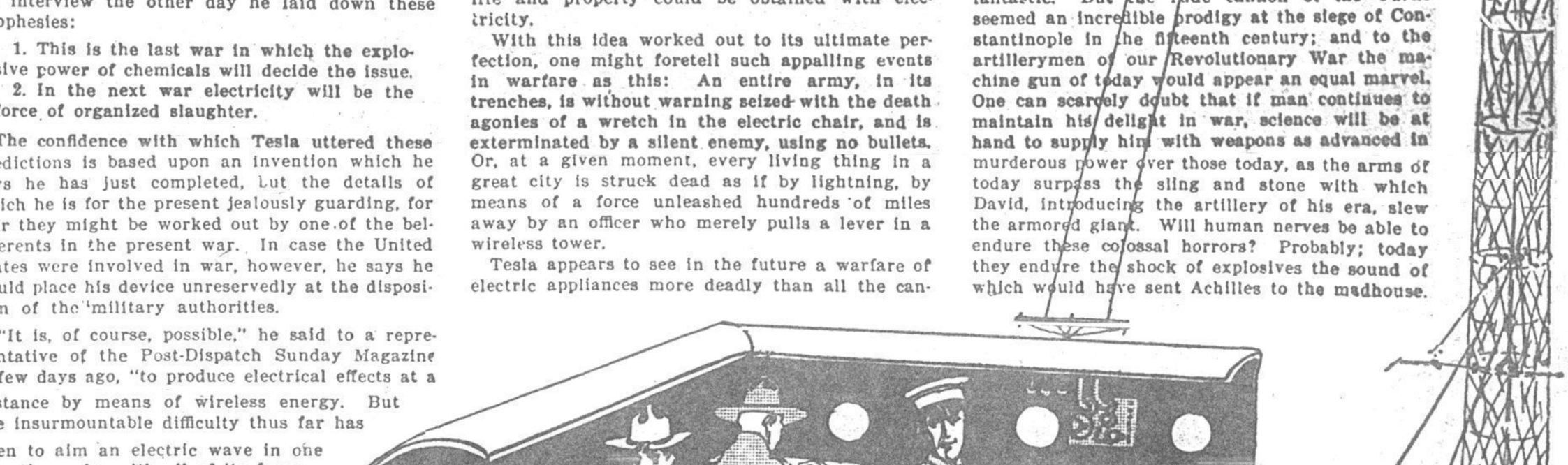
"I hope this is the invention that will make war impossible."

Another device for which inventors are seeking is one that will be able, by means of the wireless current, to explode at a distance the enemy's magazines of ammunition. If this were perfected, one man in London, by pressing a button, could set fire to all the explosives in the Krupp factories and blow that institution into bits; or he could blow up all the cartridges and explosives in the German army. Or another man in Berlin could with one stroke blow the English fleet out of the water with its own powder. In an article in a Paris newspaper recently, Marconi, father of wireless telegraphy, declared that such an invention would mean the abolition of firearms and a reversion to hand-to-hand fighting.

A Dutch inventor named Lanzius, now in New York, claims to have made such a device. An Italian inventor won considerable notoriety for himself two years ago by demonstrating an apparatus which he declared would explode ammunition at a distance by means of a wireless current—but he was shown to be a fraud. A young New Yorker, who already has several authentic inventions to his credit, declares he has perfected a method of emitting wireless current which will melt all metals within a certain radius. A California inventor asserts that he can create a flame at a distance by means of wireless, and offers to set fire to any fleet approaching the Pacific coast.

The Germans are reported to have used heat to destroy the barbed wire entanglements of the Russians. Tesla believes that the result was obtained, if at all, by the projection of a flame produced by hydrogen gas under high pressure. Such a flame can readily be projected for 100 feet, which might be sufficient when the trenches are close enough together. In such a flame barbed wire would melt like wax.

In all of the belligerent countries and in those which fear they may sometime become belligerents the best brains are hard at work on the problem of contriving new methods of murder more deadly and more wholesale than those now employed. Some of their dreams of future warfare may seem fantastic. But the rude cannon of the Turks seemed an incredible prodigy at the siege of Constantinople in the fifteenth century; and to the artillerymen of our Revolutionary War the machine gun of today would appear an equal marvel. One can scarcely doubt that if man continues to maintain his delight in war, science will be at hand to supply him with weapons as advanced in murderous power over those today, as the arms of today surpass the sling and stone with which David, introducing the artillery of his era, slew the armored giant. Will human nerves be able to endure these colossal horrors? Probably; today they endure the shock of explosives the sound of which would have sent Achilles to the madhouse.



Best Primary Capacity for Tesla Coils.—It has generally been assumed that to produce a maximum voltage on the secondary terminals the resonance relation $L_1C_1 = L_2C_2$, as proposed by Drude, was sufficient, these symbols referring to the inductance and capacity of the primary and secondary respectively. Recently, however, Taylor Jones has shown that the above condition does not apply if the primary capacity alone is varied. If the coupling coefficient has the value $k^2 = 0.36$, favored by Drude, the best capacity is at least twice as great as the resonance value. W. Morris Jones, in a communication to the *Philosophical Magazine*, has experimentally tested these results. With $k^2 = 0.348$, this value nearly agreeing with that which Drude recommends, he found that the maximum was obtained with a ratio of 3.3 $L_1C_1 = L_2C_2$, and the primary capacity was much greater than for the resonance value given by the expression first referred to above. He also found that the experimental curve differed considerably from the theoretical curve.—London *Electrician*, Jan. 21, 1916.

The Electrical Experimenter

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The Future of Wireless

AT the present state of the art, Wireless can be sub-divided into three classes:

1st. Wireless Telegraphy or Radiotelegraphy.
2nd. Wireless Telephony or Radiotelephony.
3rd. Wireless transmission of Power. The latter we may term as *Radiokinetics.*

As is well known, the first two are already in every-day use, all over the world. The third is as yet undeveloped, but already it looms large above the horizon.

Like all great things, Wireless has had its share of trials and tribulations. It takes time to develop an entirely new art. Moreover, Wireless received a black eye in its earliest infancy in this country. As will be recalled, a number of unscrupulous individuals unloaded millions of dollars of worthless stock on a credulous public, before the art had sufficiently advanced to make possible a successful commercial exploitation.

Practical commercial Wireless Telegraphy is not much older than ten years to-day. Commercial Radiotelephony has but made its appearance during the past one or two years, while Radiokinetics does not exist at all as yet.

But let us consider how the three classes of Wireless line up as far as their ultimate usefulness and commercial practicability are concerned. Let us look the problem square in the face and let us see what we shall find.

It is our opinion that a purely Wireless Telegraph Company can never reach such immense proportions as our wire telegraph companies. The reason is obvious. The wire telegraph companies are too well intrenched to be driven out of the field; it is quite certain that wireless telegraphy can no more hope to supersede wire telegraphy, than the telephone superseded the wire telegraph. Aside from this it seems hopeless for any one large central wireless plant to send out and receive within a single hour, 8,366 separate messages, as is the case for instance with one of the New York offices of the Western Union Telegraph Company. Wireless will probably never lend itself to such exploitation. Its greatest use will always be long distance transmission of intelligence, either over land or water or both, and between land and ship or vice versa, or between ships. This is its true field and here the wire companies cannot compete. This naturally limits its possibilities. Thus, while the future of Wireless telegraphy does not seem too rosy, we need not feel discouraged. The young man who embarks in radiotelegraphy to-day, will use it only as a stepping stone towards something infinitely greater. This was the exact case of E. N. Vail, the present head of the American Telephone and Telegraph Co., popularly known as the Telephone Trust. Vail was originally a telegraph man when he was called in by Bell and his associates; had he not known all about telegraphy he probably would not be the president of the huge corporation to-day.

This brings us to Radiotelephony. To us there does not seem one field in the entire electrical industry that is destined to a greater and speedier development than this one. We venture to say that within the next fifteen years, Radiotelephony will become one of the greatest electrical industries, for it supplies one of the predominating wants of the times.

The radiotelephone can be used by anyone, just as easily as the wire phone. To operate the instrument it is only necessary to take down the receiver and talk. But three months ago it was demonstrated that it is eminently practical to catch the wireless voice—on the wing as it were—and connect it with an existing wire telephone line. Vice versa, President Vail talked into a wire telephone at New York, where his voice was transmitted to Arlington; here it "took wings" and was wafted without wires to Honolulu, some 4,000 miles distant. This accomplishment more than anything else has opened the public's eyes.

We prophesy that in less than 15 years every automobile, whether pleasure or commercial, will carry its small radiophone outfit. Its occupants will thus be in constant touch with their homes or offices and vice versa, a convenience much needed to-day. Imagine the immense usefulness of such a device. Nor is this an idle dream. There is at least one company in existence to-day capable of filling an order to equip autos with radiophones having a 20 mile range. Nor will there be much confusion of voices becoming mixed up in transit; our tuning apparatus is becoming more accurate each day and it will be an easy matter to tune out unwanted voices. It will take considerable capital and a host of trained men to turn out enough radiophones to equip several million automobiles, aeroplanes, motorboats, yachts, and large vessels, but it will be done nevertheless and soon at that. Every farmer will have his Wireless Telephone to talk with his neighbors. Every train will have its radiophone enabling passengers to talk to their homes or offices. The radiophone will link moving humanity with the stationary one, the same as the wire telephone linked humanity together before. To us there is nowhere a brighter future than in the vast possibilities of the Radiophone.

As to Radiokinetics, this will surely follow the Radiotelephone in due time. Its future is probably even brighter than the latter. Already Tesla speaks of transmitting energy by the thousands of horsepower wirelessly. Who dares predict what this branch of wireless will bring during the next twenty years?

H. GERNSBACK.

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THE ELECTRICAL EXPERIMENTER

H. GERNSBACK EDITOR
H. W. SECOR ASSOCIATE EDITOR

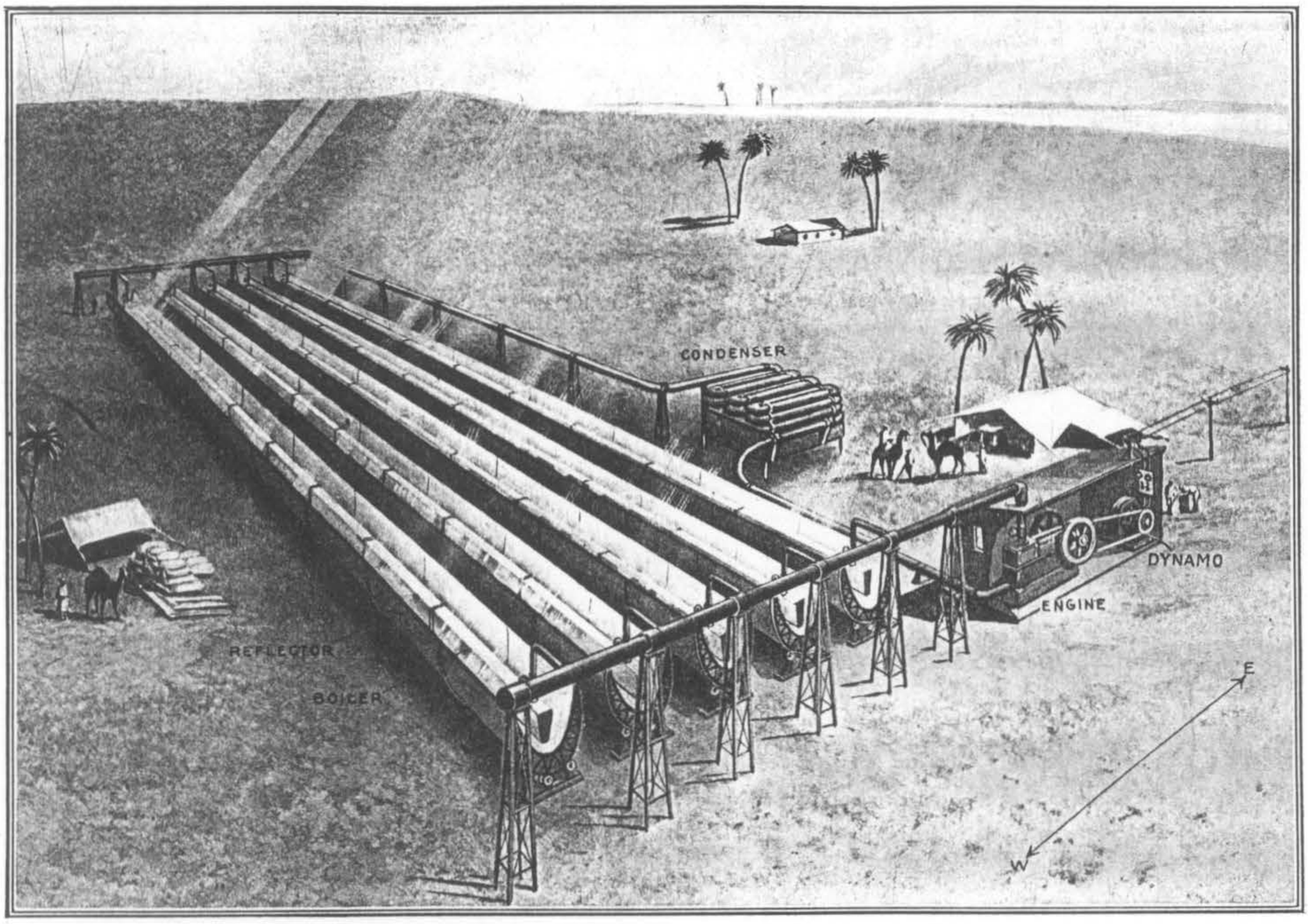
Vol. III. Whole No. 35 MARCH, 1916 Number 11

The Utilization of the Sun's Energy

Years Ago Man Endeavored to Make Practical Use of the Energy Contained in the Sun's Rays—Even Tesla, the Electrical Wizard, Has Patented a Sun Motor, While the Shuman-Boy's Engine and Sun Boiler Has Developed 100 H. P. There Is Great Promise Held Forth to Future Engineers Who May Work on This Problem.

IT has been given to astrophysicists to measure the heat generated by the sun and calculate the force emanating from it. We know that the surface of our luminary gives out a heat estimated to be about 6,000° centigrade, and that its light equals that of 27,000,000,000 candlepower a quarter of a mile away. The heat which the earth receives from the sun in the course of a year would suffice to melt a belt of ice about 55 yards in thickness extending clear around the earth. Only the 2,735-millionth part of the total energy given off by the sun reaches our earth and, if this were lacking, our planet, with all its thousandfold life, its thick forests and fruitful plains, would turn into a dead, rigid ball of rock, for the average annual temperature, which is now one of 13° centigrade of warmth for Europe, would, without the heat of the sun, sink to 73° centigrade of frost, it is calculated.

Every sort of light with which we illuminate our home when the greater light has sunk beneath the horizon, every fire that warms us when the solar rays can no longer do so, is a product originating in the sun. The chip of wood with which the untaught son of nature brightens his hut, the twigs with which he stokes his fire, what are they but pieces of trees that grew in the sunlight? The gas of the city dweller, the coals with which he heats his house and from which the gas has been sucked, what are they but transformed sunbeams? The coal in the grate is the petrified wood of perished forests that covered the earth's surface millions of years ago, and flourished in the rays of the same sun that ripens our corn to-day. Petroleum, that mysterious earth-oil, comes from the bodies of millions of dead and



A Successful 100 H.P. Sun Power Plant Located at Meadi, on the Nile, Egypt.

gone animals, chiefly natives of the sea, which lived in the gray ages and fed on things growing in the sun. Alcohol is also a plant product, and the candle our ancestors took to be an ideal light, is won

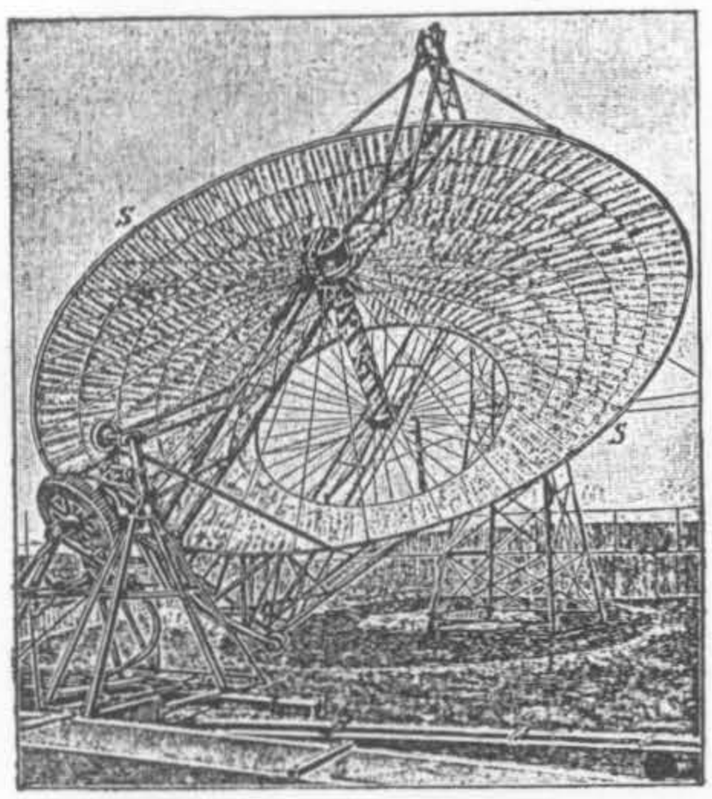


Fig. 1. Common Form of Sun Motor Adopted by Experimenters, Utilizing a Large Number of Mirrors and a Central Boiler.

from the animal and plant kingdom. The smoking fish oil lamps of the Eskimo are indirectly dependent on the sun for their fuel. And what of our own electric light? The dynamo developing the electricity is driven by steam, and the steam engine has to be fed with coal or with other materials gained from the animal and plant kingdoms. How about the waterfall? It would not exist if the sun did not suck up water from the earth's surface, and which is again deposited on the earth in the form of rain.

If it were rendered possible to use the sun's heat itself for the firing of furnaces an ideal state of affairs would be attained. There was a sun motor used for some time on an ostrich farm (see Fig. 1) in South Pasadena, Cal. This consisted of a concave mirror made of single glass planes set together, and measured about 12 yards in diameter. The sun's rays were collected and focussed on to a water tank, let into the mirror in the shape of a cylinder, 2½ yards long, which acted as its axis. When the water tank remained empty on a sunny day its walls grew red hot in less than an hour. The 400 quarts of water it contained was brought to the boiling point in 15 minutes and the steam developed drove a motor of 10 horsepower, which in turn worked a pulley raising 5,600 quarts of water per hour; a decidedly noteworthy performance.

The temperature of the sun, as aforementioned, has been calculated to be about 6,000 degrees centigrade. Several authorities point out that this terrific heat therefore precludes any possibility of the sun being a molten mass in the process of combustion. It has been thought recently by many to be a great mass of matter possessing to a remarkable degree radio-activity akin to radium. Helmholtz proposed that the sun could keep on producing energy at its present rate by accounting for same on the basis of a slight annual shrinkage in its size. From observations and measurements of this heavenly body made from year to year it has been computed that the age of the sun would, on the shrinkage basis, be 17,000,000 years.

The radiant energy received from the sun at the outer surface of the earth's atmosphere is equivalent to 7,300 horsepower per acre. Of this about 70 per cent. or, roughly speaking, 5,000 horsepower per acre, is transmitted through the atmosphere to the land surface proper of the earth, at noon on a clear day. Lesser amounts, of course, are received in the early morning and late afternoon, owing to the greater thickness through which the energy must pass.

Relative to the basis upon which solar energy is calculated for the earth's surface, this is generally made, it may be said, on the "solar constant," as it is termed, ascertained from 696 tests conducted by the Smithsonian Institute of Washington, in various parts of the world, which resulted in accepting 1.93 calories per square centimeter per minute, equal to 7.12 British thermal units per square foot per minute. This is an average value, all things considered.

Only about three-fifths of the solar radiation produce any impression on the earth, and it is only the radiant energy which falls on some material body that is converted into heat. The best body for this conversion having been ascertained to be a dead black one.

Many scientists and philosophers in the past century have tried various methods by which to concentrate the sun's rays, such as schemes utilizing an immense number of lenses built in the form of a huge cone, as previously described and illustrated at Fig. 1. A European experimenter in the year 1820 constructed one similar to this, but on a small scale. This model concentrated the rays sufficiently to melt tin at a distance of 68 yards from the apparatus, and also it was possible to cook food and melt silver instantaneously.

In the year 1882 a Frenchman by the name of M. Pifres devised a solar engine which was built on the roof of a building in Paris to drive a printing press, and the paper so published was called the "Soleil Journal." Capt. John Ericson experimented with solar engines from 1868 to 1886 with more or less success, but nothing remarkable or practical was developed. Another early worker was A. G. Eneas. His solar engines are described in United States patents issued in 1901, bearing the numbers 670,916 and 670,917.

Getting down to basic and simplified apparatus for utilizing such radiant energy as that possessed by the sun's rays, both visible and invisible, we may consider the apparatus of this nature devised by Dr. Nikola Tesla, the well-known electrical scientist. His United States patents on "Apparatus for the Utilization of Radiant Energy" bear the numbers 685,957 and 685,-958. This apparatus, intended to absorb and transform such radiant energy as that given forth by the sun, is shown in the illustration at Fig. 2.

Tesla says of this matter that his own experiments and observations have led him to the conclusion that such sources of radiant energy as the sun throws off with great velocity, minute particles of matter which are strongly electrified, and are, therefore, capable of charging an electrical conductor, or, if not so, may at any rate discharge an electrified conductor either by carrying off bodily its charge or otherwise. His patents in this direction are based on alleged discovery by him that when such rays or radiations are permitted to fall upon or impinge against an insulated conducting body P connected to one terminal of a condenser, such as C in Fig. 2, while the other terminal of the condenser is made by independent means to receive or carry away electricity, a current flows into the condenser so long as the insulated body P is exposed to such rays; so that an indefinite, yet measurable, accumulation of electrical energy in the condenser takes place.

This energy, after a suitable time interval, during which the rays are allowed to act in the manner aforementioned may manifest itself in a powerful discharge, which may be utilized for the operation or control of a mechanical or electrical device consisting of an instrument R, to be operated and a circuit-controlling device d (Fig. 2-A).

Tesla bases his theory on the fact that the earth is negatively charged with electricity and he considers same to act as a vast reservoir of such a current. By the action of the sun's rays on the plate P there is an accumulation of electrical energy in the condenser C. A feeble current is supposed to flow continuously into the condenser and in a short time it is expected to become charged to a relatively high potential, *even to the point of rupturing the dielectric.* This accumulated charge can then, of course, be used to actuate any device desired.

An illustration of a proposed form of apparatus which may be used in carrying out his discovery is referred to in Fig. 2-B. In this figure, which in general arrangement of the elements is identical to Fig. 2-A, the device d is shown as composed of two very thin conducting plates, t t^1, placed in close proximity and very mobile, either by reason of extreme flexibility or owing to the character of their support. To improve their action they may be enclosed in a receptacle from which the air may be exhausted. The plates t t^1 are connected in series with a working circuit, including a suitable receiver, which in this case is shown as consisting of an electromagnet M, a movable armature a, a retractile spring b and a ratchet-wheel w, provided with a spring pawl r, which is pivoted to armature a, as illustrated. When the radiations of the sun or other radiant energy source fall upon plate P a current flows into the condenser, as before explained, until the potential therein rises sufficiently to attract and bring into con-

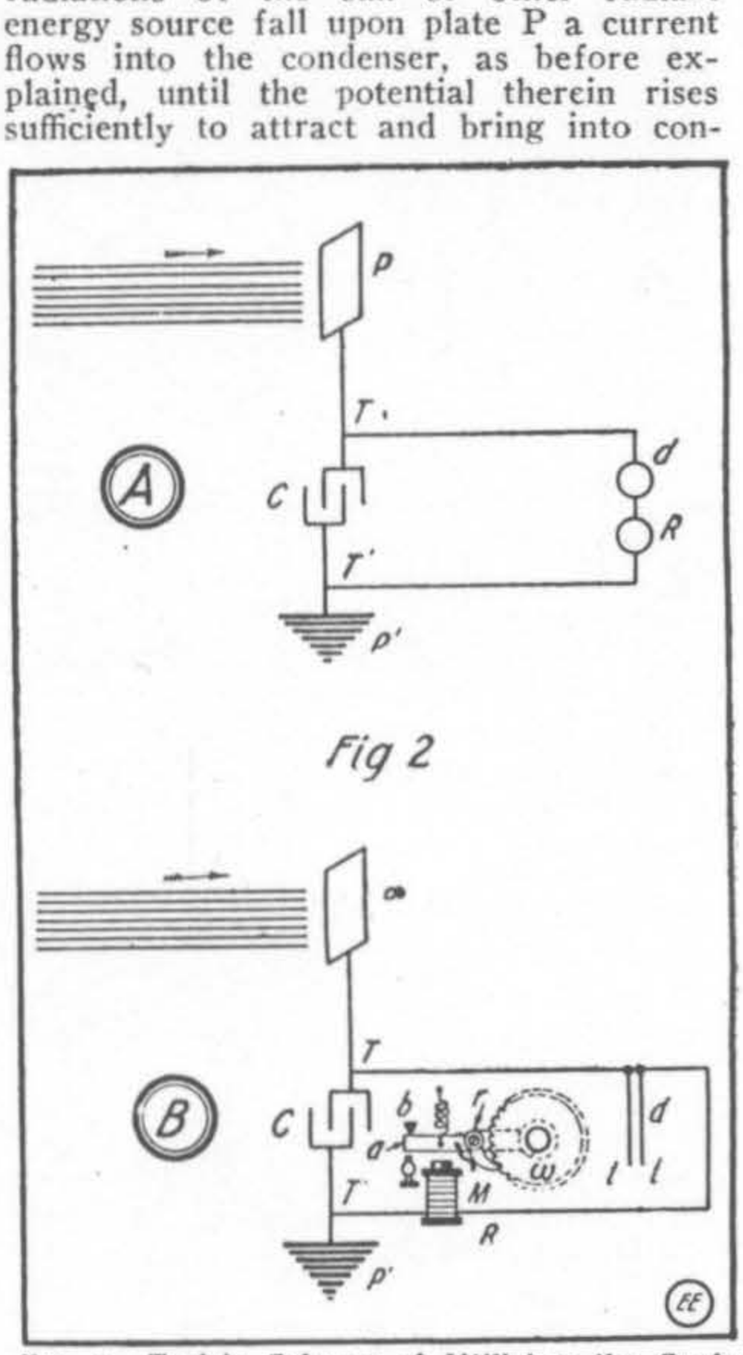


Fig. 2. Tesla's Scheme of Utilizing the Sun's Energy.

tact the two plates t t. thereby closing the circuit connected to the two condenser terminals. This permits a flow of current which energizes the magnet M, causing it to draw down the armature a and impart

(*Continued on page* 662.)

THE UTILIZATION OF THE SUN'S ENERGY.

(*Continued from page 606.*)

a partial rotation to the ratchet wheel w. As the current ceases the armature is retracted by the spring b, without, however, moving the wheel w. With the stoppage of the current the plates t t cease to be attracted and separate, thus restoring the circuit to its original condition.

Coming now to later developments of a practical nature in the line of solar engines and boilers, we may take up the work of Mr. Shuman, of Philadelphia, Pa., who later collaborated with a Mr. Boys, of England. They were able in their final developments to operate a 100 horsepower engine by means of solar energy. This plant was built at Meadi on the Nile, Egypt, and is shown in the large illustration here reproduced at Fig. 3. Prior to this excellent work, however, we may consider briefly the early solar engines developed and tried out at Philadelphia, Pa., by Frank Shuman, upon which work he started in 1906.

A year later he had running at Tacony, Pa., a practical plant of this type, which developed about 3½ horsepower by using 1,200 square feet of sunshine that was allowed to fall on a fixed, horizontal water box. This box was fitted with a glass top and a series of parallel horizontal black pipes were immersed in the water. These pipes, containing ether, exposed 900 square feet of surface to the solar radiation. The water also became heated and carried the heat to the underside of the pipes, thus realizing a greater efficiency. The ether boiled and its "steam" drove a small vertical, single cylinder engine. The exhaust ether vapor passed into an air surface condenser and the liquid ether from this was pumped back into the tubes of the sun boiler. It was found that this plant worked well even with snow on the ground, which is explainable from the fact that the permeability of the atmosphere is about 20 per cent. greater in winter than in summer.

Further tests and refinements to the Tacony plant by Mr. Shuman resulted in 1911 in an engine and boiler which showed considerable strides forward in their design, the ratio of 245 square feet of sunshine per one brake horsepower having been attained.

It may be mentioned here that the pipes constituting the sun boilers have invariably been *blackened*. For low temperatures lampblack has been used as the absorber, but where high temperatures were required platinum black was used.

The illustration Fig. 3 is that of the solar energy plant built at Meadi on the Nile, Egypt, by Messrs. Shuman and Boys in conjunction with several English scientists, including Mr. A. S. E. Ackerman, B.Sc. This plant made use of a 100 horsepower Shuman engine coupled with suitable auxiliary apparatus, as before mentioned. Five absorbers of the reflection type were utilized, as the illustration portrays. Each one measured 15 feet wide by 205 feet long. These were placed north and south geographically speaking, and were automatically heeled over, by being placed on suitable wheels, from an easterly aspect in the morning to a westerly one in the evening, so as to actually follow the sun. This caused an approximately even absorption of the solar rays all day.

The total area of sunshine so collected at this plant was 13,269 square feet. Cast iron boilers of suitable design were placed at the focus point of the reflectors, as shown in the illustration. They were covered with a single layer of glass which enclosed an air space around the boilers proper. The concentration value of this arrangement was 4½ to 1. The maximum pounds of steam generated was 12 pounds per 100 square feet of sunshine, or the equivalent, to 183 square feet per brake horsepower. The best hours' run developed, at atmospheric pressure, 1,442 pounds of steam. Hence (allowing 22 pounds steam per brake horsepower) the maximum output for an hour was 55.5 horsepower (about ten times better than any previous results). This means 63 brake horsepower per acre of land occupied by the plant. Moreover, no marked reduction in the horsepower produced was noticeable in the early hours of the morning or in the late hours of the afternoon.

The engineers of the concern which made these tests at Meadi recommended that such solar plants were feasible and practical and that undoubtedly they would be a very good thing in such arid regions for irrigation purposes. One argument brought against them, however, was that the power would not be available in cloudy weather, but then the irrigation would not be necessary, was the reply.

Thus the fight goes on between Dame Nature and the scientists. Whether we shall ever have an efficient solar boiler and engine is a problem worth thinking about and a very interesting one at that, as we possess no greater source of natural energy, to be had without taxation or special leases from some money-grabbing coal, oil or other baron, than that of the sun. Some day we may be able to derive all necessary light and power, for our homes at least, by means of a solar-electric plant located on the roof, and who shall say that we must be taxed for utilizing such energy?

The Tesla High Frequency Oscillator

By H. Winfield Secor, E.E.

TESLA, probably the highest authority in high frequency electrical engineering to-day, has not been dreaming these past few years, although we have not heard much from him, except through the daily newspapers, which now and then publish some world-startling interview describing a "marvelous" Tesla wave with which it is possible to communicate with Mars and several hundred other astounding stunts that the winner of the Noble physics prize probably never even thought of, much less attempted to accomplish.

Most of our readers have, no doubt, seen pictures of the famous Tesla wireless tower located at Shoreham, Long Island, and which structure has involved the expenditure of a vast sum of money. From this lofty structure, which was designed in the neighborhood of 20 years ago by Dr. Tesla and his associates, there was to be propagated an electric wave of such intensity that it could charge the earth to such an extent that the effect of the wave or charge could be felt in the utmost confines of the globe.

Our front cover illustration shows the Tesla tower in (theoretical) operation and, in line with some of the latest statements from this marvelous man, there may be perceived several dreadnoughts being blown to atoms, which is due to the high tension electric wave sent out from this center of vast electrical activity. Tesla, for obvious patent reasons, does not go into details just how whole fleets of a hostile navy can be destroyed in this way by means of powerful electric waves, but quite possibly he has in mind the fact that the latter can be tuned, undoubtedly, to a particular wave of certain frequency and power to accomplish this result when liberated from such a mighty station or oscillator as that located on Long Island. Such ships as the great steel shell dreadnoughts of to-day would, of course, have a large electrical capacity and this would help out the Tesla theory which covers the transmission and reception of an electric wave of sufficient intensity to do great good or damage, as the case might be.

The illustration on the front cover of this issue shows future possibilities which may be developed on the Tesla theory as a foundation. The location of the oscillator tower, from which the electrical energy is transmitted, and also the position of the war vessels being blown up are not to be considered literally in the way they are here shown. As a matter of fact, the enemy could soon shell the tower down.

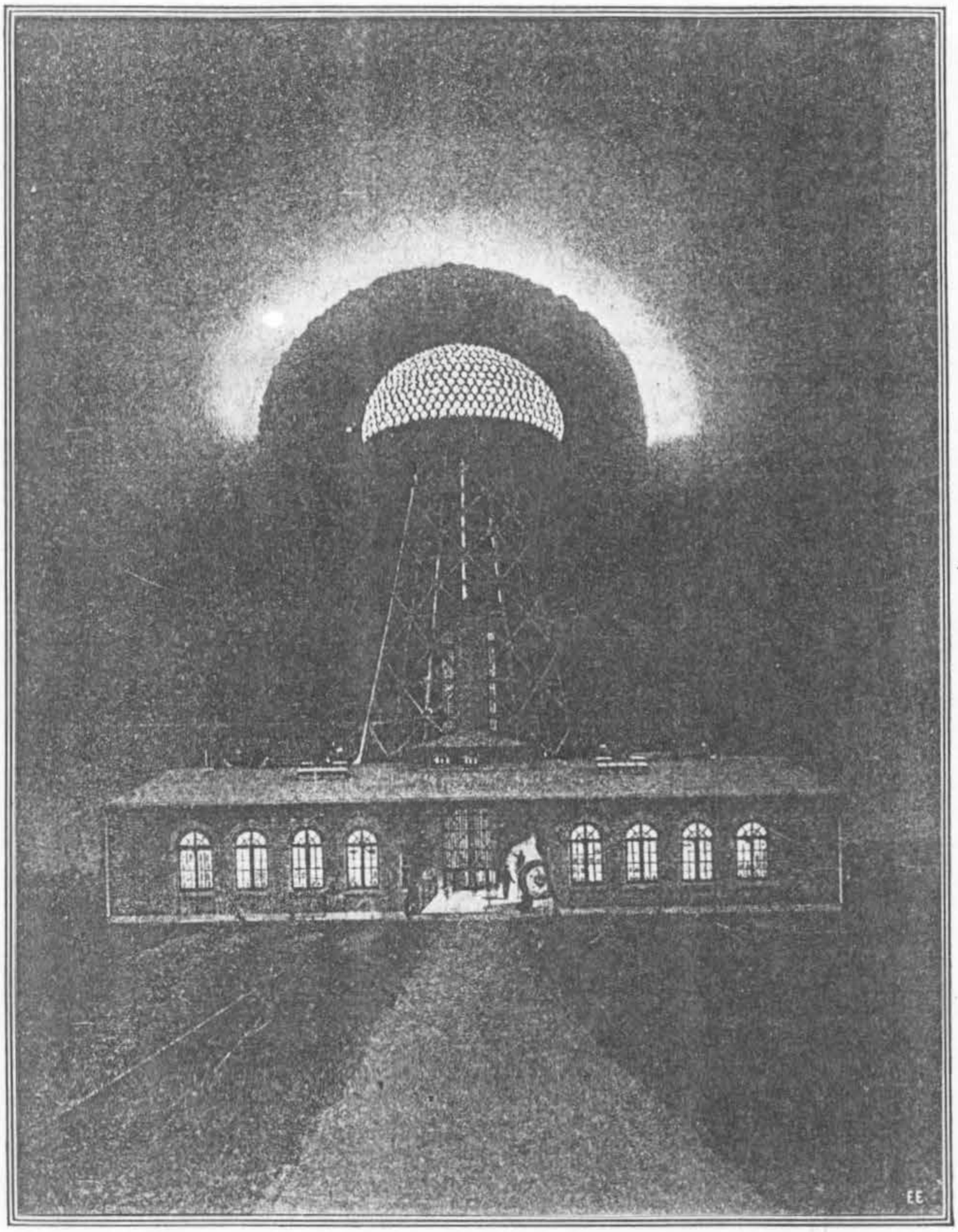


Fig. 1. Probable Appearance of the Wonderful Tesla Oscillator Tower at Night—It Is Located at Shoreham, L. I., and Is Intended for Radiating Electrical Energy in the Form of High Frequency Waves Propagated Thru the Earth Itself—Tower Stands 185 Feet High.

and hence it becomes evident that if this system is ever perfected and applied practically, the elevated radio energy transmitting station will have to be placed at a considerable distance inland. Again, as this wireless energy can be transmitted hundreds and even thousands of miles without any appreciable loss, according to Tesla's beliefs and statements, no disadvantage or inefficiency would be incurred by so locating the tower away from the coast; but conjointly, on this theory, the invading fleet of war vessels could be destroyed when they were still several hundred miles off shore. Hence, it would be impossible for them to hurl projectiles this distance. Also presumably this method of detonating the powder magazines of the war vessels could be applied to similar containers of high explosives on land, such as those carried by the heavy artillery corps of an invading army.

Further, it may be said that Tesla, all in all, does not believe in the modern Hertzian wave theory of wireless transmission at all. Several other engineers of note have also gone on record as stating their belief to be in accordance with Dr. Tesla's. More wonderful still is the fact that this scientist promulgated his basic theory of *earth current* transmission a great many years ago in some of his patents and other publications. Briefly explained, the Tesla theory is that a wireless tower, such as that here illustrated and specially constructed to have a high capacity, acts as a huge electric condenser. This is charged by a suitable high frequency, high voltage apparatus and a current is discharged into the earth periodically and in the form of a high frequency alternating wave. The electric wave is then supposed to travel through the earth along its surface shell and in turn to manifest its presence at any point where there might be erected a similar high capacity tower to that above described.

A simple analogy to this action is the following: Take a hollow spherical chamber filled with a liquid, such as water; and then, at two diametrically opposite points, let us place, respectively, a small piston pump, such as a bicycle pump, and an indicator, such as a pressure gauge. Now, if we suck some of the water into the pump and force it back into the ball by pushing on the piston handle, this change in pressure will be indicated on the gauge secured to the opposite side of the sphere. In this way the Tesla earth currents are supposed to act.

The patents of Dr. Tesla are basically quite different from those of Marconi and others in the wireless telegraphic field. In the nature of things this would be expected to be the case, as Tesla believes and has designed apparatus intended for the *transmission of large amounts of electrical energy,* while the energy received in the transmission of intelligence wirelessly amounts to but a few millionths of an ampere in most cases by the time the current so transmitted has been picked up a thou-

sand miles away. In the Hertzian wave system, as it has been explained and believed in, the energy is transmitted with a very large loss to the receptor by electromagnetic waves which pass out laterally from the transmitting wire into space. In Tesla's system the energy radiated is not used, but the current is led to earth and to an elevated terminal, while the energy is transmitted by a process of conduction. That is, the earth receives a large number of powerful high frequency electric shocks every second, and these act the same as the pump piston in the analogy just cited. These electrical impulses or shocks given to the earth are to be picked up at receiving stations by erecting a suitable capacity in the form of a metallic tower, as will be described more in detail hereafter.

Quoting from one of Tesla's early patents on this point: "It is to be noted that the phenomenon here involved in the transmission of electrical energy is one of *true conduction* and is not to be confounded with the phenomena of *electrical radiation* which have heretofore been observed, and which, from the very nature and mode of propagation, would render practically impossible the transmission of any appreciable amount of energy to such distances as are of practical importance."

He states further: "From my experiments and observations I conclude that with electromotive impulses not greatly exceeding 15,000,000 or 20,000,000 volts, the energy of many thousands of horse-power may be transmitted over vast distances, measured by many hundreds and even thousands of miles, with terminals not more than 30,000 to 35,000 feet above the level of the sea; and even this comparatively small elevation will be required chiefly for reasons of economy, and if desired it may be considerably reduced; since, by such means as have been described, practically any potential that is desired may be obtained and the currents through the air strata may be rendered very small, whereby the loss in the transmission may be reduced. It will be understood that the transmitting as well as the receiving coils, transformers, or other apparatus may be in some cases movable—as, for example, when they are carried by vessels floating in the air, or by ships at sea."

Tesla is not an idle dreamer, as many men are inclined to believe, but back in the year 1898 he succeeded, in some very elaborate tests carried out in Colorado, in producing high frequency electrical discharges, the like of which had never before been witnessed by man, nor have they been duplicated since, to our best knowledge. Some of these sparks measured 100 feet in length and produced a roar like the Niagara Falls. The multitude of mighty sparks and flashes produced a discharge so terrific that no human being could stay in the building in which they took place. Some of the sparks were as thick as a man's arm and others manifested even greater intensity. They were produced by a gigantic Tesla high frequency coil with which experimenters of to-day are more or less familiar in a small way. About 300 kilowatts were utilized in producing these discharges, which resembled actual lightning bolts and not imitation ones. The amperage measured 800 and the voltage was up in the millions. The illustration of these sparks, as well as Tesla's early work along this line, have been covered in previous issues of *The Electrical Experimenter.*

Regarding the Tesla tower on Long Island and the general engineering features of same, we may refer to his patent which covers the design of the high frequency apparatus of mastodonic design and capable of charging the structure at several million volts pressure. The external appearance of the Tesla generating plant and antenna support (185 feet high) are shown

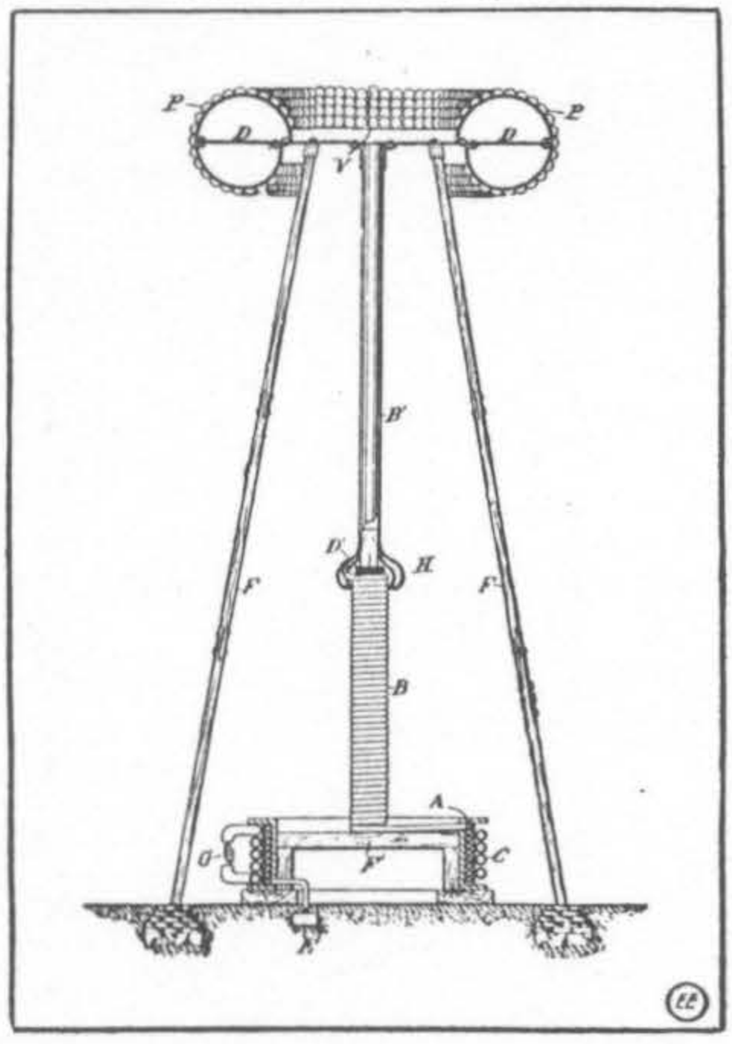


Fig. 2. Structure of the Tesla High Frequency Tower and Exciting Coils.

at Fig. 1. The huge high frequency step-up transformer is shown diagrammatically at Fig. 2.

Referring to this great structure which involves several peculiar design features, we see at the upper extremity a large capacity, D. This is made up of a metal framework upon which there is mounted a vast number of hemi-spherical metal electrodes. These are advocated for the reason that the minimum electrical leakage will then ensue. As points, of course, discharge any high tension current as rapidly as possible, they are done away with, as this is exactly what Tesla does not desire to have take place in this instance. The complete electrode comprises a suitably shaped metallic ring and the half-spherical electrodes appear at P P. Hence, within a reasonably small space an extremely large electrical capacity is formed. This capacity rests upon insulating supports, which in turn are well insulated from the earth.

The high frequency exciting circuit comprises a massive coil, A, which is in close inductive relation with the primary winding C, one end of which is connected to a ground plate, E. The other end of the coil is led through a separate self-induction and auto-transformer coil, B, and the metallic cylinder B^1 to the terminal D. At

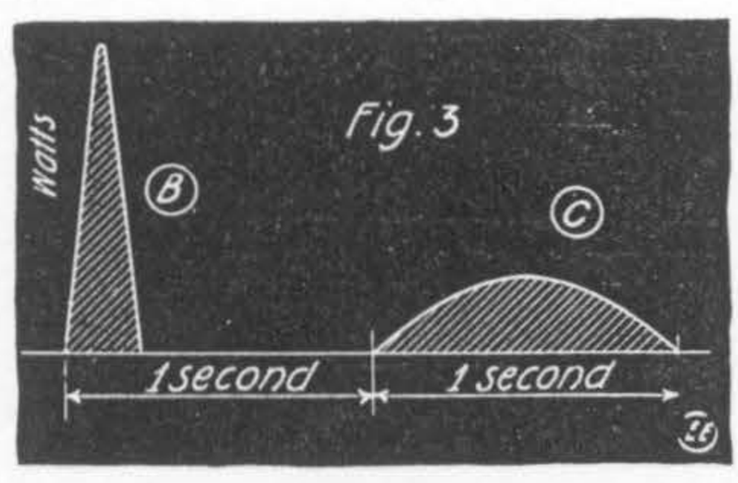


Fig. 3. Diagram Showing How the Rate at Which Energy Is Dissipated Increases as the Time Element Decreases.

the apex of the mast the connection with D is to be made at or near the center, Tesla specifies, in order to secure a symmetrical distribution of the current. Otherwise, when the frequency is very high and the flow of large volume, the performance of the apparatus might be impaired. The primary C is excited in any desired manner, from a suitable source of current G, which may be an alternator or condenser, the important requirement being that the resonant condition is established; that is to say, that the terminal D is charged to the maximum pressure developed in the circuit.

The adjustments should be made with particular care when the transmitter is one of great power, not only on account of economy, but also in order to avoid danger. It has been shown that it is practicable to produce in a resonating circuit as E A B B D immense electrical activities, measured by *tens and even hundreds of thousands of horsepower,* and in such a case, if the points of maximum pressure should be shifted below the terminal D, along coil B, *a ball of fire* might break out and destroy the support F or anything else in the way. An induced earth current out of phase with a "tower capacity" current meeting at any point along the coil, etc., would buck each other and so balls of fire could be produced; the instantaneous value of the energy so involved being truly astonishing. For the better appreciation of the nature of this danger it should be stated that the destructive action may take place with inconceivable violence. This will cease to be surprising when it is borne in mind that the entire energy accumulated in the excited circuit (instead of requiring, as under normal working conditions, one-quarter of the period or more for its transformation from static to kinetic form) may spend itself in an incomparably smaller interval of time, *at a rate of many millions of horsepower.* The accident is likely to occur when, the transmitting circuit being strongly excited, the impressed oscillations upon it are caused, in any manner more or less sudden, to be more rapid than the free oscillations.

It may seem quite impossible for many of our readers to comprehend the large figures cited by Tesla with regard to the voltage and horsepower liberated or propagated from such a structure as he has designed. However, by referring to Fig. 3, this matter can be more readily understood. This diagram shows how a graphic curve, C, would appear for, say, 100 horsepower liberated or passing through a circuit for the time period of one second. Now consider that instead of this 100 horsepower of energy being allowed to pass along in normal fashion for a period of one second, that it is heaped up or liberated in about one-fifth of a second as at B. The horsepower or watts, let us say in this case, would be dissipated at a much higher intensity rate than was the case at C. In other words, the rate of dissipation in this instance would be 500 horsepower for one-fifth of a second instead of 100 horsepower for one second.

Now consider that a Tesla current as produced by an oscillatory discharge from condensers and the like take place in very small fraction of time, then Tesla's statements in his patent and aforementioned with regard to the production of hundreds of thousands of horsepower is not so fallacious at it may seem. In an interview with one of our editorial staff he has vouchsafed the information that the oscillator here pictured is supposed to be excited with an input of 300 kilowatts. The average person then begins to gasp for air. An input of only 300 kilowatts! How, then, could this tower be caused to oscillate and liberate energy at the rate of hundreds of

(*Continued on page* 663.)

THE TESLA HIGH FREQUENCY OSCILLATOR.

(*Continued from page* 615.)

thousands of horsepower? However, this figures out better than might be expected offhand. With an input of 300 kilowatts at the Tesla coil primary exciting such a structure and considering that this amount of energy is discharged through the earth in six-thousandths (.006) of a second, then the rate of liberation of the energy will be 120,000 horsepower.

Many perhaps would doubt that even with their small experimental high frequency sets, where a high frequency ammeter placed in the high frequency circuit may register but *1 ampere effective current,* yet an average maximum surge for the oscillation passing through the circuit may and often does reach the value of *over 116 amperes.* As the amplitudes of each succeeding high frequency alternation is less than the one preceding it, of course the first oscillations are much higher than the average amplitude just mentioned, and consequently the peak value of the current which flows through the electrode and into a person (who may happen to be connected in series with a 110-volt, 32 candlepower lamp for demonstration purposes) may reach a very much higher figure than 116 amperes.



Photo by Press Illustrating Co., N.Y.

TESLA'S LABORATORY AT SHOREHAM, L.I., U. S A.
THE BOYS HAVE NOT BROKEN A WINDOW PANE



Photo by Press Illustrating Co., N.Y.

A CORNER OF TESLA'S LABORATORY WHICH SHOWS
THAT HE PACKED AND LEFT HURRIEDLY

Tesla's Million Dollar Folly

IF you consult "Who's Who in America" you will find the following paragraph —"Tesla, Nikola, electrician, b. Smiljan, Lika (border country of Austria-Hungary), 1857: s. of Greek clergyman and orator and of Georgina Mandic, who was an inventor, as was her father." There follows a long and impressive list of his discoveries and accomplishments, hardly intelligible to the average reader unversed in the mysteries of electricity. To the world he is best known as the discoverer of the alternating current system and as the man who harnessed Niagara Falls.

Like all geniuses, he is a dreamer and a spender. His dreams have been so real to him that he has persuaded investors to back him in many enterprises. The greatest monument to his unfinished dreams is his immense laboratory at Shoreham, L.I. Fifteen years ago he was given a large tract of land in the town then called Wardencliffe. A local builder hastened to erect houses for the workmen that came from the city and the town felt that great prosperity was ahead of it. A huge brick building was finished and above it a steel tower capped by a copper dome one hundred and eighty-five feet above the ground. Workmen reported that pipes had been sunk in the earth to almost an equal number of feet. Carefully crated machinery arrived by train and was installed in the brick laboratory and a group of silent workmen worked day by day.



Photo by Press Illustrating Co., N.Y.

A TOWER 185 FEET HIGH WITH A COPPER COVERED DOME NEAR TESLA'S LABORATORY

The purpose behind all this investment and energy was a mystery to the town. Gradually whispers were heard—"He intends to furnish power for New York City"; "he will electrify the railroads of Long Island"; "the Tower can be seen from the Connecticut shore; it will be a signal station from whose copper dome messages will be flashed," etc. No one that knew would say whether the whispers contained a germ of truth and gradually the wonder grew less and the mystery in their midst became an old story. A couple of years passed by and no wonderful results came.

Evidently the dream was proving difficult to materialize. Suddenly, almost in a night, the inventor and his workmen departed. For a time a watchman patrolled the grounds, then he too went to other fields, leaving the sleeping plant to take care of itself. It has had a long nap in the sleepy town some sixty odd miles from New York City. Adventuresome boys used to climb the steps of the tower until they became so rotten as to make them unsafe. One day they discovered a loosened window catch and made their way inside the laboratory. There everything seemed left as for a day—chairs, desks and papers in business-like array. The great wheels seemed only awaiting Monday life. But the magic word has not been spoken and the spell still rests on the great plant. It is reported that the books and papers have been taken away but otherwise the place is the same as when left some dozen years ago. Its existence has almost passed from the minds of men—even the general passenger agent of the railroad, whose tiny station is within three minutes of the laboratory, did not know of the million dollar failure. There are rumors that another dream of the famous electrician is soon to assume reality. Then perhaps, the dead will come to life and the monument become the mecca of admiring scientists.

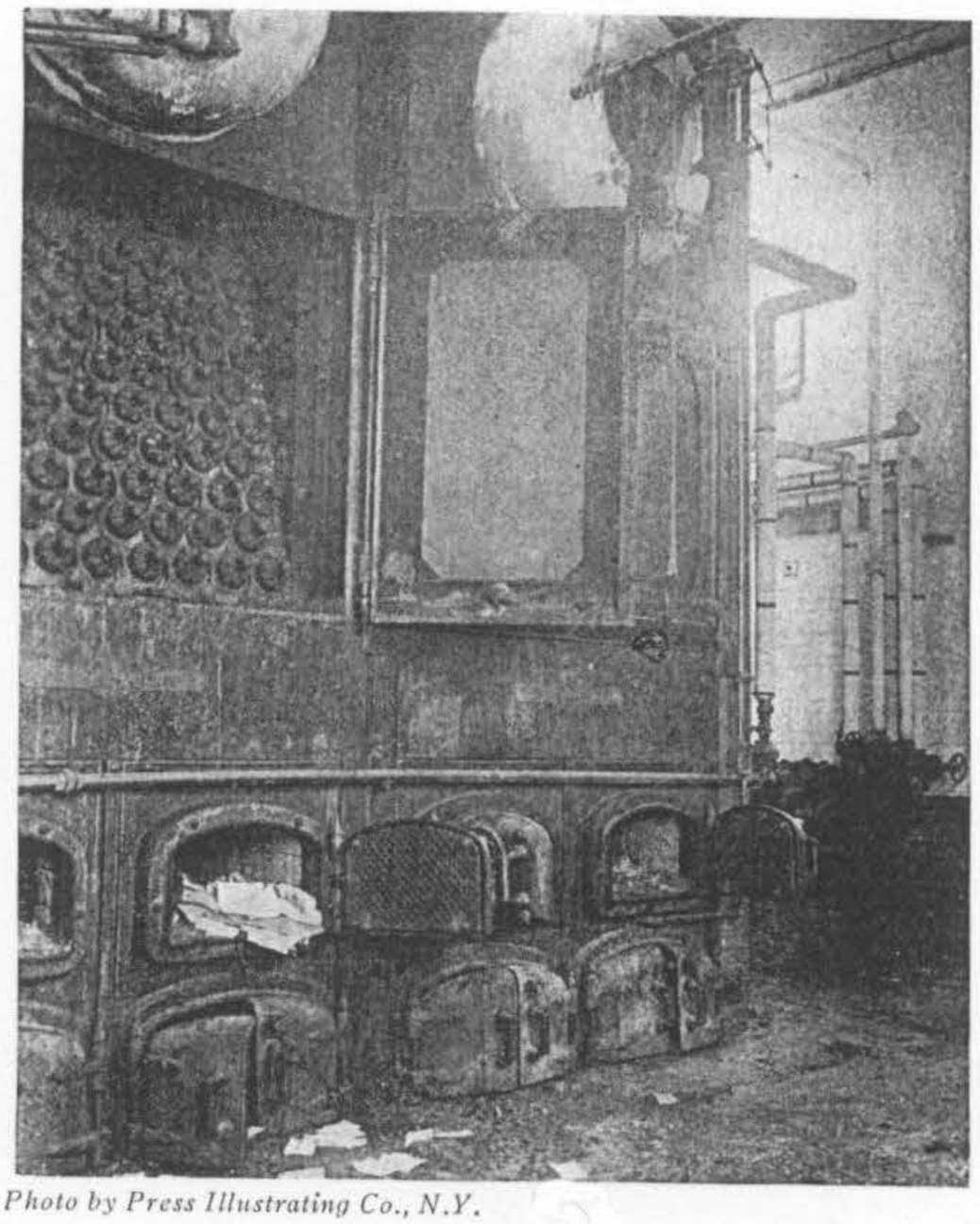


Photo by Press Illustrating Co., N.Y.

A FURNACE IN TESLA'S LABORATORY

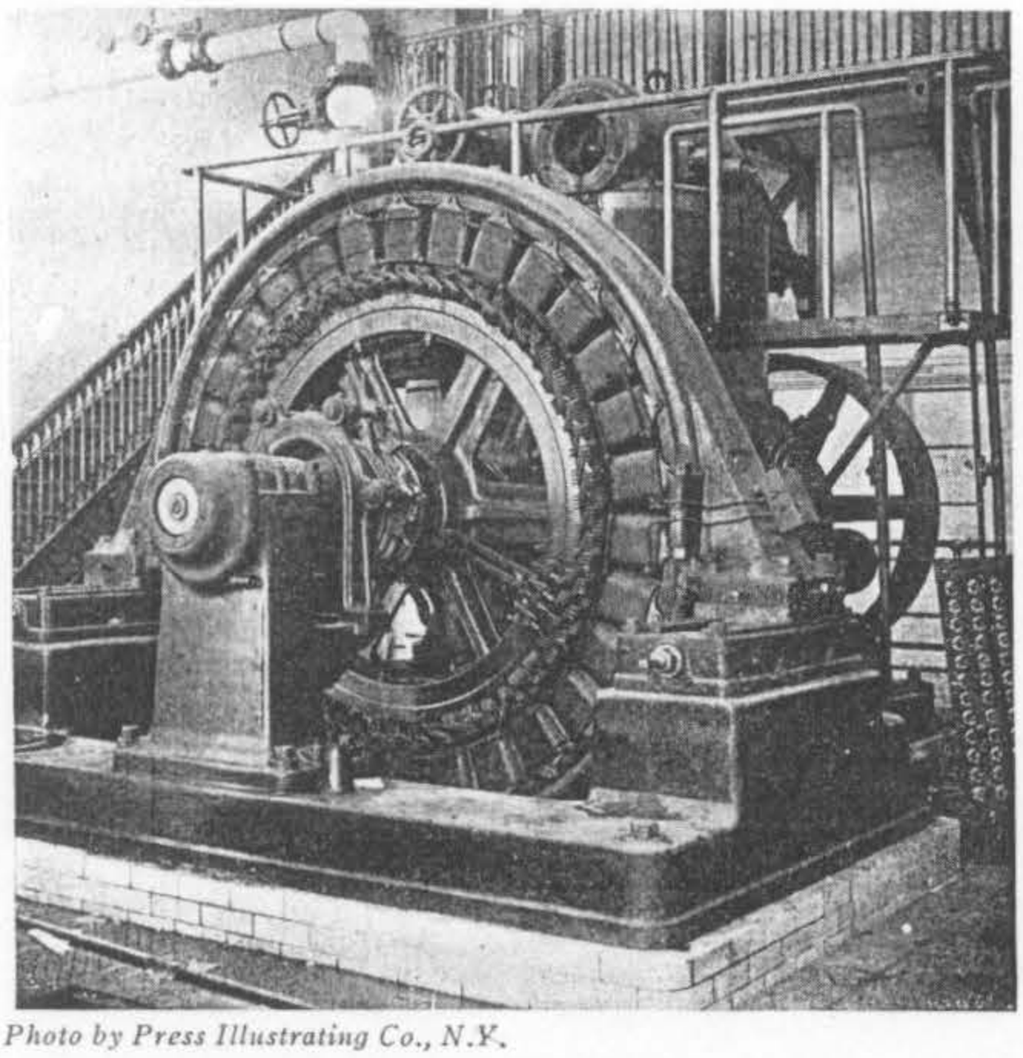


Photo by Press Illustrating Co., N.Y.

MACHINERY IN TESLA'S LABORATORY WAITING FOR THE MAGIC WORD TO BE SPOKEN

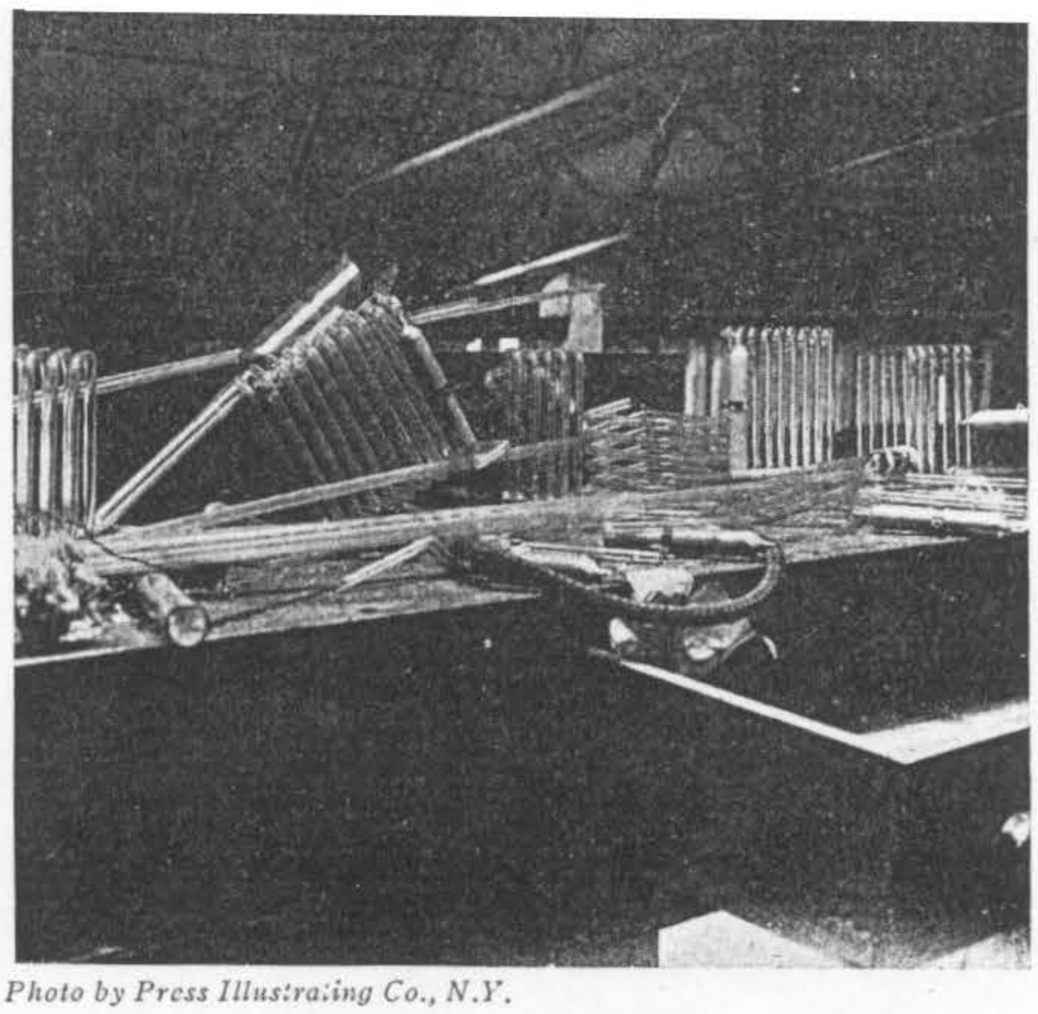


Photo by Press Illustrating Co., N.Y.

APPARATUS IN TESLA'S LABORATORY, SOMEWHAT THE WORSE FOR ITS LONG WAIT

The New York Times March 2, 1916

TESLA'S PORTRAIT SHOWN.

Painted by Princess Under Light Arranged by Inventor.

Nikola Tesla, inventor in the realm of electricity has had his portrait painted under a special man-made north light, and last night it was shown for the first time by the artist, the Princess Lwoff-Parlaghy, at a reception which she gave at her new studio, 109 East Thirty-ninth Street, especially to exhibit it.

It was one of the beliefs of Mr. Tesla that there was something unlucky about posing for a picture and so he never sat to any before he entered the studio of the Princess. The room which she had chosen did not have a skylight in it and the much desired north exposure was missing. So it was that at the suggestion of Mr. Tesla, a cluster of powerful incandescents was put up in the corner of the apartment and the rays, filtered through blue glass, were just of the right quality. The portrait was shown under the same illumination.

Mr. Tesla having solved the problem of the artificial sun fell to thinking about other parts of the universe, and there he sat oblivious to his surroundings. So it was that the painter was able to produce a likeness in which there is no evidence that the subject was conscious that anybody was even watching him, much less studying his features from the other side of an easel.

Among those who attended the reception were Mrs. C. B. Alexander, Henry P. Davison, the Countess de Ritterberg, and Mrs. E. T. Isham.

The New York Tribune March 2, 1916

CARE FREE, PRINCESS ENTERTAINS "AT HOME"

Not a Word of Her Past Troubles as Guests View Portraits.

Princess Lwoff-Parlaghy was "at home" last night, far away from the hateful, menacing shadows of the Plaza Hotel. It was a much toned down princess who lingered long over plebian hands and partook of dainty Russian dishes with plain folk. With a great crimson mantle thrown over her shoulders carelessly, the princess for one night belied her hyphen.

Inside 109 East Thirty-ninth Street is the princess's studio. There hung a portrait of a thin-faced man, and the blue light bathed it with the rays of daylight. Gorgeously clad women and slim-limbed men passed by it, commented in low tones and passed on to a room in pink and gold, where refreshments were served.

But Nikola Tesla, whose portrait the princess had painted, planted himself in front of it and gazed enraptured. The other folk passed from the portrait of smiling Andrew Carnegie to a pastel study of Thomas Edison, both from the brush of the princess. If anybody remarked about the troubles of the princess at the Hotel Plaza it must have been done in furtive secrecy.

"I have moved from the Plaza long. so long ago," she smiled, as she stabbed a thin slice of boiled tongue with the daintiest of forks. "My bills have been all paid, and now I am of conscience free."

When the princess was through receiving she returned. Once she had commanded a newspaper writer to sign a legal document offering to pay a forfeit of $300 to charity if anything was printed about their interview that she did not like. But last night the princess simply offered more slices of chicken, more wine, more cream and cake and Russian salad.

"Mr. Tesla is wonderful," she rhapsodied.

"The princess," said Mr. Tesla, out of hearing, "has made me look so intellectual."

The New York Herald March 18, 1916

NAMES RECEIVER FOR NIKOLA TESLA

Justice Finch Learns That Inventor Finds It Difficult to Pay for Food and Clothing.

Nikola Tesla, inventor, finds it difficult to pay for food and clothing, despite his unusual success in the electrical world, according to his testimony at the Waldorf-Astoria in the city's action to recover $935.25 for personal taxes. The city obtained a judgment in 1909.

Asked by counsel how he lived, Mr. Tesla, according to minutes filed in the Supreme Court yesterday, replied:—"Mostly on credit. I have a bill at the Waldorf-Astoria that I have not paid for several years."

"Do you own any shares in the Nikola Tesla Company?"

"No. I did own about nine-tenths of the $500,000 of capital stock, but I had to raise money. I pledged much stock for money to be advanced to the company to build an electric plant."

"Has the company any assets?"

"None now. It's getting a little on royalties—not enough to pay expenses, about $350 or $400 a month."

"Do you own any patents?"

"No; all my intentions are assigned to the company. There were two hundred patents. Some have run out and some have been lost through non-payment of fees."

Mr. Tesla said there were "scores of judgments" entered against him and "four or five proceedings now pending." He said no one owed him anything. Justice Finch appointed Robert Marsh receiver for Mr. Tesla.

The New York Times March 18, 1916

TESLA HAS ONLY CREDIT.

Inventor, at Supplementary Inquiry, Denies Owning Anything

Testimony given by Nicola Tesla, the electrical inventor, in a supplementary proceeding begun by the city to collect a judgment for $935 for personal taxes, was filed yesterday with County Clerk Schneider. Mr. Tesla said under oath that he was penniless, and had been living on credit. His home is the Waldorf. He was asked:

"How do you live?"

"Mostly on credit," he replied. "I have a bill at the Waldorf that I have not paid for several years."

"Are there any other judgments against you?"

"Scores of them.

"Does anybody owe you any money?"

"No sir."

"Have you any jewelry?"

"No, Sir; jewelry I abhor."

Mr.. Tesla said he was the President and Treasurer of the Tesla Company of 8 West Fortieth Street. The company was organized in 1895 with $5,000 capital, which was afterward increased to $500,000. He owned nine-tenths of the stock, but he said it had all been pledged between 1898 and 1902 inclusive. Asked if the company was earning anything Mr. Tesla replied that its income was about $350 or $400 a month, "just enough to pay expenses." The company started with 200 patents, but all of them, except a few, had run out or had been lost for non-payment of fees.

Asked with whom he had pledged his stock Mr. Tesla replied that it was given to bankers, to friends, to judgment creditors, to two friends and others. Mr. Tesla said that he owned no real estate in this country, and that he had no automobiles or any property whatever. Once he had $1,000 in a trust company but that was gone. The Secretary of his company, he said, was George Scherff a bookkeeper employed at 17 Battery Place. Among the directors of the company were Diaz Brutrago and Fritz Lowenstein.

Justice Finch of the Supreme Court appointed Robert McC. Marsh receiver for Mr. Tesla.

TESLA, INVENTOR, CAN'T PAY TAXES

Once Owner of $500,000 Plant Sued for $935—Now Lives on Credit.

Thirty-three years of unceasing efforts for humanity by Nikola Tesla, inventor and engineer, whose name is known wherever electricity is used, have proved to be a labor of love alone. The man who ranks with Edison and Marconi yesterday confessed himself not only unable to pay his personal taxes, but dependent on credit for the necessities of life.

As a living proof of the inability of a genius to convert his gifts into cash, Tesla presented himself as Exhibit A in supplementary proceedings instituted by Corporation Counsel Hardy for $935 personal taxes. Justice Finch, of the Supreme Court, has appointed R. McMath receiver for the inventor. Eighty independent inventions, every one of which has been adopted by the engineering world, have failed to place a penny in the pocket of the man who created them.

Only a few years ago Tesla owned nine-tenths of the stock of the Nikola Tesla Company, a $500,000 corporation, with offices at 8 West Fortieth Street. All of this stock was used as security on loans to be used in making new inventions. Just now the inventor has neither place of business nor home. He is occupying a room at the Waldorf-Astoria which, according to his testimony, he is allowed to occupy while owing the hotel a bill that has been unpaid for years.

"How do you live?" asked Corporation Counsel Hardy, who examined Tesla.

"Why, mostly on credit," he answered, after some hesitation.

"Has the Tesla company any assets?"

"No, not now," said its founder. "It is getting a little in royalties, but not enough to pay expenses."

"Do you own any patents?"

"No, not any more. All of them have been assigned to various creditors or to the company. There were more than 200 patents."

In answer to a question whether there were any judgments against him Tesla said there were scores of them—and more pending. He said he had no money in the bank nor elsewhere. When asked whether he had any jewelry he said he abhorred it.

Probably the greatest of Tesla's numerous inventions was that of the alternating motor, into which was compressed the maximum of horse power in the minimum of space and weight of material. His 200-horsepower engine was of such size that it could be placed in a receptacle little larger than a hat box.

A 10-horsepower engine was constructed by Tesla of such diminutive proportions that it might be dangled from the hand by a string. The possibilities of this method of storing power, as well as the numerous uses to which an alternating motor might be put, were such that scientists unhesitatingly said it would bring untold wealth to its inventor.

The Tesla arc light, methods of eliminating waste in distribution of electricity, development of wireless telegraphy and numerous other practical inventions at various times promised to bring wealth to their creator. But money was as hard to lure into the pockets of Tesla as engineering ideas were easy to bring from his brain. Practically all of his engineering dreams have come true without bringing about the realization of one of his modest dreams of financial independence.

Largely as a matter of form, the Justice appointed a receiver for Tesla because of the city's claim against him. Neither Tesla nor the receiver expects to find anything to receive.

The New York World March 18, 1916

TESLA NO MONEY WIZARD; SWAMPED BY DEBTS, HE VOWS

Inventor Testifies He Owes the Waldorf, Lives Mostly on Credit, Hasn't a Cent in Bank, and "Hocked" Stock in His Company.

Nikola Tesla, electrical wizard, is so hard up that he cannot pay the city $935 personal taxes. He says so himself and states in effect that being a wizard isn't always a profitable business.

That Mr. Tesla owes so much money he hasn't the slightest idea when he will be able to meet his obligations became known yesterday when Corporation Counsel Hardy filed in the Supreme Court the minutes of an examination he made of Tesla in supplementary proceedings.

The inventor said he possessed no real estate or stocks and that his belongings, all told, were negligible.

"But don't you live at the Waldorf-Astoria?" he was asked.

"I do, and I owe the hotel a bill which has not been paid for several years," was the reply.

"Well, how do you live?"

"Mostly on credit."

Mr. Tesla said that at one time he had owned nine-tenths of the stock of the Nikola Tesla Company, but he had pledged the stock for money to build an electric plant. He added that the company now has no assets, but is receiving enough royalties on patents to pay expenses.

All of Tesla's inventions—about 200—have been made over to the company, according to the witness.

Asked concerning his debts he said there were "scores of them" and that five or more proceedings were pending against him. No one owed him any money, he declared, and he had no money in bank.

"Well, haven't you got any jewelry?" asked the Corporation Counsel.

"No jewelry; I abhor it."

"Any automobiles?"

"No."

"Any horses?"

"No."

The inventor said he is still President and Treasurer of the Nikola Tesla Company.

Justice Finch yesterday appointed Robert Marsh receiver for the inventor.

The Brooklyn Eagle March 25, 1916

NIKOLA TESLA TOWER AT SHOREHAM SOLD

Landmark in North Shore Village Is Purchased by Manhattan Attorney.

WIRELESS EXPERIMENTS THERE.

Property Assessed at $15,000 Is Bought for Investment, New Owner Says.

(Special to The Eagle.)

Shoreham, L. I., March 25—The Nikola Tesla property, the site of the tower which has been the landmark for over a decade on the North Side, has been sold to Lester S. Holmes, an attorney of Manhattan. The property comprises 176 acres of land immediately adjoining the railroad station, a brick building, formerly used by Tesla as a laboratory, and the 150-foot tower. The price paid has not been made public. The property was carried on the tax books of Brookhaven town at an assessed valuation of $15,000. Correction for equalization would undoubtedly bring the value of the property over $25,000.

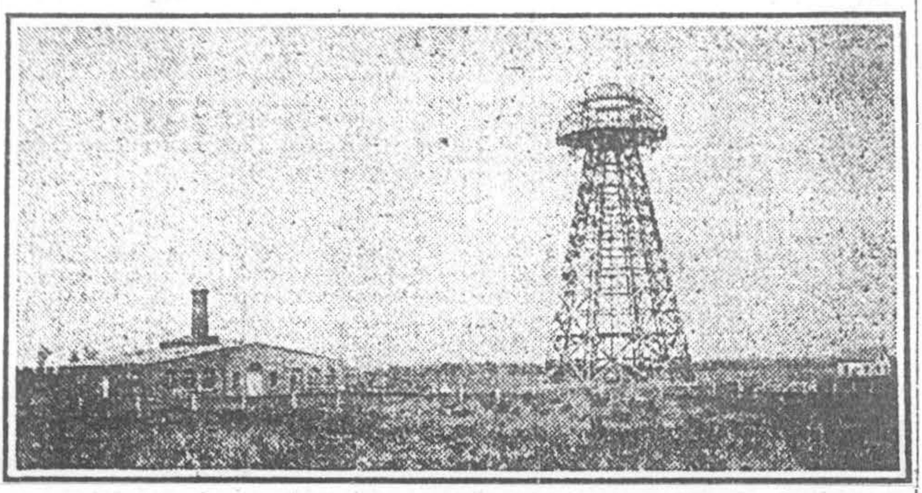
About fifteen years ago Nikola Tesla established the plant at what was then known as Wardencliff. Here he carried on experiments in the wireless transmission of power with currents of the magnitude of lightning, and it was from this plant that he was at one time incorrectly accredited with making efforts to communicate with the planet Mars. The same property figured in the news a few years ago when some difficulties arose over taxes.

Attorney Holmes, the purchaser of the property, stated at his office in Manhattan, yesterday, that he had no intention of using the property as an electrical experimental station, but had purchased it merely as a business proposition. He stated that he had no special plans at the present time for the use of the property.

That the laboratory and tower will no longer be used as an experimental station is further indicated by the fact that the machinery and electrical apparatus in the laboratory building, as well as its other furnishings, have been removed and the place closed.

The Brooklyn Eagle March 26, 1916

Tesla's Tower at Shoreham, Unique Long Island Landmark, Passes From Inventor's Hands



(Special to The Eagle.)

Shoreham, L. I., March 25—Standing like one of the fabled Martian giants from H. G. Wells' tale of the "War of the Worlds," the tall Tesla tower has graced the landscape of this village for a decade and a half of years. One of the most picturesque sights on Long Island, it was the cause of much wonder on the part of visitors to this section of the island. Now the tower and the building at its base, as well as the land surrounding it, have passed from the ownership of its builder, Nikola Tesla. The property, as was told in The Eagle today, has recently been transferred to Lester S. Holmes, a Manhattan lawyer. The fate that awaits the unique structure is now a matter of conjecture, for the new owner has not announced any plans for the disposition of the property.

The tower stands just over the brow of a small hill a short distance from the Shoreham section. Close to its base is a brick building, and below it is a well of generous width and depth. From the tower the surrounding country spreads out in pleasing prospect to the south, and to the north is the broad expanse of Long Island Sound. Residents of this neighborhood whose curiosity surpassed their awe have until a short time ago mounted the steps of the tower to view the countryside, the summit of the tower being a very commanding position from which places many miles away can be seen. A few of the more reckless have even penerated the depths of the well beneath the tower.

Aside from the scientific interest which attaches itself to the place because of its association with the work of Nikola Tesla, a more romantic local itnerest has always surrounded the place. It is not too much to say that the place has often been viewed in the same light as the people of a few centuries ago viewed the dens of the alchemists or the still more ancient wells of the sorcerers. An atmosphere of mystery hung over the place, an unearthly influence seemed to be radiated from the alembic topped tower, as if drawn down from interstellar space and spread over the countryside to inspire wonder and awe in the minds of the nearby farmers and villagers, who knew only that Tesla was searching for or working with wonder currents that had something to do with wireless and electricity.

Tower Long a Puzzle to Neighborhood.

Those who knew of the existence of the broad and deep well were convinced that he had found this electrical fluid and was drawing it from the earth. If such was not the case, they argued, why did he have that deep well with machinery at the bottom of it? To others who had read accounts in newspapers of wireless telegraphy and its wonders the argument that he was drawing this wonderful fluid from the air, the storehouse of lightning, held more force.

The tower stands in front of a one-story brick building of considerable length, and viewing the group from the rear, the tower appears to be surmounting the building. Four tall wooden timbers stretch from a height of over 100 feet. This skeleton structure has a spread of 40 or 50 feet across the base. Each timber inclines toward the center as it rises in the air, but instead of forming the apex of a pyramid, another skeleton-like structure, having the form of a half sphere, with the lower half missing, sets upon it like a crown. The diameter of this ball is about the same as the width of the base.

This half ball on top of the tower is a unique piece of work, even without considering its electrical character. It might well have served for the model for the tower of jewels, which was the most striking feature at the San Francisco World's Fair. As the World's Fair tower was set with jewels, so was this half ball studded with metal hemispheres over its entire surface.

No Metal Used in the Structure.

Another unusual feature of the structure is that no metal was used in its construction, except such as was used directly in the electrical circuits for which it was designed. The flights of stairs which provided the means of mounting the cage-like top were constructed without the use of nails, each step being fastened in place with wooden pegs. This same system was observed throughout the structure.

Until about five years ago Nikola Tesla was a familiar figure going to and from his plant. During the past five years the place has been but little used by its builder. The strange electrical fittings and machinery of the laboratory stood unused, and the place had all the aspects of desolation. The tower was frequently visited by parties in the neighborhood, who mounted the steps to the cage on top to view the surrounding landscape, but recently the lower flight of these steps has been removed, effectually preventing further use of the tower as an observation point.

Within the past few months the laboratory in the brick building has been stripped of its machinery and furniture and the place closed, apparently to remain closed permanently.

The purchaser of the land and buildings stated that he has no intention of putting the tower and building to the same uses as did Tesla. Beyond that, he has not made any plans for the use of the property. To the statement that he did not intend to use the place for any electrical experiments Mr. Holmes added that he had purchased the place, which includes 176 acres, merely as a business proposition.

Tesla Coils.—W. Morris Jones.—It is generally assumed that a Tesla coil gives the best effect (i.e., the highest secondary potential for a given primary discharge potential) when the two circuits are so adjusted that, separated, their periods of oscillations are equal. This condition is expressed by the relation $L_1C_1 = L_2C_2$ and is commonly called the condition for "resonance" or "synchronism." In a recent paper Taylor Jones has shown that the above condition does not apply if the adjustment is made by varying the primary capacity alone, but that in this case the "optimum" value of C_1 is considerably greater than the resonance value. The author gives the results of an experimental investigation in which the chief conclusions of the theory were confirmed.—*Philos. Magazine*, January, 1916.

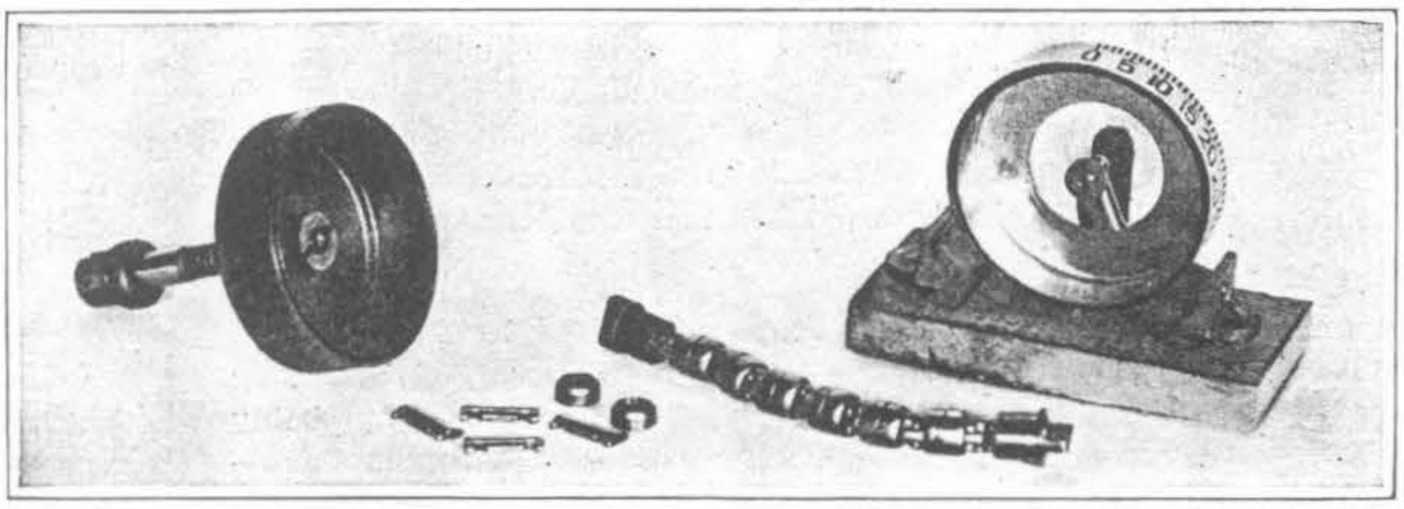
An Automobile Speedometer That Operates by Air Friction

DEPENDING upon the principle of air friction and consisting essentially of two metal cups fitting one into the other, but not touching at any point, a speedometer has been developed to a commercial stage after three years' experimenting on the part of a leading watch company.

The new speedometer is unique in that it does not employ the centrifugal nor the magnetic principle as do the other types of speedometer in general use; instead, it relies on the friction of air as developed by metal surfaces. The two main components of the speedometer in question are a driving cup, which is rotated by power from one of the automobile wheels through the flexible shafting, and, suspended over and around it, a driven cup. The driven cup, which is also the indicating one since the numerals representing the miles per hour attained are marked on its periphery, is inverted over and around the driving cup, as will be noticed in one of the accompanying illustrations. This cup, as is also true of the driving cup, in reality consists of a double cup.

The driving cup of the speedometer comprises two concentric brass cups with a spacing of .108 centimeters between the two vertical walls, called "ribs" for convenience, both of which are rigidly mounted on a vertical shaft so as to revolve in perfect unison. Likewise the driven or indicating cup is made up of two aluminum cups attached together so as to form a single cup insofar as its mechanical operation is concerned. These cups are extremely light, being made of aluminum .008 centimeter thick. This means that 313 of these cup thicknesses would be required to total a thickness of 1 inch.

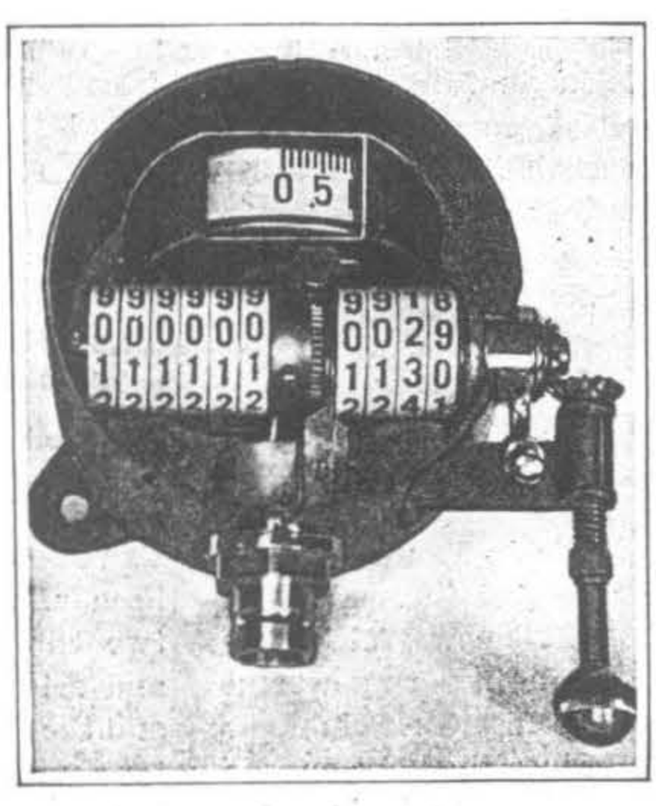
The driven cup when in position in the instrument has its inner rib floating in the annular space between the ribs of the brass cup, while the outer rib of the aluminum floats outside of the brass cup. There is an air space of .5 millimeter between the ribs of the brass and aluminum cups. In one of the accompanying views may be seen how the two cups are telescoped.



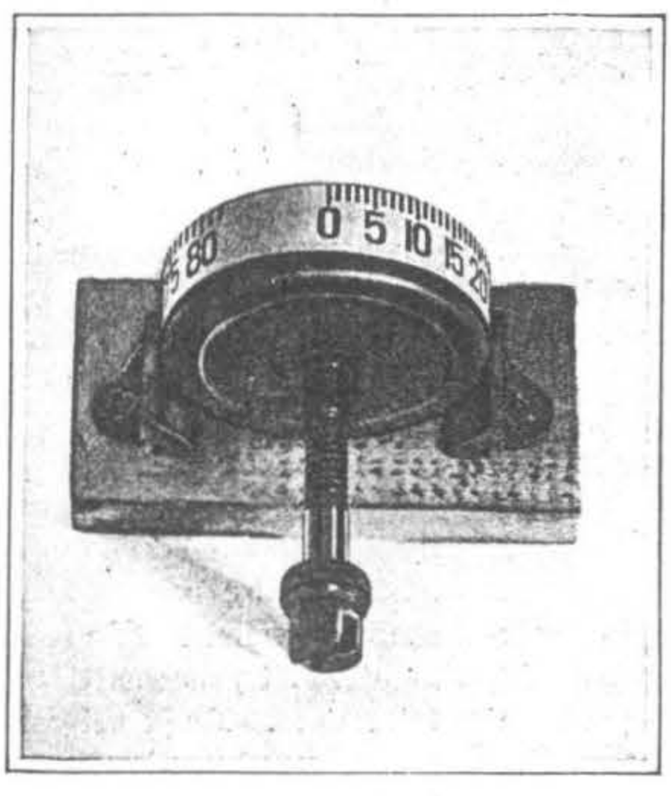
Brass and aluminum cups used in the new air-friction type speedometer, and parts and section of the flexible shaft which is assembled without a rivet

The operation of the new speedometer is of the utmost simplicity: the revolving of the brass cup generates the air friction which, were it not for a regulating hairspring serving normally to maintain the aluminum cup at the zero marking, would cause the latter to revolve; in other words, the air friction developed serves as a means of transferring the driving power from the brass cup to the aluminum cup. The hairspring is so adjusted as to permit the aluminum cup to be affected by the air friction in direct proportion to the speed of the brass cup, so that the reading of the instrument will be correct.

The air friction developed in the instrument has been proved to be directly proportional to the speed of the revolving cup. It is this fact that has made possible a uniform calibration without introducing compensating devices to gain this end. Comprehensive laboratory tests are reported to have proved that air friction is not influenced by heat, cold or altitude up to 10,000 feet. The revolving cups, contrary to expectations, do not have to be carried in an airtight compartment, and no sealing is necessary. The regulation between the tension of the hairspring and the tendency of the aluminum cup to rotate under the influence of the air friction is so delicate that the instrument indicates immediately all speed changes, and indicates as low as one half mile per hour. Yet the instrument is so sturdy that its accuracy is not affected by vibration in regular service.



Air-friction type speedometer completely assembled, showing the arrangement of the parts

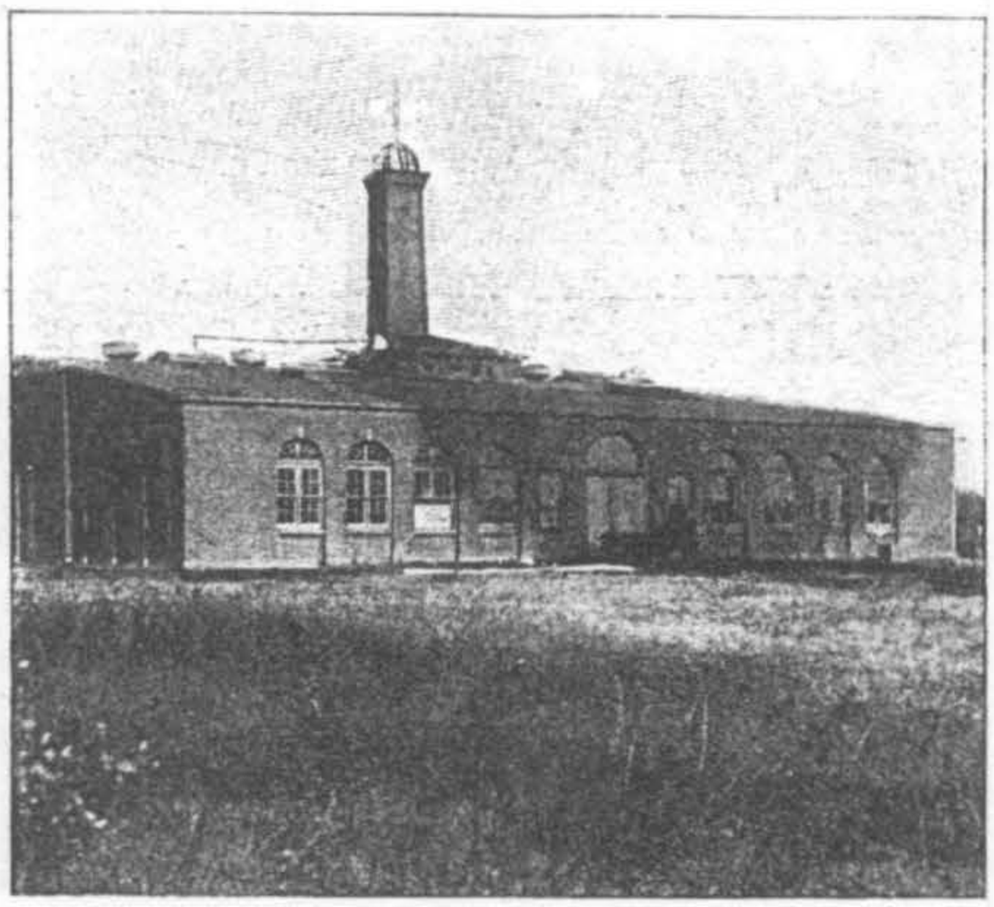


Method of mounting the driving and driven cups in the new speedometer

SCIENCE - AND - INVENTION

TESLA'S MILLION-DOLLAR MYSTERY

NEAR SHOREHAM, on Long Island, stands a great lattice-work tower nearly two hundred feet high, with a copper mushroom for a top. This is Nikola Tesla's great electric tower, whose purposes have never been accurately known. He has asserted that he was prepared to send electric signals by actually increasing and diminishing the electric charge of the earth, and the tower has been generally connected with this assertion. The tower and the laboratory with it, tho representing a large outlay, have remained idle for years. Of late there have been rumors that some use, either practical or experimental, was to be made of the plant, and one or two journals have published articles filled with somewhat fantastic predictions, seemingly divorced from clear explanation. On the other hand, *Export American-Industries* (New York, March) calls the plant "Tesla's Million-Dollar Folly." Under this head it says:



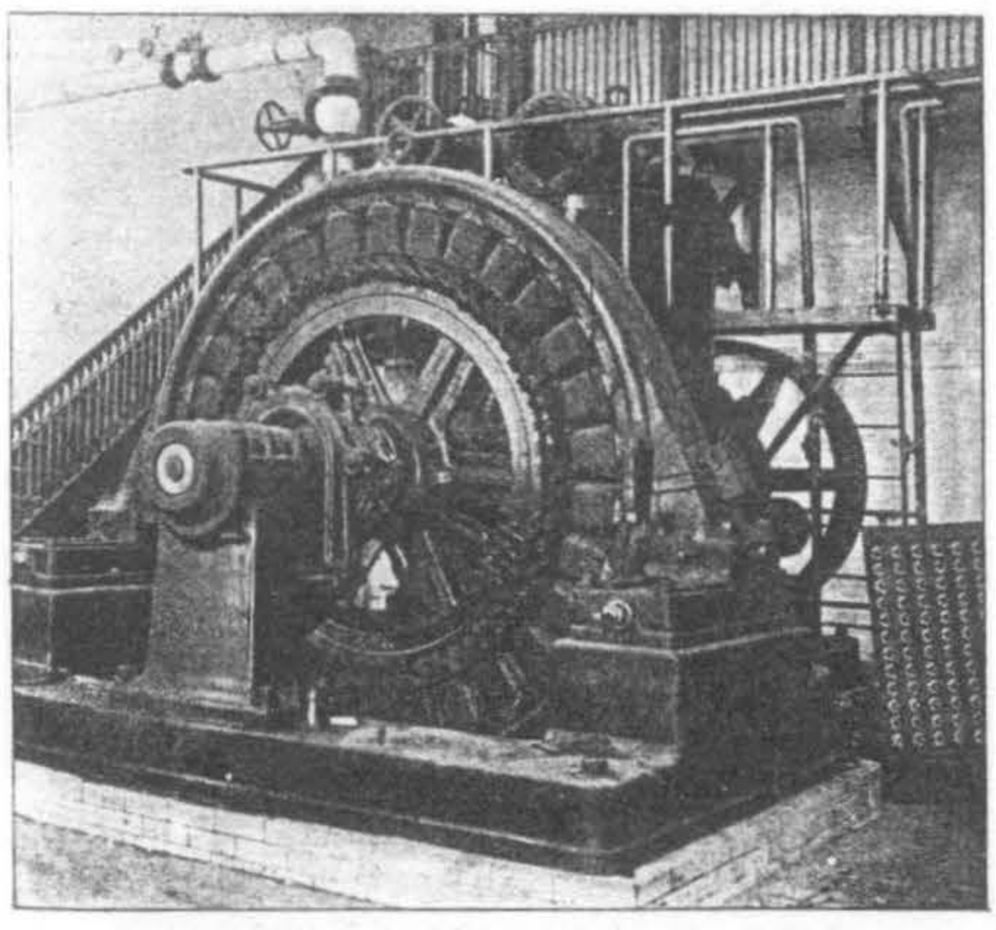
THE FORSAKEN LABORATORY

Mysteriously abandoned on completion twelve years ago.

"If you consult 'Who's Who in America' you will find the following paragraph—'Tesla, Nikola, electrician, b. Smiljan, Lika (border country of Austria-Hungary), 1857: s. of Greek clergyman and orator and of Georgina Mandic, who was an inventor, as was her father.' There follows a long and impressive list of his discoveries and accomplishments, hardly intelligible to the average reader unversed in the mysteries of electricity. To the world he is best known as the discoverer of the alternating-current system and as the man who harnessed Niagara Falls.

"Like all geniuses, he is a dreamer and a spender. His dreams have been so real to him that he has persuaded investors to back him in many enterprises. The greatest monument to his unfinished dreams is his immense laboratory at Shoreham, L. I. Fifteen years ago he was given a large tract of land in the town then called Wardencliffe. A local builder hastened to erect houses for the workmen that came from the city, and the town felt that great prosperity was ahead of it. A huge brick building was finished, and above it a steel tower capped by a copper dome 185 feet above the ground. Workmen reported that pipes had been sunk in the earth to almost an equal number of feet. Carefully crated machinery arrived by train and was installed in the brick laboratory, and a group of silent workmen worked day by day.

"The purpose behind all this investment and energy was a mystery to the town. Gradually, whispers were heard—'He intends to furnish power for New York City'; 'He will electrify the railroads of Long Island'; 'The tower can be seen from the Connecticut shore; it will be a signal-station from whose copper dome messages will be flashed,' etc. No one that knew would say whether the whispers contained a germ of truth, and gradually the wonder grew less and the mystery in their midst became an old story. A couple of years passed by and no wonderful results came. Evidently the dream was proving difficult to materialize. Suddenly, almost in a night, the inventor and his workmen departed. For a time a watchman





THE HUGE MACHINERY STANDS SILENT, AND THE OFFICES SHOW SIGNS OF HURRIED DEPARTURE.

"The magic word has not been spoken, and the spell still rests on the great plant."

patrolled the grounds; then he too went to other fields, leaving the sleeping plant to take care of itself. It has had a long nap in the sleepy town some sixty odd miles from New York City. Adventuresome boys used to climb the steps of the tower until they became so rotten as to make them unsafe. One day they discovered a loosened window-catch and made their way inside the laboratory. There everything seemed left as for a day—chairs, desks, and papers in businesslike array. The great wheels seemed only awaiting Monday life. But the magic word has not been spoken, and the spell still rests on the great plant. It is reported that the books and papers have been taken away, but otherwise the place is the same as when left some dozen years ago. Its existence has almost passed from the minds of men—even the general passenger-agent of the railroad, whose tiny station is within three minutes of the laboratory, did not know of the million-dollar failure. There are rumors that another dream of the famous electrician is soon to assume reality. Then, perhaps, the dead will come to life and the monument become the Mekka of admiring scientists."



NOT BUILT TO BE BUT A LANDMARK.

Like the rest of Tesla's mystery, the purpose of this mushroom tower, with its 185 feet of structure and its copper-covered dome, is unknown. But Tesla still dreams, and it may yet come to life.

TESLA'S MILLION-DOLLAR MYSTERY.

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Tesla's Early Work With Radio Controlled Vessels

ALTHOUGH present day inventors are prone to shout loudly about their marvelous schemes for controlling torpedoes, boats or other mobile bodies by wireless, it is interesting at this time to take note of the fact that a very complete patent on an ingenious radio control system for torpedoes, etc., was issued to Nikola Tesla in the year 1898, or over eighteen years ago. At that time the science of radio telegraphy was barely on the threshold of possibilities and how far ahead of his time this great scientist is will be the more evident after perusing the following paragraphs:

The illustrations herewith are photographs of the early models constructed by Dr. Tesla and which were actually tried out with entire success. The diagrammatic illustrations will help to explain the working parts of the telemechanical models as outlined in his patent. Fig. 1 shows a model vessel corresponding to that shown in the sectional views, while Fig. 2 represents a model constructed at an earlier date.

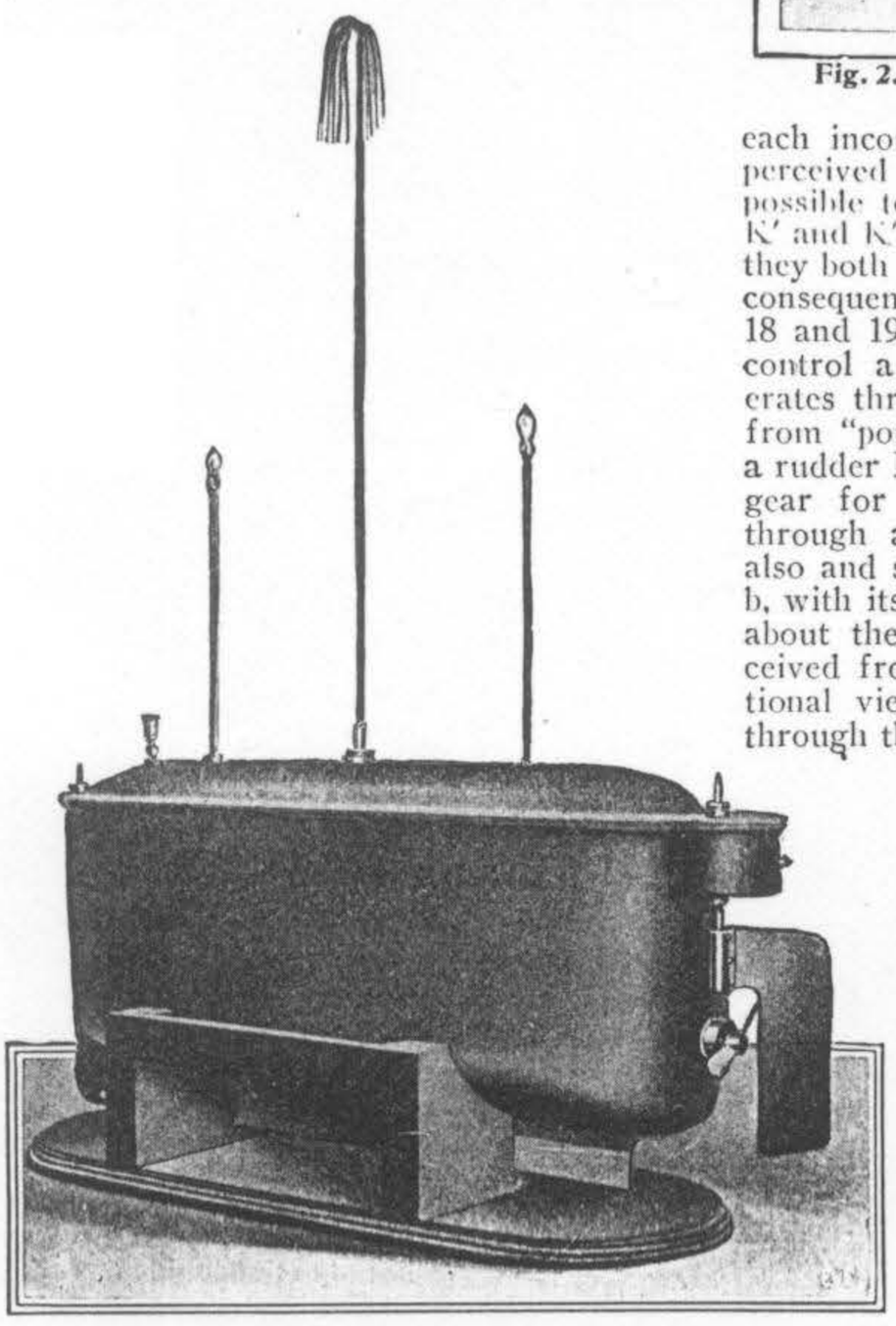


Fig. 1. Tesla's Radio-Controlled Boat Model, Which Was Built Over Eighteen Years Ago.

Referring to diagrams 3, 4, 5 and 6 respectively, we have in general a radio wave sensitive device resembling the well-known coherer at c. This is supported in a special movable holder on the de-cohering or resetting mechanism a and f. The radio receptor circuit connected with the coherer c leads to a grounded connection at B′ (see Fig. 4), and an elevated aerial or antenna system E′. A radio transmitting station on shore utilizes a spark gap S, with an elevated aerial and ground circuit hooked-up in the usual manner. A source of high potential current at T is provided to charge the spark gap, thus sending out periodically radio waves of a given frequency. A control switch is mounted on the end of the cabinet at T, and this passes over four points T, T′, U, U′. This part of the radio control arrangement will be referred to later.

When an incoming wave passes through the coherer circuit, it causes the relay a and the de-cohering device f to function, and simultaneously a commutator device j′ and j″ to rotate a quarter of a revolution for each incoming wave impulse. As will be perceived by referring to Fig. 6, it is thus possible to cause two major control relays K′ and K″, to be closed alternately or again they both may be left open-circuited, and in consequence their local or armature circuits 18 and 19 will be left open. These relays control a reversible motor, F, which operates through a worm gear drive to turn from "port" to "starboard," or vice versa, a rudder F′. Referring to Fig. 3, the worm gear for motor F moves the rudder F′ through a gear H″, as becomes evident; also and simultaneously the movable sleeve b, with its attached insulated disk L′ moves about the fixed vertical rod H. As perceived from the various diagrams and sectional views, this disk L′ when rotated through the agency of the steering motor F, will cause a series of metal segments 9, 10, 11, etc., to pass under a set of spring metal brushes 1, 2, 3, 4, etc., which are secured to the fixed insulating member L. The movement of this connector disk controls the circuit of the propelling motor D, connected through a shaft in the usual manner to a screw-propeller C (see Fig. 3). The energy for operating the motor, etc., is obtainable from the storage or other batteries E, carried in the moving vessel.

Tesla in his early patent mentions specifically that the transmitting and receiving radio circuits should be tuned to corresponding wave lengths or at least a harmonic of same. He also mentions that it is possible (although not considered in the present discussion) to control as many as fifty or a hundred circuits, each tuned to a distinct and different transmitting wave length. Of course a different transmitting wave length would be sent out for each control step desired to be put in action at the receiving device in this case.

The coherer of this early vintage is very interesting and comprises a metal cylinder

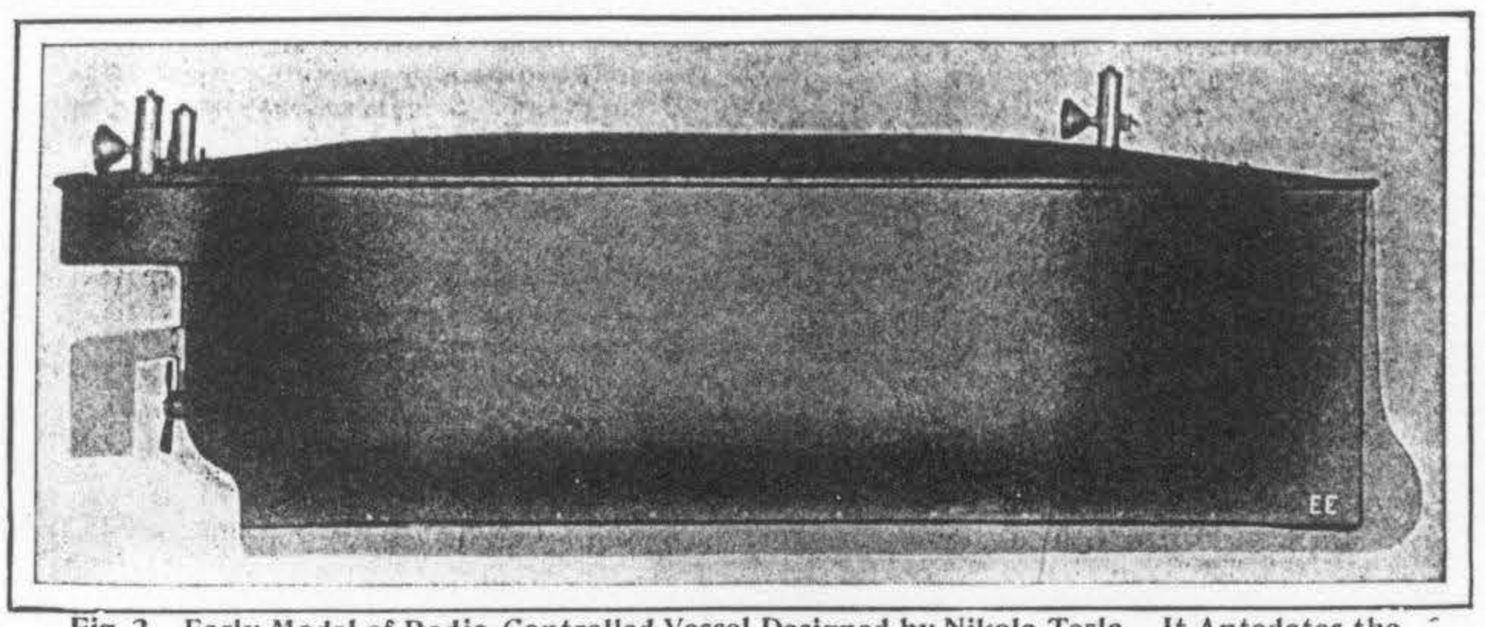


Fig. 2. Early Model of Radio-Controlled Vessel Designed by Nikola Tesla. It Antedates the Model Shown at Fig. 1.

c (detail in Fig. 5), with insulating heads c′, through which passes a central metallic rod c″. A small quantity of grains d, of conducting material (such as an oxidized metal) is placed in the cylinder. A metallic strip d′, secured to an insulated post d″, bears against the side of the metal cylinder c, forming one part of the circuit. The central rod c″ is connected to the frame of the instrument and so to the other part of the circuit, through the forked metal arm e, the ends of which are fastened with two nuts to the projecting ends of the rod, by which means the cylinder c is supported.

In order to interrupt the flow of battery current, which is started through the action of the sensitive coherer, special means are provided, which are as follows: The armature e′ of the relay magnets a, when attracted by the latter, closes a circuit containing a battery b′ and magnet f. The armature-lever f′ of this magnet is fixed to a rocker-shaft f″, to which is secured an anchor-escapement g. This controls the movements of a spindle g′, driven by a clock-train K. The spindle g′ has fixed to it a disk g″ provided with four pins b″; hence for each oscillation of the escapement g, the spindle g′ is turned through *one-quarter* of a revolution. One of the spindles in the clock-train, as h, is geared so as to make *one-half* of a revolution for each quarter-revolution of spindle g′. The end of the former spindle extends through the side of the frame and carries an eccentric cylinder h′, which passes through a slot in a lever h″, pivoted to the side of

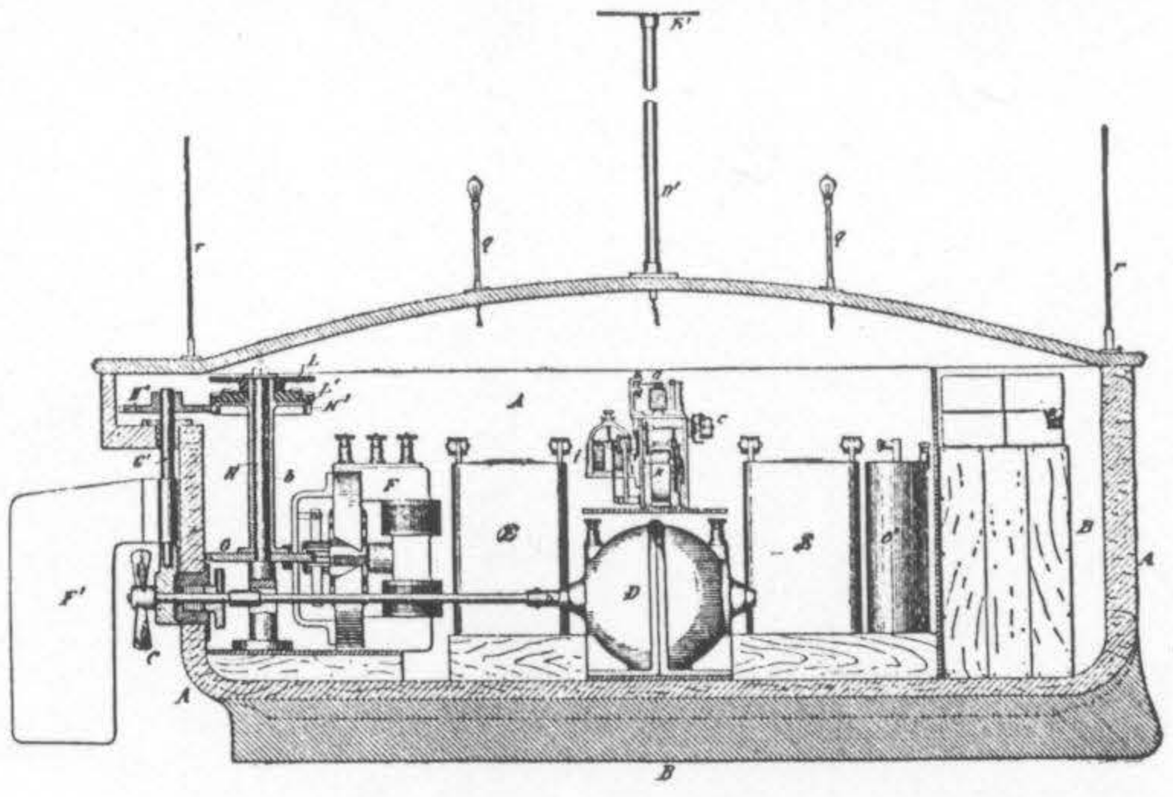
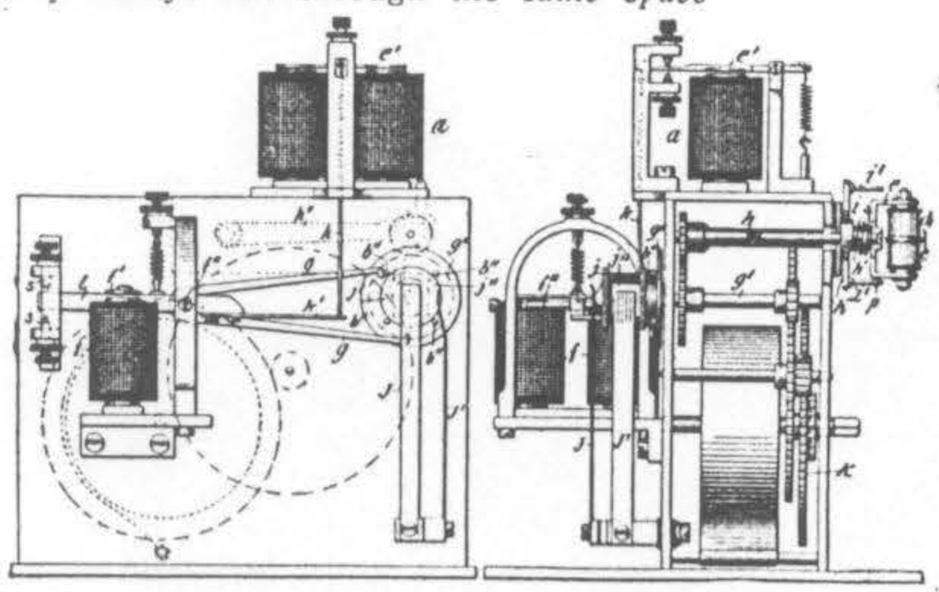


Fig. 3. Sectional View of Telemechanical Vessel Illustrated at Fig. 1.

the frame. The forked arm e, which supports the cylinder c, is pivoted to the end of eccentric h', and the eccentric and said arm are connected by a spiral spring i. Two pins i'i' extend out from the lever h", and one of these is always in the path of a projection on arm e. They operate to prevent the turning of cylinder c with the spindle h and the eccentric.

It will be evident that a half-revolution of the spindle h will wind up the spring i and at the same time raise or lower the lever h", and these parts are so arranged that just before the half-revolution of the spindle is completed the pin i', in engagement with projection or stop-pin p, is withdrawn from its path, and the cylinder c, obeying the force of the pring i, *is suddenly turned end for end,* its motion being checked by the other pin i'. The adjustment relatively to armature f' of magnet f is furthermore so made that the pin i' is withdrawn at the moment when the armature has nearly reached its extreme position in its approach toward the magnet—that is, when the lever l, which carries the armature f', almost touches the lower one of the two stops s s (Fig. 5), which limits its motion in both directions.

The normal position of the cylinder c is vertical, and when turned in the manner described, the grains in it are simply shifted from one end to the other; but inasmuch as they always fall through the *same space* and are subjected to the *same agitation* they are caused, after each operation of the relay, to offer precisely the same resistance to the flow of the battery current, until another radio impulse from afar reaches the receiving-circuit.



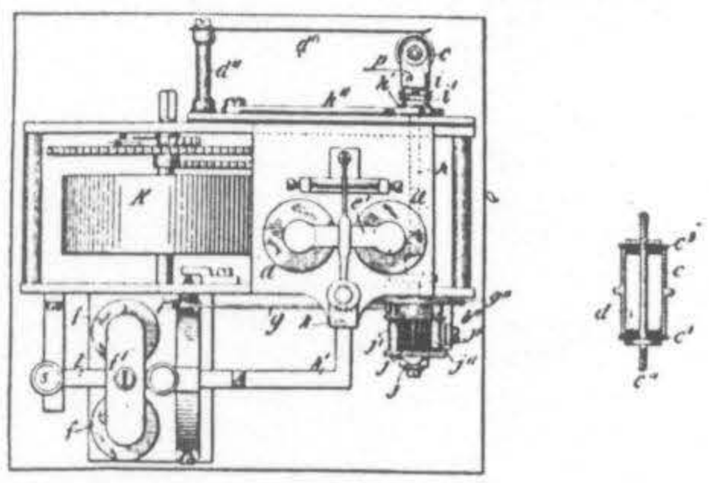


Fig. 5. Details of Clever Coherer, De-coherer and Double Relay Scheme.

The relay-magnet a should be of such character as to respond to a very weak current and yet be positive in its action. To insure the retraction of its armature e' after the current has been established through the magnet f and interrupted by the inversion of the sensitive device c, a light rod k is supported in guides on the frame, in position to be lifted by an extension k' of the armature-lever l, and to raise slightly the armature e'. As a feeble current may normally flow through the sensitive device and the relay-magnet a, which would be sufficient to hold though not draw the armature down, it is well to observe this precaution.

The operation of the relay-magnet a, and the consequent operation of the electromagnet f, as above described, are utilized to control the operation of the propelling-engine and the steering apparatus in the following manner: On the spindle g', which carries the escapement-disk g" (Figs. 4 and 6), is a cylinder j of insulating material, with a conducting plate or head at each end. From these two heads, respectively, contact plates or segments, j' j" extend on diametrically opposite sides of the cylinder. The plate j" is in electrical connection with the frame of the instrument through the head from which it extends, while insulated strips J J' bear upon the free end or head of the cylinder and the periphery of the same, respectively. Three terminals are thus provided; one always in connection with plate j', the other always in connection with the plate j", and the third adapted to rest on the strips j' and j" in succession, or upon the immediate insulating-spaces, according to which of the four distinct positions the commutator is brought to by the clock-train and the anchor-escapement.

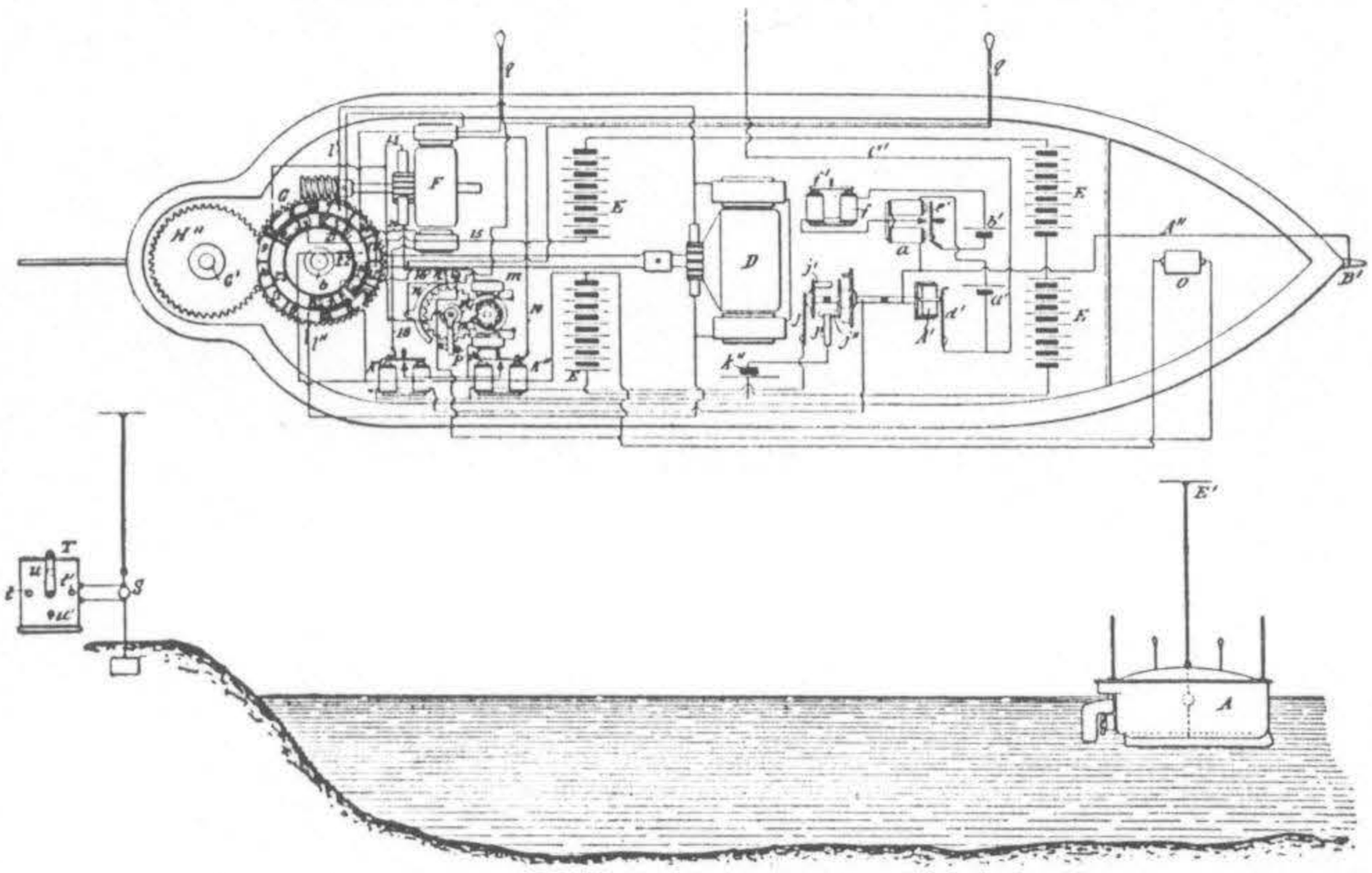


Fig. 4. Plan View of Radio-Controlled Boat and Shore Wireless Station.

At K' and K" (Figs. 4 and 6) are two relay-magnets conveniently placed in the rear of the propelling-engine. One terminal of a battery k" is connected to one end of each of the relay-coils, the opposite terminal to the brush J', and the opposite ends of the relay-coils to the brush J and to the frame of the instrument, respectively. As a consequence of this arrangement either the relay K' or K" will be energized, as the brush J' bears upon the plate j' or j", respectively; or both relays will be inactive while the brush J' bears upon an insulating-space between the plates j' and j". While one relay, as K', is energized its armature closes a circuit through the motor F, which is rotated in a direction to *throw the rudder to port.* On the other hand, when relay K" is active another circuit through the motor F is closed, which reverses its direction of rotation and shifts the *rudder to starboard.*

A small auxiliary motor, m, may be employed to control signaling lights erected on masts above the deck of the vessel, so that the operator on shore can tell in the dark just how and in what direction the telemechanical vessel is progressing through the water. This signaling motor arrangement is connected in series with the armature of the steering motor F, so that whenever either one of the circuits of the latter is closed through relay K' or K", the motor m is likewise rotated, but in any case in the *same direction.* The signal lamps may be colored to facilitate matters. By this mechanism it is also possible, by sending out a predetermined series of electric wave impulses, to cause its spring repelled switch arm m" to come in contact finally with switch point n', thus closing a circuit through a special device o, which might, for instance, be the detonating cap of an explosive chamber in the case of a radio-controlled torpedo.

With regard to the method of handling the entire outfit, we may now have reference to Figs. 4 and 6. Here S designates

(*Continued on page 136*)

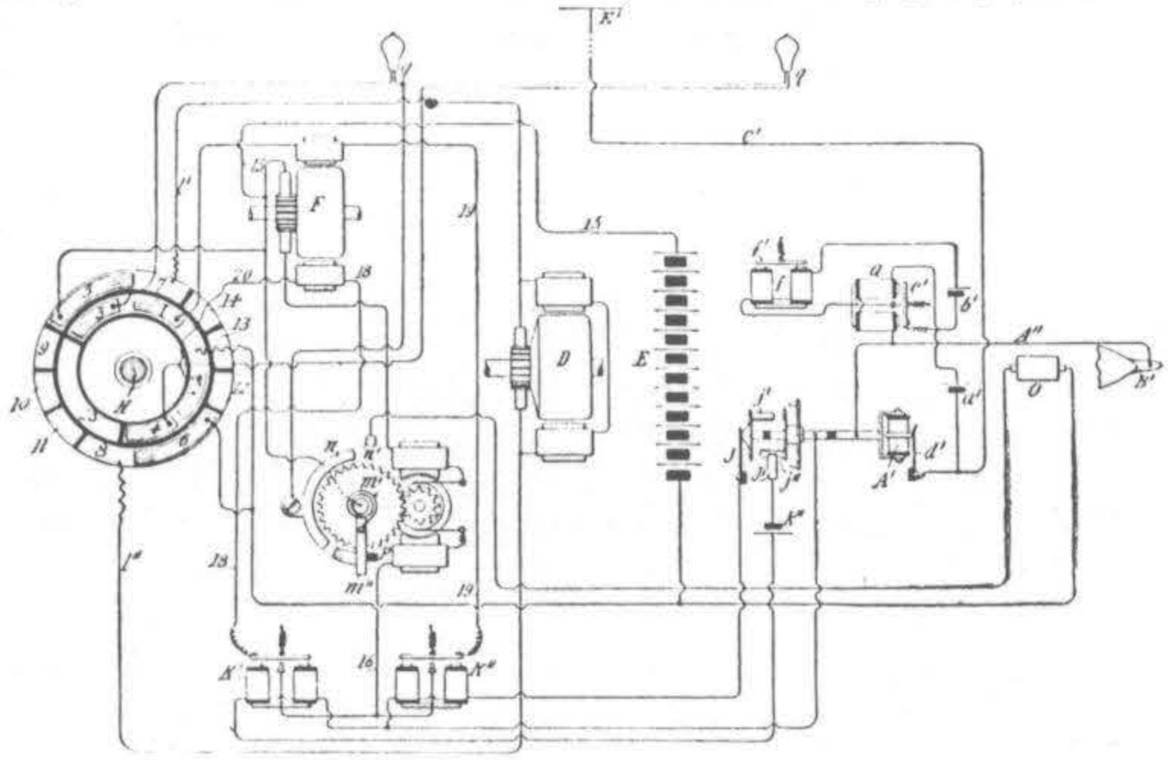


Fig. 6. Circuits of Model Vessel, Including Radio Apparatus.

TESLA'S EARLY WORK WITH RADIO CONTROLLED VESSELS.

(*Continued from page 89*)

any source of electrical disturbance or oscillations, the generation of which is controlled by a suitable switch at T. The handle of the switch is movable in one direction only and stops on four points t, t′, u and u′, so that as the handle passes from stop to stop, oscillations are produced by the source during a very short time interval. There are thus produced four etheric wave disturbances during one revolution and the receiving-circuit is affected four times: but it will be understood from the foregoing description of the controlling devices on this vessel that the rudder will be moved twice, once to right and once to left. Preferably the handle of the switch is placed so that when it is arrested on points t t′ that is to the right or left of the operator—he is reminded that the vessel is being deflected to the right or left from its course, by which means the control is naturally facilitated. The normal positions of the handle are therefore at u u′ when the rudder is not acted upon, and it remains on the points u u′ only so long as necessary. Since, as before stated, the working of the apparatus is quite sure, the operator is enabled to perform any such operations as provision is made for, *without even seeing the vessel.*

The manner of using the apparatus and the operation of the several component parts comprising the same is in detail as follows: Normally the plate L′ is turned so that brush 2 rests upon the insulated segment 23 and brush 6 upon one of the insulated short segments in the rear of the circle. Under these conditions the rudder will be turned to starboard and the circuit of the propelling motor D interrupted between brushes 5 and 6. At the same time only one of the circuits of motor F—that

controlled by relay K'—is capable of being closed, since brush 2, which connects with the other, is out of contact with the long segment 21.

Assuming now that it is desired to start the vessel and direct it to a given point, the handle T, at the transmitting station, is turned from its normal position on point u' to the point t on the switch-box. This sends out an electrical (etheric) disturbance, which, passing through the receiving-circuit on the vessel affects the sensitive device A' and starts the flow of current through the local circuit, including said device, the relay a, and the battery a'. This, as has been previously explained, turns the cylinder j and causes the brush J' to pass from an insulation space to the contact j'. The battery K" is thus closed through relay K" and the latter closes that circuit of the motor F which, starting from plate 22 (which is permanently connected with one pole of the main battery) is completed through the brush 1, the field of motor F, wire 19, the armature of relay K", wire 16, the motor m, the brushes and commutator of motor F and wire 15 to the opposite terminal of the battery D. Motor F is thus set in operation to shift the rudder to port; but the movement of plate L' which follows, brings the brush 6 back onto segment 8 and closes the circuit of the propelling-motor which starts the vessel. The motor F is permitted to run until the rudder has been turned sufficiently to steer the vessel in the desired direction, when the transmitter handle T is turned to the point u. This produces another action of the relay a and brush J' is shifted to the insulation and both relays K' and K" are inactive. The rudder remains in the position to which it has been shifted by the motor F. If it be then desired to shift it to "starboard," or in the *opposite direction* to that in which it was last moved, the handle T is simply turned to point t' and allowed to remain there until the motor F which is now operated by relay K', the circuit of which is closed by strip J' coming into contact with plate j", has done its work. The movement of handle T to the next point throws out both relays K' and K", and the next movement causes a shifting of the rudder to "port," and so on.

Suppose, however, that after the rudder has been set at any angle to its centre position, it be desired to shift it still farther in the *same direction.* In such case the handle is moved quickly over two points, so that the circuit which would move the rudder in the opposite direction is closed for too short a time interval to produce an appreciable effect and is allowed to rest on the third point until the rudder is shifted to the desired position, when the handle is moved to the next point, which again throws out both relays K' and K". It will be understood that if the handle T be held for a sufficiently long time upon either point t or t', the motor F will simply turn the plate L' in one direction or the other until the circuits of motors D and F are both broken. It is furthermore evident that one relay K' or K" will always be operative to start the motor F.

As previously explained, the longest period of operation of which the motor F is capable, under ordinary conditions of use, does not permit the motor m to shift the arm m' into contact with the plate n; but if the handle T be turned with a *certain rapidity, then a series of current impulses* will be directed through motor m; but as these tend to rotate the motor F in opposite directions they do not sensibly affect the latter, but act to rotate the motor m against the force of the coiled spring m'.

This invention will prove useful in many ways, says Tesla. Vessels or vehicles of any suitable kind may be used, as life, despatch or pilot boats or the like, or for carrying letters, packages, provisions, instruments, objects, or materials of any description for establishing communication with inaccessible regions and exploring the conditions existing in them, for killing or capturing whales or other animals of the sea, and for many other scientific, engineering or commercial purposes, but it could also be used in warfare, for by its certain and unlimited destructiveness it will tend to bring about and maintain permanent peace among nations.

On the contrary, however, this invention has not been commercially exploited, and Tesla's dreams are so far unrealized.

The New York Times July 27, 1916

MARCONI CO. ANSWERS SUIT.

Asks That Tesla Company's Complaint Be Dismissed.

The answer of the Marconi Wireless Telegraph Company to the suit of the Nikola Tesla Company for an alleged infringement of its patents was filed yesterday in the Federal District Court. Through its counsel, Sheffield & Betts, the Marconi Company denied that Mr. Tesla was at any time the original or first inventor of the alleged new and useful method of signaling set forth in the complaint. The answer also denied that the patents issued on March 17 and April 14, 1903, were duly or lawfully granted to Mr. Tesla because he had not complied in all respects with the conditions and requirements of the patent laws. The defendant company asks that the complaint be dismissed.

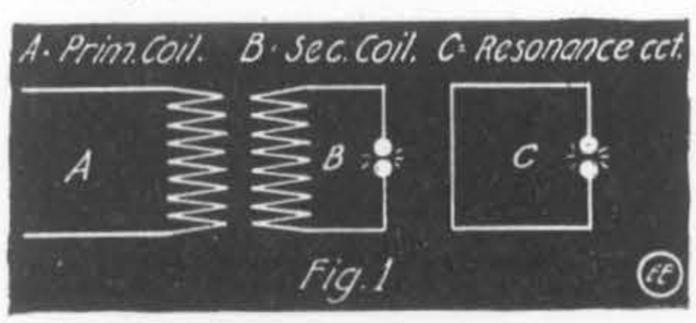
The suit is one of many brought by Mr. Tesla to protect what he asserts are his rights in certain wireless patents. The suits began when the Marconi Company alleged ownership of all basic patent rights in the transmission of wireless messages. In August, 1914, the Marconi Company sued Fritz Lowenstein, a German engineer, on the claim that certain wireless apparatus sold by him to the United States Navy violated Marconi Patent 763,772. It was said at the time that Mr. Tesla would testify for Mr. Lowenstein that the latter's devices were developed from the Tesla patents, which were granted prior to the Marconi patent.

The Marvels of Modern Physics

By Rogers D. Rusk, B. Sc.

HIGH FREQUENCY PHENOMENA.

CURRENTS of high frequency and high potential exhibit many phenomena which are entirely different from those of ordinary currents. A discharge which would ordinarily be fatal, will not even be felt by

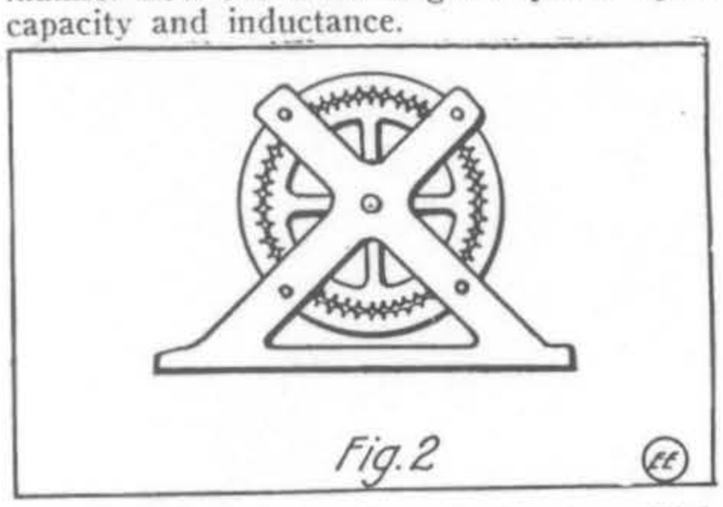


A Closed Wire Loop with Micrometer Spark Gap at "C," Enabled Hertz to Prove the Existence of Electromagnetic Waves in the Ether.

the body if it is of high frequency. An incandescent lamp may be short-circuited by a heavy copper bar and yet such a current will light it, while vacuum tubes may be caused to glow brilliantly without any metal connections at all. This, of course, does not at first seem reasonable until the phenomenon and conditions are explained.

By the frequency of a current is meant the rapidity of its alternations or reversals in direction. Joseph Henry, of Washington, first discovered that the discharge of a Leyden jar or condenser is oscillatory, and Sir Oliver Lodge was able to visibly analyze such a spark discharge by means of a rapidly rotating mirror. This gave him definite knowledge that each discharge, instead of being a single spark, was a quick succession of flashes in opposite directions, beginning with a heavy flash and rapidly dying down to zero. The discharge of an open induction coil will seldom exceed ten thousand alternations per second, while the discharge from a suitable condenser may range from a few hundreds of oscillations per second to several billion, depending on the capacity and inductance of the circuit.

These terms—capacity and inductance—may be more readily understood if they are likened to the elasticity and inertia of a vibrating spring. In either case both qualities must be present in order that vibrations or oscillations shall occur. As a spring swings past its zero to be pulled back in the opposite direction, so does a Leyden jar over-discharge itself, then re-discharges in the opposite direction, and repeats this until the current falls away to zero. Such oscillations generate the familiar electromagnetic waves of wireless telegraphy, and because the oscillations rapidly die out so also do the waves, and we then say that they are strongly *damped*. From the above, one can see in a simple manner how the wave-length depends upon capacity and inductance.

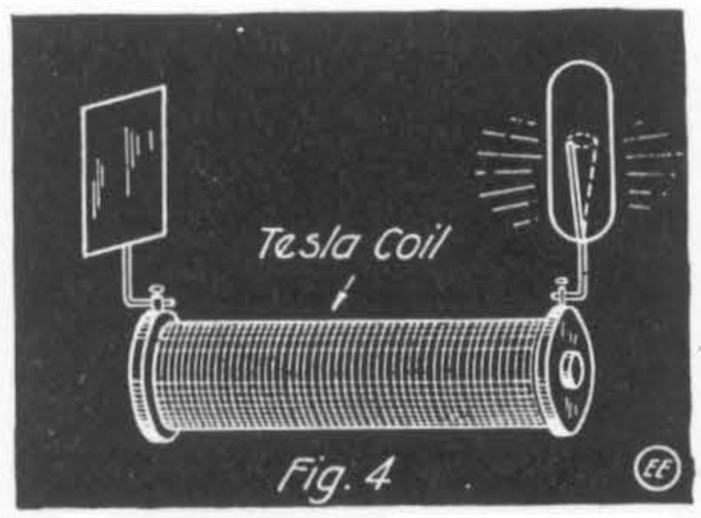


The High Frequency Alternator Produces High Frequency Current by Electro-Dynamic Means.

In order to create more permanent oscillations a source of constant and high potential may be shunted around the condenser, causing a continual process of charging and discharging. The first experiments along this line were performed by Dr. Hertz of the University of Bonn, who used merely an open induction coil. After their discoverer, they are known as *Hertz effects*.

While operating a coil with an exceedingly rapid vibrator, he noticed that sparks were jumping from several metallic objects about the room. By means of his resonator shown in Fig. 1, Hertz was able to prove that certain waves were sent out from the sparking circuit which could be caught by another circuit of proper wave-length, in which they would set up a *sympathetic* current capable of giving sparks. The best position for resonance was readily found by adjusting the length of the rectangle "C," and by placing it in different positions, the plane and direction of the wave was determined. The two circuits responded to each other just as two tuning forks of like pitch will respond sympathetically.

Following up these trail-blazing experiments, Nikola Tesla achieved fame by a number of more striking ones. Tesla determined to produce high frequency currents direct from the dynamo, and with this in view he constructed a number of machines, the plan of one of which is shown in Fig. 2, which he called *high frequency alternators*. The coils are very small and the poles hardly more than fine teeth. With such a machine Tesla was able to obtain a frequency of 10,000 per second,

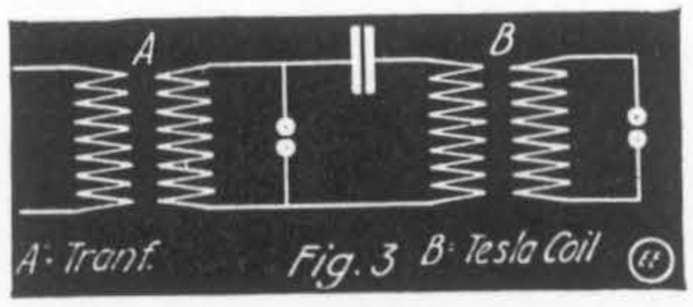


A Thin Wire Inside an Evacuated Tube and Connected to One Pole of a Tesla Coil, Will Rotate as Shown by the Dotted Lines.

and 10 amperes at 100 volts. The machine, small as it was, had 400 poles on the field, 400 coils on the armature and was run at 3,000 revolutions per minute. In a later machine a frequency of 15,000 per second was obtained. Since then others have labored in the same field, Duddell by using an induction disk with a fine toothed edge obtained at first a frequency of 50,000 per second and later the marvelous one of 120,000, although with the latter the current was reduced to .1 of an ampere and the voltage to 2 volts.

Professor Trowbridge, who was experimenting at the same time, produced sparks from 6 to 7 feet long from a condenser discharge which he calculated to be 3,000,000 volts! His method of obtaining such a voltage was simple but ingenious. Using 20,000 small storage cells, he charged the plates of a large condenser which were arranged in multiple. Reversing their arrangement he connected the plates in series and thus had an enormous potential though an exceedingly small current at his disposal. However, he was outdone by Tesla, who by his well-known Tesla coil or secondary transformer, produced a roaring spark of sixteen feet in length in 1900. He virtually reproduced lightning itself by a deafening discharge that crashed between electrodes a hundred feet apart. The voltage was in the billions and the current about 800 amperes.

The secondary transformer or Tesla coil used by him is shown diagrammatically in Fig. 3, where it is readily seen that the current from the induction coil sets up oscillations in the secondary circuit through in-



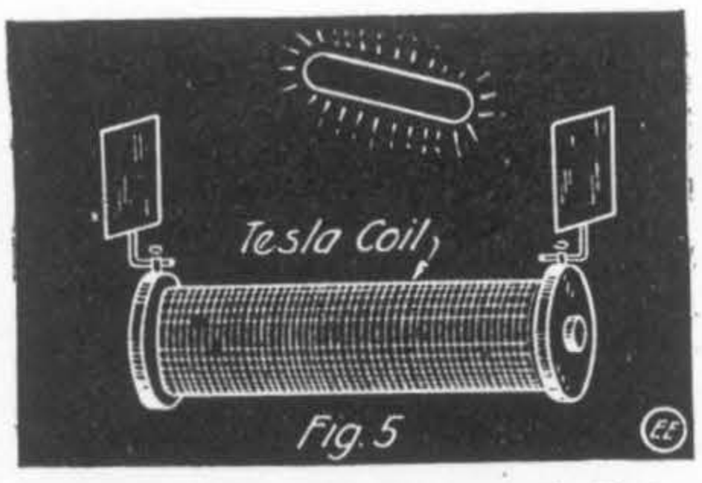
Tesla Scheme for the Production of High Frequency Currents

duction which are of both enormous voltage and very high frequency due to the capacity and inductance of the circuit.

The effect of such a spark on the body is peculiar. Where it strikes the body direct it may be more painful than the ordinary spark, but if made to strike an electrode of some metal touching the body or held in the hand, the whole discharge may be taken without any shock whatever. In such a situation sparks may be drawn from any part of the person and a gas jet may be lighted with the finger without even being insulated from the ground. To prove that an amount of current is really being conducted by the body, an incandescent lamp held in the hand, between it and the terminal, may be lighted.

Two probable reasons are advanced to explain the absence of sensation. In the first place an electric current starts to travel on the surface and spreads in a comparatively gradual manner to the interior of a conductor. When the successive impulses of the current are very short it travels *only on the surface* and therefore it is called the *skin effect*. Secondly, the sensory nerves of the body do not respond to such a short stimulus as probably the *millionth* part of a second.

The above mentioned skin effect is responsible for another statement at the beginning of this article. The larger a conductor is, the less will the current penetrate beneath the surface, and consequently the greater will be the resistance. This is at first a seeming incompatability, but a mathematical investigation will show the exact rule, that the effective resistance to a high frequency current varies *directly* as the diameter of the conductor. Thus if a current is passed through a very heavy bar, the effective resistance of the bar will be so great as to make it possible to light a lamp by touching its terminals only a few inches



An Evacuated Glass Tube Placed in the Electrostatic Field of a Tesla Coil Will Glow; the Forerunner of Wireless Lights.

apart upon the bar, although the lamp might seem to be virtually short-circuited.

Tesla labored long attempting to produce

(*Continued on page 375*)

THE MARVELS OF MODERN PHYSICS.

(*Continued from page 330*)

light direct for illuminating purposes without the necessity of cumbersome conductors. He noticed five distinct forms of secondary discharge from his coil, controlled by a change in frequency or strength. Three were different forms of brush discharge; one a weak, sensitive, threadlike discharge, and one a powerful flaming discharge. Under certain conditions brush streamers issued from all parts of the coil, even through the insulation, while the brush in its hottest form resembled a jet of burning gas, giving off ozone freely. By stretching parallel wires across a room, a sheet of light may be caused to appear between them while an incandescent bulb or a vacuum tube would glow with a pale bluish luminescence if held near one pole of the coil. The effect of such a current upon air or gas is to alternately attract and repel the particles, setting them in exceeding rapid vibration, thus a large amount of heat is generated and luminosity occurs. Something of this condition, it is suggested, may explain some of the phenomena of the *Aurora*, and if such effects could be regulated over a large area of air space, storms and rains could likely be controlled.

There are a great many Tesla effects of wondrous and striking interest and of much scientific importance, with reference to artificial illumination. With a vacuum tube and a single conducting wire shown in Fig. 4, Tesla obtained a high degree of luminosity. If the filament inside of the tube was flexible it would often rotate in a circle as shown by the dotted lines due to its bombardment by air particles. Mr. Tesla himself believed that a new era of illumination would soon be entered upon, following the discovery that luminosity could be produced directly by the high frequency discharge, or indirectly, as in Fig. 5, with an unconnected tube within the influence of the electrostatic field. Less progress has been made in this direction than might have been expected, though the Moore lamp is of such a type. It is a long tube made to fit the room, and taking about .3 ampere at 12,000 volts. The color of the light is affected by the kind of gas present in the tube, and daylight itself may be quite successfully rivalled. A low efficiency and complication of details detract from the popularity of the light, however.

The latest use for light frequency currents is the production of a wave suitable for wireless telephony, and one of the best present methods for producing these currents is by the musical arc discovered by Duddell. He shunted a condenser and inductance around an arc light circuit and found that the condenser rapidly charged and discharged itself through the arc, setting up oscillations of great regularity and persistence. Such a simple arrangement gave a frequency of 10,000 per second. Valdemar Poulsen, by surrounding the arc with hydrogen and placing it in a magnetic field, obtained much higher frequencies—up to 1,000,000 per second, due to the cooling effect of the hydrogen and the tendency of the magnetic field to blow the arc. The waves sent out by such a device are of such high frequency and constancy as to permit transmitting the human voice with all of its delicate inflections.

This alluring field of high frequency currents, is *not* like many attractions, gilt on the outside only, but is solid gold. What it holds for us in the future we do not know, for achievements of the past are only a foretaste.

[*Eighth paper of a series prepared especially for* THE ELECTRICAL EXPERIMENTER *by Mr. Rusk.—Editor.*]

The New York Times September 21, 1916

GIVES TO MARCONI WIRELESS DETECTOR

Judge Mayer Holds De Forest Device Is an Infringement of Dr. Fleming's Invention.

MAKES MESSAGES RESONANT

Basic System Purchased by Marconi Company Has Never Been Improved Upon, Court Holds.

The contention of the Marconi Wireless Telegraph Company of America that the De Forest Radio Telephone and Telegraph Company had infringed its rights to the sole use and ownership of the patent covering the Fleming detector was sustained yesterday in an opinion written by Judge Julius M. Mayer of the Federal District Court. Dr. John Ambrose Fleming, an English educator, invented the detector in 1905, and almost immediately thereafter the Marconi Company obtained the rights to its use.

While the invention is more than ten years old, it has never been improved upon by any other discovery for making more resonant the messages sent through the air. It was preceded by many other contrivances, variously known as the coherer, which was a glass tube filled with filings; the Crystal detector, the magnetic detector, and the electro-lytic detector that was invented by Professor Fessenden. Dr. Fleming's invention located the detector away from the immediate neighborhood of the receiving apparatus. It made it possible to hear at some distance from the instrument, and so assured the accurate taking of the words without frequent reliance upon the context, as was necessary under the older devices.

William E. Vansize of counsel for the Marconi Company said yesterday that the De Forest Company had been using a device set within the globe of a lamp, but that the idea was taken from the invention of Dr. Fleming, and was clearly an infringement of the patent owned by the Marconi Company.

In his decision Judge Mayer said that no matter what differences of opinion might exist between men of science in respect to the theories by which they accountd for the movement and action of the unseen forces concerning which testimony had been taken during the trial of the cause the solution of the issues at bar was not very difficult, because courts placed their decisions upon things demonstrable and could speculate as to theories concerning which authorities did not agree. Then the decision read:

> Within the limits of an opinion it is, of course, impossible to analyze at length a mass of experiments, tests, and theses and an infinity of detail necessarily involved in testimony of experts in an art of this kind. But if plaintiff's theory that its own device and that of defendants operate on the same principle has not been proved—at least defendant's theory has not been demonstrated and, finally, the physical facts all support plaintiff's claims.

Judge Mayer complimented Mr. De Forest on the contributions he had made to science. Then the court found for the plaintiff, dismissed the counterclaims made by the defendant, but said that there was no evidence against Mr. De Forest personally.

Dr. Lee De Forest, President of the De Forest Radio Telephone and Telegraph Company, said last night that an appeal would be taken from Judge Mayer's decision by his company. He added that while the Marconi Company also was found to have infringed he believed they would not appeal, since the royalties they might be able to exact from the De Forest concern for infringement of the Fleming valve patent would be far in excess of the amount they would be called upon to pay for infringing the audion amplifier. The latter, he said, was widely used, particularly by the American Telephone and Telegraph Company on its transcontinental lines and by amateur wireless operators all over the country, while the United States Government had bought more than 10,000 of them. The infringement decision, he explained, lay in electric bulb, though this was employed in taking practical advantage of a principle altogether different from that upon which the Fleming valve was based, though the latter was the first device embracing the use of a lamp to be patented. Dr. De Forest thought the Marconi Company would not attempt to force discontinuation of the audion device as, he said, it had proved a far more satisfactory amplifier than the Fleming valve.

Lightning Made to Order

By Samuel Cohen

ONE of the most perplexing problems that scientists have attacked during recent years involved either the harnessing or imitation of the forces of Nature. Many of our greatest scientists in all parts of the globe have spent fabulous sums and years of patient study on such problems, but most of them have signally failed; a number of eminent scientists even claim that such conundrums will never be thoroughly solved.

This, however, appears, in our present day, to be highly doubtful. As early as 1890 Dr. Nikola Tesla undertook to solve the problem, and some years later succeeded in demonstrating to the world that it is quite possible to imitate certain natural dynamic forces on a scale of surprisingly vast magnitude.

Most of us know that *Lightning* is a natural electrical discharge taking place between two adjacent clouds, each having been charged with electricity of opposite polarity. As soon as they approach sufficiently close, the electric potential between them becomes so terrific that the air strata between is ruptured, thus producing a vivid spark, followed by thunder, which is caused by the sudden rush of air into the evacuated space produced by the electric discharge. Lightning may be caused also by a discharge taking place between a cloud and the earth. The process by which the clouds are electrically charged is still a mystery, and we must wait until some future genius will explain to us the exact phenomena that takes place in the upper atmosphere, where such electrical disturbances take place.

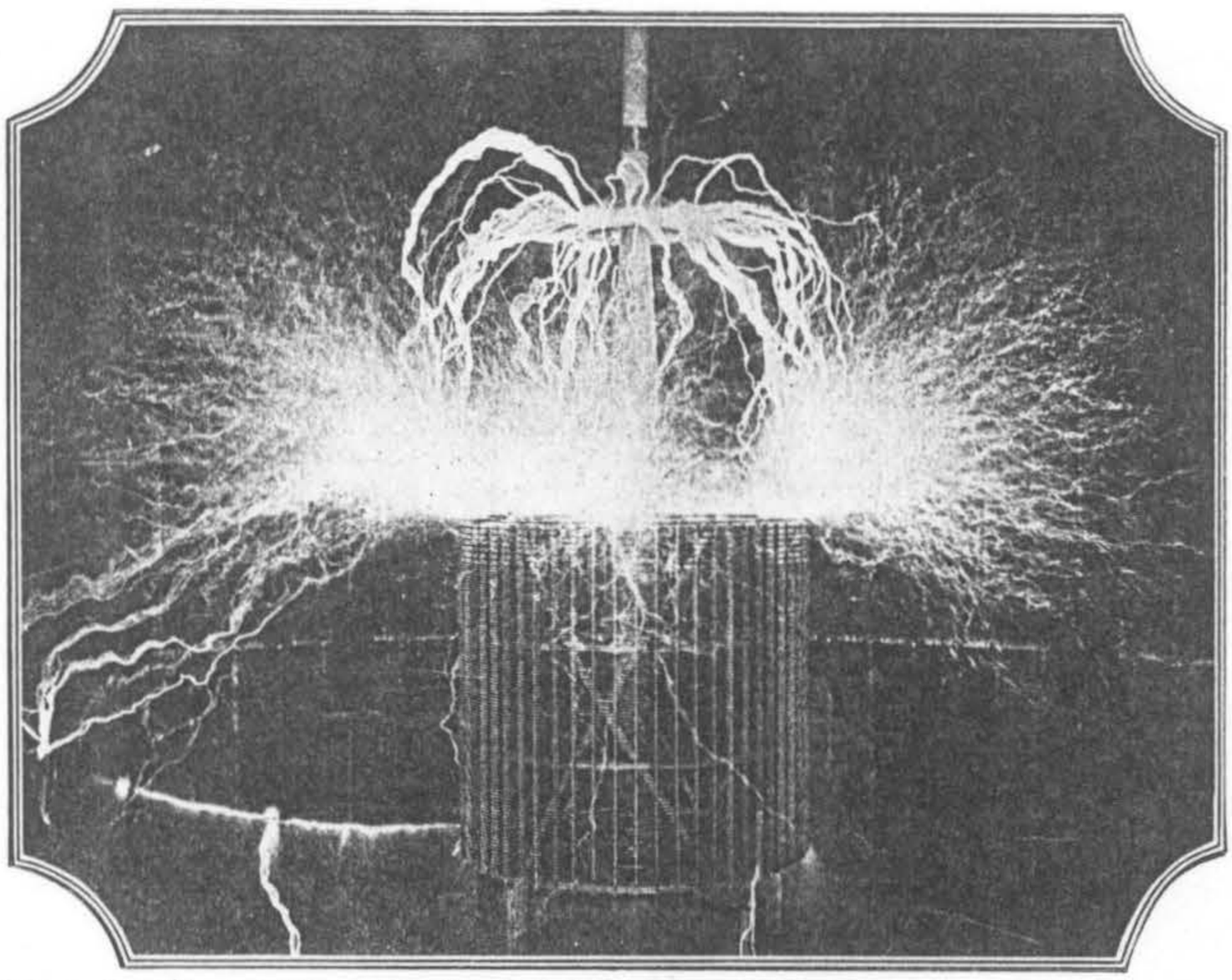


Fig. 1. The Wonderful Tesla, 300 K.W. High-Frequency Oscillator Coil in Full Activity, Discharging Sparks Like Veritable Bolts of Thor and Measuring 65 Feet Across.

Fig. 2. A Close View of the Tesla Coil and Massive Metal Ball Which Acts as a Reservoir for the Electric Charges.

Dr. Nikola Tesla, who is perhaps the greatest living authority on alternating currents of both high and low frequency, has performed some of the most marvelous experiments ever dreamed of with high potential, high frequency currents. As early as 1890 this savant had produced electrical disturbances in his laboratory at Colorado Springs equal to the lightning produced by Nature. Although a number of years have elapsed since these experiments were conducted, not a single scientist or engineer has been able to produce such awe-inspiring, electrical performances as did Dr. Tesla. It is true that he is far ahead of his time in many of his inventions, yet he has ably demonstrated that it is possible to imitate some of Nature's secret forces. It should be noted that his sole purpose was not simply to imitate these forces, but he was performing certain experiments on the problem of radio transmission of electrical energy through space. The startling *lightning* effects here shown were produced during the course of these experiments.

During a recent interview the writer had with Dr. Tesla, the photographs herewith reproduced were kindly loaned to accompany this article. Two of these photos were never shown to the public before. Our front cover, painted by Mr. George Wall, is an exact reproduction in colors corresponding to Fig. 1. The man was seated near the apparatus solely for the purpose of showing the relative size of the high frequency oscillation coil. The photograph was obtained by double exposure; that is, the plate was exposed with the man, while the apparatus was not in operation; then he was removed and another exposure made of the sparks on the same plate, as it would not be very healthy for anyone to be there when the experiment is conducted.

In Fig. 1 we see the Tesla electric oscillator in full activity at twelve million

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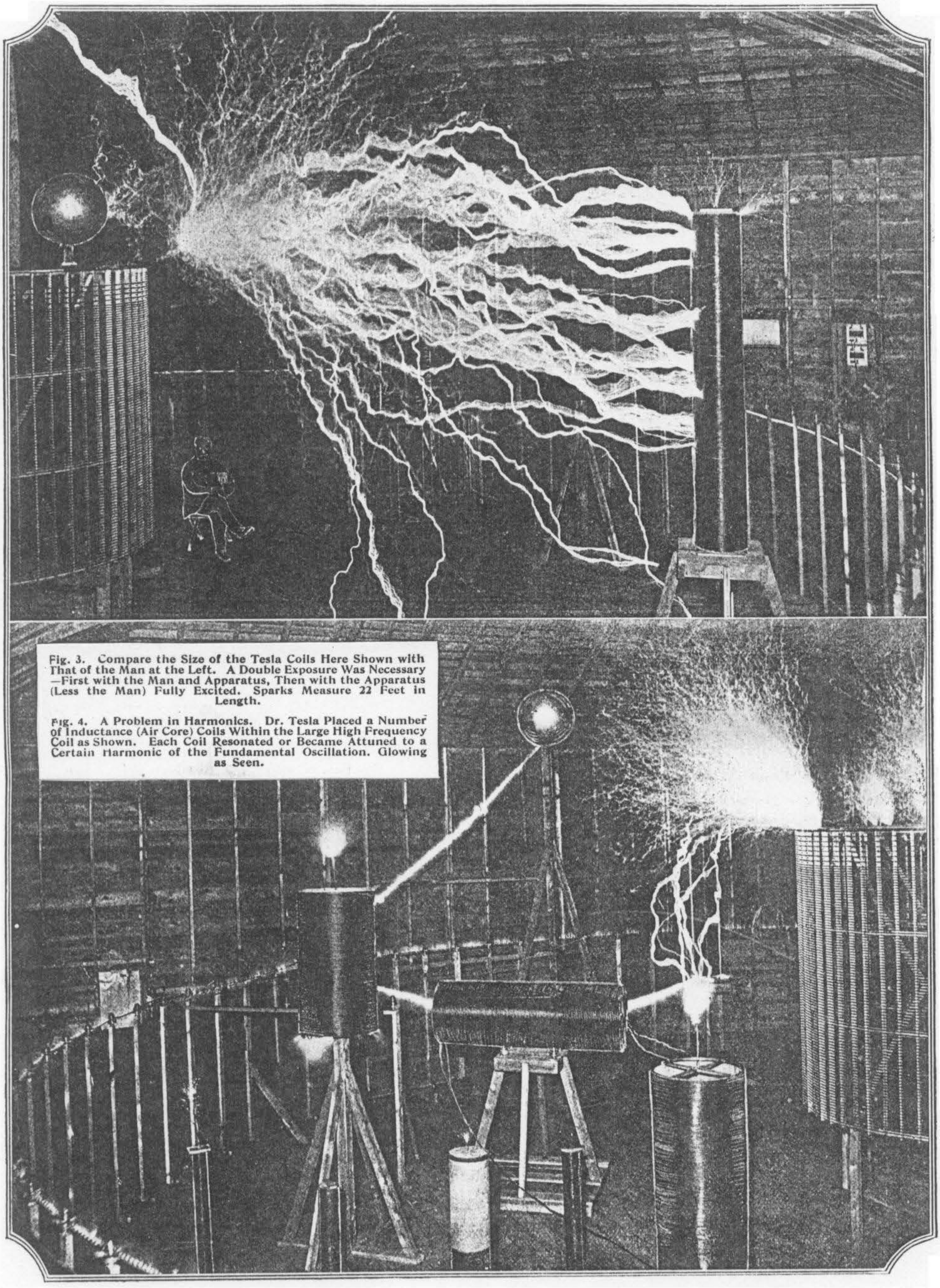


Fig. 3. Compare the Size of the Tesla Coils Here Shown with That of the Man at the Left. A Double Exposure Was Necessary —First with the Man and Apparatus, Then with the Apparatus (Less the Man) Fully Excited. Sparks Measure 22 Feet in Length.

Fig. 4. A Problem in Harmonics. Dr. Tesla Placed a Number of Inductance (Air Core) Coils Within the Large High Frequency Coil as Shown. Each Coil Resonated or Became Attuned to a Certain Harmonic of the Fundamental Oscillation. Glowing as Seen.

sparks an inch long were drawn from the water main at a distance of three hundred feet from the laboratory.

One very interesting experiment conducted by Dr. Tesla showed how it is possible to tune several coils to different frequencies with respect to the fundamental frequency generated by the main exciting coil. A photograph showing this experiment is reproduced at Fig. 4. The large coil on the right, discharging strongly, is tuned to the fundamental vibration which is fifty thousand cycles per second; the two larger vertical coils to twice that number; the smaller coils, wound with white wire, to four times that number and the remaining small coils to higher harmonics. The vibrations produced by the oscillator were so intense that they affected perceptibly a small coil tuned to the twenty-sixth harmonic above the fundamental.

The scientific world is keeping its eyes peeled for the next epochal movement in the problem of transmitting energy *via wireless*. And the world expects Dr. Nikola Tesla to do this.

LIGHTNING MADE TO ORDER.

(*Continued from page 474*)

volts and a frequency of one hundred thousand per second! The flame-like discharge measures sixty-five feet across. This experiment was performed for the purpose of showing how the nitrogen of the atmosphere could be made to combine with the oxygen. The large wire cage measured 20 feet in diameter and 30 feet in height. This is not the actual coil which is excited by the primary of the Tesla transformer, but a separate helix which is attuned to a certain frequency of the secondary of the transformer. This is apparent by noting the large circular fence-like wall in the rear, which measures 60 feet in diameter and which is wound full with heavy copper wire.

The primary is carefully imbedded in the ground and connected with the regular oscillating circuit, comprising high tension oil condensers and the inductance incorporated in the primary of the Tesla transformer, also a spark discharger. In all these experiments the primary of the low tension transformer was excited with 300 kilowatts of electrical energy.

A very striking experiment showing the emission of an electrical discharge from a large sphere is shown in Fig. 2. The ball has a surface of twenty square feet which represents a large reservoir of electricity. The inverted circular pan underneath with sharp rim has an opening thru which the electricity can escape before filling the reservoir. The quantity of electricity liberated is so enormous that, although most of it escapes thru the rim of the pan or opening provided, the ball of the reservoir is nevertheless alternately emptied and filled to overflowing, as is evident from the discharge escaping on the top of the ball.

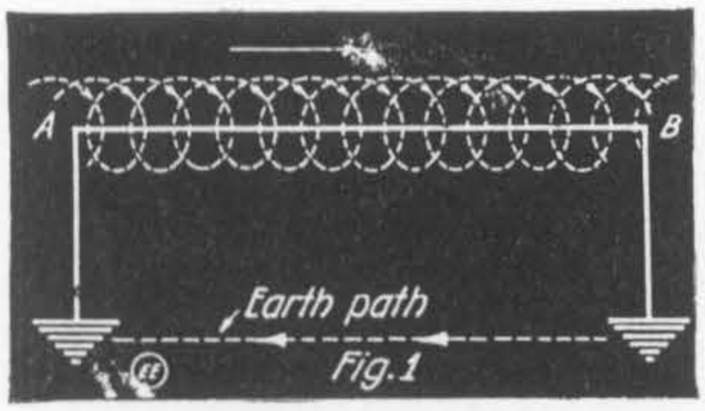
The coil shown in Fig. 3 creates an alternative movement of electricity from the earth into a large reservoir and back, at the rate of one hundred thousand pulsations per second. The adjustments were such that the reservoir fills and bursts at each alternation just at the moment when the electrical pressure reaches the maximum. The discharge escapes with a deafening noise, striking an unconnected coil twenty-two feet away, and creating such a disturbance of electricity in the earth, that heavy

The Marvels of Modern Physics

By Rogers D. Rusk, B. Sc.

THE WIRELESS ERA.

THE Wireless Era is a name frequently given to the scientific period upon which we are now entering, by people who realize only vaguely themselves what they actually mean by it. In reality there



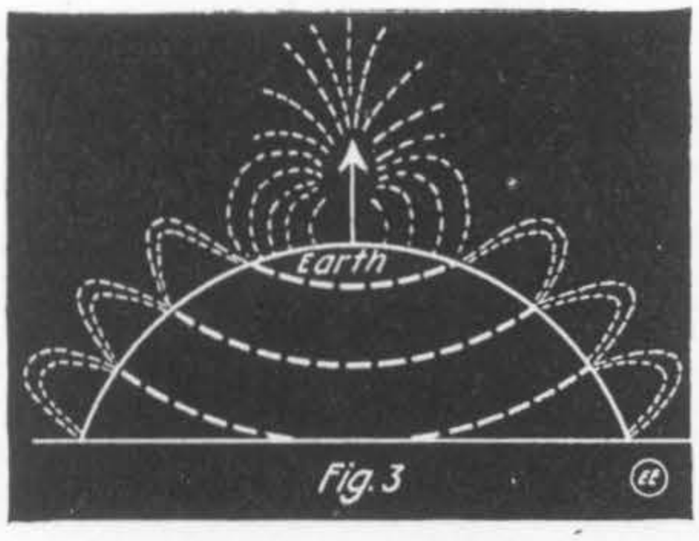
Illustrating How a Current of Electrical Energy Is Transmitted by Ether Whirls to a Point by a Conductor.

is a surprising relation between *wire* and *wireless* transmission. That they are not distinctly different phenomena may put new meaning in the phrase, "Wireless Era."

The question has often been asked "Will all wires be done away with in the future?" Now the theory most generally accepted at present is that the energy of an electric current in ordinary wire transmission does not reside *in* the wire, but in the ether surrounding the wire, and that the wire is, as its name implies, merely a conductor to conduct or lead the current here or there. To make this clear, let us imagine a current moving in the wire in Fig. 1, from A to B and returning by the ground. The dotted spiral lines represent the strain in the ether due to the electro-static and the electro-magnetic lines of force about the wire. The important point to notice is that the current, without this field, would be lifeless and inert because the magnetic field represents the energy of motion of the current; it would then have no energy of motion, for the energy is really stored up in the ether and is transmitted by it.

Let us look beneath the surface a moment at wireless transmission. In Fig. 2, the wireless waves are represented as traveling from aerial A to B. We cannot doubt for a moment but what the energy is transmitted by the ether, as no conducting medium is present. Therefore, the main difference between *wire* and *wireless* transmission seems to be that while in *wire* transmission the energy is directed to a definite point, in *wireless* it spreads out and dissipates itself in all directions.

A further study of Figs. 1 and 2 may reveal the reason for this. In a steady di-



This Diagram Gives a General Idea as to How a Radio Station Throws Off "Ether-Ripples" of Radiant Energy, the Same as When You Throw a Stone into a Still Pond.

rect current the field is steady and continuous. Change this current, however, to an alternating one and the field or ether strain varies accordingly, producing an undulatory motion of the ether. That is, the field about the wire rises and falls periodically. With an ordinary alternating current the strain in the ether is most noticeable just about the wire and becomes negligible a short distance away, although theoretically the waves may travel at each reversal a long distance before being dissipated. Let us raise the potential and frequency, however, and see what happens. The field rises to full strength in a very short time, and the waves follow each other at a greater speed. This means that radiation is going to amount to much more than before. The waves are going to be stronger, and their number will be multiplied many times. If instead of using a wire to direct the energy from A to B, we shorten the circuit very much, making it merely a local circuit at A, and if we put another small or local circuit at B, then some of the radiant energy from A will be intercepted at B, and these waves passing B will induce a slight current at B. *This* is wireless transmission. See what a gradual step it is instead of a very sudden one from wire to wireless transmission. In one case we have a small radiation factor, due to a real current in a conductor. In the other case we have a high radiation factor due to the absence of a long conductor. In the first the energy is directed; while in

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FINAL CALL

On November 1st, 1916, the subscription price of "The Electrical Experimenter" advances to $1.50 in U.S. (Canada and Foreign $2.00.) This is the last chance to subscribe at the old rates ($1.00 in U.S., Canada and Foreign $1.50). No subscription for more than five years at the old rate accepted. THE PUBLISHERS.

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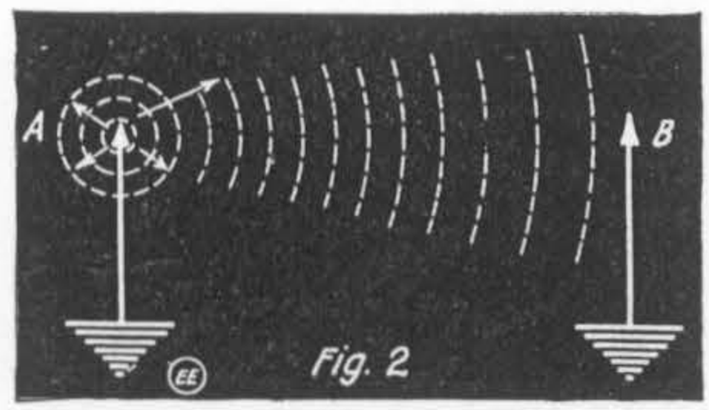
the second, it spreads out in all directions. The medium of transmission of the energy is the same in either case. The result is that in one case a large per cent of the energy reaches its destination, while in the other case only a very small per cent does.

The field about a wire carrying a direct current acts quite like an invisible whirlpool which pulls the electrons, or charged particles in the wire, along. The field, in turn, grows with the current, for the action is an inter-dependent one, and the result is a continuous current. If, with an alternating current, the oscillation frequency is high, the current does not have time between reversals to penetrate the wire deeply, and it is found that the current exists only on the surface of the wire. This is the well known *skin effect* and shows again that the energy must reside in the external field, and that it takes some appreciable time to start the electrons in motion. This is what we call a current *in a wire*.

Wireless telegraphy came into prominence in 1896, when Dr. Guglielmo Marconi first demonstrated its commercial value. Since then its importance has increased by leaps and bounds. The submarine has been directed from the shore by wireless; the human voice has been transmitted hundreds and thousands of miles; and various kinds of mechanism have been controlled by it. However, the glaring predictions of a wireless era for a while somewhat unduly inflamed the imagination of the public. Let us look at the facts.

It is very significant that one prediction of a few years ago has not been realized, and that was concerning the wireless transmission of power. *Power* and *energy* are



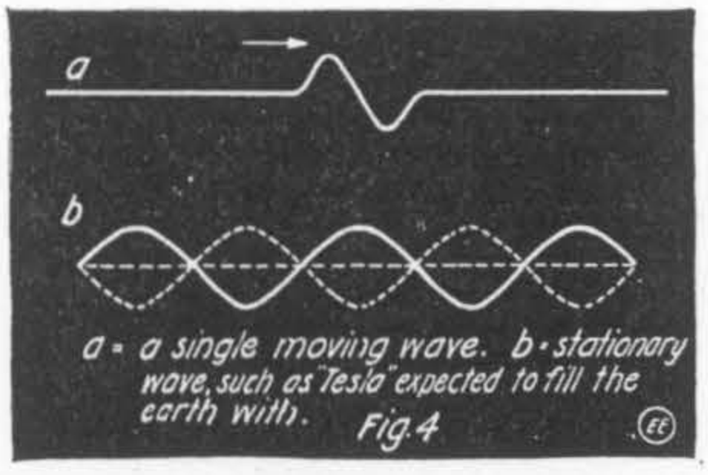
Representing the Detection, at a Point "B," of Radiant Electric Energy.

two different things. Energy is any capacity for doing work, while power is the rate at which work is done. Now sufficient energy may be sent across the ocean to easily operate a delicate detector, but the rate at which any work is done is ridiculously minute. Energy has been transmitted but the power was negligible. When a submarine is controlled at a distance, it is not power from the shore which operates the machinery, but rather *power* from some source on board the boat itself which is controlled by the *energy* transmitted from the shore. The strength of the waves decrease too rapidly with the distance to allow of any great amount of energy being transmitted. Most everyone remembers the rule that the intensity of light varies inversely as the square of the distance from the source. Applying this to wireless, and neglecting other losses, at the distance of one mile the energy would only be

$$\frac{1}{25{,}000{,}000}$$

of its original value. This in itself would stamp the wireless transmission of power as impracticable unless a different method of transmission than that now in use were discovered.

Nikola Tesla believed he had solved the problem and in 1905 took out patents for a system of wireless transmission of power, with the ether as the medium. In brief, by his system, he intended setting up powerful, stationary, electric waves, setting the whole earth in vibration due to the reflection and superimposition of waves from all parts of the earth. The principle is similar to that of a string tied at one end and waved back and forth by the hand at the other. Waves from the hand would travel to the opposite end and be reflected back



If we Tie a String at one End and Oscillate its Free End Back and Forth, There Will Be "Stationary" Waves Set up Along it as at B. Tesla Expected to Vibrate the Earth with such Waves.

(see Fig. 4) creating nodes and loops of vibration in the string. The proposition, it was claimed, had been partially demonstra-

(*Continued on page 538*)

THE MARVELS OF MODERN PHYSICS.

(*Continued from page 485*)

ted, and on the strength of this a wonderful station was built on Long Island. Every reader of scientific periodicals is familiar with its picture and history. At present it is deserted, but Tesla is still working upon the subject. The problem, however, is as yet unsolved. We will not say it is impossible of solution, for do we not have real wireless transmission of power as an everyday occurrence in the ordinary transformer? Though there is no metallic connection between the primary and secondary coils, yet there is an immense transfer of power at only a slight loss. Notice how near the ideal conditions are, however. The distance is negligibly small, and even the medium itself is improved by the presence of a soft iron core. It is too common a fact for us to consider it wonderful, and yet the result is the same as that which has puzzled many scientific minds to reproduce or duplicate through any great distance.

As wireless telegraphy and telephony supplement, rather than take the place of the ordinary systems and as the transmission of power is the back-bone of commerce and industry, it seems the wires are here to stay for a long time to come. However, we must not disrespect the possibility of just as revolutionary discoveries in the future as have occurred in the past, hard as they are for us to even conceive of now. Why, even wireless telegraphy would not have approached the success it has, if the energy radiated directly by the Hertzian oscillator had been depended upon. In the first place the decrease of energy, as shown by the above law, would have been so great as to have been discouraging; and secondly, the fact that radiation travels in straight lines would have made long distance communication impossible, owing to the curvature of the earth. Both of these theories were advanced early in the development of the subject, and when approached near at hand were neither of them found as forbidding as they had seemed. It was shortly found that when the sending station was suitably grounded, that the waves actually follow the surface of the earth, and the invention of sensitive detectors made the transmission of a large amount of energy unnecessary for signaling. Many such facts about wireless telegraphy are a mystery to the average person, and although the mathematics of radiation were actually worked out over sixty years ago by James Clerk Maxwell and his co-workers, many of the exact physical actions which take place are but little understood even by the brilliant scientists of the present day. Much more is known, however, than formerly.

The wireless wave follows the earth as a huge conductor, because when the oscillations occur in the aerial, shown in Fig. 3, the lines of force moving up and down the aerial with the oscillating charge, throw off loops as shown, which are waves traveling partly *in* and partly *above* the earth. These travel off exactly like ripples on a pond, and also follow the curvature of the earth. They are much stronger than if radiated in all directions. It is evident they are not as *wireless* as they might seem, for the earth acts as a huge conductor. In early experiments between Lynn, Mass., and Schenectady, N.Y., communication was found impossible, due to the dry rock mountains intervening which acted as effective, *non-conducting* carriers. Not long afterward communication was established between Clifden, Ireland, and Buenos Aires, S.A., a distance of six thousand miles, the intervening water being a good *conducting* medium.

Wireless telegraphy and telephony are now of immeasurable commercial value, to say nothing of their importance from a purely scientific standpoint. It may even be said that we have been approaching as a limit the *wire* transmission of power for some years. In 1890 a power line was established, thirteen miles long, at Portland, Oregon, which transmitted current at 4,000 volts. In 1903, in Mexico, a line was built 104 miles long, to operate at 60,000 volts, while in 1913 the Pacific Light & Power Company of Los Angeles, Cal., began operating a line 240 miles long at 150,000 volts. This latter means a comparatively small current and a small conductor acting more and more as a guide rather than a vehicle for the power. Has a limit been reached; or will this record distance and voltage soon be eclipsed? It is a problem the engineers and scientists will try to solve in the near future.

The wireless era does not mean an era where wires are taken down and thrown on the scrap heap. We must not look for scientific miracles for nature follows natural laws. It means an age where an extra gift has been given to man, enabling him to extend his influence beyond the sphere of base matter; to annihilate distance and gain control over the finer forces of nature.

[*This is the tenth paper of a series prepared exclusively for "The Electrical Experimenter" by Mr. Rusk.—Ed.*]

TESLA VS. MARCONI COMPANY.

The answer of the Marconi Wireless Telegraph Company to the suit of the Nikola Tesla Company for an alleged infringement of its patents, was filed recently in the Federal District Court. The Marconi Company denied that Mr. Tesla was at any time the original or first inventor of the alleged new and useful method of signaling set forth in the complaint. The answer also denied that the patents issued on March 17 and April 14, 1903, were duly or lawfully granted to Mr. Tesla, because he had not complied in all respects with the conditions and requirements of the patent laws. The defendant company asks that the complaint be dismissed.

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MARK SULLIVAN, EDITOR

WONDERS OF THE FUTURE

BY NIKOLA TESLA

Nikola Tesla is an inventor, electrical wizard, and seer. He is the discoverer of alternating-current power transmission, the system of electrical conversion and distribution by oscillatory discharges, transmission of energy through a single wire without return, a system of wireless transmission of intelligence, transformer, etc. His laboratory is at Shoreham, L. I.

MANY a would-be discoverer, failing in his efforts, has felt regret at having been born at a time when, as he thinks, everything has been already accomplished and nothing is left to be done. This erroneous impression that, as we are advancing, the possibilities of invention are being exhausted is not uncommon. In reality it is just the opposite. What has been so far done by electricity is nothing as compared with what the future has in store. Not only this, but there are now innumerable things done in old-fashioned ways which are much inferior in economy, convenience, and many other respects to the new method. So great are the advantages of the latter that whenever an opportunity presents itself the engineer advises his client to "do it electrically."

Water power offers great opportunities for novel electrical applications, particularly in the department of electrochemistry. The harnessing of waterfalls is the most economical method known for drawing energy from the sun. This is due to the fact that both water and electricity are incompressible. The net efficiency of the hydroelectric process can be as high as 85 per cent. The initial outlay is generally great, but the cost of maintenance is small and the convenience offered ideal. My alternating system is invariably employed, and so far about 7,000,000 horsepower has been developed. As generally used, we do not get more than six-hundredths of a horsepower per ton of coal per year. This water energy is therefore equivalent to that obtainable from an annual supply of 120,000,000 tons of coal, which is from 25 to 50 per cent of the total output of the United States.

Great possibilities also lie in the use of coal. From this valuable mineral we chiefly draw the sun's stored energy, which is required to meet our industrial and commercial needs. According to statistical records the output in the United States during an average year is 480,000,000 tons. In perfect engines this fuel would be sufficient to develop 500,000,000 horsepower steadily for one year, but the squandering is so reckless that we do not get more than 5 per cent of its heating value on the average. A comprehensive electrical plan for mining, transporting, and using coal could much reduce this appalling waste. What is more, inferior grades, billions of tons of which are being thrown away, might be turned to profitable use.

Similar considerations apply to natural gas and mineral oil, the annual loss of which amounts to hundreds of millions of dollars. In the very near future such waste will be looked upon as criminal and the introduction of the new methods will be forced upon the owners of such properties. Here, then, is an immense field for the use of electricity in many ways. The manufacture of iron and steel offers another large opportunity for the effective application of electricity.

In the production of pig iron about one ton of coke is employed for every ton. Thus 31,000,000 tons of coke are used a year. There are 4,000,000 cubic feet of gases from the blast furnaces which may be used for power purposes. It is practicable to obtain 2,500,000 horsepower electrical energy in this way.

In the manufacture of coke some 41,000,000 tons of coal are employed in this country. From the gases produced in this process some 1,500,000 horsepower could be produced in the form of electrical energy.

I have devoted much thought to this industrial proposition, and find that with new, efficient, extremely cheap, and simple thermodynamic transformers not less than 4,000,000 horsepower could be developed in electric generators by utilizing the heat of these gases, which, if not entirely wasted, are only in part and inefficiently employed.

With systematic improvements and refinements much better results could be secured and an annual revenue of $50,000,000 or more derived. The electrical energy could be advantageously used in the fixation of atmospheric nitrogen and production of fertilizers, for which there is an unlimited demand and the manufacture of which is restricted here on account of the high cost of power. I expect confidently the practical realization of this project in the very near future, and look to exceptionally rapid electrical development in this direction.

But the time is very near when we shall have the precipitation of the moisture of the atmosphere under complete control, and then it will be possible to draw unlimited quantities of water from the oceans, develop any desired amount of energy, and completely transform the globe by irrigation and intensive farming. A greater achievement of man through the medium of electricity can hardly be imagined.

The present limitations in the transmission of power to distance will be overcome in two ways: through the adoption of underground conductors insulated by power, and through the introduction of the wireless art.

When these advanced ideas are practically realized we shall get the full benefit of water power, and it will become our chief dependence in the supply of electricity for domestic, public, and other uses in the arts of peace and war.

A vast and absolutely untouched field is the use of electricity for the propulsion of ships. The leading electrical company in this country equipped a large vessel with high-speed turbines and electric motors. The new equipment was a signal success. Applications of this kind will multiply at a rapid rate, for the advantages of the electrical drive are now patent to everybody. Gyroscopic apparatus will probably play an important part, as its general adoption on vessels is sure to come. Very little has yet been done in the introduction of electrical drive in the various branches of industry and manufacture, but the prospects here are unlimited.

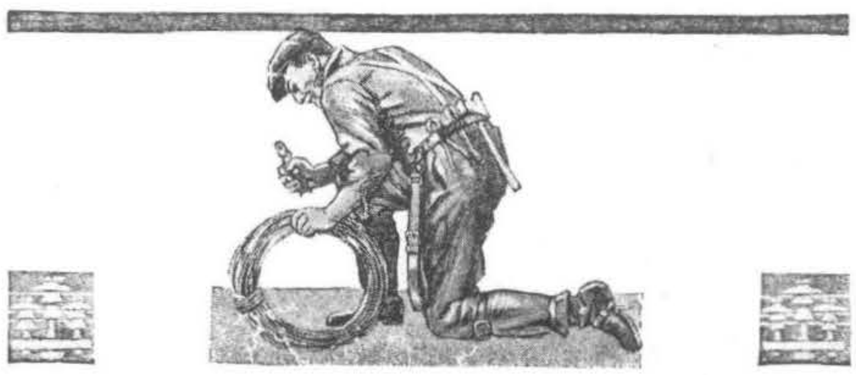
Books have already been written on the uses of electricity in agriculture, but the fact is that very little has been practically done. The beneficial effects of electricity of high tension have been unmistakably established, so that we are warranted in believing that a revolution will be brought about through the extensive adoption of agricultural electrical apparatus. The safeguarding of forests against fires, the destruction of microbes, insects, and rodents will, in due course, be accomplished by electricity.

In the not far distant future we shall see a great many new uses of electricity that will aim at safety. The safety of vessels at sea will be particularly affected. We shall have electrical instruments which will prevent collisions, and we shall even be able to disperse fogs by electric force and powerful and penetrative rays. I am hopeful that within the next few years wireless plants will be installed for the purpose of illuminating the oceans. The project is perfectly feasible; if carried out it will contribute more than any other provision to the safety of property and human lives at sea. The same plant could also produce stationary electrical waves and enable ships to get any time accurate bearings and other valuable practical data, thus making the present means unnecessary. It could also be used for time signaling and many other such purposes.

In the great departments of electric light and power great opportunities are offered through the introduction of many kinds of novel devices which can be attached to the circuits at convenient hours to equalize the loads and increase the revenues from the plants. I myself have knowledge of a number of new appliances of this kind. The most important of them is probably an electrical ice machine which obviates entirely the use of dangerous and otherwise objectionable chemicals. The new machine will also require no attention and will be very economical in operation. In this way refrigeration will be effected very cheaply and conveniently in every household.

An interesting fountain, electrically operated, has already been brought out. It will very likely be extensively introduced, and will afford an unusual and pleasing sight in squares, parks, and hotels.

Cooking devices for all domestic purposes are now being made, and there is a large demand for practical designs and suggestions in this field, and for electric signs and other attractive means of advertising which can be electrically operated. Some of the effects which it is possible to produce by electric currents are wonderful and lend themselves to exhibitions. There is no doubt that much can be done in this direction. Theatres, public halls, and private dwellings are in need of a great many devices and instruments for convenience, and offer ample opportunities to ingenious and practical inventors.



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Wonders of the Future

Continued from page 8

Great improvements are also still possible in telegraphy and telephony. The use of a new receiving device, the sensitiveness of which can be increased almost without limit, will enable us to telephone through aerial lines or cables of any length by reducing the necessary working current to an infinitesimal value. This invention will enormously extend the wireless transmission of intelligence in all its departments.

The next art to be introduced is that of picture transmission telegraphically. Existing apparatus will be used. This idea of telegraphing or telephoning pictures was arrived at long ago, but practical difficulties have hampered commercial realization. There have been promising experiments, and there is every reason to believe that success will soon be achieved. Another valuable invention will be a typewriter electrically operated by the human voice. This advance will be of the utmost value, as it will do away with the operator and save a great deal of labor and time in business offices.

Many municipal improvements based on the use of electricity are soon to be introduced. There will be smoke annihilators, dust absorbers, ozonizers, sterilizers of water, air, food, and clothing, and accident preventers on streets, elevated roads, and in subways. It will become next to impossible to contract diseases from germs or get hurt in the city. Country folk will go to town to rest and get well.

Electrotherapy is another great field in which there are unlimited possibilities for the application of electricity. High-frequency currents especially have a great future. The time is bound to come when this form of electrical energy will be on tap in every private residence. It is possible that we may be able to do away with the customary bath. The cleaning of the body can be instantaneously effected simply by connecting it to a source of electric energy of very high potential, which will result in the throwing off of dust or any small particles adhering to the skin. Such a bath, besides being dry and time-saving, would also be of beneficial therapeutic influence. New electric devices that will be a blessing to the deaf and blind are coming.

Electrical instruments will soon become an important factor in the prevention of crime. In court proceedings electric evidence can be made decisive. It will, no doubt, be possible before very long to flash any image formed in the mind on a screen and make it visible to a spectator at any place desired. The perfection of this sort of reading thought will create a revolution for the better in all our social relations. It is true that cunning lawbreakers will avail themselves of the same means to further their nefarious business.

The present international conflict is a powerful stimulus to invention of destructive devices and implements. An electric gun will soon be brought out. The wonder is that it was not invented long ago. Dirigibles and aeroplanes will be furnished with small electric generators of high tension, from which the deadly currents will be conveyed through tin wires to the ground. Battleships and submarines will be provided with electric and magnetic feelers so delicate that the approach of any body under water or in darkness may be easily detected. Torpedoes and floating mines will direct themselves automatically and without fail get in fatal contact with the object to be destroyed —in fact, these are almost in sight. The art of telautomatics, or wireless control of automatic machines at a distance, will play a very important rôle in future wars and, possibly, in the later phases of the present one. Such contrivances, which act as if endowed with intelligence, may take the shape of aeroplanes, balloons, automobiles, surface, or underwater boats, or any other form according to the requirement in each special case. They will have far greater ranges and will be much more destructive than the implements now employed. I believe that the telautomatic aerial torpedo will make the large siege gun, on which so much dependence is now placed, utterly obsolete.

Dr. Nikola Tesla and His Achievements*

By SAMUEL COHEN

PERHAPS the ever-broadening field of invention has never known a genius more successful in developing far-reaching and original inventions than Dr. Nikola Tesla, whose name is known in every corner of the globe for his scientific achievements.

Dr. Tesla was born in 1857 in Smiljan, Lika, border country of Austria-Hungary, His early education was obtained in the elementary school of his native place. He continued his studies in the public school in Gospic, Lika, and after spending a period of four years in the Lower Real School in Groatia, he graduated in 1873.

His parents originally desired him to study for the clergy, which can be readily understood when one considers that Dr. Tesla's father was himself a very noted clergyman and orator. However, young Tesla had his mind set on mathematics and physics, and after prevailing upon his parents for permission to study engineering, he entered the Polytechnic School at Gratz, where for four years he studied mathematics, physics and mechanics, after which followed a two year course in philosophic studies at the University of Prague, Bohemia. His practical career started in 1881 in Budapest, Hungary, where he made his *first* electrical invention, a *telephone repeater*—and conceived the idea of the *rotating magnetic field*, which later made him world famous. It may not be amiss to devote a few moments here to the manner in which this prince of savants approached the idea of the rotating field and *induction motor*.

One day while attending the University, one of the Professors was demonstrating an experiment with the Gramme armature type of dynamo, when the idea occurred to the young physicist that the sparking at the commutator, which he alone had minutely observed, could be eliminated. The professor immediately denied that this was possible, but with a steady mind and self-conviction, young Tesla determined to work out his ideas, with the result that the modern induction motor was developed, which operates solely from alternating current and requires no commutator of any kind, thus overcoming the nuisance of sparking inherent in former type direct current machines.

Realizing the value of his invention he left for France in an effort to interest some one in his device, but his efforts proved fruitless. At the time he was employed by a prominent European engineering concern, but hearing of the rapid growth of the electrical industry in America, he promptly decided to come to this country, which he did in 1884, and since then has been a naturalized citizen of the United States. To this country he brought with him the various models of the first induction motors, which were eventually shown to George Westinghouse, the great American inventor, and it was in the Westinghouse shops that the induction motor was perfected by Nikola Tesla. Numerous patents were taken out on this phenomenal prime-mover, all of which are under Dr. Tesla's name, and he was therefore the first person, beyond the shadow of a doubt, to introduce the rotating field principle, in perfecting the induction motor, which is to-day universally used.

Fig. 1 shows the first induction motor, and altho unique in construction, it developed ¼ horse power at 1800 revolutions per minute and weighed but 20 pounds.

Large sums of money were expended by Dr. Tesla to protect his patents on this prime-mover, and he was at the time not permitted to express himself in print or give the history of his invention; thus, many erroneous impressions were entertained regarding his inventions. He was far ahead of Ferraris, Schallenberger and

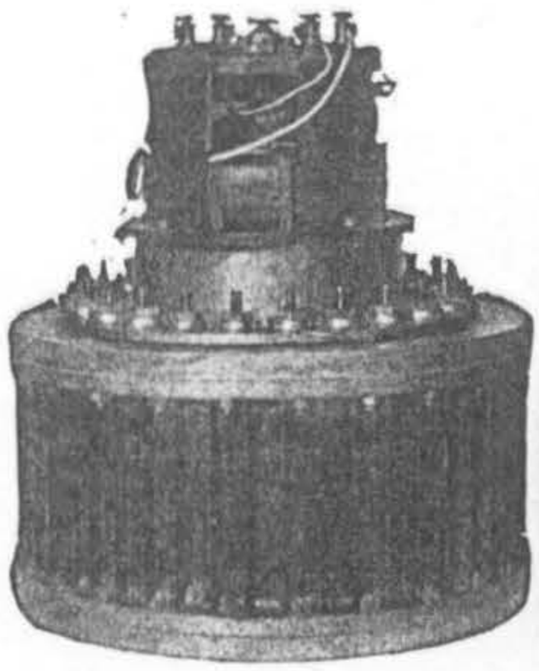


Fig. 4. A Massive Mercury Interrupter Devised by Tesla for Handling 50 H. P. of Electrical Energy at a Rate of 100,000 Breaks Per Second.

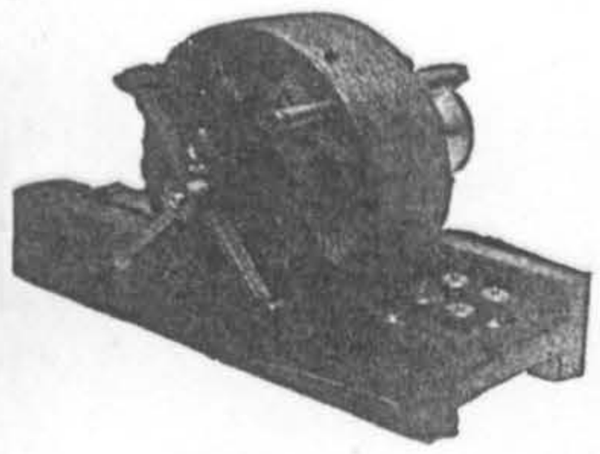


Fig. 1. Shows the First Alternating Current Induction Motor, Perfected by Dr. Tesla Prior to the Year 1884, in Which Year He Came to America to Take Up His Life Work.

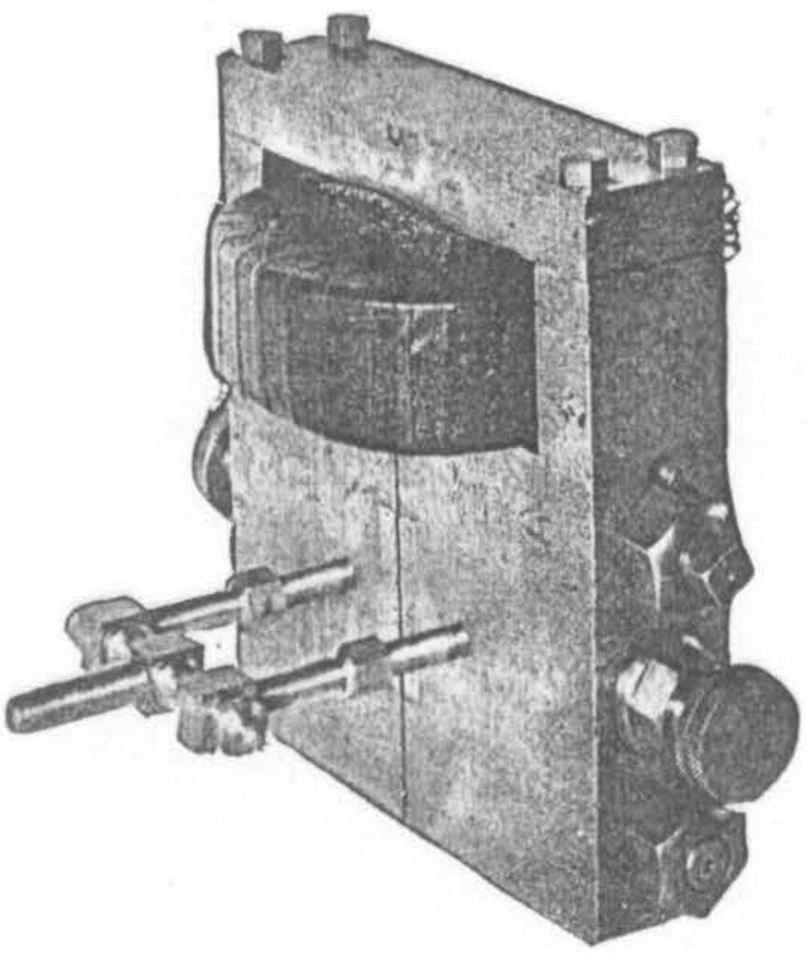


Fig. 6. Unique Alternating Current Generator for Exciting Tesla's Early "Beat" Receptor. Actuated by Comprest Air or Steam Which Vibrates a Special Diafram-Coil.

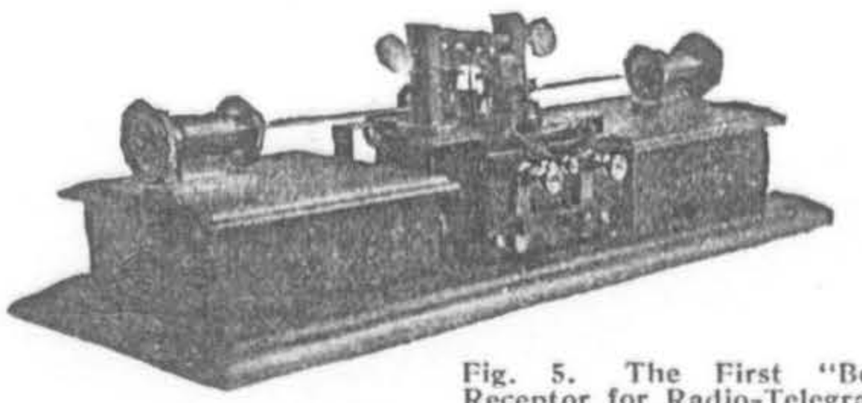


Fig. 5. The First "Beat" Receptor for Radio-Telegraphy invented by Tesla, Which Foreshadowed the "Heterodyne."

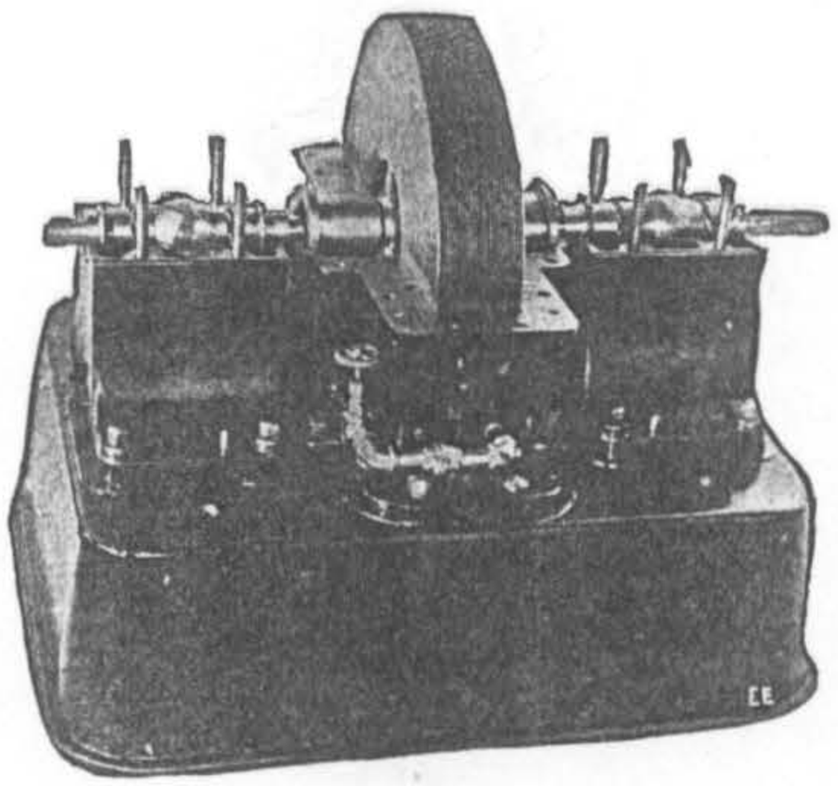


Fig. 7. The Wonderful "Tesla" Steam Turbine; the Steam Flows Radially Up Between the Vanes, Not Against Them.

*Special interview exclusively for THE ELECTRICAL EXPERIMENTER.

many other early, able investigators.

Later another type of machine was brought out by him, in connection with his work in electric power transmission. This one had a field energized by currents of different phase relation (i.e., while one current was at zero amplitude the other would be at maximum, etc.), producing a rotating field in which conductors were employed, and in this way the high frequency current was obtained. This type of machine was subsequently developed by Goldschmidt and is now known under that name, altho Tesla described this principle in a patent dated 1889.

His next work which attracted universal attention was the production of high frequency currents at high potentials. Our readers are no doubt familiar with the tremendous electrical discharges which have been illustrated in several of the previous issues of THE ELECTRICAL EXPERIMENTER. All these experiments were first performed by this genius and never duplicated. One of the first high tension apparatus built by Dr. Tesla is shown in Fig. 2. Incidentally we might mention that this instrument was first used in Europe by Lord Kelvin, the noted English mathematician and scientist, who used it for his lecture demonstrations at the Royal Society. The apparatus consists of a step-up transformer, and a specially built kick-coil, which boosted the secondary transformer voltage to an enormous value. This coil is seen resting horizontally at the back. The terminals of this coil are connected to the large spark gap, which, when the apparatus was excited, was filled with a spark two feet long. The high tension condenser is inclosed within the cabinet. The large coil is used as kick-coil for increasing the voltage. With this device Dr. Tesla was able to obtain a potential of one million volts, which is quite extraordinary with such small apparatus.

Dr. Tesla can rightfully claim priority in employing *conical coils* for high frequency work, as Fig. 3 shows the first conical coil ever employed for such work, as early as 1892. This coil was excited by means of a powerful transformer. The discharger consisted of a multiple gap, commonly called to-day the quenched gap, which will be noted at the left of the huge coil. An interesting feature of this coil is that a finer wire winding is used at the upper end so as to increase the voltage at that point.

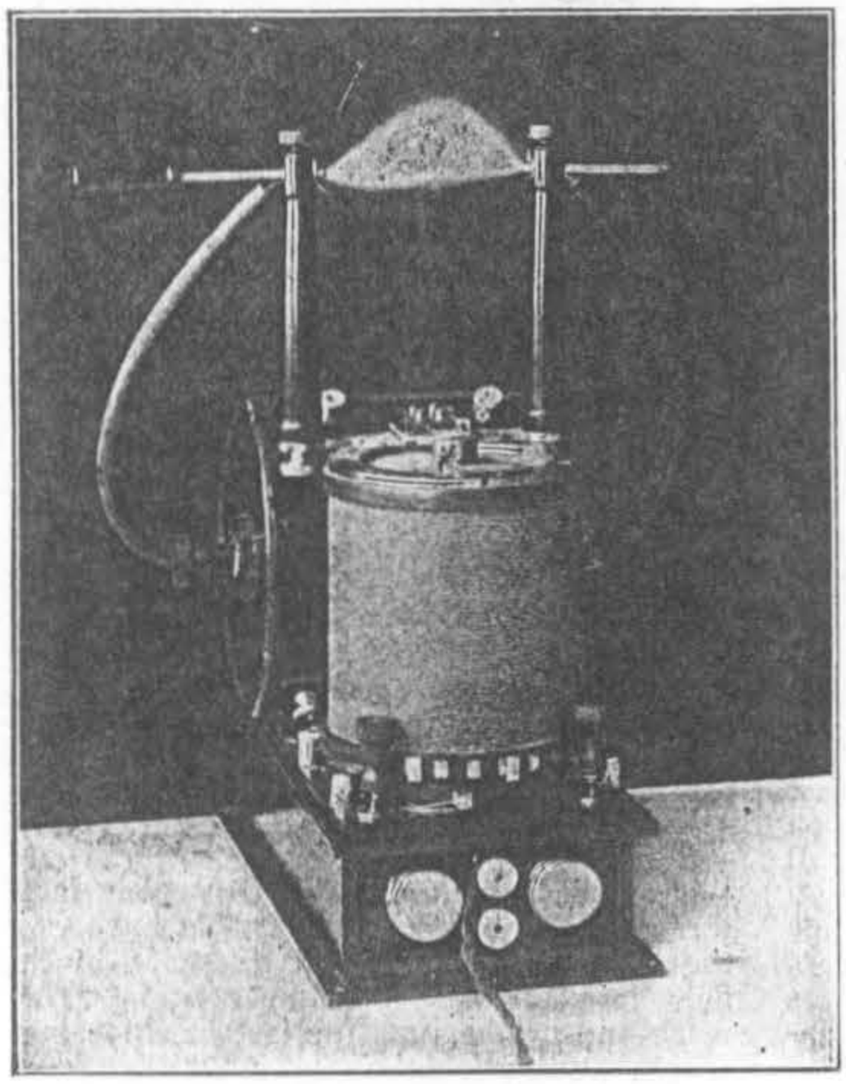


Fig. 2. An Early "Tesla" High Frequency Developing 2 Sq. Ft. of Streamers With 25 Watts Input. First Used in Europe by the Late Lord Kelvin in His Lectures Before the British Association for the Advancement of Science.

The machine in the foreground is a *50,000 volt direct current dynamo,* which was employed in many of his experiments on high potential electricity. In conjunction with the experiments on high voltage *direct current,* Dr. Tesla developed numerous interrupters for breaking these tremendous currents, the largest one ever built being that shown in Fig. 4. This massive circuit-breaker handled with great ease 50 horse-power of electrical energy at an interruption rate of 100,000 breaks per second. The interrupter consisted of a large chamber in which a circular suction cog was placed, driven at tremendous speed by a motor stationed on top. The rotor or cog operated in a column of mercury in such a manner that each stud of the cog made contact with the pool of mercury, thus making and breaking the electrical circuit. Dr. Tesla employed this interrupter for his wireless researches in 1900.

Dr. Tesla's most important work at the end of the nineteenth century was his original system of *transmission of energy by wireless.* In 1900 Tesla obtained his two fundamental patents on the transmission of true wireless energy covering both methods and apparatus and involving the use of four tuned circuits. He also obtained a number of other patents at the same time, describing many other improvements. Among these may be mentioned his application of refrigeration and the oscillatory systems with which he obtained remarkable results in his well-equipt laboratory on Houston Street, New York City.

In 1901 and 1902 several patents were granted to him describing a number of improvements, among which two have assumed great importance in the radio art; one of these is known under the name of the "tone wheel" and the other the "tikker." Others are making claim to these inventions, but Tesla was far ahead of any of them.

At a little later date Tesla secured two patents on what he termed the *principle of individualization,* involving the use of more than one oscillation for the operation of the receiver This property is now known under the commercial name of *beat* receptors. In long protracted interference proceedings carried on in 1903, however, Tesla has been accorded full and undisputed priority over Fessenden and other claimants. His first *beat* receiver is shown in Fig. 5, which consisted of a steel band stretched above a powerful electro-magnet excited by a high frequency current, causing the steel band to vibrate at an enormous rate. A small sensitive electro-magnet is placed in proximity to the band, in which is produced an alternating e.m.f., and this is acted upon by the received wave.

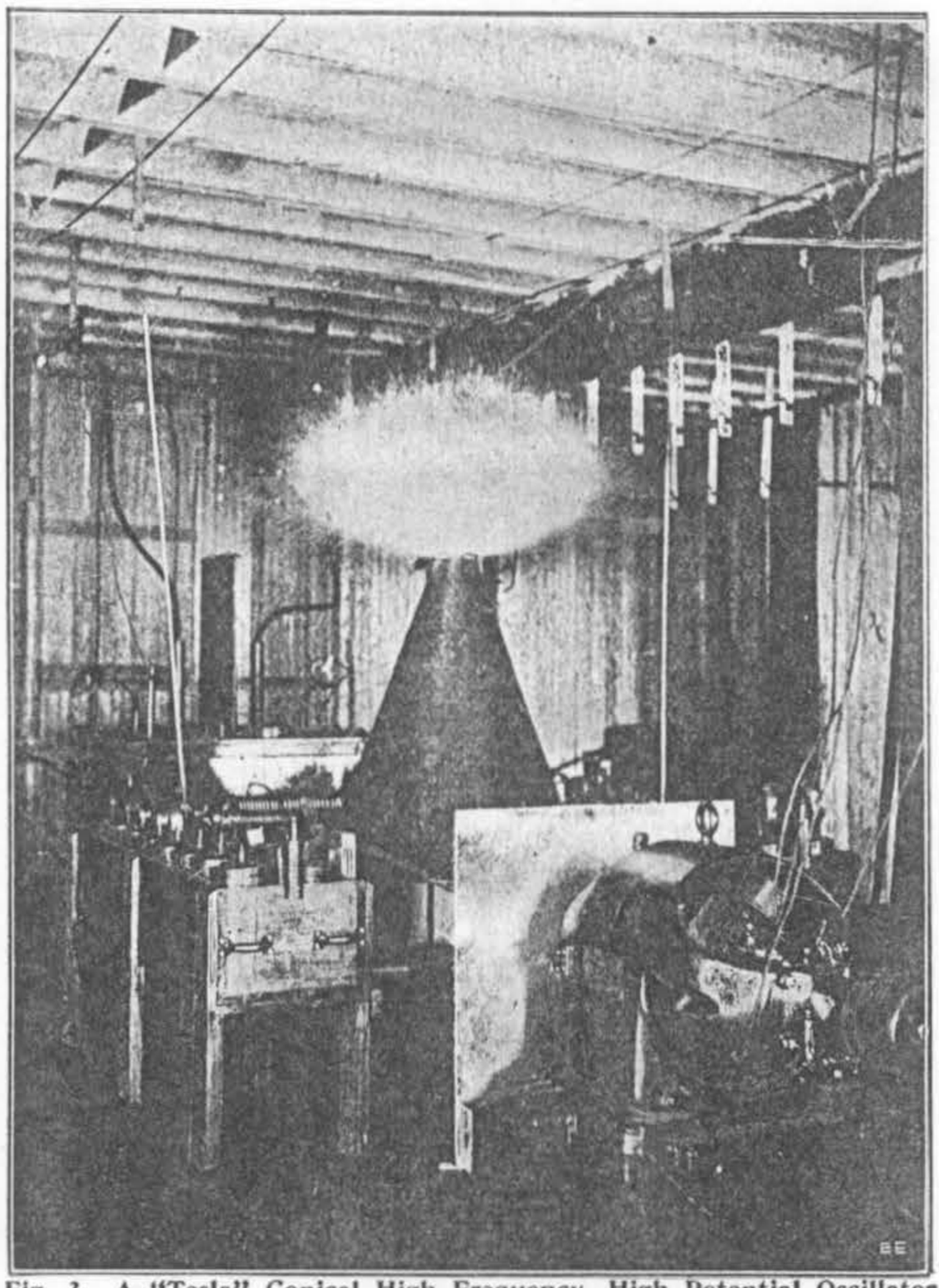


Fig. 3. A "Tesla" Conical High Frequency, High Potential Oscillator Coil Delivering a Very Powerful Discharge Several Feet in Diameter. The Condensers May Be Seen at Right and Left of Coil, as Well as 50,000 Volt D. C. Dynamo in Foreground.

The apparatus is timed by adjusting the periodicity of the band until the received wave is made audible. The large electro-magnet was usually excited by means of an alternating current generator, and this is illustrated in Fig. 6. Like all Tesla inventions, the construction of this oscillator is very unique, consisting of two chambers in the center of which is placed a vibrating membrane. This is inclosed in a magnetic field, consisting of a powerful coil encircling the device as seen and which was excited by a direct current. The membrane was caused to vibrate by passing interrupted, comprest air thru the two chambers by the inlet pipes as indicated. In the process of vibration, an e.m.f. is produced in a coil secured to the vibrating disc.

A patent was granted to Dr. Tesla in 1914 on an improvement of far-reaching importance in wireless work. The application was filed in 1902. It describes a new form of transmitter with which, according to Tesla's statement, an unlimited quantity of energy can be transmitted from a small and compact plant. This transmitter possesses the wonderful feature whereby *static*—the one nuisance of the radio art, and any other interference can be completely eliminated, because of the speed with which the receivers can be

(*Continued on page 777*)

ENGLISH WOMEN LEARNING WIRELESS.

British women are being trained in wireless operation. Almost a year ago the Marconi organizations in England determined to test the suitability of women as wireless operators, and establish a school at one of their stations, where instruction of a practical and theoretical nature has been given to women. The school has been well attended. So far as it has gone the experiment is regarded as encouraging, and some of the pupils have been already drafted to stations, where they are taking night duty in turn with men. The criticism has been made that sending by female operators has a tendency to be too light. This defect varies in individual cases, however, and many of the women learners, it is thought, will become efficient wireless operators.

DR. NIKOLA TESLA AND HIS ACHIEVEMENTS.

(*Continued from page 713*)

operated; it being possible to throw them in and out of tune by a variation of not more than one thousandth of one per cent of the wave length. He has also evolved a *static preventer* which has been successfuly tested several years ago. He is at present engaged in preparing these instruments for the market.

This great scholar and philosopher has not devoted his time to electrical devices alone, but recently turned his attention to a new form of prime-mover, which will develop more power than any other motor or engine, and he has stated that it is within the limits of practicability to develop 20 horse-power for each pound of engine weight. The Tesla turbine is shown in Fig. 7. It consists simply of a number of flat steel discs properly balanced. At the lower end of the case an inlet is situated thru which steam or comprest air is forced at a pressure of 100 to 200 pounds per square inch. The steam does not exert pressure against the rotor blades sidewise as in other types, but shoots thru between the blades edgewise. The velocity of the moving steam jet and the peculiar frictional effect resulting is sufficient to rotate the turbine spindle and blades at high speed and with unprecedented torsion or turning effort in foot-pounds. This machine herewith illustrated develops 200 horse-power, and there is no reason why such a machine could not be employed for drawing automobiles, aeroplanes and other vehicles, due to its marvelous simplicity and extreme lightness of construction.

It is further understood that he is perfecting a turbo-driven generator for high frequency currents to be used chiefly in radio-telephonic work. It will be very small, compact and entirely reliable, and will no doubt revolutionize wireless telephony.

This master magician of modern electrical science has spent a fabulous amount of time and money in perfecting his inventions, and we are bound to await with great expectancy the next great stride in scientific development which will mark another epochal invention of Dr. Nikola Tesla.

GENERAL, SPORTING AND HORSE AND CARRIAGE NEWS

THE NEW

FIRST SECTION—PART II.— The New York Herald February 15, 1917

NIKOLA TESLA DECLARES ELECTRIC DRIVE FOR BATTLE SHIPS SUPERIOR TO ANY OTHER FORM OF EQUIPMENT

Inventor Answers Criticisms of This Form of Construction and Declares It Would Be a Means of Preventing Vast Waste by Making Naval Vessels Useful in Times of Peace—Foresees New Methods in War.

Says an 80,000 Ton Battle Ship, Costing $50,000,000, Is Practicable

WASHINGTON, D. C., Saturday.

An 80,000 ton battle ship, mounting fifteen 18-inch guns, having a speed of 25 knots and costing $50,000,000, would be the largest war craft which the United States could employ, according to a report to Congress prepared by the Navy Department in response to a request for specifications of the biggest fighting craft that could use the Panama Canal and American harbors.

The report says that such a vessel would have a length of 975 feet, a beam of 108 feet, a secondary battery of twenty-one 6-inch guns, four 21-inch torpedo tubes and a 12,000 mile radius of action.

To develop the value of such a vessel it would be necessary to lay down not fewer than five, the report adds.

The European war, the report says, has as yet brought no conclusive answer to the question of what types are most desirable, and the General Board is not prepared to recommend so radical a departure as the 80,000 ton ship would represent. The $25,000,000 battle ships asked for in the pending naval bill represent the greatest increase in size and power for battle ship types in any single year.

By NIKOLA TESLA.

The ideal simplicity of the induction motor, its perfect reversibility and other unique qualities render it eminently suitable for ship propulsion, and ever since I brought my system of power transmission to the attention of the profession through the American Institute of Electrical Engineers I have vigorously insisted on its application for that purpose. During many years the scheme was declared to be impracticable and I was assailed in a manner as vicious as incompetent. In 1900, when an article from me advocating the electric drive appeared in the Century Magazine, Marine Engineering pronounced the plan to be the climax of asininity," and such was the fury aroused by my proposals that the editor of another technical periodical resigned and severed his connection rather than to allow the publication of some attacks.

A similar reception was accorded to my wireless boat repeatedly described in the HERALD of 1899. The patents on these inventions have since expired and they are now common property. Meanwhile insane antagonism and ignorance have been replaced by helpful interest and appreciation of their value. Recently the Navy Department has let contracts aggregating $10,000,000 for the construction of seven war vessels with the induction motor drive, and an equal sum is appropriated to cover the cost of four huge battle cruisers which are to be fitted out in the same way. This latter project is resisted by some shipbuilders, turbine makers, electrical manufacturers and engineers who, for fear of a fatal mistake by the government and under the sway of patriotic motives, urged upon the authorities the employment of the geared turbine.

Controversial Correspondence.

Numerous letters of protest have been written to C. A. Swanson, of the Senate Naval Committee, but what has so far come out of this correspondence is purely controversial and of no profit whatever to those who seek information. It is remarkable that the question should have been raised at this critical moment, when speedy preparation against threatening national perils is recognized as imperative, and in view of this no doubt should be permitted to remain in the public mind as to the superiority of the equipment recommended by the naval experts. In the following I shall endeavor to make this clear to the general reader.

The most efficient means of propulsion is a jet of water expelled astern from the body of the vessel. Though the theoretical laws governing its action were precisely expressed fifty years ago by Rankine, a singular and inexplicable prejudice against this device still prevails among engineers and writer of text books on hydraulics. But the far sighted are keenly alive to its possibilities. While our present motive resources do not admit of an advantageous use of the jet, it can be confidently predicted that it will soon be instrumental in a more complete conquest of the deep. I firmly believe that at this writing it is being applied to the submarines devastating the oceans, for their silence alone can explain why they escape so easily detection by microphonic instruments. The sound emitted is the Achilles talon of the undersea boat. Its suppression materially increases the destructiveness of the new weapon.

The Helical Propeller.

However, under the existing conditions the best results are obtained in all kinds of surface craft with a helical propeller, which is operated in four different ways. First, straight from the shaft of the prime mover; second, by means of a gear wheel; third, through a hydraulic transformer, and, fourth, by an electric transmitter of power. As the screw in order to save energy must be revolved at a moderate rate, the first mentioned, or "direct drive," lends itself best to a reciprocating or rotary engine. The former is clumsy, the latter impossible, and competition has forced the turbine on the market. But, excessive speed being indispensable to its good performance, it had to be adapted to the propeller. This was, in a measure, accomplished by "tuning"—that is, passing the steam through a number of turbines in succession—a plan obviously entailing great drawbacks, financial and otherwise. Need of reducing the bulk and cost of the machinery and insuring better working then compelled the adoption of the second arrangement—"geared turbine drive"—in which a peculiar pinioned wheel, first introduced by De Laval, transmits motion to the screw. Next, efforts to do away with certain limitations of this combination resulted in the third, or "hydraulic drive," the turbine actuating the propeller through a centrifugal pump and water motor. Finally, as the furthest step toward perfection, the last named disposition—"electric drive"—was resorted to. In this case the turbine imparts rotation to a dynamo, which in turn runs a motor carrying the screw on its shaft.

Advantages of Types.

Each of these forms has its supporters and champions. In principle the first would be the preferable were it not handicapped in many respects. The second type is cheap, but the gear is a serious objection. Though less economical, the third commends itself by a number of practical and valuable features. As to the last, it is not only very efficient but obtains results impossible with other forms. The law of survival of the fittest is asserting itself, and the struggle for supremacy is now on between the geared turbine and the electric drive.

Through gradual improvement of the cutting tools, scientific design, metallurgical advances and refinement of lubricants, the so-called herringbone gear has been brought to great perfection. De Laval attained an efficiency of ninety-seven per cent and MacAlpine, Melville and Westinghouse ninety-eight and one-half per cent in the transmission from the driving to the driven shaft. On the other hand, ninety-three and three-quarters per cent may be considered as the maximum with electrical apparatus. This means that with the gear the same turbine would impart five per cent more power to the propeller, which should increase the speed of the cruiser from thirty-five to a little more than thirty-five and one-half knots. As it also appears at first sight that the electric drive requires additional space, is heavier and more costly, it is only natural for those who have not made a thorough study of all its phases to decide in favor of the gear,

Some Fatal Mistakes.

But a careful inquiry into the subject would induce them to reverse their opinion. In estimating the relative merits of these essential different propelling means they make two fatal mistakes. The first is to take the power transmitted under abnormal conditions as a criterion; the second to draw a parallel between instalments entirely unlike, one primitive, the other elaborate, the former being incapable of fulfilling important functions of the latter. When premises are erroneous deductions therefrom must needs be faulty. Thus the opponents of the electric drive have been led to the conclusion that it is less efficient than the gear, of greater weight, more expensive and uncertain of success. How much truth there is in these contentions will be apparent from an examination of well established facts.

The electric drive is of complex influence on results in ship operation. For the sake of brevity it will be viewed only in the following principal aspects:—(1) turbine performance, (2) power transmitted to the propeller, (3) efficiency of the screw, (4) low power cruising, (5) high power action, (6) fuel consumption by auxiliaries and apparatus for ship use, (7) general economy and, (8) promptness and precision of control of all effects, internal and external.

The present turbines are extremely unsuitable for ship propulsion. They offer a striking example of an antiquated invention of small value elevated to a position of extraordinary commercial utility through profound research and astonishing mechanical skill. With hundreds of thousands of thin blades easily destroyed, buckets that through corrosion and erosion soon become wasteful and small clearances between surfaces rotating at terrific rates, they are a cause of constant danger and hazard.

Irreversible Turbines.

But their cardinal defect is that they are irreversible, which necessitates the employment of separate turbines for backing. These, besides involving great expense and considerable friction loss, impose narrow limits on the temperature of the working medium. Very high superheat, so desirable in thermo-dynamic conversion, is out of the question in such perishable structures, but from 200 to 300 degrees F. are permissible.

To that extent, then, the turbine is at an advantage when driving a dynamo. Two hundred degrees superheat will usually effect a saving of about twenty-three per cent of steam and ten per cent of fuel. This, however, is not the only gain. The turbine, freed from all the impediments of the gear drive, is capable of being safely run at a higher peripheral speed with a correspondingly increased efficiency and output. Thus, by moderate superheat and other simple and allowable expedients, it becomes practicable to develop twenty-five per cent more power from the same fuel, and this alone would make the electric drive decidedly superior to its competitor.

A Mechanical Tour de Force.

As regards the power transmitted from the turbine to the propeller, it will seem in the light of the preceding that the gear is better by five per cent. That may be the case in exceptional tests, but it is quite different in actual service. To this is to be traced the error of those who are taking results obtained at constant load as standard of comparison. The perfection of the modern high speed gear was a veritable tour de force of the scientific machinist. It is a wonderful device, but it also has its inseparable weaknesses and shortcomings. Since the friction loss in it is sensibly constant through a wide range of performance, a relatively great amount of energy is absorbed at small load. The gear is likewise very sensitive to shocks and vibrations, which break down the capillary oil film, vital to smooth running. In consequence, there is great waste of power when the resisting force is subject to frequent and sudden fluctuations. Measurements I made with turbine gears have shown that while the efficiency with steady and normal effort was ninety-six per cent, not more than ninety per cent was realized with a rapidly varying load. This is what might be expected in practice. Any one who has listened to the tortured engines of a steamship in heavy sea could not have failed to observe how the turning effort varies as the vessel rolls, pitches and ploughs through billows and conflicting undercurrents. A similar state of things is apt to confront a war ship in action, as was evidenced in recent naval engagements, when mountains of water were raised by the exploding shells. Under such circumstances the gear is at a great disadvantage, as the electric drive is susceptible to these drawbacks in a much smaller degree. The idea that the gear transmits more of the primary power to the propeller than the combination of dynamo and motor is, therefore, largely illusionary. There is ample evidence, experimental and inferential, that rather the opposite is true.

Superiority of Electric Drive.

Considering the efficiency of the screw as distinct from that attained in the transmission of power, it is admittedly better with the electric drive, this conclusion being entirely based on the superior adaptability and flexibility of the system. But there are deeper causes which should be taken into account. The interposition of electromagnetic means between the turbine and propeller materially reduces the loss due to shocks, vibrations, racing and other disturbances owing to inherent elastic resilience and equalising tendency. The saving of energy thus effected at high speed and in a heavy sea is considerable.

Economy in cruising is one of the most desirable qualities of a war vessel. This is its ordinary use, for the chance of ever being engaged in battle is remote. The bitterest opponents of the electric drive do not deny that it excels in this feature, upon which the manufacturer chiefly relies in guaranteeing a fuel consumption from 10 to 12 per cent smaller than with the gear. The latter is hopelessly condemned by inability of adjustment to varying speed and wasteful in cruising operations, while the former is readily adaptable and economical under all conditions.

Another quality of the electric drive, which may prove especially valuable in action, is its capacity of carrying great overload without danger, owing to the nature of the connection between the turbine and propeller, as explained. The gear is rigid and unyielding and any increase of effort, particularly if sudden, may cause a breakdown.

Saving of Power.

Referring to the auxiliaries proper and other apparatus for ship use, to which are chargeable approximately 20 per cent of the fuel consumed, a very substantial saving of power will be achieved through the introduction of the electrical method.

Quite apart from this central station supply will be operative in reducing other waste, many accessories will be dispensed with and general economy materially increased.

But from the military point of view the quickness, ease and precision of control will perhaps be the most significant of the advantages gained. Everything may be made to respond instantly to the pressure of a button. By reversing the motors the vessel may be brought from full speed to a stop within its length. It will be possible to make it go through all evolutions with extraordinary rapidity and a perfection of manoeuvre, undreamed of before, will be attained.

A curious mistake is made by the advocates of the turbine gear in estimating relative weight. It hardly needs be stated that it is unfair, if not absurd, to compare arrangements of widely different character and scope. Only such as are capable of accomplishing the same results should be considered. Now, a gear drive corresponding to the electric would consist of four main turbines with gears, four reversing turbines of the same capacity, and eight smaller driving and réversing turbines for cruising. This agglomeration of complex and not all too rugged machinery, with its network of water, air and oil pipes, valves, pumps and attachments, would by far exceed in weight the proposed electric drive, and would also require better structural protection, not to speak of other defects and shortcomings.

Question of Weight.

It should be observed, however, that the weights must be taken in their relation to that of the ship. One equipment may be heavier than another, but if it is more efficient and thereby reduces the weight of fuel and other cargo, it is for all purposes the lighter of the two.

The same is true of the cost. Comparative figures mean nothing. The question is whether the investment of capital is justified by what is to be accomplished. But enough has been said to show that for results in all respects equivalent, assuming them to be possible, the gear type, notwithstanding all claims to the contrary, would be more expensive.

That the electric drive is experimental and uncertain of performance is the least tenable of adverse assertions. In the first place, it has been successfully employed on a number of vessels and a great many more are being built. It also was found to be capable of an efficiency higher than that of any other form. But this is quite immaterial. The confidence that in the present instance all expectations will be realized is not based on a few demonstrations, but on years of experience with

(CONTINUED ON PAGE 2, COLUMN 1.)

TESLA FAVORS ELECTRIC DRIVE FOR BATTLE SHIPS

(CONTINUED FROM PAGE ONE.)

power plants ever since my system was commercially inaugurated. Tens of millions of horse power of induction motors are now in use the world over and no failure is recorded.

New Cruisers' Requirements.

The new cruisers will require 180,000 horse power each, which, if necessary can be developed by four units of 45,000 horse power. Turbines of that capacity have been constructed and are in operation today. Dynamos of corresponding output have been installed at several places and are supplying light and power to large cities and districts. Induction motors of 15,000 horse power are being turned out by the manufacturers and can be produced in any size that may be desired, for of all kinds of motors this is the simplest and most dependable. Long since the whole system has been worked out and perfected to the least detail. The project is colossal, but it can be readily carried out by any of the new concerns who are possessed of the proper facilities. Not even a new tool has to be made. There is nothing whatever untried or hazardous about the electric drive.

Much stress is laid on reports, still to be verified, that it was rejected by England and Germany. But this is of no consequence. It has been rejected here more than once. Besides, there was war in the air of Europe and the time for radical innovations unpropitious. Moreover, the Diesel engine was looming up with large possibilities and Dr. Föttinger's hydraulic drive was being tried. The beginning must be made somewhere and it would be deplorable indeed if the United States, where the invention was first announced and introduced on a gigantic scale, were the last to recognize it. Such mistakes have happened only too often. The foreign navies are not in the habit of keeping the press informed of their doings and it is safe to predict that if progress in this country is much retarded there will be a repetition of previous disappointments.

It is unnecessary to dwell on other objections which are of minor importance and of no bearing on the principle. Without going into tedious technical discussion, it may be stated that the electric drive, if judiciously designed, will have not less than twenty-five per cent of fuel and, with due regard to this and certain specific and invaluable advantages, will be lighter, cheaper and in every respect more dependable than the gear. In fact, I believe that a scheme can be devised permitting the placing of all vital parts below the water line. In view of this, it is to be hoped that the Secretary of the Navy will not pay attention to the protests of rivals, however patriotic, but will cause the good work to be pushed to completion with all the power at his command.

These statements are to be understood as reflecting the present state of the art. The advent of a reversible turbine will profoundly affect the situation in favor of the gear. Such a machine has been perfected and was described in the HERALD of October 15, 1911. It is the lightest prime mover ever produced and can be operated without trouble at red heat, thereby obtaining a very high economy in the transformation of heat energy. I anticipate its speedy and extensive application to ship propulsion. But although an ideally simple and very inexpensive drive will be thus provided, there will still be weighty reasons for adopting the electric method on war ships. In order to dissipate all doubt created in the mind by diversified engineering opinion, I will make known but one of them, which in itself is sufficiently consequential and convincing to dispense with further arguments.

Disarmament Impossible.

It is idle to dream of disarmament and universal peace in the face of the terrible events which are now unfolding. They prove conclusively that no country will be allowed to control all others by any means. Before all peoples can feel secure of their national existence and worldwide harmony established certain obstacles will have to be removed, the chief of which are German militarism, British domination of the seas, the rising tide of Russian millions, the yellow peril and the money power of America. These adjustments will be slow, in conformity with natural laws. International friction and armed conflict will not be banished from the earth for a long period to come. The drag on human progress would not be so great if war energy could be maintained in purely potential form. This can and will be done through the universal introduction of wireless power. Then all destructive energy will be obtained without effort, merely by controlling the life sustaining forces of peace.

The maintenance of war ships and other military implements involves an appalling waste. A vessel costing twenty millions of dollars is rendered virtually worthless in the short span of ten years, depreciating at the mean rate of two million dollars a year, interest not considered. Hardly more than one out of fifty serves its real purpose. To lessen this ruinous loss and exploit certain inventions I elaborated a scheme some years ago. It was recognized as rational but financially and in other ways difficult of realization. Now, when national economy and preparedness have become burning questions, it assumes special import and significance.

To Use War Ships in Peace.

The underlying idea is to make war ships available for purposes of peace in a profitable manner, at the same time improving them in a number of features. I am aware of the proposal lately advanced to employ them as carriers of commerce, but this is not feasible and would be an impediment to further perfection. My project primarily contemplated the instalment of the electric drive and the use of the turbo-dynamos for light and power supply and manufacture of various valuable products and particles aboard or on land. This would be a step in the direction of present development meeting the objects of both military and industrial preparedness. I further intended the creation of a type of vessel on radically different principles, which would be a precious asset in peace and ever so much more destructive in war. The new cruisers, if equipped as planned by the Navy Department, will constitute four floating central stations of 180,000 horse power each. The turbines and dynamos are designed for highest efficiency and operate under most favorable conditions. The power they are capable of developing represents a market value of several million dollars a year and could be advantageously utilized at places where fuel can be readily obtained and transport is convenient. The plants would also prove of great value in cases of emergency. They could be quickly sent to any point along the coast of the United States or elsewhere and would enable the government to lend speedy assistance whenever necessary.

But this is not all. There is another and still more potent reason for adopting the electric method. It is founded on the knowledge that at a time not distant the present means and methods of warfare will be revolutionized through novel applications of electric force.

Electricity and Life

By FREDERICK FINCH STRONG, M.D.
Lecturer on Electro-therapeutics, Tufts Medical School, Boston

SCIENTIFIC progress during the past three decades has perhaps surpast that of all preceding ages; but we are still in the kindergarten class when we compare what is known with that which is still to be discovered. To *discover* means practically the same as to *uncover,* implying that the truth or fact was there all the time but was hidden, covered, occluded, or *occult;* and is it not a fact that many of the electrical discoveries of to-day would have been regarded as *supernatural* or *occult* by the scientists of a few generations ago? Of course there is nothing supernatural in the strict sense of the term, but many things remain *occult,* altho science is daily uncovering new and hitherto undreamed-of marvels.

There exist great *Cosmic Forces* of which we still know but little. Gravitation is one of these; we know something of its laws and the results of its action, but nothing whatever of its real nature. Electricity is another; of this we know somewhat more, and we now recognize it in a variety of forms, as light, heat, chemical action, magnetism, etc., but its *true nature* is still a deep mystery. *Life-force* or *vital energy* is another great Cosmic Principle; thru its action electrons are formed into atoms, atoms into molecules, molecules into crystals and chemical compounds, and these into the bodies of plants, animals and of man. We have no name for this force, but thru its action the great Cosmic Scheme of Evolution goes on. In India they call it by a Sanscrit name—*Prana.* Here in the Occident we have not yet officially recognized this force; it is quite unorthodox to even suggest that it exists—simply because we have not been able to measure and record it by our still comparatively crude laboratory instruments.



Demonstrating in a Startling Manner, the Appearance of the Human (the Author's) Body When Charged With a High Frequency Current. This Picture Shows Exactly How a Person Charged From a Powerful High Frequency Apparatus Would Appear to Our Unaided Eyes, Were They Attuned to Respond to Vibrations of One or Two Millions Per Second, Instead of From 380 to 760 Million-Millions Per Second (the Range of Normal Human Vision). This Display Greatly Resembles the Natural Aura Surrounding the Human Body, but which Average Persons Can See Only by Gazing Thru Special Chemical Screens.

A few years ago, when almost every scientist was a materialist, we believed in nothing but matter and force; to-day science recognizes the necessity of a third basic principle, *Intelligence* or *Mind;* without this we can satisfactorily account for none of the facts of the world in which we find ourselves. Its manifestations in matter thru the Cosmic Forces give us at least a working hypothesis of life.

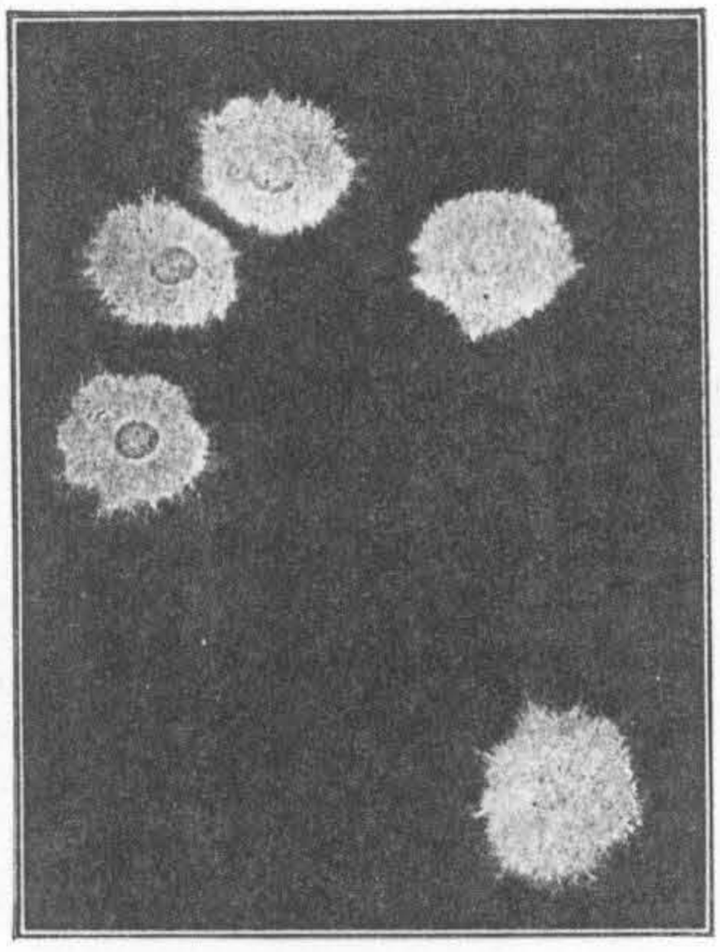
As electricity has been the great field for the investigations of the past century so will the nature and manifestation of the *Life-force* be the source of the discoveries of the future. Even to-day we may hazard a few statements regarding this hypothetical *Prana* or *Vital-force.* For example, it comes to us—like all other active forces—from the Sun. It is stored and transmitted by plants and by the oxygen of the air, and in the human body it appears to be distributed thru the great Sympathetic Nervous System to every organ and tissue of the body. The Sympathetic nerves radiate from the Solar Plexus—our *Sun-center.* If bacteria or poisons interfere with this circulation, as for example in *infantile paralysis,* the muscles from which the supply of life force is cut off, lose their power of reaction and wither away. It is in this connection that we may study the action of certain electric currents as applied to the treatment of disease. It would seem that certain types of alternating currents of high frequency and voltage greatly facilitate the distribution of this vital principle (Nerve-force, Prana, or whatever you choose to call it), and this explains the action of one of the most valuable of recent medical discoveries.

In 1893, Dr. Nikola Tesla described in a magazine article the remarkable effects upon himself and his assistants resulting from their exposure to the action of alternating currents of exceedingly high-voltage and frequency during some research work. He prophesied that when electrical oscillations were fully understood and applied by physicians that a *universal healing agent* would have been obtained—one which would so increase the vital energy and resistive reaction of the human body as to enable it to throw off all disease. The present writer, acting on this hint, constructed a high-frequency apparatus, tested it on a number of patients and reported his results to a local medical society in 1895. So far as can be learned this was the first clinical work ever done with the Tesla Current, altho d'Arsonval in Paris was then experimenting with his relatively low voltage currents, produced from 3,000 cycle alternators. Later, Apostoli, Denoyes, and others reported remarkable results from the currents induced in the bodies of patients placed inside of huge solenoids or wire coils thru which high frequency currents were passing. The effects obtained were: increase of strength, appetite and weight, induction of natural restful sleep, and increase in tissue combustion and elimination.

Early in 1895 the author devised the first *Vacuum electrodes* for applying Tesla currents to the patient. To-day thousands of physicians are using this device, often *mis*calling it the Violet-ray Treatment. This is of course a misnomer, the violet light in the tube having nothing whatever to do with the healing effect produced by the transmitted electrical oscillations.



Electrical Autograph of the Human Hand, Showing the Radiations from it When Charged with a Powerful High Frequency Current.



A Striking Electrical Autograph of the Tips of the Four Fingers and Thumb of the Author's Left Hand. A High Frequency Current Charged the Hand while It Rested on a Photograph Plate, With the Results Shown.

(*Continued on page 831*)

ELECTRICITY AND LIFE.

(*Continued from page 798*)

Some years ago the great Swedish scientist, Arrhenius, was reported to have subjected one-half of a class of school children to the action of high-frequency currents, one hour daily for several months, at the end of which time there was marked increase in the average growth, weight, general health and mental ability in the electrified pupils as compared with those not so treated. At the present time high-frequency currents are actually being used in truck-gardens to promote the growth and increase the size of vegetables for table use.

The high-frequency currents, in short, act as *vitality boosters*—no other form of electricity will do this. *Galvanism, Faradism, Static* electricity are all valuable agents in the hands of the Electro-therapeutic specialist, but they have little direct action in promoting cell vitality and growth, as do the high-frequency currents when properly applied.

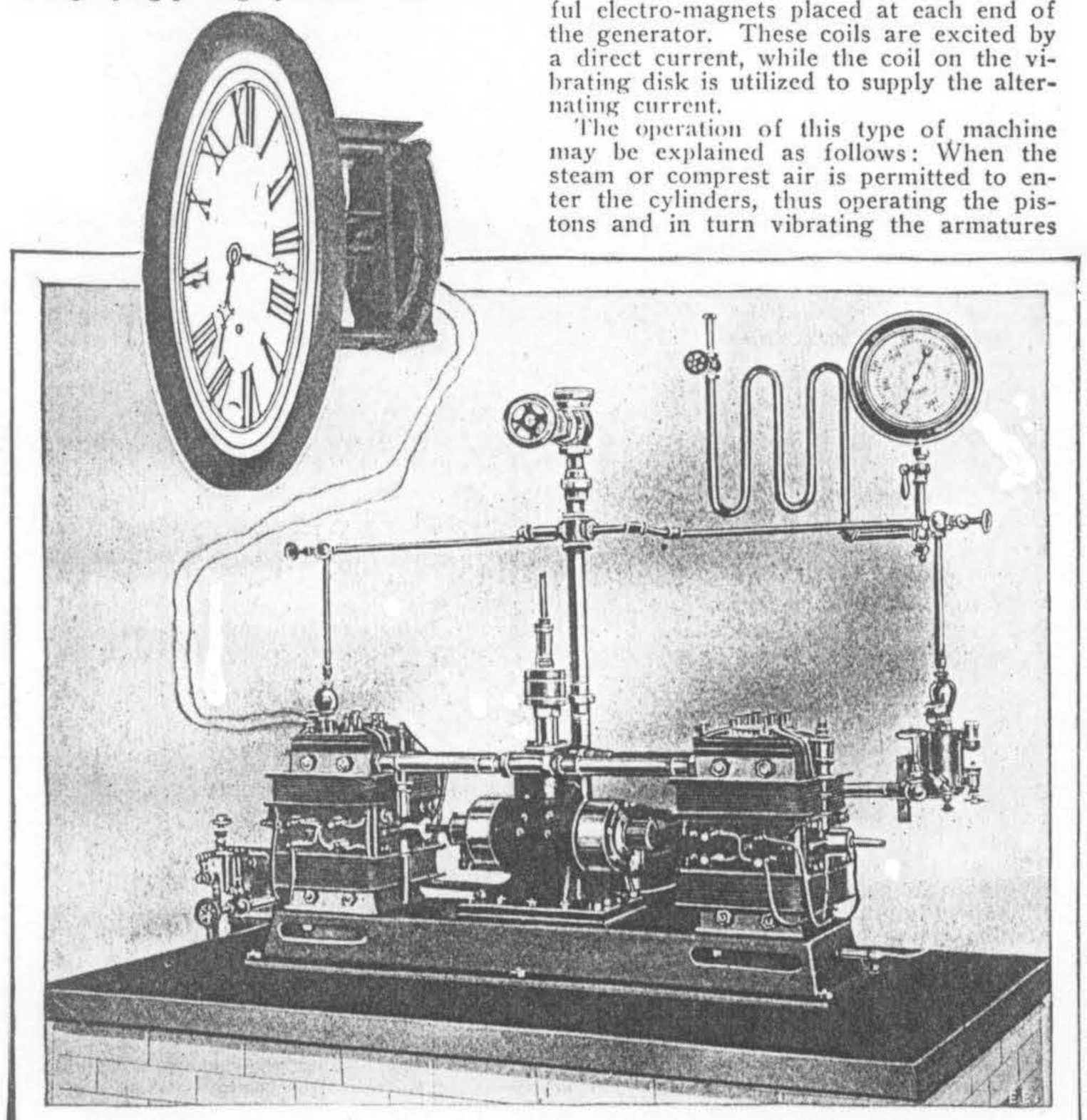
Authorities explain the action of high-frequency currents in various ways, the favorite theory being that the healing effect is due solely to the liberation of heat in the tissues. It is perfectly true that in many diseases the heat liberated in the body by the passage of from 400 to 2,500 milliamperes at a frequency of about one million cycles is an important agent in promoting an artificial inflammatory reaction and increasing circulation. The heat is, however, only one of the *secondary* forces generated by the current; there are many other factors in the vitalizing effect. The thermic theory will, for example, not explain the increased growth of plants produced by the action of high-frequency currents of very high voltage and low amperage. In medical practise often the most marked results are obtained by the use of Tesla currents of low intensity, but of exceedingly high potentiality. The author can account for these effects only on the theory that these currents, when of proper frequency, are *synchronous with the normal rate of sympathetic nerve vibration,* and in this way increase the flow of the mysterious *Pranic* force thru which function and tissue growth are maintained.

High-frequency currents are now extensively used by the medical profession to increase cell growth, metabolism and functional activity. They tend to normalize the blood pressure and are the only agents that are of real curative value in certain stages of Arterio-sclerosis (hardening of the arteries). They greatly augment the defensive powers of the organism, enabling it to resist and overcome disease-producing agencies. The prejudice against high-frequency currents on the part of many physicians may be attributed to the fact that they do not employ proper technique or that they use an apparatus which does not admit of proper variation of frequency, amperage and voltage, in order to suit the requirements of the individual case.

In the next article the author will describe the details of construction of an apparatus suitable for the generation of high-frequency currents for therapeutic use and the technique for their application.

A Novel Tesla Steam-Electric Clock

Among the various wonderful inventions of Dr. Nikola Tesla we find one of the most interesting clocks ever made, and the accompanying photographs show the necessary equipment for this highly ingenious and novel electric clock.



A Steam-Electric Clock Devised Some Years Ago by Dr. Nikola Tesla, the Electrical Wizard. It Comprises an Air or Steam Engine Which Operates Two Special Oscillating Alternators. These Are Wired Up to a Special Motor on the Clock—the Entire Combination Keeping Extremely Accurate Time, It Is Said.

The clock proper, shown above, is apparently no different from any other standard clock. However, the mechanical movement has been removed and substituted by another special movement linked up with an alternating current motor of special construction which can be seen at the extreme right of the clock. The field consists of a number of rectangular coils placed in torroidal form and connected in series. The rotor or armature is constructed of a circular iron disc, the periphery of which consists of a large number of poles. The speed of this rotor is controlled by the current input. Connections between the rotor shaft and that of the clock hands is obtained by means of a number of reduction gears properly calculated so as to obtain the correct time, when the hands are acted upon by the motor.

The source of current for driving this remarkable electric clock motor is obtained from an alternating current generator of very unique construction and design, this machine being illustrated here. It consists of two steam or comprest air cylinders, built in one frame as shown. A piston is placed in each of the cylinders which operate alternately with respect to each other. The connecting rods of each piston are linked with a vibrating membrane of each dynamo; these are seen at each end. A coil is placed on each membrane and connected to a special commutator. The electro-magnet or coil is operated in a powerful magnetic field, made up of two powerful electro-magnets placed at each end of the generator. These coils are excited by a direct current, while the coil on the vibrating disk is utilized to supply the alternating current.

The operation of this type of machine may be explained as follows: When the steam or comprest air is permitted to enter the cylinders, thus operating the pistons and in turn vibrating the armatures or coils, an electro-motive force is induced in the coil by virtue of being moved in the magnetic field surrounding it. The period or frequency of vibration of this current depends upon the rapidity of the armature movement. Both generators are linked in such a manner that an alternating current of uniform form and periodicity is obtained.

The motor on the clock is connected with this special generator and the current is so adjusted that a uniform velocity of the rotor is always obtained in order to obtain absolutely correct time from the clock.

A large number of such clocks were installed in the laboratory of Dr. Nikola Tesla a number of years ago which are driven by a single generating unit. It is said that the accuracy of time attained by this ingenious clock system is far better than with any other system known.

The New York Herald April 15, 1917

Nikola Tesla Tells of Country's War Problems

Needs in Aerial and Naval Spheres and Means for Combating Hostile Attack Described—Numerous Devices of American Invention Already Exist—Others Required.

By Nikola Tesla.

The conquest of elements, annihilation of distance in the transmission of force and numerous other revolutionary advances have brought us face to face with problems new and unforeseen. To meet these is an imperative necessity rendered especially pressing through the struggle which is now being waged between nations on a stupendous scale unprecedented in history.

This country, finding it impossible to remain longer an inactive witness of mediaeval barbarism and disregard of sacred rights, has taken up arms in a spirit broad and impartial and in the interest of humanity and peace. Its participation will be absolutely decisive as regards the final result, but those who expect a speedy termination of the conflict should undeceive themselves.

War, however complex, is essentially a mechanical process, and, in conformity with a universal principle, its duration must be proportionate to the masses set in motion. The truth of this law is borne out by previous records, from which it may be calculated that, barring conditions entirely out of the ordinary, the period should be from five to six years.

Great freedom of institutions, such as we are privileged to enjoy, is not conducive to safety. Militarism is objectionable, but a certain amount of organized discipline is indispensable to a healthy national body. Fortunately, the recognition of this fact has not come too late, for there is no immediate danger, as alarmists would make us believe. The geographical position of this country its vast resources and wealth, the energy and superior intelligence of its people, make it virtually unconquerable.

We Would Win in the End.

There is no nation to attack us that would not be ultimately defeated in the attempt. But events of the last three years have shown that a combination of many inimical powers is possible, and for such an emergency the United States is wholly unprepared. The first efforts must therefore be devoted to the perfection of the best plea for national protection. This idea has taken hold of the minds of people and great results may be expected from its creative imagination fired by this occasion, such as may in a large measure recompense for the awful wastage of war.

While the chief reliance in this perilous situation must be placed on the army and navy, it is of the greatest importance to provide a big fleet of aeroplanes and dirigibles for quick movement and observation; also a great number of small high speed craft capable of fulfilling various vital duties as carriers and instruments of defence. These, together with the wireless, will be very effective against the U-boat, of which the cunning and scientific enemy has made a formidable weapon, threatening to paralyze the commerce of the world.

As the first expedient for breaking the submarine blockade, the scheme of employing hundreds of small vessels, advanced by Mr. W. Denman, chairman of the United States Shipping Board, is a most excellent one, which cannot fail to succeed. Another measure which will considerably reduce the toll is to use every possible means for driving the lurking enemy far out into the sea, thus extending the distance at which he must operate and thereby lessening his chances. But a perfect apparatus for revealing his presence is what is most needed at this moment.

Several Devices Known.

A number of devices, magnetic, electric, electro-magnetic or mechanical, more or less known, are available for this purpose. In my own experience it was demonstrated that the small packet boat is capable of effecting a sensitive magnetic indicator at a distance of a few miles. But this effect can be nullified in several ways. With a different form of wireless instrument devised by me some years ago it was found practicable to locate a body of metallic ore below the ground, and it seems that a submarine could be similarly detected.

Sound waves may also be resorted to, but they cannot be depended upon. Another method is that of reflection, which might be rendered practicable, though it is handicapped by experimental difficulties well nigh insuperable. In the present state of the art the wireless principle is the most promising of all, and there is no doubt that it will be applied with telling effect. But we must be prepared for the advent of a large armored submarine of great cruising radius, speed and destructive power which will have to be combatted in other ways.

For the time being no effort should be spared to develop aerial machines and motor boats. The effectiveness of these can be largely increased by the use of a turbine, which has been repeatedly referred to in the HERALD and is ideally suited for such purposes on account of its extreme lightness, reversibility and other mechanical features.

Electricity and Life

The Construction of High-Frequency Apparatus for Medical and Lecture Use.

By FREDERICK FINCH STRONG, M. D.
Lecturer on Electro-therapeutics, Tufts Medical School, Boston

(Second Article)

IN the March number of THE ELECTRICAL EXPERIMENTER the author pointed out that high-frequency currents, when properly tuned, acted as "Vital Boosters," increasing all the functions of the body and helping it to resist and

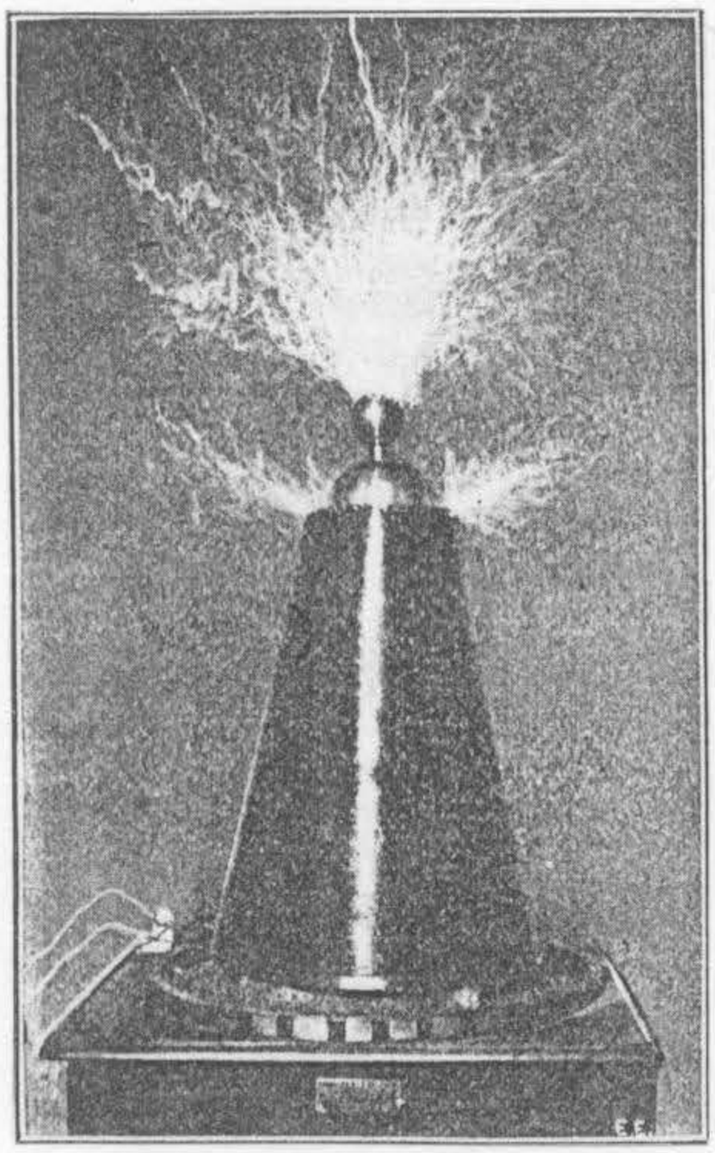


Fig. 1. View of the Strong Conical Oudin High Frequency Coil Delivering a Veritable Tree of Sparks Several Feet in Length.

throw off disease. This vitalizing effect is not due to the mere liberation of heat in the tissues, for it is produced by the very high-voltage ("Tesla") currents as well as by the heavy amperage ("D'Arsonval") currents from which the thermic effects are usually obtained.

When the writer demonstrated the first therapeutic Tesla Coil and the first Vacuum Electrode—(in 1896 before a Boston Medical Society)—and suggested that this method was destined to come into general use as a vitalizing agent, he was laughed at by his colleagues; yet to-day there is scarcely a well equipt physician's office in this country or in Europe that does not contain some form of therapeutic high-frequency apparatus. Even the barber-shops of the present time have their small "Violet Ray" outfits; and these are not by any means "fakes" for they produce real results, such as the relief of headache, neuralgia, skin diseases, et cetera.

Unlike other forms of electricity, these currents may be administered to patients with perfect safety. In twenty years' experience in electro-therapeutics the author has never known of harmful results from the use of Tesla Currents applied thru a vacuum electrode. The heavy amperage ("D'Arsonval") currents, owing to their deep thermic effects, should be used only under the direction of a physician. The writer is a firm believer in the use of Tesla currents in the home—if each member of the family could receive ten-minute daily treatments from a small high-frequency apparatus, the general standard of health would be greatly increased. This has been demonstrated in hundreds of cases.

The author has interviewed a number of the more prominent authorities on medical electricity and they agree as to the vitalizing effects resulting from daily high frequency treatment.

Anyone who possesses a ¼ or ½ K.W. wireless transformer, operating on 110 volt, 60 cycle A.C., can easily construct an efficient high-frequency outfit for medical or lecture use. The complete equipment includes a .01 microfarad glass plate condenser, Tesla coil, inductance, spark gap and electrodes.

The Tesla coil is made as follows: (Fig. 3) On a paper mailing tube 2½" diam. and 14" long wind 480 turns of No. 34 D.C.C. copper magnet wire. Set up the tube in the lathe, apply a coat of orange shellac, spin on the wire, apply a second coat of shellac and allow to dry thoroly. The winding occupies twelve inches, leaving a margin of one inch on each end of the tube. Leads of light auto (ignition) cable are soldered to the ends of the winding. A strip of waxed, corrugated paper M, 5" wide is wrapt around the center of the secondary tube and on this is wound the primary, consisting of four turns of heavy high tension auto cable, and thoroly secured by tape; at least a foot of cable should project from each end of the winding to form the primary leads. Place the coil in a wax tight box made without nails and embed it in a mixture of four parts rosin and one part beeswax. It is safer to boil the coil for an hour in the insulating mixture before placing it in the box. Coils made in this way by the writer are still giving good service after fifteen years of use.

The greatest source of trouble in a medical high-frequency outfit is the spark gap; the one described below is the outcome of many years experiment. If properly

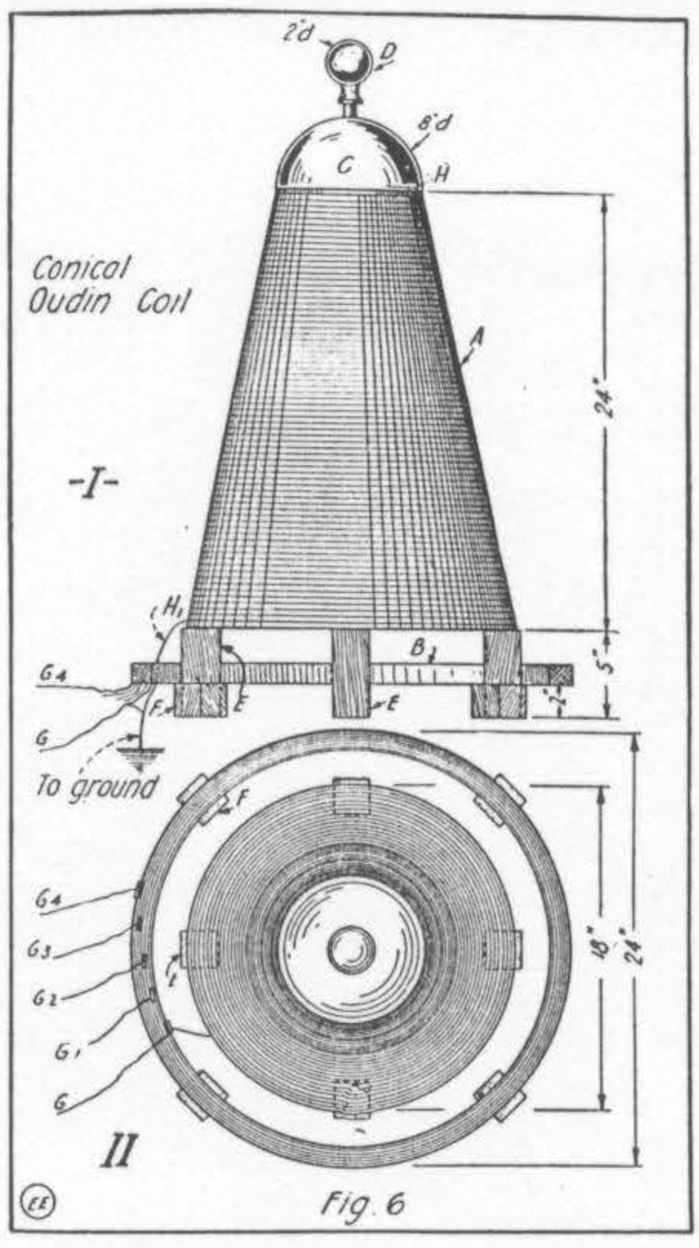


Fig. 6

Details Are Given In This Article for Constructing a Reliable and Powerful Oudin or Tesla High Frequency Coil, Suitable for Physicians' Use. This Type of Coil is the Most Efficient Ever Designed.

made it will run daily for months without deterioration. The spark takes place between two pieces of brass rod 1¼" diam. and 3¾" long, turned and tapt as shown. The sparking surfaces are turned in annular grooves with a 60 degree tool. If

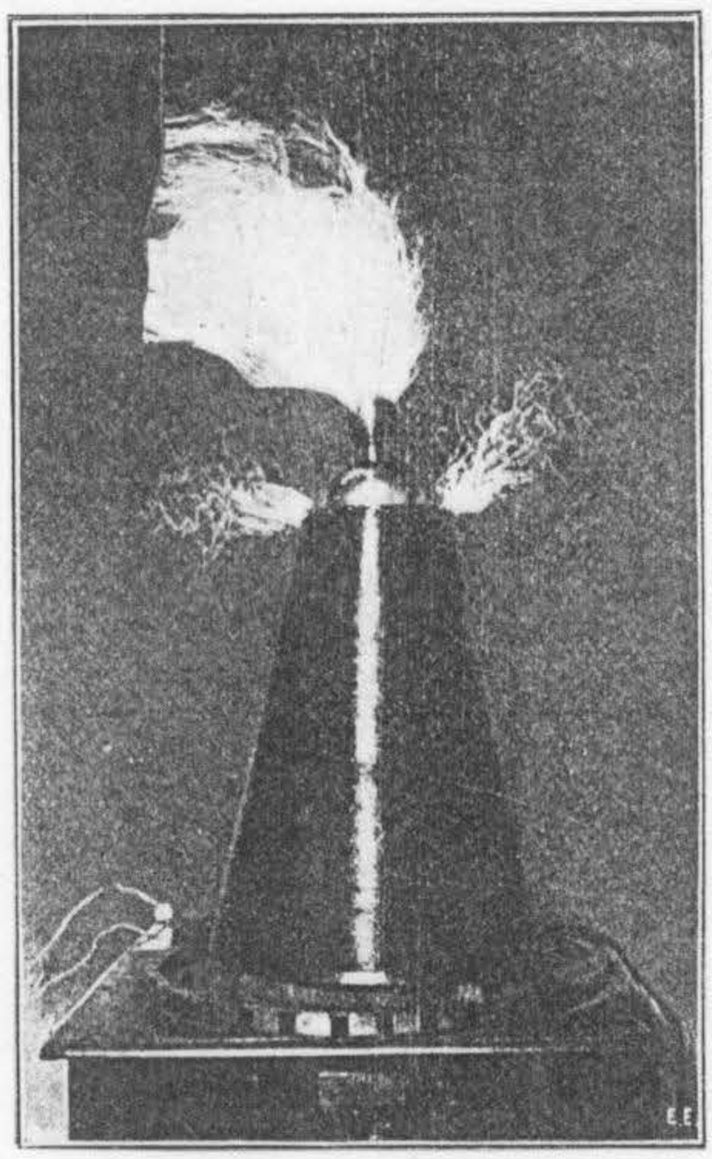


Fig. 2. Another View of the Strong High Frequency Coil Producing a Perfect Sheet of Flaming Sparks to a Grounded Conductor. The Exciting Energy Is but 1 Kilowatt.

your lathe has an automatic cross-feed you may set it to twenty turns to the inch, and turn a spiral groove instead of the annular rings. After finishing, the brass pieces are *heavily silver plated* and mounted in the usual manner as shown. (Fig. 4.) For currents over ¼ K.W., a plate of silver should be soldered to the brass before turning the grooves. This gap will also give greater efficiency in wireless work as compared with the usual stationary gap.

The connections for the various parts of the apparatus are shown in Fig. 5. An important feature is the use of an external inductance or tuning coil "d" in series with the Tesla coil. It consists of 32 turns of No. 8 bare copper wire, wound on a frame 8" diam., with ¼" between turns. Edgewise wound flat copper strip is better but more expensive. (d Fig. 8.) This coil when used in series with the Tesla primary enables us to tune the oscillating system in perfect resonance when the capacity of the patient's body is added to the Tesla terminal. Effects are produced which are impossible with any other method. The beautiful *High-frequency Effluve* or brush-discharge, so valuable in treating pulmonary diseases, and which so few modern high-frequency machines can produce, is obtainable by the use of this series inductance. It may also be used, by short-circuiting the Tesla primary, as an auto-transformer from which may be derived heavy "D'Arsonval" and "Diathermic" currents as described in the next article of this series.

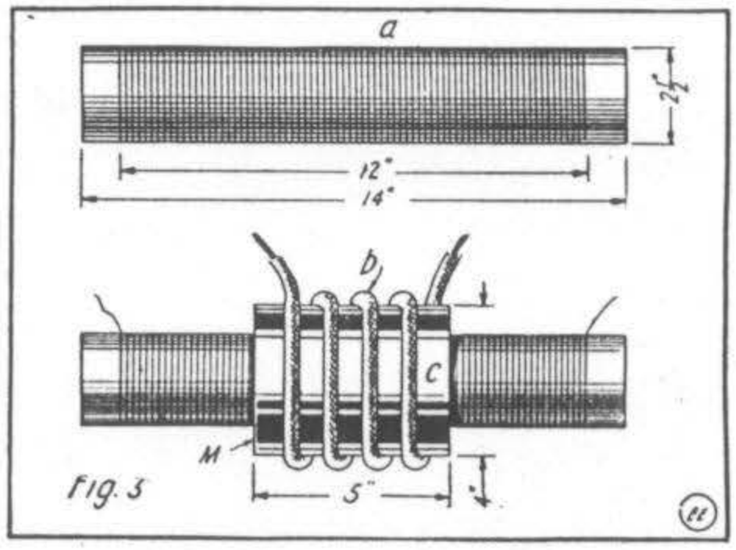
For stage demonstration and public lecture work the writer employs a large high-frequency resonator which produces a tree-

(*Continued on page 59*)

ELECTRICITY AND LIFE.

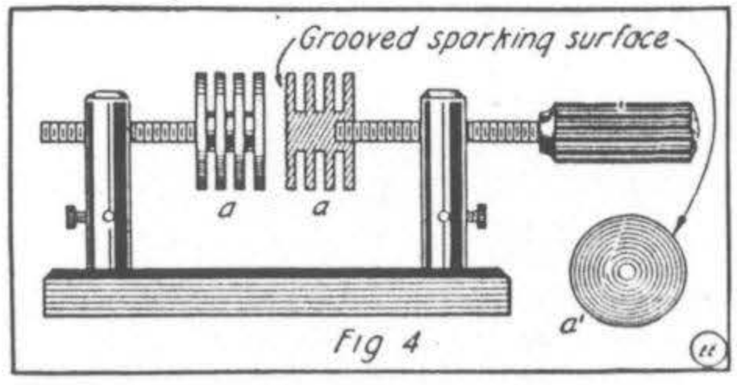
(*Continued from page 24*)

like discharge three feet in diameter (Fig. 1), and gives a heavy arc over two feet in



How Small Size Tesla Coil for Medical Treatment Is Built; "b" Is the Primary, "a" the Secondary.

length. (Fig. 2.) This shows remarkable efficiency when it is considered that the resonator is excited by a "Type E" transformer drawing only 1 K.W. and a con-

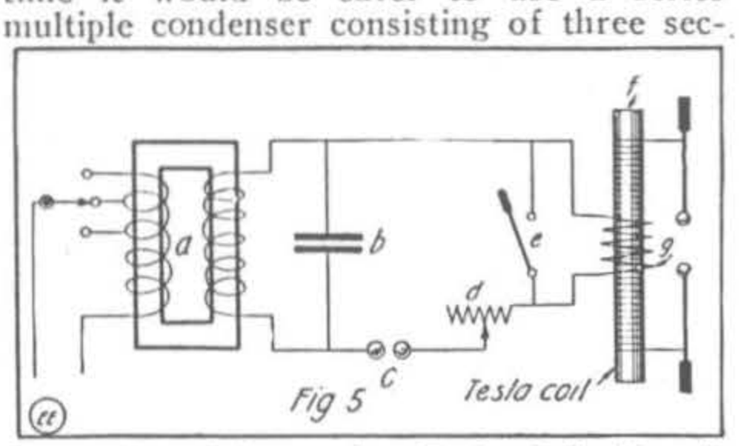


Unique Stationary Spark Gap Having Grooved Faces, as Devised by Dr. Strong.

denser of but .01 m.f. capacity. A small rotary spark gap is used such as is supplied by the E. I. Co. This result is made possible by the use of the separate inductance in series with the resonator primary (exactly the same as that described in connection with the therapeutic apparatus) (d Fig. 8). The writer believes his resonator gives the most spectacular discharge ever obtained from 1 kilowatt of energy.

Ordinary plate condensers are used, made from 8 x 10 inch negative glass, coated on both sides with tin-foil 6 x 8 inches (a Fig. 7). Six pairs of plates assembled into a

unit and boiled in wax give a capacity of .01 m.f. For safety it is better to employ four of these sections connected in pairs of .02 m.f. each (b Fig. 7). To run this resonator at full power for long periods of time it would be safer to use a series multiple condenser consisting of three sec-

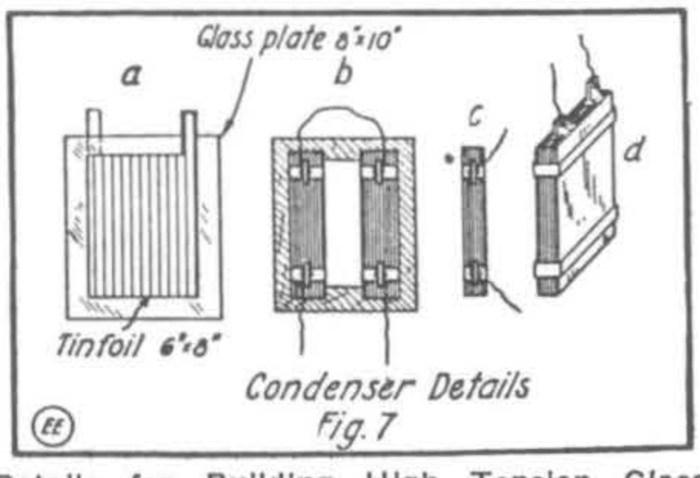


Connection Scheme for Tesla Coil "f—g," Shorting Switch "e," Tuning Inductance "d," Spark Gap "c," Condenser "b" and Step-up Exciting Transformer "a."

tions of .03 m.f. each in series. Such a condenser would contain 108—8 x 10 inch plates, and would be expensive, bulky and very heavy. For this reason the writer has found it much more convenient to use a single 12 plat (.01 m.f.) condenser across the transformer secondary and to replace it when it punctures. The large resonator was operated for six months in lecture and experimental work before a condenser section broke down.

The cone for the secondary of the large resonator is of hea paperboard and was built for the author by Bicknell and Fuller of Boston. Its dimensions (see Fig. 6) were suggested by Mr. Earle L. Ovington, the cone being similar in shape to those used by Mr. Ovington in the New York Electrical show several years ago. Any amateur can make a cone of this kind by superimposing strips of heavy paper, soaked in paste, over a wooden framework. The secondary winding consists of 400 turns of No. 27 D.C.C. copper magnet wire. Two parallel strands of wire are wound onto the cone, the adjacent turns in contact; after winding, one strand of wire is removed, leaving a space equal to the diameter of the wire between each of the 400 turns. The cone and winding is then treated with several coats of *"Armalac"* (ordinary shellac will not answer).

The primary consists of five turns of thin copper ribbon 1 inch wide, ⅛ inch paperboard strips being placed between the turns. The diameter of the coil is 24". When completed it is taped and rotated in a pan of melted wax until thoroly impregnated. The terminal shown in the photographs is made from a large brass oil-can, the stem being removed and replaced by a 3" brass "bed-ball." The terminal is not attached to the cone but simply rests on its upper surface in contact with the end of the secondary wire. The primary and secondary are separately supported by

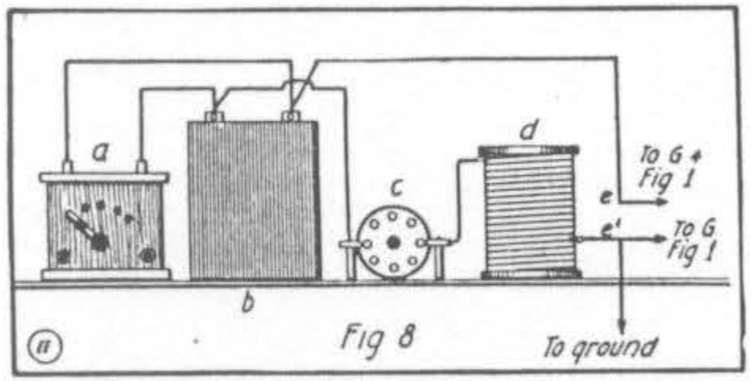


Details for Building High Tension Glass Plate Condenser to Be Connected in Tesla Coil Circuit.

quare wooden blocks; the coupling is rather loose, the bottom of the resonator being at least two inches above the primary. The lower end of the secondary coil is attached to the inner primary terminal and grounded.

Perfect resonance is obtained by varying the number of turns in the inductance coil in series with the primary. (Fig. 8.) This tuning system enables us to perform many brilliant experiments *otherwise impossible*, such as illuminating wires stretched across a lecture hall, lighting an inverted umbrella, etc. Some new and very spectacular experiments with this large resonator will be described and illustrated in an article in next month's "ELECTRICAL EXPERIMENTER," entitled "Methods of employing high-frequency currents in medical and lecture work."

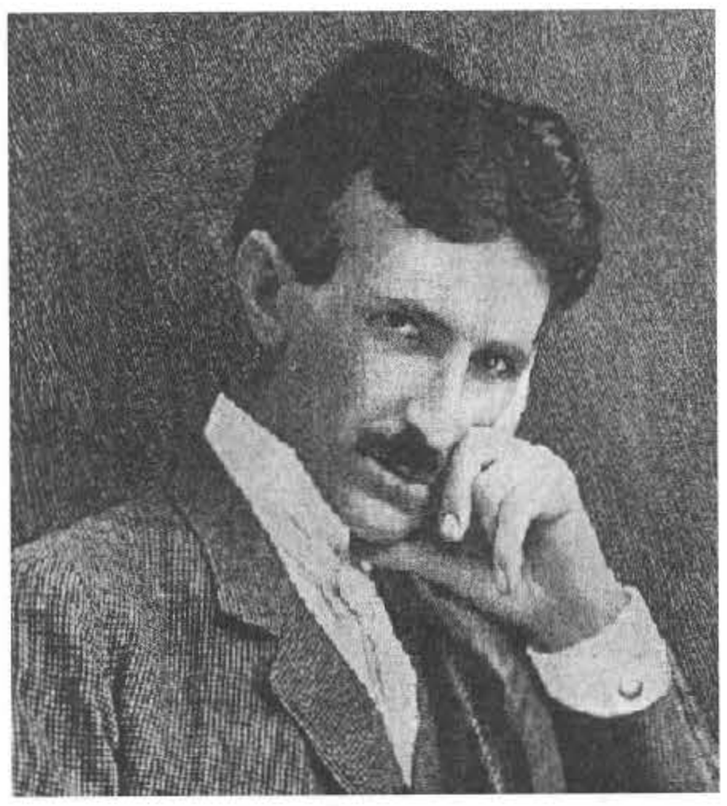
The author is greatly indebted to Mr. O. K. Luscolm, for advice and assistance which made possible the successful construction of the large resonator.



Method of Connecting Transformer, H. T. Condenser, Rotary Spark Gap and Tuning Inductance "d" to Large Oudin Coil.

Personal and Biographical

NIKOLA TESLA, who was awarded the seventh Edison medal on December 13, 1916, "for meritorious achievements in his early original work in polyphase and high-frequency electric currents," will receive the medal at a presentation to be made at the annual meeting of the American Institute of Electrical Engineers in the Engineering Societies Building, 29 West Thirty-ninth Street, New York City, on May 18 at 8:30 p. m. President H. W. Buck will preside, and addresses will be made by Dr. A. E. Kennelly, chairman of the Edison Medal Committee; Charles A. Terry, of New York, and B. A. Behrend, of Boston. The Edison Medal was established upon the initiative of a group of friends



Nickola Tesla.

and associates of Thomas A. Edison, for the purpose of recounting and celebrating the achievements of a quarter of a century in the art of electric lighting, with which the name of Edison is imperishably identified. It was decided that the most effective means of accomplishing this object would be by the establishment of a gold medal, which should, during the centuries to come, serve as an honorable incentive to scientists, engineers and artisans to maintain by their works a high standard of accomplishment. The Edison Medal was, therefore, established and endowed with a trust fund, under an indenture dated February 11, 1904, whereby the American Institute of Electrical Engineers agreed to award the medal annually. It is awarded each year by a committee consisting of 24 members of the Institute to a resident of the United States of America and its dependencies, or of the Dominion of Canada, "for meritorious achievement in electrical science or electrical engineering or the electrical arts."

C. H. HOLDEN, formerly sales manager of the P. R. Manufacturing Company, Detroit, Mich., has been appointed central district manager for Edwards & Company, manufacturers of electric bells and other specialties, New York City, and has established a sales office at 9 South Clinton Street, Chicago.

NEWS OF THE INDUSTRY

Chronicle of Important Events and General Activities in the Technical, Commercial and Manufacturing Fields

NIKOLA TESLA IS AWARDED THE EDISON MEDAL BY A. I. E. E.

"Meritorious Achievements in His Early Original Work in Polyphase and High-Frequency Currents" to Be Honored on May 18

The seventh Edison medal, which was awarded to Nikola Tesla on Dec. 13, 1916, "for meritorious achievements in his early original work in polyphase and high-frequency electric currents," will be presented to Mr. Tesla at the annual meeting of the American Institute of Electrical Engineers in the auditorium of the Engineering Societies Building, 29 West Thirty-ninth Street, New York, on Friday evening, May 18, 1917, at 8.30 p. m. Ladies are invited to attend this meeting.

President H. W. Buck will preside, and addresses will be made by Dr. A. E. Kennelly, chairman of the Edison medal committee; Charles A. Terry, New York, and B. A. Behrend, Boston.

HISTORY OF THE EDISON MEDAL

The Edison medal was established upon the initiative of a group of friends and associates of Thomas A. Edison for the purpose of recounting and celebrating the achievements of a quarter of a century in the art of electric lighting, with which the name of Edison is imperishably identified. It was decided that the most effective means of accomplishing this object would be by the establishment of a gold medal which during the centuries to come should serve as an honorable incentive to scientists, engineers and artisans to maintain by their works a high standard of accomplishment.

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Nikola Tesla

THE award of the Edison medal to Nikola Tesla is most appropriate, in view of the early contribution that he made to alternating-current motors. In order to recognize that contribution, one must go back to the period, thirty years ago, when alternating-current engineering was greatly handicapped by the absence of motors capable of being installed on alternating-current circuits. Direct-current motors were well advanced, and there were many of them, particularly in America; but, except for synchronous single-phase motors and a few small series motors, the alternating-current motor was unknown. The synchronous motor was impracticable, because it had to be started and brought up to speed. Alternating current was used only for lighting. In the rivalry which then existed between the direct-current and alternating-current systems the former could claim to deliver both light and power, while the latter could deliver only light, although, with the aid of the transformer, it could do so at a relatively great economical distance.

It was at this point that Tesla invented the polyphase alternating-current system and polyphase motors, which, whether of the synchronous or of the asynchronous type, had the advantage of a definite starting torque. It is generally understood that he was not the only inventor of the polyphase motor. The same idea seems to have occurred to one or two other independent inventors in Europe. But not only was Tesla the sole American independent inventor of the polyphase motor, but he was also the only inventor of it in the whole world who had faith in it. He believed in it enthusiastically and urged its claims both publicly and privately. He built the first small polyphase motor, which behaved very satisfactorily, and he urged the building of larger ones. Much experimenting, designing and discarding had to be done before large polyphase motors could be built successfully, and the progress was slow; but Tesla's faith was unshakable and his claims were prophetic. A less enthusiastic nature might have quailed before the discouragements and have allowed success to escape.

The polyphase motor was not Tesla's only pioneer contribution to electrical progress. He was a tireless experimenter, and his experiments carried him very early into the field of high-frequency phenomena. He worked first with high-frequency alternators, or alternators

which, in 1890, were considered to give a high frequency. Later he developed the well-known Tesla induction coil, or high-frequency oscillator. With this new source he was able to demonstrate, during 1891 and 1892, in England, France and America, a number of entirely new electrical phenomena which at lower frequencies had previously been unobtainable. His lectures were given at the Royal Institution in London, the Franklin Institute in Philadelphia, and in various other places. The experimental phenomena he produced were dazzling and classical. They deservedly brought him great renown.

The high-frequency phenomena which Tesla first developed and displayed had scientific rather than practical interest; but Tesla called attention to the fact that by taking his electric oscillator, grounding one side of it and connecting the other to an insulated body of large surface, it should be possible to transmit electric oscillations to a great distance, and to communicate intelligence in this way to other oscillators in sympathetic resonance therewith. This was going far toward the invention of radio-telegraphy as we know it to-day.

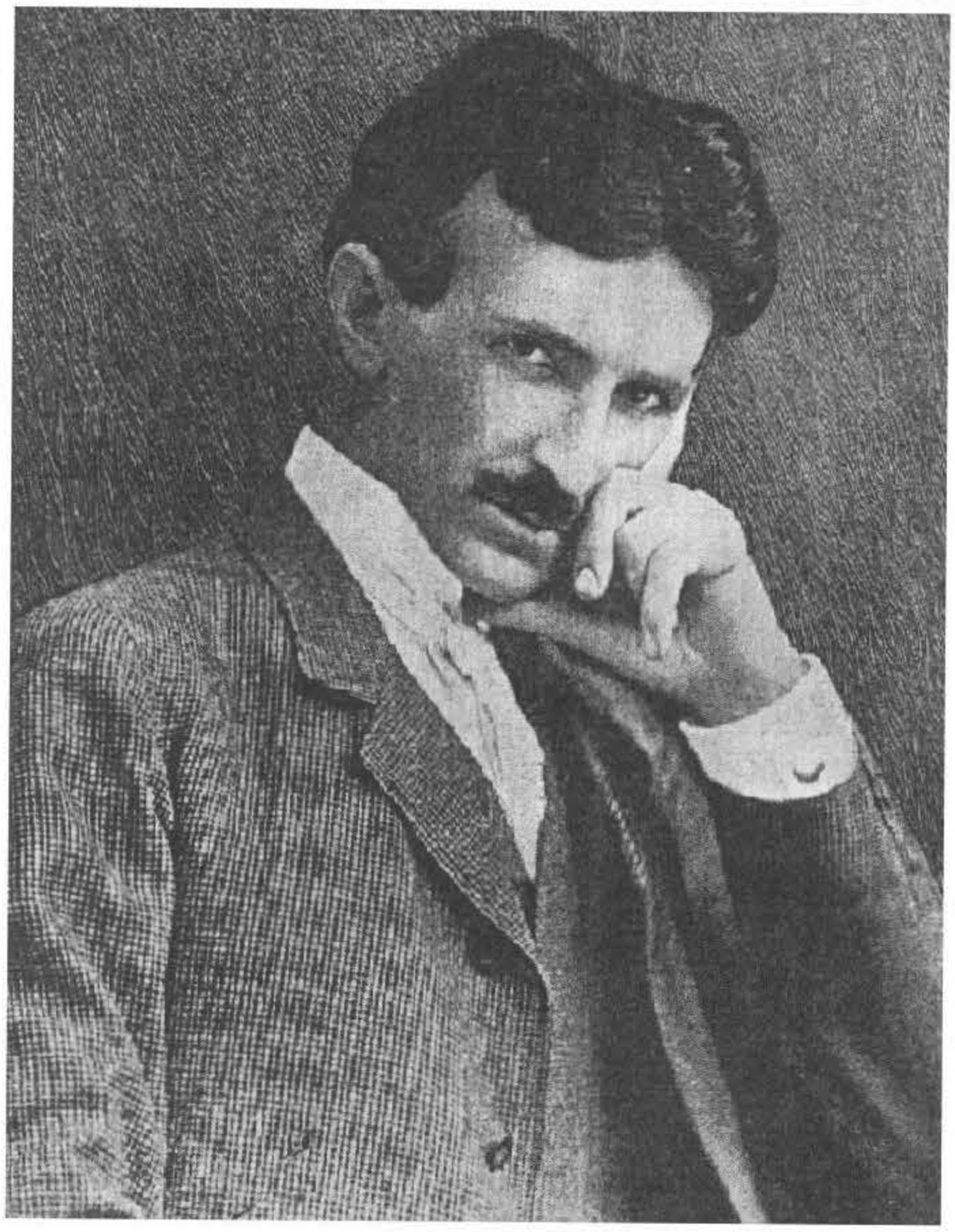
For the above reasons we welcome and acclaim the award to Nikola Tesla which the American Institute of Electrical Engineers has made of its Edison medal. We of this generation are prone to forget the great efforts and the unwearying patience which have been necessary in the past to produce those results which are now the every-day electrical commonplaces of life, and it is well to signalize them, lest the next generation in its turn should forget the results of the pains and labor of this.

NIKOLA TESLA BECOMES THE RECIPIENT OF EDISON MEDAL

Presentation of Award for Early Original Work and Tributes to the Inventor—New A. I. E. E. Officers

Presentation of the Edison medal to Nikola Tesla and formal report upon the newly elected officers were the announced features of the annual meeting of the American Institute of Electrical Engineers in New York on the evening of May 18.

As stated previously in the ELECTRICAL WORLD, the Edison medal is presented to Mr. Tesla for "early original work in polyphase and high-frequency electric currents." Dr. A. E. Kennelly as chairman of the Edison medal committee outlined the origin and purpose of this honor and gave a brief history of past awards.



Nikola Tesla

Charles A. Terry, whose subject was a presentation of historical facts regarding the Tesla patents, contributions to the arts, etc., said in part:

MR. TERRY'S TRIBUTE TO TESLA

"It is the God-given desire to accomplish and to give that has produced the Michael Angelos, Galileos, the Sir Christopher Wrens, the Livingstones, Newtons, Franklins, Westinghouses, Edisons and scores of other makers of history—men whose names we retain in affectionate remembrance because they earnestly responded to the call from within and by patient toil conceived thoughts and discovered things of value which they promulgated for the benefit of their fellow men. Twenty-nine years ago this month there was presented before this Institute a paper of unusual import. It is entitled 'A New System of Alternate-Current Motors and Transformers.' The author, Nikola Tesla, was then only thirty-one years of age and had been for only four years a resident of this country. His early life was spent near his birthplace not far from the eastern Adriatic coast. His father, a Greek clergyman, and his mother, herself of an inventive mind, secured for their young son a comprehensive training in mathematics, physics and philosophy. At the age of twenty-two he had completed his studies in engineering at the Polytechnic School in Grätz and also a course in the University of Prague, and in 1881 he began his practical work at Budapest. In 1883 he was at Strasbourg, engaged in completing the lighting of a newly erected railway station. Shortly after finishing this undertaking he came to the United States.

"Throughout all these years his desire had been to find an opportunity to demonstrate the truth of a conviction which became fixed in his mind while studying direct-current motors in school at Grätz in 1878. The conviction was that it should be possible to create a rotating magnetic field without the use of commutators. While at Strasbourg Tesla had succeeded in producing the rotation of a pivoted iron disk placed in a coil traversed by alternating currents, a steel bar being projected into the coil in the neighborhood of the disk. His conception of the reason for this rotation at that time was that a lag occurred in the subsidence of the magnetism of both the disk and the steel bar between successive current waves, and that the mutual repulsions caused the disk to revolve. By some fortunate process of reasoning he conceived while in Budapest in 1882 that by using two or more out-of-phase alternating currents respectively passing through geometrically displaced coils it would be possible to develop his long-sought progressively shifting magnetic field.

"Lack of funds and facilities for working out his theory compelled still further postponement, but in 1885 Tesla had the good fortune to interest men of means in a direct-current arc light which he had devised, and subsequently a laboratory was equipped for him in Liberty Street, New York, and here at last he found opportunity to demonstrate the correctness of his long-cherished theory. In 1887 he was able to exhibit to his business associates and to Prof. William A. Anthony, whose expert opinion they sought, motors having such progressively shifting fields without the use of commutators as he had foreseen nine years before.

"Having thus demonstrated the correctness of his theory and the feasibility of its application, it remained for Tesla to work out various practical methods of applying the principle, and the rapidity and wonderful way in which he surrounded the entire field of constant-speed, synchronous, induction and split-phase motors is beautifully set forth in his paper of May 18 and in the numerous patents issued May 1, 1888, and succeeding years, covering the forms of electric motors, which have since become the almost universal means for transforming the energy of alternating currents into mechanical energy.

"It is somewhat difficult to eliminate from our minds the developments of the last thirty years which have now become every-day features of the electrical industry and to realize the meagerness of the then existing knowledge of alternating-current phenomena. The com-

mercial use of alternating-current systems of distribution was then scarcely two years old. The Gaulard & Gibbs system of series transformers had been used abroad in a limited way for a slightly longer period, but the multiple-arc system based upon the so-called 'Stanley rule,' which initiated the great development of the present system, was not put in practical operation in the pioneer Great Barrington plant until March, 1886. It was then recognized that while the alternating current possessed wonderful possibilities for electrical distribution for lighting purposes, two almost necessary devices were lacking to render it a complete success, one a meter, the other a power motor. Prof. Elihu Thomson promptly devised a successful form of meter, the motive portion of which comprised a laminated field and armature, the coils of the latter being periodically close-circuited during revolution by a commutator. To fill the demand for a power motor, however, the most promising device then suggested was a series commutator motor with laminated field and armature cores, but no satisfactory results had been obtained. Such was the situation when Tesla's achievement was announced in the Institute paper to which reference has been made.

"Among the first to recognize the immense impor-



tance of Mr. Tesla's motors were Mr. Westinghouse and his advisers, T. B. Kerr, Mr. Byllesby, Mr. Shallenberger and Mr. Schmid, and Mr. Westinghouse secured an option which shortly resulted in the purchase of the patents, thus bringing under one ownership the alternating-current transformer system of distribution and the Tesla motor. It is interesting to note here that Mr. Shallenberger had about two weeks before the publication of the Tesla patents independently devised an alternating-current meter the principle of operation of which was that of the Tesla motor, and whatever might have been Mr. Shallenberger's natural disappointment upon finding himself thus anticipated, he at once recognized that to Mr. Tesla belonged the honor of being the first to solve the great fundamental problem of an alternating-current motor. A warm friendship between these two men began at once and continued through Mr. Shallenberger's life, and Mr. Tesla rejoiced to accord to Mr. Shallenberger full credit for the latter's brilliant work in producing what is now the standard meter for alternating currents.

"Owing in a measure to the circumstance that the then prevailing rate of alteration of the alternating-current system was 16,000, the commercial introduction of Tesla motors was somewhat retarded during the first few years, that rate being found less adapted to the motor work than a lower rate. To-day, however, wherever alternating-current systems are used Tesla motors abound. Without such motors the alternating-current system would have remained seriously restricted in its use.

"It will be appropriate to refer to the opinion of Judge Townsend of the United States Circuit Court, rendered in August, 1900, from which I quote the following: 'The Tesla discovery for which these patents were granted revolutionized the art of electrical power transmission, as well demonstrated in the record from both judicial and scientific standpoints.' "

Mr. Terry went on to enumerate Tesla's experimental work in connection with wireless transmission of power and the control of the movements of torpedoes and boats, as well as his contributions in the field of the Roentgen ray, his various electrical inventions, and the bladeless steam turbine for which commercial success is hoped.

B. A. Behrend, in a tribute to Tesla, said:

TRIBUTE OF B. A. BEHREND

"By an extraordinary coincidence, it is exactly twenty-nine years ago, to the very day and hour, that there stood before this Institute Nikola Tesla, and he read a description of his great discovery of the generation and utilization of polyphase alternating currents. He left nothing to be done for those who followed him. His paper contained the skeleton even of the mathematical theory.

"Three years later, in 1891, there was given the first great demonstration, by Swiss engineers, of the transmission of power at 30,000 volts from Lauffen to Frankfort by means of Mr. Tesla's system. A few years later this was followed by the development of the Cataract Construction Company, under the presidency of our member, Edward D. Adams, and with the aid of the engineers of the Westinghouse company. It is interesting to recall here to-night that in Lord Kelvin's report to Mr. Adams, Lord Kelvin recommended the use of direct current for the development of power at Niagara Falls and for its transmission to Buffalo.

"The basis for the theory of the operating characteristics of Mr. Tesla's rotating-field induction motor, so necessary to its practical development, was laid by the brilliant French savant Prof. André Blondel, and by Professor Kapp of Birmingham. It fell to my lot to complete their work and to co-ordinate—by means of the simple 'circle diagram'—the somewhat mysterious and complex experimental phenomena. As this was done twenty-one years ago, it is particularly pleasing to me, upon the coming of age of this now universally accepted theory—tried out by application to several million horsepower of machines operating in our great industries—to pay my tribute to the inventor of the motor and the system which have made possible the electric transmission of energy. His name marks an epoch in the advance of electrical science. From that work has sprung a revolution in the electrical art."

President H. W. Buck was scheduled to present the medal to Tesla.

ELECTION OF OFFICERS

The newly elected officers, who were the directors' nominees, are: President, E. W. Rice, Jr., Schenectady, N. Y.; vice-presidents, Frederick Bedell, Ithaca, N. Y.; John H. Finney, Washington, D. C., and A. S. McAllister, New York; managers, Walter A. Hall, West Lynn, Mass.; E. H. Martindale, Cleveland, Ohio; William A. Del Mar, New York, and Wilfred Sykes, Pittsburgh, Pa.; treasurer, George A. Hamilton, Elizabeth, N. J.

The New York Times May 19, 1917

Edison Medal Goes to Nikola Tesla

Nikola Tesla, inventor, was last night adjudged by the American Institute of Electrical Engineers to have contributed the greatest progress to electrical science and electrical engineering during the year 1916. The Edison medal which is awarded each year to the person deemed foremost in this field was presented to him at the annual meeting of the institute, in the Engineering Societies Building, No. 33 West Thirty-ninth street.

The medal is a gold plaque, with the bust of Mr. Edison raised upon one surface. It was presented by H. W. Buck, president of the institute.

The annual report of the Board of Directors was presented, showing a total membership of 8,710. Total revenue during the year was $117,843.68, and total expenses $105,069.21.

Nikola Tesla Receives Edison Medal

Notable Program at Annual Meeting of American Institute of Electrical Engineers—Interesting Insight into Mr. Tesla's Life and Work as Disclosed in His Address of Acceptance

Nikola Tesla, inventor and scientist, was presented the seventh annual Edison Medal at the annual meeting of the American Institute of Electrical Engineers held at New York City on May 18. Announcement of this award was made in our issue of May 5. This notable event, with the memorable addresses made by A. E. E. Kennelly, Charles A. Terry, B. A. Behrend, and particularly by Mr. Tesla himself, formed the principal item of the evening's program, which also included the annual report of the Board of Directors and announcement of letter ballot on the annual election of officers, which are reported elsewhere in this issue. After these business matter, had been disposed of, President Buck called on A. E. Kennelly, chairman of the Edison Medal Committee.

Dr. Kennelly gave an account of how the Edison Medal originated in a group of Mr. Edison's friends setting apart a fund in 1904 for the annual award to a living electrician of a medal for "meritorious achievement in electrical science and art." A deed of gift was drawn up designating the American Institute of Electrical Engineers to appoint from its officers and members a committee of 24 to determine the awards. Six noted electrical men have been recipients of the Edison Medal, as follows: Elihu Thomson, Frank J. Sprague, George Westinghouse, William Stanley, Charles F. Brush and Alexander Graham Bell. Dr. Kennelly stated that the medal award to Mr. Tesla was particularly for his development of the rotating magnetic field which is the fundamental principle that made possible the use of alternating current for operating motors, and also for his investigations of the phenomena of high-frequency currents.



Nikola Tesla.

Mr. Terry's Address.

Charles A. Terry, who was associated with Mr. Tesla in some of his research work, then made an eloquent address on Mr. Tesla's electrical achievements. After dwelling on the unselfish creative impulse of the inventor, Mr. Terry said: "Twenty-nine years ago this month there was presented before this Institute a paper of unusual import. It was entitled 'A New System of Alternate-Current Motors and Transformers.' The author, Nikola Tesla, was then only 31 years of age, and but four years a resident of this country. His early life was spent near his birthplace not far from the Eastern Adriatic Coast. His father, a Greek clergyman, and his mother, herself of an inventive mind, secured for their young son a comprehensive training in mathematics, physics and philosophy. At the age of 22 he had completed his studies in engineering at the Polytechnic School in Gratz and also a course in the University of Prague; and in 1881 began his practical work at Budapest. In 1883 he was located at Strasburg, engaged in completing the lighting of a newly erected railway station. Shortly after finishing this task he came to the United States. Mr. Tesla's first work in this country was upon new designs of direct-current arc and incandescent lighting systems for the Edison Company.

"Throughout all these years his desire had been to find an opportunity to demonstrate the truth of a conviction which became fixed in his mind while studying direct-current motors in school at Gratz in 1878; the conviction was that it should be possible to create a rotating magnetic field without the use of commutators. * * *

"By some fortunate process of reasoning he conceived, while in Budapest in 1882, that by using two or more out-of-phase alternating currents respectively passing through geometrically displaced coils it would be possible to develop his long sought progressively shifting magnetic field.

"Lack of funds and facilities for working out his theory compelled still further postponement, but in 1885 Tesla had the good fortune to interest men of means in a direct-current arc light which he had devised, and subsequently a laboratory was equipped for him in Liberty Street, New York, and here at last he found opportunity to demonstrate the correctness of his long cherished theory. In 1887 he was able to exhibit to his business associates and to Prof. William A. Anthony, whose expert opinion they sought, motors having such proggressively shifting fields without the use of commutators, as he had foreseen nine years before.

"Having thus demonstrated the correctness of his theory and the feasibility of its application, it remained for Tesla to work out various practical methods of applying the principle, and the rapidity and wonderful way in which he surrounded the entire field of constant-speed synchronous, induction and split-phase motors is beautifully set forth in his paper of May 18, 1888, and in the numerous patents issued May 1, 1888, and succeeding years, covering the forms of electric motors which have since become the almost universal means for transforming the energy of alternating currents into mechanical energy. * * *

"Among the first to recognize the immense importance of Mr. Tesla's motors were Mr. Westinghouse and his advisors, Mr. Kerr, Mr. Byllesby, Mr. Shallenberger and Mr. Schmid, and in June Mr. Westinghouse secured an option which shortly resulted in the purchase of the patents, thus bringing under one ownership the alternating-current transformer system of distribution, and the Tesla motor. * * *

"The impress made upon the world by the deeds of a great inventor can not be measured by the number of patents which he has received nor by the monetary reward secured nor by the mere exploitation of his name. Often his greatest gifts are in the form of inspiring contributions to the literature, filled with suggestions of lines of thought which lead others to work in untried fields. This is especially true of a series of lectures delivered by Mr. Tesla upon the subject of high-frequency, high-potential currents. The first of the series was given at Columbia College in 1891, before this Institute. During 1892 and 1893 this lecture with additional data and experiments was repeated in London, Paris, Philadelphia and St. Louis. * * * During these lectures he exhibited to the audience numerous experiments displaying striking and instructive phenomena. He also described many novel pieces of apparatus, such, for instance, as his high-frequency generator and induction coils and his magnetically quenched arc. * * *"

Mr. Terry quoted from many noted contemporaries of Mr. Tesla at that time their appreciation of the pioneer nature and

importance of his investigations in high-frequency phenomena and wireless transmission. As early as February, 1892, he had predicted these developments and "in his lecture before the National Electric Light Association at St. Louis in March, 1893, Mr. Tesla elaborated certain views regarding the importance of resonance effects in this field. * * * He then announced that his conviction had grown so strong that he no longer looked upon the plan of transmitting intelligence as a mere theoretical possibility, and referring to the existing belief of some that telephony to any distance might be accomplished 'by induction through the air,' concisely set forth his theory as follows: 'I cannot stretch my imagination so far, but I do firmly believe that it is practical to disturb by means of powerful machines the electrostatic condition of the earth and thus transmit intelligible signals and perhaps power.' * * *

"Throughout Tesla's work with high-potential currents he had persistently in mind the wireless transmission of power in large quantities. It was in the furtherance of this line of investigation that he expended large amounts of money and years of labor at Wardenclyffe, Long Island, and at Telluride, Colo. Late in 1914 he secured a patent upon an application filed twelve years before upon an apparatus for transmitting electric energy with which he hopes to be able to transmit unlimited power with high economy to any distance without wires. While as yet these efforts have not resulted in commercial exploitation, the future may prove that his dream of thus transmitting energy in substantial amounts is of that class which in time comes true, as in the case of his dream of wireless telegraphy.

"Another use to which Tesla adapted the results of his high-frequency investigations was the control of the movements of torpedoes and boats. In 1898 he patented such an apparatus and also built and successfully operated such a craft. The movements of the propelling engine, the steering and other mechanisms were controlled wirelessly from the shore or other point through a distance of two miles. Apparently this, like some of his other inventions, was ahead of its time. * * *

"Another field of investigation in which Mr. Tesla has contributed valuable material is related to the Roentgen ray. In the ELECTRICAL REVIEW during March and April, 1896, there appeared a number of communications from Mr. Tesla which, while giving full credit to Roentgen for his magnificent discovery, make public much additional data derived from his own careful experiments in this line of research. * * * .

"Among the many other inventions to which Mr. Tesla has devoted much time and energy may be mentioned a thermomagnetic motor and a pyromagnetic generator, anti-sparking dynamo brush and commutator, auxiliary brush regulation of direct-current dynamos, unipolar dynamos, mechanical and electrical oscillators, electrotherapeutic apparatus, the oxidation of nitrogen by high-frequency currents, and an electrolytic registering meter. * * *

"One other line of endeavor entirely outside of electricity to which Tesla has given much attention is the development of a bladeless steam turbine in which the friction of the passing steam as distinguished from its direct impact is availed of. The steam is admitted between plain parallel rotating discs and passing spirally from the circumference toward the axial center imparts energy to the disks. Such a turbine can be run at exceedingly high temperatures, is readily reversible and, having no blades, is extremely simple and free from liability to accidental derangement. With great ingenuity Tesla has succeeded in producing such machines of considerable power and having exceedingly interesting characteristics. It is to be hoped that with his indefatigable zeal Tesla will soon succeed in perfecting the commercial application of this invention. It is not possible in this brief survey even to touch upon many of the lines of Mr. Tesla's varied activities, but we must content ourselves with this inadequate presentation of typical evidences of the fascinating genius of this man."

ADDRESS BY B. A. BEHREND.

"By an extraordinary coincidence, it is exactly 29 years ago, to the very day and hour, that there stood before this Institute Nikola Tesla," said Mr. Behrend. He then quoted from Mr. Tesla's paper on that notable occasion. Continuing, he said:

"Not since the appearance of Faraday's experimental researches in electricity has a great experimental truth been voiced so simply and so clearly as this description of Mr. Tesla's great discovery of the generation and utilization of polyphase alternating currents. He left nothing to be done for those who followed him. His paper contained the skeleton even of the mathematical theory.

"Three years later, in 1891, there was given the first great demonstration, by Swiss engineers, of the transmission of power at 30,000 volts from Lauffen to Frankfort by means of Mr. Tesla's system. A few years later this was followed by the development of the Cataract Construction Company, under the presidency of our member, Edward A. Adams, and with the aid of the engineers of the Westinghouse Company. It is interesting to recall here tonight that in Lord Kelvin's report to Mr. Adams, Lord Kelvin recommended the use of direct current for the development of power at Niagara Falls and for its transmission to Buffalo.

"The due appreciation or even enumeration of the results of Mr. Tesla's invention is neither practicable nor desirable at this moment. There is a time for all things. Suffice it to say that, were we to seize and to eliminate from our industrial world the results of Mr. Tesla's work, the wheels of industry would cease to turn, our electric cars and trains would stop, our towns would be dark, our mills would be dead and idle. Yea, so far-reaching is this work that it has become the warp and woof of industry. * * *"

PRESENTATION OF THE MEDAL.

President H. W. Buck, in presenting the medal to Mr. Tesla, referred to the developments of some 30 years ago when direct currents were used almost exclusively and it remained for Mr. Tesla to make alternating currents available for miscellaneous purposes by his great conception of the rotating field. This made power transmission immediately practicable and permitted the development of the Niagara Falls enterprise and countless other power developments necessitating the use of polyphase currents. Mr. Buck also spoke of Tesla's pioneer work in high-voltage and high-frequency currents, which laid the foundation for such important later developments.

MR. TESLA'S ADDRESS OF ACCEPTANCE.

In accepting the Edison Medal, Mr. Tesla expressed his deep gratitude for the sympathy and appreciation shown him. He admitted that "a gigantic revolution has been wrought in the transmission and transformation of energy. While we are pleased with the results achieved," he said, "we are pressing on, inspired with the hope and conviction that this is just the beginning, a forerunner of further and still greater accomplishments." He then entered upon a fascinating account of some features of a personal and more intimate character bearing on his work, which lack of space unfortunately prevents giving in full.

"In the first place, I come from a very wiry and long-lived race. Some of my ancestors have been centenarians, and one of them lived 129 years. I am determined to keep up the record, and believe there is a prospect of accomplishing it. Then, nature has given me a vivid imagination which, through incessant exercise and training, through the study of scientific subjects, and the verification of theories through experiment, has become very accurate in results, so that I have been able to dispense, to a large extent, with the slow labors, wasteful and expensive processes of practical development of the ideas I conceive. It has made it possible for me to explore extended

fields with great rapidity and get results with the least expenditure of vital energy. By this means, I may tell you also, I am able to picture the objects of my desires in forms so real and tangible that I can rid myself of that morbid craving for perishable possessions to which so many succumb. * * *

"My life was also wonderful in another respect, for physical endurance or energy. If you inquire into the career of successful men in the inventor's profession, you will find, as a rule, that they are as remarkable for their physical as for their mental capacities. I know that when I worked with Edison, after all of his assistants had been exhausted, he said to me, 'I never saw such a thing, you take the cake.' That was the characteristic way for Edison to express what I did. We worked from in the morning at half past ten until five o'clock the next morning. I carried this on for nine months without a single day's exception, but everybody else gave up. Edison stuck, but he occasionally dozed off on the table. * * *

"When I turned my thoughts to inventions, I found that I could visualize my conceptions with the greatest facility. I did not need any models and drawings or experiments, I could do it all in my mind, and I did. The way I unconsciously evolved what I considered a new method in materializing inventive concepts and ideas, is exactly opposed to the purely experimental method, of which undoubtedly Edison is the greatest and most successful exponent. The moment you construct a device to carry into practice a crude idea you will find that you will be engrossed with the details and effects of the apparatus. As you go on changing and constructing, you will lose the forces of concentration, and you will lose sight of the great underlying principle. You obtain results, but at the sacrifice of quality. I did not construct. When I got an idea, I started right away to build it up in my mind. I changed the structure, I made improvements, I experimented, and I ran the device in my mind. It is absolutely the same to me whether I place my turbine in my mind or have it in my shop actually running in my test. It makes no difference. The results are the same. In this way you see I can develop and perfect an invention without touching anything, and when I have gone so far that I have put into that device every possible improvement I can think of, that I can see no fault in it any more, I then construct it, and every time my device works as I conceived it would, my experiment comes out exactly as I plan it, and in twenty years there has not been a single, solitary experiment which did not come out exactly as I thought it would."

Mr. Tesla then related some very interesting experiences of his youth in which he had hairbreadth and almost miraculous escapes that led his parents to set him apart for the ministry. At the age of 18 during a violent epidemic of cholera he contracted the disease with several complications that made everyone despair of his recovery. "My father came, sat on my bed and said to me, 'Are you going to get well?' I said to him, 'I will get well if you will let me study engineering.' He said, 'Certainly I will, you will have to go to the best polytechnic school in Europe.' My father kept his word, and after a year of roaming through the mountains and getting myself in good physical shape, I went to the Polytechnic School at Gratz, one of the finest in Europe. * * *

"The first year at the polytechnic school was passed in this way—I got up at three o'clock in the morning and I worked until eleven o'clock at night, for one whole year, without a single day's exception. Well, you know when a man with a reasonably healthy brain works that way he must do something. Of course, I did. I graduated nine times that year and some of the professors were not satisfied with giving me the highest distinction, because they said that did not express their idea of me, and here is where I come to the rotating field. In addition to the regular graduating papers they gave me some certificates. I got these certificates and showed them to my father. I thought it would be a great triumph for him. My father took the certificates and threw them into the waste basket. He said, 'Oh, I know how these certificates are obtained.' That almost killed my ambition, and later, after my father died, I was mortified to find a pack of letters, from which I could see that there had been considerable correspondence going on between my father and the professors at the school, and the professors had written to the effect that unless he took me away from the school I would kill myself with work. Then I understood why he had slighted my success, which I was told was greater than any which had been achieved by any student before; in fact, the best students had only graduated twice, and I had graduated nine times. My work in the first year had this result—that the professors became very much interested in me and very much attached to me.

"It was in the second year of my studies that we got a gramme machine there from Paris. This was a machine with a horseshoe form of laminated magnets, and there was an armature in it with a commutator. I put that together and we connected it up and showed the various effects of currents. During this time that Professor Poeschl was demonstrating we had some trouble with the brushes. The brushes sparked very badly, and I said, 'Well, why should not we operate without the brushes?' Professor Poeschl said it could not be done, but in view of my success in the past year he gave me the honor of delivering a lecture. He said: 'Mr. Tesla may accomplish great things, but he certainly never can produce this,' and he showed that this would be tantamount to converting a steadily pulling force, like gravity, into a rotary effort, which was a sort of perpetual-motion machine, an impossible idea. * * * I showed them that I was right and it was possible. It was not a perpetual-motion idea. It was not a thing which was impossible, it could be done, and I started then to work.

"I will not tire you with an extended account of this undertaking, but I will say that my work was like this—I began in 1877 in the summer, and then I would get a picture in my mind. I would picture, for instance, a direct-current machine and run it and see how these currents changed in the armature, and whatever I imagined, I would put together and operate everything in my mind, and I continued that practice until 1882. I could not visualize just exactly how to do it, but I felt I was approaching a solution. I was on my vacation and sure enough the idea came to me. I will never forget the moment. I was walking with a friend of mine in the city park at Budapest, and I was reciting poems from Faust. It was nothing for me to recite from memory the contents of an entire book, with every word between the covers, from the first to the last, and my sister and brother had a much better memory than mine. Just as the sun was setting I felt wonderfully inspired, and the idea came to me like a flash, and I saw the whole thing clearly, I saw my generator, I saw the motor, and saw the connections, saw it work, in my mind, and I took a stick and drew on the sand the diagrams which were drawn in my paper before the American Institute of Electrical Engineers, and which were illustrated in my plans as clearly as possible, and from that time I carried this image in my mind. Now, remember, if I had been a man who had had some of the practical gifts of Edison, I would have gone right away to perform an experiment and push the invention along, but I did not need to experiment—as I say, I can so picture, and consider what I picture as real and forcible, that I do not need any experimenting, nor is it particularly interesting to me. I went on and improved the plan continuously, invented new forms, and the day before I came to America, every form, every construction, every arrangement which I expressed in my patents, was developed in my mind, except just two or three forms which appear in later developments, otherwise I had all the forms shown in the thirty or forty patents granted to me then in my mind. In 1882 I performed two experiments in Strasburg, as Mr. Terry pointed out, and there at the railroad station I obtained the first rotation.

"I have come now to an interesting point when I came to America. I had made some improvements in dynamos for a French company who were getting their machinery from America. The improved forms were so much better that the manager of the works said to me, 'You must go to America, and you must design these machines for the French company.' So, after ineffectual efforts on the other side to get somebody to interest himself in my plans financially, I came to America. * * * Then came another event. I met Edison, and the effect that Edison produced upon me was rather extraordinary. When I saw this wonderful man, who had had no training at all, no advantages, and did it all himself, and see the great results by virtue of his industry and application, I felt mortified that I had squandered my life—you see I had studied a dozen languages, I had delved in literature, and had spent the best years of my life in ruminating through libraries and reading all sorts of stuff that fell into my hands. I thought to myself, what a terrible thing it was to have wasted my life on those useless things, and if I had only come to America right then and there and devoted all of my brain power and inventiveness to my work, what could I have not done? In later life I realized I might not have produced anything without the scientific training I got, and it is a question as to whether my theory as to my possible accomplishments was correct. In Edison's works we passed a year of the most strenuous labor, and then certain people approached me with a proposition to form my own company.

"Well, I went into the proposition, and we developed an arc light, and to show you how prejudiced the people were against the alternating current, as one of the speakers indicated, I told these friends of mine I had a great invention relating to alternating-current transmission, and they said: 'No, we want the arc lamp. We don't want this alternating-current system.' Finally I brought out an arc lamp, perfected it, and the city adopted it. Then I succeeded in organizing another company, in April, 1886, and then a laboratory was put up, and then I rapidly developed these matters, and finally the Westinghouse people approached us, and an arrangement was made, and then you know what happened since then. The invention has swept the world.

"Mr. Behrend has referred to other inventions of mine. I will say just a few words, because some of my work has been misunderstood. It seems to me that I ought to tell you a few words about other efforts that have absorbed my attention later. In 1894 I delivered a lecture at the Royal Institution and Lord Raleigh surprised me by acknowledging my work in very generous terms, something that is not customary, and among other things he stated that I had really an extraordinary gift for invention. Up to that time, I can assure you, I never realized that I was an inventor at all. I looked upon the rotating-field discovery as simply a mathematical deduction. It was a logical, step by step, deduction. I forced this invention, as it were, by screws and levers. I did not get an inspiration, as it were. My machines were developed all in my mind. When I tried the first experiments they meant nothing to me. I had already demonstrated them perfectly. So when I went home, in 1892, and heard these remarks of Lord Raleigh, I began to think and said to myself, 'Why, certainly I must have been an inventor.'

"I remember that I constructed turbines and clocks and such things, and so I said to myself, 'If I really have a gift for invention, then I am going to bend it to some great purpose and some great task and not squander my efforts in small things.' I began to think just what was the greatest thing to accomplish. One day I was working in the forest and a storm came up. I ran under a tree for shelter, and the air was very heavy, and all at once there was a lightning flash, and immediately after the lightning flash a torrent of rain came. That gave me a fair start. I realized that the sun was lifting the water and vapor, and the wind swept it over the regions where it accumulated and reached the condition where at a certain point it was condensed and fell to the earth again, and this life-sustaining stream of water was entirely dominated by some other power, and lightning or some other agency of this kind, simply came in as a trigger mechanism to relieve the energy at the proper moment. I started out and attacked the problem of constructing some kind of a machine which would this kind simply came in as a trigger mechanism to relieve the enable us to precipitate this water wherever desired.* *

THE COLORADO EXPERIMENTS.

"That led me to the production of very intense electrical effects. At the same time my wireless work, which I had already begun, was exactly in that direction, and so I devoted myself to the perfection of some device, and in 1908, I filed an application describing an apparatus with which I think this wonder can be achieved. The Patent Office examiner was from Missouri, and he would not believe it could be done, and so my patent was never granted, but in Colorado I constructed apparatus by which I produced certain effects, at least, which were greater than those of lightning—I do not mean, for instance, in potential. The highest potential I reached was something like 20,000,000 volts, and that is insignificant as compared to lightning, but certain effects in my apparatus were greater than those produced by lightning. For instance, I got in my attenna currents of 1000 or 1100 amperes, and you know that in the biggest wireless plants only 250 amperes were used —I do not know what is the biggest one now—but 250 amperes is very large, and I know in Colorado I succeeded one day in precipitating a mist. Of course, there was a mist outside, but when I turned on the current the mist in the laboratory became so great that I called the attention of my assistant that when the hand was held just a few inches from the face it could not be seen, so that I am positive of my conviction that we are able to erect a plant of proper design in an arid region, that we can work this plant according to certain observations and rules, and that we can draw from the ocean unlimited amounts of water for irrigation and power purposes. If I do not live to carry it out, somebody else will, but I am sure that I am right.

"As to the transmission of power through space, that is a matter which I have considered certain, absolutely certain, years ago. Years ago I was in a position to erect a plant to transmit wireless power to any distance without limitation, other than the physical limitations of the globe. In my system it makes no difference what the distance is. The efficiency of the transmission can be as high as 96 per cent, or 97 per cent, and there is no loss except those losses which are inevitable in the running of the machinery. And when there is no receiver there is no loss anywhere. When the receiver is put on, it draws energy. That is the opposite of the Hertz wave system. In that system you have a plant of 1000 horsepower, that is 1000 horsepower radiating all the time, but if I have a plant of 1000 horsepower under my system, this only consumes the few horsepower necessary to maintain the electric vibration, and the rest of the system is idle, exactly as the Edison lamps are idle when the lamps and dynamos are shut off.

"I have made advances along this line in later years which will contribute to the practical features of the system. Recently we have obtained a patent on a transmitter with which it is practicable to transfer unlimited amounts of energy to any distance. I had a very interesting experience with Mr. Stone, whom I consider, if not the ablest, certainly one of the ablest living experts. I said to Mr. Stone: 'Did you see my patent?' He replied: 'Yes, I saw it, but I thought you were crazy.' When I explained to Mr. Stone he said: 'Now, I see why that is great,' and he understood how this energy is transmitted.

"Now, gentlemen, we are coming to great results, but we must be prepared for a condition of paralysis for quite a while. We are facing an enormous crisis such as the world has never seen before, and until the situation clears the best thing we can do is to devise some scheme for overcoming the submarines, and that is what I am doing now."



THE ELECTRICAL EXPERIMENTER

H. GERNSBACK EDITOR
H. W. SECOR ASSOCIATE EDITOR

Vol. V. Whole No. 52 August, 1917 Number 4

Tesla's Views on Electricity and the War

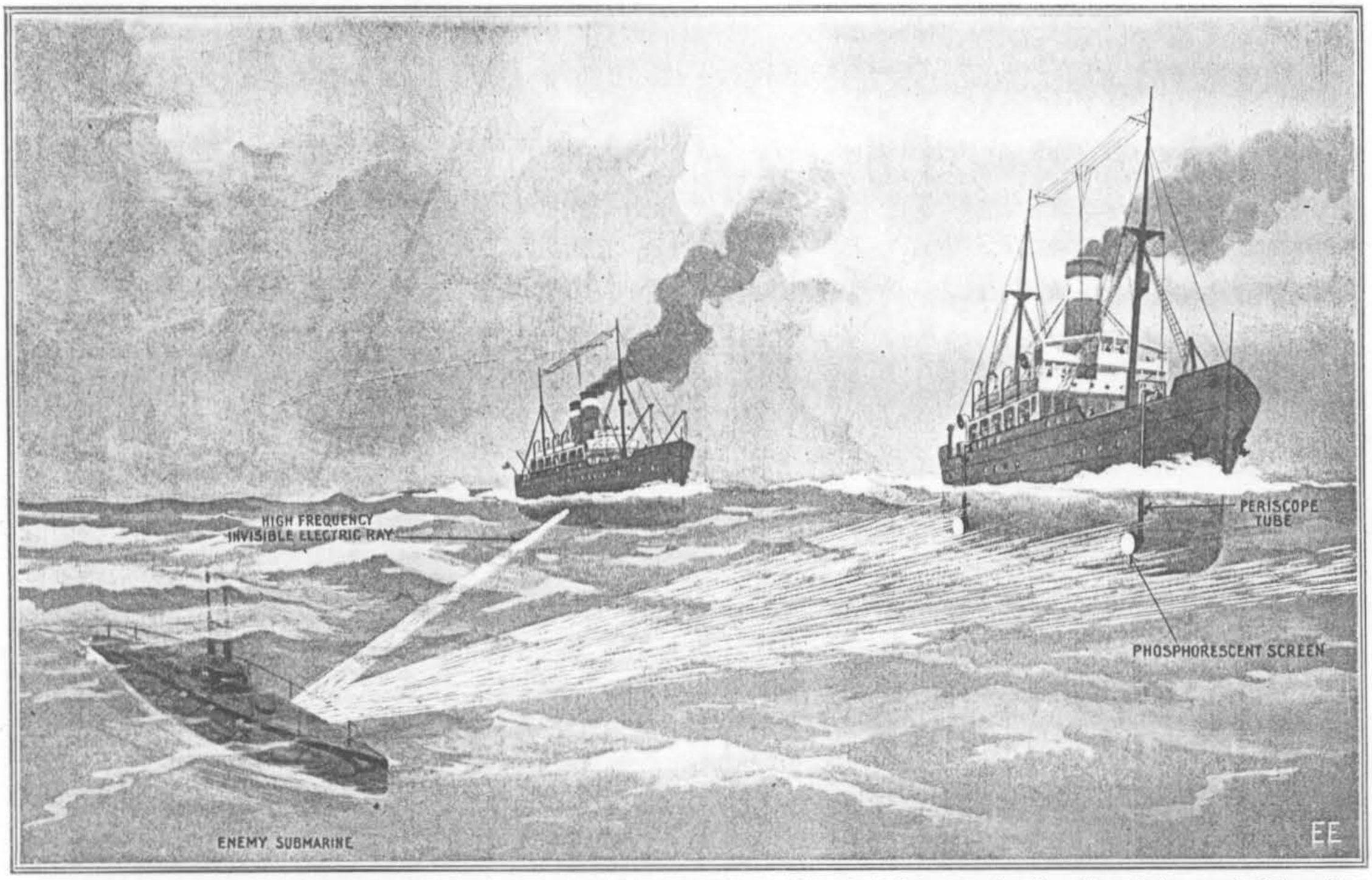
By H. WINFIELD SECOR

Exclusive Interview to THE ELECTRICAL EXPERIMENTER

NIKOLA TESLA, one of the greatest of living electrical engineers and recipient of the seventh "Edison" medal, has evolved several unique and far-reaching ideas which if developed and practically applied should help to partially, if not totally, solve the much discust submarine menace and to provide a means whereby the enemy's powder and shell magazines may be exploded at a distance of several miles.

There have been numerous stories bruited about by more or less irresponsible self-styled experts that certain American inventors, including Dr. Tesla, had invented among other things an *electric ray* to destroy or detect a submarine under water at a considerable distance. Mr. Tesla very courteously granted the writer an interview and some of his ideas on electricity's possible rôle in helping to end the great world-war are herein given:

The all-absorbing topic of daily conversation at the present time is of course the "U-boat." Therefore, I made that subject my opening shot.



Nikola Tesla, the Famous Electric Inventor, Has Proposed Three Different Electrical Schemes for Locating Submerged Submarines. The Reflected Electric Ray Method Is Illustrated Above; the High-Frequency Invisible Electric Ray, When Reflected by a Submarine Hull, Causes Phosphorescent Screens on Another or Even the Same Ship to Glow, Giving Warning That the U-boats Are Near.

"Well," said Dr. Tesla, "I have several distinct ideas regarding the subjugation of the submarine. But lest we forget, let us not underestimate the efficiency of the means available for carrying on submarine warfare. We may use microphones to detect the submarine, but on the other hand the submarine commander may employ microphones to locate a ship and even torpedo it by the range thus found, without ever showing his periscope above water.

"Many years ago while serving in the capacity of chief electrician for an electric plant situated on the river Seine, in France, I had occasion to require for certain testing purposes an extremely sensitive galvanometer. In those days the quartz fiber was an unknown quantity—and I, by becoming specially adept, managed to produce an extremely fine cocoon fiber for the galvanometer suspension. Further, the galvanometer proved very sensitive for the location in which it was to be used; so a special cement base was sunk in the ground and by using a lead sub-base suspended on springs all mechanical shock and vibration effects were finally gotten rid of.

"As a matter of actual personal experience," said Dr. Tesla, "it became a fact that the small iron-hull steam mail-packets (ships) plying up and down the river Seine

at a distance of *3 miles* would distinctly affect the galvanometer!"

"How could this be applied to the submarine problem?" I asked.

"Well, for one thing," the scientist replied, "I believe this *magnetic* method of locating or indicating the presence of an iron or steel mass might prove very practical in locating a hidden submarine. And it is of course of paramount importance that we do find a means of accurately locating the sub-sea fighters when they are submerged, so that we can, with this information, be ready to close in on them when they attempt to come to the surface. Especially is this important when several vessels are traveling in fleet formation; the location and presence of the enemy submarine can be radiographed to the other vessels by the one doing the *magnetic surveying* and, by means of nets in some cases, or gun-fire and the use of hydro-aeroplanes sent aloft from the ships, the enemy under water stands a mighty good chance of being either 'bombed,' shelled or netted.

"However, a means would soon be found of nullifying this *magnetic detector* of the submerged undersea war-craft. They might make the 'U-boat' hulls of some non-magnetic metal, such as copper, brass, or aluminum. It is a good rule to always keep in mind that for practically every good invention of such a kind as this, there has always been invented an opposite, and equally efficient counteracting invention."

"How about this new *electric ray* method of locating submarines?" I ventured to ask.

"Yes, yes, I am coming to that," the master electrician parried. "Now suppose that we erect on a vessel, a large rectangular helice or inductance coil of insulated wire. Actual experiments in my laboratory at Houston Street (New York City), have proven that the presence of a local iron mass, such as the ship's hull, would not interfere with the action of this device. To this coil of wire, measuring perhaps 400 feet in length by 70 feet in width (the length and breadth of the ship) we connect a source of extremely high frequency and very powerful oscillating current. By this means there are radiated powerful oscillating electro-static currents, which as I have found by actual experiment in my Colorado tests some years ago, will first affect a metallic body (such as a submarine hull, even tho made of brass or any other metal), and in turn cause that mass to react inductively on the exciting coil on the ship. To locate an *iron* mass it is not necessary to excite the coil with a high frequency current; the critical balance of the coil will be affected simply by the presence of the magnetic body. To be able to accurately determine the direction and range of the enemy submarine four exciting inductances should be used. With a single inductance, however, it would be possible to determine the location of a submarine by running the ship first in one direction and then in another, and noting whether the reactive effect caused by the presence of the submarine hull increased or decreased. The radiating inductance must be very sharply attuned to the measuring apparatus installed on the ship, when no trouble will be found in detecting the presence of such a large metallic mass as a submarine, even at a distance of 5 to 6 miles; of this I feel confident from my past experiments in the realm of ultra-high frequency currents and potentials."

"What particular experiments do you have in mind, Dr. Tesla?" I asked.

"The Colorado tests of 1898-1900. Wonderful were the results there obtained, both those anticipated as well as those unexpected. As an example of what has been done with several hundred kilowatts of high frequency energy liberated, it was found that the dynamos in a power house six miles away were repeatedly burned out, due to the powerful high frequency currents set up in them, and which caused heavy sparks to jump thru the windings and destroy the insulation! The lightning arresters in the power house showed a stream of blue-white sparks passing between the metal plates to the earth connection. I could walk on the sand (ordinarily considered a very good insulator) several hundred feet from my large high frequency oscillator, and sparks jumped from my shoes! At such distances all incandescent lamps glowed by wireless power, and banks of lamp, connected to a few turns of wire arranged in a coil on the ground, were lighted to full brilliancy. The effect on metallic objects at considerable distances was really remarkable."

I asked him about the "Ulivi ray," which was accorded considerable newspaper publicity some time ago.

"The 'Ulivi ray' really was transplated from this country to Italy," asserted Dr. Tesla. "It was simply an adaptation of my ultra-powerful high-frequency phenomena as carried out in Colorado and cited previously. With a powerful oscillator developing thousands of horsepower it would become readily possible to detonate powder and munition magazines by means of the high frequency currents induced in every bit of metal, even when located five to six miles away and more. Even a powder can would have a potential of 6,000 to 7,000 volts induced in it at that distance.

(*Continued on page* 270)

TESLA'S VIEWS ON ELECTRICITY AND THE WAR.

(*Continued from page 230*)

"At the time of those tests I succeeded in producing the most powerful X-rays ever seen. I could stand at a distance of 100 feet from the X-ray apparatus and see the bones of the hand clearly with the aid of a fluoroscope screen; and I could have easily seen them at a distance several times this by utilizing suitable power. In fact, I could not then procure X-ray generators to handle even a small fraction of the power I had available. But I now have apparatus designed whereby this tremendous energy of hundreds of kilowatts can be successfully transformed into X-rays."

"Could these ultra-powerful and unusually penetrating X-rays be used to locate or destroy a submarine with?" I interjected.

"Now we are coming to the method of locating such hidden metal masses as submarines by an *electric ray,*" replied the electrical wizard. "That is the thing which seems to hold great promises. If we can shoot out a concentrated ray comprising a stream of minute electric charges vibrating electrically at tremendous frequency, say millions of cycles per second, and then intercept this ray, after it has been reflected by a submarine hull for example, and cause this intercepted ray to illuminate a fluorescent screen (similar to the X-ray method) on the same or another ship, then our problem of locating the hidden submarine will have been solved.

"This electric ray would necessarily have to have an oscillation wave length extremely short and here is where the great problem presents itself; *i.e.,* to be able to develop a sufficiently short wave length and a large amount of power, say several hundred thousand or even several thousand horse-power. I have produced oscillators having a wave length of but a *few millimeters.*

"Suppose, for example, that a vessel is fitted with such an electric ray projector. The average ship has available from say 10,000 to 15,000 H.P. The exploring ray could be flashed out intermittently and thus it would be possible to hurl forth a very formidable beam of pulsating electric energy, involving a discharge of hundreds of thousands of horse-power. The electric energy would be taken from the ship's plant for a fraction of a minute only, being absorbed at a tremendous rate by suitable condensers and other apparatus, from which it could be liberated at any rate desired.

"Imagine that the ray has been shot out and that in sweeping thru the water it encounters the hull of a submarine. What happens? Just this:—The ray would be reflected, and by an appropriate device we would intercept and translate this reflected ray, as for instance by allowing the ray to impinge on a phosphorescent screen, acting in a similar way to the X-ray screen. The ray would be *invisible* to the unaided eye. The reflected ray could be firstly, intercepted by the one or more ships in the fleet; or secondly, it would be possible for the ship originating the ray to intercept the refracted portion by sending out the ray intermittently and also by taking advantage of what is known as the *after-glow effect,* which means that the ray would affect the registering screen an appreciable time after its origination. This would be necessary to allow the ship to move forward sufficiently to get within range of the reflected ray from the submarine, as the reflection would not be in the same direction as the originating ray.

"To make this clearer, consider that a concentrated ray from a searchlight is thrown on a balloon at night. When the spot of light strikes the balloon, the latter at once becomes visible from many different angles. The same effect would be created with the electric ray if properly applied. When the ray struck the rough hull of a submarine it would be reflected, but not in a centrated beam—it would spread out; which is just what we want. Suppose several vessels are steaming along in company; it thus becomes evident that several of them will intercept the reflected ray and accordingly be warned of the presence of the submarine or submarines. The vessels would at once lower their nets, if so equipt, order their gun crews to quarters and double the look-out watch. The important thing to know is that submarines are present. Forewarned is forearmed!

"The Teutons are clever, you know; very, very clever, but we shall beat them," said Dr. Tesla confidently. [*It may be of interest to our readers to know that several important electrical war schemes will shortly be laid before the War and Navy Departments by Dr. Tesla, the details of which we naturally cannot now publish.*]



THE ELECTRICAL EXPERIMENTER

H. GERNSBACK EDITOR
H. W. SECOR ASSOCIATE EDITOR

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U. S. Blows Up Tesla Radio Tower

SUSPECTING that German spies were using the big wireless tower erected at Shoreham, L. I., about twenty years ago by Nikola Tesla, the Federal Government ordered the tower destroyed and it was recently demolished with dynamite. During the past month several strangers had been seen lurking about the place.

Tesla erected the tower, which was about 185 feet high, with a well about 100 feet deep, for use in experimenting with the transmission of electrical energy for power and lighting purposes by wireless. The equipment cost nearly $200,000.

The late J. P. Morgan backed Nikola Tesla with the money to build this remarkable steel tower, that he might experiment in wireless even before people knew of Marconi. A complete description, revised by Dr. Tesla himself, of this unique and ultra-powerful radio plant was given in the March, 1916, issue of THE ELECTRICAL EXPERIMENTER. Everyone interested in the study of high frequency currents should not fail to study that discourse as it contains the theory of how this master electrician proposed to charge this lofty antenna with thousands of kilowatts of high frequency electrical energy, then to radiate it thru the earth and run ships, factories and street cars with "wireless power."

Most of our readers have, no doubt, read about the famous Tesla wireless tower, which structure involved the expenditure of a vast sum of money and engineering talent. From this lofty structure, which was designed some 20 years ago by Dr. Tesla and his associates, there was to be propagated an electric wave of such intensity that it could charge the earth to such a potential that the effect of the wave or charge could be felt in the utmost confines of the globe.

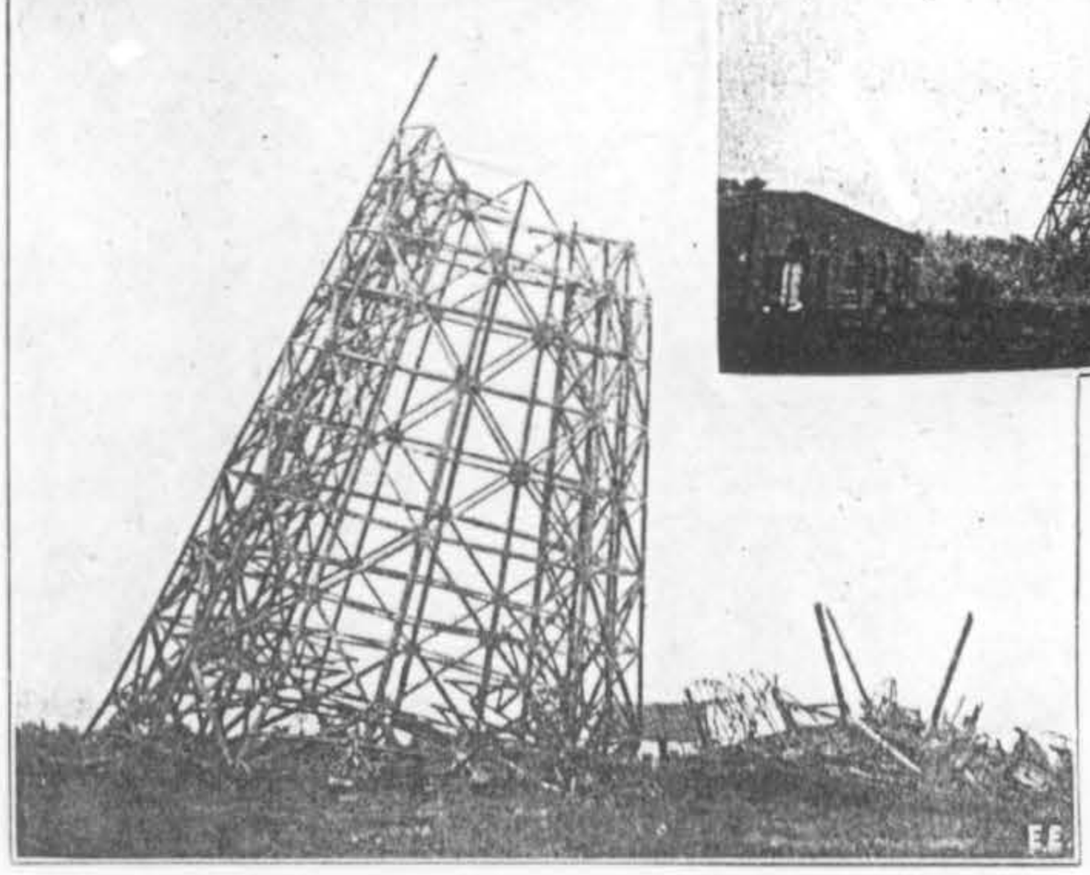
Further, it may be said that Tesla, all in all, does not believe in the modern Hertzian wave theory of wireless transmission at all. Several other engineers of note have also gone on record as stating their belief to be in accordance with Dr. Tesla's. More wonderful still is the fact that this scientist promulgated his basic theory of *earth current* transmission a great many years ago in some of his patents and other publications. Briefly explained, the Tesla theory is that a wireless tower, such as that here illustrated and specially constructed to have a high capacity, acts as a huge electric condenser. This is charged by a suitable high frequency, high voltage apparatus and a current is discharged into the earth periodically and in the form of a high frequency alternating wave. The electric wave is then supposed to travel thru the earth along its surface shell and in turn to manifest its presence at any point where there might be erected a similar high capacity tower to that above described.

A simple analogy to this action is the following: Take a hollow spherical chamber filled with a liquid, such as water; and then, at two diametrically opposite points, let us place, respectively, a small piston pump, such as a bicycle pump, and an indicator, such as a pressure gage. Now, if we suck some of the water into the pump and force it back into the ball by pushing on the piston handle, this change in pressure will be indicated on the gage secured to the opposite side of the sphere. In this way the Tesla earth currents are supposed to act.

The patents of Dr. Tesla are basically quite different from those of Marconi and others in the wireless telegraphic field. In the nature of things this would be expected to be the case, as Tesla believes and has designed apparatus intended for the *transmission of large amounts of electrical energy*, while the energy received in the transmission of intelligence wirelessly amounts to but a few millionths of an ampere in most cases by the time the current so transmitted has been picked up a thousand miles away. In the Hertzian wave system, as it has been explained and believed in, the energy is transmitted with a very large loss to the receptor by electro-magnetic waves which pass out laterally from the transmitting wire into space. In Tesla's system the energy radiated is not used, but the current is led to earth and to an elevated terminal, while the energy is transmitted by a process of *conduction*. That is, the earth receives a large number of powerful high frequency electric shocks every second, and these act the same as the pump piston in the analogy.

Quoting from one of Tesla's early patents on this point: "It is to be noted that the phenomenon here involved in the transmission of electrical energy is one of *true conduction* and is not to be confounded with the phenomena of *electrical radiation*, which have heretofore been observed, and which, from the very nature and mode of propagation, would render practically impossible the transmission of any appreciable amount of energy to such distances as are of practical importance."





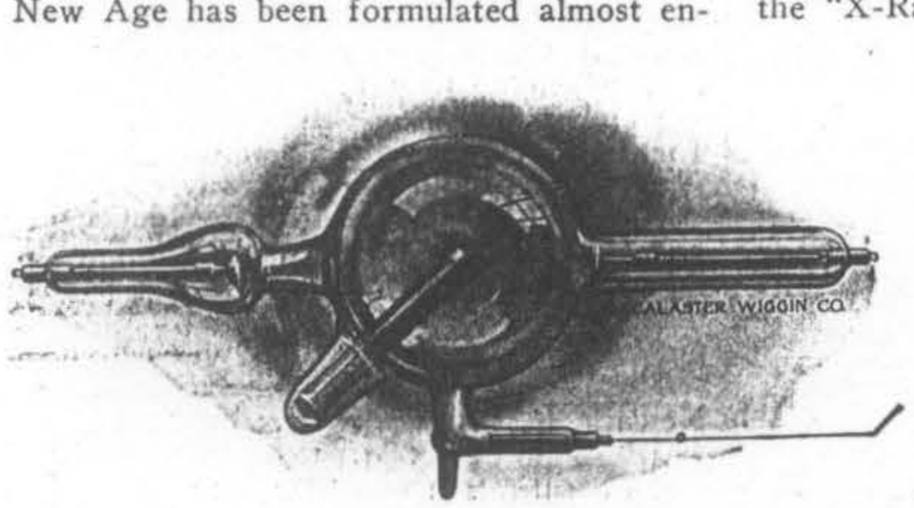
Two Views of the Last Minutes of Tesla's Gigantic Radio Tower at Shoreham, L. I., New York, As It Was Being Demolished by the Federal Government. It Was Suspected That German Spies Were Using the Tower for Radio-Communication Purposes. It Stood 185 Feet Above the Ground and Cost About $200,000. Tesla Had Not Used It For Several Years.

Photos by American Press Association

X-Ray Tubes for High Frequency Coils

By Dr. FREDERICK FINCH STRONG
Lecturer on Electro-therapeutics, Tufts Medical School, Boston

IN all the history of scientific achievement there has been perhaps no discovery of such a startling and revolutionary character as that of the X-Ray. The *Electron theory,* which forms the basis of the chemistry and physics of our New Age has been formulated almost entirely from deduction made possible by the work of Roentgen and the Curies.



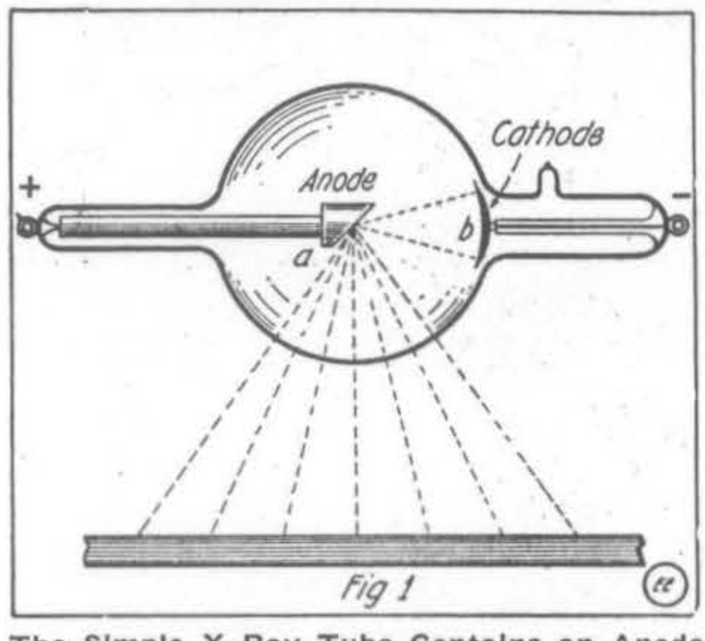
Standard Form of Single-Focus High Frequency X-Ray Tube. The First Powerful X-Ray Tubes Were Excited By a High Frequency Oscillator.

If we review the history of these discoveries we find that they have resulted from long series of researches dealing with the phenomena of electrical discharges in partial vacua.

The air pump was invented in 1650 by Otto von Guericke; by its use Sir W. Snow Harris, in 1834 was able to show that the spark-length of a given electrical machine increases in inverse ratio to the pressure of the gas thru which it passes. His tubes were exhausted to about one five-hundredth of an atmosphere, and the dischage took the form of a pencil of violet-pink light.

Geissler, in 1838, experimented with discharges in low vacua, and invented the beautiful tubes which bear his name. By improving the air-pump, he was able to withdraw all but one ten-thousandth of the original air from the glass tube, and change the color of the glow, in the electrified space from violet-pink to a pure white.

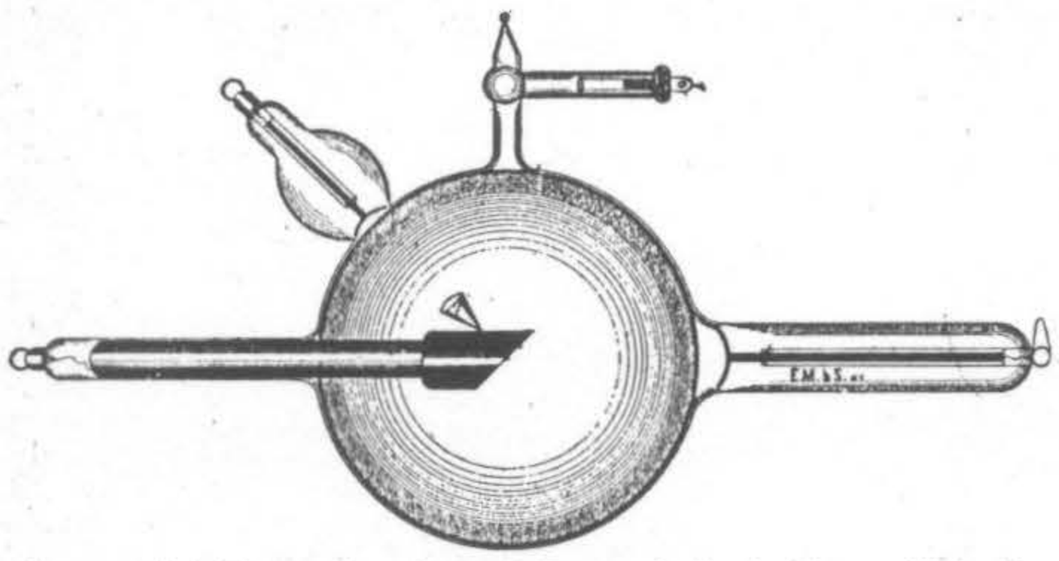
The invention of the mercury air-pump by Sprengel in 1865, made it possible for Sir William Crookes in 1878, to study electrical discharges in rarefied gases with pressures as low as *one one-millionth* of an atmosphere. He gave to the world the "Crookes tube," with which Lenard in 1894, proved the existence of the "Cathode rays," and from which in 1895, Roentgen accidentally discovered a new form of emitted energy which he tentatively called the "X-Ray."



The Simple X-Ray Tube Contains an Anode or Target "a" and an Aluminum Cathode "b." The Cathodic Electron Bombardment of Target "a" Causes X-Rays to be Produced At Right Angles or Downward As Shown.

We all recall the circumstances of this discovery. Roentgen was experimenting with a Crookes tube enveloped in an opaque cover, when he noticed a bright glow on a nearby card, coated with Platinum-Barium-Cyanid. The glow continued even when the uncoated surface of the card was presented to the tube, and further experiment showed that the interposition of the experimenter's hand between the covered tube and the fluorescent screen would cause a shadow-picture of the bones to appear upon the glowing surface.

The publication of Roentgen's discovery led investigators in all parts of the world to study the new phenomena. Static machines and Ruhmkorff induction coils were at first employed to excite the Crookes tubes; but the intensity of the resulting X-rays was not very great. In those days an induction coil giving a four-inch spark was regarded as exceedingly powerful. We know now that such an apparatus is entirely inadequate to the production of X-rays for any practical purpose.



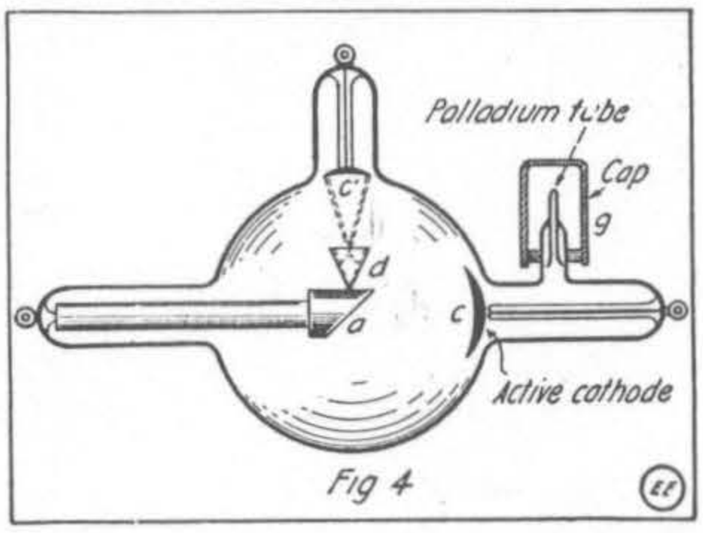
Commercial Form of a Second Type of Single-Focus High Frequency X-Ray Tube Shown Sectionally in Fig. 4. These Tubes Are Adapted to High Power Tesla or Oudin Coils.

Tesla and Elihu Thompson advocated high-frequency currents for X-ray generation, and in 1896 the Knott Apparatus Company of Boston designed the first practical commercial X-ray machine. It consisted of an open-core transformer, glass-plate condenser and Tesla coil, immersed in oil, and a rotary spark-gap not unlike those now used in Radio-telegraphy.

A few months later, the writer made the first practical high-frequency apparatus having solid insulation instead of oil, and suitable for therapeutic as well as X-ray work. The many types of high-frequency machines that are now made for physicians' use are but variations and improvements of this original apparatus.

At the present time the professional Roentgenologist uses almost exclusively powerful apparatus of the high-tension transformer type; the high-voltage, low-frequency, alternating current being rectified by a high-tension commutator operated by a synchronous motor. With such an apparatus and suitable X-ray tubes, a skiagram of the adult thorax or abdomen may be made in the *fraction of a second.*

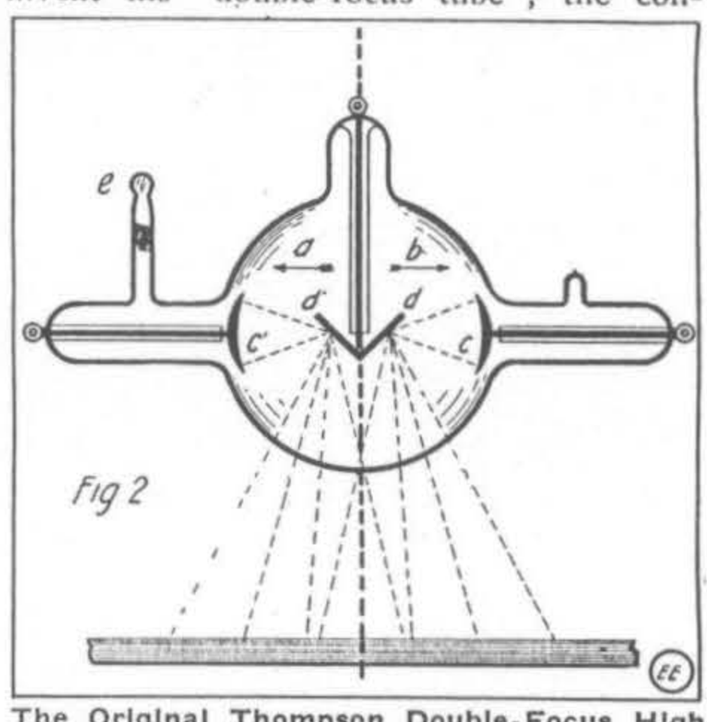
For the general practitioner, the dentist and the amateur experimenter, however, the high-frequency apparatus is still the most convenient and inexpensive device for exciting X-ray tubes, and produces results quite adequate to their respective needs.



Special Form of X-Ray Tube of the Single-Focus Type, Fitted With Palladium Vacuum Regulator and Focussing Mirror "C", Also Copper Cone "d," for Dissipating Auxiliary Cathode Stream.

The construction of an X-ray tube is familiar to all:—in its simplest form it consists of a Crookes tube (as shown in Fig. 1), containing an anode or target (a), faced with platinum or tungsten, and a concave aluminum cathode (b). A high-voltage, unidirectional current flowing thru the tube causes streams of electrons to pass from the cathode to the target, which is set at an angle of forty-five degrees to the axis of the tube. The electronic stream ("Cathode rays"), is reflected at right angles and part of the energy is transformed into X-rays, which emerge from the glass in a divergent cone, as shown. Such a tube is not suited for use with alternating or oscillating currents, as a double set of rays would be produced; this would tend to melt the aluminum cathode and cause the absorption of the residual gas in the tube so that it would soon be too "hard" to use.

This led Elihu Thompson, in 1896, to invent his "double-focus tube"; the construction and operation of the Thompson double-focus tube is shown in Fig. 2.



The Original Thompson Double-Focus High Frequency X-Ray Tube Which Really Comprised Two Distinct Bulb Elements.

(*Continued on page* 328)

X-RAY TUBES FOR HIGH-FREQUENCY COILS.

(*Continued from page* 309)

It is really a combination of two distinct tubes, as indicated by the heavy vertical dotted line. When the current passes in the direction of the arrow (b) X-rays are produced from the cathode and target (c and d) in the righ-hand half of the tube; alternations in the opposite direction, indicated by the arrow (a), produce a stream of rays from the left half of the tube. This is the most efficient form of high-frequency X-ray tube, as it uses both sets of alternations. It is now practically obsolete, however, as it was found that the two sets of X-rays overlapt and produced double outlines in the skiagram.

At the present time there are two types of X-ray tubes made for use with high-frequency currents. The one shown in Fig. 3 has a target of heavy copper faced with tungsten, and is mounted opposite the active cathode (c); when the current flows in the opposite direction the electronic stream from the small cathode (c^1) becomes choked out and dispersed by the constricted glass neck (d), which acts, in a measure, as a valve, eliminating the inverse discharge.

Another type of modern high-frequency X-ray tube is shown in Fig. 4, in which the cathode rays from the small aluminum mirror (c^1) focus inside a small copper cone (d), in which they are converted into heat and take no part in the production of the X-rays.

Tubes of these types may be operated by the current from a Tesla coil or from an Oudin resonator. In a previous article in the May issue of the ELECTRICAL EXPERIMENTER the writer has given details for the construction of apparatus of both these types.

When the Tesla coil is used its terminals are connected to the two aluminum cathodes (c and c^1); the Oudin coil has but one active terminal which should be connected to the active cathode (c); the small cathode (c^1) may be grounded, but this is not absolutely necessary.

X-ray tubes are spoken of as "hard" and "soft"—a "hard" tube is one which has been exhausted to a very high degree—(say, one-ten-millionth of an atmosphere)—a "soft" tube has a lower degree of exhaustion (between *one-five-hundred-thousandth* and *one-one-millionth* of an atmosphere). More current is needed to operate a hard tube, but it gives deep penetration and works more quickly. The soft tube, on the other hand, produces strong contrasts in the skiagram or fluoroscope.

Tubes have a tendency to become hard by use, the trace of residual air or gas being gradually driven out thru the intermolecular spaces of the glass by the electronic bombardment. So it is necessary to provide the tube with some means for replacing these lost ions at intervals.

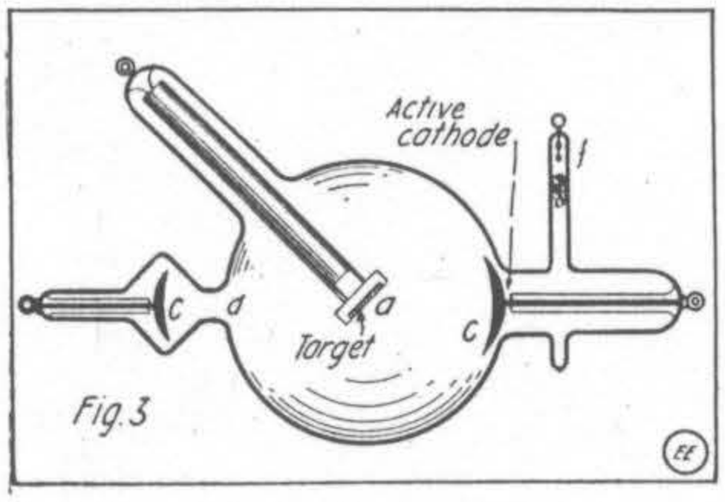
The first is of the thermic type and is now seldom used (see e, Fig. 2); it consists of a small bulb containing potassium chlorat sealed into the side of the X-ray tube. By heating this bulb with a match or spirit-lamp, a trace of oxygen is given off, which reduces the pressure in the tube to the required degree. The modern high-frequency tubes use the forms known as the "spark regulator" and the "osmotic regulator."

The first is the more common type and is shown in (f, Fig. 3). A platinum wire is sealed in the regulator tube which contains a gas-producing chemical, such as manganese dioxid, or sodium formate, f.

In practise a piece of E-shaped stiff brass wire set in a rubber handle is used to divert a portion of the current from the active terminal to the wire in the regulator; the heat from the current liberating the gas and softening the tube.

A regulator of the osmotic type is shown at (g, Fig. 4). It consists of an extremely small tube of metallic palladium sealed into the side of the X-ray bulb, the inner end of the metal tube being open while the outer end is closed. Ordinarily the tube is protected by a cylindrical glass cap. If the latter be removed, and the flame of a spirit-lamp be applied to the closed extremity of the palladium tube, hydrogen ions from the interior of the flame will be drawn thru the intermolecular spaces of the heated metal into the X-ray bulb.

Amateurs and physicians using X-ray outfits often desire to view considerable areas of the body simultaneously; this can be done only by using a large fluorescent screen and covering the X-ray tube with opaque material. Ordinary fluoroscopic screens are coated with barium-platinum-



One Form of Commercial High-Frequency X-Ray Bulb of the Single-focus Type, Utilizing An Active Cathode "C", Also a Small Cut-off Cathode "C'". The Inverse Cathodic Stream from "C'" Is Choked Off and Dispersed by the Constricted Glass Neck "D", Which Acts As a Valve.

cyanid and cost about $0.25 per sq. inch. A very good screen may, however, be easily made by evenly coating a sheet of white cardboard with a solution of sodium silicat and immediately sifting on it finely powdered calcium tungstat. Gently raise the screen on its edge and tap it to shake off the excess of tungstat; then allow to dry. A still simpler experimental screen may be made by painting a card several times with a strong solution of quinine bi-sulfate.

SPIES AND WIRELESS

HOW DID THE GERMANS LEARN of the dispatch of our troops to France? Not from secret wireless stations on our own coast, concludes the editor of *The Electrical Experimenter* (New York, September). Their operation would be too dangerous, and they would be unnecessary. Wireless was doubtless used, he believes, but it was probably operated from an enemy submarine far out at sea, having connection with the shore that could be operated more secretly than any system of wireless telegraphy. Wireless information spreads like sound; any one can pick it up who is within "hearing." A message over a wire is like one sent through a speaking-tube; only the person at the other end can hear it. Telegraphy by wire is far more private than wireless; the only trouble is to install the wire. In this case, the editor thinks, a private portable cable could easily have been run from the wireless station at sea to some secluded spot on the coast. There may be dozens of these outfits in existence to-day—who knows? Says the paper named above:

"When Admiral Sims took his fleet to England, Berlin knew the fact four days ahead of the arrival of our ships. Again, when our first transports were sent to France, Berlin knew that too, two days before our ships reached France; hence, the flotilla of submarines lying in ambush.

"The question is, how did the enemy get the intelligence? Our officials frankly admit that they don't know. In some quarters the opinion prevails that the information was sent by mail or by wire to Mexico—in clever code, of course—and thence sent across the Atlantic over the powerful Mexico City radio plant. This may be possible, but we much doubt it.

"We can be certain that a nation that attained as high a scientific development as Germany will use subtler and surer means to convey priceless intelligence. Besides, the roundabout route through Mexico is certainly far too slow and too dangerous, all messages being closely watched by our alert officials.

"No, we must look elsewhere. An enemy usually attacks at the most vulnerable or exposed spot. Unfortunately we have thousands of such spots, namely, our endless coast-lines. On the coast of Long Island and Maine, for instance, there are countless thousands of spots where a human being is hardly ever seen. There are hundreds of secluded little inlets and sheltered spots from which intelligence could be sent out in a ridiculously simple manner, and perfectly safe too for the sender.

"No, we don't think he would be so foolish as to operate even a mediocre radio outfit, for our Navy has too many ears. What, for instance, is to prevent a spy from sending messages daily to a submarine lying still some ten or more miles off the coast? This could be accomplished by various methods. One is by means of the Fessenden underwater oscillator; twenty to thirty miles can be covered very easily. And if we don't know that this sort of thing is going on, we'll never discover the spy. And we insist once more that no man in his right senses will use a radio outfit—it is too dangerous.

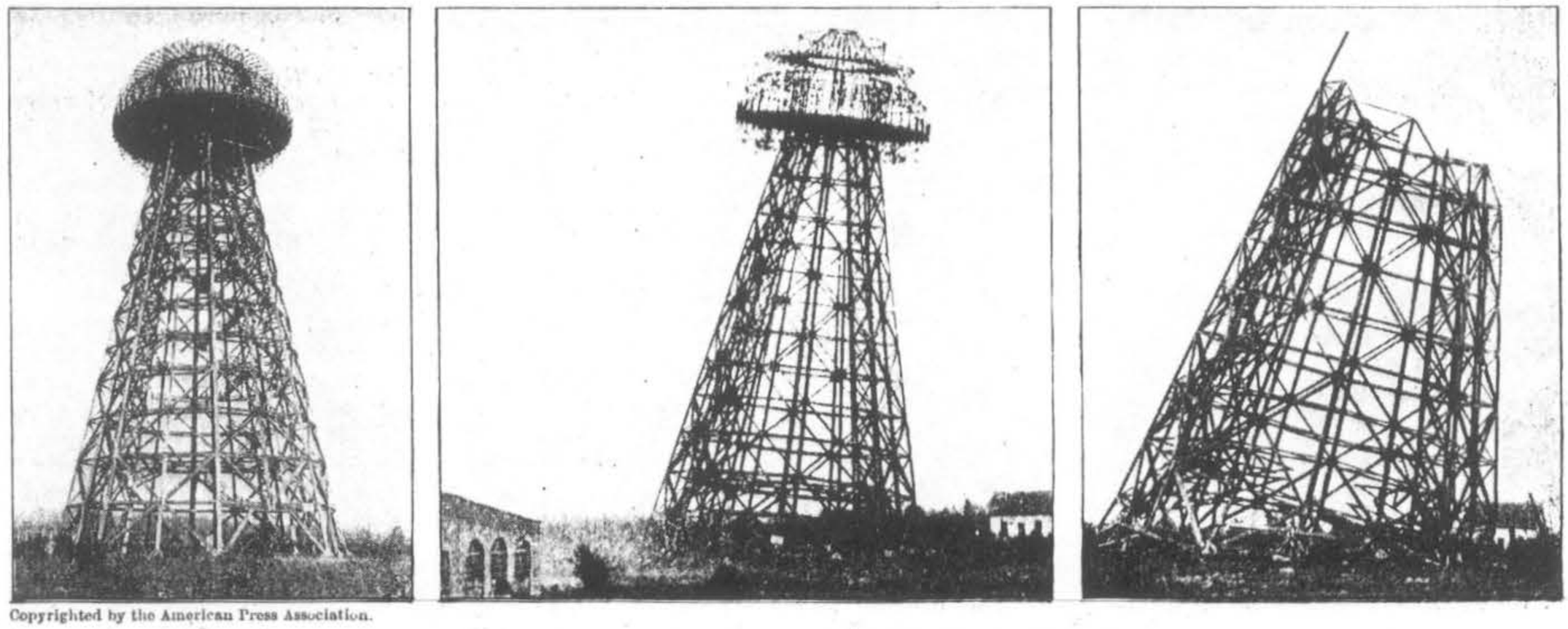
"Then, again, what is to prevent an enemy submarine from bringing over an electric cable ten or twenty miles long, unreeling it on a shallow sand bank (using a motor-boat to accomplish this), and establishing a secure terminal in one of the secluded spots on the coast. The other end, twenty miles out in the ocean, could end in a submerged buoy. The submarine then has nothing to do but to hover about that buoy, while the land operator presses his key at certain prearranged hours of the day. By means of an electromagnet inside of the buoy, the metal shell of the latter is struck, spelling out the Morse or other code signals. The sound can be muffled, of course, to such an extent that only a submarine with underwater microphones can hear the sounds over a radius of a few hundred feet.

"Then by using its own powerful radio, the submarine can send the message across the Atlantic. By radiating certain long, undamped waves, detection becomes almost impossible. For as soon as the message is sent the *U*-boat submerges and lies motionless for the next twenty-four hours if necessary.

"Now, this may or may not be the exact means how the trick is done; at any rate, we feel that the intelligence leaves by way of our coast-line—it is too vulnerable and too inviting.

"The remedy? Intensified and intelligent coast-patrols—thousands of them. Then let us sink supersensitive microphones two or three miles apart along our entire coast-line. This will do two things: First, every underwater signal could be heard, no matter where; secondly, hostile *U*-boats could be heard readily and accurately located.

"We owe it to our soldiers to take every precaution humanly possible. We do not wish to wait till a score of our transports have been sunk."



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TESLA'S TOWER, DESTROYED ON SUSPICION OF SERVING THE PURPOSES OF GERMAN SPIES.

THE LAST OF TESLA'S TOWER

THE MYSTERIOUS STEEL TOWER built by Nikola Tesla at Shoreham, L. I., about twenty years ago, in connection with some of his experiments, was demolished by order of the Government recently. The tower was described not long ago in these columns at the time when rumor pointed to the resumption of experimental work there. This rumor proved unfounded, and since the entrance of the United States into the war it has been suspected that the tower was being used for wireless purposes by German spies. Strangers are said to have been seen about the place during the past month. Tesla erected the tower, which was about 185 feet high, with a well 100 feet deep, for use in experimenting with the transmission of electrical energy for power and lighting purposes by wireless. The equipment cost nearly $200,000. Says a writer in *The Electrical Experimenter* (New York, September):

"The late J. P. Morgan backed Nikola Tesla with the money to build this remarkable steel tower, that he might experiment in wireless even before people knew of Marconi.

"Briefly explained, the Tesla theory is that a wireless tower, such as that here illustrated and specially constructed to have a high capacity, acts as a huge electric condenser. This is charged by a suitable high-frequency, high-voltage apparatus, and a current is discharged into the earth periodically and in the form of a high-frequency alternating wave. The electric wave is then supposed to travel through the earth along its surface shell, and in turn to manifest its presence at any point where there might be erected a similar high-capacity tower to that above described.

"A simple analogy to this action is the following: Take a hollow spherical chamber filled with a liquid, such as water; and then, at two diametrically opposite points, let us place, respectively, a small piston pump, such as a bicycle pump, and an indicator, such as a pressure gage. Now, if we suck some of the water into the pump and force it back into the ball by pushing on the piston handle, this change in pressure will be indicated on the gage secured to the opposite side of the sphere. In this way the Tesla earth-currents are supposed to act.

"The patents of Dr. Tesla are basically quite different from those of Marconi and others in the wireless-telegraphic field. In the nature of things this would be expected to be the case, as Tesla believes, and he has designed apparatus intended for the transmission of large amounts of electrical energy, while the energy received in the transmission of intelligence wirelessly amounts to but a few millionths of an ampere in most cases by the time the current so transmitted has been picked up a thousand miles away. In the Hertzian-wave system, as it has been explained and believed in, the energy is transmitted with a very large loss to the receptor by electromagnetic waves which pass out laterally from the transmitting-wire into space. In Tesla's system the energy radiated is not used, but the current is led to earth and to an elevated terminal, while the energy is transmitted by a process of conduction. That is, the earth receives a large number of powerful high-frequency electric shocks every second, and these act the same as the pump piston in the analogy.

"Quoting from one of Tesla's early patents on this point: It is to be noted that the phenomenon here involved in the transmission of electrical energy is one of true conduction and is not to be confounded with the phenomena of electrical radiation, which have heretofore been observed, and which, from the very nature and mode of propagation, would render practically impossible the transmission of any appreciable amount of energy to such distances as are of practical importance.' "

SEVENTY-THIRD YEAR

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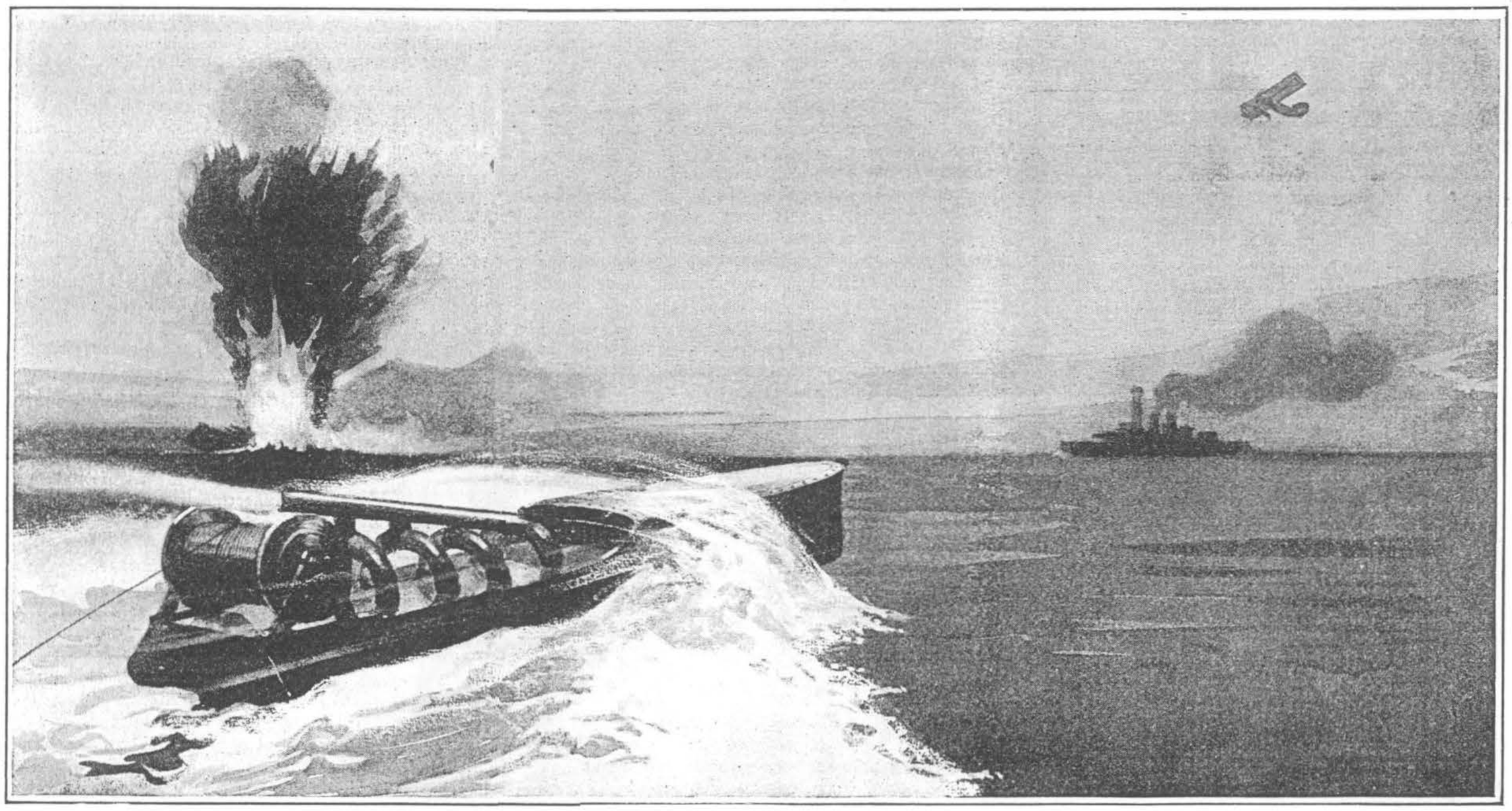

Our artist's conception of the electrically-operated crewless raiders employed by the Germans against the British monitors patrolling the waters off the Belgian coast

German Raiders Which Put Out to Sea Without Crews

ONCE more the Germans have sprung a surprise on the Allied forces, this time in the shape of a crewless raider that is electrically-operated through a cable from a shore station. Already several of these craft have been encountered by British warships cruising off the Belgian coast, but at the moment of writing all such attacks have failed of result.

The crewless raider idea is by no means new. As far back as 1885, the British Admiralty experimented with a similarly controlled vessel known as the "Vernon." In our own country the same idea was put forward some twenty years ago, in the form of the Sims-Edison directive torpedo, which was driven by an electric motor carried within the shell of the torpedo. This crewless craft was steered by exciting certain magnets that controlled the steering gear. Current for operating the motor and magnets was supplied through a flexible cable that was wound upon a reel carried within the shell of the torpedo, with one end connected to the shore. As the torpedo traveled through the water the cable was paid out in its wake, just as in the case of a cable ship. The torpedo proper was maintained at the proper depth by attaching it to a canoe-shaped float. To enable the operator to follow the course of the torpedo, two small poles were carried on the float, and by keeping his eye on these, the operator was supposed to be able to steer the deadly weapon toward its target. By night two colored lights were carried at the top of the masts, and each was hooded in such a manner that while it was visible to the operator, it remained invisible to the enemy.

The "Victoria," an Australian invention, differed from the last-mentioned in being entirely submergible and in using compressed air as its motive power. When first started it hauled a cable after it, unwinding it from a reel on shore. The first part of the journey was covered at a moderate speed. When the operator had guided his craft to within striking distance of the enemy, however, an electrical impulse was sent through the cable in order to release a reel on the torpedo, which then began to pay out cable in its wake. At the same time the impulse also started the air engines at full speed, and the final dash for the ship was made. Still another type of crewless destroyer was the "Brennon," which received considerable attention as the result of its being taken up by the British Admiralty and subjected to exhaustive experiments.

But all directive torpedoes were found to be only moderately successful, and none of them gained much favor with the naval authorities. For one thing, the trailing cable presented numerous difficulties in operation; and the craft, equipped with either an electric motor or a pneumatic engine, was not over-powerful for the work at hand. The main objection, however, was in the matter of visibility: the Sims-Edison torpedo, for instance, could only be followed by the eye to a distance of about two miles, beyond which it was lost to sight. This short range naturally proved a serious obstacle, for in coast defense work it is necessary to be able to strike at an enemy at a far greater distance—at least at a distance as great as the range of his guns.

During 1898 Nikola Tesla, the well-known inventor of New York city, proposed a crewless raider or torpedo operated by wireless waves, and obtained a patent on such a device. Practical wireless telegraphy was then barely a year old, and it is very doubtful indeed if he would have had much success with his radio control if it had been put to a practical test. And even allowing that it would have proved successful, Tesla only solved half the problems, namely, those having to do with the trailing cable; there still remained the paramount question of visibility.

Since Tesla's wireless raider, inventors in practically every country in the world have at some time or another suggested radio-controlled craft for destroying hostile warships, in some instances even building and trying out such vessels with promising results. For our part, John Hays Hammond, Jr., developed a radio-controlled craft which performed remarkably well in experiments at Gloucester Bay, Mass., and it is quite likely that this young inventor achieved the greatest advancement in this field.

Still, naval authorities in the past have preferred to make use of more conventional weapons such as the torpedo, the submarine and the torpedo boat destroyer, leaving the crewless raider aside for future consideration. The last-mentioned weapon, to their mind, was only applicable to coast defense work, and then only under certain ideal and rare conditions.

Coming to the present crewless raiders of the Germans, we learn from statements of the British Admiralty that these are electrically-controlled boats propelled by twin gasoline engines, partially closed in, and are capable of traveling at a high rate of speed. Each raider carries a drum with between 30 and 50 miles of insulated, single-core cable, which is paid out in the wake of the vessel and through which the mechanism is controlled from shore. The forepart carries a considerable charge of high explosive, probably from 300 to 500 pounds, which is arranged to explode on impact.

The method of operating the crewless raider is to start the engines, after which the men leave the boat. A seaplane, protected by a strong fighting patrol, then accompanies the vessel at a distance of from three to five miles and signals to the shore operator of the helm. These signals need only be "starboard," "port," or "steady."

By an obviously clever grouping of the wireless idea, the high-speed gasoline craft, and the electrically-controlled plan, the Germans have made use of the crewless raider scheme in a twentieth century way. They have not overcome the disadvantages of a trailing cable, to be sure; but they have overcome the problem of visibility, for the aerial observer in the seaplane which

(Concluded on page 390)

German Raiders Which Put Out to Sea Without Crews

(*Concluded from page 377*)

convoys the raider is at all times within visual distance. Since power to drive the craft is entirely self-contained and need not be transmitted through the cable, the Germans have been able to use a much smaller cable and thus overcome the difficulties in this direction. It is evident that they use a one-wire cable, depending on the salt water for the return current to complete the circuit. The mechanism aboard the boat probably includes a contact making device operating by steps, so that certain combinations of impulses sent over the single-wire cable bring any desired set of contacts into position to perform the required operation.

Just how effective the crewless raider is in practice still remains to be proved. Perhaps the Germans, over-confident of their scheme, have been rather premature in launching their latest naval surprise. Perhaps the crewless raiders are best adapted to work at night or during foggy weather, when the craft, by means of hooded lamps as in the case of the old Sims-Edison torpedo, can remain invisible to the enemy while its course is in plain view of the seaplane observer.

But why have the Germans revived this idea? The answer is not difficult to find. For months past British monitors of shallow draft have been operating off the coast of Flanders, harassing with their heavy guns the German troops and organizations on the Belgian shore and hinterland. At times the Germans have had their communications seriously threatened by the shelling from the British monitors, and at all times they have been seriously troubled by these barge-like ships mounting huge 16-inch guns.

How to do away with the British monitors has been a sore problem with the Germans. Their shore batteries have been unable to inflict serious damage on the enemy because of their being outranged. Submarines could not be used against the British monitors because the waters off the coast are too shallow. Only a major naval attack could solve the problem—and then only if the German fleet were fortunate enough to escape the main British fleet.

By a gradual process of considering and eliminating every means of dealing with the troublesome British patrols, the Germans finally hit upon the crewless raider idea, which they have now tried, but so far without success. Surprise was the biggest factor in favor of the revived weapon; and though this factor is now gone, it will be interesting to note what success, if any, the Germans have in the future.

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THE TECHNICAL STORY OF THE FREQUENCIES

BY B. G. LAMME

ABSTRACT OF PAPER

The various frequencies used in alternating-current work in America are first mentioned, and the primary reasons for their introduction are given. This covers, to a certain extent, the merits and demerits of each frequency as then understood, and the reasons each one met certain pressing commercial conditions at the time it was brought out. This is followed by a discussion of various alternating-current applications which were more or less dependent upon frequency.

It is shown that there was an apparent need for two standard frequencies in the region of 60 and 25 cycles, and, further, why 60 and 25 cycles have prevailed. The special fields of application of each one are discussed fully and it is shown why 25 cycles tended to dominate the field.

The persistent developments of the designing engineers gradually overcame the limitations in various types of 60-cycle apparatus so that eventually the 60-cycle system in its application approached more and more closely to the 25-cycle and, in the end, has taken the lead.

The outcome of the battle of the frequencies was determined far more by the conditions in the operating field than by the exploitation of any particular system by designing engineers. As a consequence, the energies of the engineers were directed exclusively toward overcoming the defects and limitations of the systems and not expended in fighting each other.

THE STORY of how and why the various commercial frequencies came into use and then dropped out again, in most cases, is not primarily the story of the frequencies themselves, but of the various uses to which the alternating current has been applied.* In other words, fundamental changes in the application of alternating current have led to radical changes in the frequencies. Some of the applications which have had a determining factor on the frequency of the supply system are as follows; incandescent lighting, transformers, transmission systems, arc lighting, induction motors, synchronous converters, constructional conditions in rotating machinery, and operating conditions. A brief consideration of these items individually,

*It should be distinctly understood that this paper covers only the story of American development.

from the present viewpoint, indicates that while some of them had, at one time, very considerable influence in determining frequency conditions, yet, in a number of cases, the original reasons have disappeared through improvements and refinements, as will be described later.

At various times the following standard frequencies have been in use in this country, namely, 133⅓, 125, 83⅓, 66 2/3, 60, 50, 40, 30 and 25 cycles per second. These did not appear chronologically in the order given above, and a few odd frequencies in a few special applications are omitted.

In the following, the various frequencies will be considered more or less in the order of their development and basic reasons will be given for their choice, and the writer will endeavor to show why certain of them have persisted, while others have dropped out. It will also be shown why the commercial situation has first tended strongly toward certain frequencies and afterwards swung toward others.

133 and 125 Cycles

In the earliest alternating work, the whole service consisted of incandescent lighting, and the electric equipment was made up of small high-speed belted single-phase generators and house-to-house distributing transformers. As the transformers were of small capacity and as their design was in a very crude state, it was believed that a relatively high frequency would best meet the transformer conditions. A choice of such an odd frequency as 133⅓ cycles per second, is due to the fact that in those early days (1886 to 1893) frequencies were usually designated in terms of alternations per minute. One of the earliest commercial generating units constructed by the Westinghouse company had a speed of 2000 rev. per min. and had eight poles. This presented a fairly convenient constructional arrangement for the surface-wound type of rotating armature, which was the only one recognized at that time. The speed of 2000 rev. per min., with eight poles, gave 16,000 alternations per minute, or 133⅓ cycles per second according to our present method of designation. Thus the earliest frequency in commercial use in this country was fixed, to a certain extent, by constructional reasons, although the house-to-house transformer problem apparently indicated the need for a relatively high frequency. The Thomson-Houston company adopted a standard frequency of 15,000 alternations per minute, (125 cycles) instead

of the Westinghouse 16,000, but the writer does not know why this difference was made. However, the two frequencies were so close together that practically they could be classified as one.

At this time, it should be borne in mind, there were no real transmission problems, no alternating-current arc lighting, no induction motors and the need for uniform rotation of the generators was not recognized. The induction motor, in its earliest stages, came in 1888 and considerable work was done on it in 1889 and 1890, but it required polyphase supply circuits and comparatively low frequency and, therefore, it had no connection whatever with the then standard single-phase, 133⅓ and 125-cycle systems. The synchronous converter was also unheard of (one might say almost undreamed of) at that time.

60 Cycles

In 1889 or 1890 it was beginning to be recognized in this country that some lower frequency than 125 and 133⅓ cycles would be desirable. Also about this time direct-coupled and engine-type alternators were being considered in Europe and it was felt that such construction would eventually come into use in America. It was appreciated that in such case, 133⅓ cycles would present very considerable difficulties compared with some much lower frequency, due to the large number of poles which would be required. For instance, an alternator direct driven by an 80-rev. per min. engine would require 200 poles to give the required frequency and such construction was looked upon as being practically prohibitive. About this time Mr. L. B. Stillwell, then with the Westinghouse company, made a very careful study of this matter of a new frequency, in connection with the possibilities of engine-type generators, and after analyzing a number of cases, it appeared that 7200 alternations per minute (60 cycles per second), was about as high as would be desirable for the various engine speeds then in sight. Transformer constructions and arc lighting were also considered in this analysis. While it was deemed that a somewhat higher frequency might be better for transformers, yet a lower frequency than 60 cycles was considered as possibly better for engine-type generators. A compromise between all the various conditions eventually led to 60 cycles as the best frequency. However, while this frequency originated about 1890, it did not come into use suddenly, for it was impossible to introduce such a radical change in a brief time. Moreover, the direct-coupled

or engine-type generator was slow in coming into general use and, therefore, there was not the necessity for the introduction of this low frequency in many of the equipments sold from 1890 to 1892. However, by 1893, 60 cycles became pretty firmly established and was sharing the business with the $133\frac{1}{3}$-cycle systems. It should be borne in mind that, at this time, the adoption of this frequency was not considered as a direct means for bringing forward the polyphase induction motor, for the earlier 60-cycle systems, like the 125- and $133\frac{1}{3}$-cycle, were all single-phase. Also, it was then thought that the polyphase motor would possibly require a still lower frequency and, moreover, the polyphase system was looked upon as in a class by itself, suitable only for induction motor work. At that time the introduction of polyphase generators for general service was not contemplated. This followed about two or three years later.

In 1890 the Westinghouse company, which had been developing the Tesla polyphase motor, laid aside the work, largely on account of there being no suitable general supply systems for this type of motor. The problem was again revived in 1892, in an experimental way, with a view to bringing out an induction motor which might be applied on standard frequencies such as could be used in commercial supply circuits for lighting and other purposes. It should be understood that at this time such circuits were not in existence but were being contemplated. In 1893, after the polyphase motor had been further developed up to the point where it showed great commercial possibilities, the best means for getting it on the market were carefully considered. It was decided that the best way to promote the induction motor business was to create a demand for it on commercial alternating-current systems. This meant that, in the first place, such systems must be created. Therefore, it was decided to undertake to fill the country with polyphase generating systems, which were primarily to be used for the usual lighting service. It was thought that, with such systems available, the time would soon come when there would be a call for induction motors. In this way experience would be obtained in the construction and operation of polyphase generators and the operating public would not be unduly handicapped in the use of such generators, compared with the older single-phase types.

An early example of this new practise was in the 2000-kw. polyphase generating units used for lighting the Chicago World's Fair in 1893. Here the single-phase type still persisted, as each

generator unit was made up of two similar frames placed side by side, but with their single-phase armatures d'splaced one-half pole pitch from each other so that the combined machine delivered two single-phase currents displaced 90 degrees from each other. It was considered that each circuit could be regulated independently for lighting service, and polyphase motors could be operated from the two circuits. These generators (at that time the largest in this country) were designed in 1892 and were of 60 cycles. These, therefore, indicate the tendency at that time toward lower frequency and polyphase generation, although commercial polyphase motors were not yet on the market.

25 CYCLES

At the same time that 60 cycles was selected as a new standard it was recognized that at some future time there would be a place for some much lower frequency, but it was not until two years later that this began to narrow down to any particular frequency. In 1892 the first Niagara electrification, after several years consideration by eminent authorities, had centered on polyphase alternating current as the most desirable system. The engineers of the promoting company had also worked out what they considered the most suitable construction of machine. This involved 5000-h. p. units at 250 revolutions per minute. Prof. George Forbes, one of the engineers of the company had furnished the electrical designs for a machine with an external rotating field and an internal stationary armature. His design used eight poles, thus giving 2000 alternations per minute, or $16\frac{2}{3}$ cycles per second. Quite independently of this, the Westinghouse company, in 1892, had been working on the development of synchronous converters, using belted 550-volt d-c. generators with two-phase collector rings added. The tests on these machines had shown the practicability of such conversion and had even proved at this early date, that the converter copper losses were much lower than in the corresponding d-c. generators. Thus it is an interesting fact that the first evidence of this important principle was obtained from a shop test rather than by calculation. The writer, from an analysis of the tests, which were made under his immediate direction, concluded that the armature copper losses must be considerably lower than in the same machine used as a d-c. generator. He also brought the matter to the attention of Mr. R. D. Mershon, then with the Westinghouse company, and the problem was then worked out mathematically by him

and the writer, in two quite different ways, but with similar results, showing that the converter did have actually very much reduced copper losses.

As a result of this work of the Westinghouse company on the synchronous converter, it was decided that, to make such machines practicable, some suitable relatively low frequency was required. This appeared to be about 30 cycles. About this time the construction of the Niagara generators was taken up with the Westinghouse company to see whether it would construct these machines according to the designs submitted by the promoting company's engineers. These designs were gone over as carefully as the knowledge of such apparatus, at that time, permitted, and many apparent defects and difficulties were pointed out. The Westinghouse company then proposed, as a substitute, a 16-pole, 250-rev. per min. machine (the speed being definitely fixed at 250 rev. per min.). This gave $33\frac{1}{3}$ cycles or as near to the Westinghouse proposed 30-cycle system, as it was possible to get. Then many arguments were brought forward, pro and con, for the two machines and frequencies. Prof. Forbes' preference for $16\frac{2}{3}$ cycles was based partly on the possibilities it presented for the construction and operation of commutator type motors, just as with direct-current circuits. The Westinghouse contention was that this frequency was too low for any kind of service except possibly commutator type machines. Tests were made with incandescent lights and it was found that at $33\frac{1}{3}$ cycles there was little or no winking of light, while at $16\frac{2}{3}$ cycles, the winking was extremely bad. Tables were also made up, showing the limited number of speed combinations at $16\frac{2}{3}$ cycles for induction motors, in case such should come into use. This showed how superior the $33\frac{1}{3}$ cycles would be as regards such apparatus. It was also brought out that synchronous converters, when such became commercial, would be much better adapted for the higher frequency, as the choice of speeds would be much greater. From the present viewpoint the arguments appear to have been much in favor of the Westinghouse side of the case.

As a consequence of all this discussion the suggestion was advanced by some one, that a 12-pole, 250-revolution machine, (that is, 3000 alternations, or 25 cycles), might meet sufficiently the good qualities of both of the proposed frequencies and would thus be a good compromise. In consequence a 12-pole, 25-cycle machine was worked up by the Westinghouse company and

eventually this frequency was adopted for the Niagara generators. Afterwards, while these generators were being constructed it was brought out pretty strongly that the great advantage of this frequency would be in connection with synchronous converter operation, but that it was also extremely well adapted for slow-speed engine-type generators, which were then coming into use. In consequence of the prominence given this frequency it was soon adopted as a standard low frequency, especially in those plants where synchronous converters were expected to form a prominent part of the system.

However, while 60 and 25 cycles came into use, as described above, it must be recognized that they had competitors. For instance, $66\frac{2}{3}$ cycles (8000 alternations or one-half of 16,000) was used to a considerable extent by one of the manufacturing companies. Also 50 cycles came into use in certain plants and, to a certain extent, is still retained, but has become the standard high frequency of Europe. Instead of 25 cycles, the Westinghouse company advocated 30 cycles for some of its plants, largely because with the 20 per cent higher speeds permissible with such frequencies, the capacities of induction motors could be correspondingly increased and also incandescent lighting was more satisfactory. However, it was soon recognized that the $66\frac{2}{3}$ and 30-cycle variations from the two leading frequencies of 60 and 25 cycles were hardly worth while, and they were gradually dropped, except in plants already installed. A brief attempt was made at a somewhat later period to place 40 cycles upon the market as a substitute for both 25 and 60 cycles. This was done under the impression that 40 cycles would give a universal system for arc and incandescent lighting, transmission, induction motors, synchronous converters and about everything else. This frequency possessed many merits and it was thought, at one time, that it might win out, but apparently the two other frequencies were too well established, and the 40-cycle system eventually lost ground.

The problem of the frequencies finally narrowed down to the two standards, and these two were accepted because it was thought that they covered such entirely different fields of service that neither of them could ever expect to cover the whole. In other words, two standards were required to cover the whole range of service. It was recognized that 25 cycles would not take care of alternating-current arc lighting and that it was questionable for incandescent lighting in general. In other ways,

such as suitability for engine-type construction, application to induction motors and synchronous converters and transmission of power to long distances, it met the needs of an ideal system, as then understood. Also, in parallel operation of engine-type alternators, which was one of the serious problems of those days, the 25-cycle machines were unquestionably superior to the 60-cycle ones, due to the lesser displacement of the e. m. f. waves with respect to each other with a given angular variation in the engine speeds. However, although the 25-cycle system presented so many advantages, it could not take care of the lighting business, and, therefore, could not entirely dominate the situation.

As regards 60 cycles, it was felt that this could handle the direct lighting situation in a very satisfactory manner and was possibly better suited for transformers than 25 cycles, although there were differences of opinion in this matter, especially when it came to the larger capacities. It was reasonably well adapted for induction motors in general, but not for very low speeds. In matters of transmission and in the operation of synchronous converters it was thought to be vitally defective.

From the above consideration it would appear that the 25-cycle systems presented the stronger showing as a whole and, therefore, there was a decided tendency toward this frequency, except in those cases where lighting directly from the alternating-current system was considered of prime importance. In those systems, such as many of the Edison companies, where low-voltage three-wire direct current was used from synchronous converters, the tendency was almost solidly toward the 25-cycle system. In those days the central station, which had been committed to the 60-cycle system so deeply that it could not change, was looked upon with commiseration. Sixty-cycle plants were looked upon, to a certain extent, as a necessary evil. In fact, so strong was the tendency toward 25 cycles that in many cases 25-cycle plants were installed for industrial purposes, where 60 cycles would have been better. The 25-cycle synchronous converter development advanced by leaps and bounds and the machines were so good in their operation that it was believed that 60-cycle converters could never be really competitive with them.

On the other hand, in those large plants, which were so "unfortunate" as to have 60 cycles installed, many apparent makeshifts were adopted to meet the various service requirements.

In arc lighting, incandescent lighting, transformers and motors there was no need for makeshifts. However, in conversion to direct current, one of the greatest difficulties appeared. There were many who advocated motor-generators for this purpose, largely because the 60-cycle converter was thought to be impracticable, in spite of the fact that the manufacturing companies were putting them on the market. The 60-cycle converter at that time bore a bad name. It is now recognized that many of the faults of the early 60-cycle synchronous converter operation were not in the converters themselves, but were, to a considerable extent, in the associated apparatus. Low-speed engine-type, 60-cycle generators were not always adapted for operation of synchronous converters. In fact, in numerous cases such generators would not operate in an entirely satisfactory manner in parallel with each other, and yet when it was attempted to operate synchronous converters from these same generators the unsatisfactory results were not blamed upon the generating system but upon defects of the converters themselves. Unfortunately, defects in the generating and transmission systems usually appeared in the converters as sparking and flashing, and such troubles naturally would be credited to defects in the construction of the converters themselves. In fact, in those days, 60-cycle converters were expected to do things which now are considered as absurd. For instance, in one case in the writer's knowledge a 60-cycle synchronous converter was criticized as being a very badly designed piece of apparatus, due to serious flashing at times. Investigation developed that this converter was expected to operate on either one of two independent 60-cycle systems with no rigid frequency relation to each other. The converter in service was thrown from one system to the other indiscriminately, and sometimes it flashed in the transfer and sometimes it did not. The machine was considered to be "no good" because it would not always stand such switching.

At one time the writer stood almost alone in his belief that the 60-cycle synchronous converter presented commercial possibilities sufficient to make it a strong future contender with the 25-cycle machine, provided proper supply conditions were furnished and certain difficulties in the proportions of the converter itself were overcome. One basis for his contention was that in some of the 60-cycle plants, where the generator rotation was quite uniform, the converters were evidently much superior in their operation to other plants, using low-speed engine-type

generators with considerable periodic variations. In such plants the hunting tendency of the converters was very greatly reduced, with consequent improvement in sparking and general operation. It was early recognized that hunting was a very harmful condition, both in 60- and 25-cycle synchronous converters, but whereas it was a relatively rare condition in 25-cycle plants it was much more common with 60 cycles. However, the operating public was not particularly concerned whether the trouble was in the generating plant or in the converters themselves, as long as such trouble existed and was not overcome. Very early in the synchronous converter development it was found that hunting would produce sparking or flashing at the commutators of the converters. However, even in those plants where there was no hunting apparent, there was difficulty at times due to flashing, especially with sudden change of load, which resulted in temporary increase in the d-c. voltage. This was a difficulty which was inherent in the converter itself and could not be blamed entirely upon the generating or transmitting conditions, for 25-cycle machines were practically free from this trouble under similar conditions of operation. Investigation developed the fact that this flashing trouble was due largely to unduly high value of the maximum volts between commutator bars. This difficulty was recognized long before it was overcome, simply because certain physical limitations in construction had to be removed. There were two ways in which the maximum volts per bar could be reduced, namely, by increasing the number of commutator bars per pole and by decreasing the ratio of the maximum volts to the average volts per bar, that is, by increasing the ratio of the pole width to the pole pitch, but both of these involved structural limitations in the allowable peripheral speeds of the commutator and the armature core. Here is where a little elementary mathematics comes in. The peripheral speed of the commutator is directly proportional to the distance between adjacent neutral points on the commutator, and the frequency. Therefore, with a given frequency the distance between the adjacent neutral points is directly proportional to the peripheral speed. Thus, with a commutator speed of 4500 ft. per min. which was then considered an upper limit, the distance between adjacent neutral points on a 60-cycle converter is only $7\frac{1}{2}$ in. (19 cm.) This distance is thus fixed mathematically and is independent of the number of poles or revolutions per minute, or anything else, except the peripheral

speed and the frequency. With this distance of $7\frac{1}{2}$ in., (19 cm.), about the only choice in commutator bars per pole was 36, giving an average of $16\frac{2}{3}$ volts per bar on a 600-volt machine, and nearly 20 volts per bar with momentary increase of voltage to 700, which is not uncommon in railway service.

However, it is not this average voltage which fixes the flashing conditions, but it is the maximum voltage between bars, and this is dependent upon the average voltage and upon the ratio of the pole width to the pole pitch. Here is where one of the serious difficulties came in. The pole pitch is directly dependent upon the peripheral speed of the armature core and the frequency. Therefore, in a 60-cycle machine, if the peripheral speed is fixed, the pole pitch is practically fixed. For example, with an armature peripheral speed of 7200 ft. per min., (which was considered high at that time,) the pole pitch becomes 12 in. (30.48 cm.), regardless of any other considerations, and here was where a most serious difficulty was encountered. If a sufficiently wide neutral zone for commutation was allowed the interpolar space became so wide that there was not enough left for a good pole width. For instance, if the interpolar space was made 6 in. (15.24 cm.) wide, in order to give a sufficiently wide commutating zone to prevent sparking or flashing, due to fringing of the main field, then this left only 6 in. for the pole face. With this relatively narrow pole face the ratio of the maximum volts to the average volts was so high that with the 36 commutator bars per pole the machine was sensitive to arcing between commutator bars, thus resulting in flashing. By widening the pole face this particular difficulty would be lessened or overcome, but with the fixed pole pitch of 12 in. (30.48 cm.) the neutral zone would be so narrowed as to make the machine sensitive to sparking and flashing at the brushes. Thus, no matter which way we turned we encountered trouble. Obviously there were two directions of improvement, namely, by increasing the number of commutator bars, thus reducing the average voltage, and by increasing the pole pitch, thus allowing relatively wider poles with a given interpolar space. These two conditions look simple and easy, but it took several years of experience to attain them. When we have reached apparent physical limitations in a given construction, especially when such limitations are based upon long experience, we have to feel our way quite slowly toward higher limitations. For instance, in the case of the 60-cycle converters we could not boldly jump our

peripheral speeds 20 to 25 per cent higher and simply assume that everything was all right. We first had to build apparatus and try it out for a year or so. Troubles, due to peripheral speed, do not always become apparent at once, and thus time tests are necessary. Therefore, while the peripheral speeds of the 60-cycle synchronous converters were actually increased 20 to 25 per cent practically in one jump, yet it took two or three years of experimentation and endurance tests before the manufacturers felt sure enough to adopt the higher speeds on a broad commercial scale. Thus, while the change from the older more sensitive type of 60-cycle converter to the later type occurred commercially within a comparatively short period, yet the actual development covered a much longer period.

Let us see now what an increase of 25 per cent in the peripheral speeds actually meant. As regards the commutator, the number of bars could be increased 25 per cent, that is, from 36 up to 45 per pole, which was comparable with ordinary d-c. generator practise. In the second place, an increase of 25 per cent in the peripheral speed of the armature core meant a 15-in. (38.1-cm.) pole pitch, where 12 in. (30.8 cm.) was used before. Assuming, as before, a 6-in. (15.24-cm.) interpolar space, then the pole face itself became 9 in. (22.8 cm.) in width instead of 6 in. (15.24 cm.) or an improvement of 50 per cent. In fact, this latter improvement was so great that some manufacturers did not consider it necessary to increase the number of commutator bars, although in the Westinghouse machines both steps were made.

The above improvements so modified the 60-cycle converter that it began to approach the 25-cycle machine in its general characteristics. It was still quite expensive compared with the 25-cycle, due to the large number of poles, and its efficiency was considerably lower than its 25-cycle competitor, on account of high iron and windage losses. However, due to the need for such a machine it was gradually making headway, in spite of handicaps in cost and efficiency.

Almost coincident with the initiation of the above improvements in the 60-cycle converter, came another factor which has had much to do with the success of this type of machine. This was the advent of the turbo-generator for general service. As stated before, one of the handicaps of the 60-cycle converter was in the non-uniform rotation of the engine-type generators which were common in the period from 1897 to about 1903 or 1904. But, about this latter date, the turbo-generator was making

considerable inroads on the engine-type field and within a relatively short period it so superseded the former type of unit, that it was recognized as the coming standard for large alternating power service. With the turbo-generator came uniform rotation and this at once removed one of the operating difficulties of the 60-cycle converters. However, in the early days of the turbo-generator, 25 cycles still was in the lead and many of the earlier generators were made for this frequency, especially in the larger units. But it was not long before it was recognized that 60 cycles presented considerable advantage in turbo-generator design due to the higher permissible speeds. In the earlier days of turbo-generator work, this was not recognized to any extent, as the speeds of all units were so low that the effect of any speed limitations was not yet encountered. For instance, a 1500-kw., 60-cycle turbo-generator would be made with six poles for 1200 revolutions, while a corresponding 25-cycle unit would be made with two poles for 1500 revolutions. This slightly higher speed at 25 cycles about counterbalanced the difficulties of the two-pole construction compared with the six-pole. However, before long, more experience enabled the 1200 r.p.m., 60-cycle machine to be replaced by 1800 revolutions, and a little later by two pole machines at 3600 revolutions. This, of course, turned the scales very much in the other direction. In larger units, however, the advantage still appeared to be in favor of 25 cycles, but in the course of development, 1500 revolutions was adopted quite generally for 25-cycle work, and this was the limiting speed, as such machines had only two poles, or the smallest number possible with ordinary constructions. On the other hand, for 60 cycles, 1800 revolutions was adopted quite generally for units up to almost the extreme capacities that had been considered, consequently the constructional conditions in the large machines swung in favor of 60 cycles. Therefore, with the coming of the steam turbine and the development of high-speed turbo-generator units, the tendency has been strongly toward 60 cycles. This, with the greater perfection of the 60-cycle converter, had much to do with directing the practise away from the 25 cycles.

However, there were other conditions which tended strongly toward 60 cycles. In the early development of the induction motor, the 25-cycle machines were considerably better than the 60-cycle and possibly little or no more expensive. However, as refinements in design and practise came in, certain important advantages of the 60-cycle began to crop out. For instance,

with 25 cycles there is but little choice in speed, for small and moderate size motors. At this frequency a four-pole motor has a synchronous speed of only 750. The only higher speed permissible is 1500 revolutions with two poles, and it so happens that in induction motors the two-pole construction is not materially cheaper than the four pole, consequently the principal advantage in going to 1500 revolutions was only in getting a higher speed where such was necessary for other reasons than first cost. However, in 60 cycles the case is quite different, where a four-pole machine can have a speed of 1800 revolutions, synchronous, a six-pole 1200, an eight-pole 900 and a ten-pole 720 revolutions. In other words, there are four suitable speed combinations where a 25-cycle motor has practically only one. Moreover, with the advance in design it developed that these higher speed 60-cycle motors could be made with nearly as good performance as with the 25-cycle motors of same capacity, and at somewhat less cost. However, leaving out the question of cost, the wider choice of speeds alone would be enough to give the 60-cycle motor a pronounced preference for general service.

However, there is one exception to the above. Where very low-speed motors are required, such as 100 rev. per min., the 60-cycle induction motor is at a considerable disadvantage compared with 25 cycles, or this has been the case in the past. It is partly for this reason that the steel mill industry, through its electrical engineers, adopted 25 cycles as standard some ten or fifteen years ago. At that time, it was considered that in mill work, in general, there would be need for very low-speed motors in very many cases. However, due to first cost, as well as other things, there has been a tendency toward much higher speeds in steel mill work, through the use of gears and otherwise, so that part of this argument has been lost. However, there still remain certain classes of work where direct-connected very low-speed induction motors are desirable and where 25 cycles would appear to have a distinct advantage.

In view of the above considerations, steel mill work has heretofore gone very largely toward 25 cycles, particularly where the mills installed their own power plants. However, in recent years there has been a pronounced tendency toward purchase of power, by steel mills, from central stations, and the previously described tendency of central stations toward 60 cycles has forced the situation somewhat in the steel mills, particularly in those cases where the central power supply company can furnish

power at more reasonable rates than the steel mill can produce in its own plant. This, therefore, has meant a tendency toward 60 cycles in steel mill work, even with the handicap of inferior low-speed induction motors. But, on the other hand, remedies have been brought forward even for this condition. The great difficulty in the construction of low-speed, 60-cycle induction motors is in the very large size and cost if constructed for normal power factors, or the very low power factor and poor performance if constructed of dimensions and costs comparable with 25 cycles. In the latter case the extra cost is not entirely eliminated because a low power factor of the primary input implies additional generating capacity, or some means for correcting power factor on the primary system. However, in some cases it is entirely practicable to correct the power factor in the motors themselves by the use of so called "phase advancers" of either the Leblanc or the Kapp type. Such phase advancers are machines connected in the secondary circuits of induction motors and so arranged as to furnish the necessary magnetizing current to the rotor or secondary instead of to the primary. In this way the primary current to the motor will represent largely energy and the power factors can be made equal to, or even much better than in, the corresponding 25-cycle motor; or, in some cases, the conditions may be carried even further so that the motor is purposely designed with a relatively poor power factor, in order to further reduce the size and cost, and the phase advancers are made correspondingly larger. In those cases where the cost of the phase advancer is relatively small compared with the main motor, there may be a considerable saving in the cost of the main motor and then adding part of the saving to the cost of the phase advancer.

One difficulty in the use of phase advancers is found in the variable speeds required in some kinds of mill work. In those cases where flywheels driven by the main motors are desirable to take up violent fluctuations in load, it is necessary to have considerable variations in the speed of the induction motor, in order to bring the stored energy of the flywheel into play. Unfortunately this variable speed in the induction motor is one of the most difficult conditions to take care of with a phase advancer, so that here is a condition where the 60-cycle motor is at a decided disadvantage.

Thus it may be seen from the above that even in the steel mill field, where the induction motor has the most extreme applications, there is quite a strong tendency toward 60 cycles, due to the purchase of power from central supply systems.

There remains one more important element which has had something to do with the tendency toward 60 cycles, namely, the transmission problem. In the earlier days of transmission of alternating current, 25 cycles was considered very superior to 60 cycles due to the better inherent voltage regulation conditions. At one time, it was thought that 60 cycles had a very limited field for transmission work. However, a number of power companies in the far west had installed 60-cycle plants, principally for local service and with the growth of these plants came the necessity for increased distance of transmission through development of water powers. At first it was thought they were badly handicapped by the frequency, but gradually the apparent disadvantages of their systems were overcome and the distances of transmission were extended until it became apparent that they could accomplish practically the same results as with 25 cycles. Part of this result has been obtained by the use of regulating synchronous condensers. It is a curious fact that the possibility of synchronous motors used as condensers for correction of disturbances on transmission systems, has been known for about 25 years, but it is only within quite recent years that they have come into general use as a solution of the transmission problem, and largely in connection with 60-cycle plants. In 1893 the writer applied for a patent on the use of synchronous motors as condensers for controlling the voltage at any point on a transmission system by means of leading or lagging currents in the condenser itself. A broad patent was obtained, but there was no particular use made of it until it had practically expired.

Another improvement came along which still further helped to advance 60 cycles to its present position, namely, the use of commutating poles in synchronous converters. The principal value of commutating poles in the 60-cycle converters, has not been so much in an improvement in commutation over the older types of machines, as in allowing a very considerable reduction in the number of poles with corresponding increase in speed, resulting in reduction in dimensions. As a direct result of this increase in speed the efficiencies of the converters have been increased. If, for instance, the speed of a given 60-cycle converter can be doubled by cutting its number of poles to one-half, while keeping the same pole pitch and the same limiting peripheral speed, then obviously the amount of iron in the armature core is practically halved and, at the same magnetic densities the iron loss is also practically halved. Also with the same

peripheral speed and half diameter of armature the windage losses can be decreased materially. Thus the two principal losses in the older converters have been very much reduced. There have also been reductions in the total watts for field excitation, and in other parts, so that, as a whole, the efficiency for a given capacity 60-cycle converter has been brought up quite close to that of the corresponding 25-cycle machine, even when the latter is equipped with commutating poles. This gain of the higher frequency compared with the lower is due to the fact that the lower-frequency machine was much more handicapped in its possibilities of speed increase, and furthermore, the iron losses and windage represented a much smaller proportion of the total losses in the low-frequency machine. This improvement in the efficiency of the 60-cycle converter together with the lower losses in the 60-cycle transformer as compared with the 25-cycle, has brought the 60-cycle equipment almost up to the 25-cycle, so that the difference at present is not of controlling importance. This development has given further impetus toward the acceptance of 60 cycles as a general system.

Formerly a serious competitor with the 60-cycle converter was the 60-cycle motor-generator. This was installed in many cases because it was considered more reliable and more flexible in operation than the synchronous converter. Both of these claims were true to a certain extent. However, with improvements in the synchronous coverter the difference in reliability practically disappeared, but there remained the difference in flexibility. In the motor-generator set, the d-c. voltage could be varied over quite a wide range, while in the older 60-cycle rotaries the d-c. voltage held a rigid relation to the alternating supply voltage. However, with the development and perfection of the synchronous booster type of converter, flexibility in voltage was obtained with relatively small increase in cost and minor loss in economy. This has been the last big step in putting the 60-cycle converter at the front as a conversion apparatus, so that today it stands as the cheapest and most economical method of converting alternating current to direct current. Moreover, while the 25-cycle synchronous converter has apparently reached about its upper limit in speed, there are still possibilities left for the 60-cycle converter.

In line with the above it is of interest to note that for units of 1000 kw. and less, the 60-cycle converter has nearly driven the 25-cycle out of business from the manufacturing standpoint.

For the very large size converters, 25 cycles still has the call, but largely in connection with many of the railway and three-wire systems, which have been installed for many years; that is, the growth of this business is in connection with existing generating systems. However, the 60-cycle converter, in large capacity units, is gaining ground rapidly and it is of interest to note that the largest converters yet built, namely, 5800 kw., are of the 60-cycle type.

One most interesting point may be brought out in connection with the above described "battle of the frequencies", namely, it was fought out in the operating field, and between conditions of service, and not between the manufacturing companies. This is a very good example of how such matters should be handled. Here the engineers of the manufacturing companies were expending their efforts to get all possible out of both frequencies, and consequently development proceeded apace. When 60-cycle frequency seemed to be overshadowed by its 25-cycle competitor, the engineers took a lesson from the latter and proceeded to overcome the shortcomings of the former. It was no innate preference of the designing engineers that has brought the higher frequency to the fore; it was the recognition that it had greater merits as a general system, if its weak points could be sufficiently strengthened; and, therefore, the engineers turned their best efforts toward accomplishing this result.

It must not be assumed, for a moment even, that because 60 cycles appears to be the future frequency in this country, that 25 cycles was a mistake. Decidedly it was not. In reality it formed a most important step toward the present high development of the electric industry. Many things we are now accomplishing with 60 cycles would possibly never have been brought to present perfection, if the success of the corresponding 25-cycle apparatus had not pointed the way. The success of the 25-cycle converter, and the high standard of operation attained, gave ground for belief that practically equal results were obtainable with 60 cycles. Therefore, the 25-cycle frequency served a vast purpose in electrical development; it was a high class pacemaker, and it isn't entirely out-distanced yet.

There has been considerable speculation as to what two standard frequencies would have met the needs of the service in the best manner, and would have resulted in the greatest development in the end. It has been claimed by some, that 50 and 25 cycles would have been better than 60 and 25. In the earlier

days possibly the former would have been better, but as a result both standards might have persisted longer. In any case, the general advantages would have been small. In one class of machines, namely, frequency changers, consisting of two alternators coupled together, the 25-50 combination would certainly have been advantageous.

Again it has been questioned whether 30 and 60 cycles would not have been a better choice. This was the original Westinghouse choice of frequencies, but not on account of frequency changers. As stated before, it was felt that 30 cycles could do about all that 25 cycles could, and would give an advantage of 20 per cent higher speed in motors and converters, with correspondingly higher capacities. Also for direct coupled alternators, the two-to-one ratio of frequencies would fit in nicely with engine speeds, in many cases. Possibly, from the present viewpoint, the choice of thirty cycles, would have longer retained the double standard.

Something further may be said regarding the 40-cycle system, brought out by the General Electric Company. This contained many very good features, for the time it was brought out. It was then believed that if the 60-cycle frequency was retained, the double standard was necessary. The 40-cycle system was an attempt to eliminate this double standard. It apparently furnished a better solution than 60 cycles then promised for the synchronous converter problem, and was a fair compromise in about everything else. But it came too late, for the 25-cycle system was too firmly entrenched, and for further development, the designing engineers preferred to expend their energies in seeing what could be accomplished with 60 cycles, as this seemed to present greater possibilities than either 25 or 40, if it could be sufficiently perfected. Thus the 40-cycle system probably missed success due to being just a little too late.

As to 50 cycles, it was stated that this is still in use to a limited extent. Most of the 50-cycle plants in this country are in California. Such plants were started during the nebulous period of the frequencies, and have persisted, to a certain extent, partly because certain 60-cycle apparatus could be easily modified to meet the 50-cycle requirements. Also, as 50 cycles is the standard in many foreign countries to which this country exports equipment, the use of 50 cycles in some home plants has not been unduly burdensome from the manufacturers' standpoint.

In addition to the preceding, there have been certain classes

of electric service which have depended upon frequency, but which have not been a determining factor in fixing any particular frequency. Among these may be considered commutating types of a-c. apparatus. The first a-c. commutating motors of any importance, which appeared, were, of course, the 25-cycle, single-phase railway motors. These as a rule have operated from their own generating plants, or from other plants through frequency-converting machinery. One exception in the railway work may be noted in the use of 15 cycles on the Visalia plant in California. There is a pretty well defined opinion among certain engineers experienced in such apparatus that some low frequency, such as 15 cycles, would present very considerable advantages in the use of single-phase railway motors in very heavy service, such as on some of the western mountain roads. Here the problem is to get the largest possible motor capacity on a given locomotive, and the main advantage of the lower frequency would be in allowing a very materially higher capacity within a given space. This does not imply reduced weight or cost compared with the 25 cycles, but simply means greater motor capacity. With the modern, more highly developed, single-phase types of railway motors, it would appear that there may be very considerable possibilities in 15 cycles.

Outside of the railway field, there has been more recently a development of various types of a-c. commutating apparatus, principally in connection with heavy steel mill electrification work. Such apparatus has been largely in the form of three-phase commutating machines and these have been used principally in connection with speed control of large induction motors. As these regulating machines are usually connected in the secondary circuits of induction motors, the frequency supplied is represented by the slip frequency. Consequently where the slip frequency never rises to a large percentage of that of the primary system, such commutating motors are applicable without undue difficulties. Such motors, presumably are better adapted for 25-cycle mill equipments than for 60-cycle, but due to the tendency, already described, for steel mills to go to 60 cycles on purchased power, it has been necessary to build these three-phase commutating motors for the regulation of 60-cycle main motors, in many cases.

There is still another class of service, which has come in recently, where the choice of frequency is of much importance, but where there is no great necessity for adhering to any standard,

namely, in heavy ship propulsion by electric motors. As each ship equipment is a complete system in itself, and as it cannot tie up with other systems, there is not any controlling need for maintaining any definite frequency or voltage. Except in similar vessels, there is little chance for duplication in parts, as the various equipments vary so much in size and capacity. In consequence it has been found advisable, at least up to the present time, to design each propulsion equipment for that frequency which best suits the generator and motor speeds, taking into account the various operating conditions and limitations, such as the different running speeds, steaming radius, etc. In consequence, different maufacturers bidding on such equipments may specify different frequencies, depending upon the constructional features of their particular types of apparatus. At the present time with the relatively small amount of experience obtained with the electrical propulsion of ships, it looks as if it would be a considerable handicap to attempt to adopt some standard frequency for all service. Later, with wide experience, it may be possible to adopt some compromise frequency, which will not unduly handicap any of the service.

Conclusion

It has been the writer's intention to show that, as a rule, the choice of frequency has been a matter of most serious consideration, based upon service conditions at the time. Moreover, in view of the wide range of conditions encountered, it is surprising how few frequencies have been seriously considered in this country. Occasion has arisen, times without number, where an obvious solution of a given problem would lie in modification of the frequency to allow the use of apparatus and equipment already designed, but the engineers of the manufacturing organization have steadily held out against such policy, regardless of the apparent need of the moment. The swing of the pendulum from 60 cycles to 25 cycles and back, has covered a period of many years and, therefore, cannot be considered as a fad of the moment, but is the result of well defined tendencies, backed by the best engineering experience available. As a rule no manufacturer has made any particular frequency his "pet," but all have worked to develop each system to its utmost.

DISCUSSION ON "THE TECHNICAL STORY OF THE FREQUENCIES" (LAMME), WASHINGTON, D. C., JANUARY 18, 1918.

H. B. Brooks: Mr. Lamme's instructive paper appeals strongly to those of us who have followed the development of the a-c. art from the beginning.

In addition to the early frequencies of 133 and 125 cycles, I recall that the Slattery a-c. system, made by the Fort Wayne Jenney Electric Light Co., was operated at 140 cycles. That was the day of the "system;" each inventor who designed an alternator felt in duty bound to design a complete system, including generators, transformers, station instruments, switches, cutouts, sockets, and in some cases the lamps also.

Mr. Lamme has not referred to the attempt which was made at an early stage of the art to limit the frequency to a single value, namely, zero. I refer to a rather short but bitter attempt by the advocates of d-c. distribution to have the alternating current outlawed on the ground of its alleged great risk to life.

It may be of interest to glance at the frequency situation abroad. In Italy, which is poor in coal but rich in water power five frequencies are in use, of which 42 cycles is in the lead, with 50 cycles a close second. Around Rome, 46 cycles is used, and there are also some 16 and 25-cycle installations throughout the country. The Italian Electrotechnical Association is planning a campaign to standardize frequencies.

London is probably the worst example of the independent growth of small detached generating systems with no thought of possible future interconnection. Merz and McLellan studied the situation and made a report in 1914 to the London County Council, from which it appeared that there were in the central area of London 41 generating stations representing 31 systems and 8 frequencies. The report advocates the adoption of 50 cycles as a standard frequency for London.

In contrast to the medley of plants and frequencies in London, the cities of Hamburg and Berlin each have electric supply from a single company. The frequency of the Berlin system is 50 cycles. The business in Paris is practically all in the hands of a single company, operating at 25 and 42 cycles.

A single standard frequency would have great advantages. It would permit the interconnection of transmission systems wherever this might be expedient. This question of interconnection is an important one in England at the present time, as the demands for power for war industries have overloaded some systems which are not readily able to tie in with others for mutual assistance.

A standard frequency would benefit the manufacturer by reducing the number of designs, patterns, and stock of generators, transformers, motors and meters. The user would benefit from the consequent reduction of cost, and would be able to move equipment from one locality to another without finding it inapplicable to the new supply conditions.

From the standpoint of export trade, it would be desirable to have an international standard frequency. While the attainment of this ideal appears to be far off, it is a matter which may well be kept in mind by the national engineering societies and the International Electrotechnical Commission, in order that so far as possible the trend of standardization in the different countries may be along converging lines.

I would like to ask Mr. Lamme whether the higher peripheral speeds which have greatly contributed to the success of the 60-cycle converter are made possible by the use of materials of greater tensile strength, or by improved methods of utilizing the materials heretofore available.

B. G. Lamme: The improvements have been almost entirely in the design of the machines. We are using practically the same materials that were used in the older machines, but we are proportioning the parts in such a way that they are better sustained, that is, we know more about the stresses and how to take care of them.

G. S. McCumber: I have one question that I wanted to ask. Mr. Lamme referred to the chief disadvantage of the 60-cycle system, I assume that he intended increased voltage drop and the lower power factor, but I wanted to know also whether there was any disadvantage due to such other factors as additional difficulties in insulation, corona losses or anything of that kind.

Also one other question. Reference was made to the fact that in heavy ship propulsion a variable frequency system was employed, and I wonder if he would state for us what the standard frequencies or the normal range frequencies are on which that system was based.

Robert Dalgleish: Mr. Lamme in speaking of 60-cycle converters brings to my mind the question as an operating engineer—the problem of the 25-cycle converter, which most all of us are now using. The question arises, is the 60-cycle converter in the high voltages, such as 600, in railway operation as successful as it is in the lighting voltages; and is the possibility of the future of the railway turbo-generators—and naturally the converter—to be 60-cycle instead of 25? I can appreciate that the companies who are at present equipped with 25-cycle turbo-generators are naturally going to stick to that. With the question of future installations, where the installation is entirely new, will it be an installation of 60-cycle or 25-cycle turbo-generators?

Mr. Hunt: I would like to ask Mr. Lamme what the present limit of size of the 60-cycle rotary converter is, and what are the chief limitations in design that makes that size the limit.

B. G. Lamme: Before I answer any of the questions brought up, I want to bring out more clearly what it meant to the manufacturing companies to adhere to a standard frequency. You may not appreciate, unless you have been in the manufacturing business, how easy it is to change the frequency, in many cases.

For, instance suppose a manufacturer has built a 60-cycle, 3300-volt machine at 150 r. p. m. and somebody comes along and wants a 100-r. p. m., 2200-volt machine of somewhat less capacity. The 60-cycle machine already constructed may fit the new conditions in everything except frequency. If a frequency of 40-cycles would be acceptable, then the old machine could be used without any change, but it would introduce a special frequency. Thousands of cases have come up where we could take some existing machine and meet the customer's condition, if it were not for the frequency. I have seen many cases where an existing machine was all right to meet new conditions except that it would have two poles too many or too few, and it looked so easy to make a minor change in the frequency instead of in the machine. In such cases, however, if the customer could not change his speed conditions, the manufacturer would change his design rather than modify the frequency.

There has been an enormous amount of money spent in making such changes, but the engineers of the manufacturing companies feel that they have really spent less money in making them than they would have spent in the end if they had allowed changes in frequency; for every change, no matter how small, means confusion in the end: The engineers of the manufacturing companies have been stubborn on that matter and for a good reason. That is why we have had so little variation in the frequencies in this country.

It has been asked whether the 60-cycle converter in the higher voltages, such as 600 for railway service, is as successful as it is in the lighting voltages. In reply to this I will say that, as the tendency for the last few years has been largely toward 60 cycles in new plants, which may be called upon to handle railway service as well as lighting, it has been necessary to develop the 60-cycle converter for 600-volt railway service up to the point where it compares quite favorably with similar 25-cycle machines. This is indicated by the fact that below 1000-kw. capacities there is but relatively small business in 25-cycle converters; whereas, there is quite a good business in 60 cycles. Above 1000 kw. there is a very strong tendency also toward the 60-cycle converter. In fact, while the 25-cycle rotary converter business is quite large in the units above 1000 kw., yet such machines are sold very largely to 25-cycle plants already installed, or to extensions of such plants.

As to the limit of capacity for which 60-cycle converters can be built, one answer is that the real limit is in the pocketbook of the customer. Such machines can be built of almost any capacity, if there is a demand for them. We could make 10,000-kw., 60-cycle converters today, if anybody wanted them, just as we could make 10,000-kw., 25-cycle machines. The largest 60-cycle converter is of about 5500 kw. compared with 4000 kw. for 25 cycles. Therefore, the 60 cycle is already ahead of the

25 cycle, as far as maximum capacity is concerned; but from the quantitative standpoint the large 25-cycle converters are still ahead because there were so many 25-cycle generating plants installed in the past entirely for railway work through rotary converters.

As to Mr. McCumber's questions regarding the relative disadvantages of voltage drop, insulation difficulties, corona losses, etc., in 60-cycle transmission, I will say that I am not an authority on transmission difficulties, but I understand that all the above troubles were quite serious in the early days, and that much doubt was expressed regarding the possibilities of maintaining satisfactory voltage conditions at the end of a 60-cycle line. Apparently they feared poor regulation more than any other feature. Possibly some of the difficulties in the early times worried the engineers more in the prospect than in the realization, for, apparently, when they came to operate such 60-cycle lines, they did not have as much trouble as was expected and the regulation trouble was overcome in a number of cases by the addition of synchronous condensers.

I remember, not so many years ago, that all of us pitied the Californians, for their adoption of 60 cycles as a general standard, in transmission work. It was thought that they had made a serious mistake, but now they are right in line, although they probably didn't foresee it. They had committed themselves to 60 cycles and they couldn't very well change.

As to the basic frequency used for ship propulsion, as such are variable frequency systems, it may be said that there is no definite frequency except for the highest speed which the apparatus will stand. A number of the battleship equipments have used 35 cycles for the full speed condition with variation from this down to half value or even less. On some of the other vessels as high as 50 and 60 cycles are used. The choice of frequency has been largely dependent upon the motor-speed combinations required.

The Magnetic Storm

By H. GERNSBACK

"WHY" Sparks had stopt reading the New York *Evening World:* He contemplated his old meerschaum pipe meditatively while with his long and lanky index finger, stained by many acids, he carefully rubbed a long, thin and quivering nose. This was always a sign of deep, concentrated thought of the nose's owner. It also, as a rule, induced the birth of a great idea.

Again, and very slowly he re-read the article, which millions that same day had read casually, without a quiver, let alone, a nose quiver. The newspaper item was simple enough:

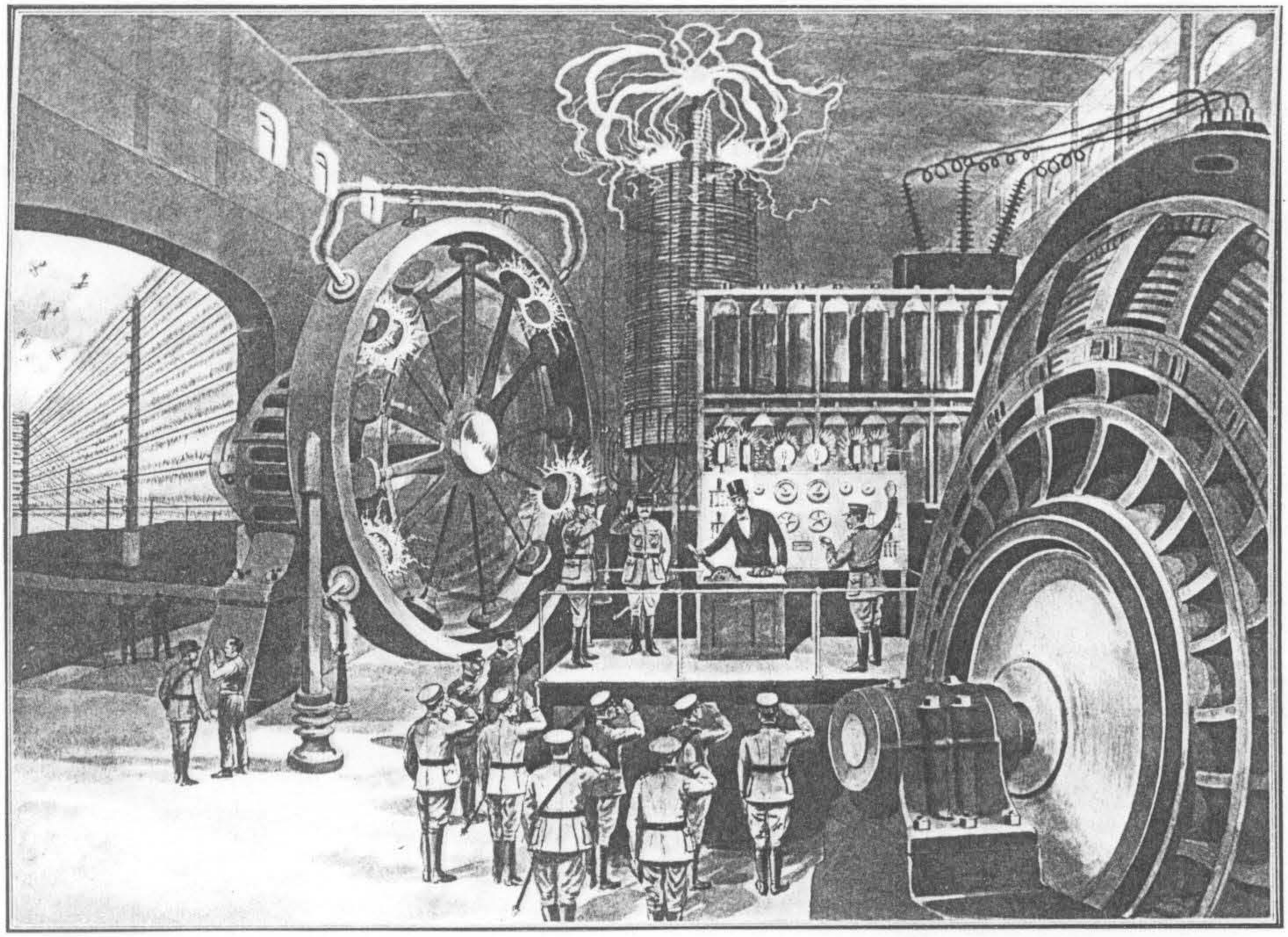
> NEW YORK, Aug. 10, 1917.—An electromagnetic storm of great violence swept over the eastern section of the United States last night. Due to a brilliant Aurora Borealis,—the Northern Lights,—telegraph and long distance telephone, as well as cable communications were interrupted for hours. No telegraphic traffic was possible between New York and points West. It was impossible to work any of the transatlantic cables between 12:15 A. M. and 9:15 A. M., every one of them having "gone dead." The Aurora Borealis disturbances affected all telegraph and telephone lines extending between Chicago and the eastern cities. On telegraph wires of the Postal Telegraph Co. without regular battery being applied at terminal offices, grounded lines showed a potential of 425 volts positive, varying to 225 volts negative; the disturbance continuing between 12:15 A. M. and 9:15 A. M.
>
> At Newark, N. J., in the Broad Street office a Western Union operator was severely shocked, trying to operate the key, while long sparks played about his instruments.

Sparks rose excitedly and began pacing the cement floor of the vast Tesla laboratory, totally oblivious to the fact that he was sucking a cold pipe. The more he paced about, the more excited he became. Finally he flung himself into a chair and began feverishly to make sketches on big white sheets of drawing paper.

"Why" Sparks had been just an ordinary "Bug," an experimenter, when he entered Tesla's great research laboratory at the beginning of the great war in 1914. Tesla liked the keen, red-haired tousled boy, who always seemed to divine your thoughts before you had uttered five words. His clear blue eyes, lying deep in their sockets, sparkled with life and intelligence and what Sparks did not know about electricity was mighty little indeed. I believe there is no electrical book in existence that Sparks had not devoured ravenously in his spare hours, while having lunch or else while in bed, in the small hours of the morning. His thirst for electrical knowledge was unbounded, and he soaked up every bit of information like a sponge. Yes, and he retained it, too. In short, the young prodigy was a living electrical cyclopedia and highly valued by his associates. No wonder Tesla in three short years had made him superintendent of the laboratory.

Of course, Sparks' first name was not really "Why." But someone had dubbed him with this sobriquet because of his eternal "But *why* is this,"—"*Why*, why should we not do it this way"—"*Why* do you try to do that?" In short his first word always seemed to be "Why"—it had to be, in his unending quest for knowledge. And his "Why" was always *very* emphatic, explosive-like, imperative, from which there was no escape.

Ah, yes, his first name. To tell the honest



. . . The President of the Glorious French Republic Shouts Dramatically: "Messieurs . . . le jour de Gloire est Arrivé . . . VIVE-LA-FRANCE!!"—and Throws in the Huge Switch With Its Long Ebonite Handle. . . .

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truth I don't know it. Last year in the spring when I went up to the laboratory, I thought I would find out. So when I finally located the young wonder, behind a bus bar, where he was drawing fat, blue sparks by means of a screwdriver, I told him that I intended to write something about him and his wonderful electrical knowledge. Would he be good enough to give me his *real* first name?

He was watching a big fuse critically, and in an absent-minded manner exploded: *"Why"?* That finished my mission. So for all I know his real name is "Why" Sparks.

But we left Sparks with his drawings, in the laboratory. That was on a certain evening last fall. To be exact it was about 10 o'clock. At 10:05 Tesla accompanied by two high Army officials strolled into the laboratory where Sparks was still feverishly engaged with sketches lying all about him.

Tesla who was working out a certain apparatus for the Government had dropt in late to show Major General McQuire the result of six weeks' labors. The apparatus had been completed that day and the General, a military electrical expert, had come over specially from Washington to see the "thing" work.

But before Tesla had a chance to throw in the switch of the large rotary converter, Sparks had leaped up, and was waving excitedly a large drawing in Tesla's face. He gushed forth a torrent of sentences, and for fully five minutes Tesla and the two Army officials were listening spell-bound to the young inventor. For a minute or two the three men were speechless, looking awe-struck at Sparks, who having delivered himself of his latest outburst, now became normal again and lit up his still cold pipe.

It was Tesla who first found his voice. "Wonderful, wonderful. Absolutely wonder-ful, Sparks. In a month you will be the most talked of man on this planet. And his *idea is* sound." This to the General. "Absolutely without a flaw. And so simple. Why, oh why! did I not think of it before? Come, let me shake the hand of America's youngest and greatest genius!" Which he did.

There then followed an excited thirty-minute conversation with the two army men and an endless long distance talk with the War Department at Washington. Then there was a rush trip to Washington by Tesla and Sparks, conferences at the War Department, and finally a few days later Sparks went to the White House and was presented to the President, who was highly enthusiastic about the model which Sparks and Tesla demonstrated to the head of the Nation. Still later there were certain rush orders from the War Department to the General Electric and Westinghouse Companies for many big, queer machines, and these same machines were shortly . . . But here the Censor bids us an emphatic "Halt." One may not even now divulge certain military information. You appreciate that.

* * * *

Baron von Unterrichter's flying "Circus" was getting ready to bomb a certain American depot behind the lines. The Americans of late had shot down entirely too many of the Baron's flyers. Only yesterday von der Halberstadt—a German ace himself—and one of von Unterrichter's closest friends had been downed, and killed right inside of the German lines. So the Baron was out for blood this sunny morning. As he put it:

*"Verdammte Yankee Schweinehunde,** we will show them who is master of the air hereabouts," shaking his fist at the American lines beyond.

*For translation of foreign terms see end of this story.

"Sie, Müller," this to an orderly.

"Zu Befehl, Herr Leutnant," replied the young orderly as he came on the run, clicking his heels together, hand at his cap.

"Versammlung, sofort," barked the chief, as he hastened Müller off to summon post haste every man of the aerial squadron for the usual conference before the attack.

In less than ten minutes the thirty flyers were standing drawn up at military attention before their chief, forming a half circle about him. Von Unterrichter's instructions were simple enough. This was a reprisal raid; von der Halberstadt's death must be avenged, fearfully avenged. No quarter was to be given.

IN THE SEPTEMBER "E.E." YOU WILL FIND:

"New Aerial Lasso to Destroy Enemy Aeroplanes," by H. Gernsback.

"Recent Electrical Ideas Applied to Submarines and Torpedoes."

"Telephoning Directly To and From Moving Trains."

"A New Wave Motor That Uses the Energy in Every Motion," by E. D. Stodder, an expert on Wave Motors.

"The Einthoven Galvanometer—Its Theory and Construction Details with Photos of Instrument Actually Built," by Samuel D. Cohen.

"Coney Island's New 1918 War Feature—'Over There'—Read How Electricity Works the Whole Show," by George Holmes.

"Artificial Diamonds and Rubies—How They Are Made in the Electric Furnace."

"The Phenomena of Electrical Conduction in Gases V—Weighing an Ion," by Rogers D. Rusk, M.A.

"An Electrical Laboratory Switchboard—How to Build a Real One." by Harlan Danner.

"Glass-blowing Lessons—How to Heat and Bend, As Well As Build Glass Chemical Apparatus—Part I," by Prof. Herbert E. Metcalf.

"Ohm's Law Applied to Alternating Current Circuits—A Clear Exposition of All the Usual Problems," by Arno A. Kluge, Instructor in Radio, University of Nebraska.

"New Direct Reading Radio Chart Which Solves All Calculations in Wave-length, Inductance and Capacity," prepared by a Marconi Radio Engineer.

"Popular Astronomy — Third Paper," by Isabel M. Lewis.

"How and Why of Radio Apparatus—Part X," by H. Winfield Secor.

"Dieses Amerikanische Gesindel!"—here his voice rose to a shrill pitch, "must be taught to respect us, as never before. The orders are to bomb every American base hospital within the sector. . . ."

At this several of the men recoiled involuntarily, which did not escape the keen eye of von Unterrichter, who now incensed to blind fury, by this show of "softheartedness," as he put it, exhorted his men in his harshest possible terms. "And as for their flyers, you must not give quarter. You must not be satisfied with disabling their machines. Kill them! *Schiesst die Lumpen zusammen!* Pump nickel into them, if you see that they may land unharmed"—this in direct violation of all flying etiquette—a thing abhorred by any decent flyer as a rule. It is bad enough to have your machine shot down, but "sitting on a disabled enemy's tail," and pouring machine gun fire into a helpless man, struggling in mid-air,—where was German prestige coming to with such methods. Plainly the men did not like such liberties with their honor, but orders are orders. They grumbled audibly and cast not very encouraging looks at their chief. Even his parting shout: *"Vorwärts—für Gott und Vaterland,"* failed to bring the usual cheers.

Promptly on the minute of 10 fifteen flyers of the "Circus" rose, like a flock of big white sea gulls, heading in "V" formation towards the American lines. Von Unterrichter was leading his herd in a big *Fokker.* He was out for blood and he meant to have it. His face was set, his jaws clenched like a vise. Hate was written in large characters over every feature of his face. . . . Why didn't these *Dollarjäger* stay home and mind their own business chasing their dollars? What right did they have in this fray, anyway. *"Elendige Schweinebande,"* he spoke out loud, to better vent his overpowering hate.

But where were the Yankee *Flieger* today? The Baron's "Circus" was up one thousand meters and less than a mile away from the American first line trenches, but still no machine in sight, either American or French. Strange. Quite an unheard of occurrence. Afraid? *"Unsinn,"* he muttered to himself, they were not the sort to be afraid. Von Unterrichter knew that. For the first time he felt a vague sort of uneasiness creeping over him. He could not understand. There was not a *Flieger* anywhere in sight. None on the ground either, as he scanned the vast saucer below him thru his *Zeiss.* Was it a new trick, was . . .

Before he finished his train of thought, his engine stopt dead. Cursing volubly he made ready to "bank" his machine in order to volplane down behind his own lines. He congratulated himself that his engine had not stopt later while over the enemy's lines, but his pleasure was short-lived. For he suddenly became aware of the fact that there was a supreme quiet reigning all about him. Why did he not hear the loud roar of the other fourteen engines, now that his own engine was quiet? Looking around he perceived with horror that every one of the fourteen machines of the "Circus" had simultaneously "gone dead," too, *all of them now volplaning earthward.*

Sick with an unknown terror, von Unterrichter made a clumsy landing in the midst of his other flyers, all of them pale, some shaking, some with a strange animal expression in their eyes. *What unknown, invisible hand had with one stroke disabled the fifteen engines, one thousand meters above the ground?*

"Himmelkreuzdonnerwetter," shrieked von Unterrichter jumping to the ground, near his airdrome. "I . . . I . . . cannot" . . . here his voice broke. For the first time in his life the young Prussian was speechless. He then stamped his foot in a frenzied fury, but finally gave vent to a full round of cursing, as only a Prussian can curse. At last he collected his senses sufficiently to look for the cause of the mysterious occurrence. It only took five minutes to find it. His mechanician pointed to the magneto.

"Kaput," he said laconically, if not grammatically.

"Auseinander nehmen," commanded the chief.

It took the deft mechanician but a minute to take the magneto apart, and to withdraw the armature. He gave it one look and with a sickly smile uttered:

"Ausgebrannt, Herr Leutnant." *Herr Leutnant* took the armature into his own hands and inspected it critically. Sure enough it was burnt out, if ever there was a burnt out armature. Perhaps fused would be a better term. The armature was

(Continued on page 267)

THE MAGNETIC STORM

(*Continued from page* 233)

beyond repair, a child could see that. He flung it away and went over to the next nearest flyer. But the mechanic had already located the trouble—in the magneto. Burnt out, too!

Von Unterrichter unutterably sick at heart, aimlessly wandered about the other machines. In each case the result was the same: *Every magneto armature of the fifteen flyers was burnt out,* the wires fused together, all insulation gone!

"Aber so 'was", muttered von Unterrichter, looking about him helplessly. It took fully five minutes before it filtered thru his thick Prussian skull that this disaster that overtook his "circus" could by no means be a coincidence.

"Verfluchte Amerikaner", he said, "probably a new *Teufelmaschine* of Edison!"

But what would the *Kommando* say to this? Instantly he stiffened as he jumped into a waiting automobile, attached to the airdrome.

"Zum Kommando, schnell", he ordered the driver as he sank back into his seat. He must report this queer business to headquarters at once. The driver cranked the engine, then cranked it some more. Pfut . . . pfut . . . pfut . . . spluttered the engine asthmatic-like, but it did not start. He tried again. Same result.

(*Continued on page* 268)

"Donnerwetter nochmal", stormed the Baron vexed over the delay, *"was ist denn jetzt los,* why in thunder don't you start, you miserable dog?" But the engine would not start. The perplexed chauffeur climbed into the seat of the old style car, which still had its faithful spark coils, so necessary to the ignition system. But the spark coil refused to work, altho the storage battery was fully charged and all the connections were right. Cautiously he pulled out one of the spark coil units from its box. One look told the story.

"Ausgebrannt, Herr Leutnant," he said weakly, for he had seen the burnt out magneto armatures a few minutes before.

Von Unterrichter, with eyes almost popping out of his head, was struck absolutely speechless for half a minute. *"Heiliger Strohsack"*, he muttered awestruck, remembering his young sister's favorite expression, whenever something out of the ordinary happened to her. He finally collected himself sufficiently and jumped out of the car.

"Zum Telefon", he muttered to himself. He must report this uncanny occurrence at once to the *Kommando*. Not a second was to be lost. He at last understood that something momentous had happened. He made the airdrome on the run and tho it was only 200 yards away he surprised himself at the speed he made. Puffing volubly he arrived at the telephone. He gave the handle several quick turns, *grasped the receiver and simultaneously bellowed into the mouthpiece in front of him:

"Hallo, hallo" . . . but he went no further. The receiver flew from his ear, for there had been a loud clattering, rattling, earsplitting noise in the instrument that almost burst his eardrum. He made a foolish grimace, as he held his ear with his hand. Cautiously he approached the receiver to within a few inches of his other ear and listened. All was quiet, not a sound. Mechanically he unscrewed the receiver cap and looked at the two bobbins. *They were charred and black.* The telephone was dead. . . .

The instrument slipt from his hand and dangling by its red and purple cord went crashing against the wall of the airdrome, while von Unterrichter limply sank into a chair.

Once more he got up and walked out. He must get into touch with his General at all costs. This was becoming too serious. Ah . . . he had it, the field telegraph. There was one at the other end of the building. He went there as fast as his legs could carry him. He opened the door of the little office but one look sufficed. The young man in charge of the telegraph sat dejected in a corner, a dumb expression in his eyes. Long purple sparks were playing about the instruments on the table. A child could have seen that it was impossible to either send or receive a telegram under such conditions. . . . Ah! an inspiration. . . .

"Dummkopf", he muttered to himself, "Why didn't I think of it before. *Die Funkenstation!* Surely the wireless must work! Ha, ha, there are no wires *there* at least to burn out!"

The radio station was over a kilometer away. He knew it well, for he had flown over it a great many times. To get there quick, that was the question. The *Kommando* was at least eight kilometers to the rear, and he knew he could not make that distance on foot very quickly. Ah, yes, there was a horse somewhere around. The

*All German telephones are magneto operated. To call Central you must turn the handle of the ringing magneto.

cavalry horse was located soon, and as the young airman walked hurriedly about, troubled as he was, he could not help noticing the listless attitude of every man he past. Men were whispering in a hushed manner, alarm was plainly written in their faces—the fear of the unknown.

Von Unterrichter jumped on to his horse and galloped in the direction of the field radio station. It did not take him long to reach it, and long before he dismounted he could see the bright blue spark of the sending station.

"Gott sei Lob", he uttered to himself as he jumped to the ground, "at least that's working."

Note here the curious mechanism of the Prussian mind. A Prussian officer, the most arrogant, distasteful creature imaginable, is always the great brave hero when he knows that he is fighting with all the advantages on his side. As Heinrich Heine, the poet,—himself a German-hater,—puts it:

"The Germans have no self-respect. They are the only men in the world who, as private soldiers, will stand still while an officer kicks them or bespatters them with mud. They receive the mud with smiles and stand expectantly, cap in hand."

It is the Prussian-German sort of "honor" that makes a Zabern affair possible, where a foul-mouthed young officer, with his sword, beats a helpless, crippled Alsatian cobbler insensible.

A coward at heart, always ready to blaspheme his maker, when things go right, the Prussian quickly turns to his German *Gott,* as soon as things go against him.

Heine,—himself a German, and he ought to know,—will tell you so.

Now it so happened that von Unterrichter had been an expert wireless man before the war, and while he did not know a great deal about electricity, he well knew how to send and receive messages.

He ran to the wagon which carried the mobile radio field apparatus and peremptorily ordered the operator in charge away. *"Aber Herr Leutnant"*, expostulated the thus rudely interrupted man, "I tell you . . ."

"Maul halten", thundered von Unterrichter, with which he sat down, clamping the operator's receivers on his own head.

He prest the key impulsively, and noted with grim satisfaction that the loud blue spark crashed merrily in the not very up-to-date spark gap.

As he sent out the call mechanically, he wondered vaguely what the matter could be with the government, because it did not even supply a modern, up-to-date *Löschfunkenstrecke* — quenched spark gap — for field use. Things must be pretty bad when the government must economize even a few beggarly pounds of brass, so necessary for a noiseless spark gap.

But he could not give that matter further attention for he had thrown the aerial switch from "sending" to "receiving."

He had strained his ears for a reply from the operator from the *Kommando*, but, as the switch was thrown, instead of a reply there was a loud, constant roar in the receivers, so loud that it was painful. Off came the headgear, while von Unterrichter once more sank into a chair.

He was a pitiful spectacle to look at, the fate of a 20th Century man flung back a hundred years. His eyes roamed idly about till the distant railroad embankment struck his eye. No train was moving. Everything was at a standstill—how could a train move without a telegraph? How could a train be dispatched—there would be a thousand collisions. He turned to the radio operator, who as yet had not grasped the situation in its entirety.

"Nordlicht, nicht wahr, Herr Leutnant?" he began, thinking no doubt that the phenomenon was an ordinary form of Aurora Borealis,—the northern lights,—in other words, a magnetic storm, that would be over soon.

"Dummes Rindsvieh" . . . snapt the *Herr Leutnant,* who knew better by this time. Indeed he was to know still more at once, for while he was speaking there came to his ear a low dull roar, a sound he had heard once before, way back in 1914 when the Germans had retreated very much in a hurry beyond the Marne.

Panic seized him. Yes the sound was unmistakable. The German army once more was in full retreat—no it was a rout—a panic-stricken rabble that made its way back.

Like lightning the news had spread among the men at the front that uncanny things were afoot, that all communications had been annihilated with one stroke, that no orders could be sent or received except by prehistoric couriers, that the *Grosses Kommando* was cut off from the army, and that in short the German army as far as communication was concerned, had suddenly found itself a century back.

For what had happened to von Unterrichter that morning, had happened on a large scale not only to every one along the front, *but all over Germany as well!* Every train, every trolley car, every electric motor or dynamo, every telephone, every telegraph had been put out of commission. With one stroke Germany had been flung back into the days of Napoleon. Every modern industry, every means of traffic—except horse-drawn vehicles—were at a standstill. For days the German retirement went on, till on the fifteenth day, the entire German army had retired behind the natural defenses of the Rhine, the victorious Allies, pressing the fleeing hordes back irresistibly.

And it must have been a bitter pill for the German high command to swallow when they saw that the Allied fliers were constantly flying behind their own lines and that as the Allies advanced, *their* automobiles and *their* trains seemed to run as well as ever *behind* their own lines. But no German succeeded in flying an aeroplane or in running an automobile. That mysterious force obviously was trained only against the Huns, but was harmless behind the Allied lines. Nor did the Germans find out to this date what caused their undoing.

Peace having not been declared as yet, I cannot, of course, divulge the full details of the scheme of just how the Germans were finally flung across the Rhine. That, of course, is a military secret.

But I am permitted to give an outline of just what happened on that memorable morning, when the German "Kultur" was flung back into the dark ages where it belongs.

* * * *

But first we must go back to Tesla's laboratory once more, back to that evening when "Why" Sparks first overwhelmed Tesla and his companions with his idea. This is in part what Sparks said:

"Mr. Tesla! In 1898 while you were making your now historic high-frequency experiments in Colorado with your 300-kilowatt generator, you obtained sparks 100 feet in length. The noise of these sparks was like a roaring Niagara, and these spark discharges were the largest and most wonderful produced by man down to this very day. The Primary coil of your oscillator measured 51 *feet in diameter,* while you used 1100 amperes. The voltage probably was over 20 million. Now, then in your book, *High Frequency Currents,* among other things you state that the current which you produced by means of this mammoth electric oscillator was so terrific that its effect was felt 13 miles away. Altho there were no wires between your laboratory and the Colorado Electric Light & Power Co., five miles distant, your *"Wireless" Energy* burnt out several armatures of the large dynamo generators, *simply by long distance induction from your high frequency oscillator.* You subsequently raised such havoc with the Lighting Company's dynamos that you had to modify your experiments, altho you were over five miles away from the Lighting Company.*

"Now then, if in 1898, twenty years ago, you could do that, why, WHY cannot we go a step further in 1918, when we have at our command vastly more powerful generators and better machinery. If you can burn out dynamo armatures 13 miles distant with a paltry 300 kilowatts, *why* cannot we burn out every armature within a radius of 500 miles or more.

"The primary coil of your oscillator in 1898 was 51 feet in diameter. WHY *cannot we build a primary 'coil' from the English Channel down to Switzerland, paralleling the entire Western front?* This is not such a foolish, nor such a big undertaking as you might think. My calculations show that if we were to string highly insulated copper wires one-quarter inch thick on telegraph poles behind the front, the problem would become a simple one. Ordinary telegraph poles can be used, and each pole is to carry twenty wires. Beginning three feet above the ground, each wire is spaced two feet distant from the next one. These wires run continuous from the sea to Switzerland. Moreover, every ten miles or

*The above occurrences as well as the cited experiments and effects of the Tesla currents are actual facts checked by Mr. Tesla himself, who saw the proof of this story.—*Editor.*

so we place a huge 3,000 kilowatt generating plant with its necessary spark gaps, condensers, etc. The feed wires from these generating plants then run into the thick wires, strung along the telegraph poles, forming the gigantic Tesla Primary Coil. Of course, you realize that in a scheme of this kind it is not necessary to run the telegraph poles actually parallel with every curve of the actual front. That would be a waste of material. But we will build our line along a huge flat curve which will sometimes come to within one-half mile of the front, and sometimes it will be as much as fifteen miles behind it. The total length of the line I estimate to be about 400 miles. That gives us 40 generating plants or a total power of 120,000 kilowatts! A similar line is built along the Italian front, which is roughly one hundred miles long at present. That gives us another 30,000 kilowatts, bringing the total up to 150,000! Now then, the important part is to project the resultant force from this huge Tesla primary coil *in one direction only*, namely that facing our erstwhile friends, the Huns. This I find can be readily accomplished by screening the wires on the telegraph poles at the side facing our way as well as by using certain impedance coils. The screen is nothing else but ordinary thin wire netting fastened on a support wire between the telegraph poles. This screen will then act as a sort of electric reflector. So." . . . Sparks demonstrated by means of one of his sketches.

"Everything completed we turn on the high-frequency current into our line from the sea to little Switzerland. Immediately we shoot billions of volts over Germany and Austria, penetrating every corner of the Central empires. *Every closed coil of wire thruout Germany and Austria, be it a dynamo armature, or a telephone receiver coil, will be burnt out, due to the terrific electromotive force set up inductively to our primary current.* In other words every piece of electrical apparatus or machinery *will become the secondary of our Tesla coil, no matter where located.* Moreover the current is to be turned on in the day time only. It is switched off during the night. The night is made use of to advance the telegraph poles over the recaptured land,—new ones can be used with their huge primary coil wires, for I anticipate that the enemy *must* fall back. Turning off the power does not work to our disadvantage, for it is unreasonable to suppose that the Teutons will be able to wind and install new coils and armatures to replace all the millions that were burnt out during the day. Such a thing is impossible. Besides, once we get the Germans moving, it ought to be a simple matter to follow up our advantage, for you must not forget that we will destroy ALL their electrical communications with one stroke. No aeroplane, no automobile, will move thruout the Central States. In other words, we will create a titanic artificial *Magnetic Storm* such as the world has never seen. But its effect will be vastly greater and more disastrous than any natural magnetic storm that ever visited this earth. Nor can the Germans safeguard themselves against this electric storm any more than our telegraph companies can when a real magnetic storm sweeps over the earth. Also, every German telegraph or telegraph line in occupied France and Belgium will be our ally! These insulated metallic lines actually help us to "guide" our energy into the very heart of the enemy's countries. The more lines, the better for us, because all lines act as feed wires for our high frequency electrical torrents. . . ."

* * * *

A few kilometers north of Nancy, in the Department of Meurthe et Moselle, there is a little town by the name of Nomeny. It is a progressive, thrifty little French town of chief importance principally for the reason that here for four years during the great war the French army has been nearer to the German frontier than at any other point, with the exception of that small portion of Alsace actually in the hands of the French.

Nomeny in the military sense is in the Toul Sector, which sector early in 1918 was taken over by the Americans. If you happened to go up in a captive balloon near Nomeny you could see the spires of the Cathedral of Metz, the great German fortress, but 16 kilometers away, always presuming that the air was clear and you had a good glass.

On a recent warm summer morning there were queer doings at a certain point in the outskirts of Nomeny. All of a sudden this point seemed to have become the center of interest of the entire French, British and American armies. Since dawn the military autos of numerous high Allied officers had been arriving while the gray-blue uniforms of the French officers were forever mixing with the business-like khaki of the British and Americans.

The visitors first gave their attention to the camouflaged, odd-looking telegraph poles which looked like huge harps, with the difference that the many wires were running horizontally, the telegraph line stretching from one end of the horizon to the other. A few hundred yards back of this line there was an old brewery from which ran twenty thick wires, conecting the brewery with the telegraph poles. To this brewery the high officers next strolled. An inspection here revealed a ponderous 3,000 kilowatt generator purring almost silently. On its shining brass plate was the legend: "Made in U. S. A." There was also a huge wheel with large queer, round zinc pieces. Attached to the axis of this wheel was a big electric motor, but it was not running now. There were also dozens of huge glass jars on wooden racks lined against the wall. Ponderous copper cables connected the jars with the huge wheel.

One of the French officers, who previous to the war had been an enthusiastic Wireless Amateur, was much interested in the huge wheel and the large glass bottles. "Aha", said he, turning to his questioning American confrère, *"l' éclateur rotatif et les bouteilles de Leyde."*

There was little satisfaction in this, but just then a red-haired, tousled young man who seemed to be much at home in the brewery, came over and adjusted something on the huge wheel.

"What do you call all of these do-funnies?' 'our young officer asked of him, pointing at the mysterious objects.

"Rotary spark gap and Leyden jars," was the laconic reply. The officer nodded. Just then there was a big commotion. The door flew open and a French officer standing at attention shouted impressively:

"Le Président de la République!"

Instantly every man stood erect at attention, hand at the cap. A few seconds later and President Poincaré walked in slowly, at his side General Pétain. It was then five minutes to 10.

President Poincaré was introduced to the red-haired, tousled young man whom he addrest as *Monsieur* Sparks. *Monsieur* Sparks speaking a much dilapidated French, managed, however, to explain to his *excellence* all of the important machinery, thanks to a sleepless night with a French dictionary.

Monsieur Poincaré was much imprest and visibly moved, when a French officer had gone over Sparks' ground, and re-explained the finer details.

The President now takes his stand on an elevated platform near a huge switch which has an ebonite handle about a foot long. He then addresses the distinguished assembly with a short speech, all the while watching a dapper young French officer standing near him, chronometer in hand.

Somewhere a clock begins striking the hour of ten. The President still speaks but finishes a few seconds later. The distinguished assemblage applauds and cheers vociferously, only to be stopt by the dapper young officer who slowly raises his right hand, his eyes glued to the chronometer. Immediate silence prevails, only interrupted by the soft purring of the huge generator. The dapper young officer suddenly sings out:

"Monsieur le Président! A-ten-tion! ALLEZ!!"

The President of the glorious French Republic then shouts dramatically: *"Messieurs . . . le jour de gloire est arrivé . . . VIVE—LA—FRANCE!!"*—and throws in the huge switch with its long ebonite handle.

Instantly the ponderous rotary spark gap begins to revolve with a dizzying speed, while blinding blue-white sparks crash all along the inside circumference with a noise like a hundred cannons set off all at once. The large brewery hall intensifies the ear-splitting racket so much that every one is compelled to close his ears with his hands.

Quickly stepping outside the party arrives just in time to see fifteen Boche airplanes volplaning down and disappearing behind the German lines. A French aerial officer who had observed the German aeroplanes, drops his glass, steps over to the President, salutes smartly and says impressively:

"Le 'cirque' du Baron d'Unterrichter! Ils sont hors de combat!"

Hors de combat is correct. Von Unterrichter was not to fly again for many a week.

We look around to tell the glad news to General Pétain, but the latter has disappeared into a low brick building where he now sits surrounded by his staff, poring over military maps ornamented with many vari-colored pencil marks, as well as little brightly-colored pin flags. Telephone and telegraph instruments are all about the room.

Again the President shakes hands with *Monsieur* Sparks, congratulating him on his achievement. Luncheon is then served in the former office of the brewery, gayly bedecked with the Allied flags along the walls. But even here, far from the titanic rotary spark gap, its crashing sparks are audible. Looking thru the window we see a wonderful sight. Altho it is broad daylight, the entire queer telegraph line is entirely enveloped in a huge violet spray of electric sparks. It is as if "heat-lightning" were playing continuously about the whole line. No one may venture within fifty feet of the line. It would mean instant death by this man-made lightning.

Luncheon is soon over and more speeches are made. Suddenly the door flings open and General Pétain steps in. One look at his remarkable features, and all talk stops as if by magic. He crosses the room towards the President, salutes and says in a calm voice, tho his eyes betray his deep emotion:

"Monsieur le Président, toute l'armée Allemande est en retraîte!!"

And so it was. The greatest and final retreat of the Kaiser's "invincible" hordes was in full swing towards the Rhine.

More congratulations are to be offered to Sparks. A medal, . . . Heavens, where is that young man? But Sparks has slipt over to his machines and is standing in front of the noisy "thunder and lightning" wheel eyeing it enthusiastically.

"Why, oh WHY, do they call you *éclateur!*" he says. "Spark Gap is good enough for me!" "Oh, boy!! But you aren't doing a thing to those *Germins!*"

THE END

Translation of German and French Terms Used in This Story.

GERMAN

Verdammte Yankee Schweinehunde: Damned Yankee Pig-Dogs!
Sie, Müller: You, Müller!
Zu Befehl, Herr Leutnant: At your orders, Lieutenant!
Versammlung, sofort: Assembly, at once!
Dieses Amerikanische Gesindel: This American rabble!
Schiesst die Lumpen zusammen: Shoot the ragamuffins together!
Vorwärts für Gott und Vaterland: Onward, for God and Fatherland!
Dollarjäger: Dollar Chasers.
Elendige Schweinebande: Miserable band of pigs.
Unsinn: Nonsense.
Flieger: Flyer (aeroplane).
Himmelkreuzdonnerwetter: A popular German cuss word. Literally it means "sky-cross-thunder." English equivalent is "A thousand thunders."
Kaput: German slang, equivalent to our slang "busted."
Auseinander nehmen: Take it apart!
Ausgebrannt: Burnt-out.
Aber so 'was: Such a thing (of all things).
Verfluchte Amerikaner: Cursed Americans.
Teufelmaschine: Diabolic machine.
Zum Kommando, schnell: Quick, to Headquarters!
Donnerwetter nochmal: By all thunders!
Was ist denn jetzt los? What's up now?
Heiliger Strohsack: Holy bag-of-straw; equivalent to "Holy Gee."
Dummkopf: Blockhead.
Die Funkenstation: The Radio Station.
Gott sei Lob: God be thanked.
Aber, Herr Leutnant: But, Lieutenant!
Maul halten: Shut up.
Löschfunkenstrecke: Quenched Spark Gap.
Nordlicht, nicht wahr?: Northern lights, is it not?
Dummes Rindsvieh: Stupid piece of cattle.
Grosses Kommando: General Headquarters.

FRENCH

L'éclateur rotatif et les bouteilles de Leyde: Rotary spark gap and Leyden jars.
Le President de la République: The President of the Republic.
Monsieur le President! Attention! Allez! Mr. President! Ready! Go!
Messieurs, le jour de gloire est arrivé, vive la France!: Gentlemen, the day of glory has arrived, long live France!
(This is from the second verse of the "Marseillaise")
Le "cirque" du Baron d'Unterrichter! Ils sont hors de combat!: Baron von Unterrichter's circus! They are out of the fighting!
Monsieur le Président, toute l' armée Allemande est en retraite: Mr. President, the entire German army is in retreat.

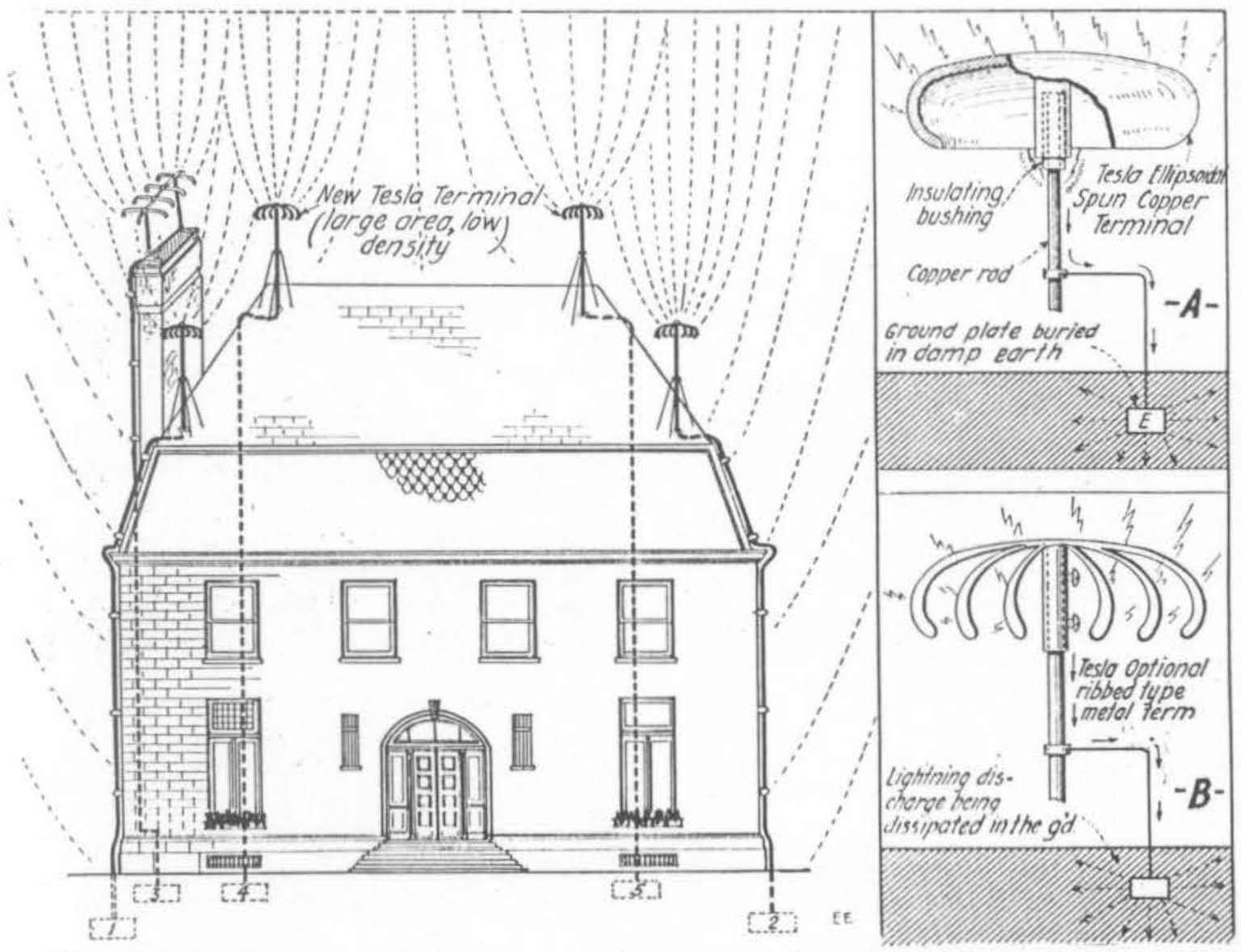
Tesla Has New Pointless Lightning Rod

SINCE the introduction of the lightning rod over one hundred years ago by Benjamin Franklin, its adoption as a means of protection against destructive atmospheric discharges such as lightning bolts, has been practically universal. In a recent discussion on the subject of lightning protection, Dr. Nikola Tesla of New York, brings out many interesting facts not generally known concerning the real efficacy of the ordinary lightning rod as installed on houses, barns and public buildings all over the world.

Says, Dr. Tesla, "The efficacy of the ordinary lightning rod is to a certain degree unquestionably establisht thru statistical records, but there is generally prevalent, nevertheless, a singular theoretical fallacy as to its operation, and its construction is radically defective in one feature, namely its typical pointed terminal." In his new form of lightning protecting rod and terminal here illustrated, Tesla avoids all such points on the metal parts facing skyward, and uses an entirely different form and arrangement of terminals.

In permitting leakage into the air, the needle-shaped lightning rod is popularly believed to perform two functions: one to drain the ground of its negative electricity, the other to neutralize the positive electricity of the clouds. To some degree it does both. But a systematic study of electrical disturbances in the earth has made it palpably evident that the action of Franklin's conductor, as commonly interpreted, is chiefly illusionary. Actual measurement proves the quantity of electricity escaping even from many points, to be entirely insignificant when compared with that induced within a considerable terrestrial area, and of no moment whatever in the process of dissipation. But it is true that the negatively charged air in the vicinity of the rod, rendered conductive thru the influence of the same, facilitates the passage of the bolt. Therefore it increases the probability of a lightning discharge in the vicinity. The fundamental facts underlying this type of lightning-rod are: First, it attracts lightning, so that it will be struck oftener than would be the building if it were not present; second, it renders harmless most, *but not all,* of the discharges which it receives; third, by rendering the air conductive, and for other reasons, it is sometimes the cause of damage to neighboring objects; and fourth, on the whole, its power of preventing injury predominates, more or less, over the hazards it invites.

By contrast, Tesla's new lightning protector is founded on principles diametrically opposite. Its terminal has a *large surface.* It secures a very *low density* and preserves the insulating qualities of the ambient medium, thereby minimizing leakage, and thus acting as a quasi-repellant to increase enormously the safety factor.



Nikola Tesla, Expert on High Frequency Currents, Such As Lightning Discharges, Has Recently Patented the New "Rounded" Form of Lightning Rod, Which He States Is Superior to the Time-Honored "Pointed" Rods so Familiar to All of Us. Also, Dr. Tesla Has Good Reasons For This Radical Departure in Lightning Rod Design.

An understanding of but part of the truths relative to electrical discharges, and their misapplication due to the want of fuller appreciation has doubtless been responsible for the Franklin lightning rod taking its conventional *pointed form,* but theoretical considerations, and the important discoveries that have been made in the course of investigations with a Tesla wireless transmitter of great activity by which arcs of a volume and tension actually comparable to those occurring in nature were obtained, at once establish the fallacy of the hitherto prevailing notion on which the Franklin type of rod is based and show the distinctive novelty of this new lightning protector.

Practical estimates of the electrical quantities concerned in natural disturbances show, moveover, how absolutely impossible are the functions attributed to the pointed lightning conductor. A single cloud may contain several billion electric units, or more, inducing in the earth an equivalent amount, which a number of lightning rods *could not neutralize in many years.* Particularly to instance conditions that may have to be met, reference is made to an actual case (in 1904) wherein it appears that upon one occasion approximately 12,000 strokes occurred within two hours, all within a radius of less than 31 miles from the place of observation.

But altho the pointed lightning rod is quite ineffective in the one respect noted, it has the property of attracting lightning to a high degree,—first, on account of its shape and secondly, because it ionizes and renders conductive the surrounding air. This has been unquestionably establisht in long continued tests with the Tesla wireless transmitter above-mentioned, the inventor claims, and in this feature lies the chief disadvantage of the Franklin type of protector.

In Fig. A and Fig. B, different forms of such low density terminals and the arrangement of the same are illustrated. In Fig. A, there is a cast or spun metal shell of ellipsoidal outline, having on its under side a sleeve with a bushing of porcelain or other insulating material, adapted to be slipt tightly on a metal rod, which may be an ordinary lightning conductor. Fig. B shows another form of terminal made up of rounded or flat metal bars radiating from a central hub, which is supported directly on a metal rod and in electrical contact with the same. The special object of this type is to reduce the wind resistance, but it is essential that the bars have a *sufficient area to insure small electro-static density,* and also that they are close enough to make the aggregate capacity nearly equal to that of a continuous shell of the same outside dimensions. The general view of the building shows a cupola-shaped and earthed metal dome carried by a chimney, serving in this way the twofold practical purpose of hood and protector.

From the foregoing it will be clear that in all cases the new Tesla terminal prevents leakage of electricity and attendant ionization of the air. It is immaterial to this end whether it is insulated or not. Should it be struck the current will pass readily to the ground either directly or, as in Fig. A, thru a small air-gap between. But such an accident is rendered extremely improbable owing to the fact that there are everywhere points and projections on which the terrestrial charge attains a high density and where the air is ionized. Thus the action of the improved protector is equivalent to a repellant force. This being so, it is not necessary to support it at a great height, but the ground connection should be made with the usual care and the conductor leading to it must be of as small a self-induction and resistance as practicable. Tesla has taken out a patent on this new lightning protector.

TESLA COAL MINE

BY J. W. BECKMAN

(A renewal of interest in the lignite deposits of the West has accompanied the fuel shortage and the development of methods for efficiently utilizing low grade coals. A suggestion is here made of some of the possibilities of the greatest of the lignite mines in California.—The Editor.)

The state of California can boast many natural resources but lacks in a marked degree high grade coal. There are only a few known coal deposits in California and these are all lignite, among them being the Stone Canyon, the Ione, Black Diamond, an undeveloped deposit in Mendocino county, and the Tesla coal mine. The only mine that has really been worked on a large scale and showed a large production is the Tesla mine. For many years it supplied the coal for all the railroads in the San Joaquin valley and supplied fuel to the cities of Stockton, Oakland, San Francisco and others, but a lignite coal, such as the Tesla coal is, could not compete with the cheap oil which came in as a fuel in the early part of 1900. Due to unfortunate financial circumstances, combined with the severe competition cheap oil was offering the coals from the Tesla mine, it was completely abandoned in 1907. Approximately three to four million dollars had been spent on the mine—tunnels averaging a total length of about eight miles had been driven through the seams and approximately twelve million tons of coal of various qualities had been blocked out and are still untouched.

The coal seams, of which there are a great number, stand practically vertical and vary from a few feet to fifteen feet in width. The various seams produce different quality coal. The best coal, as to ash content, is superior to most of the soft coals of Pennsylvania, while the lower grade coals run as high as twenty per cent of ash. The difference between Pennsylvania soft coal and a lignite lies principally in the fact that the Pennsylvania coal will coke while the lignite will not coke.

Lignite contains all the volatiles and fixed carbons necessary to make a desirable fuel. Many lignites are known by their slacking qualities, while the Tesla lignites in most of the seams do not slack at all.

When the coal mines were abandoned in 1907 mechanical stokers were novelties and powdered coal as a fuel had not been thought of. Within the last few years powdered coal has been introduced as one of the most efficient ways by which coals of all grades can be utilized under boilers. Coals, even with a high ash content, are as easily handled as those of low ash content and the combustion of the coal is complete. An efficiency of 98% is practically standard practice and the condition in the combustion chamber is equal to that where oil is fired.

The Tesla coal mine with its high grade lignites will offer coals in the San Francisco and adjacent territory suitable for powdered coal fuel. In the state of Washington many large boiler plants are at present supplied with powdered coal equipment, where low grade lignites from the state of Washington are being burned with complete satisfaction and efficiency.

A ton of lignite burned in powdered condition will give an approximately equal efficiency to four or five barrels of oil. With the simple and efficient method of handling powdered coal under boilers, it is possible to produce electric power by steam at very low figures. In the East in the state of Pennsylvania some enormous power plants are being erected at the mouths of mines where powdered fuel will be used exclusively.

The Tesla coal mine is located on a branch of the Western Pacific Railway and is only thirty miles from San Francisco Bay. In view of its close proximity to the industrial district, coupled with the modern steam power plant developments, it offers an unusual opportunity for the establishing of a steam electric plant which would be able to supply energy to this territory.

Between the coal veins of the Tesla mine there are very extensive deposits of clays of varying composition. These clay deposits open up possibilities in the clay industry which are enormous. While the Tesla mine was in operation fire bricks were made of the very best quality. Sewer tile and common brick were also manufactured from raw materials mined together with the coal.

The Tesla mine was recently purchased by the Beckman & Linden Engineering Corporation of San Francisco and plans are already under way by which to develop its resources. It is hoped to be able to get some of the coal out even this season and to some extent relieve the oppressive oil situation in the state.

Future plans are being made for the establishing of a steam power station at the mine, from which it is estimated power can be delivered at a profit for $15.00 per horsepower a year. Some plans which are being considered are the manufacture of various clay products, such as fire bricks, sewer pipe, and others. The advantage of controlling the fuel necessary in burning the clay products, as well as the clay deposits themselves, is apparent.

Nikola Tesla and His Inventions

By H. Gernsback

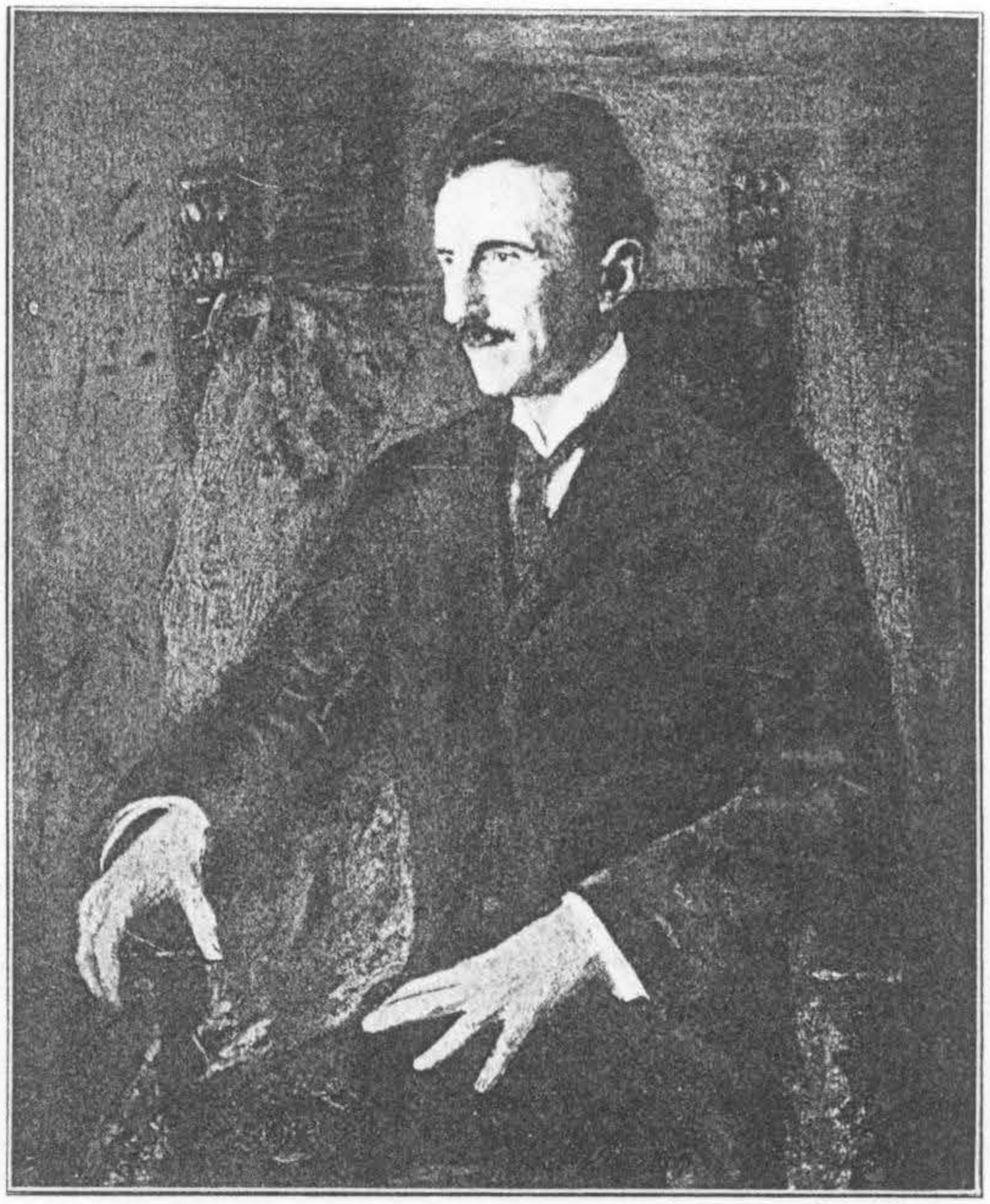
AN ANNOUNCEMENT

SEVERAL years ago, in the course of a discussion, a well-known journalist asked me whom I considered at present the world's greatest inventor. I said: "If you mean the man who really *invented,* in other words, *originated* and *discovered* — not merely *improved* what had already been invented by others, then without a shade of doubt, Nikola Tesla is the world's greatest inventor, not only at present, but in all history."

My friend was much surprised and voiced his astonishment. "Surely," said he, "you do not mean to place Tesla ahead of such great men as Archimedes, Faraday or Edison?"

"That is exactly what I mean," I replied, "and before twenty-five years have elapsed the world at large will echo my opinion."

"But listen," persisted my friend, "who on earth is this man Tesla anyway? What are his wonderful inventions, what great thing has he ever done? How is it that the world at large does not know him?"



Nikola Tesla, from a Painting by the Famous Princess Lwoff-Parlaghy. This Picture Has Never Been Published Before.

"To begin with, and the better to impress you," I replied, "Tesla has secured more than one hundred patents on inventions, many of which have proved revolutionary. Science accords to him over 75 original *discoveries,* not mere mechanical improvements. Tesla is an originator in the sense that Faraday was an originator. Like the latter he is a pioneer blazing the trail; aside from this he is a discoverer of the very highest order."

"Ninety percent of the entire electrical industry pays tribute to his genius. All electrical machinery using or generating alternating current is due to Tesla. High tension current transmission without which our long distance trolley cars, our electrified lines, our subways would be impossible, are due to the genius of Tesla. The Tesla Induction Motor, the Tesla Rotary Converter, the Tesla Phase System of Power Transmission, the Tesla Steam and Gas Turbine and the Tesla Coil and Oscillation Transformer are perhaps his better known inventions.

"As to your last question, namely, why the world at large does not know Tesla, it is answered best by stating that he has committed the unpardonable crime of not having a permanent press agent to shout his greatness from the housetops. Then, too, most of Tesla's inventions, at least to the public mind, are more or less intangible on account of the fact that they are very technical and, therefore, do not catch the popular imagination, as, for instance, wireless, the X-ray, the airplane, or the telephone."

The trouble with Nikola Tesla is that he lives a century ahead of his time. He has often been denounced as a dreamer even by well informed men. He has been called crazy by others who ought to know better. For Tesla talks in a language that most of us do not as yet understand. But as the years roll on Science more and more appreciates his greatness, and begins to pay him tribute more and more.

In 1893, three years prior to the earliest attempts in Hertz wave telegraphy, Tesla first described his wireless system and took out patents on a number of novel devices which were then but imperfectly understood. Even the electrical world at large laughed at these patents. But large wireless interests had to pay him tribute in the form of real money, because his "fool" patents were recognized to be fundamental. He actually antedated every important wireless invention.

A few weeks ago the world read thru news dispatches of a great wireless discovery—the static eliminator. But Tesla had not only patented systems overcoming this and other forms of interference but had actually constructed and successfully operated devices years ago in Colorado, under conditions where static interference was troublesome to an extraordinary degree. A photograph of one form of his apparatus is published with a note from him for the first time elsewhere in this issue of the ELECTRICAL EXPERIMENTER. And so it goes. The world smiles an unbelieving smile, but Tesla's master mind invariably sets the world aright.

I first read about Tesla in a well-known German weekly publication when I was less than 15 years old. The Editor of that publication reproduced his picture on a full page and paid high tribute to Tesla, hailing him as the world's coming greatest electrician.

H. W. Buck, Chief Engineer, President of the American Institute of Electrical Engineers, among others, said: "The work of Nikola Tesla in his great conception of his rotary field seems to me one of the greatest feats of imagination which has ever been attained by human mind."

Lord Kelvin, before the British Association, commenting upon the Tesla Transformer exhibited, said: "This is a wonderful development of the induction coil destined to be of great importance."

Electrical Review, commenting upon the wireless: "Mr. Tesla's

researches in this field have attracted world-wide attention, and his is undoubtedly the master mind."

Der Electro-Technische Anzeiger, Berlin, and *Elektrizität,* Leipzig, Germany, (commenting upon Tesla's work): "It is a combination of the grandest power of technical performance with the most vivid imagination, such as has never before manifested itself in the human mind."

Brigadier Allen, of the United States War Department (commenting upon Tesla's Turbine): "Something new in the world. Officers are greatly impressed with it."

While studying abroad I read every scrap of his work I could lay my hands on. I performed most of his high frequency experiments, and the more I saw of his work the more imprest I became. Some years ago as Editor of *Modern Electrics,* I met him in a New York shop where his famous turbine models were first built. I was fascinated with the tall, gaunt man, then about 50 years old, but looking less than 30. His extraordinary face, with his deep set blue eyes, proclaimed the intense thinker—the philosopher. A few minutes' chat with him left me more than ever convinced of his greatness.

Further contacts during the past few years still enhanced my opinion of him. Tesla is a man of extraordinary knowledge. He is remarkably well read and has a photographic memory whereby it is possible for him to recite page after page of nearly every classical work, be it Goethe, Voltaire or Shakespeare. He speaks and writes twelve languages. He is an accomplished calculator, who has little use for tables and text-books and holds the sliding rule in contempt. Tesla has received numerous honors and distinctions of all kinds. He is a knight of several orders, holder of many titles and diplomas. Some time ago he was awarded the Elliott Cresson gold medal by the Franklin Institute and last year the Edison medal by the American Institute of Electrical Engineers. Many extraordinary distinctions have been offered to him which he has declined. As of timely interest one instance may be mentioned. At the announcement of Tesla's high frequency discoveries, while the former Emperor of Germany was all-powerful and great men were eager for his favors, Tesla received an invitation from him and the Empress to repeat his celebrated experiments at the Royal Palace in Berlin. He forgot all about it and did not answer for one year, when he politely apologized for his inability to avail himself of the honor. Later the invitation was renewed and nearly two years past before Tesla answered to the same effect. After a lapse of time, however, upon the announcement of another important invention, he received the invitation for the third time, with the assurance that an altogether unusual honor was reserved for him. "Well, boys," said Tesla to his assistants after he laid the invitation which he never answered aside, "the Emperor must be a great man. I do not think that I would be capable of acting in this way if I were in his place." Perhaps the most remarkable tribute was paid to him when he made his famous experiments in Colorado in 1899. It was by J. Pierpont Morgan, the elder, who donated $150,000, which enabled Tesla to produce artificial lightning and incidentally to electrify the entire earth.

BY *special arrangement the ELECTRICAL EXPERIMENTER will, beginning with the next issue, publish a series of articles entitled "My Inventions", by Nikola Tesla. The great inventor will contribute a signed article monthly, which articles will run for several years. Most of this material has never appeared in print before. The articles will be publisht in book form later. We consider this announcement the most important we ever made.* THE PUBLISHERS.

Some of Tesla's inventions have been of far-reaching importance in the War. The resources and productive powers of the country have been greatly increased thru extended use of his system of alternating current transmission and transformation of energy. Nearly ten million horsepower of water falls have been harnest by this means, thus saving forty percent of the entire coal output of the United States. The railroads have been electrified and his induction motor has revolutionized the steel industry and operation of factories. His electric drive has been adopted on the largest cruisers and battleships as the most perfect means of propulsion. His wireless inventions have proved indispensable and his oscillatory apparatus has been of inestimable service in chirurgical and therapeutic treatment in the field.

The technical prints abound with his work, his inventions, his discoveries. The following is only a partial list of terms now adopted and published in text books and technical works:

Tesla two-phase, three-phase, multi-phase, poly-phase system of power transmission
Tesla principle
Tesla rotating magnetic field
Tesla rotating magnetic field transformer
Tesla induction motor
Tesla split-phase motor
Tesla system of distribution
Tesla rotary transformer
Tesla system of transformation by condenser discharges
Tesla coil
Tesla oscillation transformer
Tesla electrical oscillator
Tesla mechanical oscillator
Tesla high frequency machines
Tesla dynamo-electric oscillator
Tesla tube
Tesla lamp
Tesla high-potential methods
Tesla inductor
Tesla marvels
Tesla impedence phenomena
Tesla electro-therapy
Tesla electrical massage
Tesla currents
Tesla transmission
Teslaic experiments
Tesla capacity
Tesla arclight system
Tesla third brush regulation
Tesla devices
Tesla sparks
Tesla arrangements
Tesla theory
Tesla point
Tesla Steam Turbine
Tesla Gas Turbine
Tesla Water Turbine
Tesla Pump
Tesla Compressor
Tesla Igniter
Tesla condensers
Tesla electro-static field
Tesla effects
Tesla wireless system
Tesla methods of wireless transmission
Tesla magnifying transmitter
Tesla telautomata
Tesla insulation
Tesla underground transmission, etc.

NIKOLA TESLA, *in the opinion of authorities, today is conceded to be the greatest inventor of all times. Tesla has more original inventions to his credit than any other man in history. He is considered greater than Archimedes, Faraday, or Edison. His basic, as well as revolutionary, discoveries for sheer audacity have no equal in the annals of the world. His master mind is easily one of the seven wonders of the intellectual world.*

H. GERNSBACK.

The other night the Editors of the "Experimenter had the opportunity of passing an evening with Tesla. We talked about many things, so interesting, that I will reserve them for another article—but mostly, of course, the conversation centered about Tesla himself.

"Dr. Tesla," I said to him, "you are aware of our great admiration for you, which may or may not be important. But the great public knows little of your mark. Even many of those technically educated—excuse the frankness—think that you are

(*Continued on page* 657)

NIKOLA TESLA AND HIS INVENTIONS.

(*Continued from page* 615)

either a dreamer or, worse yet, crazy. The fact is the world does not understand you because you live in the next century. Moses was a great man, but the Bible teaches us that he was "heavy of tongue" and could not make himself understood. His brother therefore always spoke in his stead, announcing to his hearers what Moses had to say. Why not let the EXPERIMENTER be your brother? Why not let us translate your work into a language that the man in the street can readily understand? We have the knowledge and the technical training to do your inventions justice by means of graphic illustrations and wash drawings. The public does not want patent drawings or patent language. It wants pictures and plain English. You are a great inventor, but your 21st Century training prevents you from making yourself understood to a 20th Century public. My plan is to run one of your inventions every month, in plain English fully illustrated. That means that it will probably take over two years to deal with all of your more important inventions. At the end of this period the articles can be published in book form, a thing that does not exist at present. The plan is twofold. First, the world at large will at last understand the highly important work you have accomplished and will fully recognize you. Second, it will be of greatest benefit to Science, to whom your inventions will then not be the sealed book they are today."

Knowing that Tesla had in the past continuously refused similar offers of dozens of great publishers of this country as well as abroad, I was not at all sanguine of my own plan. Great was my surprise therefore, that he not only gave his consent, but he actually agreed to prepare each article personally with the Editors' collaboration.

Dr. Tesla wants it expressly understood that he is undertaking this great work chiefly to educate the young generation. He felt that he could not possibly reach such a large electrically trained young manhood, save thru the medium of the ELECTRICAL EXPERIMENTER. With its circulation above 100,000, all enthusiastic experimenters, Tesla feels that his greatest mission in life, namely, to assist our rising generation, will come near fulfillment.

Nikola Tesla's articles will therefore run serially every month in the ELECTRICAL EXPERIMENTER. The articles will be entitled: "My Inventions" —by Nikola Tesla. Every article will be entirely original; each will be illustrated with our own new illustrations and with such wash drawings as made this journal so successful. The first article will appear in our February number.

We wish to congratulate EXPERIMENTER readers for having obtained for them probably the greatest technical news feature of a generation. I caution you: *Expect much!*



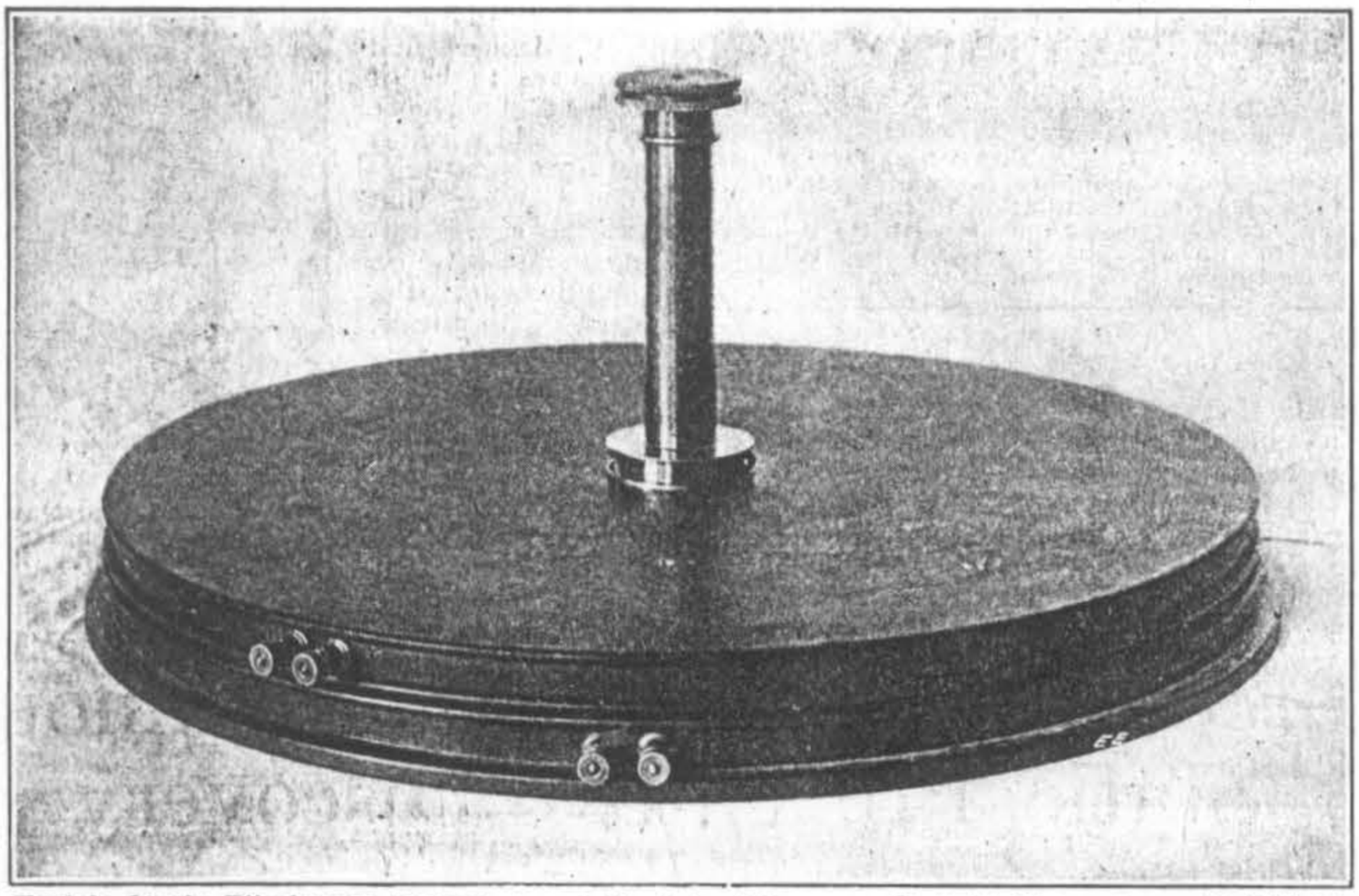
The Effect of Statics on Wireless Transmission

By NIKOLA TESLA

Written for the ELECTRICAL EXPERIMENTER

A FEW statements regarding these phenomena, in response to a request of the ELECTRICAL EXPERIMENTER, may be useful at the present time in view of the increasing interest and importance of the subject.

The commercial application of the art has led to the construction of larger transmitters and multiplication of their number, greater distances had to be covered and it became imperative to employ receiving devices of ever increasing sensitiveness. All these and other changes have cooperated in emphasizing the trouble and seriously impairing the reliability and value of the plants. To such a degree has this been the case that conservative business men and financiers have come to look upon this method of conveying intelligence as one offering but very limited possibilities, and the Government has deemed it advisable to assume control. This unfortunate state of affairs, fatal to enlistment of capital and healthful competitive development, could have been avoided had electricians not remained to this day under the spell of a delusive theory and had the practical exploiters of this advance not permitted enterprise to outrun technical competence.



Tesla's Static Elimination, Patented and Used by Him over Twenty Years Ago. It Will Be Fully Described in an Early Issue of the Electrical Experimenter

With the publication of Dr. Heinrich Hertz's classical researches it was an obvious inference that the dark rays investigated by him could be used for signalling purposes, as those of light in heliography, and the first steps in this direction were made with his apparatus which, in 1896, was found capable of actuating receivers at a distance of a few miles. Three years prior to this, however, in lectures before the Franklin Institute and National Electric Light Association, I had described a wireless system radically opposite to the Hertzian in principle inasmuch as it depended on currents conducted thru the earth instead of on radiations propagated thru the atmosphere, presumably in straight lines.

The apparatus then outlined by me consisted of a transmitter comprising a primary circuit excited from an alternator or equivalent source of electrical energy and a high potential secondary resonant circuit, connected with its terminals to ground and to an elevated capacity, and a similar tuned receiving circuit including the operative device. On that occasion I exprest myself confidently on the feasibility of flashing in this manner not only signals to any terrestrial distance but transmitting power in unlimited amounts for all sorts of industrial purposes. The discoveries made and experimental results attained I made with a wireless power-plant erected in 1899, some of which were disclosed in the Century Magazine of June, 1900, and several U. S. patents subsequently granted to me have, I believe, borne-out strikingly my foresight. In the meantime the Hertzian arrangements were gradually modified, one feature after another being abandoned, so that now not a vestige of them can be found and my system of four tuned circuits has been universally adopted, not only in its fundamentals but in every detail as the "quenched sparks", "ticker", "tone wheel", high frequency and rotating field alternators, forms of discharges and mercury breaks, frequency changers, coils, condensers, regulating methods and devices, etc. This fact would give me supreme satisfaction were it not that the engineers, misinterpreting the nature of the effects, are making installments so defective in construction and mode of operation as to preclude the possibility of the great realization which might be brought within easy reach by proper application of the underlying principles and one of which—the most desirable at present—is the complete elimination of all static and other interference.

During the past few years several emphatic announcements have been made that a perfect solution of this problem had been discovered, but it was manifest from a casual perusal of these publications that the experts were ignoring certain truths of vital bearing on the question, and so long as this was the case no such claim could be substantiated. I achieved early success by keeping these steadily in mind and applying my efforts from the outset in the right and correct scientific direction.

I may contribute to the clearness of the subject in answering a question which I have been asked by the Editors of the ELECTRICAL EXPERIMENTER with reference to the report contained in the last issue, that signals had been received around the globe. an achievement the practicability of which I have fully demonstrated by experiment eighteen years ago.

The question is, how can Hertz waves be conveyed to such a distance in view of the curvature of the earth? A few words will be sufficient to show the absurdity of the prevailing opinion propounded in text books.

We are living on a conducting globe surrounded by a thin layer of insulating air, above which is a rarefied and conducting atmosphere. If the earth is represented by a sphere of 12½" radius, then the layer which may be considered insulating for high frequency currents of great tension is less than 1/64 of an inch thick. It is held that the Hertz waves, emanating from a transmitter, get to the distant receiver by successive reflections. The utter impossibility of this will be evident when it is shown by a simple calculation that the amount of

(*Continued on page* 658)

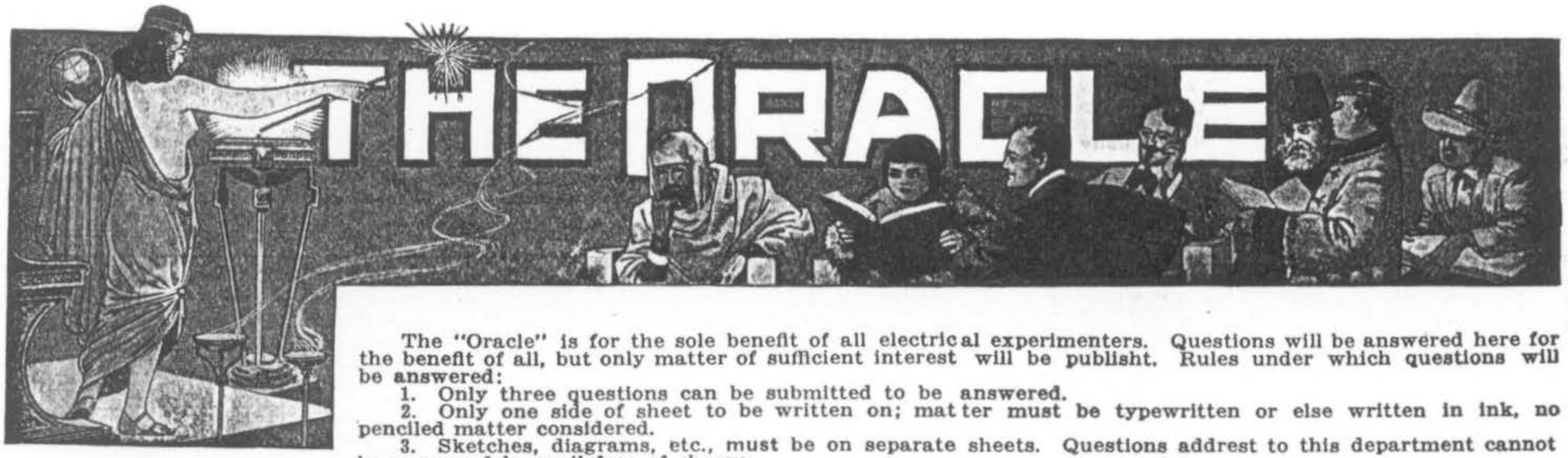
THE EFFECT OF STATICS ON WIRELESS TRANSMISSION.

(*Continued from page* 627)

energy received, even if it could be collected in its totality, is infinitesimal and would not actuate the most sensitive instrument known were it magnified many million times. The fact is these waves have no perceptible influence on a receiver if situated at a much smaller distance. It should be remembered, moreover, that since the first attempts the wave lengths have been increased until those advocated by me were adopted, in which this form of radiation has been reduced to one-billionth.

When a circuit, connected to ground and to an elevated capacity oscillates, two effects separate and distinct are produced; Hertz waves are radiated in a direction at right angles to the axis of symmetry of the conductor, *and simultaneously a current is passed through the earth.* The former propagates with the speed of light, the latter with a velocity proportionate to the cosecant of an angle which from the origin to the opposite point of the globe varies from zero to 180°. Expressed in words, at the start the speed is infinite and diminishes, first rapidly and then slowly until a quadrant is traversed when the current proceeds with the speed of light. From that region on the velocity gradually increases, becoming infinite at the opposite point of the globe. In a patent granted to me in April, 1905, I have summed up this law of propagation in the statement that the projections of all half waves on the axis of symmetry of movement are equal, which means that the successive half waves, tho of different length, cover exactly the same area. In the near future many wonderful results will be obtained by taking advantage of this fact.

There is a vast difference between these two forms of wave movement in their bearing on the transmission. The Hertz waves represent energy which is radiated and unrecoverable. The current energy, on the other hand, is preserved and can be recovered theoretically, at least, in its entirety. If the experts will free themselves from the illusions under which they are laboring, they will find that to overcome static disturbances all that is needed is a properly constructed transmitter and receiver without any additional devices or preventives. I have, however, devised several forms of apparatus eliminating statics even in the present defective wireless installations in which they are magnified many times. Such a form of instrument which I have used successfully is shown in the annexed photograph. These phenomena have been studied by me for a number of years and I have found that there are nine or ten different causes tending to intensify them, and in due course I shall give a full description of the various improvements I have made, in the ELECTRICAL EXPERIMENTER. For the present I would only point out that in order to perfectly eliminate the static interference, it is indispensable to redesign the whole wireless apparatus as now employed. The sooner this is understood the better it will be for the further evolution of the Art.



The "Oracle" is for the sole benefit of all electrical experimenters. Questions will be answered here for the benefit of all, but only matter of sufficient interest will be publisht. Rules under which questions will be answered:

1. Only three questions can be submitted to be answered.
2. Only one side of sheet to be written on; matter must be typewritten or else written in ink, no penciled matter considered.
3. Sketches, diagrams, etc., must be on separate sheets. Questions addrest to this department cannot be answered by mail free of charge.
4. If a quick answer is desired by mail, a nominal charge of 25 cents is made for each question. If the questions entail considerable research work or intricate calculations a special rate will be charged. Correspondents will be informed as to the fee before such questions are answered.

TESLA COIL FOR 2-INCH SPARK COIL.

(974) R. Conover, New York, N. Y., inquires of "The Oracle":

Q. 1. For data on a Tesla coil suitable for use on a 2-inch spark coil as an exciter.

A. 1. The ordinary Tesla coil, especially designed to work with a spark up to 2 inches on the primary side will do, and is briefly described as follows. The primary should consist of 14 turns No. 10 solid, rubber-covered copper wire in one layer on a spool 4½ inches in diameter, while the secondary consists of a coil 2¾ inches in diameter and 12 inches long, wound its full length with a layer No. 28 enamel wire.

This size of Tesla coil can be furnished by the leading companies who advertise in our magazine. It is best to use two one-pint Leyden jars connected in parallel or a one-quart Leyden jar.

The construction for a glass plate condenser for the above Tesla coil is as follows: Procure five glass plates 6x7x1/16" and four pieces of tin-foil 5x6 inches. The tin-foil should be placed between the five plates so that two ends of the tin-foil protrude from the sides of the glass. The size of the spark obtained from the above Tesla coil will be about ¾ to 1 inch and can be taken thru the body without any harm.

The New York Times January 19, 1919

EVOLVES NEW THEORIES.

Tesla Says Wireless Waves Pass Through the Earth, Not the Air.

The forthcoming issue of The Electrical Experimenter will contain an article by Nikola Tesla, inventor, in which he takes issue with the generally accepted theories of the moon's axial rotation, the pointed lightning rod, and the passage of wireless messages through the air.

Dr. Tesla says that "the moon does rotate, not on its own, but about an axis passing through the centre of the earth, the true and only one." He says that wireless messages pass directly through the earth itself, instead of following the earth's curvature through the air, between stations of any great distance apart. He believes that some day there will be a great station that will keep the earth charged with just enough electricity to make wireless sending very simple. Disagreeing with Franklin that the pointed lightning rod makes surrounding air attractive to heavenly bolts, Dr. Tesla says that he has invented a rod with rounded surface which repels lightning.

The New York American January 21, 1919

TESLA SIGNALS MARS BY RADIO

Inventor Believes Future Communication Among Planets by Such Means Possible.

Nikola Tesla, scientist and inventor, last night expressed his faith in future communication among the planets by means of radio. Commenting on the Marconi interview in London, Mr. Tesla said for the New York American:

"The statement of Mr. Marconi interests me, inasmuch as I recall that in 1900 when I announced the results with my wireless plant in Colorado he claimed it would be 200 years before we would succeed in flashing a signal even across the Atlantic on account of the big wall of water between the American and European continents.

"The truth of the matter is that in 1899 I obtained signals which proved to have emenated from a planet. As I eliminated the effect of the sun, the moon and Venus on my instruments I concluded the source of the electrical disturbance was Mars, which at that time was nearly in opposition. I expressed myself on this subject in the Century Magazine of June, 1900, and in the Harvard Illustrated Magazine in 1906.

"It is difficult for me to see, however, how Mr. Marconi could have noted such feeble disturbances as I observed with the rough and unresponsive commercial apparatus he is employing. The apparatus I used was millions of times more sensitive, and it was only by resorting to certain methods of magnification that I have managed to observe anything at all.

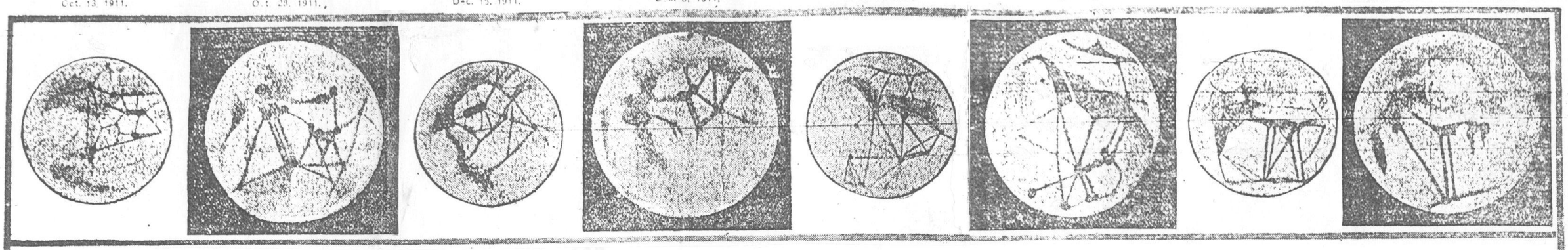
"With my transmitter in Colorado I have produced actions which in their effects on a planet were at least a hundred times greater than obtainable with any wireless plant in existence. And it is by no means impossible that intelligent beings living on Mars might have detected them.

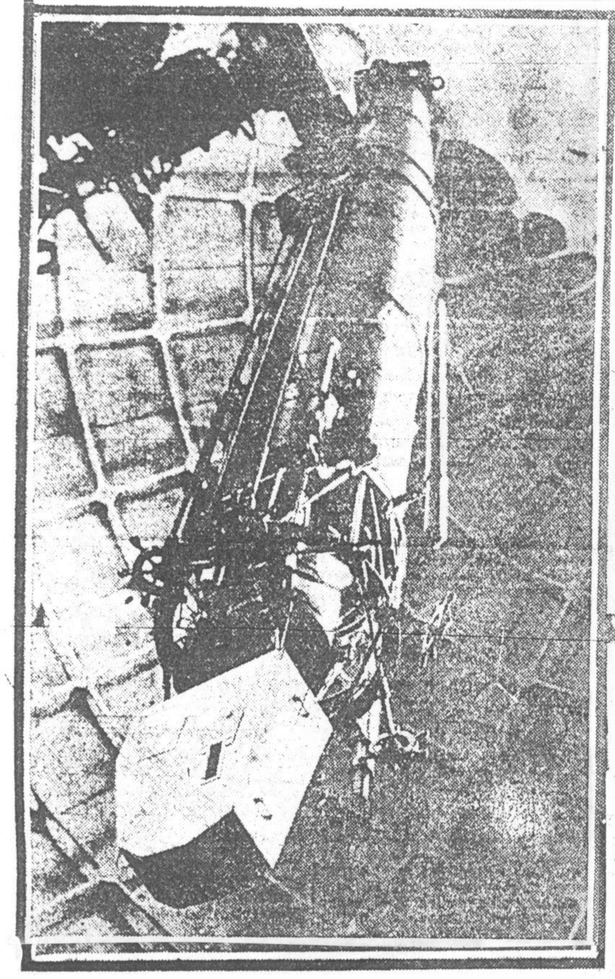
"As to intelligible communication among the planets; the problem of conveying through space knowledge of form has occupied me for years and I have found a solution. But my idea is still in the undeveloped, experimental state."

TALKING WITH THE STARS NEXT WONDER SAYS SIGNOR MARCONI

NOTE THE STRIKING SIMILARITY OF THESE PHOTOS. THEY WERE TAKEN BY PROF. LOWELL, OF HARVARD, AND JARRY-DESLOGES, OF FRANCE, AT DIFFERENT TIMES AND PLACES.

By LOWELL. Oct. 13, 1911. | By JARRY-DESLOGES. Oct. 29, 1911. | By LOWELL. Dec. 15, 1911. | By JARRY-DESLOGES. Dec. 3, 1911. | By LOWELL. Dec. 5, 1911. | By JARRY-DESLOGES. | By LOWELL. | By JARRY-DESLOGES.





Copyright by International Film Service.

HUGE TELESCOPE AT LICK OBSERVATORY, MOUNT HAMILTON.



PHOTO © BY PACH BROS.

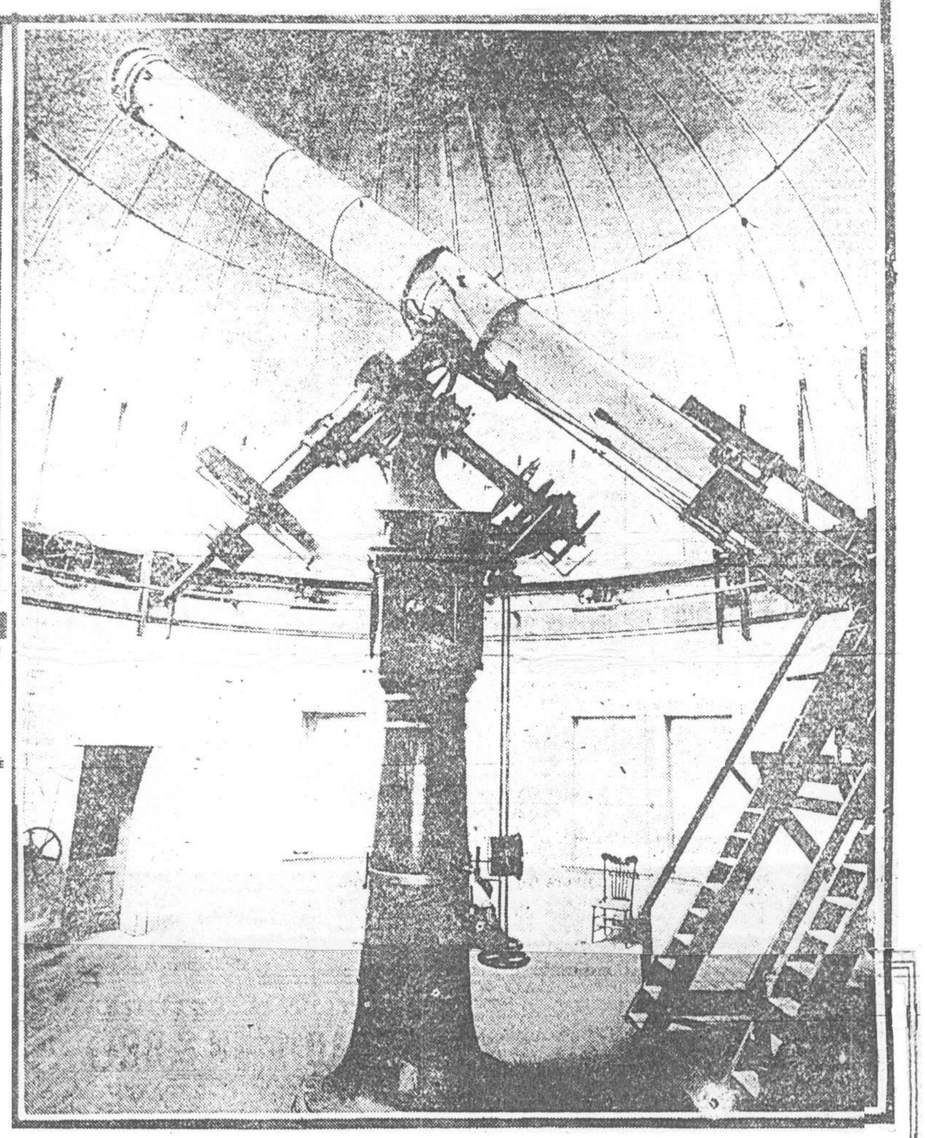
SIGNOR GUGLIELMO MARCONI.



PHOTO BY VANDERWEYDE

PROF. PERCIVAL LOWELL.

Widespread interest has been caused by a cablegram from London quoting Guglielmo Marconi as predicting we may be able to talk with Mars and other planets. In fact, Signor Marconi has described, according to the London Daily Chronicle, mysterious signals from "some place beyond the earth." In a subjoined article Garrett P. Serviss, famous scientist and who writes for the Hearst publications, who is inclined to give credence to Signor Marconi's statement, suggests that these reported signals may be from Venus. On the other hand, Professor Harold Jacoby, head of the department of astronomy at Columbia University, treats Marconi's startling prophecy with unconcealed incredulity. But despite conflicting opinion the much discussed subject of communication between the earth and the heavenly bodies as revived by Signor Marconi has made a strong impression. As Mr. Serviss says in his optimistic article, Marconi is a man whose statements are not to be taken lightly. Then, too, there was the case of the late Professor Percival Lowell, of Harvard, who ridiculed the theory of Mars being inhabited and yet whose photographs of that planet so strikingly resembled those taken by Jarry-Desloges, famous French astronomer. These pictures reproduced on this page were regarded by many scientists as corroboration of the theory that there are, indeed, human beings on Mars.



TWENTY-INCH TELESCOPE AT THE UNIVERSITY OF DENVER.

Scientists have obtained much valuable information by means of both of the mammoth lenses here shown in their attempts to pierce the mysteries of the heavenly bodies billions of miles away from the earth.

SERVISS SEES POSSIBILITY OF DREAM COMING TRUE

By GARRETT P. SERVISS.

There is nothing surprising to me in the statements attributed to Mr. Marconi by the English interviewer, Mr. Begbie, concerning the possibility of communicating between the earth and the heavenly bodies, even the most distant stars, by means of the same ætheric waves that are employed in ordinary wireless telegraphy.

Of course such a possibility exists, but it requires a certain degree of courage and independence of thought for a man of science to openly declare it, because of the narrowness of view and stupid clannishness of some academic scientists, who are ready to sneer at everything that they cannot fit into their prepared formulae.

The late Percival Lowell, who did more than any other man has ever done toward solving the only truly important problem concerning the other planets—viz, the question whether they are, have been, or will be inhabited—was a favorite butt of that class of scientists who represent the doubting Thomases, being constitutionally incapable of understanding anything that springs from the use of man's highest faculty—Intuition.

NOT TO BE TAKEN LIGHTLY.

I am glad that this statement has been obtained from Mr. Marconi, because coming from the man who first made wireless telegraphy a practical success, and who has overcome difficulty after difficulty in the development of that seemingly impossible art, it will possess a weight that it could not have coming from any other. It is true that he does not make any definite prediction, but that is characteristic of him, for, as learned when I knew him during his early experiments with wireless transmission on this side of the ocean, he is a man who, while freely using his imagination to illuminate his way, does not take imagined facts for real ones until he has tested them. This makes his present statement so much the more significant.

Mr. Marconi's outline of the matter seems to me perfectly logical. In the first place, the electric waves used for wireless messages are not confined to the atmosphere or to the earth. They are formed in the ether which extends apparently all through space. Like the waves of light they go on at an immense speed forever. As a star can send its waves of light to us over a distance so vast that they may be years on the way, so these electric waves, which are very large compared with the light waves, but like them travel through the ether, should also be capable of passing freely from planet to planet or star to star. That they really do so Mr. Marconi has no doubt whatever. And that fact, says he, "makes me hope for a very big thing in future."

When I hear that Mr. Marconi hopes for a big thing as the result of the application of scientific knowledge and a trained imagination to the achievement of some great object of human desire, I am certain that he has good ground to go on; that he has had some experience which warrants him in expecting a further advance. Now, he himself, as represented in Mr. Begbie's interview, tells us what that experience is—and, as I shall show in a moment, it startlingly recalls something Mr. Tesla observed years ago—it is that he has "often received strong signals out of the ether which seemed to come from some place outside the earth, and which might, conceivably, have proceeded from the stars."

SIGNALS FROM VENUS?

If for "stars" we substitute "planets" we may, perhaps, be nearer to the real mark in guessing about the origin of the strange "signals" noticed by Mr. Marconi. If I were going to make another guess, based on the assumption that the signals really did come from another planet outside the earth, I would choose Venus as their probable source. Venus is physically the twin of the earth. We cannot see her surface because of her dense atmosphere and numerous clouds, but she seems to possess the principal things needed to maintain inhabitants even closely resembling ourselves.

In judging how much weight is to be given to Mr. Marconi's statement that the "signals" seemed to come from some place outside the earth, we have the very important fact that Mr. Marconi is presumably the greatest expert now living on the subject of ætheric waves in their practical aspects. This has been the constant subject of his thoughts and experiments for many years. He has dealt with them, measured them, created them, guided them, modified them, contrived instruments of almost unimaginable delicacy for their detection, handled them familiarly, so to speak, in all their forms, so that when he says that certain phenomena of this sort do not seem to have originated on the earth, we may safely assume that, at least, we are not misled by groundless fancies of someone who does not know what he is talking about, but lets an uncontrolled imagination lead him about by the nose.

Now, here is an exceedingly interesting fact. A considerable number of years ago, at least ten, as I remember, Mr. Nicolo Tesla, making experiments with powerful electric waves on Pike's Peak, reported that he had at certain times received something in the nature of impulses, or signals, out of the ether which did not seem to originate on the earth, and which led him to reflect on the possibility that the inhabitants of Mars or Venus might be trying to communicate with the earth, and were sending through the ether something that might be compared to dots and dashes in the hope that, if no more, they might provoke a response in kind.

LED TO SAME CONCLUSION.

The reader will notice how remarkably this experience of Mr. Tesla's, which the academic scientists of certain kind, treated with their customary narrow arrogance, agrees with what Mr. Marconi is now reported to have noticed. And note that both of them, independently, are led by their familiarity with the peculiarities of the phenomena they are dealing with, to the same conclusion, viz.: that the signals had an extra terrestrial origin. They also seem both to have been impressed with some peculiarity of the phenomena observed which led them to think of the possibility that there was an intelligent purpose behind what was going on.

In the interview, Mr. Marconi dwells upon two highly important points. In the first place he calls attention to the obvious difficulty that the inhabitants of two different planets could not expect, except through a miracle, to be able to understand one another's language, and he suggests, as has before been done when this matter was under discussion, that mathematics being a kind of universal language, some kind of intelligible communication might be exchanged by simply transmitting signals plainly conveying fundamental mathematical relations, such as two and two equal four. Thus a medium of communication from mind to mind in different worlds might gradually be built up. With regard to this it may be said that supposing the inhabitants of Venus in an effort to attract the attention of those of the earth should only receive in reply a series of signals, having no other meaning than that of being in the nature of a response to their own, and an assurance that theirs had been received, even that would be a source of immense satisfaction in itself alone, even if they were not sure whether the response came from the earth, or from some other planet. The feeling that anyhow they were not alone in the universe would come to them, as a similar feeling came to Monte Cristo in his dungeon when he heard the tools of the Abbe Feria digging in his invisible tunnel.

Then, in the second place, Mr. Marconi does not fail to touch upon the ever interesting point that, since there is reason to believe that some of the planets of our system, and those of other systems as well, are evolutionally older than our earth, and consequently that their inhabitants may be much further advanced in intelligence, knowledge and mastery over nature than we have yet become, there would be a great advantage for us in getting into communication with such worlds, which would be teachers for us, capable perhaps of advancing our minds by their instructions further in a decade than we could of ourselves go in many centuries. All of these details are not mentioned in the abstract of Mr. Marconi's statement telegraphed to this country, but they are unavoidable sequences of the general idea.

"Communication with intelligences on other stars," says Mr. Marconi, "may some day be possible," and then he very properly ridicules those who pooh-pooh the idea of other planets being inhabited, saying: "It is silly to say that other planets are uninhabited because they have no atmosphere, or are so hot, or so different from the earth. If there were no fish in the sea we should say life there is impossible, and so it is impossible for man."

This is the true philosophy of science, and I hope that interstellar, or at least interplanetary, communication may be established during Mr. Marconi's lifetime, and that he may have the pleasure of recognizing the first unmistakable message from the inhabitants of another world and responding to it.

PROF. JACOBY SCOUTS MARCONI HOPE OF TALK WITH STARS

Now that peace has been declared along comes William Marconi, who says he has during the last ten years been trying to communicate with the stars.

"Messages that I sent off ten years ago have not yet reached some of the nearest stars. When they arrive there why should they stop?" asked Signor Marconi.

"But how does he know they haven't reached these stars, where he sent them?" wants to know Professor Harold Jacoby, who teaches the secrets of the stars to Columbia students.

"Assuming that it would take ten years or more to get there, why shouldn't it take just as long for them to get an answer?" he continued. "I should say that that bit of news is about ten years too soon in appearing, or rather it will not be news unless it appears at the proper time.

"Seriously, an announcement of this sort always stirs up excitement, for the intense interest in inhabitants of other worlds which we all feel is the cause of much of the supposed evidence as to such inhabitants as Mars is popularly supposed to have.

"As a matter of fact, we possess no reliable evidence on the question of Mars. With regard to possible planets circulating around distant stars as their suns, the evidence in our possession is, of course, absolutely nothing.

"It would be incorrect to say no other distant star has an attendant planet in the same stage of development as our earth or in some other stage of development permitting the existence of intelligent inhabitants."

"But," declared Professor Jacoby, "astronomical science concerns itself only with positive evidence, not with mere speculations or imagings. And positive evidence is lacking."

So Professor Jacoby's opinion can be gathered—in regard to the announcement of William Marconi that he awaits a "ring" from Mars or other stars—that his news-sense is askew and that a story to be a story should break at just the psychological moment. And that ten years from now will be plety of time to turn that interview with personages on Mars.

Some Star Signalled Us, Marconi Thinks; Says We May Send Answer

LONDON, Jan. 21.—Mysterious "signals" from "some place beyond the earth" are said to have been described recently to a representative of the Daily Chronicle by the great Italian inventor and scientist, Guglielmo Marconi. Signor Marconi, according to this writer, intimated that than ours" might easily be the next world sensation.

The great Italian's theory, the article in the Chronicle declares, is that ether waves, projected by wireless, do not stop at the edge of the atmospheric envelope which surrounds this planet, but go on and on until they strike a solid terminus.

"Messages," Signor Marconi is reported to have said, "that I sent off as long ago as ten years may not have yet reached the stars. Even if they have it may be that translations have not yet beene made, nor means developed with which to send replies."

At the same time, the Chronicle writer says, Marconi pointed out that "inexplicable" ether waves, or signals, have been received at various wireless stations, and that these might conceivably" be attempted messages from the twinkling constellations which science has already proved to us to be similar in many respects to our own world.

Harold Begbie, the Chronicle representative who interviewed the eminent Italian student, protested that it might be many years before the other constellation could "signal" to our world, on account of language differences.

The New York Post January 22, 1919

Would Talk With Mars by Pictures

Life Highly Developed There, Tesla Thinks—Inventor Says Marconi's Experience Was Like One of His Own Twenty Years Ago

Talking to Mars or any other planet or star inside or outside our solar system—the old ante-bellum subject—is up for discussion once more, a welcome testimony that the war is over and the world has returned to peace pursuits. The report that William Marconi had said that of late he had received strong wireless signals which seemed to come from some place outside the earth caused a reflective smile to spread over the face of his colleague in radio science, Nicola Tesla, who has been studying interplanetary communication for many years.

"What is the outlook for talking to Mars?" Mr. Tesla was asked. "Marconi seems to think that he has been receiving radio flashes from other planets." The inventor was seated in his office, 8 West Fortieth Street, surrounded by great photographs of his radio machinery, some showing the striking electrical experiments which won him much fame in wireless telegraphy as early as twenty years ago. On his desk were two large autographed portraits of his friends, the late Lord Kelvin and the late J. Pierpont Morgan.

"Years ago I recorded the fact that in 1899 I received faint extraplanetary signals in my laboratory in Colorado Springs," said Mr. Tesla. "They were barely perceptible, but their measured regularity was such that they could not have been accidental static disturbances. They possessed order. Of course, I could not say with certainty that they came from Mars, although that is my belief. In our solar system, Venus, the earth and Mars represent, respectively, youth, full growth and old age. Venus, with its mountains rising dozens of miles into the atmosphere, is probably as yet unfitted for such existence as ours, but Mars must have passed through all terrestrial states and conditions.

"Civilized existence rests on the development of the mechanical arts. The force of gravity on Mars being only two-fifths of that on the earth, all mechanical problems must be much easier of solution. The planet being much smaller, the contact between individuals and the mutual exchange of ideas must have been much quicker. There are many other reasons why intellectual life on that planet should have been phenomenal in its evolutions.

"I announced in an article, which was published in the *Harvard Illustrated Magazine* in 1906, that I was convinced that the radio signals which I received about six years before were from distant planets. I signalled back with my powerful radio transmitter, and I am certain that in my experiments in 1899 and 1900 I produced disturbances on Mars. Whether there were instruments to receive them and intelligence to recognize them as interplanetary messages is another question.

"But the matter of establishing communication with other planets is not a job for a single individual, but for the whole human race," and Mr. Tesla went on to explain that contact having been established with an outside world, vast difficulties would lie in setting up a code of communication. He thought the first step would probably lie through the science of mathematics as suggested by Mr. Marconi. But he felt that it would be difficult to advance very far by the means of words, that in mental or physical vision lay the foundation of all knowledge.

"But pictures have been transmitted by telegraph," he continued. "Then why not by wireless? Granted always that on some of the neighboring planets there exist intelligent beings, as far advanced in civilization as we, or farther advanced, who understand wireless telegraphy, we should be able to flash pictures—say of the human face—by wireless, and receive in return pictures by wireless. When that step is taken the whole riddle of interplanetary communication is solved.

"Now a speculation of this sort will always seem foolish, visionary, and idle unless we start from the premise that other planets of the universe are inhabited by life form just as intelligent as the human beings of this world. I assume that such is the case. In fact it is a mathematical certainty. It is ridiculous to think that life has not developed on the innumerable planets surrounding us."

Mr. Tesla said that in view of the fact that Mars was only about 35,000,000 miles from the earth when the two planets approached closest to each other, it would take a radio impulse less than five minutes to flash between the earth and Mars. The minimum distance between the planets was reached in 1909. We shall again be within a hailing distance of 35,000,000 miles from Mars in 1924.

Another advocate of the system of signalling by mathematical code is William Smith Wensley, of 288 Park Avenue, Newark, N. J., who some time ago published a pamphlet outlining his system. Mr. Wensley proposes not to use radio signals, but diagrams of vegetation which could be seen from Mars with powerful telescopes, just as astronomers on this earth can view the canals of Mars. Mr. Wensley proposes to talk only to the Martians, whom he supposes to be as intelligent as the Earthians.

"As anything two miles or more wide on Mars is easily seen in a photograph," writes Mr. Wensley, "our smallest figures should be made as wide and preferably a mile longer and wider. In sending our first message on that basis about our decimal system, the column of ten signs for figures would be over seventy miles long, counting three miles between each two signs, or a total of twenty-seven miles for spaces. These figures could be made at minimum expense by the Government growing a crop of uniform color in the figures of the diagram. The spaces between the figures should be kept harrowed so as to show no color. Rotation of crops could easily be provided for. These different things could be done by owners of farms under contract with the Government."

Mr. Wensley thinks that huge pictures of men, women, horses, camels, and other animals can be shown in the same way, each labelled by a number, thus codes for nouns might be established. Verbs, he states, can be indicated by action pictures, such as may be found on the pages of old-fashioned primers.

Overturning a Few of Our Most Confirmed Notions

The Illusion of the Axial Rotation of the Moon

THESE are amazing theories brought forward by Nikola Tesla in "The Electrical Experimenter" for February. The first of them smashes our venerable conception about the moon's rotation. Tesla declares:

"It is well known since the discovery of Galileo that the moon, in travelling through space, always turns the same face toward the earth. This is explained by stating that while passing once around its mother-planet the lunar globe performs just one revolution on its axis. The spinning motion of a heavenly body must necessarily undergo modifications in the course of time, being either retarded by resistances internal or external, or accelerated owing to shrinkage and other causes. An unalterable rotational velocity through all phases of planetary evolution is manifestly impossible. What wonder, then, that at this very instant of its long existence our satellite should revolve exactly so, and not faster or slower. But many astronomers have accepted as a physical fact that such rotation takes place. It does not, but only appears so; it is an illusion, a most surprising one, too.

"I will endeavor to make this clear by reference to Figure 1, in which E represents the earth and M the moon. The movement through space is such that the arrow, firmly attached to the latter, always occupies the position indicated with reference to the earth. If one imagines himself as looking down on the orbital plane and follows the motion he will become convinced that the moon does turn on its axis as it travels around. But in this very act the observer will have deceived himself. To make the delusion complete let him take a washer similarly marked and, supporting it rotatably in the centre, carry it around a stationary object, constantly keeping the arrow pointing toward the latter. Though to his bodily vision the disk will revolve on its axis, such movement does not exist. He can dispel the illusion at once by holding the washer fixedly while going around. He will now readily see that the supposed axial rotation is only apparent, the same appearance can also be produced in another way. The moon does rotate, not on its own, but about an axis passing through the centre of the earth, the true and only one.

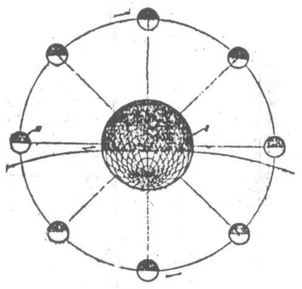


Fig. 1

It is well known that the Moon, M, always turns the same face toward the Earth, E, as the black arrows indicate. The parallel rays from the Sun illuminate the Moon in its successive orbital positions as the unshaded semicircles indicate. Bearing this in mind, do you believe that the Moon rotates on its own axis?

"The unfailing test of the spinning of a mass is, however, the existence of energy of motion. The moon is not possessed of such vis viva. If it were the case then a revolving body as M' would contain mechanical energy other than that of which we have experimental evidence. Irrespective of this so exact a coincidence between the axial and orbital periods is, in itself, immensely improbable, for this is not the permanent condtion toward which the system is tending. Any axial rotation of a mass left to itself, retarded by forces external or internal, must cease. Even admitting its perfect control by tides the coincidence would still be miraculous. But when we remember that most of the satellites exhibit this peculiarity, the probability becomes infinitesimal,

"Three theories have been advanced for the origin of the moon. According to the oldest, suggested by the great German philosopher Kant and developed by Laplace in his monumental treatise 'Mécanique Céleste,' the planets have been thrown off from larger central masses by centrifugal force. Nearly forty years ago Prof. George H. Darwin in a masterful essay on tidal friction furnished mathematical proofs, deemed unrefutable, that the moon had separated from the earth. Recently this established theory has been attacked by Prof. T. J. J. See in a remarkable work on the 'Evolution of the Stellar Systems,' in which he propounds the view that centrifugal force was altogether inadequate to bring about the separation and that all planets, including the moon, have come from the depths of space and have been captured. Still a third hypothesis of unknown origin exists which has been examined and commented upon by Prof. W. H. Pickering in 'Popular Astronomy of 1907,' and according to which the moon was torn from the earth when the latter was partially solidified, this accounting for the continents, which might not have been formed otherwise.

"Undoubtedly planets and satellites have originated in both ways, and, in my opinion, it is not difficult to ascertain the character of their birth. The following conclusions can be safely drawn:

1. A heavenly body thrown off from a larger one cannot rotate on its axis. The mass, rendered fluid by the combined action of heat and pressure, upon the reduction of the latter immediately stiffens, being at the same time deformed by gravitational pull. The shape becomes permanent upon cooling and solidification and the smaller mass continues to move about the larger one as though it were rigidly connected to it except for pendular swings or librations due to varying orbital velocity. Such motion precludes the possibility of axial rotation in the strictly physical sense. The moon has never spun around, as is well demonstrated by the fact that the most precise measurements have failed to show any measurable flattening in form.

2. If a planetary body in its orbital movement turns the same side toward the central mass this is a positive proof that it has been separated from the latter and is a true satellite.

3. A planet revolving on its axis in its passage around another cannot have been thrown off from the same, but must have been captured."

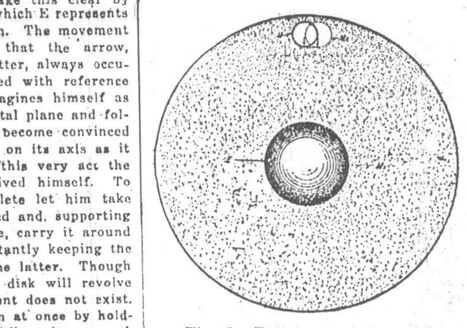


Fig. 2. Tesla's conception of the rotation of the Moon, M, around the Earth, E; the Moon, in this demonstration hypothesis, being considered as embedded in a solid mass, M'. If, as commonly believed, the Moon rotates, this would be equally true for a portion of the mass, M', and the part common to both bodies would turn simultaneously in "opposite" directions.

impression being produced by successive changes of position in space.

"But more convincing proofs can be given that the moon does not, and cannot revolve on its axis. With this object in view attention is called to Figure 2, in which both the satellite, M, and earth, E, are shown imbedded, in a solid mass, M' (indicated by stippling) and supposed to rotate so as to impart to the moon its normal translatory velocity. Evidently, if the lunar globe could rotate as commonly believed, this would be equally true of any other portion of mass M', as the sphere M', shown in dotted lines, and then the part common to both bodies would have to turn simultaneously in opposite directions. This can be experimentally illustrated in the manner suggested by using, instead of one, two overlapping rotatable washers, as may be conveniently represented by circles M and M', and carrying them around a centre as E, so that the plain and dotted arrows are always pointing toward the same centre. No further argument is needed to demonstrate that the two gyrations cannot coexist or even be pictured in the imagination and reconciled in a purely abstract sense.

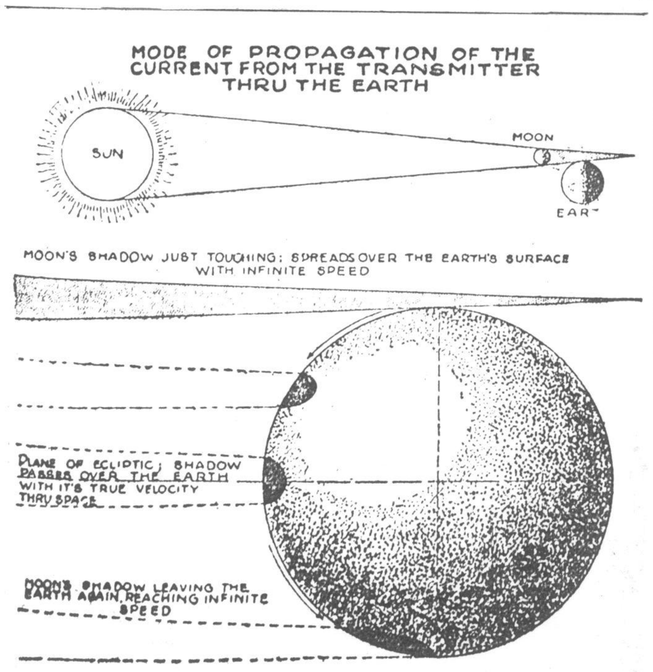


Fig. 8. This diagram illustrates how, during a solar eclipse, the Moon's shadow passes over the Earth with changing velocity, and should be studied in connection with Fig. 9. The shadow moves downward with infinite velocity at first, then with its true velocity through space, and finally with infinite velocity again.

What?

Is it possible the moon doesn't turn on its own axis? That the theory of the lightning rod is half baked? That wireless messages don't travel through the air at all? According to Nikola Tesla, writing in "The Electrical Experimenter," these conditions exist, right here in our midst, despite our blissful ignorance.

How We've Misunderstood Wireless!

AND finally the scientist, having settled the fate of the moon and the lightning, turns to the marvellous modern achievement, the wireless. He writes:

"To the popular mind this sensational advance conveys the impression of a single invention, but in reality it is an art, the successful practice of which involves the employment of a great many discoveries and improvements. I viewed it as such when I undertook to solve wireless problems and it is due to this fact that my insight into its underlying principles was clear from their very inception.

"In the course of development of my induction motors it became desirable to operate them at high speeds and for this purpose I constructed alternators of relatively high frequencies. The striking behavior of the currents soon captivated my attention and in 1889 I started a systematic investigation of their properties and the possibilities of practical application. The first gratifying result of my efforts in this direction was the transmission of electrical energy through one wire without return, of which I gave demonstrations in my lectures and addresses before several scientific bodies here and abroad in 1891 and 1892. During that period, while working with my oscillation transformers and dynamos of frequencies up to 200,000 cycles per second, the idea gradually took hold of me that the earth might be used in place of the wire, thus dispensing with artificial conductors altogether.

"The immensity of the globe seemed an unsurmountable obstacle, but after a prolonged study of the subject I became satisfied that the undertaking was rational, and in my lectures before the Franklin Institute and National Electric Light Association early in 1893 I gave the outline of the system I had conceived. In the latter part of that year, at the Chicago World's Fair, I had the good fortune of meeting Prof. Helmholtz, to whom I explained my plan, illustrating it with experiments. On that occasion I asked the celebrated physicist for an expression of opinion on the feasibility of the scheme. He stated unhesitatingly that it was practicable, provided I could perfect apparatus capable of putting it into effect, but this, he anticipated, would be extremely difficult to accomplish.

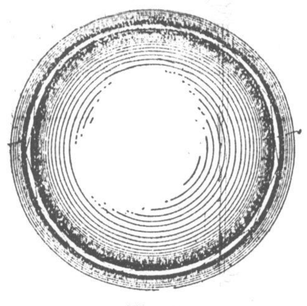


Fig. 7

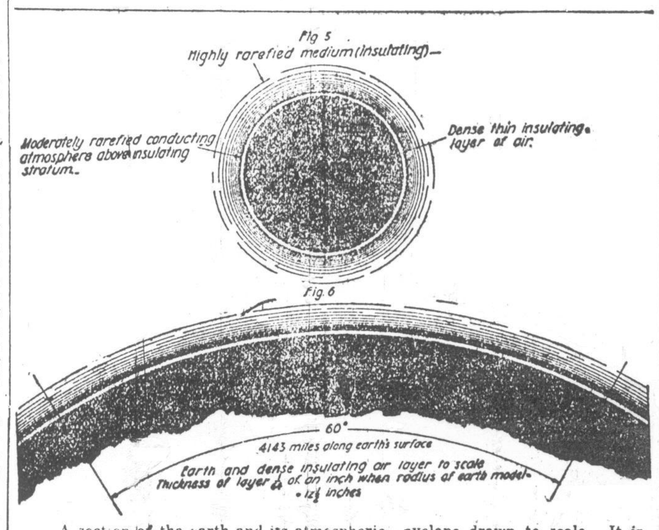
"I resumed the work very much encouraged and from that date to 1896 advanced slowly but steadily, making a number of improvements, the chief of which was my system of concatenated tuned circuits and method of regulation, now universally adopted.

"Imagine the earth to be a bag of rubber filled with water, a small quantity of which is periodically forced in and out of the same by means of a reciprocating pump. . . . If the strokes of the latter are effected in intervals of more than one hour and forty-eight minutes, sufficient for the transmission of the impulse through the whole mass, the entire bag will expand and contract and corresponding movements will be imparted to pressure gauges or movable pistons with the same intensity, irrespective of distance. By working the pump faster, shorter waves will be produced which, on reaching the opposite end of the bag, may be reflected and give rise to stationary nodes and loops, but in any case, the fluid being incompressible, its inclosure perfectly elastic, and the frequency of oscillations not very high, the energy will be economically transmitted and very little power consumed so long as no work is done in the receivers. This is a crude but correct representation of my wireless system in which, however, I resort to various refinements. Thus, for instance, the pump is made part of a resonant system of great inertia, enormously magnifying the force of the impressed impulses. The receiving devices are similarly conditioned and in this manner the amount of energy collected in them vastly increased.

"The Hertz wave system is in many respects the very opposite of this. To explain it by analogy, the piston of the pump is assumed to vibrate to and fro at a terrific rate and the orifice through which the fluid passes in and out of the cylinder is reduced to a small hole. There is scarcely any movement of the fluid and almost the whole work performed results in the production of radiant heat, of which an infinitesimal part is recovered in a remote locality. However incredible, it is true that the minds of some of the ablest experts have been from the beginning, and still are, obsessed by this monstrous idea, and so it comes that the true wireless art, to which I laid the foundation in 1893, has been retarded in its development for twenty years. This is the reason why the 'statics' have proved unconquerable, why the wireless shares are of little value and why the government has been compelled to interfere.

"We are living on a planet of well-nigh inconceivable dimensions, surrounded by a layer of insulating air above which is a rarefied and conducting atmosphere (Fig. 5). This is providential, for if all the air were conducting the transmission of electrical energy through the natural media would be impossible. My early experiments have shown that currents of high frequency and great tension readily pass through an atmosphere but moderately rarefied, so that the insulating stratum is reduced to a small thickness as will be evident by inspection of Fig. 6, in which a part of the earth and its gaseous envelope is shown to scale. If the radius of the sphere is 12½", then the non-conducting layer is only 1/64" thick, and it will be obvious that the Hertzian rays cannot traverse so thin a crack between two conducting surfaces for any considerable distance, without being absorbed.

"The theory has been seriously advanced that these radiations pass around the globe, by successive reflections, but to show the absurdity of this suggestion reference is made to Fig. 7 in which this process is diagrammatically indicated. Assuming that there is no refraction, the rays, as shown on the right, would travel along the sides of a polygon drawn around the solid, and inscribed into the conducting gaseous boundary, in which case the length of the side would be about 400 miles. As one-half the circumference of the earth is approximately 12,000 miles long there will be, roughly, thirty deviations. The efficiency of such a reflector cannot be more than 25 per cent, so that if none of the energy of the transmitter were lost in other ways, the part recovered would be measured by the fraction (¼)³⁰. Let the transmitter radiate Hertz waves at the rate of 1,000 kilowatts. Then about one hundred and fifteen billionth part of one watt is all that would be collected in a perfect receiver. In truth, the reflections would be much more numerous, as shown on the left of the figure, and owing to this and other reasons, on which it is unnecessary to dwell the amount recovered would be a vanishing quantity.



A section of the earth and its atmospheric envelope drawn to scale. It is obvious that the Hertzian rays cannot traverse so thin a crack between two conducting surfaces for any considerable distance without being absorbed, says Dr. Tesla, in discussing the ether space-wave theory.

"Consider now the process taking place in the transmission by the instrumentalities and methods of my invention. For this purpose attention is called to Fig. 8, which gives an idea of the mode of propagation of the current waves and is largely self-explanatory. The drawing represents a solar eclipse with the shadow of the moon just touching the surface of the earth at a point where the transmitter is located. As the shadow moves downward it will spread over the earth's surface, first with infinite and then gradually diminishing velocity until at a distance of about 6,000 miles it will attain its true speed in space. From there on it will proceed with increasing velocity, reaching infinite value at the opposite point of the globe. It hardly need be stated that this is merely an illustration and not an accurate representation in the astronomical sense.

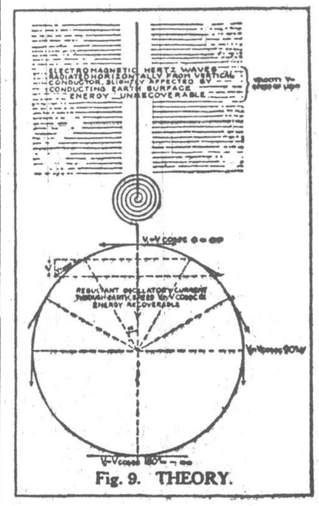


Fig. 9. THEORY.

"The exact law will be readily understood by reference to Fig. 9, in which a transmitting circuit is shown connected to earth and to an antenna. The transmitter being in action, two effects are produced: Hertz waves pass through the air, and a current traverses the earth. The former propagate with the speed of light and their energy is unrecoverable in the circuit. The latter proceeds with the speed varying as the cosecant of the angle which a radius drawn from any point under consideration forms with the axis of symmetry of the waves. At the origin the speed is infinite but gradually diminishes until a quadrant is traversed, when the velocity is that of light. From there on it again increases, becoming infinite at the antipole. Theoretically the energy of this current is recoverable in its entirety, in properly attuned receivers.

"Some experts, whom I have credited with better knowledge, have for years contended that my proposals to transmit power without wires are sheer nonsense, but I note that they are growing more cautious every day. The latest objection to my system is found in the cheapness of gasolene. These men labor under the impression that the energy flows in all directions and that, therefore, only a minute amount can be recovered in any individual receiver. But this is far from being so. The power is conveyed in only one direction, from the transmitter to the receiver, and none of it is lost elsewhere. It is perfectly practicable to recover at any point of the globe energy enough for driving an airplane, or a pleasure boat or for lighting a dwelling. I am especially sanguine in regard to the lighting of isolated places and believe that a most economical and convenient method can hardly be devised. The future will show whether my foresight is as accurate now as it has proved heretofore."

The Fallacy of Franklin's Pointed Lightning Rod

TESLA next addresses himself to the lightning rod, and comments as follows:

"The display of atmospheric electricity has since ages been one of the most marvellous spectacles afforded to the sight of man. Its grandeur and power filled him with fear and superstition. For centuries he attributed lightning to agents godlike and supernatural and its purpose in the scheme of this universe remained unknown to him. Now we have learned that the waters of the ocean are raised by the sun and maintained in the atmosphere delicately suspended and that they are wafted to distant regions of the globe, where electric forces assert themselves in upsetting the sensitive balance and causing precipitation, thus sustaining all organic life. There is every reason to hope that man will soon be able to control this life-giving flow of water and thereby solve many pressing problems of his existence.

"Atmospheric electricity became of special scientific interest in Franklin's time, Faraday had not yet announced his epochal discoveries in magnetic induction but static frictional machines were already generally used in physical laboratories. Franklin's powerful mind at once leaped to the conclusion that frictional and atmospheric electricity were identical. To our present view this inference appears obvious, but in his time the mere thought of it was little short of blasphemy. He investigated the phenomena and argued that if they were of the same nature then the clouds could be drained of their charge exactly as the ball of a static machine, and in 1749 he indicated in a published memoir how this could be done by the use of pointed metal rods.

"The earliest trials were made by Dalbrand in France, but Franklin himself was the first to obtain a spark by using a kite, in June, 1752. When these atmospheric discharges manifest themselves to-day in our wireless station we feel annoyed and wish that they would stop, but to the man who discovered them they brought tears of joy.

"The lightning conductor in its classical form was invented by Benjamin Franklin in 1755 and immediately upon its adoption proved a success to a degree. As usual, however, its virtues were often exaggerated. So, for instance, it was seriously claimed that in the city of Pietermaritzburg (capital of Natal, South Africa) no lightning strokes occurred after the pointed rods were installed, although the storms were as frequent as before. Experience has shown that just the opposite is true. A modern city like New York, presenting innumerable sharp points and projections in good contact with the earth, is struck much more often than an equivalent area of land. Statistical records, carefully compiled and published from time to time, demonstrate that the danger from lightning to property and life has been reduced to a small percentage by Franklin's invention, but the damage by fire amounts, nevertheless, to several million dollars annually. It is astonishing that this device, which has been in universal use for more than one century and a half, should be found to involve a gross fallacy in design and construction which impairs its usefulness and may even render its employment hazardous under certain conditions.

. . . . .

"All points or projections on the surface of a conductor of such vast dimensions as the earth would be quite ineffective were it not for other influences. These will be elucidated with reference to Figure 4, in which our artist of the Impressionist school has emphasized Franklin's notion that his rod was drawing electricity from the clouds. If the earth were not surrounded by an atmosphere which is generally oppositely charged it would behave, despite all its irregularities of surface, like a polished sphere. But owing to the electrified masses of air and cloud the distribution is greatly modified. Thus in Figure 4 the positive charge of the cloud induces in the earth an equivalent opposite charge, the density at the surface of the latter diminishing with the cube of the distance from the static centre of the cloud. A brush discharge is then formed at the point of the rod and the action Franklin anticipated takes place. In addition, the surrounding air is ionized and rendered conducting and, eventually, a bolt may hit the building or some other object in the vicinity. The virtue of the pointed end to dissipate the charge, which was uppermost in Franklin's mind, is, however, infinitesimal. Careful measurements show that it would take many years before the electricity stored in a single cloud of moderate size would be drawn off or neutralized through such a lightning conductor. The grounded rod has the quality of rendering harmless most of the strokes it receives, though occasionally the charge is diverted with damaging results. But, what is very important to note, it invites danger and hazard on account of the fallacy involved in its design. The sharp point which was thought advantageous and indispensable to its operation is really a defect detracting considerably from the practical value of the device. I have produced a much improved form of lightning protector characterized by the employment of a terminal of considerable area and large radius of curvature which makes impossible undue density of the charge and ionization of the air. These protectors act as quasi-repellents and so far have never been struck though exposed a long time. Their safety is experimentally demonstrated to greatly exceed that invented by Franklin. By their use property worth millions of dollars which is now annually lost can be saved."

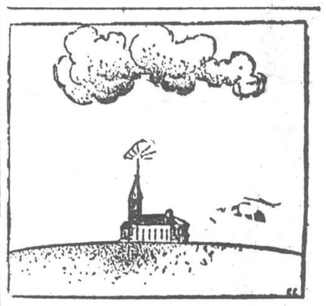


Fig. 4. Tesla explains the fallacy of the Franklin pointed lightning rod, here illustrated, and shows that usually such a rod could not draw off the electricity in a single cloud in many years. The density of the dots indicates the intensity of the charges.

Aeronautics: A Question About Its Future

WHAT is to become of aeronautics after the war? This problem is discussed in "Le Petit Journal" of Paris by Jacques Mortane.

Considering the enormous progress aviation has made during and on account of the war, he says, only one answer to the above question is possible. Regular aerial lines of communication will be established throughout the world. And these lines will serve not only passenger traffic and the mails, but they will be used in increasing proportions for long-distance freight transportation.

The establishment of regular commercial air routes, however, has to be accompanied by the working out of an international code of air navigation.

For one thing, how will the air be mapped out between the different nations? Shall each country have not only its own aerial fleet and stations, but also its own exclusive lines? Is it possible at all to establish a rigid system of right of way in the air? How far will the jurisdiction of a country apply to lines internationally used?

But there are other no less complicated problems. What qualifications will be demanded from commercial pilots? Will a pilot's certificate issued in one country, be accepted as valid in another? This question involves the safety not only of aerial shipping itself, but also that of the population above whose heads the shipping passes.

Will there be a standardization of machines? This is an important question, as it pertains to the safety of traffic and to the facilities of relaying and repairs.

What about aerial customs regulations and policing?

It is comparatively little known that as early as 1910 an international conference was held in Paris to consider some of the above outlined questions. Difficulties of a military character, however, prevented reaching an agreement.

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EDITORIAL

The New Wireless

IT will come as a profound shock to all wireless enthusiasts, scientific and amateur alike, that their present-day notions on wireless are totally erroneous and not based upon actual facts. For years we clung to the theory that a wireless message radiates from the aerial wires of the sending station and speeds over the surface of the earth thru the ether towards the receiving station. We thought that we were sending out pure Hertzian waves from our transmitters. We thought that we received these waves over the aerial wires of our receiving station. All of these theories are wrong and will be relegated shortly into the past along with the early notion that the earth stood still, while sun, moon and stars revolved around it.

Remain only the physical facts that we did send and did receive messages without wires—but they are not sent by means of pure Hertz waves, nor do they go by way of the ether as radiations.

In a highly illuminating article printed elsewhere in this issue, Nikola Tesla explodes all of our present orthodox views as to wireless propagation and makes it clear that the earth is the sole medium thru which our wireless impulses travel, in the form of true conduction. Particularly does this hold true for long distance messages: Here we are sending out a compound impulse three quarters of which is a galvanic current, traveling thru the conducting earth, the other quarter or less is in the form of Hertz waves, going by way of the ether. This explains why we can send signals to airplanes and vice versa; but even here we probably have to do not with pure Hertz waves: it is almost certain that we have capacity-inductive effects as well.

Tesla maintaining that there can be no long distance effects by radiations transmitted thru the ether, but rather only by currents thru the earth, it follows that in his opinion all our radio apparatus is designed and operated faultily. Indeed, this is not a brand new idea of the famous inventor. He has been preaching it ever since he took out his first patents and described his system in 1893—long before Marconi thought of wireless But he was preaching to a stone deaf scientific world.

But how simple it all becomes when we stop to apply a little reason and logic to Tesla's claims. For instance, we can send radio impulses three to five times as far over salt water as over land. Why? Simply because the impulses go *thru* the water, which is a much better conductor than earth alone. If we were sending pure Hertzian waves, why do we connect one wire at both sending and receiving station to the ground? Hertz never dreamt of such a thing. If you are still unconvinced that the earth is the chief medium of transmission, disconnect your ground wires entirely and try to send and receive. Now you may work with Hertz waves, but the distances you can bridge will be pitifully small.

Already Tesla's logic is filtering into our radio scientists' minds. *All the big stations are beginning to scrap their towers and aerial wires, at least for receiving. They now bury their "aerial" wires in the ground,* and lo! they can receive signals twice as far as before. Incredible, but it is being done every day. And—wonders upon wonders—how we will laugh at our present and past blindness—*the static interference is practically gone* the minute we pull our aerial wires down and bury them! Static Electricity? There never was a reason for having the bugaboo, for there is no "static" in the ground.

But Tesla goes much farther. In time he will show the world wireless power transmission effected *not by ether waves but by currents thru the earth,* which is a first rate conductor. Like all big things, the problem is simple. At some point on the globe he will erect a station powerful enough to charge the whole earth with electricity—and keep it charged. To do this we need about 10,000 kilowatts. Then at *any* point on the globe the current can be tapt by means of suitable apparatus. Like a bell ringing transformer, *connected* to your supply line, no current is consumed unless you close the secondary circuit. Tesla's world wireless works just that way. *No current is consumed till it is tapt at the distant receiving station.*

H. GERNSBACK.

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Famous Scientific Illusions

By NIKOLA TESLA

Written specially for the Electrical Experimenter

In this original and revolutionizing discussion, Nikola Tesla gives us something really new to think about. First—Does the moon rotate on its axis? Second—Is the Franklin pointed lightning rod correct in theory and operation? Third—Do wireless signals fly thru space by means of so-called Hertzian waves in the ether, or are they propagated thru the earth at prodigious velocity by means of earth-bound oscillations? World-famous conundrums these—questions which have been answered in many ways by some of the greatest scientists. Dr. Tesla explains these three predominant scientific fallacies in a masterly way, so that everyone can understand them.

THE human brain, with all its wonderful capabilities and power, is far from being a faultless apparatus. Most of its parts may be in perfect working order, but some are atrophied, undeveloped or missing altogether. Great men of all classes and professions—scientists, inventors, and hard-headed financiers—have placed themselves on record with impossible theories, inoperative devices, and unrealizable schemes. It is doubtful that there could be found a single work of any one individual free of error. There is no such thing as an infallible brain. Invariably, some cells or fibers are wanting or unresponsive, with the result of impairing judgment, sense of proportion, or some other faculty. A man of genius eminently practical, whose name is a household word, has wasted the best years of his life in a visionary undertaking. A celebrated physicist was incapable of tracing the direction of an electric current according to a childishly simple rule. The writer, who was known to recite entire volumes by heart, has never been able to retain in memory and recapitulate in their proper order the words designating the colors of the rainbow, and can only ascertain them after long and laborious thought, strange as it may seem.

Our organs of reception, too, are deficient and deceptive. As a semblance of life is produced by a rapid succession of inanimate pictures, so many of our perceptions are but trickery of the senses, devoid of reality. The greatest triumphs of man were those in which his mind had to free itself from the influence of delusive appearances. Such was the revelation of Buddha that self is an illusion caused by the persistence and continuity of mental images; the discovery of Copernicus that, contrary to all observation, this planet rotates around the sun; the recognition of Descartes that the human being is an automaton, governed by external influence and the idea that the earth is spherical, which led Columbus to the finding of this continent. And tho the minds of individuals supplement one another and science and experience are continually eliminating fallacies and misconceptions, much of our present knowledge is still incomplete and unreliable. We have sophisms in mathematics which cannot be disproved. Even in pure reasoning, free of the shortcomings of symbolic processes, we are often arrested by doubt which the strong-

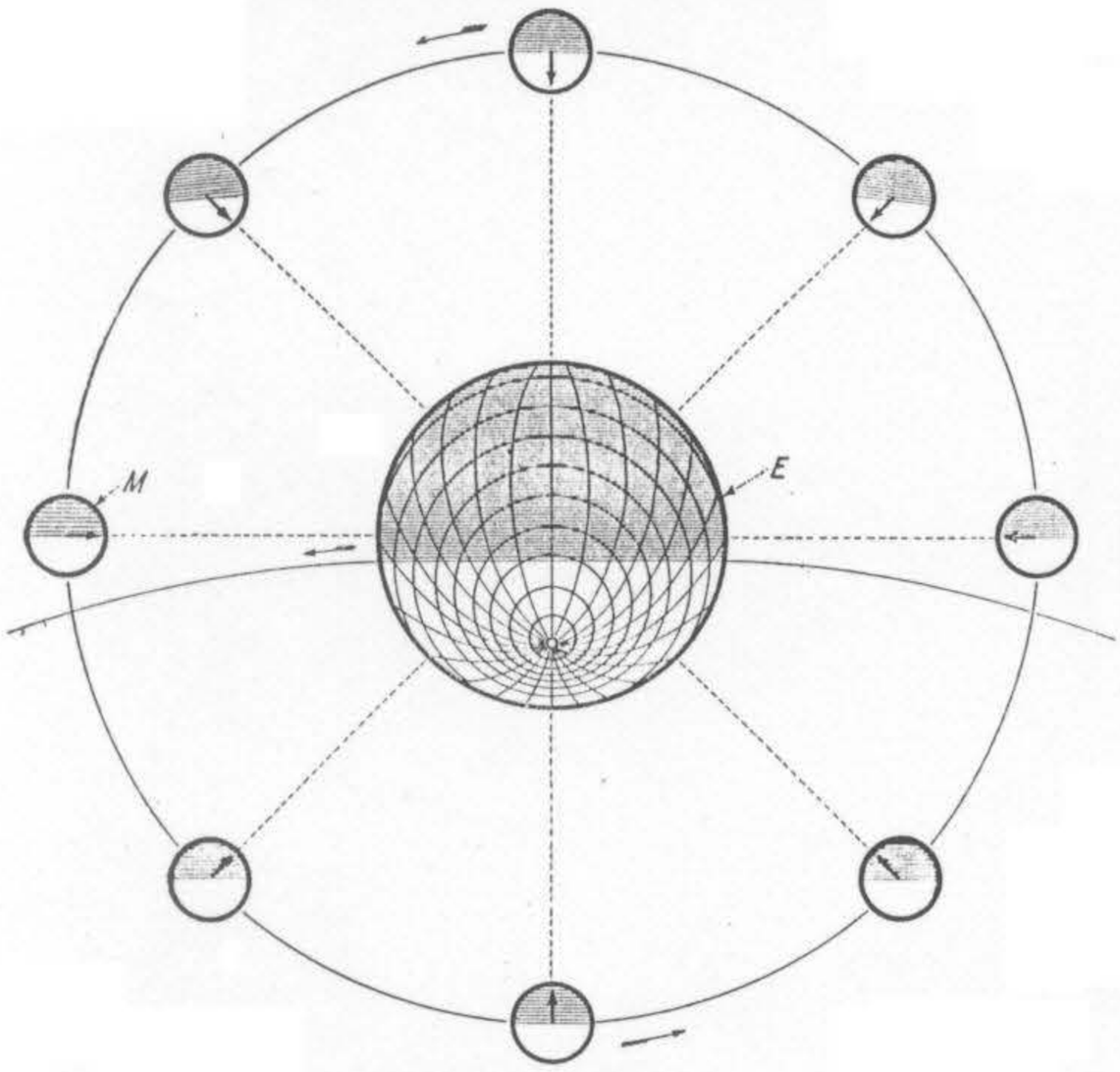

Fig. 1

It Is Well Known That the Moon, M., Always Turns the Same Face Toward the Earth, E, as the Black Arrows Indicate. The Parallel Rays From the Sun Illuminate the Moon In Its Successive Orbital Positions as the Unshaded Semi-circles Indicate. Bearing This In Mind, Do You Believe That the Moon Rotates on Its Own Axis?

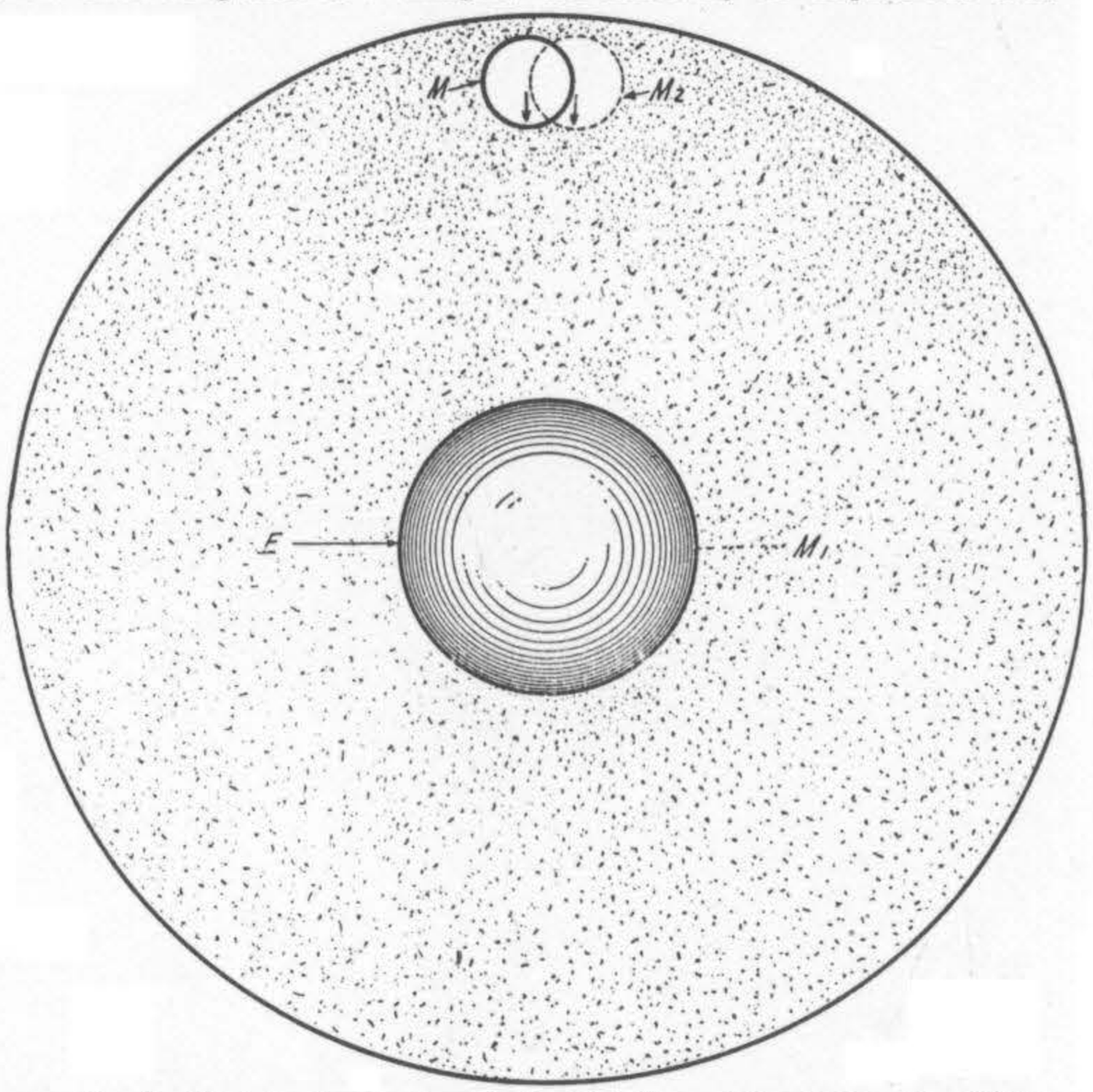

Fig. 2.—Tesla's Conception of the Rotation of the Moon, M, Around the Earth, E; the Moon, In This Demonstration Hypothesis, Being Considered as Embedded In a Solid Mass, M_1. If, As Commonly Believed, the Moon Rotates, This Would Be Equally True For a Portion of the Mass M_2, and the Part Common to Both Bodies Would Turn Simultaneously In "Opposite" Directions.

FOR over a century and a half the whole world, educated and otherwise, thought that the moon revolved around its axis. Nikola Tesla in the present highly instructive article disproves that theory and will convince scientists and all others alike that the moon does no such thing.

For thousands of years it was thought that the sun and stars revolved around the earth and all kinds of experimental proofs were furnished to substantiate this theory. The illustrious Galileo thought different, and everyone today knows that the earth revolves around the sun.

So it is with Tesla's discovery. Tesla also, in the second part of the present paper, shows us that the ancient and time-worn theory advanced by Benjamin Franklin as to the lightning conductor is not substantially correct as viewed by latter day science. It will come as a shock even to our professors that the lightning rod actually aids the lightning in hitting the building. The reason is that the lightning rod helps in ionizing (making conductive) the surrounding air.

Mr. Tesla has devised a lightning conductor with no points, and there is no doubt whatsoever that his theory is right. Scientists the world over will acknowledge this very shortly.

In a third section of the same paper Tesla explodes still another popular delusion, viz., that wireless waves follow the curvature of the earth when messages are transmitted, let us say from a point in the United States to a point in Europe. In his revolutionary arguments, supported by facts as well as by logic, Tesla shows why the currents do not travel around the earth but directly thru it. In other words, Tesla maintains that wireless communication is accomplished ONLY thru the medium of the earth itself. His contention seems very sound. If it were not so, let every wireless station, commercial or otherwise, do away with its ground connection. None could then operate as is well known, except perhaps over very limited distances.

Mr. Tesla's present article will arouse world-wide comment due to the revolutionary philosophy contained therein. We are sure our readers will appreciate Mr. Tesla's most timely and illuminating article on this but little understood subject.

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est intelligences have been unable to dispel. Experimental science itself, most positive of all, is not unfailing.

In the following I shall consider three exceptionally interesting errors in the interpretation and application of physical phenomena which have for years dominated the minds of experts and men of science.

I. The Illusion of the Axial Rotation of the Moon.

It is well known since the discovery of Galileo that the moon, in travelling thru space, always turns the same face towards the earth. This is explained by stating that while passing once around its mother-planet the lunar globe performs just one revolution on its axis. The spinning motion of a heavenly body must necessarily undergo modifications in the course of time, being either retarded by resistances internal or external, or accelerated owing to shrinkage and other causes. An unalterable rotational velocity thru all phases of planetary evolution is manifestly impossible. What wonder, then, that at this very instant of its long existence our satellite should revolve exactly so, and not faster or slower. But many astronomers have accepted as a physical fact that such rotation takes place. It does not, but only appears so; it is an illusion, a most surprising one, too.

I will endeavor to make this clear by reference to Fig. 1, in which E represents the earth and M the moon. The movement thru space is such that the arrow, firmly attached to the latter, always occupies the position indicated with reference to the earth. If one imagines himself as looking down on the orbital plane and follows the motion he will become convinced that the moon *does* turn on its axis as it travels around. But in this very act the observer will have deceived himself. To make the delusion complete let him take a washer similarly marked and supporting it rotatably in the center, carry it around a stationary object, constantly keeping the arrow pointing towards the latter. Tho to his bodily vision the disk will revolve on its axis, such movement does not exist. He can dispel the illusion at once by holding the washer fixedly while going around. He will now readily see that the supposed axial rotation is only apparent, the impression being produced by successive changes of position in space.

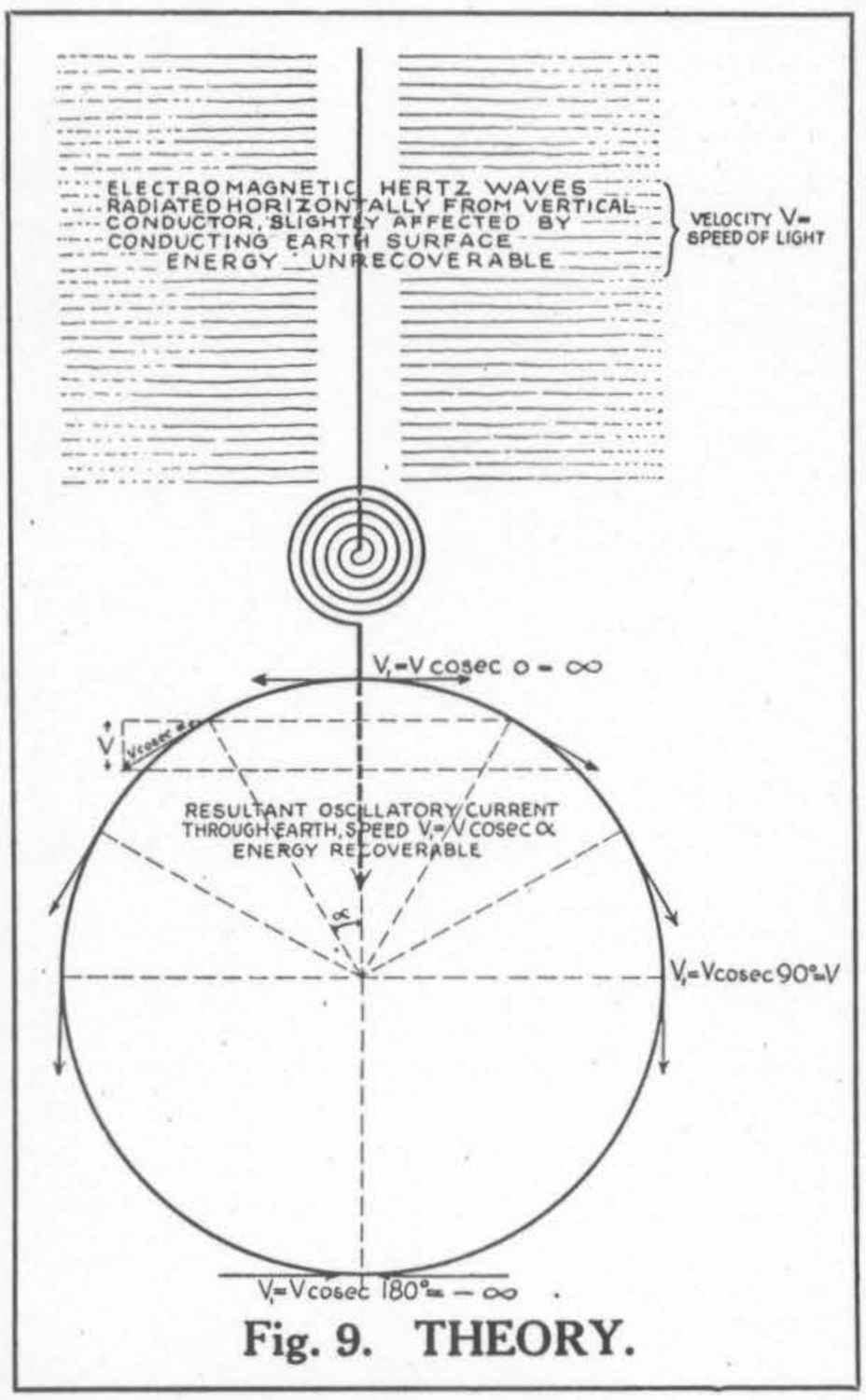
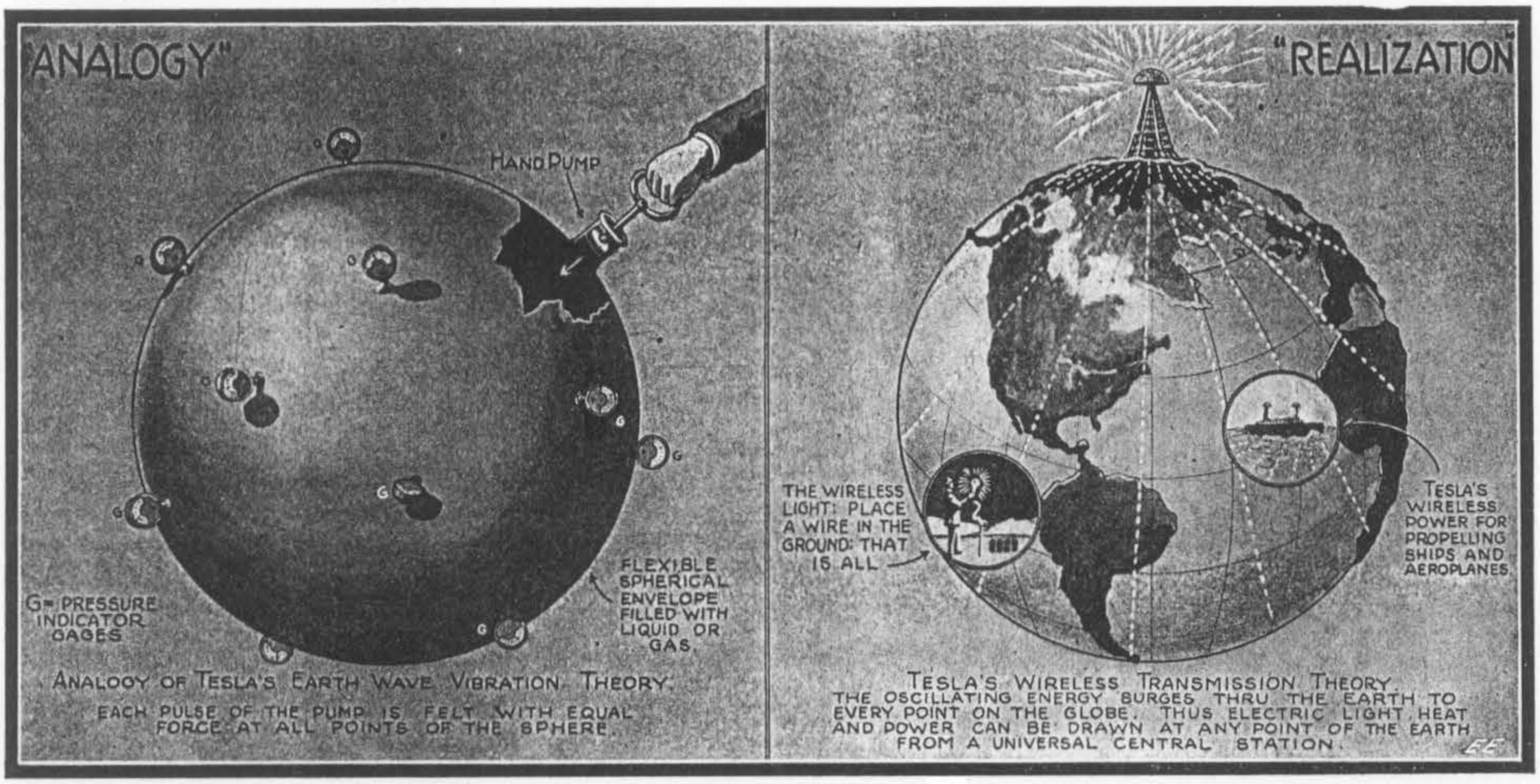


Fig. 9. THEORY.

But more convincing proofs can be given that the moon does not, and cannot revolve on its axis. With this object in view attention is called to Fig. 2, in which both the satellite, M, and earth, E, are shown embedded in a solid mass, M_1 (indicated by stippling) and supposed to rotate so as to impart to the moon its normal translatory velocity. Evidently, if the lunar globe could rotate as commonly believed, this would be equally true of any other portion of mass M_1, as the sphere M_2, shown in dotted lines, and then the part common to both bodies would have to turn *simultaneously in opposite directions.* This can be experimentally illustrated in the manner suggested by using instead of one, two overlapping rotatable washers, as may be conveniently represented by circles M and M_2, and carrying them around a center as E, so that the plain and dotted arrows are always pointing towards the same center. No further argument is needed to demonstrate that the two gyrations cannot co-exist or even be pictured in the imagination and reconciled in a purely abstract sense.

The truth is, the so-called "axial rotation" of the moon is a phenomenon deceptive alike to the eye and mind and devoid of physical meaning. It has nothing in common with real mass revolution characterized by effects positive and unmistakable. Volumes have been written on the subject and many erroneous arguments advanced in support of the notion. Thus, it is reasoned, that if the planet did *not* turn on its axis it would expose the whole surface to terrestrial view; as only one-half is visible, it *must* revolve. The first statement is true but the logic of the second is defective, for it admits of only one alternative. The conclusion is not justified as the same appearance can also be produced in another way. The moon does rotate, not on its own, **but about an axis passing thru the center of the earth, the true and only one.**

The unfailing test of the spinning of a mass is, however, the existence of



Tesla's World-Wide Wireless Transmission of Electrical Signals, As Well As Light and Power, Is Here Illustrated In Theory, Analogy and Realization. Tesla's Experiments With 100 Foot Discharges At Potentials of Millions of Volts Have Demonstrated That the Hertz Waves Are Infinitesimal In Effect and Unrecoverable; the Recoverable Ground Waves of Tesla Fly "Thru the Earth". Radio Engineers Are Gradually Beginning to See the Light and That the Laws of Propagation Laid Down by Tesla Over a Quarter of a Century Ago Form the Real and True Basis of All Wireless Transmission To-Day.

energy of motion. The moon is not possest of such *vis viva*. If it were the case then a revolving body as M_1 would contain mechanical energy other than that of which we have experimental evidence. Irrespective of this so exact a coincidence between the axial and orbital periods is, in itself, immensely improbable for this is not the permanent condition towards which the system is tending. Any axial rotation of a mass left to itself, retarded by forces external or internal, must cease. Even admitting its perfect control by tides the coincidence would still be miraculous. But when we remember that most of the satellites exhibit this peculiarity, the probability becomes infinitestimal.

Three theories have been advanced for the origin of the moon. According to the oldest suggested by the great German philosopher Kant, and developed by Laplace in his monumental treatise "Mécanique Céleste", the planets have been thrown off from larger central masses by centrifugal force. Nearly forty years ago Prof. George H. Darwin in a masterful essay on tidal friction furnished mathematical proofs, deemed unrefutable, that the moon had separated from the earth. Recently this established theory has been attacked by Prof. T. J. J. See in a remarkable work on the "Evolution of the Stellar Systems", in which he propounds the view that centrifugal force was altogether inadequate to bring about the separation and that all planets, including the moon, have come from the depths of space and have been captured. Still a third hypothesis of unknown origin exists which has been examined and commented upon by Prof. W. H. Pickering in "Popular Astronomy of 1907", and according to which the moon was torn from the earth when the later was partially solidified, this accounting for the continents which might not have been formed otherwise.

Undoubtedly planets and satellites have originated in both ways and, in my opinion, it is not difficult to ascertain the character of their birth. The following conclusions can be safely drawn:

1. A heavenly body thrown off from a larger one cannot rotate on its axis. The mass, rendered fluid by the combined action of heat and pressure, upon the reduction of the latter immediately stiffens, being at the same time deformed by gravitational pull. The shape becomes permanent upon cooling and solidification and the smaller mass continues to move about the larger one as tho it were rigidly connected to it except for pendular swings or librations due to varying orbital velocity. Such motion precludes the possibility of axial rotation in the strictly physical sense. The moon has never spun around as is well demonstrated by the fact that the most precise measurements have failed to show any measurable flattening in form.

2. If a planetary body in its orbital movement turns the same side towards the central mass this is a positive proof that it has been separated from the latter and is a true satellite.

3. A planet revolving on its axis in its passage around another cannot have been thrown off from the same but must have been captured.

Fig. 5

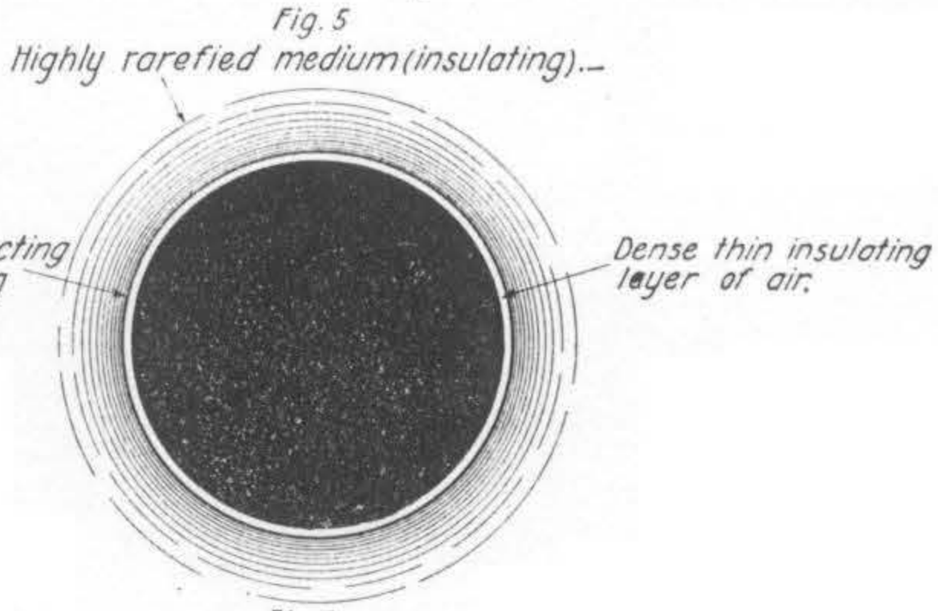
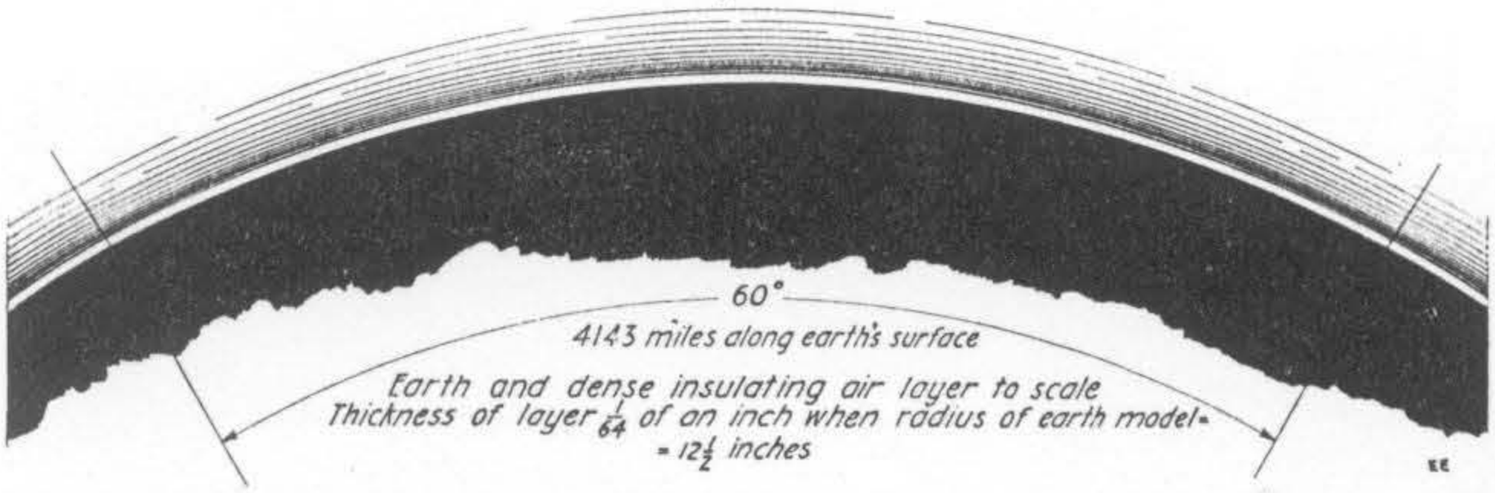


Fig. 6



A Section of the Earth and Its Atmospheric Envelope Drawn to Scale. It Is Obvious That the Hertzian Rays Cannot Traverse So Thin a Crack Between Two Conducting Surfaces For Any Considerable Distance, Without Being Absorbed, Says Dr. Tesla, in Discussing the Ether Space Wave Theory.

II. The Fallacy of Franklin's Pointed Lightning-Rod.

The display of atmospheric electricity has since ages been one of the most marvelous spectacles afforded to the sight of man. Its grandeur and power filled him with fear and superstition. For centuries he attributed lightning to agents god-like and supernatural and its purpose in the scheme of this universe remained unknown to him. Now we have learned that the waters of the ocean are raised by the sun and maintained in the atmosphere delicately suspended, that they are wafted to distant regions of the globe where electric forces assert themselves in upsetting the sensitive balance and causing precipitation, thus sustaining all organic life. There is every reason to hope that man will soon be able to control this life-giving flow of water and thereby solve many pressing problems of his existence.

Atmospheric electricity became of special scientific interest in Franklin's time. Faraday had not yet announced his epochal discoveries in magnetic induction but static frictional machines were already generally used in physical laboratories. Franklin's powerful mind at once leaped to the conclusion that frictional and atmospheric electricity were identical. To our present view this inference appears obvious, but in his time the mere thought of it was little short of blasphemy. He investigated the phenomena and argued that if they were of the same nature then the clouds could be drained of their charge exactly as the ball of a static machine, and in 1749 he indicated in a publisht memoir how this could be done by the use of pointed metal rods.

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Fig. 8.—This Diagram Illustrates How, During a Solar Eclipse, the Moon's Shadow Passes Over the Earth With Changing Velocity, and Should Be Studied In Connection With Fig. 9. The Shadow Moves Downward With Infinite Velocity at First, Then With Its True Velocity Thru Space, and Finally With Infinite Velocity Again.

Famous Scientific Illusions

(*Continued from page* 694)

The earliest trials were made by Dalibrand in France, but Franklin himself was the first to obtain a spark by using a kite, in June, 1752. When these atmospheric discharges manifest themselves today in our wireless station we feel annoyed and wish that they would stop, but to the man who discovered them they brought tears of joy.



Fig. 7

The Theory Has Been Seriously Advanced and Taught that the Radio Ether Wave Oscillations Pass Around the Earth by Successive Reflections, as Here Shown. The Efficiency of Such a Reflector Cannot be more than 25 Per Cent; the Amount of Energy Recoverable in a 12,000-mile Transmission being but One Hundred and Fifteen Billionth Part of One Watt, with 1,000 Kilowatts at the Transmitter.

The lightning conductor in its classical form was invented by Benjamin Franklin in 1755 and immediately upon its adoption proved a success to a degree. As usual, however, its virtues were often exaggerated. So, for instance, it was seriously claimed that in the city of Piatermaritzburg (capital of Natal, South Africa) no lightning strokes occurred after the pointed rods were installed, altho the storms were as frequent as before. Experience has shown that just the opposite is true. A modern city like New York, presenting innumerable sharp points and projections in good contact with the earth, is struck much more often than equivalent area of land. Statistical records, carefully compiled and publisht from time to time, demonstrate that the danger from lightning to property and life has been reduced to a small percentage by Franklin's invention, but the damage by fire amounts, nevertheless, to several million dollars annually. It is astonishing that this device, which has been in universal use for more than one century and a half, should be found to involve a gross fallacy in design and construction which impairs its usefulness and may even render its employment hazardous under certain conditions.

For explanation of this curious fact I may first refer to Fig. 3, in which *s* is a metallic sphere of radius *r*, such as the capacity terminal of a static machine, provided with a sharply pointed pin of length *h*, as indicated. It is well known that the latter has the property of quickly dissipating the accumulated charge into the air. To examine this action in the light of present knowledge we may liken electric potential to temperature. Imagine that sphere *s* is heated to *T* degrees and that the pin or metal bar is a perfect conductor of heat so that its extreme end is at the same temperature *T*. Then if another sphere of larger radius, v_1, is drawn about the first and the temperature along this boundary is T_1, it is evident that there will be between the end of the bar and its surrounding a difference of temperature $T - T_1$, which will determine the outflow of heat. Obviously, if the adjacent medium was not affected by the hot sphere this temperature difference would be greater and more heat would be given off. Exactly so in the electric system. Let *q* be the quantity of the charge, then the sphere—and owing to its great conductivity also the pin—will be at the potential $\frac{q}{r}$. The medium around the point of the pin will be at the potential $\frac{q}{r_1} = \frac{q}{r+h}$ and, consequently, the difference $\frac{q}{r} - \frac{q}{r+h} = \frac{qh}{r(r+h)}$. Suppose now that a sphere *S* of much larger radius $R = nr$ is employed containing a charge Q this difference of potential will be, analogously $\frac{Qh}{R(R+h)}$. According to elementary principles of electro-statics the potentials of the two spheres *s* and *S* will be equal if $Q = nq$ in which case $\frac{Qh}{R(R+h)} =$

(*Continued on page* 730)

FAMOUS SCIENTIFIC ILLUSIONS.

(*Continued from page 728*)

$\frac{nqh}{nr(nr+h)} = \frac{qh}{r(nr+h)}$. Thus the difference of potential between the point of the pin and the medium around the same

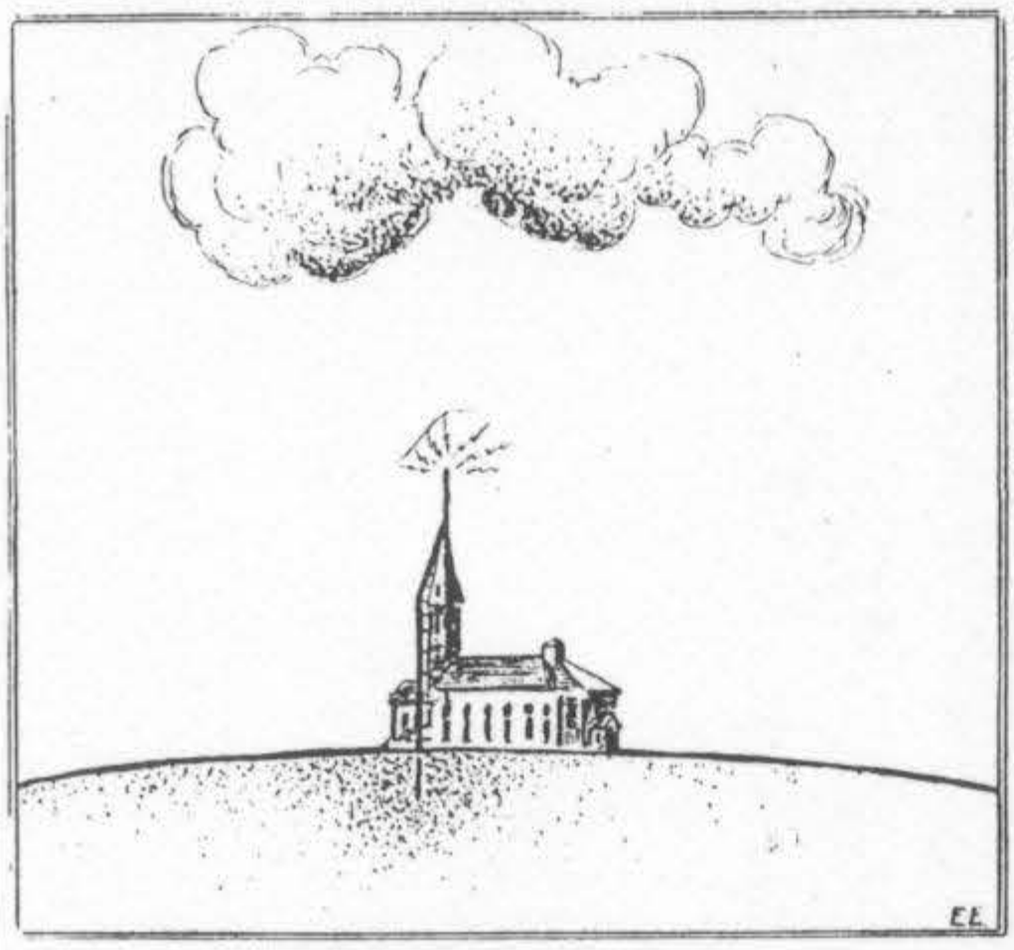

Fig. 4. Tesla Explains the Fallacy of the Franklin Pointed Lightning Rod, Here Illustrated, and Shows that Usually Such a Rod Could Not Draw Off the Electricity In a Single Cloud In Many Years. The Density of the Dots Indicates the Intensity of the Charges.

will be smaller in the ratio $\frac{r+h}{nr+h}$ when the large sphere is used. In many scientific tests and experiments this important observation has been disregarded with the result of causing serious errors. Its significance is that the behavior of the pointed rod entirely depends on the linear dimensions of the electrified body. Its quality to give off the charge may be entirely lost if the latter is very large. For this reason, all points or projections on the surface of a conductor of such vast dimensions as the earth would be quite ineffective were it not for other influences. These will be elucidated with reference to Fig. 4, in which our artist of the Impressionist school has emphasized Franklin's notion that his rod was drawing electricity from the clouds. If the earth were not surrounded by an atmosphere which is generally oppositely charged it would behave, despite all its irregularities of surface, like a polished sphere. But owing to the electrified masses of air and cloud the distribution is greatly modified. Thus in Fig. 4, the positive charge of the cloud induces in the earth an equivalent *opposite* charge, the density at the surface of the latter diminishing with the cube of the distance from the static center of the cloud. A brush discharge is then formed at the point of the rod and the action Franklin anticipated takes place. In addition, the surrounding air is ionized and rendered conducting and, eventually, a bolt may hit the building or some other object in the vicinity. The virtue of the pointed end to dissipate the charge, which was uppermost in Franklin's mind is, however, infinitesimal. *Careful measurements show that it would take many years before the electricity stored in a single cloud of moderate size would be drawn off or neutralized thru such a lightning conductor.* The grounded rod has the quality of rendering harmless most of the strokes it receives, tho occasionally the charge is diverted with damaging results. But, what is very important to note, it invites danger and hazard on account of the fallacy involved in its design. The sharp point which was thought advantageous and indispensable to its operation, is really a defect detracting considerably from the practical value of the device. I have produced a much improved form of lightning protector characterized by the employment of a terminal of considerable area and large radius of curvature which makes impossible undue density of the charge and ionization of the air.* *These protectors act as quasi-repellents and so far have never been struck tho exposed a long time.* Their safety is experimentally demonstrated to greatly exceed that invented by Franklin. By their use property worth millions of dollars which is now annually lost, can be saved.

III. The Singular Misconception of the Wireless.

To the popular mind this sensational advance conveys the impression of a single invention but in reality it is an art, the successful practise of which involves the employment of a great many discoveries and improvements. I viewed it as such when I undertook to solve wireless problems and it is due to this fact that my insight into its underlying principles was clear from their very inception.

In the course of development of my induction motors it became desirable to operate them at high speeds and for this purpose I constructed alternators of relatively

*Refer to the October, 1918, issue of this journal wherein Dr. Tesla's new form of non-pointed lightning rod was fully described and illustrated.

(*Continued on page 732*)

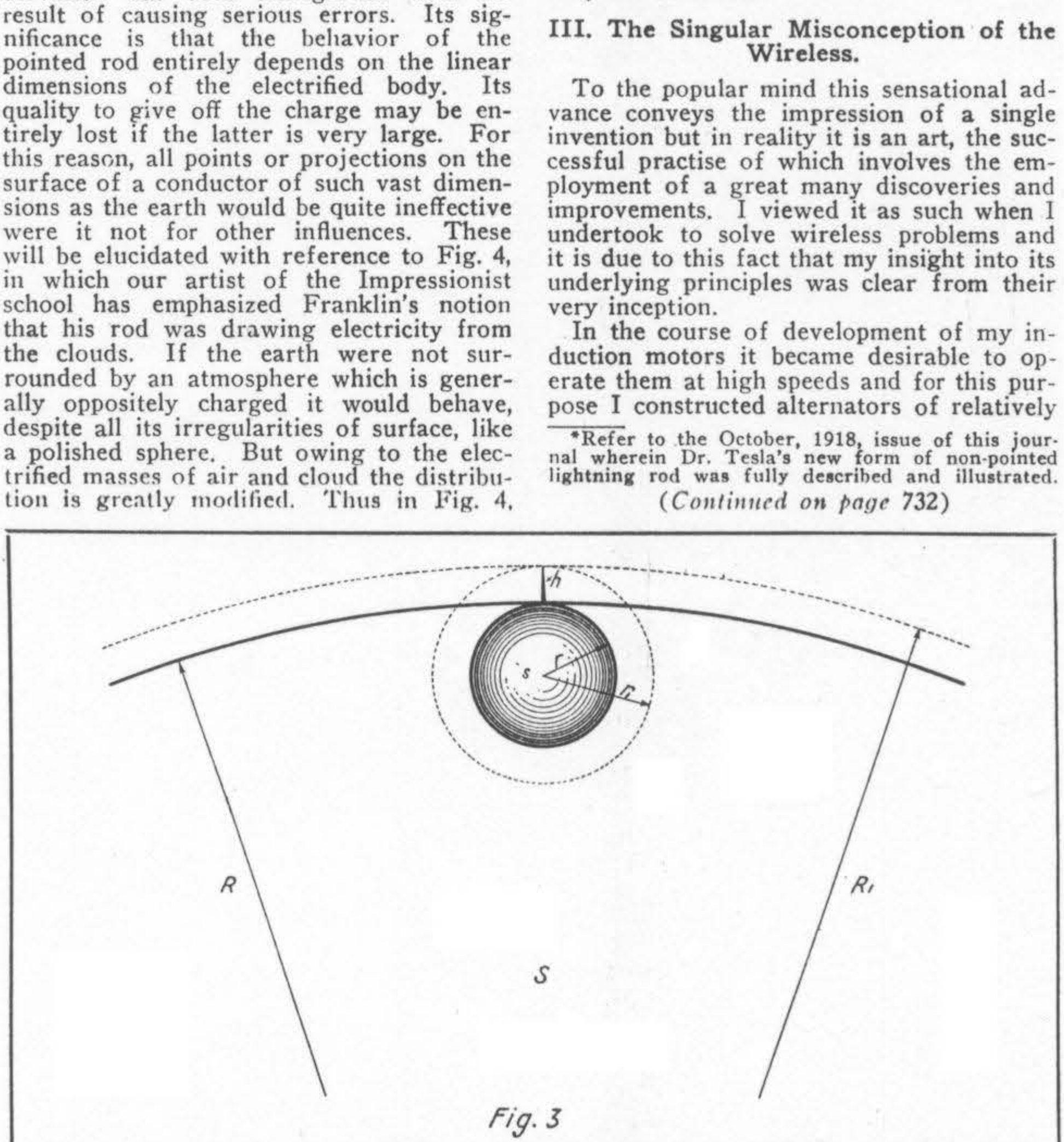

Fig. 3

Diagram Used to Explain the Fallacy of the Franklin Pointed Lightning Rod, and an Analogy Whereby the Author Shows In a Clear Manner How the Charged Sphere May for Illustration be Considered as Heated to a High Degree, and the Heat Allowed to Escape at a Known Rate

FAMOUS SCIENTIFIC ILLUSIONS

(*Continued from page* 730)

high frequencies. The striking behavior of the currents soon captivated my attention and in 1889 I started a systematic investigation of their properties and the possibilities of practical application. The first gratifying result of my efforts in this direction was the transmission of electrical energy thru *one wire* without return, of which I gave demonstrations in my lectures and addresses before several scientific bodies here and abroad in 1891 and 1892. During that period, while working with my oscillation transformers and dynamos of frequencies up to 200,000 cycles per second, the idea gradually took hold of me that the earth might be used in place of the wire, thus dispensing with artificial conductors altogether. The immensity of the globe seemed an unsurmountable obstacle but after a prolonged study of the subject I became satisfied that the undertaking was rational, and in my lectures before the Franklin Institute and National Electric Light Association early in 1893 I gave the outline of the system I had conceived. In the latter part of that year, at the Chicago World's Fair, I had the good fortune of meeting Prof. Helmholtz to whom I explained my plan, illustrating it with experiments. On that occasion I asked the celebrated physicist for an expression of opinion on the feasibility of the scheme. He stated unhesitatingly that it was practicable, provided I could perfect apparatus capable of putting it into effect but this, he anticipated, would be extremely difficult to accomplish.

I resumed the work very much encouraged and from that date to 1896 advanced slowly but steadily, making a number of improvements the chief of which was my system of *concatenated tuned circuits* and method of regulation, now universally adopted. In the summer of 1897 Lord Kelvin happened to pass thru New York and honored me by a visit to my laboratory where I entertained him with demonstrations in support of my wireless theory. He was fairly carried away with what he saw but, nevertheless, condemned my project in emphatic terms, qualifying it as something impossible, "an illusion and a snare." I had expected his approval and was pained and surprised. But the next day he returned and gave me a better opportunity for explanation of the advances I had made and of the true principles underlying the system I had evolved. Suddenly he remarked with evident astonishment: "Then you are not making use of Hertz waves?" "Certainly not," I replied, *"these are radiations.* No energy could be economically transmitted to a distance by any such agency. In my system the process is one of *true conduction* which, theoretically, can be effected at the greatest distance without appreciable loss." I can never forget the magic change that came over the illustrious philosopher the moment he freed himself from that erroneous impression. The skeptic who would not believe was suddenly transformed into the warmest of supporters. He parted from me not only thoroly convinced of the scientific soundness of the idea but strongly exprest his confidence in its success. In my exposition to him I resorted to the following mechanical analogues of my own and the Hertz wave system.

Imagine the earth to be a bag of rubber filled with water, a small quantity of which is periodically forced in and out of the same by means of a reciprocating pump, as illustrated. If the strokes of the latter are effected in intervals of more than one hour and forty-eight minutes, sufficient for the transmission of the impulse thru the whole mass, the entire bag will expand and contract and corresponding movements will be imparted to pressure gauges or movable pistons with the same intensity, irrespective of distance. By working the pump faster, shorter waves will be produced which, on reaching the opposite end of the bag, may be reflected and give rise to stationary nodes and loops. but in any case, the fluid being incompressible, its inclosure perfectly elastic, and the frequency of oscillations not very high, the energy will be economically transmitted and very little power consumed so long as no work is done in the receivers. This is a crude but correct representation of my wireless system in which, however, I resort to various refinements. Thus, for instance, the pump is made part of a resonant system of great inertia, enormously magnifying the force of the imprest impulses. The receiving devices are similarly conditioned and in this manner the amount of energy collected in them vastly increased.

The Hertz wave system is in many respects the very opposite of this. To explain it by analogy, the piston of the pump is assumed to vibrate to and fro at a terrific rate and the orifice thru which the fluid passes in and out of the cylinder is reduced to a small hole. There is scarcely any movement of the fluid and almost the whole work performed results in the production of radiant heat, of which an infinitesimal part is recovered in a remote locality. However incredible, it is true that

the minds of some of the ablest experts have been from the beginning, and still are, obsest by this monstrous idea, and so it comes that the true wireless art, to which I laid the foundation in 1893, has been retarded in its development for twenty years. This is the reason why the "statics" have proved unconquerable, why the wireless shares are of little value and why the Government has been compelled to interfere.

We are living on a planet of well-nigh inconceivable dimensions, surrounded by a layer of insulating air above which is a rarefied and conducting atmosphere (Fig. 5). This is providential, for if all the air were conducting the transmission of electrical energy thru the natural media would be impossible. My early experiments have shown that currents of high frequency and great tension readily pass thru an atmosphere but moderately rarefied, so that the insulating stratum is reduced to a small thickness as will be evident by inspection of Fig. 6, in which a part of the earth and its gaseous envelope is shown to scale. If the radius of the sphere is 12½" then the non-conductive layer is only 1/64" thick and it will be obvious that the Hertzian rays cannot traverse so thin a crack between two conducting surfaces for any considerable distance, without being absorbed. The theory has been seriously advanced that these radiations pass around the globe by *successive reflections*, but to show the absurdity of this suggestion reference is made to Fig. 7 in which this process is diagrammatically indicated. Assuming that there is no refraction, the rays, as shown on the right, would travel along the sides of a polygon drawn around the solid, and inscribed into the conducting gaseous boundary in which case the length of the side would be about 400 miles. As one-half the circumference of the earth is approximately 12,000 miles long there will be, roughly, thirty deviations. The efficiency of such a reflector cannot be more than 25 per cent, so that if none of the energy of the transmitter were lost in other ways, the part recovered would be measured by the fraction $(\frac{1}{4})^{30}$. Let the transmitter radiate Hertz waves at the rate of 1,000 kilowatts. Then about *one hundred and fifteen billionth part of one watt* is all that would be collected in a *perfect* receiver. In truth, the reflections would be much more numerous as shown on the left of the figure, and owing to this and other reasons, on which it is unnecessary to dwell, the amount recovered would be a vanishing quantity.

Consider now the process taking place in the transmission by the instrumentalities and methods of my invention. For this purpose attention is called to Fig. 8, which gives an idea of the mode of propagation of the current waves and is largely self-explanatory. The drawing represents a solar eclipse with the shadow of the moon just touching the surface of the earth at a point where the transmitter is located. As the shadow moves downward it will spread over the earth's surface, first with infinite and then gradually diminishing velocity until at a distance of about 6,000 miles it will attain its true speed in space. From there on it will proceed with increasing velocity, reaching infinite value at the opposite point of the globe. It hardly need be stated that this is merely an illustration and not an accurate representation in the astronomical sense.

The exact law will be readily understood by reference to Fig. 9, in which a transmitting circuit is shown connected to earth and to an antenna. The transmitter being in action, two effects are produced: Hertz waves pass thru the air, and a current traverses the earth. The former propagate with the speed of light and their energy is *unrecoverable* in the circuit. The latter proceeds with the speed varying as the cosecant of the angle which a radius drawn from any point under consideration forms

with the axis of symmetry of the waves. At the origin the speed is infinite but gradually diminishes until a quadrant is traversed, when the velocity is that of light. From there on it again increases, becoming infinite at the antipole. Theoretically the energy of this current is *recoverable* in its entirety, in properly attuned receivers.

Some experts, whom I have credited with better knowledge, have for years contended that my proposals to transmit power without wires are sheer nonsense but I note that they are growing more cautious every day. The latest objection to my system is found in the cheapness of gasoline. These men labor under the impression that the energy flows in all directions and that, therefore, only a minute amount can be recovered in any individual receiver. But this is far from being so. The power is conveyed in only one direction, from the transmitter to the receiver, and none of it is lost elsewhere. It is perfectly practicable to recover at any point of the globe energy enough for driving an airplane, or a pleasure boat or for lighting a dwelling. I am especially sanguine in regard to the lighting of isolated places and believe that a more economical and convenient method can hardly be devised. The future will show whether my foresight is as accurate now as it has proved heretofore.

Beginning: "My Inventions," by Nikola Tesla

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ELECTRICAL EXPERIMENTER

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SCIENCE AND INVENTION

THE TESLA WIRELESS LIGHT

SEE PAGE 692



My Inventions

By Nikola Tesla

1. MY EARLY LIFE

THE progressive development of man is vitally dependent on invention. It is the most important product of his creative brain. Its ultimate purpose is the complete mastery of mind over the material world, the harnessing of the forces of nature to human needs. This is the difficult task of the inventor who is often misunderstood and unrewarded. But he finds ample compensation in the pleasing exercises of his powers and in the knowledge of being one of that exceptionally privileged class without whom the race would have long ago perished in the bitter struggle against pitiless elements.

Speaking for myself, I have already had more than my full measure of this exquisite enjoyment, so much that for many years my life was little short of continuous rapture. I am credited with being one of the hardest workers and perhaps I am, if thought is the equivalent of labor, for I have devoted to it almost all of my waking hours. But if work is interpreted to be a definite performance in a specified time according to a rigid rule, then I may be the worst of idlers. Every effort under compulsion demands a sacrifice of life-energy. I never paid such a price. On the contrary, I have thrived on my thoughts.

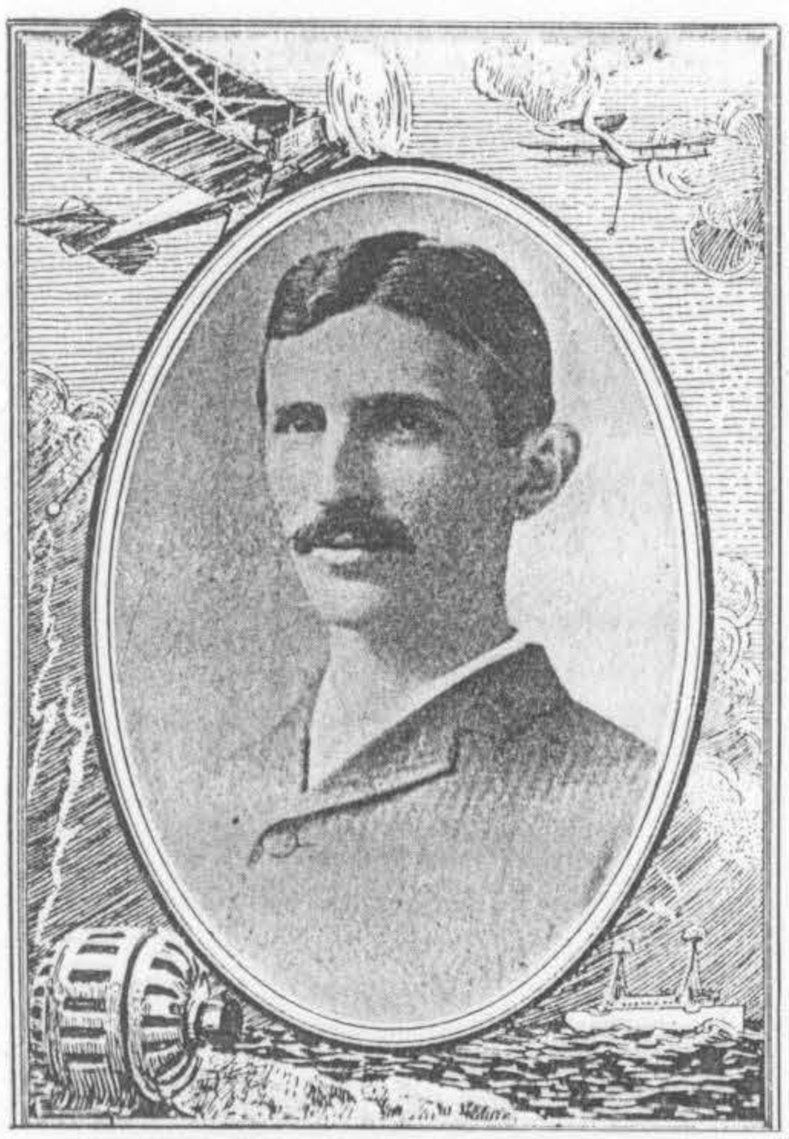
In attempting to give a connected and faithful account of my activities in this series of articles which will be presented with the assistance of the Editors of the ELECTRICAL EXPERIMENTER and are chiefly addrest to our young men readers, I must dwell, however reluctantly, on the impressions of my youth and the circumstances and events which have been instrumental in determining my career.

Our first endeavors are purely instinctive, promptings of an imagination vivid and undisciplined. As we grow older reason asserts itself and we become more and more systematic and designing. But those early impulses, tho not immediately productive, are of the greatest moment and may shape our very destinies. Indeed, I feel now that had I understood and cultivated instead of suppressing them, I would have added substantial value to my bequest to the world. But not until I had attained manhood did I realize that I was an inventor.

This was due to a number of causes. In the first place I had a brother who was gifted to an extraordinary degree—one of those rare phenomena of mentality which biological investigation has failed to explain. His premature death left my parents disconsolate. We owned a horse which had been presented to us by a dear friend. It was a magnificent animal of Arabian breed, possest of almost human intelligence, and was cared for and petted by the whole family, having on one occasion saved my father's life under remarkable circumstances. My father had been called one winter night to perform an urgent duty and while crossing the mountains, infested by wolves, the horse became frightened and ran away, throwing him violently to the ground. It arrived home bleeding and



Nikola Tesla at the Age of 23.
From An Unpublished Photograph.



Mr. Tesla at the Age of 29.

HOW does the world's greatest inventor invent? How does he carry out an invention? What sort of mentality has Nikola Tesla? Was his early life as commonplace as most of ours? What was the early training of one of the World's Chosen? These, and many other very interesting questions are answered in an incomparable manner by Nikola Tesla himself in this, his first article.

In his autobiography, treating mainly on his early youth, we obtain a good insight into the wonderful life this man has led. It reads like a fairy tale, which has the advantage of being true. For Tesla is no common mortal. He has led a charmed life—struck down by the pest, the cholera and what not—given up by doctors at least three times as dead—we find him at sixty, younger than ever. But—read his own words. You have never read the like before.

—Editor.

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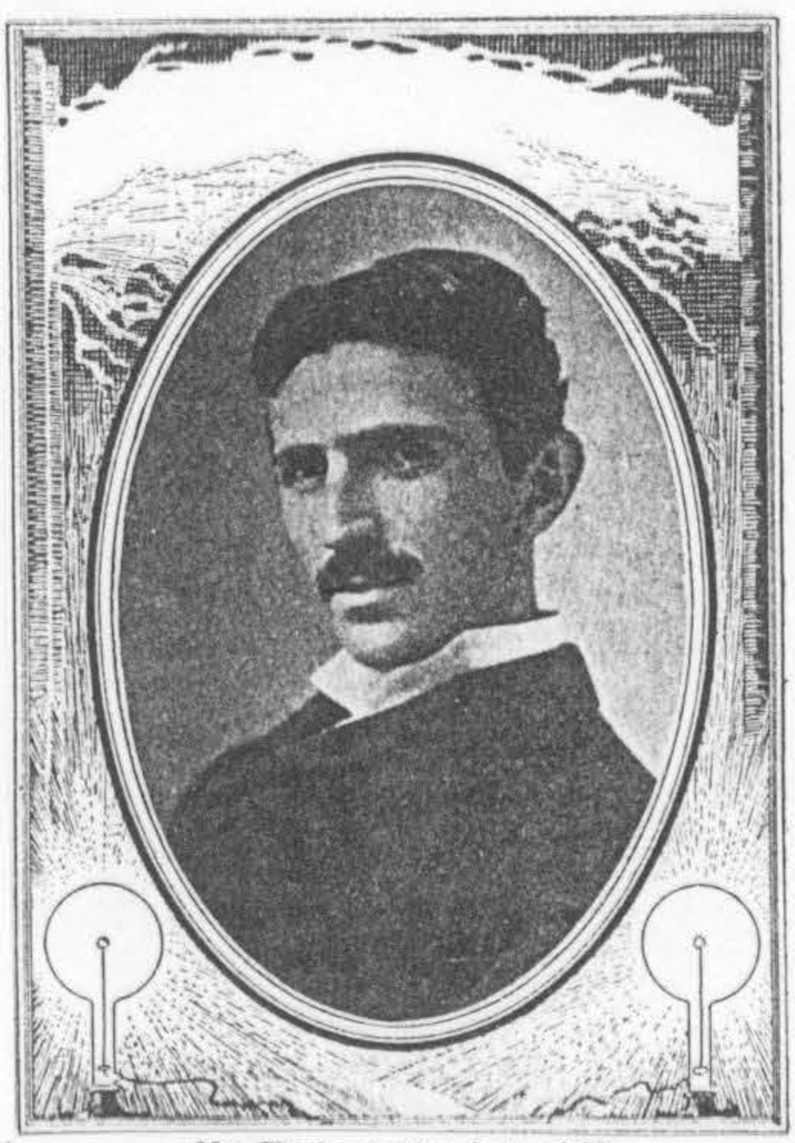


Mr. Tesla at the Age of 39.

exhausted, but after the alarm was sounded immediately dashed off again, returning to the spot, and before the searching party were far on the way they were met by my father, who had recovered consciousness and remounted, not realizing that he had been lying in the snow for several hours. This horse was responsible for my brother's injuries from which he died. I witnest the tragic scene and altho fifty-six years have elapsed since, my visual impression of it has lost none of its force. The recollection of his attainments made every effort of mine seem dull in comparison.

Anything I did that was creditable merely caused my parents to feel their loss more keenly. So I grew up with little confidence in myself. But I was far from being considered a stupid boy, if I am to judge from an incident of which I have still a strong remembrance. One day the Aldermen were passing thru a street where I was at play with other boys. The oldest of these venerable gentlemen—a wealthy citizen—paused to give a silver piece to each of us. Coming to me he suddenly stopt and commanded, "Look in my eyes." I met his gaze, my hand outstretched to receive the much valued coin, when, to my dismay, he said, "No, not much, you can get nothing from me, you are too smart." They used to tell a funny story about me. I had two old aunts with wrinkled faces, one of them having two teeth protruding like the tusks of an elephant which she buried in my cheek every time she kist me. Nothing would scare me more than the prospect of being hugged by these as affectionate as unattractive relatives. It happened that while being carried in my mother's arms they asked me who was the prettier of the two. After examining their faces intently, I answered thoughtfully, pointing to one of them, "This here is not as ugly as the other."

Then again, I was intended from my very birth for the clerical profession and this thought constantly opprest me. I longed to be an engineer but my father was inflexible. He was the son of an officer who served in the army of the Great Napoleon and, in common with his brother, professor of mathematics in a prominent institution, had received a military education but, singularly enough, later embraced the clergy in which vocation he achieved eminence. He was a very erudite man, a veritable natural philosopher, poet and writer and his sermons were said to be as eloquent as those of Abraham a Sancta-Clara. He had a prodigious memory and frequently recited at length from works in several languages. He often remarked playfully that if some of the classics were lost he could restore them. His style of writing was much admired. He penned sentences short and terse and was full of wit and satire. The humorous remarks he made were always peculiar and characteristic. Just to illustrate, I may mention one or two instances. Among the help there was a cross-eyed man called Mane, employed to do work around the farm. He was chopping wood one day. As he swung the axe my father, who stood nearby and felt very uncomfortable, cautioned him, "For God's sake, Mane, do not strike at what you are looking but at what you intend to hit." On another occasion he was taking out for a drive a friend who carelessly permitted his costly fur coat to rub on the carriage wheel. My father reminded him of it saying, "Pull in your coat, you are ruining my tire." He had the odd habit of talking to himself and would often carry on an animated conversation and indulge in heated argument, changing the tone of his voice. A casual listener might have sworn that several people were in the room.

Altho I must trace to my mother's influence whatever inventiveness I possess, the training he gave me must have been helpful. It comprised all sorts of exercises—as, guessing one another's thoughts, discovering the defects of some form or expression, repeating long sentences or performing mental calculations. These daily lessons were intended to strengthen memory and reason and especially to develop the critical sense, and were undoubtedly very beneficial.

My mother descended from one of the oldest families in the country and a line of inventors. Both her father and grandfather originated numerous implements for household, agricultural and other uses. She was a truly great woman, of rare skill, courage and fortitude, who had braved the storms of life and past thru many a trying experience. When she was sixteen a virulent pestilence swept the country. Her father was called away to administer the last sacraments to the dying and during his absence she went alone to the assistance of a neighboring family who were stricken by the dread disease. All of the members, five in number, succumbed in rapid succession. She bathed, clothed and laid out the bodies, decorating them with flowers according to the custom of the country and when her father returned he found everything ready for a Christian burial. My mother was an inventor of the first order and would, I believe, have achieved great things had she not been so remote from modern life and its multifold opportunities. She invented and constructed all kinds of tools and devices and wove the finest designs from thread which was spun by her. She even planted the seeds, raised the plants and separated the fibers herself. She worked indefatigably, from break of day till late at night, and most of the wearing apparel and furnishings of the home was the product of her hands. When she was past sixty, her fingers were still nimble enough *to tie three knots in an eyelash.*

There was another and still more important reason for my late awakening. In my boyhood I suffered from a peculiar affliction due to the appearance of images, often accompanied by strong flashes of light, which marred the sight of real objects and interfered with my thought and action. They were pictures of things and scenes which I had really seen, never of those I imagined. When a word was spoken to me the image of the object it designated would present itself vividly to my vision and sometimes I was quite unable to distinguish whether what I saw was tangible or not. This caused me great discomfort and anxiety. None of the students of psychology or physiology whom I have consulted could ever explain satisfactorily these phenomena. They seem to have been unique altho I was probably predisposed as I know that my brother experienced a similar trouble. The theory I have formulated is that the images were the result of a reflex action from the brain on the retina under great excitation. They certainly were not hallucinations such as are produced in diseased and anguished minds, for in other respects I was normal and composed. To give an idea of my distress, suppose that I had witnest a funeral or some such

(*Continued on page* 743)

NIKOLA TESLA
THE MAN
By H. Gernsback

THE door opens and out steps a tall figure—over six feet high—gaunt but erect. It approaches slowly, stately. You become conscious at once that you are face to face with a personality of a high order. Nikola Tesla advances and shakes your hand with a powerful grip, surprising for a man over sixty. A winning smile from piercing light blue-gray eyes, set in extraordinarily deep sockets, fascinates you and makes you feel at once at home.

You are guided into an office immaculate in its orderliness. Not a speck of dust is to be seen. No papers litter the desk, everything just so. It reflects the man himself, immaculate in attire, orderly and precise in his every movement. Drest in a dark frock coat, he is entirely devoid of all jewelry. No ring, stickpin, or even watch-chain can be seen.

Tesla speaks—a very high almost falsetto voice. He speaks quickly and very convincingly. It is the man's voice chiefly which fascinates you.

As he speaks you find it difficult to take your eyes off his own. Only when he speaks to others do you have a chance to study his head, predominant of which is a very high forehead with a bulge between the eyes—the neverfailing sign of an exceptional intelligence. Then the long, well-shaped nose, proclaiming the scientist.

How does this man, who has accomplished such a tremendous work, keep young and manage to surprise the world with more and more new inventions as he grows older? How does this youth of sixty, who is a professor of mathematics, a great mechanical and electrical engineer and the greatest inventor of all times, keep his physical as well as remarkable mental freshness?

To begin with, Tesla, who is by birth a Serbian, comes from a long-lived hardy race. His family tree abounds with centenarians. Accordingly, Tesla—barring accidents—fully expects to be still inventing in A. D. 1960.

But the chief reason for his perpetual youth is found in his gastronomical frugality. Tesla has learned the great fundamental truth that most people not only eat all of their bodily ills, but actually eat themselves to death by either eating too much or else by food that does not agree with them.

When Tesla found out that tobacco and black coffee interfered with his physical well-being, he quit both. This is the simple daily menu of the great inventor:

Breakfast: One to two pints of warm milk and a few eggs, prepared by himself—yes, he is a bachelor!

Lunch: None whatsoever, as a rule.

Dinner: Celery or the like, soup, a single piece of meat or fowl, potatoes and one other vegetable; a glass of light wine. For dessert, perhaps a slice of cheese, and invariably a big raw apple. And that's all.

Tesla is very fussy and particular about his food: he eats very little, but what he does eat must be of the very best. And he knows, for outside of being a great inventor in science he is an accomplished cook who has invented all sorts of savory dishes.

His only vice is his generosity. The man who, by the ignorant onlooker has often been called an idle dreamer, has made over a million dollars out of his inventions—and spent them as quickly on new ones. But Tesla is an idealist of the highest order and to such men money itself means but little.

NIKOLA TESLA AND HIS INVENTIONS.

(*Continued from page* 697)

nerve-racking spectacle. Then, inevitably, in the stillness of night, a vivid picture of the scene would thrust itself *before* my eyes and persist despite all my efforts to banish it. Sometimes it would even remain fixt in space tho I pushed my hand thru it. If my explanation is correct, it should be possible to project on a screen the image of any object one conceives and make it visible. Such an advance would revolutionize all human relations. I am convinced that this wonder can and will be accomplished in time to come; I may add that I have devoted much thought to the solution of the problem.

To free myself of these tormenting appearances, I tried to concentrate my mind on something else I had seen, and in this way I would often obtain temporary relief; but in order to get it I had to conjure continuously new images. It was not long before I found that I had exhausted all of those at my command; my "reel" had run out, as it were, because I had seen little of the world—only objects in my home and the immediate surroundings. As I performed these mental operations for the second or third time, in order to chase the

appearances from my vision, the remedy gradually lost all its force. Then I instinctively commenced to make excursions beyond the limits of the small world of which I had knowledge, and I saw new scenes. These were at first very blurred and indistinct, and would flit away when I tried to concentrate my attention upon them, but by and by I succeeded in fixing them; they gained in strength and distinctness and finally assumed the concreteness of real things. I soon discovered that my best comfort was attained if I simply went on in my vision farther and farther, getting new impressions all the time, and so I began to travel—of course, in my mind. Every night (and sometimes during the day), when alone, I would start on my journeys—see new places, cities and countries—live there, meet people and make friendships and acquaintances and, however unbelievable, it is a fact that they were just as dear to me as those in actual life and not a bit less intense in their manifestations.

This I did constantly until I was about seventeen when my thoughts turned seriously to invention. Then I observed to my delight that I could visualize with the greatest facility. I needed no models, drawings or experiments. I could picture them all as real in my mind. Thus I have been led unconsciously to evolve what I consider a new method of materializing inventive concepts and ideas, which is radically opposite to the purely experimental and is in my opinion ever so much more expeditious and efficient. The moment one constructs a device to carry into practise a crude idea he finds himself unavoidably engrost with the details and defects of the apparatus. As he goes on improving and reconstructing, his force of concentration diminishes and he loses sight of the great underlying principle. Results may be obtained but always at the sacrifice of quality.

My method is different. I do not rush into actual work. When I get an idea I start at once building it up in my imagination. I change the construction, make improvements and operate the device in my mind. It is absolutely immaterial to me whether I run my turbine in thought or test it in my shop. *I even note if it is out of balance.* There is no difference whatever, the results are the same. In this way I am able to rapidly develop and perfect a conception without touching anything. When I have gone so far as to embody in the invention every possible improvement I can think of and see no fault anywhere, I put into concrete form this final product of my brain. Invariably my device works as I conceived that it should, and the experiment comes out exactly as I planned it. In twenty years there has not been a single exception. Why should it be otherwise? Engineering, electrical and mechanical, is positive in results. There is scarcely a subject that cannot be mathematically treated and the effects calculated or the results determined beforehand from the available theoretical and practical data. The carrying out into practise of a crude idea as is being generally done is, I hold, nothing but a waste of energy, money and time.

My early affliction had, however, another compensation. The incessant mental exertion developed my powers of observation and enabled me to discover a truth of great importance. I had noted that the appearance of images was always preceded by actual vision of scenes under peculiar and generally very exceptional conditions and I was impelled on each occasion to locate the original impulse. After a while this effort grew to be almost automatic and I gained great facility in connecting cause and effect. Soon I became aware, to my surprise, that every thought I conceived was suggested by an external impression. Not only this but all my actions were prompted in a similar way. In the course of time it became perfectly evident to me that I

was merely an *automaton* endowed with power of movement, responding to the stimuli of the sense organs and thinking and acting accordingly. The practical result of this was the art of *telautomatics* which has been so far carried out only in an imperfect manner. Its latent possibilities will, however, be eventually shown. I have been since years planning self-controlled automata and believe that mechanisms can be produced which will act as if possest of reason, to a limited degree, and will create a revolution in many commercial and industrial departments.

I was about twelve years old when I first succeeded in banishing an image from my vision by wilful effort, but I never had any control over the flashes of light to which I have referred. They were, perhaps, my strangest experience and inexplicable. They usually occurred when I found myself in a dangerous or distressing situation or when I was greatly exhilarated. In some instances I have seen all the air around me filled with tongues of living flame. Their intensity, instead of diminishing, increased with time and seemingly attained a maximum when I was about twenty-five years old. While in Paris, in 1883, a prominent French manufacturer sent me an invitation to a shooting expedition which I accepted. I had been long confined to the factory and the fresh air had a wonderfully invigorating effect on me. On my return to the city that night I felt a positive sensation that my brain had caught fire. I saw a light as tho a small sun was located in it and I past the whole night applying cold compressions to my tortured head. Finally the flashes diminished in frequency and force but it took more than three weeks before they wholly subsided. When a second invitation was extended to me my answer was an emphatic NO!

These luminous phenomena still manifest themselves from time to time, as when a new idea opening up possibilities strikes me, but they are no longer exciting, being of relatively small intensity. When I close my eyes I invariably observe first, a background of very dark and uniform blue, not unlike the sky on a clear but starless night. In a few seconds this field becomes animated with innumerable scintillating flakes of green, arranged in several layers and advancing towards me. Then there appears, to the right, a beautiful pattern of two systems of parallel and closely spaced lines, at right angles to one another, in all sorts of colors with yellow-green and gold predominating. Immediately thereafter the lines grow brighter and the whole is thickly sprinkled with dots of twinkling light. This picture moves slowly across the field of vision and in about ten seconds vanishes to the left, leaving behind a ground of rather unpleasant and inert grey which quickly gives way to a billowy sea of clouds, seemingly trying to mould themselves in living shapes. It is curious that I cannot project a form into this grey until the second phase is reached. Every time, before falling asleep, images of persons or objects flit before my view. When I see them I know that I am about to lose consciousness. If they are absent and refuse to come it means a sleepless night.

To what an extent imagination played a part in my early life I may illustrate by another odd experience. Like most children I was fond of jumping and developed an intense desire to support myself in the air. Occasionally a strong wind richly charged with oxygen blew from the mountains rendering my body as light as cork and then I would leap and float in space for a long time. It was a delightful sensation and my disappointment was keen when later I undeceived myself.

During that period I contracted many strange likes, dislikes and habits, some of which I can trace to external impressions while others are unaccountable. I had a

violent aversion against the earrings of women but other ornaments, as bracelets, pleased me more or less according to design. The sight of a pearl would almost give me a fit but I was fascinated with the glitter of crystals or objects with sharp edges and plane surfaces. I would not touch the hair of other people except, perhaps, at the point of a revolver. I would get a fever by looking at a peach and if a piece of camphor was anywhere in the house it caused me the keenest discomfort. Even now I am not insensible to some of these upsetting impulses. When I drop little squares of paper in a dish filled with liquid, I always sense a peculiar and awful taste in my mouth. I counted the steps in my walks and calculated the cubical contents of soup plates, coffee cups and pieces of food,—otherwise my meal was unenjoyable. All repeated acts or operations I performed had to be divisible by three and if I mist I felt impelled to do it all over again, even if it took hours.

Up to the age of eight years, my character was weak and vacillating. I had neither courage or strength to form a firm resolve. My feelings came in waves and surges and vibrated unceasingly between extremes. My wishes were of consuming force and like the heads of the hydra, they multiplied. I was opprest by thoughts of pain in life and death and religious fear. I was swayed by superstitious belief and lived in constant dread of the spirit of evil, of ghosts and ogres and other unholy monsters of the dark. Then, all at once, there came a tremendous change which altered the course of my whole existence.

Of all things I liked books the best. My father had a large library and whenever I could manage I tried to satisfy my passion for reading. He did not permit it and would fly into a rage when he caught me in the act. He hid the candles when he found that I was reading in secret. He did not want me to spoil my eyes. But I obtained tallow, made the wicking and cast the sticks into tin forms, and every night I would bush the keyhole and the cracks and read, often till dawn, when all others slept and my mother started on her arduous daily task. On one occasion I came across a novel entitled "Abafi" (the Son of Aba), a Serbian translation of a well known Hungarian writer, Josika. This work somehow awakened my dormant powers of will and I began to practise self-control. At first my resolutions faded like snow in April, but in a little while I conquered my weakness and left a pleasure I never knew before—that of doing as I willed. In the course of time this vigorous mental exercise became second nature. At the outset my wishes had to be subdued but gradually desire and will grew to be identical. After years of such discipline I gained so complete a mastery over myself that I toyed with passions which have meant destruction to some of the strongest men. At a certain age I contracted a mania for gambling which greatly worried my parents. To sit down to a game of cards was for me the quintessence of pleasure. My father led an exemplary life and could not excuse the senseless waste of time and money in which I indulged. I had a strong resolve but my philosophy was bad. I would say to him, "I can stop whenever I please but is it worth while to give up that which I would purchase with the joys of Paradise?" On frequent occasions he gave vent to his anger and contempt but my mother was different. She understood the character of men and knew that one's salvation could only be brought about thru his own efforts. One afternoon, I remember, when I had lost all my money and was craving for a game, she came to me with a roll of bills and said, "Go and enjoy yourself. The sooner you lose all we possess the better it will be. I know that you will get over it." She was right. I conquered my passion

then and there and only regretted that it had not been a hundred times as strong. I not only vanquished but tore it from my heart so as not to leave even a trace of desire. Ever since that time I have been as indifferent to any form of gambling as to picking teeth.

During another period I smoked excessively, threatening to ruin my health. Then my will asserted itself and I not only stopt but destroyed all inclination. Long ago I suffered from heart trouble until I discovered that it was due to the innocent cup of coffee I consumed every morning. I discontinued at once, tho I confess it was not an easy task. In this way I checked and bridled other habits and passions and have not only preserved my life but derived an immense amount of satisfaction from what most men would consider privation and sacrifice.

After finishing the studies at the Polytechnic Institute and University I had a complete nervous breakdown and while the malady lasted I observed many phenomena strange and unbelievable.

(*To be continued in our March issue*)

My Inventions

By Nikola Tesla

2. MY FIRST EFFORTS IN INVENTION

I SHALL dwell briefly on these extraordinary experiences, on account of their possible interest to students of psychology and physiology and also because this period of agony was of the greatest consequence on my mental development and subsequent labors. But it is indispensable to first relate the circumstances and conditions which preceded them and in which might be found their partial explanation.

From childhood I was compelled to concentrate attention upon myself. This caused me much suffering but, to my present view, it was a blessing in disguise for it has taught me to appreciate the inestimable value of introspection in the preservation of life, as well as a means of achievement. The pressure of occupation and the incessant stream of impressions pouring into our consciousness thru all the gateways of knowledge make modern existence hazardous in many ways. Most persons are so absorbed in the contemplation of the outside world that they are wholly oblivious to what is passing on within themselves. The premature death of millions is primarily traceable to this cause. Even among those who exercise care it is a common mistake to avoid imaginary, and ignore the real dangers. And what is true of an individual also applies, more or less, to a people as a whole. Witness, in illustration, the prohibition movement. A drastic, if not unconstitutional, measure is now being put thru in this country to prevent the consumption of alcohol and yet it is a positive fact that coffee, tea, tobacco, chewing gum and other stimulants, which are freely indulged in even at the tender age, are vastly more injurious to the national body, judging from the number of those who succumb. So, for instance, during my student years I gathered from the published necrologues in Vienna, the home of coffee drinkers, that deaths from heart trouble sometimes reached *sixty-seven per cent* of the total. Similar observations might probably be made in cities where the consumption of tea is excessive. These delicious beverages superexcite and gradually exhaust the fine fibers of the brain. They also interefere seriously with arterial circulation and should be enjoyed all the more sparingly as their deleterious effects are slow and imperceptible. Tobacco, on the other hand, is conducive to easy and pleasant thinking and detracts from the intensity and concentration necessary to all original and vigorous effort of the intellect. Chewing gum is helpful for a short while but soon drains the glandular system and inficts irreparable damage, not to speak of the revulsion it creates. Alcohol in small quantities is an excellent tonic, but is toxic in its action when absorbed in larger amounts, quite immaterial as to whether it is taken in as whiskey or produced in the stomach from sugar. But it should not be overlooked that all these are great eliminators assisting Nature, as they do, in upholding her stern but just law of the survival of the fittest. Eager reformers should also be mindful of the eternal perversity of mankind which makes the indifferent *"laissez-faire"* by far preferable to enforced restraint. The truth about this is that we need stimulants to do our best work under present living conditions, and that we must exercise moderation and control our appetites and inclinations in every direction. That is what I have been doing for many years, in this way maintaining myself young in body and mind. Abstinence was not always to my liking but I find ample reward in the agreeable experiences I am now making. Just in the hope of converting some to my precepts and convictions I will recall one or two.

A short time ago I was returning to my hotel. It was a bitter cold night, the ground slippery, and no taxi to be had. Half a block behind me followed another man, evidently as anxious as myself to get under

(*Cont. on page* 839)

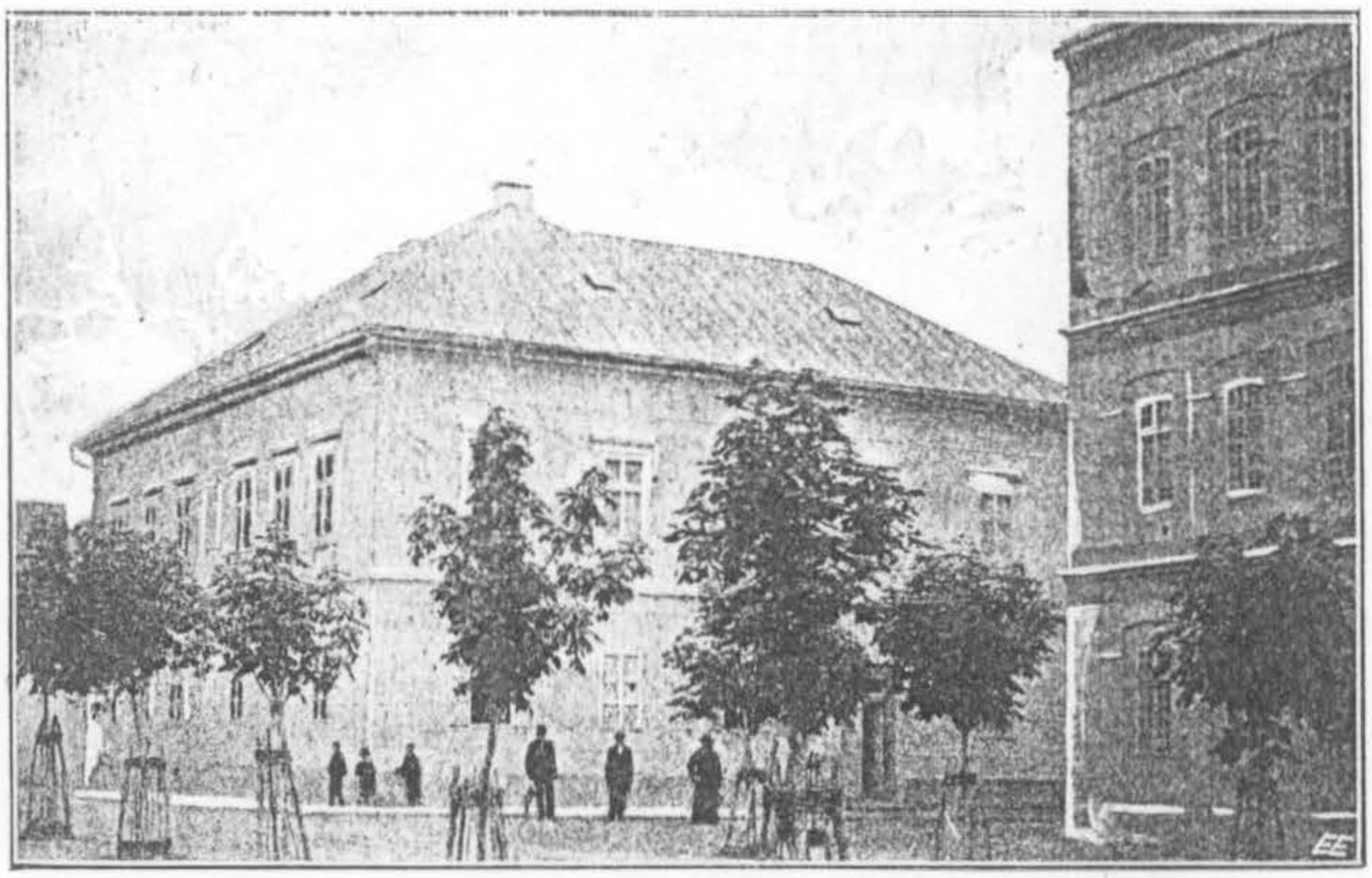
BOYS will be boys, the world over. The Boy Tesla was no exception to the universal rule, as this, his second autobiographical article clearly proves.

Mr. Tesla in his own inimitable, delightful way, here paints with a literary artist's brush his own intimate boyhood in charming as well as vivid colors.

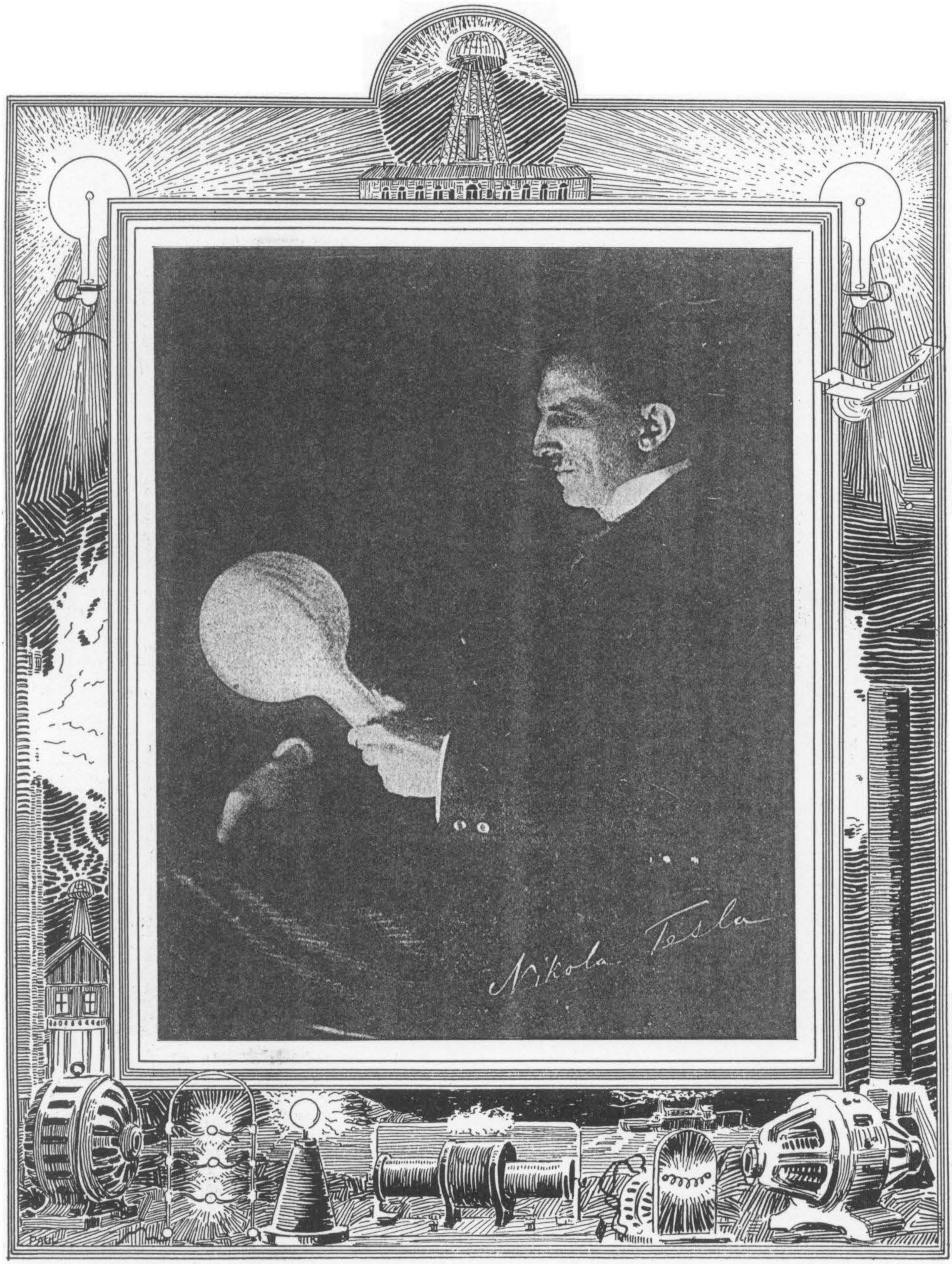
We have often heard of Tesla, the dreamer. But if he is entitled to the epithet, his early boyhood certainly fails to reveal it. Tesla did not allow much grass to grow under his feet while a boy, for he assuredly was a strenuous, red-blooded youngster.

You will wish to read all about the greatest inventor's early boyhood. It is doubly valuable because it comes from his own pen. We promise you an interesting twenty-minutes' entertainment.

—EDITOR.



This Photograph Shows in the Background the House in Which Mr. Tesla's Family Resided. The Edifice at the Right Is the "Real Gymnasium" Where He Studied. The Ecclesiastic Gentleman Is His Uncle, the Metropolitan of Bosnia, Who Was a Great Statesman and Who Thwarted the Designs of Austria Upon Serbia at a Critical Period.



An interesting study of the great inventor, contemplating the glass bulb of his famous wireless light. A full description of the invention will appear shortly in the ELECTRICAL EXPERIMENTER. *This is the only profile photograph of Mr. Tesla in existence. It was taken specially for the* ELECTRICAL EXPERIMENTER.

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MY INVENTIONS.

(*Continued from page 776*)

cover. Suddenly my legs went up in the air. In the same instant there was a flash in my brain, the nerves responded, the muscles contracted, I swung thru 180 degrees and landed on my hands. I resumed my walk as tho nothing had happened when the stranger caught up with me. "How old are you?" he asked, surveying me critically. "Oh, about fifty-nine," I replied. "What of it?" "Well," said he, "I have seen a cat do this but never a man." About a month since I wanted to order new eyeglasses and went to an oculist who put me thru the usual tests. He lookt at me increduously as I read off with ease the smallest print at considerable distance. But when I told him that I was past sixty he gasped in astonishment. Friends of mine often remark that my suits fit me like gloves but they do not know that all my clothing is made to measurements which were taken nearly 35 years ago and never changed. During this same period my weight has not varied one pound.

In this connection I may tell a funny story. One evening, in the winter of 1885, Mr. Edison, Edward H. Johnson, the President of the Edison Illuminating Company, Mr. Batchellor, Manager of the works, and myself entered a little place opposite 65 Fifth Avenue where the offices of the company were located. Someone suggested guessing weights and I was induced to step on a scale. Edison felt me all over and said: "Tesla weighs 152 lbs. to an ounce," and he guest it exactly. Stript I weighed 142 lbs. and that is still my weight. I whispered to Mr. Johnson: "How is it possible that Edison could guess my weight so closely?" "Well," he said, lowering his voice, "I will tell you, confidentially, but you must not say anything. He was employed for a long time in a Chicago slaughter-house where he weighed thousands of hogs every day! That's why." My friend, the Hon. Chauncey M. Depew, tells of an Englishman on whom he sprung one of his original anecdotes and who listened with a puzzled expression but—a year later—laughed out loud. I will frankly confess it took me longer than that to appreciate Johnson's joke.

Now, my well being is simply the result of a careful and measured mode of living and perhaps the most astonishing thing is that three times in my youth I was rendered by illness a hopeless physical wreck and given up by physicians. More than this, thru ignorance and lightheartedness, I got into all sorts of difficulties, dangers and scrapes from which I extricated myself as by enchantment. I was almost drowned a dozen times; was nearly boiled alive and just mist being cremated. I was entombed, lost and frozen. I had hair-breadth escapes from mad dogs, hogs, and other wild animals. I past thru dreadful diseases and met with all kinds of odd mishaps and that I am hale and hearty today seems like a miracle. But as I recall these incidents to my mind I feel convinced that my preservation was not altogether accidental.

An inventor's endeavor is essentially life-saving. Whether he harnesses forces, improves devices, or provides new comforts and conveniences, he is adding to the safety of our existence. He is also better qualified than the average individual to protect himself in peril, for he is observant and resourceful. If I had no other evidence that I was, in a measure, possest of such qualities I would find it in these personal experiences. The reader will be able to judge for himself if I mention one or two instances. On one occasion, when about 14 years old, I wanted to scare some friends who were bathing with me. My plan was to dive under a long floating structure and slip out quietly at the other end. Swimming and diving came to me as naturally as to a

duck and I was confident that I could perform the feat. Accordingly I plunged into the water and, when out of view, turned around and proceeded rapidly towards the opposite side. Thinking that I was safely beyond the structure, I rose to the surface but to my dismay struck a beam. Of course, I quickly dived and forged ahead with rapid strokes until my breath was beginning to give out. Rising for the second time, my head came again in contact with a beam. Now I was becoming desperate. However, summoning all my energy, I made a third frantic attempt but the result was the same. The torture of suppress breathing was getting unendurable, my brain was reeling and I felt myself sinking. At that moment, when my situation seemed absolutely hopeless, I experienced one of those flashes of light and the structure above me appeared before my vision. I either discerned or guest that there was a little space between the surface of the water and the boards resting on the beams and, with consciousness nearly gone, I floated up, prest my mouth close to the planks and managed to inhale a little air, unfortunately mingled with a spray of water which nearly choked me. Several times I repeated this procedure as in a dream until my heart, which was racing at a terrible rate, quieted down and I gained composure. After that I made a number of unsuccessful dives, having completely lost the sense of direction, but finally succeeded in getting out of the trap when my friends had already given me up and were fishing for my body.

That bathing season was spoiled for me thru recklessness but I soon forgot the lesson and only two years later I fell into a worse predicament. There was a large flour mill with a dam across the river near the city where I was studying at that time. As a rule the height of the water was only two or three inches above the dam and to swim out to it was a sport not very dangerous in which I often indulged. One day I went alone to the river to enjoy myself as usual. When I was a short distance from the masonry, however, I was horrified to observe that the water had risen and was carrying me along swiftly. I tried to get away but it was too late. Luckily, tho, I saved myself from being swept over by taking hold of the wall with both hands. The pressure against my chest was great and I was barely able to keep my head above the surface. Not a soul was in sight and my voice was lost in the roar of the fall. Slowly and gradually I became exhausted and unable to withstand the strain longer. Just as I was about to let go, to be dashed against the rocks below, I saw in a flash of light a familiar diagram illustrating the hydraulic principle that the pressure of a fluid in motion is proportionate to the area exposed, and automatically I turned on my left side. As if by magic the pressure was reduced and I found it comparatively easy in that position to resist the force of the stream. But the danger still confronted me. I knew that sooner or later I would be carried down, as it was not possible for any help to reach me in time, even if I attracted attention. I am ambidextrous now but then I was left-handed and had comparatively little strength in my right arm. For this reason I did not dare to turn on the other side to rest and nothing remained but to slowly push my body along the dam. I had to get away from the mill towards which my face was turned as the current there was much swifter and deeper. It was a long and painful ordeal and I came near to failing at its very end for I was confronted with a depression in the masonry. I managed to get over with the last ounce of my force and fell in a swoon when I reached the bank, where I was found. I had torn virtually all the skin from my left side and it took several weeks before the fever subsided and I was well. These are only two

of many instances but they may be sufficient to show that had it not been for the inventor's instinct I would not have lived to tell this tale.

Interested people have often asked me how and when I began to invent. This I can only answer from my present recollection in the light of which the first attempt I recall was rather ambitious for it involved the invention of an *apparatus* and a *method*. In the former I was anticipated but the latter was original. It happened in this way. One of my playmates had come into the possession of a hook and fishing-tackle which created quite an excitement in the village, and the next morning all started out to catch frogs. I was left alone and deserted owing to a quarrel with this boy. I had never seen a real hook and pictured it as something wonderful, endowed with peculiar qualities, and was despairing not to be one of the party. Urged by necessity, I somehow got hold of a piece of soft iron wire, hammered the end to a sharp point between two stones, bent it into shape, and fastened it to a strong string. I then cut a rod, gathered some bait, and went down to the brook where there were frogs in abundance. But I could not catch any and was almost discouraged when it occurred to me to dangle the empty hook in front of a frog sitting on a stump. At first he collapsed but by and by his eyes bulged out and became bloodshot, he swelled to twice his normal size and made a vicious snap at the hook. Immediately I pulled him up. I tried the same thing again and again and the method proved infallible. When my comrades, who in spite of their fine outfit had caught nothing, came to me they were green with envy. For a long time I kept my secret and enjoyed the monopoly but finally yielded to the spirit of Christmas. Every boy could then do the same and the following summer brought disaster to the frogs.

In my next attempt I seem to have acted under the first instinctive impulse which later dominated me—to harness the energies of nature to the service of man. I did this thru the medium of May-bugs—or June-bugs as they are called in America—which were a veritable pest in that country and sometimes broke the branches of trees by the sheer weight of their bodies. The bushes were black with them. I would attach as many as four of them to a cross-piece, rotably arranged on a thin spindle, and transmit the motion of the same to a large disc and so derive considerable "power." These creatures were remarkably efficient, for once they were started they had no sense to stop and continued whirling for hours and hours and the hotter it was the harder they worked. All went well until a strange boy came to the place. He was the son of a retired officer in the Austrian Army. That urchin ate May-bugs alive and enjoyed them as tho they were the finest blue-point oysters. That disgusting sight terminated my endeavors in this promising field and I have never since been able to touch a May-bug or any other insect for that matter.

After that, I believe, I undertook to take apart and assemble the clocks of my grandfather. In the former operation I was always successful but often failed in the latter. So it came that he brought my work to a sudden halt in a manner not too delicate and it took thirty years before I tackled another clockwork again. Shortly thereafter I went into the manufacture of a kind of pop-gun which comprised a hollow tube, a piston, and two plugs of hemp. When firing the gun, the piston was prest against the stomach and the tube was pushed back quickly with both hands. The air between the plugs was comprest and raised to high temperature and one of them was expelled with a loud report. The art consisted in selecting a tube of the proper taper from the hollow stalks which were

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MY INVENTIONS

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did very well with that gun but my activities interfered with the window panes in our house and met with painful discouragement. If I remember rightly, I then took to carving swords from pieces of furniture which I could conveniently obtain. At that time I was under the sway of the Serbian national poetry and full of admiration for the feats of the heroes. I used to spend hours in mowing down my enemies in the form of corn-stalks which ruined the crops and netted me several spankings from my mother. Moreover these were not of the formal kind but the genuine article.

I had all this and more behind me before I was six years old and had past thru one year of elementary school in the village of Smiljan where I was born. At this juncture we moved to the little city of Gospic nearby. This change of residence was like a calamity to me. It almost broke my heart to part from our pigeons, chickens and sheep, and our magnificent flock of geese which used to rise to the clouds in the morning and return from the feeding grounds at sundown in battle formation, so perfect that it would have put a squadron of the best aviators of the present day to shame. In our new house I was but a prisoner, watching the strange people I saw thru the window blinds. My bashfulness was such that I would rather have faced a roaring lion than one of the city dudes who strolled about. But my hardest trial came on Sunday when I had to dress up and attend the service. There I met with an accident, the mere thought of which made my blood curdle like sour milk for years afterwards. It was my second adventure in a church. Not long before I was entombed for a night in an old chapel on an inaccessible mountain which was visited only once a year. It was an awful experience, but this one was worse. There was a wealthy lady in town, a good but pompous woman, who used to come to the church gorgeously painted up and attired with an enormous train and attendants. One Sunday I had just finished ringing the bell in the belfry and rushed downstairs when this grand dame was sweeping out and I jumped on her train. It tore off with a ripping noise which sounded like a salvo of musketry fired by raw recruits. My father was livid with rage. He gave me a gentle slap on the cheek, the only corporal punishment he ever administered to me but I almost feel it now. The embarrassment and confusion that followed are indescribable. I was practically ostracised until something else happened which redeemed me in the estimation of the community.

An enterprising young merchant had organized a fire department. A new fire engine was purchased, uniforms provided and the men drilled for service and parade. The engine was, in reality, a pump to be worked by sixteen men and was beautifully painted red and black. One afternoon the official trial was prepared for and the machine was transported to the river. The entire population turned out to witness the great spectacle. When all the speeches and ceremonies were concluded, the command was given to pump, but not a drop of water came from the nozzle. The professors and experts tried in vain to locate the trouble. The fizzle was complete when I arrived at the scene. My knowledge of the mechanism was nil and I knew next to nothing of air pressure, but instinctively I felt for the suction hose in the water and found that it had collapsed. When I waded in the river and opened it up the water rushed forth and not a few Sunday clothes were spoiled. Archimedes running naked thru the streets of Syracuse and shouting Eureka at the top of his voice did not make a greater impression than myself. I was carried on the shoulders and was the hero of the day.

Upon settling in the city I began a four-years' course in the so-called Normal School preparatory to my studies at the College or *Real-Gymnasium*. During this period my boyish efforts and exploits, as well as troubles, continued. Among other things I attained the unique distinction of champion crow catcher in the country. My method of procedure was extremely simple. I would go in the forest, hide in the bushes, and imitate the call of the bird. Usually I would get several answers and in a short while a crow would flutter down into the shrubbery near me. After that all I needed to do was to throw a piece of cardboard to detract its attention, jump up and grab it before it could extricate itself from the undergrowth. In this way I would capture as many as I desired. But on one occasion something occurred which made me respect them. I had caught a fine pair of birds and was returning home with a friend. When we left the forest, thousands of crows had gathered making a frightful racket. In a few minutes they rose in pursuit and soon enveloped us. The fun lasted until all of a sudden I received a blow on the back of my head which knocked me down. Then they attacked me viciously. I was compelled to release the two birds and was glad to join my friend who had taken refuge in a cave.

In the schoolroom there were a few mechanical models which interested me and turned my attention to water turbines. I constructed many of these and found great pleasure in operating them. How extraordinary was my life an incident may illustrate. My uncle had no use for this kind of pastime and more than once rebuked me. I was fascinated by a description of Niagara Falls I had perused, and pictured in my imagination a big wheel run by the Falls. I told my uncle that I would go to America and carry out this scheme. Thirty years later I saw my ideas carried out at Niagara and marveled at the unfathomable mystery of the mind.

I made all kinds of other contrivances and contraptions but among these the arbalists I produced were the best. My arrows, when shot, disappeared from sight and at close range traversed a plank of pine one inch thick. Thru the continuous tightening of the bows I developed skin on my stomach very much like that of a crocodile and I am often wondering whether it is due to this exercise that I am able even now to digest cobble-stones! Nor can I pass in silence my performances with the sling which would have enabled me to give a stunning exhibit at the Hippodrome. And now I will tell of one of my feats with this antique implement of war which will strain to the utmost the credulity of the reader. I was practicing while walking with my uncle along the river. The sun was setting, the trout were playful and from time to time one would shoot up into the air, its glistening body sharply defined against a projecting rock beyond. Of course any boy might have hit a fish under these propitious conditions but I undertook a much more difficult task and I foretold to my uncle, to the minutest detail, what I intended doing. I was to hurl a stone to meet the fish, press its body against the rock, and cut it in two. It was no sooner said than done. My uncle looked at me almost scared out of his wits and exclaimed *"Vade retro Satanas!"* and it was a few days before he spoke to me again. Other records, however great, will be eclipsed but I feel that I could peacefully rest on my laurels for a thousand years.

(*In the April issue Mr. Tesla will describe in detail how he conceived one of his most important and far reaching inventions*: *"The Rotary Magnetic Field."—Editor.*)

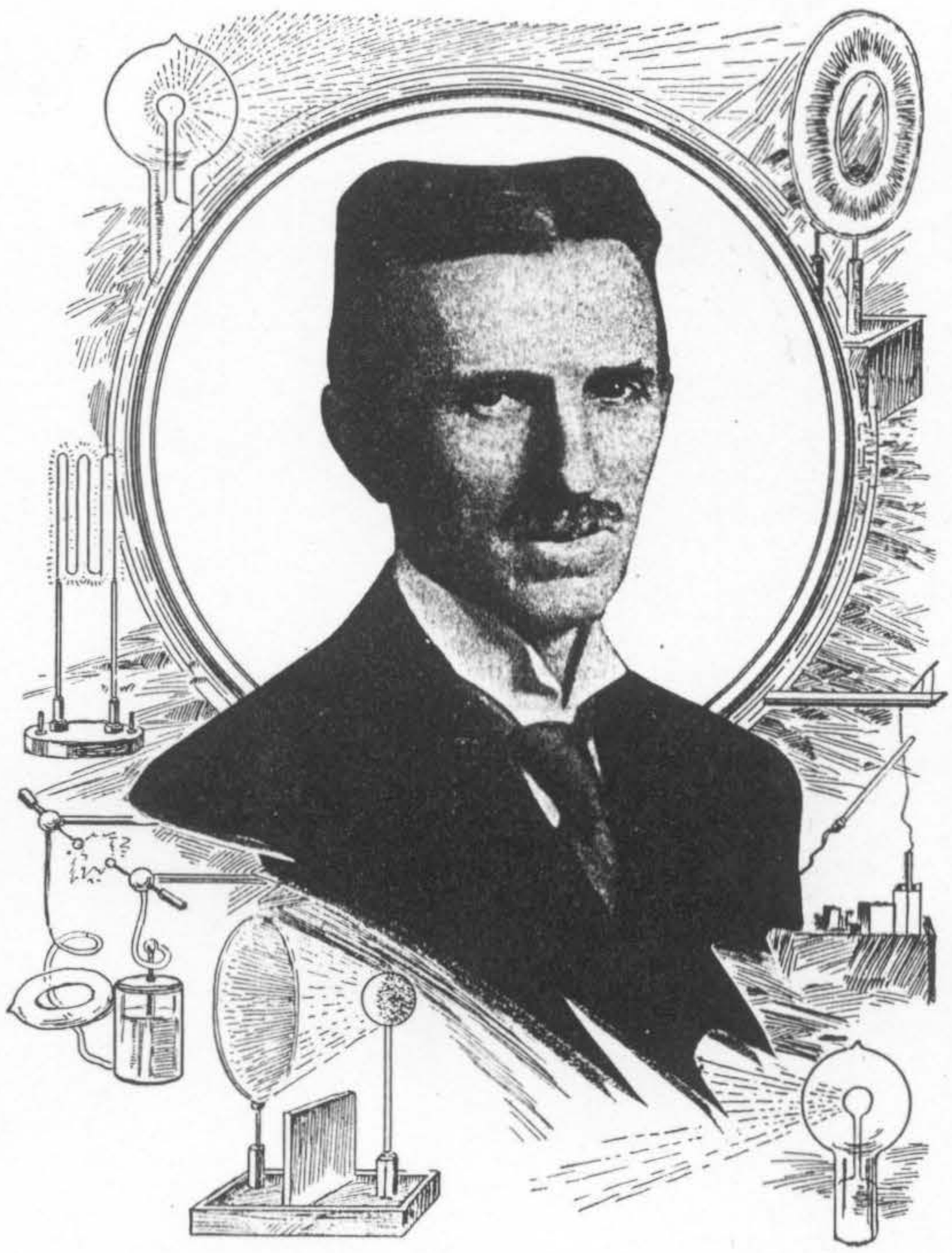
My Inventions

By Nikola Tesla

III. MY LATER ENDEAVORS

The Discovery of the Rotating Magnetic Field

AT the age of ten I entered the Real Gymnasium which was a new and fairly well equipt institution. In the department of physics were various models of classical scientific apparatus, electrical and mechanical. The demonstrations and experiments performed from time to time by the instructors fascinated me and were undoubtedly a powerful incentive to invention. I was also passionately fond of mathematical studies and often won the professor's praise for rapid calculation. This was due to my acquired facility of visualizing the figures and performing the operations, not in the usual intuitive manner, but as in actual life. Up to a certain degree of complexity it was absolutely the same to me whether I wrote the symbols on the board or conjured them before my mental vision. But free-hand drawing, to which many hours of the course were devoted, was an annoyance I could not endure. This was rather remarkable as most of the members of the family excelled in it. Perhaps my aversion was simply due to the predilection I found in undisturbed thought. Had it not been for a few exceptionally stupid boys, who could not do anything at all, my record would have been the worst. It was a serious handicap as under the then existing educational regime, drawing being obligatory, this deficiency threatened to spoil my whole career and my father had considerable trouble in railroading me from one class to another.



Nikola Tesla at 60. A Very Recent Portrait of the Great Inventor. An Excellent Likeness.

In the second year at that institution I became obsest with the idea of producing continuous motion thru steady air pressure. The pump incident, of which I have told, had set afire my youthful imagination and imprest me with the boundless possibilities of a vacuum. I grew frantic in my desire to harness this inexhaustible energy but for a long time I was groping in the dark. Finally, however, my endeavors crystallized in an invention which was to enable me to achieve what no other mortal ever attempted. Imagine a cylinder freely rotatable on two bearings and partly surrounded by a rectangular trough which fits it perfectly. The open side of the trough is closed by a partition so that the cylindrical segment within the enclosure divides the latter into two compartments entirely separated from each other by air-tight sliding joints. One of these compartments being sealed and once for all exhausted, the other remaining open, a perpetual rotation of the cylinder would result, at least, I thought so. A wooden model was constructed and fitted with infinite care and when I applied the pump on one side and actually observed that there was a tendency to turning, I was delirious with joy. Mechanical flight was the one thing I wanted to accomplish altho still under the discouraging recollection of a bad fall I sustained by jumping with an umbrella from the top of a building. Every day I used to transport myself thru the air to distant regions but could not understand just how I managed to do it. Now I had something concrete—a flying machine with nothing more than a rotating shaft, flapping wings, and—a vacuum of unlimited power! From that time on I made my daily aërial excursions in a vehicle of comfort and luxury as might have befitted King Solomon. It took years before I understood that the atmospheric pressure acted at right angles to the surface of the cylinder and that the slight rotary effort I observed was due to a leak. Tho this knowledge came gradually it gave me a painful shock.

I had hardly completed my course at the Real Gymnasium when I was prostrated with a dangerous illness or rather, a score of them, and my condition became so desperate that I was given up by physicians. During this period I was permitted to read constantly, obtaining books from the Public Library which had been neglected and entrusted to me for classification of the works and preparation of the catalogues. One day I was handed a few volumes of new literature unlike anything I had ever read before and so captivating as to make me utterly forget my hopeless state. They were the earlier works of Mark Twain and to them might have been due the miraculous recovery which followed. Twenty-five years later, when I met Mr. Clements and we formed a friendship between us, I told

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Mr. Tesla's articles started in our February issue

him of the experience and was amazed to see that great man of laughter burst into tears.

My studies were continued at the higher Real Gymnasium in Carlstadt, Croatia, where one of my aunts resided. She was a distinguished lady, the wife of a Colonel who was an old war-horse having participated in many battles. I never can forget the three years I past at their home. No fortress in time of war was under a more rigid discipline. I was fed like a canary bird. All the meals were of the highest quality and deliciously prepared but short in quantity by a thousand percent. The slices of ham cut by my aunt were like tissue paper. When the Colonel would put something substantial on my plate she would snatch it away and say excitedly to him: "Be careful, Niko is very delicate." I had a voracious appetite and suffered like Tantalus. But I lived in an atmosphere of refinement and artistic taste quite unusual for those times and conditions. The land was low and marshy and malaria fever never left me while there despite of the enormous amounts of quinin I consumed. Occasionally the river would rise and drive an army of rats into the buildings, devouring everything even to the bundles of the fierce paprika. These pests were to me a welcome diversion. I thinned their ranks by all sorts of means, which won me the unenviable distinction of rat-catcher in the community. At last, however, my course was completed, the misery ended, and I obtained the certificate of maturity which brought me to the cross-roads.

THIS installment, no doubt the most interesting of the three published so far, reveals many extraordinary occurrences and experiences in the world's greatest inventor's life—experiences such as do not fall to the lot of ordinary mortals. And Tesla, the many sided, aside of inventing, knows the rare art of painting word-pictures. He does so here in a masterly fashion. He tells us how he finally conceived the induction motor—perhaps his greatest discovery—the invention which changed the face of the globe, the invention which made possible the street car, the subway, the electric train, power transmission, the harnessing of water falls and countless others. But let Tesla tell you himself how it all came about. It is a classic worth reading.

EDITOR.

During all those years my parents never wavered in their resolve to make me embrace the clergy, the mere thought of which filled me with dread. I had become intensely interested in electricity under the stimulating influence of my Professor of Physics, who was an ingenious man and often demonstrated the principles by apparatus of his own invention. Among these I recall a device in the shape of a freely rotatable bulb, with tinfoil coatings, which was made to spin rapidly when connected to a static machine. It is impossible for me to convey an adequate idea of the intensity of feeling I experienced in witnessing his exhibitions of these mysterious phenomena. Every impression produced a thousand echoes in my mind. I wanted to know more of this wonderful force; I longed for experiment and investigation and resigned myself to the inevitable with aching heart.

Just as I was making ready for the long journey home I received word that my father wished me to go on a shooting expedition. It was a strange request as he had been always strenuously opposed to this kind of sport. But a few days later I learned that the cholera was raging in that district and, taking advantage of an opportunity, I returned to Gospic in disregard of my parents' wishes. It is incredible how absolutely ignorant people were as to the causes of this scourge which visited the country in intervals of from fifteen to twenty years. They thought that the deadly agents were transmitted thru the air and filled it with pungent odors and smoke. In the meantime they drank the infected water and died in heaps. I contracted the awful disease on the very day of my arrival and altho surviving the crisis, I was confined to bed for nine months with scarcely any ability to move. My energy was completely exhausted and for the second time I found myself at death's door. In one of the sinking spells which was thought to be the last, my father rushed into the room. I still see his pallid face as he tried to cheer me in tones belying his assurance. "Perhaps," I said, "I may get well if you will let me study engineering." "You will go to the best technical institution in the world." he solemnly replied, and I knew that he meant it. A heavy weight was lifted from my mind but the relief would have come too late had it not been for a marvelous cure brought about thru a bitter decoction of a peculiar bean. I came to life like another Lazarus to the utter amazement of everybody. My father insisted that I spend a year in healthful physical outdoor exercises to which I reluctantly consented. For most of this term I roamed in the mountains, loaded with a hunter's outfit and a bundle of books, and this contact with nature made me stronger in body as well as in mind. I thought and planned, and conceived many ideas almost as a rule delusive. The vision was clear enough but the knowledge of principles was very limited. In one of my inventions I proposed to convey letters and packages across the seas, thru a submarine tube, in spherical containers of sufficient strength to resist the hydraulic pressure. The pumping plant, intended to force the water thru the tube, was accurately figured and designed and all other particulars carefully worked out. Only one trifling detail, of no consequence, was lightly dismist. I assumed an arbitrary velocity of the water and, what is more, took pleasure in making it high, thus arriving at a stupendous performance supported by faultless calculations. Subsequent reflections, however, on the resistance of pipes to fluid flow determined me to make this invention public property.

Another one of my projects was to construct a ring around the equator which would, of course, float freely and could be arrested in its spinning motion by reactionary forces, thus enabling

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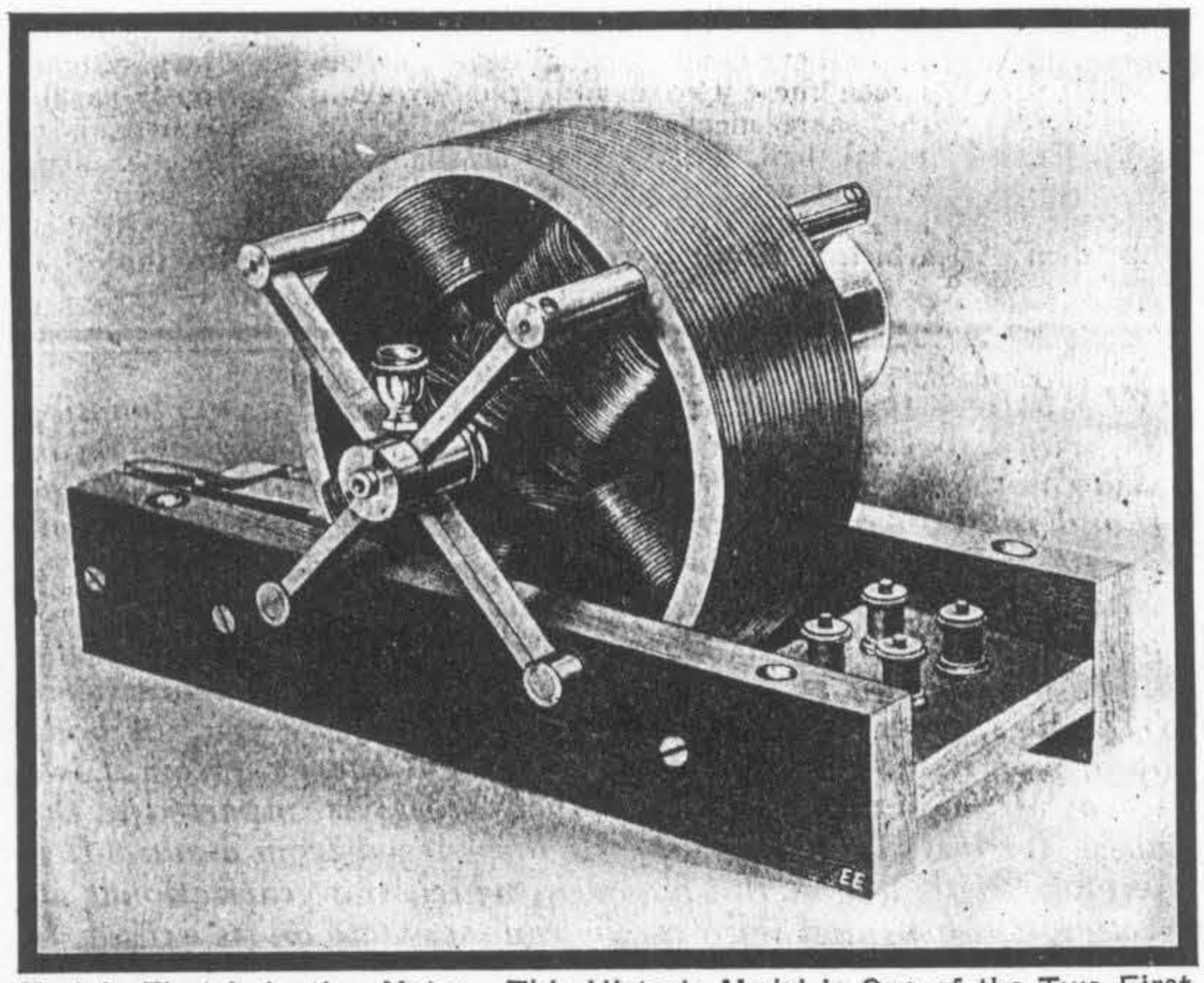

Tesla's First Induction Motor. This Historic Model is One of the Two First Presented Before the American Institute of Electrical Engineers.

WHAT IS THE INDUCTION MOTOR?

The induction motor operates on alternating current. It has no commutator like a direct current motor, nor slip rings like an alternating current motor. Contrary to the two types just cited the "field" current is not steady, but the current itself rotates constantly pulling around with it—by induction—the only moving part of the motor—the rotor—or armature. Having no armature nor slip rings, the induction motor never sparks. It consequently knows no "brush" trouble. It needs no attention because of its ruggedness. Only the bearings wear out. Its efficiency too is higher. On account of all this the induction motor is used in a prepondering proportion in street cars, electric trains, factories. etc.

MY INVENTIONS

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travel at a rate of about one thousand miles an hour, impracticable by rail. The reader will smile. The plan was difficult of execution, I will admit, but not nearly so bad as that of a well-known New York professor, who wanted to pump the air from the torrid to the temperate zones, entirely forgetful of the fact that the Lord had provided a gigantic machine for this very purpose.

Still another scheme, far more important and attractive, was to derive power from the rotational energy of terrestrial bodies. I had discovered that objects on the earth's surface, owing to the diurnal rotation of the globe, are carried by the same alternately in and against the direction of translatory movement. From this results a great change in momentum which could be utilized in the simplest imaginable manner to furnish motive effort in any habitable region of the world. I cannot find words to describe my disappointment when later I realized that I was in the predicament of Archimedes, who vainly sought for a fixt point in the universe.

At the termination of my vacation I was sent to the Polytechnic School in Gratz, Styria, which my father had chosen as one of the oldest and best reputed institutions. That was the moment I had eagerly awaited and I began my studies under good auspices and firmly resolved to succeed. My previous training was above the average, due to my father's teaching and opportunities afforded. I had acquired the knowledge of a number of languages and waded thru the books of several libraries, picking up information more or less useful. Then again, for the first time, I could choose my subjects as I liked, and free-hand drawing was to bother me no more. I had made up my mind to give my parents a surprise, and during the whole first year I regularly started my work at three o'clock in the morning and continued until eleven at night, no Sundays or holidays excepted. As most of my fellow-students took things easily, naturally enough I eclipsed all records. In the course of that year I past thru nine exams and the professors thought I deserved more than the highest qualifications. Armed with their flattering certificates, I went home for a short rest, expecting a triumph, and was mortified when my father made light of these hard-won honors. That almost killed my ambition; but later, after he had died, I was pained to find a package of letters which

(*Continued on page* 907)

MY INVENTIONS.

(*Continued from page* 905)

the professors had written him to the effect that unless he took me away from the Institution I would be killed thru overwork. Thereafter I devoted myself chiefly to physics, mechanics and mathematical studies, spending the hours of leisure in the libraries. I had a veritable mania for finishing whatever I began, which often got me into difficulties. On one occasion I started to read the works of Voltaire when I learned, to my dismay, that there were close on one hundred large volumes in small print which that monster had written while drinking seventy-two cups of black coffee per diem. It had to be done, but when I laid aside the last book I was very glad, and said, "Never more!"

My first year's showing had won me the appreciation and friendship of several professors. Among these were Prof. Rogner, who was teaching arithmetical subjects and geometry; Prof. Poeschl, who held the chair of theoretical and experimental physics, and Dr. Allé, who taught integral calculus and specialized in differential equations. This scientist was the most brilliant lecturer to whom I ever listened. He took a special interest in my progress and would frequently remain for an hour or two in the lecture room, giving me problems to solve, in which I delighted. To him I explained a flying machine I had conceived, not an illusionary invention, but one based on sound, scientific principles, which has become realizable thru my turbine and will soon be given to the world. Both Professors Rogner and Poeschl were curious men. The former had peculiar ways of expressing himself and whenever he did so there was a riot, followed by a long and embarrassing pause. Prof. Poeschl was a methodical and thoroly grounded German. He had enormous feet and hands like the paws of a bear, but all of his experiments were skillfully performed with clock-like precision and without a miss.

It was in the second year of my studies that we received a Gramme dynamo from Paris, having the horseshoe form of a laminated field magnet, and a wire-wound armature with a commutator. It was connected up and various effects of the currents were shown. While Prof. Poeschl was making demonstrations, running the machine as a motor, the brushes gave trouble, sparking badly, and I observed that it might be possible to operate a motor without these appliances. But he declared that it could not be done and did me the honor of delivering a lecture on the subject, at the conclusion of which he remarked: "Mr. Tesla may accomplish great things, but he certainly never will do this. It would be equivalent to converting a steadily pulling force, like that of gravity, into a rotary effort. It is a perpetual motion scheme, an impossible idea." But instinct is something which transcends knowledge. We have, undoubtedly, certain finer fibers that enable us to perceive truths when logical deduction, or any other willful effort of the brain, is futile. For a time I wavered, imprest by the professor's authority, but soon became convinced I was right and undertook the task with all the fire and boundless confidence of youth.

I started by first picturing in my mind a direct-current machine, running it and following the changing flow of the currents in the armature. Then I would imagine an alternator and investigate the processes taking place in a similar manner. Next I would visualize systems comprising motors and generators and operate them in various ways. The images I saw were to me perfectly real and tangible. All my remaining term in Gratz was past in intense but fruitless efforts of this kind, and I almost came to the conclusion that the problem was insolvable. In 1880 I went to Prague, Bohemia, carrying out my father's wish to complete my education at the University there. It was in that city that I made a decided advance, which consisted in detaching the commutator from the machine and studying the phenomena in this new aspect, but still without result. In the year following there was a sudden change in my views of life. I realized that my parents had been making too great sacrifices on my account and resolved to relieve them of the burden. The wave of the American telephone had just reached the European continent and the system was to be installed in Budapest, Hungary. It appeared an ideal opportunity, all the more as a friend of our family was at the head of the enterprise. It was here that I suffered the complete breakdown of the nerves to which I have referred. What I experienced during the period of that illness surpasses all belief. My sight and hearing were always extraordinary. I could clearly discern objects in the distance when others saw no trace of them. Several times in my boyhood I saved the houses of our neighbors from fire by hearing the faint crackling sounds which did not disturb their sleep, and calling for help.

In 1899, when I was past forty and carrying on my experiments in Colorado, I could hear very distinctly thunderclaps at a distance of 550 miles. The limit of audition for my young assistants was scarcely more than 150 miles. My ear was thus over thirteen times more sensitive. Yet at that time I was, so to speak, stone deaf in comparison with the acuteness of my hearing while under the nervous strain. In Budapest I could hear the ticking of a watch with three rooms between me and the time-piece. A fly alighting on a table in the room would cause a dull thud in my ear. A carriage passing at a distance of a few miles fairly shook my whole body. The whistle of a locomotive twenty or thirty miles away made the bench or chair on which I sat vibrate so strongly that the pain was unbearable. The ground under my feet trembled continuously. I had to support my bed on rubber cushions to get any rest at all. The roaring noises from near and far often produced the effect of spoken words which would have frightened me had I not been able to resolve them into their accidental components. The sun's rays, when periodically intercepted, would cause blows of such force on my brain that they would stun me. I had to summon all my will power to pass under a bridge or other structure as I experienced a crushing pressure on the skull. In the dark I had the sense of a bat and could detect the presence of an object at a distance of twelve feet by a peculiar creepy sensation on the forehead. My pulse varied from a few to two hundred and sixty beats and all the tissues of the body with twitchings and tremors which was perhaps the hardest to bear. A renowned physician who gave me daily large doses of Bromid of Potassium pronounced my malady unique and incurable. It is my eternal regret that I was not under the observation of experts in physiology and psychology at that time. I clung desperately to life, but never expected to recover. Can anyone believe that so hopeless a physical wreck could ever be transformed into a man of astonishing strength and tenacity, able to work thirty-eight years almost without a day's interruption, and find himself still strong and fresh in body and mind? Such is my case. A powerful desire to live and to continue the work, and the assistance of a devoted friend and athlete accomplished the wonder. My health returned and with it the vigor of mind. In attacking the problem again I almost regretted that the struggle was soon to end. I had so much energy to spare. When I undertook the task it was not with a resolve such as men often make. With me it was a sacred vow, a question of life and death. I knew that I would perish if I failed. Now I felt that the battle

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MY INVENTIONS.

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was won. Back in the deep recesses of the brain was the solution, but I could not yet give it outward expression. One afternoon, which is ever present in my recollection, I was enjoying a walk with my friend in the City Park and reciting poetry. At that age I knew entire books by heart, word for word. One of these was Göethe's "Faust." The sun was just setting and reminded me of the glorious passage:

"Sie rückt und weicht, der Tag ist überlebt,
Dort eilt sie hin und fördert neues Leben.
Oh, dass kein Flügel mich vom Boden hebt
*Ihr nach und immer nach zu streben!**

* * * * * * *

Ein schöner Traum indessen sie entweicht,
Ach, zu des Geistes Flügeln wird so leicht
Kein körperlicher Flügel sich gesellen!"†

As I uttered these inspiring words the idea came like a flash of lightning and in an instant the truth was revealed. I drew with a stick on the sand the diagrams shown six years later in my address before the American Institute of Electrical Engineers, and my companion understood them perfectly. The images I saw were wonderfully sharp and clear and had the solidity of metal and stone, so much so that I told him: "See my motor here; watch me reverse it." I cannot begin to describe my emotions. Pygmalion seeing his statue come to life could not have been more deeply moved. A thousand secrets of nature which I might have stumbled upon accidentally I would have given for that one which I had wrested from her against all odds and at the peril of my existence.

* "The glow retreats, done is the day of toil;
It yonder hastes, new fields of life exploring;
Ah, that no wing can lift me from the soil,
Upon its track to follow, follow soaring!"

† A glorious dream! though now the glories fade.
Alas! the wings that lift the mind no aid
Of wings to lift the body can bequeath me."

My Inventions

By Nikola Tesla

IV. The Discovery of the Tesla Coil and Transformer

FOR a while I gave myself up entirely to the intense enjoyment of picturing machines and devising new forms. It was a mental state of happiness about as complete as I have ever known in life. Ideas came in an uninterrupted stream and the only difficulty I had was to hold them fast. The pieces of apparatus I conceived were to me absolutely real and tangible in every detail, even to the minutest marks and signs of wear. I delighted in imagining the motors constantly running, for in this way they presented to the mind's eye a more fascinating sight. When natural inclination develops into a passionate desire, one advances towards his goal in seven-league boots. In less than two months I evolved virtually all the types of motors and modifications of the system which are now identified with my name. It was, perhaps, providential that the necessities of existence commanded a temporary halt to this consuming activity of the mind. I came to Budapest prompted by a premature report concerning the telephone enterprise and, as irony of fate willed it, I had to accept a position as draftsman in the Central Telegraph Office of the Hungarian Government at a salary which I deem it my privilege not to disclose! Fortunately, I soon won the interest of the Inspector-in-Chief and was thereafter employed on calculations, designs and estimates in connection with new installations, until the Telephone Exchange was started, when I took charge of the same. The knowledge and practical experience I gained in the course of this work was most valuable and the employment gave me ample opportunities for the exercise of my inventive faculties. I made several improvements in the Central Station apparatus and perfected a telephone repeater or amplifier which was never patented or publicly described but would be creditable to me even today. In recognition of my efficient assistance the organizer of the undertaking, Mr. Puskas, upon disposing of his business in Budapest, offered me a position in Paris which I gladly accepted.

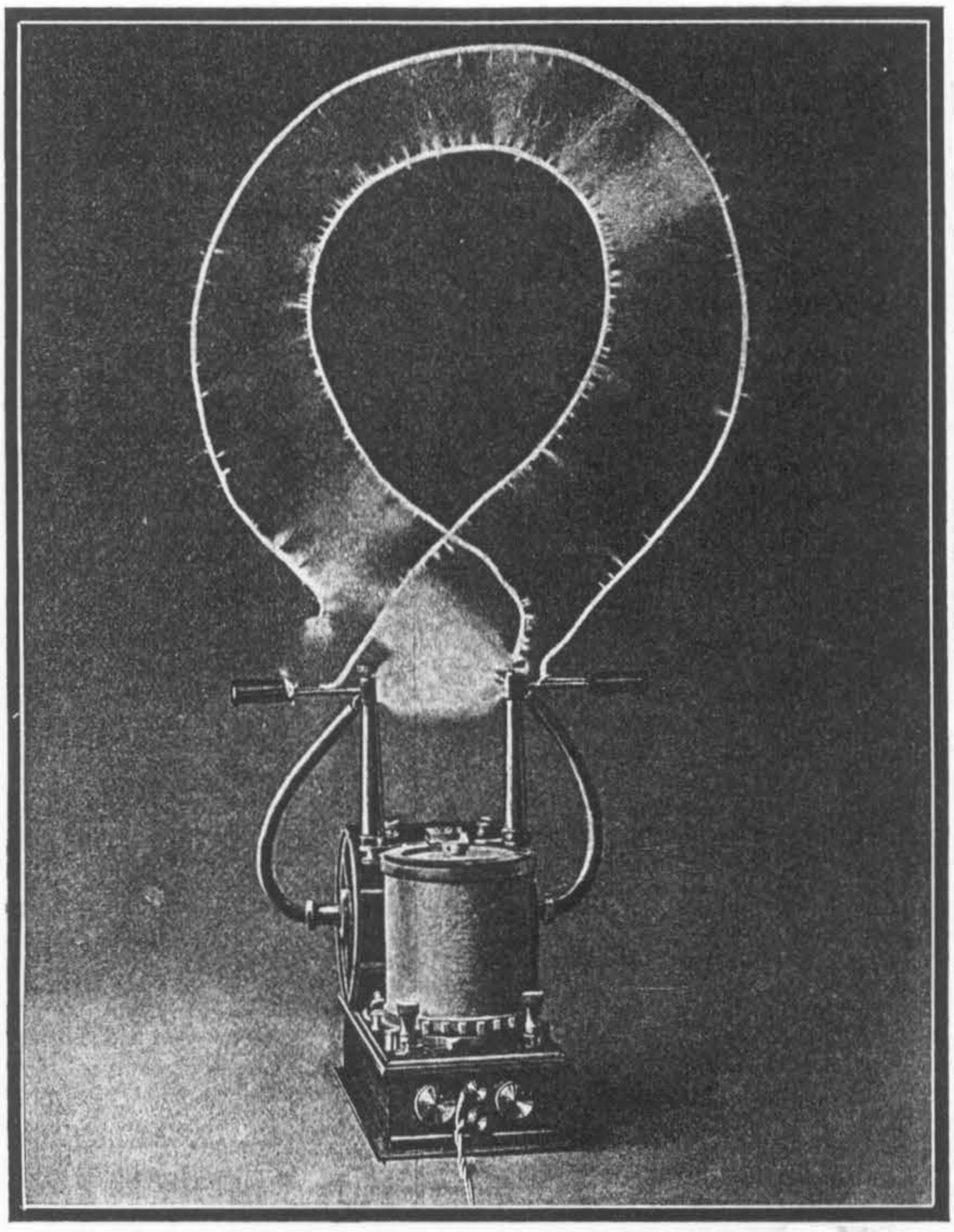

Fig. 1—Tesla Oscillation Transformer (Tesla Coil) Presented by Lord Kelvin Before the British Association in August, 1897. This Small and Compact Instrument, Only 8 Inches High, Developed Two Square Feet of Streamers With Twenty-Five Watts From the 110 Volt D. C. Supply Circuit. The Instrument Contains a Tesla Primary and Secondary, Condenser, and a Circuit Controller.

I never can forget the deep impression that magic city produced on my mind. For several days after my arrival I roamed thru the streets in utter bewilderment of the new spectacle. The attractions were many and irresistible, but, alas, the income was spent as soon as received. When Mr. Puskas asked me how I was getting along in the new sphere, I described the situation accurately in the statement that "the last twenty-nine days of the month are the toughest!" I led a rather strenuous life in what would now be termed "Rooseveltian fashion." Every morning, regardless of weather, I would go from the Boulevard St. Marcel, where I resided, to a bathing house on the Seine, plunge into the water, loop the circuit twenty-seven times and then walk an hour to reach Ivry, where the Company's factory was located. There I would have a woodchopper's breakfast at half-past seven o'clock and then eagerly await the lunch hour, in the meanwhile cracking hard nuts for the Manager of the Works, Mr. Charles Batchellor, who was an intimate friend and assistant of Edison. Here I was thrown in contact with a few Americans who fairly fell in love with me because of my proficiency in—billiards. To these men I explained my invention and one of them, Mr. D. Cunningham, Foreman of the Mechanical Department, offered to form a stock company. The proposal seemed to me comical in the extreme. I did not have the faintest conception of what that meant except that it was an American way of doing things. Nothing came of it, however, and during the next few months I had to travel from one to another place in France and Germany to cure the ills of the power plants. On my return to Paris I submitted to one of the administrators of the Company, Mr. Rau, a plan for improving their dynamos and was given an opportunity. My success was complete and the delighted directors accorded me the privilege of developing automatic regulators which were much desired. Shortly after there was some trouble with the lighting plant which has been installed at the new rail-

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Mr. Tesla's articles started in our February issue

road station in Strassburg, Alsace. The wiring was defective and on the occasion of the opening ceremonies a large part of a wall was blown out thru a short-circuit right in the presence of old Emperor William I. The German Government refused to take the plant and the French Company was facing a serious loss. On account of my knowledge of the German language and past experience, I was entrusted with the difficult task of straightening out matters and early in 1883 I went to Strassburg on that mission.

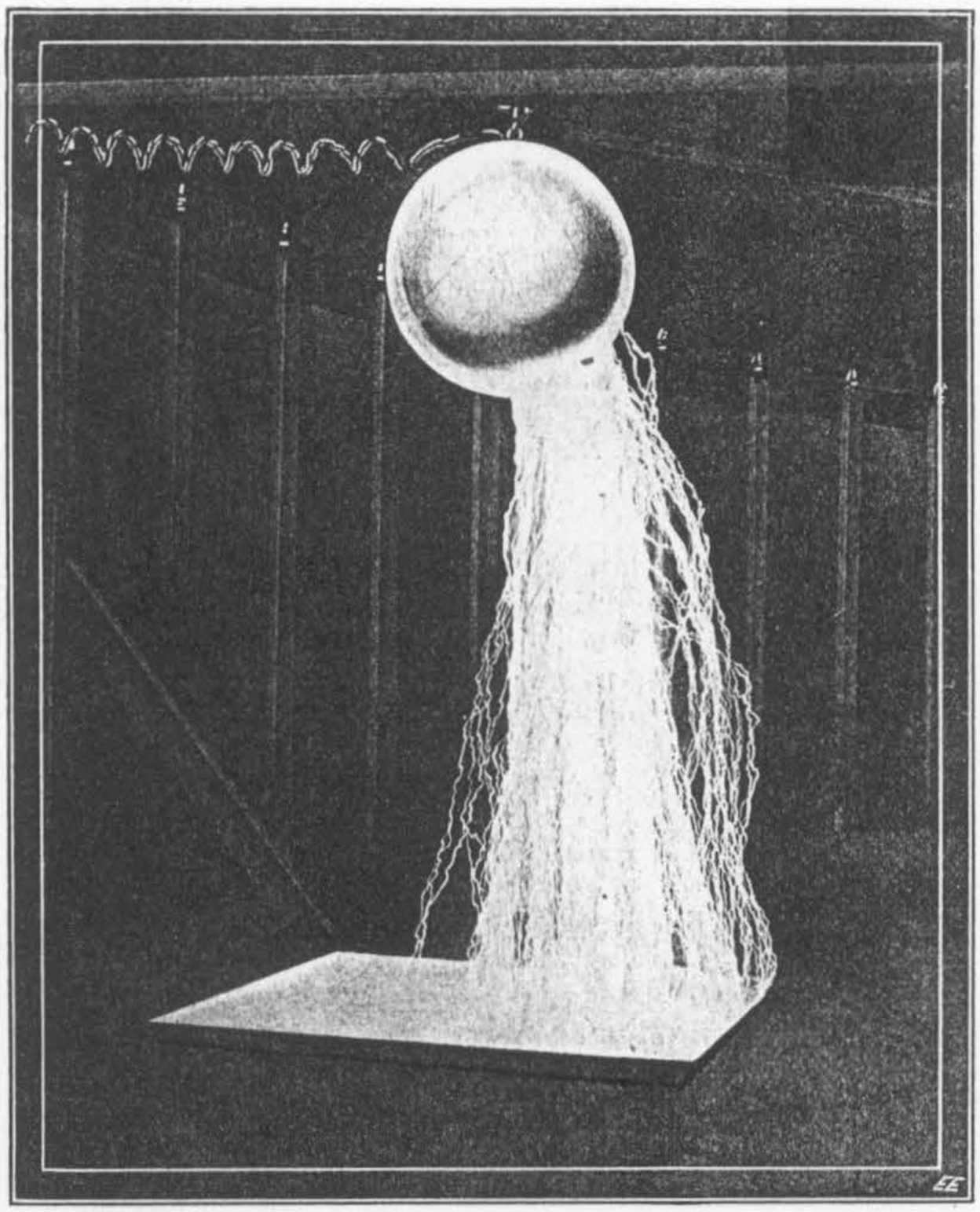

Fig. 2—This Illustrates Tests With Spark Discharges From a Ball of Forty Centimeters Radius in Tesla's Wireless Plant Erected at Colorado Springs in 1899. The Ball Is Connected to the Free End of a Grounded Resonant Circuit Seventeen Meters in Diameter. The Disruptive Potential of a Ball, Is, According to Tesla, in Volts Approximatelly V = 75,400 r (r Being in Centimeters), That Is, in This Case 75,400 x 40 = 3,016,000 Volts. The Gigantic Tesla Coil Which Produced These Bolts of Thor Was Capable of Furnishing a Current of 1,100 Amperes in the High Tension Secondary. The Primary Coil Had a Diameter of 51 Feet! This Tesla Coil Produced Discharges Which Were the Nearest Approach to Lightning Ever Made by Man.

The First Induction Motor Is Built.

Some of the incidents in that city have left an indelible record on my memory. By a curious coincidence, a number of men who subsequently achieved fame, lived there about that time. In later life I used to say, "There were bacteria of greatness in that old town. Others caught the disease but I escaped!" The practical work, correspondence, and conferences with officials kept me preoccupied day and night, but as soon as I was able to manage I undertook the construction of a simple motor in a mechanical shop opposite the railroad station, having brought with me from Paris some material for that purpose. The consummation of the experiment was, however, delayed until the summer of that year when I finally had the satisfaction of *seeing rotation effected by alternating currents of different phase, and without sliding contacts or commutator,* as I had conceived a year before. It was an exquisite pleasure but not to compare with the delirium of joy following the first revelation.

Among my new friends was the former Mayor of the city, Mr. Bauzin, whom I had already in a measure acquainted with this and other inventions of mine and whose support I endeavored to enlist. He was sincerely devoted to me and put my project before several wealthy persons but, to my mortification, found no response. He wanted to help me in every possible way and the approach of the first of July, 1919, happens to remind me of a form of "assistance" I received from that charming man, which was not financial but none the less appreciated. In 1870, when the Germans invaded the country, Mr. Bauzin had buried a good sized allotment of St. Estèphe of 1801 and he came to the conclusion that he knew no worthier person than myself to consume that precious beverage. This, I may say, is one of the unforgettable incidents to which I have referred. My friend urged me to return to Paris as soon as possible and seek support there. This I was anxious to do but my work and negotiations were protracted owing to all sorts of petty obstacles I encountered so that at times the situation seemed hopeless.

German "Efficiency".

Just to give an idea of German thoroness and "efficiency," I may mention here a rather funny experience. An incandescent lamp of 16 c.p. was to be placed in a hallway and upon selecting the proper location I ordered the *monteur* to run the wires. After working for a while he concluded that the engineer had to be consulted and this was done. The latter made several objections but ultimately agreed that the lamp should be placed two inches from the spot I had assigned, whereupon the work proceeded. Then the engineer became worried and told me that Inspector Averdeck should be notified. That important person called, investigated, debated, and decided that the lamp should be shifted back two inches, which was the place I had marked. It was not long, however, before Averdeck got cold feet himself and advised me that he had informed *Ober-Inspector* Hieronimus of the matter and that I should await his decision. It was several days before the *Ober-Inspector* was able to free himself of other pressing duties but at last he arrived and a two-hour debate followed, when he decided to move the lamp two inches farther. My hopes that this was the final act were shattered when the *Ober-Inspector* returned and said to me: "*Regierungsrath* Funke is so particular that I would not dare to give an order for placing this lamp without his explicit approval." Accordingly arrangements for a visit from that great man were made. We started cleaning up and polishing early in the morning. Everybody brushed up, I put on my gloves and when Funke came with his retinue he was ceremoniously received. After two hours' deliberation he suddenly exclaimed: "I must be going," and pointing to a place on the ceiling, he ordered me to put the

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THE proverbial trials and tribulations known to every inventor were not spared Tesla, the world's greatest inventor of all times. In this article we see him, arrived at young manhood, struggling along in a cold world. Already his fame has spread far and wide and his genius is recognized. But converting genius and fame into dollars and cents is quite a different matter, and the world is full of unappreciative and unscrupulous men. Tesla, the idealist, cared little for money and thus was promptly taken advantage of. But let Tesla himself tell you in his own inimitable style. It is a wonderful story.

In this month's installment Tesla also tells us how he made one of his most important as well as sensational discoveries—the Tesla Coil. Few inventions have caused such a sensation as this one which culminated in the only man-made lightning ever produced. The Tesla coil has so many uses and has been built in so many styles that it would take a catalog to list them all. From the spectacular high frequency stunts on the stage down to the "violet" ray machine in your home; all are Tesla coils in one form or another.

Wireless without the Tesla Coil would not be possible today. Without an oscillation transformer, spark gap and condenser—which is a Tesla Coil—the sending station would be crippled.

But it is for industrial purposes where the Tesla Coil will shine brightest in the future. The production of Ozone, the extraction of Nitrogen from the air in huge quantities—all are children of Tesla's fertile brain. His coil is the key to them all.

EDITOR.

My Inventions

(*Continued from page* 17)

lamp there. It was the exact spot which I had originally chosen.

So it went day after day with variations, but I was determined to achieve at whatever cost and in the end my efforts were rewarded. By the spring of 1884 all the differences were adjusted, the plant formally accepted, and I returned to Paris with pleasing anticipations. One of the administrators had promised me a liberal compensation in case I succeeded, as well as a fair consideration of the improvements I had made in their dynamos and I hoped to realize a substantial sum. There were three administrators whom I shall designate as A, B and C for convenience. When I called on A *he* told me that B had the say. This gentleman thought that only C could decide and the latter was quite sure that A alone had the power to act. After several laps of this *circulus viciosus,* it dawned upon me that my reward was a castle in Spain. The utter failure of my attempts to raise capital for development was another disappointment and when Mr. Batchellor prest me to go to America with a view of redesigning the Edison machines, I determined to try my fortunes in the Land of Golden Promise. But the chance was nearly mist. I liquefied my modest assets, secured accommodations and found myself at the railroad station as the train was pulling out. At that moment I discovered that my money and tickets were gone. What to do was the question. Hercules had plenty of time to deliberate but I had to decide while running alongside the train with opposite feelings surging in my brain like condenser oscillations. Resolve, helped by dexterity, won out in the nick of time and upon passing thru the usual experiences, as trivial as unpleasant, I managed to embark for New York with the remnants of my belongings, some poems and articles I had written, and a package of calculations relating to solutions of an unsolvable integral and to my flying machine. During the voyage I sat most of the time at the stern of the ship watching for an opportunity to save somebody from a watery grave, without the slightest thought of danger. Later when I had absorbed some of the practical American sense I shivered at the recollection and marvelled at my former folly.

Tesla in America

I wish that I could put in words my first impressions of this country In the Arabian Tales I read how genii transported people into a land of dreams to live thru delightful adventures. My case was just the reverse. The genii had carried me from a world of dreams into one of realities. What I had left was beautiful, artistic and fascinating in every way; what I saw here was machined, rough and unattractive. A burly policeman was twirling his stick which looked to me as big as a log. I approached him politely with the request to direct me. "Six blocks down, then to the left," he said, with murder in his eyes. "Is this America?" I asked myself in painful surprise. "It is a century behind Europe in civilization." When I went abroad in 1889—five years having elapsed since my arrival here—I became convinced that *it was more than one hundred years AHEAD of Europe* and nothing has happened to this day to change my opinion.

Tesla Meets Edison

The meeting with Edison was a memorable event in my life. I was amazed at this wonderful man who, without early advantages and scientific training, had accomplished so much. I had studied a dozen languages, delved in literature and art, and had spent my best years in libraries reading all sorts of stuff that fell into my hands, from Newton's "*Principia*" to the novels of Paul de Kock, and felt that most of my life had been squandered. But it did not take long before I recognized that it was the best thing I could have done. Within a few weeks I had won Edison's confidence and it came about in this way.

The S. S. *Oregon,* the fastest passenger steamer at that time, had both of its lighting machines disabled and its sailing was delayed. As the superstructure had been built after their installation it was impossible to remove them from the hold. The predicament was a serious one and Edison was much annoyed. In the evening I took the necessary instruments with me and went aboard the vessel where I stayed for the night. The dynamos were in bad condition, having several short-circuits and breaks, but with the assistance of the crew I succeeded in putting them in good shape. At five o'clock in the morning, when passing along Fifth Avenue on my way to the shop, I met Edison with Batchellor and a few others as they were returning home to retire. "Here is our Parisian running around at night," he said. When I told him that I was coming from the *Oregon* and had repaired both machines, he looked at me in silence and walked away without another word. But when he had gone some distance I heard him remark: "Batchellor, this is a d—n good man," and from that time on I had full freedom in directing the work. For nearly a year my regular hours were from 10.30 A. M. until 5 o'clock the next

morning without a day's exception. Edison said to me: "I have had many hard-working assistants but you take the cake." During this period I designed twenty-four different types of standard machines with short cores and of uniform pattern which replaced the old ones. The Manager had promised me fifty thousand dollars on the completion of this task but it turned out to be a practical joke. This gave me a painful shock and I resigned my position.

Immediately thereafter some people approached me with the proposal of forming an arc light company under my name, to which I agreed. Here finally was an opportunity to develop the motor, but when I broached the subject to my new associates they said: "No, we want the arc lamp. We don't care for this alternating current of yours." In 1886 my system of arc lighting was perfected and adopted for factory and municipal lighting, and I was free, but with no other possession than a beautifully engraved certificate of stock of hypothetical value. Then followed a period of struggle in the new medium for which I was not fitted, but the reward came in the end and in April, 1887, the Tesla Electric Company was organized, providing a laboratory and facilities. The motors I built there were exactly as I had imagined them. I made no attempt to improve the design, but merely reproduced the pictures as they appeared to my vision and the operation was always as I expected.

In the early part of 1888 an arrangement was made with the Westinghouse Company for the manufacture of the motors on a large scale. But great difficulties had still to be overcome. My system was based on the use of low frequency currents and the Westinghouse experts had adopted 133 cycles with the object of securing advantages in the transformation. They did not want to depart from their standard forms of apparatus and my efforts had to be concentrated upon adapting the motor to these conditions. Another necessity was to produce a motor capable of running efficiently at this frequency on two wires which was not easy of accomplishment.

At the close of 1889, however, my services in Pittsburg being no longer essential, I returned to New York and resumed experimental work in a laboratory on Grand Street, where I began immediately the design of high frequency machines. The problems of construction in this unexplored field were novel and quite peculiar and I encountered many difficulties. I rejected the inductor type, fearing that it might not yield perfect sine waves which were so important to resonant action. Had it not been for this I could have saved myself a great deal of labor. Another discouraging feature of the high frequency alternator seemed to be the inconstancy of speed which threatened to impose serious limitations to its use. I had already noted in my demonstrations before the American Institution of Electrical Engineers that several times the tune was lost, necessitating readjustment, and did not yet foresee, what I discovered long afterwards, a means of operating a machine of this kind at a speed constant to such a degree as not to vary more than a small fraction of one revolution between the extremes of load.

The Invention of the Tesla Coil

From many other considerations it appeared desirable to invent a simpler device for the production of electric oscillations. In 1856 Lord Kelvin had exposed the theory of the condenser discharge, but no practical application of that important knowledge was made. I saw the possibilities and undertook the development of induction apparatus on this principle. My progress was so rapid as to enable me to exhibit at my lecture in 1891 a coil giving sparks of *five inches*. On that occasion I frankly told the

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My Inventions

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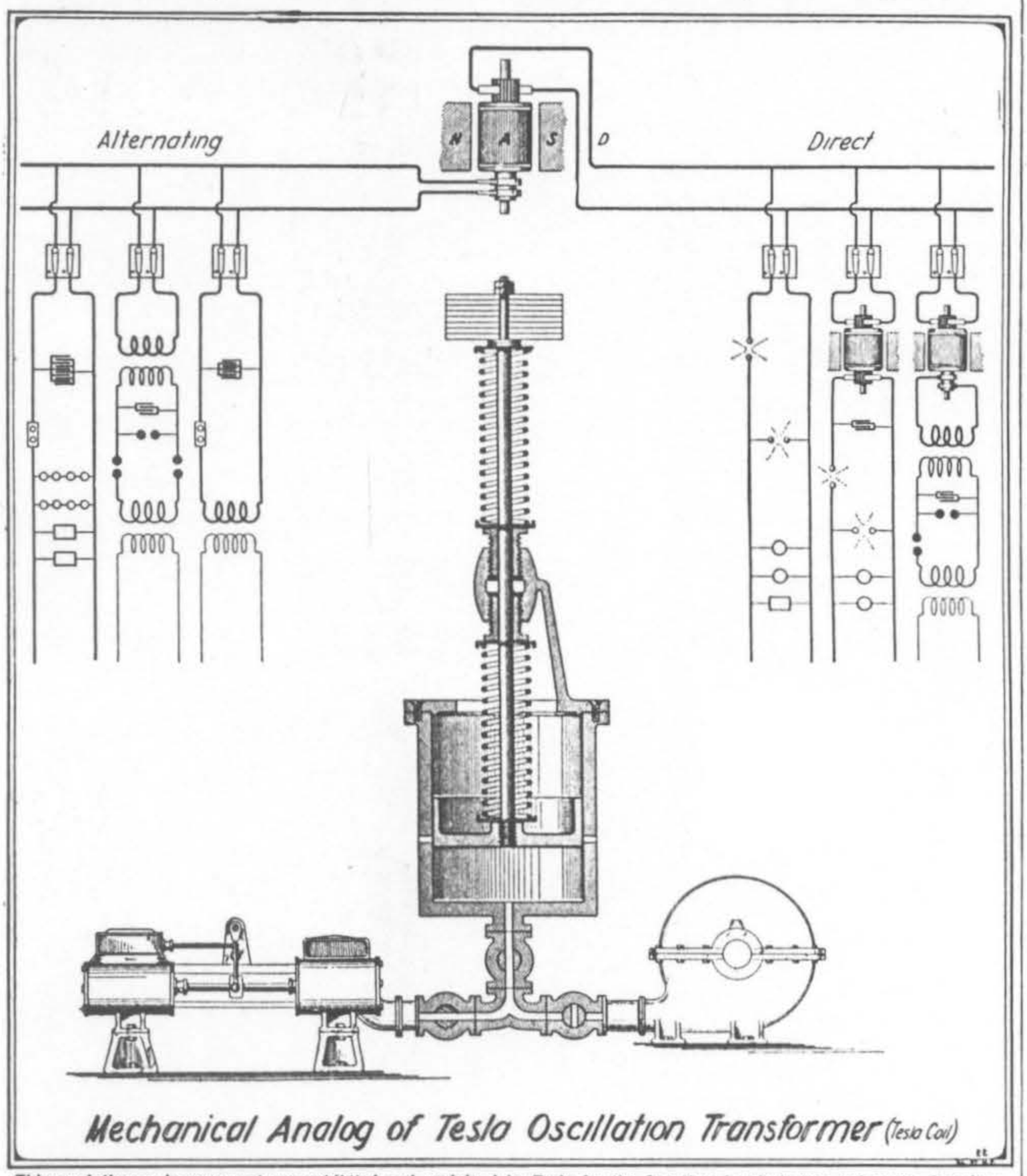
engineers of a defect involved in the transformation by the new method, namely, the loss in the spark gap. Subsequent investigation showed that no matter what medium is employed, be it air, hydrogen, mercury vapor, oil or a stream of electrons, the efficiency is the same. It is a law very much like that governing the conversion of mechanical energy. We may drop a weight from a certain height vertically down or carry it to the lower level along any devious path, it is immaterial insofar as the amount of work is concerned. Fortunately however, this drawback is not fatal as by proper proportioning of the resonant circuits an *efficiency of* 85 *per cent* is attainable. Since my early announcement of the invention it has come into universal use and wrought a revolution in many departments. But a still greater future awaits it. When in 1900 I obtained powerful discharges of 100 feet and flashed a current around the globe, I was reminded of the first tiny spark I observed in my Grand Street laboratory and was thrilled by sensations akin to those I felt when I discovered the *rotating magnetic field*.



Mechanical Analog of Tesla Oscillation Transformer (Tesla Coil)

This revolutionary improvement was exhibited and explained by Tesla for the first time in his lecture before the American Institute of Electrical Engineers May 20, 1891. It has made possible to generate automatically damped or undamped oscillations of any desired frequency and, what is equally important, of perfectly constant period. It has been instrumental in many great achievements and its use has become universal. The underlying principle may be briefly stated as follows: A source of electricity is made to charge a condenser and when the difference of potential at the terminals of the latter has reached a predetermined value, an air-gap is bridged, permitting the accumulated energy to be discharged through a circuit under resonant conditions, this resulting in a long series of isochronous impulses. These are either directly used or converted to any desired volume or pressure by means of a second circuit inductively linked with the first and tuned to the same. The above diagram is taken from Tesla's lecture before the Franklin Institute and National Electric Light Association in 1893 and shows more elaborate arrangements of circuits, now quite familiar, for the conversion of ordinary direct or alternating currents into high frequency oscillations by this general method. In the mechanical apparatus illustrated, an attempt is made to convey an idea of the electrical operations as closely as practicable. The reciprocating and centrifugal pumps, respectively, represent an alternating and a direct current generator. The water takes the place of the electric fluid. The cylinder with its elastically restrained piston represents the condenser. The inertia of the moving parts corresponds to the self-induction of the electric circuit and the wide ports around the cylinder, through which the fluid can escape, perform the function of the air-gap. The operation of this apparatus will now be readily understood. Suppose first that the water is admitted to the cylinder from the centrifugal pump, this corresponding to the action of a continuous current generator. As the fluid is forced into the cylinder, the piston moves upward until the ports are uncovered, when a great quantity of the fluid rushes out, suddenly reducing the pressure so that the force of the compressed spring asserts itself and sends the piston down, closing the ports, whereupon these operations are repeated in as rapid succession as it may be desired. Each time the system, comprising the piston, rod, weights and adjustable spring, receives a blow, it quivers at its own rate which is determined by the inertia of the moving parts and the pliability of the spring exactly as in the electrical system the period of the circuit is determined by the self-induction and capacity. Under the best conditions the natural period of the elastic system will be the same as that of the primarily impressed oscillations, and then the energy of the movement will be greatest. If, instead of the centrifugal, the reciprocating pump is employed, the operation is the same in principle except that the periodic impulses of the pump impose certain limitations. The best results are again obtained when synchronism is maintained between these and the natural oscillations of the system.

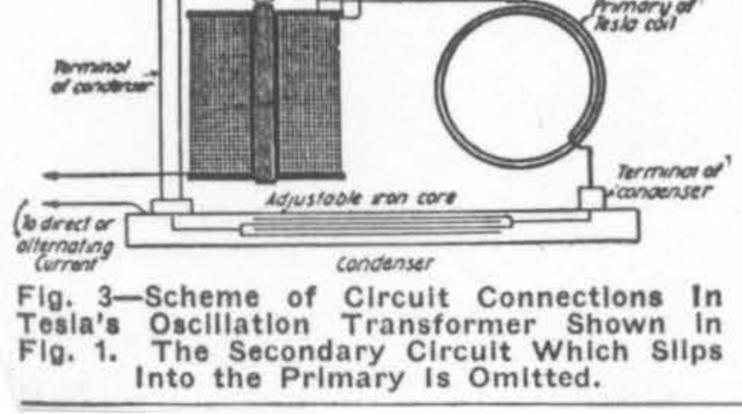


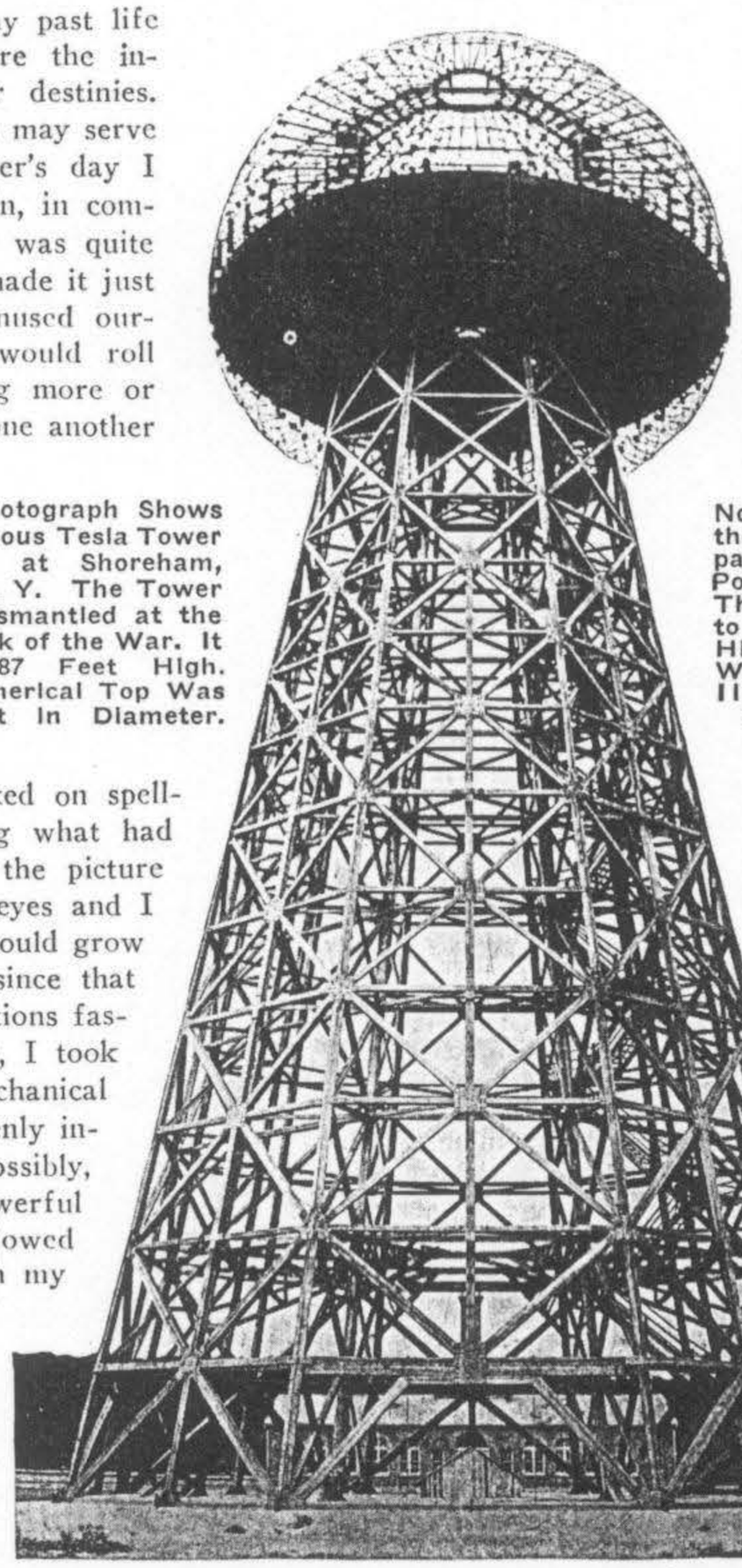
Fig. 3—Scheme of Circuit Connections In Tesla's Oscillation Transformer Shown in Fig. 1. The Secondary Circuit Which Slips Into the Primary Is Omitted.

My Inventions

By Nikola Tesla

V. The Magnifying Transmitter

AS I review the events of my past life I realize how subtle are the influences that shape our destinies. An incident of my youth may serve to illustrate. One winter's day I managed to climb a steep mountain, in company with other boys. The snow was quite deep and a warm southerly wind made it just suitable for our purpose. We amused ourselves by throwing balls which would roll down a certain distance, gathering more or less snow, and we tried to outdo one another in this exciting sport. Suddenly a ball was seen to go beyond the limit, swelling to enormous proportions until it became as big as a house and plunged thundering into the valley below with a force that made the ground tremble. I looked on spellbound, incapable of understanding what had happened. For weeks afterward the picture of the avalanche was before my eyes and I wondered how anything so small could grow to such an immense size. Ever since that time the magnification of feeble actions fascinated me, and when, years later, I took up the experimental study of mechanical and electrical resonance, I was keenly interested from the very start. Possibly, had it not been for that early powerful impression, I might not have followed up the little spark I obtained with my coil and never developed my best invention, the true history of which I will tell here for the first time.



This Photograph Shows the Famous Tesla Tower Erected at Shoreham, L. I., N. Y. The Tower Was Dismantled at the Outbreak of the War. It Was 187 Feet High. The Spherical Top Was 68 Feet In Diameter.

Note the Huge Size of the Structure by Comparing the Two-story Power Plant in the Rear. The Tower Which Was to be Used by Tesla in His "World Wireless," Was Never Finished. Illustration Opposite Shows It Completed.

Scrapping the World's Engines.

"Lionhunters" have often asked me which of my discoveries I prize most. This depends on the point of view. Not a few technical men, very able in their special departments, but dominated by a pedantic spirit and near-sighted, have asserted that excepting the induction motor I have given to the world little of practical use. This is a grievous mistake. A new idea must not be judged by its immediate results. My alternating system of power transmission came at a psychological moment, as a long-sought answer to pressing industrial questions, and altho considerable resistance had to be overcome and opposing interests reconciled, as usual, the commercial introduction could not be long delayed. Now, compare this situation with that confronting my turbine, for example. One should think that so simple and beautiful an invention, possessing many features of an ideal motor, should be adopted at once and, undoubtedly, it would under similar conditions. But the prospective effect of the rotating field was not to render worthless existing machinery; on the contrary, it was to give it additional value. The system lent itself to new enterprise as well as to improvement of the old. My turbine is an advance of a character entirely different. It is a radical departure in the sense that its success would mean the abandonment of the antiquated types of prime movers on which billions of dollars have been spent. Under such circumstances the progress must needs be slow and perhaps the greatest impediment is encountered in the prejudicial opinions created in the minds of experts by organized opposition. Only the other day I had a disheartening experience when I met my friend and former assistant, Charles F. Scott, now professor of Electrical Engineering at Yale. I had not seen him for a long time and was glad to have an opportunity for a little chat at my office. Our conversation naturally enough drifted on my turbine and I became heated to a high degree. "Scott," I exclaimed, carried away by the vision of a glorious future, "my turbine will scrap all the heat-engines in the world." Scott stroked his chin and looked away thoughtfully, as though making a mental calculation. "That will make quite a pile of scrap," he said, and left without another word!

IMAGINE a man a century ago, bold enough to design and actually build a huge tower with which to transmit the human voice, music, pictures, press news and even power, thru the earth to any distance whatever without wires! He probably would have been hung or burnt at the stake. So when Tesla built his famous tower on Long Island he was a hundred years ahead of his time. And foolish ridicule by our latter day arm-chair "savants," does not in the least mar Tesla's greatness.

The titanic brain of Tesla has hardly produced a more amazing wonder than this "magnifying transmitter." Contrary to popular belief his tower was not built to radiate Hertzian waves into the ether. Tesla's system sends out thousands of horsepower thru the earth—he has shown experimentally how power can be sent without wires over distances from a central point. Nor is there any mystery about it how he accomplishes the result. His historic U. S. patents and articles describe the method used. Tesla's Magnifying Transmitter is truly a modern lamp of Aladdin.

EDITOR.

"Aladdin's Lamp".

These and other inventions of mine, however, were nothing more than steps forward in certain directions. In evolving them I simply followed the inborn instinct to improve the present devices without

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Mr. Tesla's articles started in our February issue



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THIS PHOTOGRAPH OF A MODEL SHOWS HOW THE TESLA TOWER BUILT ON LONG ISLAND, EIGHTEEN YEARS AGO, WOULD HAVE LOOKED COMPLETED. FROM ITS APPEARANCE NOBODY WOULD INFER THAT IT WAS TO BE USED FOR THE GREAT PURPOSES WHICH ARE SET FORTH IN HIS ACCOMPANYING ARTICLE.

My Inventions

By Nikola Tesla

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any special thought of our far more imperative necessities. The "Magnifying Transmitter" was the product of labors extending through years, having for their chief object the solution of problems which are infinitely more important to mankind than mere industrial development.

If my memory serves me right, it was in November, 1890, that I performed a laboratory experiment which was one of the most extraordinary and spectacular ever recorded in the annals of science. In investigating the behaviour of high frequency currents I had satisfied myself that an electric field of sufficient intensity could be produced in a room to light up electrodeless vacuum tubes. Accordingly, a transformer was built to test the theory and the first trial proved a marvelous success. It is difficult to appreciate what those strange phenomena meant at that time. We crave for new sensations but soon become indifferent to them. The wonders of yesterday are today common occurrences. When my tubes were first publicly exhibited they were viewed with amazement impossible to describe. From all parts of the world I received urgent invitations and numerous honors and other flattering inducements were offered to me, which I declined.

In Faraday's Chair

But in 1892 the demands became irresistible and I went to London where I delivered a lecture before the Institution of Electrical Engineers. It had been my intention to leave immediately for Paris in compliance with a similar obligation, but Sir James Dewar insisted on my appearing before the Royal Institution. I was a man of firm resolve but succumbed easily to the forceful arguments of the great Scotchman. He pushed me into a chair and poured out half a glass of a wonderful brown fluid which sparkled in all sorts of iridescent colors and tasted like nectar. "Now," said he, "you are sitting in Faraday's chair and you are enjoying whiskey he used to drink." In both aspects it was an enviable experience. The next evening I gave a demonstration before that Institution, at the termination of which Lord Rayleigh addressed the audience and his generous words gave me the first start in these endeavors. I fled from London and later from Paris to escape favors

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My Inventions

By Nikola Tesla

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showered upon me, and journeyed to my home where I passed through a most painful ordeal and illness. Upon regaining my health I began to formulate plans for the resumption of work in America. Up to that time I never realized that I possessed any particular gift of discovery but Lord Rayleigh, whom I always considered as an ideal man of science, had said so and if that was the case I felt that I should concentrate on some big idea.

Nature's Trigger.

One day, as I was roaming in the mountains, I sought shelter from an approaching storm. The sky became overhung with heavy clouds but somehow the rain was delayed until, all of a sudden, there was a lightning flash and a few moments after a deluge. This observation set me thinking. It was manifest that the two phenomena were closely related, as cause and effect, and a little reflection led me to the conclusion that the electrical energy involved in the precipitation of the water was inconsiderable, the function of lightning being much like that of a sensitive trigger. Here was a stupendous possibility of achievement. If we could produce electric effects of the required quality, this whole planet and the conditions of existence on it could be transformed. The sun raises the water of the oceans and winds drive it to distant regions where it remains in a state of most delicate balance. If it were in our power to upset it when and wherever desired, this mighty life-sustaining stream could be at will controlled. We could irrigate arid deserts, create lakes and rivers and provide motive power in unlimited amounts. This would be the most efficient way of harnessing the sun to the uses of man. The consummation depended on our ability to develop electric forces of the order of those in nature. It seemed a hopeless undertaking, but I made up my mind to try it and immediately on my return to the United States, in the summer of 1892, work was begun which was to me all the more attractive, because a means of the same kind was necessary for the successful transmission of energy without wires.

Four Million Volts.

The first gratifying result was obtained in the spring of the succeeding year when I reached tensions of about 1,000,000 volts with my conical coil. That was not much in the light of the present art, but it was then considered a feat. Steady progress was made until the destruction of my laboratory by fire in 1895, as may be judged from an article by T. C. Martin which appeared in the April number of the *Century Magazine*. This calamity set me back in many ways and most of that year had to be devoted to planning and reconstruction. However, as soon as circumstances permitted, I returned to the task. Although I knew that higher electro-motive forces were attainable with apparatus of larger dimensions, I had an instinctive perception that the object could be accomplished by the proper design of a comparatively small and compact transformer. In carrying on tests with a *secondary in the form of a flat spiral*, as illustrated in my patents, the absence of streamers surprised me, and it was not long before I discovered that this was due to the position of the turns and their mutual action. Profiting from this observation I resorted to the use of a high tension conductor with turns of considerable diameter sufficiently separated to keep down the distributed capacity, while at the

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same time preventing undue accumulation of the charge at any point. The application of this principle enabled me to produce pressures of 4,000,000 volts, which was about the limit obtainable in my new laboratory at Houston Street, as the discharges extended through a distance of 16 feet. A photograph of this transmitter was published in the *Electrical Review* of November, 1898. In order to advance further along this line I had to go into the open, and in the spring of 1899, having completed preparations for the erection of a wireless plant, I went to Colorado where I remained for more than one year. Here I introduced other improvements, and refinements which made it possible to generate currents of any tension that may be desired. Those who are interested will find some information in regard to the experiments I conducted there in my article, "The Problem of Increasing Human Energy" in the *Century Magazine* of June, 1900, to which I have referred on a previous occasion.

The Magnifying Transmitter.

I have been asked by the ELECTRICAL EXPERIMENTER to be quite explicit on this subject so that my young friends among the readers of the magazine will clearly understand the construction and operation of my "Magnifying Transmitter" and the purposes for which it is intended. Well, then, in the first place, it is a *resonant transformer* with a secondary in which the parts, charged to a high potential, are of considerable area and arranged in space along ideal enveloping surfaces of very large radii of curvature, and at proper distances from one another thereby insuring a *small electric surface density everywhere* so that *no leak can occur even if the conductor is bare*. It is suitable for any frequency, from a few to many thousands of cycles per second, and can be used in the production of currents of tremendous volume and moderate pressure, or of smaller amperage and immense electro-motive force. The maximum electric *tension is merely dependent on the curvature of the surfaces* on which the charged elements are situated and the area of the latter.

100 Million Volts Possible.

Judging from my past experience, as much as 100,000,000 volts are perfectly practicable. On the other hand currents of many thousands of amperes may be obtained in the antenna. A plant of but very moderate dimensions is required for such performances. Theoretically, a terminal of less than 90 feet in diameter is sufficient to develop an electro-motive force of that magnitude while for antenna currents of from 2,000-4,000 amperes at the usual frequencies it need not be larger than 30 feet in diameter.

In a more restricted meaning this wireless transmitter is one in which the Hertz-wave radiation is an entirely negligible quantity as compared with the whole energy, under which condition the damping factor is extremely small and an enormous charge is stored in the elevated capacity. Such a circuit may then be excited with impulses of any kind, even of low frequency and it will yield sinusoidal and continuous oscillations like those of an alternator.

Taken in the narrowest significance of the term, however, it is a resonant transformer which, besides possessing these qualities, is accurately proportioned to fit the globe and its electrical constants and properties, by virtue of which design it becomes highly efficient and effective in the

wireless transmission of energy. Distance is then absolutely eliminated, there being *no diminution in the intensity of the transmitted impulses.* It is even possible to make the actions *increase with the distance from the plant* according to an exact mathematical law.

This invention was one of a number comprised in my "World-System" of wireless transmission which I undertook to commercialize on my return to New York in 1900. As to the immediate purposes of my enterprise, they were clearly outlined in a technical statement of that period from which I quote:

"The 'World-System' has resulted from a combination of several original discoveries made by the inventor in the course of long continued research and experimentation. It makes possible not only the instantaneous and precise wireless transmission of any kind of signals, messages or characters, to all parts of the world, but also the inter-connection of the existing telegraph, telephone, and other signal stations without any change in their present equipment. By its means, for instance, a telephone subscriber here may call up and talk to any other subscriber on the Globe. An inexpensive receiver, not bigger than a watch, will enable him to listen anywhere, on land or sea, to a speech delivered or music played in some other place, however distant. These examples are cited merely to give an idea of the possibilities of this great scientific advance, which annihilates distance and makes that perfect natural conductor, the Earth, available for all the innumerable purposes which human ingenuity has found for a line-wire. One far-reaching result of this is that any device capable of being operated thru one or more wires (at a distance obviously restricted) can likewise be actuated, without artificial conductors and with the same facility and accuracy, at distances to which there are no limits other than those imposed by the physical dimensions of the Globe. Thus, not only will entirely new fields for commercial exploitation be opened up by this ideal method of transmission but the old ones vastly extended.

"The 'World-System' is based on the application of the following important inventions and discoveries:

"1. *The 'Tesla Transformer.'* This apparatus is in the production of electrical vibrations as revolutionary as gunpowder was in warfare. Currents many times stronger than any ever generated in the usual ways, and sparks over one hundred feet long, have been produced by the inventor with an instrument of this kind.

"2. *The 'Magnifying Transmitter.'* This is Tesla's best invention—a peculiar transformer specially adapted to excite the Earth, which is in the transmission of electrical energy what the telescope is in astronomical observation. By the use of this marvelous device he has already set up electrical movements of greater intensity than those of lightning and passed a current, sufficient to light more than two hundred incandescent lamps, around the Globe.

"3. *The 'Tesla Wireless System.'* This system comprises a number of improvements and is the only means known for transmitting economically electrical energy to a distance without wires. Careful tests and measurements in connection with an experimental station of great activity, erected by the inventor in Colorado, have demonstrated that power in any desired amount can be conveyed, clear across the Globe if necessary, with a loss not exceeding a few per cent.

"4. *The 'Art of Individualization.'* This invention of Tesla is to primitive 'tuning' what refined language is to unarticulated expression. It makes possible the transmission of signals or messages absolutely secret and exclusive both in the active and passive aspect, that is, non-interfering as well as non-interferable. Each signal is like an individual of unmistakable identity and there is virtually no limit to the number of stations or instruments which can be simultaneously operated without the slightest mutual disturbance.

"5. *The terrestial Stationary Waves."* This wonderful discovery, popularly explained, means that the Earth is responsive to electrical vibrations of definite pitch just as a tuning fork to certain waves of sound. These particular electrical vibrations, capable of powerfully exciting the Globe, lend themselves to innumerable uses of great importance commercially and in many other respects.

"The first 'World-System' power plant can be put in operation in nine months. With this power plant it will be practicable to attain electrical activities up to ten million horsepower and it is designed to serve for as many technical achievements as are possible without due expense. Among these the following may be mentioned:

"(1) The inter-connection of the existing telegraph exchanges or offices all over the world;

"(2) The establishment of a secret and non-interferable government telegraph service;

"(3) The inter-connection of all the present telephone exchanges or offices on the Globe;

"(4) The universal distribution of general news, by telegraph or telephone, in connection with the Press;

"(5) The establishment of such a 'World-System' of intelligence transmission for exclusive private use;

"(6) The inter-connection and operation of all stock tickers of the world;

"(7) The establishment of a 'World-System' of musical distribution, etc.;
"(8) The universal registration of time by cheap clocks indicating the hour with astronomical precision and requiring no attention whatever;
"(9) The world transmission of typed or hand-written characters, letters, checks, etc.;
"(10) The establishment of a universal marine service enabling the navigators of all ships to steer perfectly without compass, to determine the exact location, hour and speed, to prevent collisions and disasters, etc.;
"(11) The inauguration of a system of world-printing on land and sea;
"(12) The world reproduction of photographic pictures and all kinds of drawings or records."

I also proposed to make demonstrations in the wireless transmission of power on a small scale but sufficient to carry conviction. Besides these I referred to other and incomparably more important applications of my discoveries which will be disclosed at some future date.

A plant was built on Long Island with a tower 187 feet high, having a spherical terminal about 68 feet in diameter. These dimensions were adequate for the transmission of virtually any amount of energy. Originally only from 200 to 300 K.W. were provided but I intended to employ later several thousand horsepower. The transmitter was to emit a wave-complex of special characteristics and I had devised a unique method of telephonic control of any amount of energy.

The tower was destroyed two years ago but my projects are being developed and another one, improved in some features, will be constructed. On this occasion I would contradict the widely circulated report that the structure was demolished by the Government which owing to war conditions, might have created prejudice in the minds of those who may not know that the papers, which thirty years ago conferred upon me the honor of American citizenship, are always kept in a safe, while my orders, diplomas, degrees, gold medals and other distinctions are packed away in old trunks. If this report had a foundation I would have been refunded a large sum of money which I expended in the construction of the tower. On the contrary it was in the interest of the Government to preserve it, particularly as it would have made possible—to mention just one valuable result—the location of a submarine in any part of the world. My plant, services, and all my improvements have always been at the disposal of the officials and ever since the outbreak of the European conflict I have been working at a sacrifice on several inventions of mine relating to aerial navigation, ship propulsion and wireless transmission which are of the greatest importance to the country. Those who are well informed know that my ideas have revolutionized the industries of the United States and I am not aware that there lives an inventor who has been, in this respect, as fortunate as myself especially as regards the use of his improvements in the war. I have refrained from publicly expressing myself on this subject before as it seemed improper to dwell on personal matters while all the world was in dire trouble. I would add further, in view of various rumors which have reached me, that Mr. J. Pierpont Morgan did not interest himself with me in a business way but in the same large spirit in which he has assisted many other pioneers. He carried out his generous promise to the letter and it would have been most unreasonable to expect from him anything more. He had the highest regard for my attainments and gave me every evidence of his complete faith in my ability to ultimately achieve what I had set out to do. I am unwilling to accord to some small-minded and jealous individuals the satisfaction of having thwarted my efforts. These men are to me nothing more than microbes of a nasty disease. My project was retarded by laws of nature. The world was not prepared for it. It was too far ahead of time. But the same laws will prevail in the end and make it a triumphal success.

My Inventions

By Nikola Tesla

VI. THE ART OF TELAUTOMATICS

How Tesla's Mind Recuperates.

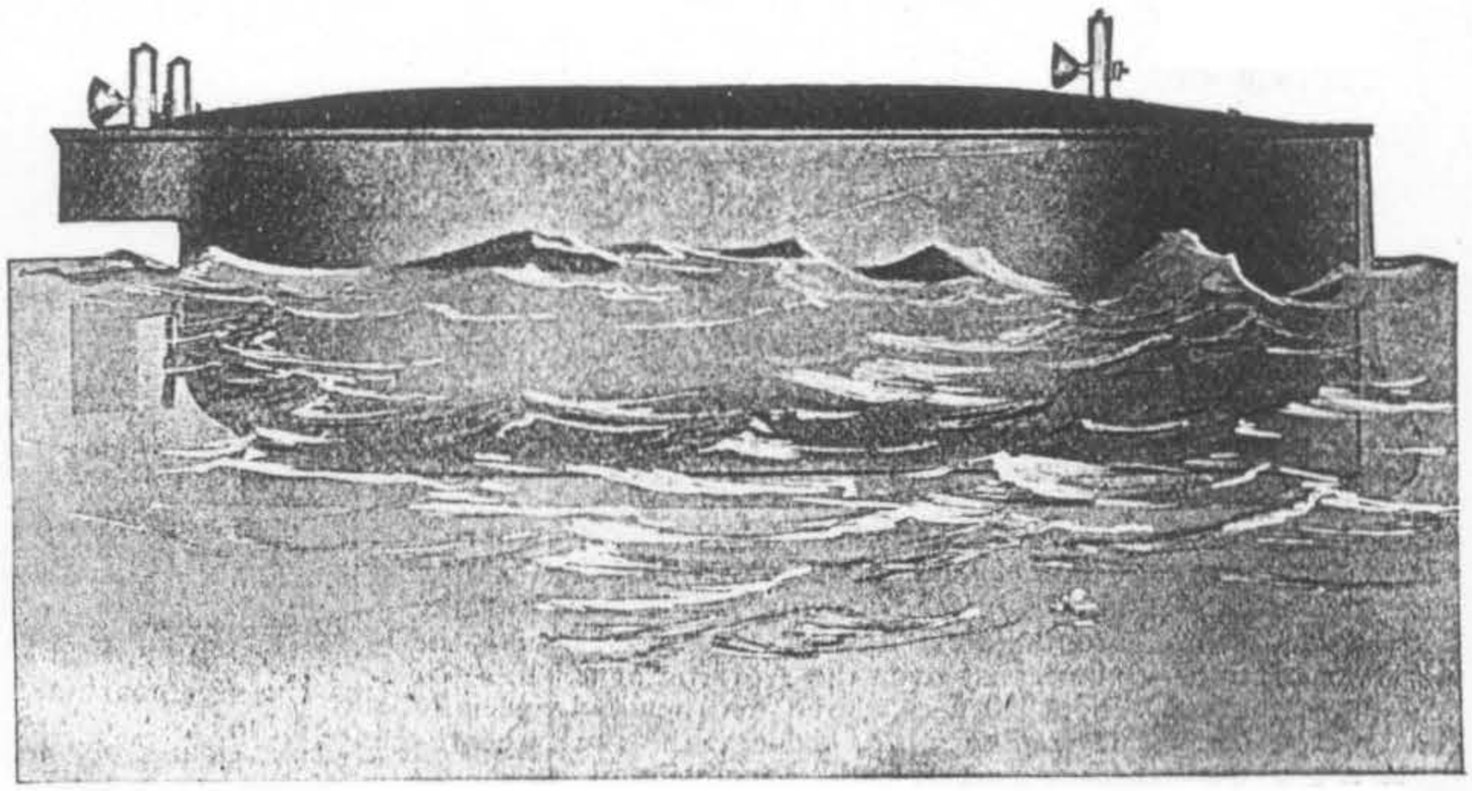
NO subject to which I have ever devoted myself has called for such concentration of mind and strained to so dangerous a degree the finest fibers of my brain as the system of which the Magnifying Transmitter is the foundation. I put all the intensity and vigor of youth in the development of the rotating field discoveries, but those early labors were of a different character. Although strenuous in the extreme, they did not involve that keen and exhausting discernment which had to be exercised in attacking the many puzzling problems of the wireless. Despite my rare physical endurance at that period the abused nerves finally rebelled and I suffered a complete collapse, just as the consummation of the long and difficult task was almost in sight. Without doubt I would have paid a greater penalty later, and very likely my career would have been prematurely terminated, had not providence equipt me with a safety device, which has seemed to improve with advancing years and unfailingly comes into play when my forces are at an end. So long as it operates I am safe from danger, due to overwork, which threatens other inventors and, incidentally, I need no vacations which are indispensable to most people. When I am all but used up I simply do as the darkies, who "naturally fall asleep while white folks worry." To venture a theory out of my sphere—the body probably accumulates little by little a definite quantity of some toxic agent and I sink into a nearly lethargic state which lasts half an hour to the minute. Upon awakening I have the sensation as though the events immediately preceding had occurred very long ago, and if I attempt to continue the interrupted train of thought I feel a veritable mental nausea. Involuntarily I then turn to other work and am surprised at the freshness of the mind and ease with which I overcome obstacles that had baffled me before. After weeks or months my passion for the temporarily abandoned invention returns and I invariably find answers to all the vexing questions with scarcely any effort. In this connection I will tell of an extraordinary experience which may be of interest to students of psychology. I had produced a striking phenomenon with my grounded transmitter and was endeavoring to ascertain its true significance in relation to the currents propagated through the earth. It seemed a hopeless undertaking, and for more than a year I worked unremittingly, but in vain. This profound study so entirely absorbed me that I became forgetful of everything else, even of my undermined health. At last, as I was at the point of breaking down, nature applied the preservative inducing lethal sleep. Regaining my senses, I realized with consternation that I was unable to visualize scenes from my life except those of infancy, the very first ones that had entered my consciousness. Curiously enough, these appeared before my vision with startling distinctness and afforded me welcome relief. Night after night, when retiring, I would think of them and more and more of my previous existence was revealed. The image of my mother was always the principal figure in the spectacle that slowly unfolded, and a consuming desire to see her again gradually took possession of me. This feeling grew so strong that I resolved to drop all work and satisfy my longing. But I found it too hard to break away from the laboratory, and several months elapsed during which I had succeeded in reviving all the impressions of my past life up to the spring of 1892. In the next picture that came out of the mist of oblivion, I saw myself at the *Hotel de la Paix* in Paris just coming to from one of my peculiar sleeping spells, which had been caused by prolonged exertion of the brain. Imagine the pain and distress I felt when it flashed upon my mind that a dispatch was handed to me at that very moment bearing the sad news that my mother was dying; I remembered how I made the long journey home without an hour of rest and how she passed away after weeks of agony! It was especially remarkable that during all this period of partially obliterated memory I was fully

IN this article, Dr. Tesla dwells on the future possibilities of his magnifying transmitter, especially in connection with the art of Telautomatics, which was first conceived by him and doubtless constitutes one of his most brilliant gifts to the world.

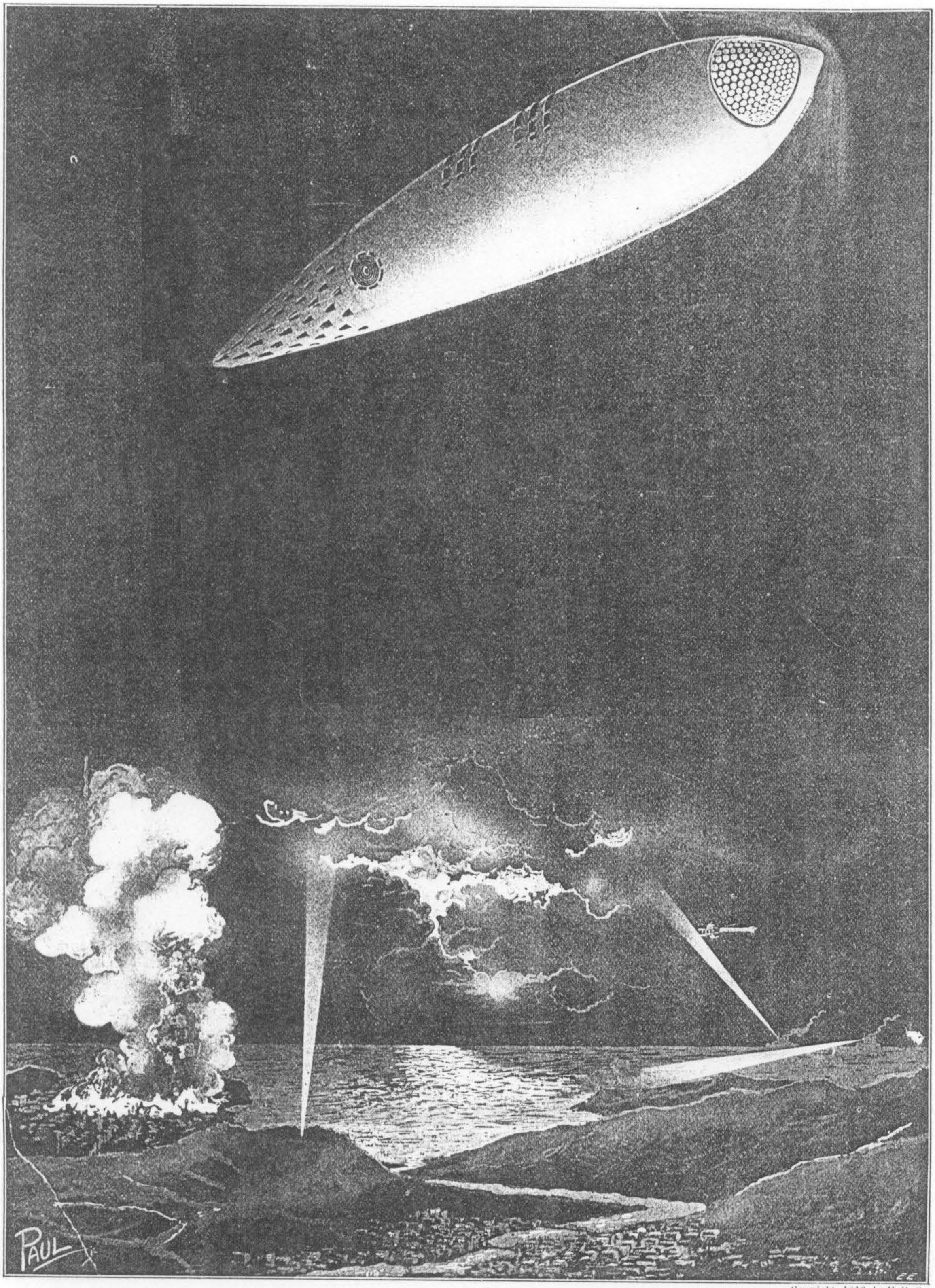
Tesla was the first to build and successfully operate Automata in the form of boats steered and otherwise controlled by tuned wireless circuits and agents ensuring reliable action despite of all attempts to interfere.

But this was only the first step in the evolution of his invention. What he wanted, was to produce machines capable of acting as though possessed of intelligence. It will be readily perceived that if Dr. Tesla has practically realized his conception, the world will witness a revolution in every field of endeavor. In particular will his inventions affect the art of warfare and the peace of the world.

Dr. Tesla dwells eloquently on a number of topics agitating the public mind, and this article of his is perhaps the most brilliant and absorbing he has written.



One of the Telautomatic Boats (Submersible) Constructed By Tesla and Exhibited By Him In 1898. Controlled By Wireless Without Aerials.



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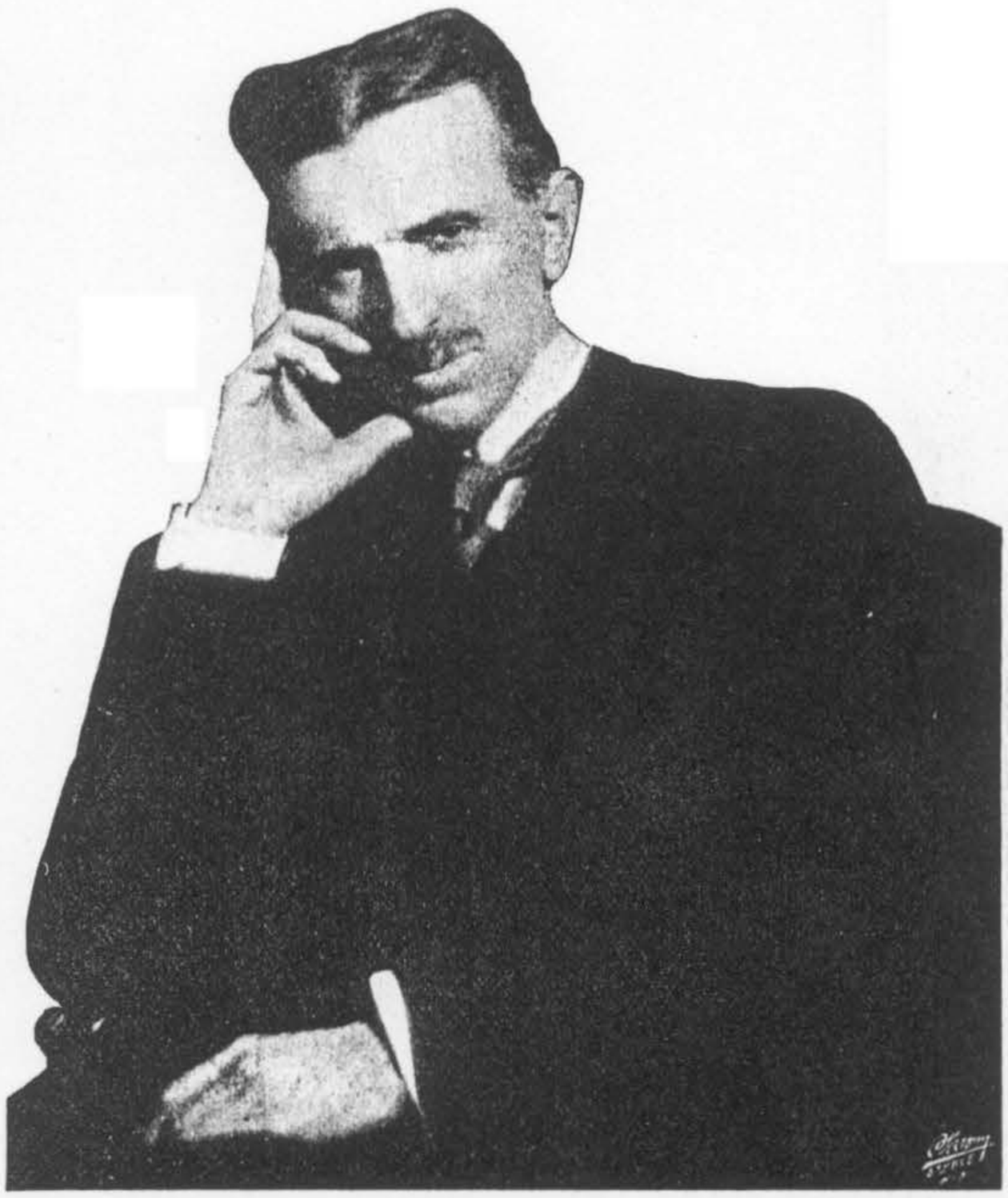
Tesla's New Self-Propelled Aerial Tel-Automaton. Devoid of Propeller, Sustaining Wings and All Other Means of External Control. Can Attain a Speed of 350 Miles Per Hour, and Will Reach a Predetermined Point a Thousand Miles Away Accurately Within a Few Feet.

alive to everything touching on the subject of my research. I could recall the smallest details and the least insignificant observations in my experiments and even recite pages of text and complex mathematical formulae.

My belief is firm in a law of compensation. The true rewards are ever in proportion to the labor and sacrifices made. This is one of the reasons why I feel certain that of all my inventions, the Magnifying Transmitter will prove most important and valuable to future generations. I am prompted to this prediction not so much by thoughts of the commercial and industrial revolution which it will surely bring about, but of the humanitarian consequences of the many achievements it makes possible. Considerations of mere utility weigh little in the balance against the higher benefits of civilization. We are confronted with portentous problems which can not be solved just by providing for our material existence, however abundantly. On the contrary, progress in this direction is fraught with hazards and perils not less menacing than those born from want and suffering. If we were to release the energy of atoms or discover some other way of developing cheap and unlimited power at any point of the globe this accomplishment, instead of being a blessing, might bring disaster to mankind in giving rise to dissension and anarchy which would ultimately result in the enthronement of the hated regime of force. The greatest good will come from technical improvements tending to unification and harmony, and my wireless transmitter is preeminently such. By its means the human voice and likeness will be reproduced everywhere and factories driven thousands of miles from waterfalls furnishing the power; aerial machines will be propelled around the earth without a stop and the sun's energy controlled to create lakes and rivers for motive purposes and transformation of arid deserts into fertile land. Its introduction for telegraphic, telephonic and similar uses will automatically cut out the statics and all other interferences which at present impose narrow limits to the application of the wireless. This is a timely topic on which a few words might not be amiss.



Dr. Tesla is Rapidly Becoming Younger. Judge for Yourself from His Latest Photograph.

Tesla Raps "Static" Men Vigorously.

During the past decade a number of people have arrogantly claimed that they had succeeded in doing away with this impediment. I have carefully examined all of the arrangements described and tested most of them long before they were publicly disclosed, but the finding was uniformly negative. A recent official statement from the U. S. Navy may, perhaps, have taught some beguilable news editors how to appraise these announcements at their real worth. As a rule the attempts are based on theories so fallacious that whenever they come to my notice I can not help thinking in a lighter vein. Quite recently a new discovery was heralded, with a deafening flourish of trumpets, but it proved another case of a mountain bringing forth a mouse. This reminds me of an exciting incident which took place years ago when I was conducting my experiments with currents of high frequency. Steve Brodie had just jumped off the Brooklyn Bridge. The feat has been vulgarized since by imitators, but the first report electrified New York. I was very impressionable then and frequently spoke of the daring printer. On a hot afternoon I felt the necessity of refreshing myself and stepped into one of the popular thirty thousand institutions of this great city where a delicious twelve per cent beverage was served which can now be had only by making a trip to the poor and devastated countries of Europe. The attendance was large and not over-distinguished and a matter was discussed which gave me an admirable opening for the careless remark: "This is what I said when I jumped off the bridge." No sooner had I uttered these words than I felt like the companion of Timotheus in the poem of Schiller. In an instant there was a pandemonium and a dozen voices cried: "It is Brodie!" I threw a quarter on the counter and bolted for the door but the crowd was at my heels with yells: "Stop, Steve!" which must have been misunderstood for many persons tried to hold me up as I ran frantically for my haven of refuge. By darting around corners I fortunately managed—through the medium of a fire-escape—to reach the laboratory, where I threw off my coat, camouflaged myself as a hard-working blacksmith, and started the forge. But these precautions proved unnecessary; I had eluded my pursuers. For many years afterward, at night, when imagination turns into spectres the trifling troubles of the day, I often thought, as I tossed on the bed, what my fate would have been had that mob caught me and found out that I was not Steve Brodie!

Now the engineer, who lately gave an account before a technical body of a novel remedy against statics based on a "heretofore unknown law of nature," seems to have been as reckless as myself when he contended that these disturbances propagate up and down, while those of a transmitter proceed along the earth. It would mean that a condenser, as this globe, with its gaseous envelope, could be charged and discharged in a manner quite contrary to the fundamental teachings propounded in every elemental text-book of physics. Such a supposition would have been condemned as erroneous, even in Franklin's time, for the facts bearing on this were then well known and the identity between atmospheric electricity and that developed by machines was fully established. Obviously, natural and artificial disturbances propagate through the earth and the air in exactly the same way, and both set up electro-motive forces in the horizontal, as well as vertical, sense. Interference can not be overcome by any such methods as were proposed. The truth is this: In the air the potential increases at the rate of about fifty volts per foot of elevation, owing to which there may be a difference of pressure amounting to twenty, or even forty thousand volts between the upper and lower ends of the antenna. The masses of the charged atmosphere are constantly in motion and give up electricity to the conductor, not continuously but rather disruptively, this producing a grinding noise in a sensitive telephonic

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receiver. The higher the terminal and the greater the space encompast by the wires, the more pronounced is the effect, but it must be understood that it is purely local and has little to do with the real trouble. In 1900, while perfecting my wireless system, one form of apparatus comprised four antennae. These were carefully calibrated to the same frequency and connected in multiple with the object of magnifying the action, in receiving from any direction. When I desired to ascertain the origin of the transmitted impulses, each diagonally situated pair was put in series with a primary coil energizing the detector circuit. In the former case the sound was loud in the telephone; in the latter it ceased, as expected, the two antennae neutralizing each other, but the true statics manifested themselves in both instances and I had to devise special preventives embodying different principles.

The Remedy for Static.

By employing receivers connected to two points of the ground, as suggested by me long ago, this trouble caused by the charged air, which is very serious in the structures as now built, is nullified and besides, the liability of all kinds of interference is reduced to about one-half, because of the directional character of the circuit. This was perfectly self-evident, but came as a revelation to some simple-minded wireless folks whose experience was confined to forms of apparatus that could have been improved with an axe, and they have been disposing of the bear's skin before killing him. If it were true that strays performed such antics, it would be easy to get rid of them by receiving without aerials. But, as a matter of fact, a wire buried in the ground which, conforming to this view, should be absolutely immune, is more susceptible to certain extraneous impulses than one placed vertically in the air. To state it fairly, a slight progress has been made, but not by virtue of any particular

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method or device. It was achieved simply by discarding the enormous structures, which are bad enough for transmission but wholly unsuitable for reception, and adopting a more appropriate type of receiver. As I pointed out in a previous article, to dispose of this difficulty for good, a radical change must be made in the system, and the sooner this is done the better.

Radio Government Control Not Wanted.

It would be calamitous, indeed, if at this time when the art is in its infancy and the vast majority, not excepting even experts, have no conception of its ultimate possibilities, a measure would be rushed through the legislature making it a government monopoly. This was proposed a few weeks ago by Secretary Daniels, and no doubt that distinguished official has made his appeal to the Senate and House of Representatives with sincere conviction. But universal evidence unmistakably shows that the best results are always obtained in healthful commercial competition. There are, however, exceptional reasons why wireless should be given the fullest freedom of development. In the first place it offers prospects immeasurably greater and more vital to betterment of human life than any other invention or discovery in the history of man. Then again, it must be understood that this wonderful art has been, in its entirety, evolved here and can be called "American" with more right and propriety than the telephone, the incandescent lamp or the aeroplane. Enterprising press agents and stock jobbers have been so successful in spreading misinformation that even so excellent a periodical as the *Scientific American* accords the chief credit to a foreign country. The Germans, of course, gave us the Hertz-waves and the Russian, English, French and Italian experts were quick in using them for signaling purposes. It was an obvious application of the new agent and accomplished with the old classical and unimproved induction coil—scarcely anything more than another kind of heliography. The radius of transmission was very limited, the results attained of little value, and the Hertz oscillations, as a means for conveying intelligence, could have been advantageously replaced by sound-waves, which I advocated in 1891. Moreover, all of these attempts were made three years after the basic principles of the wireless system, which is universally employed to-day, and its potent instrumentalities had been clearly described and developed in America. No trace of those Hertzian appliances and methods remains today. We have proceeded in the very opposite direction and what has been done is the product of the brains and efforts of citizens of this country. The fundamental patents have expired and the opportunities are open to all. The chief argument of the Secretary is based on interference. According to his statement, reported in the New York *Herald* of July 29th, signals from a powerful station can be intercepted in every village of the world. In view of this fact, which was demonstrated in my experiments of 1900, it would be of little use to impose restrictions in the United States.

America First.

As throwing light on this point, I may mention that only recently an odd looking gentleman called on me with the object of enlisting my services in the construction of world transmitters in some distant land. "We have no money," he said, "but carloads of solid gold and we will give you a liberal amount." I told him that I wanted to see first what will be done with my inventions in America, and this ended the interview. But I am satisfied that some dark forces are at work, and as time goes on the maintenance of continuous communication will be rendered more difficult. The only remedy is a system immune against interruption. It has been perfected, it exists, and all that is necessary is to put it in operation.

The terrible conflict is still uppermost in the minds and perhaps the greatest importance will be attached to the Magnifying Transmitter as a machine for attack and defense, more particularly in connection with *Telautomatics*. This invention is a logical outcome of observations begun in my boyhood and continued thruout my life. When the first results were publisht the *Electrical Review* stated editorially that it would become one of the "most potent factors in the advance and civilization of mankind." The time is not distant when this prediction will be fulfilled. In 1898 and 1900 it was offered to the Government and might have been adopted were I one of those who would go to Alexander's shepherd when they want a favor from Alexander. At that time I really thought that it would abolish war, because of its unlimited destructiveness and exclusion of the personal element of combat. But while I have not lost faith in its potentialities, my views have changed since.

The Road to Permanent Peace.

War can not be avoided until the physical cause for its recurrence is removed and this, in the last analysis, is the vast extent of the planet on which we live. Only thru annihilation of distance in every respect as, the conveyance of intelligence, transport of passengers and supplies and transmission of energy will conditions be brought about some day, insuring permanency of friendly relations. What we now want most is closer contact and better understanding between individuals and communities all over the earth, and the elimination of that fanatic devotion to exalted ideals of national egoism and pride which is always prone to plunge the world into primeval barbarism and strife. No league or parliamentary act of any kind will ever prevent such a calamity. These are only new devices for putting the weak at the mercy of the strong. I have exprest myself in this regard fourteen years ago, when a combination of a few leading governments—a sort of Holy Alliance—was advocated by the late Andrew Carnegie, who may be fairly considered as the father of this idea, having given to it more publicity and impetus than anybody else prior to the efforts of the President. While it can not be denied that such a pact might be of material advantage to some less fortunate peoples, it can not attain the chief object sought. Peace can only come as a natural consequence of universal enlightenment and merging of races, and we are still far from this blissful realization. As I view the world of today, in the light of the gigantic struggle we have witnest, I am filled with conviction that the interests of humanity would be best served if the United States remained true to its traditions and kept out of "entangling alliances." Situated as it is, geographically, remote from the theaters of impending conflicts, without incentive to territorial aggrandizement, with inexhaustible resources and immense population thoroly imbued with the spirit of liberty and right, this country is placed in a unique and privileged position. It is thus able to exert, independently, its colossal strength and moral force to the benefit of all, more judiciously and effectively, than as member of a league.

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The Mechanistic Theory of Life.

In one of these biographical sketches, published in the ELECTRICAL EXPERIMENTER, I have dwelt on the circumstances of my early life and told of an affliction which compelled me to unremitting exercise of imagination and self-observation. This mental activity, at first involuntary under the pressure of illness and suffering, gradually became second nature and led me finally to recognize that I was but an automaton devoid of free will in thought and action and merely responsive to the forces of the environment. Our bodies are of such complexity of structure, the motions we perform are so numerous and involved, and the external impressions on our sense organs to such a degree delicate and elusive that it is hard for the average person to grasp this fact. And yet nothing is more convincing to the trained investigator than the mechanistic theory of life which had been, in a measure, understood and propounded by Descartes three hundred years ago. But in his time many important functions of our organism were unknown and, especially with respect to the nature of light and the construction and operation of the eye, philosophers were in the dark. In recent years the progress of scientific research in these fields has been such as to leave no room for a doubt in regard to this view on which many works have been published. One of its ablest and most eloquent exponents is, perhaps, Felix Le Dantec, formerly assistant of Pasteur. Prof. Jacques Loeb has performed remarkable experiments in heliotropism, clearly establishing the controlling power of light in lower forms of organisms, and his latest book, "Forced Movements," is revelatory. But while men of science accept this theory simply as any other that is recognized, to me it is a truth which I hourly demonstrate by every act and thought of mine. The consciousness of the external impression prompting me to any kind of exertion, physical or mental, is ever present in my mind. Only on very rare occasions, when I was in a state of exceptional concentration, have I found difficulty in locating the original impulses.

Lack of Observation a Form of Ignorance.

The by far greater number of human beings are never aware of what is passing around and within them, and millions fall victims of disease and die prematurely just on this account. The commonest, every-day occurrences appear to them mysterious and inexplicable. One may feel a sudden wave of sadness and rake his brain for an explanation when he might have noticed that it was caused by a cloud cutting off the rays of the sun. He may see the image of a friend dear to him under conditions which he construes as very peculiar, when only shortly before he has passed him in the street or seen his photograph somewhere. When he loses a collar button he fusses and swears for an hour, being unable to visualize his previous actions and locate the object directly. Deficient observation is merely a form of ignorance and responsible for the many morbid notions and foolish ideas prevailing. There is not more than one out of every ten persons who does not believe in telepathy and other psychic manifestations, spiritualism and communion with the dead, and who would refuse to listen to willing or unwilling deceivers. Just to illustrate how deeply rooted this tendency has become even among the clear-headed American population, I may mention a comical incident.

Psychic Phenomena in the Manufacture of Flivvers.

Shortly before the war, when the exhibition of my turbines in this city elicited widespread comment in the technical papers, I anticipated that there would be a scramble among manufacturers to get hold of the invention, and I had particular designs on that man from Detroit who has an uncanny faculty for accumulating millions. So confident was I that he would turn up some day, that I declared this as certain to my secretary and assistants. Sure enough, one fine morning a body of engineers from the Ford Motor Company presented themselves with the request of discussing with me an important project. "Didn't I tell you?" I remarked triumphantly to my employees, and one of them said, "You are amazing, Mr. Tesla; everything comes out exactly as you predict." As soon as these hard-headed men were seated I, of course, immediately began to extol the wonderful features of my turbine, when the spokesmen interrupted me and said, "We know all about this, but we are on a special errand. We have formed a psychological society for the investigation of psychic phenomena and we want you to join us in this undertaking." I suppose those engineers never knew how near they came to being fired out of my office.

Confuting Spiritism.

Ever since I was told by some of the greatest men of the time, leaders in science whose names are immortal, that I am possesst of an unusual mind, I bent all my thinking faculties on the solution of great problems regardless of sacrifice. For many years I endeavored to solve the enigma of death, and watched eagerly for every kind of spiritual indication. But only once in the course of my existence have I had an experience which momentarily impressed me as supernatural. It was at the time of my mother's death. I had become completely exhausted by pain and long vigilance, and one night was carried to a building about two blocks from our home. As I lay helpless there, I thought that if my mother died while I was away from her bedside she would surely give me a sign. Two or three months before I was in London in company with my late friend, Sir William Crookes, when spiritualism was discussed, and I was under the full sway of these thoughts. I might not have paid attention to other men, but was susceptible to his arguments as it was his epochal work on radiant matter, which I had read as a student, that made me embrace the electrical career. I reflected that the conditions for a look into the beyond were most favorable, for my mother was a woman of genius and particularly excelling in the powers of intuition. During the whole night every fiber in my brain was strained in expectancy, but nothing happened until early in the morning, when I fell in a sleep, or perhaps a swoon, and saw a cloud carrying angelic figures of marvelous beauty, one of whom gazed upon me lovingly and gradually assumed the features of my mother. The appearance slowly floated across the room and vanished, and I was awakened by an indescribably sweet song of many voices. In that instant a certitude, which no words can express, came upon me that my mother had just died. And that was true. I was unable to understand the tremendous weight of the painful knowledge I received in advance, and wrote a letter to Sir William Crookes while still under the domination of these impressions and in poor bodily health. When I recovered I sought for a long time the ex-

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ternal cause of this strange manifestation and, to my great relief, I succeeded after many months of fruitless effort. I had seen the painting of a celebrated artist, representing allegorically one of the seasons in the form of a cloud with a group of angels which seemed to actually float in the air, and this had struck me forcefully. It was exactly the same that appeared in my dream, with the exception of my mother's likeness. The music came from the choir in the church nearby at the early mass of Easter morning, explaining everything satisfactorily in conformity with scientific facts.

This occurred long ago, and I have never had the faintest reason since to change my views on psychical and spiritual phenomena, for which there is absolutely no foundation. The belief in these is the natural outgrowth of intellectual development. Religious dogmas are no longer accepted in their orthodox meaning, but every individual clings to faith in a supreme power of some kind. We all must have an ideal to govern our conduct and insure contentment, but it is immaterial whether it be one of creed, art, science or anything else, so long as it fulfills the function of a dematerializing force. It is essential to the peaceful existence of humanity as a whole that one common conception should prevail.

Tesla's Astounding Discovery.

While I have failed to obtain any evidence in support of the contentions of psychologists and spiritualists, I have proved to my complete satisfaction the automatism of life, not only through continuous observations of individual actions, but even more conclusively through certain generalizations. These amount to a discovery which I consider of the greatest moment to human society, and on which I shall briefly dwell. I got the first inkling of this astounding truth when I was still a very young man, but for many years I interpreted what I noted simply as coincidences. Namely, whenever either myself or a person to whom I was attached, or a cause to which I was devoted, was hurt by others in a particular way, which might be best popularly characterized as the most unfair imaginable, I experienced a singular and undefinable pain which, for want of a better term, I have qualified as "cosmic," and shortly thereafter, and invariably, those who had inflicted it came to grief. After many such cases I confided this to a number of friends, who had the opportunity to convince themselves of the truth of the theory which I have gradually formulated and which may be stated in the following few words:

Our bodies are of similar construction and exposed to the same external influences. This results in likeness of response and concordance of the general activities on which all our social and other rules and laws are based. We are automata entirely controlled by the forces of the medium, being tossed about like corks on the surface of the water, but mistaking the resultant of the impulses from the outside for free will. The movements and other actions we perform are always life preservative and tho seemingly quite independent from one another, we are connected by invisible links. So long as the organism is in perfect order it responds accurately to the agents that prompt it, but the moment that there is some derangement in any individual, his self-preservative power is impaired. Everybody understands, of course, that if one becomes deaf, has his eyesight weakened, or his limbs injured, the chances for his continued existence are lessened. But

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By Nikola Tesla

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this is also true, and perhaps more so, of certain defects in the brain which deprive the automaton, more or less, of that vital quality and cause it to rush into destruction. A very sensitive and observant being, with his highly developed mechanism all intact, and acting with precision in obedience to the changing conditions of the environment, is endowed with a transcending mechanical sense, enabling him to evade perils too subtle to be directly perceived. When he comes in contact with others whose controlling organs are radically faulty, that sense asserts itself and he feels the "cosmic" pain. The truth of this has been borne out in hundreds of instances and I am inviting other students of nature to devote attention to this subject, believing that thru combined and systematic effort results of incalculable value to the world will be attained.

Dr. Tesla's First Automaton.

The idea of constructing an automaton, to bear out my theory, presented itself to me early but I did not begin active work until 1893, when I started my wireless investigations. During the succeeding two or three years a number of automatic mechanisms, to be actuated from a distance, were constructed by me and exhibited to visitors in my laboratory. In 1896, however, I designed a complete machine capable of a multitude of operations, but the consummation of my labors was delayed until late in 1897. This machine was illustrated and described in my article in the Century Magazine of June, 1900, and other periodicals of that time and, when first shown in the beginning of 1898, it created a sensation such as no other invention of mine has ever produced. In November, 1898, a basic patent on the novel art was granted to me, but only after the Examiner-in-Chief had come to New York and witnesst the performance, for what I claimed seemed unbelievable. I remember that when later I called on an official in Washington, with a view of offering the invention to the Government, he burst out in laughter upon my telling him what I had accomplished. Nobody thought then that there was the faintest prospect of perfecting such a device. It is unfortunate that in this patent, following the advice of my attorneys, I indicated the control as being effected thru the medium of a single circuit and a well-known form of detector, for the reason that I had not yet secured protection on my methods and apparatus for individualization. As a matter of fact, my boats were controlled thru the joint action of several circuits and interference of every kind was excluded. Most generally I employed receiving circuits in the form of loops, including condensers, because the discharges of my high-tension transmitter ionized the air in the hall so that even a very small aerial would draw electricity from the surrounding atmosphere for hours. Just to give an idea, I found, for instance, that a bulb 12″ in diameter, highly exhausted, and with one single terminal to which a short wire was attached, would deliver well on to one thousand successive flashes before all charge of the air in the laboratory was neutralized. The loop form of receiver was not sensitive to such a disturbance and it is curious to note that it is becoming popular at this late date. In reality it collects much less energy than the aerials or a long grounded wire, but it so happens that it does away with a number of defects inherent to the present wireless devices. In demonstrating my invention before audiences, the visitors were requested to ask any questions, however involved, and the automaton

would answer them by signs. This was considered magic at that time but was extremely simple, for it was myself who gave the replies by means of the device.

At the same period another larger tetautomatic boat was constructed, a photograph of which is shown in this number of the ELECTRICAL EXPERIMENTER. It was controlled by loops, having several turns placed in the hull, which was made entirely water-tight and capable of submergence. The apparatus was similar to that used in the first with the exception of certain special features I introduced as, for example, incandescent lamps which afforded a visible evidence of the proper functioning of the machine.

Telautomatics of the Future.

These automata, controlled within the range of vision of the operator, were, however, the first and rather crude steps in the evolution of the Art of Telautomatics as I had conceived it. The next logical improvement was its application to automatic mechanisms beyond the limits of vision and at great distance from the center of control, and I have ever since advocated their employment as instruments of warfare in preference to guns. The importance of this now seems to be recognized, if I am to judge from casual announcements thru the press of achievements which are said to be extraordinary but contain no merit of novelty, whatever. In an imperfect manner it is practicable, with the existing wireless plants, to launch an aeroplane, have it follow a certain approximate course, and perform some operation at a distance of many hundreds of miles. A machine of this kind can also be mechanically controlled in several ways and I have no doubt that it may prove of some usefulness in war. But there are, to my best knowledge, no instrumentalities in existence today with which such an object could be accomplished in a precise manner. I have devoted years of study to this matter and have evolved means, making such and greater wonders easily realizable. As stated on a previous occasion, when I was a student at college I conceived a flying machine quite unlike the present ones. The underlying principle was sound but could not be carried into practice for want of a prime-mover of sufficiently great activity. In recent years I have successfully solved this problem and am now planning aerial machines devoid of sustaining planes, ailerons, propellers and other external attachments, which will be capable of immense speeds and are very likely to furnish powerful arguments for peace in the near future. Such a machine, sustained and propelled entirely by reaction, is shown on one of the pages and is supposed to be controlled either mechanically or by wireless energy. By instailing proper plants it will be practicable to project a missile of this kind into the air and drop it almost on the very spot designated, which may be thousands of miles away. But we are not going to stop at this. Telautomata will be ultimately produced, capable of acting as if possesst of their own intelligence, and their advent will create a revolution. As early as 1898 I proposed to representatives of a large manufacturing concern the construction and public exhibition of an automobile carriage which, left to itself, would perform a great variety of operations involving something akin to judgment. But my proposal was deemed chimerical at that time and nothing came from it.

At present many of the ablest minds are trying to devise expedients for preventing a repetition of the awful conflict which is only theoretically ended and the duration and main issues of which I have correctly predicted in an article printed in the *Sun* of December 20, 1914. The proposed League is not a remedy but, on the con-

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My Inventions

By Nikola Tesla

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trary, in the opinion of a number of competent men, may bring about results just the opposite. It is particularly regrettable that a punitive policy was adopted in framing the terms of peace, because a few years hence it will be possible for nations to fight without armies, ships or guns, by weapons far more terrible, to the destructive action and range of which there is virtually no limit. Any city, at a distance, whatsoever, from the enemy, can be destroyed by him and no power on earth can stop him from doing so. If we want to avert an impending calamity and a state of things which may transform this globe into an inferno, we should push the development of flying machines and wireless transmission of energy without an instant's delay and with all the power and resources of the nation.

The New York Tribune February 2, 1919

Correspondence

A Review reader comments on the article by Tesla printed on this page last week. . . . Says the scientist ought to give publicity to his definition of axial rotation.

SIR: I note the article by Tesla quoted from "The Electrical Experimenter" for February, in which he speaks of the illusion of the axial rotation of the moon.

Professor Young, of Princeton, in his "Elements of Astronomy," Section 154, says: "The moon rotates on its axis once a month. . . . It is difficult for some to see why a motion of this sort should be considered a rotation of the moon," etc.

The underlying difficulty is probably a difference of definition. It seems clear that if the earth were suddenly eliminated the moon would continue its journey on the elliptical course around the sun at the same speed as at present, and that a person on its surface would experience approximately thirteen solar nights and thirteen solar days in a year, as at present, and one extra sidereal day, for the same reason that while we have 365 solar days in our year we have an additional star day. The only effect of the absence of the earth would be to terminate the semi-wavy course of the moon, which is always concave to the sun, but more or less so at different parts of the month.

It is not surprising that the moon shows no flattening at the poles in view of the fact of its comparatively small size and its extremely slow revolution. Even the earth spinning twenty-eight times faster is not greatly flattened.

It would be rather difficult to persuade an inhabitant of the moon that the globe on which he stood did not revolve when in the course of the year he saw the stars and the sun travel across his zenith exactly the way he would do on the earth.

The moon may indeed obtain such axial motion as it has from the earth, but having long since obtained it, it would not be instantly dissipated by the withdrawal of its source.

I think Tesla ought to give publicity to his definition of axial rotation.

CHARLES E. MANIERRE.

The New York Times February 3, 1919

CELESTIAL MOVIES.

Mr. MARCONI's talk of wireless dispatches to the stars has set them off. Now comes NICOLA TESLA with a reminder that nearly twenty years ago he received "faint extraplanetary signals whose measured regularity was "such that they could not have been "accidental. I signaled back with my "powerful radio transmitter," he continues, "and I am certain that I produced disturbances on Mars." This seems an unkindly act; perhaps Mars, like Earth, has disturbances enough of its own without getting others inflicted on it from external space.

Mr. TESLA has small confidence in the Marconian idea of getting into communication by way of mathematics, because it would be hard to carry on conversation by figures; not so very hard, though, for it is done in most diplomatic and military codes. But he would prefer to send pictures by wireless; the human face, for example. This is tempting as a commercial enterprise; if Martian taste is presumed to resemble that on earth—and such a presumption underlies every proposal for communication—it may be supposed that the first faces wirelessed to Mars will be those of movie favorites. With this beginning whole feature films can be sent by radio across the solar system and released in Mars on the night that sees their première on Broadway.

But in all this there is the same fallacy that vitiates Mr. MARCONI's proposal to communicate by mathematics—the supposition that the laws of knowledge, or the canons of taste, are universal. Suppose you wireless your face to Mars, and then you receive the answer, delicate but firm, that Mars does not like your face and has no desire to see more of it. This would be a regrettable rebuff to scientific investigation, and one which we should do well to avoid. If civilization on Mars is as old as we are asked to believe, the Martians have no doubt acquired their own taste in faces.

The New York Tribune February 23, 1919

Correspondence

Tesla answers Mr. Manierre and further explains the axial rotation of the moon

SIR:

In your article of February 2 Mr. Charles E. Manierre, commenting upon my article in "The Electrical Experimenter" for February, which appeared in The Tribune of January 26, suggests that I give a definition of axial rotation.

I intended to be explicit on this point, as may be judged from the following quotation: "The unfailing test of the spinning of a mass is, however, the existence of energy of motion. The moon is not possessed of such vis viva." By this I meant that "axial rotation" is not simply 'rotation upon an axis" as nonchalantly defined in dictionaries, but is a circular motion in the true physical sense—that is, one in which half the product of the mass with the square of velocity is a definite and positive quantity.

The moon is a nearly spherical body, of a radius of about 1,081.5 miles, from which I calculate its volume to be approximately 5,300,216,300 cubic miles. Since its mean density is 3.27, one cubic foot of material composing it weighs close to 205 pounds. Accordingly, the total weight of the satellite is about 70,969,000,000,000,000,000 and its mass 2,483,500,000,000,000,000 terrestrial short tons. Assuming that the moon does physically rotate upon its axis, it performs one revolution in 27 days 7 hours 43 minutes and 11 seconds, or 2,360,591 seconds. If, in conformity with mathematical principles, we imagine the entire mass concentrated at a distance from the centre equal to two-fifths of the radius, then the calculated rotational velocity is 3.04 feet per second, at which the globe would contain 11,474,000,000,000,000,000 short foot tons of energy, sufficient to run 1,000,000,000 horsepower for a period of 1,323 years. Now, I say that there is not enough of that energy in the moon to run a delicate watch.

In astronomical treatises usually the argument is advanced that "if the lunar globe did not turn upon its axis it would expose all parts to terrestrial view. As only a little over one-half is visible it must rotate." But this inference is erroneous, for it only admits of one alternative. There are an infinite number of axes besides its own on each of which the moon might turn and still exhibit the same peculiarity.

I have stated in my article that the moon rotates about an axis, passing through the centre of the earth, which is not strictly true, but does not vitiate the conclusions I have drawn. It is well known, of course, that the two bodies revolve around a common centre of gravity which is at a distance of a little over 2,899 miles from the earth's centre.

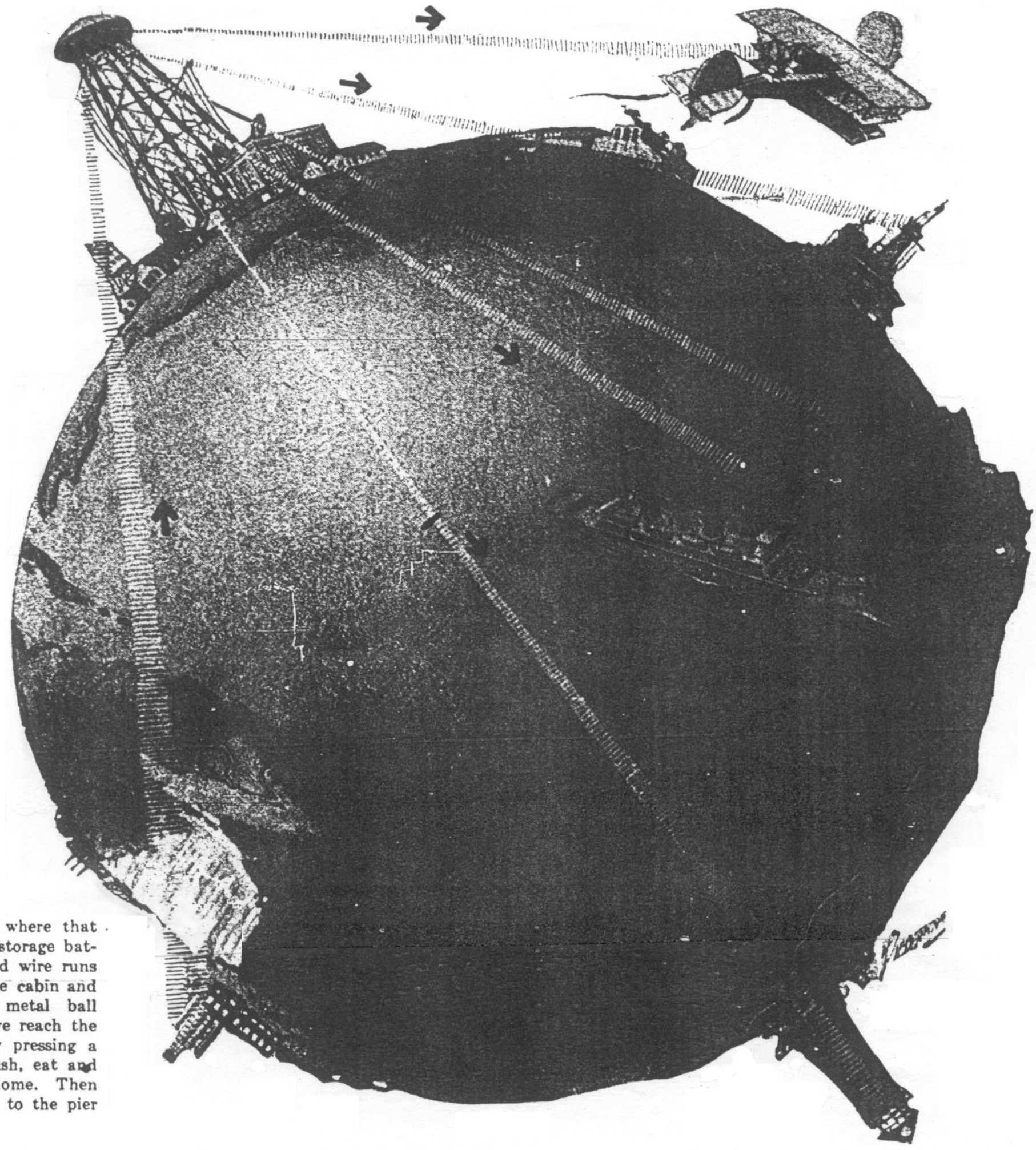
Another mistake in books on astronomy is made in considering this motion equivalent to that of a weight whirled on a string or in a sling. In the first place, there is an essential difference between these two devices though involving the same mechanical principle. If a metal ball attached to a string is whirled around and the latter breaks an axial rotation of the missile results which is definitely related in magnitude and direction to the motion preceding. By way of illustration: If the ball is whirled on the string clockwise, ten times a second, then when it flies off it will rotate on its axis twenty times a second, likewise in the direction of a clock. Quite different are the conditions when the ball is thrown from a sling. In this case a much more rapid rotation is imparted to it in the opposite sense. There is no true analogy to these in the motion of the moon. If the gravitational string, as it were, would snap, the satellite would go off in a tangent without the slightest swerving or rotation, for there is no momentum about the axis and, consequently, no tendency whatever to spinning motion.

Mr. Manierre is mistaken in his surmise as to what would happen if the earth were suddenly eliminated. Let us suppose that this would occur at the instant when the moon is in opposition. Then it would continue on its elliptical path around the sun, presenting to it steadily the face which was always exposed to the earth. If, on the other hand, the latter would disappear at the moment of conjunction, the moon would gradually swing around through 180 degrees and, after a number of oscillations, revolve again with the same face to the sun. In either case there would be no periodic changes, but eternal day and night, respectively, on the sides turned toward and away from the luminary.—NIKOLA TESLA.

TESLA'S LATEST MARVELS

Based on the Wireless Transmission of Electrical Energy Direct from Natural Sources Throughout the Entire Globe.

By Arthur Wynne.



The Earth as a Conductor of Electricity—Picture-diagram illustrating Tesla's project of transmitting through earth and air stupendous forces of natural energy, which, stored in power stations, can be applied direct to all motors and machinery, and for every purpose of heating and lighting.

THIS space has been reserved for a serious, scientific treatise on recent important developments and discoveries in the field of wireless transmission of electrical energy. But let us forget all about that for the time being and take a pleasure trip instead to the land of Make Believe. It will be far more entertaining; and besides, when the journey is ended, we may know more about the subject than if we travelled concatenated tuned circuits, or lost ourselves in a maze of kilowatts, statics and radiations, or ventured beyond our depth in Hertz waves.

It is summertime in the land of Make Believe, and we are off for a fishing trip in a big pleasure boat. There is plenty of room aboard for a party of twelve or more. There is a roomy cabin, noticeably free from the smell of gasoline and machinery oil. In fact, the only machinery aboard is an electric motor coupled to the driving shaft of the propeller. We are making ten knots an hour and we are out for a good time, so why worry ourselves with questions as to where that motor gets its energy? There are no storage batteries on the boat. One insulated feed wire runs from the motor to the ceiling of the cabin and from there up the mast to a bright metal ball at the top. It stops there. When we reach the fishing ground we stop the motor by pressing a button. We anchor, or drift, catch fish, eat and enjoy ourselves until it is time to go home. Then our well-behaved craft carries us back to the pier without mishap.

NEXT day we go up in a Make Believe airplane. It looks much like an ordinary airplane, but the wing spread is less. The reason for this, we are told, is because the airplane is much lighter than an ordinary plane. due to the fact that our plane has no engine—nothing but a lightweight motor, a twin brother of the motor we saw on the pleasure boat. The motor drives the propeller blades, but we cannot see what is driving the motor. An insulated wire leads from the motor to a ball above the higher plane, and that is all.



Dr. Nikola Tesla, who announces the culmination of wonderful discoveries begun in 1898.

Anyway, we have faith in the thing, and we climb aboard. The pilot presses a button, the motor begins to hum and the propeller to spin, and we are off.

"Suppose the motor stops while we are above the clouds," "we suggest. "What's going to happen?"

"We'll glide," is the comforting assurance of the pilot.

Sure enough, the motor does stop, and we glide until it starts again.

AND that night, seated in the Make Believe club house, we read by electric light which looks familiar and home-like. The club electrician may show us, if we are interested, the electric light meter in the basement, and he will help us to trace the feed wire right from the meter to the roof of the club house where it terminates in a metal ball perched on the top of the small round flagstaff.

NEXT morning we leave Make Believe land and pay a visit to South America. In British Guiana there is a mighty river called the Petara. At one place, Kaieteur, the river makes a clear drop of 822 feet, and at the foot of the cataract the waters of the Potara branch off in various directions. The Kaieteur cataract is the show place of British Guiana.

Twenty-eight thousand cubic feet of water pass over the edge of the cataract every second. This vast volume of water, properly applied, would be capable of furnishing four times as much power as we derive to-day by the harnessing of Niagara Falls. At Niagara the fall of water is eighteen million cubic feet per minute, but a flow of only fifteen thousand feet per second is diverted above the falls and harnessed for the use of man.

ALTHOUGH everybody is familiar in a general way with the meaning of the term "harnessing Niagara," it will not hurt to refresh our memory. At Niagara the motive power which furnishes electric light, power and heat to many municipalities, including the city of Buffalo, is not derived directly from the Falls themselves, but from the water of the Niagara River drawn off by an enormous tunnel at a distance of about one mile above the Falls. The tunnel is 6807 feet long, 21 feet high, 18 feet 10 inches wide at its widest part and 14 feet wide at the base. In shape it resembles a gigantic horseshoe. This tunnel was cut through solid rock. It took 1,000 rock men three years to make the excavation. The tunnel leads out of a pit 178 feet deep, 40 feet long and 18 feet wide, and has an outlet below the Falls. The enormous hydraulic pressure in a pit 178 feet deep drives the water through the tunnel with a force that may be considered almost irresistible. The tunnel has a slight grade, from 4 to 7 feet per 1,000 feet. The water rushing through the tunnel turns wheels geared to electric generators. It has been estimated that the 18,000,000 cubic feet of water which flow over the Falls every minute are capable of furnishing 7,000,000 horsepower, sufficient to furnish light to 25 cities of the size of New York.

NOW we can pay another visit to the great Kaieteur cataract in British Guiana and visualize the harnessing of all its enormous water power by the tunnel and water wheel process employed at Niagara. And, having seen how all that energy, theoretically 2,100,000 horse power, is obtainable, we may be curious to know what connection it has with the mysterious force which propelled our Make Believe pleasure boat and airplane and illuminated the Make Believe clubhouse. Here is where day-dreaming ends and we begin to study this subject from the materialistic point of view.

AS far back as 1898 several scientific journals published an announcement credited to Dr. Nikola Tesla, in which the assertion was made that he had found it possible to send out from an aerial terminal an estimated electrical pressure of 2,500,000 volts which would be effective at an unlimited distance. The Electrical Review, in commenting on that matter, said at that time:

"Tesla now proposes to transmit without the use of any wires, through the natural media—the earth and the air—great amounts of power to distances of thousands of miles. This will appear a dream—a tale from the Arabian Nights. But from the extraordinary discoveries Tesla has made during a number of years of incessant labor, it is evident that his work in this field has passed the stage of laboratory experiment and is ready for a practical test on an industrial scale. The success of his efforts means that power from such sources as Niagara will become available in any part of the world, regardless of distance."

THAT was twenty-one years ago, when wireless telegraphy was still in the land of Make Believe. Tesla made certain experiments and got certain results.

And a few days ago he explained to me his perfected plan for applying harnessed energy to the world-wide operation of the wheels of industry, including our little Make Believe pleasure boat and airplane, and even the illumination of the club house.

Briefly explained, the plan is to generate electrical energy at the source of supply, Niagara, Kaieteur or Rjukan, for instance, and transmit it by wireless to the nearest receiving stations in other countries. Distance will be no impediment to the transmission of this energy, but various conveniently situated receiving stations can be established for storage and supply. This energy is not to be scattered promiscuously to the four winds of heaven for the free use of all who care to "tap" it. It will be controlled, Dr. Tesla said, by a secret key or combination like that of a safe, so that only those for whom the power is intended will get it.

"SOME experts, whom I credited wih better knowledge," said Dr. Tesla, "for years contended that my proposals to transmit power without wires were sheer nonsense, but I note that they are growing more cautious every day. These men labor under the impression that the energy flows in all directions and that, therefore, only a minute amount can be recovered in any individual receiver. But this is far from being so. The power is conveyed in only one direction, from the transmitter to the receiver, and none of it is lost elsewhere.

"It is quite practicable to recover at any point of the globe energy enough for driving an airplane, or a pleasure boat, or for lighting a dwelling. I am very sanguine in regard to the lighting of isolated places, and believe that a more economical and convenient method can hardly be devised. The future will show whether my foresight is as accurate now as it has proved hitherto."

Dr. Tesla declared that he and all his followers believe that nothing can stop now a tremendous development in the wireless transmission of power, provided the Government does not impose restrictions which will hamper the enterprises and discourage capital.

THAT PROSPECTIVE COMUNICATION WITH ANOTHER PLANET

Nikola Tesla Enters Into the Subject From the Practical Standpoint

WHEN the brilliant electrician, Nikola Tesla, was informed by a newspaper reporter some weeks ago that William Marconi had received strong wireless signals seeming to come from beyond the earth, something like corroboration resulted. Nikola Tesla, as he is quoted in the New York *Evening Post,* remembered that years ago he recorded extra-planetary signals in his laboratory at Colorado Springs. These extra-planetary signals were barely perceptible at the time, but their measured regularity was such that they could not, in Tesla's opinion, have been accidental static disturbances. They possessed order. Mr. Tesla admits that he could not say with certainty that they came from Mars, altho, as quoted in the New York newspaper, this remains his belief. In our solar system, he adds, Venus, the earth and Mars represent respectively youth, full growth and old age.

"Venus, with its mountains rising dozens of miles into the atmosphere, is probably as yet unfitted for such existence as ours, but Mars must have passed through all terrestrial states and conditions.

"Civilized existence rests on the development of the mechanical arts. The force of gravity on Mars being only two-fifths of that on the earth, all mechanical problems must be much easier of solution. The planet being much smaller, the contact between individuals and the mutual exchange of ideas must have been much quicker. There are many other reasons why intellectual life on that planet should have been phenomenal in its evolutions."

Tesla is certain that the signals he transmitted in reply to those he detected years ago must have produced disturbances on the planet Mars. Whether there were instruments there to receive them or intelligence to recognize them as interplanetary messages is another question. He thinks the first step in communication with another planet must be made through the science of mathematics, as suggested by Marconi. Tesla feels that it will be difficult, however, to advance far by means of cosmic Esperanto because conversation can not be carried on with figures. It is not likely that anywhere in the universe there can be "knowledge without form." In mental or in physical vision is comprized the foundation of all knowledge. Now, pictures have been transmitted by telegraph. Why not by wireless?

"Granted always that on some of the neighboring planets there exist intelligent beings, as far advanced in civilization as we, or farther advanced, who understand wireless telegraphy, we should be able to flash pictures—say of the human face—by wireless, and receive in return pictures by wireless. When that step is taken the whole riddle of interplanetary communication is solved.

"Now, a speculation of this sort will always seem foolish, visionary, and idle unless we start from the premise that other planets of the universe are inhabited by life-form just as intelligent as the human beings of this world. I assume that such is the case. In fact, it is a mathematical certainty. It is ridiculous to think that life has not developed on the innumerable planets surrounding us."

In view of the fact that Mars is but thirty-five million miles from the earth when the two planets come closest together, Tesla says it would take a radio impulse less than five minutes to flash between the pair. The minimum distance between the planets was arrived at in 1909. "We shall again be within a hailing distance of 35,000,000 miles from Mars in 1924." It should be noted that Tesla does not accept many of the assumptions upon which physicists base some current theories affecting the subject of wireless communication. He has recently set forth anew in *The Electrical Experimenter* his reasons for denying not only the axial rotation of the moon — "a phenomenon deceptive alike to the eye and mind and devoid of physical meaning" — but the Hertzian wave-hypothesis as usually expounded. Hence some at least of the arguments by means of which his theory of communication with other planets is attacked carry no weight with him. Tesla asks us to imagine the earth to be a bag of rubber, filled with water, a small quantity of which is periodically forced in and out of the same by means of a reciprocating pump:

"If the strokes of the latter are effected in intervals of more than one hour and forty-eight minutes, sufficient for the transmission of the impulse through the whole mass, the entire bag will expand and contract and corresponding movements will be imparted to pressure gauges or movable pistons with the same intensity, irrespective of distance. By working the pump faster, shorter waves will be produced which, on reaching the opposite end of the bag, may be reflected and give rise to stationary nodes and loops, but in any case, the fluid being incompressible, its inclosure perfectly elastic, and the frequency of oscillations not very high, the energy will be economically transmitted and very little power consumed so long as no work is done in the receivers. This is a crude but correct representation of my wireless system, in which, however, I resort to various refinements. Thus, for instance, the pump is made part of a resonant system of great inertia, enormously magnifying the force of the impressed impulses. The receiving devices are similarly conditioned and in this manner the amount of energy collected in them vastly increased.

"The Hertz wave system is in many respects the very opposite of this. To explain it by analogy, the piston of the pump is assumed to vibrate to and fro at a terrific rate and the orifice through which the fluid passes in and out of the cylinder is reduced to a small hole. There is scarcely any movement of the fluid and almost the whole work performed results in the production of radiant heat, of which an infinitesimal part is recovered in a remote locality. However incredible, it is true that the minds of some of the ablest experts have been, and still are, obsessed by this monstrous idea."

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EDITORIAL

Underground Wireless

ELSEWHERE in this issue is disclosed in full detail for the first time what U. S. Navy officials term as the greatest American War Invention: "Underground and Sub-sea Wireless."

Last month we hinted editorially on the theoretical aspect of the problem—this month we are face to face with the accomplisht fact. The war has revolutionized not only peoples, nations and the whole world, but many hitherto unshakable scientific institutions as well. For over twenty years the wireless aërial—the elevated aërial wire system—was synonymous with the wireless art. The great radio station, the trans-atlantic liner, could not well be imagined without its ubiquitous stretch of elevated wires. The greatest pride of the radio amateur, the aërial on top of his house, which to him was symbolic of the young art, is doomed. This change has been brought about over night by the magic wand of science and her servant—Mr. James Harris Rogers, American, of Hyattsville, Md.

The aërial wires, down for the duration of the war, will never go up, at least as far as amateurs and private stations are concerned. As for the commercial stations, their towers too are doomed shortly for the scrap-heap. During the war Mr. Rogers developed underground and sub-sea wireless—for receiving at least—to a heretofore undreamt of state of perfection. His receiving station at Hyattsville never mist a word transmitted from French, English, Italian as well as German high power stations. *He received his messages from Europe when a thunderstorm, accompanied by terrific lightning, was going on directly above his head.* Recently, too, *he has done away entirely with static.*

When the big station at Arlington, near Washington, was out of touch with Europe, due to static disturbances, Mr. Rogers went right on receiving over his buried underground wires, just as if static never existed. Indeed the Rogers invention knows no static. Static being an atmospheric condition, a ground antenna naturally will not be affected by it.

But the most spectacular feature of Mr. Rogers' revolutionizing invention probably is his "Sub-sea Wireless." Scientists the world over, Marconi included, declared it an utter impossibility to communicate by wireless with a totally submerged submarine. Mr. Rogers, however, goes right ahead and does it, not only in fresh water *but thru salt water as well.* Indeed he establisht wireless communication with a submarine *whose aërial wires were 25 feet below the surface of the ocean!*

Altho Mr. Rogers, during the war, gave most of his attention toward receiving messages, he has made considerable progress in underground radio transmission as well. His experiments prove conclusively that, while underground radio receiving is here to stay, underground sending too will soon be practical enough, even for high power stations. It is merely a question of good insulation at present, and the end of this year, we are quite confident, will bring the solution of the problem. The Navy Department has just succeeded in transmitting a distance of 50 miles with the underground system.

At first it would seem reasonable that only long wave lengths could be used with the Rogers system. But this is not the case. Underground Radio-telephone messages, seven miles distant, come in just as clear on 300 meters wave length as does the Nauen (Germany) station with 12,600 meters wave length. This indeed is good news for our amateurs.

But in the meanwhile, all of our pet theories on wireless are thrown in a sad chaos. For we do not know as yet how the Rogers system works. We can now expect a war to the knife between our wave-propagation theorists and the new school of ground-impulse savants. Mr. Rogers himself takes the view—and he is seconded by Tesla—that the transoceanic messages which he receives over his underground system *are not Hertzian waves*—pure or even converted—but merely high frequency ground impulses.

The future may tell us which school is right.

H. GERNSBACK.

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Tesla's Egg of Columbus

How Tesla Performed the Feat of Columbus Without Cracking the Egg

PROBABLY one of the most far-reaching and revolutionary discoveries made by Mr. Tesla is the so-called *rotating magnetic field*. This is a new and wonderful manifestation of force —a magnetic cyclone—producing striking phenomena which amazed the world when they were first shown by him. It results from the joint action of two or more alternating currents definitely related to one another and creating magnetic fluxes, which, by their periodic rise and fall according to a mathematical law, cause a continuous shifting of the lines of force. There is a vast difference between an ordinary electro-magnet and that invented by Tesla. In the former the lines are stationary, in the latter they are made to whirl around at a furious rate. The first attracts a piece of iron and holds it fast; the second causes it to spin in any direction and with any speed desired. Long ago, when Tesla was still a student, he conceived the idea of the rotating magnetic field and this remarkable principle is embodied in his famous *induction motor* and system of transmission of power now in universal use.

In this issue of the ELECTRICAL EXPERIMENTER Mr. Tesla gives a remarkable account of his early efforts and trials as an inventor and of his final success. Unlike other technical advances arrived at thru the usual hit and miss methods and hap-

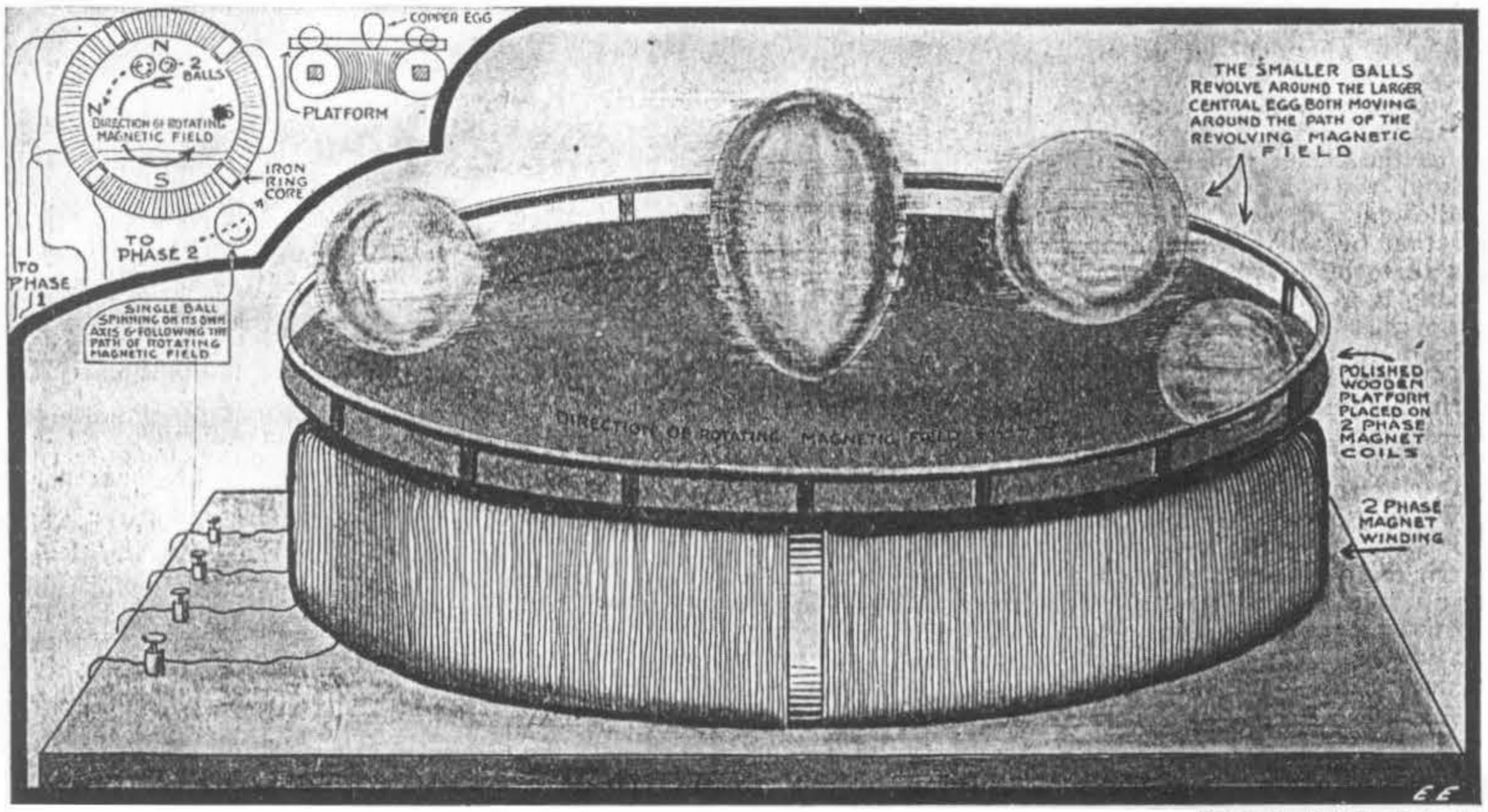

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Fig. 2. Illustrating the Polyphase Coil and Rotating Megnetic Field Which Caused Copper Eggs to Spin.
Fig. 3. Insert: Detail of Coil Apparatus Showing Coil Connections to Different Phases.

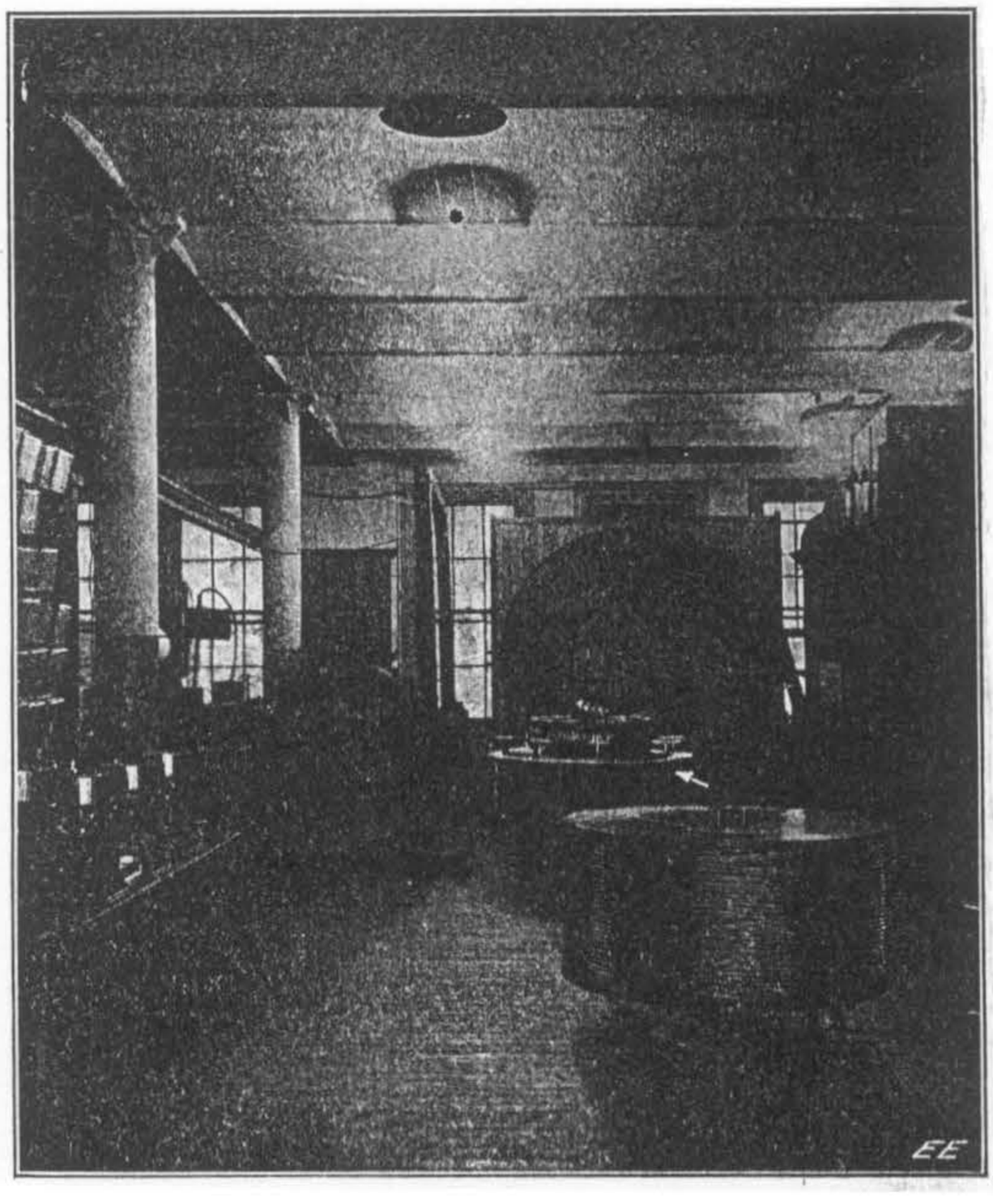


Fig. 1. This hitherto unpublisht photograph is extremely interesting as it shows not only "Tesla's Electric Egg" apparatus in the center of the background, but also a comprehensive view of a corner of his famous Houston Street laboratory of a decade ago. At the left may be seen a number of Tesla's oscillators or high frequency generators, while in the rear may be noted a large high frequency transformer of the spiral type, the diameter of which was a little over nine feet. The electric egg apparatus comprising a two-phase A.C. circular core and winding, rests on a table, and this particular model measured about two feet across. In making the demonstrations, Tesla applied as much as 200 H.P. from a two-phase alternator to the exciting coils, and so intense was the revolving magnetic field created in the surrounding space, that small delicately pivoted iron discs would revolve in any part of the hall, and a great many other devices could be simultaneously operated from this magnetic field when thus excited. The frequency of the two-phase A.C. energizing the coils, was varied from 25 to 300 cycles, the best results being obtained with currents of from 35 to 40 cycles. This laboratory was lighted by Tesla's vacuum tubes, several of which may be seen on the ceiling, and each of which emitted 50 C.P. The coil resting on three legs and observed in the immediate foreground is the primary of a resonant Tesla transformer which collected energy from an oscillatory circuit encircling the laboratory, no matter in what position the transformer was placed. A low tension secondary of one or two turns of heavy cable (not visible) was provided for stepping down the energy collected by "mutual induction," and supplied the current to incandescent lamps, vacuum tubes, motors and other devices. When the circuit around the hall was strongly excited, the secondary furnished energy at the rate of about three-quarters of one horse-power.

hazard experimentation, the rotating field was purely the work of scientific imagination. Tesla developed and perfected, entirely in his mind, this great idea in all its details and applications *without making one single experiment.* Not even the usual first model was used. When the various forms of apparatus he had devised were tried for the first time they worked exactly as he had imagined and he took out some forty fundamental patents covering the whole vast region he had explored. He obtained the first rotations in the summer of 1883 after five years of constant and intense thought on the subject and then undertook

the equally difficult task of finding believers in his discovery. The alternating current was but imperfectly understood and had no standing with engineers or electricians and for a long time Tesla talked to deaf ears. But, ultimately, his pains were rewarded and early in 1887 a company bearing his name was formed for the commercial introduction of the invention.

Dr. Tesla recently told the editors an amusing incident in this connection. He had approached a Wall Street capitalist—a prominent lawyer—with a view of getting financial support and this gentleman called in a friend of his, a well-known engineer at the head of one of the big corporations in New York, to pass upon the merits of the scheme. This man was a practical expert who knew of the failures in the industrial exploitation of alternating currents and was distinctly prejudiced to a point of not caring even to witness some tests. After several discouraging conferences Mr. Tesla had an inspiration. Everybody has heard of the "Egg of Columbus." The saying goes that at a certain dinner the great explorer asked some scoffers of his project to balance an egg on its end. They tried it in vain. He then took it and cracking the shell slightly by a gentle blow, made it stand upright. This may be a myth but the fact is that he was granted an audience by Isabella, the Queen of Spain, and won her support. There is a suspicion that she was more imprest by his portly bearing than the prospect of his discovery. Whatever it might have been, the Queen pawned her jewels and three ships were equipt for him and so it happened that the Germans got all that was coming to them in this war. But to return to Tesla's reminiscence. He said to these men, "Do you know the story of the Egg of Columbus?" Of course they did. "Well," he continued, "what if I could make an egg stand on the pointed end without cracking the shell?" "If you could do this we would admit that you had gone Columbus one better." "And would you be willing to go out of your way as much as Isabella?" "We have no crown jewels to pawn," said the lawyer, who was a wit, "but there are a few ducats in our buckskins and we might help you to an extent."

Mr. Tesla thus succeeded in capturing the attention and personal interest of these very busy men, extremely conservative and reluctant to go into any new enterprise, and the rest was easy. He arranged for a demonstration the following day. A rotating field magnet was fastened under the top board of a wooden table and Mr. Tesla provided a copper-plated egg and several brass balls and pivoted iron discs for convincing his prospective associates. He placed the egg on the table and, to their astonishment, it stood on end, but when they found that it was *rapidly spinning* their stupefaction was complete. The brass balls and pivoted iron discs in turn were set spinning rapidly by the rotating field, to the amazement of the spectators. No sooner had they regained their composure than Tesla was delighted with the question: "Do you want any money?" "Columbus was never in a worse predicament," said the great inventor, who had parted with his last portrait of George Washington in defraying the expenses of the preparation. Before the meeting adjourned he had a substantial check in his pocket, and it was given with the assurance that there was more to be had in the same bank. That started the ball rolling. Tens of millions of horsepower of Tesla's induction motors are now in use all over the world and their production is rising like a flood.

In 1893 Mr. Albert Schmid, then Superintendent of the Westinghouse Electric and Mfg. Co. constructed a powerful rotating field ring with an egg made of copper, and larger than that of an ostrich, for Dr. Tesla's personal collection at the Chicago World's Fair. This piece of apparatus was one of the most attractive novelties ever publicly shown and drew enormous crowds every day. Subsequently it was taken to Mr. Tesla's laboratory and served there permanently for demonstrating rotating field phenomena. In his experiments it was practicable to use as much as 200 *horsepower* for a short time, without overheating the wires and the effects of the magnetic forces were wonderfully fascinating to observe. This is the very ring indicated in the accompanying photograph (Fig. 1), giving a view of Mr. Tesla's former laboratory at 46 E. Houston Street, New York. It is shown in detail in Fig. 2, and the mode of winding is illustrated in diagram (Fig. 3). Originally the two-phase arrangement was provided but Mr. Tesla transformed it to the three- and four-phase when desired. On top of the ring was fastened a thin circular board, slightly hollowed, and provided around its circumference with a guard to prevent the objects from flying off.

Even more interesting than the spinning egg was the exhibition of *planetary motion*. In this experiment one large, and several small brass balls were usually employed. When the field was energized all the balls would be set spinning, the large one remaining in the center while the small ones revolved around it, like moons about a planet, gradually receding until they reached the outer guard and raced along the same.

But the demonstration which most imprest the audiences was the simultaneous operation of numerous balls, pivoted discs and other devices placed in all sorts of positions and *at considerable distances from the rotating field*. When the currents were turned on and the whole animated with motion, it presented an unforgettable spectacle. Mr. Tesla had many vacuum bulbs in which small, light metal discs were pivotally arranged on jewels and these would spin anywhere in the hall when the iron ring was energized.

Rotating fields of 15,000 horsepower are now being turned out by the leading manufacturers and it is very likely that in the near future capacities of 50,000 horsepower will be employed in the steel and other industries and ship propulsion by Tesla's electric drive which, according to Secretary of the Navy Daniels' statement, has proved a great success.

But any student interested in these phenomena can repeat all the classical experiments of Tesla by inexpensive apparatus. For this purpose it is only necessary to make two slip ring connections on an ordinary small direct current motor or dynamo and to wind an iron ring with four coils as indicated in diagram Fig. 3. No particular rule need be given for the windings but it may be stated that he will get the best results if he will use an iron ring of comparatively *small section* and wind it *with as many turns of stout wire as practicable*. He can heavily copper plate an egg but he should bear in mind that Tesla's egg is not as innocent as that of Columbus. The worst that can happen with the latter is that it might be,—er—over ripe! but the Tesla egg may explode with disastrous effect because the copper plating is apt to be brought to a high temperature thru the induced currents. The sensible experimenter will, therefore, first suck out the contents of the egg—thus satisfying both his appetite and thirst for knowledge.

Besides the rotating field apparatus Mr.

(*Continued on page* 808)

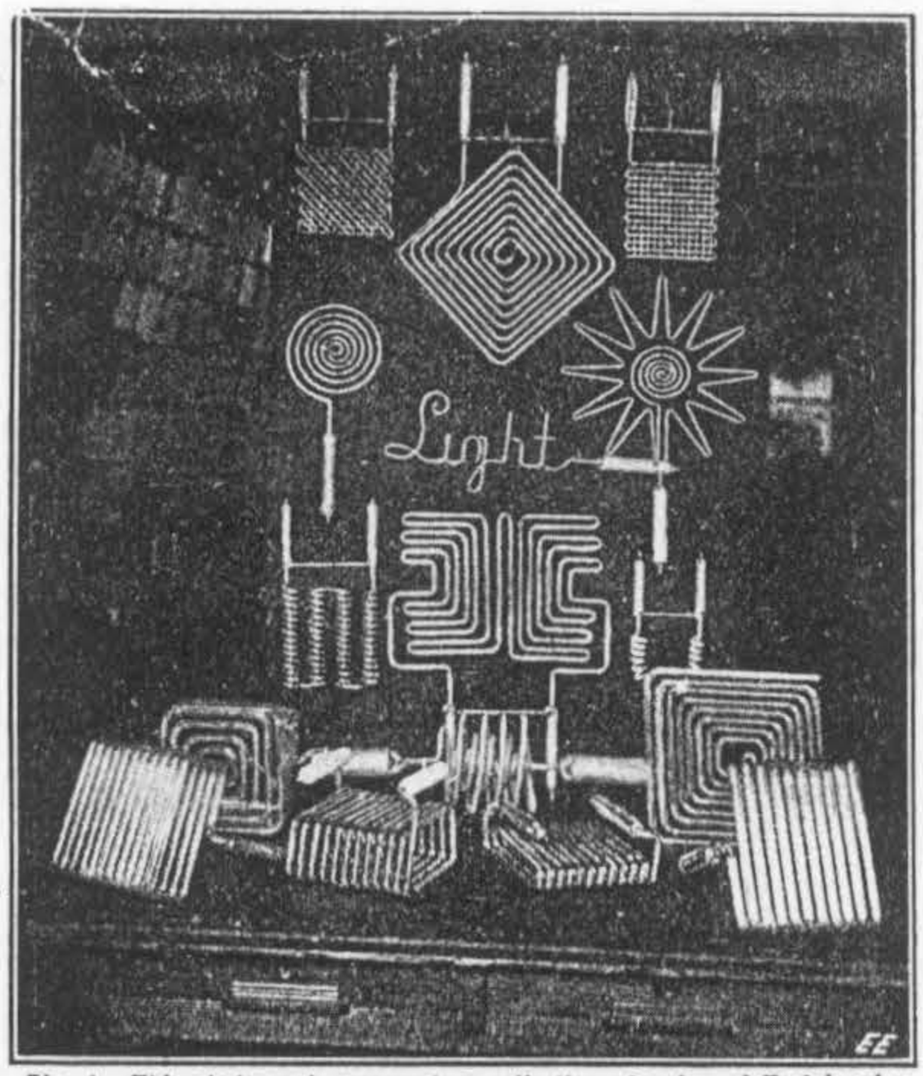


Fig. 4. This photograph represents a collection of a few of Tesla's wireless lamps, such as he proposes to use in lighting isolated dwellings all over the world from central wireless plants. The two lamps at either corner at the bottom are illuminated, owing to the fact that a high frequency oscillator was in operation some distance away when this photograph was being taken. These tubes were filled with various gases for experimental research work in determining which was most efficient.

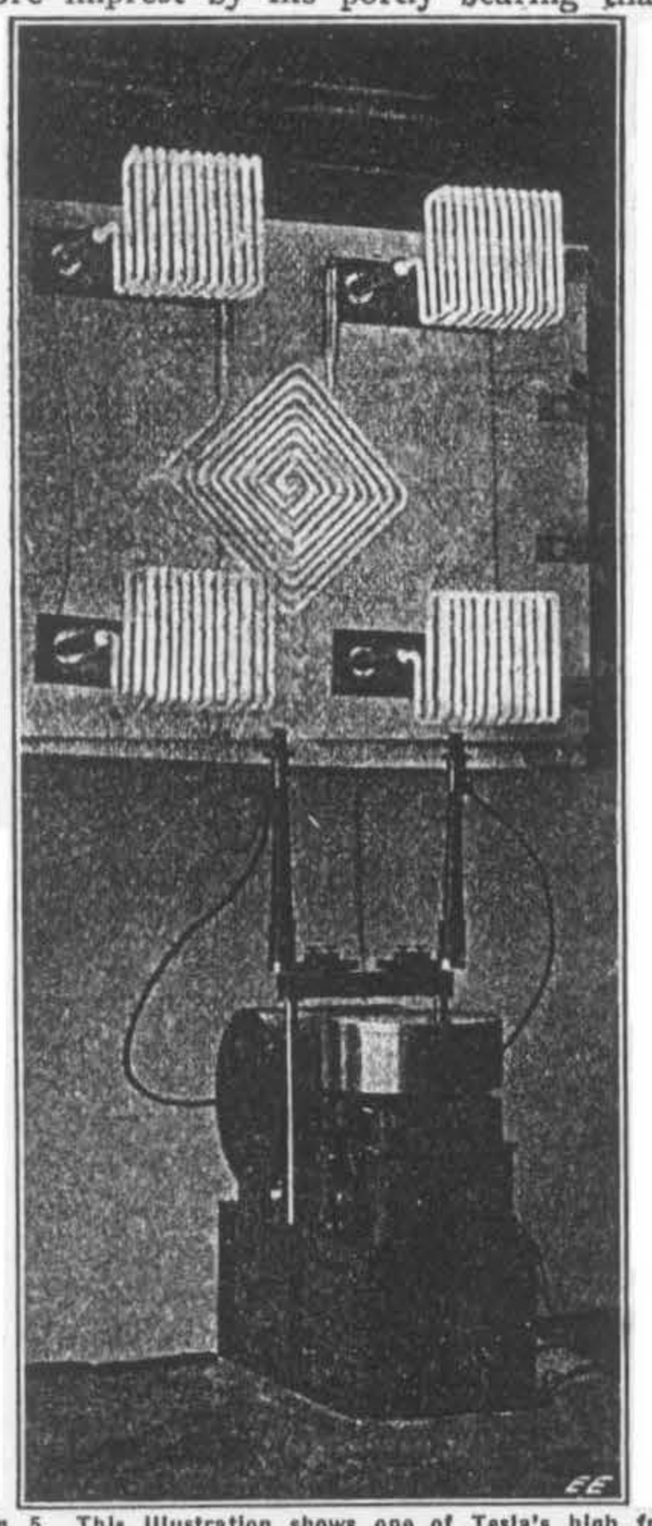


Fig. 5. This illustration shows one of Tesla's high frequency oscillation generators and a bank of his high frequency lamps lighted by the same. These highly evacuated, gas filled tubes were operated in different ways. In some cases they were connected to one wire only; in other instances to two wires, in the manner of ordinary incandescent lamps. Often, however, they were operated without any connection to wires at all, i.e., by "wireless energy", over quite appreciable distances, which could have been greatly extended with more power. The oscillator comprises a Tesla high potential transformer which is excited from a condenser and circuit controller, as described in his patents of 1896. The primary exciting element comprised a powerful electro-magnet actuating an armature, and this circuit was connected with 110 volt, 60 cycle A.C. or D.C. When the oscillator was put into operation, the interrupter actuated by the electro-magnet connected to the 110 volt circuit, became simultaneously the spark gap for the high potential exciting circuit, which included this vibrator, spark gap, a high tension condenser and the primary of the high frequency Tesla transformer. The lamps were connected to the secondary of the latter, the terminals of which are seen in the rear of the machine.

THE TESLA EGG OF COLUMBUS.

(*Continued from page 775*)

Tesla had other surprises for his audiences, which were even more wonderful. So, for instance, the coil on three legs, visible in the foreground, was used to operate wireless motors, lamps and other devices, and the spiral coil in the background served to show extraordinary high potential phenomena, as streamers of great length.

America's Greatest War Invention

The Rogers Underground Wireless

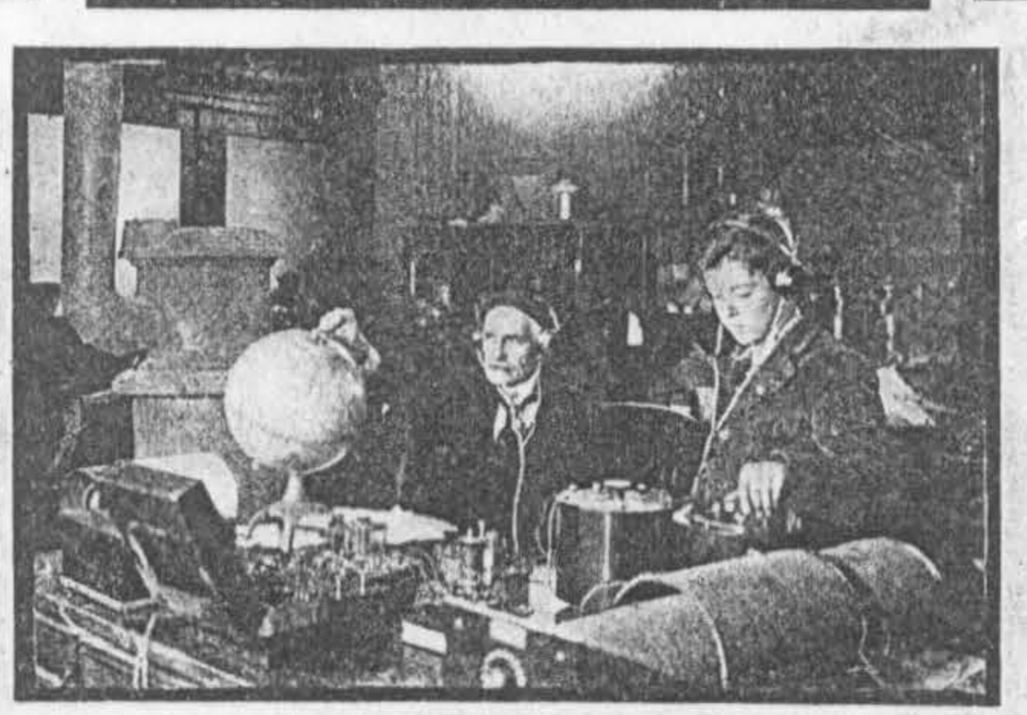
(Special Interview to the ELECTRICAL EXPERIMENTER.)

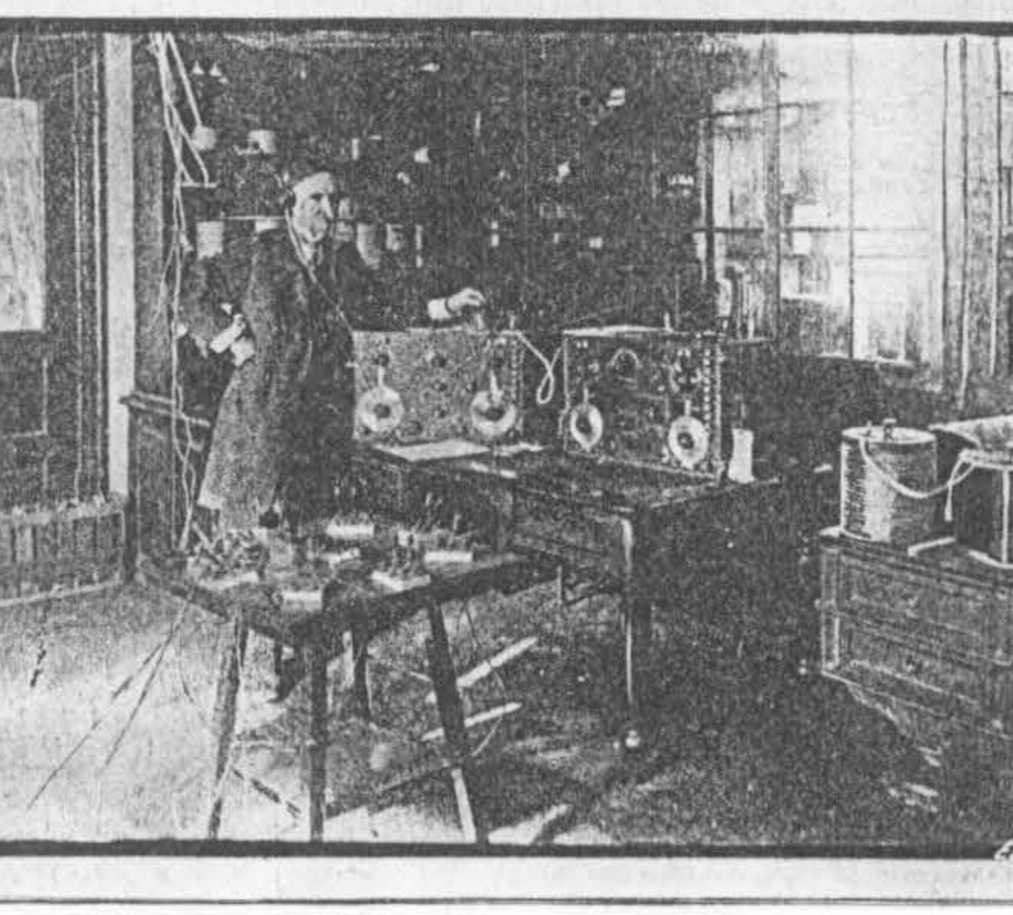
By H. Winfield Secor
(Associate Member Institute Radio Engineers.)

An invention which has been termed the greatest American war achievement is the Rogers underground and sub-sea radio system. The Rogers system does away entirely with aerial wires, and it is only a matter of months now before all aerial wire systems the world over will be pulled down. Wonderful things have been accomplisht by the new Rogers underground system, chief of which is the total elimination of static and the increase of the loudness of received signals, which is often as high as 5000 times the usual strength. Interference, too, is done away with almost entirely now. The Rogers invention is of tremendous importance and revolutionizes our previous ideas on wireless to an extent never dreamt of before. We urge every one interested in radio to read the accompanying authoritative article which discloses the full technical data on the new system for the first time in any periodical.

THE greatest invention in the field of wireless telegraphy since Marconi first placed commercial radio-communication on a firm basis by his historic experiments in Italy, and later in England, is without a shade of doubt this latest triumph of radio research—the "Underground and Sub-sea Wireless", conceived and developed to a working stage by an American scientist and inventor, James Harris Rogers. Mr. Rogers is known as a second Edison, among his towns-people in Hyattsville, Maryland, where he has lived for many years, and now the whole world acclaims him.







Photos by International Film Service

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It Is Revealed Now That the Navy Department Had Been Using a Powerful Undersea Wireless During the War. The Instruments and System Were Invented by James H. Rogers, of Hyattsville, Md., and were Adopted by the Navy Department as an Invaluable Addition to the Wireless System of the Navy. The Two Lower Photos Show the Inventor, Mr. Rogers, in His Laboratory at Hyattsville.

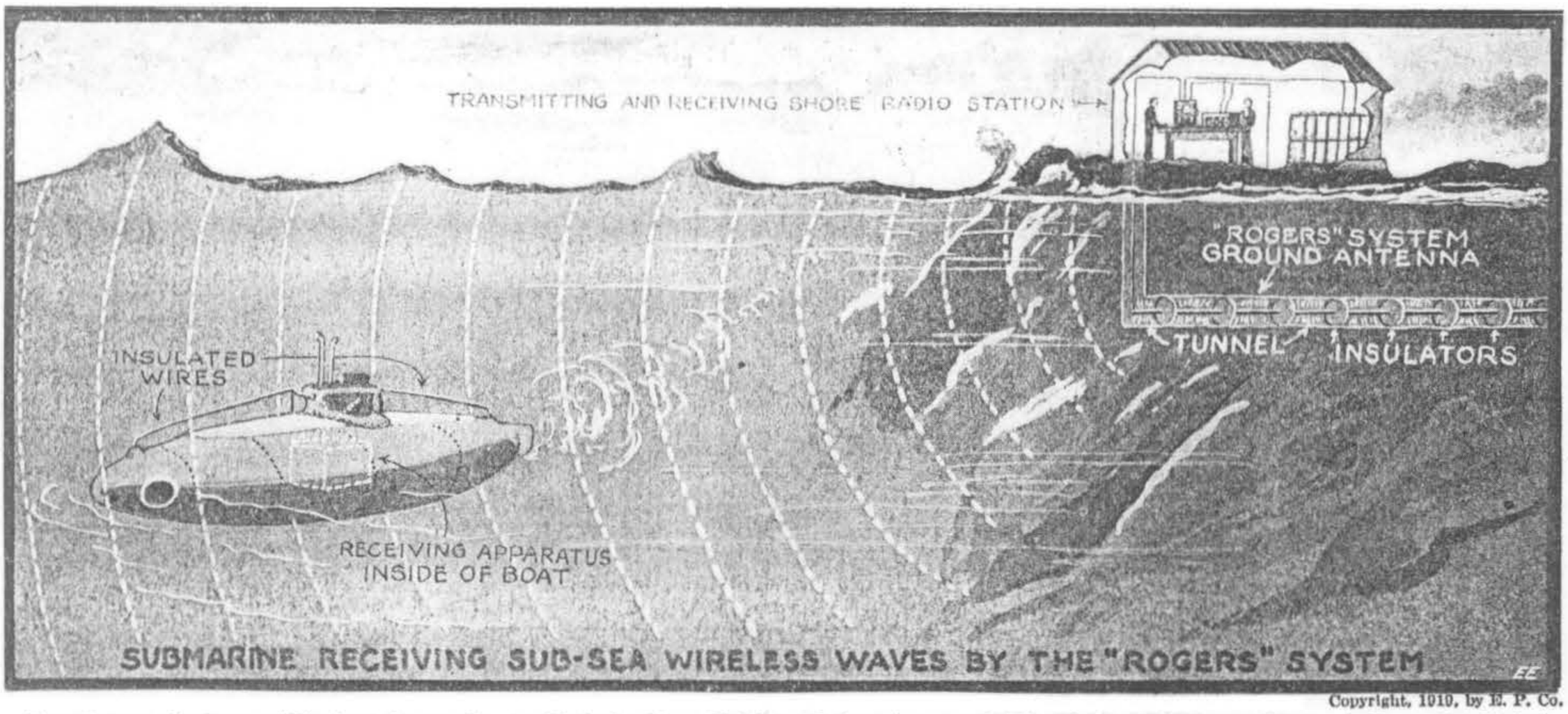
Top Photo Shows Antenna Wires Being Placed in River by Mr. Rogers' Assistants. The Inventor Has Found that His System Works Just as Well Under Water as Thru the Earth. All of the High Power Stations in the World, from Nauen and Lyons to Honolulu, Are Heard in Mr. Rogers' Laboratory at Hyattsville, Md., Shown in the Center and Lower Views Herewith. The Author of This Article Also Heard the Transatlantic Stations Coming in Loud and Clear. Mr. Rogers' Invention Is the Greatest in the War and Is so Recognized by the Government.

Who is Mr. Rogers?

James Harris Rogers, practically unknown a few years ago in radio circles, except by a few select radio men who were investigating his invention for the Navy Department, has practically become overnight the center of all attractions in the field of science. Mr. Rogers is a son of the confederacy and a veteran of the great Civil War. He has followed electrical experimenting ever since and has been a strong devotee of radio telegraphy since Marconi performed his first experiments in this new branch of applied science. He is a refined, cultured southern gentleman who makes you feel at home at once; an invariable attribute of all of the truly great. Mr. Rogers was one of the first inventors of the "printing telegraph" and his full-sized working models saw actual commercial service on a circuit between Baltimore and Washington, also in New York, back in 1880. These were seen by the writer and are wonderful pieces of mechanism.

The Rogers laboratory, which comprises several large rooms, is lined on all sides with glass cabinets containing electrical apparatus which he has invented from time to time thru his studious career. A novel and original high frequency generator was another of the devices that greatly interested the writer. It employed a jet of water shunted by a large capacity, the stream of water being connected to a high potential source of direct current. High frequency currents of any range up to the limit of audibility, or about 30,000 cycles per second, could be readily obtained with this apparatus. The writer merely cites these facts to substantiate the standing of Mr. Rogers in the scientific field. Hundreds of other electrical inventions have been made by this modest genius of the quiet little Maryland town of Hyattsville, and the principal outstanding fact of all of his work is that he can show you a working model of each of these inventions, unlike many other inventors whose ideas exist only on paper, and which often fall down, miserably, when actually built and tested.

In this connection it is interesting to consider for a moment that not one of the new wireless "static and interference preventers" proposed to the government radio experts during the war, proved practicable in the least.



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The Rogers Undersea Wireless Opens Up an Entirely New Field to Submarines and Ship Communication. Marconi Recently Stated that Submarines Had to Come to the Surface to Intercept Radio Messages, but the Rogers Invention Has Upset All This. On a Recent Test a U.S. Subsea Boat Submerged Off the American Coast to a Depth of 8 Feet and Picked Up Nauen, the German Station. At Depths of 21 Feet Stations with Wave Lengths over 12,000 Meters Were Easily Picked Up. Transmission to Submarines Has Also Been Accomplisht.

Official recognition of Mr. Rogers as the one and only original inventor of "Under-ground and Sub-sea Wireless Communication," was soon forthcoming, and here it is in brief. These two official letters of recognition of Mr. Rogers' wonderful and revolutionizing invention represent but a very small fraction of those he has received from radio engineers of high repute in all parts of the world, congratulating him on his masterly work. The Navy Department has just permitted information on the Rogers system to be given out, and how well they kept their secret during the World War, during which time this system has been in use by the Navy Department, may be judged by the fact that radio men everywhere are amazed at this feat. The distinguished radio savant Prof. George W. Pierce of Harvard University, congratulated Mr. Rogers heartily when he first tested and heard the new system work thru salt water, which he at first thought absolutely impossible.

Below we give the two letters of official recognition by the Navy Department of Mr. Rogers' accomplishments, which are all that we have space for.

In response to an inquiry from Clarence J. Owens, director general of the Southern Commercial Congress, Admiral Griffin, U. S. N., chief of the bureau of steam engineering, wrote under date of December 27, 1918, as follows:

"In reply to your question regarding the originator of the underground radio system, you are advised that Mr. J. H. Rogers of Hyattsville, Md., was the originator of this system. There have been other claimants to methods of underground radio signalling, but none were useful, within the Navy Department's knowledge to the extent of being a valuable asset to the general scheme of radio communications. The introduction of Mr. Rogers' receiving system marked the beginning of the use of underground aërials for receiving, to great advantage over raised aërials, and has been valuable to the Navy during the war."

Rear Admiral Strother Smith, then Capt. Smith, wrote Mr. Rogers on December 7, 1917:

"It is a great pleasure to me to feel that I have been instrumental in bringing the result of your work before the Navy Department and assisting somewhat in putting it into actual practise. Out of the many thousand ideas presented you can realize that a very, very small percentage are valuable and it is worth at least a year's work to get one that I feel will give lasting benefit to the service that I take pleasure in serving."

The Navy Department Interested.

Thru Dr. George H. Lamar and Senator Blair Lee the discovery and the status of the patents were brought to the attention of Secretary Daniels of the Navy. Secretary Daniels ordered inquiry into Mr. Rogers' claims, which showed that his invention worked, and requested Secretary Lane to give special consideration to pending patent applications.

Secretary Daniels then submitted the Rogers system to Rear Admiral (then Captain) Strother Smith, who called into consultation Capt. Hooper. These officers made a thoro study of the system and found it practicable. Capt. Hooper ordered it installed at New Orleans first and since then it has been employed at Belmar, N. J.,* and other stations.

* At the time of writing this article the Belmar Trans-Atlantic Receiving Station is still employing the Rogers underground antenna.

For a decade Mr. Rogers has been studying radio subjects, and long before the United States entered the war he had experimented with the problem of ridding aërial communication of this static atmospheric electricity. He disagreed with all authorities who believed that the air, and not the earth and water, was best suited for wireless communication.

At first Mr. Rogers used the earth alone for sending messages to amateurs stationed near by. Using an audion bulb, he then buried a wire from his laboratory and heard Philadelphia and other stations. Further experiments were conducted at a laboratory

Hyattsville, Md.,
January 13, 1919.

Dr. Nikola Tesla,
New York City, N. Y.

Dear Dr. Tesla:—

I have just read with great interest your article in the Electrical Experimenter. For years I have been a firm believer in the theory that far distant aerials were actuated thru the medium of the Earth and not thru the ether above, and it is a source of great satisfaction that so illustrious a personage as yourself has held to the same belief. I have never met a scientist who would entertain such a proposition until I demonstrated to them results described in the enclosed paper, illustrating one of the ways I have found for utilizing the energy so clearly and forcibly described by you. I am, nevertheless, confronted by some who will not give up old theories. If you would do me the great honor of writing a few lines upon the scientific feature I would deem it a great favor.

Should you chance to be in Washington at any time I will be highly gratified to have you visit my laboratory and witness the results obtained.

Very sincerely,

(Signed) J. Harris Rogers.

To the American Radio Amateur:

WITHIN the next few months peace will be declared and the amateur will be allowed to operate his station as before. Thanks to Mr. James H. Rogers, it will not, however, be necesary for you to put up an aerial again—at least not for receiving. Elevated aerials will be a thing of the past, and well they may.

But ordinarily the amateur would not be permitted to use the underground aerial system on account of Mr. Rogers' fundamental patents. The writer, however, in conversation with Mr. Rogers, prevailed upon him to allow amateurs the free use of his revolutionary, as well as epoch-making invention.

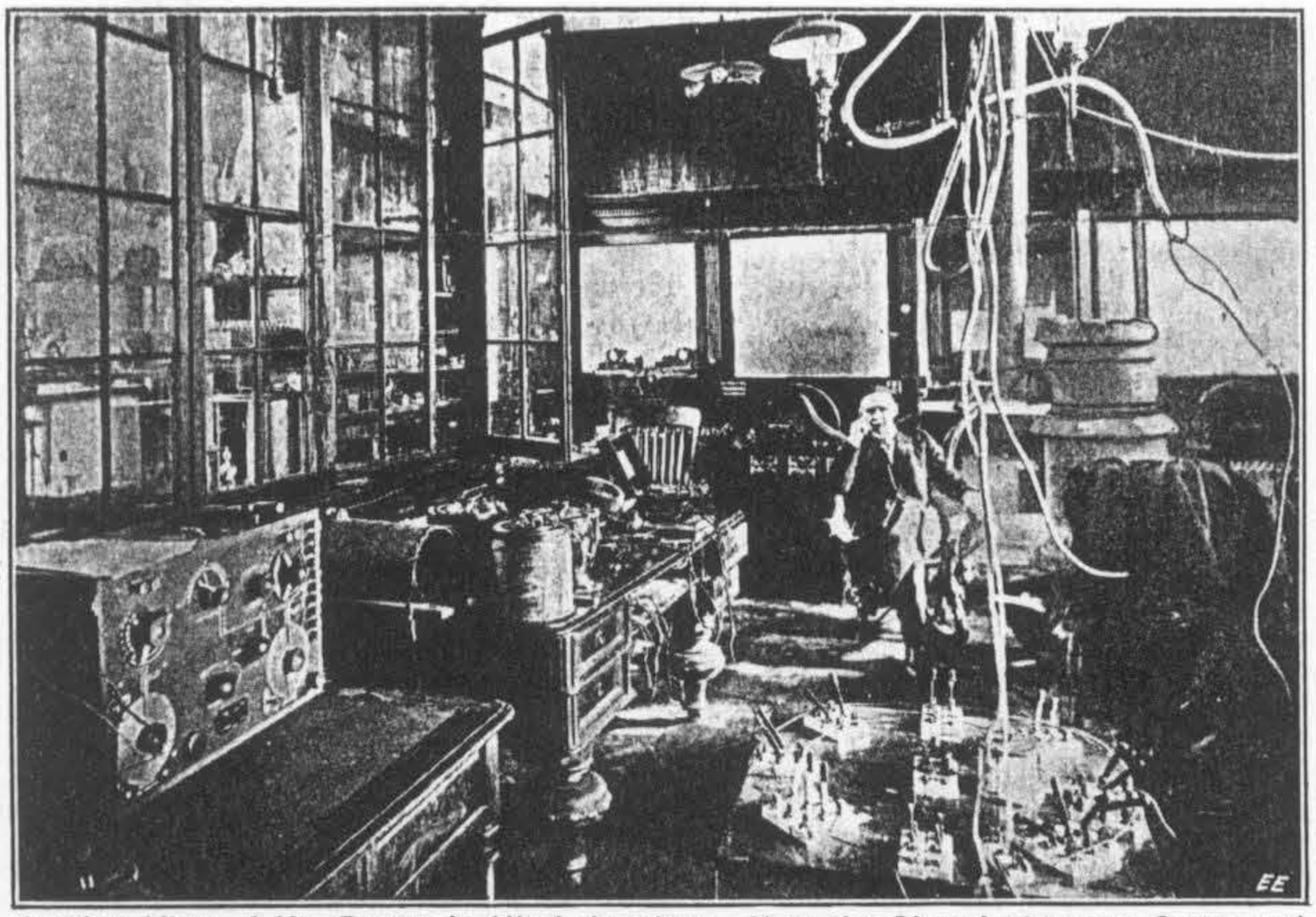
Mr. Rogers thru the ELECTRICAL EXPERIMENTER therefore wishes to announce that he personally has no objection if amateurs use his system privately. It should be understood that the inventor only gives this permission to amateurs as such, and that this permission, of course, does not extend to firms or corporations or to individuals engaged in commercial Radio work.

We wish to congratulate our readers upon this important decision of Mr. Rogers, who certainly deserves the everlasting gratitude of all American Radio Amateurs.

H. GERNSBACK.

near Bladensburg, which he calls "Mount Hooper," in honor of Commander Hooper of the Navy, who rendered excellent service in adapting the invention to the needs of the Navy Department.

When Mr. Rogers first stated that messages could be received and sent from submarines when submerged it was unanimously declared to be impossible and the officials of the Bureau of Standards were not alone in this belief, as no less a personage than Marconi declared at a banquet given in his honor in Washington, that when wireless was used on submarines, **"it was necessary for the submarine to come to the top in order to catch the ether waves."**



Another View of Mr. Rogers In His Laboratory. Note the Glass Instrument Cases, and In the Background May Be Seen His Early Printing Telegraph Model.

To demonstrate more clearly the underground system and to show how it could be used in trench warfare, Mr. Rogers constructed an underground station, wholly inclosed beneath the surface of the earth, there being no visual existence of it outside. This place in Prince Georges county was visited by some very noted men, including Dr. Abraham, the head of the French Scientific Commission, who, upon entering the cave at Mount Hooper exprest his amazement and remarked, "the Germans can't get us here." Lieutenant Paternot, of the French Scientific Commission and the radio representative of France, also heard his native stations talking and exprest equal satisfaction, pleasure and amazement.

How He Conceived the Underground System.

The writer asked Mr. Rogers just how he came to form the idea of the "Underground and Subsea Radio." He explained that from his very first study of the method of transmitting radio signals by means of an elevated antenna, the question constantly presented itself to his mind—"If 50 units of power are past into the aërial, then what becomes of the equal amount of energy which passes into the ground?" He became so obscest with this conundrum that he finally asked several prominent radio savants this question. What do you suppose the answer was?—"It is dissipated in the form of heat in the ground," they answered. But still Mr. Rogers thought they were wrong and now he has proved it. Another early idea of his in the theoretical aspect of radio-communication was as follows, and very logical it was, too, as you will agree: He held that if the outer crust of the earth is a *conductor,* and the surrounding atmospheric envelope is an *insulator,* then how infinitely better must the former be for the transmission of any form of electric current.

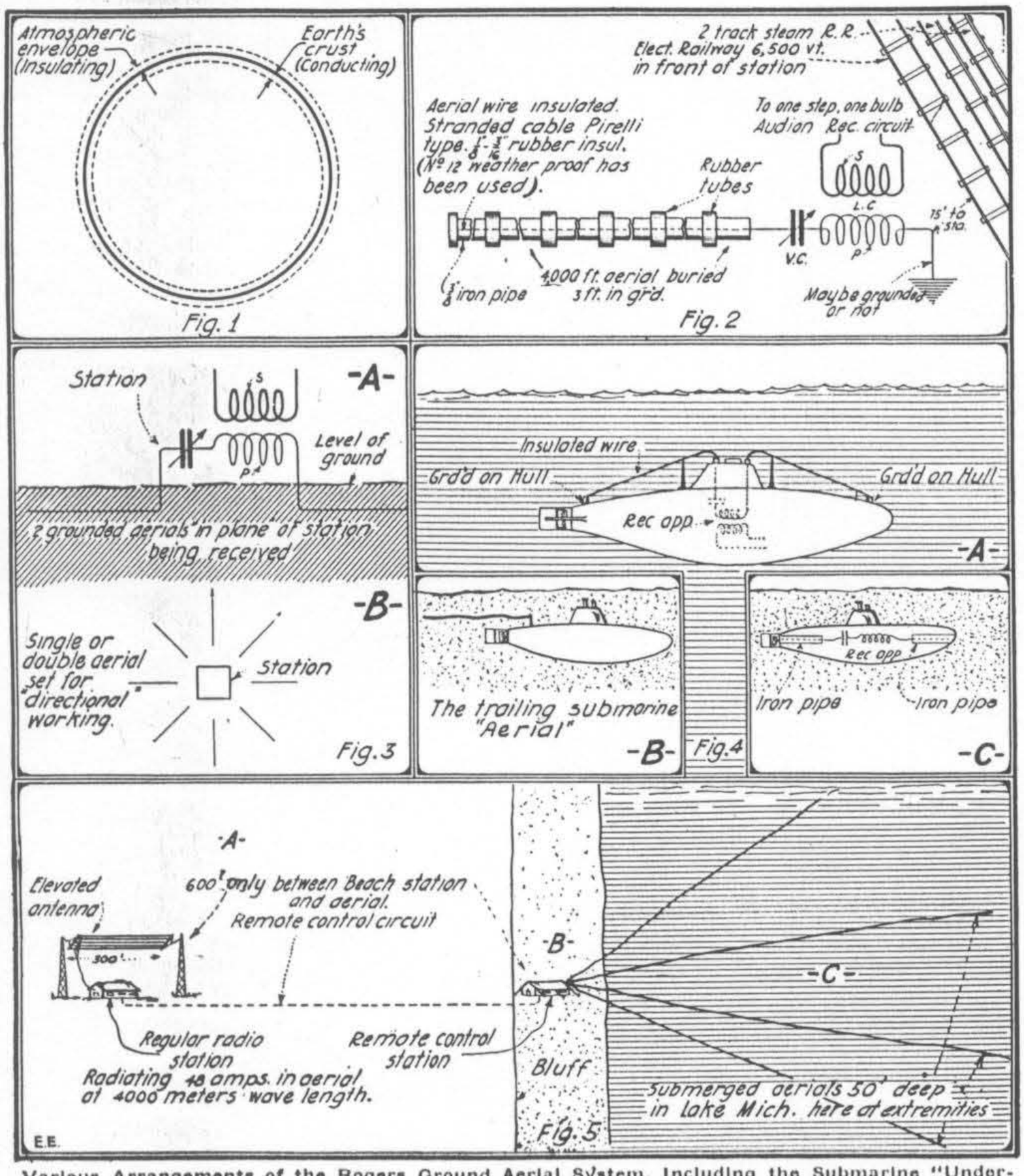
To Mr. Rogers' mind it was more reasonable to suppose that the energy liberated at the base of an aërial was propagated thru the earth as well as thru the ether above, and that an elevated aërial, at great distance, would be actuated by them as effectually as if the waves reached the same point thru the ether above; when the waves thru the earth reached the base of the aërial the potential of the plate would be raised and lowered and the aërial would accordingly be energized. Thus was his basic and original idea conceived and settled upon.

Mr. Rogers' first trial with the underground wireless to nearby radio amateurs began about seven years ago, but his theory of the reason why it must work was formulated over ten years ago. Further, he conjectured that much less power would be required to propagate a wave or current thru the earth's conducting crust, which for one thing has smaller geometrical dimensions, than to propagate it thru the insulating atmospheric envelope alone. See Fig. 1.

The Theory of Operation.

A number of other radical ideas were entertained for several years by Mr. Rogers, and in the course of time he has found that his ideas were correct—it worked! it worked! And now the radio experts far and wide are holding a *post mortem* inquest on their theories and how it all happened. To start with, Mr. Rogers stated, "special credit is due the following gentlemen, who have re-

(*Cont. on page* 832)



Various Arrangements of the Rogers Ground Aerial System, Including the Submarine "Underwater" Antenna.

THE ROGERS UNDERGROUND WIRELESS.

(*Continued from page 789*)

mained enthusiastic and sincere in all the tests and installations made of my under-ground radio system thru all the trials and disappointments of its development, even when the system seemed to prove unworkable. Their perseverance and high skill in the radio art has hastened the official endorsement and the installation of the buried and submerged antenna." Commander A. Hoyt Taylor, D.Sc., U. S. N.; Dr. L. W. Austin, of the Bureau of Standards; Admiral Strother Smith, U. S. N.; Commander Hooper, U. S. N.; G. H. Clark, Expert Radio Aid, U. S. N.; Dr. George W. Pierce, of Harvard University; and Ensign A. Crossley, U. S. N., who has been actively engaged on the installation of the Rogers system at the Great Lakes Naval Radio Station, besides New Orleans, New London, Conn. (test station, now abandoned), and Norfolk, Va.

Like many other great inventions the exact mode of operation is hard to ascertain and define. The views of Mr. Rogers on the operation of this wireless system are briefly defined as follows:—First, that the electric energy liberated at the base of an antenna will be propagated thru the earth even in the absence of etheric space waves above, if such a condition were possible, and which in reality does occur when great distances are signalled over, so he believes. Second, that the propagation of earth waves no more depend upon the ether waves above the surface of the earth than these etheric space waves depend upon the earth waves. Further, that both waves are propagated simultaneously, one above and the other below the surface of the earth, and that at the initial start each is dependent upon the other, altho thereafter neither is dependent upon the other. Furthermore, Mr. Rogers believes that the ether waves gradually die out in intensity in proportion to the earth's curvature, and the distance over which they are propagated, and that at great distances the ether space waves do not have any appreciable effect upon receiving appliances, and that these are energized solely by the energy transmitted thru the earth.

These ground currents travel with the speed of light and are picked up at the receiving station. The space waves persist for an appreciable distance, which accounts for air-plane to air-plane and air-plane-to-earth radio-communciation, but it is the belief of Mr. Rogers that in such long distance radio transmission as half-way around the globe (12,000 miles) that it is the ground wave current that does the work, and that the free space wave above the surface of the earth never reaches the station, due to the high resistance of the atmospheric envelope.

One of the Naval experts present mentioned that it has been found, that the penetration of the ground wave component increases with an increase in wave length. This is an important fact and helps to explain the operation of this new radio system, with its aërials buried in the ground. He also mentioned that "Radio to Mars" or other planets would be impossible, if we are to believe in the well-known "Heaviside" ionization layer, surrounding the earth at a height computed at from 30 to 50 miles, for no etheric wave can pass this layer without being reflected back to the earth, or at least restrained within this passageway.

Rogers System Elliminates "Static" and "Interference".

Mr. Rogers stated that his underground antenna, in itself, did not solve entirely the static or interference problem, but it made the nearest approach to this ideal condition —the goal of all radio engineers—than had ever been accomplisht before. This problem has, thanks to a new arrangement perfected by Commander A. Hoyt Taylor, D.Sc., been solved and *static and interference have been practically totally eliminated, for all-year-around radio service.* Think what an advance this means! Further, *there is no rise and fall in the signal strength during the night or day, at any time of the year, due to the sun's ionization effect, as is the case where elevated antennae are employed.* The U. S. Naval reports and tests made with the Rogers' ground aërial in comparison with the usual form of elevated aërial, several of which are appended herewith, show the incomparable efficiency of this new radio system.

What the Facts Show.

First we will mention the test which Mr. Rogers and a naval officer conducted for the writer. The apparatus used in these tests are shown in the accompanying photographs. They included several large tuning inductances, variable condensers, a one-step audion amplifier (single Audiotron bulb only!) and two pairs of Baldwin 'phones (telephone receivers). This apparatus was connected up to one of Mr. Rogers' latest buried antennas—a single rubber covered, stranded copper cable, about the size of a small ignition cable, extending westward for a distance of 4,000 feet, so as to be in a plane with the high power European radio stations. *This cable is encased in iron pipe* (*gas pipe*), each 20 foot section of which is insulated from the abutting sections by means of a rubber hose (garden hose) slipt over the pipe ends for a few inches. This is buried in a dirt trench about 3 feet deep, filled in with soil. The cable is insulated at the free end and is connected up as in Fig. 2. The rubber covered wire alone has been used in all sub-aqueous tests, and gives fine results when simply buried in the ground, the decay not being so rapid as probably would be imagined. This latest aërial in the iron pipe is a new development and experiments are still going on with it. It works wonderfully well. The 4,000 foot aërial here described is best suited to receiving wave lengths of 6,000 to 16,000 meters. For shorter wave lengths aërials of smaller dimensions are employed.

"Here's the 'Lyons' station in France," said Mr. Rogers. A turn of the knob on the specially calibrated condenser, and there was "Lyons" (France)—sure enough. *Static and interference were unheard.* Next the great stations across the broad Atlantic, at Nauen, Germany; Carnarvon, Wales (England); and Rome, Italy, were heard with equal loudness and clarity. This laboratory station, which has been used by the Navy Department during the war, has picked up practically all the high power stations on the globe. American stations were then picked up by changing the wave length, and finally a test was made on a short (250 feet in length) buried ground antenna, adapted to receiving wave lengths of 200 to 800 meters. Wireless telephone messages were picked up from Washington, a distance of about seven miles. It is most interesting to note at this juncture, as the Naval tests at Norfolk, Va., on a similar aërial have shown, that a radio message from an airplane cannot be picked up on the underground aërial, until the 'plane is directly over the station. This would seem to prove two things—first, that the short waves sent out by the airplane radio set do not penetrate into the ground very far, if at all,—and second, that airplane radio transmission and reception are effected solely by etheric waves.

Referring to Figures 3 and 4, we find several interesting points. Fig. 3-A, shows how a double ground aërial is sometimes connected. Also, as in the case of Mr. Rogers' test station, several sets of these buried antennae are best employed, distributed about the station as shown in Fig. 3-B.

The Rogers underground antenna system has been used at the Belmar, N. J., station during the war with most gratifying results, as reported by the Navy Department, and its successful and unfailing operation during the twenty-four hours of the day, resulted in trebling and quadrupling the capacity of this great trans-Atlantic highway of intelligence communication. The official reports in connection with the work accomplished with the underground Rogers system at Belmar state that not a single word of communication was lost during the reception of thousands of important official messages from Europe. The station at Tuckerton, N. J., has also been equipt with the Rogers underground aërial system and all of the larger stations of the Allied Powers in Europe have been copied successfully thru the 24 hours, at this point also.

Submarine Wireless.

Perhaps the most interesting tests of all are those which were made on *submerged* submarines *in salt water!* The aerial in this case was of heavily insulated stranded cable, stretched from stem to stern as Fig. 4-A illustrates. The two aërials were brought down thru the conning tower and joined to the receiving apparatus. A second form of aërial is illustrated at Fig. 4-B, where the insulated aërial wires are placed in iron pipes within the submarine. Here are the results of some of these tests, which do not include the transmitting tests to the submarine, from a ground antenna on shore. When submerged 8 feet, the German station at Nauen was picked up by the submarine while lying off the American coast! *Submarines have, in other official tests, picked up distant stations when submerged* 21 *feet, on a wave length of* 12,600 *meters or greater wave lengths.*

One of the naval officers, who has had much to do with the testing of the Rogers' system, stated that experience had demonstrated that *in fresh water the submerged antenna may be placed at any depth.* Salt water acts differently, but the aërial may be submerged any desired depth for wave lengths above 10.000 meters.

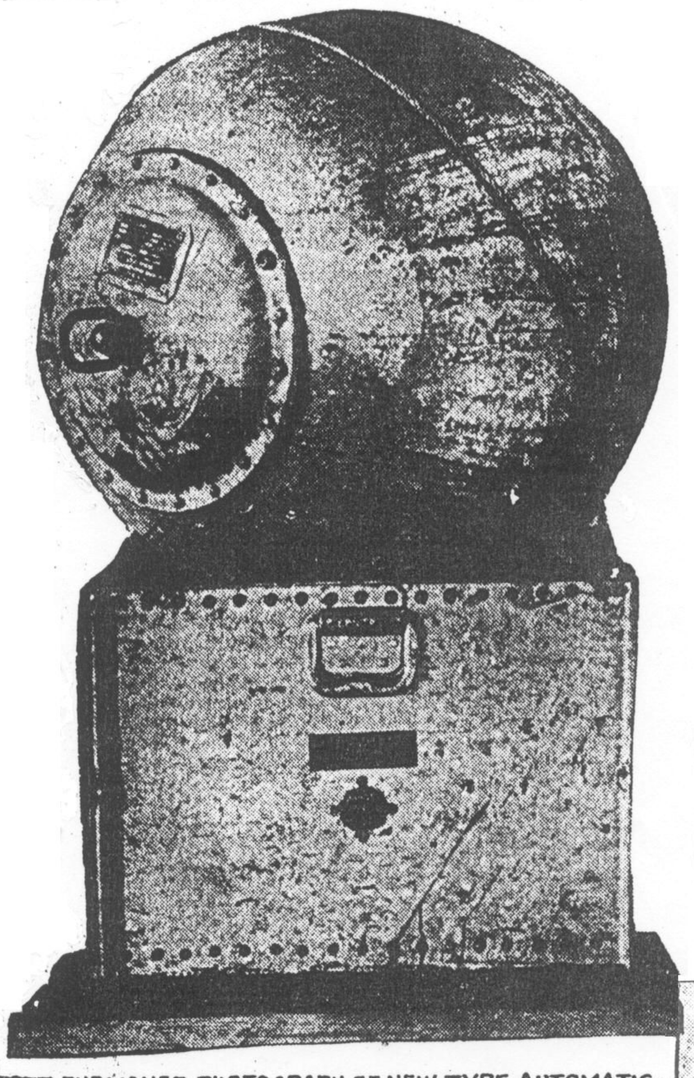
The same officer, who has made a close study of all American and European work in radio, explained how the best work ever done in radio was accomplisht at the Great Lakes Naval Station, on the shore of Lake Michigan. Fig. 5 gives the general arrangement of this station. The test station was on the beach and acted as a "remote control" station for the standard station at A. The shortest distance between a "receiving and control station" in the naval radio service heretofore has been 36 *miles.* Here a distance of 600 feet only, separate the elevated aërial of the main station from the submerged Rogers antenna terminating at the test station, B. Said he, "Now let the inventors of 'static and interference' preventers trot out their little pets, and show what they can DO! Here's what this station *actually did on schedule service*: *With* 48 *amperes, at* 4,000 *meters wave length, being radiated in the elevated main antenna—the beach station,* ONLY 600 FEET AWAY, *was picking up Nauen on* 12,600 *meters, and New Orleans on* 5,000 *meters, without any interference or static —all on the Rogers sub-aqueous aërials.* These were rubber-covered cables spreading in different directions, any one of which could be used, and laying 50 feet deep in the water at their outer extremities.

Imagine such a wonderful performance! But this is not all. The official tests show that the station at Cavite, P. I., 8,100 miles away, was received regularly on the Rogers sub-aqueous aërials at the Lake Michigan Station, *on schedule service,* at 11 A. M. and 5:30 P. M. daily, the working periods of that station.

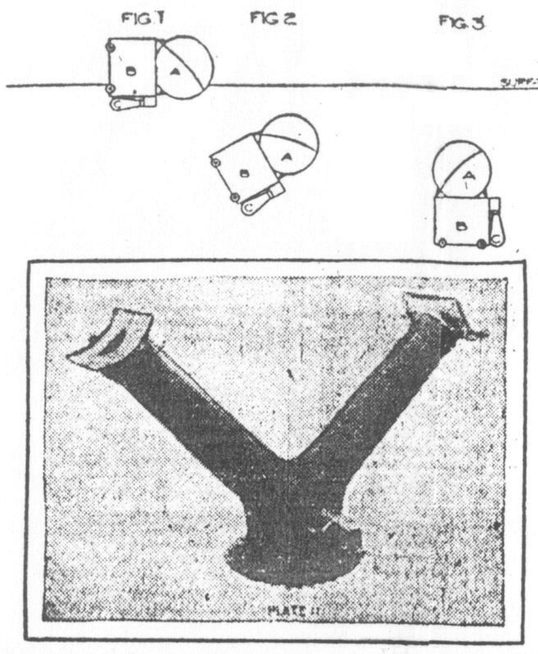
Transmitting On Underground Aerials.

Tests were made by the naval experts, as well as by Mr. Rogers in his very first experiments in transmission from a ground or under-water antenna. *These were all successful.* It is only a matter of properly insulating the antenna so that it will not break down under the high potential applied to it by the transmitter. The early tests by the inventor were made with a one inch spark coil to the Bureau of Standards Radio Laboratory, a distance of seven miles, *the received signals having an audibilty of* 2,000, *i.e.,* 2,000 *times the strength of a clear, readable signal.* The audibility of the signals at the Washington Navy Yard

SOME SCIENTIFIC MARVELS DEVELOPED BY THE GREAT WORLD WAR



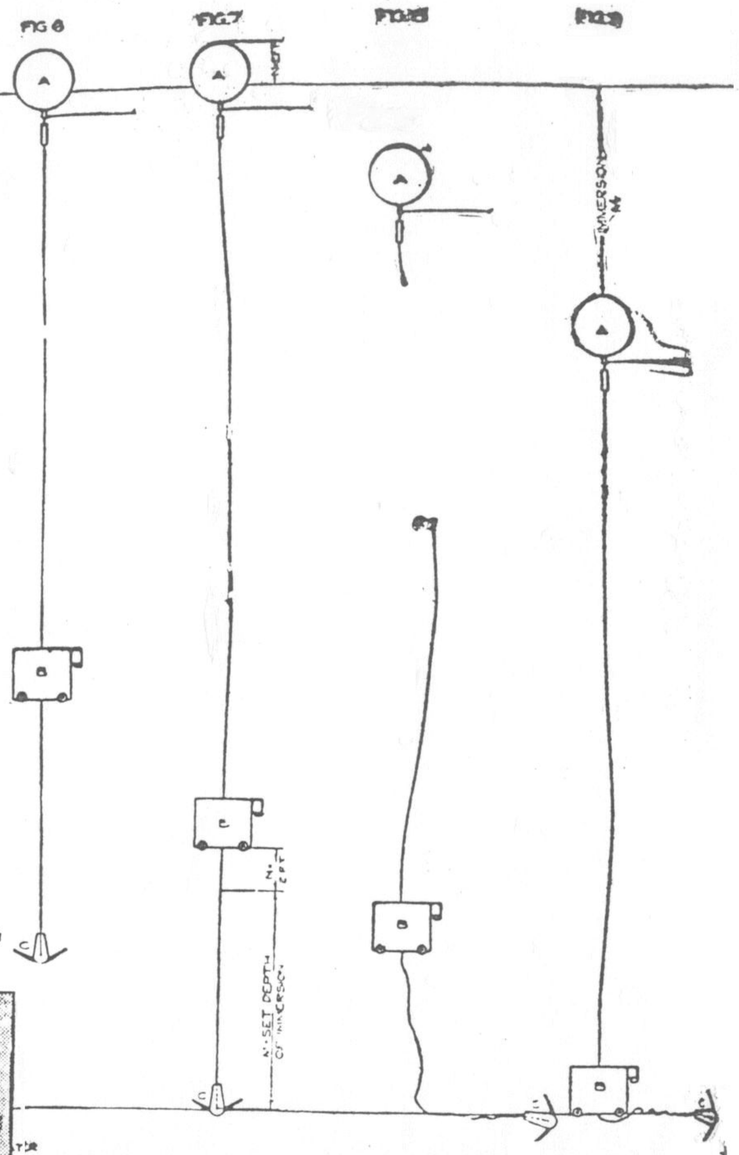
FIRST PUBLISHED PHOTOGRAPH OF NEW TYPE AUTOMATIC-DEPTH SUBMARINE MINE, WITH BOX-LIKE ANCHOR THAT CONTAINS MECHANISM THAT REGULATES THE DEPTH. HUNDREDS OF THOUSANDS OF THESE WERE LAID IN A BARRAGE ACROSS THE NORTH SEA.



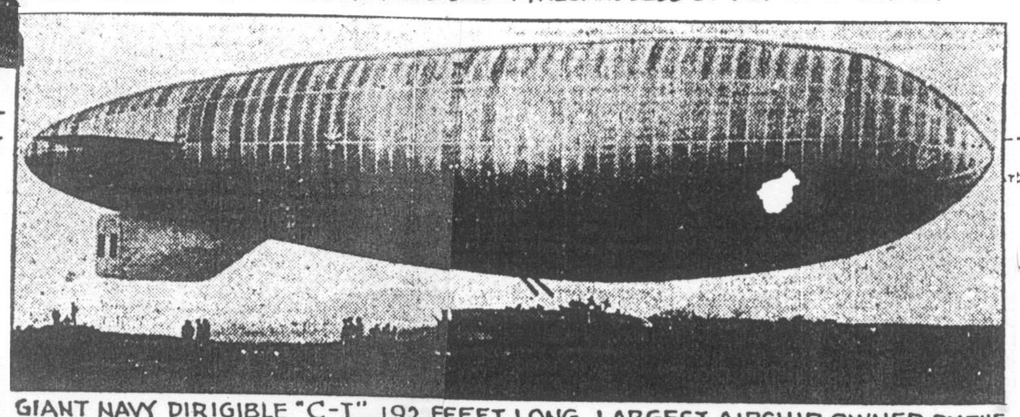
THE "Y-GUN"~ NAVY'S INGENIOUS DEVICE FOR TOSSING TWO DEPTH BOMBS AT ONCE OVER THE SIDES OF A DESTROYER

	FUNCTIONS			
	A	B	C	REMARKS
FIGURE 1.	FIXED	FIXED	FIXED	ON STRIKING WATER
FIGURE 2.	FIXED	FIXED	FIXED	SINKING BUT RIGHTING SELF
FIGURE 3.	FIXED	FIXED	FIXED	SINKING AFTER RIGHTING SELF
FIGURE 4	FIXED	FIXED	FREE AND FALLING	PRESSURE HAS OPERATED PLUMMET RELEASE
FIGURE 5.	FREE AND RISING	FREE AND FALLING	FREE AND FALLING	PLUMMET OPERATES MINE RELEASE
FIGURE 6.	ON SURFACE	FREE AND FALLING	FREE AND FALLING	PLUMMET AT FULL LENGTH
FIGURE 7	ON SURFACE	FREE AND FALLING	TOUCHED BOTTOM.	CABLE DRUM LOCKED
FIGURE 8	SUBMERGING	FREE AND FALLING	ON BOTTOM	MINE SUBMERGING IN POSITION
FIGURE 9.	IN POSITION	IN POSITION	ON BOTTOM	IN FIRING POSITION

DIAGRAMS SHOWING OPERATION OF SELF DETERMINING SUBMARINE MINE, SHOWING HOW IT FINDS ITS PREDETERMINED DEPTH, REGARDLESS OF DEPTH OF WATER—



A-MINE, B-ANCHOR, C-PLUMMET, M-IMMERSION IN FEET, N-2 FT.-DISTANCE MINE SETS OUT OF WATER~



GIANT NAVY DIRIGIBLE "C-I", 192 FFEET LONG, LARGEST AIRSHIP OWNED BY THE AMERICAN GOVERNMENT. DISCOVERY OF METHOD OF PRODUCING HELIUM GAS CHEAPLY FROM NATURAL GAS WELLS INSURES SAFETY OF AIRSHIP FROM FIRE.

A New Era in Invention—Shipbuilding Methods and Devices Worked Out by Scientifically Trained Minds of This Country.

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By FRANK P. STOCKBRIDGE.

It is hardly going too far to say that the most important collection of scientifically trained minds ever assembled in one place, and set to work upon a single group of related problems, was the organization of scientists, inventors and technical engineers gathered at the Navy Department in Washington known as the Naval Consulting Board, headed by the most famous inventor in the world, Thomas A. Edison. Very few people in the Navy Department, and still fewer outside of the Navy Department, realise that for practically the entire period of America's participation in the war Mr. Edison made his personal headquarters in a room in the Navy Department, close to that of the Secretary of the Navy.

He spent almost all of his time, day and night as is his custom, working upon scientific and technical problems which were under consideration by the Naval Consulting Board; to his genius not only as an individual scientist and inventor but as a guide and inspiration to others, were due many of the devices and methods adopted by our navy both for offensive and defensive purposes which proved of immeasurable value in the destruction of German submarines and in keeping the German fleet bottled up at Wilhelmshaven and Heligoland.

Before the armistice was signed the quarters of the Naval Consulting Board and its staff of technicians had expanded until they occupied almost one entire wing of the gigantic new Navy Building in Washington, that wonderful piece of solid concrete construction containing forty-three acres of floor space, which was built, figuratively speaking, almost overnight, by the Navy Bureau of Yards and Docks. Many of the scientific discoveries and inventions which had their practical application developed by the Naval Consulting Board, are still secrets and will continue to be secrets, revealed only to the officers and men charged with responsibility for their operation.

Our army is being demobilized; its military activities are terminated for the time being at least, and in the hope of every American, permanently. But even a league of nations cannot relieve a country, with a seacoast like ours, from the necessity of policing our own shores; a league of nations, indeed, may conceivably require America to participate in the organization, maintenance and operation of an international sea police that will call for even greater naval resources than the signing of the armistice found us possessed of, efficient and extensive as those were.

From War Work to Peace.

So while the concern of the public, other than mere curiosity, with the scientific achievements of the army, is centered chiefly and properly upon the possible application of these technical developments to the pursuits of peace, the matter of our naval strength is one of continuing interest in peace as well as in war, and even though there may be little or no direct application to industry and commerce resulting from the scientific researches and developments of the Naval Consulting Board, some of these secrets, which can now be disclosed for the first time, have an interest and importance extending beyond their usefulness in the war which has just terminated.

Of these technical secrets, so far as they may now be disclosed, perhaps the most important, as they certainly are the most spectacular, are the depth bomb and the Y-gun for tossing it over the side, the method of planting mine fields so that the mines will float at an exact predetermined depth below the surface, the discovery of a non-inflammable buoyant gas for observation balloons and dirigibles, and [illegible] telephone [illegible] with its adaptation to the purpose of detecting thep resence and location of submarines.

Frequent as have been the references in the newspapers to the depth bomb, or, as it is called in the navy, the depth charge, the principle upon which it operates has never been explained. It ie not permissible even yet to disclose the exact details of its operation, but the rather romantic story of its genesis may be told now.

The idea of the depth bomb had its origin in the most audacious scientific "fake" of recent years. About five years ago the scientific world was startled by the announcement that a young Italian inventor had perfected a method of setting off explosives at a distance by means of wireless impulses. The story was plausible. Such wonderful things had already been accomplished by wireless, and the exact nature and possibilities of the Herzian waves were still shrouded in so much mystery, even to the scientists who had been working with them, that anything seemed possible.

Control By Wireless.

The success of John Hays Hammond, Jr., in controlling the machinery and steering of a boat at a distance by wireless had received much deserved publicity; I shall refer in a later article to some of Mr. Hammond's contributions to our navy's technical resources during the war. Nicola Tesla had demonstrated wonderful phenomena attributable to the wireless transmission of electrical impulses.

So when this young Italian announced that he could not only set off a charge of explosives at a distance of several kilometres by wireless impulses, but could control and direct those impulses so that they would travel only at a certain angle and in a given direction, even the most wary scientists received the announcement with an open mind, while technical men not specially skilled in wireless affairs were almost convinced by the mere statement.

The naval value of such an invention would obviously be enormous. If wireless impulses could be directed against an enemy battleship, and thereby cause its mechanism to explode, naval warfare would be revolutionized if not abolished. It is no wonder, therefore, that the Italian Admiralty accepted the young inventor's invitation to a demonstration of his remarkable achievement. Two wireless power stations had been set up some distance apart. It was explained by the inventor that he had not yet so perfected the details that he was able to turn the Herzian waves at will in any direction.

High Explosive Bomb.

He had, however, arranged his wireless projectors, he said, so that the waves from the two crossed at or about a certain point and at this angle, formed by the two streams of wireless waves, any explosive that might be present would be immediately set off.

He had prepared a bomb. The bomb contained a charge of high explosive. It was surrounded by buoyant material wrapped tightly with many wrappings of heavy cord, and varnished so as to be waterproof; the bomb obviously contained no mechanism other than the charge of explosive. The angle formed by the crossing of the two lines of wireless waves, the inventor explained, occurred somewhere in mid-channel in one of the Italian rivers. He was not able to determine the exact point, so the bomb was dropped into the stream and allowed to float down.

Sure enough, when it reached a point approximately where the inventor said it would intercept the two wireless impulses, the bomb exploded. The Admirals and Italian Government officials present were [illegible] impressed. They begged for another demonstration. Not long afterward the same experiment was tried with the same result. The story got into the newspapers. It was printed in the European press; it was cabled to America. Full-page articles were given in the Sunday papers and several other demonstrations were regarded as of sufficient importance to justify cabling the news that they had occurred.

Then, one day, the cables carried the news that the young Italian inventor had eloped with the daughter of the Admiral who had been supervising the experiments for the Italian Government. Nothing more was heard of the inventor. Partially completed bombs found in his laboratory were examined. It was found that they would explode, when placed in water, after a certain period of immersion.

A tiny, almost invisible pin-hole, penetrating from the outside to the interior, admitted water after a slight lapse of time, to contact with a pellet of metallic sodium. Sodium, on contact with water, bursts into a violent flame with accompanying high temperature, and it was this little pellet of sodium that set off the explosive charge, through the action of the water, when the bomb had been in the stream long enough for the water to reach the sodium. The wireless control stations were "fakes." The entire object, so far as anyone has discovered, of the young inventor's effort, was to win the affections of the Admiral's daughter. In this respect his invention may be said to have been a success.

Water Contact Explosive.

It was the suggestion of setting off an explosive by means of water contact which could be delayed until the bomb had been in the water a certain length of time or had reached a certain depth that formed the basis of the invention of the submarine depth charge. The depth charge itself looks like nothing so much as an ordinary galvanized ash can. It is a cylinder, thirty inches high and twenty inches in diamenter. It contains in its interior about seventy-five pounds of trinitroxylol, an explosive even more powerful than the famous TNT.

The mechanism by which this explosive is set off is simple and sturdy enough to be practically fool-proof, and yet at the same time can be regulated with such delicacy of adjustment that the charge will inevitably explode at precisely the predetermined depth, as indicated by a scale and an adjustable pointer on the exterior of the bomb. Water is not admitted to the interior until the external pressure has rached a point which depends upon the depth below the surface. The instant this depth is reached, however, whether it be thirty feet or three hundred feet, the explosion occurs, and so precise and accurate is the operation of the depth charge that there is not recorded a single failure to perform exactly as planned.

Depth bombs are fired in pairs from the Y-gun. In the beginning of their usefulness they were simply dropped overboard from the stern of a destroyer or submarine chaser, which immediately proceeded to go away from there at full speed. By means of the Y-gun, two depth charges at once are tossed overboards striking the water a sufficient distance from the vessel to minimize the danger; although at no time do naval men care to linger long in the neighborhood where a depth charge has just been dropped.

The Y-gun looks like nothing so much as the familiar "siamese coupler" seen in front of tall buildings, to enable the Fire Department to attach two lines of hose to a single standpipe. It is merely a gun with two barrels, set at an angle of about ninety degrees to each other, both barrels being fired by a single charge which is placed in a chamber in the neck of the Y. The depth charge is laid on its side in a cradle, shaped to hold it in position, the cradle having attached to it a stem or arbor which exactly fits the bore of the Y-gun.

Navy Invents Y-gun.

The powder charge used to fire the Y-gun is not as great as that used in the ordinary one-pounder naval quick firing gun. Nothing could be simpler and, as the experience of our destroyers and submarine chasers—all of which are equipped with the Y-gun and a supply of depth charges—demonstrates, nothing could be more effective for the destruction of submarines, once their presence has been detected, than the depth charge. From the viewpoint of military effectiveness the depth charge and the Y-gun probably rank first among the scientific achievements of the Naval Consulting Board.

The biggest single military job our navy did in the war was the laying of a mine barrage across the principal channels of the North Sea, a barrage which could have have been and doubtless would have been extended, had the war continued, so as to make it absolutely certain that any attempt on the part of the German fleet to come out would have resulted in complete disaster. The speed and efficency with which these mines were laid excited the wonder and admiration of the personnel of the British naval forces with which our navy was co-operating.

The mines themselves are marvels of Yankee ingenuity, as well as the method of laying them. A mine laying ship could steam ahead at full speed and lay mines at exactly regular intervals, each mine being anchored in place and so attached to its anchor as to float at an exact predetermined depth below the surface of the water. Our North Sea barrage consisted of some hundreds of thousands of mines placed at three different depths in parallel rows, from seven to fifteen feet below the surface of the water.

How mines can be tossed overboard in a heavy sea, with the sure knowledge that they will remain floating at a fixed spot and at a fixed depth below the level of the water, is a puzzle that even many men in the navy who have been actually engaged in this mine laying work do not fully understand. It is easy to understand how a certain length of cable may be attached to an anchor at one end and a mine at the other and if the depth of the water is known of course the length of the cable can be adjusted to hold the mine at a certain depth below the surface. This is the old fashioned method.

Need Careful Soundings.

It involves very careful soundings for every mine and of a certain amount of guesswork and chance. The water at the point where one mine is placed may be a hundred feet deep; twenty yards farther on, where the next mine is planted, it may be 200 feet feet deep. Another twenty yards and the depth may be 300 feet. These variations in depth make no difference whatever with the laying of the new American naval mines, the mechanism of which I shall attempt to describe as clearly as possible.

The mine itself is a simple affair, consisting of a spherical buoyant chamber containing in its interior a quantity of high explosive and with projections so arranged that a vessel striking the mine from any angle or on any side will immediately set off the explosive. The Yankee trick that enabled us to lay this great North Sea barrage lies in the mine anchor and the mechanism which it contains. The mine anchor is a cubical box of galvanized sheet iron. It is weighted on the bottom sufficiently to furnish a firm anchorage, even in storm weather, for the bomb that floats above it and to which it is attached by a thin wire cable.

Inside the square box of the anchor is a reel from which run two lengths of wire cable. One of these is attached to the mine itself and is long enough to reach from the surface approximately to the bottom in any depth of water in which it is practicable to lay mines. The other cable is attached to a solid lump of metal called a plummet. Before it is launched the mine nests in the open top of the box-like anchor and is attached by a simple catch which loops over a projection on the mine itself. On the bottom of the anchor box are four flanged wheels which run on rails laid on the deck of the mine laying ship.

These rails lead to the stern of the ship and end there at a port through which the mine is launched overboard. Two, three, four or more lines of rails, leading into the launching ports from switches and side tracks inside the ship, where the mines are stored, make it possible to launch mines at the rate of two or three a minute or even faster if necessary.

The trick that determines the depth below the surface at which the mine will float once it is anchored safely at the bottom is turned by adjusting the length of the cable to which the plummet is attached before the mine is launched. Is it desired to have the mine float at a depth of seven feet below the surface? Then the plummet line is exactly seven feet long, and this is what happens when the mine, nested in its anchor box, is dropped overboard:—

Water Frees Trigger.

First the entire apparatus starts to sink, the weight of the anchor dragging the buoyant mine below the surface. A few feet below the surface the water pressure acts upon a trigger, releasing it, and thereby unfastening the catch that holds the mine to the anchor box. The mine rises to the surface, the anchor box continues to sink, its downward progress now accelerated, since it is relieved of the buoyancy of the mine. But the solid plummet has reached the end of its cable and is hanging at the same distance below the anchor that it is desired to have the mine float below the surface.

So long as the weight of the plummet is suspended from the anchor box the windlass or reel from which the mine cable is paid out continues to function and the anchor descends, with the mine itself still floating on the surface. The instant the plummet touches bottom the removal of the strain on the plummet cable releases a catch inside the anchor box, which locks the reel and prevents the paying out of any more cable.

If the plummet cable is seven feet long it is quite apparent that this locking of the reel will occur when the anchor is just seven feet from the bottom. But the anchor continues to sink and pull the mine down with it, now that the mine cable no longer runs freely from the reel. The mine itself, therefore, is drawn down from the surface to a depth of seven feet or to such other depth as may have been determined in advance by the length of the cable of its particular plummet.

This method of planting mines, and the mine anchor mechanism that makes it possible to lay them rapidly and in large numbers, has been among the most carefully guarded of the navy secrets.

Because so much has been said and written about military and naval aviation the impression prevails that the dirigible balloon has proved a failure and that lighter than air types of aircraft are of no importance. Quite the contrary is true. The so-called "sausage" type of captive balloon is one of the most important elements in the observation service of war on land. The development by the navy of the kite balloon, which at a height of a mile or less is towed behind a ship, gives a wider range of observation of the enemy's movements than would be possible in any other way. And the dirigible itself, both the rigid or Zeppelin and non-rigid or "Blimp" type, have been highly developed by the navy.

A very important part of our Navy Department's programme for a larger navy consists in material additions to the fleet of dirigible balloons, and it is due to the work of the scientists of the Naval Consulting Board that the dirigible has now become very much the safest and surest machine for aerial navigation.

Instead of the Zeppelin being a failure, it was in every respect, except that of its extreme vulnerability to direct attack, a great success. The Zeppelin, like every other type of balloon, had the weakness, however, that the only lighter than air gas available in large quantities for filling it was hydrogen, which is the most inflammable of all gases. A single incendiary bullet piercing the envelope of a military balloon ignites the hydrogen, and the balloon crashes to earth in flames. It was only by being set afire that Zeppelins were brought down.

To obtain a substitute for hydrogen was regarded as impossible. The problem was undertaken by American scientists, however, and efforts were directed toward possible sources of supply of the gas helium, the strange substance found in minute quantities in atmospheric air, discovered about fifteen years ago by Lord Rayleigh and Sir William Ramsay. Helium is only slightly heavier than hydrogen, but it is entirely non-inflammable.

Army and navy scientific investigators and experts of the Bureau of Mines co-operated in the effort to solve the problem. It was known that helium is found wherever radio-active minerals are present. Some of the oil wells in the Texas field were known to produce radio-active substances. A series of experiments disclosed the presence of helium in fairly large quantities in the natural gas obtained from wells in the vicinity of Petrolia, Texas.

By a process of refrigeration and compression this gas was treated first for the removal of its gasolene content and then for the extraction of the helium. It was found that, taking the value of the gasolene and other by-products into consideration, the actual cost of the helium so produced was only ten cents a cubic foot. The cheapest it had ever before been produced for was $1,500 a cubic foot!

Government Now Owns Pipe Lines.

As a result of long and patient experiment and triumph over obstacles the United States now owns pipe lines connecting a number of Texas gas wells with a central compression and storage plant where helium is confined under pressure in hermetically sealed tanks, in which it can easily be transported to any point where balloons are to be charged. With the navy planning the establishment of balloon observation posts every few miles along all our coasts, as well as the construction of many more great dirigibles, some of them of the Zeppelin type, the importance of this source of supply of a safe gas for inflating balloons can hardly be overestimated.

So far from having finally settled the controversy between the advocates of the heavier than air airplane and the lighter than air airship, the experience of the war has simply opened the question still wider. The advisability of an unlimited supply of helium gas at a low price has already given encouragement to the adherents of the dirigible as opposed to the plane, and predictions of globe encircling non-stop flights in aircraft, capable of carrying a hundred or more passengers are being made.

The New York Tribune March 2, 1919

Correspondence

A Reply to Dr. Tesla

SIR: Those who read the article of Dr. Nikola Tesla in The Tribune of January 26, which was followed by my letter and his recent reply, know that he takes the position that there is no axial rotation of the moon to be inferred from its always presenting one side to the earth.

My suggestion was that his difference with the astronomers might be one of definition. This has turned out to be the case, at least in part. Professor Young, of Princeton, says, at page 165 of his "General Astronomy." "a body 'rotates' when a line drawn through its centre of gravity outward, through any point selected at random in its mass, describes a circle in the heavens. In every rotating body one such line can be so drawn that the circle described by it in the sky becomes infinitely small. This is the axis of the body." Admittedly the moon rotates in the sense of this definition. It would seem advisable to hold to established meanings of words which have acquired a definite value in any science.

The additional requirement that there be also the existence of energy of motion I think Professor Young would not have objected to except on the score of surplusage. For whatever cause, the turning of the moon is a fact, and it is a familiar law that a body continues in a state of rest or motion until acted upon by some force. A boy's top is set in motion by the boy, but would continue spinning indefinitely except for the friction between it and its support and the lesser friction of the air. Parts of the moon's mass on one side of its axis are travelling toward the sun at various speeds, dependent on their distance from the axis, and an equal number are always travelling in the opposite direction with like speeds. To stop this would take an amount of energy which exactly measures the spinning energy of the moon.

May I quote, also, from "The Tides," by Darwin, chapter 16, on "Tidal Friction," and with reference to the probable genesis of the moon. He says, at page 286: "Doubtless, the moon once rotated rapidly on her axis and the frictional resistance of her (molten) tides must have impeded her rotation . . . The rate of her rotation was (so) reduced. She rotated more slowly, until the tides solidified, and thence forward and to the present day she has shown the same face to the earth." And page 289: "We know that there are neither oceans nor atmosphere on the moon, but if there were such, the moon would have been subject to solar tidal friction and would now be rotating slower than she revolves."

CHARLES E. MANIERRE.

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EDITORIAL

Interplanetary Messages

A FEW weeks ago Marconi startled the world by stating that he had often received strong wireless signals which seemed to come from beyond the earth. In a recent interview publisht in the *New York Evening Post* Nikola Tesla, too, reminds us that he had made known to the world years ago the fact that extra-planetary signals were recorded in his Colorado Laboratory. That was in 1899, before the world dreamt of wireless.

Even today announcements such as the above are made light of by editorial writers and others of limited scientific perception. For the earth-bound layman still persists that intelligence can only exist on Earth. Such childish reasoning shows what sort of "intelligence" blossoms on this planet. It never occurs to these reviewers to question why Nature in her Wisdom should have singled out the little speck called Earth, on which to plant beings endowed with reason. Why should there be such an exception? Life in some form or other is certain of being found on myriads of worlds thruout the Universe. And if one world dies, all life does not die with it. Svante Arrhenius shows us how life-bearing spores are carried by the pressure of light thru interstellar space, notwithstanding the absolute zero which prevails there.

In our planetary system, conditions for life, such as we know it, probably only exists on two planets: Mars and Venus. Life on the latter being more or less doubtful, due to its heavy water-laden atmosphere, there remains Mars, a body much older in evolution than the earth. Conditions on Mars we know by direct observation as well as deduction are favorable for life, and we may be certain that it exists there. And if we once grant this, we must also grant that it must have existed for hundreds of thousands of years prior to that on Earth; consequently Martian civilization must be thousands of years ahead of ours.

From this we must deduce again that the Martians probably signaled to us ages ago, when prehistoric man still roamed the forests. But why go so far back? Suppose the Martians had sent us radio messages only thirty years ago. We could never have received them, for we then had no means of recording them. Detectors and audions were undreamt of.

In all this warped logic, we presuppose wireless signals. But why should a civilization so far ahead of ours use—to them—obsolete radio waves, which, like as not, can never hope to bridge 35 million miles! If the Martians are signaling to us, you may be certain that they use an entirely different means than Radio. To be sure, it may turn out to be one of the many wave forms of the ether, but we can only make a poor guess at it today. Meanwhile Martian signals probably fly about our heads day and night, as they may have for thousands of years, but we are still deaf and blind to them. The Martian Wave Detector still remains uninvented. At that the Martians probably have used many methods on us. It is not even impossible that they may have used reflected sun rays. Bell and Tainter in 1880 demonstrated a "wireless" telephone—the Photophone—by making use of a vibrating light ray falling upon a selenium cell. Speech was transmitted over many miles this way. With necessary refinements such a system might bridge interplanetarian space.

As to one planet understanding the other, that is of course child's play. Still, many humorous editorial writers have misgivings on that score. They are afraid that on Mars 2 + 2 might equal, perhaps, 5 or 3, so how could we get together, they ask.

A simple example might serve as an illustration. Suppose an American and a Frenchman, neither knowing the other's language, were connected by a long telegraph line. Both are ignorant of the code. But both have enough sense to tap the key. Suppose both have the desire to enter into communication, what will they do? Tap out dots from one to ten, of course. Thus . .. . etc. It will not take them many months, if they keep at it, to work out a sort of "international" language by means of dots. And the higher their intelligence, the quicker will they understand each other.

That is the basis of interplanetarian communication.

H. GERNSBACK.

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The Moon's Rotation

By NIKOLA TESLA

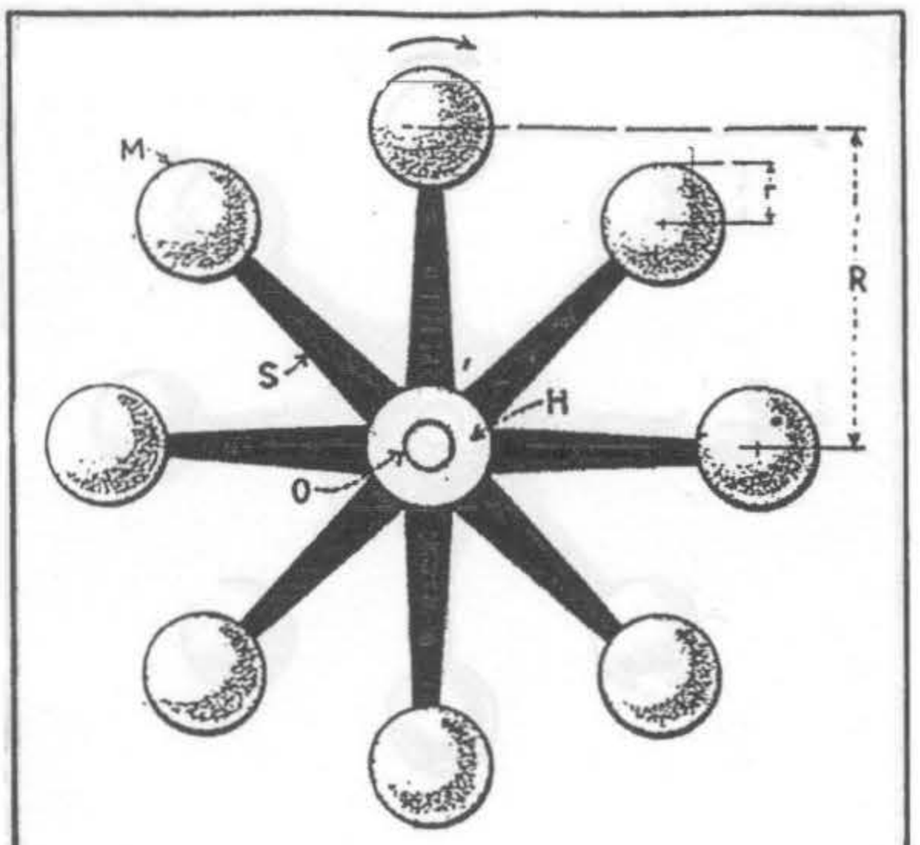
SINCE the appearance of my article entitled the Famous Scientific Illusions" in your February issue, I have received a number of letters criticizing the views I exprest regarding the moon's "axial rotation." These have been partly answered by my statement to the *New York Tribune* of February 23, which allow me to quote:

In your issue of February 2, Mr. Charles E. Manierre, commenting upon my article in the *Electrical Experimenter* for February which appeared in the *Tribune* of January 26, suggests that I give a definition of axial rotation.

I intended to be explicit on this point as may be judged from the following quotation: "The unfailing test of the spinning of a mass is, however, the existence of *energy of motion.* The moon is not posest of such *vis viva.*" By this I meant that "axial rotation" is not simply "rotation upon an axis nonchalantly defined in dictionaries, but is a circular motion in the true physical sense—that is, one in which half the product of the mass with the square of velocity is a definite and positive quantity. The moon is a nearly spherical body, of a radius of about 1,087.5 miles, from which I calculate its volume to be approximately 5,300,216,300 cubic miles. Since its mean density is 3.27, one cubic foot of material composing it weighs close on 205 lbs. Accordingly, the total weight of the satellite is about 79,969,000,000,000,000,000, and its mass 2,483,500,000,000,000,000 terrestrial short tons. Assuming that the moon does physically rotate upon its axis, it performs one revolution in 27 days, 7 hours, 43 minutes and 11 seconds, or 2,360,591 seconds. If, in conformity with mathematical principles, we imagine the entire mass concentrated at a distance from the center equal to two-fifths of the radius, then the calculated rotational velocity is 3.04 feet per second, at which the globe would contain 11,474,000,000,000,000,000 short foot tons of energy sufficient to run 1,000,000,000 horsepower for a period of 1,323 years. Now, I say, that there is not enough of that energy in the moon to run a delicate watch.

In astronomical treatisies usually the argument is advanced that "if the lunar globe did not turn upon its axis it would expose all parts to terrestrial view. As only a little over one-half is visible it *must* rotate." But this inference is erroneous, for it only admits of one alternative. There are an infinite number of axis besides its own in each of which the moon might turn and still exhibit the same peculiarity.

I have stated in my article that the moon rotates about an axis passing thru the center of the earth, which is not strictly true but it does not vitiate the conclusions I have drawn. It is well known, of course, that the two bodies revolve around a common center of gravity, which is at a distance of a little over 2,899 miles from the earth's center.



If You Still Think That the Moon Rotates on Its Axis, Look at This Diagram and Follow Closely the Successive Positions Taken by One of the Balls M While It Is Rotated by a Spoke of the Wheel. Substitute Gravity for the Spoke and the Analogy Solves the Moon Rotation Riddle.

Another mistake in books on astronomy is made in considering this motion equivalent to that of a weight whirled on a string or in a sling. In the first place there is an essential difference between these two devices tho involving the same mechanical principle. If a metal ball, attached to a string, is whirled around and the latter breaks, an axial rotation of the missile results which is definitely related in magnitude and direction to the motion preceding. By way of illustration—if the ball is whirled on the string clockwise ten times per second, then when it flies off, it will rotate on its axis ten times per second, likewise in the direction of a clock. Quite different are the conditions when the ball is thrown from a sling. In this case a *much more rapid* rotation is imparted to it in the *opposite sense.* There is no true analogy to these in the motion of the moon. *If the gravitational string, as it were, would snap, the satellite would go off in a tangent without the slightest swerving or rotation, for there is no moment about the axis and, consequently, no tendency whatever to spinning motion.*

Mr. Manierre is mistaken in his surmise as to what would happen if the earth were suddenly eliminated. Let us suppose that this would occur at the instant when the moon is in *opposition.* Then it would continue on its eliptical path around the sun, presenting to it steadily the face which was always exposed to the earth. If, on the other hand, the latter would disappear at the moment of *conjunction,* the moon would gradually swing around thru 180° and, after a number of oscillations, revolve, again with the same face to the sun. In either case there would be no periodic changes but eternal day and night, respectively, on the sides turned towards, and away from, the luminary.

Some of the arguments advanced by the correspondents are ingenious and not a few comical. None, however, are valid.

One of the writers imagines the earth in the center of a circular orbital plate, having fixedly attached to its periperal portion a disk-shaped moon, in frictional or geared engagement with another disk of the same diameter and freely rotatable on a pivot projecting from an arm entirely independent of the planetary system. The arm being held continuously parallel to itself, the pivoted disk, of course, is made to turn on its axis as the orbital plate is rotated. This is a well-known drive, and the rotation of the pivoted disk is as palpable a fact as that of the orbital plate. But, the moon in this model only revolves about the center of the system *without the slightest angular displacement* on its own axis. The same is true of a cart-wheel to which this writer refers. So long as it advances on the earth's surface it turns on the axle in the true physical sense: when one of its spokes is always kept in a perpendicular position the wheel still *revolves* about the earth's center, *but axial rotation has ceased.* Those who think that it then still exists are laboring under an illusion.

An obvious fallacy is involved in the following abstract reasoning. The orbital plate is assumed to gradually shrink, so that finally the centers of the earth and the satellite coincide when the latter revolves simultaneously about its own and the earth's axis. We may reduce the earth to a mathematical point and the distance between the two planets to the radius of the moon without affecting the system in principle, but a further diminution of the distance is mani- (Cont. on p. 892)

WE believe the accompanying illustration and its explanation will dispel all doubts as to whether the moon rotates on its axis or not. Each of the balls, as M, depicts a different position of, and rotates exactly like, the moon keeping always the same face turned towards the center O, representing the earth.

But as you study this diagram, can you conceive that any of the balls turn on their axis? Plainly this is rendered physically impossible by the spokes. But if you are still unconvinced, Mr. Tesla's experimental proof will surely satisfy you. A body rotating on its axis must contain rotational energy. Now it is a fact, as Mr. Tesla shows, that no such energy is imparted to the ball as, for instance, to a projectile discharged from a gun. It is therefore evident that the moon, in which the gravitational attraction is substituted for a spoke, cannot rotate on its axis or, in other words, contain rotational energy. If the earth's attraction would suddenly cease and cause it to fly off in a tangent, the moon would have no other energy except that of translatory movement, and it would not spin like the ball.—Editor.

The Moon's Rotation

(*Continued from page* 866)

festly absurd and of no bearing on the question under consideration.

In all the communications I have received, tho different in the manner of presentation, the successive changes of position in space are mistaken for axial rotation. So, for instance, a positive refutation of my arguments is found in the observation that the moon exposes all sides to other planets! It revolves, to be sure, but none of the evidences is a proof that it turns on its axis. Even the well-known experiment with the Foucault pendulum, altho exhibiting similar phenomena as on our globe, would merely demonstrate a motion of the satellite about *some* axis. The view I have advanced is NOT BASED ON A THEORY but on facts *demonstrable by experiment*. It is not a matter of *definition* as some would have it. A MASS REVOLVING ON ITS AXIS MUST BE POSEST OF MOMENTUM. If it has none, there is no axial rotation, all appearances to the contrary notwithstanding.

A few simple reflections based on well establisht mechanical principles will make this clear. Consider first the case of two equal weights w and w_1, in Fig. 1, whirled about the center O on a string s as shown. Assuming the latter to break at a both weights will fly off on tangents to their circles of gyration, and, being animated with different velocities, they will rotate around their common center of gravity o. If the weights are whirled n times per second then the speed of the outer and the inner one will be, respectively, $V = 2(R + r)\,n$ and $V_1 = 2\pi(R - r)\,n$, and the difference $V - V_1 = 4\pi r n$, will be the length of the circular path of the outer weight. Inasmuch, however, as there will be equalization of the speeds until the mean value is attained, we shall have $\frac{V - V_1}{2} = 2\pi r n = 2\pi r N$, N being the number of revolutions per second of the weights around their center of gravity. Evidently then, the weights continue to rotate at the original rate and in the same direction. I know this to be a fact from actual experiments. It also follows that a ball, as that shown in the figure, will behave in a similar manner for the two half-spherical masses can be concentrated at their centers of gravity and m and m_1, respectively, which will be at a distance from o equal to $\frac{3}{8}r$.

This being understood, imagine a number of balls M carried by as many spokes S radiating from a hub H, as illustrated in Fig. 2, and let this system be rotated n times per second around center O on frictionless bearings. A certain amount of work will be required to bring the structure to this speed, and it will be found that it equals exactly half the product of the masses with the square of the tangential velocity. Now if it be true that the moon rotates in reality on its axis *this must also hold good for EACH of the balls as it performs the same kind of movement*. Therefore, in imparting to the system a given velocity, energy must have been used up in the axial rotation of the balls. Let M be the mass of one of these and R the radius of gyration, then the rotational energy will be $E = \frac{1}{2}M\,(2\pi Rn)^2$. Since for one complete turn of the wheel every ball makes one revolution on its axis, according to the prevailing theory, the energy of axial rotation of each ball will be $e = \frac{1}{2}M\,(2\pi r_1 n)^2$, r_1 being the radius of gyration about the axis and equal to 0.6325 r. We can use as large balls as we like, and so make e a considerable percentage of E and yet, it is positively established by experiment that each of the rotating balls contain only the energy E, no power whatever being consumed in the supposed axial rotation, which is, consequently, wholly illusionary. Something even more interesting may, however, be stated. As I have shown before, a ball flying off will rotate at the rate of the wheel and in the same direction. But this whirling motion, unlike that of a projectile, neither adds to, nor detracts from, the energy of the translatory movement which is exactly equal to the work consumed in giving to the mass the observed velocity.

From the foregoing it will be seen that in order to make one physical revolution on its axis the moon should have twice its present angular velocity, and then it would contain a quantity of stored energy as given in my above letter to the *New York Tribune*, on the assumption that the radius of gyration is 2/5 that of figure. This, of course, is uncertain, as the distribution of density in the interior is unknown. But from the character of motion of the satellite it may be concluded with certitude *that it is devoid of momentum about its axis.* If it be bisected by a plane tangential to the

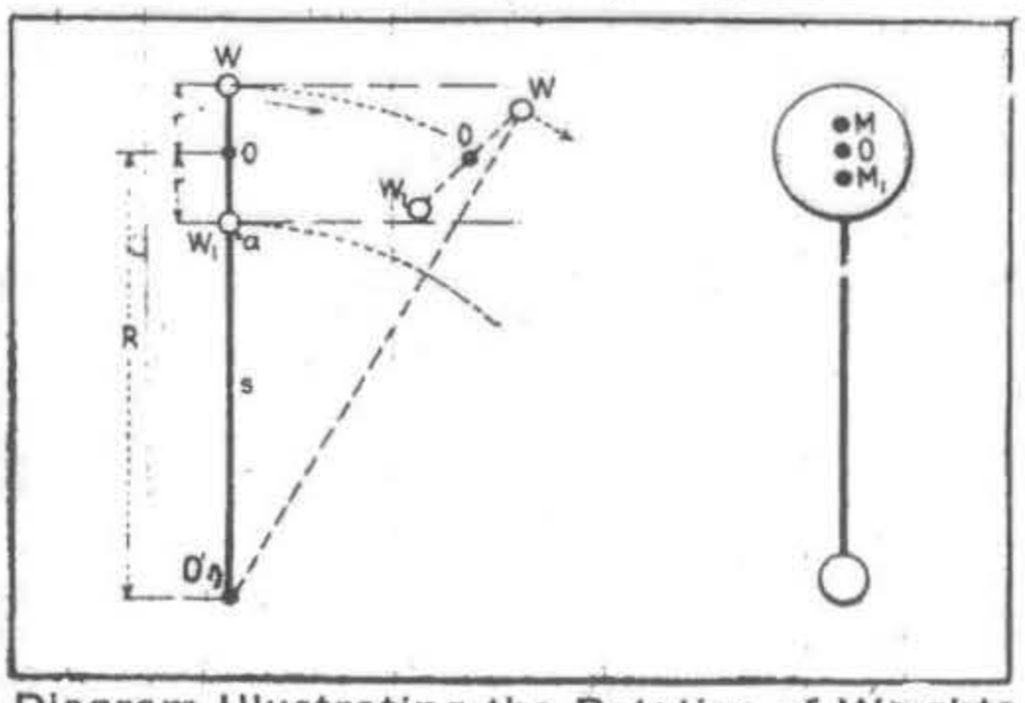


Diagram Illustrating the Rotation of Weights Thrown Off By Centrifugal Force.

orbit, the masses of the two halves are inversely as the distances of their centers of gravity from the earth's center and, therefore, if the latter were to disappear suddenly, no axial rotation, as in the case of a weight thrown off, would ensue.

The Moon's Rotation

By NIKOLA TESLA

In this article Dr. Tesla proves conclusively by theory and experiment that all the kinetic energy of a rotating mass is purely translational and that the moon contains absolutely no rotational energy, in other words, does not rotate on its axis.—EDITOR.

IN revising my article on "The Moon's Rotation", which appeared in the April issue of the ELECTRICAL EXPERIMENTER, I appended a few remarks to the original text in further support and eluci-

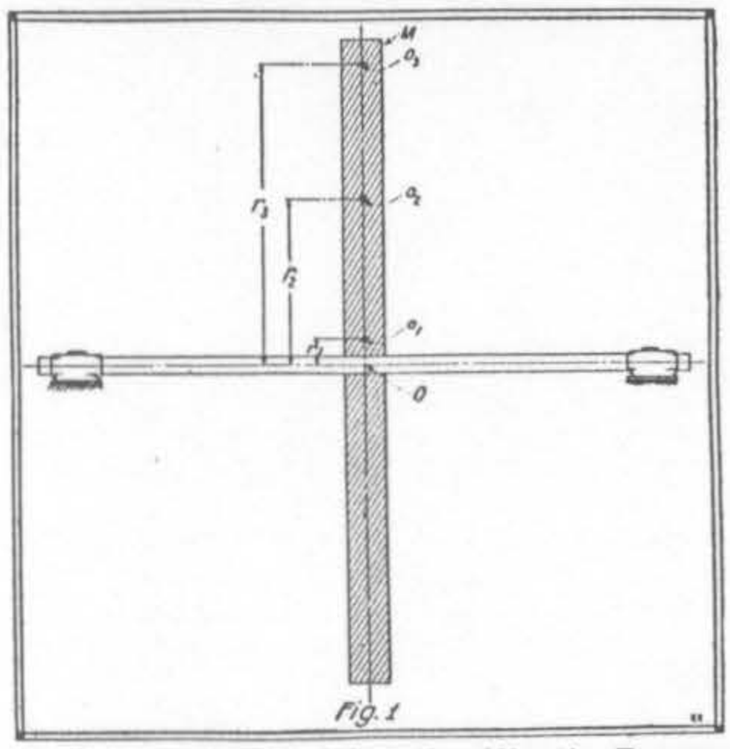


Fig. 1. In Determining the Kinetic Energy of a Rotating Mass, This Figure Shows the Selection of a Number of Points Taken Within the Straight Rod or Mass M, at Successive Distances from the Axis of Rotation O, Knowing These Values and the Speed of Rotation the Kinetic Energy of the Mass Is Readily Computed.

dation of the theory advanced. Due to the printer's error these were lost and, in consequence, I found it necessary to forward another communication which, unfortunately, was received too late for embodiment in the May number. Meanwhile many letters have reached me in which certain phenomena presented by rotating bodies, as the moon's librations of longitude, are cited as evidences of energy due to spinning motion, i. e., proofs of axial rotation of the satellite in the true physical sense. I trust that the following amplified statement will meet all of the objections raised and convert to my views those who are still unconvinced.

The kinetic energy of a rotating mass can be determined in four ways which are illustrated in diagrams, Figs. 1, 2, 3 and 4 and may be found more or less suitable.

Referring to Fig. 1, the method consists in selecting judiciously a number of points as o_1, o_2, o_3, etc., within the straight rod or mass M, respectively at distances r_1, r_2, r_3, etc., from the axis of rotation 0 and calculating the square root of the mean square of these distances. Its value being R_g, denoted radius of gyration, the *effective* velocity of the mass at n revolutions per second will be $V_e = 2\pi R_g n$ and its kinetic energy $E = \frac{1}{2} M V_e^2 = \frac{1}{2} M (2\pi R_g n)^2$.

In Fig. 2 the mass M, rotating n times per second about an axis 0 at right angles to the plane of the paper, is divided into numerous elements or small parts, most conveniently very thin concentric laminae, as l_1, l_2, l_3, etc., at distances r_1, r_2, r_3, etc., from 0. Since the kinetic energy of each part is equal to half the product of its mass and the square of the velocity, the sum of all these elemental energies $E = \frac{1}{2} \Sigma m V^2 = \frac{1}{2} m_1 V_1^2 + \frac{1}{2} m_2 V_2^2 + \frac{1}{2} m_3 V_3^2 + \ldots\ldots = \frac{1}{2} m_1 (2\pi r_1 n)^2 + \frac{1}{2} m_2 (2\pi r_2 n)^2 + \frac{1}{2} m_3 (2\pi r_3 n)^2 + \ldots\ldots$.

A different form of expression for the energy of a rotating body may be obtained by determining its moment of inertia. For this purpose the mass M (in Fig. 3), rotating n times per second about an axis 0, is separated into minute parts, as m_1, m_2, m_3, etc., respectively at distances r_1, r_2, r_3, etc., from the same. The sum of the products of all these small masses and the squares of their distances is the moment of inertia I, and then $E = \frac{1}{2} I \omega^2$, $\omega = 2\pi n$ being the angular velocity.

It is obvious that in all these instances many points or elements will be required for great accuracy but, as a rule, very few are sufficient in practice.

Still another way to compute the kinetic energy is illustrated in Fig. 4, in which case the quantity I is given in terms of the moment of inertia I_c about another axis parallel to 0 and passing thru the center of gravity C of mass M. In conformity with this the energy of motion $E = \frac{1}{2} M V^2 + \frac{1}{2} I_c \omega^2$ in which equation V is the velocity of the center of gravity.

The preceding is deemed indispensable as I note that the correspondents, even those who seem thoroly familiar with mechanical principles, fail to make a distinction between theoretical and physical truths which is essential to my argument.

In estimating the kinetic energy of a rotating mass in any of the ways indicated we arrive, thru suitable conceptions and methods of approximation, at expressions which may be made quantitatively precise to any desired degree, but do not truly de-

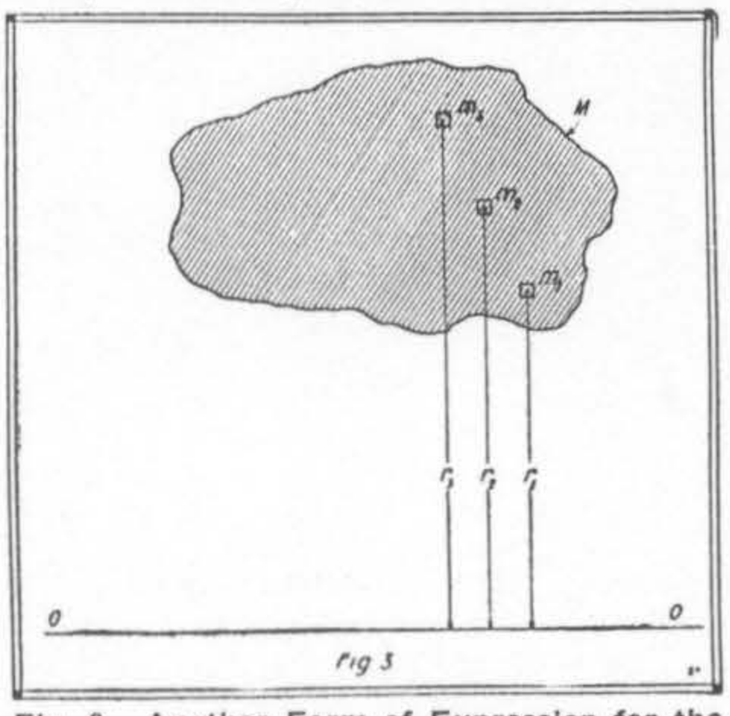


Fig. 3. Another Form of Expression for the Energy of a Rotating Body May Be Obtained by Determining Its Moment of Inertia. Here the Mass M Is Subdivided Into Minute Parts m_1, m_2, m_3, ... etc. The Sum of the Products of These Masses and the Squares of Their Distances Is the Moment of Inertia, Which with the Angular Speed, Gives the Kinetic Energy E.

fine the actual condition of the body. To illustrate, when proceeding according to the plan of Fig. 1, we find a certain hypothetical velocity with which the entire mass should

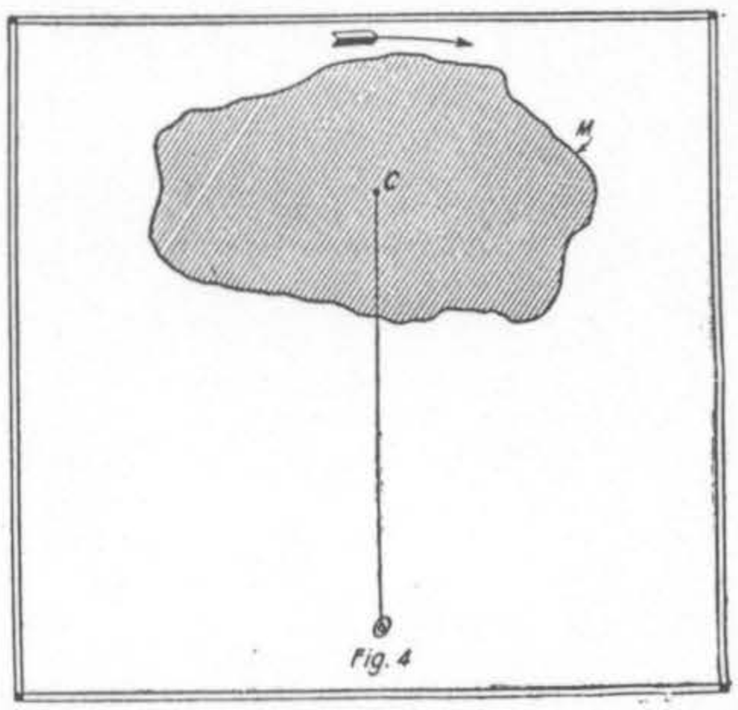


Fig. 4. In this Case the Motion Is Resolved Into Two Separate Components—One Translational About O and the Other Rotational About C. The Total Kinetic Energy of the Mass Equals the Sum of These Two Energies.

move in order to contain the same energy, a state wholly imaginary and irreconcilable with the actual. Only, when *all* particles of the body have the same velocity, does the

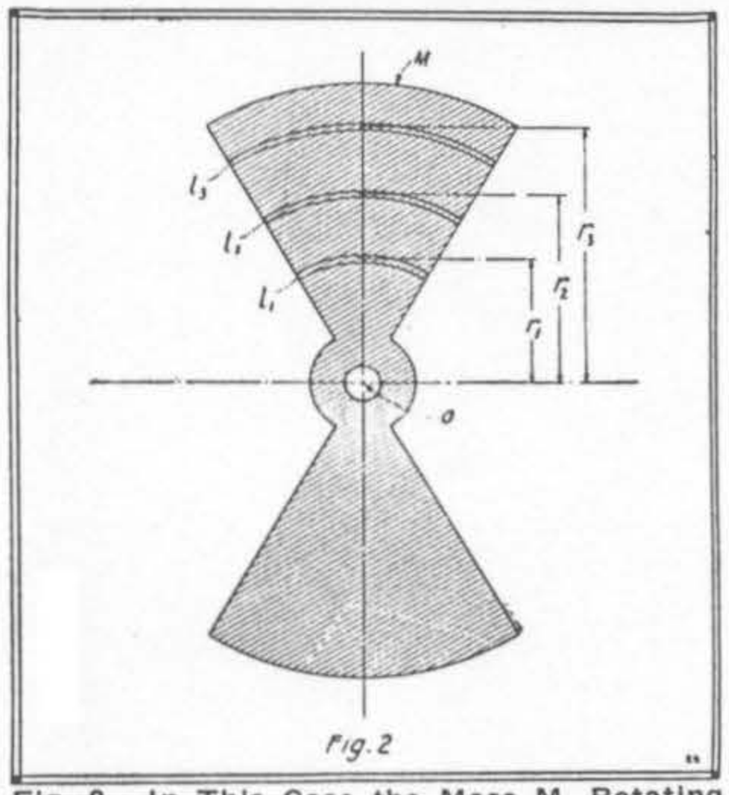


Fig. 2. In This Case the Mass M, Rotating n Times Per Second, About An Axis O, Is Divided Into Numerous Elements or Small Parts at Various Radii from O. Knowing the Kinetic Energy of Each Part, the Whole Kinetic Energy of the Mass Is Easily Determined by Taking a Summation of the Individual Quantities.

product $\frac{1}{2} M V^2$ specify a physical fact and is numerically and descriptively accurate. Still more remote from palpable truth is the equation of motion obtained in the manner indicated in Fig. 4, in which the first term represents the kinetic energy of translation of the body as a whole and the second that of its axial rotation. The former would demand a movement of the mass in a definite path and direction, all particles having the same velocity, the latter its simultaneous motion in another path and direction, the particles having different velocities. This abstract idea of angular motion is chiefly responsible for the illusion of the moon's axial rotation, which I shall endeavor to dispel by additional evidences.

With this object attention is called to Fig. 5 showing a system composed of eight balls M, which are carried on spokes S, radiating from a hub H, rotatable around a central axis 0 in bearings supposed to be frictionless. It is an arrangement similar to that before illustrated with the exception that the balls, instead of forming parts of the spokes, are supported in screw pivots *s*, which are normally loose but can be tightened so as to permit both free turning and rigid fixing as may be desired. To facilitate observation the spokes are provided with radial marks and the lower sides of the balls are shaded. Assume, first, that the drawing depicts the state of rest, the balls being rotatable without friction, and let an angular velocity $\omega = 2\pi n$ be imparted to the system in the clockwise direction as indicated by the long solid arrow. Viewing a ball as M, its successive positions 1, 2, 3—8 in space, and also relatively to the spoke, will be just as drawn, and it is evident from an inspection of the diagram that while moving with the angular velocity ω about 0, in the clockwise direction, the ball turns, with respect to its axis, at the same angular velocity but in the opposition direction, that of the dotted arrow. The combined result of these two motions is a translatory movement of the ball such that all particles are animated with the same velocity V, which is that of its center of gravity. In this case, granted that there is absolutely no friction the

kinetic energy of each ball will be given by the product of ½ M V² not approximately, but with mathematical rigor. If now the pivots are screwed tight and the balls fixt rigidly to the spokes, this angular motion relatively to their axes becomes physically impossible and then it is found that the kinetic energy of each ball is increased, the increment being exactly the energy of rotation of the ball on its axis. This fact, which is borne out both by theory and experiment, is the foundation of the general notion that a gyrating body—in this instance ball M—presenting always the same face towards the center of motion, *actually* rotates upon its axis in the same sense, as indicated by the short full arrow. *But it does not tho to the eye it seems so.* The fallacy will become manifest on further inquiry.

To begin with, observe that when a mass, say the armature of an electric motor, rotating with the angular velocity ω, is reversed, its speed is $-\omega$ and the difference $\omega - (-\omega) = 2\omega$. Now, in fixing the ball to the spoke, the change of angular velocity is only ω; therefore, an additional velocity ω would have to be imparted to it in order to cause a clockwise rotation of the ball on its axis in the true significance of the word. The kinetic energy would then be equal to the sum of the energies of the translatory and axial motions, not merely in the abstract mathematical meaning, but as a physical fact. I am well aware that, according to the prevailing opinion, when the ball is free on the pivots it does not turn on its axis at all and only rotates with the angular velocity of the frame when rigidly attached to the same, but the truth will appear upon a closer examination of this kind of movement.

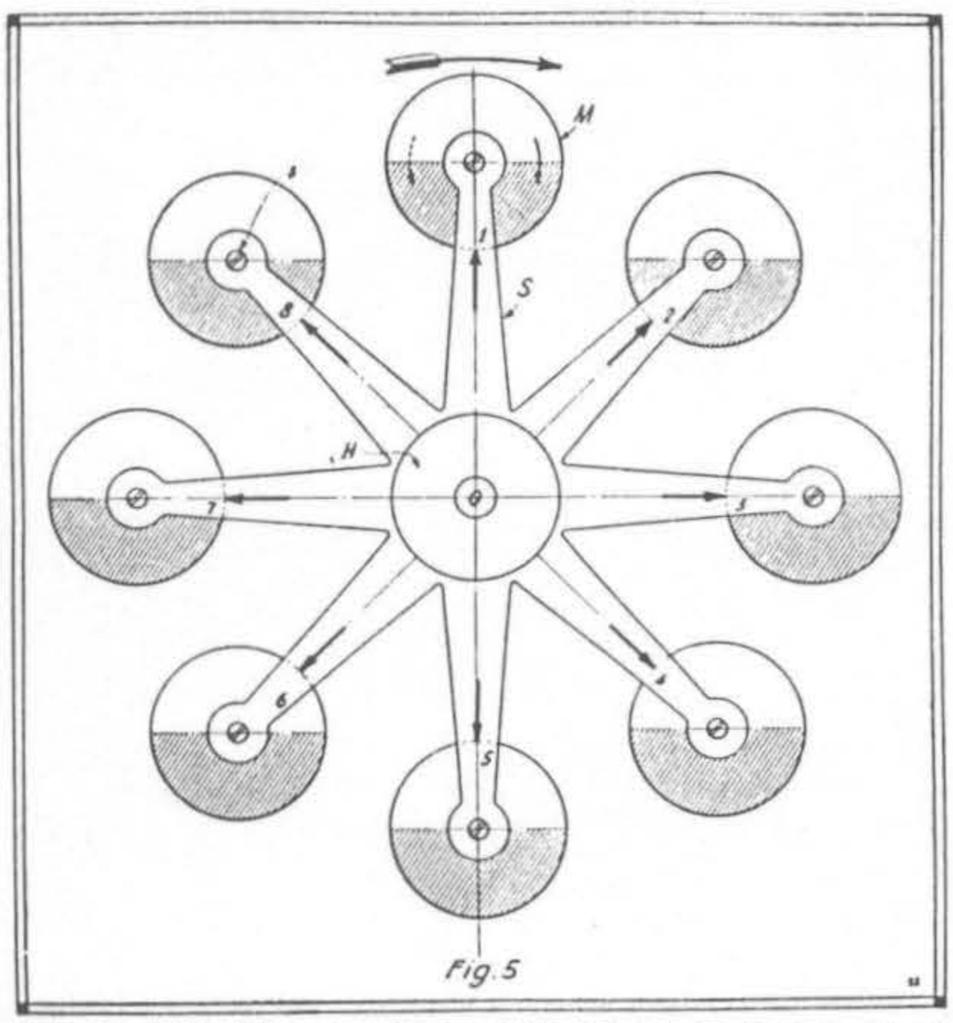


Fig. 5. This Diagram Represents a System Composed of 8 Balls M, Carried on Spokes S, and Rotating Around Center O. The Balls Are Freely Rotatable on Pivots Which Can Be Tightened. With This Model the Fallacy of the Moon's Rotation on Its Axis Is Demonstrable.

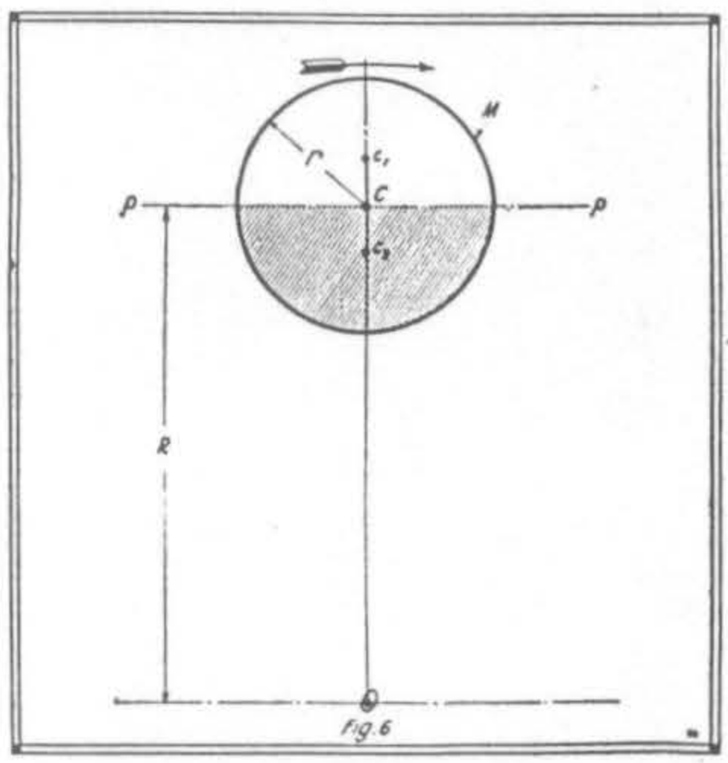


Fig. 6. Diagram Showing a Ball Having Mass M, of Radius r, Rotating About Center O, and Used in the Theoretical Analysis of the Moon's Motion.

Let the system be rotated as first assumed and illustrated, the balls being perfectly free on the pivots, and imagine the latter to be gradually tightened to cause friction slowly reducing and finally preventing the slip. At the outset all particles of each ball have been moving with the speed of its center of gravity, but as the bearing resistance asserts itself more and more the translatory velocity of the particles nearer to the axis 0 will be *diminishing*, while that of the diametrically opposite ones will be *increasing*, until the maxima of these changes are attained when the balls are firmly held. In this operation we have thus deprived those parts of the masses which are nearer to the center of motion, of some kinetic energy of *translation* while adding to the energy of those which are farther and, obviously, the gain was greater than the loss so that the *effective* velocity of each ball as a whole was increased. *Only so* have we augmented the kinetic energy of the system, not by causing *axial rotation* of the balls. The energy E of each of these is *solely* that of translatory movement with an effective velocity V_e as above defined such that $E = \frac{1}{2} M V_e^2$. The axial rotations of the ball in either direction are but apparent; *they have no reality whatever* and call for no mechanical effort. It is merely when an extraneous force acts independently to turn the whirling body on its axis that energy comes into play. Incidentally it should be pointed out that in true axial rotation of a rigid and homogenous mass all symmetrically situated particles contribute equally to the momentum which is not the case here. That there exists not even the slightest tendency to such motion can, however, be readily established.

For this purpose I would refer to Fig. 6 showing a ball M of radius r, the center C of which is at a distance R from axis 0 and which is bisected by a tangential plane pp as indicated, the lower half sphere being shaded for distinction. The kinetic energy of the ball when whirled n times per second about 0 is according to the first form of expression $E = \frac{1}{2} M V_e^2 = \frac{1}{2} M (2\pi R_g n)^2$, M being the mass and R_g the radius of gyration. But, as explained in connection with Fig. 4, we have also $E = \frac{1}{2} M V^2 + \frac{1}{2} I_c \omega^2$, $V = 2\pi R n$ being the velocity of the center of gravity C and I_c the moment of inertia of the ball, about the parallel axis passing thru C and equal to $\frac{2}{5} M i^2$ so that $E = \frac{1}{2} M (2\pi R n)^2 + \frac{1}{5} M r^2 (2\pi n)^2$. Neither of these two expressions for E describes the actual state of the body but the first is certainly preferable conveying, as it does, the idea of a single motion instead of two, one of which moreover is devoid of existence. I shall first undertake to demonstrate that there is no torque or rotary effort about center C and that the kinetic energy of the supposed axial rotation of the ball is mathematically equal to zero. This makes it necessary to consider the two halves separated by the tangential plane pp wholly independent from one another. Let c_1 and c_2 be their centers of gravity, then $Cc_1 = Cc_2 = \frac{3}{8} r$. In order to ascertain the kinetic energy of the hemispheres we have to find their radii of gyration which can be done by determining the moments of inertia Ic_1 and Ic_2 about parallel axes passing thru c_1 and c_2. Complex calculation will be avoided by remembering that the moment of inertia of either one of the half spheres about an axis thru C is $I_C = \frac{1}{2} \times \frac{2}{5} M r^2 = \frac{1}{5} M r^2$, and since $M = 2 m$, $I_C = \frac{2}{5} m r^2$. This can be exprest in terms of the moments Ic_1 and Ic_2; namely, $I_C = Ic_1 + m (\frac{3}{8} r)^2 = Ic_2 + m (\frac{3}{8} r)^2$. Hence $Ic_1 = Ic_2 = I_C - m (\frac{3}{8} r)^2 = \frac{2}{5} m r^2 - 9/64\ m r^2 = 83/320\ m r^2$. Following the same rule the moments of inertia of the half spheres about the axis passing thru the center of motion 0 can be found. Designating the moments for the upper and lower halves of the ball, respectively, I_{O1} and I_{O2} we have $I_{O1} = m (R + \frac{3}{8} r)^2 + Ic_1 = m (R + \frac{3}{8} r)^2 + 83/320\ m r^2$ and $I_{O2} = m (R - \frac{3}{8} r)^2 + Ic_2 = m (R - \frac{3}{8} r)^2 + 83/320\ m r^2$. Thus for the upper half sphere the radius of gyration $R_{g1} =$

$$\sqrt{\frac{I_{O1}}{m}} = \sqrt{(R + \tfrac{3}{8} r)^2 + 83/320\ r^2}$$

and for the lower one $R_{g2} =$

$$\sqrt{\frac{I_{O2}}{m}} = \sqrt{(R - \tfrac{3}{8} r)^2 + 83/320\ r^2}$$

These are the distances from center 0, at which the masses of the half spheres may be concentrated and then the algebraic sum of their energies—which are wholly translatory those of axial rotation being nil—will be exactly equal to the total kinetic energy of the ball as a unit. The

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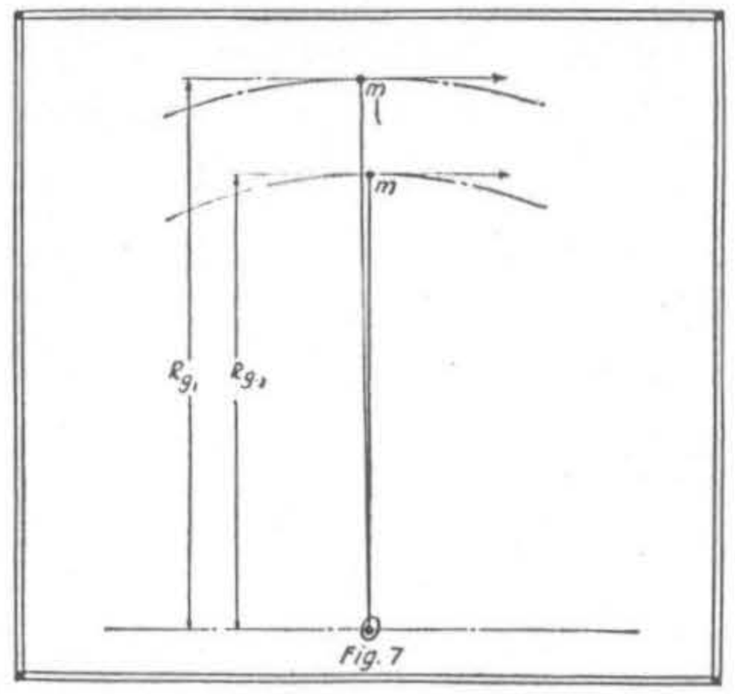

Fig. 7. Here Two Masses m-m, Are Considered as Condensed Into Points, Attached to Weightless Strings of Different Radii. If Both Strings Are Cut, and the Masses Considered as Joined, Then There Will Be No Rotation About the Common Center of Gravity.

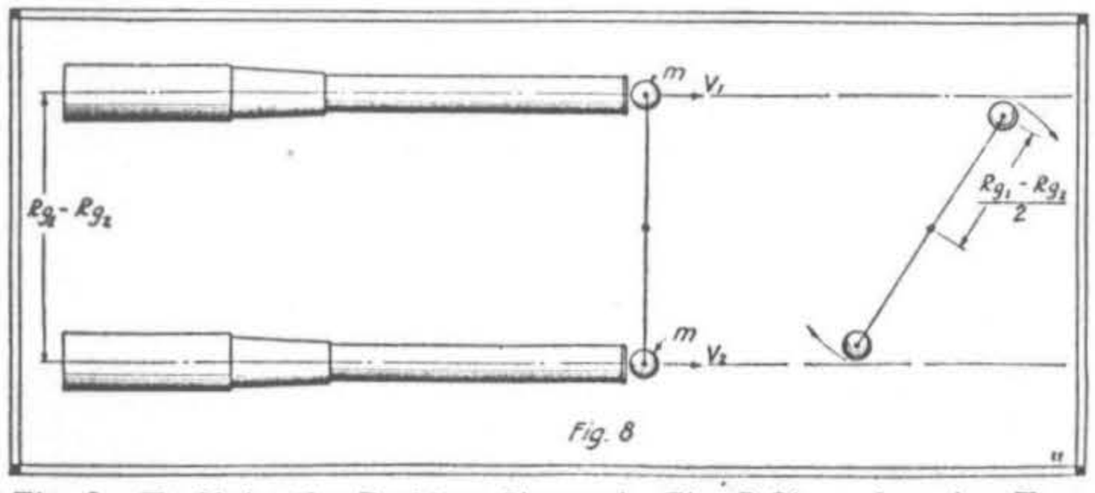

Fig. 8. To Make the Problem Shown In Fig. 7 Clear, Imagine Two Rifle Barrels Parallel to Each Other. If Two Balls M-M Are Fired Simultaneously, Joined by a Theoretical Bond, They Will Revolve About Their Common Center of Gravity, Proving That the Moon Possesses Only Kinetic Energy of Translation.

The Moon's Rotation

By Nikola Tesla

(*Continued from page* 133)

significance of this will be understood by reference to Fig. 7 in which the two masses, condensed into points, are represented as attached to independent weightless strings of lengths R_{g1} and R_{g2} which are purposely shown as displaced but should be imagined as coincident. It will be readily seen that if both strings are cut in the same instant the masses will fly off in tangents to their circular orbits, the angular movement becoming rectilinear without any transformation of energy occurring. Let us now inquire what will happen if the two masses are rigidly joined, the connection being assumed imponderable. *Here we come to the real bug in the question under discussion.* Evidently, so long as the whirling motion continues, and both the masses have precisely the same angular velocity, this connecting link will be of no effect whatever, not the slightest turning effort about the common center of gravity of the masses or tendency of equalization of energy between them will exist. The moment the strings are broken and they are thrown off they will begin to rotate but, as pointed out before, this motion neither adds to or detracts from the energy stored. **The rotation is, however, not due to an exclusive virtue of angular motion, but to the fact that the tangential velocities of the masses or parts of the body thrown off are different.**

To make this clear and to investigate the effects produced, imagine two rifle barrels, as shown in Fig. 8, placed parallel to each other with their axes separated by a distance $R_{g1} - R_{g2}$ and assume that two balls of same diameter, each having mass m, are discharged with muzzle velocities V_1 and V_2, respectively equal to $2\pi n R_{g1}$ and $2\pi n R_{g2}$ as in the case just considered. If it be further supposed that at the instant of leaving the barrels the balls are joined by a rigid but weightless link they will rotate about their common center of gravity and in accordance with the statement in my previous article above mentioned, the relation will exist $\frac{V_1 - V_2}{2} = \pi n (R_{g1} - R_{g2})$

n being the number of revolutions per second. The equalization of the speeds and kinetic energies of the balls will be, under these circumstances, very rapid but in two heavenly bodies linked by gravitational attraction, the process might require ages. Now, this whirling movement is real and requires energy which, obviously, must be derived from that originally imparted and, consequently, must reduce the velocity of the balls in the direction of flight by an amount which can be easily calculated. At the moment of discharge the total kinetic energy was $E = \frac{1}{2} m V_1^2 + \frac{1}{2} m V_2^2$ which is evidently equal to $m V_3^2$, V_3 being the effective velocity of the common center of gravity, from which follows that $V_3 = \sqrt{\frac{V_1^2 + V_2^2}{2}}$. The speed of revolution of the masses is, of course, $\frac{V_1 - V_2}{2}$ and the rotational energy of both balls, which must be considered as points, is $e = m\left(\frac{V_1 - V_2}{2}\right)$. The kinetic energy of translation in the direction of flight is then $\frac{1}{2} m V_1^2 + \frac{1}{2} m V_2^2 - m\left(\frac{V_1 - V_2}{2}\right)^2 = m\left(\frac{V_1 + V_2}{2}\right)^2 = m V_4^2$, $V_4 = \frac{V_1 + V_2}{2}$ being the speed of the

common center of gravity, so that $V_3 - V_4$ is the loss of velocity in the direction of flight owing to the rotation of the two mass points. If instead of these we would deal with the balls as they are, their rotational energy

$$e_1 = e + i\,\omega^2 = m\left(\frac{V_1 + V_2}{2}\right)^2 + i\,(2\pi n)^2$$

i being the moment of inertia of each ball about its axis.

As will be seen, we arrive at precisely the same results whether the movement is rectilinear or in a circle. In both cases the total kinetic energy can be divided into two parts, respectively of the same numerical values, *but there is an essential difference.* In angular motion the axial rotation is nothing more than an *abstract conception;* in rectilinear movement it is a *positive event.*

Virtually all satellites rotate in like manner and the probability, that the acceleration or retardation of their axial motions—if they ever existed—should come to a stop precisely at a definite angular velocity, is infinitesimal while it is almost absolutely certain that all movement of this kind would ultimately cease. The most plausible view is that no true moon has ever rotated on its axis, for at the time of its birth there must have been some deformation and displacement of its center of gravity thru the attractive force of the mother planet so as to make its peculiar position in space, relative to the latter, in which it persists irrespective of distance, more or less stable. In explanation of this, suppose that one of the balls as M in Fig 5 is not of homogenous material and that it is similarly supported but on an axis passing thru its center of gravity instead of form. Then, no matter in what position the ball is fixed on the pivots, its kinetic energy and centrifugal pull will be the same. Nevertheless a directive tendency will exist as the two centers do not coincide and there is, consequently, no *dynamic* balance. When permitted to turn freely on the axis of gravity the body, of whatever shape it may be, will tend to place itself so that the line joining the two centers points to O and there may be two positions of stability but, generally, if the center of gravity is not greatly displaced, the heavier side will swing outwardly. Such condition may obtain in the moon if it had solidified before receding from the earth to great distance, when the

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The Moon's Rotation

By Nikola Tesla

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arrangement of the masses in its interior became subject to gravitational forces of its own, vastly greater than the terrestrial. It has been suggested that the planet is egg-shaped or ellipsoidal but the departure from spherical form must be inconsiderable. It may even be a perfect sphere with the centers of gravity and symmetry coinciding and still rotate as it does. Whatever be its origin and past history, the fact is, that at present all its parts have the same angular velocity as though it were rigidly connected with the earth. This state must endure forever unless forces from without the luna-terrestrial system bring about different conditions and thus the hope of the star-gazers that its other side may become visible some day must be indefinitely deferred.

A motion of this character, as I have shown, precludes the possibility of axial rotation. The easiest way to free ourselves of this illusion is to conceive the satellite subdivided into minute and entirely independent parts, as dust particles, which have different orbital, but rigorously the same angular, velocities. One must at once recognize that the kinetic energy of such an agglomeration is solely translational, there being absolutely no tendency to axial rotation. This makes it also perfectly clear why the moon, provided its distance does not greatly increase, *must* always turn the same face to us even *without any inherent directive tendency* nor so much as *the slightest effort from the earth.*

Referring to the librations of longitude, I do not see that they have any bearing on this question. In astronomical treatises the axial rotation of the moon is accepted as a material fact and it is thought that its angular velocity is constant while that of the orbital movement is not, this resulting in an apparent oscillation revealing more of its surface to our view. To a degree this may be true, but I hold that the mere change of orbital velocity, as will be evident from what has been stated before could not produce these phenomena, for no matter how fast or slow the gyration, the position of the body relative to the center of attraction remains the same. The real cause of these axial displacements is the changing distance of the moon from the earth owing to which the tangential components of velocity of its parts are varied. In *apogee*, when the planet recedes, the radial component of velocity decreases while the tangential increases but, as the decrement of the former is the same for all parts, this is more pronounced in the regions facing the earth than in those turned away from it, the consequence being an axial displacement exposing more of the eastern side. In *perigee*, on the contrary, the radial component increases and the effect is just the opposite with the result that more of the western side is seen. The moon actually swings on the axis passing thru its center of gravity on which it is supported like a ball on a string. The forces involved in these pendular movements are incomparably smaller than those required to effect changes in orbital velocity. If we estimate the radius of gyration of the satellite at 600 miles and its mean distance from the earth at 240,000 miles, then the energy necessary to rotate it once in a month would be only $\left(\frac{600}{240{,}000}\right)^2 = \frac{1}{160{,}000}$ of the kinetic energy of the orbital movement.

Science in Slang

Jazz Stokes on Wireless Dope

By EMERSON EASTERLING

"I SAW a while back in a paper that Tesla and Marconi were expressing their ideas on interplanetary wireless communication. It don't look very reasonable to me that it could be done in the way that they proposed it, but I don't say that the feat is impossible," remarked Jazz Stokes the other night.

"How does a wireless wire?" asked Bender.





Heiney Hertz — Who While Monkeying Around Spark Coils and a Micrometer Spark Gap, Fell over the Hertzian Wave.

"It don't wire, that is why they call it wireless," returned Jazz.

"Well," I put in, "of course, Punk and I know all there is to know about wireless; but for Bender's sake I wish you would tell us a little about wireless."

"You are probably familiar with the African tum-tums and the Indian signal fires," he began. "They were the original form of wireless.

"A scientist by the name of Hertz, Herr Heinrich Hertz, got to monkeying around with spark coils and developing the micrometer spark gap or resonator. This apparatus worked on the principle that electro-magnetic waves radiate from a point of discharge. The twinkling spark between the gap was due to induced current, being virtually a secondary coil of one turn. Well, this set Heiney to deducing, and he deduced the present Hertzian theory of wireless wave radiation.

"While Hein*rich,* never having caught up with the second syllable of his first name, died a poor man, Nick Tesla hadn't been napping either. The whole wireless dope to this bird was an unsealed book as early as 1893, when Marconi still slid down the banister in his knickers. Thus we see Nikola two-stepping it nonchalantly to the Pat. Office, where he grabs the first REAL wireless patent along in 1900. The old boy had it all down in black on white, aerial, ground, spark gap, *et al*—the real, honest to goodness dope. This earned him the title of "Papa of the Wireless." But in those days there were no detectors and few experimenters to boot. So the then wiseacres sniffed at Nick's Patents, tapt their foreheads significantly and made known that this wireless stuff was all loco, bunque, and then some. The same ginks today however sing a different tune and admit that in 1900 THEY were fast asleep and deader than an Egyptian mummy, with heads as solid.

"Then along comes Kid Marconi and devils around with oscillators, sending waves thru buildings and other masses until he gets to work and builds a real wireless telegraphing station. By sticking his aerials up so as to clear the buildings and other masses he finds that he can send and receive for miles instead of blocks. In 1901, on the twelfth day of December, he shoots a 'can-you-get-it' across the Atlantic—and they got it. Soon all the first class vessels were equipt with radio men and added antennae to their rigging, so that they could let the world know that all was off with them by their C. Q. D. and S. O. S. yelps, instead of leaving floating spars upon the briny deep for some brig to sight later.

"Marconi went on improving his apparatus and handled the financial end so that besides being a first rate experimenter and Italian gentleman of standing, he don't have to eat macaroni with a pencil.

"The world wallows along, and the patent offices pile up the documents in the wireless department, when an ardent bird, Dr. Lee de Forest, waltzes on the stage of industry to the tune of ''N' EVERYTHING' and shows us *something.* You might mistake it for an incandescent bulb, but it is as much like a light globe as a Victrola is like a centre table. We call it the Audion Amplifier, and with it in your receiving set you are able to make a squeal a scream. The wireless nuts first found that it was a scream when the ionizing sunlight failed to close the Hula-hula island and 'Frisco communication in the wee sma' hours of the morning, after the hour that the other detectors went bad on 'em.

"For Bender's sake I will give you 'Kicks'* the line up on a simple wireless station. First the transmitting apparatus obtains its juice from batteries or other sources. Is that plain? Yes, well next there is a spark coil that steps the voltage up to a dangerous stage and a spark gap that lets the high tension current break down across the air space. This discharge sets up an oscillating current of high frequency. To increase the efficiency there are condensers inserted in the circuit—these store



Doc "Nick" Tesla—Papa of the Wireless, Who Grabbed the First REAL Wireless Patent in 1900

up and discharge the juice like a nigger squirting prune juice thru his teeth, only very much faster."

Taking a pen and pad from his pocket, Jazz proceeded, "It is like this—see the K is the key; C, coil; c', condenser; A, aerial; G, ground; and B is for the source of juice. Then the receiving station is like this—A, aerial; D, detector; R, receiver. There is added more stuff to sensitize the layout, but they would only look like a telephone central station wiring diagram here on paper, and besides, there are more different kinds than there are ways for a young boy to go wrong.

"In Guglielmo Marconi's original contraption the Signor used a *coherer,* where we use a detector or audion now. The coherer works by being welded by the incoming waves, the electrical resistance being less when the filings in the coherer are welded. The current is so regulated that when the wave waltzes in and unites the nickel and silver filings, the sounder that is connected in the circuit bangs down with a faint tap. The coherer is tapt by a de-coherer, jarring the nickel and silver filings loose for the next dot or dash—*ad infinitum.*

"The detector rectifies the oscillating current, making it fit to vibrate the diafram on the receiver that the 'Radio-bug' has glued to his ear.

"The audion is an incandescent bulb with a parallel grid and plate, working on the theory that current will flow



Kid Marconi Who Devilled Around Oscillators and Who Shot "Can-You-Get-It" Across the Atlantic.

*That word is Kick and not Hick. Kick is a San Francisco slang word—it means almost anything, originating from a kick in booze and now applying to almost anything, good, bad, and indifferent.

(*Continued on page* 911)

SCIENCE IN SLANG.

(*Continued from page* 885)

one way only where the electrodes are of unequal temperature. With the audion, music has even been transmitted with charming effect, and over many miles. With a clever man at the adjusters, a long dash can be construed into a melody. An A flat can be made to sound like a Z sharp; in other words, you would be unable to hear it. As yet they have not got it down so pat that they can run the sound waves into the visual strata and make 'You Made Me What I Am To-day, Now Aren't You Satisfied?' evolve into a likness of Bill Hohenzollern, or "They Are Wearing Them Higher in Hawaii" into an X-ray.

"Tesla, De Forest and Marconi do not hold the whole stage in the wireless field. Prof. Fessenden has bushels of patents in the Pat. office on the stuff, and there are a lot of other guys who have earned the price of a meal from some little thing that makes

(*Continued on page* 918)

SCIENCE IN SLANG.

(*Continued from page* 911)

the wireless more of a success, but who have not had the public notified that they pulled a good one.

"Old Doc. Fleming got a good one in the form of a 'valve,' which is a lot like the audion. It was a close second in the patent office and only lost first place by much wrinkles and perspiration on the part of a wise old judge who weighed the proposition like a pair of assayer's scales.

"Then suddenly just when we kiss the dear old war good-bye, in drops old man Jimmy Rogers. He steps up on the platform, puts up his hand and says, says he: 'Sh, boys, before you put up your aerial zing-magics, see me! Nix on those aerial wires!' We say: 'Thehellusay. Whazzematter with our good old aerial?'

"'Not much,' says Jimmy, 'except that aerials are all wrong. Besides you don't need 'em. Just you take a hundred feet of rubber covered auto cable and bury it three feet underground into a trench, savvy? Hook the loose end to what was once your aerial connection and, presto, in come the messages louder'n a goat on a tin roof. *And* you receive *twice* as far as before, AND the old girl static, who used to tease the life out of you, is gone for good, along with the war. Simple, if you know how!'

"I guess that is about all for to-day—now for tomorrow. We may be able to carry around in our pockets a 'phone that will enable us to talk to our colored friend in Africa—when we are in Siberia or Sing-Sing. The present wireless is a great success—so was the Roman chariot, but the Handley-Page aircraft has it over the old go-cart in more ways than altitude.

"Where are we in the art of cultivation? We thought that we had it down like a scenario until Luther Burbank showed us that cactus did not have to have their stickers and the little posies that we wear on our coat lapels could aspire to the rainbow. Way back in the old ignorant days, when a gink thought that it was no worse to marry his sister and raise a colony than we consider a divorce or Wall Street play, there lived an old bird who observed that a little hoeing and so forth would not hurt a wheat stalk and that other growths were helped thereby. I don't remember the guy's name—it was so long ago—but it seems he was an Egyptian. I would not say for sure though.

"Now look how long ago it was when we got out of the boyhood stage in the electrical game—there are a string of years ahead of us yet—perhaps some electrical Burbanks will show up. Don't get it in your head I am slighting Edison, Tesla, Steinmetz, Marconi, De Forest, Fessenden, and others who now have the WATT under the microscope and wearing their glasses at that. What would Caesar have done had he possest a machine gun or a telephone—what would Edison do with the observations and discoveries of the years to come? Men, we are moving! Moving as men have never moved before!"

TESLA ON HIGH FREQUENCY GENERATORS.

Editor, ELECTRICAL EXPERIMENTER:

It is to be regretted that a letter addrest to me by Mr. J. Harris Rogers, in your care, was published in the march number of the ELECTRICAL EXPERIMENTER, altho the concurrence of our views in some wireless features might have made this desirable to so wide-awake and enterprising a periodical as yours.

Mr. Rogers seems to be a very appreciative gentleman and nothing would be farther from my thoughts than to detract anything from his merit, but in a separate contribution, which I expect to prepare for your next issue, I shall express myself on this subject without prejudice and in the interest of truth. However, the article by your Mr. H. Winfield Secor on "America's Greatest War Invention—The Rogers Underground Wireless" contains a reference to "a novel and original high frequency generator" of Mr. Rogers' invention. May I not —to use the President's elegant expression —call attention to the fact that this device was described by me years ago, as will be evident from the following excerpt of a communication which appeared in the *Electrical Review* of March 15, 1899. In speaking of circuit controllers, I said: "I may mention here, based on a different principle, which is incomparably more effective, more efficient, and also simpler on the whole. It comprises a fine stream of conducting fluid which is made to issue, with any desired speed, from an orifice connected with one pole of a generator, thru the primary of the induction coil, against the other terminal of the generator placed at a small distance. This device gives discharges of a remarkable suddenness, and the frequency may be

(*Continued on page* 914)

TESLA ON HIGH FREQUENCY GENERATORS.

(*Continued from page* 909)

brought within reasonable limits, almost to anything desired. I have used this device for a long time in connection with ordinary coils and in a form of my own coil with results greatly superior in every respect to those obtainable with the form of your letter, make a few statements referring to such make-and-break devices in general, and various forms based on this new principle."

I may add that a great many forms of this apparatus were constructed and employed by me for a long time, proving very convenient and useful. Water does not give particularly good results, being incapable of causing very abrupt changes, but electrolytes have the property of diminishing enormously in resistance when they are heated and the effects are much more intense. Salts of lithium are especially efficient.

NIKOLA TESLA.

New York, February 20, 1919.

COMING INVENTIONS 2

THE THOUGHT RECORDER

By H. GERNSBACK

When the writer first conceived the idea of the thought recorder, he asked three prominent scientists regarding their views on recording thoughts electrically. The letters are reproduced herewith excerpted. It will be noted that Nikola Tesla disagrees with the writer as to thought transmission at all, but his letter nevertheless will give considerable food for thought to many readers.

Dr. Lee de Forest, inventor of the audion, is not too sure about thought transmission.

Dr. Greenleaf Whittier Pickard, the inventor of the silicon and pericon detector, as well as many other wireless specialties, has several interesting ideas, and his letter will certainly prove a revelation, particularly to those interested in radio.

IN studying the evolution of the human specie we must go back to the time when man proper, as we know him, had not as yet arrived on this planet. Our great biologists have irrefutable evidence that everything in Nature works on a slow, laborious plan, one specie being developed slowly into another from the smallest animalculae up to present man. When man was still in the what we may call animal stage, i.e., when he was not "thinking," as that term is understood, he was wholly guided by instinct. His "thoughts," if so they may be called, were probably on a much lower plane than thoughts of the average dog. The chances are that the present day dog probably "thinks" much better than prehistoric man. We also find that thought and language go hand in hand. Crudely speaking, prehistoric man had no better language than any highly developed animal, such as a dog, cat or a horse.

Thru thousands of years of evolution, however, instinct developed into crude thought, and finally there came a time when prehistoric man really began to think, as we know the term. That was the time when he began to utter his thoughts by means of his voice. At first only a few crude words were formulated, and probably consisted of not much more than the gibberish of a chimpanzee. Little by little organized thought arrived, and words, translated into speech kept pace with the advancing thought of man. As the human race kept advancing at a slow pace, its thinking qualities increased little by little, and the senses correspondingly became more sharpened.

This is especially true of the human thinking machinery which perhaps has advanced more rapidly than the senses. Thus we find that certain senses have even been retarded, such as, for instance, sight, smell and hearing. When man lived his wild life it was very necessary for these senses to be much sharper than they are at present; hence our poor hearing, bad sight and very much poorer smell. On the other hand, as the battle for existence becomes more and more acute, and as moreover the battle is not as much physical as mental, it follows that the mind and its thinking machinery should naturally become more and more developed, which, in fact, it does. We may safely say that within the next hundred thousand years—which is only a small span of time in man's evolution—the human mind will be an entirely different sort of apparatus than it is today. Man's mental power will be infinitely greater than what it is at present. Already we have indications that man's thoughts, or the effects therefrom, do not necessarily have to remain *within* his skull, but that they actually radiate from the latter in a very imperfect manner. As the human race advances, there is no doubt that thought transference proper will become an accomplished fact. It has already been shown experimentally by Di Brazza, as well as Charpentier, that concentrated thinking will produce certain external effects, as for instance, a slight fluorescence on a zinc sulfid screen, or a suitably excited X-ray screen. This would tend to prove that thoughts are of an electrical nature, having probably a very short wave length. As most electrical effects in space are depend-

(*Continued on page* 84)

THREE FAMOUS SCIENTISTS' VIEWS ON THOUGHT TRANSMISSION

Altho I am clinging to ideals, my conception of the universe is, I fear, grossly materialistic. As stated in some of my published articles, I have satisfied myself thoroly thru careful observation carried on for many years that we are simply automata acting in obedience to external influences, without power or initiative. The brain is not an accumulator as commonly held in philosophy, and contains no records whatever of a phonographic or photographic kind. In other words, there is no stored knowledge or memory as usually conceived, our minds are blanks. The brain has merely the quality to respond, becoming more and more susceptible as the impressions are often repeated, this resulting in memory.

There is a possibility, however, which I have indicated years ago, that we may finally succeed in not only reading thoughts accurately, but reproducing faithfully every mental image. It can be done thru the analysis of the retina, which is instrumental in conveying impressions to the nerve centers and, in my opinion, is also capable of serving as an indicator of the mental processes taking place within. Evidently, when an object is seen, consciousness of the external form can only be due to the fact that those cones and rods of the retina which are covered by the image are affected differently from the rest, and it is a speculation not too hazardous to assume that visualization is accompanied by a reflex action on the retina which might be detected by suitable instruments. In this way it might also be possible to project the reflex image on a screen, and with further refinement, resorting to the principle involved in moving pictures, the continuous play of thoughts might be rendered visible, recorded and at will reproduced.

Nikola Tesla.

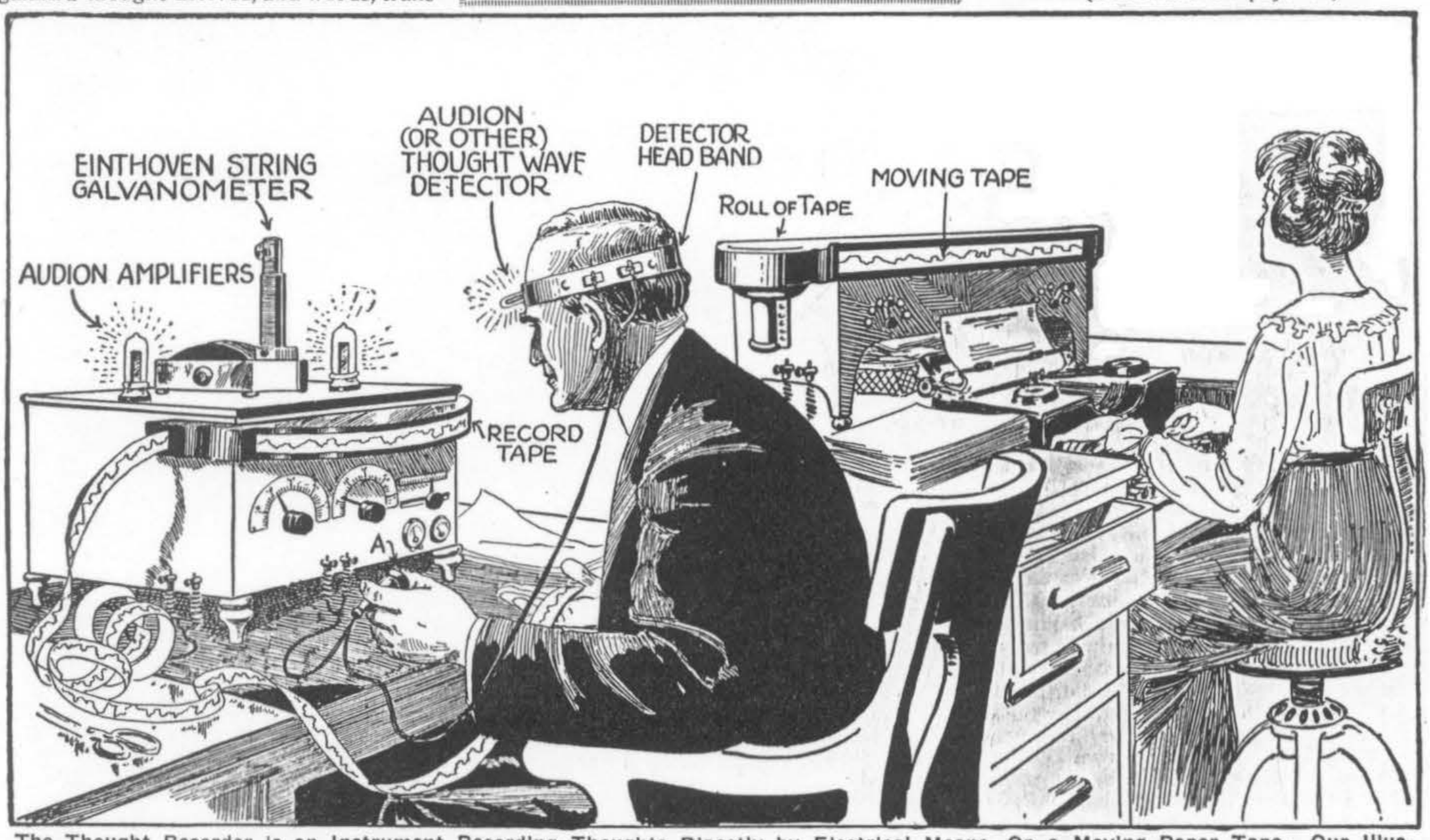
Your article should be an interesting one, particularly as to the audion suggestion. The audion, however, seems to have a certain wavelength limitation, so that unless the waves to be recorded lie between about 3×10^{10} cm. and 3×10^{2} cm., they are not apt to be "picked up."

A more likely range to search would be from 3×10^{2} cm. down to 3×10^{10} cm., that is, down to the harder Gamma rays, or to even shorter wavelengths, starting with the shorter Hertzian waves. Here the audion would be useless, save as a second stage in the detection, i.e., as an amplifier for some other form of detector.

Greenleaf W. Pickard.

While I have little doubt that there is such a thing in nature as transference of thought from one brain to another, I am not aware that sufficient data has ever been gathered on such a highly abstruse subject to permit forming any definite opinion.

Lee De Forest.



The Thought Recorder is an Instrument Recording Thoughts Directly by Electrical Means, On a Moving Paper Tape. Our Illustration Shows What a Future Business Office Will Look Like When the Invention, Which as Yet Only Exists in the Imagination, Has Been Perfected. By Pushing the Button A, the Tape is Started and Stopt Automatically So That Only Thoughts That Are Wanted Are Recorded.

THE THOUGHT RECORDER

(*Continued from page* 12)

ent upon wave motion, it should not be surprising therefore that thoughts or active thinking should give rise to wave motion as well.

This theory is greatly strengthened by the fact that it has been proven beyond doubt that active thinking necessitates an expenditure of energy. If you sit perfectly quiet in a chair without expending any visible muscular energy, and if you concentrate very hard upon a certain problem, it is not infrequent that perspiration appears on your forehead from the simple effort of thinking. Of course, this is rather a complex phenomenon, as the perspiration is not produced directly, but rather indirectly by the nerve centers working upon the human organs, principally the heart. Nevertheless, we know that thinking proper calls for an expenditure of energy in the brain itself. That this energy is considerable can also be shown experimentally.

It therefore cannot come as a surprise that the act of thinking should give rise to a direct wave motion, sending out from the brain certain waves in an analogous manner, to the spoken word which produces sound waves of a certain wave length. It is quite probable, however, that thought waves are simply another form of ether waves, the same as radio waves or light waves. Just as light rays traverse thru a thick glass pane without suffering any appreciable loss, just so will thought waves probably pass readily thru the human skull. If once we admit this theory it follows that it should be possible to detect such waves, and the only thing we need to know about them are the wave length and other important characteristics. We may take it for granted that the human brain, sensitive as it is, probably is not at all sensitive to these waves, and that by suitable apparatus it should become possible to detect such waves.

Just what apparatus are necessary to detect thought waves, or the effects therefrom, the writer does not venture to predict, but there is no doubt that the apparatus will be eventually found. Very little is known about the emission of the thought waves, and as a matter of fact the entire mechanism which produces thoughts is practically an unknown quantity, but every effect can be translated and recorded if once we understand its fundamentals.

Thus, fifty years ago the recording of the voice would have appeared just as fantastic as the recording of thought appears today. People then rightly said, how could it be possible to hold the spoken word; it goes into the air and vanishes instantly. But once acoustics were better understood, it became a simple matter for the inventor of the phonograph to record the voice. Similarly, the day will come when thoughts will be recorded in an analogous manner. All that is necessary, as stated above, is suitable apparatus, and this should be easy to find.

The writer, in suggesting the audion as a thought-wave detector, does not do so because he thinks that it is suitable in all respects, or even feasible. His main idea is to set the stone rolling, and get other people to think about the problem, when sooner or later something surely will emerge. The writer has suggested the audion because it is known as one of the most sensitive electrical detecting apparatus for wave motion which we have today. If thoughts give rise to electrical waves, then by winding a few turns of wire on a headband and slipping it over the head, it should be possible to detect the presence of thought waves in the audion. On the other hand, too, the audion is enormously sensitive to capacity effects,

as is well known. Thus, for instance, an oscillating audion is so sensitive that when the human hand is approached to it at a distance of even two feet, the presence of the hand will be heard plainly in the telephone receiver. If this is the case, the disturbance created in the mind should certainly make its presence felt in the audion, for thinking being first of a chemical nature, the act certainly must give rise to capacity effects. But let us assume that active thinking does not give rise to waves, electrical or otherwise, then the mere chemical action (and resulting capacity effects) should produce a disturbing influence upon the audion. These variations, if ever so slight, could then be amplified by the use of an audion or other amplifier, and the resultant effect be sent into an Einthoven string galvanometer. The small mirror attached to the string of the galvanometer will send its luminous pencil upon a light-sensitive paper tape which moves at a certain rate of speed in front of the mirror. The result will be a wavy line traced upon the paper tape in the well-known manner. The paper tape traveling on will pass thru its fixing tank, and from there will emerge from the outside of the machine after it has past thru a small drying chamber heated by electrical coils.

From this, it will be understood that a man sitting in front of his Thought Recorder will be able to actually see on a tape his recorded thoughts, the same as the telegrapher working on a trans-Atlantic cable watches his tape and its wavy line produced by the Syphon recorder, emerging from the latter. Of course, it will be necesary for everyone to learn the "thought alphabet" just as the stenographer today must learn the various characters, or as the child is taught how to read and write, and as the cable operator must learn how to read the Syphon recorder "alphabet." All this, however, is simple, and is only an educational feature once the apparatus has been invented.

The objection naturally comes to the mind immediately that even if we have a machine to record the thoughts, all we will get on the tape will be a jumble of confused thoughts, and we might get a lot of things on the tape that were not meant for recording or registering at all. Such criticism, of course, is beyond controversy for the simple reason that when you write a letter by hand or on the typewriter, you have also at first a lot of confused thoughts, but you do not record such thoughts even by hand or by machine. It often happens after you have written down certain thoughts that you must change them. The same is true of the thought recorder, of course.

Here the man who is doing the recording has a push button in his hand, shown at A in our illustration; if he does not press the button nothing is recorded. Once he wishes to record his thoughts in an orderly manner, he pushes the button and the tape begins moving simultaneously—he will begin thinking in an orderly and slow manner the subject he wishes to record. He will think just as hard and just the same as if he were to pen down his thoughts by hand. The machine will then do the rest. If he thinks the wrong thoughts, naturally the wrong thoughts will be recorded, exactly the same as if he had written them by hand. There is no difference. In our illustration, our artist has endeavored to show what will happen in the future business office when the thought recorder comes into universal use. The business man of tomorrow will dictate his correspondence on the thought recorder, while his stenographer, who is perfectly familiar with his "thought writing," will type out the correspondence from the tape, which is kept moving by electric motors, in front of her eyes. A foot pedal stops or starts the motor, and there is also a reversing attachment so the tape will run backwards should she wish to re-read a certain portion of the tape.

Cold Light

By ROGERS D. RUSK, M. A.

COLD light is one of the wonders of the modern age. Light without heat seems like a contradiction, nevertheless it is a scientific fact. Since the discovery of the electrical

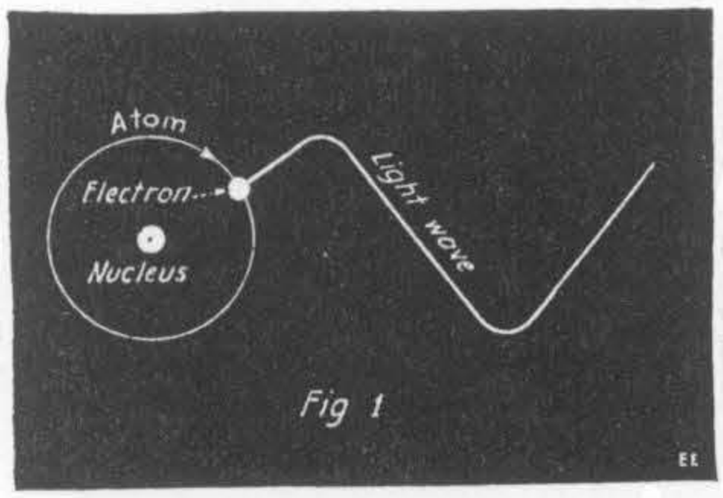


Diagram Illustrating the Old Theory of Light Produced by Electricity. In This Explanation the Electron is Considered as Continuously Producing Light Waves by Its Rotation. The Newer Theory of Light and Heat Waves is Shown at Fig. 2.

nature of light, the possibility of transforming electricity directly into light, without the production of heat, has been a tempting goal. For centuries, scientists dreamed of solving the mystery of the *firefly* and the *Aurora Borealis*, but dreamed in vain. They saw light without heat produced in Nature, but could not produce it themselves.

Today the discovery that light may be produced without heat, by means of electrical ionization, seems to be the key to the situation, and we can only wonder where it may lead us. At the present time over 96 per cent of all the energy used in the fifty million incandescent lamps in the United States, instead of being turned into light, *is wasted in the form of heat!* Moreover the astonishing production of light without heat by ionization has given us a new view of the relation between light and electricity and the great problem of the origin of light.

It used to be thought that light could only be produced by incandescence, that is, thru heating of a solid body to white heat. Strange as it may seem, the candle and the kerosene lamp are really incandescent lights. The light they give off is due to white-hot particles of carbon liberated in the combustion process. Even the light from an arc lamp is mainly due to the crater in the positive carbon being heated to incandescence.

The fact that heat is not the only factor which effects the production of light can be easily seen in two ways. First, salts of sodium, potassium and lithium may be thrown in the same flame at exactly the same temperature, but the first gives off a bright yellow light, the second a violet, and the third a deep red. Second, light is produced by an electric spark in a partial vacuum, such as a Geissler tube, *with little or no heat at all.* In both of these cases the light *must* be produced by the breaking up of the molecules, of the solid or gas, into electrically charged particles, or ions, in a manner to be explained later.

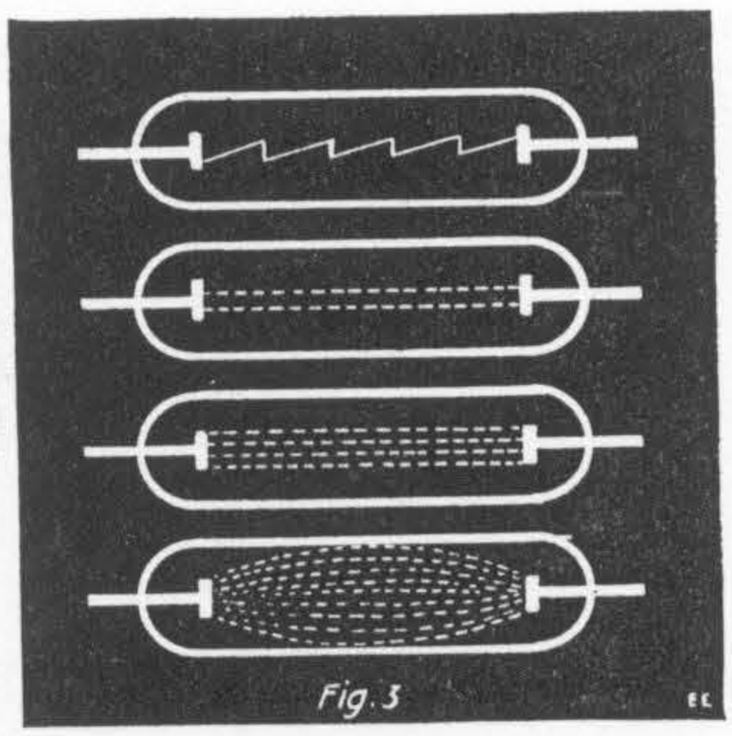
The idea of using cold light for illuminating purposes seems to have first occurred to Nikola Tesla. Very early in his career he suggested that the effects produced in Geissler tubes might be utilized in that way. Not until recent years, however, did his suggestion bear fruit in the shape of the now famous Moore *vacuum tube* light, invented by McFarland Moore, which produces a fine soft light from a glass tube thirty to forty feet long, filled with carbon dioxid. The heat which this light produces is almost negligible.

Cold light is a term used to indicate luminous radiation *without* heat radiation, and that means maximum efficiency, i.e., a colder and a colder source. The old fashioned kerosene lamp wastes 36.4 calories of heat per second for every candlepower of light produced. The gas mantle wastes 11, and the tungsten lamp but from 1. to 2. calories.

Considering electric lights only, the heat loss in tungsten lamps has been reduced by the introduction of gases such as nitrogen into the bulb, but arc lights have made a greater development. The invention of the enclosed arc reduced the heat loss without reducing the illumination. Then the invention of the flaming arc increased the illumination without increasing the temperature of the arc. The latter is the most interesting development because part of the light from the flaming arc is *cold light,* from the chemicals in the flame which are ionized by the electric current. The cold light from these ions plus the light from the incandescent carbons makes the flaming arc nearly *three hundred per cent* more efficient than the ordinary incandescent lamp.

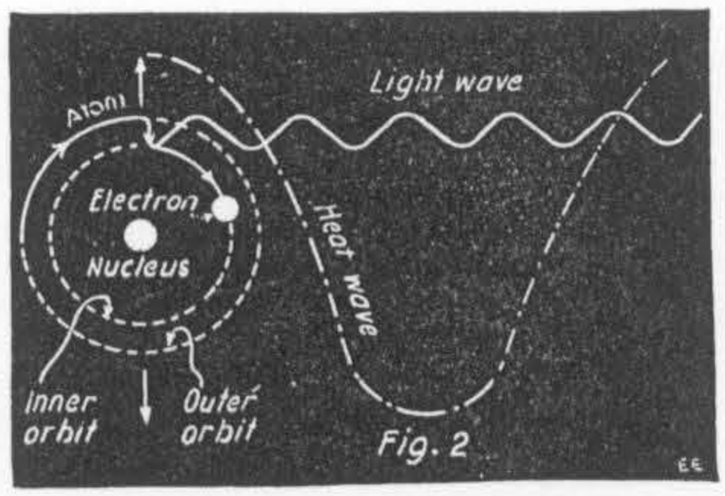
The first flaming arc appeared in 1900, known as the Bremer arc, and using carbons impregnated with several chemical salts. Later Steinmetz and Whitney used the rare metals titanium and chromium in their arcs and produced a still more efficient light. About the same time the *mercury vapor* light was invented, which gave a brilliant bluish white light from the mercury ions in the arc. Later still is the discovery by two scientists, Franck and Hertz, that an electric current of only 4 volts, when past thru *cold iodin vapor,* produces a faint light of definite color. When the voltage is raised to twelve, another color is obtained. This is *true cold light,* produced directly from the molecules as they are ionized by the current. How this is possible, and how light and heat may be produced independently of each other, will now be shown.

What the actual source of a light wave is has been one of the mysteries of science since the beginning of history. The discovery by Maxwell, Hertz and others that light is an electro-magnetic vibration, caused scientists to look for the electric charges which produce these waves. When the electron was discovered it was thought that the solution had been found, but there



How "Cold Light" May be Obtained by Exhausting an Ordinary Glass Tube. When Air is Pumped Out of a Tube In Which There is an Electric Spark Discharge, a Stage is Reached Where the Whole Tube is Filled with a Soft Luminous glow—Cold Light.

was still one great drawback. Scientists said that as the electron revolved about its axis in the molecule it produced light waves just like a paddle wheel in a body of water. But as all molecules of all substances con-



The New Theory of Light and Heat Waves, Which Says that Light is Produced Intermittently. Here Light is Produced by the Electron Jumping from One Orbit to Another, as the Circular Orbital Paths Indicate.

tain electrons which are constantly in motion, then all substances should give off light all the time. This was ridiculous, as everything in the world and the whole universe would be of a dazzling brightness like the sun.

The discoveries of today are changing this idea completely. One of the world's greatest physicists, Planck, says electrons cannot give off light waves continuously, but emit definite quantities at intervals. This theory he calls the *quanta theory,* and another physicist, Bohr, says the time the light is given off is when the motion of the electron is suddenly changed from its normal continuous motion, by its jumping from one atom to another, or from one orbit to another about the same atom. This is a very simple theory, but it is often the simplest theory which best explains the facts. When trillions of trillions of electrons are doing this at the same time, the light is to all purposes continuous. These theories have received added confirmation from work done recently by Prof. Millikan of Chicago University, who gained fame by his original measurements of the electron itself.

The principle of the new theory can be easily explained by an illustration. If a ball is whirled in a circle on the end of a string, the pull on the string is steady and continuous as long as the ball whirls with the same speed. However, if the ball is suddenly stopt or hit by something which makes it change its course, a jerk or a wave will be felt in the string. Now an electron does the same thing, only the jerk or wave is sent out in all directions by the electro-magnetic field about the electron. This jerk or wave is the little quantity which Planck calls a "quanta". The familiar way in which an electron is pictured as continuously producing light waves, by its rotation, is shown in Fig. 1, but this is wrong according to the above theory. What really must happen is shown in Fig. 2, where the two circles represent different orbits and the full line represents the path of the electron jumping from one orbit to another and at the same time emitting a quantity of radiation or *light.* The way in which electricity or some other agency causes this disturbance of the electron is not fully understood.

The most remarkable thing about it all is that heat and light waves may be produced independently. A heat wave is produced by the vibration of the whole molecule or atom as shown by the big arrows and dotted wave line in Fig. 2. And under

(*Continued on page* 73)

COLD LIGHT

(*Continued from page* 23)

proper conditions the small light wave may be given off by the electron without affecting the whole molecule in the least. *That is cold light.*

An interesting experiment can be performed with a vacuum tube, which illustrates completely the principle of light production by ionization, and at the same time explains the principle of the Moore light. Few people, other than scientists, realize what a peculiar thing the production of light in a vacuum or Geissler tube is. The light is evidently not the product of heat, but depends on the fact that the electric spark breaks the gas molecules up into charged particles or ions. And this phenomena is most noticeable when a certain degree of exhaustion is reached in the tube.

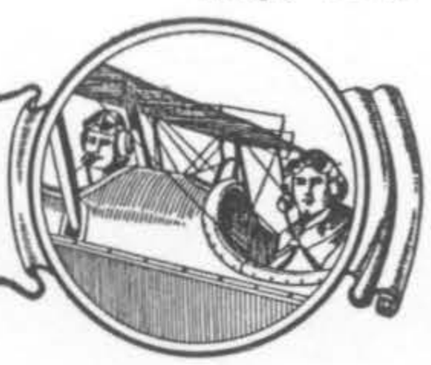
When air is pumped out of a tube in which there is an electric spark discharge, several different stages, as shown in Fig. 3, are successively reached. At first the discharge in the tube is the ordinary disruptive spark. In the next stage it forms a quiet thread of light thru the tube. Then the thread of light becomes a broad pencil of light, and finally with more exhaustion the whole tube is filled with a soft luminous glow, which is technically known as the *positive column.* This is the point of highest conductivity of the tube, and may be reached with an ordinary air pump. With further exhaustion, by means of a special air pump, the resistance increases, the cold light disappears, and the point is reached where X-ray phenomena and fluorescence appear. The color of the light in the tube depends on the gas used in the tube and is undoubtedly the product of the ions. Just before the war a Frenchman, Claude, devised a means of producing in quantities the rare gas, *neon,* which gives an intense yellow light in a vacuum tube. The carbon dioxid which Moore uses gives a white light. Other gases, possibly rare ones, may be found which are better still, and *helium* has been suggested as a standard by some. However, up until the time the U. S. Government discovered the way of producing it in immense quantities for balloon work, during the war, it was too rare to be practical. The more the conditions in such a light can be improved, and the more nearly the light is a pure ionization or cold light, the higher the luminous efficiency will be. An interesting table is given, showing the progress which has been made up to the present, including the vacuum tube.

Luminous Efficiency of Various Illuminants

Candle	2 per cent
Gas mantle	5 per cent
Carbon lamp	6 per cent
Flaming arc	15 per cent
Vacuum tube	40 per cent



RADIO DEPARTMENT

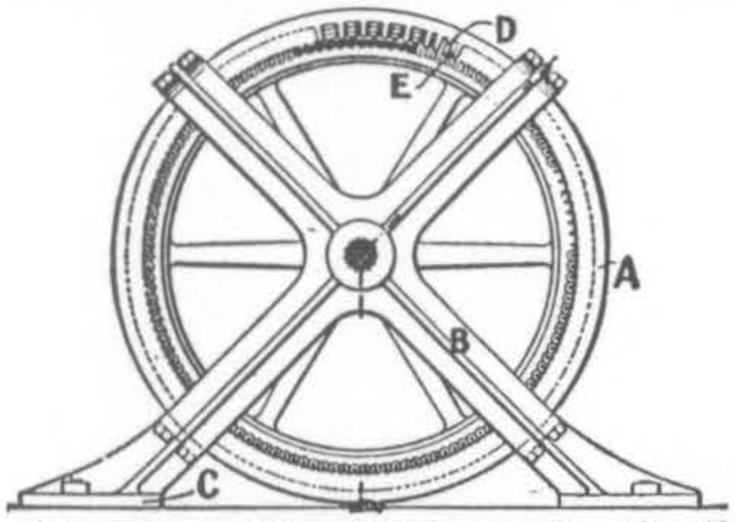


The True Wireless

By NIKOLA TESLA

Written Exclusively for The Electrical Experimenter

EVER since the announcement of Maxwell's electro-magnetic theory scientific investigators all the world over had been bent on its experimental verification. They were convinced that it would be done and lived in an atmosphere of eager expectancy, un-



Alternator of 10,000 Cycles p.s., Capacity 10 K.W., Which Was Employed by Tesla in His First Demonstrations of High Frequency Phenomena Before the American Institute of Electrical Engineers at Columbia College, May 20, 1891. Fig. 1.

usually favorable to the reception of any evidence to this end. No wonder then that the publication of Dr. Heinrich Hertz's results caused a thrill as had scarcely ever been experienced before. At that time I was in the midst of pressing work in connection with the commercial introduction of my system of power transmission, but, nevertheless, caught the fire of enthusiasm and fairly burned with desire to behold the miracle with my own eyes. Accordingly, as soon as I had freed myself of these imperative duties and resumed research work in my laboratory on Grand Street, New York, I began, parallel with high frequency alternators, the construction of several forms of apparatus with the object of exploring the field opened up by Dr. Hertz. Recognizing the limitations of the devices he had employed, I concentrated my attention on the production of a powerful induction coil but made no notable progress until a happy inspiration led me to the invention of the oscillation transformer. In the latter part of 1891 I was already so far advanced in the development of this new principle that I had at my disposal means vastly superior

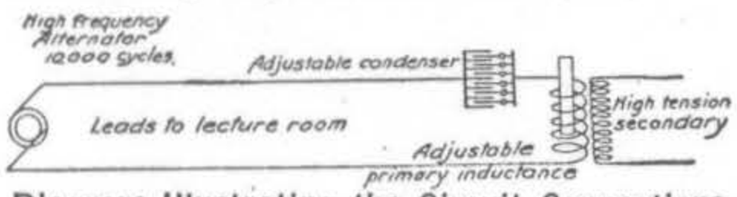
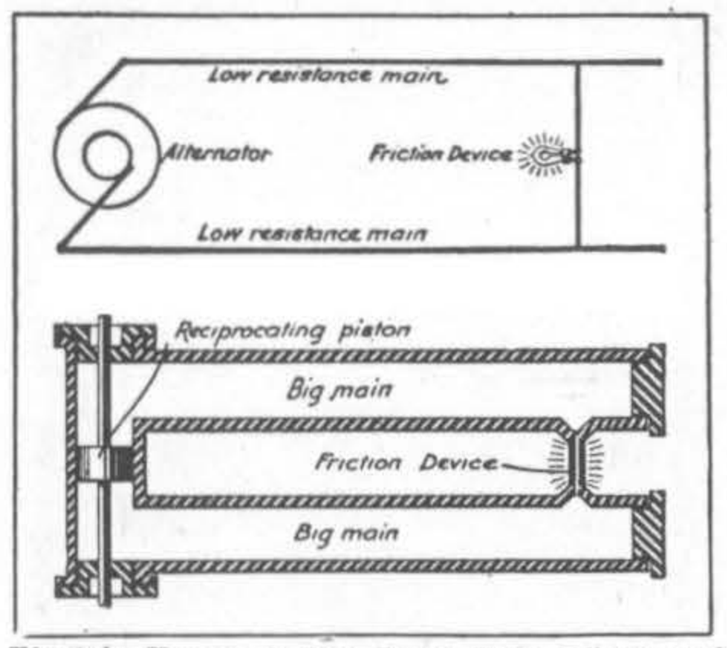


Diagram Illustrating the Circuit Connections and Tuning Devices Employed by Tesla In His Experimental Demonstrations Before the American Institute of Electrical Engineers With the High Frequency Alternator Shown In Fig. 1. Fig. 2.

to those of the German physicist. All my previous efforts with Rhumkorf coils had left me unconvinced, and in order to settle my doubts I went over the whole ground once more, very carefully, with these improved appliances. Similar phenomena were noted, greatly magnified in intensity, but they were susceptible of a different and more plausible explanation. I considered this so important that in 1892 I went to Bonn, Germany, to confer with Dr. Hertz in regard to my observations. He seemed disappointed to such a degree that I regretted my trip and parted from him sorrowfully. During the succeeding years I made numerous experiments with the same object, but the results were uniformly negative. In 1900, however, after I had evolved a wireless transmitter which enabled me to obtain electro-magnetic activities of many millions of horse-power, I made a last desperate attempt to prove that the disturbances emanating from the oscillator were ether vibrations akin to those of light, but met again with utter failure. For more than eighteen years I have been reading treatises, reports of scientific transactions, and articles on Hertz-wave telegraphy, to keep myself informed, but they have always imprest me like works of fiction.

The history of science shows that theories are perishable. With every new truth that is revealed we get a better understanding of Nature and our conceptions and views are modified. Dr. Hertz did not discover a new principle. He merely gave material support to a hypothesis which had been long ago formulated. It was a perfectly well-established fact that a circuit, traversed by a periodic current, emitted some kind of space waves, but we were in ignorance as to their character. He apparently gave an experimental proof that they were transversal vibrations in the ether. Most people look upon this as his great accomplishment. To my mind it seems that his immortal merit was not so much in this as in the focusing of the investigators' attention on the processes taking place in the ambient medium. The Hertz-wave theory, by its fascinating hold on the imagination, has stifled creative effort in the wireless art and retarded it for twenty-five years. But, on the other hand, it is impossible to over-estimate the beneficial effects of the powerful stimulus it has given in many directions.

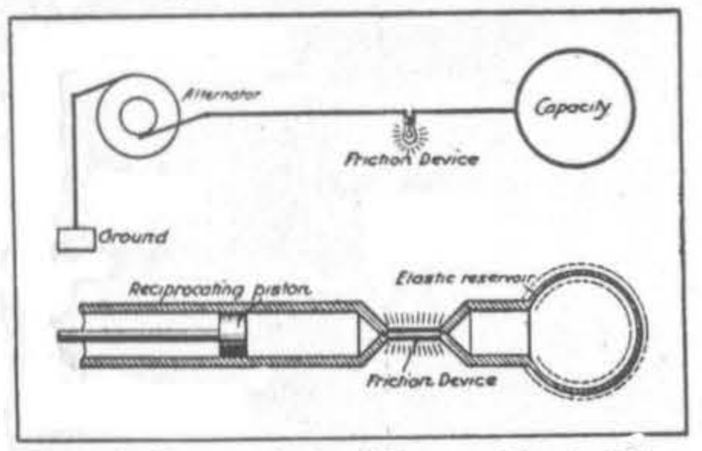
As regards signaling without wires, the application of these radiations for the purpose was quite obvious. When Dr. Hertz was asked whether such a system would be of practical value, he did not think so, and he was correct in his forecast. The best that might have been expected was a method of communication similar to the



Electric Transmission Thru Two Wires and Hydraulic Analog. Fig. 3.

heliographic and subject to the same or even greater limitations.

In the spring of 1891 I gave my demonstrations with a high frequency machine before the American Institute of Electrical Engineers at Columbia College, which laid the foundation to a new and far more promising departure. Altho the laws of electrical resonance were well known at that time and my lamented friend, Dr. John Hopkinson, had even indicated their specific application to an alternator in the Proceedings of the Institute of Electrical Engineers, London, Nov. 13, 1889, nothing had been done towards the practical use of this knowledge and it is probable that those experiments of mine were the first public exhibition with resonant circuits, more particularly of high frequency. While the spontaneous success of my lecture was due to spectacular features, its chief import was in showing that all kinds of devices could be operated thru a single wire without return. This

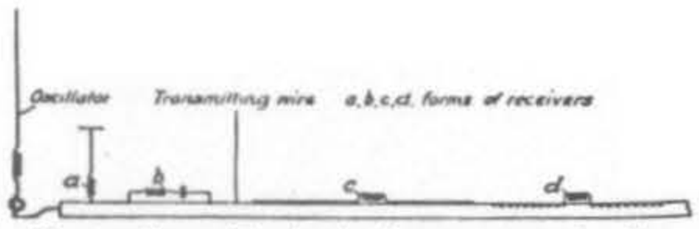


Electric Transmission Thru a Single Wire Hydraulic Analog. Fig. 4.

was the initial step in the evolution of my wireless system. The idea presented itself to me that it might be possible, under ob-

IN this remarkable and complete story of his discovery of the "True Wireless" and the principles upon which transmission and reception, even in the present day systems, are based, Dr. Nikola Tesla shows us that he is indeed the "Father of the Wireless." To him the Hertz wave theory is a delusion; it looks sound from certain angles, but the facts tend to prove that it is hollow and empty. He convinces us that the real Hertz waves are blotted out after they have traveled but a short distance from the sender. It follows, therefore, that the measured antenna current is no indication of the effect, because only a small part of it is effective at a distance. The limited activity of pure Hertz wave transmission and reception is here clearly explained, besides showing definitely that in spite of themselves, the radio engineers of today are employing the original Tesla tuned oscillatory system. He shows by examples with different forms of aërials that the signals picked up by the instruments must actually be induced by earth currents—not etheric space waves. Tesla also disproves the "Heaviside layer" theory from his personal observations and tests.

EDITOR.



Illustrating Typical Arrangements for Collecting Energy in a System of Transmission Thru a Single Wire. Fig. 5.

servance of proper conditions of resonance, to transmit electric energy thru the earth, thus dispensing with all artificial conductors. Anyone who might wish to examine impartially the merit of that early suggestion must not view it in the light of present day science. I only need to say that as late as 1893, when I had prepared an elaborate chapter on my wireless system, dwelling on its various instrumentalities and future prospects, Mr. Joseph Wetzler and other friends of mine emphatically protested against its publication on the ground that such idle and far-fetched speculations would injure me in the opinion of conservative business men. So it came that only a small part of what I had intended to say was embodied in my address of that year before the Franklin Institute and National Electric Light Association under the chapter "On Electrical

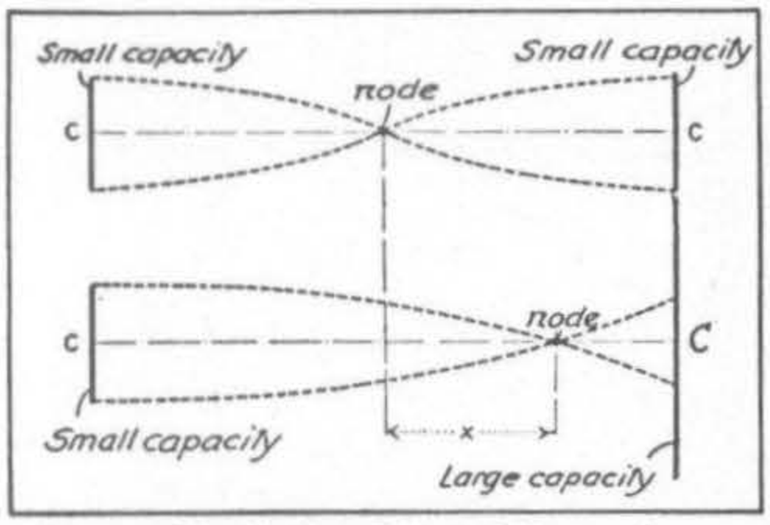
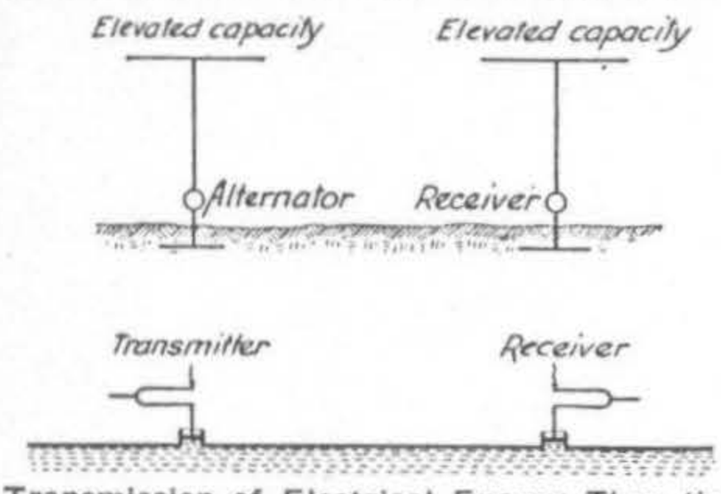


Diagram Elucidating Effect of Large Capacity on One End. Fig. 6.

Resonance." This little salvage from the wreck has earned me the title of "Father of the Wireless" from many well-disposed fellow workers, rather than the invention of scores of appliances which have brought wireless transmission within the reach of every young amateur and which, in a time not distant, will lead to undertakings overshadowing in magnitude and importance all past achievements of the engineer.

The popular impression is that my wireless work was begun in 1893, but as a matter of fact I spent the two preceding years in investigations, employing forms of apparatus, some of which were almost like those of today. It was clear to me from the very start that the successful consummation could only be brought about by a number of radical improvements. Suitable high frequency generators and electrical oscillators had first to be produced. The energy of these had to be transformed in effective transmitters and collected at a distance in proper receivers. Such a system would be manifestly circumscribed in its usefulness if all extraneous interference were not prevented and exclusiveness secured. In time, however, I recognized that devices of this kind, to be most effect-

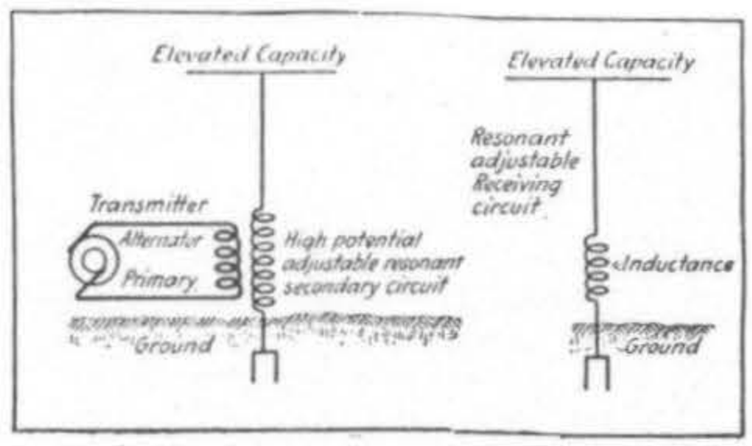


Transmission of Electrical Energy Thru the Earth as Illustrated in Tesla's Lectures Before the Franklin Institute and Electric Light Association in February and March, 1893, and Mechanical Analog of the Same. Fig. 7.

ive and efficient, should be designed **with due regard to the physical properties of this planet and the electrical conditions obtaining on the same.** I will briefly touch upon the salient advances as they were made in the gradual development of the system.

The high frequency alternator employed in my first demonstrations is illustrated in Fig. 1. It comprised a field ring, with 384 pole projections and a disc armature with coils wound in one single layer which were connected in various ways according to requirements. It was an excellent machine for experimental purposes, furnishing sinusoidal currents of from 10,000 to 20,000 cycles per second. The output was comparatively large, due to the fact that as much as 30 amperes per square millimeter could be past thru the coils without injury.

The diagram in Fig. 2 shows the circuit arrangements as used in my lecture. Resonant conditions were maintained by means

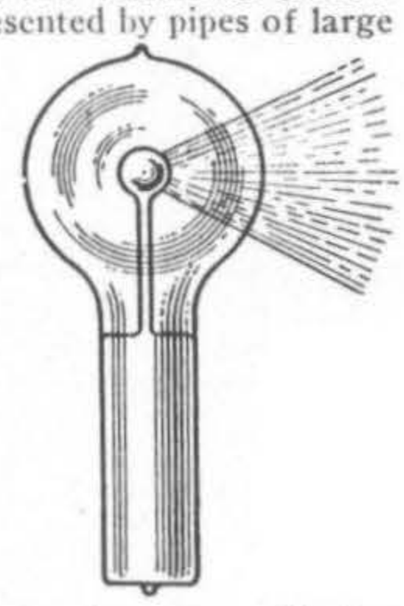


Tesla's System of Wireless Transmission Thru the Earth as Actually Exposed in His Lectures Before the Franklin Institute and Electric Light Association in February and March, 1893. Fig. 8.

of a condenser subdivided into small sections, the finer adjustments being effected by a movable iron core within an inductance coil. Loosely linked with the latter was a high tension secondary which was tuned to the primary.

The operation of devices thru a single wire without return was puzzling at first because of its novelty, but can be readily explained by suitable analogs. For this purpose reference is made to Figs. 3 and 4.

In the former the low resistance electric conductors are represented by pipes of large



The Forerunner of the Audion—the Most Sensitive Wireless Detector Known, as Described by Tesla in His Lecture Before the Institution of Electrical Engineers, London, February, 1892. Fig. 9.

section, the alternator by an oscillating piston and the filament of an incandescent lamp by a minute channel connecting the pipes. It will be clear from a glance at the diagram that very slight excursions of the piston would cause the fluid to rush with high velocity thru the small channel and that virtually all the energy of movement would be transformed into heat by friction, similarly to that of the electric current in the lamp filament.

The second diagram will now be self-explanatory. Corresponding to the terminal capacity of the electric system an elastic reservoir is employed which dispenses with the necessity of a return pipe. As the piston oscillates the bag expands and contracts, and the fluid is made to surge thru the restricted passage with great speed, this

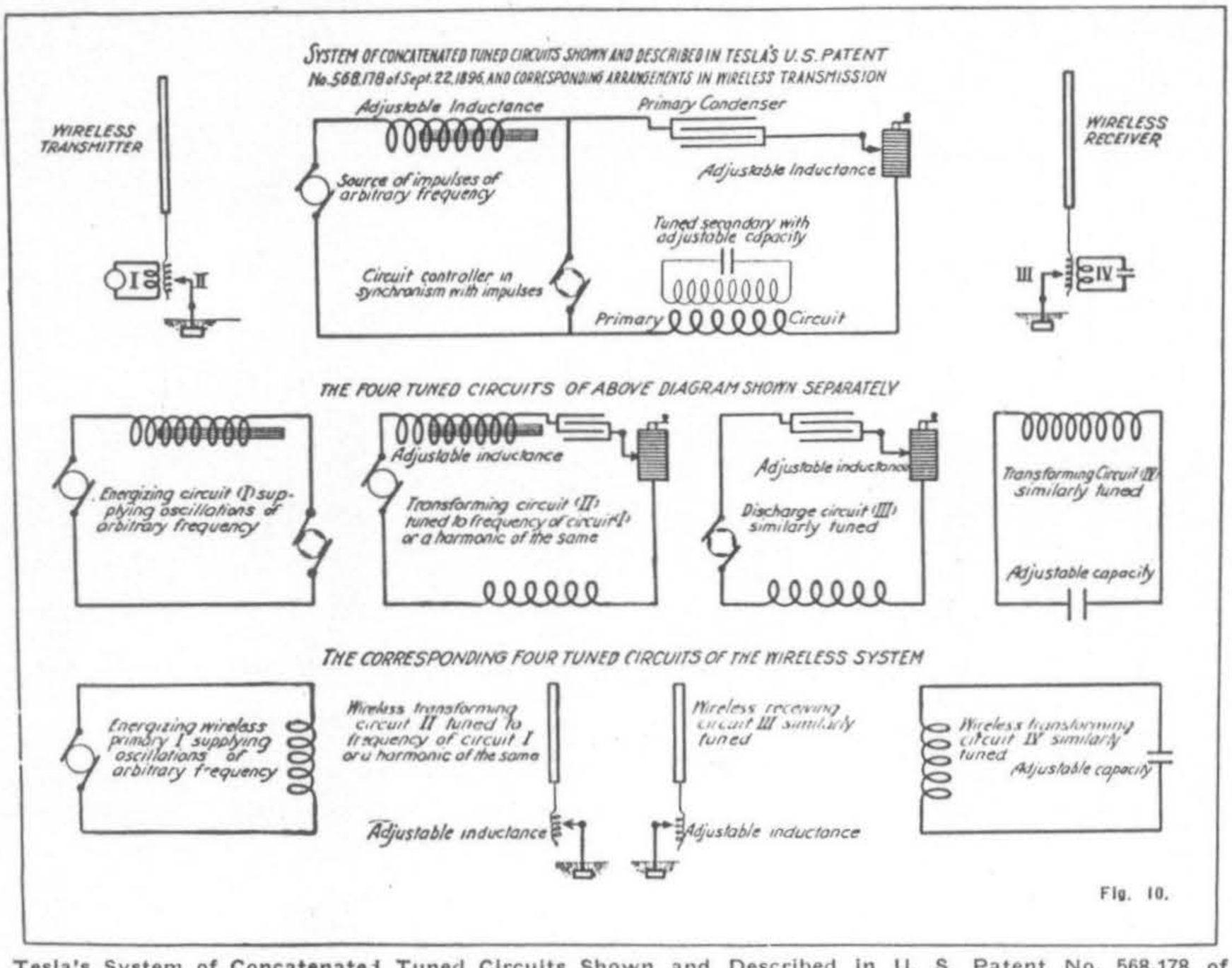
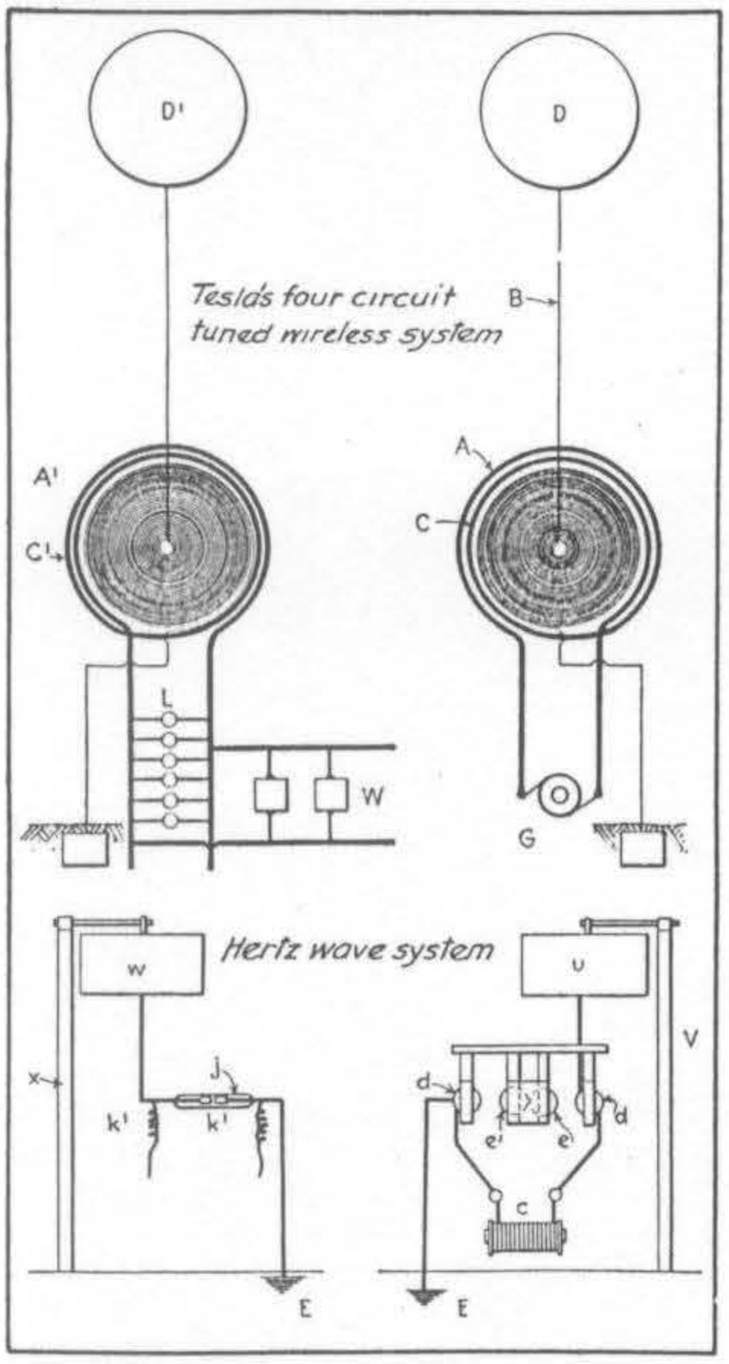


Fig. 10.

Tesla's System of Concatenated Tuned Circuits Shown and Described in U. S. Patent No. 568,178 of September 22, 1896, and Corresponding Arrangements in Wireless Transmission.

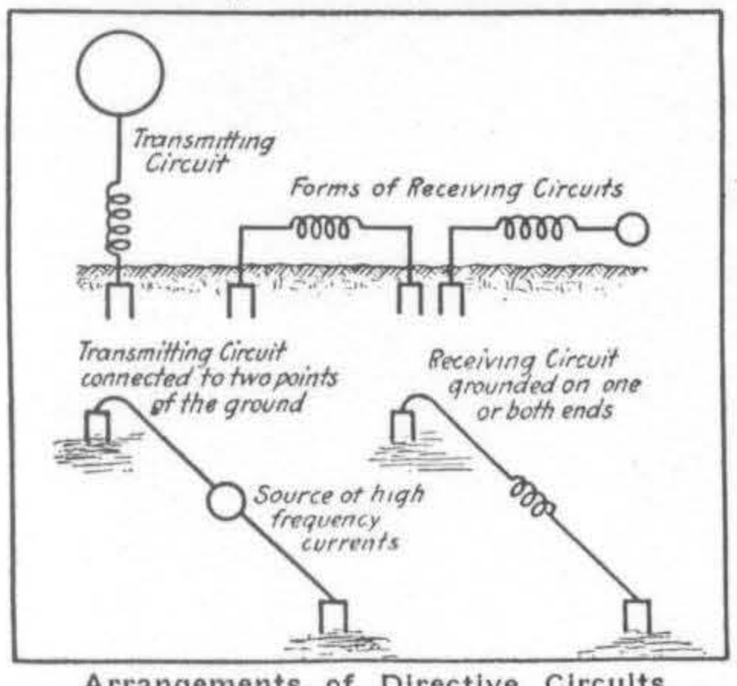
resulting in the generation of heat as in the incandescent lamp. Theoretically considered, the efficiency of conversion of energy should be the same in both cases.

Granted, then, that an economic system of power transmission thru a single wire is



Tesla's Four Circuit Tuned System Contrasted With the Contemporaneous Hertz-wave System. Fig. 11.

practicable, the question arises how to collect the energy in the receivers. With this object attention is called to Fig. 5, in which a conductor is shown excited by an oscillator joined to it at one end. Evidently, as the periodic impulses pass thru the wire, differences of potential will be created along the same as well as at right angles to it in the surrounding medium and either of these may be usefully applied. Thus at *a*, a circuit comprising an inductance and capacity is resonantly excited in the transverse, and at *b*, in the longitudinal sense. At *c*, energy is collected in a circuit parallel to the conductor but not in contact with it, and again at *d*, in a circuit which is partly sunk into the conductor and may be, or not, electrically connected to the same. It is important to keep these typical dispositions in mind, for however the distant ac-



Arrangements of Directive Circuits Described in Tesla's U. S. Patent No. 613,809 of November 8, 1898, on "Method of and Apparatus for Controlling Mechanism of Moving Vessels or Vehicles." Fig. 12.

tions of the oscillator might be modified thru the immense extent of the globe the principles involved are the same.

Consider now the effect of such a conductor of vast dimensions on a circuit exciting it. The upper diagram of Fig. 6 illustrates a familiar oscillating system comprising a straight rod of self-inductance $2L$ with small terminal capacities cc and a node in the center. In the lower diagram of the figure a large capacity C is attached to the rod at one end with the result of shifting the node to the right, thru a distance corresponding to self-inductance X. As both parts of the system on either side of the node vibrate at the same rate, we have evidently, $(L + X)\ c = (L - X)\ C$ from which $X = L \frac{C - c}{C + c}$. When the capacity C becomes commensurate to that of the earth, X approximates L, in other words, the node is close to the ground connection. *The exact determination of its position is very important in the calculation of certain terrestrial electrical and geodetic data* and I have devised special means with this purpose in view.

My original plan of transmitting energy without wires is shown in the upper diagram of Fig. 7, while the lower one illustrates its mechanical analog, first publisht in my article in the *Century Magazine* of June, 1900. An alternator, preferably of high tension, has one of its terminals connected to the ground and the other to an elevated capacity and impresses its oscillations upon the earth. At a distant point a receiving circuit, likewise connected to ground and to an elevated capacity, collects some of the energy and actuates a suitable device. I suggested a multiplication of such units in order to intensify the effects, an idea which may yet prove valuable. In the analog two tuning forks are provided, one at the sending and the other at the receiving station, each having attached to its lower prong a piston fitting in a cylinder. The two cylinders communicate with a large elastic reservoir filled with an incom-

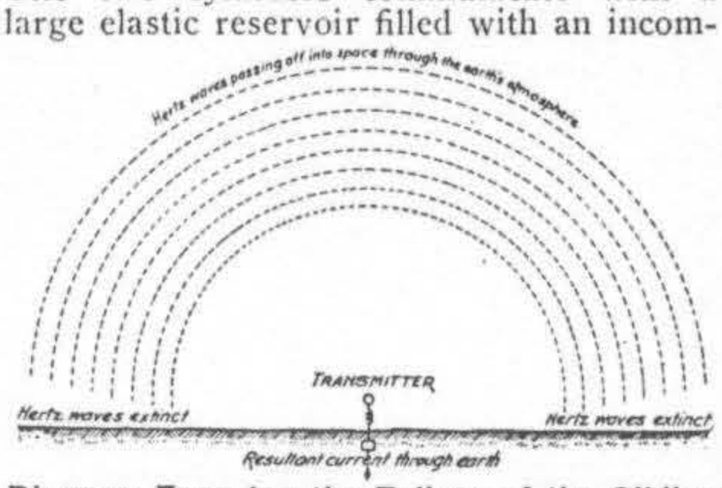


Diagram Exposing the Fallacy of the Gliding Wave Theory as Propounded in Wireless Text Books. Fig. 13.

pressible fluid. The vibrations transmitted to either of the tuning forks excite them by resonance and, thru electrical contacts or otherwise, bring about the desired result. This, I may say, was not a mere mechanical illustration, but a simple representation of my apparatus for submarine signaling, perfected by me in 1892, but not appreciated at that time, altho more efficient than the instruments now in use.

The electric diagram in Fig. 7, which was reproduced from my lecture, was meant only for the exposition of the principle. The arrangement, as I described it in detail, is shown in Fig. 8. In this case an alternator energizes the primary of a transformer, the high tension secondary of which is connected to the ground and an elevated capacity and tuned to the imprest oscillations. The receiving circuit consists of an inductance connected to the ground and to an elevated terminal without break and is resonantly responsive to the transmitted oscillations. A specific form of receiving device was not mentioned, but I had in mind to transform the received currents and thus make their volume and tension suitable for any purpose. This, in substance, is the system of today and I am not aware of a single authenticated instance of successful transmission at considerable distance by different instrumentalities. It might, perhaps, not be clear to

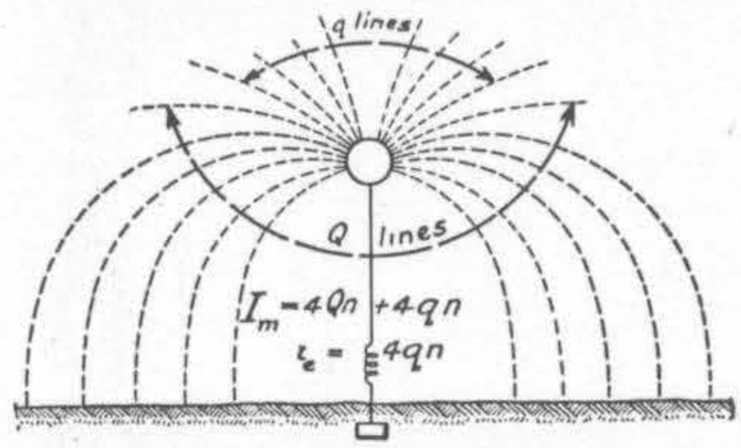


Fig. 14. Diagram Explaining the Relation Between the Effective and the Measured Current in the Antenna.

those who have perused my first description of these improvements that, besides making known new and efficient types of apparatus, I gave to the world a wireless system of potentialities far beyond anything before conceived. I made explicit

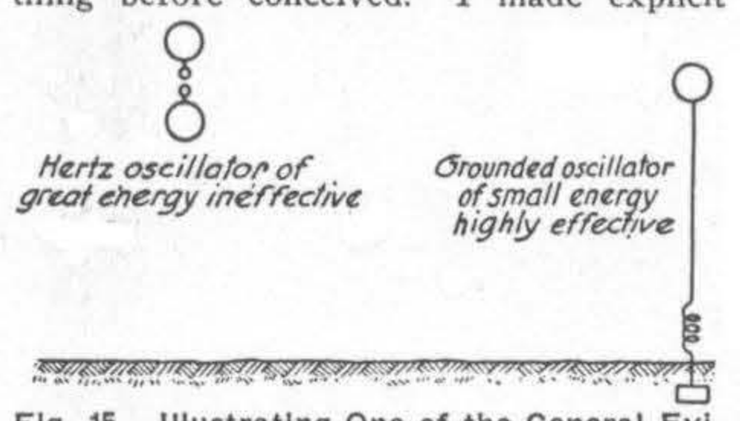


Fig. 15. Illustrating One of the General Evidences Against the Space Wave Transmission.

and repeated statements that I contemplated transmission, absolutely unlimited as to terrestrial distance and amount of energy. But, altho I have overcome all obstacles which seemed in the beginning unsurmountable and found elegant solutions of all the problems which confronted me, yet, even at this very day, the majority of experts are still blind to the possibilities which are within easy attainment.

My confidence that a signal could be easily flashed around the globe was strengthened thru the discovery of the "rotating brush," a wonderful phenomenon which I have fully described in my address before the Institution of Electrical Engineers, London, in 1892, and which is illustrated in Fig. 9. This is undoubtedly the most delicate wireless detector known, but for a long time it was hard to produce and to maintain in the sensitive state. These difficulties do not exist now and I am looking to valuable applications of this device, particularly in connection with the high-speed photographic method, which I suggested, in wireless, as well as in wire, transmission.

Possibly the most important advances during the following three or four years were my system of concatenated tuned circuits

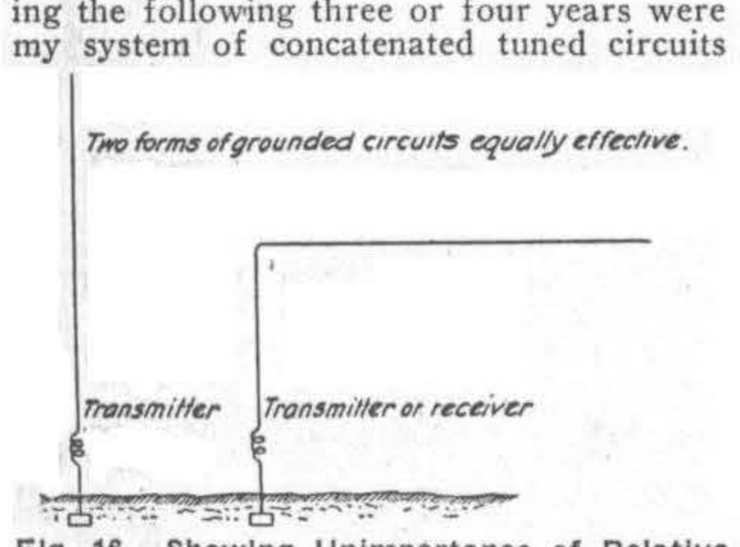


Fig. 16. Showing Unimportance of Relative Position of Transmitting and Receiving Antennae In Disproval of the Hertz-wave Theory.

and methods of regulation, now universally adopted. The intimate bearing of these inventions on the development of the wireless art will appear from Fig. 10, which illus-

(*Continued on page* 61)

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(*Continued from page* 30)

trates an arrangement described in my U. S. Patent No. 568178 of September 22, 1896, and corresponding dispositions of wireless apparatus. The captions of the individual diagrams are thought sufficiently explicit to dispense with further comment. I will merely remark that in this early record, in addition to indicating how any number of resonant circuits may be linked and regulated, I have shown the advantage of the proper timing of primary impulses and use of harmonics. In a farcical wireless suit in London, some engineers, reckless of their reputation, have claimed that my circuits were not at all attuned; in fact they asserted that I had looked upon resonance as a sort of wild and untamable beast!

It will be of interest to compare my system as first described in a Belgian patent of 1897 with the Hertz-wave system of that period. The significant differences between them will be observed at a glance. The first enables us to transmit economically energy to any distance and is of inestimable value; the latter is capable of a radius of only a few miles and is worthless. In the first there are no spark-gaps and the actions are enormously magnified by resonance. In both transmitter and receiver the currents are transformed and rendered more effective and suitable for the operation of any desired device. Properly constructed, my system is safe against static and other interference and the amount of energy which may be transmitted is *billions of times greater* than with the Hertzian which has none of these virtues, has never been used successfully and of which no trace can be found at present.

A well-advertised expert gave out a statement in 1899 that my apparatus did not work and that it would take 200 years before a message would be flashed across the Atlantic and he even accepted stolidly my congratulations on a supposed great feat. But subsequent examination of the records showed that my devices were secretly used all the time and ever since I learned of this I have treated these Borgia-Medici methods with the contempt in which they are held by all fair-minded men. The wholesale appropriation of my inventions was, however, not always without a diverting side. As an example to the point I may mention my oscillation transformer operating with an air gap. This was in turn replaced by a carbon arc, quenched gap, an atmosphere of hydrogen, argon or helium, by a mechanical break with oppositely rotating members, a mercury interrupter or some kind of a vacuum bulb and by such *tours de force* as many new "systems" have been produced. I refer to this of course, without the slightest ill-feeling, let us advance by all means. But I cannot help thinking how much better it would have been if the ingenious men, who have originated these "systems," had invented something of their own instead of depending on me altogether.

Before 1900 two most valuable improvements were made. One of these was my individualized system with transmitters emitting a wave-complex and receivers comprising separate tuned elements coöperatively associated. The underlying principle can be explained in a few words. Suppose that there are n simple vibrations suitable for use in wireless transmission, the probability that any one tune will be struck by an extraneous disturbance is $\frac{1}{n}$. There will then remain $n-1$ vibrations and the chance that one of these will be excited is $\frac{1}{n-1}$, hence the probability that two tunes would be struck at the same time is $\frac{1}{n\,(n-1)}$. Similarly, for a combination of three the chance will be $\frac{1}{n\,(n-1)\,(n-2)}$ and so on. It will be readily seen that in this manner any desired degree of safety against the statics or other kind of disturbance can be attained provided the receiving apparatus is so designed that its operation is possible only thru the joint action of all the tuned elements. This was a difficult problem which I have successfully solved so that now *any desired number of simultaneous messages is practicable in the transmission thru the earth as well as thru artificial conductors.*

The other invention, of still greater importance, is a peculiar oscillator enabling the transmission of energy without wires in any quantity that may ever be required for industrial use, to any distance, and with very high economy. It was the outcome of years of systematic study and investigation and wonders will be achieved by its means.

The prevailing misconception of the mechanism involved in the wireless transmission has been responsible for various unwarranted announcements which have misled the public and worked harm. By keeping steadily in mind that the transmission thru the earth is in every respect identical to that thru a straight wire, one will gain a clear understanding of the phenomena and will be able to judge correctly the merits of a new scheme. Without wishing to detract from the value of any plan that has been put forward I may say that they are devoid of novelty. So for instance in Fig. 12 arrangements of transmitting and receiving circuits are illustrated, which I have described in my U. S. Patent No. 613809 of November 8, 1898 on a Method of and Apparatus for Controlling Mechanism of Moving Vessels or Vehicles, and which have been recently dished up as original discoveries. In other patents and technical publications I have suggested conductors in the ground as one of the obvious modifications indicated in Fig. 5.

For the same reason the statics are still the bane of the wireless. There is about as much virtue in the remedies recently proposed as in hair restorers. *A small and compact apparatus has been produced which does away entirely with this trouble,* at least in plants suitably remodelled.

Nothing is more important in the present phase of development of the wireless art than to dispose of the dominating erroneous ideas. With this object I shall advance a few arguments based on my own observations *which prove that Hertz waves have little to do with the results obtained even at small distances.*

In Fig. 13 a transmitter is shown radiating space waves of considerable frequency. It is generally believed that these waves pass along the earth's surface and thus affect the receivers. I can hardly think of anything more improbable than this "gliding wave" theory and the conception of the "guided wireless" which are contrary to all laws of action and reaction. Why should these disturbances cling to a conductor where they are counteracted by induced currents, when they can propagate in all other directions unimpeded? The fact is that the radiations of the transmitter passing along the earth's surface are soon extinguished, the height of the inactive zone indicated in the diagram being some function of the wave length, the bulk of the waves traversing freely the atmosphere. Terrestrial phenomena which I have noted conclusively show that there is no *Heaviside layer,* or if it exists, it is of no effect. It certainly would be unfortunate if the human race were thus imprisoned and forever without power to reach out into the depths of space.

The actions at a distance cannot be proportionate to the height of the antenna and the current in the same. I shall endeavor to make this clear by reference to diagram in Fig. 14. The elevated terminal charged to a high potential induces an equal and opposite charge in the earth and there are thus Q lines giving an average current $I = 4Qn$ which circulates locally and is useless except that it adds to the momentum. A relatively small number of lines q however, go off to great distance and to these corresponds a mean current of $i_e = 4qn$ to *which is due the action at a distance.* The total average current in the antenna is thus $I_m = 4Qn + 4qn$ and its intensity is no criterion for the performance. The electric efficiency of the antenna is $\frac{q}{Q+q}$ and this is often a very small fraction.

Dr. L. W. Austin and Mr. J. L. Hogan have made quantitative measurements which are valuable, but far from supporting the Hertz wave theory they are evidences in disproval of the same, as will be easily perceived by taking the above facts into consideration. Dr. Austin's researches are especially useful and instructive and I regret that I cannot agree with him on this subject. I do not think that if his receiver was affected by Hertz waves he could ever establish such relations as he has found, but he would be likely to reach these results if the Hertz waves were in a large part eliminated. At great distance the space waves and the current waves are of equal energy, the former being merely an accompanying manifestation of the latter in accordance with the fundamental teachings of Maxwell.

It occurs to me here to ask the question—why have the Hertz waves been reduced from the original frequencies to those I have advocated for my system, when in so doing the activity of the transmitting apparatus has been reduced a billion fold? I can invite any expert to perform an experiment such as is illustrated in Fig. 15, which shows the classical Hertz oscillator and my grounded transmitting circuit. It is a fact which I have demonstrated that, altho we may have in the Hertz oscillator an activity thousands of times greater, the effect on the receiver is not to be compared to that of the grounded circuit. This shows that *in the transmission from an airplane we are merely working thru a condenser,* the capacity of which is a function of a logarithmic ratio between the length of the conductor and the distance from the ground. The receiver is affected in exactly the same manner as from an ordinary transmitter, the only difference being that there is a certain modification of the action which can be predetermined from the electrical constants. It is not at all difficult to maintain communication between an airplane and a station on the ground, on the contrary, the feat is very easy.

To mention another experiment in support of my view, I may refer to Fig. 16 in which two grounded circuits are shown excited by oscillations of the Hertzian order. It will be found that the antennas can be put out of parallelism without noticeable change in the action on the receiver, this proving that it is due to currents propagated thru the ground and not to space waves.

Particularly significant are the results obtained in cases illustrated in Figures 17 and 18. In the former an obstacle is shown in the path of the waves but unless the receiver is within the effective *electrostatic* influence of the mountain range, the signals are not appreciably weakened by the presence of the latter, because the currents pass under it and excite the circuit in the same way as if it were attached to an energized wire. If, as in Fig. 18, a second range happens to be beyond the receiver, it could only strengthen the Hertz wave effect by reflection, but as a matter of fact it detracts

(*Continued on page* 87)

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greatly from the intensity of the received impulses because the electric niveau between the mountains is raised, as I have explained in connection with my lightning protector in the EXPERIMENTER of February.

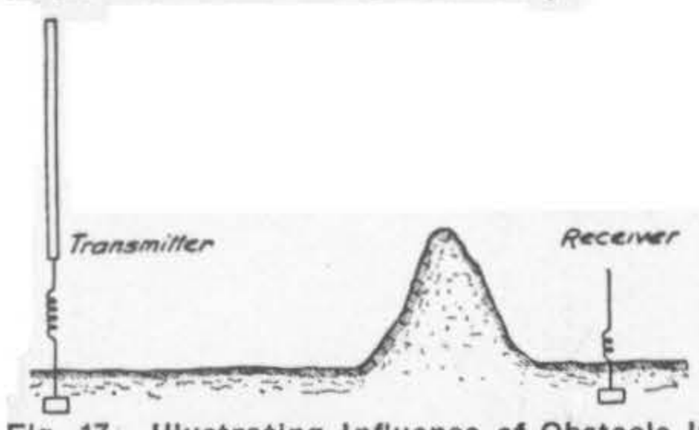

Fig. 17. Illustrating Influence of Obstacle in the Path of Transmission as Evidence Against the Hertz-wave Theory.

Again in Fig. 19 two transmitting circuits, one grounded directly and the other thru an air gap, are shown. It is a common observation that the former is far more effective, which could not be the case in a transmission with Hertz radiations. In like manner if two grounded circuits are observed from day to day the effect is found to increase greatly with the dampness of the ground, and for the same reason also the transmission thru sea-water is more efficient.

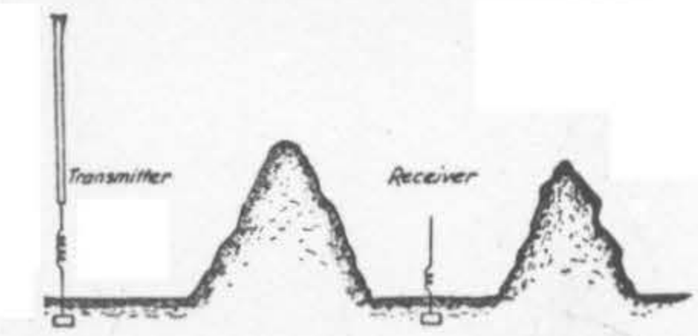

Fig. 18. Showing Effect of Two Hills as Further Proof Against the Hertz-wave Theory.

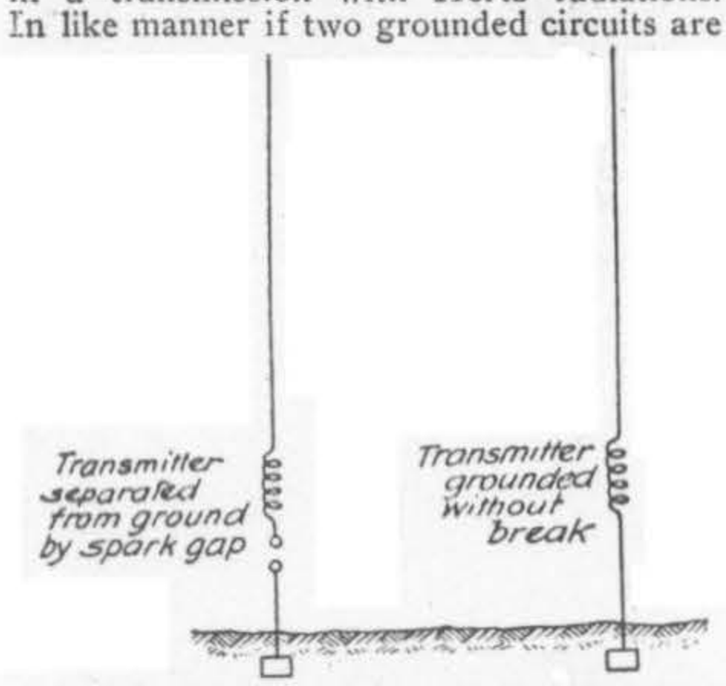

Fig. 19. Comparing the Actions of Two Forms of Transmitter as Bearing Out the Fallacy of the Hertz-wave Theory.

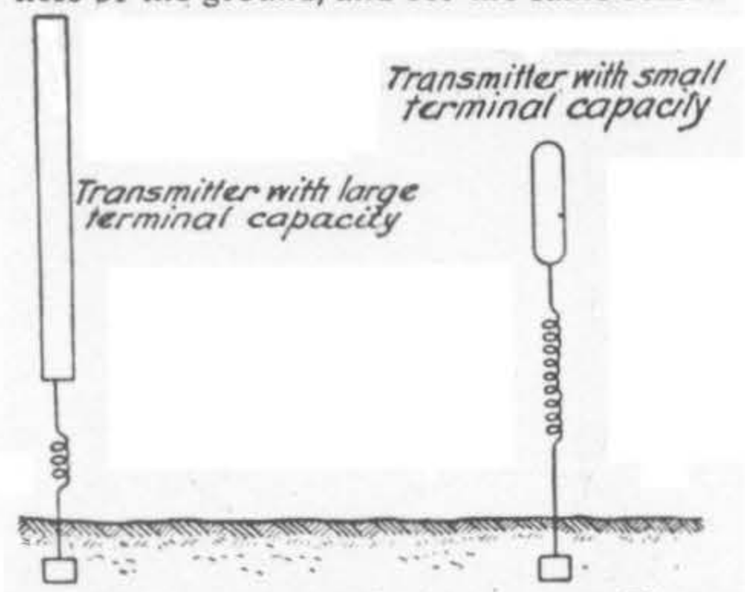

Fig. 20. Disproving the Hertz-wave Theory by Two Transmitters, One of Great and the Other of Small Energy.

An illuminating experiment is indicated in Fig. 20 in which two grounded transmitters are shown, one with a large and the other with a small terminal capacity. Suppose that the latter be 1/10 of the former but that it is charged to 10 times the potential and let the frequency of the two circuits and therefore the currents in both antennas be exactly the same. The circuit with the smaller capacity will then have 10 times the energy of the other but the effects on the receiver will be in no wise proportionate.

The same conclusions will be reached by transmitting and receiving circuits with wires buried underground. In each case the actions carefully investigated will be found to be due to *earth currents*. Numerous other proofs might be cited which can be easily verified. So for example *oscillations of low frequency* are ever so much more effective in the transmission which is inconsistent with the prevailing idea. My observations in 1900 and the recent transmissions of signals to very great distances are another emphatic disproval.

The Hertz wave theory of wireless transmission may be kept up for a while, but I do not hesitate to say that in a short time it will be recognized as one of the most remarkable and inexplicable aberrations of the scientific mind which has ever been recorded in history.

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The Edison Medal

In February, 1904, a fund was provided and a deed of gift creating the Edison Medal executed between twenty-three individuals and the New York Trust Company, such deed being amended in March, 1908, to include as one of the parties thereto the American Institute of Electrical Engineers, whereby it was provided, among other things, as follows:—

> "The Institute shall, through a Committee to be duly appointed and authorized by it and known as The Edison Medal Committee, cause a gold medal to be executed from said die, or according to said design and specifications, and shall award said medal to some one resident of the United States of America and its Dependencies, or of the

Dominion of Canada for "Meritorious Achievement" in Electrical Science or Electrical Engineering or the Electrical Arts, whenever in the judgment of said Committee a resident of either of said countries is properly deserving of such award; provided, nevertheless, the requisite funds have accrued from said investment to so be made by the Trust Company."

In compliance with the obligation assumed by it the American Institute of Electrical Engineers in May, 1909, approved a set of by-laws of The Edison Medal Committee creating the machinery and prescribing the method of procedure to be thereafter followed in awarding the Edison Medal. Since that time awards have been made as per the following list of names and for the accomplishments as set forth, it being the privilege and duty of The Edison Medal Committee both to make the award and to state with great care, as briefly as may be, the reasons for their action. The list of distinguished men who have been honored by these awards is the best testimony of the way in which this important matter has been handled by the Committee having it in charge:—

1909—ELIHU THOMSON— "For Meritorious Achievement in Electrical Science, Engineering and Arts, as exemplified in his contributions thereto during the past thirty years."

1910—FRANK J. SPRAGUE—"For Meritorious Achievement in Electrical Science, Engineering and Arts, as exemplified in his contributions thereto.

1911—GEORGE WESTINGHOUSE—"For Meritorious Achievement in Connection with the Development of the Alternating Current System for Light and Power".

1912—WILLIAM STANLEY—"For Meritorious Achievement in Invention and Development of Alternating Current Systems and Apparatus".

1913—CHARLES F. BRUSH—"For Meritorious Achievement in the Invention and Development of the Series Arc Lighting System".

1914—ALEXANDER GRAHAM BELL—"For Meritorious Achievement in the Invention of the Telephone".

1916—NIKOLA TESLA—"For Meritorious Achievement in his early original work in Polyphase and High-frequency Electrical Currents".

1917—JOHN J. CARTY—"For his work in the Science and Art of Telephone Engineering"

1918—BENJAMIN G. LAMME—"For Invention and Development of Electrical Machinery".

CALVERT TOWNLEY

The Achievements of Benjamin G. Lamme

Address of Presentation of the Edison Medal

B. A. Behrend

An address delivered on the occasion of the Presentation of the Edison medal to Mr. Lamme by the American Institute of Electrical Engineers in the Auditorium of the Engineering Societies Building, New York City, May 16, 1919.

THE DEVELOPMENT of the electrical industry in America is contemporaneous with the great industrial organization created by Mr. George Westinghouse and in the examination of its pioneers we are invariably arrested by the personality of Mr. Benjamin G. Lamme, whom it is our pleasure to honor tonight as the recipient of the Edison Medal. It is interesting to note that the medalist has just completed thirty years of service with the Westinghouse Company. There is something intensely significant in this fact. During these thirty years there have risen and there have vanished, like the colors in a kaleidoscope, many able and brilliant men who were connected with the Westinghouse Company in one capacity or another. Steadfast, patient and strong, there has remained the personality of Mr. Lamme to grow stronger with the years, so as finally to embody in himself, as it were, the thoughts of the engineering staff. I must confess that I have always enjoyed Mr. Lamme's versatile personality and that, in this sense, I may perhaps be accused of hero worship. Let the subject matter be one of engineering, one of politics, of the engaging problems of the day or of his favorite subject of archeology, his wholesome, sound sense and penetrative, subtle intellect will always impress his listeners. In point of illustration, here are a few pithy sentences taken at random from some of Mr. Lamme's writings. "A brilliant mind with little persistency back of it will usually accomplish less than a much less brilliant mind backed by great persistency."—"It is on account of specialization that it is so important that the young engineer of today obtain a broad knowledge of the fundamentals of his chosen line of engineering."—"Such a course of advanced training would attract a great many students regardless of the fact that the training would be of little or no use to them."



Benj. G. Lamme

Endowed with a most unusual memory, and a facility for mental calculation to a point of efficiency which makes him spurn the ubiquitous slide rule, he combines an imaginative faculty of a most curious order. Passionately fond of every variety of intricate puzzles, some of which he invented himself, devoted to reading imaginative stories and tales of which he has collected a large number in his library, he is forever dissecting and analyzing the problems which come within his scope.

After this introduction to the medalist's personality, let me take you in mind to the fertile farm-land of Southern Ohio. There, by the Valley Pike, in Clarke County, between Dayton and Springfield, about two score and ten years ago, Benjamin Garver Lamme was born. The life on that farm gave him the rugged, constitution without which even his great talents would not have carried him through. "The personal fly-wheel," as he calls it, has often served him in good stead. Though extremely fond of squirrel-hunting, it is to be assumed that our young friend, Benjamin, must have liked other things better than farming. The early morning hours in 1887 and 1888, we are told, were often spent in poring over the pages of Sylvanus P. Thompson's "Dynamo-Electric Machinery." Ohio State University, the cradle of a group of talented men,—Sabine, Storer, Feicht, Skinner, Scott, Mershon—was also Mr. Lamme's Alma Mater. We see him interterested in everything, the coach of the men of lesser gifts, and graduating eventually as mechanical engineer. After working on the flow of air and gas in pipes for the professor of geology, he applied for a position to Mr. Westinghouse, who had then just organized the Philadelphia Company for the development and exploitation of the wells of natural gas, and thus secured a "job" in Pittsburgh. After a few months,

his employer, Mr. T. A. Gillespie, recommended him to the Electric Company, where we find him in 1889 in the testing department under Mr. Albert Schmid. The conscientious apprentice was instructed to polish the brass on an 1100 volt alternator and he showed his thoroughness in omitting no brass parts, not even the current-carrying brushes. To some unknown, fortunate circumstances we evidently owe the fact of his survival. With oil can in hand, scrupulously watching the bearings of the machines entrusted to his charge, Benjamin Lamme is a familiar sight in the memory of his early associates.

Soon he became foreman of the testing department, and within a year his mind began to turn to inventions. From 1889, in increasing numbers from year to year, he obtained patents, reaching the rate of ten a year in 1898. Then we note a slight decline, only to attain a rate of sixteen patent applications a year in 1904. He has obtained at the present time the surprising total of 153.

The earlier activity was associated with the development of the rotary converter, the later with that of the single-phase system. It is interesting here to compare the medalist's own estimate of his connection with these developments, and I quote:—

> "A year or so ago, in discussing the subject concerning which you have just written me, you mentioned that the single-phase railway motor or system is the one by which I was best known. This appears to be true, but it has seemed to me unfortunate that it should be so, as I do not consider it as the one thing for which I should have the most credit.
>
> As you may know, the rotary converter, as it stands today, covering almost the entire field of railway business, has reached its commanding position very greatly through my efforts. In the early days of the rotary converter, beginning in 1893, this device was looked upon with a great deal of doubt. In the early days of commercial application, I had to fight the battle for the converter pretty much by myself. That I made a successful fight is indicated by the fact that, in the period between 1898 and 1902, the Westinghouse Company was probably furnishing 75 percent of all the rotary converters then built and this business was becoming of very considerably proportions."

That he was early in this field is indicated by the fact that nearly all the patents taken out on rotary converters in those days were in his name. Many of the modern necessities in rotary converters were originated and first used by him in such apparatus. I may cite the damper as one of these examples. While it developed afterwards that Leblanc had a broad patent on the damper, yet at the time that Mr. Lamme developed and used it on the rotary converter, he was not aware of Leblanc's patent, and he may claim the credit of being the first to use such dampers to overcome fundamental rotary converter difficulties. The entire problem of hunting, which at one time threatened to put the rotary converter in the discard, was overcome by his early work. This, however, was only an incident in the development. When it came to 60 cycle converters, he stood practically alone for many years, and his work has been instrumental in giving these machines the final high position which they now hold in the industry.

He has always led in the battle for higher speeds, resulting in smaller, cheaper and more efficient converters. Therefore, considering all these things, I believe we may state that there is more credit due him than to any other one person for the present leading position which the rotary converter holds in the electrical field. Yet to consider this as a larger and more important work than the single-phase system is, in my opinion, one of those strange vagaries of judgment often affecting us in connection with our own work.

Again, he can claim to have been the leader in the direct-current railway motor development, as far as fixing types of apparatus is concerned. His earliest single-reduction railway motor, the Westinghouse No. 3, or rather its experimental predecessor, contained most of the fundamental features found in the present universal type of railway motor. This early motor was of approximately cylindrical type with four internal radial poles and was of the ironclad, or partially-enclosed type. This was a most radical departure from former constructions and at once overcame many of the earlier difficulties. The armature of the experimental machine, and of all later machines, was of the slotted type, with open slots and with machine-wound coils. At this time this was the only railway motor of the kind, and these features have since been universally adopted. In addition, the two-circuit or series type of armature winding was first developed and used on this motor and this type of winding is now in universal use for railway motors and almost all other multipolar machines of small and moderate size. Many other features of this early construction are still retained in modern railway motors. Therefore, he may claim credit for having established the present universal type of railway motor.

Considering the direct-current generator, and particularly the railway generator, while there were more workers in this field, yet I feel that he should have much credit for establishing certain fundamental features in the early machines, which are retained or considered necessities even at the present time. He was the first to bring out the railway generator with slotted armature, both for the partially closed and the open slots. The form-wound armature coil of copper strap on edge, used with open slot direct-current armatures, was worked out by him. These earliest machines had a very high saturation in the armature teeth, in order to give stability and prevent distortion. This is also modern practice. When the limits of the two-circuit winding were reached and multiple windings began to be used extensively, he devised in America the polyphase equalizing connections which are now considered a necessity in such machines. He also used the fractional pitch or chorded armature winding for direct-current machines, for the purpose of reducing the commutating constants, thus improving the range of operation without shifting the brushes. Therefore, in this line of apparatus, many of his original features of

construction are still in use after twenty or twenty-five years of development.

In his work on rotary converters, railway motors, and direct-current generators, it can surely be said that he has had much to do with solving the problem of commutation, in the sense of determining the conditions which affect commutation and taking advantage of those characteristics and features which improve commutating conditions. In his papers on the theory of commutation, which were published by the Institute some years ago, I believe that he went considerably further into the subject than any one else had done up to that time. Quite a number of manufacturing engineers have taken up the method given in this paper and adopted it as a basis for their work, with very considerable benefits in the way of improved accuracy in their calculations, and increased outputs from a given amount of material. This paper, however, was more or less a result of all his previous experience and investigation on the subject, and it is simply an indication of how far he had gone into the general subject of commutation.

While he was not among the first to develop induction motors, yet he was among the first to produce commercial induction motors, as his work began in the latter part of 1892. His leading work in this line was the recognition of the principles upon which the Westinghouse type "C" motor was brought out. Up to that time (about 1895) it was generally held that the cage-wound motor was necessarily one with a small starting torque and that, in order to give high starting torque, it had to be made with a high secondary resistance and, therefore, high slip at normal load conditions. From his analysis of the design characteristics of the motor, he drew the conclusion that it was not a question of high secondary resistance and high slip, but one of the ratio of the reactance of the motor to the secondary resistance; that is, by reducing the reactance instead of solely increasing the secondary resistance, high starting torque could be obtained, but at the expense of high starting input. He then proposed to design such motors with relatively much lower reactance than had hitherto been the case, and thus obtained starting torques of several times the normal running torque, and which he reduced by the use of lower starting voltages by autotransformers or autostarters. He worked up many experimental motors and proved this principle and also, through his method of analysis, determined how to reduce the reactance of the motor by using widely distributed windings, and by giving careful attention to the elements of the magnetic circuit, without materially increasing its size and cost. The results, put in practice, were the line of type "C" motors. This radical type took the market and forced the situation to such an extent that it gave great impetus to the industrial application of polyphase currents.

In the task of entering intimately into Mr. Lamme's work, we are aided fortunately by the possession of historical sketches, from his own pen, of the direct-current railway motor, the alternating-current generator, and the direct-current generator. To these we must refer the readers who wish to follow his work in the evolution of electrical machinery.* The universal type of single-reduction railway motor owes to him a great debt, and the rotary converter, especially the 60 cycle types, are largely his creation.* These conceptions found their early and practical expression in the 1500 kw rotary converters and the 5000 kw flywheel generators of the Interborough Rapid Transit Company's Manhattan Station. The electrical dimensions of the first vertical generators of the Cataract Construction Company were Mr. Lamme's part in the great power development at Niagara Falls, and it must be gratifying to him that he was thus connected with this interesting historical landmark in electric power transmission.

There are many other fields in which he has had a hand. In the single-phase railway system, which he created, he deserves much credit for the fact that he successfully commutated alternating currents, after it had been quite definitely accepted as being one of the impracticable or impossible things. Of course, the development of the single-phase railway system was a direct result of the successful development of a commutating alternating-current motor. I think Mr. Lamme's leadership in the single-phase railway field has followed logically from his work in the transformation of Nikola Tesla's great creative ideas into commercial form. Mr. Lamme's principal, Mr. George Westinghouse, staunchly believed in the universal application of alternating currents and, as the difficulty of collecting alternating currents from two trolleys precluded, in the minds of the railroad men, the use of the polyphase system for railway work, Mr. Westinghouse and Mr. Lamme were led logically to the hope of developing a single-phase motor and adapting it to the railway field. This Mr. Lamme succeeded in doing originally by boldly adopting a low frequency of sixteen cycles and designing for it a series-wound alternating-current commutator motor. A little later, however, he discarded this frequency and developed a 25-cycle single-phase motor, in which the use of resistance leads, reducing the transformer current in the short-circuited coils, is one of the salient elements. Thus resulted the 25 cycle single-phase railway motor so widely adopted in Europe and to a degree in America. Surely, the electrification of the New York, New Haven & Hartford Railway will always be associated with Mr. Lamme's name. No more bitter debates were ever heard on the floor of this Institute than those on the relative merits of the single-phase and the direct-current systems. Yet even the most re-

*Published in THE ELECTRIC JOURNAL as follows:—"The Alternating-Current Generator in America", Vol. XI, Feb. '14, p. 73; Mar. '14, p. 120; Apr. '14, p. 221. "The Development of the Direct-Current Generator in America", Vol. XII, Feb. '15, p. 65; Mar. '15, p. 115; Apr. '15, p. 164; May '15, p. 212. "The Development of the Street Railway Motor in America", Vol. XV, Oct. '18, p. 408; Nov. '18, p. 454.

lentless opponents of the single-phase system must admit in justice that Mr. Lamme's conception of railroad electrification stood for the use of a high voltage working conductor, as he recognized that the 600-volt third-rail system imposed too great a burden upon extensive railroad electrification. In setting himself the task of producing a motor which, while possessing the characteristics of the series direct-current motor, would operate on any trolley potential, however high, and in successfully solving this problem, and fearlessly applying it to the New Haven system with 11 000 volts on the working conductor, Mr. Lamme gave an impetus to the entire field of railroad electrification which will always be a milestone in the electrical industry, and in the field of transportation. Suffice it to say that the feverish activity in the development of rival systems, the general adoption of the overhead trolley, the doubling and quadrupling of the direct-current voltage thereon, have been due to Mr. Lamme's bold creative work. From it has sprung a new life, a true "instauratio magna", in the electric transportation system the world over.

Fifteen years have passed; both systems are still in use almost literally side by side, neither having succeeded in displacing the other, and prophecy would be idle. Be the fate of the single-phase system what it may, the medalist will always be remembered as its successful pioneer.

With the advent of the steam turbine, Mr. Lamme turned his universal genius to the development of a type of turboalternator known as the "parallel-slot" type. It is one of the most ingenious designs which have been developed in this difficult art. While the types which he designed have not been enduring, yet they served as pace makers in the race towards the present high speeds and high economies resulting from such speeds. Therefore, I feel that he accomplished very considerable results in this field. Bold and venturesome, he urged increased speeds, ever higher and higher, and tenaciously adhered to this policy. Great credit is due him for this fearless advocacy.

Two years ago, when the Secretary of the United States Navy established the Naval Consulting Board, the Directors of the Am. Inst. of Electrical Engineers were requested to nominate, and to recommend to the Secretary of the Navy, two members of their great body who, in their opinion, would best fulfil the requirements to be made of that newly created Board. It was a great pleasure for the present speaker that he then had an opportunity to commend Mr. Lamme's name. It is yet too early to appraise the good work done by Mr. Lamme on the Naval Consulting Board in his capacity as Chairman of the Inventions Committee.

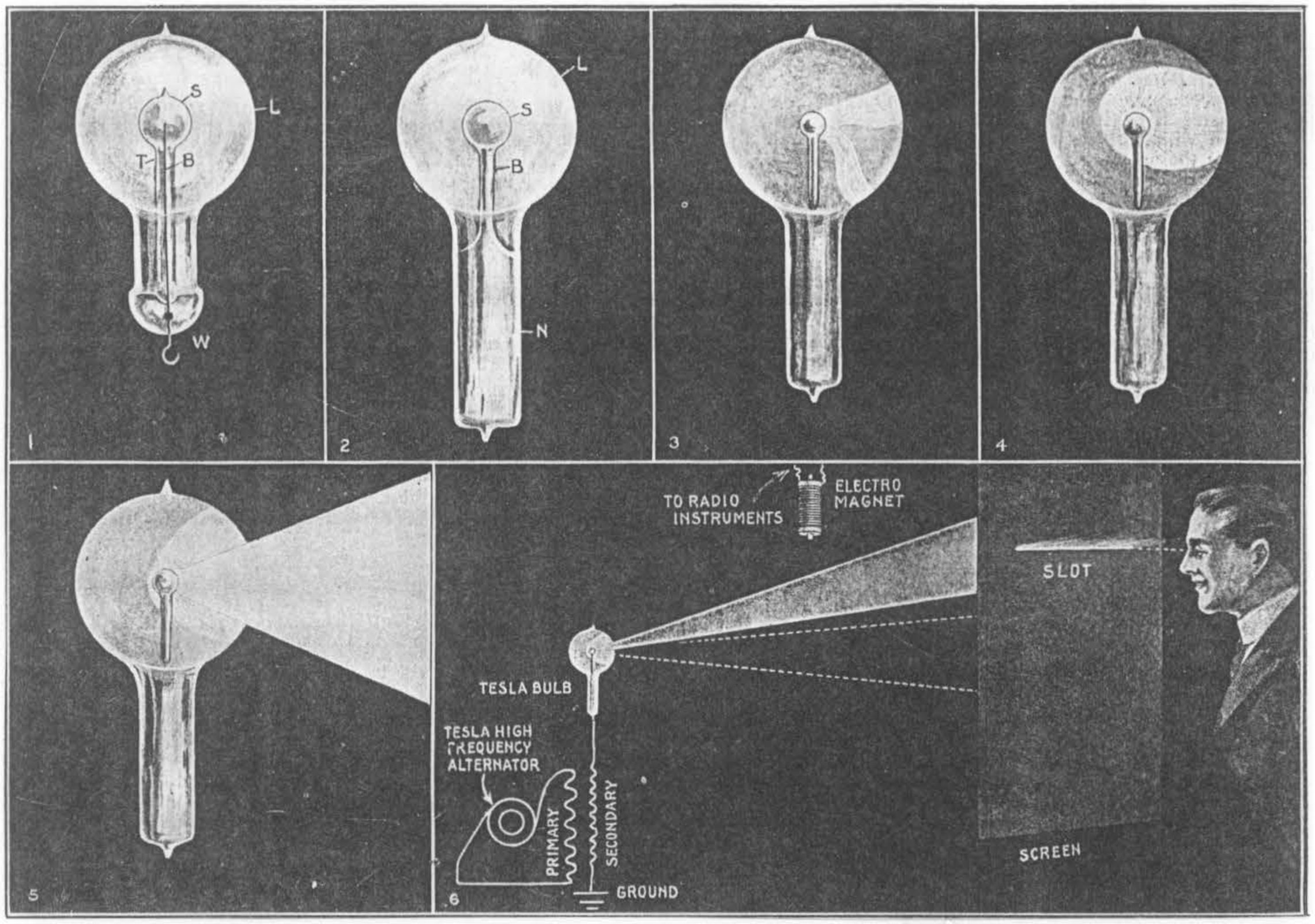
As an "engineer-teacher", he has had remarkable success. Storer, Renshaw, Hanker, Wilson, Hague, Laffoon, and others sat across the desk from him and profited by his sound sense and versatile intellect. The methods of calculation of electrical machinery in use at the Westinghouse works were inaugurated by him and still bear the marks of his individuality.

Men like Benjamin Lamme are, as it were, the integrated personalities of an organization. They figuratively represent the aggregate. Such men are rare, indeed. When they appear among us, a dynamic equilibrium, so to speak, of intellect, shrewd common sense, and exceptional health, they present the picture of success. Somehow, in the twenty-two years I have known Benjamin Lamme, he has always called to mind the figure of another great American, of bygone years, who also worked in the field of electricity. In appearance even, but surely in his astute, sententious wisdom, I am reminded of Benjamin Franklin, more than a mere namesake.

Mr. Lamme, it is a great pleasure to be here tonight and to pay you my homage in these words.



Tesla Bulbs



Early in Nikola Tesla's Researches—in Fact as Far Back as 1892—He Discovered a Most Peculiar and Wonderful Vacuum Bulb Phenomena. The Effect was That, Under Certain Critical Conditions, This Bulb Would Cause a Ray to Be Shot off in the Manner Shown, Which Ray Would Revolve or Oscillate Under the Influence of a High-Frequency Current and in Synchrony with It. By Utilizing This Principle, Dr. Tesla Believes It is Possible to Produce a Radio Detector More Sensitive Than the Audion or Fleming Valve.

IN the May issue in his article, "True Wireless," Nikola Tesla mentions the forerunner of the Audion, a Vacuum Bulb, which he used in his earlier experiments.

We have been in receipt of numerous letters from many individuals interested in this bulb who desire further particulars as to its operation, etc.

Accordingly, we publish herewith some excerpts from a lecture by Dr. Tesla delivered before the Institution of Electrical Engineers and Royal Institution, London, February, 1892.

"I think it best at this juncture to bring before you a phenomenon, observed by me some time ago, which to the purely scientific investigator may perhaps appear more interesting than any of the results which I have the privilege to present to you this evening.

"It may be quite properly ranked among the brush phenomena—in fact, it is a brush, formed at, or near, a single terminal in high vacuum.

"In bulbs provided with a conducting terminal, tho it be of aluminum, the brush has but an ephemeral existence, and cannot, unfortunately, be indefinitely preserved in its most sensitive state, even in a bulb devoid of any conducting electrode. In studying the phenomenon, by all means a bulb having no leading-in wire should be used. I have found it best to use bulbs constructed as indicated in Figs. 1 and 2.

"In Fig. 1 the bulb comprises an incandescent lamp globe L, in the neck of which is sealed a barometer tube b, the end of which is blown out to form a small sphere *s*. This sphere should be sealed as closely as possible in the center of the large globe. Before sealing, a thin tube *t*, of aluminum sheet, may be slipt in the barometer tube, but it is not important to employ it.

"The small hollow sphere *s* is filled with some conducting powder, and a wire *w* is cemented in the neck for the purpose of connecting the conducting powder with the generator.

"The construction shown in Fig. 2 was chosen in order to remove from the brush any conducting body which might possibly affect it. The bulb consists in this case of a lamp globe L, which has a neck *n*, provided with a tube *b* and small sphere *s*, sealed to it, so that two entirely independent compartments are formed, as indicated in the drawing. When the bulb is in use the neck *n* is provided with a tinfoil coating, which is connected to the generator and acts inductively upon the moderately rarefied and highly conducting gas inclosed in the neck. From there the current passes thru the tube *b* into the small sphere *s*, to act by induction upon the gas contained in the globe L.

"It is of advantage to make the tube *t* very thick, the hole thru it very small, and to blow the sphere *s* very thin. It is of the greatest importance that the sphere *s* be placed in the center of the globe L.

"Figs. 3, 4, 5, indicate different forms, or stages, of the brush. Fig. 1 shows the brush as it first appears in a bulb provided with a conducting terminal; but, as in such a bulb it very soon disappears—often after a few minutes—I will confine myself to the de-

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Tesla Bulbs

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scription of the phenomenon, as seen in a bulb without conducting electrode. It is observed under the following conditions:

"When the globe L (Figs. 1 and 2) is exhausted to a very high degree, generally the bulb is not excited upon connecting the wire *w* (Fig. 1), or the tinfoil coating of the bulb (Fig. 2) to the terminal of the induction coil. To excite it, it is usually sufficient to grasp the globe L with the hand. An intense phosphorescence then spreads at first over the globe, but soon gives place to *a white, misty light.* Shortly afterward one may notice that the luminosity is unevenly distributed in the globe, and after passing the current for some time the bulb appears as in Fig. 4. From this stage the phenomenon will gradually pass to that indicated in Fig. 5, after some minutes, hours, days or weeks, according as the bulb is worked. Warming the bulb or increasing the potential hastens the transit.

"When the brush assumes the form indicated in Fig. 5, it may be brought to a state of *extreme sensitiveness to electrostatic and magnetic influence.* The bulb hanging straight down from a wire, and all objects being remote from it, *the approach of the observer at a few paces from the bulb will cause the brush to fly to the opposite side, and if he walks around the bulb it will always keep on the opposite side.* It may begin to spin around the terminal long before it reaches the sensitive stage. *When it begins to turn around, principally, but also before, it is affected by a magnet,* and at a certain stage it is susceptible to magnetic influence to an astonishing degree. A small permanent magnet, with its poles at a distance of no more than two centimeters, will affect it visibly at a distance of two meters, slowing down or accelerating the rotation according to how it is held relatively to the brush. I think I have observed that at the stage when it is most sensitive to magnetic, it is not most sensitive to electrostatic, influence.

"When the bulb hangs with the globe L down, the rotation is always clockwise. In the southern hemisphere it would occur in the opposite direction, and on the equator the brush should not turn at all. The rotation may be reversed by a magnet kept at some distance. The brush rotates best, seemingly, when it is at right angles to the lines of force of the earth. It very likely rotates, when at its maximum speed, in synchronism with the alternations, say, 10,000 times a second. The rotation can be slowed down or accelerated by the approach or receding of the observer, or any conducting body, but it cannot be reversed by putting the bulb in any position. When it is in the state of the highest sensitiveness and the potential or frequency be varied, the sensitiveness is rapidly diminished. Changing either of these but little will generally stop the rotation. The sensitiveness is likewise affected by the variations of temperature. To attain great sensitiveness it is necessary to have the small sphere *s* in the center of the globe *L,* as otherwise the electrostatic action of the glass of the globe will tend to stop the rotation. The sphere *s* should be small and of uniform thickness; any dissymmetry of course has the effect to diminish the sensitiveness.

"The fact that the brush rotates in a definite direction in a permanent magnetic field seems to show that in alternating currents of very high frequency the positive and negative impulses are *not* equal, but that one always preponderates over the other.

"Of course, this rotation in one direction may be due to the action of the two elements of the same current upon each other, or to the action of the field produced by one of the elements upon the other, as in a

series motor, without necessarily one impulse being stronger than the other. The fact that the brush turns, as far as I could observe, in any position, would account for this theory. In such case it would turn at any point of the earth's surface. But, on the other hand, it is then hard to explain why a permanent magnet should reverse the rotation, and one must assume the preponderance of impulses of one kind.

"As to the causes of the formation of the brush or stream, I think it is due to the electrostatic action of the globe and the dissymmetry of the parts. If the small bulb *s* and the globe L were perfect concentric spheres, and the glass thruout of the same thickness and quality, I think the brush would not form, as the tendency to pass would be equal on all sides. That the formation of the stream is due to an irregularity is apparent from the fact that it has the tendency to remain in one position, and rotation occurs most generally only when it is brought out of this position by electrostatic or magnetic influence. When in an extremely sensitive state it rests in one position, and most curious experiments may be performed with it. For instance, the experimenter may, by selecting a proper position, approach the hand at a certain considerable distance to the bulb, and he may cause the brush to pass off by merely stiffening the muscles of the arm. When it begins to rotate slowly, and the hands are held at a proper distance, it is impossible to make even the slightest motion without producing a visible effect upon the brush. A metal plate connected to the other terminal of the coil affects it at a great distance, slowing down the rotation often to one turn a second.

"I am firmly convinced that such a brush, when we learn how to produce it properly, will prove a valuable aid in the investigation of the nature of the forces acting in an electrostatic or magnetic field. If there is any motion which is measurable going on in the space, such a brush ought to reveal it. It is, so to speak, a beam of light—frictionless, devoid of inertia.

"I think that it may find practical applications in telegraphy. With such a brush it would be possible to send dispatches across the Atlantic, for instance, with any speed, since its sensitiveness may be so great that the slightest changes will affect it. If it were possible to make the stream more intense and very narrow, its deflections could be easily photographed.

"I have been interested to find whether there is a rotation of the stream itself, or whether there is simply a stress traveling around the bulb. For this purpose I mounted a light mica fan so that its vanes were in the path of the brush. If the stream itself was rotating the fan would be spun around. I could produce no distinct rotation of the fan, altho I tried the experiment repeatedly; but as the fan exerted a noticeable influence on the stream, and the apparent rotation of the latter was, in this case, never quite satisfactory, the experiment did not appear to be conclusive.

"I have been unable to produce the phenomenon with the disruptive discharge coil, altho every other form of these phenomena can be well produced by it—many, in fact, much better than with coils operated from an alternator.

"It may be possible to produce the brush by impulses of one direction, or even by a steady potential, in which case it would be still more sensitive to magnetic influence."

Fig. 6 shows a practical application of the Tesla bulb. The bulb itself, as will be seen, is excited by means of a Tesla high frequency alternator which, in turn, is connected to the primary of a transformer. The secondary of the transformer is grounded at one end, while the other end of the transformer connects with the Tesla bulb.

Dr. Tesla, in an interview, stated that

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Tesla Bulbs

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the best way to use the bulb for such experiments is when the shaft of light is in the position as shown in Figs. 5 and 6, at rest, but in a state of equilibrium inconceivably delicate. This is fully described above in Dr. Tesla's lecture. The inventor states that in such a condition, the shaft of light is marvelously sensitive to magnetic disturbances. Dr. Tesla informs us that a toy permanent horseshoe magnet not longer than ½" and with its poles ⅛" apart could with ease throw the shaft of light out of its normal direction across the whole room. In our illustration, an electromagnet is shown a few inches away from light ray, and we can imagine a slot in a screen in such a way that normally no light falls thru it. If, however, very faint radio-telegraphic impulses surge thru the electromagnet, the light ray will immediately become displaced, and will fall into the slot. Inasmuch as this shaft of light has no inertia, it will follow exactly the dot and dash impulses surging thru the electromagnet, no matter how rapidly they take place. They can then either be read off by the eye, or if desired, can be registered upon a fast moving film. This method will, of course, only be used where the transmission is made at high speed, and where it would be impossible for an operator at the receiving end to follow the dots and dashes with the eye.

The method shown by us in Fig. 6, of course, represents only one. Many others can undoubtedly be evolved to use the Tesla bulb to advantage.

STATEMENT OF THE OWNERSHIP, MANAGEMENT, CIRCULATION, ETC., REQUIRED BY THE ACT OF CONGRESS OF AUGUST 24, 1912, of Electrical Experimenter, published monthly at New York, N. Y., for April 1, 1919.

State of New York, County of New York—ss.

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Hugo Gernsback, who, having been duly sworn according to law, deposes and says that he is the Editor of the Electrical Experimenter, and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management, etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, embodied in section 443, Postal Laws and Regulations:

1. That the names and addresses of the publisher, editor, managing editor, and business manager are: Publisher, The Experimenter Publishing Co., 233 Fulton Street, New York City; Editor, Hugo Gernsback, 233 Fulton Street, New York City; Managing Editor, Harry Winfield Secor, 233 Fulton Street, New York City; Business Manager, Hugo Gernsback, 233 Fulton Street, New York City.

2. That the owners are: Experimenter Publishing Co., 233 Fulton Street, New York City; Hugo Gernsback, 233 Fulton Street, New York City; Sidney Gernsback, 233 Fulton Street, New York City; Mrs. K. Hymes, 233 Fulton Street, New York City; Harry Winfield Secor, 233 Fulton Street, New York City.

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: None.

4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but, also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

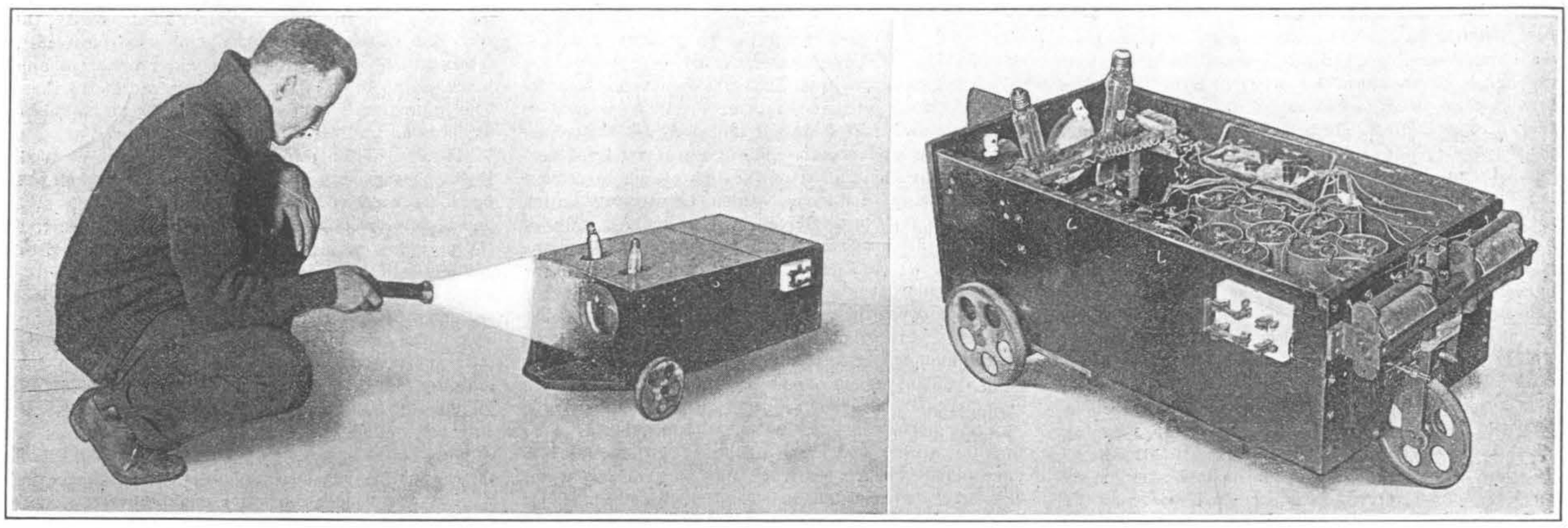
5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the six months preceding the date shown above is —(Required only of daily publications.)

(SEAL) H. GERNSBACK.

Sworn to and subscribed before me this 4th day of April, 1919.

BEATRICE K. OWEN.

(My commission expires March 30, 1921.)



The Electric Dog following its luminous master, and a general view of its internal arrangement

The Electric Dog

Use of the Selenium Cell to Make an Orientation Mechanism

By Benjamin Franklin Miessner

THE principle of orientation is well exemplified in nature. A large variety of plants, flowers, and other living examples of the realm of botany, are endowed with the power of turning themselves for the purpose of gaining the beneficial effect of the sun's rays. A very common and good example of these is the sunflower, so named because of this well-defined ability to follow the path of the sun from east to west across the heavens.

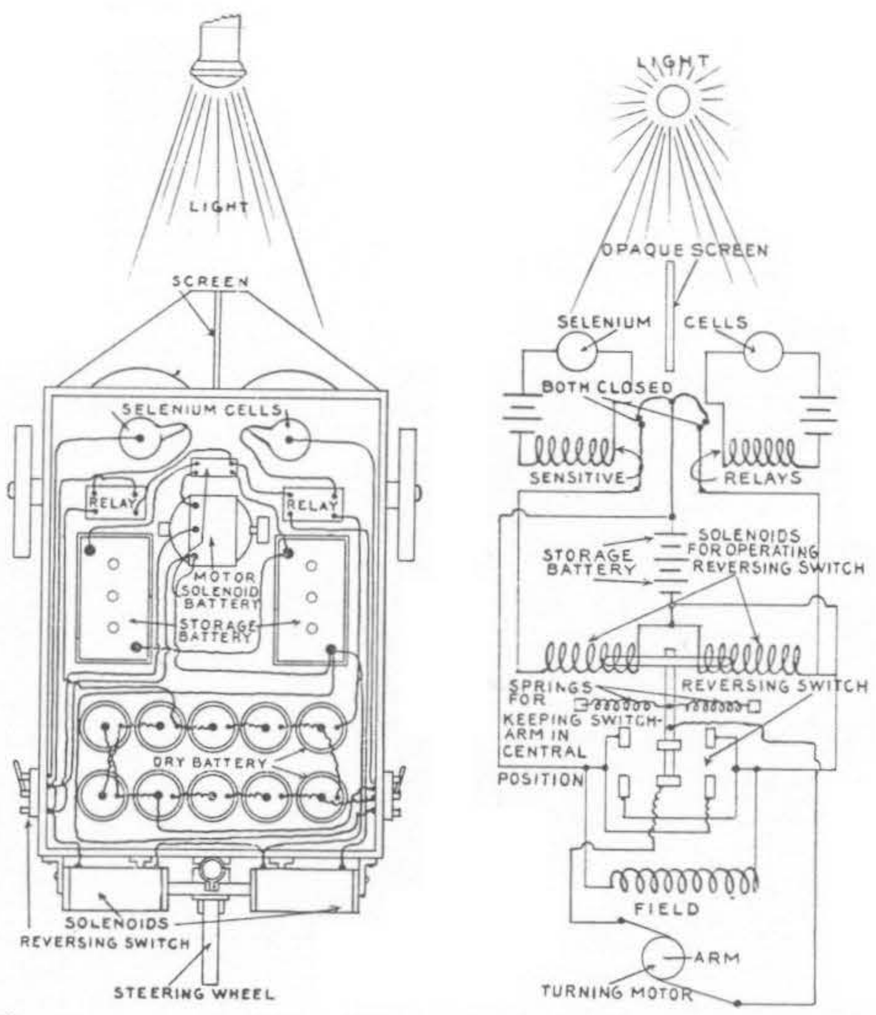
The mechanism herein described is merely an example of one of the many ways in which an inanimate object may be made to act like one possessed of life and as such capable of reacting like living objects from the effects of external stimuli.

Nikola Tesla, in a classic discussion, "The Problem of Increasing Human Energy,"[1] expressed the firm belief that every man, every living organism, is "merely an automaton endowed with power of movement, which responds to external stimuli beating upon its sense organs, and thinks and acts accordingly." He goes on to say: "With these experiments it was only natural that, long ago, I conceived the idea of constructing an automaton which would mechanically represent me and which would respond, as I do myself, but of course, in a much more primitive manner, to external influences. Such an automaton, evidently, had to have motive power, organs for locomotion, directive organs, and one or more sensitive organs so adapted as to be excited by external stimuli. This machine would, I reasoned, perform its movements in the manner of a living being, for it would have all the chief mechanical characteristics or elements of the same. . . . Whether the automaton be of flesh and bone, or of wood and steel, it mattered little provided it could perform all the duties required of it like an intelligent being. To do so, it had to have an element corresponding to the mind, which would effect the control of all of its movements and operations, and cause it to act, in any unforseen case that might present itself, with knowledge, reason, judgment, and experience. But this element I could easily embody in it by conveying to it my own intelligence, my own understanding."

In 1898 Tesla evolved the first practical telautomaton, which was in the form of a crewless boat that could be controlled from the shore or another boat by radiated energy. By means of this invention, which is the model from which all the wireless-directed torpedoes of today have been copied, Tesla was able to make an inanimate machine perform movements with the intelligence, reason, experience, and judgment of a living being.

This first automaton, it will be seen, was one which acted with the intelligence transmitted to it from the mind of its master, rather than with any intelligence which was an inherent part of its own makeup. Although, without a single doubt the intelligence of such an automaton as Mr. Tesla constructed, and which I in recent years have perfected for military purposes, would in any case be far superior to that of a machine possessed of its own mechanical brain, my work on the electric dog represents an attempt to evolve an automaton which would conduct itself in much the same manner as do some of the lower forms of animal life, that is by purely *reflex* action.

In its first form the orientation mechanism was, like the sunflower, capable only of so turning itself as to face the source of energy producing the stimulation of its sensitive organs. This apparatus I devised for use with a searchlight-selenium system of torpedo control for Mr. John Hays Hammond, Jr., with whom I was associated at that time. The purpose of this mechanism was to keep continuously facing the controlling searchlights on shore or ship, a selenium cell connected to the control switches on the torpedo. Should the rays of the enemy's searchlights reach the receiving selenium cell in sufficient intensity, interference destructive to the original control would result.



The arrangement of the electric dog (left), and a conventional representation (right) of the electric elements involved

It is this problem of interference which has ever baffled the most advanced in this new art in their efforts to prodouce an automaton able to recognize the voice of its master absolutely and without fail despite the efforts of others to imitate or reproduce that voice in the minutest detail. It is this problem which has made necessary the national and international laws relative to the use of radiotelegraphic apparatus. It is, I think, a problem of constructing an automaton which is possessed of more than human intelligence, for that automaton must be able to recognize the call of its master, and not the imitations of others, however perfect they may be. We ourselves cannot perform such a feat. The only method which can be applied successfully in rendering an automaton susceptive only to the call of its master is *to prevent the calls of others from reaching it*. This the orientation mechanism has done for the searchlight-selenium or infra-red ray systems of torpedo control.

It was about the time of our first experiments with the orientation mechanism that Professor Jaques Loeb first announced the results of his experiments and investigations with moths and the reasons for the familiar attractive effect on them by sources of light. He found that the moth flies into a flame because its flight is automatically directed by some kind of reflex action due to the stimulation of light-sensitive organs on either side of its body. Professor Loeb found further that when one alone of these organs is exposed to illumination the moth experiences an unpleasant sensation that induces a reflex action which causes the moth to turn the exposed side of its body away from the light in its effort to dispel the unpleasant sensation. As soon, however, as the other side becomes exposed to the radiation, the pain and reflex action is again set up, the same cycle of events being repeated. The forward flight of the moth therefore carries it directly toward the source of light.

Here in the moth we have the case of a living automaton capable of orientating itself with respect to a source of radiated energy, and possessed at the same time with organs of locomotion, an automaton which performs its motions mechanically in response to external stimuli.

The next form of my orientation mechanism was a reproduction of the moth mechanism, that is, one which, like the moth, was provided with means of propulsion. In its present form the electric dog consists of a rectangular box about three feet long, one and one-half feet wide and one foot high. This box contains all the instruments and mechanism, and is mounted upon three wheels, two of which are geared to a driving motor; the third, on the rear end, is so mounted that its bearings can be turned in a horizontal plane for steering, much like the front wheel of a child's velocipede. Two large, glass lenses on the forward end, separated by a protruding, nose-like partition, appear very much like huge eyes.

If a pocket flash light be turned on the machine it will immediately spring into action, but will stop as suddenly if the light be snapped off or turned away. If the light be held stationary and directed upon the dog, it will amble up until its own motion causes it to come directly under the light, and therefore into such a position that the light will not shine in its glass eyes; there it stops and the whining of its driving motor also ceases. If now one turns the flashlight into its eyes and walks about the room the dog will immediately respond and follow the moving light wherever it goes, with a loud metallic clank at each wag of its steering-wheel tail. This wagging of the tail occurs at every turn or every time at which, for any reason, the light fails to reach one of the great eyes. It always turns on these occasions so that the eye cut off from the light by the nose-like screen, will again see the light. So long as the light reaches both

[1] *Century Magazine*, June, 1900.

eyes in equal intensity, as when the source is directly ahead, the rear wheel is in the central position, and the dog moves ahead without turning. By turning over a switch, the dog can be made to back away from the light in a most surprising manner.

The electric dog is purely an automaton capable of self-propulsion and of self-direction, and the principle involved is applicable to any form of energy capable of transmission to a distance through the natural media. A suitable energy detector, which acts as the sensitive receptive organ, must be used; it must be capable, with the aid of auxiliary devices, of producing definite mechanical movements when influenced by the energy of the external stimulus. Thus, for visible waves in the ether, we use the selenium cell or its equivalent; with the infra-red or heat waves in the ether we use a sensitiye thermopile, bolometer, radiometer or other heat detecting instrument; for the ultra-violet, the trigger vacuum tube; for sound waves in air or dater, the microphone; for Hertzian waves in the ether, the radio detectors; in the case of Hertzian waves where the energy cannot well be directed as in the case of the other wave motions, the directive element must be incorporated in the receiver itself, that is, it must in all cases be so arranged that the direction from which the stimulating energy comes to it can be easily determined.

I have applied the Bellini-Tosi radio-goniometer and other radio direction finders as a means of determining the direction of the source of energy when electromagnetic waves are used. Two strongly directive antennae are supported with a certain small angle between their best directions for reception; each has connected to it a radio receiver terminating in a sensitive relay, and these control the dog mechanism exactly as do the selenium-controlled relays in the light-controlled dog. When the dog faces the source of the waves neither receiving set receives the full amount of energy; if for any reason the source moves or the dog changes its direction of motion, one of the receivers will receive a larger amount of energy while the other receives less; the result is that the balance is disturbed, a switch is moved to one side, and the steering apparatus is so operated as to bring the dog back into its original motion toward the source of energy. When refinements in radio direction finders are accomplished this form of electric dog will be well worthy of cosideration for a protection against intentional interference in torpedo control systems using Hertzian waves.

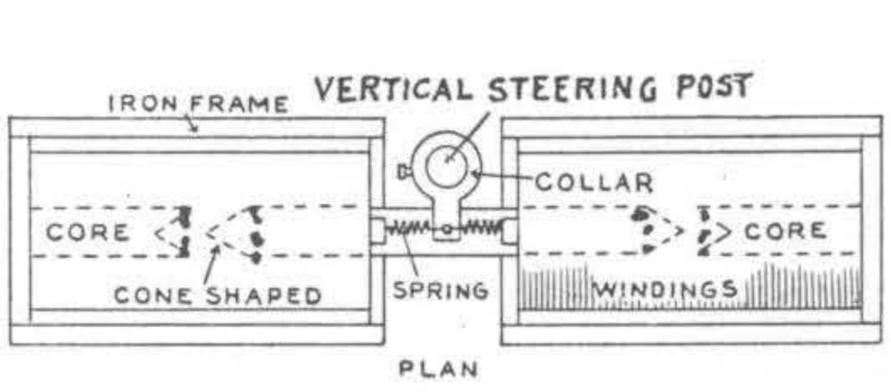
Automatic control of torpedoes has been made possible by the electric dog. Since 1911, when my experiments were materialized into the mechanism here pictured and described, I have developed plans for automatic torpedoes capable of following the sources of a number of different kinds of radiated energy, such as the sound waves resulting from the motion of a ship in the water, and from the ship's machinery, the heat radiated from its funnels, the light waves reflected from its surface. Every known form of energy capable of being radiated through the natural media has been considered in detail. Light waves and selenium were adopted in the present mechanism, because of the availability of suitable apparatus of sufficient sensitivity. I have recently given particular attention to radiant heat as the control energy and have succeeded in developing rugged and extremely sensitive receptive devices by means of which considerable simplification of apparatus and increased reliability are secured.

Although often demonstrated privately before interested scientific men in Gloucester and New York, the electric dog was first shown in public in a lecture-demonstration given by the writer on "Selenium, its Applications and Possibilities in Electrotechnics," before the Indianapolis Lafayette branch of the American Institute Electrical Engineers, at Purdue University, in January, 1915. I have devised numerous other applications of the electric dog principle, a rather novel one being an apparatus which will automatically control the pointing of guns, telscopes, and similar devices. Guns of the larger calibres, when used under the conditions imposed aboard ships, are much in need of some such automatic control. A master controller would effect the control of any or all guns on a ship merely by throwing in the connecting switch at each gun.

The electric dog follows a light, which quite naturally is surrounded by comparative darkness. In the case of the automatic torpedo or gun pointer this condition is completely reversed, that is, the source of attraction is a dark spot amid slightly brighter surroundings, or amid surroundings which are slightly different in their light-reflecting qualities.

The dog orients itself in a single plane, the horizontal; the gun pointer must be able to orient itself in both the horizontal and vertical planes simultaneously, and so must be provided with two sets of control apparatus, which operate in planes at right angles to one another. By providing telescopic attachments for the selenium cells, the turret-turning and gun elevating motors may be controlled in such a way that the gun will always be pointed in the proper direction for effective firing at the distant target. As with the present system of manual control, the telescopic sights must be set in accordance with the measurements of range finders and spotters.

With such a double orientator a new defense against the submarine becomes possible. Captain K. O. Leon of the Swedish navy has already applied the electric dog principle to the automatic direction of torpedoes, the sound waves sent out through the water from the hull of a ship acting as the attracting stimulus, it is but a step to apply a double orientator of this type to torpedoes that will seek out and destroy any submarines within its range of hearing. This same type of automatic director is suitable for use with aerial torpedoes, explosive-laden mechanical moths, which will sweep down upon the ships of the air with a sting that will blow them into a thousand pieces. The electric dog which now is but an uncanny scientific curiosity may within the very near future become in truth a real "dog of war," without fear, without heart, without the human element so often susceptible to trickery, with but one purpose; to overtake and slay at the will of its master whatever comes within range of its senses.



Plan and elevation of the steering-wheel and its connections

Electrical Oscillators

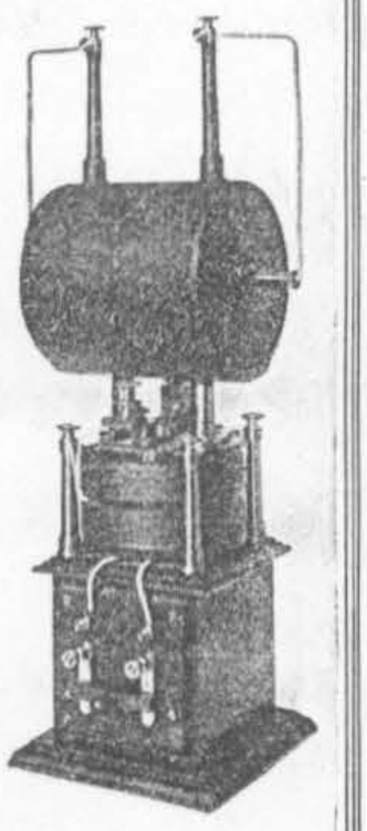


Fig. 1. Oscillator with detachable transformer for experimental purposes

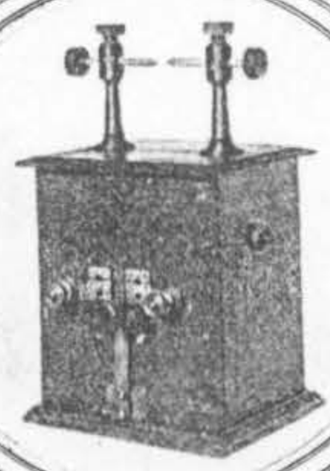


Fig. 2. Small Tesla Coil for gas engine ignition and similar uses

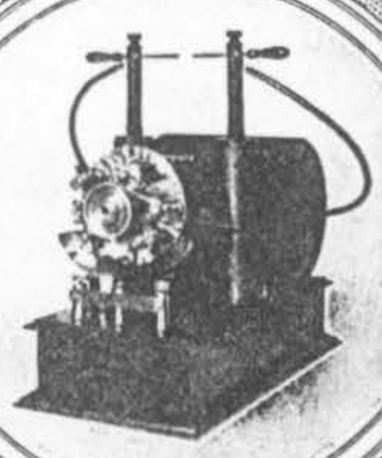


Fig. 3. Tesla Transformer, 12 inch spark, chiefly for wireless

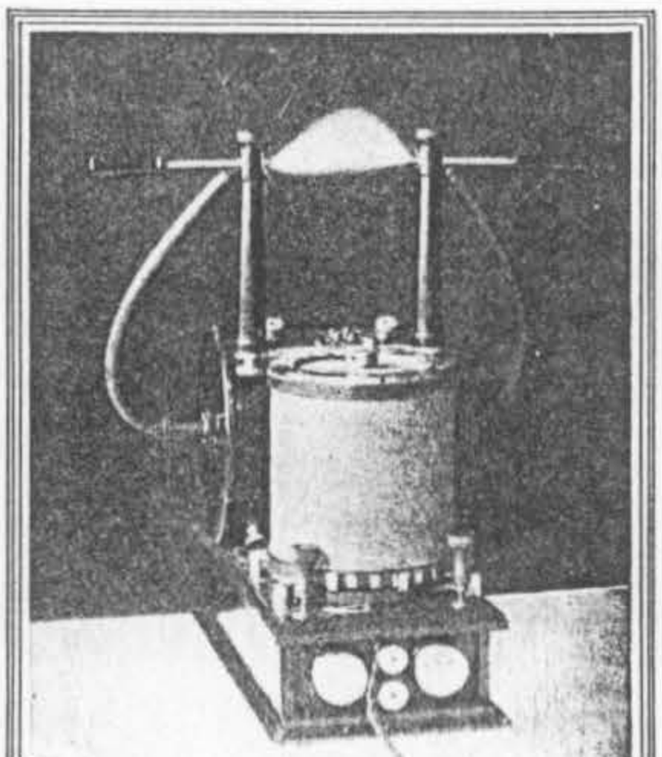


Fig. 4. Tesla Oscillator in action, generating undamped waves

Fig. 5. Later type of Tesla Transformer

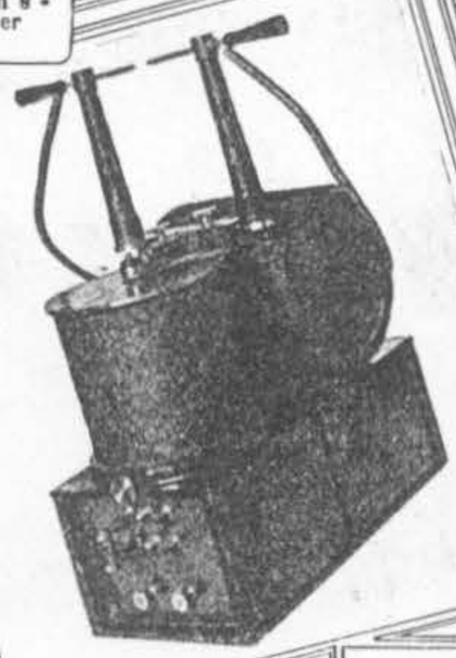


Fig. 6. Small oscillator for production of ozone

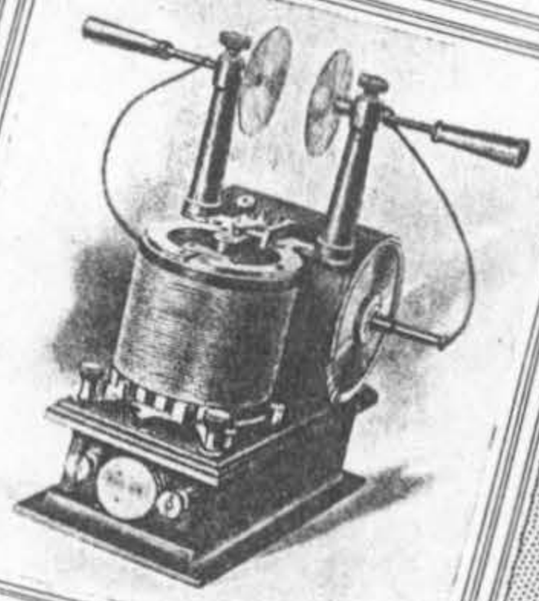


Fig. 7. Large Tesla Transformer for various purposes

Fig. 8. Tesla Transformer with rotary break for wireless

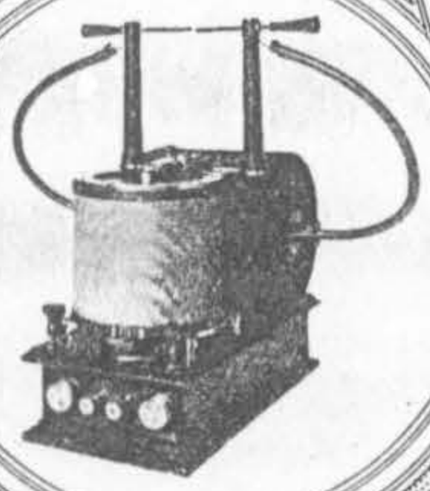


Fig. 10. Large Tesla Transformer with hermetically sealed mercury interrupter

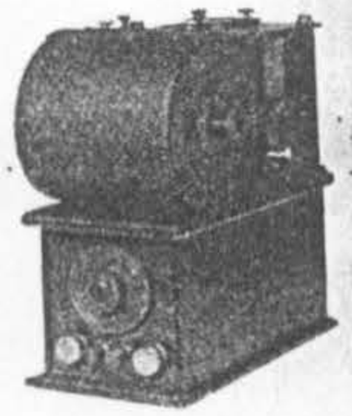


Fig. 9. Tesla Transformer with mercury interrupter

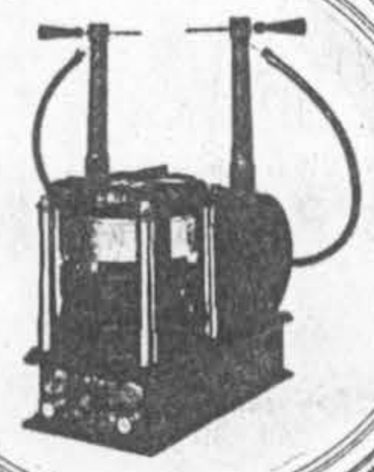
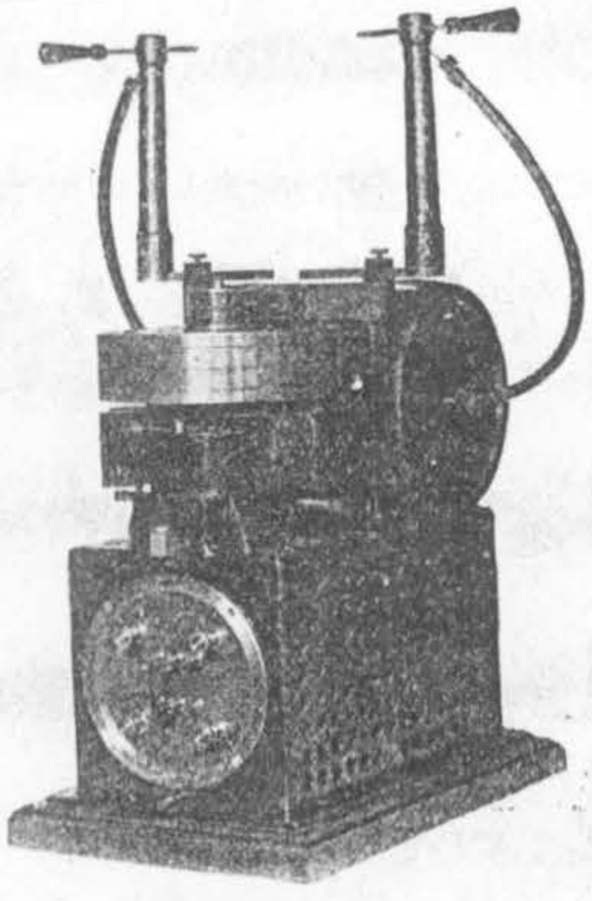


Fig. 12. Another type of Tesla Transformer with sealed mercury interrupter



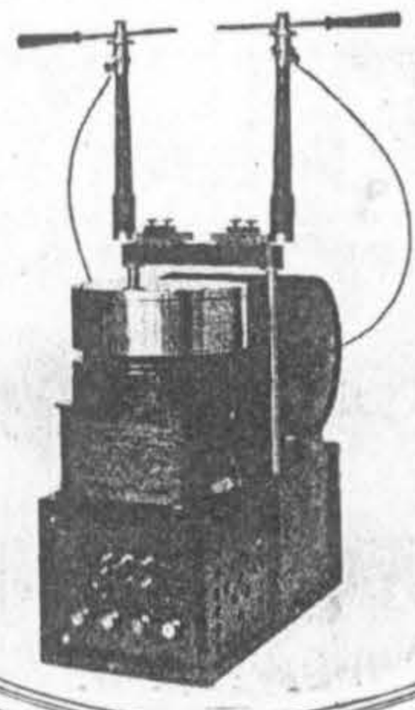
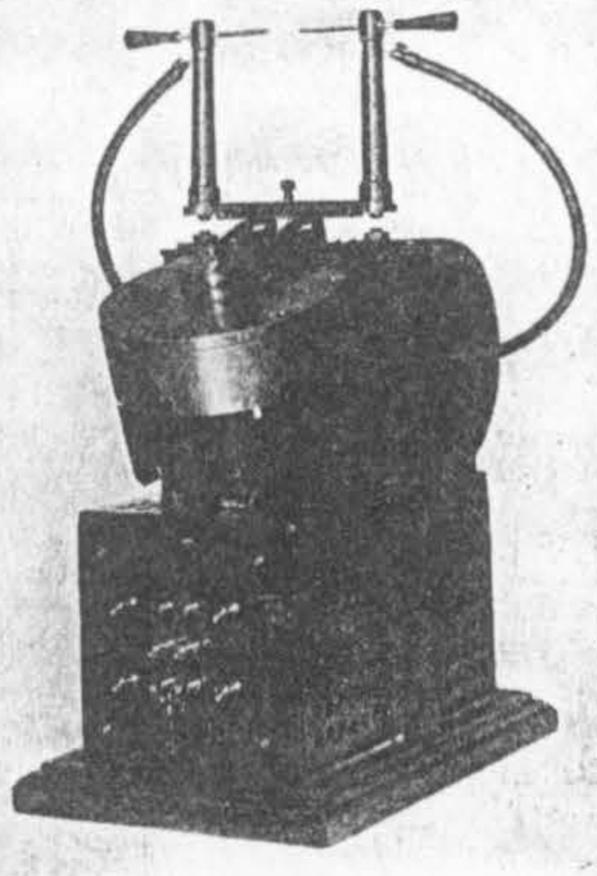


Fig. 11. Tesla Transformer with sealed mercury interrupter for low tension work



Electrical Oscillators

By NIKOLA TESLA

MR. TESLA makes a very important contribution to the electrical arts with this article.

The pioneer of all high frequency apparatus divulges much that is new and startling in these pages. Few people realize the enormous value of Mr. Tesla's machines and the many different important uses to which they can be applied in our everyday lives. New and startling uses are being found every year for these machines.

It is characteristic of Mr. Tesla that he has developed and actually built an astounding variation of these machines, and we regret that we can publish only a very few of the more important models.

Most of the Tesla coils shown have never been publisht before. —EDITOR.

FEW fields have been opened up the exploration of which has proved as fruitful as that of high frequency currents. Their singular properties and the spectacular character of the phenomena they presented immediately commanded universal attention. Scientific men became interested in their investigation, engineers were attracted by their commercial possibilities, and physicians recognized in them a long-sought means for effective treatment of bodily ills. Since the publication of my first researches in 1891, hundreds of volumes have been written on the subject and many invaluable results obtained thru the medium of this new agency. Yet, the art is only in its infancy and the future has incomparably bigger things in store.

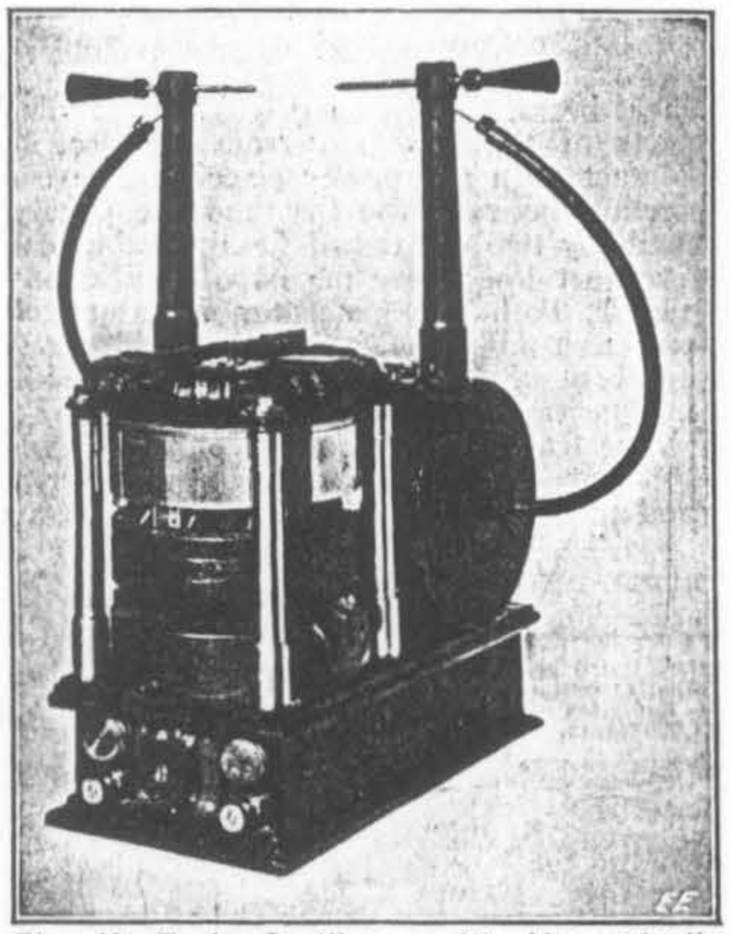


Fig. 13—Tesla Oscillator with Magnetically Controlled, Sealed Mercury Interrupter.

From the very beginning I felt the necessity of producing efficient apparatus to meet a rapidly growing demand and during the eight years succeeding my original announcements I developed not less than fifty types of these transformers or electrical oscillators, each complete in every detail and refined to such a degree that I could not materially improve any one of them today. Had I been guided by practical considerations I might have built up an immense and profitable business, incidentally rendering important services to the world. But the force of circumstances and the ever enlarging vista of greater achievements turned my efforts in other directions. And so it comes that instruments will shortly be placed on the market which, oddly enough, were perfected twenty years ago!

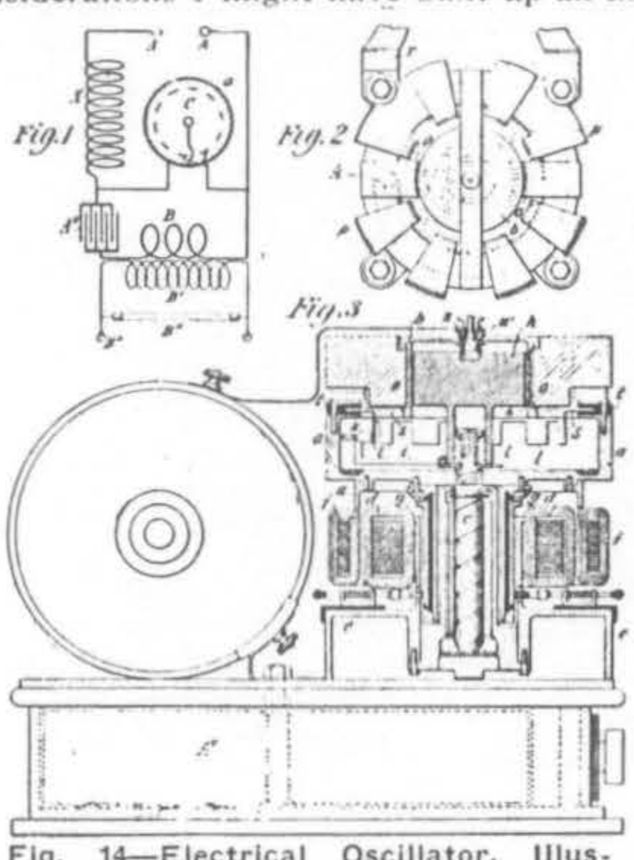


Fig. 14—Electrical Oscillator, Illustrated in Fig. 13, Showing Details and Circuit Connections.

These oscillators are expressly intended to operate on direct and alternating lighting circuits and to generate damped and undamped oscillations or currents of any frequency, volume and tension within the widest limits. They are compact, self-contained, require no care for long periods of time and will be found very convenient and useful for various purposes as, wireless telegraphy and telephony; conversion of electrical energy; formation of chemical compounds thru fusion and combination; synthesis of gases; manufacture of ozone; lighting; welding; municipal, hospital, and domestic sanitation and sterilization, and numerous other applications in scientific laboratories and industrial institutions. While these transformers have never been described before, the general principles underlying them were fully set forth in my publisht articles and patents, more particularly those of September 22, 1896, and it is thought, therefore, that the appended photographs of a few types, together with a short explanation, will convey all the information that may be desired.

The essential parts of such an oscillator are: a condenser, a self-induction coil for charging the same to a high potential, a circuit controller, and a transformer which is energized by the oscillatory discharges of the condenser. There are at least three, but usually four, five or six, circuits in tune and the regulation is effected in several ways, most frequently merely by means of an adjusting screw. Under favorable conditions an efficiency as high as 85% is attainable, that is to say, that percentage of the energy supplied can be recovered in the secondary of the transformer. While the chief virtue of this kind of apparatus is obviously due to the wonderful powers of the condenser, special qualities result from concatenation of circuits under observance of accurate harmonic relations, and minimization of frictional and other losses which has been one of the principal objects of the design.

(*Continued on page* 259)

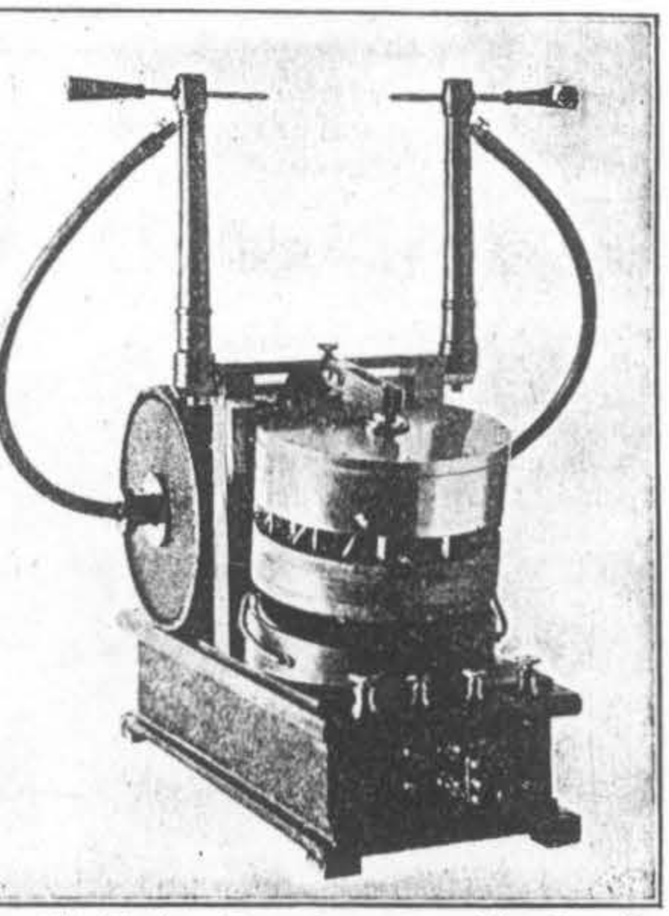


Fig. 15—Tesla Transformer with Gravity Controlled, Sealed Mercury Interrupter.

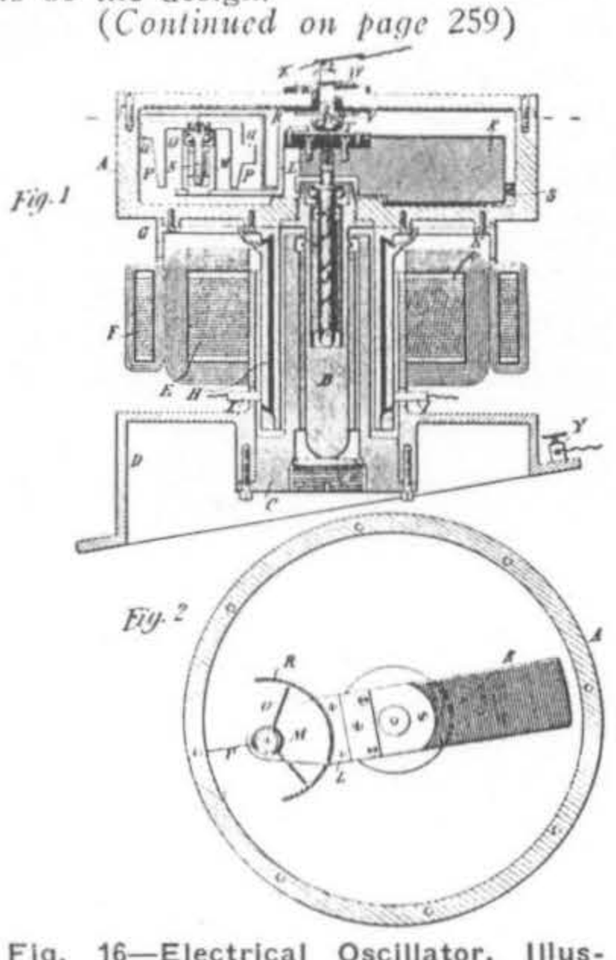


Fig. 16—Electrical Oscillator, Illustrated in Fig. 15, Showing Details of Motor and Break Mechanism.

SPECIAL NOTICE

Last month we announced another special feature article by Mr. Tesla, which altho made in good faith by us was not authorized by him. Due to very important duties of Mr. Tesla, it was impossible for him to furnish his historical article this month, so the special feature article publisht on this page takes its place. An important historical article will appear in the August issue.—Editor.

Electrical Oscillators

By Nikola Tesla

(*Continued from page 229*)

Broadly, the instruments can be divided into two classes: one in which the circuit controller comprises solid contacts, and the other in which the make and break is effected by mercury. Figures 1 to 8, inclusive, belong to the first, and the remaining ones to the second class. The former are capable of an appreciably higher efficiency on account of the fact that the losses involved in the make and break are reduced to the minimum and the resistance component of the damping factor is very small. The latter are preferable for purposes requiring larger output and a great number of breaks per second. The operation of the motor and circuit controller of course consumes a certain amount of energy which, however, is the less significant the larger the capacity of the machine.

In Fig. 1 is shown one of the earliest forms of oscillator constructed for experimental purposes. The condenser is contained in a square box of mahogany upon which is mounted the self-induction or charging coil wound, as will be noted, in two sections connected in multiple or series according to whether the tension of the supply circuit is 110 or 220 volts. From the box protrude four brass columns carrying a plate with the spring contacts and adjusting screws as well as two massive terminals for the reception of the primary of the transformer. Two of the columns serve as condenser connections while the other pair is employed to join the binding posts of the switch in front to the self-inductance and condenser. The primary coil consists of a few turns of copper ribbon to the ends of which are soldered short rods fitting into the terminals referred to. The secondary is made in two parts, wound in a manner to reduce as much as possible the distributed capacity and at the same time enable the coil to withstand a very high pressure between its terminals at the center, which are connected to binding posts on two rubber columns projecting from the primary. The circuit connections may be slightly varied but ordinarily they are as diagrammatically illustrated in the ELECTRICAL EXPERIMENTER for May on page 89, relating to my oscillation transformer photograph of which appeared on page 16 of the same number. The operation is as follows: When the switch is thrown on, the current from the supply circuit rushes thru the self-induction coil, magnetizing the iron core within and separating the contacts of the controller. The high tension induced current then charges the condenser and upon closure of the contacts the accumulated energy is released thru the primary, giving rise to a long series of oscillations which excite the tuned secondary circuit.

This device has proved highly serviceable in carrying on laboratory experiments of all kinds. For instance, in studying phenomena of impedance, the transformer was removed and a bent copper bar inserted in the terminals. The latter was often replaced by a large circular loop to exhibit inductive effects at a distance or to excite resonant circuits used in various investigations and measurements. A transformer suitable for any desired performance could be readily improvised and attached to the terminals and in this way much time and labor was saved. Contrary to what might be naturally expected, little trouble was experienced with the contacts, altho the currents thru them were heavy, namely, proper conditions of resonance existing, the great flow occurs only when the circuit is closed and no destructive arcs can develop. Origi-

nally I employed platinum and iridium tips but later replaced them by some of meteorite and finally of tungsten. The last have given the best satisfaction, permitting working for hours and days without interruption.

Fig. 2 illustrates a small oscillator designed for certain specific uses. The underlying idea was to attain great activities during minute intervals of time each succeeded by a comparatively long period of inaction. With this object a large self-induction and a quick-acting break were employed owing to which arrangement the condenser was charged to a very high potential. Sudden secondary currents and sparks of great volume were thus obtained, eminently suitable for welding thin wires, flashing lamp filaments, igniting explosive mixtures and kindred applications. The instrument was also adapted for battery use and in this form was a very effective igniter for gas engines on which a patent bearing number 609,250 was granted to me August 16, 1898.

Fig. 3 represents a large oscillator of the first class intended for wireless experiments, production of Röntgen rays and scientific research in general. It comprises a box containing two condensers of the same capacity on which are supported the charging coil and transformer. The automatic circuit controller, hand switch and connecting posts are mounted on the front plate of the inductance spool as is also one of the contact springs. The condenser box is equipt with three terminals, the two external ones serving merely for connection while the middle one carries a contact bar with a screw for regulating the interval during which the circuit is closed. The vibrating spring itself, the sole function of which is to cause periodic interruptions, can be adjusted in its strength as well as distance from the iron core in the center of the charging coil by four screws visible on the top plate so that any desired conditions of mechanical control might be secured. The primary coil of the transformer is of copper sheet and taps are made at suitable points for the purpose of varying, at will, the number of turns. As in Fig. 1 the inductance coil is wound in two sections to adapt the instrument both to 110 and 220 volt circuits and several secondaries were provided to suit the various wave lengths of the primary. The output was approximately 500 watt with damped waves of about 50,000 cycles per second. For short periods of time undamped oscillations were produced in screwing the vibrating spring tight against the iron core and separating the contacts by the adjusting screw *which also performed the function of a key.* With this oscillator I made a number of important observations and it was one of the machines exhibited at a lecture before the New York Academy of Sciences in 1897.

Fig. 4 is a photograph of a type of transformer in every respect similar to the one illustrated in the May, 1919, issue of the ELECTRICAL EXPERIMENTER to which reference has already been made. It contains the identical essential parts, disposed in like manner, but was specially designed for use on supply circuits of higher tension, from 220 to 500 volts or more. The usual adjustments are made in setting the contact spring and shifting the iron core within the inductance coil up and down by means of two screws. In order to prevent injury thru a short-circuit, fuses are inserted in the lines. The instrument was photographed in action, generating undamped oscillations from a 220 volt lighting circuit.

Fig. 5 shows a later form of transformer principally intended to replace Rhumkorf coils. In this instance a primary is employed, having a much greater number of turns and the secondary is closely linked with the same. The currents developed in the latter, having a tension of from 10,000 to 30,000 volts, are used to charge con-

(*Continued on page 276*)

Electrical Oscillators

By Nikola Tesla

(*Continued from page* 260)

densers and operate an independent high frequency coil as customary. The controlling mechanism is of somewhat different construction but the core and contact spring are both adjustable as before.

Fig. 6 is a small instrument of this type, particularly intended for ozone production or sterilization. It is remarkably efficient for its size and can be connected either to a 110 or 220 volt circuit, direct or alternating, preferably the former.

In Fig. 7 is shown a photograph of a

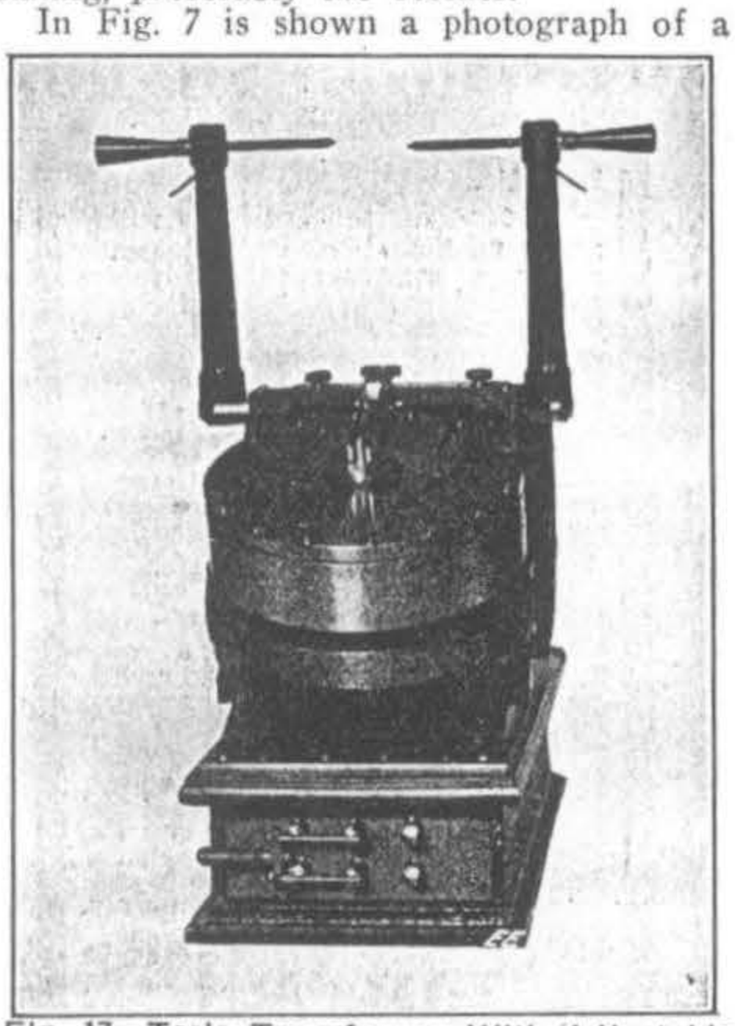


Fig. 17. Tesla Transformer With Adjustable Mercury Controller.

larger transformer of this kind. The construction and disposition of the parts is as before but there are two condensers in the box, one of which is connected in the circuit as in the previous cases, while the other is in shunt to the primary coil. In this manner currents of great volume are produced in the latter and the secondary effects are accordingly magnified. The introduction of an additional tuned circuit secures also other advantages but the adjustments are rendered more difficult and for this reason it is desirable to use such an instrument in the production of currents of a definite and unchanging frequency.

Fig. 8 illustrates a transformer with rotary break. There are two condensers of the same capacity in the box which can be connected in series or multiple. The charging inductances are in the form of two long spools upon which are supported the secondary terminals. A small direct current motor, the speed of which can be varied within wide limits, is employed to drive a specially constructed make and break. In other features the oscillator is like the one illustrated in Fig. 3 and its operation will be readily understood from the foregoing. This transformer was used in my wireless experiments and frequently also for lighting the laboratory by my vacuum tubes and was likewise exhibited at my lecture before the New York Academy of Sciences above mentioned.

Coming now to machines of the second class, Fig. 9 shows an oscillatory transformer comprising a condenser and charging inductance enclosed in a box, a transformer and a mercury circuit controller, the latter being of a construction described for the first time in my patent No. 609,251 of August 16, 1898. It consists of a motor driven hollow pulley containing a small quantity of mercury which is thrown outwardly against the walls of the vessel by centrifugal force and entrains a contact wheel which periodically closes and opens the condenser circuit. By means of adjusting screws above the pulley, the depth of immersion of the vanes and consequently, also, the duration of each contact can be varied at desire and thus the intensity of the effects and their character controlled. This form of break has given thoro satisfaction, working continuously with currents of from 20 to 25 amperes. The number of interruptions is usually from 500 to 1,000 per second but higher frequencies are practicable. The space occupied is about 10″ x 8″ x 10″ and the output approximately ½ K.W.

In the transformer just described the break is exposed to the atmosphere and a slow oxidation of the mercury takes place. This disadvantage is overcome in the instrument shown in Fig. 10, which consists of a perforated metal box containing the condenser and charging inductance and carrying on the top a motor driving the break, and a transformer. The mercury break is of a kind to be described and operates on the principle of a jet which establishes, intermittently, contact with a rotating wheel in the interior of the pulley. The stationary parts are supported in the vessel on a bar passing thru the long hollow shaft of the motor and a mercury seal is employed to effect hermetic closure of the chamber enclosing the circuit controller. The current is led into the interior of the pulley thru two sliding rings on the top which are in series with the condenser and primary. The exclusion of the oxygen is a decided improvement, the deterioration of the metal and attendant trouble being eliminated and perfect working conditions continuously maintained.

Fig. 11 is a photograph of a similar oscillator with hermetically inclosed mercury break. In this machine the stationary parts of the interrupter in the interior of the pulley were supported on a tube thru which was led an insulated wire connecting to one terminal of the break while the other was in contact with the vessel. The sliding rings were, in this manner, avoided and the construction simplified. The instrument was designed for oscillations of lower tension and frequency requiring primary currents of comparatively smaller amperage and was used to excite other resonant circuits.

Fig. 12 shows an improved form of oscillator of the kind described in Fig. 10, in which the supporting bar thru the hollow motor shaft was done away with, the device pumping the mercury being kept in position by gravity, as will be more fully explained with reference to another figure. Both the capacity of the condenser and primary turns were made variable with the view of producing oscillations of several frequencies.

Fig. 13 is a photographic view of another form of oscillatory transformer with hermetically sealed mercury interrupter, and Fig. 14 diagrams showing the circuit connections and arrangement of parts reproduced from my patent, No. 609,245, of August 16, 1898, describing this particular device. The condenser, inductance, transformer and circuit controller are disposed as before, but the latter is of different construction, which will be clear from an inspection of Fig. 14. The hollow pulley *a* is secured to a shaft *c* which is mounted in a vertical bearing passing thru the stationary field magnet *d* of the motor. In the interior of the vessel is supported, on frictionless bearings, a body *h* of magnetic material which is surrounded by a dome *b* in the center of a laminated iron ring, with pole pieces *oo* wound with energizing coils *p*. The ring is supported on four columns and, when magnetized, keeps the body *h* in position while the pulley is rotated. The latter is of steel, but the dome is preferably made of German silver burnt black by acid or nickeled. The body *h* carries a short tube *k* bent, as indicated, to catch the fluid as it is whirled around, and project it against the teeth of a wheel fastened to the pulley. This wheel is insulated and contact from it to the external circuit is established thru a mercury cup. As the pulley is rapidly rotated a jet of the fluid is thrown against the wheel, *thus making and breaking contact about* 1,000 *times per second.* The instrument works silently and, owing to the absence of all deteriorating agents, keeps continually clean and in perfect condition. The number of interruptions per second may be much greater, however, so as to make the currents suitable for wireless telephony and like purposes.

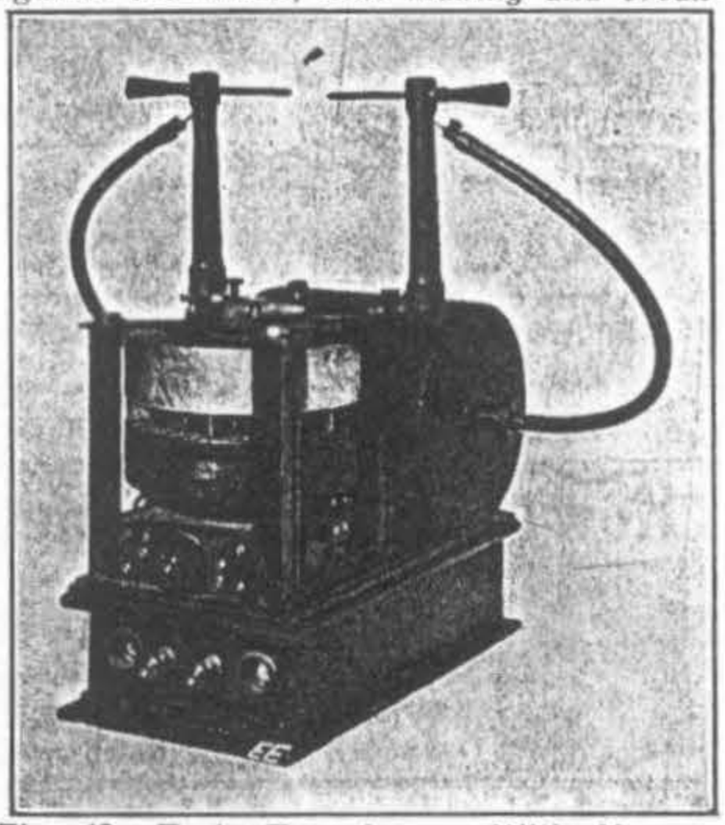


Fig. 18. Tesla Transformer With Mercury Jet Interrupter.

A modified form of oscillator is represented in Figs. 15 and 16, the former being a photographic view and the latter a diagrammatic illustration showing the arrangement of the interior parts of the controller. In this instance the shaft *b* carrying the vessel *a* is hollow and supports, in frictionless bearings, a spindle *j* to which is fastened a weight *k*. Insulated from the latter, but mechanically fixt to it, is a curved arm L upon which is supported, freely rotatable, a break-wheel with projections QQ. The wheel is in electrical connection with the external circuit thru a mercury cup and an insulated plug supported from the top of the pulley. Owing to the inclined position of the motor the weight *k* keeps the break-wheel in place by the force of gravity and as the pulley is rotated the circuit, including the condenser and primary coil of the transformer, is rapidly made and broken.

Fig. 17 shows a similar instrument in which, however, the make and break device is a jet of mercury impinging against an insulated toothed wheel carried on an insulated stud in the center of the cover of the pulley as shown. Connection to the condenser circuit is made by brushes bearing on this plug.

Fig. 18 is a photograph of another transformer with a mercury circuit controller of the wheel type, modified in some features on which it is unnecessary to dwell.

These are but a few of the oscillatory transformers I have perfected and constitute only a small part of my high frequency apparatus of which I hope to give a full description, when I shall have freed myself of pressing duties, at some future date.



THE ORACLE

The "Oracle" is for the sole benefit of all electrical experimenters. Questions will be answered here for the benefit of all, but only matter of sufficient interest will be publisht. Rules under which questions will be answered:

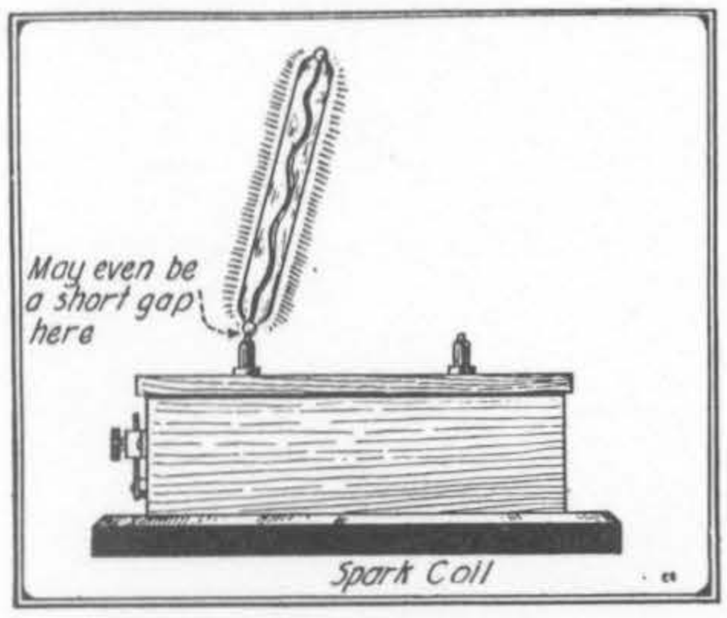
1. Only three questions can be submitted to be answered.
2. Only one side of sheet to be written on; matter must be typewritten or else written in ink, no penciled matter considered.
3. Sketches, diagrams, etc., **must** be on separate sheets. Questions addrest to this department cannot be answered by mail free of charge.
4. If a quick answer is desired by mail, a nominal charge of **25 cents** is made for each question. If the questions entail considerable research work or intricate calculations a special rate will be charged. Correspondents will be informed as to the fee before such questions are answered.

TESLA COIL AND GEISSLER TUBE HOOK-UPS.

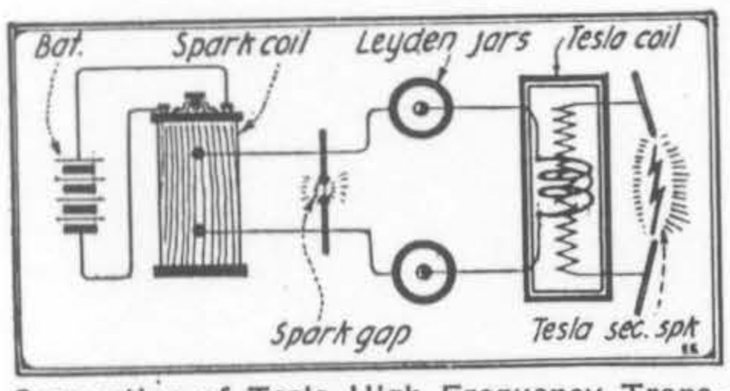
(1012) A. Terkel, Reedley, Cal., asks:

Q. 1. For a diagram of connections for Tesla coil, Geissler tubes, etc.

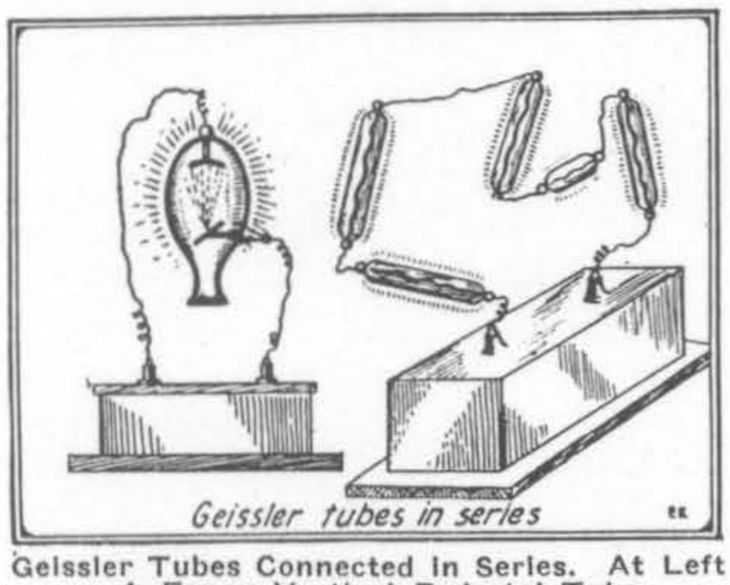
A. 1. We are pleased to give you herewith the diagram of connections for two inch spark coil, Tesla coil, Leyden jars, Geissler tubes, etc.



Lighting Geissler Tube from One Terminal of Spark Coil.



Connection of Tesla High Frequency Transformer, Leyden Jars, Spark Coil and Gap.



Geissler Tubes Connected in Series. At Left —A Fancy Vertical Pedestal Tube.

The "August" Electrical Experimenter

"Bombs—How to Handle Them"—by Owen Eagan, Bomb Expert, Department of Combustibles, New York City Fire Department. A complete authoritative article with remarkable photographs by America's greatest expert on bombs and explosives, which tells you what to do should you receive a bomb by mail.

"A New Hydrostatic Wheel-less Railway"—by H. Gernsback. A Railway which has seen actual service. Without wheels it runs on a "film of water."

"Insanity from the Teeth?—What the X-Ray Shows"—by Dr. Henry A. Cotton.

"Electrical Refrigeration"—by Grace T. Hadley.

"Hot-Air and Other Engines"—by John J. Furia.

"Sir William Crookes' Researches on Psychical Phenomena" by Herewood Carrington, Ph.D.

"My Inventions" Part 6—by Dr. Nikola Tesla himself.

"Changing Nature's Face"—How Dynamite, plus Electricity, is used for clearing stump and rock-strewn property, blasting irrigating ditches, and changing the course of rivers.

"Experiments in Physics"—A new series. No. 1, perpetual motion, and popular fallacies concerning it exploded. By John J. Furia, Department of Physics, New York University.

"Loop Antennae"—An article of interest to all "Wireless Bugs." By Prof. Lloyd M. Knoll.

"Invention of the Crystal Detector" —by Greenleaf Whittier Pickard.

TESLA AND OUDIN COIL DATA.

(1014) E. W. Thatcher, Oberlin, Ohio, wants data:

Q. 1. For building Tesla and Oŭdin coils.

A. 1. We refer you to copy of this magazine wherein you will find the complete construction of a Tesla high frequency coil, also the Oŭdin coil. The article in question appeared in the May, 1917, issue of the ELECTRICAL EXPERIMENTER.

NIKOLA TESLA TELLS HOW WE MAY FLY EIGHT MILES HIGH AT 1,000 MILES AN HOUR

By NIKOLA TESLA

In an interview with Frederick M. Kerby

As the inventor of the alternating current, the world is indebted to Mr. Tesla for the use of electricity carried long distances. He now discusses the probability that airplanes will rise to great heights and travel at speeds that seem incredible. This article is written, in part by Mr. Tesla himself. The rest is written from stenographic notes. It gives, very likely, a glimpse of the immediate future.

SITTING in his office on the twenty-fifth floor of the Woolworth Tower, Mr. J. Pierpont Jones, American business man, will one day glance at his watch and discover it is 3 o'clock in the afternoon.

"By George," he will say, buzzing for his secretary, "If I don't hurry I'll be late for that dinner engagement at the Savoy!" And as his secretary answers the buzzer:

"Charles, when does the next London bus leave?"

"Three-thirty, sir," says Charles. "You can make it if you hurry. The car is waiting."

And fifteen minutes later Mr. J. Pierpont Jones will emerge from the elevator on the aeronautic landing stage of lower Manhattan, climb into the hermetically sealed steel fuselage of the New York-London Airline Limited, which will rise promptly at 3.30 p. m. At seven that night he will climb out of his compartment on the landing stage on the Thames Embankment, and descend to meet his friend for dinner.

The three-hour aeroplane trip from New York to London, flying above the storm level at eight miles above the earth's surface is the possibility of the immediate future.

This is not my own prediction. It is the result of sixteen pages of close calculations in higher mathematics made by Nikola Tesla, to test and check up other pages of intricate calculations made by Samuel D. Mott, charter member of the Aero Club of America.

Mr. Mott asserts that the three-hour trip to London from New York is a question of rising into rarefied air where the air pressure is only one-fifth what it is at the earth's surface, at

which point an "altiplane," as he has named the flying machine of the future, may be expected to fly five times as fast as at the earth's surface. And if the speed of the aeroplane is increased not five times but only one-fifth, Mr. Mott says the trip will be made anyhow in the rarefied air eight miles above the earth's surface in not more than twelve hours running time.

And Nikola Tesla agrees that taking a plane to such an altitude must result in great increase of speed, although he does not wish, in the absence of exact knowledge of certain factors entering into the problem, to predict exact speeds.

Speaking before the Pan-American Aeronautic Convention at Atlantic City, Mr. Mott asserted that in order to avoid being weather-bound as were the aviators at Newfoundland, it will be necessary to construct planes that will rise above the storm limit.

"I submit," he said, "that waiting indefinitely for ideal weather conditions for long-distance flying over land or sea will not do for the demands of commerce. Therefore I would bring to your attention the possibilities of the altitude plane or alti-plane, as distinguished from the airplane or hydroplane, to go into the stillness of nature above the weather.

What The Problem Is

"The problem is evidently one of equipment of our planes to function in rarefied air, and protection of navigators against its tenuity; likewise protection of their body warmth and comfort in extremes of temperature. How high we may go no one may know until tested. Personally I believe it possible to go fifteen or twenty miles aloft, if necessary. It is obviously a matter of equipment plus climbing ability of aircraft designed for the purpose.

"What is the object of high flying? Daily experience shows us that high speed and density are incompatible. We know that we must furnish aircraft with four times the power to go twice as fast, and the marine engineer knows that he must furnish eight times the power to go twice as fast. In other words, from the ultimate height of the air to the earth's core pressure is progressive. Thirty-three feet below the ocean's surface the pressure doubles. For every 1,000 feet ascent the pressure diminishes roughly one-half pound per square inch. The pressure two miles high is 9.8 pounds per square inch; at one mile high, 10.88; at three-quarters of a mile, 12.06; one-half mile, 13.33; one-quarter mile, 14.2, and at sea level, 14.7 pounds, or, in round numbers, 15 pounds per square inch.

"The unknown factor in the high altitude problem is this: Will an altiplane in one-fifth density (eight miles high), with equal push, go five times faster or one-fifth faster? The rest is a matter of simple equipment and good construction. In either case the gain is substantial. If the former were true a voyage between New York and London can be made in about three hours by going eight miles high. If the latter is true the same voyage can be made in about twelve hours running time, assuming a surface speed of 200 miles an hour, which is practically a question of power.

"To my mind it is plain that the high altitudes will be determining factors in long distance flying. Greater speed, greater distance, more comfort and less danger in the quiet environment, less danger because when we double the time to do a risky thing we double the risk incurred; less gasolene, less weight and expense, for if environment permits us to go 100 miles with twice the fuel we formerly used to go twenty-five miles our economic gain is obviously 100 per cent, because we may then go 100 miles with the amount of fuel we formerly consumed to go fifty miles."

That aerial navigation at higher altitudes will undoubtedly result in great increase of speed is also the opinion of Nikola Tesla, to whom I took Mr. Mott's conclusions in order to get the opinion of this man who has made a life-time study of the air as a medium for the transmission or electrical energy.

"In the propulsion of aerial vessels problems are involved entirely different from those presented in the navigation of the water," said Tesla. "The atmosphere may be likened to a vast ocean, but if one imagines a submarine vessel constructed like an aeroplane one immediately realizes how inefficient it would be. The energy used in propelling a body through a medium of any kind is wasted in three different ways: first, by skin friction; second, wave making; third, production of eddies. On general principles, however, the resistance can be divided into two parts: one which is due to the friction of the medium and the other to its stickiness, or viscosity, as it is termed. The first is proportionate to the density; the second to this peculiar property of the fluid.

"Everybody will readily understand that the denser the medium the harder it is to push a body through it, but it might not be clear to every person what this other resistance—this viscosity—means. This will be understood if we compare, for instance, water and oil. The latter is lighter, but much more sticky, so that it is a greater obstacle to propulsion than water. Air is a very viscuous substance and that part of resistance which is due to this quality is considerable. We must take this latter resistance into account in calculating how fast an aeroplane could fly in the upper reaches of the air.

"Now, the idea is to fly at a great height where the air is rarefied, and therefore much less power is required to propel the machine through it. If we take the pressure at sea-level at 14.7 pounds and the temperature at 15 degrees centigrade, then, without introducing several corrections that would make for greater accuracy, the pressures at different heights are about as follows: At 1,000 feet above sea-level, 14.178 lbs.; at one-mile, 12.1457 lbs.; at two miles, 10.035 lbs.; at eight miles, 3.1926 lbs.; at fifteen miles ,0.8392 lbs. and at twenty miles, 0.323 lbs.

Condition Eight Miles Up

"According to these figures that I have worked out, at a height of eight miles the density of the air is 0.2172 or about 22-100th of that at sea level; at fifteen miles it is 0.057, and at twenty miles only 0.0219, or nearly 22-1000th of that at sea-level.

"Let us suppose then that an aeroplane rises to a height of eight miles where the pressure of the air will be only 3.1926 lbs., or, in other words, the density 0.2172 of that at sea-level. Since, as pointed out, the purely frictional resistance is proportionate to the density of the air, it is obvious that, if there were no other resistance to overcome, only about 22 per cent of power or roughly one-fifth, would be required to propel the vessel at that height, so that extremely high speed, as Mr. Mott points out, would be obtainable.

"And though the other resistance, which is due to the stickiness of the medium, will not be diminished at the same ratio, and therefore the gain will not be strictly in proportion to the decrease of density of the air, nevertheless, the total resistance will be reduced, if not to 22 per cent, perhaps to 30 per cent, so that there will be a great excess of power available for more rapid flight.

"Even allowing for the decreased thrust of the propeller due to the thinness of the air, which cannot be overcome by driving the screw faster, there still will be the very considerable gain and the aircraft will be propelled at a higher speed.

"Of course many incertitudes still exist in the theoretical treatment of a question like this, as there are a number of factors which affect the result and in regard to which we have not yet complete information.

At An Altitude of Twenty Miles

"I doubt that it will be possible to rise as high as fifteen or twenty miles, which is the opinion expressed by Mr. Mott. At the height of twenty miles there is only about 7 per cent of oxygen in the air instead of 21 per cent which is present close to the ground, and there would be great trouble in securing the oxygen supply for the combustion of the fuel, not to speak of other limitations.

"However, at a height of eight miles the decrease of oxygen can be overcome for both engine and aviator. Of course provision would have to be made for supplying the aviator and passengers with oxygen. In all probability they would have to be entirely enclosed just as a diver is enclosed. Our highest mountains are five miles and the rarefication of the air makes climbing them difficult. Above five miles provision would certainly have to be made for supplying the aviator. If he were not enclosed the decrease of pressure due to the thinner air would result disastrously. The human mechanism is adjusted to a pressure of nearly 15 pounds per square inch; and if that pressure is reduced to about three pounds, as it would be at an altitude of eight miles, the aviator's ear drums would burst, and even the blood would be forced through the pores and would ooze out of the body."

Tesla explained that the effect would be the same as that of bringing a deep-sea fish, accustomed to live a mile below the surface, to the surface of the water. The fish simply explodes, for lack of the pressure which its body is built to withstand.

With proper protection of the aviator and an artificial supply of oxygen Tesla believes that flights at the eight-mile altitude are quite possible.

"Then there will be great progress with the lighter than air machine and we may soon expect the advent of a dirigible of the Zeppelin type as a common vehicle for travel. Contrary to the general belief, such a vessel can be propelled more rapidly than an airplane and it will be, on the whole, much safer. Furthermore it will give to the passengers the comforts that are necessary in order to make this form of travel popular. Of course in the practical use of these monstrous structures, formidable obstacles will be encountered. They are susceptible to damage by storms, and I believe also from certain danger from lightning, which will not be obviated by the use of helium gas. But I expect to see these difficulties overcome.

The dirigible, supplied with sufficient power, need not fear the storm; it can rise above it, or go around it. The only danger from storm in any case lies in being blown from the course, for while the ship is moving with the storm it is in no danger, since it travels at the same speed as the wind, and the passengers would be in absolutely quiet air, so that a candle might be lighted on deck. Methods of docking and housing the big ships must be devised, but several have been proposed that reduce the danger of landing by making it unnecessary for the ship to come to earth."

But the revolutionizing influence on aircraft of the future Mr. Tesla believes to lie in the possibility of transmitting power to them through the air.

"For years," he said, "I have advocated my system of wireless transmission of power which is now perfectly practicable and I am looking confidently to its adoption and further development. In the system I have developed, distance is of absolutely no consequence. That is to say, a Zeppelin vessel would receive the same power whether it was 12,000 miles away or immediately above the power plant. The application of wireless power for aerial propulsion will do away with a great deal of complication and waste, and it is difficult to imagine that a more perfect means will ever be found to transport human beings to great distances economically. The power supply is virtually unlimited, as any number of power plants can be operated together, supplying energy to airships just as trains running on tracks are now supplied with electrical energy through rails or wires.

"The transmission of power by wireless will do away with the present necessity for carrying fuel on the airplane or airship. The motors of the plane or airship will be energized by this transmitted power, and there will be no such thing as a limitation on their radius of action, since they can pick up power at any point on the globe.

"The advance of science to this point, however, is attended with terrible risks for the world. We are facing a condition that is positively appalling if we ever permit warfare to invade the earth again. For up to the present war the main destructive force was provided by guns which are limited by the size of the projectile and the distance it can be thrown. *In the future nations will fight each other thousands of miles apart. No soldier will see his enemy. In fact future war will not be conducted by men directly but by the forces which if let loose may well destroy civilization completely.* If war comes again, I look for the extensive use of self-propelled air vehicles carrying enormous charges of explosive which will be sent from any point to another to do their destructive work, with no human being aboard to guide them. The distance to which they can be sent is practically unlimited and the amount of explosive they can carry is likewise practically unlimited. It is practicable to send such an air vessel say to a distance of four or five thousand miles and so control its course either gyroscopically or electrically that it will land at the exact spot where it is intended to have it land, within a few feet, and its cargo of explosive can there be detonated.

"This cannot be done by means of the present wireless plants, but with a proper plant it can be done, and we have here the appalling prospect of a war between nations at a distance of thousands of miles, with weapons so destructive and demoralizing that the world could not endure them. That is why there must be no more war."

The New York Telegram August 11, 1919

World Fed by Electricity to Defeat High Living Cost, Is Plan of Nikola Tesla

Harness Rays of Sun to Fertilize the Earth His Plan.

PHOTOGRAPHS BY TELEGRAPH ALSO ASSURED.

By RUTH RAPHAEL.

Feed the world with electricity.

That is how Nikola Tesla, the "electrical wizard," plans to defeat the high cost of living and meet the demands of starving Europe.

It was Nikola Tesla who first solved the problem of transmitting power. He now declares that power can be turned to fertilizing the earth by harnessing the rays of the sun.

"I have found a way of applying the sun's energy to the soil, fertilizing it, avoiding the death of millions and giving greater strength to those who exist," was his astonishing and matter-of-fact statement, as he sat at his desk in his suite of offices at No. 8 West Fortieth street.

"By burning the nitrogen of the air I have turned it into a fertilizer.

"I have also invented a machine by which it is possible to create lakes and rivers in the desert.

"This should give to the world unlimited industrial resources. These inventions should enable the United States to give plenty of food to every one."

Utilize the Soil.

In answer to the question which has resounded throughout the nation until Washington pricked up its ears, "How can we reduce the high cost of living?" Dr. Tesla declares:—"Increase the productivity of the soil."

To do this, he says, the soil must be fertilized by artificial means.

The question of food production resolves itself, he says into the question, "How can we best fertilize the soil?"

How to produce the necessary nitrogen?

"That has for years been a problem which took a strong hold on the imagination of scientific men," said Dr. Tesla.

"And right here electricity comes to our aid.

"Through electricity many compounds of nitrogen may be manufactured all over the world at a small cost and in any desired amount and by means of these compounds the soil can be fertilized and its productiveness increased.

Gives Cheap and Healthful Food.

"An abundance of cheap and healthful food may in this way be obtained.

"Of all the thousand evils which may be mentioned as weakening the race, the most important by far is the want of food, brought on by poverty, destitution and famine.

"Yearly millions die for want of food, not only for absolute want, but for the lack of healthful nutriment.

"How to provide good and plentiful food is therefore the greatest question of the day."

Dr. Tesla discovered his theory some time ago—before the pressing need for increased food production closed down, like a coffin lid, upon the world.

"Why was your discovery never used before?" I asked.

He smiled.

"What was it the poet said?" he murmured. Ah, yes—'I wanted bread; they gave me a stone.'

"The people," he added, "are slow to see the light."

It took some years, he explained, to convince them that talking across the ocean by wireless could be done.

"But now they are using my invention the world over," he said, tasting the full joy of his own achievement, which he has lived to see immortalized.

Can See Thousands of Miles.

"I have also invented a machine which enables me to see you as clearly as I do now, thousands of miles away, even if you were sitting at the Antipodes.

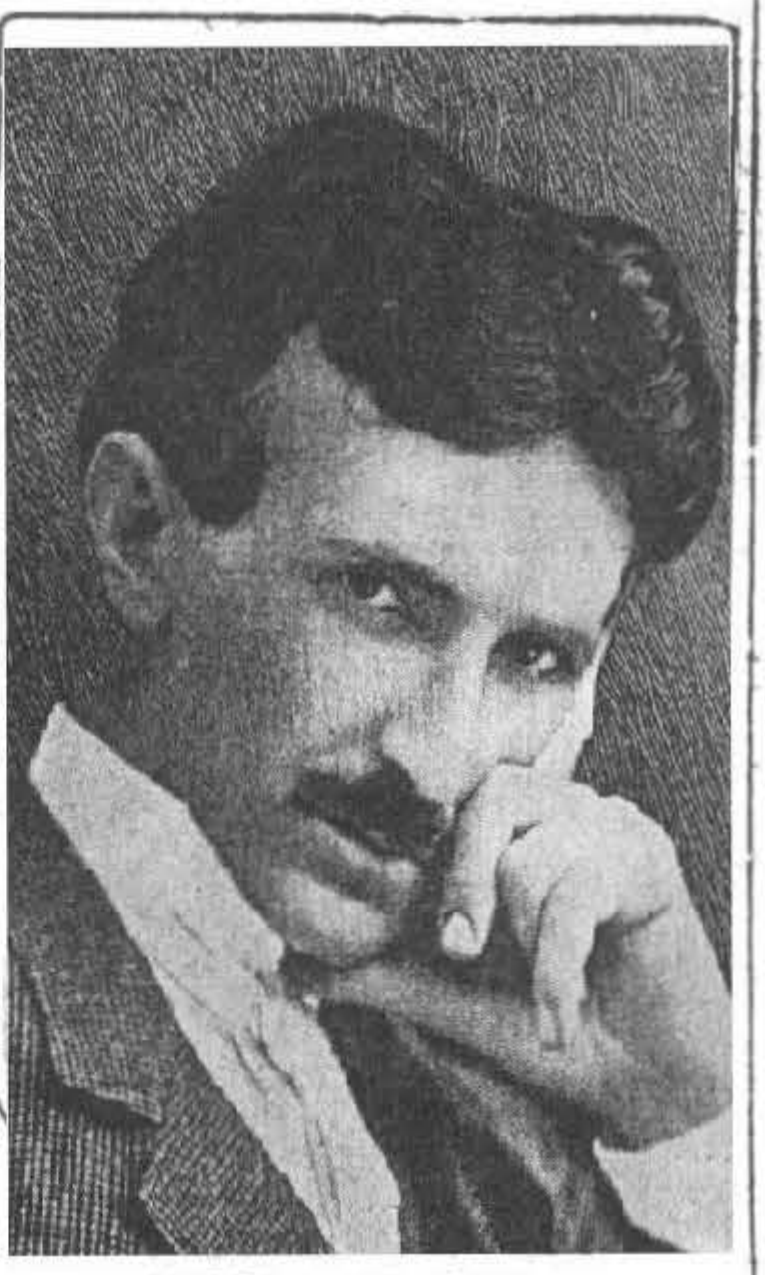
"And why not? It simply transmits your likeness, as well as your speech."

"Why has it not been used?" I asked.

"It would take two years to build the machine," he replied, "and, as I said before, people are slow in seeing the light.

But [illegible] photography will come," he declared "and the idea will be developed without limit."

"Why not invent a cure to prevent Bolshevism?" I suggested, feeling that he surely must have some such machine



NICOLA TESLA

tucked away in the right drawer of his desk.

"It is not necessary," he smiled. "All we need to do to prevent Bolshevism is to give the people horse sense, and to get horse sense one needs only to live in America for one year on one's own resources."

Although born in Austria-Hungary, Dr. Tesla is a naturalized citizen, having lived in America since 1884.

His conversation is tinged with a deep patriotism, although his definition of patriotism is "national egotism."

Through his invention of transmitting electricity he claimed that he has "reduced the size of the earth to a pea," thereby reducing the possibilities of misunderstanding, which is bred by unfamiliarity.

Has Machine to End War.

He is the man who has invented a machine so deadly that it will "abolish war."

By the use of wireless control of automatic machines at a distance a whole city could be destroyed, he declared, and drew out from a sheaf of papers, a photograph of a machine deadly enough, he said, to wipe out the city of London.

"We will never be able to abolish wars by agreements among nations," he asserted. "Only by making war so destructive that it cannot be endured can we hope to establish a permanent world peace."

Asked to predict the future of electricity, the inventor replied:—

Operate Typewriter by Voice.

"We will soon have a typewriter electrically operated by the human voice. This will fill a long-felt want, as it will do away with the operator and save a great deal of time and labor in offices.

We will also see many municipal improvements operated by electricity, such as smoke annihilators, dust absorbers and accident preventers on streets, elevated roads and subways.

"Soon it will be practically impossible to contract disease germs or get hurt in the city, and we will have the people from the woods and country flocking to Broadway to rest up and get well.

Dr. Tesla predicted that in court proceedings, electric evidence will often decide the case.

Soon, he declared, it will be possible to flash any image formed in thought on a screen and render it visible at any place desired.

He also forecasts that we will be "dry cleaned," which will be convenient and time saving, he tells us, and which will do away with the customary bath.

Very simple—just a question of throwing off the dust by electricity.

Invents While Talking.

"And what are you inventing now?" I asked the electrical dreamer.

"I couldn't tell you for a million dollars," he returned with a smile. "It will be worth that much to me."

"When do you work?" I questioned again

"All the time," he answered. "While I have been talking to you, I have made two inventions."

"Did I suggest them?" I asked.

"Ah, I will not tell you," he laughed, "for then you would claim a share in the royalties."

To the Editor of the Electrical Experimenter:

I regret that owing to circumstances beyond my control it was deemed advisable to postpone the publication of the article which I had intended for your August number. But the objections to its appearance will be shortly removed and I shall be pleased to forward it in due course for embodiment in your October issue.

Irrespective of this, I think it well on this occasion to notify your readers, as a precaution, that I am not one of those who display the sign "Do it now" on their desks and office doors. My motto is "Do not do it now. Think it over".

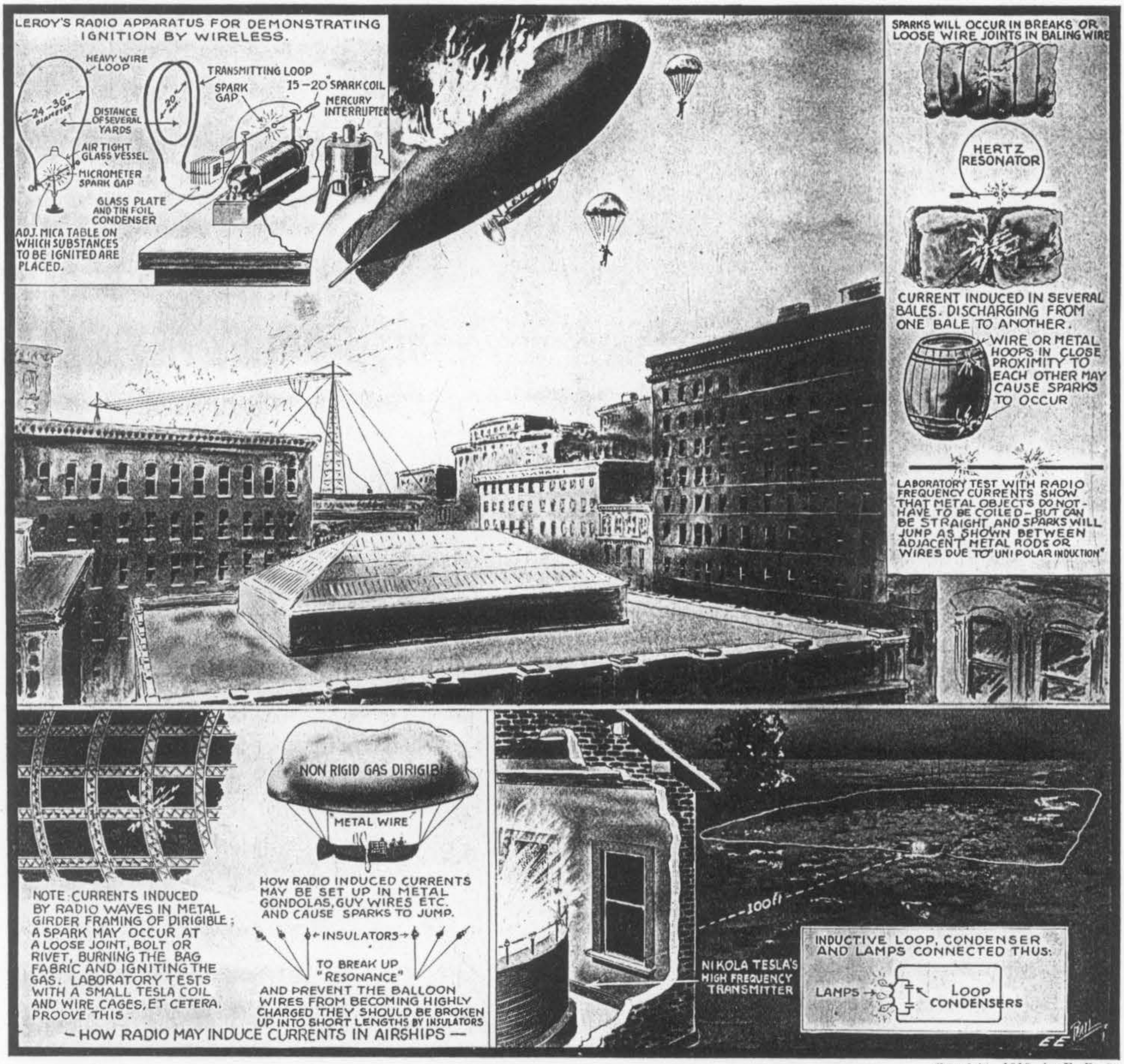
Very truly yours,

N. TESLA.

Can Radio Ignite Balloons?

The Opinions of Nikola Tesla and Other Radio Experts

AS a result of the newest theory, that powerful induced currents emanating from the Naval Radio Station in Chicago produced the spark that ignited the Goodyear dirigible airship which plunged in flames thru the roof of a bank building in that city, resulting in death for thirteen persons and injury to



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Herewith Are Shown Some of the Plausible Reasons Why the Recent Chicago "Blimp" Disaster Might Have Been Caused By a Spark Induced By An Adjacent Radio Station. The Photo In the Lower Right-hand Corner Shows Three Incandescent Lamps Lighted to Full Candlepower, At a Distance of 100 Feet from Dr. Nikola Tesla's Colorado High Frequency Power Plant. The Oscillator Was Worked At Less Than Five Per Cent of Its Total Capacity.

twenty-seven others, naval communication officers will aid the authorities in fixing responsibility for the disaster. It was ascertained that technical experts had suggested *this* theory, because the big ship sailed over or near the Transportation building, from the roof of which are projected the antennae of the Naval Radio Station. The building thru the skylight of which the blazing dirigible fell was the Illinois Trust and Savings Bank.

Lieut. F. S. Mason, of the Great Lakes Naval Training Station, district communication service officer, while refraining from agreeing with the theory, said he would cooperate with the investigating officials. Pilot John Boettner, of the ill-fated dirigible, said he had not been aware of the location of the naval radio station. H. M. Byllesby, head of a large engineering corporation and foreman of the coroner's jury of technical men, said experts had suggested the *radio theory* to him.

Col. J. C. Morrow, chief air officer of the central department of the army, the principal witness at the inquest, was a passenger in the dirigible on a trip preceding the fatal one. At that time he said the ship was in safe condition. The pilot he considered competent. He thought the possibility of sparks from the exhaust igniting the gas bag very remote, but said he had not formed an opinion as to the cause of the accident.

(*Continued on page* 591)

Can Radio Ignite Balloons?

(*Continued from page* 516)

WHAT NIKOLA TESLA SAYS

Probably no other living electrician could be found today who can more authoritatively state just what effect can be produced at a distance by radio currents, than Dr. Nikola Tesla. He has produced and measured the greatest electrical discharges ever developed by man—sparks 70 to 100 feet in length, which manifested their influence 12 miles and more distant. In a special interview with the ELECTRICAL EXPERIMENTER representative, Dr. Tesla said in regard to the present blimp disaster:

"Referring to electrical or radio wave action at a distance, I know from experience that if proper precautions are not taken, fires of all kinds and explosions can be produced by wireless transmitters. In my experiments in Colorado, when the plant was powerfully excited, the lightning arresters for *twelve miles around* were bridged with continuous arcs, much stronger and more persistent than those which ordinarily took place during an electric storm. I have excited loops (coil aerials) and lighted incandescent lamps at a considerable distance from the laboratory without even using more than five or ten per cent of the capacity of the transmitter. When the oscillator was excited to about 4,000,000 volts and an incandescent lamp was held in the hand about *fifty or sixty feet from the laboratory,* the filament was often broken by the vibration set up, giving some idea of the magnitude of the electromotive forces generated in the space. The accompanying illustration shows one of my experiments in which I lighted several lamps at a distance of 100 feet from the laboratory, purely by wireless energy. Such induced currents might easily fire a gas balloon under the proper conditions. When the large transmitter coil, 51 feet in diameter, which I had in the center of the laboratory, was powerfully energized, butterflies were carried around in a circle as in a hurricane and could not get out, no matter how they tried. I was unable to satisfactorily explain the gyrations in the circle, altho I can well understand that the charged coil might, by repulsion, keep them in the center. Perhaps the most remarkable of all the observations was the production of sparks in the sand when one walked at some distance from the building. At night a continuous stream of tiny sparks could be seen between the heels and the earth and between the grains of sand. Another most curious effect was the action on horses, which shows how very sensitive they are to electric shock. When I operated with undamped waves, the oscillator being perfectly silent (no streamers whatever), a horse at a distance of perhaps *one-half a mile,* would become scared and gallop away the instant the switch was thrown on. I suppose the capacity of the body was sufficiently great to derive a rather strong current thru the legs which would frighten the animal. When using damped waves the roar was so strong that it could be plainly heard ten miles away and despite all precautions, such as using cotton in the ears, one would get a singular sensation in the head as if something was bursting, similar to that I observed with Röntgen Rays in 1896 or '97, when I was operating with a powerful apparatus designed for their production.

"In my experiments in New York in the laboratories at 35 South Fifth Avenue and at Houston Street, I have exhibited to thousands of people effects of loops or coil antennae. In one experiment, for instance, I would tune a coil about 30 inches in diameter with which I would collect at

any place in a large hall, *nearly three-quarters of a horsepower,* lighting incandescent lamps, producing long discharges, streamers, etc. One of my exhibits, which was particularly appreciated, was a coil carried on the head which, when resonantly excited, would develop streamers several feet long.

"As regards that deplorable accident to the blimp in Chicago, of course a powerful wireless plant is capable of setting up, at a few hundred feet distance, electro-motive forces of such magnitude that if there is even moderate rise thru resonance, long sparks may result. *In Colorado I drew* 1-*inch sparks between my body and an iron pipe buried in the ground about* 100 *feet from the laboratory.* I think it perfectly practicable to produce an explosion by wireless designedly at a considerable distance from a wireles transmitter, and I look upon the accident as very likely having been due to some such cause. By taking proper precautions, however, it is possible to entirely eliminate this danger and I have devoted much thought to the subject, having early recognized the peril to such bags filled with hydrogen. According to my ideas, the accident is not so much chargeable to the plant as to the neglect of proper precautions on the aërial vessel itself. Such a vessel has a considerable span and the guy wires, gondola and other metallic parts constitute a considerable capacity, so that an appreciable amount of energy can be deprived from a wireless plant at a great distance, as it is well shown in the ease with which messages are transmitted to, and received from, aërial vessels.

"Why do the naval and other authorities allow such forms of aircraft to use an explosive gas like *hydrogen?* A short time ago the press was filled with the wondrous stories of how the U. S. Government experts had perfected the manufacture of the new and non-inflammable balloon gas—*helium,* to such an extent that it was very cheap and readily obtainable in quantities. Funny, how these "new" inventions require so long a time to reach the public and those who need them. Helium, extracted from illuminating gas, is not new or wonderful at all. My friend, Sir James Dewar, showed me experiments with it over 20 years ago."

How radio waves, even at distances of several miles, can cause sparks to occur among bales of cotton, baled with wire hoops, etc., is shown in one of the accompanying illustrations. The cotton bale wires have currents induced in them every time a radio message is sent from the ship or in its vicinity. This induced current is practically never strong enough to heat up the wire, but should one of these wires break and form a spark gap, then very often the induced current will cause a spark to jump the gap. That is enough to start a fire. Where wired bales are packed close together in the hold of a steamer, in trains, or warehouses, here also radio waves are liable to cause fairly strong electrical oscillations to be set up by resonance in adjacent loops on the bales, as the diagram shows. Result, a spark occurs, and another fire of "unknown origin" has started.

M. George A. Leroy, a French chemist, in his municipal laboratory at Rouen, France, very ably demonstrated that wireless waves could without doubt cause fires at a distance. His apparatus is shown schematically herewith.

Mr. Leroy's apparatus has been christened by him the "Igniting Resonator." The apparatus he used consists of a glass bulb having four apertures; one at either side and one at the top and bottom, respectively. The substance to be tested with this igniter resonator can be placed in the airtight glass compartment and the two electrodes very accurately adjusted by micrometer screws fitted to them. The transmitter comprises a spark coil giving a 15-to-20-

inch spark, which was connected with a spark gap, glass plate and tin-foil condenser and a loop antenna or spiral comprising a few turns of heavy wire, about 2 feet in diameter. Several yards distant, Mr. Leroy placed his receiving coil or igniting resonator, which included a loop or heavy copper conductor about three feet in diameter. The action on the device was similar to that of the Hertzian resonator, i. e., whenever the spark coil or transmitting helix were excited, allowing a spark to jump the gap, electromagnetic waves were set up in the intervening ether, causing corresponding currents to be induced or set up in the receiving loop. As in the historic experiments of Hertz, this loop will gather sufficient energy from the etheric waves to cause a small spark to jump a gap connected across the terminals of the loop, as the accompanying diagram clearly shows.

Mr. Leroy carried out many different experiments with his apparatus, placing the glass spark chamber of the igniting resonator in a bath of oil or vaseline, which can be heated when desired by incandescent lamps, etc.

One of the most interesting experiments carried out by Mr. Leroy was that with miniature bales of cotton, which were enclosed in jute wrappers and provided with iron wire bands, in the way cotton is usually packed for shipment. "Spontaneous combustions in cotton warehouses and in shipholds loaded with cotton or similar material, are not always what they seem," says Mr. Leroy, in describing his experiments and results with the radio igniter. One of the hoops encircling the bale of raw cotton may break or become loose under the action of shock or from some other cause, and the gap created by the breaking of the wire, forms a miniature Hertzian resonator. When a wireless station situated in the immediate vicinity, or perhaps at some quite distant point, starts in to transmit (and the more powerful the station the more pronounced the effect and danger from fire of course), currents will be induced in the iron wire around the bales or other packages, and sparks may pass between the various metal members. Especially will they be inclined to jump small gaps in the wire which occur in the immediate loop. We may say right here, that to a layman all of this phenomena may seem somewhat far-fetched, and not within the realm of everyday possibilities, but anyone who has experimented with high frequency currents, as generated from even a small size oscillator, will at once be convinced that these effects can and do take place under most unbelievable conditions. Of course, one objection that the average electrical and radio reader will probably think of, is that if the cotton bales, et cetera, are placed in a steel vessel, that this metallic hull will act as a screen, and that the bales will not have any current induced in their wire loops, but while this may be partially so, in some cases it is not always so by any means; especially when the home transmitting station, such as on ship-board, starts in operating. In this case, the steel hull of the boat is charged whenever the transmitting key is deprest.

The secret, if so we may call it, of the production of inflammatory sparks or discharges in metallic bodies such as here described, lies in the phenomena known as "resonance." This means that the nearer the metallic members come in tune with the radio waves, the more pronounced the induction effects produced in any instance. It is of course readily conceivable that a cargo of cotton bales presents many peculiar conditions of resonance, due to the varying capacities and inductances of the various loops. In fact, so obvious and possible is this condition, that a wooden vessel carrying bales of cotton or other material having wire or metal members to hold them, and providing she is fitted with a

wireless station of even a few kilowatts, that the Editors would prefer to stay on land than go to sea on such a ship.

One of the accompanying photographs shows how a great multitude of close oscillatory circuits are provided unwittingly in all-framed or rigid gas airships, and even in the non-rigid gas airships there is usually a sufficient amount of metal present in the gondola, wires and other fittings to form one or more resonant circuits, which may cause a spark at an imperfect joint or other gap. It should be remembered, as laboratory tests have demonstrated beyond cavil, that it is not necessary to have a metal wire coil *in spiral form* in order to have powerful currents induced of sufficient strength to cause a spark to jump from it; a straight metallic wire, bar or even tools, lying within a few yards of small high frequency coil, will pick up sufficient energy to cause sparks to jump from them, and they will sometimes glow with a vivid brush discharge when viewed in a darkened room.

Signals to Mars Based on Hope of Life on Planet

Written Specially for the Herald
By NIKOLA TESLA.

THE idea that other planets are inhabited by intelligent beings might be traced to the very beginnings of civilization. This, in itself, would have the significance, for many of the ancient beliefs had their origin in ignorance, fear or other motives—good or evil, and were nothing more than products of untrained overtortured imagination. But when a conception lives through ages in the minds, growing stronger and stronger with increasing knowledge and intellectual development, it may be safely concluded that there is a solid truth underlying the instinctive perception. The individual is short lived and erring; man, relatively speaking, is imperishable and infallible. Even the positive evidences of the sense and the conclusions of science must be hesitatingly accepted when they are directed against the testimony of the entire body of humanity and the experience of centuries.

Modern investigation has disclosed the fact that there are other worlds, situated much the same as ours, and that organic life is bound to develop wherever there is heat, light and moisture. We know now that such conditions exist on innumerable heavenly bodies. In the solar system, two of these are particularly conspicuous—Venus and Mars. The former is, in many respects, like the earth and must undoubtedly be the abode of some kind of life, but as to this we can only conjecture, for the surface is hidden from our view by a dense atmosphere. The latter planet can be readily observed and its periodic changes, which have been exhaustively studied by the late Percival Lowell, are a strong argument in support of the supposition that it is populated by a race vastly superior to ours in the mastery of the forces of nature.

If such be the case then all that we can accomplish on this globe is of trifling importance as compared with the perfection or means putting us in possession of the secrets they must have discovered in their struggle against merciless elements. What a tragedy it would be were we to find some day that this wonderful people had finally met its inevitable fate and that all the precious intelligence they might have and, perhaps, had tried to convey to us, was lost.

But although scientific research during the last few decades has given substance to this traditional belief, no serious attempt to establish communication could have been made until quite recently for want of proper instrumentalities.

Light Ray Project.

Long ago it was proposed to employ rays of light for this purpose and a number of men of science had devised specific plans which were discussed in the periodicals from time to time. But a careful examination shows that none of them is feasible, even on the assumption that the interplanetary space is devoid of gross matter, being filled only with a homogeneous and inconceivably tenuous medium called the ether. The tails of the comets and other phenomena, however, would seem to disprove this theory, so that the successful exchange of signals by that kind of agency is very improbable.

While we can clearly discern the surface of Mars, it does not follow that the reverse is true. In perfect vacuum, of course, a parallel beam of light would be ideally suited for the transmission of energy in any amount for, theoretically, it could pass through infinite distance without any diminution of intensity. Unfortunately, this as well as other forms of radiant energy are rapidly absorbed in traversing the atmosphere.

It is possible that a magnetic force might be produced on the earth sufficient to bridge the gap of 50,000,000 miles and, in fact, it has been suggested to lay a cable around the globe with the object of magnetizing it. But certain electrical observations I made in studying terrestrial disturbances prove conclusively that there can not be much iron or other magnetic bodies in the earth beyond an insignificant quantity in the crust. Everything indicates that it is virtually a ball of glass and it would require many energizing turns to produce perceptible effects at great distance in this manner. Moreover, such an undertaking would be costly and, on account of the low speed of the current through the cable, the signalling would be extremely slow.

The Miracle Performed.

Such was the state of things until twenty years ago when a way was found to perform this miracle. It calls for nothing more than a determined effort and a feat in electrical engineering which, although difficult, is certainly realizable.

In 1899, I undertook to develop a powerful wireless transmitter and to ascertain the mode in which the waves were propagated through the earth. This was indispensable in order to apply my system intelligently for commercial purposes and, after careful study, I selected the high plateau of Colorado (6,000 feet above sea level) for the plant which I erected in the first part of that year. My success in overcoming the technical difficulties was greater than I had expected and in a few months I was able to produce electrical actions comparable to, and in a certain sense surpassing, those of lightning. Activities of 18,000,000 horsepower were readily attained and I frequently computed the intensity of the effects in remote localities. During my experiments there, Mars was at a relatively small distance from us and, in that dry and rarefied air, Venus appeared so large and bright that it might have been mistaken for one of those military signalling lights. Its observation prompted me to calculate the energy transmitted by a powerful oscillator at 50,000,000 miles, and I came to the conclusion that it was sufficient to exert a noticeable influence on a delicate receiver of the kind I was, in the meanwhile, perfecting.

My first announcements to this effect were received with incredulity but merely because the potencies of the instrument I had devised were unknown. In the succeeding year, however, I designed a machine for a maximum activity of 1,000,000,000 horsepower which was partly constructed on Long Island in 1902 and would have been put in operation but for reverses and the fact that my project was too far in advance of the time.

It was reported at that period that my tower was intended for signalling to Mars, which was not the case, but it is true that I made a special provision for rendering it suitable to experiments in that direction. For the last few years there has been such a wide application of my wireless transmitter that experts have become, to an extent, familiar with its possibilities, and, if I am not mistaken, there are very few "doubting Thomases" now. But our ability to convey a signal across the gulf separating us from our neighboring planets would be of no avail if they are dead and barren or inhabited by races still undeveloped. Our hope that it might be different rests on what the telescope has revealed, but not on this alone.

Vast Power Found.

In the course of my investigations of terrestrial electrical disturbances in Colorado I employed a receiver, the sensitiveness of which is virtually unlimited. It is generally believed that the so-called audion excels all others in this respect and Sir Oliver Lodge is credited with saying that it has been the means of achieving wireless telephony and transforming atomic energy. If the news is correct that scientist must have been victimized by some playful spirits with whom he is communicating. Of course, there is no conversion of atomic energy in such a bulb and many devices are known which can be used in the art with success.

My arrangements enabled me to make a number of discoveries, some of which I have already announced in technical periodicals. The conditions under which I operated were very favorable for no other wireless plant of any considerable power existed and the effects I observed were thereafter due to natural causes, terrestrial or cosmic. I gradually learned how to distinguish in my receiver and eliminate certain actions and on one of these occasions my ear barely caught signals coming in regular succession which could not have been produced on the earth, caused by any solar or lunar action or by the influence of Venus, and the possibility that they might have come from Mars flashed upon my mind. In later years I have bitterly regretted that I yielded to the excitement of ideas and pressure of business instead of concentrating all my energies on that investigation.

The time is ripe now to make a systematic study of this transcending problem, the consummation of which may mean untold blessings to the human race. Capital should be liberally provided and a body of competent experts formed to examine all the plans proposed and to assist in carrying out the best. The mere initiation of such a project in these uncertain and revolutionary times would result in a benefit which can not be underestimated. In my early proposals I have advocated the application of fundamental mathematical principles for reaching the first elementary understanding. But since that time I have devised a plan akin to picture transmission through which knowledge of form could be conveyed and the barriers to the mutual exchange of ideas largely removed.

Success in Trials.

Perfect success can not be attained in any other way for we know only what we can visualize. Without perception of form there is no precise knowledge. A number of types of apparatus have been already invented with which transmission of pictures has been effected through the medium of wires, and they can be operated with equal facility by the wireless method. Some of these are of primitively simple construction. They are based on the employment of like parts which move in synchronism and transmit in this manner records, however complex. It would not require an extraordinary effort of the minds to hit upon this plan and devise instruments on this or similar principles and by gradual trials finally arrive at a full understanding.

The HERALD of September 24 contains a despatch announcing that Professor David Todd, of Amhurst College, contemplates an attempt to communicate with the inhabitants of Mars. The idea is to rise in a balloon to a height of about 50,000 feet with the manifest purpose of overcoming the impediments of the dense air stratum. I do not wish to comment adversely upon this undertaking beyond saying that no material advantage will be obtained by this method, for what is gained by height is offset a thousandfold by the inability of using powerful and complex transmitting and receiving apparatus. The physical stress and danger confronting the navigator at such an altitude are very great and he would be likely to lose his life or be permanently injured. In their recent record flights Roelfs and Schroeder have found that at a height of about six miles all their force was virtually exhausted. It would not have taken much more to terminate their careers fatally. If Professor Todd wants to brave these perils he will have to provide special means for protection and these will be an obstacle to his observations. It is more likely, however, that he merely desires to look at the planet through a telescope in the hope of discerning something new. But it is by no means certain that this instrument will be efficient under such conditions

"Cold Fire"

By H. Gernsback

Charging the Body with High Frequency Currents.

EVER since Nikola Tesla began experimenting with the high frequency currents which bear his illustrious name, the world has stood aghast at the many and wonderful effects made possible only by his discoveries.

Most of our readers are no doubt familiar with nearly all high frequency "stunts," emanating either from the stage or from the laboratory, and not much that is new can be written upon the subject.

But not so long ago the writer, while waiting for an electric train out on Long Island, amusedly watched two boys who took turns in jumping upon a live third rail, carrying 500 volts. They would jump upon the rail with both feet at once, and then balanced themselves upon the rail. There is, of course, no danger to this as long as *both* feet are on the rail. One foot on the rail with the other foot on the ground means certain death. The explanation, as most of our readers know, is that when you stand on the rail with both feet, there is *no return circuit*. The body in this case takes on a charge of 500 volts, which, however, is not felt at all by the experimenter, the same as you are not conscious that over 14 pounds of weight are pressing down upon your body on every square inch of you at all times, due to atmospheric pressure.

This made the writer wonder what would happen if you stood on one pole of a very powerful Tesla coil. In a recent conversation with Dr. Nikola Tesla, the inventor pointed out that he had indeed performed many such experiments in his Colorado laboratory many years ago. The currents which he then used were far greater and higher than those produced anywhere now. Thousands of horsepower were used by him at that time. Dr. Tesla explained that he frequently stood upon one pole of his mastodonic coils while the full current was on. Of course, he had to stand upon a metallic plate, but he had to be careful so that no sparks jumped from his body to other objects or to the ceiling. This would have meant instant electrocution. Dr. Tesla pointed out that as the human body has a certain capacity, it radiated a good deal of energy into the surrounding air. Due to the tremendous current the sensation was anything but comfortable. The current heating the blood vessels raised the bodily temperature, and the experiment for this reason alone could not be extended for any great length of time. Dr. Tesla explained that during the experiment sparks and long spark-streams would envelop his entire body. At the extremities, elbows, knees, hip bones, nose, ears, etc., the spark display was most pronounced. Streams five to ten feet long would shoot out from the extremities with a crackling noise. Due to the exceedingly high frequencies used, however, the sparks did neither sting nor burn the flesh. Mr. Nikola Tesla's own words, his body, indeed, was enveloped in "cold fire." Dr. Tesla also explained that during the experiments his hair would rise on end, producing the same effect as if a large static machine had been used, with the well-known result, on the hair.

The other day we endeavored to repeat Dr. Tesla's experiments, and the illustrations shown here are the result. We called upon the Electrical Testing Laboratories of New York, who have one of the most powerful high frequency machines in the country. Altho but a pigmy alongside of Dr. Tesla's Colorado thunderers, the machine gives 500,000 volts and uses 20 kilowatts. The transformer is sunk into oil, and when the full load is on throws streams six to seven feet long. The noise of the tremendous sparks can be heard for blocks.

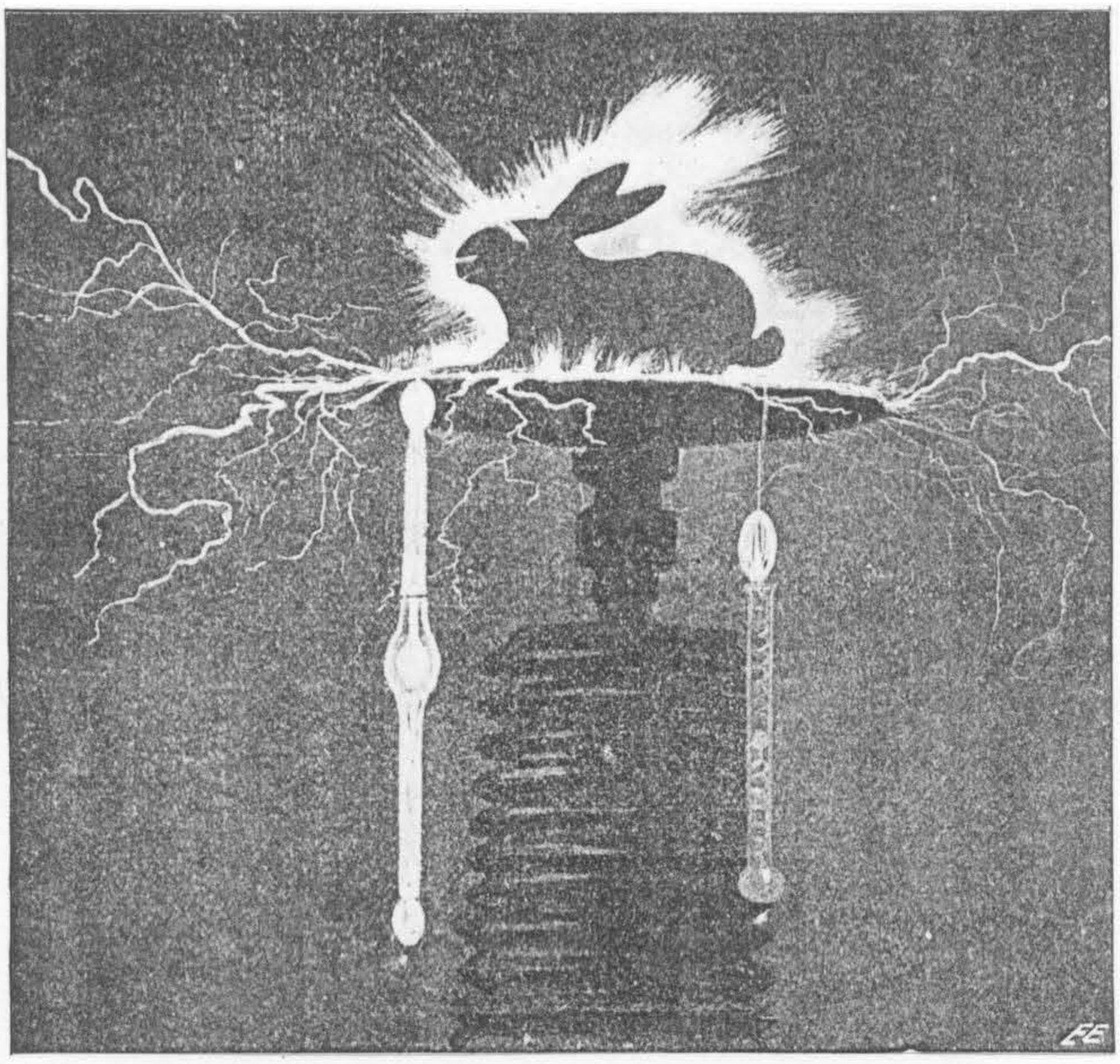
We first took a rabbit and placed him upon the metal plate of the "high" terminal of the transformer. At first he was much frightened and jumped off the plate at about 5 kilowatts. Long sparks had shot out from his nose and above his eyes and at the end of the ears. So the writer wetted the platform with water, because he thought that sparks might be jumping into the rabbit's belly and legs which insulated the fur part of his body, giving rise to stinging sparks. An improvement was seen immediately. The rabbit now held perfectly still for about 20 seconds, taking the full charge of 20 kilowatts at 500,000 volts. Long spark streamers, four or five feet long, shot from brer' rabbit's nose, ears and back, and, curious to note, immediately above the eyes. Here the sparks were so hot that they singed the hair. So the writer wetted the spots above the eyes, and after that the rabbit took the full charge, never moving once for twenty seconds at a time. See Fig. 2. Altho long streamers came principally from the nose, the photograph does not show it. After awhile the rabbit seemed to enjoy the performance, and right after his séance



Fig. 1. A dry bath with "cold fire." Altho millions of volts are used in the process, this form of bath is quite pleasant. The currents throw off all dead skin, scale and dirt clinging to the skin. Besides the treatment is distinctly invigorating, leaving the skin rosy and all a-tingling. Every home will soon be equipt with a huge Tesla coil.

he was as lively as ever, eating a big carrot at once. He is still well and about now.

We next wished to try a human being instead of the rabbit, but the management of the laboratory, due to possible danger, would not grant permission. It was explained that the frequency of the big machine was too low for the experiment, which had never been tried before on a human being, so we desisted. The photograph shown in Fig. 1 was made with a regulation Tesla coil of a very high frequency, but of comparatively low power. Only 1 K.W. was used. The subject, Mr. Joseph Kraus, field editor of this publication, experienced hardly any sensation worth mentioning. Only at the extremities, such as the ears and the nose, a slight prickling sensation, not at all uncomfortable, was felt. The feet were wetted with salt water to insure perfect contact.



Bre'r Rabbit taking a trifling 500,000 volts at 20 kilowatts, and liking it well, thank you! He held still for 20 seconds, only blinking once in awhile. He was not chained nor held down otherwise. "Movie" operators were at hand and filmed him, too. He is still alive, so Sis needn't worry that we killed him.
Fig. 2.

And the value of these experiments? As Dr. Tesla points out, if these machines come into daily use, and duly invade our homes, it will be possible for us to have a dry bath, more sanitary and infinitely better than our present water baths. If the current conditions are right, the body will throw off scale, dead skin, dust and dirt particles, hurling them far from the body. For it should not be forgotten that Tesla currents travel mostly over the skin, ridding it of all impurities. But that is not all. The unquestioned therapeutical effects to the human body are of great value, not only to the muscles but to the entire nervous system. Tesla currents, by softening the arteries, make the old feel younger, and the young, younger and more aggressive. Women, particularly, should derive great benefits from their future high frequency dry baths.

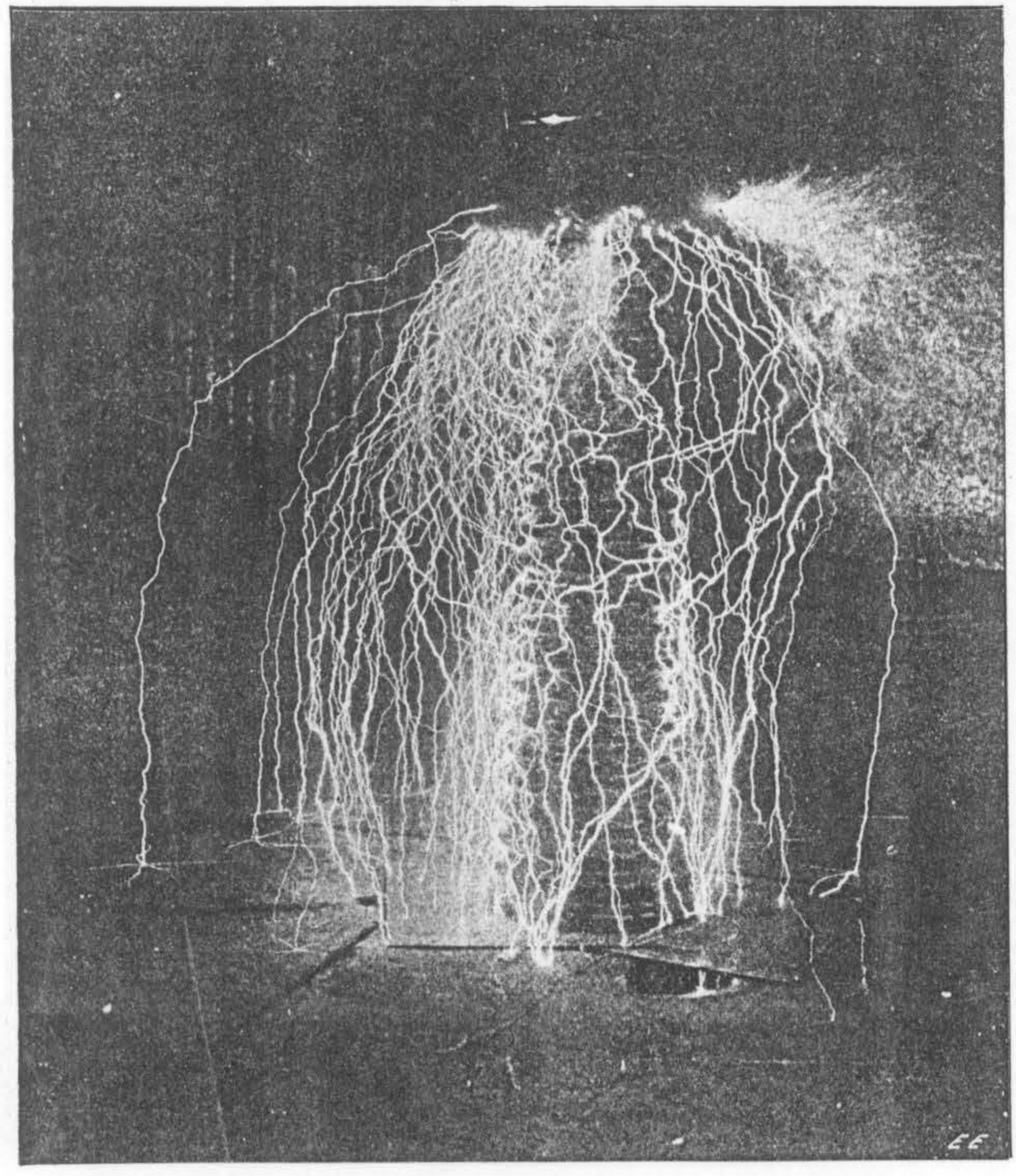


Fig. 3. This shows a wonderful corona and flash-over on a 37-inch porcelain pedestal insulator. This corona is occurring at a potential of 234,000 volts and 51,000 cycles per second.

Largest High Frequency Laboratory of the World.

The insulating of apparatus for voltages of from 100,000 to 150,000 at sustained frequencies varying from 15,000 to 500,000 cycles per second, such as used in radio telegraphy, is a far more difficult problem than that of insulating for the same voltages at "commercial" frequencies, such as 60 cycles per second.

To study this problem, the Federal Telegraph Company built at its plant at Palo Alto, California, a high voltage laboratory, in which it is possible to duplicate the high voltage and high frequency phenomena which have to be met with in operating a high power radio station.

The laboratory is unique in that it is capable of generating a potential *to earth* of a half a million volts, which is about as high as is obtainable in any of the 60-cycle high voltage laboratories of the country, and at the same time this voltage is generated at a sustained frequency of 50,000 to 100,000 cycles per second. Thus, this laboratory is the largest of its kind in the United States, and, as far as is known, the largest in the world.

Photograph No. 3 shows a corona and flash-over on a 37" porcelain pedestal

(Continued on page 709)

"Cold Fire"

By H. Gernsback

(*Continued from page 633*)

(standard 110,000 volt insulator for 60-cycle work, such as is used in electrical power transmission equipment) equipped with a "corona" or flux distributing shield. This flash-over is occuring at 234,000 volts and 51,000 cycles per second. Without the corona shield, corona will form on the metal cap of the insulator and flash-over will occur at voltages slightly less than 100,000 at a frequency of 51,000 cycles per second.

Science in Slang

By EMERSON EASTERLING

"I SAW in a magazine some time ago some guy's idea about entering into a gab-feast with the Martians, or Martonians, or Marites—or whatever you want to call 'em," remarked one of our crowd as we sat in the Union Depot at Portland, Oregon, waiting for a train to Pendelton.

"Yes," replied Jazz, "I saw that. It struck me as being sort of sensational stuff. I guess it is alright—in some respects—but there is a lot of stuff evidently overlooked."

"How is that?" asked Punk, looking up from his *Police Gazette*.

"For one thing," began Jazz, "did you see the write-up?"

"Oh," returned Punk. "I have seen some of the bird's stuff on the subject O. K.—but all that stuff is so far from home that I never paid much attention to it."

"Well," continued Jazz Stokes, "as I was going to say—the late Percy Lowell gazed up at the Martian bunch of dirt and discovered that it was stript all over with stringy marks. If you had seen them without any explanation you might have pronounced them railway tracks, or road ways—but old Lowell must have been awful 'dry,' or something; so he thunk up the canal idea. It took."

"I thought that a bird by the name of Schiaparelli—a German wop, or something — discovered the canals," put in Bender.

"I believe you are right," returned Stokes. "It was Sarsaparelli that dug up the canals and Lowell that extended the theory and kept them open to the astronomical public.

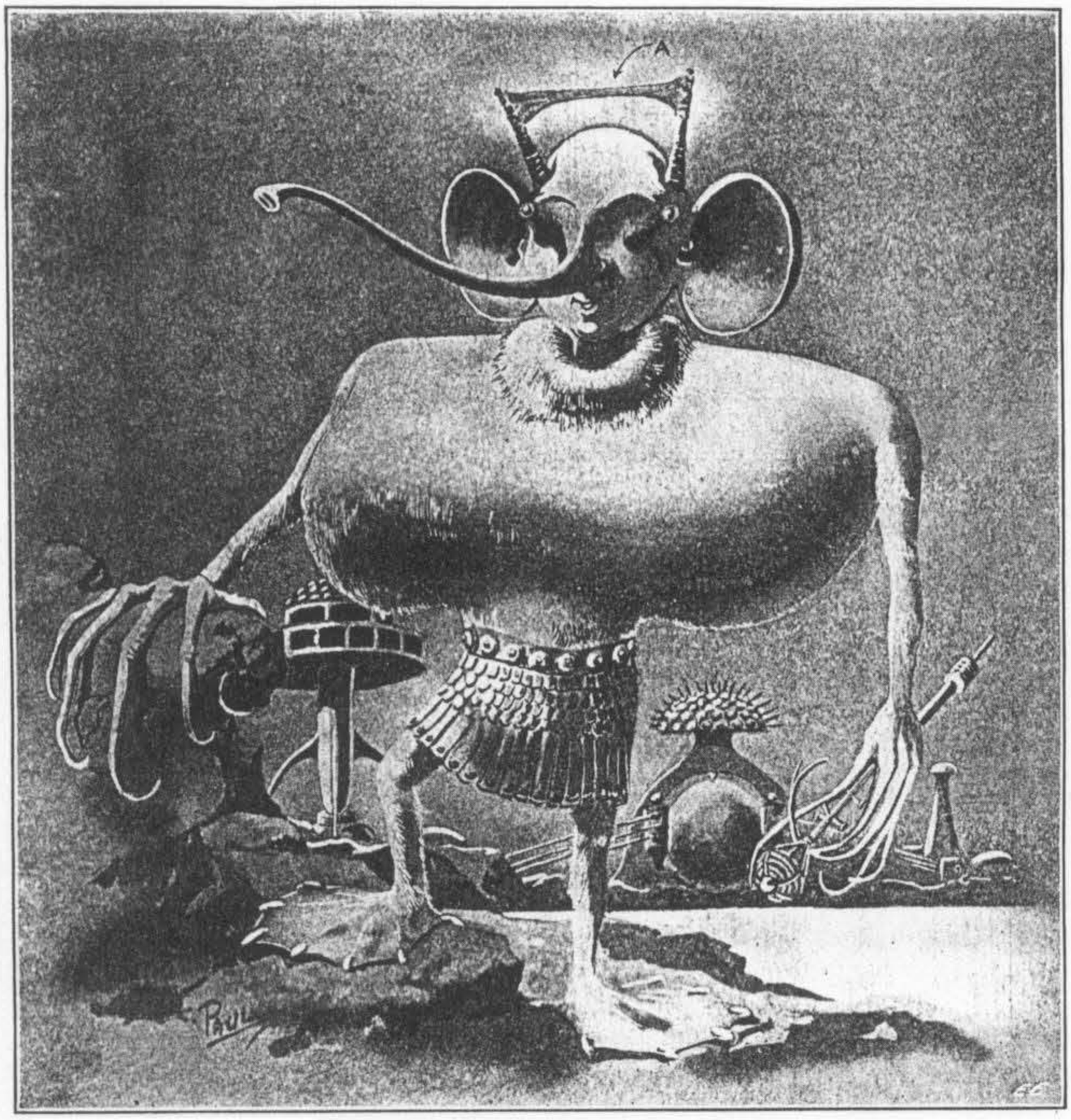
"Anyway, a Harvard 'Proff' by the name of Pickering got it into his head that we could construct a huge mirror and do flash light stunts on them and take chances on them catching on, and some more on our getting them if they do catch on."

"He was not a proff in finance, was he?" questioned V. Dago Hule, with a sort of a smile.

"Proff Wood (not referring to his head exactly) figured out a plan wherein we

Talking with Mars

would stretch a few hundred acres of black cloth over some blinding sands of the great African desert and have some monster motors to roll and unroll the 'window shades' in such a fashion as to give them an optical impression that we are kidding them into saying 'Hello' to us by some such way. Of course such a stunt would cost the price of a young war—but what's a billion or two to a scientist's young life! Wood himself didn't intend to foot the bill."



AS SCIENCE SEES THE MARTIAN.

Due to the very rare Martian atmosphere, the Martian's chest must be enormous to accommodate his ponderous lungs, necessary to supply his oxygen. Rare atmosphere conducts sound very poorly, hence the large ears, required to catch the very weak sounds. Due to the poor atmosphere, it is exceedingly cold on Mars, except at the equator. Hence Martians are covered with a while polar fur from head to foot. A rare atmosphere conducts odors but poorly—hence the elephantine nose, which goes to the odor as the oder can't come to the Martian. Gravity on Mars being much less than on earth—1 lb. on earth weighs 0.35 lbs on Mars—the pull on his body is very small. Therefore, his height is from 10 to 12 feet. To support such a tall body where gravity is small, better footing is necessary, hence the big feet. The tremendously civilized Martian always rides or flies from place to place; his legs are thus almost useless, hence devoid of muscles, consequently thin. The Martians stopped all physical work millions of years ago; machines do his work. His arms thus are weak and thin. But the hands and eyes—the Martian's most important organs—are used and worked constantly—therefore are developed wonderfully. As his food is all taken in highly concentrated form and as he does not talk, the Martian's mouth has shrunk to very small dimensions. Talking in a rare atmosphere being almost impossible, the Martian communicates by his telepathic organ, "A," a sort of sensitive skin stretched between antler-like prominences on top of his head. The same organ sends out the telepathic waves.—H. G.

"Don't you think that that was just a sort of figure of speech? I don't think that he really thought of doing exactly what he said. He probably proposed that as some example of how it could be done—don't you think?" rattled off Bender.

"More than likely—I don't know—besides I don't much care. But both the men are exceptionally intellectual specimens of our modern breed.

"A Frog by the name of Flammarion, a 'proff' in some *La Belle Universite* or something, let's out some of his think tank juice and proposes to have an immense bank of incandescent globes layed out on a dark stretch of land and let some official throw in and out the switch to the tune of 'Do you get us, Mars?'"

"Well," interrupted Punk, handing his *Police Gazette* to a preacher, "have you any better hunch for our transetherial communication? Why tear down when you can't put up a better castle than you ripped out—even if the one that you propose is warmer than the one you jerked out of commission?"

"Well," replied Jazz, "can't I kid the kids? They are smart men and have a few smart faults. They have it all over the rest of us in many ways — but they cannot be perfect in all ways. In one or two respects they have fell down in their hypothetical proposals. Some of us who sit back and find fault with the Peace Treaty and so forth see a weak joint in their pipe dreaming and up with the 'heehaw.'

"Now will you let me rave?

"In the first place: how are we to know that the beings that inhabit Mars — if it is inhabited — are gifted with a physical and mental combination that results in what we explain as sight? We don't know but what they have evoluted past us—if we are evoluting—and are getting into their knowledge what we do with sight by some other sense? As the dog, for instance, has its sense of smell developed to a much greater degree than has the human race, so might we have our sense of sight developed to a much greater degree than have the Martians. And are we sure that they have developed up in the same way that we have? Take the different forms of life on our own planet: how different

(Continued on page 699)

Science In Slang

By Emerson Easterling

(Continued from page 669)

are they; and cousins, we might say. How about the life forms on the other planet? A different compositional environment would produce a different sort of beings, wouldn't it? You know that Man was manufactured out of the dust of the Earth. Well, Mars has a little differently compounded dust—not much, I guess, but somewhat different—sufficient to make a different being. Of course that is just my idea of it—but all of this Mars stuff is mostly *idea*.

"If we concede that Mars is on the lookout for some expression from us, or is waiting for some response to some of their signals that past over our heads; what do you think that they dream we are trying to tell them by the evidence given in the way of smoke and surface altering in our past battles—especially the last European shooting match? Don't you think that they could see us making the big smoke and everything? Of course, accepting that they can see."

"I don't suppose that they could hear us—thru all that thirty-five or forty million miles of ether," put in Bender.

"They may have their sense of hearing developed like a dog's smell," said Punk sardonically.

"Talking of the optical demonstrations that are proposed to attract Mars' attention, what do you suppose they think of our volcanos? I suppose they understand them, probably know more about such things than we do———"

"Prohibition and the sex question included," snapt in Punk, licking his lips and not even looking at the pretty young woman that past by our crowd and almost turned the subject.

"I suppose that their time intervals are the same as ours—being that that goes in as one of the basic creative fundamentals—if you know what that means, I don't, hardly. In that respect we are homogenous—if there is any one at the other end of our proposition to make a *we*.

"The telegraph idea will probably make the gap better than the ash and darkness stuff. The etherial disturbances are more than likely better adapted to the Martians' receivability. Perhaps they have not developed along that line tho. Perhaps they have not the natural resources in the electrical line, due to different mineral composition or planetary relation. However, I don't think that that would make any difference, tho.

"Anyway we will sit tight and watch such guys as Marconi, Tesla, Wood and the like and see what turns up with Mars at the other end of the line. We are *doing* things today in that line. We, the world in general, will not be more surprised at finding that we have neighbors on Mars than were we at the discovery of the force of electricity, the air-ship, the telephone, wireless, or the shimmie.

"Our train is ready to get on its way to Pendleton," spoke up Punk, "Row-de-dow!"

"Here's to talking to Mars over the back yard fence," said Stokes, as we walked out thru the gate to our waiting train. "We may pick up a paper tomorrow and read that some one has just received a message from Mars."

"Yes," replied Bender, "and it might be a false alarm too."

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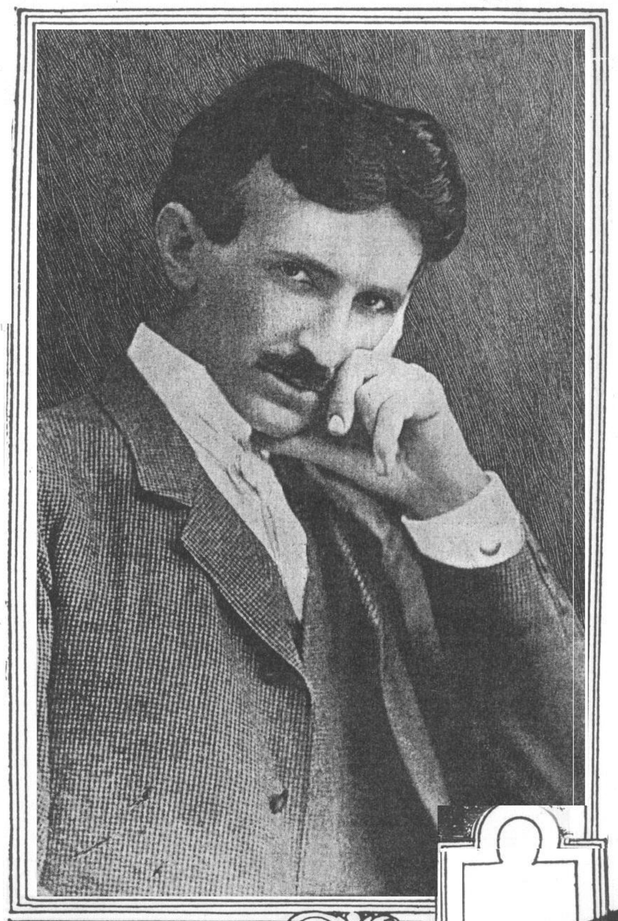
Marconi Credits Mystery Flash to Far Planet

Strange Wireless Signals Stimulate Inventor's Belief We Soon May Communicate With Mars or Other Celestial Bodies—Edison and Tesla Regard Success Possible



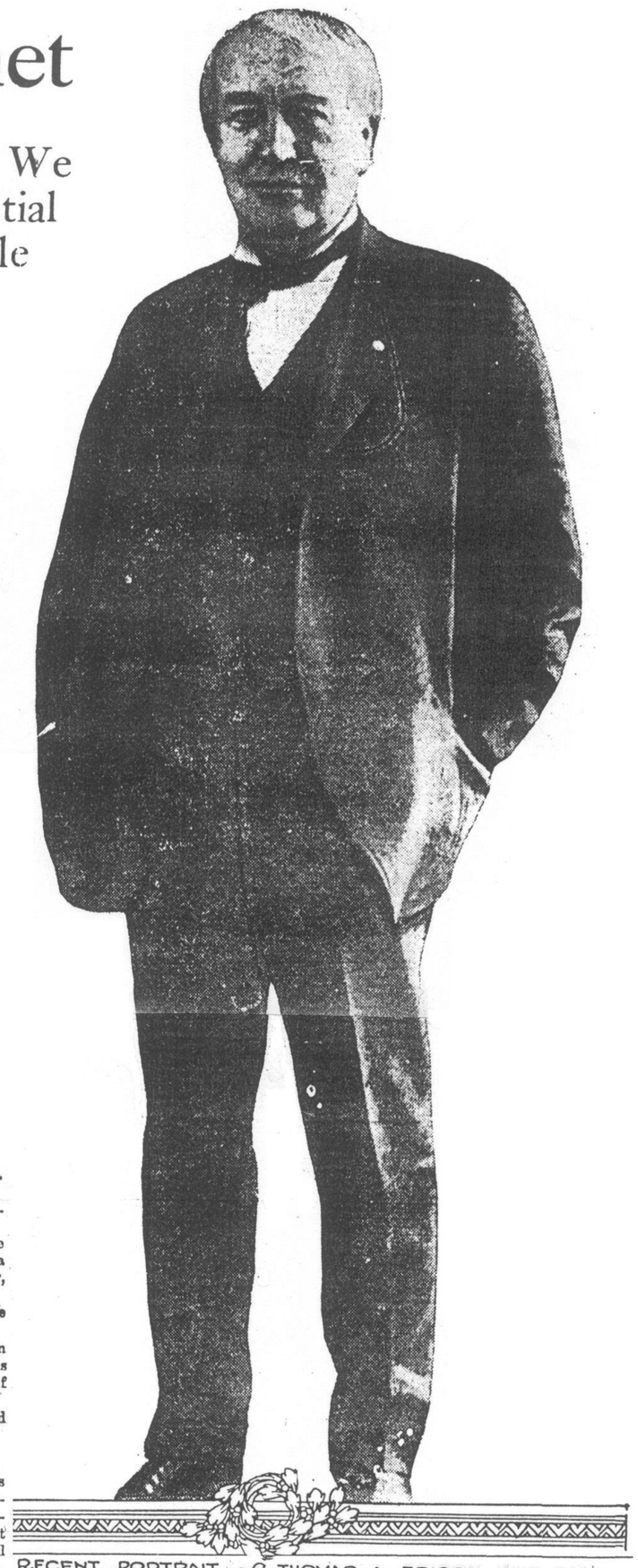
NIKOLA TESLA WHO FIRMLY BELIEVES WE MAY SIGNAL OTHER PLANETS.



GUGLIELMO MARCONI WIRELESS AUTHORITY WHO HAS RECEIVED MYSTERIOUS MESSAGES



THE LATE PROF. PERCIVAL LOWELL WHO STUDIED POSSIBLE PLANETARY MESSAGES



RECENT PORTRAIT OF THOMAS A. EDISON WHO SAYS PLANET COMMUNICATION IS NOT IMPOSSIBLE

By EDWARD MARSHALL.

HERE is one of the most amazing newspaper articles which was ever published. In it Marconi declares belief that he has been receiving signals from the stars. In it Edison says that this is not at all impossible and that the wizard of wireless is quite right. In it Tesla announces his belief in the startling possibility which the Marconi statement suggests, and goes further, directing attention to his own experiments and statements made some years ago, indicating the inevitability of such signalling.

The discovery, if discovery it proves to be (and the testimony of these three great men, most able of the world's investigators makes it reasonable to call it that, makes it unreasonable indeed to call it anything less definite), opens fields so wide that they well may appeal to the human mind which speculatively begins their exploration.

They well may hold vast secrets whose revelation will revolutionize the thought of all humanity, they may clarify and simplify religious theories, putting behind faith proof undeniable, and taking from the back of superstition the last prop which holds it up to fool mankind.

May Reveal Great Secrets

They may reveal material secrets of an epoch-making magnitude, metamorphosing theories which have been accepted as fundamental fact, adding new principles which will give us basis for tremendous progress.

The statement by the famous Italian engineer, who is known throughout the world as the discoverer, or at least the first perfector, of wireless telegraphy, was made in London to a member of my staff there, Mr. H. M. Forbes, a well known and entirely reliable journalist. What he wrote upon the subject afterward was submitted to the great Italian for revision, and therefore, as I shall quote it, actually represents the views of Signor Marconi.

The Edison and Tesla statements were made to me, Mr. Edison's at his laboratory in Orange, N. J., and Mr. Tesla's at his hotel in New York, after they had read Marconi's statement.

"During my experiments," Marconi said, "I have received signals which conceivably might have been sent from or have arisen in interplanetary space."

"You mean they may have been sent by beings upon other planets to the inhabitants of this one?"

"Yes." The word was positively spoken.

But let me quote his statement consecutively and in full. It is purposely made non-scientific, so that the untrained mind may grasp the great inventor's meaning.

Mr. Forbes called on Marconi during one of the latter's frequent visits to London, where he spends much of his time.

"Then you regard interplanetary communication as a possibility?" asked Mr. Forbes.

"Yes; the idea of interplanetary communication appears to me to be by no means outside the range of possibility.

"I shall be in no way surprised if, in case there be existent upon Mars beings of an intelligence analagous to that of human beings, they find a means of getting into communication with us on this planet.

"Immense things remain to be learned. We have only nibbled at the edge of the vast feast of knowledge which awaits us in the science of astronomy. It will link up with the science of electricity. Indeed it already has done so. Thus linked almost anything may be expected of the two.

"Coupled with wireless, especially, the science of astronomy presents a study of superlatively engrossing interest. The fact that scientific understanding upon this planet, upon the little earth, may be far less advanced than that on other planets in no wise detracts from this interest.

May Have Tried to Signal Us.

"For all we know for years past, possibly for centuries uncounted, many of the 'stars' that we see in the firmament may have been in communication one with the other. Thinking it, we inevitably must be stimulated to great effort toward realization for ourselves of such possibilities if they exist.

"What reflection at first could be more staggering to the human imagination and then a greater urge toward renewed and ceaseless study than the thought that, through the ages, messages flashed from one celestial sphere to another may have helped to develop whatever conscious life exists upon the communication spheres, to urge along on them through the exchange of thought whatever there exists of the nature of that which we call 'civilization.'

"We upon the earth have worked alone and stumblingly. If those dwelling in other worlds have had the help of other beings, so that each finds itself in possession of a progression representative of the sum of the wisdom existing among all the communicating spheres, they may have far surpassed us."

"What first suggested to you this idea?" Mr. Forbes inquired.

And here comes the most amazing thing Marconi said, one of the most amazing things that any man ever has said.

"During my experiments with wireless," said the great inventor, "I have encountered many striking phenomena.

"I have received signals which quite conceivably might have arisen somewhere in interplanetary space!

"The marvels of the cosmos are unlimited. It is idle to suppose that our comparatively insignificant planet sets the fashion, leads the van, represents a development higher than or even as high as that which exists on other spheres.

"And our own planet is a storehouse of wonders. That being so, we may rest assured that the same is true of the vast hosts of stars at which we gaze with eyes which see no details, but yet must widen in wonder.

"It would be foolish to suppose, for instance, that life cannot exist under conditions other than terrestrial, that is, under conditions different from these existing on this planet."

I assumed that he referred to these facts already fully established through astronomy as to the wide difference existing among the stellar throng with regard to volume, mass, density, atmosphere, &c.

"We cannot say," said Mr. Marconi, "that such diversity must be accepted as an insuperable obstacle to the manifestation of conscious and effective life."

"Do you contend, then, that there may be upon other planets intelligent life concerning which we are quite ignorant?"

"It is certainly within the bounds of possibility."

"And do you consider it possible that life as on those other planets existing may have qualities not only different but superior to the qualities of this earth's human beings? Some have argued that whereas terrestrial man is endowed with five senses beings possessed of many more may exist on other planets. Do you think this is an entirely unreasonable assumption?"

"I do not regard it as at all unreasonable."

"May there be in existence elsewhere in the realms of space beings with a magnetic sense, a sense of orientation, or, perhaps, an electric sense?"

"Discoveries to that effect would cause me no surprise."

"If beings existed possessed of an electric sense highly developed might this render them capable of the reception of wireless messages?"

"Who can say? It seems not beyond the range of possibility."

What Mr. Edison Thinks.

Mr. Marconi went no further in his speculations with regard to these extraordinary and till now scientifically untouched puzzles. He left the subject wrapped in profound mystery, but he had suggested startling possibilities and declared that he was working at the task of trying to penetrate it. Mr. Forbes's record of the startling interview was sent to me at once.

I took the article, as I received it from my London office, to Mr. Edison at his Orange laboratory. He did not fail to take the matter very seriously, although he instantly explained that he lays no claim to being expert in the science of the wireless.

"The thought," said Mr. Edison, "of course is not a new one. Humanity, almost as far back as our records go and very likely far beyond, has been trying to communicate with these heavenly bodies which we call the stars.

"We all have wondered if, some day, signals between the earth and other planets would not be a possibility. Most of us who have studied any of these problems have wondered if efforts to signal us have not been made already by inhabitants of other planets.

"I have thought about the matter and have seen some signs of which I must be careful not to exaggerate the importance or significance. I remember that one day while seated under a tree at the apex of a large mass of iron ore, I was eating my lunch near my reduction plant, when I noted that the magnetic needle of my compass jumped about astonishingly. It was very strange.

Marconi's Suggestion Reasonable.

"At once the thought came to my mind that signals sent through interstellar space might be responsible for the disturbance. Not long afterward I made the definite suggestion that a scientifically kept watch for interstellar signalling should be established in Michigan, where enormous masses of ore might be expected particularly to attract magnetic signals from space if any should be sent.

"Marconi's suggestion is more reasonable, for it would be easier to send static signals through space than it would be to send them through the atmosphere. Resistance would be less. He is quite right when he maintains that the development of wireless is only in its infancy.

"Of course I do not know that any of the planets are inhabited, or, if any planet is, what the nature of its inhabitants may be. If such inhabitants exist they surely are suited to whatever their environment may be, and that may mean that they are very different from us.

Disease Vapor in Space.

"We have no reason positively to declare that definite influences even other than electrical have not reached us out of space. There was the Spanish influenza, so called, for example. We are not sure that it originated on this planet. It spread everywhere irrespective of the lines of human travel. It has been established, for example, that it appeared upon Pacific Ocean islands which had had no communication with any infected portion of the world; or, indeed, any portion of the world whatever. Ships reaching utterly isolated islands found half of their inhabitants ill or dead of the disease.

"Some scientific man has said that we were passing through a cloud of benzol vapor floating in space. Benzol is poisonous. It might affect all humanity physically; it might affect all human thought, distorting it, for it is known to have an influence on the brain.

"It is not unreasonable to suppose that more than once we have passed through realms of space permeated with vapors of one kind or another. If this occurs it is not unreasonable to expect them to affect humanity.

"If any development of signalling occurs it will be accomplished by some pure scientist with the unstinted aid of commercial men of imagination and not afraid to spend of effort and of money. The astronomer is a pure scientist, who can have no hope of large material reward, or any, indeed, beyond his own satisfaction of achievement and the commendation of his fellow men.

"Wireless would seem to be the medium of which we most reasonably may expect something in the way of signals from the other planets if we ever are to receive such signals. It operates in that unknown and wonderful substance or mechanism which we call the ether and which fills all space. Atmosphere is local to us.

"It has been suggested, and I neither indorse nor reject the idea, that the activity of our wireless effort during the war may have attracted the attention of experimenters upon other planets. I doubt that, but I do not deny it. It is my thought that when we begin to signal we shall have discovered new means, more powerful and effective than any we at present know. Of course, we may expect the future to produce exactly that.

Signals From Intelligent Beings.

"If the theory suggested by Marconi is accurate and signals are being sent out by some one or more of the other planets they must be the work of beings of intelligence—these planets must have inhabitants, in other words. As a matter of fact it is an inexcusable and stupid bit of egotism for us to assume that only this small earth has produced life and intelligence.

"The intellectual individuals, if there be any, upon the other worlds may be very different from those upon this earth. They may be different in form and different in many ways, utterly unlike mankind. But to assume that they do not

Continued on Eighth Page.

Marconi Credits Mystery Flash to Far Planet

Continued from First Page.

exist is sheer conceit—conceit of this small world which astronomers have proved to us is by no means the most important even in the solar system. And there are systems far greater and more potent than the solar system.

"Great discoveries are to be made. We know that, for we have made some great ones. He who scoffs at any theory put forth by a sober minded scientific man striving to find truth is merely silly.

"The human mind is capable of things that seem extraordinarily great to us. Perhaps they would seem puny to the inhabitants of Mars, but to us they seem tremendous. There is nothing in the problem Marconi has laid before the world which is beyond the power of human intelligence to solve.

"Consider Champollion's deciphering of the Rosetta Stone. It took him forty years to work out its hieroglyphics, but he worked them out and learned their meaning beyond the shadow of a doubt. It enabled him to read the hieroglyphics of the whole region and added greatly to the sum of human knowledge.

May Signal Other Worlds.

"Perhaps some time we may signal other worlds, if any are inhabited and if their inhabitants are as intelligent as we are. If they are not, why then, of course, the case is hopeless. We have no reason to assume that this should be. And, as Marconi says, we need not feel sure that lack of such conditions on the planets as make life possible upon this earth makes certain that these planets cannot be inhabited. It is not inconceivable that bodies may be built which will endure environments very different from ours.

"Our atmosphere helps us only by permitting the combustion of bodily fuel.

"We human beings use air and carbon for fuel. A tree uses them only for construction purposes. Some day I shall tell you of my theory that each human being on this earth is a collection of a multitude of tiny entities. Well, suppose these entities elsewhere should have within themselves the necessary apparatus for existence!"

Nikola Tesla was not in the least surprised when I went to him and told him of the statement which had come across the sea to me from Mr. Marconi and of what Mr. Edison had said.

Terrestrial Vibrations Recognized

"For years I have contended that exactly these things some day would occur," said he. "Indeed, I myself have observed effects which might have been signals from somewhere in interstellar space. I will not express an opinion as to whence they came. They were not from the sun nor the moon, nor from Venus, because I eliminated the effects of these bodies on my instruments.

"I could not have been deceived by earth vibrations, mistaking them for signals from afar, because terrestrial vibrations are easily recognized. They could be distinguished absolutely.

"No; the effects which I received accurately corresponded with disturbances which might have emanated from Mars. I admit that they excited me. I decided that, indeed, they actually came from Mars.

"This is all a matter of perfectly well known record.

"People have been backward in these things. There has been too great a tendency to call any one 'impractical' who dared to look too far in advance of the well beaten path. What is being 'practical'? One must have imagination in order to be truly practical.

"I know scientific men who have spent years in attempts to do some obviously impossible thing and who yet have been called 'practical' because if they succeeded in accomplishing that for which they were striving they would make much money.

"The same men would have jeered not long ago at the suggestion that we on the earth might receive signals from Mars. Big things are not 'practical.' They are wonderful. Many scientific minds, like many minds which are not scientific, shy at anything which is wonderful. Yet the simplest things in nature are wonderful almost beyond the limits of the human imagination.

"Men ignorant of the way in which plants grow would jeer at a farmer if suddenly they should be so placed that they saw him planting seeds. They would declare him an 'impractical' creature because the fruition of his efforts if at all possible of realization is so remote. They want immediate results.

Nature and Seed Growing.

"The sending to and reception from Mars of signals would be an achievement by no means as wonderful as nature's simple process of making seeds grow in the ground.

"In the *Harvard Illustrated Magazine* for March, 1907, I declared that experiments to this end should be undertaken. I had made this statement first in the early part of 1900, while still vividly impressed by certain observations I had made not long before. I dwelt upon them in an article in the *Century Magazine* during the same year. In order to correct an erroneous report a statement was also published also in *Collier's Weekly* in February, 1901, defining my position in general terms.

"During all the period since and as the result of ceaseless thought and work I have found no reason to alter my original views.

"The observations of Professor Lowell have been accepted by many in the light in which he interprets them, although there are those who disagree with him. The light in which he sees them indicates the possibility of intelligent, very intelligent indeed, life on Mars.

"Personally I can but hope that the great astronomer has been true that Mars is not a cold, dead sphere, but, instead, the abode of happy and very highly developed creatures, from whom we may learn and to whom, conceivably, when signalling becomes perfected, we may impart perhaps a little knowledge.

"In 1907 I wrote: 'In the light of glorious possibility, signalling to that planet presents itself as a definitely practical proposition, which to carry out no sacrifice could be too great. Can it be done? What chance is there that it will be done?'

"As to the experiences of Signor Marconi I have heard nothing save that which you have read to me in the article from your correspondent in London. But the dates which I have given you show you how long it has been since I myself achieved results and how long the matter has been among the foremost topics in my mind.

"I long have believed and still believe that if sentient beings are alive on Mars, or even elsewhere, communication with them is not beyond the bounds of science as it is developing upon this earth."

I asked a question of the scientist.

"And is it conceivable to you that we shall be able to read such signals as may come to us out of the void, or that we shall be able to send signals which by any possibility could be intelligible to the beings who may receive them?"

May Find Basic Symbol.

"It is not unreasonable to suppose," said Mr. Tesla, "that if there be Martians of developed intellect some symbol may be found which may be used as the first basis upon which understanding may be built.

"A straight line, a geometrical figure, and these used in groups, must convey to any mind a definite idea.

"If there be Martians they probably think and reason as we do. It is not impossible that Martians have developed quite as far as we have and possibly much further. It is not unlikely that the Martians even now have maps of our earth as those which Prof. Pickering has made of Mars. They may know more of us than we have learned of them.

"If this be true, then it can be occasion for no wonder if they really are endeavoring to signal us. We are sufficiently advanced in electrical science to know that the sending of signals from Mars to the earth would be a simpler matter than the sending of signals from the earth to Mars.

"The presence of organic life is almost certain upon these innumerable other worlds, which are situated much as ours is and are supplied with light, heat and moisture. In such worlds organic life is certain to develop.

"In our own solar system we have two known to meeet these basic requirements. They are Mars and Venus.

"About Venus, which seems to be much

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Marconi Credits Mystery Flash to Far Planet

Continued from Preceding Page.

like our earth, we can guess little, for the reason that its surface is hidden from our most powerful lenses by a dense atmosphere which at present we have no means of penetrating with sight.

"Mars, on the other hand, is open to the gaze of such men as Pickering and the late Prof. Lowell. Their observations lead us to believe that it is peopled by a race far superior to our own in intelligence.

"If this be really the fact, then the accomplishment of some means of communication becomes the most important task which the human mind is capable of conceiving, for communication would put us in possession of the many secrets which these beings must have discovered in their battle against merciless elements.

"That in the face of the fact of the good reasons for belief that Mars may have its beings, far more intelligent than we, no great concerted human effort has been made to reach them with such signals as conceivably might be sent in their direction through the intervening space is a monstrous evidence of human inefficiency and indifference.

"In the year 1899 I erected a plant on a high plateau in Colorado and in a few months was able to produce electrical actions comparable to and in a certain extent surpassing lightning. Without difficulty I obtained activities of 18,000,000 horsepower.

"It soon became plain to me that a powerful oscillator was within the range of possibility which would exert a noticeable influence upon a delicate receiver, which I was at the moment perfecting, at a distance of 50,000,000 miles.

"My announcements were received with incredulity because my plans were not fully comprehended, but the following year I designed a machine to have a maximum activity of one billion horsepower. This was partly constructed on Long Island and would have been put in operation had it not been for handicaps of a trivial nature having no connection with the electrical and mechanical problems involved. The plain fact is—my project was too far in advance of the time.

"In the course of my electrical experiments in Colorado I employed a receiver the sensitiveness of which is virtually unlimited. The conditions under which I operated were very favorable, for no other wireless plant of considerable power existed then.

"Inevitably the effects which I observed must have been due to natural causes, terrestrial or cosmic. On one occasion, after I had become expert in the use of my receiver, my ear barely caught what seemed to be signals coming in regular succession.

"I knew that they could not have been produced upon the earth and I was sure that they could not have been caused by any solar or lunar activitly or by the influence of Venus.

"The possibility that they came from Mars occurred to me, but the pressure of other affairs (and now I deeply regret this) prevented me from continuing my experiments.

"This problem is the greatest, the most fascinating, to-day confronting human imagination. Either by public or private means capital in such amounts as might be required, regardless of anything but ultimate success, should be provided and a body of competent experts organized for the examination of all plans and the execution of the best.

"The success of such experiments might mean untold and untellable blessings for the human race. Once let communication be established and ideas can be transmitted. I already have devised a plan akin to picture transmission by means of which we could convey to the inhabitants of Mars knowledge of form and readily establish understanding with them not only regarding primitive ideas but the most involved conceptions."

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Scientists, Agreeing Martians Are Super-Race, Believe That Planet May Be Signaling to Us

Life on Our Distant Neighbor Is "Grand, Intense, Formidable," Says M. Perrier

By Arnold D. Prince

IF IT should prove to be the case after all that those mysterious Marconi "messages" came from Mars or even Venus, the next problem of importance will be the kind of people who sent them. For, of course, if the earth is to have new neighbors with whom to exchange gossip across the back yard of the sidereal firmament, it will want to know something about them. It will want to know something of their habits, appearance, how they dress, act and possibly their views on interplanetary relations. All sorts of situations may arise wherein a mutual understanding of personal traits, characteristics and general disposition will aid in establishing and preserving amicable relations.

Signor Marconi, unfortunately, was not able to throw much light on the subject. Virtually all that came within the scope of his observation was that when prosecuting wireless experiments certain "signals occurred" with persistent regularity which could not be explained on the theory of casual interference. As these signals had been received "simultaneously at New York and London with identical intensity," he admitted the possibility of their being attempts by the inhabitants of "other planets to communicate" with us.

enus or Mars?

Subsequent discussion, in which scientists in Great Britain, France and the United States participated, disclosed an almost hopeless confusion of views on the reasonableness of this conclusion, but resulted in an agreement on one point at least, which was that if any attempts had been made to communicate at all, they must have originated from Mars or Venus, the only worlds outside our own upon which there is a possibility of human habitation.

What kind of people, then, inhabit these two planets? In seeking an answer to this question the inquirer is thrown back almost exclusively, of course, on the conclusions of the scientists who have made a study of the subject. No one, so far as known, is in a position to give first hand information. Nor is there anything specially helpful in such suggestions as emanated recently from one authority, who, when asked his opinion as to the population on Venus, replied with hopeful animation that they were "chorus girls." Such jocularity is merely beclouding the issue and adding difficulties to a problem that is difficult enough as it is.

Among scientists who have won the right to speak with authority the foremost was the late Professor Percival Lowell, director of the observatory at Flagstaff, Ariz.

Professor Lowell was the brother of Abbott Lawrence Lowell, president of Harvard University. Before taking charge at Flagstaff he had been attached to the observatory at Harvard and had conducted astronomical investigations in many parts of the world, including Japan, Tripoli, the Andes and other countries. He had delivered lectures on his findings before important scientific societies in Great Britain and the United States.

Not only was Professor Lowell convinced that Mars was inhabited, but he believed the people had a much higher degree of intelligence than those on earth. He dwelt particularly on their inventive genius.

Great Inventors

"Quite possibly," wrote Professor Lowell in his book, "the Martian folk are possessed of inventions of which we have not dreamed, and with them electrophones and kinetoscopes are things of a bygone past, preserved with veneration in museums as relics of the clumsy contrivances of the simple childhood of the race.

"Certainly, what we see hints at the existence of beings who are in advance of, not behind, us in the journey of life.

"Startling as the outcome of these observations may appear at first, in truth there is nothing startling about it whatever. Such possibility has been quite on the cards ever since the existence of [illegible] was recognized by the Chaldean shepherds, or whoever the still more primitive astronomers may have been. Its strangeness is a purely subjective phenomenon, arising from the instinctive reluctance of mind to admit the possibility of peers. Such would be comic were it not the inevitable consequence of the constitution of th universe. To be shy of anythin resembling himself is part and parcel of man's own individuality.

"Like the savage, who fears nothing so much as a strange man; lik Crusoe, who grows pale at the sigh of footprints not his own, the civilized thinker turns from the though of mind other than he himsel knows."

The peculiar relevancy of thi view to the discussion resulting fror Signor Marconi's announcement wil strike any one who reads Professo Lowell's statement. His brothe scientists were indeed "shy," as h had predicted, of the deduction reached by him, but they at leas contained the views of the Flagsta astronomer as to the kind of peopl who, if we accept the pleasing poss bility suggested by Signor Marcon are trying to "strike up a speakin acquaintance" with us. Not only ar they masters in the knowledge o electricity, but they have alread relegated to the museum of antiqu ties many of the discoveries in tha field which we, here on earth, loo upon as last minute achievements i scientific effort.

Professor Lowell, while comment ing strongly on the intellectual at tainments of the Martians, mad little or no reference to the actual appearance of the folk living on that distant planet. True, he did say in another part of his book that they probably were not interested in party politics, and that, judging from their canals, they were favored by a "comprehensiveness" of mind much more embracive than that "which presided over the various departments of our own public works" in the United States, but as politicians look much like other persons very little could be gained from that.

First Martian Pictures

It was M. Edmond Perrier, director of the museum of the Jardin des Plantes, in Paris, who constructed the first picture of the Martians, as he conceived them.

At the time M. Perrier undertook this task the division among the authorities on Professor Lowell's theory had assumed wide proportions. Some were decidedly "cold" to the notion that Mars—the question as to Venus was temporarily in eclipse—was inhabited at all, and they considered it futile and profitless, therefore, to attempt to depict a non-existent people. Others, as has happened even recently, considered the matter in a light vein, thinking to get some humor out of it, and one newspaper carried a cartoon, captioned "Hello Central," showing Professor Lowell "calling up" Mars.

Still another group seemed to take it as a personal affront that the astronomer had sought to enlarge their list of acquaintances by introducing a race about which they had absolutely no knowledge.

M. Perrier approached the problem from a highly speculative viewpoint, but made clear the fact, nevertheless, that he saw no reason for condemning the position of Professor Lowell.

"Dreams are not a crime," contended the French scholar, "and in this case contradiction is difficult."

The director of the museum of the Jardin des Plantes led up to his description of the inhabitants of Mars by establishing the premise that conditions on Mars are not inimical to human life. Rain, snow, thunder and hail are known there, as on earth. There are seaweeds in the ocean, grass and trees on the land, fields available for cultivation and a friendly soil to provide food for the people.

"The life which animates the earth also animates other planets," said the French savant. "From what goes on around us we may divine what is happening elsewhere by examining the exact conditions under which each planet finds itself en rapport with every other. On the planets which are furthest away, it is impossible that human beings should exist, for no organism could, for example, be formed in the alkaline seas of Jupiter, while Mercury, which is too near the sun, could not engender life. Only Venus, the Earth and Mars are habitable."

On Mars, M. Perrier went on, life is "grand, intense, formidable." The mean temperature is 40 degrees Fahrenheit, as against 75 degrees on earth, the winters are more severe, the summers warmer, the year longer and the seasons more marked than ours.

The sea animals are much like ours, the fishes have a sense of hearing, there are insects in the animal kingdom and flowers and butterflies, but the humans are very, very different.

Before going on and giving M. Perrier's picture of the kind of people the Martians are, and in order to reassure such sensitive souls as may fear to establish speaking relations with a people too alien in appearance to make acceptable neighbors, it should be stated that M. Perrier does not agree with the conception of the Martians set forth by H. G. Wells in his book "War of the Worlds." Mr. Wells, in that work, caused the Martians to resemble cuttlefish, with round, gray bodies, with "sort of faces" and long, groping tentacles.

This conception, M. Perrier asserted, did the Martians a great injustice and created a prejudice against them, which is not only unscientific and unsound, but entirely undeserved.

The Martians, the French scholar held, bear a certain resemblance to man, although many of their features are more prominent. For this, the difference in the forces of gravity and in environment are chiefly responsible, he said. Their ears, for example, are very large.

Continuing, the director of the museum of the Jardin des Plantes said:

"The low atmospheric pressure has produced a considerable development of the pulmonary apparatus, and consequently the general character of the Martians has been influenced by this development, which is unknown on earth.

Why Martians Are Tall

"The men on Mars are tall because the force of gravity is slight. They are blond, because the daylight is less intense. They have less powerful limbs. They have some of the characteristics of our Scandinavian type, although they probably have larger skulls.

"Their large blue eyes, their strong noses, their large ears, constitute a type of beauty which we doubtless would not appreciate except as suggesting superhuman intelligence."

Going further into details, M. Perrier concluded that the jaw of the Martian is narrower than ours because time and evolution have removed him further from his animal forebears than they have us. His lung capacity is enormous because of the thin atmosphere, although his legs are extremely thin, due to the little effort needed in walking. He has little or no neck.

Touching on the question of intelligence, the French savant deduced that the Martians have solved the problem of existence, and know no such thing as industrial strife. Being older, they are also wiser than we. They have long since conquered disease, and know the hour of their demise, awaiting the event calmly.

They have overcome poverty, are too sophisticated to engage in war, and need no law or government to keep them orderly. Philosophers and brothers, they live in amity and understanding, devoting all their thought to the promotion of large undertakings in which selfishness, avarice and earthly trifles have no part.

They are, in a word, as different from the fanciful and unpleasing picture painted by Wells as are we from the Simian types referred to by Darwin.

Returning to the question of flora and fauna, M. Perrier concluded that because of the reduced force of gravity, animals are much larger on Mars than here, and hop, run and fly about much more easily. Grass is higher, fruit is bigger, and the flowers possess undreamed of beauty. The light is something like our dusk, and the general landscape much more attractive than on earth.

"The year on Mars is twice as long as our earthly one," he explained, "and hence plants and insects have twice the time in which to evolve. Mars is the land of huge plants and ideal flowers, of birds abnormally powerful in song and wondrous in appearance, and of four-footed animals with extraordinarily developed fur and skin."

Neither M. Perrier nor the other scientists who believe in the habitability of other worlds paid so much attention to Venus. They agreed, however, with the head of the Jardin des Plantes that as this planet is much younger than the earth, life there is much less advanced. Because of the greater nearness to the sun, the climate is something like that in our tropics, and the air is always misty. Animals and plants are much like ours, especially at the poles, where the temperature is not so high, but humans are not much beyond the development that existed on earth during the secondary geological period.

Not From Venus

In other words, there is much less likelihood that those strange Marconi signals came from Venus than that they came from Mars.

Having thus disposed of the kind of beings supposed to exist on the only two eligible planets, two other questions arise—Why are the Martians or the Venusians trying to communicate with us, that is, if they are? and, What atmospheric conditions will we on earth have to overcome in order to reply to them?

As to the first question, a possible explanation may be found in the so-called cataclysm on Mars that was reported by the British Astronomical Association in 1909. In that year some such similar catastrophe has overtaken the Martians, who, in their desperation, are attempting to communicate the fact to us?

In August, 1909, astronomers working at their telescopes had reported what they surmised to be a new fracture of the southern polar cap and the appearance of a dark streak along the line of the break. About the same time a brilliant spot, which may have been a segment of the shattered terrain, had separated itself from the polar cap and had moved over to one of the dusky areas of the planet, partly hiding it from view.

Great Convulsion Possible

All this seemed to strengthen the theory of a huge convulsion advanced by the British scientists, although, as seems to be the fate of all questions concerning this much discussed and little understood celestial body, eminent authorities at once took opposing ground on the subject.

Professor Harold Jacoby, Rutherford Professor of Astronomy at Columbia University, contended that "the Martians are not likely to have their world destroyed any more than are we," adding that if any such catastrophe as hinted had actually occurred the news would have become known through some quicker channel than the British Astronomical Association. By this, it should be explained hastily, Professor Jacoby did not mean that the scientists across the Atlantic were slower in observation than others, but only that the disaster would have been revealed by telescopes everywhere long before a formal report could have been prepared.

Professor F. R. Moulton, of the University of Chicago, also doubted the accuracy of the report, and Professor Lowell himself, author of the notion that Mars is inhabited, was not particularly impressed with it.

Professor Lowell, it will be remembered, held to the belief that the Martians were anything but a starving, needy people, and he constantly sought to fortify his position by offering new proofs of their prosperity, advancement and skill. In 1914 he found a new opportunity for strengthening his pet belief by announcing that, instead of losing any of their canals the Martians had built two new ones, which could be seen plainly through the telescope.

"We have actually seen them formed under our eyes," Professor Lowell said at the time, "and the importance of it can hardly be overestimated. The phenomenon transcends any natural law, and is only explicable so far as can be seen by the presence out yonder of animate will." By animate will he meant, of course, human beings.

Professor Lowell was admittedly the leading spokesman for the Martians, and anything he said was worthy of the most respectful consideration, but in view of recent developments many thinkers are asking if, after all, he was not mistaken in at least one particular, and if the "signals" picked up in New York and London were not efforts on their part to notify the earth folk of their desperate plight. No unusual manifestations to support this view have been witnessed recently on the distant planet, but it is at least a new guess on the subject, which is all that its originators claim for it.



SCIENTISTS agree that the people of Mars differ from us in many ways. The Martians are believed to have very large noses and ears and immense lung development, because of the rarefied atmosphere. Their legs are poorly developed, because matter on Mars weighs less than here and sturdy legs are not needed to bear their weight. Birds and butterflies are very large and beautiful

Professor Lowell Held That Martians Were Far Advanced in Inventions and Science

Tesla Believes It

To Nikola Tesla there is nothing remarkable or impossible in the suggestion that the mysterious signals are from the Martians. Discussing the question, he said:

"To most people the mere idea of flashing a signal over the immense gulf of 50,000,000 or 100,000,000 miles will naturally appear preposterous, but as I have stated in an article I wrote for 'The Harvard Illustrated Magazine' of March, 1907, it is simply a feat of electrical engineering, apparently hazardous, but made perfectly feasible through inventions with which the experts are familiar.

"That the planets are inhabited is a foregone conclusion. It would be stupid to deny the existence of conditions suitable for the development of organic life on other planets."

The next question is how the earth is to reply to these signals, supposing they are signals at all, and what are the atmospheric obstacles that will have to be overcome.

Mars at times is only 50,000,000 miles away from the earth and at other times 250,000,000. It is frequently surrounded by vapors, as is the case, too, with Venus, which would be extremely difficult of penetration by light radiation, but the chief problem to be met would be the creation of a wireless apparatus of sufficient strength to send a message over the required distance. Dr. Charles P. Steinmetz, chief consulting engineer of the General Electric Company, believes such an instrument possible, provided the world devoted itself to the invention with the same thoroughness it employed in the great war, but estimates it would cost at least $1,000,000,000 to do it.

Wireless messages have been transmitted over a distance of from 3,000 to 4,000 miles when conditions were favorable, although an official of the Radio Corporation of America, of which the Marconi system is a part, said that signals had been sent as far as 10,000 miles under unusual circumstances.

"But there is one thing that should be remembered," said David Sarnoff, commercial manager of the Radio Corporation of America, "that there are a great many conditions in the atmosphere of which we do not know, even when sending a message, say, across the Atlantic or even a shorter distance.

"We know something about wave lengths, and we know what happens when we send a message and when we receive it, but what happens en route is still pretty much of a mystery.

Niagara Falls Would Help

"In connection with the actual practicalities in sending a wireless message over such a distance as that between the earth and Mars, that, I may say, is something about which the newspaper men know almost as much as we do. But the chief problem, it would seem to me, would be to find an instrument powerful enough, rather than anything else, and this would be no small achievement. We would have to harness Niagara Falls and every other power producing agency that I know of to do it."

Electricity travels at a speed of a little more than 186,000 miles a second, and a message going at that rate would take a little more than twenty-two minutes to reach Mars when it is at its furthest point from the earth, and about four minutes and twenty-one seconds when it is nearest. According to the same calculation it would take two minutes and eighteen seconds to send a radiogram to Venus, two minutes and fifty-nine seconds to the sun, two seconds to the moon, thirty-five minutes to Jupiter, one hour and nine minutes to Saturn, two hours and thirty-two seconds to Uranus and four hours and two minutes to Neptune.

Those Martian Radio Signals

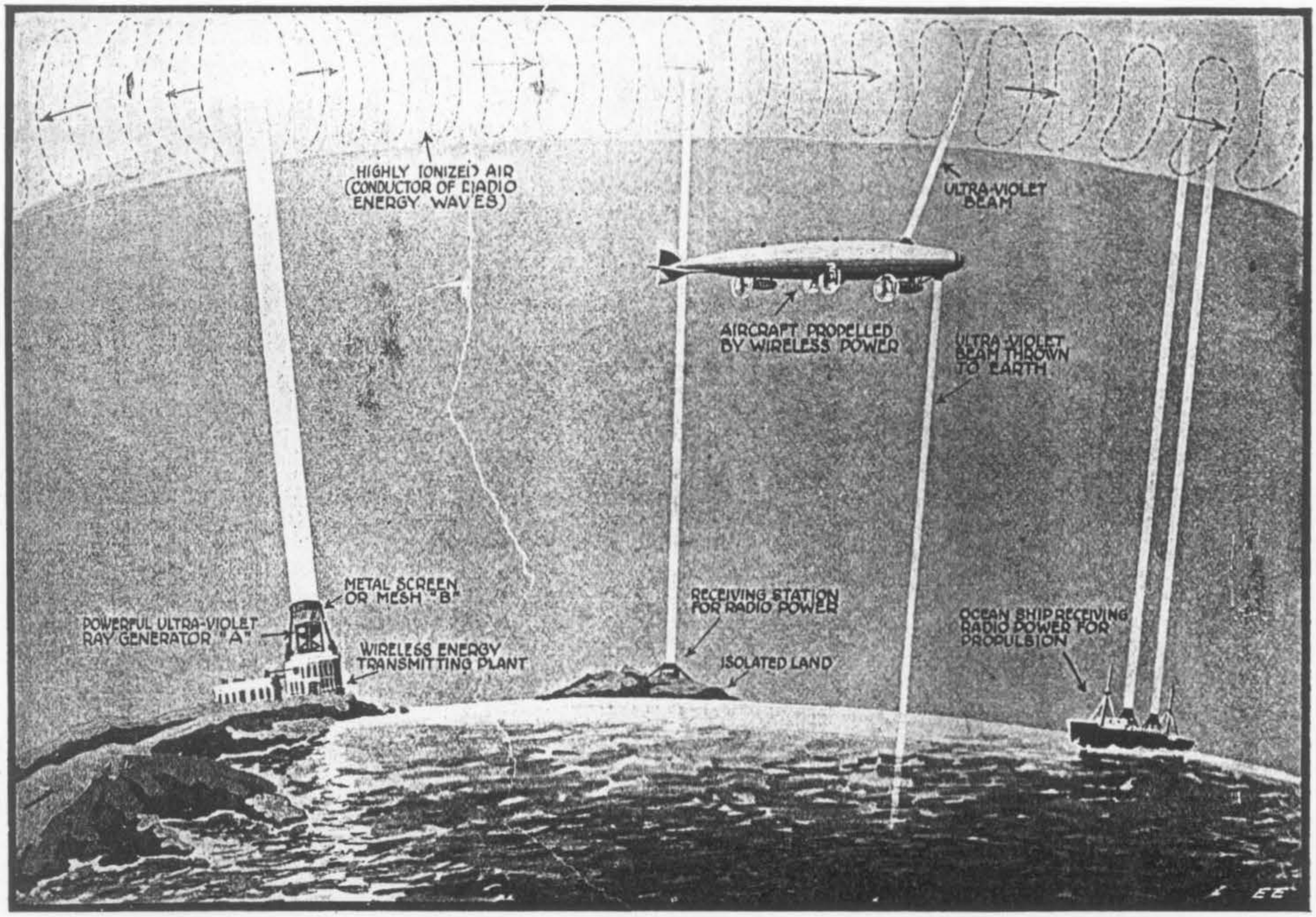
MARS is again in the public eye. For several weeks past there has been almost no end to the opinions of the leading scientists and radio experts of this and other countries regarding the mysterious wireless signals received by Marconi, the inventor of practical wireless telegraphy, at several of his stations. Marconi has stated publicly that the signals, because of their exceptionally long and fixed wave length, as well as their marked similarity to the Continental-Morse code, lead one to believe that they are perhaps generated from some point outside the earth, and if so, most likely Mars.

At this late date when so many dreams of yesterday have become stern realities, it would be foolhardy indeed to discredit Marconi's statement on the face of it; for, to be sure, there is no definite proof either way to show that he is right or wrong in his hypothesis. Examining the facts in the case, we learn that the signals are of an exceptionally long wave length—a wave length far in excess of those generally employed for long-distance work. Next, we learn that the wave length is practically constant, which would naturally lead one to believe that the signals are artificially generated. Then we are told that the signals are received with equal strength at stations spaced several thousand miles apart, which is a truly remarkable fact, since, so far, any signals generated with our most powerful transmitters rapidly lose strength the farther they have to travel. Finally, the signals are said to simulate the Continental-Morse code, which is that almost universally used in radio work.

Turning to the other side of the case, we find ready explanations for these facts which soon weaken the possibility of Martian signals. In the first place, we have absolutely no proof that there are inhabitants on Mars. Secondly, if there are Martians, would it not be rather a strange coincidence if they had worked out radio telegraphy and a code along the same lines as we have? And would it not be strange that they have succeeded in obtaining sufficient power and apparatus to transmit over the tremendous distance of 50,000,000 miles? Then there is this striking flaw in Marconi's suggestion, namely, that the signals have been received only at his stations. The Eiffel Tower station at Paris, some of our Navy stations, and other radio stations equipped to receive exceptionally long-wave signals report that they have not heard the signals to which Marconi refers, although they have searched for them.

That the signals are due to atmospheric disturbances or possibly sun spots seems a most plausible explanation, although there is the matter of constancy of wave length to weaken it. Generally, atmospheric and other natural disturbances have a wide wave length, a fact which causes them to interfere with radio communication, since they cannot be tuned out with ordinary circuits. But when it comes to the signals resembling the Continental-Morse code, this is nothing unusual. At times the natural disturbances occur at such intervals that one is apt to confound them with regular signals until it is discovered that they are meaningless.

All in all, this matter deserves careful study when a scientist of Mr. Marconi's standing takes it so seriously. With the facts so far in hand, most scientists and radio men lean toward the opinion that the signals are simply natural disturbances, or possibly some new radio station of extreme power in some far corner of the earth. Perhaps it may be the Japanese, who are known to be developing new radio systems with some success. Again it may be the Russian Bolsheviki, who have turned to radio as a convenient means of propagating their cause at home and abroad. But we must all await further and more definite information before passing judgment one way or the other in this interesting controversy.



Showing the Wireless Transmission of Power by Means of Ionized Searchlight Beams. Powerful Tesla Currents of High Potential and Frequency Are Imprest on the Ionized Beams and Received from Similar Beams as Shown.

Wireless Transmission of Power Now Possible

By THOMAS W. BENSON

RECENT developments tend to fulfill the old, old dream of power transmission without wires. For years men have labored in vain to transmit power without wires and thus solve a myriad of transportation problems, such as propelling vehicles, ships, trains, aircraft, etc., without having to include a source of power in their construction. It makes one's head almost reel to think of the possibilities in such an achievement and now the dream promises to come true.

By one bold stroke an English genius, Mr. John Hettinger, has unthinkingly opened up the way for its realization. Like numerous other inventions, the way lay before our very eyes, but we were all too blind to see it.

While working on a means for transmitting radio waves without material aerials, Mr. Hettinger hit upon the idea of using ionized light beams as elevated conductors. Obviously simple when one thinks of it.

It is a well-known fact that an ionized gas is a conductor; in fact, the conductivity of a gas is a measure of its ionization. Furthermore, it is possible to ionize a gas by means of a stream of ultra violet rays. Working with these facts, Mr. Hettinger devised means to utilize them for radio transmission in the following manner.

As shown in Fig. 1, a source of ultra violet rays, an arc or mercury vapor lamp, A, is arranged to throw a beam of ionizing rays vertically.

These rays result in an ionized stream of air that acts as a conductor, the surrounding un-ionized air being practically a perfect insulator. By making connection to this conducting beam with a metallic screen or mesh at B, it can be utilized as an aerial for radio communication.

We are perfectly aware that this ionized beam rapidly loses its conducting power

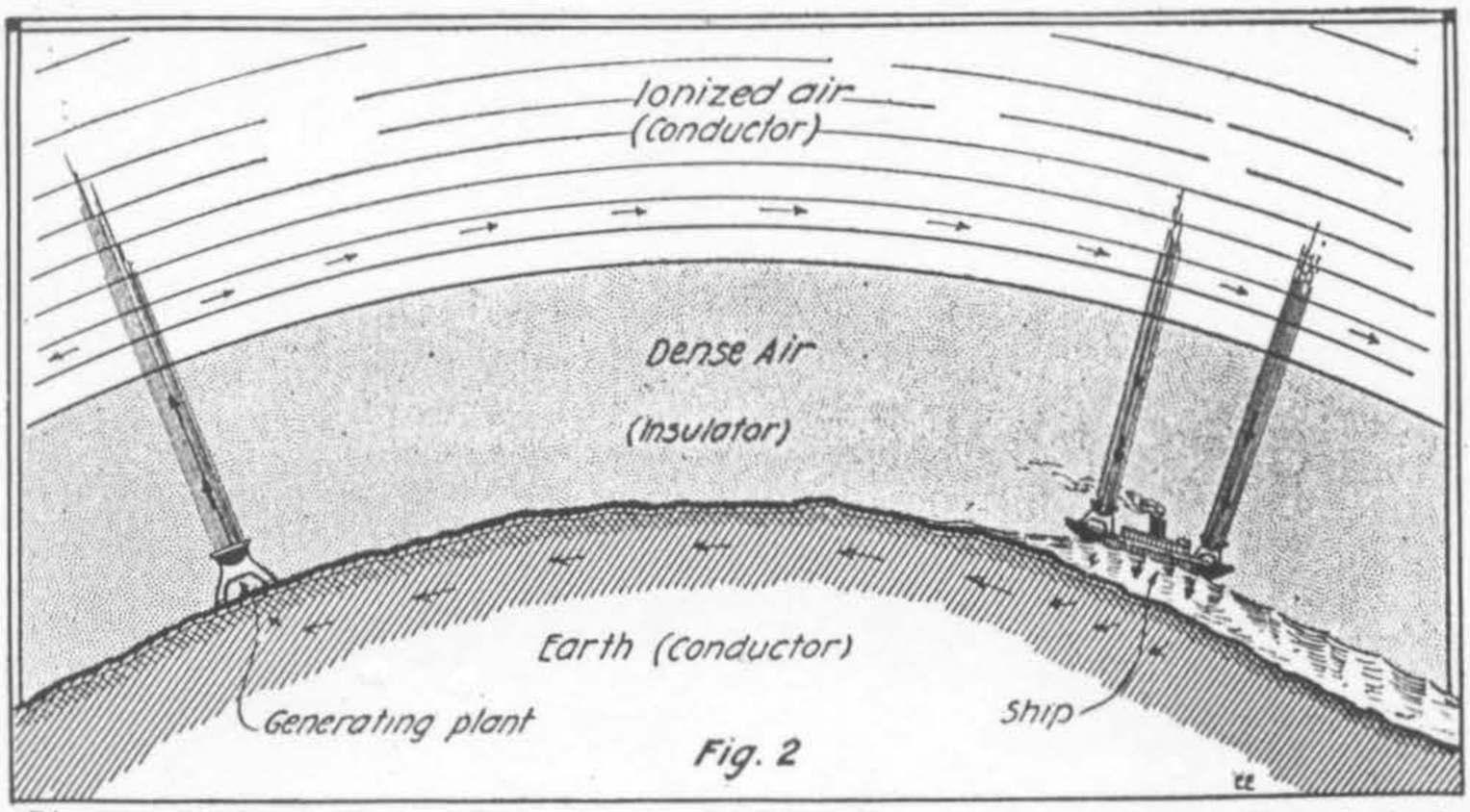


Diagram of the Author's Scheme for the Wireless Transmission of Power Thru Ionized Light Beams and the Upper Ionized Strata of the Atmosphere.

as the distance from the source increases, therefore the effective height of such an arrangement is determined by the intensity of the ray generator. So much for the idea as applied to radio communication.

But let us consider further. In studying the spectrum we find that the sunlight on reaching the earth contains few ultra violet rays of shorter wavelengths than 3,000 Angstrom units, yet we are able to generate much shorter rays with an arc light. It is unreasonable to assume that shorter waves do not leave the sun, and in view of the fact that it has been determined that the upper stratum of our atmosphere is ionized, it is accepted that the shorter rays are absorbed to cause this ionization.

It will now be apparent that a very good condition exists for the transmission of energy without wires. As shown in Fig. 2, we have the earth, a good conductor, surrounded with a blanket of insulating air about ten miles thick, beyond which, up to about a hundred miles, the air is highly rarefied and kept in a state of ionization by light from the sun and stars.

Hence, we have two good conductors separated by several miles of atmosphere, practically a perfect insulator, an ideal arrangement for our purposes. We have but to connect a source of current to the earth and to the ionized strata of air and energy can be transmitted entirely around the earth without wires. The energy could be utilized in any part of the earth by merely connecting to the pair of conductors.

This condition has been recognized for some time, but the difficulty lies in making connections to the upper layer of conducting atmosphere. It is hardly practical to construct towers six or seven miles high for the purpose, then again the energy could not be utilized without using a similar structure at the point of reception, which makes this scheme hardly feasible for aircraft or moving vehicles.

Return then to the ionized stream for radio aerials. We can easily construct arcs that will throw a beam ten or twenty miles. Then why not make connection to that upper stratum with an ionized stream of air? Wonderful in its simplicity.

In Fig. 2 the writer attempts to portray a generating station embodying these principles. In the main building will be housed the generating units for supplying the current to the arc and the primary of the high voltage apparatus for transmission of energy. Supported on the roof of this structure will be a monstrous arc lamp

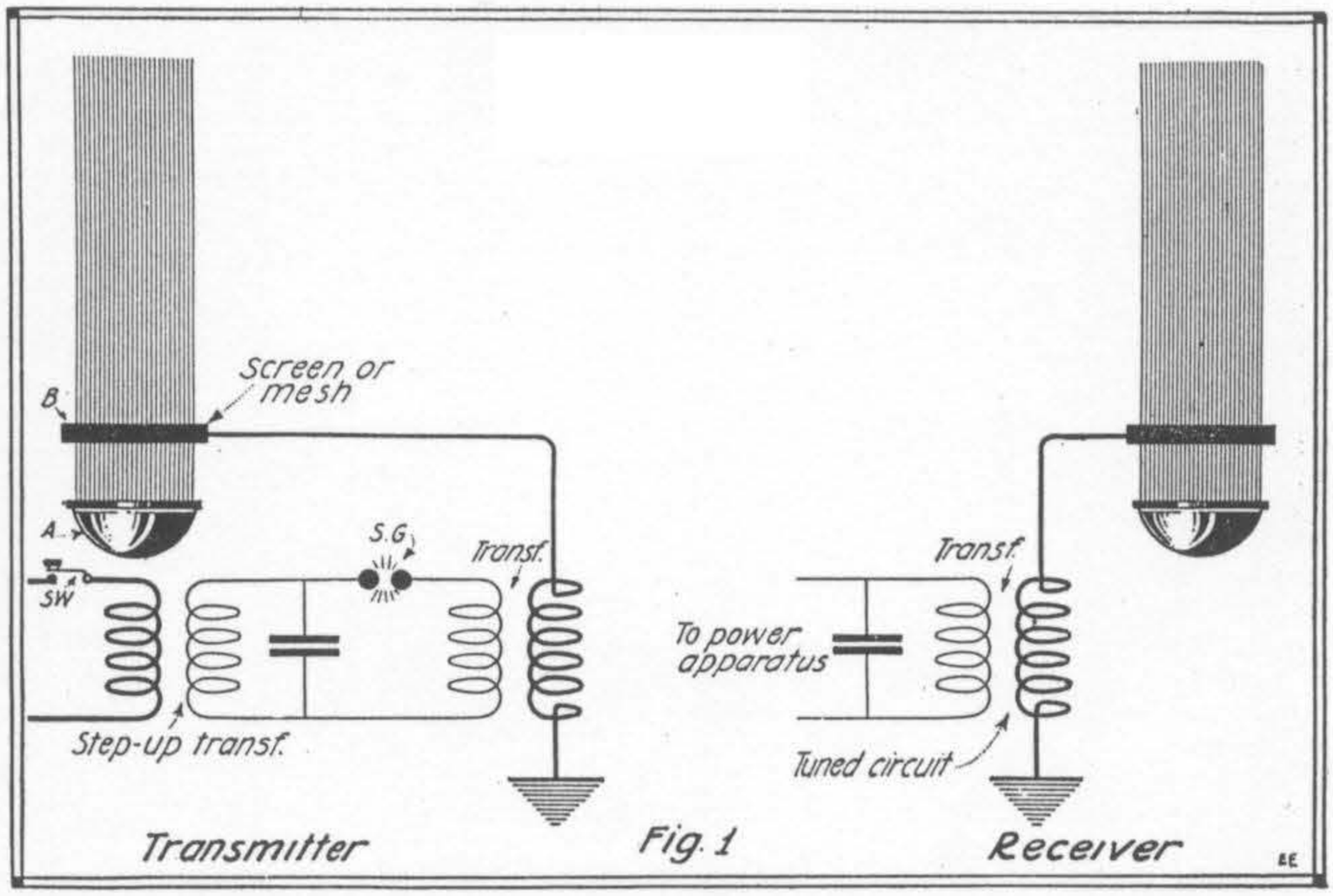


Diagram Showing the Transmitting and Receiving Circuits for the Transmission and Reception of Electric Power by Wireless.

capable of throwing a stream of ultra violet rays for at least ten miles. In this beam is supported a conducting screen to make connection to the conducting stream of ionized air. The insulation of these parts present no great difficulties to modern engineering.

The building will also house a huge step-up transformer, a set of high voltage condensers, a spark gap either of the rotary or quenched type and a huge oscillation transformer or Tesla coil. These instruments are connected in the usual manner and tuned so that the inductance in the circuit and the capacity formed by the earth and ionized upper strata will have a well defined oscillation period.

By these means the whole earth will become an electrified body, energy to be drawn at any point by simply making metallic connection to the earth and pointing a beam of light vertically, a screen being used to take the energy that will flow down the beam. An inductance coil being necessary in the circuit to insure resonance with the transmitter at the receiving set. After once started, the receiving energy can be used to keep the arc going.

Ships will have an arc and reflector mounted on the masts, aeroplanes have two arcs, one on top, the other below, and so on.

This scheme will not interfere with present short range transmission, it being hardly practical for each home to have an arc on the roof when one arc would serve for a town and several for a large city.

Rather its benefit will lie in the utilization of water falls far from civilization, now unused on account of difficulties in transmitting the power hundreds or thousands of miles.

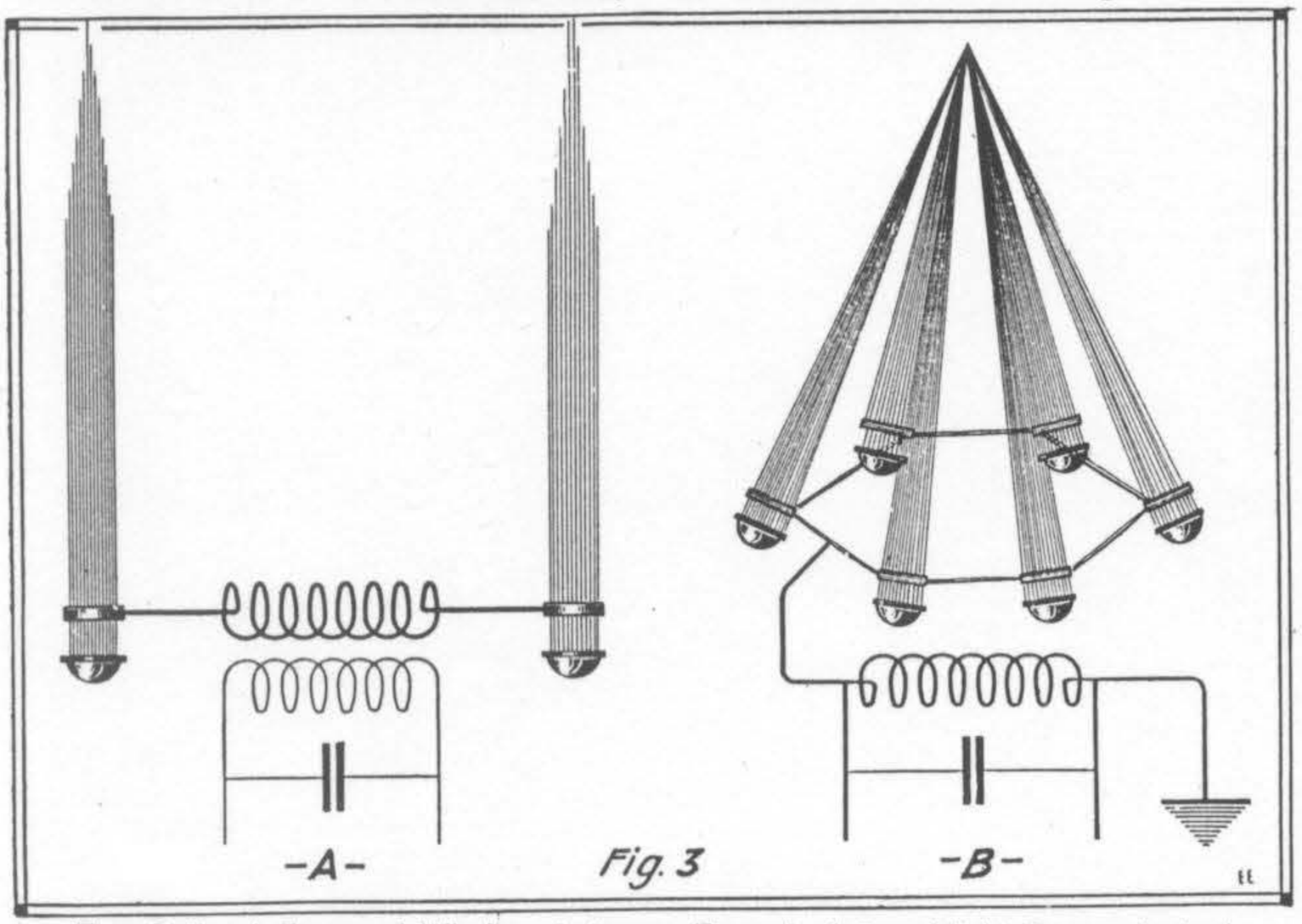
Aside from the transmission of power other advantages may accrue. Will such a stress between the earth and upper air strata reduce the presence of dust particles in the atmosphere? Or, again, cause the immediate condensation of fogs and moisture in the air to give us perfectly cloudless days? Perhaps it will become simply a matter of changing the frequency or voltage of the current to cause rain or to prevent it.

Then the question of effect on radio communication: will it make our present sets obsolete, a transmitter of the future being connected directly to the power set and acting by superimposing different frequencies on the power frequency? Or will radio-telephony work hand in hand with the power system, the voice currents being imprest on the power circuit and filtered out at the receiver?

There are a thousand and one things such an arrangement might effect. Will trees and vegetation increase in growth as experiments in electrical culture would indicate? What effect would such stresses have on germs and bacilli? Their numbers will be decreased by the destructive effects of the ultra-violet light. Will man grow to an unsuspected height and become uniformly healthier due to the electrical treatment he would be constantly undergoing?

And so on—conjecture is without bounds, but the scheme is practical to all appearances; it requires but some financial genius to give it a trial.

And to think it all was within reach such a short time ago! Had Tesla but put a gigantic arc on top of the tower of his experimental station in Long Island accurate data would be at hand now—were it but even a promise it would mean another step towards the final mastery of all matter by man.



Two Optional Forms of Wireless Antennae Formed of Searchlight Beams—Ionized Atmospheric Streams.

Hello Mars!

By H. WINFIELD SECOR

Shall We Ever Be Able to Signal Mars Intelligently?

IN the past ten years, and particularly in the last twelvemonth, there has been evidenced a great deal of activity on the part of scientists in all parts of the world, on the subject of communicating with Mars, or possibly Venus. The present discussion has nothing to do with the astronomical facts of the case, for these are already well known,—at least so far as the distance between the Earth and Mars is concerned, and other heavenly bodies.

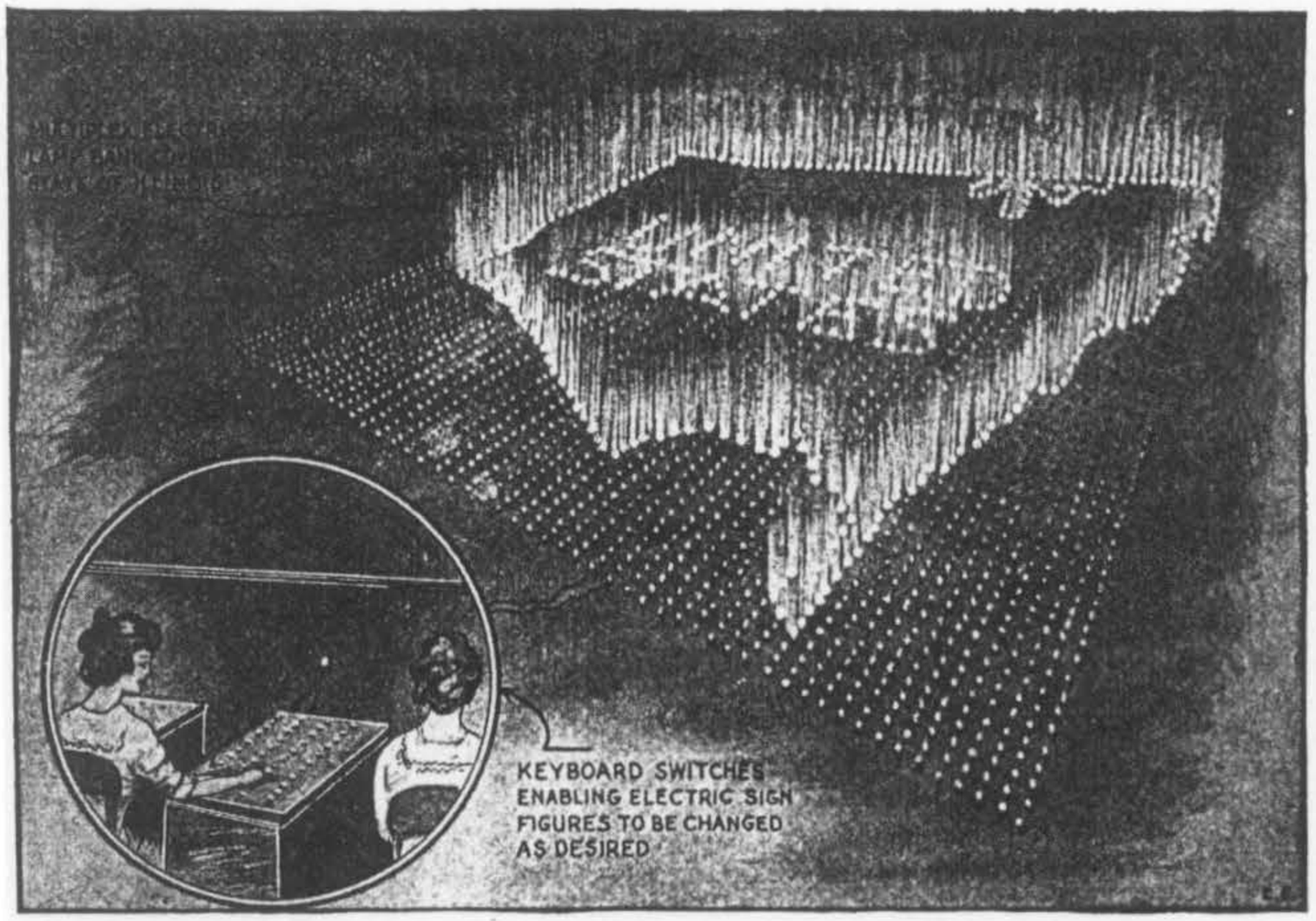


Fig. 7. One Writer on the Subject of Inter-Mars Communication Has Suggested That We Place Lamps, Thousands Upon Thousands of Them, Over a Large Territory—as Big as the State of Illinois—These Lamps To Be Fitted with Quick-Acting Shutters, Electrically Operated. The Lamps Are Also To Be Connected to Suitable Keyboards so That by Depressing a Given Pattern of Keys, Any Design Such as a "Map" of the United States, with the Letters "U-N-I-T-E-D S-T-A-T-E-S" Illuminated Can Be Flashed Out of the Entire Lamp Field as Here Shown, etc. Any Desired Letter or Picture Could Be Flashed on This Multiple Lamp Bank, as Becomes Evident.

The main thing that we do not know about Mars, is whether or not it is inhabited, but we will leave all of the vast and profound theories on the possibility of Mars' inhabitation, to the astronomers and others who are capable of investigating these facts.

So far as we are concerned in the present instance, we will assume that there is such a being as a "Martian". Next, the all-important and preponderant phase of the Mars' inhabitation theory is—how, and in what way could we start picking up conversation or communication with our distant neighbors, intelligently.

It seems quite evident, that once we have outlined and developed the proper method of procedure to start transmitting and possibly interpreting the Martian signals, as well as making sure that our method is correct, that the Martian may, with his supposedly far greater intellectual development, (owing to the greater age of Mars as compared with the Earth,) understand what we are trying to say to him.

It is nothing short of startling to read some of the newspaper details that come from all parts of the world, suggesting the "simple schemes" whereby we can open up communication with a people of whom we know absolutely nothing about. Think of it! Aside from the fact that we have to doubt their very existence, we do not have the slightest conception of what they look like, nor what their language may be!

One of the latest Martian communication converts is Dr. Charles Proteus Steinmetz, probably the world's greatest electrical engineer today, and one of our foremost mathematicians. If anyone should be able to conceive of a scheme for opening up conversation by wireless telephone or telegraph, or other means, with a strange neighbor so distant as the Martians, Dr. Steinmetz should certainly be fully qualified.

Dr. Steinmetz, in a recent statement, said that wireless communication with Mars is not at all improbable, and he suggested that signals might be transmitted by radio from a gigantic wireless plant on the Earth, which would be charged with all the electric power generated in the United States. This could be accomplished for the tidy little sum of about one billion dollars, according to Dr. Steinmetz, and would require steel towers at least 1,000 feet in height, in order to transmit radio messages or signals to the planet Mars,—which never comes any nearer the Earth than 35,000,000 miles, and at certain periods is 230,000,000 miles away. After mentioning the fact that we might accomplish the interpretation, after several years' recording, of the stray wireless signals mentioned by Marconi and Tesla as being picked up in their powerful radio stations, he goes on to say,—"If Mars was trying to communicate with this world, it is doubtful if it would ever be possible to decipher the code, but it would be some satisfaction to know that one planet could send messages to the other, and that intelligent beings were inhabiting the planet from which these messages came. We know enough about Mars to assume that there are inhabitants there," said Dr. Steinmetz, "and as it is a much older planet than ours, its inhabitants ought to be more advanced in scientific and educational investigations."

But—*"It is doubtful if it would ever be possible to decipher the code . . . "*—read that line over!—for it means a whole bookful when you start to really think about it.

A SIMPLE EARTH-MARS CODE FOR NUMERICS.

There is, perhaps, no use of talking about communicating with Mars, or as we said before, with a people of whom we know absolutely nothing, but for the present we will consider that they are duly existing, and that they are, as some of our leading scientists and astronomers have argued,

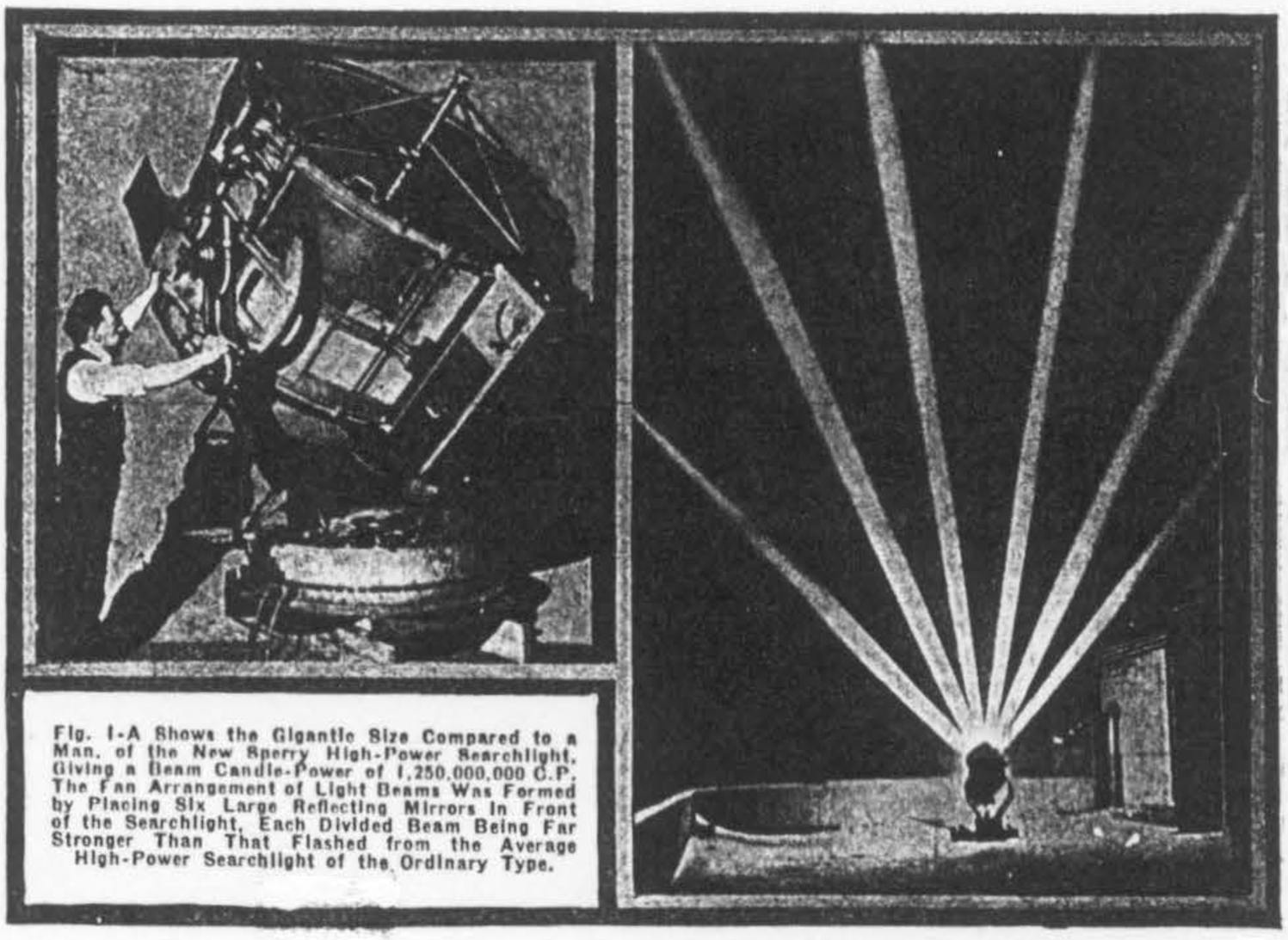


Fig. 1-A Shows the Gigantic Size Compared to a Man, of the New Sperry High-Power Searchlight, Giving a Beam Candle-Power of 1,250,000,000 C.P. The Fan Arrangement of Light Beams Was Formed by Placing Six Large Reflecting Mirrors in Front of the Searchlight, Each Divided Beam Being Far Stronger Than That Flashed from the Average High-Power Searchlight of the Ordinary Type.

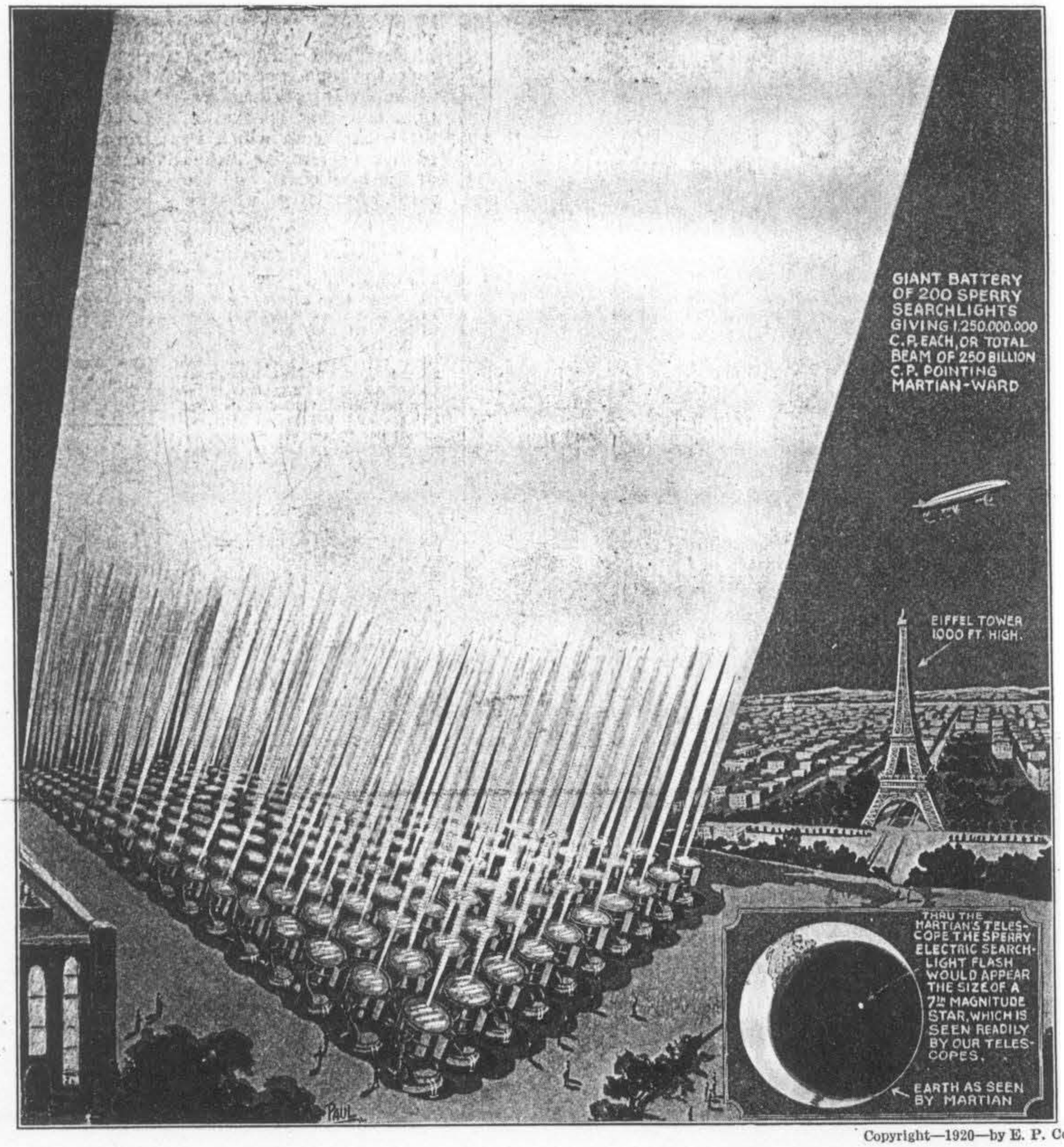


Fig. 1. The Latest Proposal as to How to Signal the Inhabitants of Mars Is That of Mr. Elmer G. Sperry, Inventor of the World's Most Powerful Electric Searchlight, Shown at Fig. 1-A. Mr. Sperry Proposes That We Employ a Battery of 200 of His 1,250,000,000 C.P. Searchlights In One Gigantic Bank, so as to Concentrate Their Rays in One Powerful Beam of Light. It Is Calculated That the Martians, If Such There Be, Cannot Miss This Blinding Flash of Light, Which Would Appear to Them as a Star of the 7th Magnitude, Which Is Easily Picked Up by Our Earthly Telescopes. This Beam of Light, Totaling 250,000,000,000 Candle-Power, Would Rival the Sun Itself.

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thousands of years in advance of us when it comes down to scientific matters including the languages. Probably they have but one language on the order of our rapidly growing universal language—*Esperanto*.

All well and good, but without wasting any more time conjecturing on the ways and means of interplanetary communication, let us start with the fundamentals of the understanding between any two Earthly human beings. To do this, as one professor of languages recently suggested to the writer, we certainly will have to step back to the period when we were little children. Go straight back to the days of the kindergarten, and then we are ready to start learning the real fundamentals of communication and understanding via the language route between humans. But before going further, we might take a glance at Fig. 2, which shows the simplest scheme for teaching or endeavoring to communicate to another person, the elements of numeric computation.

Fig. 2 shows that two dots, plus two dots, equal four dots. Little children are often taught in this way by several different schemes, how to count. Some of our ablest scientists and astronomers have suggested times beyond number, that this is a very good and plausible way to start communicating with the Martians, and not only this, but they often carry this idea to the point where it is claimed that eventually languages or codes explaining the languages may be transmitted and interpreted either by us or by the Martians.

It takes but a little reflection to see that, while presumably and with average intelligence no greater than ours, in a short time a person who doesn't know our language at all, should be able to perceive if shown a blackboard with this arrangement of dots, that we were trying to impress upon him the fact that two dots, plus two dots, equal four dots. Well and good, but when it comes to communicating letters or words of a language by this method, it would seem to be quite impossible, and altho the writer has discust this scheme with several experts on languages, they have not been able to think of a single method whereby it could be carried out.

So we go back once more to the little children in the kindergarten class. We will

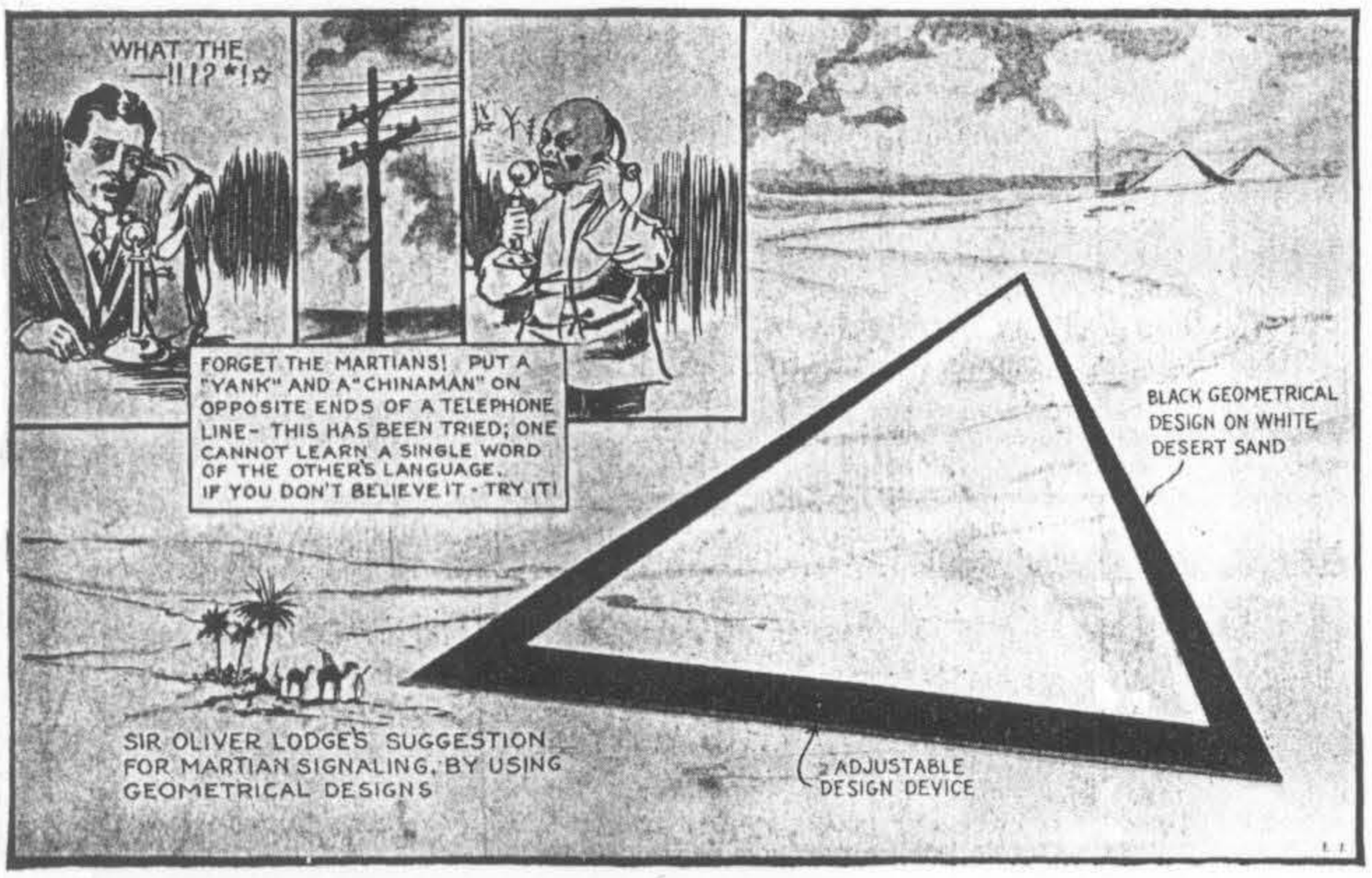
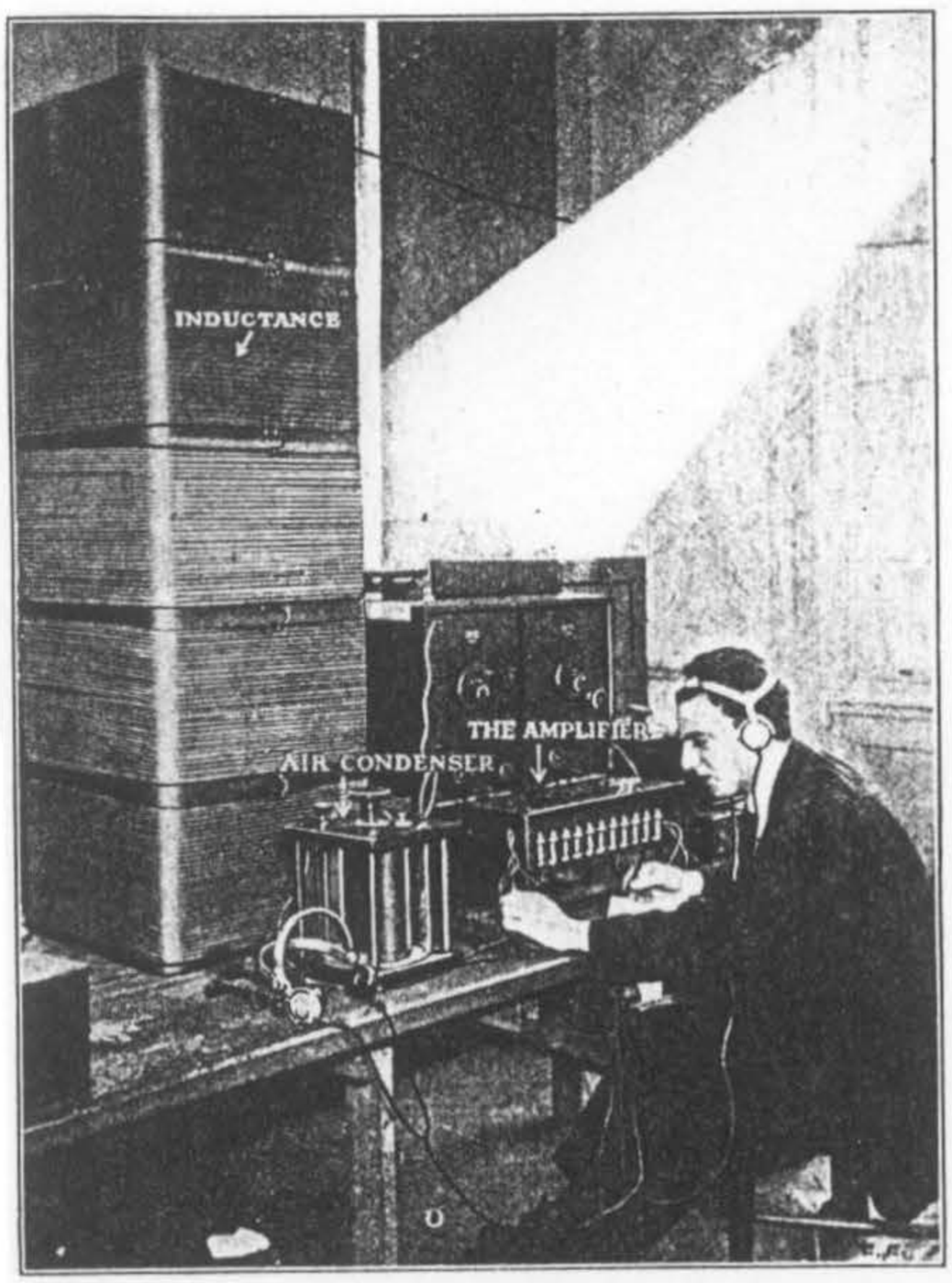


Fig. 5 (Inset). You Do Not Have to Endeavor to Open Up Wireless Telephone Communication with the "Martians" In Order to at Once Perceive That You Have "Started Something"—so Far as It Is Possible to "Talk," or for That Matter If It Would Ever Be Possible for You to Learn Even One Word of Martian. The Experiment of Placing a Chinaman and a Yankee on Opposite Ends of a Telephone Line Has Been Tried for a Considerable Time Period, and Neither One Could Assimilate or Interpret one Word of Each Other's Language, Altho They Talked Long and Often, Over the Telephone. Fig. 6. Sir Oliver Lodge Suggests That We Build Large Geometrical Figures in Black on the White Sands of the Sahara Desert, and He Believes That the Martians Will Understand It, as Geometry Is a Universal Study and Science.



And Wonder of Wonders!—Here Is the Very High-Powered Marconi Radio Station at Which the Mysterious Dots and Dashes Filtered In from the Ether—and Furthermore These Signals Are Believed by the Great Marconi Himself to Quite Possibly Be "Signals of Inter-Communication" Hurled at Us Thru Millions and Millions of Miles of Interstellar Space, Via Wireless, by the Martians. At Left We See the 100,000-Meter Wave Inductance. At Right the Wonderful Eleven-Stage Audion Amplifier, Magnifying the Signals 10,000,000 Fold.

leave numbers out of the question, because we cannot carry on a conversation very well with a set of figures,—or at least we will presume that this is not the case with the Martians. How is a child taught the letters of the alphabet and their final correlation into words,—and again,—the meaning of these words?

When you have thoroly philosiphized on this elemental detail of pedagogy, you at once become cognizant of the highly important fact that the little child who does not know anything about the language he is to be taught, cannot tell what such a simple word as "R-A-T" means. He can be taught the sounds of the letters of the alphabet so as to pronounce them—and also how to write them—but as soon as he has finished with this, think of asking him to define the word "rat"—a simple three-letter combination. Now, it is at once evident that the child has no more idea of what R-A-T means or stands for than the wood tie-post to which you hitch Old Dobbin—except for one potent and all-important consideration, and that is—that in the books from which he studies or else by means of the blackboard and the skilled artistry of the teacher, *he is shown a rat*, or possibly he might be shown a live one in a cage, or a dead one—but in any case he does two things when he first learns the meaning of any word, in this case "rat." He is first taught to pronounce and how to form the letters of the word in writing, and then he is shown simultaneously in some form the object which the word represents.

Some one may object at this point and say it is not so in every case that an object representing the word *is shown simultaneously* with the mastery of the word, but the answer is that if this is not done, then the teacher or the governess will have to launch forth on a lengthy *word-picture* explaining about the *rat*, let us say, and what it looks like.

This basic element of learning any language is more forcefully shown at Fig. 3, where there is also shown what we shall call, for the sake of supposition, a real Martian word, G-O-U-K-A! Now just consider for one moment—no matter how familiar you may be with secret codes and ciphers—and try to think how you would look this *first Martian word* squarely in the face and endeavor to understand what object it represents! Does it represent a sea? Does it represent a house?—or a Martian horse?—or does it mean a declaration of war between two Martian nations—and so on and so forth.

Consider that the writer is a Martian and that thru your powerful earthly telescope some dark night you are confronted by a burst of light from Mars and upon directing your telescope more minutely and accurately towards this illuminated spot on the distant planet you read in outlines of fire this word. There is no use of taking any other words, for this one serves its purpose

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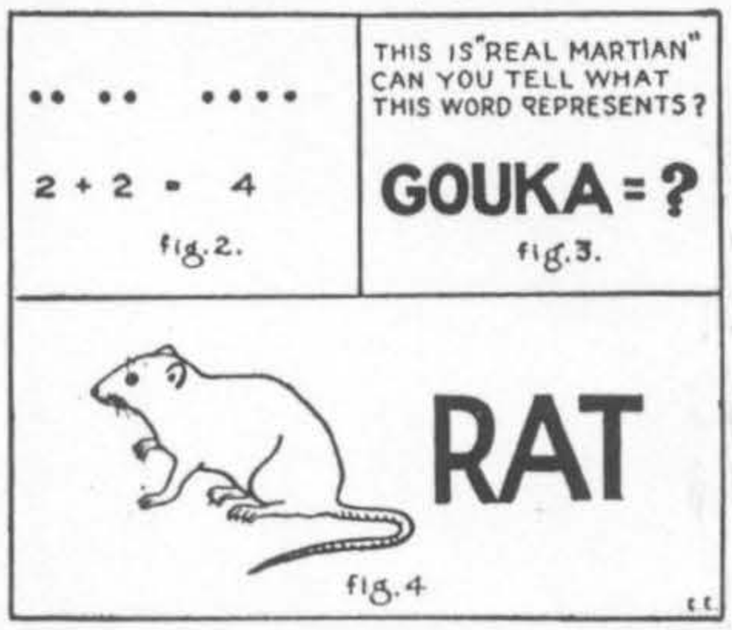
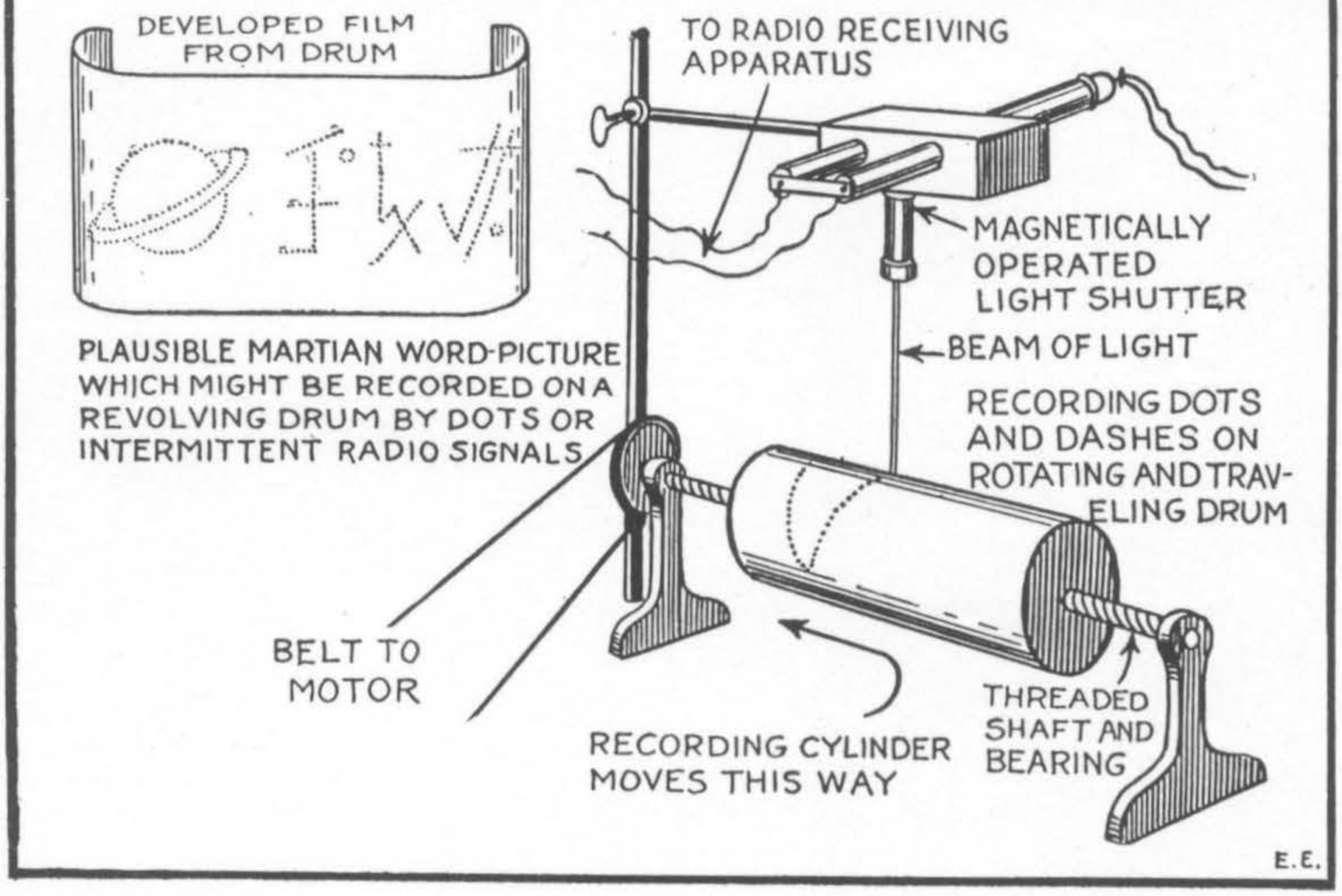


At Fig. 2 We Have the System—Commonly Advocated For Opening Up Communication Between the Earth and Mars by Means of Signals Sent by Light, Radio, etc. This Is to Give the Martian to Understand That We Earthians Count Two Dots Plus Two Dots as Four Dots. It Is Conjectured That In a Short Time We Can Thus Inter-Communicate Very Nicely with Our Martian Neighbors. If You Think, However, That Such a System as This Will Eventually Lead to Inter-"Language" Communication and Understanding, Try and Dope Out What the (Assumed) Martian Word "G-O-U-K-A" Means. Fig. 3. In the Next Issue We Will Tell You. Fig. 4. The Most Logical Method of Establishing Any Inter-Language Communication with a Strange People, Such as the Martians, Surely Seems To Be by Means of "Word Pictures," Such as Shown Here, Flashed or Otherwise Transmitted Simultaneously, in Such a Manner That the Picture Can Be Built Up. Otherwise, if the Martian Received the Letters R-A-T by Radio and Could Understand Them, but Did not Know What Our Animal the "Rat" Looked Like—He Would Have Some Tall Difficulty in Trying to Find Out What R-A-T Meant, Granting, of Course, That He Knew Our Alphabet—For the Chances Are That Animal Life Is Different on Both Planets.

The Mysterious Stray Wireless Signals Which Have Been Recorded by the Marconi Trans-Atlantic Station, May Have Some Meaning Which We Do Not Understand as Yet. It Has Been Suggested by One Authority That Possibly if We Have the Proper Apparatus or Scientific Means For Interpreting These Apparently Meaningless Jumbles of Dots and Dashes, That We May Cause Them to Produce a "Picture." Suppose, For Example, That You Had a Revolving Drum Which Was Moved on Its Axis and Covered with a Photographic Paper or Film. If the Incoming Radio Dots and Dashes Were Recorded on This Drum, They Might Possibly Form a "Picture and a Word," Probably in Martian. If We Were Able to Obtain a Considerable Number of These Word Pictures We Could Eventually Figure Out What the Martian Alphabet Is. Fig. 8.



Hello Mars!

By H. WINFIELD SECOR

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well, and it is not formed of any earthly combinations or codic conjugation with which you are familiar. Can you imagine what your first effort would be towards solving this problem?

For the moment we may even consider that you have at your disposal even the interplanetary wireless telephone, but of course in its infancy, so far as communication with the Martians is concerned.

Is it not a most interesting philosophical conundrum to try and think just what you would do in this case? Would you try to talk to the Martian and encourage him in the English tongue in your endeavor to find out what the word "gouka" meant? Or perhaps, if you are a linguist of high attainment, you might possibly try talking to him in several different tongues, of which there were at the last count, 420 different species on the face of the earth.

But we won't keep you guessing any longer, because we know you will undoubtedly tire of this reasoning, and in the next issue we shall tell you what this (supposed) Martian word means.

Looking at Fig. 4 once more, take a piece of paper and cover up the little animal at the left of the word r-a-t, and just imagine what a quandary you would be in upon your first sight of the word *rat*, even tho by long and patient study you had learned the outlines of the letters and knew that they constituted elemental parts of a certain language,—it matters not which one. Remember, the Martian could not talk to you, even tho he had a wireless telephone transmitter which reached the earth, because he does not know your language. And how are you going to ask the Martian in a language which you know nothing about what the word means, and what is still worse, how would you know the proper pronunciation of the word? The answer is, you *could not!*

But supposing that after you had been looking at this word for a long, long time, that suddenly one night an outline appeared alongside of it of an animal that looked like a rat! In other words, remove your piece of paper from over this part of the illustration on the left of Fig. 4 and lo and behold! you at once perceive that R-A-T equals a rat. All your difficulties have been swept away instantly.

And so it begins to look as if the only logical method by which to start a communication with the Martians in either direction is by means of *words and pictures.* This method is not entirely new, for several of our foremost astronomers have made this suggestion; but in the latest outburst from our radio and other communication experts, who are talking of sending radio or flash-light signals to Mars, or, in other words, dots and dashes of the Morse code, forming letters of a language which *we* know,—the homely philosophy and simplicity of the kindergarten rule have been entirely forgotten, it seems!

Picture yourself standing opposite a man whom you never saw before and whose language bears no similarity whatever to yours, and that by means of a semaphore or by a wireless instrument or perhaps a telegraph sounder, he starts shooting dots and dashes at you! Suppose the dots and dashes correspond to letters in *his* language. Can you by any stretch of the imagination conceive as to how you are going to interpret these dots and dashes and finally ascertain what in Sam Hill he is driving at?

(*Continued on page* 1304)

Hello Mars!

(*Continued from page* 1302)

It is of course evident that as aforementioned, and granted that both parties have average intelligence, most likely one can make the other understand numbers from zero to nine, so that number combinations could be transmitted and interpreted—but think of hearing for the first time or, for that matter, a thousand times, a string of five dots and five dashes of the Morse code. In the other *man's* language it might mean "d" or "h" or "z" and again it might mean a house or a cat-boat or a three-ringed circus, for all you are concerned.

HOW DO WE LEARN FOREIGN "EARTHLY" LANGUAGES?

It is common to hear people say: "Why, that is easy,—when they happen to overhear a discussion of interplanetary language communication,—"If this is as hard as it sounds," say they, "then how do you account for the fact that a Frenchman readily learns German, or a German learns Dutch?" And yet it is commonplace! Very true, it is a common, ordinary everyday occurrence, but did you ever really stop to think about it at all, and how it takes place? Several very important and peculiar things happen when you learn a word of a foreign language. Supposing you are an American and that you visit France, let us say.

As you leave your ship and take a railroad train for the great city of Paris your attention is suddenly arrested by a large electric sign erected on a tall building. Remember, now, that you do not know a word of French, and assume that all of those around you knew not a single word of the English language. How would you find out what the illuminated word meant?

Possibly, if you nodded your head in the direction of the display a sufficient number of times to make the Frenchman near you eventually awaken to the fact that you were in doubt as to the word on the sign, he would make some bodily motion to give you some inkling as to what the word meant. But unless you happened to live to be so old that you could look thru a marvelously high-power telescope a couple of thousand years from now, which would magnify the Martian himself, so that you can see his bodily movements, then it is evident that you are going to have a merry old time finding out what a similar strange word, if presented to you in the form of illuminated letters on Mars or otherwise could mean.

While speaking on the subject of how we assimilate the language of another nation, it should be remembered that never do we learn a word of a strange tongue and its full meaning *unless we see in some way or other a comparative picture of what the words means.*

The American Doughboys in France picked up many French words. Of course they did, why not? The French man or woman would show him a bottle or cup, or saucepan or stove and utter at the same time the French word. Naturally, as he is an intelligent being, he will know that the particular word uttered in each case represents the object which was shown him.

So once more we see that it is in every case the simplest and the shortest method and in fact the *only logical method* whereby to teach the language of one nation to the other,—that is, by *words and pictures* simultaneously, or by a similar and equally clear illustration.

Another very important element in interlanguage relations is the fact, particularly in Europe, that there are a dozen and probably several dozen different languages, so-called, which have a very large number of common generic roots, and this explains all

(*Continued on page* 1306)

Hello Mars!

(*Continued from page* 1304)

the more clearly how it is, for example, that an European comes to America and tells you he speaks six or eight languages, or possibly ten. Of course he can do it, and so would you as an American, if you were continually thrown in with people of other nations as the people of Europe are intermixed, some of the countries being very small, and if the languages of these different peoples had numerous generic roots similar to your own. But when you meet one of these high-brows ask him if he speaks some radically different tongues, such as English, Chinese, Eskimo, Indian, Russian and Turkish, which have no similar generic roots. That is another story, you can bet!

HOW A CHINAMAN LEARNS ENGLISH.

Fig. 5 shows an interesting case right in line with the would-be Martian conversationalist's theories. This experiment has actually been tried out as a professor of languages explained to the writer, and shows just what he has always contended,—that, lacking a picture or verbal description together with a word of a strange language, or else some other visual effect, such as a motion of the body, jerking of the head, or pointing of the finger, etc., that it is practically impossible for two exponents of two radically different languages to interpret a single word of what the other is talking about.

The illustration at Fig. 5 shows how a Yankee and a Chinaman were placed on either end of a telephone line. This happened some years ago in the South Pacific Islands, where the linguist aforementioned was stationed at the time, and this gives a very good illustration of what we have been talking about, as the two languages are widely separated and have no comparisons in common. If you think they have, go into the nearest Chinese laundry and get John the Chinaman to wish you a "Happy New Year" or some equally plain or well-understood salutation in his native tongue. !**!!-?-* Would you *ever* recognize it?

Well, to make a long story short, the "Yank" gabbled away at the telephone at his end of the line—and the "Chink" did likewise. They kept this up for a good many days, in fact for several months all in all, and the sum total of all this talking and wasting of dry batteries,—not to mention the time which might have been enjoyably spent fishing on the coral shores,—was *NOTHING!*

Very few linguists have attempted to learn Chinese, but that language is no more difficult for a moment than trying to learn *Martian;* for you can go to China (if you have the price) or for that matter get acquainted with a Chinaman who speaks English, right in New York City or your home town, and after spending several months in special sessions with him you will perhaps have an idea of a few (?) Chinese words. Some languages are simple and some not so simple. Ours is fairly so, and the Chinaman thinks his is first class, altho his children spend the greater part of their lifetime mastering its intricacies.

There are about 16,000 different signs used in the Chinese language to indicate the different objects. If you want to write the word house, you make a sign like this  and if you want to become a real high-class Chinese college man, you must learn over twice this number, or 40,000 signs each signifying a different object. Suppose the Martians have such a language? How do we know? We don't; and even with word-pictures it would be a slow job, for their objects might not be familiar to us.

WHAT THOMAS A. EDISON AND SIR OLIVER LODGE SAY.

Thomas A. Edison believes, according to a recent publisht interview, that contrary to the contentions of many eminent radio scientists, the Heaviside *ionization layer* in the upper atmosphere of the earth would prevent earth-borne radio signals from passing out into interplanetary space—that these earth-borne radio signals would be propagated into interstellar space for hundreds of thousands of miles by means of the ether waves, and that it is possible that the Martians, if there are such beings, had received these signals, altho they might not have the slightest idea as to what they might mean.

As he jocularly remarked in an interview at the recent celebration of his seventy-third birthday, and granting that the messages radiated by our powerful trans-Atlantic radio stations had reached such distances as Mars, how do we know whether they are received or impinge upon a *human* or a *chimpanzee?* It is the opinion of the writer that the stray signals to which both Dr. Marconi and Dr. Tesla refer to, as having been heard in their long-distance radio stations from time to time, are either signals from unknown distant stations or else they are static disturbances caused by disturbances of the electrical equilibrium of the atmosphere, or possibly of the earth itself.

Now that everyone in the scientific world is taking a crack at the interplanetary communication game, Sir Oliver Lodge, the well-known British scientist now touring the United States, made the following suggestion:

"Nonsense," said he, when asked if he thought it possible to communicate with other planets by *wireless telegraphy.* "It would be possible to place an immense geometrical figure, say on the Sahara Desert and then, if the inhabitants of Mars are of a high order of intelligence, they may be able to distinguish the figure and determine that it had been the work of man. Geometry is a universal science, and it is not unlikely that if they are of a higher order of intelligence than we that they can interpret the gigantic figure as an effort at communication." (See illustration, Fig. 6.)

"ILLUMINATED WORD PICTURES" FOR THE MARTIANS.

A writer in the *Western Electric News* recently made the following suggestion which seems almost comic and, in fact, tragic, when we come to figure the bill, but still it has the essence of sound logic in it, when it comes down to real Earth-Martian intercommunication. He suggests that we take a large piece of ground, such as the whole State of Illinois, and install upon this nice flat piece of ground several million 1,000 candle-power flood lights fitted with reflectors and shutter attachments. These, of course, would all point sky or Martianward, then he continues: "Choose a dark night and start the flood-lights working. I would suggest that a complex net-work of shutter control circuits he hooked up with some automatic printing telegraph machines, so that by shoving a piece of perforated tape thru the automatic transmitter the whole set of lamps could be illuminated in any pattern desired

"For instance, an outline of the United States could be shown by the lamps (see Fig. 7 herewith) and at the bottom *huge letters, about three miles long,* can spell out the words 'U-N-I-T-E-D S-T-A-T-E-S.' By the aid of their modern ultra-powerful telescopes, the scientists on Mars can or should see at a glance what we were driving at, and it would not matter whether they saw the period mark or not."

SPERRY PROPOSES 250,000,000,000 C. P. MARTIAN TORCH.

And now comes a proposal by Elmer G. Sperry, inventor of the world's most powerful electric searchlight, shown in the accompanying photographs, to utilize a battery of 200 of his 1,250,000,000 C. P. searchlights in one gigantic bank and to concentrate their rays into one powerful beam of light, which it is figured that the Martians cannot miss. It is claimed that this flash of light would be visible on Mars as a star of the seventh magnitude, which is easily picked up by our telescopes.

The accompanying photographs were taken on the roof of the Sperry Gyroscope Company's factory in Brooklyn, New York, and certainly shows in a very interesting manner the great power of this most powerful electric searchlight ever built. Two hundred of these searchlights would give a total candle-power for Martian signaling of 250,000,000,000—rivaling the sun itself.

The fan arrangement of light beams in one of the photos was formed by an arrangement of six large reflecting mirrors which produced a very brilliant and spectacular effect, as will be seen. See Figs. 1 and 1-A.

MYSTERIOUS DOTS AND DASHES MIGHT FORM MARTIAN PICTURE.

Mr. H. Gernsback has suggested that if the proper interpreting apparatus was brought into play, that the mysterious dots and dashes received on the radio antenna of the Marconi station, and also those cited by Dr. Tesla, might yield some very surprising results. In other words, if these were recorded, as for instance by a light beam controlled by a set of magnets connected to the radio receiving apparatus antenna as shown at Fig. 8, on a sensitized photographic cylinder, fitted with a threaded axle or shaft, which would cause it to move longitudinally as well as rotatively, past the fluctuating light beams, that when this was unrolled from the drum there might be developed a word-picture or such as we have shown in Fig. 8.

Now, there is nothing startlingly novel about this apparatus. As a matter of fact it has been used about ten years ago for the transmission of pictures by radio and considerable success was had with this method. The pictures can be transmitted entirely either by dots or by dashes —it makes no difference which, and a minute's consideration will show that with a transmission of this kind no regular sequence of the dots or dashes is feasible or even possible.

In other words, the time element between the succeeding dots or dashes all vary and will never be alike. Due to these differences in time between succeeding signals, the radio picture is built up.

As Mr. Gernsback points out, were the Martians to send us such radio pictures, they would probably first pick out some astronomical fact, as for instance the planet Saturn with its rings. Alongside of this would then appear the symbol in the Martian language whatever they might be.

This is shown in our illustration, Fig. 8. If the Martians were to send us pictures such as these, extending over a number of months, it would be very simple for anyone versed in deciphering foreign languages to become acquainted with the Martians' alphabet or language, as the case might be, and very soon we would master the language without much trouble. By this method the Martians could show us how they transmitted the messages to us, and we in turn could then follow suit and answer back by a like method.

This idea was prompted by the fact that it is apparently almost impossible for us Earthians to interpret intermittent signals such as dots and dashes or short and long flashes of light hurled toward us by another planet, into intelligible language—and as the Martians are supposed to be far more intelligent and more scientifically developt than we, it is possible that some such scheme as this may be eventually worked out by our scientists. Many wonderful things have happened in the past twenty-five years and in the past one hundred years there has been a greater advance in science than in all the centuries that went before.

SOME OTHER OPINIONS.

Dr. James Harris Rogers, of Hyattsville, Maryland, the well-known inventor of the underground and underseas wireless, has recently announced that he is preparing to set up delicate radio receiving instruments in his laboratory capable of responding to signals up to 150,000 meters wave length. This is said to be 50,000 meters greater wave length capacity than that used at the Marconi station, where the mysterious signals have been noticed by Marconi himself and which he believes to have come from some far distant planet—such as Mars.

In a recent interview Dr. Nikola Tesla had the following to say: "That the planets are inhabited is a foregone conclusion. I believe that the time has come for a serious attempt in the direction of interplanetary communication. We can begin by erecting a plant for transmitting the signals conveying the knowledge of numbers, which would be the simplest truth that could be communicated to the Martians or other worlds' inhabitants, and which would be answered immediately if the planet is populated by a race as civilized as ours. Once the first step is successfully carried out, it would then be very easy to install more elaborate apparatus *for the transmission of pictures,* by means of which the most intricate thoughts can be communicated."

Another writer on interplanetarian communication, believes, like Sir Oliver Lodge, that geometric figures would be very plausible as the first stepping stone to open up relations between the earth and the Martians, and the sponsor of a very interesting theory, Mr. J. G. Carter of Clifton, Ohio, puts forward the suggestion that the snow flakes which fall during our winter season may even be influenced in a positive manner by agencies controlled by the inhabitants of other planets, such as Mars. This theory is based on the fact that there is a very large number of different geometric designs assumed by falling snow flakes.

In closing, we may very well take a few moments to digest some remarks of an interested reader, Mr. Martin C. Hansen, on the subject of communicating with Mars.

"From some recent newspaper clippings I have noted the following statement: 'Some wireless experts believe we shall soon be able to exchange wireless messages with such planets as may be inhabited.' YEH! says I. And again, one article claims Venus to be a 'younger' sister of the earth. Well! well!

"Now, if Venus is so much younger than the earth, then we must also concede its race of inhabitants are also younger, both in nature and inventions. If this is true then we may have to 'feel' *them* for radio signals for generations to come, before we can hope to get any answer. And just as Martians are supposed to have done the same thing with us for hundreds, if not thousands of years; so will we have to keep on signaling the Venerians.

"To return to the subject of intellectual Martians. If the Martians are so much wiser than we by a million or more years, *then they have NOT tried to wireless us for the past thousands or more years,* as they certainly ought to have telescopes and other instruments to actually ascertain what we are doing along the line of inventions and mechanics, etc., and they would not be such fools as to signal us, *when they would know we had no instruments of any kind to record their signaling.*

"If Venerians are a million years younger than we (if we knew this to be true), then we are certainly the most consummate fools in believing we can send messages to them because they are as yet the lowest cave men of the stone age."

Technical World Magazine April 1920

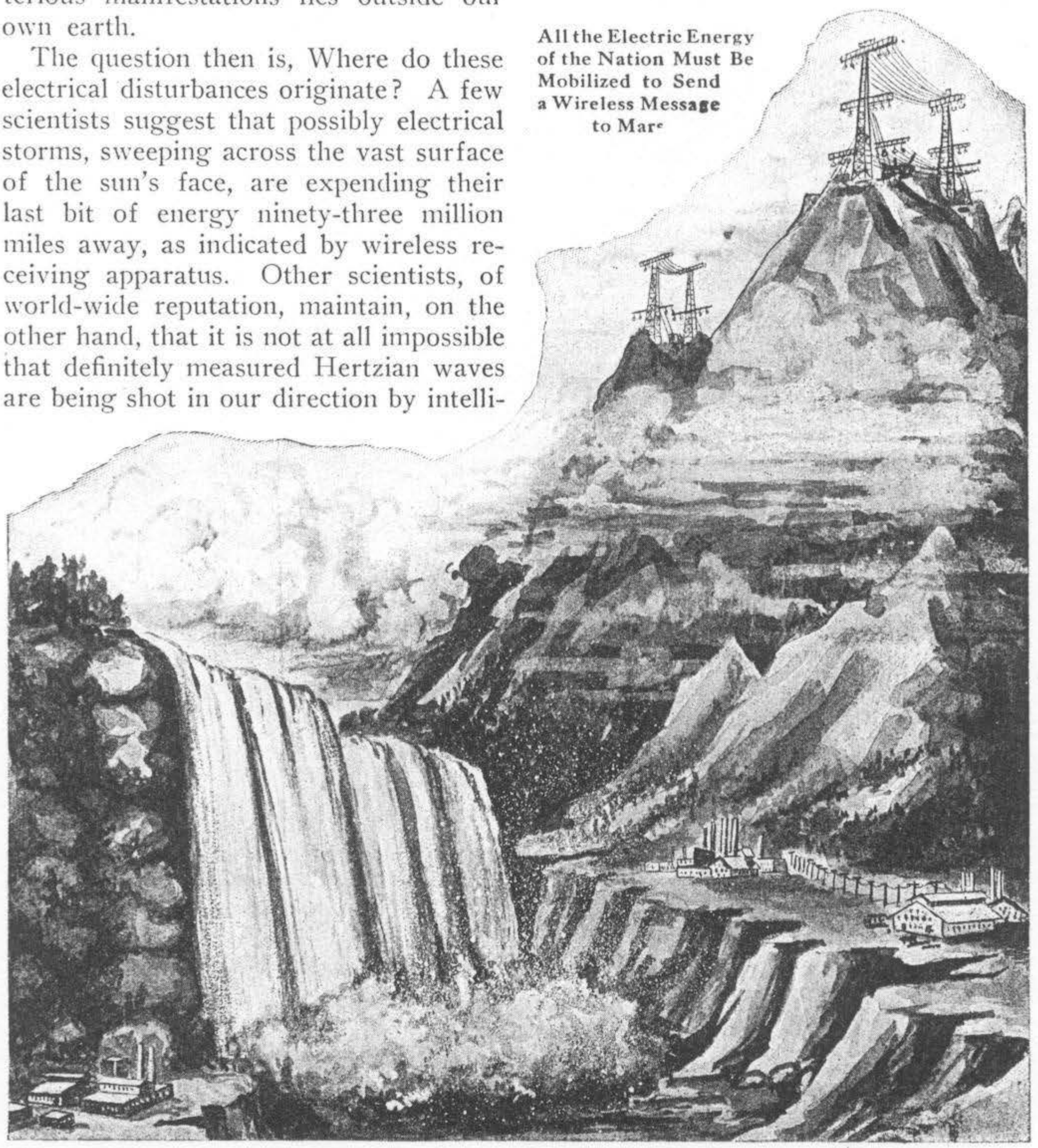
CAN WE RADIO A MESSAGE TO MARS?

By THOMAS WALLER

THE news that certain disturbances are affecting radio receiving instruments on both sides of the Atlantic has given rise to the hypothesis that some other planet is signalling us. There seems to be no question in the minds of scientists, who have considered this phenomenon, that the source of these mysterious manifestations lies outside our own earth.

The question then is, Where do these electrical disturbances originate? A few scientists suggest that possibly electrical storms, sweeping across the vast surface of the sun's face, are expending their last bit of energy ninety-three million miles away, as indicated by wireless receiving apparatus. Other scientists, of world-wide reputation, maintain, on the other hand, that it is not at all impossible that definitely measured Hertzian waves are being shot in our direction by intelligent beings of another planet in a tremendous attempt to communicate with us. If the latter are right, it is probably from either Mars or Venus that this spectacular feat of the ages is being attempted in this age of wonders.

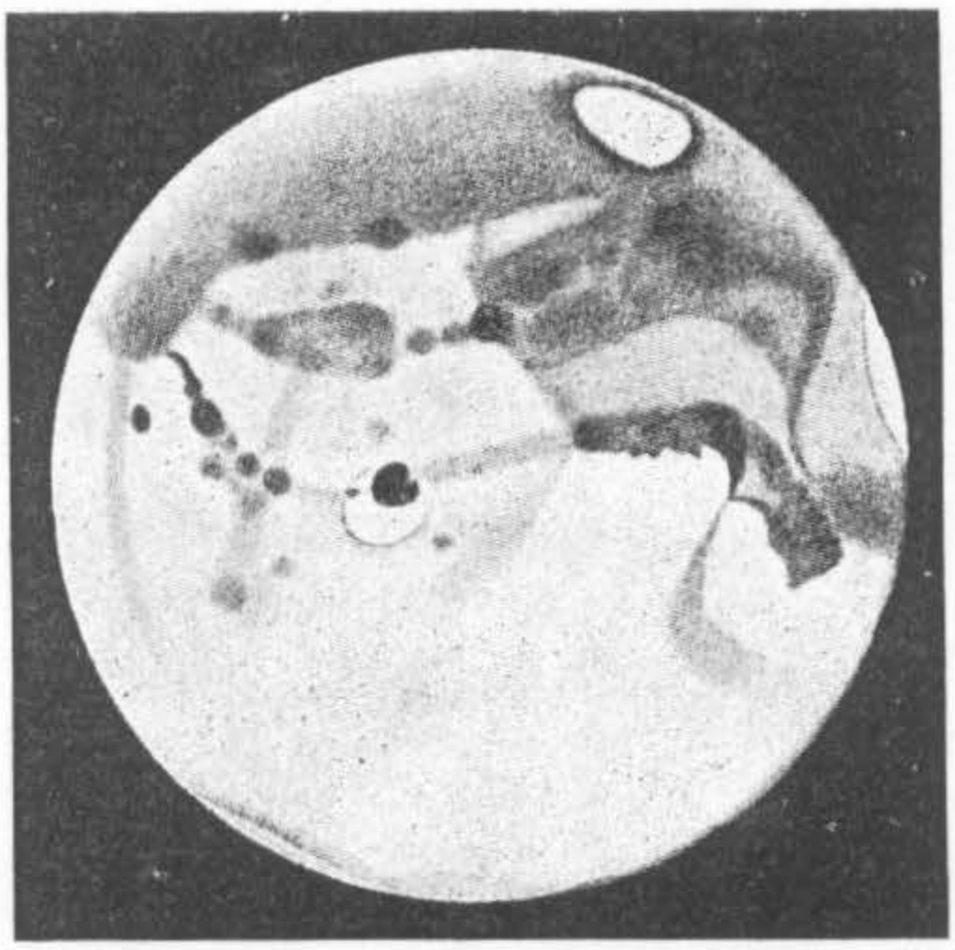
Scientists as well as the general public have a tendency to give credit, if any is



All the Electric Energy of the Nation Must Be Mobilized to Send a Wireless Message to Mars

due, to Mars. This may be partly explained by the fact that the late Percival Lowell, one of the world's most distinguished astronomers, gave wide publicity to the idea that the series of lines that cross the face of Mars may be a system of canals dug for irrigation purposes.

On the other hand, astronomers, on probable grounds, deduce the belief that it is hardly likely that animal life could exist on Venus. Its atmosphere is nearly twice as dense as that of the earth. Being much closer to the sun, it is estimated that it receives nearly twice as much light and heat as do we. With its greater density of atmosphere, combined with the greater heat, it is probable that water exists there only in the form of dry steam. This situation is not conducive to human life as we know it.



How Mars Looks on the Photographer's Plate

However, Mars, from the viewpoint of an Earthian, has distinct disadvantages as a place of abode. Its mean distance from the sun is over one hundred and forty million miles. The atmosphere is very thin, and the climate must be quite cold—at least the greater part of the time. Its inhabitants, therefore, would have to have tremendous lung capacity in order to take into the system enough oxygen from the rarefied atmosphere. Astronomers further believe that the water on Mars dries up rapidly, and that it is from the ice caps at the poles of the planet that water is obtained during certain periods when this ice begins to melt. Professor Percival Lowell maintained that the Martians ran canals across the planet from these ice caps in order to obtain the melted water for irrigation purposes in the arid regions of this planet.

A race overcoming this tremendous handicap of environment must be very well organized and efficient. This presupposes intelligence of the highest order.

In speculating upon the source of the electrical disturbances that radio operators on two continents have noted, we have reason, therefore, in giving Mars favorable consideration.

It has been suggested that in the interest of pure science and, better still, to satisfy the great curiosity of the beings of our sphere to penetrate some of the mysteries of space, we should attempt to reply to these supposed signals with others similar in kind. Physicists tell us that it would be possible to generate and hurl into space vast Hertzian, or wireless, waves that would drive as far as Mars. Indeed, relatively speaking, it might not prove as great a task to communicate in this manner through space as it has been found to communicate between two wireless stations at considerable distance on the surface of the earth.

It will be remembered that the German gun that bombarded Paris from a distance of approximately seventy-five miles accomplished its feat because of its high trajectory. Its shell reached as its zenith a point several miles above the earth's surface. Thus, before it had lost its tremendous momentum, it escaped somewhat the pulling effect of the earth and the resistance offered by the greater density of the atmosphere close to the surface of the earth. In the same way giant Hertzian waves might be shot up and out, which would quickly pass into the nebulous ether of space where resistance

to their progress would be relatively slight.

Yet, even under such favorable conditions, by the time the electrical energy had passed through the many millions of miles that lie between Mars and the earth, probably not one hundred-millionth part of its initial energy would remain. All that would be necessary, of course, would be enough to operate the receiving wireless apparatus of the Martians.

If the same set of signals were thus sent through space at a given time every day for a definite period, the Martians would then know that their signals were being responded to, and that intelligent beings actually inhabit the earth. We can imagine what excitement this would cause on Mars, and doubtless they would endeavor to answer in exactly the same way so as to let us know that our messages were being received.

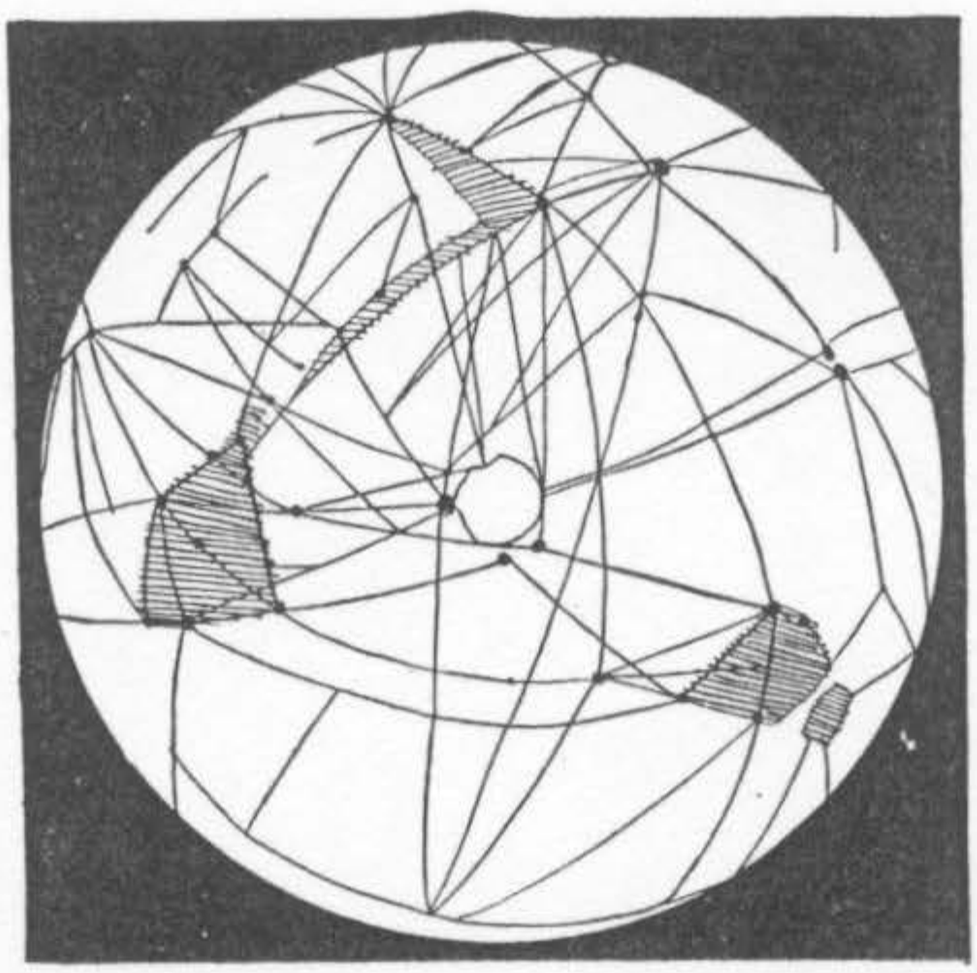


Diagram Showing the Curiously Regular Lines—Supposed to Be Canals—That Cross the Face of Mars

Why, if conscious beings are attempting to communicate with us, we have not yet noticed any regularity in the signals affecting our radio apparatus is not clear. It may be due to atmospheric conditions, just as atmospheric conditions here frequently interfere with the transmission of messages between two of our wireless stations. However, we can readily believe that if we are able to send through regularly our signals a tremendous incentive will be created among the Martians to overcome any difficulties they may have encountered in the past.

It has been suggested that to accomplish our purpose we erect upon some high point a series of truly gigantic poles and antennae. Dr. Charles P. Steinmetz, Chief Consulting Engineer of the General Electric Company at Schenectady, N. Y., suggests that we require practically all the electric power available at any one time in this one country to shoot the gigantic sparks to Mars. The cost of such an operation, including the erection of the wireless system, would not, he thinks, fall short of one billion dollars.

It seems at first sight as if this is asking a tremendous price for the privilege of making an experiment that may bring no results whatever. We are taking several things for granted. First, that Mars is inhabited; second, that its human beings have attained so high a degree of intelligence that they employ wireless; third, that the radio disturbances we have noted actually emanate from that planet. Suppose we go to all this expense and trouble, fire our electric waves hopefully, wait patiently, and then are greeted by nothing but profound silence. It is a long shot—to say the least.

But if we should receive a definite response, it is not unreasonable to believe that the whole trend of our thoughts and civilization might change for the better. Once communication were established, it is probable that some simple, brief, and understandable code might be arranged. Just what that code might be, or any part of it, it would be hard to say. Constant repetitions of certain astronomical phenomena that would appear to the gaze of the Martians at a certain moment each day or night might be the starting point. It is possible that some way might be devised for transmitting our conception of certain geometrical figures. There is even a suggestion by one man that we try to send pictures by wireless.

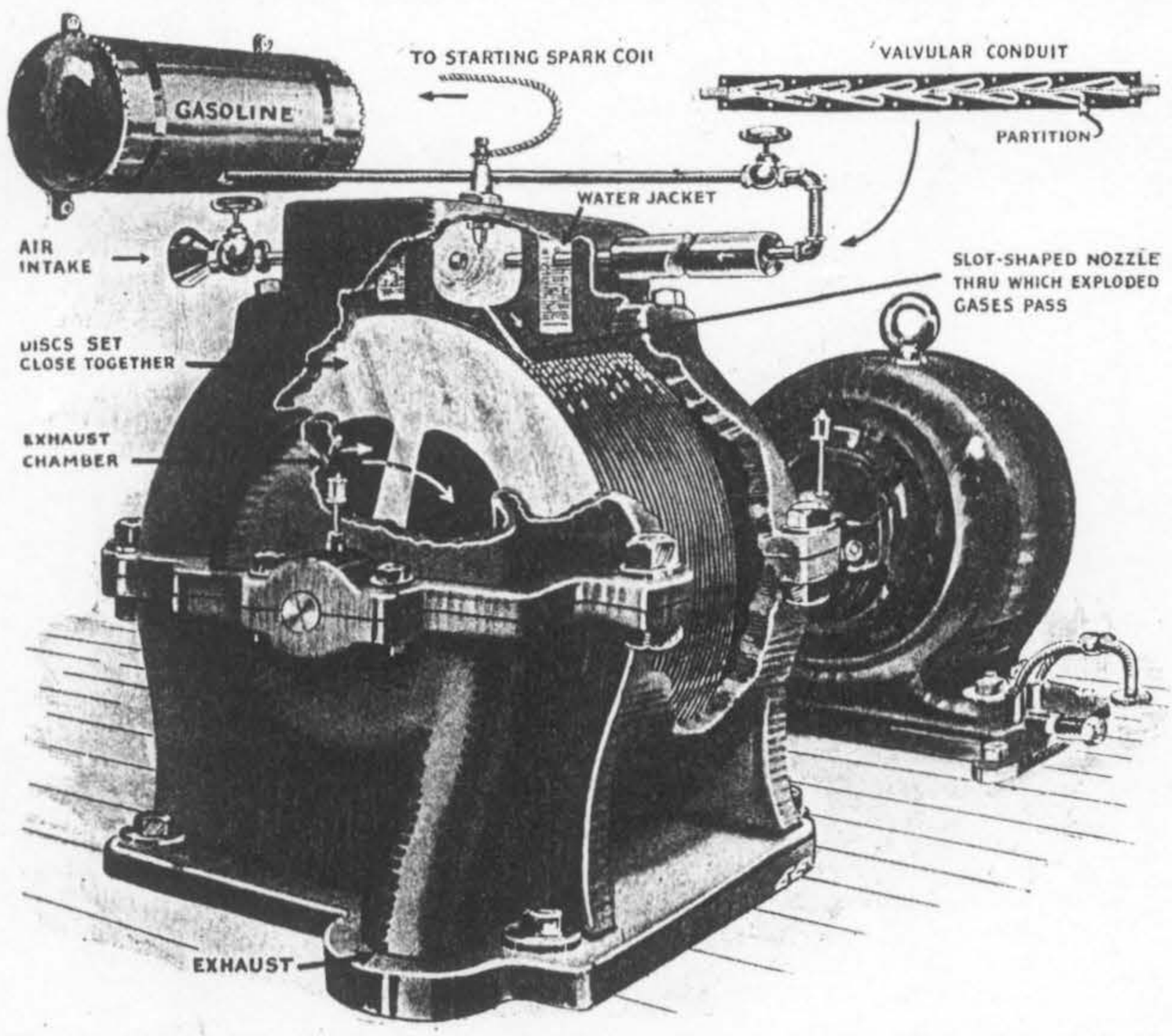
The Tesla Gasoline Turbine

By JOSEPH H. KRAUS

A Revolutionary Gas Engine That Requires No Spark Plug, No Carburetor, No Valves and No Pistons.

AN immense amount of work has been done during the past fifteen or twenty years by engineers who have endeavored to produce a simple and practical *explosive gas turbine,* but the mechanical and thermal hindrances have been so great that up to the present time no signal success has been achieved. The turbine is an ideal prime mover; simple in principle, but the accessory apparatus for operating it explosively is very complex and liable to great wear. Thus the products of an explosion must affect the rotor, during which time a number of operations have to be performed.

Fuel and air must first be admitted thru separate channels into a combustion chamber; the mixture is then ignited, all inlets and outlets closed. The comprest gases thus exploded must be directed thru a nozzle to the rotor plates or buckets and the chamber cleaned and made ready for the admission of a fresh mixture.



The Very Latest Invention in the Gasoline Engine Field Is the New Tesla "Valveless and Bucketless Gasoline Turbine," Here Illustrated. Two of the Main Features of This Remarkable Invention Are That the Usual Carburetor or Vaporizer Is Done Away With and, Secondly, No Buckets Are Necessary on the Turbine Blades, the Latter Simply Comprising a Series of Flat Steel Discs, Placed a Short Distance Apart. The Successive Explosions of the Gaseous Vapor Are Projected Thru a Nozzle on to the Blades, Thus Causing the Rotation of the Blade Members and the Shaft to Which They Are Connected. A Dynamo Is Shown Connected to the Turbine at the Right of the Picture Herewith. This Article Was Prepared in Collaboration with Dr. Tesla.

All these operations are controlled by *valves* which must be opened and closed at precise moments and therefore are generally controlled by the motion of the turbine rotor itself. Irrespective of the difficulty of keeping the valves in good order at high temperatures, at which they must operate the apparatus taken as a whole, is so complicated that the ordinary form or reciprocating type gasoline engine is more preferable.

Doctor Nikola Tesla, whom the readers of this publication know very well and whose amazing work in the various scientific fields is also universally recognized, again comes into the limelight with a very remarkable explosive gasoline turbine perfected by him recently which he describes in detail in a patent just granted. This remarkable turbine does away with all the troubles and complexity of the former attempted types. Stated briefly, the invention consists in the production of a peculiar shape *conduit,* thru which the gases are admitted into the turbine, and which has the singular property of permitting their passage in that direction only; in other words, uni-directionally.

This device when used in connection with his *bucketless* turbine produces an engine which may be explosively operated by gasoline, alcohol or other fuels and is absolutely *devoid of all valves.* It is the simplest internal combustion motor conceivable. Owing to the tremendous output of the Tesla turbine, one single disc being practically equivalent in performance to a whole bucket-wheel, a very small machine of this kind is capable of developing an astonishing amount of power. The principle of the operation will be clearly understood by the aid of the accompanying diagram.

Referring to the detailed view of the conduit, we first note a casing of metal or other suitable material which may be milled or prest from sheet metal into the desired form. From its side walls extend alternately projections terminating in buckets which in order to facilitate manufacture are congruent and spaced at equal distances.

In addition to these there are independent partitions, the purpose of which will presently be made clear. There is a nipple at each end provided for pipe connections. The bottom is solid and the upper or open side is closed by a close-fitting plate. When desired any number of such pieces may be joined in series, thus making up a valvular conduit of such length as the circumstances may require.

In elucidation of the mode of operation let it be assumed that the medium under pressure be admitted at the right. Evidently its approximate path will be as indicated by the dotted line, which is nearly straight, that is to say, if the channel be of adequate cross-section the fluid will encounter a very small resistance and pass thru, freely and undisturbed, at least to a degree. Not so if the entrance be at the opposite end.

In this case, the flow will be smooth and continuous, but intermittent, the fluid being quickly deflected and reversed in direction, set in whirling motion, brought to rest and again accelerated, these processes following one another in rapid succession. The partitions serve to direct the stream upon the buckets and to intensify the actions, causing violent surges and eddies which interfere very materially with the flow thru the conduit.

Examining more closely the mode of operation, it will be seen that in passing from one bucket to the next in the direction of disturbed flow the fluid undergoes two complete reversals or deflections upon itself thru 180 degrees, while it suffers only two small deviations of about 10 to 20 degrees when moving in the opposite sense. In each case the loss of head will be proportionate to a hydraulic coefficient dependent on the angle of deflection, from which it follows that, for the same velocity, the ratio of the two resistances will be as that of two coefficients. The theoretical value of this ratio may be 200 or more, but must be taken as appreciably less altho the surface friction too is greater in the direction of disturbed flow. In order to keep it as large as possible, sharp bends should be avoided.

The illustration shows in perspective cross-section a turbine which may be of any type but is in this instance one invented and described by Dr. Tesla, and familiar to engineers. Suffice it to state that the rotor of the same is composed of flat plates which are set in motion thru the same and viscous action of the working fluid, entering the system tangentially at the periphery or outer circumference, and leaving it at the center.

Such a machine is a thermodynamic transformer of an activity surpassing by far that of any other prime mover, it having been demonstrated in practise that each single disk of the rotor is capable of performing as much work as a whole bucket-wheel of the ordinary type. Besides, a number of other advantages, equally important, make it especially adapted for

(*Continued on page* 316)

The Tesla Gasoline Turbine

By JOSEPH H. KRAUS

(*Continued from page 277*)

operation as an internal combustion motor.

The upper part of the turbine casing has bolted to it, a separate casting, the central cavity of which forms the combustion chamber. To prevent injury thru excessive heating a cooling jacket may be used, or else water injected, and when these means are objectionable recourse may be had to air cooling, this all the more readily as very high temperatures are practicable. The top of the casting is closed by a plate with a spark-plug inserted and in its sides are screwed two of the new Tesla *valvular conduits* communicating with the central chamber. One of these is, normally, open to the atmosphere while the other connects to a source of fuel supply.

The bottom of the combustion chamber terminates in a suitable nozzle which consists of separate member of heat-resisting material. To regulate the influx of the explosion constituents and secure the proper mixture the air and gas conduits are equipt, respectively, with regulating valves. The exhaust openings of the rotor should be in communication with a ventilator, preferably carried on the same shaft and of any suitable construction. Its use, however, while advantageous, is not indispensable, the suction produced by the turbine rotor itself being, in some cases at least, sufficient to insure proper working.

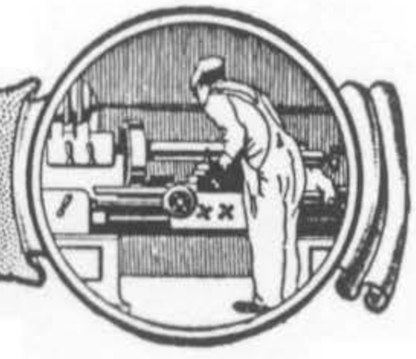
But a few words will be needed to make clear the mode of operation. The air valve being open and sparking establisht across the gap, the gas is turned on slowly until the mixture in the explosion chamber reaches the critical state and is ignited. Both the conduits behaving with respect to efflux, as closed valves, the products of combustion rush out thru the nozzle acquiring still greater velocity by expansion and, imparting their momentum to the rotor, start it from rest. Upon the subsidence of the explosion the pressure in the chamber sinks below the atmospheric, owing to the pumping action of the rotor or ventilator and new air and gas are permitted to enter, cleaning the cavity and channels and making up a fresh mixture which is detonated as before, and so on; the successive impulses of the working fluid producing an almost continuous rotary effort. After a short lapse of time, the chamber becomes heated to such a degree that the ignition device may be shut off without disturbing the establisht régime.

The turbine thus shown presents the advantages of extreme simplicity, cheapness and reliability, there being no compressor, buckets or troublesome valve mechanism. It also permits, with the addition of certain well-known accessories, the use of any kind of fuel and thus meets the pressing necessity of a self-contained, powerful, light and compact internal combustion motor for general work. When the attainment of the highest efficiency is the chief object, as in machines of large size, the explosive constituents will be supplied under high pressure and provision made for maintaining a vacuum at the exhaust. Such arrangements are quite familiar and an enlargement on this subject is deemed unnecessary.

In speaking about the rapidity of explosions, Dr. Tesla says, "I have been able to speed up the rate of such explosions until the sound of exploding gases produced a musical note. The device is by far the simplest I have ever seen and I consider myself indeed fortunate in perfecting it at this time. I have also used this valvular conduit to great effect in rarifaction of air or the compression of gases when operated by my oscillator."

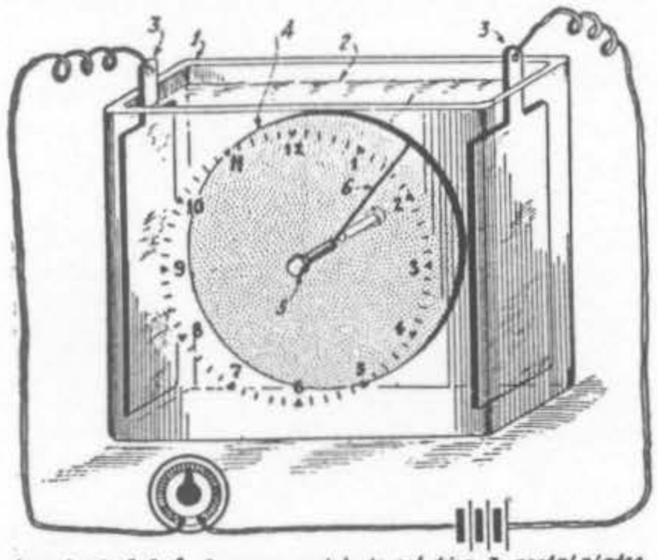


THE CONSTRUCTOR



THE TESLA CLOCK

THERE is always something extremely novel and interesting in the duplication of Dr. Tesla's experiments, but it seems that at times such attempt is rather difficult. However, that may be due to the particular care exercised by Dr. Tesla in



1. glass tank 6"x2"x5". 2. copper sulphate solution. 3. metal plates. 4. balanced copper disc. 5. jewel bearings. 6. glass thread pointer

Dr. Tesla Has Given to the Amateur Construction "Bug," a Simple Idea Which He Used Some Years Ago, In Building an Electric Clock. The Clock Is Simplicity Itself and Comprises a Well-Balanced Copper or Silver Disc, Mounted So as to Rotate In Two Jewel Bearings. Two Metal Electrodes are Placed on Either Side of the Revoluble Disc and When Current Is Applied, the Disc Rotates Very Slowly.

having his experiments exact to the minutest point, a feature which amateurs generally glide over. In the case given here, however, there will be no such difficulty in the making of a clock of this nature.

Not only is the clock unique in design, but rather serviceable if a constant E.M.F. is available. It makes an adorable clock for the amateur, even tho it varies slightly from correct time. This, of course, depends entirely on the regulation of the resistance in the controlling circuit.

A clear walled glass jar or celluloid jar is employed, a well balanced metal disc of copper or silver mounted in such a way that it is free to rotate in the centers of two jewelled bearings. These may be obtained from a clock and easily inserted by drilling a hole thru the glass or celluloid jar and securely mounting them therein with a copper washer on each side to prevent any escape of liquid.

On each side and equi-distant from the periphery of this metal disc are placed two metal electrodes similar in nature to the metal *disc,* i. e., either silver or copper. On the disc itself is fastened a thin glass thread pointer or a thin annealed iron wire, the latter being preferred.

The jar now is filled with a solution of silver nitrate if a silver disc has been used, or copper sulfate if a copper disc and copper electrodes have been used. (Electrodes can be copper strips.) If a magnet is now placed in front of the dial so that its action will take place upon the thin annealed iron wire, the disc inside can be rotated to any desired position. Current from several storage cells is now turned on.

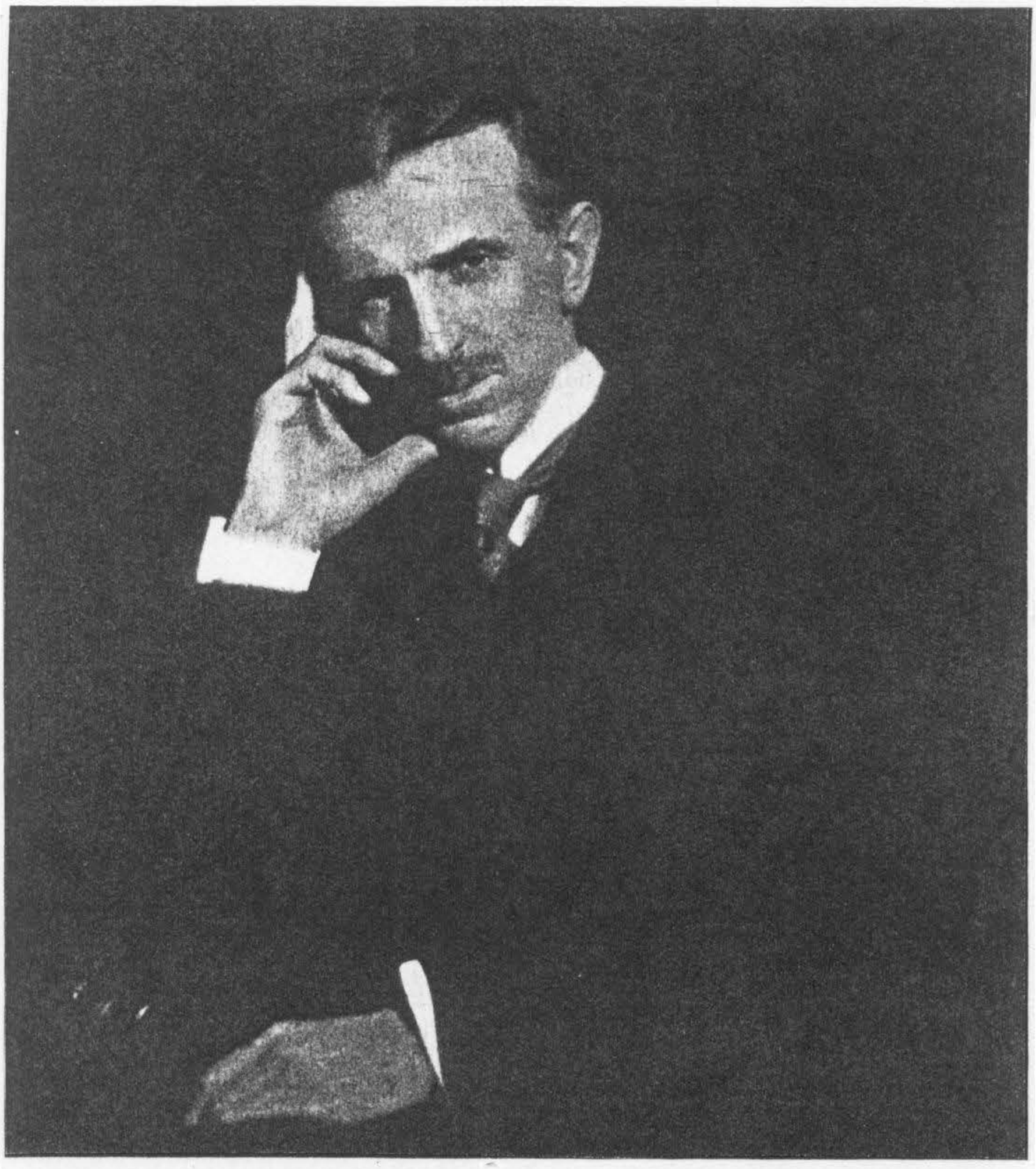
The result is that an electrolytic action takes place, metal being deposited on one side of the movable disc while it is taken off on the other side slowly and with remarkable regularity. This causes the disc to rotate slowly, due to a gravitational action, and if carefully regulated a clever timepiece is the result.

The bluish color of the copper sulfate solution makes a very pleasing aspect in a home or library, the experiment itself being one of the least difficult to reproduce. The disc is about three inches in diameter and the electrodes at each end about ½ inch wide and 4 inches long. About three volts E.M.F. will be sufficient if the amperage is quite constant.

According to Dr. Tesla, a slow deposit is more desirable and for this reason a very narrow plate will answer the purpose. If a wider plate should have been used and the disc rotate too rapidly when current is applied to the terminals, the electrodes of both sides may be coated with paraffin so that but a thin space which is cleaned of this paraffin will be effective.

The plate should be slightly wider than the thickness of the disc itself. The disc could likewise be used as one electrode and instead of the two end strips only one would be employed.

Another essential is that the bearings should be made non-corrosive and at the same time it would be better to lubricate them with a small drop of watch oil. Then when the jar is filled with the electrolyte, the oil will be retained in the bearing zone preventing a deposition of metal upon this zone and corrosion to a great extent.



Nikola Tesla

Inventor of the alternating-current motor, pioneer in high-frequency investigation and discoverer of numerous fundamental principles in electricity

ALMOST a third of a century has passed since Nikola Tesla announced his discovery of the alternating-current motor, but the principles then enunciated by him will be found in force today wherever alternating current is used. Little things frequently lead to important consequences, and the way in which Tesla was led to his discovery is an exemplification of this trite observation. He was a student in Grätz, in Austria, when he became annoyed by the sparking of a small laboratory generator, and the idea came to him that a commutatorless dynamo might be possible. This thought grew upon him, but not until four years later did he make any progress toward its realization. Then the solution suddenly came to him during a moment of recreation. In Europe it was impossible to interest capital in his discovery, so in 1884 he came to America, where his fame had preceded him. His first employment was with Edison.

He was able later on to attract capital, and in 1887 he organized a company to further his cherished plans, on which he worked nineteen hours a day. The next year, upon the issuance of the patents, he announced the discovery which was destined to have such a profound effect upon the rapid expansion of the use and application of electrical energy.

Next to this work in polyphase power transmission his researches in the field of high-frequency oscillations are probably of greatest importance. His discoveries in this field include among others the oscillation transformer, the electrical oscillator and the Tesla tube. Work on these lines led quite naturally to his investigations in the field of radio power transmission. In addition he has made various other scientific investigations, especially in the fields of low-weight, high-powered prime movers and atmospheric nitrogen production.

Mr. Tesla was born of Serbian parents at Smitjan, Lika, in Austria-Hungary, in 1857. He studied engineering at Grätz, Prague and Budapest. In 1917, on the twenty-ninth anniversary of the reading of his paper before the American Institute of Electrical Engineers, announcing his discovery in polyphase transmission, he received the Edison medal for "early original work in polyphase and high-frequency electric currents."

REPRODUCING BALL LIGHTNING

424 Hamilton Natl. Bank Bldg.,
Chattanooga, Tenn, Oct. 12, 1920.

Editor, QST:

My brother and I have been interested in building and operating some large Oudin and Tesla coils, more for the spectacular effect than anything else. While tuning up one large Oudin coil (stands about 4 feet) we had it grounded to the steam heating pipes of the building which passed directly behind the coil. The power was operated by our radio key, in fact the radio transmitting set was used. My young brother was standing with his right hand on the key and with his left, fingers up, palm extended, towards the large copper ball on top of the coil. Before he had moved his hand close enough to receive the discharge from the ball a "spark" or "fireball" broke from the STEAM PIPES, passed within about 12" of the copper ball and struck the boy on the palm. He received quite a jolt from this but nothing serious. Later he lost the skin from the palm of his hand. I could not get a good look at the "fireball" from where I was standing. We thought the matter was more of a joke than anything else and paid no attention to what really had happened.

(Continued on page 64)

Sometime later we had moved the coil several feet from the pipes and were again operating it. This time I was operating the key with the boy looking on. Another spark of "fireball" came, this time from the copper ball on top of the coil, and passed directly towards the boy, striking him in the forehead. He received nothing worse than a bad headache from this one. I was standing so that I had a clear view of the entire action. The ball appeared to be about ¾ inches in diameter, very white, and was sparkling. It traveled fairly slowly, that is, so we could see it plainly, but a little too fast for the boy to dodge well. Now I would like to know what these things were—has anyone else seen anything like them? I cannot understand why they should ignore closer objects and people and pick on that brother of mine. Maybe they do not like him.

Any assistance you can give me will be very much appreciated.

Yours very truly,
Benj. F. Painter.

Developments in Practice and Art of Telephotography

Advancement in Science of Photography and Telegraphy Combined to Perfect Transmission of Photographs—Early Inventions Improved and Applied to Modern Conditions — Television to Be Next Step

By NIKOLA TESLA

The recent successful experiments by Edouard Belin of Paris in the transmission of photographs between New York City and St. Louis, a distance of 1000 miles, have naturally aroused new interest in this rather old art. Mr. Belin's apparatus has been examined with a knowledge of previous efforts in that direction, and it must be admitted that the French inventor has achieved a marked improvement. It is true that his apparatus in many of its features is old and well known, but all the details have been worked out skilfully and his photographic reproductions are not only good likenesses of the originals but are expressive in no small degree. In common with other arts the transmission of pictures to a distance has been brought to its present state of perfection by slow and gradual improvements effected in the course of 77 years. The literature on the subject is quite voluminous and difficult to peruse, as the articles are published in various languages and scattered through numerous periodicals. Only one complete and exhaustive work has been published in German by Dr. Arthur Korn of Munich and Dr. Bruno Glatzel.

First Patents Taken Out Many Years Ago.

The original idea is due to Alexander Bain, a Scotch mechanician, who secured a British patent disclosing the invention in 1843. His plan contemplated the transmission of printed letters, drawings and pictures in the following way: At the sending station a holder with insulated metal points was arranged to glide in the direction of the lines over a frame resting on the printed page to be reproduced at a distance. Within this frame, and at right angles to its plane, a number of short wires were imbedded in sealing wax, their lower ends being in contact with the letters which in turn were all electrically connected. As the holder moved back and forth the insulated metal points would be brought in and out of contact with the upper ends of the short wires, thus controlling the flow of the current through them. Each metal point was joined by a special line to the receiving station where there was a similar holder made to slide over chemically prepared paper laid on a grounded metal plate. When a battery at the transmitting end was connected with one of its poles to the letters and the other to the ground the current impulses traversing the line wires and the chemical paper would cause changes of color in the latter, thus reproducing the characters. A great number of points and line wires were required to attain satisfactory results and, realizing this objection, Bain proposed to avail himself of only one wire, but did not give full information in this regard. Subsequently Bonnelli and other inventors made improvements in his apparatus, reducing the number of the wires to a few. There is no doubt that, despite the manifest crudity of this system, it was quite capable of being used commercially in the transmission of type as well as drawings and pictures and may yet be found valuable.

The first practical success was achieved by an Englishman, Frederick Collier Bakewell, who secured a British patent in 1847 on a process, some features of which have proved to be indispensable in later years. He employed as a transmitter a cylinder on which the characters were written with insulating ink. A metal point bore on the cylinder and advanced slightly with each revolution of the same exactly as in the older form of phonograph. A similar cylinder covered with chemical paper and equipped with a sliding point was provided at the receiving station. The cylinders being grounded and a battery included in the line wire connecting the transmitting and receiving points, the passage of the current resulted in a discoloration of the paper and reproduction of the written characters at the receiving end. Considering the period Bakewell's apparatus was surprisingly perfect, particularly in the feature of maintaining the rotating cylinders in synchronism for which purpose he provided an automatic as well as a hand correction. A controversy was waged between Bakewell and Bain for the honor of priority, but in this respect there can be no mistake. Bain was the originator of the idea, while Bakewell was the first to carry it out successfully.

Use of Chemical Paper Considered Impractical.

The use of chemical paper was considered objectionable, and in 1851 Hipp eliminated it, producing the impressions at the receiver with a magnet actuated by the transmitted impulses. It is curious, though, to observe that the modern art depends entirely on this very device. In 1855 Casselli modified the Bakewell apparatus by employing carefully synchronized pendulums at the transmitting and receiving stations, thus replacing the rotary motion by a to-and-fro movement as in the Bain arrangement. Casselli seems to have had more enterprise than his predecessors, and the apparatus which he perfected in 1860 was actually used with some success for a short time in service between Paris and several other cities in France. Its abandonment was probably due to

the slowness of transmission and lack of demand for this kind of facility. It is singular that many treatises on physics and other text books mention Casselli while ignoring Bain and Bakewell.

Shortly after this Meyer perfected a system which was used with success in France, and may be fairly considered as the first thoroughly practical application of ideas in this field. A curious improvement was made by Gérard who, in 1865, proposed the use of flat disks in place of the cylinders of Bakewell. Ever since one wire was adopted for the transmission it became an imperative necessity to maintain perfect synchronism between the transmitter and receiver, and many inventors devoted their energy to this task. D'Arlincourt resorted to tuning forks, and his idea was subsequently carried out in a more perfect manner by Lacour. At about this time the invention reached America, and in 1870 Sawyer brought his ingenuity to bear on the evolution of a process in which he employed zinc clichés. These were very reliable and constituted a signal advance.

In 1880 Edison devised an apparatus on the principle of that used by Sawyer, except that the impressions were produced on paper in bas-relief. This idea was carried further by Dennison in instruments of the reciprocating type. Through the introduction of the Tesla alternating system of power transmission a novel means was afforded for operating transmitters and receivers. The use of synchronous motors was proposed first in 1893 by Sheehy.

Developments Permit Use of Photographic Films.

In all cases without exception it was necessary to provide an actual print, drawing or sketch to be transmitted until Lenoir introduced photographic films into the art, making possible the transmission of any kind of picture. This was a great step forward, but the honor of the first practical success belongs to an American engineer, N. Amstutz, who used photographic sending clichés in relief for the first time and with complete success. Amstutz was a true pioneer, and his improvement is essential in the carrying out of the modern processes. It is true that as early as 1865 a Frenchman, Hubert, had suggested the use of letters written with thick ink, but this was of little value, and Amstutz was undoubtedly the first to produce and use the clichés on which the up-to-date art vitally depends. Perfectly satisfactory demonstrations were made with his devices in this country more than 20 years ago, when pictures were transmitted over telegraph wires to great distances. Samples of his work have been preserved which clearly show how much he was ahead of his time.

Following Amstutz, Dunlany, Palmer, Mills and other American inventors took up picture transmission with more or less success. By this time the necessity presented itself for increasing the rapidity of the process by greater speed of the devices as well as multiplex transmission. The Belgian inventor, Carbonelle, made an important improvement in this direction when he introduced the telephone diaphragm carrying a stylus for making the impressions.

Of all inventors, however, Dr. Korn was the most successful as well as prolific in the suggestion of improvements, his photographic method of recording carried out in 1903 being the most significant. The general idea of photographic recording had been already advanced by George Little, and a few years later Dillon took out a patent involving the use of sensitized paper and a mirror reflecting a beam of light on the same. But it is obvious that at that time it would have been hardly practicable to use this suggestion, as photography was not sufficiently advanced. In illustration of this it may be mentioned that in 1892 the attention of the scientific world was directed to a wonderfully sensitive receiver, consisting of an electron stream maintained in a delicately balanced condition in a vacuum bulb, by means of which it was proposed to use photography in the transmission of telegraphic and telephonic messages through the Atlantic cables, and later also by wireless. This proposal was met by unsurmountable objections to the photographic method. Indeed, the Belin process has been rendered possible largely through the great improvements in the sensitive films which have been evolved in response to the urgent demands of the motion picture and also under the stimulus of the recent war.

Selenium Cell and Vacuum Tube Used to Transmit and Receive.

In the apparatus invented by Dr. Korn a selenium cell is used at the transmitter to vary the intensity of the sending current, and at the receiving station he employs a vacuum tube of high intensity which throws its light through a fine slot on a sensitive plate. The tube is excited by high-frequency currents supplied from a Tesla transformer and may be flashed up many thousand times per second. The motion of the receiver element is effected either by a wire galvanometer, oscillograph or telephone diaphragm. The Korn system has been used for some years past with success in Germany and other countries. In fact, it has been operated for some time even by wireless. Patents on this mode of transmission have been granted in 1898 and 1899 to Küster and G. Williams, but the arrangements involved the employment of Hertz waves and were impracticable. Later Frederick Braun, Pansa and Knudsen secured patents which, however, are equally defective. Success in this direction has been achieved so far only by Korn, Berjonneau and T. Baker. Invariably the inventors employ a wire galvanometer which is especially suitable for great speed. Telautographic transmission by similar means through wires as well as wireless is now common and is effected by employing a transmitter of two components, the original idea of which is due to an Englishman, Jones, who made that suggestion as early as 1855.

Present Developments Involve Many Old Principles.

To this short story of picture transmission Belin has contributed the latest chapter. The process he has finally adopted after many years of persistent effort involves the use of two cylinders rotating in synchronism—one for transmitting and the other for reproducing. The former is of copper and is prepared for operation by

having its surface coated with a thin shellac solution, wrapping a carbon print of the photograph about it with its face to the cylinder and immersing the whole in hot water, this causing the gelatine to adhere to the cylinder surface in proportion to the degree of blackness so that a likeness of the print in bas-relief is obtained. On this cylinder bears the stylus of a microphone diaphragm which is slowly moved forward by the revolution of the cylinder as in a phonograph.



Edouard Belin and His Device for Transmission of Photographs.

In this manner the pressure of the carbon contacts is varied in conformity with the changes of the surface, and the microphone currents pass over the transmitting wire to the receiving station where they cause corresponding deflections of a mirror forming part of a highly sensitive deadbeat oscillograph. A strong beam of light reflected from the mirror traverses a screen graduated from full transparency to opacity and is led through a microscopic opening to the sensitive film wrapped around the receiving cylinder. Special provisions are made to keep the cylinders exactly in step as this is indispensable to good performance. The film is, of course, protected against the external light, and when the operation is completed it is developed as usual so that either a positive or negative print is obtained according to the position of the screen. There is nothing in his apparatus which is fundamentally novel; in fact, every feature of the same has been disclosed in the prior art. Even the graduated screen, which is one of the most essential parts, has been employed before by Dr. Korn. But Mr. Belin has displayed considerable ingenuity and skill in all the details, and his reproduced photographs are most excellent. There is every reason to believe that his efforts will be rewarded by an extensive practical application of his devices.

Television to Be Next Step in Progress of Transmission.

The transmission of photographs constitutes only the first step towards the immeasurably greater achievement of television. By this is meant instantaneous transmission of visual impressions to any distance by wire or wireless. It is a subject to which I have devoted more than 25 years of close study. Two of the impediments which years ago seemed unsurmountable have been successfully overcome, but great difficulties are still in the way. These are encountered in the inertia of the sensitive cells and the enormous speed required to make possible the vision of persons, objects or scenes as in life. It is the problem of constructing a transmitter analogous to the lens and retina of the eye, providing a medium of conveyance corresponding to the optic nerve, and a receiver organized similarly to the brain. It is a gigantic task, but I am confident that the world will witness its actual accomplishment in the near future.

The New York World March 27, 1930

TESLA SEES GAIN IN ELECTRICITY

Predicts Baby Planes and Daylight Television.

Do you use an alternating current induction motor? A high frequency coil? A filamentless vacuum lamp (such as the neon lamp)? asks H. Winfield Secor, E. E., in Science and Invention. Not only these but many other modern electrical methods and appliances are conceptions of the brain of Dr. Nikola Tesla.

For practically half a century Dr. Tesla has occupied himself with the roots and essences of his chosen subject. How essentially necessary to modern industry, offices and homes is alternating current! For most industrial requirements direct current is not suited at all. Long distance transmission of such a current is wasteful and impracticable, as no simple, efficient machinery is available for generating and transforming it at high voltages.

Alternating current, on the contrary, lend itself admirably to high voltage generation and to transformation into current of any strength or volume as well as into direct current, at the point of use. . . . Without alternating current we could not proceed with modern life. Yet more than forty years ago Dr. Tesla discovered the principle of this form of electricity, invented machinery for generating and transforming it, and introduced it to a world which until then had been limping along with direct current as best it could.

Because Dr. Tesla knows the principles of electricity and has checked his knowledge in practice he is able to speak with certainty about electricity not only of today but also of tomorrow.

"Neon lamps are in the public favor and are being used for store windows and in signs quite extensively," said Dr. Tesla, "but I had similar filamentless gas-filled electric lamps in my laboratory in Houston street over thirty years ago. I even had these lamps standardized to fifty candle power each, and used them instead of the orthodox illuminating devices. It seems that I was also far ahead of my time in the use of filamentless tubes, bent in the shapes of characters and other forms, as now extensively used. The light from properly filled vacuum tubes is of indescribable beauty, hygenic and more economical, and the lamps last forever. For these reasons I predict that very shortly the old-fashioned incandescent lamp, having a filament heated to brightness by the passage of electric current through it, will entirely disappear and that we will shortly be using new filamentless gas filled lamps in our homes, offices and factories throughout the world.

"The present day television inventors are on the wrong track, and we shall see in a future not distant a very simple means of transmitting the living daylight image over a wire or by wireless without the use of any scanning disk, special synchronizing means and all the bewildering paraphernalia now employed to give an image the size of a postage stamp, and one that is far from satisfactory at that. I made discoveries many years ago which give me every reason to believe that television of the future will have all of the complicated parts located at the transmitting or central station, and all that the subscriber will have in his home or office to receive the reproduced image will be practically nothing but a screen, together with a suitable wave or station selector."

TESLA ON MARCONI'S FEAT

To the Editor of The World:

The World editorial March 28 must have instilled a holy fear in the minds of some of your readers. Of course Marconi could not help astounding people, but surely it was wrong of him at this critical time to scare the United States Navy by the statement that he could halt the progress of electrically driven dreadnoughts, which would mean certain doom in an engagement with the enemy. The thought that my beautiful induction motors used in their propulsion might be consigned to Davy Jones's locker in this easy manner caused me some anxiety until I satisfied myself by a little calculation that the maximum power transmitted —expressed in units more appropriate than the conventional—did not exceed one-millionth of a "mouse-power."

Except to the layman there was nothing remarkable in the performance, considering that sea water has only one five-hundredths of the resistance of solid ground and that there were no towering objects in the vicinity, thus reducing very much the size of the plant. Marconi accomplished nothing more than was known before. The infinitesimal currents received were amplified, relayed repeatedly and made to actuate local means, as usual. This can be brought about in more than one way; but, as a rule, a form of amplifying three-electrode tube is employed which I described in my experimental lectures before the Franklin Institute and National Electric Light Association early in 1893. The modern tubes embodying the same principle are marvels of workmanship, but less sensitive, because they lend themselves only to relatively small voltages. If suitable means were provided, any wireless amateur could magnify as feeble a disturbance as the patter of the feet of a fly sufficiently to precipitate a veritable earthquake at the antipodes. The shrewd Italian did not give a description of his apparatus, but from his previous records one may safely infer that it is old and well known. It is gratifying, however, that he has abandoned the ridiculous arrangement of a "beam system," which he claimed to offer "limitless possibilities."

Your reference to his first announcement thirty years ago has stirred up in my memory unpleasant recollections. To the public the transmission of a weak wireless signal across the Atlantic appeared almost like a miracle, but, even if a fact, it was a paltry engineering achievement, for I had already shown by experiment over a year before that the earth may be excited like a wire of small dimensions and that the current impulse from a powerful transmitter could travel through it as much as a million miles before its energy was exhausted. But this is immaterial. I only wish to call the attention of your readers to the circumstances.

Some time after the experiments with the classical Hertz devices conducted under the auspices of the Imperial Post Office in England, Sir William Preece, then head of the department, wrote me a letter conveying the information that the tests had been abandoned as of no value, but that he believed good results possible by my system. In reply I offered to prepare two sets for trial and asked him to give me the technical particulars necessary to the design. Just then Marconi came out with the emphatic assertion that he had tried out my apparatus and that it did not work. Evidently he succeeded in his purpose, for nothing was done in regard to my proposal.

He furthermore declared at a later date that wireless communication across the Atlantic was impossible because there was a wall of water several miles high between the two continents which the rays could not traverse. But subsequent developments showed that he had used my system in secret all the time, received the plaudits of the world and accepted stolidly even my own congratulations, and it was only a long time after that he admitted it.

NIKOLA TESLA.

New York, April 11.

Great *Scientific Discovery* Impends

"I Positively Expect That Within the Next Decade New Sources of Energy Will Be Opened Up Which Will Put at the Disposal of Mankind Everywhere Power in Unlimited Amounts," Says Nikola Tesla, Noted Inventor—"I Have Made a Discovery Which I Expect to Announce Soon."

BY HARRY GOLDBERG.

NIKOLA TESLA, the noted inventor, is preparing to make public within the near future the announcement of a discovery which will make available to the world new sources of energy.

As this discovery will make it possible to tap inexhaustible streams of power at any point on the globe, great changes will follow in social life. Government will become a sort of officious policeman, busybody and benevolent tyrant which will convert the human race into a society like the bees.

What this noted scientist has found is not a form of atomic energy, which he declares to be a fantastic hope, but it is a "universal truth" of such a nature that probably it cannot even be patented. To quote his exact words:

"I positively expect that within the next decade new sources of energy will be opened up which will put at the disposal of mankind everywhere power in unlimited amounts.

"In this connection I have made a discovery which I expect to announce as soon as I have worked out the theory and design of apparatus for practical purposes.

"I want to be emphatic in my condemnation of the idea that atomic energy will ever be our source of power. This is an illusory idea against which I have preached for years. In my experiments with peculiar vacuum tubes operated under tensions of 12,000,000 volts atoms are shattered, but there is no liberation of energy observable such as would be expected according to modern theories. But even if the latter were true, it still would take much more energy to disintegrate the atom than can be recovered by harnessing the liberated energy, however great it might be.

"What I am referring to is an entirely new principle which I have already experimentally demonstrated."

ASKED if his source of energy was electricity, sun power or some other force already known, Dr. Tesla shook his head negatively and refused to affirm any guess, indicating that he would choose a scientific forum from which to make the definite announcement when he was ready.

"Will revolutionary changes follow?"

"I don't believe they will. New ideas are adopted gradually. It is inevitable that those who are in the forefront of the advance will keep their places. Our life is now so regulated that no advance whatever could completely upset the existing order."

Then he went on to inveigh against the continued invasion of personal privacy by the authorities, the interference with personal liberty, the tendency to extend the powers of government to watch over our personal health, control birth and hamper the free action of individuals.

It used to be possible, he said, for inventors to move with absolute freedom, but the world is growing so complex that in experimenting with wireless, transmission of power, television or similar development one must ask the government for permission before undertaking to grapple with electrical forces.

"But if you are referring to sweeping changes in the social system, I believe they will take place in very rapid succession and will be great in so far as the limit of accomplishments of an individual are concerned.

"The technical advances are inevitably driving us toward the grossest kind of materialism. And it will not be very long before the social system of bee life will become universal.

"The individual will not be permitted to achieve great wealth and power; his privacy will be invaded in a thousand ways. He will be [illegible]d in his efforts in every direction—will [illegible]ny disappear in the wave of collectivism [illegible]h will sweep the world.

"This materialistic tide can only be stemmed by idealism, which is a force tending to free what we call the soul of man from physical fetters. But although there might be periods of alternating dominance of these two principles—materialism and idealism—ultimately the materialistic tendencies will become dominating."

"Isn't it possible that human wants and needs will be so easily satisfied through cheap power and increased production that we will turn the increased leisure to developing the arts and the soul?"

Dr. Tesla was pessimistic. "Is the human race any less materialistic than it was a thousand years ago?"

"What shall be done with this increased leisure which will be available?"

"Too much leisure, and civilization will go to pot," he said emphatically. "Man was born to work, suffer and struggle, and if he doesn't he'll go under."

"Is life an accident?"

"No, life was inevitable."

"Only on this earth or do you believe there is life elsewhere on the planets?"

"There must be life on other planets. The sun shines. The stars give out heat. Water collects on the surface. Chemical changes occur that we do not yet understand—and there is life."

Where the average mind gapes and stares at the marvels of science, Dr. Tesla sees no cause for wonder. Radio, television, wire-evision, wireless telephone—these are merely the application of cause and effect as simple as one step after another. He pointed out that a skyscraper would be a wonder to a savage dwelling in the desert, while it is a commonplace to every one here.



Nikola Tesla, the noted American scientist, who has announced that he expects to make known soon an important discovery that may revolutionize the power world.

"Speaking of technical achievements, however extraordinary," he said, "they may be only wonderful to those who have no knowledge of the mechanism or agents limiting the effect to the cause.

"To be truly wonderful there must be about the manifestations observed an element of mystery which the human race has not yet fathomed.

"That inanimate matter should run into organic forms must be considered a wonder, because we have not yet ascertained why and how this is brought about."

"You mean, for instance, food being changed into tissue, so that life goes on?"

He nodded his head in the affirmative and continued: "The human being is one of the greatest mysteries of nature and consequently a wonder. And so is life in all its manifestations. But a time may come when all the subtle and involved processes that are part of our living existence will be laid bare and understood and then the element of wonder will be removed."

ASKED to select his choice of the greatest modern and future wonders, the electrical wizard refused to accept the popular notion of what is wonderful. His reply led him into onslaught on the scientists who have abandoned "cause and effect" and who take the position that there are accidents in nature and that anything might happen.

"To the popular mind," he said, "any manifestation resulting from any cause will appear wonderful if there is no perceptible connection between cause and effect. For instance, through the means of wireless telephone speech is carried to opposite points of the globe. To the vast majority this must appear miraculous. To the expert who is familiar with the apparatus and sees it in his mind's eye the result is obvious. It is exactly as though visible means existed to which the impetus is transmitted.

"As I revolve in my mind the thoughts in answer to your question I find the most wonderful thing is the utter aberration of the scientific mind during the last 25 years. In that time the relativity theory, the electron theory, the quantum theory, the theory of radio-activity and others have been worked out and developed to an amazing degree. And yet probably not less than 90 per cent of what is thought today to be demonstrable scientific truth is nothing but unrealizable dreams.

"What is 'thought' in relativity, for example, is not science, but some kind of metaphysics based on abstract mathematical principles and conceptions which will be forever incomprehensible to beings like ourselves whose whole knowledge is derived from a three-dimensional world."

The idea of the atom being formed of electrons and protons which go whirling around each other like a miniature sun and planets is an invention of the imagination, he said, and has no relation to the real nature of matter.

Dr. Tesla said he could think of no results of great value which stem directly from these modern conceptions. "Virtually all progress," he declared, "has been achieved by physicists, discoverers and inventors; in short, devotees of the science which Newton and his disciples have been and are propounding.

"Personally, it is only efforts in this direction which have claimed my energies. Similar remarks might be made with respect to other modern developments of thought. Take, for example, the electron theory.

"Perhaps no other has given rise to so many erroneous ideas and chimerical hopes. Everybody speaks of electrons as something entirely definite and real. Still, the fact is that nobody has isolated it and nobody has measured its charge. Nor does anybody know what it really is.

"In order to explain the observed phenomena atomic structures have been imagined, none of which can possibly exist. But the worst illusion to which modern thought has led is the idea of 'indeterminacy.' To make this clear, I may remark that heretofore we have in positive science assumed that every effect is the result of a preceding cause.

"As far as I am concerned, I can say that after years of concentrated thought and investigation there is no truth in nature of which I I would be more fully convinced. But the new theories of 'indeterminacy' state this is not true, then an effect cannot be predicted in advance.

"If two planets collide at certain time and certain place, this is to the student of positive science an inevitable result of preceding interactions between the bodies; and if our knowledge would be adequate, we would be able to foretell the event accurately.

"But in the spirit of the new theories this would simply be an accident. 'Indeterminacy' introduces into the world of inert matter a principle which might virtually be compared with the universal illusion of free will.

"Of course, there is no such thing. In years of experimenting I have found that every thought I conceive, every act I perform, is the result of external impressions on my senses.

"It is only because the vast majority of human beings are not observant sufficiently that they live in the illusion of perfect choice and freedom in their thoughts and actions. And if this holds true even in the most complex and involved manifestations of human life, it holds true with the same force in all the world of matter."

WITH this pessimistic outlook expressed earlier in the interview Dr. Tesla was not satisfied to contemplate the world spinning eternally around on its orbit.

"The earth may explode," he said. "A planet may collide with us."

"Yet it has existed a long time," it was suggested. His reply had a note of grim humor, indicating that even a scientist who locks himself away from the world may know his homely aphorisms. "A pitcher may go too often to the well," he concluded.

Dr. Tesla, the American inventor, was born at Smiljan, Austrian Croatia, in 1857. He received his early education at Karlstadt, attended the polytechnic school, Graz, Croatia, and the University of Prague. He became interested in electricity and was first employed in the Austrian government telegraph engineering department and later in Budapest and Paris. He was with the Edison Co., in the United States for a time, but afterward established the Tesla Laboratory in New York City. Mr. Tesla was the first to conceive an effective method of utilizing alternating current. He invented the principle of the rotary magnetic field embodied in the apparatus used in the transmission of power from Niagara Falls, as well as many new forms of electrical apparatus.

Dr. Tesla has devoted a great deal of thought and study to the development of the airplane, and especially to a heavier-than-air machine that would ascend vertically. He also predicted a fuelless machine that would fly. Many give him credit for being the "father of radio." As far back as the early nineties he delivered a series of lectures in which he submitted drawings and plans that later gave ideas to men who brought into being the wireless sets that were used for telegraphic communication and then gathered musical programs and what not from the air.

(Copyright, 1931.)

TESLA, 75, PREDICTS NEW POWER SOURCE

Intimates Discovery Soon to Be Announced Has to Do With Harnessing Sun Rays.

"SOLVES COSMIC PUZZLE"

Scientist, Whose Theory Is Based on 36 Years' Study, Calls Atomic Energy Idea "Illusionary."

ES JUL

Nikola Tesla, the inventor, who will celebrate his seventy-fifth birthday Friday, said in an interview yesterday that he soon would announce what he regards as "by far the most important discovery" of any he has made during his long career.

"It will throw light on many puzzling phenomena of the cosmos," he remarked, "and may prove also of great industrial value, particularly in creating a new and virtually unlimited market for steel."

"I have been wonderfully fortunate," said Mr. Tesla, who looks much younger than his years, "in the evolution of new ideas, and the thought that a number of them will be remembered by posterity makes me happy indeed. I am confident that my rotating field and induction motor, and the wireless system I have given to the world, will live long after I have gone. Nevertheless, it seems to me, my latest discoveries will be considered the most important.

"I expect that they will mark a distinct departure in science and will determine largely the direction of its future development. But they may also prove of great practical value, and in that event an industrial revolution may be inaugurated. So far I have succeeded in proving my theories by experiments, measurements and calculations based on them, which, I am confident, will prove true.

"If so, then a new source of power, available at any point of the globe, in amounts practically unlimited, will be opened up."

"From Unexpected Source."

Asked to indicate more explicitly the nature of this power, Mr. Tesla said:

"I can only say at this time that it will come from an entirely new and unsuspected source, and will be for all practical purposes constant day and night, and at all times of the year. The apparatus for capturing the energy and transforming it will partake both of mechanical and electrical features, and will be of ideal simplicity.

"At first the cost may be found too high, but this obstacle eventually will be overcome. Moreover, the instalment will be, so to speak, indestructible, and will continue to function for any length of time without additional expenditures."

"When and where do you expect to make the official announcement of your new discoveries?" the inventor was asked.

"These discoveries," he replied, "did not come to me over night, but as the result of intense study and experimentation for nearly thirty-six years. I am naturally anxious to give the facts to the world as soon as possible, but I also wish to present them in a finished form. That may take a few months or a few years."

The inventor was asked whether it would be possible to apply his new process to harnessing the energy of the cosmic ray. He smiled.

"All the energy," he said, "that the earth receives from all the suns and stars of the universe is only about one-quarter of 1 per cent of that which it receives directly from the sun. Therefore, it would be incomparably more rational to harness the heat and light rays of the sun than to attempt to capture the insignificant energy of this radiation."

"Do you think this ever will be accomplished successfully?"

"Already Being Done."

"We can do it now, and we are doing it to a certain extent. But the tremendous handicap is found in the periodic character of this kind of energy supply. Many attempts have been made in this direction, but invariably it was found that the power is too expensive."

"Does your process have to do with atomic energy?"

"The idea of atomic energy," he answered, "is illusionary, but it has taken so powerful a hold on the minds that, although I have preached against it for twenty-five years, there still are some who believe it to be realizable.

"I have disintegrated atoms in my experiments with a high potential vacuum tube I brought out in 1896, which I consider one of my best inventions. I have operated it with pressures ranging from 4,000,000 to 18,000,000 volts. More recently I have designed an apparatus for 50,000,000 volts which should produce many results of great scientific importance.

"But as to atomic energy, my experimental observations have shown that the process of disintegration is not accompanied by a liberation of such energy as might be expected from the present theories."

"What is your opinion of the source and the nature of the cosmic ray?" he was asked.

Confirmed Theory in 1899.

"I called attention," he said, "to the probable existence of this radiation while investigating Roentgen rays and radioactivity. In 1899 I erected a broadcasting plant at Colorado Springs, the first and only wireless plant in existence at that time, and there confirmed my theory by actual observation. My findings are in disagreement with the theories more recently advanced.

"I have satisfied myself that the rays are not generated by the formation of new matter in space, a process which would be like water running up hill. Nor do they come to any appreciable amount from the stars. According to my investigations the sun emits a radiation of such a penetrative power that it is virtually impossible to absorb it in lead or other substances.

"It has, furthermore, other extraordinary properties in regard to which I shall express myself at some future date. This ray, which I call the primary solar ray, gives rise to a secondary radiation by impact against the cosmic dust scattered through space. It is the secondary

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radiation which now is commonly called the cosmic ray, and comes, of course, equally from all directions in space."

The inventor advanced his theory that the phenomena of radioactivity are not the result of forces within the radioactive substances but are caused by this ray emitted by the sun. If radium could be screened effectively against this ray it would cease to be radioactive, he said.

Mr. Tesla added he has devoted a great deal of time to experimentation with rocket-propelled ships and has designed a number of machines "with practical objects in view."

"A great development in this field may be confidently expected," he said. "With such machines it will be practicable to attain speeds of nearly a mile a second through the rarefied medium above the stratosphere.

"I anticipate that such machines will be of tremendous importance in international conflicts of the future. I foresee that in times not too distant wars between various countries will be carried on without a single combatant passing the border. At this very time it is possible to construct such infernal machines which will carry any desired quantity of poisoned gases and explosives, launch them against a target thousands of miles away and destroy a whole city.

"If wars are not done away with we are bound to come eventually to this kind of warfare, because it is the most economical means of inflicting injury and striking terror in the hearts of enemies that ever has been imagined. Densely populated countries, like England and Japan, will be at a great disadvantage as compared with those embracing vast territories, such as the United States and Russia."

The New York Sun July 10, 1931

Tesla, Inventor, 75 Today

Electrical Scientist Still Works After Making Many Important Discoveries.

Nicola Tesla, electrical inventor, was 75 years old today. He was presented with a volume containing letters of felicitation and congratulation from about one hundred inventors and scientists all over the world.

Tesla has left behind him three quarters of a century of high achievement, says the Associated Press, being generally considered the father both of radio and of modern power generation and transmission, but it is in the fourth quarter he expects to do his greatest work.

Among the authors of the congratulatory letters presented the inventor today were such men as Sir Oliver Lodge, E. F. W. Alexanderson, Lee De Forest, John Hays Hammond, Jr., Robert A. Millikan, Secretary of Commerce R. P. Lamont, H. H Westinghouse, B. A. Behrend and Count Von Argo.

Doubt About His Birthday.

Persons arranging for the presentation ceremony were a little doubtful for a time whether it should be held today or yesterday, as the inventor has sometime jokingly told his friends that since he was born on the stroke of midnight he didn't know which day was his birthday. They finally decided, however, that July 10 was the proper date.

Tesla was born in Serbia, coming here as a young man and obtaining his first job in America with Thomas A. Edison. Soon, however, he founded his own company, and in 1888 he sold to Westinghouse a series of patents that revolutionized the electrical industry.

Since then he always has worked independently, delving deep into the mysteries of the earth's energy and delivering his findings to the peoples of the earth. He early became an authority on power and played a large part in the harnessing of Niagara Falls and many other large power projects. Later, he turned his attention to wireless, and on his research is based much of the developed art now known as radio.

Working on New Power Source.

A tall, thin man with angular features and graying hair who carries his years as lightly as most men of 50, he is working on power again now, power of great strength from some source he is not yet ready to divulge. He is nearing the end of a road he has been traveling for more than a quarter of a century and he expects his labor to bear fruit that will be his greatest triumph.

"I am naturally anxious to give the facts to the world as soon as possible," he said, "but I also wish to present them in a finished form. That may take a few months or a few years."

So far, he said, he has proved his theories concerning the hitherto untapped source of immense power by experiments, and he was confident that calculations based on these experiments would prove true.

"If so," he continued, "then a new source of power, available at every point of the globe, in amounts practically unlimited, will be opened up."

Tesla looks on his latest work as a lasting monument which will carry his name proudly down the ages after he is gone.

"I have been wonderfully fortunate," he says, "in the evolution of new ideas, and the thought that a number of them will be remembered by posterity makes me happy indeed. I am confident that my rotating field and induction motor and the wireless system I have given to the world will live long after I have gone. Nevertheless it seems to me my latest discoveries will be considered the most important."

The New York Sun July 11, 1931

For thirty-seven years Nikola Tesla has been outdreaming other scientists and inventors. But his fantasies of the nineties became the realities of the nineteen hundreds. Celebrating his 75th birthday he projects interplanetary exchanges of energy which will end stellar isolation.

Back in 1894 a long, lean, almost cadaverous, looking man used to enthrall Ward McAllister and other playboys at Delmonico's with dissertations on the fly—and how he could fly! And maybe man would get that way some day, too. That was Nikola Tesla from the kingdom of Lika, on the borders of Austria-Hungary, but rubbed out of existence as an independent State long before the big war. Mr. Tesla's visions suggested hashish to some rock ribbed scientists, but in 1915 he got the Nobel physics prize for his research in energy transmission, his take-off in today's prophecy. While he has called many of the modern scientific miracles in advance, some are still in suspense, notably his prediction that some day the Atlantic Ocean will be lit up like Forty-second street and Broadway by some comparatively simple electrical conjuring.

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TESLA SEEKS TO SEND POWER TO PLANETS

Inventor at 75 Declares He Has Developed Means to Create Universal Brotherhood.

FORESEES MAGIC EFFECT

Asserts We Will Communicate With Humans on Other Worlds of the Universe.

SCIENTISTS GREET HIM

Father of Radio Receives Volume of Letters From Leaders as He Celebrates His Birthday.

Nikola Tesla, father of radio and of modern power transmission and generation, celebrated his seventy-fifth birthday yesterday.

In honor of the occasion Dr. Tesla revealed in an interview that he had developed after many years of concentrated effort a means that will make it possible for man to transmit energy in large amounts, thousands of horse power, from one planet to another, which, he believes, some day will open the way for interplanetary communication.

During the day a volume was presented to him containing letters of congratulation from about 100 inventors and scientists. These included Sir Oliver Lodge, E. F. W. Alexanderson, Lee De Forest, John Hays Hammond Jr., Dr. Robert A. Millikan, Secretary of Commerce Lamont, H. H. Westinghouse, B. A. Behrend and Count von Arco.

Nearing Period of New Wonders.

"I feel," he said, "that we are nearing a period when the human mind will perform greater wonders than ever before. This is due to the continuous refinement of means and methods of observation and the ever-increasing delicacy of our perception.

"Will man conquer nature some day?" he was asked.

"As I examine the possibilities of achievement," he replied, "and the benefits which the human race may derive from them I think that nothing can be more important than interplanetary communication. It will certainly come some day, and the certitude that there are other human beings in the universe, working, suffering, struggling, like ourselves, will produce a magic effect on mankind and will form the foundation of a universal brotherhood that will last as long as humanity itself."

"Then you believe that life exists on other planets?"

"It is a mathematical certitude!"

"I wouldn't have told you that under ordinary conditions," he added with a smile, "but the seventy-fifth birthday is a rare occasion."

Doubts Physical Strength.

"How soon will you make your discovery public?"

There was a trace of regret in his voice as he answered, and the look of a man who has work enough for centuries and only a few years to do it in.

"I have been leading a secluded life," he said, "one of continuous, concentrated thought and deep meditation. Naturally enough, I have accumulated a great number of ideas. The question is whether my physical powers will be adequate to working them out and giving them to the world. It is as Goethe said:

Der Gott der mir im Busen wohnt
Kann tief mein Innerstes bewegen;
Der ueber allen meinen Kraeften thront,
Er kann nach aussen nichts bewegen.

He had not read Goethe for forty years, he said, and he quoted it from memory. The conversation turned to the subject of the human brain.

"We are all automatons," he reflected, "obeying external influences. We are entirely under the control of agents that beat on our senses from all directions of the outside world. Being merely receivers from the outside, it is a very important question how good the receivers are—some are sensitive and receive accurately. Others are sluggish and their reception is blurred. The individual who is a better machine has so much greater chance of achieving success and happiness. An individual who is an offender of law is a machine in which one or another organ has been deranged, so that the responses are no longer accurate.

"There is no chance in nature, although the modern theory of indeterminacy attempts to show scientifically that events are governed by chance. I positively deny that. The causes and effects, however complex, are intimately linked, and the result of all inferences must be inevitably fixed as by a mathematical formula.

"I also absolutely deny the existence of individuality. It took me not less than twenty years to develop a faculty to trace every thought or act of mine to an external influence. We are just waves in time and space, changing continuously, and the illusion of individuality is produced through the concatenation of the rapidly succeeding phases of existence. What we define as likeness is merely the result of the symmetrical arrangement of molecules which compose our body."

Says There Is No Soul.

"How about the soul—the spirit?" he was asked.

"Ah," he exclaimed, "but there is no soul or spirit. These are merely expressions of the functions of the body. These life functions cease with death and so do soul and spirit.

"What humanity needs is ideals. Idealism is the force that will free us from material fetters."

The inventor spent the day as usual. He went to bed at 5:30 A. M. and rose again at 10:30, after five hours' rest. However, he did not spend the entire five hours in sleep.

"I rolled around in bed," he confessed, "and worked on my problems."

The New York Sun July 14, 1931

Linking the Planets.

What NIKOLA TESLA said on his birthday about the possibilities of sending electric power to other planets is likely to seem to most persons no more than a fantastic dream. For centuries, indeed, interplanetary communication has been one of man's most fascinating and persistent dreams, each advance in aeronautics and radio seemingly bringing nearer its realization. TESLA'S admission that he has developed a means which will enable man to transmit electric energy from this globe to another planet may arouse anew all the old speculations about what kinds of living creatures, if they inhabit other worlds in space

A few moments sober thought on the problem of sending power waves to another planet leaves the lay mind baffled as to how the enormous difficulties ever can be overcome. Assuming that energy from dynamos on earth could be thrown through space millions of miles to Mars or to Venus, man has no assurance whatever that any living creatures on those planets will know where the power comes from. Perhaps it would strike the other celestial body like lightning out of a clear sky.

Surely there is not the slightest reason for mankind to believe that the creatures which may inhabit Mars, for instance, have progressed far enough in mental power to create electrical apparatus. This idea supports the doubt that another planet could reply to any communication it received from the earth. Further speculation on this aspect of the problem leads to a possibility even more discouraging. Perhaps life on Venus or on Mars, if it exists there, is in an early stage of evolution and is no more aware of the universe in which that globe moves than an ant crawling on earth is aware of the human world. It is almost inevitable that mankind should imagine the creatures of another planetary body to be of human proportions and with human faculties; yet the primordial heritage of man may make him unique in the universe so that communication with creatures of another globe would be as unthinkable as any intelligible human communication with the fish of the sea.

Some definite response is what man on earth would most earnestly seek from any other living creatures in the universe. Merely sending waves of power to a dead moon would give slight satisfaction, however marvelous it might be from a scientific standpoint. But suppose communication with Mars actually was achieved, what would be the most desirable kind of response? Perhaps the thing that would satisfy man's intensest curiosity concerning life on Mars would be a radio photograph of a Martian

Tesla Nearly Missed His Calling

Former Roommate in University Tells of Inventor's Early Life.

By CHARLES M. MEISTER

Special Correspondence to THE SUN.

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BELGRADE, Aug. 16.—Nikola Tesla, who, just before his seventy-fifth birthday, announced in America a new invention which he expects to revolutionize power production, narrowly escaped on several occasions a premature end to his scientific career.

His father was an Orthodox priest, and his mother the sister of an Orthodox bishop. They wanted him to become a priest. At one time he seemed likely to become an invalid. Later he ran away from his university and settled down as an engineer's assistant at sixty florins a month.

All this has been revealed here by Prof. Kosta Kulishich, who was Tesla's roommate when they were both studying together at Gratz, Austria. Tesla and Prof. Michael Pupin are the American-Jugoslavs regarded here as having brought the greatest honors to the race.

The inventor was born at Smilyana, in Croatia, which was then ruled by the Hapsburgs. He studied in the German primary school of the village, and was later sent to higher schools. After he finished high school his health was so bad that he was forced to remain at home for two years. It was after this period that his father asked him to study theology. Tesla refused, saying that he wished to become a teacher of physics. Because of his ill health his wishes were granted, and he matriculated at the technical faculty in Gratz.

Made 'Whoopee' on Coffee.

He and Prof. Kulishich, then a student of philosophy, became acquainted as members of the student society Serbia, and decided to room together in order to reduce their expenses. At first Tesla was very studious. His professors praised him for this, and the jealousy of other students was aroused. One day, when he was loitering in the halls of the college building, a German student slapped him on the back and said:

"You are wasting your time here. It would be better for you to go home and sit and study, so that your professors could praise you more."

"I know I can study better than you, but I'll show you that I can also be better at having a good time," Tesla said. The Serbian word he used is almost the equivalent of "making whoopee."

This usually includes a certain amount of drinking, but Tesla drank nothing but coffee. He began to stay late at the Botanical Garden, the students' favorite coffee house, playing cards, billiards and chess. His skill was such that a crowd always gather round to watch when he was playing.

Even during this period, however, he seldom missed a lecture, which is a rare record in Continental universities, where students may miss as many as they like.

On Sunday mornings, when the roommate lay late in bed, Tesla would pester Prof. Kulishich with questions about electrical matters. The roommate, who was interested in philosophy, never understood these conversations, although they continued every Sunday.

Disappears From Gratz.

Tesla's cafe activities did prevent him from studying, but he failed to pass his examinations as soon as he had been expected to. Cousins who had been sending him money, therefore, withdrew their aid. Tesla feared that his parents would do the same, and disappeared. Friends searched everywhere for him, and decided that he had drowned in the river.

His roommate discovered him by chance, thus probably preventing a great loss to science. Prof. Kulishich tells of the discovery as follows:

"Petar Resh, the director of the commercial school at Maribor, advertised for a teacher of geography and Italian. I went to Maribor to apply for the job. Passing by a cafe, I saw Tesla playing cards with two men.

"'Where have you been, Tesla,' I asked. 'We have been searching for you everywhere.'

"'I am satisfied with my present position,' he said. 'I am working for an engineer and earning sixty florins a month.'

"'But you must return to Gratz and resume your polytechnical studies.'

"'Well, we shall see about that,' said Tesla.

"I informed his family, and his father went to Maribor and persuaded him to study somewhere else. Tesla went to Prague, where he passed with the highest marks."

Joins, Then Quits Edison.

The inventor tried teaching for a year, but did not like it. He got a job in Budapest with a state telephone service, and there made his first invention, a device to increase the sound of the voice in the telephone receiver. Then he went to Paris, with the Continental Edison Company.

This resulted in his going to America. He found an improvement in the electric dynamo, and this was reported to Thomas A. Edison. The American genius was skeptical, because of Tesla's youth, but said that if he would prove his claims in New York he would receive $100,000. Tesla went at once, and succeeded so well that Edison paid him $70,000, and gave him a position in his laboratory.

The two men could not agree, however, and in 1885 Tesla founded his own company. His subsequent achievements in the electrical field are well known.

The chance which led to his discovery of the rotary magnetic field is probably not so well known, as Tesla seldom talks of his life or work.

Finds Rotary Magnetic Field.

His first home in America was a garden which Tesla decorated, in the continental fashion, with colored glass balls on sticks. Children broke in and stole the balls, so Tesla replaced them with metal ones. The stealing continued, however, so Tesla ordered his gardener to bring them into the house every night.

One evening the servant placed several balls on a transformer and was startled to see them move. He rushed to tell Tesla, who began investigations which revealed the rotary magnetic field.

His inability to get along with Edison may have been due to an independence of nature which asserted itself in his student days, and probably led to one of his inventions. When he was studying at Gratz the Gramov dynamo had just been introduced. A professor, discussing it for the benefit of the students, declared that it could not work without brushes and accumulators. Tesla asserted that it could and refused to yield to academic authority. Later he invented the brushless dynamo.

SEA-POWER PLANT DESIGNED BY TESLA

He Holds Steam Can Be Made Economically by Using Different Temperatures of Ocean.

PLANS LAND DEVICE, TOO

Both Embody Improvements in Wollaston's Toy, Says Scientist—Tests to Be Made Soon.

Designs of two new power plants, one to utilize the heat below the surface of the earth, the other to take advantage of the difference in temperature between upper and lower levels of the ocean, are announced by Dr. Nikola Tesla, the inventor, in an article in the December issue of Everyday Science and Mechanics, out tomorrow.

While many attempts have been made in the past fifty years to devise ways to utilize the heat energy of the ocean and the interior of the earth, Dr. Tesla said his designs embodied improvements which would make it possible to supply power from ocean and terrestrial sources on an economical basis in competition with other sources of power.

Only last year Professor Georges Claude of Paris constructed at Matanzas Bay, Cuba, an experimental plant for the purpose of harnessing the temperature differences in the tropical seas for power purposes. Several engineers, Dr. Tesla among them, are of the opinion, however, that the Claude plant, while workable, is too expensive to produce power on an economical basis. Dr. Tesla said his own designs do away with the most expensive and objectionable features of former experiments.

Temperatures in Tropical Seas.

"It is well known," Dr. Tesla writes, "that there exists, in tropical seas, a difference of 50 degrees Fahrenheit between the surface water and that three miles below. The temperature of the former, being subject to variations, averages 82 Fahrenheit, while that of the latter is normally at least 32 degrees Fahrenheit, or nearly so, as the result of the slow influx of the ice-cold polar stream.

"In solid land these relat[ive] temperature[s] [are] [re]versed. [For] [eve]ry degree Fahrenheit [in]crease sixty-four feet of descent. But while all this was common knowledge for at least seventy-five years and the utilization of the heat of the earth for power purposes a subject of speculation, no decided attempt to this end seems to have been made until an American engineer, whose name I have been unable to ascertain, proposed to operate engines by steam generated in high vacuum from the warm surface water and condensed by the cold water pumped from a great depth. A fully and carefully worked out plan of this kind, supported by figures and estimates, was submitted by him to prominent capitalists and business men of New York about fifty years ago."

Water can be made to boil at temperatures much below the normal boiling point of 212 degrees Fahrenheit by subjecting it to a vacuum which causes ebullition at any temperature, however low.

"This behavior of water, or liquids in general," says Dr. Tesla, "was long before beautifully exemplified in the classical device called 'cryophorus,' consisting of two communicating and exhausted bulbs partially filled with liquid, which is evaporated in one and condensed in the other. It was invented by W. H. Wollaston, a great English scientific man and investigator (1766-1828), who first commercialized platinum, and was credited by some to have anticipated Faraday in the discovery of electromagnetic rotation.

"The original instrument brought out at the beginning of the nineteenth century had one of the bulbs packed in ice with the result of freezing water in the other. In conformity with the views of that time it was thought that the cold of the ice was carried to the water, and so the Greek name, meaning 'cold-carrier,' was given to the device. But now we know that the process is of opposite character, the freezing being brought about by the transport of the latent heat of evaporation from the warm to the cold bulb. One would naturally infer that the operation would cease as soon as the water is frozen at the surface, but curiously enough the ice itself continues to yield steam, and it is only because of this that all of the water is solidified."

A Toy on a Huge Scale.

The ocean plant originally proposed by the French engineer, Professor Claude, and Dr. Tesla is no more than Wollaston's scientific toy on a huge scale, Dr. Tesla points out, adapted for continuous operation and having an engine interposed between the two communicating vessels.

The principal parts of Dr. Tesla's designs consist of a vacuum pump, a turbine, a condenser and a generator. The plan for the ocean plant has as one of the novel features a tunnel dug to the level of the cold waters, which in the design for the terrestrial plant is substituted by a heat-insulated shaft, extending a mile or less below the surface.

The vacuum pump starts the sea water boiling at surface temperature. The steam thus generated is directed [to] the turbine, which it turns, [and] on to the condenser. The [re]sult arrangement the cold [wa]ter from the depths is made to come to the surface through the tunnel and to the condenser, thus condensing the steam exhausted by the turbine. The turbine is connected with the shaft of a generator, in this manner transforming heat energy into mechanical and electrical energy.

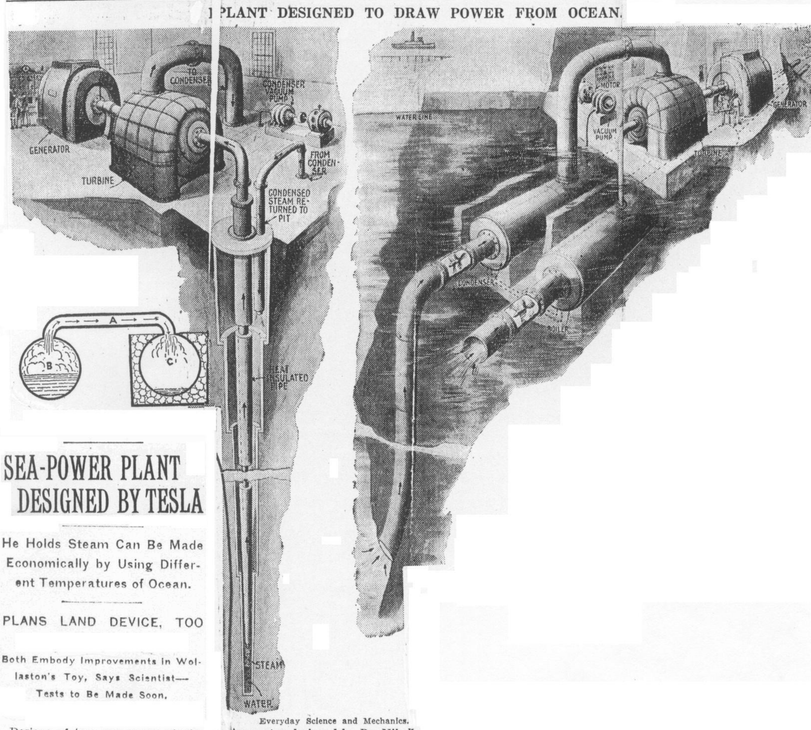
In the terrestrial power plant water is circulated to the bottom of the shaft, returning as steam to drive the turbine, and then returned to liquid form in the condenser, in an unending cycle.

Asked what constituted the chief improvements in his designs over those of his predecessors, Dr. Tesla said:

"First of all, I do away with the necessity of lifting the water which has heretofore involved the expendi-

Continued on Page Three.

PLANT DESIGNED TO DRAW POWER FROM OCEAN.



Everyday Science and Mechanics.

Apparatus designed by Dr. Nikola Tesla by which it is proposed to utilize the warmth of one layer brought into contact with the coldness of another to operate great power plants.

Continued from Page One.

ocean owing to ebb and tide. The quantity of water necessary is so enormous that it cannot be supplied with sufficient economy by centrifugal pumps, which had been heretofore proposed.

"The second improvement consists in employing screw propellers which, being rotated in solid water, can operate with an efficiency of 87 per cent. Thirdly, I do away with pipelines, which are limited in size and are otherwise objectionable, and bring the cold water up from the depths through a tunnel which is permanent and reduces greatly resistance to flow.

"A fourth improvement is the adoption of a form of apparatus which lends itself to very large units, 100,000 or 200,000 horsepower, if desired, and thus effect all those savings which are secured in this manner, and with which power engineers are thoroughly familiar.

"In embodying these improvements in my system I also dispense with other drawbacks and difficulties, such as degasification of the water and the excessive moisture in the steam. I may mention, furthermore, that I secure a perfect automatic control of the power without the usual complex appliances, by placing the condenser a little higher than the boiler, so that the condensate flows into the latter automatically through a pipe connection, without [a] pump, [it] is still too [un]der present exceptionally [low] prices [in]dustrial. However, a plant embodying all these improvements can, I believe, successfully compete with fuel under normal conditions. It must be borne in mind, however, that the ocean power plant is not perfectly constant in its performance as there are seasonal and also casual variations.

The Terrestrial Power Plant.

"For these, and other reasons, the utilization of terrestrial heat on solid land is very superior. After thirty years I have developed a plan which enables me to derive by means of a shaft of given depth many times the amount of power obtainable according to plans heretofore proposed either by myself or others, including those of Charles Parsons.

'Instead of placing the boiler at the bottom of the shaft, and so limiting the influx of heat, I utilize the heat flowing into the whole shaft, which is many times greater, of course, to generate steam. The arrangement is of ideal simplicity. The steam is drawn from the bottom of the shaft through a heavily insulated pipe to a turbine on level ground. From the turbine the steam is discharged into the condenser and the condensed water flows by gravity through another insulated pipe reaching to a depth at which the temperature of the ground exceeds that of the condensate.

"By circulating the steam in great volume through the turbine and condenser I am able to maintain a considerable temperature difference between the ground and the interior of the shaft, so that a very great quantity of heat flows into the same continually, to be transformed into mechanical work. The only requisite is a sufficient volume of condensing water, and this problem is the more easily satisfied the colder the climate.

"With my improved method it is practicable to supply all the power which a small community may require from a shaft of moderate depth, certainly less than a mile. And for isolated dwellings a few hundred feet depth would be ample, particularly if such a fluid as ether is employed for running the turbine.

"The power obtained by this method is ideal on account of its perfect constancy and the elementary simplicity of the whole plant. I have been for some time engaged in making estimates of costs of installation, and I find that it would not be prohibitive by comparison with other sources of power."

Dr. Tesla made it clear that neither of the two proposed power plants has anything to do with the work he is conducting on a new source of power, about which he told THE NEW YORK TIMES on the occasion of his seventy-fifth birthday, July 10, 1931. He confessed rather reluctantly that he is taking steps for making practical tests for both the terrestrial and ocean power plants in the near future.

The New York Sun June 22, 1932

WILLARD AND TESLA ADVOCATE REPEAL

B. & O. Head and Edison's Aid Condemn Prohibition.

Daniel Willard, president of the Baltimore & Ohio Railroad, and Nikola Tesla, the inventor, have come out openly against the Eighteenth Amendment.

Mr. Willard took the view yesterday that the modification of the law must be obtained before business conditions can become satisfactory again. Mr. Tesla looked at it from a medical stand, saying that the curtailment of alcoholic beverages removed a "harmless stimulant" from the nation's diet.

Mr. Willard said that he was inclined to be sympathetic with the thought that the revision of the amendment is necessary to economic recovery.

"The American people," he asserted, "have been going through a severe school of experience in this connection during the last ten or twelve years and I am inclined to think that they have very nearly reached a common accord concerning a number of essential points related to this problem. I am quite certain that no one today would wish to see the saloon restored as it was before prohibition."

Mr. Willard later deviated from the subject of prohibition to speak hopefully of the work of the Reconstruction Finance Corporation in balancing the budget. He also advocated an extension of the moratorium for foreign debts which he predicted would have a stimulating effect upon the business of the world.

Mr. Tesla, the seventy-five-year-old former associate of Edison, said that before prohibition went into effect he had drunk enough "to form a lake of no mean dimensions." However, he obeyed the provisions of the Volstead act, with the result that it was six months before he was able to digest a meal.

"I feel sure that if everybody had done the same," Mr. Tesla continued, "millions of Americans would have shortened their life psan and thousands would have died in the first two years. A sudden change of diet or the omission of one of its important elements, especially in advanced years, is extremely dangerous."

The New York Times June 22, 1932

TESLA, INVENTOR, 75, ATTACKS DRY LAW

Edison's Former Associate Sees Fallacy in Restriction on 'Harmless Stimulant.'

Nikola Tesla, 75-year-old inventor, whose discoveries made possible the transmission and use of alternating current, went on record yesterday as being "emphatically opposed to prohibition."

In an interview at the Hotel Governor Clinton, the former associate of Thomas A. Edison declared prohibition was unsound in principle since "it imposes restrictions on the most needed and harmless of stimulants while permitting unlimited consumption of poisons, by all classes, from chiidhood to old age."

Prior to the enactment of the dry law, Mr. Tesla said, he had consumed alcoholic beverages sufficient to "form a lake of no mean dimensions." Rather than become a lawbreaker, he obeyed the provisions of the Volstead act, but six months passed, he declared, before he could digest a meal.

"I feel sure that if everybody had done the same," Mr. Tesla continued, 'millions of Americans would have shortened their life-span and thousands would have died in the first two years. A sudden change of diet or the omission of one of its important elements, especially in advanced years, is extremely dangerous.

The New York World-Telegram July 9, 1932

Tesla, Sure Life Exists on Other Planets, Works On at 76 to Establish His Belief

Energy Transmission Is the First Requisite, Says Veteran Scientist.

By WILLIAM ENGLE,
World-Telegram Staff Writer.

Nicola Tesla discussed communication between the earth and other planets today as if he regarded this as a feat no neater than telephoning to the cordial shop around the corner.

Tomorrow he will be 76. It will be forty-six years since he came, a shy, unheralded youth, from the Province of Lika, in Eastern Austria. But the fire of his tremendous endeavor seemed to burn as fiercely this morning as it has any time down the years in which he has established his prominent place among scientists.

Interplanetary communication is only one phase of that endeavor, he hurried to say. Annihilation of distance, he said, sums it up; annihilation of distance by transmission of energy.

Certain of Life Elsewhere.

"I am in dead earnest." He spoke quietly and carefully. "I feel certain of what I tell you.

"The transmission of energy to another planet is only a matter of engineering. I have solved the problem so well I don't regard it as doubtful."

He is certain, too, he said, that there are creatures on other planets whose ways are like the ways of those on this one.

"It is mathematically certain that other planets are inhabited. Every other planet has to pass through practically the same phase of existence the earth did, and life is started on them, during that favorable phase, by rays of some sun.

"It develops in the presence of moisture and heat and light in much the same manner as life does much about it. As it always did, it concerns fundamentals; the application may come decades after his success in principle, as it has in radio and high-tension electricity.

"I'm giving all my time to annihilation of distance. Same as ever. To my mind that's the most important achievement to be hoped for in the furtherance of the intellectual development of man, as well as in the promotion of his material welfare.

Radio Just a Step.

"The wireless art already fulfills this in a large measure, but we must establish transmission of power in all its innumerable applications.

"This has been my life work and I hope to see its full fruition before I am gathered to my forefathers."

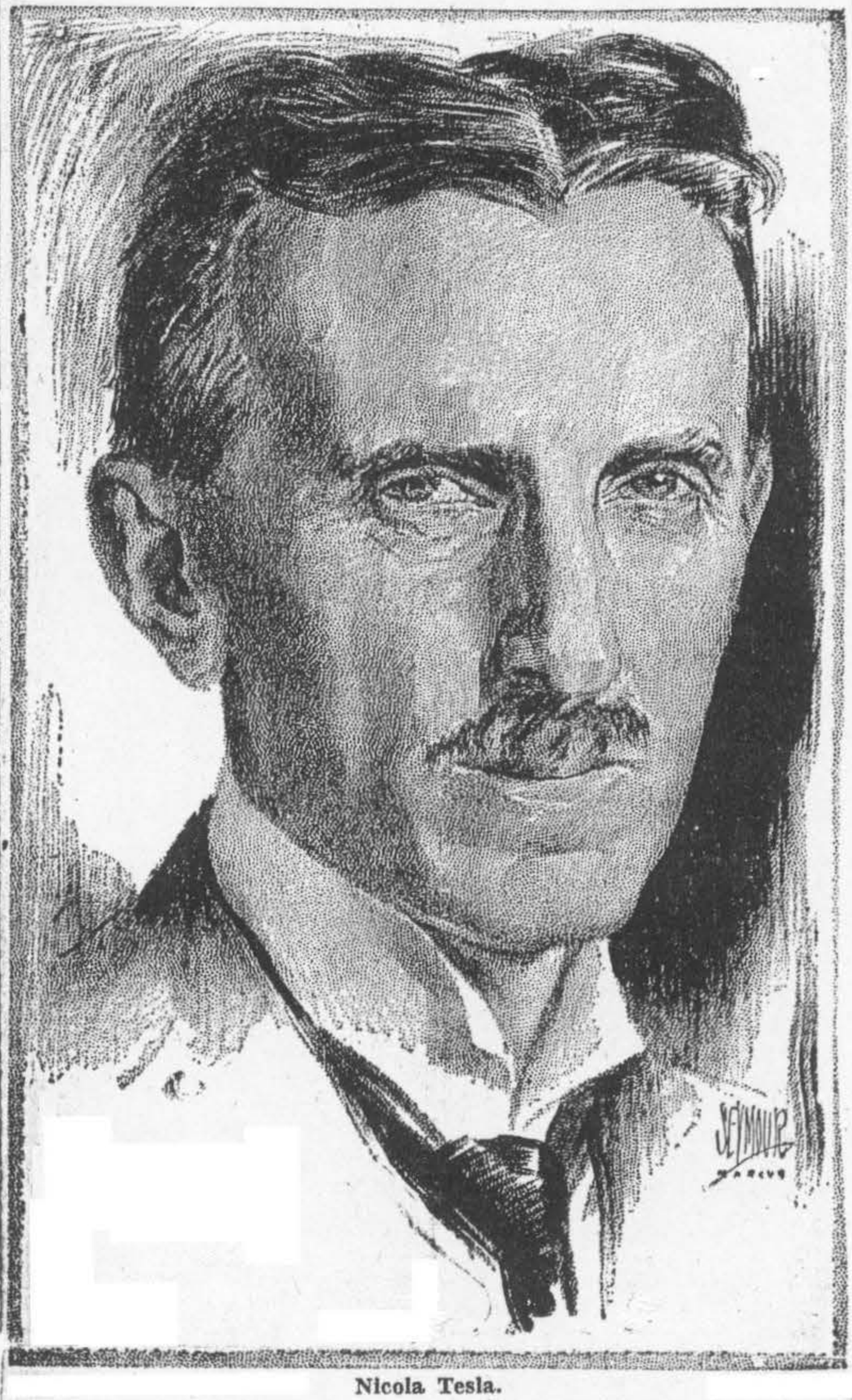
Spruce and slim, with cane and gloves and a tailored air, he did not look 50 as he rose and stood by a desk on the mezzanine floor of the hotel where, a recluse among millions, he takes cover.

Longs for His Wine.

About him there was none of the traditional coldness of the pure scientist. He felt, he said like a boy.

Why? Well, no coffee and no tea, for one thing. Another, he has never been married. He would be even more fit, he thinks, if they had not taken his wine away.

"Just the same I could climb a tree 100 feet tall."



Nicola Tesla.

The New York Times July 10, 1932

TESLA, 76, REPORTS HIS TALENTS AT PEAK

Says His New Invention, Almost Done, Will Come as "100,000 Trumpets of Apocalypse."

WILL BENEFIT STEEL TRADE

Second Discovery Would Knock Down "Walls of Jericho"—Holds Interplanetary Contact Near.

Nikola Tesla, dean of American inventors, either was 76 years old yesterday or will be today (he does not know which because he was born on the stroke of midnight), and in a self-deprecatory interview last night at a midtown hotel, where he lives, he told a little of his activities of the last year and his hopes for the future.

He expects that future to be long and productive, because it is no uncommon thing for the countrymen of his birthplace, Smiljan, in the mountains of Czechoslovakia, to live to 110 or 120, and he believes that he has more energy and alertness than ever before in his life.

"I have had a very successful year," he said with the enthusiasm of one a third his years. "I have made two inventions, among the most important of my life.

"When they are announced, one will be like the 100,000 trumpets of the Apocalypse. The other will be less sensational, but it, too, will be important. It will be like the shout with which Joseph's army brought down the walls of Jericho.

"I am elated. The practical success of these inventions is almost achieved. I hope to be able to make them known within the next year."

Invention Would Aid Steel Trade.

Dr. Tesla would not disclose the nature of these inventions in detail. He intimated that the more important of them had to do with molecular physics and that it would be of the utmost benefit to the steel industry.

"When applied in certain ways," he said, "it will yield greatly improved products and obviate much waste."

The other invention would result in a saving of energy, he said. It had nothing to do, he explained, with the problem on which he has long been working—the tapping of a tremendous and thus far unused source of energy. He has been working on that during the last year, he said, and has made great advances both in its practical application and in the theory underlying it. As to this new source of power, he said:

"When the time is ripe I propose first to announce the scientific principles underlying it only. Later I shall show its practical application through the forms of power generating apparatus. If I succeed, the world will see machines against which the largest turbo-dynamos of today will be mere playthings."

In response to questioning, Dr. Tesla said that one invention on which he had been working recently would permit the generation of all kinds of rays of almost unlimited intensities, and would afford a check on whether the present theories of atomic structure are true and workable or merely a fabric of the imagination.

Recalls His Youth.

The inventor of the arc lighting system, of the system of alternating current power transmission, the Tesla coil, of a system of wireless communication and of wireless power transmission systems, allowed his thoughts to rove back over the beginning of his career and when he was a small boy on the Austro-Hungarian border. Then he allowed them to look into the future, in which, within the lifetime of the younger generation he is convinced there will be communication among the planets.

"When I was 9 years old," he related, "I built a turbine in a mountain stream on my father's land and connected it up with bolts to all sorts of machinery. I told my uncle, 'Some day I'm going to America and I will run a big wheel at Niagara Falls.' I had read about Niagara Falls and it fascinated me. My uncle didn't take it seriously. 'You'll never see Niagara Falls,' he told me.

"But I did come to America, and I did put a big wheel in Niagara Falls."

Dr. Tesla, at the height of his career, designed the great power system at Niagara, and perhaps no boyhood dream ever was more tremendously filled than his.

The inventor's conviction of many years' standing that there is life on other planets in the solar system and that some day we will communicate with other planets has not lessened. Means of communication will readily be found, he said, and there will be no difficulty in establishing an intelligent exchange of ideas. He indicated that this might be done through some form of television which would transmit ideas much as moving pictures tell their stories to races of diverse languages.

"I have a sense that we are on the eve of a great revelation," he said, speaking of the possibility of interplanetary communication. "Whether I will live to see it is a question, but you, as a younger man, will see it. And the news of it will be the greatest sensation in the world's history."

The New York World Telegram August 10, 1932

Chewing Gum More Fatal Than Rum, Says Tesla

World-Telegram Aug 10 1932

By NIKOLA TESLA

(Nikola Tesla, dean of inventors at 76 and pioneer of radio, believes that it is essential for the welfare of the country that prohibition end soon. In this article, which he wrote for the World-Telegram, he expresses somewhat unusual arguments against it.)

MUCH has been said about prohibition and its disastrous consequences, but the sheer folly and perniciousness of this measure cannot be fully appreciated until it is considered from the scientific point of view. It then appears not only unsound in principle but utterly devoid of validity.

Chiefly as a result of dry propaganda people have been led to believe that alcoholic beverages cause serious injuries to mind and body, while other stimulants, as tea and coffee, are almost harmless. I know from careful observation and lifelong experience that the reverse is more nearly true.

Beginning with the enactment of the Volstead law I have been a moderate consumer of alcohol and it never hurt me in the least. On the contrary it helped me many times effectively over the peak of the effort.

It is in striking contrast in its medicinal and dietetic value to all other stimulants which, without exception, are injurious. Even smoking, snuffing or chewing tobacco will eventually impair the health, though not quite so much as chewing gum, which, by exhaustion of the salivary glands, puts many a foolish victim into an early grave.

But by far the greatest number of victims are claimed by tea and coffee, Dr. Alexander Haig, foremost authority on uric acid and founder of his famous diet, says of the former:—"Tea drinking is just like drug taking, in fact, and has just as terrible and fatal results.

* * *

WOMEN, in particular, should shun tea as it is a means of committing beauty suicide. In this respect coffee is the very opposite, imparting sometimes to the face a fascinating aristocratic pallor.

I have read books and articles depicting the horrible effects of alcohol on human beings, but always found that the few individuals under observation were either hopeless drunkards or had been weakened by heredity and environment. Obviously every form of excess is injurious. Such an investigation, to be of value, should be limited to moderate drinkers who number in legions and experience no ill effects. They are, as a rule, long lived and considered by life insurance companies the safest policy holders.

Alcohol is not a poison, not is it a drug. It is not classed as a poison in books on chemistry.

The truth about alcohol is that it acts as a caustic and a solvent. In small quantities it cleans and sterilizes the alimentary channels, thereby preventing infections, and proves a beneficial stimulant to thought, speech and physical exertion.

Alcohol is produced in the normal chemical reactions of the stomach and can be found in every part of the body, even in the brain of a total abstainer.

It is formed, not as a toxic inimical to life, but as a substance indispensable to vital processes.

* * *

TO illustrate prohibition's utter folly and danger it is only necessary to point out that a sudden change of diet or the omission of an essential element, especially in advanced years, may induce high blood pressures, cause malnutrition or otherwise imperil life. When the Volstead act became a law I realized that, accustomed as I was to alcohol, it would be very difficult for me to break off. Only a few days of abstinence made me a very sick man and my health soon became precarious. Finally, after several months of suffering, little by little I gained and ever since have been a total abstainer.

If an attempt is made to enforce such a law as prohibition and thereby subject a citizen to suffering, danger and possible loss of life he or his relatives should be entitled to substantial reparation and these suits once begun would soon exhaust the treasury.

The Volstead act put the country into panic and unprecedented distress. This is but an unavoidable result of depriving the nation of a revenue of about $2,000,000,000 a year and compelling it besides to pay to bootleggers nearly twice that sum annually. The tyrannical rule is killing business in some of its most important departments. The hotels and similar institutions are being rapidly forced to the wall.

I remember that in Austria a law compelled every community to keep fires going in the streets during an epidemic of cholera.

In the seventies when I myself contracted the disease all the streets of the city were filled with smoke and stench. Nevertheless the inhabitants died in heaps. Prohibition affords a parallel case. It was passed by legislators unacquainted with vital facts of life out of their own sphere. In imposing this measure the legislative bodies have evidently exceeded their authority. Under such circumstances I fail to see why a repeal should be required. Nothing more need be done than to forget the law and so permit it to pass to a state of innocuous desuetude.

Science Turns To Electricity In Cancer War

High Frequency Currents Giving Results, Physical Therapy Congress Hears

Build Up Defensive Cells

90 P. C. of Ills Originate Above Ears, Says Dr. Titus

Application of high frequency electrical current has had "highly beneficial results" in cancer treatment, Dr. Gustave Kolischer, of Mount Sinai and Michael Reese Hospital, Chicago, asserted yesterday at the American Congress of Physical Therapy. Dr. Nicola Tesla is credited as the first person to introduce electrical oscillation in therapy, corroborated Dr. Kolischer's statement during an intermission in the sectional meetings of the congress, which is holding its eleventh annual session at the New Yorker this week.

"In a great many instances," said Dr. Kolischer, "its results surpass anything that could be accomplished by the use of the cold knife, and in cases where technical reasons exclude the use of the scalpel numerous favorable results follow the administration of high frequency current."

Dr. Kolischer pointed out that the death rate, as an immediate consequence of surgical intervention, is considerably lower in electro-surgery.

"There exists in the body a system of specially endowed cells in which reside practically all the defensive potentialties of the body," he asserted. "These cells possess the faculty of digesting cancer cells and of neutralizing the harmful products of these malignant cells. It has been found that it is possible to increase the number of defensive cells by stimulating the organs in which they originally grew. Thus one is in a position to draw an increasing supply of these cells to their use in the cancer region."

The science of physical therapy developed a new line of medical specialists during the last fifteen yea. These men practice what is know as "physical medicine"—treatmen through the various energies rathe than drugs or chemicals. Dr. Victo ay explained this fu ters in medicine."

Gives Doctor Ne

"This treatment through the ...dis adds a pistol to the doctor's equipment for fighting disease," he said. "He has a sword and a gun in surgery and drugs. Now he is even more completely prepared.

"Physical medicine, as it is now called, is the youngest of all branches of medicine, yet one of the most progressive and important. Everything is based on research. The whole thing centers about the fact that through physicotherapy we are able to substitute electro-coagulation for the knife. We can make an incision which is as accurate as with a knife blade, is absolutely sterile, and hasn't the danger of profused bleeding which is ever present in ordinary surgery. The specialist in physical medicine merely applies the discoveries of physics to medicine."

Among the more important weapons used by the physical therapist are the X-ray, the ultra-violet and infra-red rays, radium, and diathermy. The latter is becoming more and more popular among the physicotherapists because through its internal heat it can solve a great many medical riddles that radium, the X-ray or the other rays cannot penetrate.

"In the cure of syphilis or any infection," asserted Dr. Levine, "the ordinary medical doctrine would be to destroy it by internal heat. This could be accomplished by giving the patient malaria fever, but what would be the gain? In his condition he would probably die from the disease. So what can be done? The physical doctor has what he calls a "fever machine" which heats the body internally but does not injure the patient's health. The patient actually has an internal fever, the sort he would have if he were ill with malaria. But he does not have the accompanying maladies, and he does not die of the treatment."

New Instruments Shown

A room, every inch of space occupied by weird instruments on black, shiny cases, displays the varied equipment of the physical therapist on the third floor of the New Yorker. There are lamps and lights for tuberculosis treatment, an important corner in the physical doctor's consultation room. There is a machine for taking off external blemishes and growths by electricity which will remove anything from a wart to a wen. Or if the patient has pneumonia, particularly pleural-pneumonia, there is a machine which sends high frequency electricity through his body until he recovers.

"More than 90 per cent of human ills originate above the ears," said Dr. Norman E. Titus, who is director of physical therapy at the Columbia University College of Physicians and Surgeons. "In the days that were the dawn of therapeutics, such forms of treatment as were available were largely used for the psychic effect upon the patient. In the Temple of Aesculapius there was an anti-chamber wherein the patient had to wait until he had a dream that he was going to get well. Only then was he admitted for treatment.

"The sun and water baths and a massage were the main treatments used for pain and diseases in the ancient days, and they are included in what is known today as physical therapy. The medical profession, until not so long ago, considered it far beneath them to touch a patient with a view to alleviating pain. The idea persisted in the minds of the medical profession that only medicatiop could produce results. As the result, many different kinds of cults have prospered because of the fact that so many human complaints were above the ears. The American Congress of Physical Therapy has spent ten years in weeding out these fanatics and their unscientific disciples who have wiggled into the field of physical therapy."

Seashore Held Healthiest

Dr. William T. Johnson, chief of the department of physical medicine at the University of Pennsylvania Graduate Hospital, gave a paper on "Air Therapy" in which he asserted that people who live near sea level in climates which subject them to extreme variations of heat and coal and varieties of weather are healthier and live longer than those used to uniformity.

"Most people," said Dr. Johnson, "would be happier if they would permit the physiological regulatory mechanism within the body to protect them from changes in the weather. They should accustom themselves to the stimulating influences of cold weather and cold winds. Protection should come from within, not from without. Most people are too temperate conscious."

Dr. Johnson doubted the conclusion of some physicians that certain climates which are over-stimulating are undesirable because persons of certain types develop goiter, pernicious anemia, diabetes and mental conditions which result in suicide. He pointed out that frequently such a climate is beneficial for the majority even though some vulnerable individuals succumb.

A method of treating certain types of neuritis of the arm by the action of ultra-violet light was submitted in a joint paper by Dr. Esther Frankel and Dr. Dsraeli Kobak, of Rush Medical College, Chicago. They found that constant application of the ultra-violet rays would cause pain eventually ease.

The usefulness of radium in treating the diseases of the cornea of the eye was discussed by Dr. Laura Lane, of the University of Minnesota, who explained her method of removing membranes which often grow over portions of the eye following injuries. These membranes, which are in reality scars and through which light will not come, have been successfully removed with radium treatments at Minnesota, she declared.

Dr. Harold Swanberg and Dr. Arthur S. Perley, radiologists of St. Mary's Hospital, Quincy, Ill., offered a joint paper maintaining that radium is superior to surgery in the treatment of certain types of cancer peculiar to women, resulting in 60 per cent cures in cases which were treated before the disease had progressed beyond the point of relief.

Tesla Predicts New Source of Power in Year

Scientist, 77 Tomorrow, to Reveal Result of Half Lifetime's Study Soon

Cheap Energy for All

Declares Generators Will Run 500 Years Unrenewed

Dr. Nikola Tesla, who will be seventy-seven years old tomorrow, looked back yesterday over a lifetime in which he has been variously called a madman and a wizard of electricity and told of his plans for the tapping of a new source of energy so vast and so revolutionary in effect that he predicts he will be remembered for this alone.

This problem he has worked on for thirty-five years and within the next year he will be able to publish his findings, he says, with experimental data that will convince scientists and the lay public alike. What the nature of the new form of energy is he would not say beyond that it was "undreamed of," that it was violently opposed" to Einsteinian physics, that the sun has something to do with it, and that the energy would be available anywhere over the earth's surface in illimitable quantities. The primary cost of securing the energy will be high, the inventor said, but once the apparatus is installed the cost of production will be negligible and the machines will last 500 years.

Possibility of Error Admitted

"There is a possibility of mistake," he said, "but I say that this thing can be done. I am as positive of it as I was of my results when working on the induction motor and the polyphase current. It will be my great work, it will be remembered when all else connected with my life has been forgotten. They thought I was a lunatic in 1896 when I first published a treatise in an electrical review on cosmic rays. Now the scientific journals are full of discussions of cosmic rays and no one calls the authors madmen—they are given Nobel prizes, instead."

Asked how it felt to be so far ahead of his time that he was subject to attacks upon his sanity, Dr. Tesla smiled and said that he had long since ceased to regard it as important.

"I live a life of seclusion," he said. "The opinion of the world does not affect me. I have placed as the real values in my life what follows after I am dead, although it has been given to me to live to see those things which were once scouted accepted as scientific dogma.

"The thing that recompenses me is that my name shall be known to generations yet unborn for the Tesla coil, the Tesla motor, and now perhaps my name will be connected with the absolutely new source of power I am about to present to the world. It is this thought in which I find my happiness and heath. A pioneer does not apply his energies in the way the world is going. Rather he goes against the current. He lets them call him a lunatic. He lets them trample him—if I should ever tell you the inside story of how I had been trampled—but never mind, it was all good for me. I have come through it. I am able to work harder than I worked a year ago. I work now with greater energy and get results more easily than ever before in my life."

Takes Ten-Mile Walk Each Day

Dr. Tesla's appearance bore out his statement about his health. He is tall, rangy, bony. His regimen at seventy-seven calls for working all day in his laboratory in midtown Manhattan and a daily walk of from eight to ten miles in all sorts of weather.

He preferred to talk while walking and lead the way from the Hotel Governor Clinton, where he has his bachelor apartment, up Seventh Avenue amid the hustle of the fur and garment centers. He strode along on his stork-like legs, with the tails of his old-fashioned long coat swinging in the breeze, with a straw hat upon his head and gray gloves in his hand.

A Scientist at 77



Herald Tribune photos—Steffen

Nikola Tesla

In facial appearance he closely resembles Cornelius MacGillicudy, better known as "Connie Mack," high cheekbones, a long, thin face and the eyes of a man who would pierce the secrets of the material world by power of external as well as internal vision. His hair is not yet entirely gray. The mustache that he once wore has been shaved off—it took too much attention, he explained. Later on it became apparent how much this man valued time. "I do not sleep well," he said. "My mind will not let me. It is going night and day. There is no more tyranical thing than a mind that is accustomed to thought. It really seems to resent me falling asleep. It pounds for attention until I wake up again.

The tough fiber that is in him he explained entirely on congenital grounds. It is nothing unusual for members of his family to live to be more than 100 years old. His grandfather died at the early age of eighty-six, following a race on horseback in which he outdistanced the youths of his Serbian village. A hernia developed. "You know, in those days and in that wild country, they did not have the skillful doctors who can take you apart and put you together again," the grandson said.

The distilled results of much living, much thought and communion with the forces of nature found expression as Dr. Tesla dodged in and out o traffic, avoided the hand-trucks of the garment trade, and conducted his peripatetic school.

"I have learned that you cannot break the laws of nature. That is death. Self-preservation is the only rigid law I know of. There is no morality in nature, beyond the necessity of preserving one's self and one's best efficiency. The social contract not to kill others comes under that heading, also. I believe in certain human truths as contained in the Bible but not in revealed religion or in theologies There seems to be an irreconcilable difference between science and that sort of religion.

"Then, too, there is a conflict between science and art. By 'art' I mean a certain integrated idealism. It is a centripetal something, opposed to the endless centrifugal forces of science. Eventually science will fly apart and fall of its own forces. There is too much for any one man to know. It is no longer possible, as in Bacon's day, for one man to take all knowledge as his province. The seeds of decay and disunion are there as the mass becomes too unwieldy—it works like everything else in nature—attractions set up repulsions, backwards and forwards it goes, now one side winning, now the other side.

Science will win in the present setup of things but it will likely carry civilization down with it when it goes. Then art will have to step in, gather up the pieces and carry on. Of course, it is possible that there will be developed scientists who are artists as well. They must realize that there is something dynamic about idealism and apply that dynamism as they would any other force. Then civilization may be able to continue. But I doubt it—forces and counter forces—attractions and repulsions—all say "No."

As he enters his seventy-eighth year, Dr. Tesla confided that he has three projects which he is working on, on the side, as a sort of relief from concentration on his power idea. One is to produce a type of radio transmission which will permit an individual wave-length for everyone of the 120,000,000 persons in the United States, thus brining about private radio telephony; second, a discovery which will revolutionize the science of metallurgy; and third, a project to remake the face of society by exposing the inmost thoughts of the human brain through photographing the retina of the eye by invisible rays.

The idea is that all concepts, in the last analysis, are visual and are photographed on the retina while the thought is held. No one could lie or deceive if this invention came into use.

"After all, they have called me a lunatic before," said Dr. Tesla. "What is one more time?"

The New York Sun July 10, 1933

TESLA CERTAIN OF HIS NEW POWER

Inventor Says Only Details Remain to Be Checked.

The closing of experiments which reveal the availability of a hitherto untapped reservoir of energy, to be developed through simple machines which will last 500 years, was announced today by Nikola Tesla, inventor and physicist. Mr. Tesla chose his seventy-seventh birthday for his announcement, which was in reality an amplification of an announcement first made on his seventy-fifth.

Even now, however, details remain to be checked before the findings may be published and the source of the power revealed. Mr. Tesla has, however, completed and checked the basic experiments, he says, and feels able to announce as a certainty what he would indicate two years ago as only a probability.

He characterized his discovery as "so basic that it will undo the Einstein theory of relativity." The machines will be simpler than "any machines ever invented for the production of power." He added that the initial costs of the machines would be relatively large, but that they would be, for the practical purposes of short-lived man, everlasting. After installation, the machines will cost almost nothing for operation, he added. "There will be unlimited power almost for the asking."

He said, however, that he expected to be considered crazy. "They called me crazy in 1896 when I announced the discovery of cosmic rays," he said. "Again and again they jeered when I discovered something new and then years later saw that I was right."

Mr. Tesla at one time worked with Thomas A. Edison. He is accepted as one of the world's outstanding electrical technicians, who had contributed much of the research on which the practical application of radio is based.

The New York Sun August 5, 1933

THE SUN'S RAYS

SUN AUG 5 1933

They Smiled at Tesla's Radio Vision

Recalling What the Great Scientist Had Prophesied Many Years Ago.

It is not necessary to explore the map to realize that the desolate spot on the far and frozen Anadyr River where Mattern was forced down is indeed remote. For it was beyond the utmost reaches of the radio. Reliance upon that encircling service was considered worldwide, which practically it is.

AUG 5 1933

But it was the misfortune or distinction of the youthful and intrepid Texan who rides clouds instead of cattle to come to earth in a No Man's Land of emptiness and ice beyond the regions of the radio Now and then, but not while the stranded airman was there, nomads pass through, tending their reindeer herds.

When the ice broke on the Anadyr a Soviet river patrol ascended that stream and brought back to a grateful world the tidings that the lone airman was alive and well. Forthwith the radio resumed the interrupted saga.

We who get much of the important world news and some of the pictures of its great happenings by radio forget how recently perfected the service without wires is.

Before wireless telegraphy, under the magical touch of Marconi, became a commercial reality, Nikola Tesla, still living, was conducting experiments in this field in his laboratory in New York. A pioneer and prophet, most of whose predictions have come to pass, Tesla was looked upon by many as a visionary, a sort of modern alchemist.

A newspaperman managed to get a substantial interview with this laboratory explorer. The substance of the inventor's talk was that from tall masts along the coast messages without the use or need of wires would be sent to ships at sea, and even across oceans, as well as continents; that sinking vessels would radio their distress and other ships, receiving these calls giving latitude and longitude, would rush to the rescue.

It was, Tesla forecast, an achievement just in the offing, a first step in the ultimate amalgamation of the affairs of mankind — a whispered protocol preparing the parliament of man.

Although a bit optimistic in radio's ethical effect upon nations and races, the inventor's laboratory demonstrations convinced the usually incredulous reporter that the cosmic lanes might indeed soon be used by coming man to flash his thoughts around the earth.

Hurrying to his typewriter, the reported prepared what he considered a knock-out feature, and took it to a Sunday editor. The man in charge there was a writer who subsequently won fame and fortune with two "best sellers" and other books. Editor and reporter were acquainted. The reception was cordial enough, but the editor said:

"This paper has the reputation of being a yellow journal, a reputation it is trying to live down. We could not afford to print such a piece of inventive lunacy."

Another paper, however, with perhaps fewer scruples then and with little reputation in that early day at stake, accepted and published the "sensational" interview, even adding what was considered then abnormal illustratons to the Tesla dream. It was treated as a semicomic prophecy.

When it is realized that the rejection of the prediction regarding the possible coming of wireless and then its publication in a rival sheet in a spirit of cachination and cartoon were episodes in the careers of men still active in New York (possibly vetoing or caricaturing some newer thing), the pace is apparent at least in man's means of communication.

Now when, as in Mattern's case, a flyer manages to stray beyond radio's far frontier, the nations, forgetting all else save the fate (or folly) of a brave spirit, man their ships and air craft in his search. Whatever his solo flight accomplishes, it has been no mean achievement to stray beyond the most call of the radio.

The New York American November 1, 1933

Device to Harness Cosmic Energy Claimed by Tesla

Predicts New Power Will Soon Displace All Present Fuels; Could Be Wirelessed.

Nikola Tesla, the celebrated physicist, recognized in the scientific world as the foremost living inventor, announces that "at a date not distant" a new source of power will be available everywhere, displacing coal, oil, gas, and the other established fuels of industry. The inventor authorizes the statement that the mechanism which is designed to revolutionize industry will be, when he presents it as his crowning achievement in the field of applied science, the result of thirty years of search and experimentation into and with the mysterious force which for want of a more precise terminology is called cosmic energy.



NIKOLA TESLA
Sees New Power in Universal Use.

"PRESENT EVERYWHERE."

Dr. Tesla said:

"This new power for the driving of the world's machinery will be derived from the energy which operates the universe, the cosmic energy, whose central source for the earth is the sun, and which is everywhere present in unlimited quantities.

"From the actual mechanical apparatus which I have developed for utilizing this energy, the power to drive engines and machines can be transmitted, either by wire or by my wireless system, as preferred, from central plants which may be located wherever desired, to any point on the globe, whether on land or sea.

"When the new power becomes commercially available, there will be no further necessity for depending on coal, oil, gas, or any other of the common fuels.

"NEED NOT BE DISTANT."

"Because no man can foretell with assurance how swiftly or how laggardly a revolutionizing scientific discovery and its mechanical complement will be commercially introduced, it is impossible for me to say how soon the new universal power will be in use. The time, however, need not be distant. The scientific uncertainties and mechanical difficulties with which I have dealt through thirty

Continued on Page 5, Column 1.

s of laboratory search and scientific experimentation have been disposed of.

"I shall not announce the scientific principles of the discovery and describe the mechanical means I have devised for carrying it out, for the present. It is sufficient at this time to say that I have performed experiments and obtained results from which I am able to calculate what the mechanism may be expected to perform. Much, of course, remains to be accomplished, but it is work not necessarily of a creative kind; it can be done by many, and hence development to the point of actual operation may be enormously speeded up.

"WILL FLO WAT NIGHT."

"Night will not interrupt the flow of the new power supply. The disappearance of the sun below the horizon will not shut it off.

"The central-plant engine which will mechanize the cosmic energy and shoot it electrically to the other side of the world or the other side of the street will operate on an entirely new principle, and will develop hundreds of thousands of horsepower.

"Any number of such central plants can be built, so there is no limit to the volume of power which it will be possible to develop for the turning of machinery—for the running of trains and automobiles, the driving of ships, the operating of factories, the myriad different motor tasks now performed by engines and machines which derive their power from the regular fuels of industry.

CITES "ABSURD REPORT."

"My statement of this discovery and invention, the result of nearly a third of a century of scientific toil, should serve to quiet the absurd report which has got about that I have perfected a portable engine which by extricating atomic energy will drive the largest steamship across the ocean. I have smashed probably trillions of atoms, and have definitely determined that they contain no available energy. The theory that they do is a futile dream. But the new cosmic power, the harnessing of the energy of the universe to the machinery of men, that is not a dream."

The world of science lists Dr. Tesla as the discoverer of wireless transmission—now commonly called radio; of the induction motor and the alternating system of power transmission universally employed for supplying electric light, heat and power; of the cosmic ray and other facts of physical science; as the inventor of the "Tesla coil" and scores of other electrical and mechanical appliances which are of the magic of present-day civilization.

WON EDISON MEDAL.

On the occasion of the conferring of the Edison Medal on Dr. Tesla, Prof. E. A. Kennelly, of Harvard University, electrical engineering authority and author, said:

"Tesla is the man who devised the rotating magnetic field that set wheels going round all over the world, and who made the phenomena of high frequency known, a revelation to science and art unto all time."

The New York Times April 8, 1934

AN INVENTOR'S SEASONED IDEAS

Nikola Tesla, Pointing to 'Grevious Errors' of the Past, Explains Radio as He Sees It at Age of 77—He Expects Television

TIMES APR 8 1934

By ORRIN E. DUNLAP Jr.

A TALL, lean inventor in a cutaway walked into his skyscraper parlor thirty-three floors above the sidewalks of New York, laid his black derby on the table, opened the window and then was ready to talk about radio's past, present and future. He was Nikola Tesla, the inventor whose discovery of the rotary magnetic field made possible the alternating-current motor. He described a system of wireless transmission of energy in 1892.

Seven milestones beyond threescore and ten, this electrical wizard, who came to America in 1884, looked back across the years, recalled where theorists often chose wrong paths at the crossroads of science and then turned his thoughts to the future in which television lurks.

A Spectacle That Frightens.

"There is something frightening about the universe when we consider that only our senses of sound and sight make it beautiful," said Mr. Tesla as his furrowed brow indicated he is puzzled with its destiny. "Just think, the universe is darker than the darkest ink; colder than the coldest ice and more silent than a silent tomb, with all the bodies rushing through it at terrific speeds. What an awe-inspiring picture, isn't it? Yet it is our brain that gives merely a physical impression. Sight and sound are the only avenues through which we can perceive it all. Often I have wondered if there is a third sense which we have failed to discover. I'm afraid not," he said after some hesitation in thought.

Looking back to the mauve decade, to the turn of the century when the world was being thrilled with new ideas and discoveries, Mr. Tesla observes a vast change in the art of invention. Man, he finds, in this streamline era of speed, has little chance to think.

* * *

Fruits of Seclusion.

THE big, modern research laboratories are but the incubators of ideas as he has watched them function. Seldom, if ever, he explains, has an original idea of any consequence been born in an elaborate laboratory. The egg of science is laid in the nest of solitude. True, it may later be incubated, hatched and nursed in the million-dollar laboratory.

"It is providential that the youth or man of inventive mind is not 'blessed' with a million dollars," said Mr. Tesla. "He would find it difficult to think. The mind is sharper and keener in seclusion and uninterrupted solitude. No big laboratory is needed in which to think. Originality thrives in seclusion free of outside influences beating upon us to cripple the creative mind. Be alone, that is the secret of invention; be alone, that is when ideas are born. That is why many of the earthly miracles have had their genesis in humble surroundings."

Radio experimenters of this age are following ancient theories, Mr. Tesla believes, and he warns that progress will be more rapid when they discard the old and adopt new ideas. His directions for getting on the right track of radio, television, power transmission by wireless and sundry other branches of science follow:

APR 8 1934

"The fascination of the electromagnetic theory of light, advanced by Maxwell and subsequently experimentally investigated by Hertz, was so great that even now, although controverted, the scientific minds are under its sway. This theory supposed the existence of a medium which was solid, yet permitted bodies to pass through it without resistance; tenuous beyond conception, and yet, according to some, one thousand times denser than platinum. According to our conceptions of mechanical principles and ages of experience, such a medium was absolutely impossible. Nevertheless, light was considered essentially a phenomenon bound up in that kind of a medium; namely, one capable of transmitting transverse vibrations like a solid.

A Question Tesla Asked.

"It is true," said Mr. Tesla, "that many scientific minds envisaged the theory of a gaseous ether, but it was rejected again and again because in such a medium longitudinal waves would be propagated with infinite velocity. Lord Kelvin conceived the so-called contractile ether, possessing properties which would result in a finite velocity of longitudinal waves. In 1885, however, an academic dissertation was published by Professor De Volson Wood, an American, at a Hoboken institution, which dealt with a gaseous ether in which the elasticity, density and specific heat were determined with rare academic elegance. But, so far, everything pertaining to the subject was purely theoretical."

What, then, can light be if it is not a transverse vibration? That was the question he asked himself and set out to find the answer.

"I consider this extremely important," aid Mr. Tesla. "Light cannot be anything else but a longitudinal disturbance in the ether, involving alternate compressions and rarefactions. In other words, light can be nothing else than a sound wave in the ether."

This appears clearly, Mr. Tesla explained, if it is first realized that, there being no Maxwellian ether, there can be no transverse oscillation in the medium. The Newtonian theory, he believes, is in error, because it fails entirely in not being able to explain how a small candle can project particles with the same speed as the blazing sun, which has an immensely higher temperature.

"We have made sure by experiment," said Mr. Tesla, "that light propagates with the same velocity irrespective of the character of the source. Such constancy of velocity can only be explained by assuming that it is dependent solely on the physical properties of the medium, especially density and elastic force.

* * *

Micro-Wave Possibilities.

COMING now to the wireless waves, it is still true that they are of the same character as light waves, only they are not transversal but longitudinal. As a matter of fact, radio transmitters emit nothing else but sound waves in the ether, and if the experts will realize this they will find it very much easier to explain the curious observations made in the application of these waves.

"It being a fact that radio waves are essentially like sound waves in the air, it is evident that the shorter the waves the more penetrative they would be. In 1899 I produced electromagnetic waves from one to two millimeters long and observed their actions at a distance. There has been a great hope expressed by various workers that introduction of these waves will have a revolutionary effect, but I am not sharing the opinion. They will be used, of course, but to a very limited extent. It is manifest that applications of the very short waves will not produce any appreciable effect upon the wireless art.

"Errors" Retard Wireless Power.

What about the possibilities of power transmission by wireless? the inquirer said.

Here again Mr. Tesla blames "a strange misconception of the experts" and "grievous errors" for retarding the idea. He believes that when it is accomplished, the power will travel on long waves and not on the wings of "uneconomically produced" short waves. He said he could vouch that the scheme of wireless power transmission is entirely practical.

"The application of short waves for power purposes," said Mr. Tesla, "involves complicated and expensive apparatus for rectification or frequency transformation, which would make any serious attempt to carry out a project of this kind much more difficult from an economical point of view."

When will television come around the corner? he was asked.

"It ought to be with us soon, and some day it will be on a par of perfection with broadcasting of music." Then with a circular sweep of his arm and added, "There will be large pictures thrown on the wall."

The New ork Sun April 23, 1934

Tesla Predicts Power by Radio

Fosesees It Running Airplanes and Providing Light for Explorers.

Power transmission by wireless soon will give the world undreamed of marvels in transportation and comfort, Nicola Tesla the Jules Verne of modern science, predicted today in an interview with the United Press.

SUN APR 23 1934

Airplanes, freed of the weight and limitations of combustion motors, will soar with unlimited cruising radii high above the Atlantic and Pacific on power supplied by a shore plant.

Whole continents will be lighted at night by a man-made aurora borealis. Oceans will be similarly illuminated.

Explorers hibernating in snow-covered shacks at the south pole, mountaineers scaling virgin peaks, ivory traders penetrating Africa's jungles will carry portable apparatus by which they will "tune in" power, emanating thousands of miles away, to light their lamps.

Development Far Off.

"I may not see these things while I am alive," Tesla said, "but there will be plenty to carry out these undertakings. That I shall not see them is a minor consideration. Contemporary success has very little attraction for me."

It is not a lack of technical development that prevents these wonders from being accomplished now, Tesla said, but only his financial inability to carry them through himself.

"I have spent my life to perfect a system to transmit energy," he said. "I have perfected an entirely new principle in power transmission. My device is capable of transmitting energy, practically without loss, to any distance whatsoever.

"You think I cannot launch this enterprise? I tell you I would have no difficulty, even in the depression. Several syndicates are mine to command. But they want to sell stock to the public. To this I would never consent.

APR 23 1934

Tesla 77 Years Old.

"My attitude is very foolish, I realize, because I am convinced that nothing great can be accomplished without the help of the public. But if I do apply my principle of power transmission I shall do it myself. It is too far ahead just now, and there are too many doubters around."

Tall, thin and austere, Tesla is an imposing figure as he approaches 77 years of age. He works daily at independent research, not connected with any of the "syndicates because I never could invent anything in factories; I couldn't concentrate and concentration is the only way to accomplish anything."

When asked by telephone for an interview, Tesla said he would meet the reporter at the Public Library.

"But will we be able to talk there?" he was asked.

"Surely," he replied.

Oblivious to Passersby.

He wore a black suit, black topcoat, black derby and carried a cane. He glanced around the spacious lobby for a place to sit. He selected a marble bench on the first landing of the stairway. A bum who had drifted in off the street was at one end of the bench, asleep or drunk. A man on another bench nearby put aside his Hebrew newspaper and listened in amazement as Tesla talked earnest-

The New York Sun July 10, 1934

INVENTS PEACE RAY

Tesla Describes His Beam of Destructive Energy

SUN JUL 10 1934

Invention of a "beam of matter moving at high velocity" which would act as a "beam of destructive energy" was announced today by Dr. Nikola Tesla, the inventor, in his annual birthday interview. Dr. Tesla is 78, and for the past several years has made his anniversary the occasion for announcement of scientific discoveries.

The beam, as described by the inventor to rather bewildered reporters, would be projected on land from power houses set 200 miles or so apart and would provide an impenetrable wall about a country in time of war. Anything with which the ray came in contact would be destroyed, the inventor indicated. Planes would fall, armies would be wiped out and even the smallest country might so insure "security" against which nothing could avail.

JUL 10 1934

Dr. Tesla announced that he plans to suggest his method at Geneva as an insurance of peace.

The New York Times July 10, 1934

NIKOLA TESLA 78 TODAY.

Inventor Who Holds 700 Patents Will Spend Day Working.

TIMES JUL 10 1934

Nikola Tesla, whose inventions revolutionized methods of generation and distribution of electrical energy and who is acknowledged one of the greatest inventors of all time, will celebrate his seventy-eighth birthday today. He will spend the day working. He lives at the Hotel New Yorker.

Dr. Tesla was born in Smiljan, in Austrian Croatia (now part of Yugoslavia. He is the son of a Greek father, a clergyman, and a Serbian mother, Georgiana Mandic, an inventor and the daughter of an inventor. In 1884 he came here at the invitation of Thomas A. Edison.

The arc lighting system, the system of alternating-current power transmission and the rotating field and induction motor are among his several hundred inventions. He holds about 700 patents.

JUL 10 1934

Beam to Kill Army at 200 Miles, Tesla's Claim on 78th Birthday

JUL 11

Death Ray Also Available as Power Agent in Peace Times, Inventor Declares

By Joseph W. Alsop Jr.

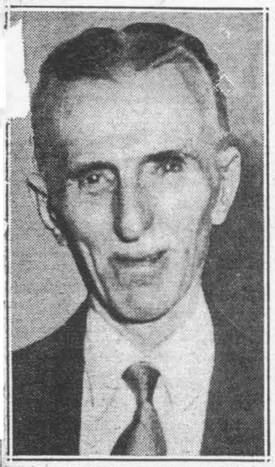
Dr. Nikola Tesla, inventor of polyphase electrical current, pioneer in high frequency transmission, predecessor of Marconi with the wireless, celebrated his seventy-eighth birthday yesterday by announcing his invention of a beam of force somewhat similar to the death ray of scientific romance.

It is capable, he believes, of destroying an army 200 miles away; it can bring down an airplane like a duck on the wing, and it can penetrate all but the most enormous thicknesses of armor plate. Since it must be generated at stationary power plants by machines which involve four electrical devices of the most revolutionary sort, Dr. Tesla considers it almost wholly a defensive weapon. In peace times, he says, the beam will also be used to transmit immense voltages of power over distances limited only by the curvature of the earth.

As a hors d'oeuvre to this Jules Vernean announcement, Dr. Tesla disclosed that he has lately perfected instruments which flatly disprove the present theory of the high physicists that the sun is destined to burn itself out until it is a cold cinder floating in space. Dr. Tesla stated that he is able to show that all the suns in the universe are constantly growing in mass and heat, so that the ultimate fate of each is explosion.

Dr. Tesla refused to describe specifically the instruments in question in both discoveries, or even to disclose the principles upon which they

(Continued on page fifteen)



Herald Tribune photo—Steffen
Dr. Nikola Tesla

JUL 11 1934

Beam to Kill Army at 200 Miles, Tesla's Claim on 78th Birthday

(Continued from page one)

are built. He said that at some date soon he expected to make the full details public in scientific journals or before scientific bodies. Since he considers the beam of force a defensive and therefore a pacifist weapon, he hopes to be able to present it in full for the first time at the [illegible] conference at Geneva. He also said that minor parts of each of the discoveries are still in the theoretical, or blueprint stage, but he pointed out that his method of work has almost always been purely mental.

The aging inventor, a tall, thin, almost spiritual figure in the sort of brown cutaway suit that older men wore before the World War, received interviewers in one of the public rooms in the Hotel New Yorker, where he lives. Before he would speak of his present work he reviewed his past achievements, which entitle him, more than Edison, Steinmetz or any other, to be called the father of the power age. He has 700 patents to his credit, and not a few of them are for epoch-making discoveries, but over and over again he has been ridiculed as a lunatic. He recalled this and his work together as if to prepare the way for his announcements.

He came to the idea of a beam of force, he said, because of his belief that no weapon has ever been found that is not as successful offensively as defensively. The perfect weapon of defense, he felt, would be a frontier wall, impenetrable and extending up to the limits of the atmosphere of the earth.

Creates Rays in Free Air

Such a wall, he believes, is provided by his beam of force. It is produced by a combination of four electrical methods or apparatuses. First and most important is a mechanism for producing rays and other energy manifestations in free air. Hitherto vacuum tubes have always been necessary. Second is an apparatus for producing unheard-of quantities of electrical current and for controlling it when produced. The current is necessary as power for the first mechanism. Without this, no rays of sufficient strength could be produced. The third is a method of intensifying and amplifying the second process, and the fourth is a method of producing "tremendous electrical repellent force."

"These four inventions in combination enable me to close free air forces beyond conception," Dr. Tesla remarked mildly. "By scientific application we can project destructive energy in thread-like beams as far as a telescope can discern an object. The range of the beams is only limited by the curvature of the earth. Should you launch an attack in an area covered by these beams; should you, say, send in 10,000 planes or an army of a million, the planes would be brought down instantly and the army destroyed.

"The plane is thus absolutely eliminated as a weapon; it is confined to commerce. And a country's whole frontier can be protected by one of the plants producing these beams every 200 miles. Nor should they be much more costly than an ordinary power plant."

It Is an Electric Gun

The beam of force itself, as Dr. Tesla described it, is a concentrated current—it need be no thicker than a pencil—of microscopic particles moving at several hundred times the speed of artillery projectiles. The machine into which Dr. Tesla combines his four devices is, in reality, a sort of electrical gun.

He illustrated the sort of thing that the particles will be by recalling an incident that occurred often enough when he was experimenting with a cathode tube. Then, sometimes, a particle larger than an electron, but still very tiny, would break off from the cathode, pass out of the tube and hit him. He said that he could feel a sharp, stinging pain where it entered his body, and again at the place where it passed out. The particles in the beam of force, ammunition which the operators of the generating machine will have to supply, will travel far faster than such particles as broke off from the cathode, and they will travel in concentrations, he said.

As Dr. Tesla explained it, the tremendous speed of the particles will give them their destruction-dealing qualities. All but the thickest armored surfaces confronting them would be melted through in an instant by the heat generated in the concussion.

Some Parts Still Unmade

Such beams or rays of particles now known to science are composed always of fragments of atoms, whereas, according to Dr. Tesla, his would be of microscopic dust of a suitable sort. The chief differentation between his and the present rays would appear to be, however, that his are produced in free air instead of in a vacuum tube. The vacuum tube rays have been projected out into the air, but there they travel only a few inches, and they are capable only of causing burns or slight disintegration of objects which they strike.

Dr. Tesla declared that the two most important of the four devices involved in his force beam generator, the mechanism for producing rays in free air and the mechanism for producing great quantities of electrical current had both been constructed and demonstrated by actual experiments. The two intensifying and amplifying apparatuses are not yet in existence, but he displayed the most perfect confidence that when they are, they will work as he expects them to do.

"These effects," he said, "are of the kind that can be calculated with the most positive accuracy. Like many other things I have done they require no previous experiment once they are properly conceived. There are a few details to be finished—my calculation might be perhaps 10 per cent off at present—and then the whole thing will be presented to the world. It has always been my practice to give the world a sort of preview of what I am doing so that a reception is prepared."

"I should also say, and this is perhaps as important as anything else about it, that in this apparatus all limitations as to electric force and the quantity of electricity transmitted have been removed."

It was evident that Dr. Tesla's work on the force beam as a peace-time means of power transmission was far less advanced than his work on it as a defensive weapon. He did not describe the nature of the receiver which will transform the force beam into useful power, though he declared that he had designed one, nor was he able to show just how the dangers of having such death-dealing but invisible beams traveling through the air could be surmounted.

Dr. Tesla was far less definite in his description of the experiments which led to his revolutionary prediction of the future of the sun and its system than he was when talking of the force beam. He had, he said, detected "certain motions in the medium that fills space, and measured the effects of these motions." The results of the experiments had led him "inescapably" to the conclusion that such bodies as the sun are taking on mass much more rapidly than they are dissipating it by the dissipation of energy in heat and light.

"Heat to Kill All Peoples"

He pointed out that his theory means a future for the earth as different from the general belief as the future of the sun. It is generally held that life on the earth will cease when the sun grows so cold that the earth temperature drops to a point where life can no longer be supported. Dr. Tesla prophesies that life on the earth will cease because the planet will grow too warm to support life, and he believes that life will then begin on outer planets now too cold. He said that his discovery not only allowed him to predict a very different future for the heavenly bodies from that now generally expected for them, but also to calculate in a new way their age.

Nor were these two discoveries, of a force beam and a new future for the universe, the only new things Dr. Tesla had to offer. The completely new and unlimited source of energy which he stated he was at work on is, he said, still under examination by him. Since he first spoke of it great strides have been made, and the complete announcement of it is to be expected in a comparatively short time.

Finally there was the electric bath. The idea of a bath of electricity to cleanse the person far more completely than water ever could has always been at the back of Dr. Tesla's mind. Many years ago he built a machine which performed the function successfully, but, because it cost too much and was not without its dangers, he dropped it as impractical. Lately he has improved it so much that he feels it is now fit for general use.

Works Twenty Hours Daily

"You may think this is a lot of work for an old man like me to have on his hands," he said with a little smile. "You may think I have too many big things—I have told you three—on my hands. But I have worked for sixty years now, and I have worked twenty hours a day. I have such a store of ideas that I can see clearly. I have concentrated on my subject. My brain works better now than it ever did when I was a young man. I am capable of far more than I was in what they call 'your prime.'"

He smiled again. The white, parchmenty skin, drawn tight over a finely built bony structure, creased round his eyes and mouth. He admitted to being a little thinner than last year, but, he explained, every one dries up as time goes on, and there is nothing in being thin that can interfere with work.

He was asked a question about birthday celebrations and congratulations. He had received congratulations from all over the world, he said, but the one which pleased him most was from his sister in Jugoslavia, Mrs. Marica Kosanovic, who is three years younger than he and "the smartest in all our family." He talked for a while of his family, recalling all the inventors there were—five recorded—and students in his ancestry.

"As for celebration," he added, "my only celebration is a little work, and these small disclosures of results."

The New York Sun July 11, 1934

Death-Ray Machine Described

JUL 11 1934

Dr. Tesla Says Two of Four Necessary Pieces of Apparatus Have Been Built.

Amplifying his birthday anniversary announcement of the prospective invention of an electrical death-ray, or force beam, that would make any country impregnable in times of war, Dr. Nikola Tesla says that two of the four pieces of necessary apparatus already have been constructed and tested.

Four machines combine in the production and use of this destructive beam, which, according to Dr. Tesla would wipe out armies, destroy airplanes and level fortresses at a range limited only by the curvature of the earth. These four are:

First, apparatus for producing manifestations of energy in free air instead of in a high vacuum as in the past. This, it is said, has been accomplished.

Second, the development of a mechanism for generating tremendous electrical force. This, too, Dr. Tesla says, has been solved. The power necessary to achieve the predicted results has been estimated at 50,000,000 volts.

Third, a method of intensifying and amplifying the force developed by the second mechanism.

Fourth, a new method for producing a tremendous electrical repelling force. This would be the projector, or gun of the invention.

JUL 11 1934

While the latter two elements in the plan have not yet been constructed, Dr. Tesla speaks of them as practically assured. Owing to the elaborate nature of the machinery involved, he admits it is merely a defense engine, though battleships could be equipped with smaller units and thus armed could sweep the seas.

In addition to the value of this engine for destruction in time of war, Dr. Tesla said it could be utilized in peace for the transmission of power. He had not developed ideas for receiving apparatus capable of transforming the destructive beam into work units, but considered this merely a matter of detail. No suggestion was made of what might happen if an enemy power obtained possession of one of these receiving outfits, and when attacked by the destructive beam simply put it to work in factories manufacturing munitions or uniforms.

Another addition to the anniversary message of the famous inventor was a positive declaration that he expected soon to construct apparatus that would disprove the theories of modern astronomers that the sun gradually was cooling off and eventually the earth would be unable to sustain life, as it would grow too cold.

The New York Sun July 11, 1934

Nikola Tesla, celebrating his seventy-eighth birthday anniversary, is pretty much the same kind of scientist. That is, he hasn't much use for "pad and pencil" scientists. He likes the empiricists, the men who try anything once, and he so classified Edison, with whom he was teamed up for a time.

SUN JUL 1 1934

His are the scriptural prerogatives of both old and young men, as he both dreams dreams and sees visions. He is tall and lean, with burning eyes, as prophets should be, and, when he tells of the whirlwinds of power which man soon is to unleash with a touch of his finger, it makes one think of Michelangelo's hand of omnipotence in the Sistine Chapel—or, less hopefully, of that beast of the Apocalypse, hidden under the back seat of a Ford car in that strange book, "Mr. Weston's Good Wine," by Theodore Powys.

Scientific diet, he says, has freed him from poison and he hopes to live on for many decades. He finds man merely incidentally conditioned to the rotation of the earth and recurrent dark hours, and that doesn't mean that regular sleep is necessary. He himself, busy in his laboratory, doesn't need much—just a cat nap once in a while. He is a bachelor.

He was born in Croatia, with a clergyman-orator for a father and a scientist for a mother. He was slated for the priesthood, ran away from college and got a little mechanical job. He came to New York in 1884 and now, each year on his anniversary, the world notes the fact that modern power generation and distribution have come from his inventions and discoveries. His was the discovery of the rotary magnetic field which made possible the alternating current motor. He has been both a pioneer and prophet. He thinks life exists on other planets.

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The New York Times July 11, 1934

TESLA, AT 78, BARES NEW 'DEATH-BEAM'

Invention Powerful Enough to Destroy 10,000 Planes 250 Miles Away, He Asserts.

DEFENSIVE WEAPON ONLY

TIMES JUL 11

Scientist, in Interview, Tells of Apparatus That He Says Will Kill Without Trace.

Nikola Tesla, father of modern methods of generation and distribution of electrical energy, who was 78 years old yesterday, announced a new invention, or inventions, which he said, he considered the most important of the 700 made by him so far.

He has perfected a method and apparatus, Dr. Tesla said yesterday in an interview at the Hotel New Yorker, which will send concentrated beams of particles through the free air, of such tremendous energy that they will bring down a fleet of 10,000 enemy airplanes at a distance of 250 miles from a defending nation's border and will cause armies of 1 mi[illegible] to drop dead in their tracks.

JUL 11 1934

"Death-Beam" Is Silent.

This "death-beam," Dr. Tesla said, will operate silently but effectively at distances "as far as a telescope could see an object on the ground and as far as the curvature of the earth would permit it." It will be invisible and will leave no marks behind it beyond its evidence of destruction.

An army of 1,000,000 dead, annihilated in an instant, he said, would not reveal even under the most powerful microscope just what catastrophe had caused its destruction.

When put in operation Dr. Telsa said this latest invention of his would make war impossible. This death-beam, he asserted, would surround each country like an invisible Chinese wall, only a million times more impenetrable. It would make every nation impregnable against attack by airplanes or by large invading armies.

But while it will make every nation safe against any attack by a would-be invader, Dr. Tesla added, the death-beam by its nature could not be employed similarly as a weapon for offense. For this death-beam, he explained, could be generated only from large, stationary and immovable power plants, stationed in the manner of old-time forts at various strategic distances from each country's border. They could not be moved for purposes of attack.

An exception, however, he added, must be made in the case of battleships, which, he said, would be able to equip themselves with smaller plants for generating the death-beam, with enough power to destroy any airplane approaching for attack from the air.

Battleships to Be Supreme.

The net result of the latter, Dr. Tesla said, will be to establish the supremacy of the battleship over the airplane, and to make the nation with the largest and best-equipped battleships supreme over the seas. Submarines would become obsolete, he asserted, as methods for detecting them are so perfected that no advantage is gained by submerging. And once found, he added, the death-beam could be employed to do its work of destruction under water, though not as effectively as in the air.

The production of the death-beam, Dr. Tesla said, involves four new inventions, which have not been announced by him. The scientific details of these inventions are to be given out by him before the proper scientific bodies in the near future. In the meantime he gave out a general statement outlining their nature.

The first invention, he said, comprises a method and apparatus for producing rays and other manifestations of energy in free air, eliminating the high vacuum necessary at present for the production of such rays and beams.

The second is a method and process for producing "very great electrical force."

The third is a method for amplifying this process in the second invention. The fourth, he said, is "a new method for producing a tremendous electrical repelling force."

The voltages to be employed in propelling the death-beam to their objective, Dr. Tesla said, will attain the lightning-like potential of 50,000,000 volts. With this enormous voltage, hitherto unattained by manmade means, microscopic particles of matter will be catapulted on their mission of defensive destruction, Dr. Tesla asserted.

The New York Herald Tribune October 6, 1934

Tesla Gets Scott Award For Electrical Inventions

New York Engineer Receives International Medal in Philadelphia

OCT 6 1934

Special to the Herald Tribune

PHILADELPHIA, Oct. 5.—Dr. Nikola Tesla, New York electrical and mechanical engineer, received tonight the John Scott award for invention. The medal and the accompanying $1,000 in cash were presented by the directors of the City Trusts in recognition of Dr. Tesla's discovery of the rotating magnetic field and the development of the induction motor.

Awards also were made to Dr. Robert F. Mehl, of Pittsburgh, director of metals research at Carnegie Institute of Technology, for his development of gamma ray photography, and to Dr. Alfred Newton Richards, professor of pharmacology at the University of Pennsylvania, for his research on the function of the kidney.

Dr. Tesla has brought forth a continuous stream of inventions for thirty-four years. He is now seventy-five. "I still am working on inventions," he told the guests at the dinner tonight. "I have new things which, before long, will revolutionize industry." He refused, however, to divulge the nature of his experiments.

OCT 6 1934

The John Scott awards were established by an Edinburgh chemist of that name. He bequeathed to the City of Philadelphia $4,000, the income of which was to be "laid out in premiums to be distributed among ingenious men and women who make useful inventions."

The New York Times February 6, 1935

Dr. Tesla Gives Home to an Errant Pigeon That Flew Into 40th-Story Room in Hotel

TIMES FEB 6 1935

Early yesterday morning, not long after it started snowing, an apologetic housekeeper on the fortieth floor of the Hotel New Yorker—one flight from the roof—telephoned down to the office that there was a bird in one of the unoccupied rooms. Apparently it had flown in at a window which had been left partly open during the night, she explained.

When the management arrived on the scene the "bird" was perched on the top of a dresser, as unaccountable as Poe's raven, and twice as ambiguous. It was a homing pigeon with a leg-band reading: "I. F. 34 N. U. 1286," and it seemed to have just got in after a long hard flight. It was caught and shut in a bathroom until its legband could be deciphered.

The news of it spread, however. At 7 o'clock, while the management was still trying to face the anomaly of a homing pigeon without a home, a chambermaid was repeating the story to Dr. Nikola Tesla, the 78-year-old scientist, in his thirty-third floor suite. Dr. Tesla, who is fond of pigeons, as the chambermaid knows from experience, promptly called the management and volunteered to take charge of the foundling.

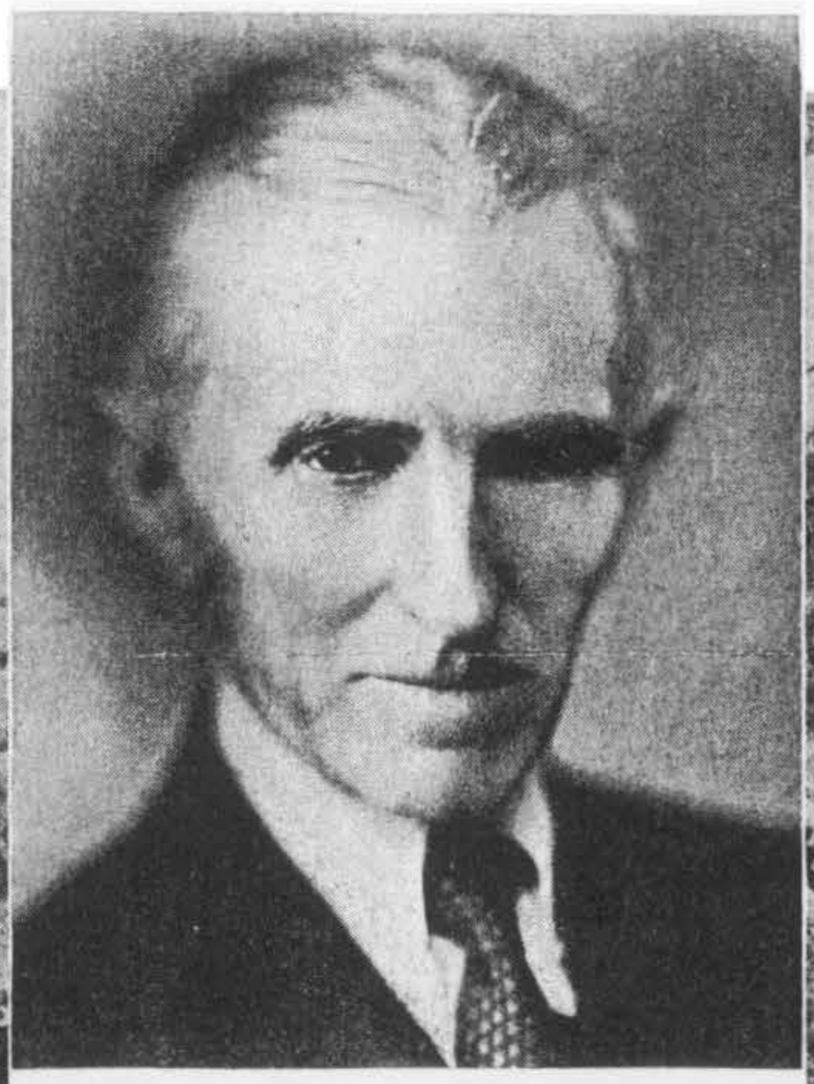
He was afraid it might be sick, instead of merely storm-driven, Dr. Tesla explained, and since he was already keeping one convalescent pigeon in his room, the two of them might be company for each other. The management gratefully assented. After looking over the bird, Dr. Tesla decided that it wasn't sick but hungry and a little upset by having gorged itself, for want of anything more edible, on snow. He decided to keep it anyway.

Though accustomed to walk ten miles daily, Dr. Tesla did not leave his apartment all day yesterday, according to hotel officials. And he is known to have dropped work on a new electrical project he has under way, lest his charge might require some little attention. The man who recently announced the discovery of an electrical death-beam, powerful enough to destroy 10,000 airplanes at a swoop, had carefully spread towels on his window ledge and set down a little cup of seed for his two pigeons.

The first pigeon was found in a dying condition ten days ago and is being nursed back to health. The second, after a good feed and rest, will be able to go along home under its own power, Dr. Tesla said. He admitted that he had made a specialty of treating sick pigeons since he was a lad of 12 in his native Croatian village of Smiljan.



Painting by Harry T. Fisk



Tesla. "It seems," he says, "that I have always been ahead of my time."



A MACHINE to END WAR

A Famous Inventor, Picturing Life 100 Years from Now, Reveals an Astounding Scientific Venture Which He Believes Will Change the Course of History

by NIKOLA TESLA

AS TOLD TO

George Sylvester Viereck

READING TIME ● 11 MINUTES 20 SECONDS

EDITOR'S NOTE: Nikola Tesla, now in his seventy-eighth year, has been called the father of radio, television, power transmission, the induction motor, and the robot, and the discoverer of the cosmic ray. Recently he has announced a heretofore unknown source of energy present everywhere in unlimited amounts, and he is now working upon a device which he believes will make war impracticable.

Tesla and Edison have often been represented as rivals. They were rivals, to a certain extent, in the battle between the alternating and direct current in which Tesla championed the former. He won; the great power plants at Niagara Falls and elsewhere are founded on the Tesla system. Otherwise the two men were merely opposites. Edison had a genius for practical inventions immediately applicable. Tesla, whose inventions were far ahead of the time, aroused antagonism which delayed the fruition of his ideas for years.

However, great physicists like Kelvin and Crookes spoke of his inventions as marvelous. "Tesla," said Professor A. E. Kennelly of Harvard University when the Edison medal was presented to the inventor, "set wheels going round all over the world. . . . What he showed was a revelation to science and art unto all time."

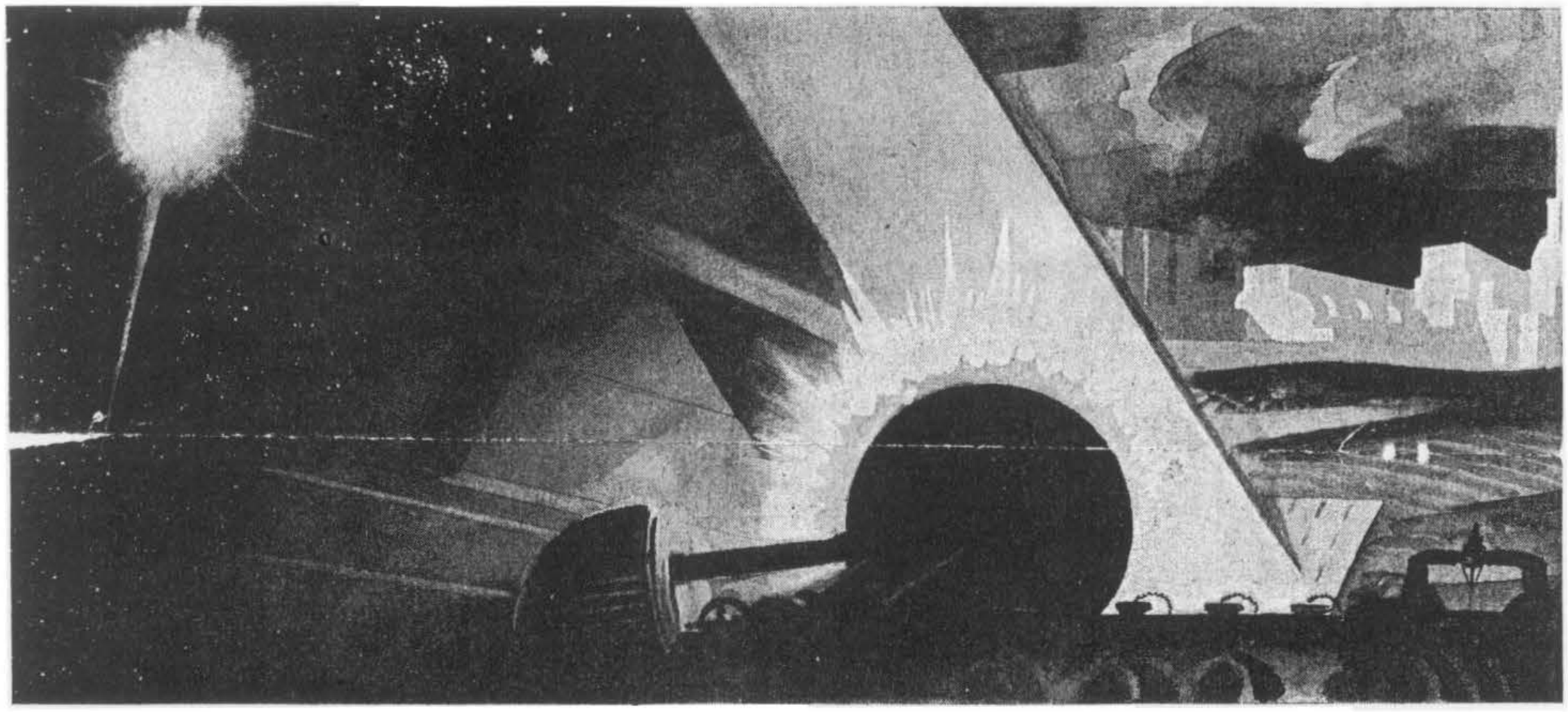
"Were we," remarks B. A. Behrend, distinguished author and engineer, "to seize and to eliminate the results of Mr. Tesla's work, the wheels of industry would cease to turn, our electric cars and trains would stop, our towns would be dark, our mills would be dead and idle."

FORECASTING is perilous. No man can look very far into the future. Progress and invention evolve in directions other than those anticipated. Such has been my experience, although I may flatter myself that many of the developments which I forecast have been verified by events in the first third of the twentieth century.

It seems that I have always been ahead of my time. I had to wait nineteen years before Niagara was harnessed by my system, fifteen years before the basic inventions for wireless which I gave to the world in 1893 were applied universally. I announced the cosmic ray and my theory of radio activity in 1896. One of my most important discoveries—terrestrial ~~resonance~~—which is the foundation of wireless power transmission and which I announced in 1899, is not understood even today. Nearly two years after I had flashed an electric current around the globe, Edison, Steinmetz, Marconi, and others declared that it would not be possible to transmit even signals by wireless across the Atlantic. Having anticipated so many important developments, it is not without assurance that I attempt to predict what life is likely to be in the twenty-first century.

Life is and will ever remain an equation incapable of solution, but it contains certain known factors. We may definitely say that it is a movement even if we do not fully understand its nature. Movement implies a body which is being moved and a force which propels it against resistance. Man, in the large, is a mass urged on by a force. Hence the general laws governing movement in the realm of mechanics are applicable to humanity.

There are three ways by which the energy which determines human progress can be increased: *First,* we



may increase the mass. This, in the case of humanity, would mean the improvement of living conditions, health, eugenics, etc. *Second,* we may reduce the frictional forces which impede progress, such as ignorance, insanity, and religious fanaticism. *Third,* we may multiply the energy of the human mass by enchaining the forces of the universe, like those of the sun, the ocean, the winds and tides.

The first method increases food and well-being. The second tends to bring peace. The third enhances our ability to work and to achieve. There can be no progress that is not constantly directed toward increasing well-being, peace, and achievement. Here the mechanistic conception of life is one with the teachings of Buddha and the Sermon on the Mount.

While I am not a believer in the orthodox sense, I commend religion, first, because every individual should have some ideal—religious, artistic, scientific, or humanitarian—to give significance to his life. Second, because all the great religions contain wise prescriptions relating to the conduct of life, which hold good now as they did when they were promulgated.

There is no conflict between the ideal of religion and the ideal of science, but science is opposed to theological dogmas because science is founded on fact. To me, the universe is simply a great machine which never came into being and never will end. The human being is no exception to the natural order. Man, like the universe, is a machine. Nothing enters our minds or determines our actions which is not directly or indirectly a response to stimuli beating upon our sense organs from without. Owing to the similarity of our construction and the same-[illegible] of our environment, we respond in like manner to similar stimuli, and from the concordance of our reactions, understanding is born. In the course of ages, mechanisms of infinite complexity are developed, but what we call "soul" or "spirit," is nothing more than the sum of the functionings of the body. When this functioning ceases, the "soul" or the "spirit" ceases likewise.

I expressed these ideas long before the behaviorists, led by Pavlov in Russia and by Watson in the United States, proclaimed their new psychology. This apparently mechanistic conception is not antagonistic to an ethical conception of life. The acceptance by mankind at large of these tenets will not destroy religious ideals. Today Buddhism and Christianity are the greatest religions both in number of disciples and in importance. I believe that the essence of both will be the religion of the human race in the twenty-first century.

The year 2100 will see eugenics universally established. In past ages, the law governing the survival of the fittest roughly weeded out the less desirable strains. Then man's new sense of pity began to interfere with the ruthless workings of nature. As a result, we continue to keep alive and to breed the unfit. The only method compatible with our notions of civilization and the race is to prevent the breeding of the unfit by sterilization and the deliberate guidance of the mating instinct. Several European countries and a number of states of the American Union sterilize the criminal and the insane. This is not sufficient. The trend of opinion among eugenists is that we must make marriage more difficult. Certainly no one who is not a desirable parent should be permitted to produce progeny. A century from now it will no more occur to a normal person to mate with a person eugenically unfit than to marry a habitual criminal.

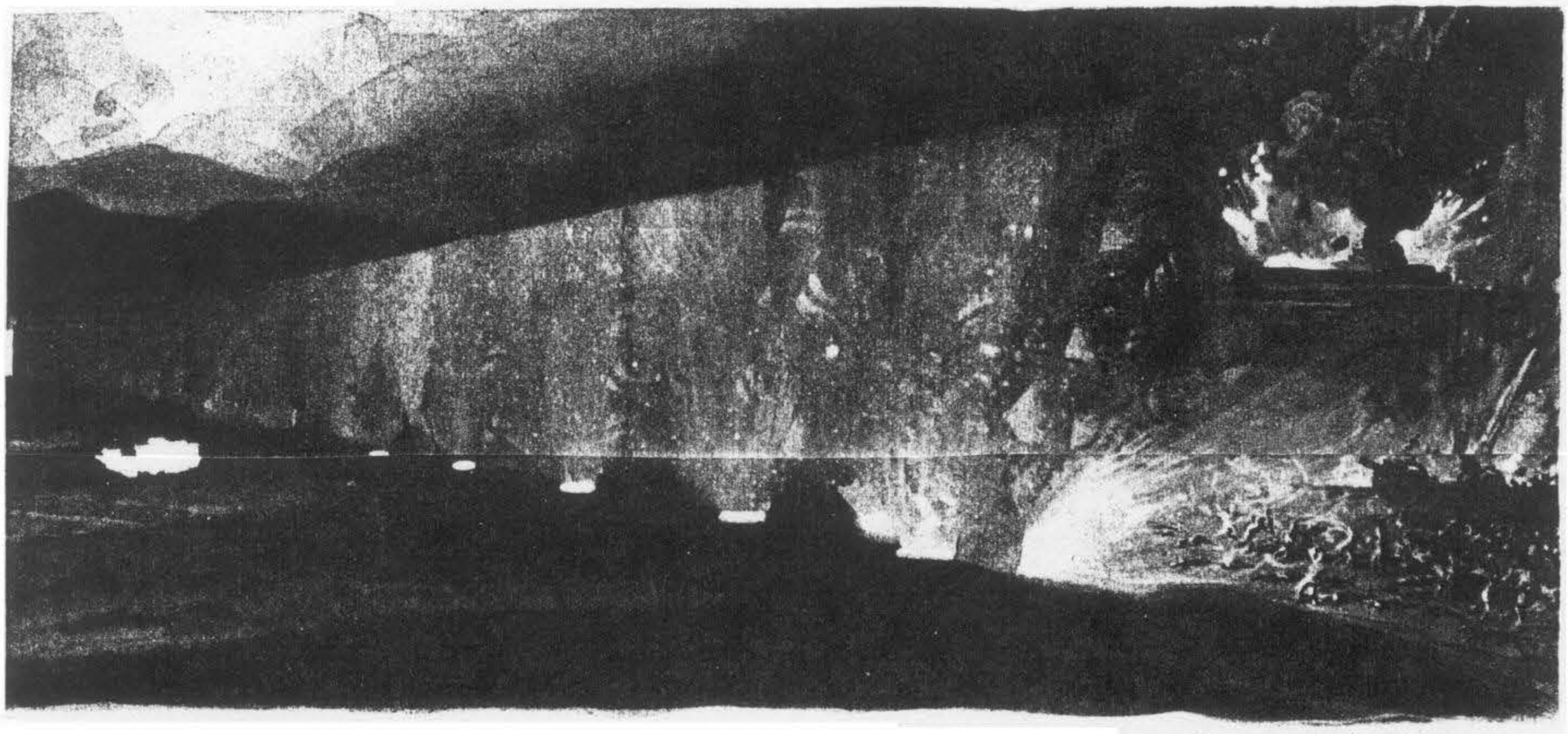
Hygiene, physical culture will be recognized branches of education and government. The Secretary of Hygiene or Physical Culture will be far more important in the cabinet of the President of the United States who holds office in the year 2035 than the Secretary of War. The pollution of our beaches such as exists today around New York City will seem as unthinkable to our children and grandchildren as life without plumbing seems to us. Our water supply will be far more carefully supervised, and only a lunatic will drink unsterilized water.

MORE people die or grow sick from polluted water than from coffee, tea, tobacco, and other stimulants. I myself eschew all stimulants. I also practically abstain from meat. I am convinced that within a century coffee, tea, and tobacco will be no longer in vogue. Alcohol, however, will still be used. It is not a stimulant but a veritable elixir of life. The abolition of stimulants will not come about forcibly. It will simply be [illegible]r fashionable to poison the system with harmful ingredients. Bernarr Macfadden has shown how it is possible to provide palatable food based upon natural products such as milk, honey, and wheat. I believe that the food which is served today in his penny restaurants will be the basis of epicurean meals in the smartest banquet halls of the twenty-first century.

There will be enough wheat and wheat products to feed the entire world, including the teeming millions of China and India, now chronically on the verge of starvation. The earth is bountiful, and where her bounty fails, nitrogen drawn from the air will refertilize her womb. I developed a process for this purpose in 1900. It was perfected fourteen years later under the stress of war by German chemists.

Long before the next century dawns, systematic reforestation and the scientific management of natural resources will have made an end of all devastating droughts, forest fires, and floods. The universal utilization of water power and its long-distance transmission will sup-

Liberty Magazine February 9, 1935



ply every household with cheap power and will dispense with the necessity of burning fuel. The struggle for existence being lessened, there should be development along ideal rather than material lines.

Today the most civilized countries of the world spend a maximum of their income on war and a minimum on education. The twenty-first century will reverse this order. It will be more glorious to fight against ignorance than to die on the field of battle. The discovery of a new scientific truth will be more important than the squabbles of diplomats. Even the newspapers of our own day are beginning to treat scientific discoveries and the creation of fresh philosophical concepts as news. The newspapers of the twenty-first century will give a mere "stick" in the back pages to accounts of crime or political controversies, but will headline on the front pages the proclamation of a new scientific hypothesis.

"It will be possible to destroy anything approaching within 200 miles. My invention will provide a wall of power," declares Tesla.

PROGRESS along such lines will be impossible while nations persist in the savage practice of killing each other off. I inherited from my father, an erudite man who labored hard for peace, an ineradicable hatred of war. Like other inventors, I believed at one time that war could be stopped by making it more destructive. But I found that I was mistaken. I underestimated man's combative instinct, which it will take more than a century to breed out. We cannot abolish war by outlawing it. We cannot end it by disarming the strong. War can be stopped not by making the strong weak but by making every nation weak or strong, able to defend itself.

Hitherto all devices that could be used for defense could also be utilized to serve for aggression. This nullified the value of the improvement for purposes of peace. But I was fortunate enough to evolve a new idea and to perfect means which can be used chiefly for defense. If it is adopted, it will revolutionize the relations between nations. It will make any country, large or small, impregnable against armies, airplanes, and other means for attack. My invention requires a large plant, but once it is established it will be possible to destroy anything, men or machines, approaching within a radius of 200 miles. It will, so to speak, provide a wall of power offering an insuperable obstacle against any effective aggression.

If no country can be attacked successfully, there can be no purpose in war. My discovery ends the menace of airplanes or submarines, but it insures the supremacy of the battleship, because battleships may be provided with some of the required equipment. There might still be war at sea, but no warship could successfully attack the shore line, as the coast equipment will be superior to the armament of any battleship.

I want to state explicitly that this invention of mine does not contemplate the use of any so-called "death rays." Rays are not applicable because they cannot be produced in requisite quantities and diminish rapidly in intensity with distance. All the energy of New York City (approximately two million horsepower) transformed into rays and projected twenty miles, could not kill a human being, because, according to a well known law of physics, it would disperse to such an extent as to be ineffectual.

My apparatus projects particles which may be relatively large or of microscopic dimensions, enabling us to convey to a small area at a great distance trillions of times more energy than is possible with rays of any kind. Many thousands of horsepower can thus be transmitted by a stream thinner than a hair, so that nothing can resist. This wonderful feature will make it possible, among other things, to achieve undreamed-of results in television, for there will be almost no limit to the intensity of illumination, the size of the picture, or distance of projection.

I do not say that there may not be several destructive wars before the world accepts my gift. I may not live to see its acceptance. But I am convinced that a century from now every nation will render itself immune from attack by my device or by a device based upon a similar principle.

At present we suffer from the derangement of our civilization because we have not yet completely adjusted ourselves to the machine age. The solution of our problems does not lie in destroying but in mastering the machine.

Innumerable activities still performed by human hands today will be performed by automatons. At this very moment scientists working in the laboratories of American universities are attempting to create what has been described as a "thinking machine." I anticipated this development.

I actually constructed "robots." Today the robot is an accepted fact, but the principle has not been pushed far enough. In the twenty-first century the robot will take the place which slave labor occupied in ancient civilization. There is no reason at all why most of this should not come to pass in less than a century, freeing mankind to pursue its higher aspirations.

And unless mankind's attention is too violently diverted by external wars and internal revolutions, there is no reason why the electric millennium should not begin in a few decades.

THE END

The New York Herald Tribune June 5, 1935

Tesla Predicts Ships Powered By Shore Beam

Scoffs at Normandie 'Speed,' Sees Success for His Plan to Use Stratosphere Ray

Would Light Sea at Night

Says French Liner's System Could Be Used in U. S. Boats

ht Clipping Bur. JUN 5 1935

Dr. Nikola Tesla, scientist and seer whose discoveries in the fields of polyphase electrical current and wireless place him in the front rank of modern inventors, refused yesterday to be awed by the record speed achievement of the French liner Normandie in crossing the Atlantic in 4 days 11 hours 42 minutes and predicted that enormous ships would cross the ocean at far greater speeds by means of a high-tension current projected from power plants on shore to vessels at sea through the upper reaches of the atmosphere.

In his room at the Hotel New Yorker, dressed in a blue bathrobe, blue socks and red slippers, Dr. Tesla expounded the principles of his fabulous method of power transmision—a method which he has been developing at irregular intervals from as far back as 1897. The virtues of stratosphere transmission, he said, lay not only in its potential increase of a vessel's speed but also in its power to eliminate the dangers of nocturnal navigation.

In short, high-tension currents of electricity passing through the stratosphere would light the sky and to a degree turn night into day. With power plants stationed at intermediate posts such as upon the Azores and Bermuda, vessels could cross the Atlantic, propelled and safeguarded at the same time by electricity generated ashore. There would no longer be danger of boiler explosions nor hazards of collisions at sea. Even on moonless, cloudy nights, there still would gleam overhead the faint rays of surging electrical currents, so strong that pilots would be able to distinguish objects miles away.

Normandie Uses U. S. Cruiser System

Dr. Tesla, a tall, slender man with straight silvery hair, lean features and brigt blue eyes that belie his seventy-eight years, prefaced his prophecies by pointing out that the Normandie's system of power generation and application was not new—but one which had been adopted long ago in some of the United States cruisers. The principle is one of his own invention.

"The Normandie," he said, "employs an 'electric drive' in which turbines drive generators and generators supply the current to independent motors. In this case the turbines are driven by steam, the generators are of the three-phase type and the motors are of the induction type.

"In many respects the machinery installed on the United States cruisers by former Secretary Josephus Daniels is more remarkable than that on the Normandie on account of the limitations of available space. Moreover, while the Normandie develops only 160,000 horsepower, the cruisers each develop 185,000 horsepower. These cruisers employ the most remarkable engine plants in the world, and I believe that this drive would not have been employed on the Normandie had it not been for the pioneering work done in the United States.

"In view of the adoption on such a large scale of these inventions of mine, it is interesting to recall that I was violently attacked only a few years ago by a professor of marine engineering at Columbia, who claimed the electrical drive was not feasible and that it was folly to undertake it.

"However splendid the machinery on the Normandie might be, the time is not distant when we will have much simpler and better means of propulsion."

Cites His Force Beam as One Way

Here Dr. Tesla recalled the possibilities of his force beam of particles which he announced last year as a potential defensive weapon of great value. One of its aspects is a death ray capable of destroying airplanes and armies. Another is a means of power transmission which could be used to relay immense voltages of power over distances limited only by the curvature of the earth.

The difficulties inherent in using this method as a means of propulsion for oceangoing ships, however, were seen by Dr. Tesla to lie in the necessity of vast outlays of capital and concerted harmonious endeavor by the chief nations of the world. The latter, he said, would be impossible to achieve at the present time. A third difficulty would be the task of keeping a ship at sea constantly in touch with a threadlike beam of particles from ashore.

Dr. Tesla, therefore, suggested that his other scheme, of stratosphere transmission of electricity, would be a far more feasible means of marine propulsion. The principles of the two plans are entirely distinct. The force beam is a thin barrage of tiny particles discharged at tremendous velocities from a kind of electrical gun. The other invention, which he has not hitherto discussed publicly, is of transmitting high tension currents through the upper air, and receiving them by means of a vertical ionizing beam which would be a sort of invisible electrode. He discussed this yesterday:

Started New Idea in 1897

"There is a method of conveying great power to ships at sea which would be able to propel them across oceans at high speed. This method I conceived between 1897 and 1899, and in Colorado Springs in 1899 I made experiments along this line on a large scale.

"The principle is this: A ray of great ionizing power is used to give to the atmosphere great powers of conduction. A high tension current of 10,000,000 to 12,000,000 volts is then passed along this ray to the upper strata of the air, which strata can be broken down very readily and will conduct electricity very well.

"A ship would have to have equipment for producing a similar ionizing ray. The current which has passed through the stratosphere will strike this ray, travel down it and pass into the engines which propel the ship.

Pet Scheme to Light Ocean

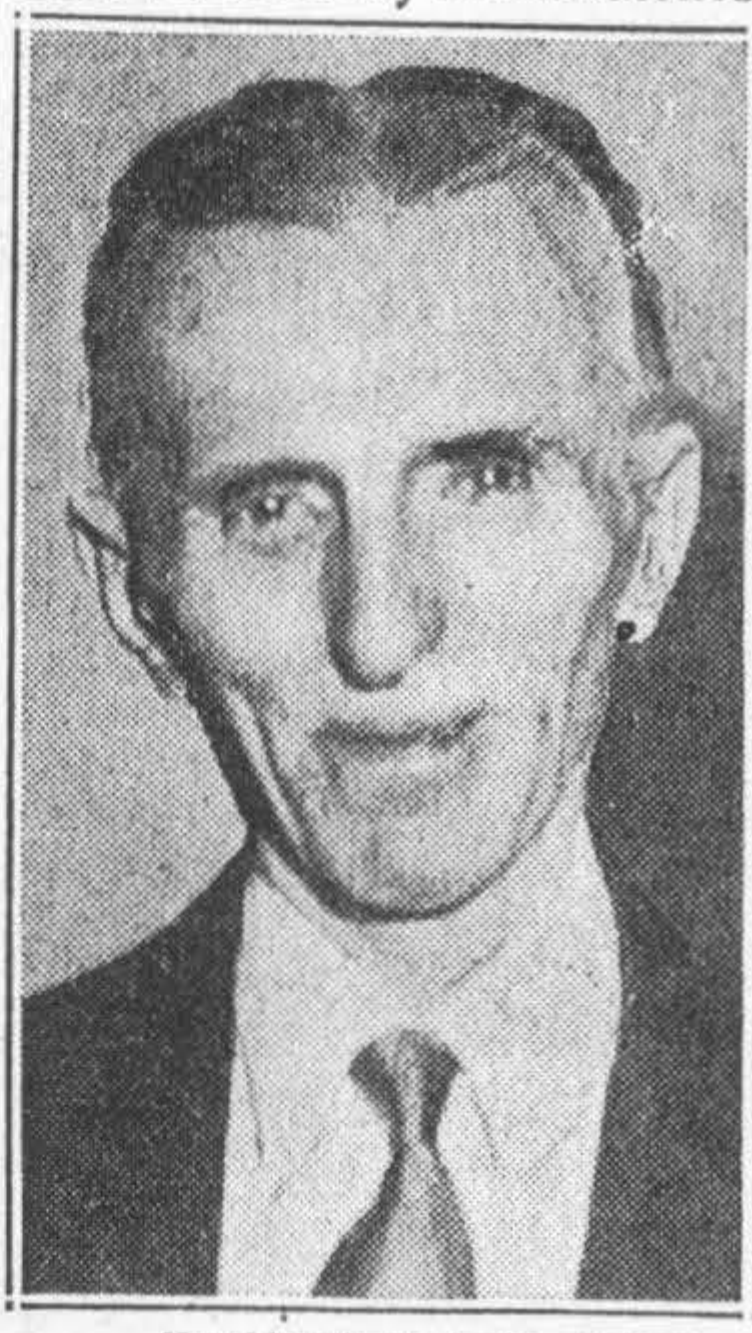
"I will confess that I was disappointed when I first made tests along this line on a large scale. They did not yield practical results. At the time I used about 8,000,000 to 12,000,000 volts of electricity. As a source of ionizing rays I employed a powerful arc reflected up into the sky. At the time I was trying only to connect a high tension current and the upper strata of the air, because my pet scheme for years has been to light the ocean at night.

"However, since 1902 I have made many improvements in my method which I know now will assure success. A power plant upon the Azores, for instance, could send a current up into the stratosphere and illuminate the sky sufficiently for pilots to discern objects upon the ocean at a safe distance."

Dr. Tesla said that he was working constantly every day to perfect his force beam, his method of stratosphere transmission of power, and a number of other inventions the nature of which he was not ready to disclose. When it was called to his attention that he was working pretty hard for a man who would be seventy-nine years old next month, he replied:

"Why, I'm young. I never think of my age. Really, you know, I'm just a youngster."

Not in Awe of Normandie



Herald Tribune photo—Steffen

Nikola Tesla

The New York Sun June 5, 1935

FASTER LINERS IS TESLA DREAM

Would Feed Power Through Stratosphere.

OCEAN TO BE ILLUMINATED

SUN JUN 5 1935

Dangers of Night Traffic at Sea to Be Eliminated.

Dr. Nikola Tesla, high priest of the mysteries of electricity, whose research and inventions in the fields of high frequency transmission and wireless have made him one of the outstanding scientists in the world, is a man not to be easily impressed.

With the tumult and shouting attendant upon the arrival of the Normandie and her record-breaking passage fresh in his ears, Dr. Tesla is inclined to view the feat as little more than a good trick, sufficiently impressive for today, but destined to be overshadowed in the future when ships will cross the ocean at high speed propelled by high tension currents transmitted through the stratosphere.

The principles of this high tension power, generated by shore plants and transmitted thorugh the upper reaches of the air, illuminating the sky, turning night into day and at the same time supplying power, have occupied Dr. Tesla's attention off and on now for the past thirty-five years. Ocean vessels utilizing such power not only would be able to make the crossing at an exceptionally high speed but would also be protected from the dangers of night navigation through the illumination furnished by the current.

78 Years Young.

Dr. Tesla, whose birth certificate shows him to be 78, but who says that he never thinks of his age and is "just a youngster," explained that the Normandie's system of power generation had been adopted some time ago by United States cruisers and was, in fact in principle, one of his own inventions.

Of his plan for transmitting power through the stratosphere, something which he has not publicly discussed before, Dr. Tesla said:

"There is a method of conveying great power to ships at sea which would be able to propel them across oceans at high speed. This method I conceived between 1897 and 1899, and in Colorado Springs in 1899 I made experiments along this line on a large scale.

"The principle is this. A ray of great ionizing power is used to giv to the atmosphere great powers c conduction. A high tension curren of 10,000,000 to 12,000,000 volts i then passed along this ray to th upper strata of the air, whic strata can be broken down ver readily and will conduct electricit very well.

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The New York Times July 7, 1935

TESLA, 79 THIS WEEK, HAS NEW INVENTIONS

TIMES JUL 7 1935

Solved Problems Experts Worked At for 100 Years, He Says —Birthday Wednesday.

Nikola Tesla, father of radio and of modern power transmission and generation, will be 79 years old on Wednesday.

Still full of enthusiasm, the man with more than 700 patents to his credit, including the Tesla Coil and the rotating field and induction motor, said in an interview yesterday at the Hotel New Yorker, where he has been living for the last two years, that he is now about to announce to the world a new invention that will solve a problem "which electrical experts of the world have been trying to solve in vain for the past hundred years."

Edison spent years on the problem, Dr. Tesla said, and so did many others, including some of the most celebrated electrical experts of the past century. Its final solution, he added, will be of great practical value.

He has also developed an apparatus that will be "of tremendous importance scientifically and commercially," Dr. Tesla said. "It will be my greatest contribution as a mechanical engineer."

He will also announce, he said, "certain new and extraordinary facts about cosmic rays."

The New York Herald Tribune July 8, 1935

Tesla, 79 on Wednesday, To Reveal New Invention

HERALD TRIB., JUL. 8 1935

Engineer Hints Solution of Wireless Power Transmission

Wednesday at noon is the day and hour set apart by Nikola Tesla, inventor and physicist, for the announcement of his greatest discovery. The place will be his residence, the Hotel New Yorker, Eighth Avenue and Thirty-fourth Street.

On Wednesday the inventor of modern power transmission, with 700 patents to his credit, including the Tesla coil, the rotating field and the induction motor, will be seventy-nine years old. For his last three birthdays, in interviews he has been preparing the world for the announcement that is now forthcoming.

The new invention, he says, will solve a problem "which electrical experts of the world have been trying to solve in vain for the last 100 years." It will be of great practical value and "will be my greatest contribution as a mechanical engineer," according to the inventor.

It is believed from certain hints which Dr. Tesla has dropped that the new discovery has to do with the wireless transmission of power.

The New York Sun July 9, 1935

3 TESLA INVENTIONS

Famous Scientist to Tell Them Tomorrow.

Nikola Tesla, physicist and inventor, will have not one but three startling discoveries to announce at a press luncheon on the occasion of his seventy-ninth birthday tomorrow, he said today at the Hotel New Yorker.

Mr. Tesla said that one of these discoveries is a new way of transmitting energy, an entirely new principle nothing like wireless. The second has to do with a new method of housing cosmic rays; and the third concerns a problem which scientists and inventors have worked on for seventy-five years but which every one has given up as utterly impossible.

The New York Sun July 10, 1935

NEW APPARATUS TRANSMITS ENERGY

Tesla Announces Method of Remote Control.

SUN JUL 10 1935

"The greatest engineering feat of the age" was announced late this afternoon by Dr. Nikola Tesla, scientist and inventor, in the course of a lengthy lecture given to the press, invited by him to celebrate his seventy-ninth birthday at a luncheon held at the Hotel New Yorker.

The feat is, in Dr. Tesla's words, a new method and an apparatus for transmitting mechanical energy accurately over any terrestial distance." The method will provide, he said, a new means of communication. It will make possible remote control of ships and airplanes; it will enable prospectors to locate deposits of minerals; with it scientists can determine the physical conditions in the earth's center.

Before making this announcement, Dr. Tesla, who entertains annually on his birthday and has announced coming marvels for the last several years, had spoken for almost five hours, much of his lecture passing in a bright stream over the head of the assembled reporters.

He found time while surveying his own past to express his sharp disagreement with the theories of Prof. Albert Einstein. He announced that the theory of relativity is "a mass of error and deceptive ideas and opposed to common sense," and that "not a single one of the relativity propositions has been proved."

Tesla, at 79, Discovers New Message Wave

JUL 11 1935

At Birthday Luncheon He Announces Machine for 1-Way Communication

Nikola Tesla announced yesterday, on his seventy-ninth birthday, the discovery of "the art of tele-geo-dynamics," or the propagation of mechanical impulses to the far ends of the earth, which can be used as an unfailing means of communication anywhere on the terrestrial globe, as a guide for ships at sea and as an indicator of where the mineral wealth of the world lies stored.

The machine by which this is accomplished was called by Dr. Tesla "my best achievement as an engineer." He spoke at a luncheon and press conference lasting six hours at the Hotel New Yorker. In addition, he disclosed his invention of an induction apparatus which provides direct current without commutators, a thing which he said "no competent engineer" would believe possible. Finally, the physicist and inventor propounded his beliefs as to cosmic rays, beliefs which were at material variance with Einsteinian physics.

The unveiling of these wonders was not done by demonstration of the machines or by presentation of mathematical proof. Dr. Tesla made his pronouncements as of facts accomplished which would be seen within the year. When asked for a demonstration, he refused to show his models or to tell where his laboratory work was done. All he would say was that he had a wealthy backer who would soon build a plant.

Of the direct-current motor without commutators, the scientist said it had "been the ambition of a lifetime," because all physicists since Faraday had said it was impossible. He rather believed the motor would prove useful in applying electric drive to gasoline automobiles and trucks.

While discussing the views he had on cosmic rays, Dr. Tesla engaged in a metaphorical castigation of Dr. Albert Einstein and other exponents of the theory of relativity. The theory he called "a beggar, wrapped in purple, whom ignorant people took for a king," and its exponents "scientific fairy-tale spinners, rather than astronomers."

When pressed for a description of the effects which make up "the art of tele-geo-dynamics," Dr. Tesla likened the waves which his machine would originate and propagate through the earth to earthquake waves, only his waves were of much smaller amplitude. These waves lost little or

(Continued on page eight)

(Continued from page one)

HERALD TRIB JUL 11 1935

some of their power with distance, he said. The greatest distance to which he had tried out the carrying power of the waves through the earth, he said, was six miles, but he felt sure they would reach to any point on the terrestrial globe. He emphasized the fact that they were mechanical and not electrical impulses, and that they were not intended for the transmission of power.

The first practical use which the tall, thin, almost cadaverous scientist envisions for the waves is communication. It will matter not where a person is, on land or sea, if he is equipped with a small receiving set which he can carry in his pocket he will be able to hear messages at from any part of the world. The waves are not instantaneous in passing through the earth, it requiring one hour and forty-nine minutes, according to Lord Kelvin, for an earthquake wave to go from one end of the earth to another. But this disadvantage is overcome by the advantage that there can be no possible interference by weather or static, Dr. Tesla says.

The second utility of the miniature earthquake waves is that they can guide a ship at sea with absolute precision. The tele-geo-dynamics machine, sending out waves from a certain fixed point, will resemble the center of infinite concentric circles traveling outward like the ripples in a pond where a stone has dropped. To keep on his course, the captain of a ship receiving these impulses has only to determine the angle at which the impulses strike the receiving set.

Will Spot Minerals in Earth

Thirdly, the terrestrial wave machine will lay bare the physical interior of the globe, providing the means of locating whatever is of value beneath the surface, the inventor says. This is not a matter of echoes received from a dynamite blast, as used in geophysical exploration for oil and other minerals, but rather a tuned system which permits of qualitative differentiation between the various ores and elements underfoot.

A supplementary use for the machine could be found in time of war said Dr. Tesla, in setting off bombs strategically placed and equipped with a receiving device.

In the course of his exposition, Dr. Tesla told of an early experiment in 1898 with a crude predecessor of tele-geo-dynamics machine in the neighborhood of 46 East Houston Street. He set the machine going and, while he was attending to something else for a few moments, it attained such a crescendo of rhythm that it started to shake the building, then it began shaking the earth nearabout. People started from their homes, believing there was an earthqquake, the Fire Department responded to an alarm frantically turned in, four tons of machinery flew across the basement and the only thing which saved the building from utter collapse was the quick action of Dr. Tesla in seizing a hammer and distroying his machine. The machine could be a Frankenstein's monster he confided, if not watched, since no substance can withstand steadily applied rhythm which finally reaches the resonance point of the substance. The Empire State Building, he said, could easily be destroyed with the steady building up of resonance from the timed strokes of a five-pound hammer.

Loath to Describe Device

Dr. Tesla appeared extremely loath to describe his machine in any detail. A multitude of questions drew from him the information that it consisted of a cylinder of finest steel, suspended in midair by a type of energy which was old in principle but which had been amplified by a secret principle and a stationery part.

"I have found means for impressing upon the floating part," he said, "powerful impulses which react on the stationery part and, through it, transmit energy to the earth." That was about all he would say about it.

Dr. Tesla started to talk about his discoveries and theories soon after he had consumed a quart of hot milk, which he had considerable difficulty in getting served to him, the while his guests had a six-course luncheon topped off with a birthday cake supporting one candle. Dr. Tesla would not even touch the cake, saying that he feared to interfere with the incrated habits of a lifetime; just inking hot milk for luncheon and eating sparingly of vegetables for dinner. He spoke rapidly for two hours, dictating his findings for the most part, then yielded to the importunities of motion picture photographers to say a few words for the newsreels.

His new motor, Dr. Tesla confessed, was a stunt something like squaring the circle.

"The results which I have attained," he said in his high, constricted voice with quite a trace of accent from his native Serbia, "will be considered absolutely impossible by any competent electrical engineer. Ever since Faraday, we have had certain laws of induction which were considered absolutely inescapable. One of these is that when lines of force are linked with a circuit and electrical current is produced in the same, it was not possible to take those lines out of the circuit without inducing an equivalent flow of current in the opposite direction.

"Thousands of inventors and scientists have bucked against this difficulty in vain, and those who were the most competent never even tried to attain such a result, being convinced that experiments in that direction were useless. Now, incredible as it seems, I have found a solution of this old problem and not only am able to produce a current in one direction in a circuit by induction, without a commutator, but also can make this current almost as steady and continuous as that from a battery. It has been the desire of my life to achieve this."

The New York Sun July 11, 1935

NIKOLA TESLA DESCRIBES NEW INVENTION

SUN JUL 11 1935



Associated Press Photos.

The scientist is shown in these candid camera studies as he told of the discovery of the "art of tele-geo-dynamics" through the invention of an apparatus for transmitting mechanical energy accurately over any terrestrial distance. The method, he said, will provide a new means of communication. It will make possible the remote control of ships and airplanes and will enable prospectors to locate mineral deposits.

The New York Times July 11, 1935

TESLA, 79, PROMISES TO TRANSMIT FORCE

Scientist on Birthday Reveals Scheme to Send Mechanical Energy All Over World.

WOULD EVEN GUIDE SHIPS

Assails Theory of Relativity as Work of Metaphysicians and Not Scientific.

TIMES JUL 11

Nikola Tesla, the man with seven hundred basic patents to his credit, who startled the world on a number of occasions in the past by achieving what others had regarded as impossible, including the large-scale generation and distribution of alternating current, yesterday treated the combined metropolitan press to a personally conducted tour of the labyrinthine laboratory of his fertile mind.

It was his seventy-ninth birthday anniversary, and, in keeping with his custom of past years, he made the day an occasion for revealing some of the latest products of his brain in the line of discovery, a field in which he rivaled and sometimes surpassed Edison during the golden era of electrical invention.

He confined himself yesterday to three of his startling adventures in the realm of theoretical and practical science. One of these, he said, "would appear almost preposterous." The second, he said with true candor, "would be considered absolutely impossible by any competent electrical engineer." The third would knock the props out from under the theory of relativity, he said, but in this case also he expressed his doubt that the modern generation of scientists would take his challenge seriously.

Cites Cosmic Ray Proof.

He described relativity as "a beggar wrapped in purple whom ignorant people take for a king." In support of his statement he cited a number of experiments he had conducted, he said, as far back as 1896 on the cosmic ray. He has measured cosmic ray velocities from Antarus, he said, which he found to be fifty times greater than the speed of light, thus demolishing, he contended, one of the basic pillars of the structure of relativity, according to which there can be no speed greater than that of light.

Mr. Tesla treated the press, reporters, camera men, news and sound reel representatives, about thirty in number, to a gourmet's luncheon in a private dining room at the Hotel New Yorker, where he has been making his home during the past two years. Mr. Tesla sat at the head of the table and talked while the reporters and camera men feasted on his bounty. He disdained each and every dish that was brought to him, not even touching his glass of water.

Toward the end of the luncheon he absented himself for a while and came back with a bottle containing a small quantity of pasteurized milk. This he poured in a silver chafing dish and heated to the proper temperature. Then came the surprise of the day—a birthday cake with a lone candle, a token of esteem by the management of the New Yorker to its distinguished bachelor guest.

His Greatest Achievement.

One of the subjects, which he hoped, he said, will come to be recognized as his "greatest achievement in the field of engineering," was, he said, the perfection by him of "an apparatus by which mechanical energy can be transmitted to any part of the terrestrial globe."

This apparatus, he said will have at least four practical possibilities. It will give the world a new means of unfailing communication; it will provide a new and by far the safest means for guiding ships at sea and into port; it will furnish a certain divining rod for locating ore deposits of any kind under the surface of the earth; and finally, it will furnish scientists with a means for laying bare the physical conditions of the earth, and will enable them to determine all of the earth's physical constants.

He called this discovery "tele-geodynamics," motion of earth-forces at a distance. It is of this, he said, that it would "appear almost preposterous." The apparatus, he added, is "ideally simple," consisting of a stationary part and a cylinder of fine steel "floating" in air. He has found means, he said, of "impressing upon the floating part powerful impulses which react on the stationary part, and through the latter to transmit energy through the earth." To do this he has "found a new amplifier for a known type of energy," and the "purpose is to produce impulses through the earth and then pick them up whenever needed."

The second invention, which, he said, "will be considered absolutely impossible by any competent electrical engineer," was described by him as a new method and apparatus for producing direct current without a commutator, "something that has been considered impossible since the days of Faraday." "Incredible as it seems," he said, "I have found a solution for this old problem."

Cosmic rays, he asserted, he found are produced by the force of "electrostatic repulsion"; they consist of powerfully charged positive particles which come to us from the sun and other suns in the universe. He determined, "after experimentation," he added, that the sun is charged "with an electric potential of approximately 215,000,000,000 volts, while the electric charge stored in the sun amounted to approximately 50,000,000,000,000,000,000 electrostatic units."

The theory of relativity he described as "a mass of error and deceptive ideas violently opposed to the teachings of great men of science of the past and even to common sense."

"The theory," he said, "wraps all these errors and fallacies and clothes them in magnificent mathematical garb which fascinates, dazzles and makes people blind to the underlying errors. The theory is like a beggar clothed in purple whom ignorant people take for a king. Its exponents are very brilliant men, but they are metaphysicists rather than scientists. Not a single one of the relativity propositions has been proved."

The New York Sun August 29, 1935

SCOFFS AT MARCONI

AUG 29 1935

Tesla Says Motor Stopping Was Tried Out in 1899.

Nikola Tesla, the seventy-nine-year-old inventor, is not at all impressed by the startling announcement of young Guglielmo Marconi, 61 years old, that he hopes to be able to bring down airplanes in flight by the effective method of stopping their engines.

At the Hotel New Yorker, where he resides, Mr. Tesla adopted today the attitude of the man who dismisses a conjuror's most astounding trick by remarking disparagingly: "Aw, he had it up his sleeve."

Signor Marconi, the father of wireless telegraphy, made the front pages of the newspapers yesterday when he announced at Santa Margherita, Italy, that he was experimenting in the use of ultra short waves which he believed could be used to halt the operation of motors, including airplane engines.

Mr. Tesla dismissed the idea as an old one which has been discussed and tried out as long ago as 1899.

"In that year," he said, "I was able to produce an effect on power plants within a radius of fifteen miles. There was danger and a certain amount of damage."

The aged scientist asserted that the use of the micro wave to halt airplane engines was beset, by insuperable difficulties. The dispersion is so great, he pointed out, that even at a distance of six miles the force becomes very small; the ignition of an airplane motor is not delicate, and "any competent electrician could screen the vulnerable parts of an engine against the radio waves."

Diesel engines are not affected, he added, because their ignition comes from compression.

The New York Times May 29, 1936

TESLA IS HONORED AT 80

MAY 2 9 1936

Birthday of the Scientist Is Observed in Yugoslavia.

Wireless to THE NEW YORK TIMES.

BELGRADE, Yugoslavia, May 28. —Nikola Tesla's eightieth birthday was celebrated today throughout Yugoslavia.

In all schools teachers described the scientist's achievements to their pupils. In Belgrade in the university's large auditorium seventy delegates representing fifteen countries attended a special meeting honoring Mr. Tesla. The session was presided over by King Peter's representative.

Regent Prince Paul conferred on Mr. Tesla the Grand Cross of the Order of the White Eagle.

Mr. Tesla cabled his thanks to the gathering, ending his message with: "Long live Yugoslavia and its royal house."

The New York Times July 11, 1936

TESLA, 80, REVEALS NEW POWER DEVICE

TIMES JUL 11 1936

Says His Wireless Invention Will Gird the Earth With Energy for Industry.

Nikola Tesla, inventor, who celebrated his eightieth birthday yesterday, foresaw an industrial civilization founded on cheap and unlimited power transmitted from a central point to any part of the globe without wires.

This new system of power transmission will have its first practical demonstration within a year, Dr. Tesla predicted. He said he had perfected the principles which will creates the necessary apparatus.

Each year on his birthday the inventor of the principle of the rotary magnetic field, new forms of dynamos, transformers and 70(other devices which have played : leading rôle in technological de velopment plays host to the press Yesterday he gave a luncheon for fifteen newspaper men and women at the Hotel New Yorker, and while his guests feasted he contented himself with three oranges and a quart of milk.

Recalls Interesting Episodes

Dr. Tesla recalled his first meeting with Thomas A. Edison, relived some of the interesting episodes in his own life, describing his researches into such varied fields as relativity, death rays, psychic phenomena, lightning machines and power development.

Between sips of the warm milk, he eyed the newspaper folk with their Scotch and sodas and confided that if he had not given up drinking alcohol with the enactment of prohibition he would live to be 150 years old.

"As it is, I believe my abstinence from alcohol during the latter part of my life has lopped off fifteen years from my life, and now I expect to live only 135 years," he remarked. "Alcohol is the elixir of life, but when this country passed the Prohibition Law I felt that as a patriotic American I should stop drinking whisky. I have not touched it since."

Meat is another food which he never touches, Dr. Tesla explained. Two quarts of milk a day provide him with all the proteins and calories he needs to remain alive, he said. Although as a rule he does not retire until 5.30 o'clock every morning, he gets up about 10 A. M. and feels full of energy.

The development of wireless transmission of power will overshadow any of his past accomplishments and will usher in a new civilization for mankind, Dr. Tesla predicted. He explained that his system will make it possible, for example, to install a hydro-electric plant at Muscle Shoals and transmit the power generated to England, China, Little America or Alaska with equal ease and at comparatively little cost.

The New York Herald Tribune November 3, 1936

Election of Gov. Landon Urged by Nicola Tesla

Inventor Abandons New Deal to Support Republican

HERALD-TRIB NOV 3 1936

Nicola Tesla, inventor, issued a statement yesterday from his apartment in the New Yorker, Eighth Avenue and Thirty-fourth Street, calling for the election of Governor Alfred M. Landon.

Mr. Tesla, who supported President Roosevelt in 1932, said that under mathematical laws the "Literary Digest" straw poll was the most accurate, because it represented the largest number of voters. It was false to assume that persons on relief would necessarily vote for the New Deal, even though it supported them, he said.

The fact that President Roosevelt has attempted to overrule the Supreme Court will detract from his vote more than any thing else, Mr. Tesla said. The dread of new taxes under the social security act also will win votes for Governor Landon, he pointed out, as well as the fact that although President Roosevelt has spent $12,000,000,000 and borrowed $13,000,000,000 more, America is only eleventh in the order of economic world recovery.

"I am looking confidently to the electon of Governor Landon not only on account of the "Digest" poll but also because the Roosevelt administration, as every unprejudiced observer must have found, so far has not been a success," he concluded.

The New York Times May 1, 1937

TESLA IS PROVIDER OF PIGEON RELIEF

Inventor Revealed as Person Who Hires Messenger Boy to Feed 3 Flocks in City

IMES MAY 1

FORMERLY DID IT HIMSELF

Nearing 81, He Now Finds It More Convenient to Engage Proxy for the Task

A red-headed boy in a Western Union uniform walked along the promenade in front of the Public Library on Fifth Avenue at Forty-second Street yesterday afternoon carrying a good-sized paper bag about which a flock of pigeons fluttered. He was doing a mission for Nikola Tesla, the famous inventor.

Mr. Tesla, at his apartment in the Hotel New Yorker, was reluctant to talk about the pigeons. Asked if it was he who had paid to have the boy feed them twice a day since last Fall, he replied:

"Yes, I take care of them all the time."

He has been interested in pigeons for seventy-five years, since he was a small boy in his native village in Austrian Croatia. He will celebrate his eighty-first birthday on July 10.

The messenger, John Lucan, has become well known to the pigeons, and they fly to meet him as he walks to the feeding place in front of the south fountain, about 10 A. M. and 3:30 P. M. every day. He looks out for any that fall ill, and sees to it that they have their share of the five pounds of corn he distributes at a feeding. Mr. Tesla used to do this himself, but lately he has found it more convenient to send the boy.

During the Winter, and until the water in the fountains is turned on, Johnny has kept a small bath for the pigeons. Sometimes he has had to break ice off it, but it has always been there, in the south fountain, where the birds came to expect it. Johnny also feeds pigeons at St. Patrick's Cathedral, and in Bryant Park, back of the library.

Mr. Tesla's commission is only one of many novel sorts carried out by the boys of the telegraph companies. For example, some of the boys have developed a technique for rice-throwing at weddings. When a couple having only a few friends in the city gets married, messengers with the proper experience may be hired to throw the rice at the right velocity to lend a sentimental touch while avoiding injury to the participants.

For several months a boy called every morning to chat with an elderly woman who felt that she needed some one to stimulate her interest in current events. He managed to find enough topics of conversation to keep the assignment going for a considerable time.

Other boys have taken children to theatres, demonstrated new articles to shopkeepers, climbed trees to rescue pet cats or birds, and minded offices while their proprietors went to lunch.

The New York Herald Tribune July 9, 1937

Tesla Devises Vacuum Tube Atom-Smasher

HERALD-TRIB JUL 9 1937

Scientist to Give Details at 80th Birthday Luncheon To Be Held Tomorrow

Announcement of a vacuum tube which will make cheap radio-active substitutes for radium available and which is said to be much more effective as an atom smasher than any device now available, will be made by Nikola Tesla, the scientist and inventor, at a birthday luncheon at the Hotel New Yorker tomorrow afternoon. Dr. Tesla will be eighty years old.

Dr. Tesla has made it a practice on his birthday during recent years to announce the fruits of his scientific investigations of the preceding year.

While no detailed information is available concerning Dr. Tesla's discovery, it is understood that it involves new principles in vacuum tubes which will operate at any voltage up to the enormous voltages used in atom smashing. It is understood that large amounts of power can be used in this tube, and it will produce heavy streams of sub-atomic particles which will increase the efficiency of the atom-smashing processes so that the transmutation of the elements can be performed on a scale which will permit direct measurements, and bring the scientists much closer to the point at which atomic energy can be released.

Another announcement to be made by Dr. Tesla will concern cosmic rays, which he has been investigating since 1896. He is expected to describe the process by which the darts of cosmic rays are produced at high altitudes in the upper realms of the atmosphere, where phenomena take place which he utilized in his system of wireless transmission of power described by him more than thirty years ago.

The Ambassadors from Yugoslavia and Czechoslovakia will attend the luncheon and confer on Dr. Tesla the Order of the White Eagle and the Order of the White Lion, respectively. These honors come as a climax to a year which has been rich in honors for Dr. Tesla. A scientific research institution established in Yugoslavia during the last year has been named the Tesla Institute. He has been elected a member of the Academy of Sciences of France, a plaque mounted in his honor, and a research section named after him which has been placed under the direction of Madame Curie.

The New York Sun July 10, 1937

TESLA IS 80 TODAY

Inventor to Receive Two Foreign Decorations

SUN JUL 10 1937

Eighty years ago today at Smiljan, Lika, on what was the border of the old Austro-Hungarian empire, Nikola Tesla was born. The great inventor to whom the world is indebted for many of the more important electrical discoveries, especially that of the rotating magnetic field, is celebrating the occasion with a private luncheon at the Hotel New Yorker.

Guests of honor will be Konstantin Fotitch and Vladimir Hurban, Ministers respectively from Jugoslavia and Czechoslovakia, each accompanied by the first secretary of legation, who are coming to confer on the inventor the decorations of their countries. Minister Fotitch is to bestow the Order of the White Eagle and Minister Hurban the Order of the White Lion.

As has become customary on his birthdays, Dr. Tesla will make announcements of what he has done in the electrical field during the year. This time, it is understood, he had been especially interested in vacuum tubes for conveying high voltages and which may make possible the creation of cheap radioactive substitutes for radium.

Dr. Tesla has received many honors during the past twelve months. His likeness has appeared on a postage stamp and the Tesla Institute for Scientific Research has been founded.

Sending of Messages to Planets Predicted by Dr. Tesla on Birthday



Times Wide World Photo.

Nikola Tesla, at left, receiving the Order of the White Lion from Vladimir Hurban, Minister from Czechoslovakia, at the luncheon for the former yesterday.

TIMES JUL 11 1937

Inventor, 81, Talks of Key to Interstellar Transmission and Tube to Produce Radium Copiously and Cheaply—Decorated by Yugosla a and Czechoslovakia

Reports of discoveries by which he will be possible to communicate with the planets and to produce radium in unlimited quantity for $1 a pound were announced by Dr. Nikola Tesla yesterday at a luncheon on his eighty-first birthday at which he was honored with high orders from the Yugoslav and Czechoslovak Governments.

Dr. Tesla, whose discoveries in electrical science have won for him recognition as the father of modern methods of generating and distributing electrical energy, asserted his "absolute" belief that he would win the Pierre Guzman prize of the Institute of France for his discovery relating to the interstellar transmission of energy.

Following his annual custom, Dr. Tesla played host to a group of newspaper men at his birthday luncheon at the Hotel New Yorker and issued the announcement of his discoveries of the last year. No apparatus or sketches were shown, but Dr. Tesla said in announcing tube, which he said would make it possible to smash the atom and produce cheap radium, that he would be able to give a demonstration in "only a little time."

Guests at Dr. Tesla's luncheon included Constantin Fotitch, Minister from Yugoslavia; Vladimir Hurban, Minister from Czechoslovakia; R. Petrovich, first secretary of the Yugoslav delegation; B. P. Stoyanovitch, Yugoslav Consul General in New York; Dr. J. Nemecek, counselor of the Czechoslav Legation, and J. Hajny, Acting Consul General in New York for Czechoslovakia.

Presenting to Dr. Tesla the Grand Cordon of the White Eagle, highest order of Yugoslavia, Mr. Fotitch announced it was the first time the order had been granted to an American for civil accomplishments. The honor was bestowed by order of King Peter through the Regent, Prince Paul.

Dr. Tesla's career has been an

DR. TESLA PREDICTS LINKING PLANETS

Continued From Page One

inspiration to the youth of his native country, the Minister said. Evidently referring to Dr. Tesla's report several years ago of inventing a "death beam" for use as a defense weapon, the Minister said:

"All your efforts are directed to find a way, by means of some new magic invention of yours, by which you will check and render futile as much as possible all those inventions which men have invented to destroy mutually one another. You feel, as we all feel in your old country, that the world has seen enough of horror and that after so many examples of heroism displayed in the Great War, humanity has found a better way only in peace."

Mr. Hurban, presenting the Grand Cordon of the White Lion, which has been granted to such other distinguished Americans as Secretary Kellogg, Elihu Root and Dr. Nicholas Murray Butler, said "our Czechoslovak nation's brotherly feeling toward you as a son of Yugoslavia made it a duty, not a privilege, to give you this decoration in the name of the President of our nation, Dr. Eduard Benes." He also presented a diploma certifying Dr. Tesla's honorary degree as a doctor of the University of Prague.

Outlines His Discoveries

Dr. Tesla, in responding, said he considered Czechoslovakia "one of the most enlightened countries in the world."

In a ten-page typewritten statement outlining his discoveries, Dr. Tesla gave a résumé of his work in the fields of gravity and cosmic rays. Asserting that "the so-called cosmic rays observed at great altitudes presented a riddle for more than twenty-six years chiefly because it was found that they increased with altitude at a rapid rate," Dr. Tesla said he had discovered "the astonishing fact that the effects at high altitudes are of an entirely different nature, having no relation whatever to cosmic rays."

He gave a detailed technical description of his conclusions from research and calculations concerning the cosmic ray, and continued:

"For the time being, I must content myself with the announcement of the salient facts, but in due course I expect to be able to give more or less accurate technical data relating to all particulars of this discovery."

Digressing from his prepared statement, he said:

"I am proud of these discoveries, because many have denied that I am the original discoverer of the cosmic ray. I was fifteen years ahead of other fellows who were asleep. Now no one can take away from me the credit of being the first discoverer of the cosmic ray on earth."

Dr. Tesla's audience stirred as he took up the next phase of his discoveries.

"I have devoted much of my time during the year past," he said, "to the perfecting of a new small and compact apparatus by which energy in considerable amounts can now be flashed through interstellar space to any distance without the slightest dispersion."

To Claim French Award

Explaining that he did not refer to his "universal peace discovery," Dr. Tesla continued:

"I am expecting to put before the Institute of France an accurate description of the devices with data and calculations and claim the Pierre Guzman prize of 100,000 francs for means of communication with other worlds, feeling perfectly sure that it will be awarded to me. The money, of course, is a trifling consideration, but for the great historical honor of being the first to achieve this miracle I would be almost willing to give my life.

"I am just as sure that prize will be awarded to me as if I already had it in my pocket. They have got to do it. It means it will be possible to convey several thousand units of horsepower to other planets, regardless of the distance. This discovery of mine will be remembered when everything else I have done is covered with dust."

Reporters questioned Dr. Tesla closely on his report of an interplanetary communication system. He said he had been working in several laboratories, but refused to disclose where they were. Asked if he had a working model of the apparatus, he said "it employs more than three dozen of my inventions; it is a complex apparatus, an agglomeration of parts."

"It is absolutely developed," he declared. "I wouldn't be any surer that I can transmit energy 100 miles than I am of the fact that I can transmit energy 1,000,000 miles up."

A different kind of energy than is commonly employed must be used, however, he said, explaining further that "you must realize it travels through a channel of less than one-half of one-millionth of a centimeter."

"I could undertake a contract to manufacture the apparatus," he asserted.

Dr. Tesla declared that "life on other planets is an infinite probability, a certitude." A difficulty in using his apparatus, he said, would lie in hitting other moving planets with "the needle-point of tremendous energy," but astronomers could help solve this problem.

The point of energy could be aimed at the moon and "we very easily could see the effects, see the splash and the volatilization of matter." He also pictured the possibility of advanced thinkers living on other planets and also experimenting in this field, but mistaking the Tesla energy rays for some form of cosmic rays.

Dr. Tesla provoked a new stir with his next announcement.

"My most important invention from a practical point of view," he said, "is a new form of tube with apparatus for its operation."

Reports Tube of New Type

Recalling experiments with other tubes, he said he had been "rewarded with complete success" and had "produced a tube which it will be hard to improve further."

"It is of ideal simplicity," he said, "not subject to wear and can be operated at any potential, however high—even 100,000,000 volts—that can be produced. It will carry heavy currents, transform any amount of energy within practical limits and it permits easy control and regulation of the same.

"I expect that this invention, when it becomes known, will be universally adopted in preference to other forms of tubes and that it will be the means of obtaining results undreamed of before.

"Among others, it will enable the production of cheap radium substitutes in any desired quantity and will be, in general, immensely more effective in the smashing of atoms and the transmutation of matter. However, this tube will not open up a way to utilize atomic or subatomic energy for power purposes."

"It will cheapen radium so," Dr. Tesla added, "that it will be just a cheap—well, it will get down to $1 a pound, in any quantity."

Expressing "annoyance" that some newspapers had indicated he would "give a full description" of his atom-smashing tube at yesterday's luncheon, Dr. Tesla said he was bound by financial obligations "involving vast sums of money" against releasing this information.

"But it is not an experiment," he declared. "I have built, demonstrated and used it. Only a little time will pass before I can give it to the world."

A final discovery announced by Dr. Tesla involved a new method and apparatus for further perfection of vacuum tubes.

"What may be accomplished by means of such vacua is a matter of conjecture, but it is obvious that they will make possible the production of much more intense effects in electron tubes," he said.

Before and during the luncheon, Dr. Tesla entertained his guests with colorful personal reminiscences and observations, including his opinions on dieting and immortality.

The New York Sun July 12, 1937

TESLA HAS PLAN TO SIGNAL MARS

Scientist, 81 Years Old, Celebrates Birthday.

DECORATED BY 2 COUNTRIES

Seeks Guzman Prize for Idea on Planet Communication.

Nikola Tesla is 81 years old. Some reference books, including "Who's Who," fix the year of his birth at 1857. He does not know whether the anniversary should have been celebrated Friday or, as it was, on Saturday, because it was just at midnight between July 9 and July 10 that he was born. But the year was 1856.

It was a most unusual birthday party the inventor held at the Hotel New Yorker, where he makes his residence. For the Ministers of his native Jugoslavia and neighboring Czechoslovakia and their staffs, and a handful of newspaper men, Dr. Tesla had provided a most unusual material and mental feast.

Figuratively, at least, they are still smacking their lips today over the food and wines and speculating about what may come from the discoveries the scientist announced, his quest for the French Academy prize for interplanetary communication, the perfection of a tube to carry immense electrical voltages, and some of the more abstract observations regarding cosmic rays and what makes this universe of ours expand and contract, oscillating instead of always expanding as some physicists hold.

Considering his years and the fact that recently he was the victim of an automobile accident which shook his system seriously, Dr. Tesla is exceedingly vigorous. His thinning hair, although predominantly white, still has considerable black. His eyes are as keen and penetrating as ever. He speaks distinctly although, of course, was a bit of the accent he has always had. But he picked up questions quickly and answered them in a manner that showed a tremendous grasp of all the latest theories of the astronomers, physicists and other scientists.

Announces Discoveries.

In recent years Dr. Tesla has made a habit of announcing on his birthdays some of the discoveries he has made in the past year. And he feels that with the passing of the years they have increased in importance. He said: "The maximum power of man is reached in his age rather than in his prime, as many suppose. Every one should have a decade to sum up the work of his lifetimes after he reaches the age of seventy-five. By then, if he has worked constantly in one field, he has gained so much experience that the solution of problems becomes much easier."

Everything at the birthday party was designed to lead up to the discussion of the inventor's latest achievements. Although he tasted only two of the courses and refrained altogether from any drink but water, he treated his guests to the finest in foods and wines.

The piece de resistance was "Canard en casserole a la Tesla," a dish he had planned himself about ten years ago, consisting of duck roasted slowly in a casserole, smothered with whole stalks of celery. It won unstinted praise from the diplomatic representatives

Dr. Tesla did take just a taste of this dish to make certain that it had been properly prepared and, as a sign of his approval had the chef come in to receive the applause of his guests. The other dish of which he partook was a jellied consomme.

Alcohol, he believes, is a great thing. Whisky and wine are preferable to coffee and tea. As his guests smacked their lips over some of the vintages he had brought forth for the occasion, they were disposed to agree with Dr. Tesla on this point.

Genius From Parents.

It was in the random conversation of the meal that one learned many intimate things about Dr. Tesla. He gave little glimpses of his boyhood life in Jugoslavia. One gathered he had acquired much of his genius from his learned father, a Slavian priest, and his mother, a practical and also a brilliant woman.

When, in 1884, Dr. Tesla landed at the Battery he had just 4 cents. He had only gone a few blocks up Broadway when he saw some men sweating over an electrical machine that had broken down.

"It was a machine I had helped to design, but I did not tell them that. I asked, 'What is the matter?' and they said, 'This thing won't work.' I asked, 'what would you give me if I fix it?' 'Twenty dollars' was the reply. I took off my coat and went to work. I had it running perfectly in an hour and had earned $20."

He shortly found it was not all as easy as that. There were many days when he did not know where the next meal was coming from. "But I was never afraid to work. I went to where some men were digging a ditch. I said I wanted to work. The boss looked at my good clothes and white hands and he laughed to the others, 'This man wants to work.' But he said 'All right. Spit on your hands. Get in the ditch. Go to work.' And I worked harder than anybody. At the end of that day I had $2. And I kept it up until I had enough to get started again."

Support Bums Today.

"Could that happen today?" he was asked. There was a serious pause, a grave frown and he said, "I am afraid not. The present is destructive. The workers are expected to support the bums."

Before the birthday cake was cut Dr. Tesla was invested with the orders which Jugoslavian and Czechoslovakian ministers had brought. Dr. Constantine Fotitch, Jugoslavian Minister, who was attended by R. Petrovich, first secretary of his legation, and B. P. Stoyanovich, the Consul-General here, bestowed the grand Cordon of the White Eagle in behalf of King Peter.

Dr. Tesla sharply assailed those physicists who contend that cosmic rays originate in far places of the universe where matter is converted into energy. He produced a formula saying "The kinetic and potential energy of a body is the result of motion and determined by the product of its mass and the square of its velocity. Let the mass be reduced, the energy is diminished by the same proportion. If it be reduced to zero, the energy is likewise zero for any finite velocity."

About half of his talk was devoted to abstract scientific problems.

Turning from the more metaphysical aspects of his studies to the practical, Dr. Tesla disclosed his greatest ambition is to be the man who evolved a method of communicating with other planets. He thinks he has found the answer and is preparing to lay its formulæ before the Institute of France in quest of the Pierre Guzman price of 100,000 francs offered for a means of communicating with other worlds.

The man who accomplishes this, he feels, will be remembered after all present inventions are forgotten.

The New York Sun May 12, 1938

TESLA RECEIVES WELFARE AWARD

Frankfurter and Martinelli Are Also Honored.

Dr. Nikola Tesla, Prof. Felix Frankfurter and Giovanni Martinelli today possessed the annua Awards of Merit conferred by the National Institute of Immigrant Welfare since 1936 on persons of foreign birth who have made significant contributions to American life in the fields of science, public affairs and the arts.

Presentation was made by Dr. Harry Woodburn Chase, chancellor of New York University and chairman of the awards committee, at the annual dinner of the Institute last night at the Hotel Biltmore.

Dr. Tesla, Yugoslavian born inventor and physicist, and an associate of the late Thomas A. Edison, had not sufficiently recovered from his injuries in an automobile accident to be able to attend. His friend, Dr. Paul R. Radosavljevich, professor of pedagogy at New York University, accepted the award for him.

"Stimulating in his teaching, prolific in his scholarly activities . . . known nationally and internationally in his profession," was the citation used in bestowing the award on Prof. Frankfurter, professor of law at Harvard Law School, who was born in Vienna and came to the United States at the age of 12.

Of Giovanni Martinelli, Metropolitan Opera tenor, who is a native of Italy, the citation said: "He has enriched the land of his adoption in so many ways that the institute honors itself in honoring him."

Leifur Magnusson, president of the institute, presided. Short addresses were made by Prof. Frankfurter, Mrs. Dave Hennen Morris, Dr. Henry Goddard Leach, Dr. Gregory Zilboorg and Dr. Leland Rex Robinson.

The New York Times July 10, 1938

DR. TESLA, 82 TODAY, POSTPONES PARTY

Wants to Finish Therapeutic Device Which He Calls Boon for Newspaper Offices

TIMES JUL 10 1938

For the first time in a number of years, Dr. Nikola Tesla, scientist and inventor, who is 82 years old today, is postponing his annual birthday party for the press so he may complete a mechanical therapeutic device for public demonstration.

Dr. Tesla said yesterday he hopes to have his apparatus completed within two weeks, and then will give a demonstration to the press.

For the last forty years Dr. Tesla has been the storm center of scientific controversy. Recognized in the early part of his career as the father of modern methods of generating and distributing electrical energy, and pre-dating even Marconi in his experiments with wireless, Dr. Tesla has been decorated by many governments for his accomplishments. In recent years, however, it has been his custom to announce at his annual parties the perfection of inventions which some scientists have challenged as fantastic.

The therapeutic device, Dr. Tesla said yesterday, is an improvement of an invention he perfected many years ago before his famous laboratory burned, about 1895. He said it will cure many internal disorders. He used it to advantage on his friend, Mark Twain, Dr. Tesla said.

"One of these devices in every newspaper office and the proverbial 'editorial grouch' will be gone," the inventor predicted.

He also expects to announce this year the perfection of another in-

The New York Herald Tribune July 26, 1939

The Soviet Sacrifice for Spain

JUL 26 1939

An Estimate That Republic Received Billion and a Half Dollars

To the New York Herald Tribune:

Your issue of July 9, 1939, contains an article relating to the seizure of Spanish gold by the Soviet government. Another one, dealing with the same subject, appeared in "The Saturday Evening Post" of April 15, 1939. Without entering into a discussion of the merits of these comments upon the question raised, I may remark that, for obvious political reasons, any expression of opinion concerning this matter by Americans is likely to be very unfavorable to the Soviet government, and in the interest of common justice it should be weighed without prejudice. But this is of relatively small consequence. What I wish to bring to the attention of fair-minded readers is that the articles referred to do not give the slightest hint in regard to the chief fact to be ascertained, which had a profound bearing on the course decided upon by the Soviets—namely, the sacrifice their struggle on behalf of the oppressed party in Spain involved. They fought vigorously for a cause considered rightful by a large portion of the population, and the ownership of gold and other property was undecided until the termination of the conflict.

* * *

Everybody knows that modern warfare is desperately expensive, but few will realize how costly it must have been for the Soviet government under the disadvantages, obstacles and handicaps confronting it. I was desirous of making an approximate estimate of the cost, and with this object in view I gathered all the available data. Considering carefully the actual outlays in money, the loss of men, of airplanes, guns and other implements of war, ships and munitions, and the supply of food, oil and all kinds of provisions transported from great distance, etc., I have satisfied myself that the Soviet government must have spent, at the very least, $1,500,000,000. If this estimate is reasonably accurate, the Spanish gold appropriated amounted only to about one-third of the cost. Any government would have acted so under similar circumstances. England, France, Germany and Italy are on record with deeds not at all commendable. What the Soviet government did was perfectly legitimate, in view of the preceding events.

The idea that the boxes brought from Spain were sufficient to cover Red Square is absurd. It would mean not five but something like one hundred times that amount of gold. The metal always is shipped in ounces and its value determined from the prevailing market quotations.

* * *

Through the attitude of England and France the Soviet government found itself isolated, and Stalin then made a proposal for non-interference. But Italy and Germany paid no attention to it and poured tens of thousands of men into Spain to Franco's assistance. Even then Russia was ready to carry on the war. She could swallow Italy at a gulp and not suffer dyspepsia, and if Hitler dared to attack her he would have been badly defeated and Germany would have become again an empire under the Hohenzollern dynasty, probably with the restoration of the status quo ante Hitler regime and recreated free Czecho-Slovakia. England and France being emphatically against Russian influence in Spain, Stalin had to withdraw, but in so doing he certainly did not "knife" the Spanish republic.

NIKOLA TESLA

New York, July 23, 1939.

The Baltimore Sun July 12, 1940

Aerial Defense "Death Beam" Offered To U. S. By Tesla

Noted Inventor Says His Ray Will Melt Plane Motors At 250-Mile Range

[Copyright by New York Times

New York, July 11—Nikola Tesla, one of the greatest electrical inventors of the century, who reached 84 yesterday, said today he was ready to divulge to the United States Government the secret of a "death beam" that would melt airplane motors at a distance of 250 miles and thus would build an invisible wall of defense around the country against attempted attack by an air force, no matter how large.

Dr. Tesla first described his "death beam" six years ago on the day he reached 78.

Dr. Tesla, who spent this birthday at work on his inventions, offered his services to the Government in reply to a question over the telephone whether his death beam had reached the stage of practical application.

At Service Of U. S.

"All my inventions," he said, "are at the service of the United States Government."

The death beam, he said, is "based on an entirely new principal of physics that no one has ever dreamed about." The principle, he added, was different from those relating to the transmission of electrical power by wireless, as announced by him several years ago.

The beam, he said, would be only one hundred-millionth of a square centimeter in diameter and could be generated from a special plant that would cost no more than $2,000,000 and would take only about three months to construct. A dozen such plants, located at strategic positions along the coast, he said, would be enough to defend the country against all possible aerial attack.

Would Melt Any Engine

The beam would melt any engine, whether Diesel or gasoline driven, and would also ignite any explosives aboard. No possible defense against it could be devised, as it would be all-penetrating, he declared.

Should the Government decide to take up his offer, he said, he would go to work at once and keep on working "until I collapse." However, he added, "I would have to insist on one condition—I would not suffer interference from any experts. They would have to trust me." He was in good health, he said, and felt confident he could undertake the task.

The beam, he said, involved four new inventions:

A method and appartus for producing rays and other manifestations of energy in free air, eliminating the necessity for high vacuums.

A method and process for producing "very great electrical force."

A method for amplifying this force.

A new method for producing "a tremendous electrical repelling force."

Voltage 50,000,000

This would be the projector, or gun, of the system. The voltages for propelling the death beam to its objective, he stated, will attain a potential of 50,000,000 volts.

With this enormous voltage, he said, microscopic electrified particles of matter will be catapulted on their mission of defensive destruction.

Dr. Tesla added he was convinced that "the battleship is doomed" and that "what happens to the armored knight will also happen to the armored vessel." The Germans, he said, are not planning to invade England, but will attack its fleet.

For this reason, he said, he was convinced that money spent on battleships would be wasted. The money planned for battleships, he said, should be "directed in channels that will improve the welfare of the country."

Tesla Is Winner Of 1915 Nobel Prize In Physics

Dr. Tesla first revealed his "death beam" six years ago, on his seventy-eighth birthday. He said then he would turn the invention over to the Geneva conference, to be used in the interests of world peace.

Winner of the 1915 Nobel prize in physics, Dr. Tesla is the discoverer of the rotary magnetic field, which made possible the alternating current motor, and the inventor of modern power transmission. He has more than 700 patents to his credit, including the Tesla coil and the induction motor.

Dr. Tesla for many years has been interested in the weapons which, in the hands of the proper persons, might bring permanent peace to the world. Twenty-five years ago he announced that he had filed applications for patents on the basic parts of an "aerial torpedo" which would have a range of 1,000 miles or more and enormous destructive power.

The New York Times September 22, 1940

Death Ray for Planes

Nikola Tesla, one of the truly great inventors who celebrated his eighty-fourth birthday on July 10, tells the writer that he stands ready to divulge to the United States Government the secret of his "teleforce," with which, he said, airplane motors would be melted at a distance of 250 miles, so that an invisible Chinese Wall of Defense would be built around the country against any attempted attack by an enemy air force, no matter how large.

TIMES SEP 22 1940

This "teleforce," he said, is based on an entirely new principle of physics that "no one has ever dreamed about," different from the principle embodied in his inventions relating to the transmission of electrical power from a distance, for which he has received a number of basic patents. This new type of force, Mr. Tesla said, would operate through a beam one one-hundred-millionth of a square centimeter in diameter, and could be generated from a special plant that would cost no more than $2,000,000 and would take only about three months to construct.

A dozen such plants, located at strategic points along the coast, according to Mr. Tesla, would be enough to defend the country against all possible aerial attack. The beam would melt any engine, whether Diesel or gasoline-driven, and would also ignite the explosives aboard any bomber. No possible defense against it could be devised, he asserts, as the beam would be all-penetrating.

High Vacuum Eliminated

The beam, he states, involves four new inventions, two of which already have been tested. One of these is a method and apparatus for producing rays "and other manifestations of energy" in free air, eliminating the necessity for a high vacuum; a second is a method and process for producing "very great electrical force"; the third is a method for amplifying this force, and the fourth is a new method for producing "a tremendous electrical repelling force." This would be the projector, or gun, of the system. The voltage for propelling the beam to its objective, according to the inventor, will attain a potential of 50,000,000 volts.

With this enormous voltage, he said, microscopic electrical particles of matter will be catapulted on their mission of defensive destruction. He has been working on this invention, he added, for many years and has recently made a number of improvements in it.

Mr. Tesla makes one important stipulation. Should the government decide to take up his offer he would go to work at once, but they would have to trust him. He would suffer "no interference from experts."

In ordinary times such a condition would very likely interpose an insuperable obstacle. But times being what they are, and with the nation getting ready to spend billions for national defense, at the same time taking in consideration the reputation of Mr. Tesla as an inventor who always was many years ahead of his time, the question arises whether it may not be advisable to take Mr. Tesla at his word and commission him to go ahead with the construction of his teleforce plant.

Such a Device "Invaluable"

After all, $2,000,000 would be relatively a very small sum compared with what is at stake. If Mr. Tesla really fulfills his promise the result achieved would be truly staggering. Not only would it save billions now planned for air defense, by making the country absolutely impregnable against any air attack, but it would also save many more billions in property that would otherwise be surely destroyed no matter how strong the defenses are as witness current events in England.

Take, for example, the Panama Canal. No matter how strong the defenses, a suicide squadron of dive bombers, according to some experts, might succeed in getting through and cause such damage that would make the Canal unusable, in which case our Navy might find itself bottled up.

Considering the probabilities in the case even if the chances were 100,000 to 1 against Mr. Tesla the odds would still be largely in favor of taking a chance on spending $2,000.000. In the opinion of the writer, who has known Mr. Tesla for many years and can testify that he still retains full intellectual vigor, the authorities in charge of building the national defense should at once look into the matter. The sum is insignificant compared with the magnitude of the stake.

The Philadelphia Inquirer October 20, 1940

Proposing the 'Death Ray' for Defense



"The beam would melt enemy airplane motors before they approached our coasts and blow up hostile bombers."





Nikola Tesla tells of amazing teleforce. (Right) Dr. Antonio Longoria is prepared to revive his "death ray."

THE man was old, but the fervor in his eyes was ageless. Deep-set, they looked out beneath the bushes of his brows.

"If only they will let me try out my new teleforce!" exclaimed Nikola Tesla, who has been called one of the greatest electrical inventors since Benjamin Franklin flew his kite. "If only they will let me show how this Nation can be made invulnerable to air attack!"

Thus, just the other day, spoke the man who years ago helped to harness Niagara Falls, through his discovery of the principle of the rotary magnetic field. The man who is known as the father of modern methods of generating and distributing electrical energy. Who in 1904 predicted that the human voice one day would girdle the globe, and whose famed Tesla coil helped to make that prediction of radio come true.

Today, at 83, Nikola Tesla lives in a New York hotel and dreams of making America one vast, impregnable fortress. He says that he can do this.

Tesla is used to skeptics who, he says, laughed at him back in the old days when he worked at Orange, New Jersey, with Thomas A. Edison. Tesla helped Edison design motors and generators. Then of course there was a great deal of laughing in 1904 over Tesla's idea that the human voice would one day wing around the world.

TODAY, trembling with excitement, this slim old man tells how his newest invention (he holds 700 patents) can melt airplane motors at a distance of 250 miles away from the American coastline, so that invading aviators would drop into the sea.

"My new teleforce," he declares, "is based on an entirely new principle of physics that nobody ever has dreamed of. It is different from the principle embodied in my inventions relating to the transmission of electrical power from a distance, for which I hold a number of basic patents."

For years Tesla worked on the problem of transmitting electrical power from a distance, without bringing this dream out of the laboratory into the workaday world. But he was not alone in his belief that it eventually will be done. The great Marconi, shortly before his death, predicted that the day would come when power would be directed through the air with little loss. And like Tesla, Marconi was reported to have been working on a war-ray. His, it was said, would when perfected be able to stop airplane and other motors many miles before invading forces could reach their goals.

For U. S. Alone

MARCONI said little about his mysterious ray, nor will Tesla discuss the details of his. It is his secret and he will not reveal it, he says, except to the United States Government, for he is afraid that it might be stolen by enemies of America, within and without. But of what it will do, he speaks freely.

"This new type of force," he said the other day, "would operate through a beam one one-hundred-millionth of a centimeter in diameter. It could be generated from a special plant that would cost no more than two million dollars and would take only about three months to construct.

"A dozen such plants, located at strategic points along the coast, would be enough to defend this country against all possible aerial attack. This beam would melt any engine, whether Diesel or gasoline-driven." (Marconi's partly-perfected beam was said to be ineffective against Diesel engines). "It would also ignite any explosives aboard any bomber. No possible defense against it could be devised, as the beam would be all-penetrating."

Four recent inventions, Tesla says, are used in the generation of the ray. Two of them already have been tested, it is said. One of these is an apparatus for producing rays "and other manifestations of energy" in free air, instead of in a vacuum.

The second is a process for producing "a very great electrical force." Next is a method for amplifying this force and finally there is a new method for producing "a tremendous electrical repelling force." This, Tesla declares, would be the projector, or gun, of the teleforce system. It would operate on a potential of 50,000,000 volts.

Dramatically, Tesla describes how "a titanic voltage would hurl into space billions of microscopic electrical particles of matter that would bring down invading airplanes as insects are dropped by a spray gun.

All this, Tesla says, he is offering to the United States, the land which welcomed him as an immigrant boy from Austria-Hungary in 1884. But there must be no "red tape," if he is to go to work setting up the first power plant. There must be no "interference from experts."

Offers like this have been made before, and tests have proved many so-called "death rays" useless. But some authorities, remembering the great achievements of Nikola Tesla, believe his claims should be investigated. Why, they ask, should such a ray be considered impossible in a world where radio is a commonplace? They recall the case of Henry Fleur, who was prosecuted in San Francisco by disgruntled investors who claimed he had bamboozled them with a death ray machine intended to kill insects.

In the courtroom, Fleur turned his machine on a couple of termites. They died in seconds. A lizard and a snake also were killed by the ray, though it took longer. Fleur was released. He said that he never would experiment with his apparatus to make it a man-killer.

Inventor's Offer

THEN there is Dr. Antonio Longoria who says that he destroyed a death ray machine which he invented in 1933 because it was too dangerous. Of this machine, Albert Burns, president of the Inventors' Congress in 1934, said that he had seen it kill pigeons, rabbits, dogs and cats at considerable distances. Now Dr. Longoria says that he is willing to re-assemble his apparatus in the event that the United States is subjected to an unwarranted attack. He claims that it worked by changing the red corpuscles of its victims' blood to white. And he says that it might be adapted to stall the motors of airplane engines in flight.

If such things are possible, some authorities ask: why not give Nikola Tesla the chance he asks to try out his defensive death ray? True, he has been called the greatest dreamer among the inventors who created the present electrical era. But many of his dreams came true. Perhaps, they say, this one might come true, too—and build a wall mightier than any in the world around 'America's borders.

The New York Sun July 9, 1941

TESLA TO REVEAL NEW INVENTIONS

Will Soon Announce What He's Doing for Defense.

Dr. Nikola Tesla, pioneer in wireless telegraphy and inventor known internationally for his research in sound and light transmission, told reporters today that his customary birthday party originally scheduled for tomorrow, which is the eighty-fifth anniversary of his birth, would be postponed for about a week and that he would make announcements concerning defense inventions on which he is working next week.

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The plans will be offered to the United States, Dr. Tesla disclosed, but declined to specify at this time the nature of his new inventions. In recent years the scientist has been experimenting with the idea of transmitting power through the ether.

Dr. Tesla who was born in what was for a time Yugoslavia, is a member of the French Academy of Sciences and has numerous other decorations. He has been living on the thirty-third floor of the Hotel New Yorker for several years, sometimes not emerging from his combination laboratory and living quarters for months at a time.

The New York Sun July 11, 1941

While there's life there's hope. But Nikola Tesla's eighty-fifth birthday finds his death ray still in the blueprint stage. The great inventor—one of the greatest of his age—says he could build a few plants, at a cost of $2,000,000 each, within three months, and melt the engine of any approaching plane at a distance of hundreds of miles. But the Government isn't listening and the few millions are lacking. The years crowd in on Mr. Tesla and his death ray.

The immigrant youth had discovered the rotary magnetic field, which made possible alternating current motors, before he arrived here in 1884, from a village in Czecho-Slovakia. He helped harness Niagara, turned in numerous inventions which became historic contributions to power transmission, was an associate of Thomas A. Edison, won the 1915 Nobel physics prize and now holds 700 patents. When he grows too old to dream, he'll have this to remember. And he also may remember that many of his earlier dreams caused amusement—as when he said it would soon be possible to telephone around the world.

Alone in his room in the Hotel New Yorker, he still delves deep in the hidden chambers of electro-mechanics, his deep-set eyes eager and intense under their bushy brows. Wireless transmission of power is still one of his many deep preoccupations.

The New York Herald Tribune January 8, 1943

Nikola Tesla Dies; Electrical Wizard Was 85

Invented Induction Motor, the Tesla Coil and More Than 900 Other Devices

Nikola Tesla, inventtor of the Tesla coil, the induction motor and more than 900 other devices in the field of electricity, died last night in his suite at the Hotel New Yorker. He was eighty-five years old.

Arrived Here With Four Cents

Nikola Tesla had four cents in his pocket when he stepped off a boat at the Battery in 1884. Although he was no nearly penniless, the twenty-seven-year-old immigrant came of highly educated and esteemed Yugoslavian parents. He thought it beneath his dignity to shine his own shoes. A few minutes after his arrival here he walked up Broadway and ran into a gang of workmen trying to repair an electrical motor. They paid him $20 to fix it.

From this bright beginning there was a temporary lapse while Tesla earned $2 a day as a ditch digger. He then joined Thomas A. Edison at his Orange, N. J. laboratory. It was while Tesla designed motors and generators that Edison induced him to begin shining his own shoes, a departure which perhaps affected the rate if not the course of his inventive productivity.

Tesla was born at Smiljan, Yugoslavia, in July, 1857. His father, a Greek Orthodox Church minister, was a noted writer, orator, linquist and mathematician. His mother was an inventor. The son first attended primary school at Gospic and the realschule in Karlstadt. He passed four years at the polytechnic school at Graz, where he saw Z. T. Gramme's electrical dynamo armature. Later he succeeded in simplifying the dynamo. He attended the University of Prague for two years, turning his attention from physics and mathematics to electricity.

Established Own Laboratory

In 1881 he began working for the Austrian government telegraph engineering department, and in the three years before he emigrated to the United States he invented a telephone repeater, built his first motor in Strasbourg, engaged in electrical engineering in Budapest and Paris and paid a visit to London, where he watched Lord Rayleigh conduct experiments.

After Tesla had been with Edison for some time, he established his own laboratory in New York, on Houston Street. After the place was destroyed by fire, he moved to apartments in hotels.

As the years passed, Tesla became known as "the electrical wizard," a label which seemed more appropriate with each of his hundreds of inventions. There were more than 900 patients in the name of Nikola Tesla. Inventions for which he became best known included the Tesla coil, or transformer, the induction motor by which electrical energy migh be changed to mechanical force more efficiently than by direct current, the rotary magnetic field principle incorporated in the transmission of power from Niagara Falls, an arc lighting system, as well as innumerable dynamos, transformers, coils, condensers and other electrical apparatus.

After he had been in this country about ten years, he created the first of a series of sensations by announcing the discovery of the cosmic ray. People smiled when Tesla came up with each new bombshell, but they came to know that, however fantastic or visionary his claims and predictions, they would be based on sound inventive genius.

In connection with the sending of electrical impulses around the globe before the day of Marconi, Tesla predicted modern radio developments with uncanny accuracy. He called it "the transmission of intelligence without wires," and foresaw an accompanying "transmission of power" without wires.

Many of those who then listened with skeptical ears lived to give respectful attention in 1937, when Tesla asserted that interplanetary communication was practicable and expressed the belief that he had been receiving signals from the inhabitants of Mars. At about the same time he announced plans for the construction of a new tube which would produce radium for as little as $1 a pound.

Backed by J. P. Morgan

On his birthday anniversaries, when he was wont to invite newspaper reporters to the party, he usually made startling headlines. In 1924, he claimed to have perfected a method of transmitting power without the use of wires, to propel ships and aircraft and to illuminate isolated homes. A generator would deposit energy in the earth, he announced, and any one provided with a "key" could unlock the power reservoir.

With the backing of the late J. P. Morgan, Tesla built a high steel wireless tower for a grand experiment, but the project ended after the death of the financier, in 1913. The plant was dismantled. In 1915 Tesla was talking of "robbing the ocean of its terrors by illuminating the sky, thus avoiding collisions at sea and other disasters caused by darkness." He planned an "air flivver" of helicopter design, but patents obtained in 1928 were never put to a test.

The New York Sun January 8, 1943

NIKOLA TESLA, INVENTOR, DIES

Electrical Engineer Was 85 Years of Age.

Nikola Tesla, inventor of more than 900 devices in the electrical field, including the Tesla coil and the induction motor, died in his suite at the Hotel New Yorker last night. He was 85 years old.

Mr. Tesla had only 4 cents in his pocket when he arrived in New York from Europe in 1884. He went to work for Thomas A. Edison at his laboratory in Orange, N. J., shortly afterward to design motors and generators. Early in 1887 he formed the Tesla Electric Company of New York, but after a fire destroyed his laboratories on Houston street, he confined his experimentation to hotel suites.

Most important of his inventions were his systems of alternating current power transmission and distribution of electrical energy. He predicted early in his career that radio communication was a thing of the near future. Since 1908 he had experimented with interplanetary communication and he was convinced that in a few years it was to be a reality.

In recent years Mr. Tesla had called in reporters on his birthdays and, with obvious relish, made startling predictions for the future. On his seventy-seventh birthday he said he would live to be 140 years old. The following year he announced that he had invented a "death beam" capable of destroying 10,000 airplanes at a distance of 250 miles and of annihilating an army of 1,000,000 soldiers in an instant.

He was born at Smiljan, Lika, a border county of Austria-Hungary, the son of a Greek Orthodox clergyman. His mother was an inventor. He worked in several countries of Europe as an electrical engineer before coming here.

Mr. Tesla never married. A nephew, Dr. Sava Kosanovich, Minister of State of the Delegation of the Royal Yugoslav Government, at 812 Fifth avenue, is making funeral arrangements.

The New York Sun January 8, 1943

Nikola Tesla.

As an inventor NIKOLA TESLA had he unusual experience of living for nalf a century after some of his most important discoveries and developments were announced to the world. He was thus able to see the application, improvement and consequences of a number of basic electrical inventions. TESLA'S motor and his system of alternating current power transmission were devised in 1888; three years later he brought out a transformer, and by 1896 was experimenting with wireless. He shared with numerous other inventors, however, the more common experience of advancing some of his scientific ideas long before the world had become sufficiently informed to understand their importance. When we remember that MARCONI'S radio as a popular interest waited for the 1920s, it is easier to understand how fantastic seemed TESLA'S proposals at the turn of the century for transmission of power without wires. In his later years when he appeared to be carried away with scientific notions of a highly impracticable kind, the world forgot the TESLA of fifty years ago, but continued to advance on inventions he had built.

NIKOLA TESLA, 86, PROLIFIC INVENTOR

Alternating Power Current's Discoverer Dies in His Hotel Suite Here

HIS 'DEATH BEAM' CLAIM

He Insisted the Invention Could Annihilate an Army of 1,000,000 at Once

Nikola Tesla, electrical inventor, died last night in his suite at the Hotel New Yorker.

According to the hotel staff, the electrical engineer and designer, who was 86 years old, had been in failing health for two years. Of vigorous temperament and with emphatic ideas on personal health as well as engineering, he had few visitors, according to the hotel management, which reported that his meals, strictly vegetarian-style, were especially prepared for him by the chef.

"He made everybody keep at a distance greater than three feet," a hotel executive recalled.

A spokesman for the hotel said that Dr. Tesla died as he had spent the last years of his life—alone. He was found dead in bed by a floor maid at 10:45 P. M. She called a house physician, who pronounced him dead.

The New Yorker management was attempting last night to locate friends of the inventor. It was believed he had a nephew living in this city.

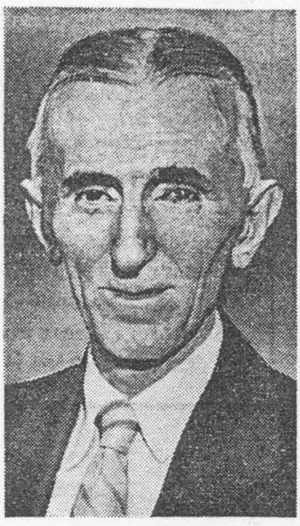
Ideas Fantastic Toward End

Nikola Tesla's ideas bordered increasingly on the fantastic as he advanced in years. On his seventy-eighth birthday he announced in an interview that he had invented a "death beam" powerful enough to destroy 10,000 airplanes at a distance of 250 miles and annihilate an army of 1,000,000 soldiers instantaneously.

In his seventy-seventh birthday interview he had no specific invention, but said he expected to live "beyond 140." The year before, however, he spoke of two great impending discoveries.

"When they are announced," he said, "one will be like the 100,000 trumpets of the Apocalypse. The other will be less sensational, but it, too, will be important. It will be like the shout with which Joshua's army brought down the walls of Jericho."

Since he made his first practical invention—a telephone repeater—in 1881, while living in Budapest, Mr. Tesla claimed to have made about 700. Many of them were of great importance, but these were nearly all invented in the last twenty years of the past century.



NIKOLA TESLA
The New York Times, 1936

Not Practical in Business.

He was greatly handicapped by lack of funds, for he was anything but a practical man as far as business was concerned. It was said that he was frequently victimized, but he did not seem to worry much as long as he had a place to work.

Tesla probably could have become a rich man had he chosen to become an employe of a large industrial concern, but he preferred poverty and freedom. Early in 1887 he had formed the Tesla Electric Company of New York, but the concern was not a financial success. For many years he did not even have a laboratory to work in, conducting his experiments in hotel rooms.

Of his inventions the most important were his systems of alternating current power transmission and distribution of electrical energy. His system of electrical conversion and distribution by oscillatory discharges was highly significant, as were his researches and discoveries in radiations, material streams and emanations.

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At one time Tesla had the financial backing of J. Pierpont Morgan the elder. He built a tall steel tower on Long Island to send out wireless power, but when his backer died no more money was forthcoming and the plan had to be abandoned.

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NIKOLA TESLA DIES; PROLIFIC INVENTOR

Alternating Power Current's Developer Found Dead in Hotel Suite Here

CLAIMED A 'DEATH BEAM'

He Insisted the Invention Could Annihilate an Army of 1,000,000 at Once

Nikola Tesla, one of the world's greatest electrical inventors and designers, was found dead last night in his suite at the Hotel New Yorker.

Engineers credit him with having devised the first practical application of alternating current; with the invention of the induction motor, and the invention and development of dynamos, transformers, condensers and specialized coils. The principle of the rotary magnetic field embodied in the plants which transmit power from Niagara Falls—in fact the bases of modern hydroelectric power—are credited to Dr. Tesla.

According to the hotel staff, Dr. Tesla, who was 86 years old, had been failing in health for two years. Of vigorous temperament and with emphatic ideas on personal health as well as engineering, he had few visitors, according to the hotel management, which reported that his meals, strictly vegetarian-style, were especially prepared for him by the chef.

"He made everybody keep at a distance greater than three feet," a hotel executive recalled.

A spokesman for the hotel said that Dr. Tesla died as he had spent the last years of his life—alone. He was found dead in bed by a floor maid at 10:45 P. M. She called a house physician, who pronounced him dead.

The New Yorker management was attempting last night to locate friends of the inventor. It was believed he had a nephew living in this city.

Ideas Fantastic Toward End

Nikola Tesla's ideas bordered increasingly on what some considered the fantastic as he advanced in years. On his seventy-eighth birthday he announced in an interview that he had invented a "death beam" powerful enough to destroy 10,000 airplanes at a distance of 250 miles and annihilate an army of 1,000,000 soldiers instantneously.

On his eighty-fourth birthday he declared he stood ready to divulge to the United States Government the secret of his "death beam" that, he said, would build an invisible Chinese Wall of defense around the country against any attempted attack by an enemy air force, no matter how large.

'All my inventions," Dr. Tesla said, "are at the service of the United States Government."

The "death beam,' he added, is "based on an entirely new principle of physics that no one has ever dreamed about." It would be only one one-hundred-millionth of a square centimeter in diameter, he said, and could be generated from a special plant that would cost no more than $2,000,000 and would take only three months to construct.

A Defense Against Invasion

A dozen such plants, located at strategic positions along the coast, Dr. Tesla said, would be enough to defend the country against all possible aerial attack. The beam would melt any engine, whether Diesel or gasoline-driven, and would also ignite the explosives aboard. No possible defense against it could be devised, as it would be all-penetrating, he declared.

Should the government decide to take up his offer, Dr. Tesla stated, he would go to work at once and keep on working "until I collapsed." However, he added, "I would have to insist on one condition—I would not suffer interference from any experts. They would have to trust me."

The beam, he said, involved four new inventions. One consisted of a method and apparatus for producing rays and other manifestations of energy in free air, eliminating the necessity for a high vacuum; a second was a method and process for producing "very great electrical force"; the third was a method for amplifying this force, and the fourth, a new method for producing "a tremendous electrical repelling force." This would be the prejector, or gun, of the system. The voltages for propelling the "death-beam" to its objective, Dr. Tesla said, would attain a potential of 50,000,000 volts.

Dr. Tesla said he was convinced "that the battleship was doomed" and that "what happened to the armored knight will also happen to the armored vessel." For this reason, he believed that money spent on battleships would be wasted, and such funds "should be directed in channels that will improve the welfare of the country."

Since he made his first practical invention—a telephone repeater—in 1881, while living in Budapest, Dr. Tesla claimed to have made about 700. Many of them were of great importance, but these were nearly all invented in the last twenty years of the past century.

Not Practical in Business.

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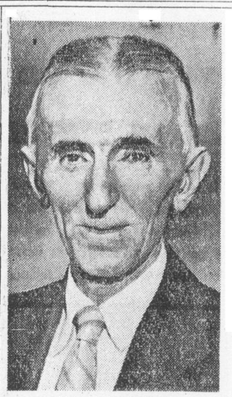

NIKOLA TESLA
The New York Times, 1936

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The New York Sun January 12, 1943

Tesla Funeral.

Funeral services for Nikola Tesla, Yugoslav-American scientist, will be conducted late today at the Cathedral of St. John the Divine. He died last Thursday at the Hotel New Yorker at the age of 86 years.

Bishop William T. Manning will offer the opening sentences of the burial office and the final prayer and blessing, assisted by Father Edward West, sacrist of the cathedral. The Serbian orthodox office for the dead will be said by the Very Rev. Dushan Shoukletovich, rector of the Serb-Orthodox Church of St. Sava, and a eulogy will be delivered by Dr. Ivan Subasich, governor of Croatia, in the Serbo-Croatian language.

Vice-President Wallace sent a message on behalf of President Roosevelt and a representative of the British Government will be at the funeral. Among the floral offerings was a wreath from King Peter II of Yugoslavia.

The New York Times January 13, 1943

2,000 ARE PRESENT AT TESLA FUNERAL

Cathedral of St. John the Divine Is Scene of Yugoslav State Function for Scientist

GREAT IN SCIENCE ATTEND

Ambassador Fotitch Heads the Procession of Mourners— Bishop Manning Assists

Inventors, Nobel Prize winners, leaders in the electrical arts, high officials of the Yugoslav Government and of New York, and men and women who attained distinction in many other fields paid tribute yesterday to Nikola Tesla, father of radio and of modern electrical generation and transmission systems, at an impressive funeral service in the Cathedral of St. John the Divine.

The service, conducted in Serbian by prominent priests of the Serbian Orthodox Church, was opened and closed by Bishop William T. Manning, assisted by Father Edward West, Sacrist of the Cathedral. The Serbian Orthodox Office for the Dead was said by the Very Rev. Dushan Shoukletovich, rector of the Serb Orthodox Church of St. Sava, who officiated in the name of the Serbian Orthodox Church in America.

City Is Represented

More than 2,000 persons attended the service. The city was represented by Newbold Morris, President of the City Council, who headed the list of honorary pallbearers. Other honorary pallbearers included Dr. Ernest F. W. Alexanderson of the General Electric Company, inventor of the Alexanderson alternator; Professor Edwin H. Armstrong of Columbia University, inventor of frequency modulation and many other important radio devices; Dr. Harvey C. Rentschler, director of the research laboratories, Westinghouse Electric and Manufacturing Company; Gano Dunn, president of the J. G. White Engineering Corporation; Colonel Henry Breckenridge, Dr. Branko Cubrilovich, Yugoslav Minister of Agriculture and Supply; Consul General D. M. Stanoyevitch of Yugoslavia and Professor William H. Barton, curator, Hayden Planetarium.

Fotitch Heads Procession

The funeral service was held as an official State function of the Yugoslav Government, which was officially represented by Constantine Fotitch, Yugoslav Ambassador to the United States. Dr. Fotitch led the procession of mourners who passed the coffin before it was closed. Oscar Gavrilovitch, Yugoslav consul in New York, headed the list of ushers.

Many telegrams were received from officials of the United States Government, prominent scientists, literary men and many others. These included messages from Mrs. Roosevelt, on behalf of herself and the President; Vice President Henry A. Wallace, Professors Robert A. Millikan, Arthur H. Compton and James Franck, all Nobel Prize winners in physics; Professor William Lyon Phelps of Yale, Jean Piccard and Major Gen. J. O. Mauborgne, U.S.A., retired.

Mrs. Roosevelt's message read: "The President and I are deeply sorry to hear of the death of Mr. Nikola Tesla. We are grateful for his contribution to science and industry and to this country."

Vice President Wallace's message read as follows:

"Nikola Tesla, Yugoslav born, so lived his life as to make it an outstanding sample of that power which makes the United States not merely an English-speaking nation but a nation with universal appeal. In Nikola Tesla's death the common man loses one of his best friends."

Scientists Pay Tribute

Drs. Millikan, Compton and Franck paid tribute to Tesla as one of the world's outstanding intellects, who paved the way for many of the important technological developments in modern times.

Among the many floral offerings was a wreath from King Peter II of Yugoslavia; the Royal Yugoslav Government, Ambassador Fotitch and many Yugoslav societies.

Chief mourner was Sava Kosanovich, nephew of Dr. Tesla and president of the Eastern and Central European Planning Board, representing Yugoslavia, Czechoslovakia, Poland and Greece.

The body was taken to Ferncliffe Cemetery, Ardsley, N. Y., where it will be in the receiving vault until plans are completed.

The New York Times January 22, 1943

TESLA LEFT NO WILL

Nephew Says Only Estate Consists of Research Data, Models

Nikola Tesla, electrical inventor and designer, who developed the inventions that became the bases of modern hydroelectric power, left no will and no estate except research data and models, according to papers filed yesterday in Surrogate's Court. Letters of administration were granted to Dr. Tesla's nephew, Sava N. Kosanovich of 112 Central Park South. Mr. Kosanovich is a national of Yugoslavia, although Dr. Tesla, who died Jan. 7 at the age of 86, was a United States citizen.

In his petition, the nephew listed the estate as of "value unknown," and set forth that a search had disclosed no will, and "that several years will be required in cataloguing, indexing and examining papers and data to ascertain the scope, meaning and significance thereof."

Besides Mr. Kosanovich, the papers listed as heirs five other nephews and nieces, all residing in Yugoslavia except Nikola Trbojevich of the Hotel Secor, Toledo, Ohio.

The New York Sun March 8, 1943

Tesla's X-Ray Experiment.

TO THE EDITOR OF THE SUN—*Sir:* Ever since Nikola Tesla died on January 7 I have been wondering where I filed a clipping from some paper of the 1890s which told of his early experiment with Roentgen rays. Finally my patience was rewarded when from a copy of "Alice in Wonderland" dropped the clipping, dated April 22, 1896—very possibly from THE SUN. It told of a long letter which Tesla wrote to the *Electrical Review* concerning a "new type of fluorescent screen" which he devised "to greatly increase the sharpness of the outlines." He wrote:

> . . . the vertebral column can be seen quite clearly, even in the lower part of the body. I have also clearly noticed the outlines of the hip bones. Looking in the region of the heart I have been able to locate it unmistakably. The background appeared much brighter, and this difference in intensity of the shadow and surrounding has surprised me. The ribs I now could see quite distinctly as well as the shoulder bones.

Though at first reading this seemed to indicate advanced research in the use of X-rays, my Britannica soon informed me that Roentgen discovered the power of X-rays in the autumn of 1895, in Germany, and that in the next "few weeks" reports came in from all over the world recording their value. So rapidly did the technic develop that "by the end of February, 1896, the method was in comparatively general use" for making radiographs. Tesla's contribution seems to have been chiefly an attempt to examine human organs by using improved apparatus.

E. N. PYTHAGOR.

Brooklyn, March 4.

Electric Sorcerer

PRODIGAL GENIUS: The Life of Nikola Tesla. By John O'Neill. 326 pp. New York: Ives Washburn. $3.75.

By WALDEMAR KAEMPFFERT

NIKOLA TESLA stalks through Mr. O'Neill's pages, the fantastic figure that he was in life—a celibate recluse who sought supreme control over matter and energy, a Dr. Faustus who cared nothing for Marguerites, a philosopher filled with a vast discontent, a poet who toyed with artificial lightning. Though he was not of this world he was something of a bon vivcur in his younger days. No one could order a dinner with nicer discrimination, no one had a finer taste in rare vintages. French, English, German, Italian and his native Serbian—he not only spoke them all but quoted their poetry to all who would listen. He lived in hotel rooms most of his life, a hermit in a metropolis, whose tall, lean figure could be seen on Fifth Avenue, sunk in his thoughts, unaware of the salutations of those who knew him, stopping only to feed the pigeons around the Public Library.

To Edison must go credit for having first built central stations, inventing electric lamps and putting us on our electrical feet. Yet not much of Edison's apparatus is left. What we see about us is largely Tesla's. The man was a pioneer who could make a fortune and spend it all on lavish experimenting and who died owing J. P. Morgan, John Jacob Astor, Austin Corbin and others several millions. All were so many rabbits in the intellectual clutch of this fascinating boa constrictor. Newspaper reporters, though they could not understand what he was talking about, were enthralled with his proposals to communicate with Mars and to transmit power without wires over vast distances. Tesla knew how to get publicity, and he liked to pose as an electric sorcerer. He would discuss his projects with apparent reluctance and in the end, as if he were utterly wearied but only having exhausted the topic, would ask for another drink, talk on billiards or quote Goethe.

LIKE a medieval practitioner of black arts, Tesla was given to mystification. He was the first to talk of "death rays." Once he set up oscillations that shook buildings near his laboratory and brought the police from headquarters. What happened is not clear, for Tesla destroyed the apparatus. The tale reminds one of his contemporary, Keeley, who was largely responsible for the popularly accepted notion that a man playing a violin can shake down a skyscraper. It may be, too, that the generators of the Colorado Springs Electric Company blew out when Tesla on Pike's Peak electrified himself and glowed weirdly. Engineers will wonder why effects that brought disaster to a power house two miles away without benefit of wires did not kill Tesla, and they will doubt if discharges of high voltage but very little amperage could do so much harm. It is not that we question Tesla but that we want more evidence than he ever supplied that an engineer can understand.

Here was a romanticist who should have been born in the Middle Ages. Electrical engineers never fully understood him. His mode of reasoning, his philosophic approach, were so much obscurantism to them. Even in the one popular article that he wrote over forty years ago for the old Century Magazine he was vague as an oriental mystic.

Soon after he came to this country Tesla was associated briefly with Edison. No greater contrast can be imagined: Edison, as practical as an Irish foreman of a railway section gang, who affected to despise theorists and mathematicians, though he did not hesitate to employ them; the Serbian, a dreamer to whom most inventions were mere toys, his own included. No wonder the two parted.



Tesla "in the Effulgent Glory of Myriad Tongues of Electric Flames."

Though he lived to be 85, Tesla crowded most of his inventive activity within twenty years. And what activity it was! Polyphase current engineering, the induction motor, the use of oil in transformers, radio, electric arcs fed by direct current in a magnetic field, gas-discharge lamps which were forerunners of Broadway's neon lights, the medical application of high-frequency currents—the record speaks for itself.

AS a practiced popularizer of science, Mr. O'Neill, who is the science editor of The New York Herald Tribune, vividly and skillfully tells the story of this extraordinary personality. His interest in his subject is more than that of the ordinary biographer. He wrote poems to Tesla as a boy, and when he made his acquaintance he sat enthralled at his feet. This biography has therefore much of O'Neill in it, which is one of its chief charms.

Because of this hero-worshiping attitude O'Neill gives Tesla far more than is his due. Tesla's great contribution to electrical engineering was his invention of alternating current machinery. Though O'Neill examines the claims of those who are regarded at least as independent inventors of this same machinery, especially the claims of Prof. Galileo Ferraris, he seems to this reviewer much too enthusiastic in Tesla's behalf. Nothing is said of S. Z. Ferranti, who in his way was just as remarkable as Tesla and who

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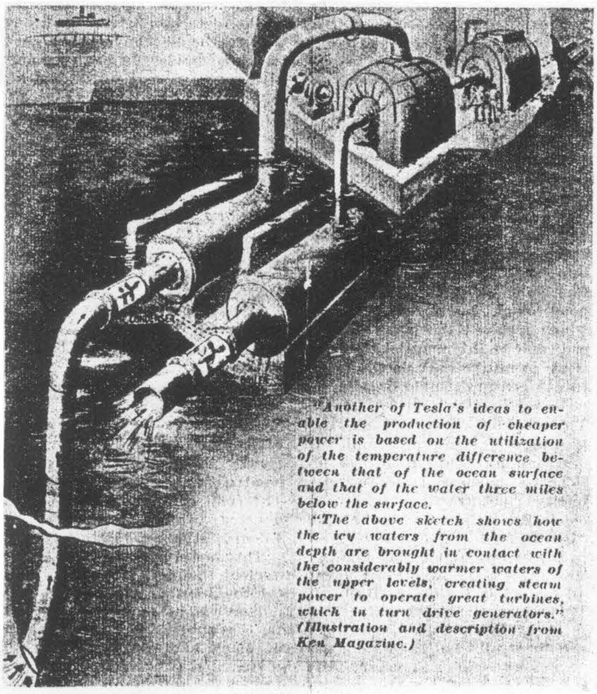

"Another of Tesla's ideas to enable the production of cheaper power is based on the utilization of the temperature difference between that of the ocean surface and that of the water three miles below the surface.

"The above sketch shows how the icy waters from the ocean depth are brought in contact with the considerably warmer waters of the upper levels, creating steam power to operate great turbines, which in turn drive generators." (Illustration and description from Ken Magazine.)

Tesla, Electric Sorcerer

(Continued from Page 6)

certainly built in London the first commercial alternating current station.

O'Neill believes seriously in Tesla that he regards him as the father of electrotherapeutics, though D'Arsonval deserves fully as much if not more credit for the use of high-frequency currents in medical practice. There is no doubt about Tesla's originality or about the grand way in which he thought and acted, but the phenomenon of simultaneous and independent invention is so well known that no physicist, however accomplished, ever stands alone.

Despite his extraordinary imagination, his profound knowledge of science and his rare gifts, Tesla remained a Victorian. When the atomic physicist gave us the electronic theory of matter and Einstein relativity Tesla would have none of them. He wanted his infinite universe, his Euclidean space, an ether which had become preposterous even when he was still in his prime. He died, lonely and misunderstood, leaving much of immense, practical importance but far more which is no clearer to us than the boasts of Paracelsus or the mystical forebodings of a Nostradamus.

O'Neill's book is the one full-length biography and the one appreciation of Tesla that we have. An immense amount of work has gone into its production. It does honor both to Tesla and its author, and it ought to be read by anyone who takes the slightest interest in this highly electrified world of ours. As for those novelists who still believe that a scientist is a wizard of the Merlin type, they will find O'Neill's Tesla made to order.